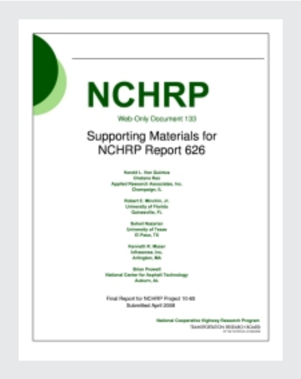

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NONDESTRUCTIVE TESTING TECHNOLOGY FOR QUALITY CONTROL AND ACCEPTANCE OF FLEXIBLE PAVEMENT CONSTRUCTION

VOLUME 2—RESEARCH REPORT

Prepared for:
National Cooperative Highway Research Program
Transportation Research Board
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Of National Academies

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ABBREVIATIONS AND NOMENCLATURE

AAD	Average Absolute Deviation
AASHTO	American Association of State Highway and Transportation Officials
ADCP	Automated Dynamic Cone Penetrometer
ASNT	American Society of Nondestructive Testing
ASTM	American Society for Testing and Materials
BCI	Base Curvature Index
CBR	California Bearing Ratio
CCC	Continuous Compaction Control
CMV	Compaction Meter Value
CT	Circular Track Texture
DBP	Deflection Basin Parameter
DCP	Dynamic Cone Penetrometer
DMI	Distance Measuring Instrument
DOT	Department of Transportation
EDG	Electrical Density Gauge
EPIC	Electronic Pavement Infrastructure, Inc.
EMAT	Electromagnetic-Acoustic Transducer
FAA	Federal Aviation Administration
FCC	Federal Communication Commission
FFT	Fast Fourier Transform
FHWA	Federal Highway Administration
FWD	Falling Weight Deflectometer
GDP	German Dynamic Plate
GPR	Ground Penetrating Radar
HMA	Hot Mix Asphalt
HWD	Heavy Weight Deflectometer
IC	Intelligent Compaction
IE	Impact Echo
IR	Infrared
IV	Impact Value
JMF	Job Mix Formula
KTC	Kentucky Transportation Center
LCL	Lower Control Limit
LSL	Lower Specification Limit
LTPP	Long Term Pavement Performance
LWD	Light Weight Deflectometer
M-D	Moisture-Density
M-E	Mechanistic-Empirical
MEPDG	Mechanistic-Empirical Pavement Design Guide
MMA	Machine Milled Accelerometer
MnROAD	Minnesota Road Research
MTV	Material Transfer Vehicle
NCAT	National Center for Asphalt Technology
NDE	Nondestructive Evaluation

NDT	Nondestructive Testing
ODMS	Onboard Density Measuring System
OGFC	Open-Graded Friction Course
OMV	Oscillo-Meter-Value
PATB	Permeable Asphalt Treated Base
PCA	Pavement Composition Analysis
PCC	Portland Cement Concrete
PFWD	Portable Falling Weight Deflectometer
PG	Performance Grade
PQI	Pavement Quality Indicator
PR	Penetration Rate
PRS	Performance Related Specification
PSPA	Portable Seismic Pavement Analyzer
PTA	Pavement Thickness Analysis
PVA	Pavement Void Analysis
PWL	Percent Within Limits
QA	Quality Assurance
QC	Quality Control
QC/QA	Quality Control/Quality Acceptance
RAP	Recycled Asphalt Pavement
RCP	Relative Compaction Profile
RDD	Rolling Dynamic Deflectometer
ROSAN	Road Surface Analyzer
RTRRM	Response-Type Road Roughness Measuring Device
RWD	Rolling Wheel Deflectometer
SASW	Spectral-Analysis-of-Surface-Waves
SHRP	Strategic Highway Research Program
SMA	Stone Matrix Asphalt
SPA	Seismic Pavement Analyzer
SPL	Standard Plate Load
SPS	Special Pavement Studies
SSG	Soil Stiffness Gauge (now referred to as the GeoGauge)
SSR	Subgrade Stress Ratio
TDR	Time Domain Reflectometry
TF	Transfer Function
TFT	TRL Foundation Tester
TTI	Texas Transportation Index
UBW	Ultrasonic Body Wave
UCL	Upper Control Limit
USL	Upper Specification Limit
USW	Ultrasonic Surface Wave
VMA	Voids in Mineral Aggregate
VTM	Voids in Total Mix

TERMS AND SYMBOLS

a	=	Acceleration
A_{GPR}	=	Amplitude of the reflection from the top of the layer
A_{GPR}	=	Regression coefficient from calibration of GPR data using cores
Apl	=	Amplitude of the reflection from a metal plate
b_{GPR}	=	Regression coefficient from calibration of GPR data using cores
CBR	=	California Bearing Ratio
C	=	Damping coefficient
$Clay$	=	Percent clay in the soil
D	=	Depth of the reflector
E	=	Young’s or elastic modulus
E	=	Emissivity of an object
E_{VIB}	=	Dynamic stiffness under vibratory loading
f	=	frequency
f_r	=	Resonance frequency
G	=	Shear modulus
IV	=	Impact Value
$k_{1,2,3}$	=	Regression constants from resilient modulus tests
K	=	Spring stiffness
L_r	=	Wave length
LL	=	Liquid limit
M	=	Constrained or Bulk modulus
M_R	=	Resilient Modulus
N	=	Phase spectrum
p_a	=	Atmospheric pressure, psi
$P_{3/8}$	=	Percent passing the 3/8 inch sieve
$P_{\#4}$	=	Percent passing the number 4 sieve
$P_{\#40}$	=	Percent passing the number 40 sieve
$P_{\#200}$	=	Percent passing the number 200 sieve
PI	=	Plasticity index
PR	=	Penetration rate (from DCP)
Q	=	Radiation emitted from an object
$Silt$	=	Percent silt in a soil
t	=	Travel time of a wave between the source aand receiver
t_{GPR}	=	Time delay between the reflections from the top and bottom of the layer from GPR readings
T_{IR}	=	Absolute temperature of an object
$T_{o[IR]}$	=	Absolute temperature of the surroundings
TF	=	Transfer function
V	=	Velocity of object from vibrations
V_{GPR}	=	Velocity from GPR reflection
V_P	=	Compression wave velocity
V_R	=	Rayleigh (surface) wave velocity

V_S	=	Shear wave velocity
w_s	=	Water content of the soil
w_{opt}	=	Optimum water content of the soil; AASHTO T 180
X	=	Receiver spacing
$X(f)$	=	FFT transform of the hammer input
$Y(f)$	=	FFT transform of the receiver output
Δ	=	Displacement
$\varepsilon_{a[GPR]}$	=	Dielectric constant of the layer
$\varepsilon_{s[GPR]}$	=	Dielectric constant of surface layer
θ	=	Bulk stress
Φ	=	Phase angle or shift
ρ	=	Mass density
$\sigma_{1,2,3}$	=	Principal stress
σ_{IR}	=	Stefan-Boltzman constant
τ_{oct}	=	Octahedral shear stress
λ	=	Lame's constant
γ	=	Density of layer
γ_{Max}	=	Maximum dry density of a material, AASHTO T 180
γ_s	=	Dry density of a material
v	=	Poisson's ratio

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Mr. Von Quintus was assisted by Dr. Chetana Rao of ARA as the Project Manager and Engineer on the team. The team also included Richard Stubstad of ARA, Dr. Kenneth Maser with Infrasense; Dr. Soheil Nazarian, with the University of Texas at El Paso (UTEP); Mr. Brian Prowell with the National Center for Asphalt Technology (NCAT); and Dr. Edward Minchin with the University of Florida, Gainesville.

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<u>Minnesota:</u> Mr. John Siekmier (Minnesota DOT), Mr. Art Bolland (Minnesota DOT), Mr. Chris Dunnick (Dunnick Brothers)

<u>Alabama:</u> Ms. Sharon Fuller (Alabama DOT), Mr. Andy Carol (Scott Bridge Company), East Alabama Paving

<u>Texas:</u> Mr. Tom Scullion (Texas Transportation Institute), Mr. Gregg Clevland (Texas DOT), Mr. James Klotz (Texas DOT), Mr. Tim Wade (Texas Turnpike Authority), Dr. Weng-On Tam (Avlis Engineering), Texas Lone Star Infrastructure

<u>Missouri:</u> Mr. John Donahue (Missouri DOT), Mr. Tim.Hellebusch (Missouri DOT)

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Ohio: Mr. Roger Green (Ohio DOT), Mr. Brian French (Ohio DOT)

NDT Devices and IC Rollers:
Mr. Chris Connelly (BOMAG), Mr. Jeff Fox(Ammann), Mr. Christopher Dumas (FHWA), Mr. Bob Horan (Salut), Mr. Scott Fielder (Humbolt Scientific, Inc. [Part A testing]), Mr. Melvin Main (Humbolt Scientific, Inc. [Part B testing]), Mr. William Beck, (Dynatest), Catepillar, Fugro/CarlBro, Transtech Systems Inc., Troxler Electroic Laboratories Inc.

ABSTRACT

This report documents the research performed under NCHRP Project 10-65. The goal of the project was to identify effective nondestructive testing (NDT) technologies that are ready for implementation into routine quality control and acceptance of flexible pavement construction based on field evaluations. The study also endeavored to recommend appropriate test protocols to aid in agency implementation. The report describes the scope of this study, describes the research activities undertaken, and presents field and laboratory test results that formed the basis for the development of the procedural manual for implementing the recommended NDT methods into routine practice.

This document will be of interest to highway materials, construction, quality assurance, pavement management, safety, design, and research engineers, as well as highway contractors and material suppliers.

The project commenced with a review of agency practices, including their quality control and acceptance procedures and material properties that are used as acceptance quality characteristics. This was followed by a review of available information on NDT technologies, their applications in testing individual flexible pavement layers, and their ability to estimate material properties which are sensitive to pavement performance. Promising technologies were evaluated through a comprehensive field testing program that was divided into two parts—Part A assessed the technologies' ability to effectively identify construction anomalies or physical differences along a project and practicality for immediate implementation into routine quality assurance; Part B used selected methods from Part A and refined the test protocols and data interpretation procedures for judging the quality of flexible pavement construction.

This report provides recommendations on technologies and protocols for use in quality control and acceptance of unbound layers, as well as hot mix asphalt layers and overlays. The report also contains three appendices containing supplemental information on NDT procedures and data collected during the project.

NCHRP Project 10-65
Volume 2—Research Report
Nondestructive Testing Technology for Quality Control and Acceptance of Flexible Pavement Construction

EXECUTIVE SUMMARY

1 INTRODUCTION

Quality assurance (QA) programs provide the owner and contractor a means to ensure that the desired results are obtained to produce high-quality, long-life pavements. Desired results are those that meet or exceed the specifications and design requirements. Traditional pavement construction quality control and quality acceptance (QC/QA) procedures include a variety of laboratory and field test methods that measure volumetric and surface properties of pavement materials. The test methods to measure the volumetric properties have changed little within the past couple of decades.

More recently, nondestructive testing (NDT) methods, including lasers, ground-penetrating radar (GPR), falling weight deflectometers (FWD), penetrometers, and infrared and seismic technologies, have been improved significantly and have shown potential for use in the QC/QA of flexible pavement construction. Furthermore, the new Mechanistic-Empirical Pavement Design Guide (MEPDG) uses layer modulus as a key material property. This should lead to increased measurement of layer moduli—a material property that can be estimated through NDT tests and is not included, at present, in the acceptance plan.

This research study investigated the application of existing NDT technologies for measuring the quality of flexible pavements. Promising NDT technologies were assessed on actual field projects for their ability to evaluate the quality of pavement layers during or immediately after placement or to accept the entire pavement at its completion. The results from this project identified NDT technologies ready and appropriate for implementation in routine, practical QC/QA operations.

1.1 Objectives

The overall objective of NCHRP Project 10-65 is to identify NDT technologies that have immediate application for routine, practical QA operations to assist agency and contractor personnel in judging the quality of hot mix asphalt (HMA) overlays and flexible pavement construction. This objective was divided into two parts, as listed below:

1. Conduct a field evaluation of selected NDT technologies to determine their effectiveness and practicality for quality control and acceptance of flexible pavement construction.
2. Recommend appropriate test protocols, based on the field evaluation and test results.

Effectiveness and practicality are key words in the first part of the objective. The field evaluation plan was developed to determine the effectiveness and practicality of different NDT technologies for use in QA programs. Both terms are defined below, as used in NCHRP Project 10-65:

- Effectiveness of NDT Technology – Ability or capability of the technology and device to detect changes in unbound materials or HMA mixtures that affect the performance and design life of flexible pavements and HMA overlays.
- Practicality of NDT Technology – Capability of the technology and device to collect and interpret data on a real-time basis to assist project construction personnel (QC/QA) in making accurate decisions in controlling and accepting the final product.

1.2 Integration of Structural Design, Mixture Design, and QA

The approach taken for this project was to use fundamental properties that are needed for both mixture and structural design for both control and acceptance of flexible pavements and HMA overlays. Figure 1 illustrates this integration or systems approach. The material or layer properties were grouped into three areas—volumetric, structural, and functional—and the NDT technologies were evaluated for their ability to estimate these properties accurately. Using the same mixture properties for accepting the pavement layer that were used for structural and mixture design allows the agency to more precisely estimate the impact that deficient materials and pavement layers have on performance. The material tests that are needed for structural and mixture design using the newer procedures are listed in Table 1.

Two structural properties that are needed to predict the performance of flexible pavements and HMA overlays are modulus and thickness. These are called "quality characteristics," and they are defined in Transportation Research Circular Number E-C037 as (TRB, 2002): "*That characteristic of a unit or product that is actually measured to determine conformance with a given requirement. When the quality characteristic is measured for acceptance purposes, it is an* ***acceptance quality characteristic*** *(AQC).*"

1.3 Products

The final deliverables for NCHRP Project 10-65 have been divided into three parts or reports. Part 1 is the procedural manual for implementing the NDT methods for QA application, Part 2 is the standard NCHRP research report, and Part 3 includes the appendices for the other two parts. Part 1 includes some of the examples for application of the modulus values for controlling and accepting flexible pavements. The appendices in Part 3 also include the data generated from this project.

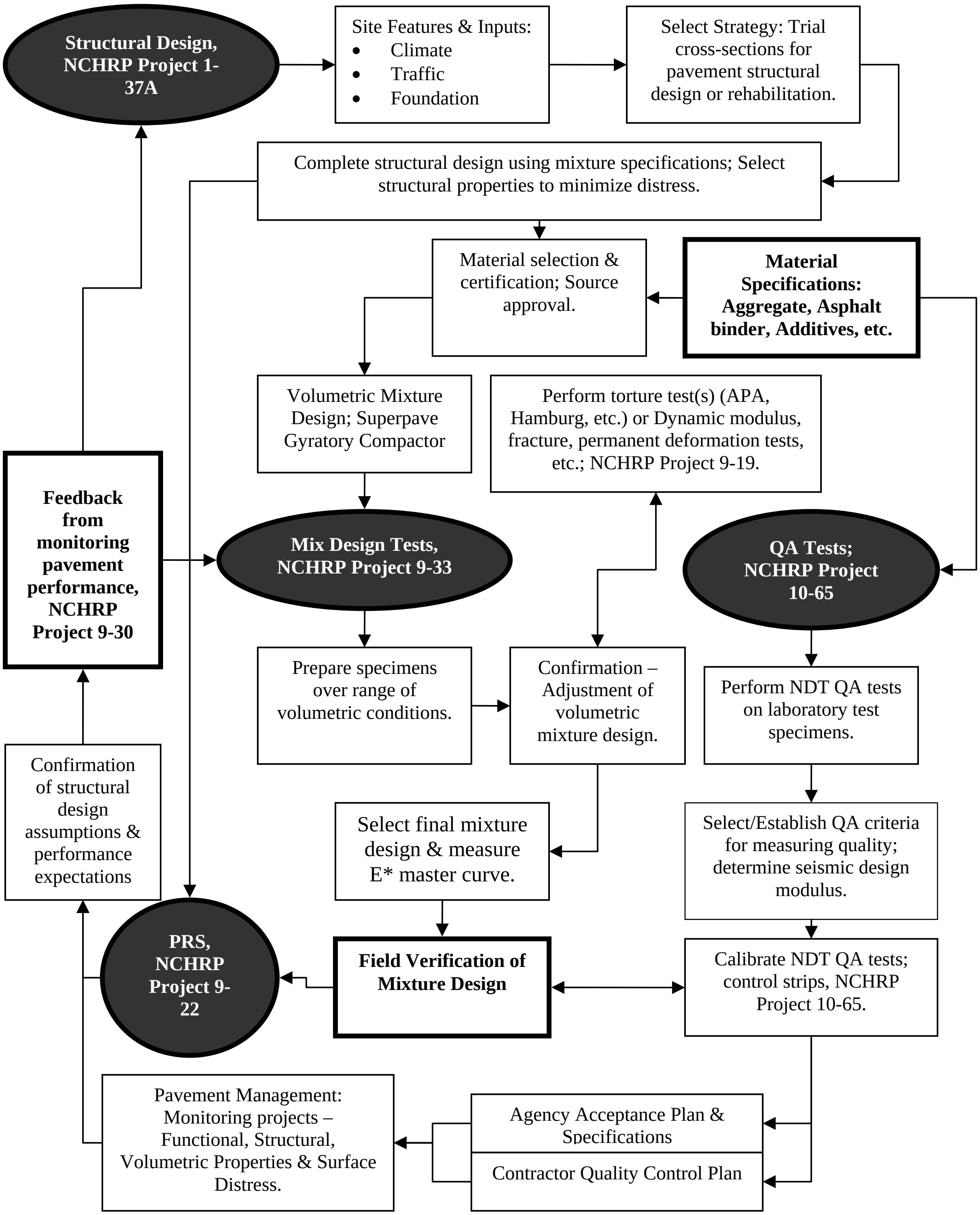

Figure 1. Example Flow Chart for the Systems Approach for Specifying, Designing, and Placing Quality HMA Mixtures

Table 1. Summary of Material and Layer Properties Used for Design and Acceptance of Flexible Pavements and HMA Overlays

<table>
<tr><th rowspan="2">Pavement Layer</th><th rowspan="2" colspan="2">Material-Layer Property</th><th colspan="3">Property Needed for:</th></tr>
<tr><th>Structural Design</th><th>Mixture Design</th><th>Acceptance</th></tr>
<tr><td rowspan="10">HMA Layers; Dense-Graded Mixtures</td><td colspan="2">Density – Air Voids at Construction</td><td>Yes</td><td>Yes</td><td>√</td></tr>
<tr><td colspan="2">Voids in Mineral Aggregate</td><td>Yes</td><td>Yes</td><td>√</td></tr>
<tr><td colspan="2">Effective Asphalt Binder Content</td><td>Yes</td><td>Yes</td><td>√</td></tr>
<tr><td colspan="2">Voids Filled with Asphalt</td><td></td><td>Yes</td><td></td></tr>
<tr><td colspan="2">Gradation</td><td>Yes</td><td>Yes</td><td>√</td></tr>
<tr><td colspan="2">Asphalt Binder Properties</td><td>Yes</td><td>Yes</td><td></td></tr>
<tr><td colspan="2">IDT Strength and Creep Compliance</td><td>Yes</td><td>Yes</td><td></td></tr>
<tr><td colspan="2">Dynamic Modulus</td><td>Yes</td><td>Yes</td><td></td></tr>
<tr><td colspan="2">Flow Time or Flow Number</td><td></td><td>Yes</td><td></td></tr>
<tr><td colspan="2">Smoothness, Initial</td><td>Yes</td><td></td><td>√</td></tr>
<tr><td rowspan="8">Unbound Layers; Dense Graded Granular Base, Embankment Soils</td><td colspan="2">Density</td><td>Yes</td><td>Yes</td><td>√</td></tr>
<tr><td colspan="2">Water Content</td><td>Yes</td><td>Yes</td><td></td></tr>
<tr><td colspan="2">Gradation</td><td>Yes</td><td>Yes</td><td>√</td></tr>
<tr><td colspan="2">Minus 200 Material</td><td>Yes</td><td>Yes</td><td>√</td></tr>
<tr><td colspan="2">Plasticity Index (Atterberg Limits)</td><td>Yes</td><td>Yes</td><td></td></tr>
<tr><td colspan="2">Resilient Modulus</td><td>Yes</td><td>Yes</td><td></td></tr>
<tr><td rowspan="2">Strength</td><td>CBR or R-Value</td><td>Yes</td><td>Yes</td><td></td></tr>
<tr><td>DCP; Penetration Rate</td><td>Yes</td><td></td><td></td></tr>
<tr><td colspan="6">IDT – Indirect Tensile
CBR – California Bearing Ratio
DCP – Dynamic Cone Penetrometer</td></tr>
</table>

2 NDT DEVICES INCLUDED IN THE FIELD EVALUATION

A large number of NDT technologies and devices have been used for pavement evaluation and forensic studies. Table 2 summarizes the technologies and methods that have been used to measure different properties and features of flexible pavements. As tabulated, GPR has been used for estimating many more volumetric properties and features than any other NDT technology, while the deflection and ultrasonic-based technologies have been used more for estimating structural properties and features.

To narrow the list of NDT devices that have potential for QA application, several highway agencies were contacted to collect information on their practices and experiences. Research reports of several agencies were also reviewed. These agencies include Arizona, California, Connecticut, Florida, Georgia, Illinois, Maryland, New Hampshire, Minnesota, Mississippi, Missouri, Nevada, Ohio, Oklahoma, Pennsylvania, Texas, Virginia, Washington, and Wisconsin Departments of Transportation (DOTs), the Federal Aviation Administration (FAA), Federal Highway Administration (FHWA), Eastern Federal Lands Division, Central Federal Lands Division, U.S. Air Force, U.S. Army Corps of Engineers Engineer Research and Development Center, Loughborogh University, Nottingham Trent University, Transport Research Laboratory (formerly known as the Transport and Road Research Laboratory [TRRL]) University of Illinois, University of Mississippi, Louisiana State University, Worcester Polytechnic Institute, and Texas Transportation Institute. Some of the equipment manufacturers and suppliers were also contacted to obtain specific information and data on the different NDT devices and technologies. The manufacturers contacted include Olson Engineering, Blackhawk, Geophysical Survey Systems, Inc. (GSSI), TransTech Systems, Inc., Dynatest, Carl Bro, and others.

The following lists the factors used to evaluate specific NDT devices that have reasonable success of being included in a QA program:

1. Accuracy and precision of the test equipment and protocols in measuring a specific material property—one of the difficulties of this category is defining the target value of some properties for nonlinear and viscoelastic materials. The accuracy and precision of the technology is also tied to the data interpretation procedures.

2. Data collection guidelines and interpretation procedures—this category examines whether there are generalized guidelines and procedures available for performing the tests and analyzing the data to estimate the material properties and/or features.

3. Availability of standardized test procedures (test protocols)—this category verifies if there is a test standard available for use in collecting NDT data to estimate the required material properties and features.

4. Data collection—production rate of the NDT equipment in collecting the data.

5. Data interpretation—time and ancillary equipment/software required to analyze and interpret the data for estimating the specific layer property.

6. Cost of the equipment—this category considers the initial cost of the test equipment, additional software and hardware requirements necessary to perform the test, and the operational and maintenance costs, including calibration.

7. Complexity of the equipment or personnel training requirements.

8. Ability of the test method and procedure to quantify the material properties needed for QA, mixture design, and structural design (see figure 1). In other words, is the NDT test result applicable to mixture and structural design?

9. Relationship between the test result and other traditional and advanced tests used in mixture design and structural design.

Table 2. Summary of NDT Methods Used to Measure Properties and Features of Flexible Pavements In Place

Type of Property or Feature		NDT Technologies and Methods: HMA Layers	NDT Technologies and Methods: Unbound Aggregate Base and Soil Layers
Volumetric	Density	• GPR Non-Nuclear Gauges; PQI, PaveTracker	• GPR • Non-Nuclear Gauges; EDG, Purdue TDR
	Air Voids or Percent Compaction	• GPR • Infrared Tomography • Acoustic Emissions • Roller-Mounted Density Devices	• GPR • Roller-Mounted Density Devices
	Fluids Content	• GPR	• GPR • Non-Nuclear Gauges; EDG, Purdue TDR
	Gradation; Segregation	• GPR • Infrared Tomography • ROSAN	NA
	Voids in Mineral Aggregate	• GPR (Proprietary Method)	NA
Structural	Thickness	• GPR • Ultrasonic; Impact Echo, SPA, SASW • Magnetic Tomography	• GPR • Ultrasonic; SASW, SPA
	Modulus; Dynamic or Resilient	• Ultrasonic; PSPA, SASW • Deflection-Based; FWD, LWD, • Roller-Mounted Response Systems; Asphalt Manager	• Impact/Penetration; DCP, Clegg Hammer • Ultrasonic; DSPA, SPA, SASW • Deflection-Based; FWD, LWD • Steady-State Vibratory; GeoGauge • Roller-Mounted Response Systems
	Bond/Adhesion Between Lifts	• Ultrasonic; SASW, Impulse Response • Infrared Tomography	NA
Functional	Profile; IRI	• Profilograph, Profilometer, Inertial Profilers	NA
	Noise	• Noise Trailers	NA
	Friction	• CT Meter, ROSAN	NA

SPA – Seismic pavement analyzer
PSPA – Portable seismic pavement analyzer
SASW – Spectral analysis of surface waves
LWD – Light weight deflectometer
ROSAN - ROad Surface ANalyzer
EDG – Electrical Density Gauge
TDR – Time Domain Reflectometry
DSPA – Dirt Seismic Pavement Analyzer

NDT Devices Included in the Field Evaluation

The following lists, in no particular order, the NDT technologies and devices that were selected for use in the field study:

1. **Deflection Based Technologies—**The FWD and LWD were selected because of the large number of devices that are being used in the U.S. and the large database that has been created under the FHWA Long Term Pavement Performance (LTPP) program. The LWD was used to evaluate individual layers, especially unbound layers, while the FWD was used to evaluate the entire pavement structure at completion to ensure that the flexible pavement structure or HMA overlay met the overall strength requirements used in the structural design process. Deflection measuring devices are readily available within most agencies for immediate use in QA.

2. **Dynamic Cone Penetrometer—**The DCP was selected because of its current use in QA operations in selected agencies and ability to estimate the in-place strength of unbound layers and materials. In addition, the DCP does not require extensive support software for evaluating the test results. DCP equipment is being manufactured and marketed by various organizations, making it readily available.

3. **Ground Penetrating Radar—**GPR was selected because of its current use in pavement forensic and evaluation studies for rehabilitation design and for estimating both the thickness and air voids of pavement layers. If proven successful, this will be one of the more important devices used for acceptance of the final product by agencies, assuming that the interpretation of the data can become more readily available on a commercial basis. The GPR air-coupled antenna was used successfully within the FHWA-LTPP program to measure the layer thickness within many of the 500-foot test sections.

4. **Seismic Pavement Analyzer—**Both the PSPA and DSPA were selected because they provide a measure of the layer modulus and can be used to test both thin, and thick layers during and shortly after placement. This technology can also be used in the laboratory to test both HMA and unbound materials compacted to various conditions—different water contents for unbound materials and soils, or temperature and asphalt content for HMA to evaluate the effect of fluids and temperature.

5. **GeoGauge—**The GeoGauge has had mixed results in testing unbound pavement layers in the past. It was selected for this study because it is simple to use and provides a measure of the resilient modulus of unbound pavement layers and embankment soils and can be used to test typical lift thicknesses.

6. **Non-Nuclear Electric Gauges; Non-Roller-Mounted Devices**—Non-nuclear density gauges have a definite advantage over the nuclear devices simply from a safety standpoint. These gauges have been used on many projects but with varying results. They were selected for the current study because the devices have been significantly improved since their previous evaluations. Moreover, many agencies are allowing their use by contractors for QC, and some agencies are beginning to use

the contractor QC results for acceptance. They also represent the baseline comparison to the results from the nuclear gauges for measuring density for use in acceptance procedures. Thus, non-nuclear density gauges that provide location-specific results were selected for evaluation under this study. The gauges selected for initial use were the PQI and PaveTracker for HMA mixtures, while the EDG was selected for unbound materials.

NDT Devices Excluded from the Field Evaluation

The following lists NDT technologies and devices excluded from the field evaluation study and explains why they were not selected:

- **Roller-Mounted-Density/Stiffness Devices**—Non-nuclear density and stiffness monitoring devices attached to the rollers (for example, the BOMAG Varicontrol and Onboard Measuring System) were excluded because these devices have not been extensively used for QC, few agencies are evaluating this technology for possible use in future, and there are a limited number of these rollers available for contractor use. Although the roller-mounted devices were excluded from the field evaluation, the roller manufacturers were contacted to determine their availability and use on selected projects.

- **Surface Condition Systems—**None of the surface condition measuring systems or devices were recommended for further evaluation under NCHRP Project 10-65. Although the initial International Roughness Index (IRI) is an input to the MEPDG, the smoothness measuring devices used for acceptance of the wearing surface are already included in the QA programs of many agencies. In addition, none of the devices provides an estimate of the volumetric and structural properties of the wearing surface.

- **Noise and Friction Methods—**Noise and friction measuring devices were excluded from further consideration, because these properties are not needed in the MEPDG or any other structural design procedure, and no agency is considering their use for acceptance.

- **Infrared Tomography—**Infrared cameras and sensors were excluded from the field evaluation because their output only provides supplemental information to current acceptance plans. In other words, the devices are used to identify "cold spots" or temperature anomalies, and other test methods are still used to determine whether the contractor has met the density specification. This statement does not imply that this technology should be abandoned or not used—the infrared cameras and sensors do provide good information and data on the consistency of the HMA being placed by the contractor. However, they do not provide information that is required for QA programs.

- **Other Ultrasonic Test Methods**—Impact echo and impulse response methods, as well as the ultrasonic scanners, were excluded because they are perceived to have a high risk of implementation into practical and effective QA operations.

- **Continuous Deflection-Based Devices—**Rolling wheel deflectometers that are under development were also excluded from the field evaluation. These devices are considered to be in the research and development stage and are not ready for immediate application into a QA program.

3 PROJECTS AND MATERIALS INCLUDED IN FIELD EVALUATION

The field evaluation was divided into two parts, referred to as Parts A and B. The primary purpose of the Part A field evaluation was to accept or reject the null hypothesis that a given NDT technology or device can accurately identify construction anomalies or physical differences along a project. A secondary purpose of this part of the field evaluation was to confirm that the NDT device can be readily and effectively implemented into routine, QA programs for flexible pavement construction and HMA overlays—an impact assessment. Part B of the field evaluation was to use those NDT technologies and devices selected from Part A and refine the test protocols and data interpretation procedures for judging the quality of flexible pavement construction. Part B also included identifying limitations and boundary conditions of selected NDT test methods.

Table 3 summarizes the projects and materials included in the field evaluation, while Table 4 lists those defects and layer differences that should have an impact on the quality characteristics measured by the QA tests. Table 5 summarizes the anomalies and differences of unbound material sections placed along each project. Likewise, Table 6 summarizes the anomalies and differences of HMA layers. None of the NDT operators were advised of these anomalies or physical differences.

4 FIELD EVALUATION OF NDT DEVICES

4.1 Identifying Anomalies and Physical Differences

A standard t-test and the Student-Newman-Keuls (SNK) mean separation procedure using a 95 percent confidence level were used to determine whether the areas with anomalies or physical differences were significantly different from the other areas tested. Table 7 summarizes the identification of the physical differences of the unbound and HMA layers within a project. The DSPA and GeoGauge are considered acceptable in identifying localized differences in the physical condition of unbound materials, while the PSPA and PQI were considered acceptable for the HMA layers.

4.2 Estimating Laboratory Measured Moduli

Laboratory measured modulus of a material is an input parameter for all layers in mechanistic-empirical (M-E) pavement structural design procedures, including the MEPDG. Resilient modulus is the input for unbound layers and soils, while the dynamic modulus is used for all HMA layers. The values determined by each of the NDT modulus estimating devices (DCP, DSPA, PSPA, GeoGauge, and deflection-based devices) were compared to the moduli measured in the laboratory on test specimens compacted to the density of the in-place layer. Different stress states were used for determining the resilient modulus of unbound layers, while different frequencies at the in-place mat temperature were used to determine the dynamic modulus of the HMA layers.

Table 3. Listing of Projects and Material Types Included in the Field Evaluation

Part	Project Identification & Location		Layer/Material Evaluated	
A	1	TH-23 Reconstruction Project; Wilmar/Spicer Minnesota	HMA	Dense-Graded Base Mixture
			Granular Base	Class 6, Crushed Aggregate
			Class 5 Embankment	Low Plasticity, Improved Soil with Gravel & Large Aggregate Particles
A	2	I-85 Overlay Project; Auburn, Alabama	HMA	12.5 mm Stone Matrix Asphalt Mix; PG76-22
A	3	US-280 Reconstruction Project; Opelika, Alabama	HMA	Coarse-Graded Base Mixture; PG67-22
			Granular Base	Crushed Limestone Base
			Embankment	Improved Soil; Aggregate-Soil Mix
A	4	I-85 Ramp Construction Project; Auburn, Alabama	Embankment	Low Plasticity, Fine-Grained Soil
A	5	SH-130 New Construction Project; Georgetown, Texas	HMA	Coarse-Graded 19mm Base Mixture; PG64-22
			Embankment	Coarse-Grained Aggregate/Soil; Improved Soil
A	6	SH-21 Widening Project; Caldwell, Texas	Subgrade	High Plasticity Fine-Grained Soil with Gravel
B	7	US-47 Widening Project; St. Clair, Missouri	HMA	Coarse-Graded Base Mixture
			HMA	Fine-Graded Wearing Surface
B	8	I-75 Rehabilitation Project, Rubblization; Saginaw, Michigan	HMA	Dense-Graded Binder Mixture; Type 3C
B	9	US-2 New Construction; North Dakota	HMA	Coarse-Graded Base Mix; PG58-28
			Granular Base	Crushed Gravel with Surface Treatment; Class 5
			Embankment	Soil-Aggregate Mixture
B	10	US-53 New Construction; Toledo, Ohio	HMA	Coarse-Graded Binder Mixture
			Granular Base	Crushed Aggregate; Type 304
B	11	I-20 Overlay; Odessa, Texas	HMA	Coarse-Graded Mixture; CMHB
B	12	County Road 103; Pecos, Texas	Granular Base	Caliche, Aggregate Base
B	13	NCAT; Alabama Overlay, Section E-5, Opelika, Alabama	HMA	Wearing Surface with 45% RAP; PG67, no modifiers used.
		NCAT; Alabama Overlay, Section E-6, Opelika, Alabama	HMA	Wearing Surface with 45% RAP; PG76 with SBS.
		NCAT; Alabama Overlay, Section E-7, Opelika, Alabama	HMA	Wearing Surface with 45% RAP; PG76 with Sasobit.
B	14	NCAT; Florida; Structural Test Sections N-1 & N-2	HMA	PMA Mixture with SBS; PG76
			HMA	Neat Asphalt Binder Mix; PG67
			Granular Base	Limerock Base
B	15	NCAT; Missouri; Structural Test Section N-10	HMA	Polymer Modified Asphalt Mix; PG76 (SBS)
			HMA	Neat Asphalt Binder Mix; PG64
			Granular Base	Crushed Limestone
B	16	NCAT; Oklahoma; Structural Test Sections N-8 & N-9	Subgrade Soil	High Plasticity Clay with Chert Aggregate
B	17	NCAT; Alabama; Structural Test Section S-11	HMA	Coarse-Graded Base Mix; PG67; Limestone
			Granular Base	Crushed Granite Base

CMHB – Coarse Matrix, High Binder Content (mixture type term used by the Texas DOT specifications)
PG – Performance Grade
PMA – Polymer Modified Asphalt
RAP – Recycled Asphalt Pavement

Table 4. Summary of the Construction Defects Exhibited on Some of the Field Evaluation Projects

Unbound Materials and Layers; Embankments	
All projects	No construction defect was observed in any of the Parts A and B projects. As listed in table 5, however, there were differences in the condition of the base materials and embankments that were planned to ensure that the NDT devices would identify those differences.
HMA Mixtures:	
• US-280 HMA Base	Truck-to-truck segregation observed in some areas. Cores were taken in these areas, but some of the cores disintegrated during the wet coring process. In addition, a significant difference in dynamic modulus was found between the initial and supplemental sections included in the test program. The supplemental section was found to have much higher dynamic modulus values. This difference was not planned.
• I-85 SMA Overlay	No defects noted.
• TH-23 HMA Base	No defects noted.
• SH-130 HMA Base	No defects noted during the time of testing, but there was controversy on the mixture because it had been exhibiting checking during the compaction process. Changes were made to the mixture during production. The change made and the time that the change was made were unclear relative to the time of the NDT evaluation.
• US-47 HMA Base	The mixture was tender; and shoved under the rollers.
• US-47 Wearing Surface	Portions of this mixture were rejected by the agency in other areas of the project.
• I-75 HMA Base, Type 3-C	No defects noted, but mixture placed along the shoulder was tender.
• I-75 HMA, Type E3 & E10	No defects noted, but portions of this mixture were rejected by the agency in other areas of the project.
• US-2 HMA Base	Checking and mat tears observed under the rollers.
• US-53 HMA Base	No defects noted.
• I-20 HMA CHMB Base	No defects noted.
• NCAT – Alabama HMA RAP; with & without modifiers	No defects noted on any of the test sections.
• NCAT – South Carolina HMA Base	No defects noted.
• NCAT – Missouri HMA Base	No defects noted.
• NCAT Florida – PMA Base	No defects noted.
• NCAT Florida – HMA Base, no modification	Checking and mat tears observed under the rollers.

Table 5. Description of Physical Differences in the Unbound Materials and Soils Placed Along Some of the Projects

Project Identification	Unbound Sections	Description of Differences Along Project
SH-21 Subgrade, High Plasticity Clay; Caldwell, Texas	Area 2, No IC Rolling	No planned difference between the points tested.
	Area 1, With IC Rolling	With IC rolling, the average density should increase; lane C received more roller passes.
I-85 Embankment, Low Plasticity Clay; Auburn, Alabama	Lane A of Sections 1 & 2	Prior to IC rolling, Lane A (which is further from I-85) had thicker lifts & a lower density.
	All Sections	After IC rolling, the average density should increase & the variability of density measurements should decrease.
TH-23 Embankment, Silt-Sand-Gravel Mix; Spicer, Minnesota	South Section – Lane C	Construction equipment had disturbed this area. In addition, QA records indicate that this area has a lower density—prior to final acceptance.
	North Section – Lane A	Area with the higher density and lower water content—a stronger area.
SH-130, Improved Embankment, Granular; Georgetown, Texas	All Sections	No planned differences between the areas tested.
TH-23, Crushed Aggregate Base; Spicer, Minnesota	Section 2 (Middle Section) – Lane C	Curb and gutter section; lane C was wetter than the other two lanes because of trapped water along the curb from previous rains. The water extended into the underlying layers.
	Section 1 (South Section) – Lane A	Area with a higher density and lower moisture content; a stronger area.
US-280, Crushed Stone Base; Opelika, Alabama	Section 4	Records indicate that this area was placed with higher water contents and is less dense. It is also in an area where water (from previous rains) accumulated.

None of the NDT devices accurately predicted the modulus values that were measured in the laboratory for the unbound materials and HMA mixtures. However, all of the modulus estimating NDT devices did show a trend of increasing moduli with increasing laboratory measured moduli.

To compensate for differences between the laboratory and field conditions, an adjustment procedure was used to estimate the laboratory resilient modulus from the different NDT technologies for making relative comparisons. The adjustment procedure assumes that the NDT response and modulus of laboratory prepared test specimens are directly related and proportional to changes in density and water content of the material. In other words, the adjustment factors are independent of the volumetric properties of the material.

Table 6. Description of the Different Physical Conditions (Localized Anomalies) of the HMA Mixtures Placed Along Projects within Part A

Project Identification	HMA Sections	Description of Differences Along the Project
TH-23 HMA Base; Spicer, Minnesota	Section 2, Middle or Northeast Section	QA records indicate lower asphalt content in this area – asphalt content was still within the specifications, but consistently below target value.
I-85 SMA Overlay; Auburn, Alabama	Section 2, Middle; All lanes	QA records indicate higher asphalt content in this area, but it was still within the specifications.
	Lane C, All Sections	This part or lane was the last area rolled using the rolling pattern set by the contractor, and was adjacent to the traffic lane. Densities lower within this area.
US-280 HMA Base Mixture; Opelika, Alabama	Initial Test Sections, defined as A; Section 2, All Lanes	Segregation identified in localized areas. In addition, QA records indicate lower asphalt content in this area of the project. Densities lower within this area.
	Supplemental Test Sections near crushed stone base sections, defined as B.	Segregation observed in limited areas.
	IC Roller Compaction Effort Section, Defined as C.	Higher compaction effort was used along Lane C.
SH-130 HMA Base Mixture; Georgetown, Texas	All Sections	No differences between the different sections tested.

Table 7. Summary of Success Rates of the NDT Devices for Identifying Physical Differences or Anomalies

NDT Gauges Included in Field Evaluation		Success Rates, %	
		Unbound Layers	HMA Layers
Ultrasonic	DSPA & PSPA	86	93
Steady-State Vibratory	GeoGauge	79	---
Impact/Penetration	DCP	64	---
Deflection-Based	LWD & FWD	64	56
Non-Nuclear Density	EDG & PQI	25	71
GPR	Single Air-Horn Antenna	33	54

Table 8 summarizes the adjustment ratios for the unbound layers included in the field evaluation (Parts A and B), while Table 9 summarizes the ratios for the HMA layers. The adjustment ratios were determined for the areas without any anomalies or physical differences from the target properties.

- **Unbound Layers**. The GeoGauge and DCP provided a reasonable estimate of the laboratory measured values (average ratios near unity), with the exception of the fine-grained, clay soils. The GeoGauge deviated significantly from the laboratory values for the fine-grained soils. The results also show that both the GeoGauge and DCP over predicted or under predicted the laboratory measured values for the same material, with few exceptions.
- **HMA Layers**. The PSPA average adjustment ratios were found to be relatively close to unity, with the exception of the I-35/SH-130 HMA base mixture. Conversely, the FWD adjustment ratios were significantly different from unity. The FWD over estimated the SMA modulus for the overlay project and under estimated the HMA base modulus for the reconstruction projects—suggesting that the calculated values from the deflection basins are being influenced by the supporting materials.

Table 8. Unbound Layer Adjustment Ratios Applied to the NDT Moduli to Represent Laboratory Conditions or Values at Low Stress States

Project Identification		Resilient Moduli, ksi		Adjustment Ratios Relating Laboratory Moduli to NDT Values			
		Laboratory Measured Value	Predicted with LTPP Equations	Geo Gauge	DSPA	DCP	LWD
Fine-Grained Clay Soils							
I-85 Low-Plastic Soil	Before IC Rolling	2.5	10.5	0.154	.0751	0.446	0.39
	After IC Rolling	4.0	13.1	0.223	0.113	0.606	0.39
NCAT; OK	High Plastic Clay	6.9	19.7	0.266	0.166	0.802	---
SH-21, TX	High Plastic Clay	26.8	19.6	1.170	0.989	3.045	2.78
Average Ratios for Fine-Grained Clay Soils				**0.454**	**0.336**	**1.225**	
Embankment Materials; Soil-Aggregate Mixtures							
TH-23, MN	South Embankment	16.0	15.7	0.696	0.367	1.053	3.13
	North Embankment	16.4	16.3	0.735	0.459	0.863	3.13
US-2, ND	Embankment	19.0	19.5	1.450	0.574	0.856	---
SH-130, TX	Improved Soil	35.3	21.9	1.337	1.029	1.657	1.43
Average Ratios for Soil-Aggregate Mixtures; Embankments				**1.055**	**0.607**	**1.107**	
Aggregate Base Materials							
Co. 103, TX	Caliche Base	---	32.3	1.214	---	1.436	---
NCAT, SC	Crushed Granite	14.3	36.1	0.947	0.156	---	---
NCAT, MO	Crushed Limestone	19.2	40.9	0.747	0.198	---	---
TH-23, MN	Crushed Stone, Middle	24.0	29.9	0.851	0.303	0.725	1.69
	Crushed Stone, South	26.0	35.6	0.788	0.235	0.560	1.69
US-53, OH	Crushed Stone	27.5	38.3	1.170	0.449	0.862	---
NCAT, FL	Limerock	28.6	28.1	0.574	0.324	0.619	---
US-2, ND	Crushed Aggregate	32.4	39.8	1.884	0.623	1.129	---
US-280, AL	Crushed Stone	48.4	49.3	1.010	0.244	0.962	1.04
Average Ratios for Aggregate Base Materials				**1.021**	**0.316**	**0.899**	
Overall Average Ratios for Processed Materials				**0.942**	**0.422**	**1.084**	

NOTES:
1. The adjustment ratio is determined by dividing the resilient modulus measured in the laboratory at a specific stress state by the NDT estimated modulus.
2. The overall average values listed above exclude those for the fine-grained clay soils.

Table 9. HMA Layer Adjustment Ratios Applied to NDT Modulus Values to Represent Laboratory Conditions

Project/Mixture	Dynamic Modulus, ksi	Ratio or Adjustment Factor	
		PSPA	FWD
I-85 AL, SMA Overlay	250	1.055	0.556
TH-23 MN, HMA Base	810	1.688	NA
US-280 AL, HMA Base; Initial Area	650	1.407	3.939
US-280 AL, HMA Base; Supplemental Area	780	1.398	2.516
I-35/SH-130 TX, HMA Base	1,750	5.117	3.253
I-75 MI, Dense-Graded Type 3-C	400	0.919	NA
I-75 MI, Dense-Graded Type E-10	590	0.756	NA
US-47 MO, Fine-Graded Surface	530	1.158	NA
US-47 MO, Coarse-Graded Base Mix	420	0.694	NA
I-20 TX, HMA Base, CMHB	340	0.799	NA
US-53 OH, Coarse-Graded Base	850	1.275	NA
US-2 ND, Coarse-Graded Base, PG58-28	510	1.482	NA
NCAT AL, PG67 Base Mix	410	0.828	NA
NCAT FL, PG67 Base Mix	390	0.872	NA
NCAT FL, PG76 Base Mix	590	1.240	NA
NCAT AL, PG76 with RAP and Sasobit	610	1.3760	NA
NCAT AL, PG76 with RAP and SBS	640	1.352	NA
NCAT AL, PG67 with RAP	450	0.881	NA
Overall Average Ratio		**1.128**	**2.566**

NOTES:
1. The adjustment factor or ratio was determined by dividing the dynamic modulus measured in the laboratory for the in place temperature and at a loading frequency of 5 Hz by the modulus estimated with the NDT device.
2. The laboratory dynamic modulus values listed above are for a test temperature of a loading frequency of 5.0 Hz at the temperature of the mixture when the NDT was performed.
3. The overall average adjust factor excludes the SH-130 mixture because it was found to be significantly different than any other mixture tested in the laboratory; which has been shaded.

4.3 Accuracy and Precision of Different NDT Devices

Tables 10 through12 summarize the statistical analyses of the NDT devices included in the field evaluation projects for unbound fine-grained soils, unbound processed materials, and HMA mixtures, respectively. This information is grouped into two areas—those NDT devices with an acceptable to excellent success rate and those with poor success rates in identifying material/layer differences.

4.4 Summary of Evaluations

The steady-state vibratory (GeoGauge) and ultrasonic (DSPA) are the two technologies recommended for use in judging the quality of unbound layers, while the ultrasonic (PSPA) and non-nuclear density gauges (the PaveTracker was used in Part B) are the technologies recommended for use of HMA layers. The GPR is recommended for layer thickness acceptance, while the IC rollers are recommended for use on a control basis for compacting unbound and HMA layers.

Table 10. NDT Device and Technology Variability Analysis Summary for the Fine-Grained Clay Soils

Material Property		NDT Devices	Statistical Value: Standard Error	Statistical Value: 95 % Precision Tolerance	Statistical Value: Pooled Standard Deviation
NDT Devices with Good Success Rates Based on Modulus or Volumetric Properties					
Structural Properties	Modulus, ksi	GeoGauge	**2.5**	**4.9**	**1.1**
		DSPA	**4.5**	**8.8**	**1.2**
	Thickness, in.	None	NA	NA	NA
Volumetric Properties	Density, pcf	None	NA	NA	NA
	Air Voids, %	None	NA	NA	NA
	Fluids Content, %	None	NA	NA	NA
NDT Devices with Poor (or Undefined) Success Rates Based on Modulus or Volumetric Properties					
Structural Properties	Modulus, ksi	DCP	**3.8**	**7.4**	**1.9**
		LWD/FWD	**5.9**	**11.6**	**2.0**
	Thickness, in.	GPR, single antenna	NA	NA	NA
Volumetric Properties	Density, pcf	GPR, single antenna	---	---	4.2
		EDG	**0.8**	**1.6**	**0.7**
	Water Content, %	EDG	**0.2**	**0.4**	**0.5**

Table 11. NDT Device and Technology Variability Analysis Summary for the Processed Materials and Aggregate Base Materials

Material Property		NDT Devices	Statistical Value: Standard Error	Statistical Value: 95 % Precision Tolerance	Statistical Value: Pooled Standard Deviation
NDT Devices with Good Success Rates Based on Modulus or Volumetric Properties					
Structural Properties	Modulus, ksi	GeoGauge	**2.5**	**4.9**	**1.8**
		DSPA	**4.5**	**8.8**	**1.5**
	Thickness, in.	None	NA	NA	NA
Volumetric Properties	Density, pcf	None	NA	NA	NA
	Air Voids, %	None	NA	NA	NA
	Fluids Content, %	None	NA	NA	NA
NDT Devices with Poor (or Undefined) Success Rates Based on Modulus or Volumetric Properties					
Structural Properties	Modulus, ksi	DCP	**3.8**	**7.4**	**5.3**
		LWD/FWD	**5.9**	**11.6**	**2.0**
	Thickness, in.	GPR, single antenna	**0.80**	**1.5**	**0.6**
Volumetric Properties	Density, pcf	GPR, single antenna	**3.4**	**6.7**	**3.0**
		EDG	**1.0**	**2.0**	**0.8**
	Water Content, %	EDG	**0.2**	**0.4**	**0.6**

Table 12. NDT Device and Technology Variability Analysis Summary for the HMA Mixtures

Material Property		NDT Devices	Statistical Value: Standard Error	Statistical Value: 95 % Precision Tolerance	Statistical Value: Pooled Standard Deviation
NDT Devices with Good Success Rates Based on Modulus or Volumetric Properties					
Structural Properties	Modulus, ksi	PSPA	**76**	**150**	**56**
Volumetric Properties	Density, pcf	PQI & PT	**1.7**	**3.4**	**2.5**
	Air Voids, %	None	NA	NA	NA
	Fluids Content, %	None	NA	NA	NA
NDT Devices with Poor (or Undefined) Success Rates Based on Modulus or Volumetric Properties					
Structural Properties	Modulus, ksi	FWD	**87**	**170.5**	**55**
	Thickness, in.	GPR, single antenna	**0.25**	**0.49**	**0.3**
		GPR, multiple antenna	**0.27**	**0.55**	**---**
Volumetric Properties	Density, pcf	GPR, multiple antenna	**1.6**	**3.1**	**---**
	Asphalt Content, %	GPR, multiple antenna	**0.18**	**0.36**	**---**
	Air Voids, %	GPR, single antenna	**0.40**	**0.8**	**2.1**
		GPR, multiple antenna	**0.22**	**0.4**	**---**

NDT Devices for Unbound Layers and Materials

- The DSPA and GeoGauge devices had the highest success rates for identifying an area with anomalies, with rates of 86 and 79 percent, respectively. The DCP and LWD identified about two-thirds of the anomalies, while the GPR and EDG had unacceptable rates below 50 percent.

- Three to five repeat measurements were made at each test point with the NDT devices, with the exception of the DCP.
    - The LWD exhibited low standard deviations that were less dependent on material stiffness with a pooled standard deviation less than 0.5 ksi. One reason for the low values is that the moduli were less than for the other devices. The coefficient of variation (COV), an estimate of the normalized dispersion, however, was higher. It is expected that the supporting layers had an effect on the results.
    - The GeoGauge had a standard deviation for repeatability measurements varying from 0.3 to3.5 ksi. This value was found to be material dependent.
    - The DSPA had the lowest repeatability, with a standard deviation varying from 1.5 to 21.5 ksi. The reason for this higher variation in repeat readings is that the DSPA sensor bar was rotated relative to the direction of the roller, while the other devices were kept stationary or do not have the capability to detect anisotropic conditions. No significant difference was found relative to the direction of testing for fine-grained soils, but there was a slight bias for the stiffer coarse-grained materials.
    - The EDG was highly repeatable with a standard deviation in density measurements less than 1 pcf, while the GPR had poor repeatability—based on point measurements. Triplicate runs of the GPR were made over the same area or sublot. For comparison to the other NDT devices, the values measured at a specific point, as close as possible, were used. Use of point specific values from

successive runs could be a reason for the lower repeatability, which are probably driver specific. One driver was used for all testing with the GPR.

- The COV was used to compare the normalized dispersion measured with different NDT devices. The EDG consistently had the lowest COV with values less than 1 percent. The GeoGauge had a value of 15 percent, followed by the DSPA, LWD, DCP, and GPR. The GPR and EDG are dependent on the accuracy of other tests in estimating volumetric properties (density and moisture contents). Any error in the calibration of these devices for the specific material is directly reflected in the resulting values, which probably explains why the GPR and EDG devices did not consistently identify the areas with anomalies or physical differences.

- Repeated load resilient modulus tests were performed in the laboratory for characterizing and determining the target resilient modulus for each material. Adjustment ratios were determined based on uniform conditions. The overall average ratio for the GeoGauge for the stiffer coarse-grained materials was near unity (1.05). For the fine-grained, less stiff soils, the ratio was about 0.5. After adjusting for laboratory conditions, all NDT devices that estimate resilient modulus resulted in low residuals (laboratory resilient modulus minus the NDT elastic modulus). However, the GeoGauge and DCP resulted in the lowest standard error. The LWD had the highest residuals and standard error.

- The DSPA and DCP measured responses represent the specific material being tested. The DCP, however, can be affected significantly by the varying amounts of aggregate particles in fine-grained soils and the size of the aggregate in coarse-grained soils. The GeoGauge measured responses are minimally affected by the supporting materials, while the LWD can be significantly affected by the supporting materials and thickness of the layer being tested. Thickness deviations and variable supporting layers are reasons for LWD's low success rate in identifying areas with anomalies or physical differences.

- No good or reasonable correlation was found between the NDT devices that estimate modulus and those devices that estimate volumetric properties.

- Instrumented rollers were used on too few projects for a detailed comparison to the other NDT devices. The rollers were used to monitor the increase in density and stiffness with increasing number of roller passes. One potential disadvantage with these rollers is that they may bridge localized soft areas. These rollers are believed to be worth future investment in monitoring the compaction of unbound materials.

- The GPR resulted in reasonably accurate estimates to the thickness of aggregate base layers. None of the other NDT devices have the capability or same accuracy to determine the thickness of the unbound layer.

NDT Devices for HMA Layers and Mixtures

- The PSPA had the highest success rate for identifying an area with anomalies with a rate of 93 percent. The PQI identified about three-fourths of the anomalies, while the FWD and GPR identified about half of those areas. The seismic and non-nuclear gauges were the only technologies that consistently identified differences between the areas with and without segregation. These two technologies also consistently found differences between the longitudinal joint and interior of the mat.

- The non-nuclear density gauges (PaveTracker) was able to identify and measure the detrimental effect of rolling the HMA mat within the temperature sensitive zone. This technology was beneficial on some of the Part B projects to optimize the rolling pattern initially used by the contractor.

- Three to four repeat measurements were made at each test point with the NDT devices.
  - The PSPA had a repeatability value, a median or pooled standard deviation, of about 30 ksi for most mixtures, with the exception of the US-280 supplemental mixture that was much higher.
  - The FWD resulted in comparable value for the SMA mixture (55 ksi), but a higher value for the US-280 mixture (275 ksi).
  - The non-nuclear density gauges had repeatability values similar to nuclear density gauges with a value less than 1.5 pcf.
  - The repeatability for the GPR device was found to be good and repeatable, with a value of 0.5 percent for air voids and 0.05 inches for thickness.

- The PSPA moduli were comparable to the dynamic moduli measured in the laboratory on test specimens compacted to the in-place density at a loading frequency of 5 Hz and the in-place mixture temperature, with the exception of one mixture—the US-280 supplemental mixture. In fact, the overall average ratio or adjustment factor for the PSPA was close to unity (1.1). This was not the case for the FWD. More importantly, without making any corrections for volumetric differences to the laboratory dynamic modulus values, the standard error for the PSPA was 76 ksi (laboratory values assumed to be the target values). The PSPA was used on HMA surfaces after compaction and the day following placement. The PSPA modulus values measured immediately following compaction were found to be similar to the values one or two days after placement—when making proper temperature corrections in accordance with the master curves measured in the laboratory.

- A measure of the mixture density or air voids is required in judging the acceptability of the modulus value from a durability stand point. The non-nuclear gauges were found to be acceptable, assuming that the gauges have been properly calibrated to the specific mixture—as for the PSPA.

- Use of the GPR single antenna method, even with mixture calibration, requires assumptions on specific volumetric properties do vary along a project. As the mixture properties change, the dielectric values may or may not be affected. Use of the proprietary GPR analysis method on other projects was found to be acceptable for the air void or relative compaction method. This proprietary and multiple antenna system, however, was not used within Part A of the field evaluation to determine its success rate in identifying localized anomalies and physical differences between different areas. Both

GPR systems were found to be very good for measuring layer thickness along the roadway.

- Water can have a definite effect on the HMA density measured with the non-nuclear density gauges (PQI). The manufacturer's recommendation is to measure the density immediately after compaction, prior to allowing any traffic on the HMA surface. Within this project, the effect of water was observed on the PQI readings, as compared to dry surfaces. The measured density of wet surfaces did increase, as compared to dry surfaces. From the limited testing completed with wet and dry surfaces, the PaveTracker was less affected by surface condition. However, wet versus dry surfaces was not included in the field evaluation plan for different devices—only the technology. Based on the data collected within the field evaluation, wet surfaces did result in a bias of the density measurements with this technology.

- Another important condition is the effect of time and varying water content on the properties of the HMA mixture during construction. There have been various studies completed on using the PSPA to detect stripping and moisture damage in HMA mixtures. For example, Hammons et al. recently used the PSPA (in combination with GPR) to successfully locate areas with stripping along selected interstate highways in Georgia (Hammons et al., 2005). The testing completed within this study also supports the use of the ultrasonic-based technology to identify such anomalies.

- The instrumented rollers used to establish the increase in stiffness with number of passes was correlated to the increases in density, as measured by different devices. These rollers were used on limited projects to develop or confirm any correlation between the NDT response and the instrumented roller's response. One issue that will need to be addressed is the effect of decreasing temperature on the stiffness of the mixture and how the IC roller perceives that increase in stiffness related to increases in density of the mat and a decrease in mat temperature as it cools. A potential disadvantage with these rollers is that they will bridge segregated areas and may not accurately identify cold spots in the HMA mat. These rollers are believed to be worth future investments in monitoring the compaction of HMA mixtures.

<u>Limitations and Boundary Conditions</u>

- All NDT devices recommended for QA application, with the exception of the GPR and IC rollers, are point specific tests. Point specific tests are considered a limitation because of the number of samples that would be required to identify localized anomalies that deviate from the population.
    - Ultrasonic scanners are currently under development so that relatively continuous measurements can be made with this technology. These scanners are still considered in the research and development stage and are not ready for immediate and practical use in a QA program.
    - GPR technology to estimate the volumetric properties of HMA mixtures is available for use on a commercial basis, but the proprietary system has only had limited verification of its potential use in QA applications and validation of all volumetric properties determined with the system.

    - Similarly, the IC rollers take continuous measurements of density or stiffness of the material being compacted. During the field evaluation, some of these rollers had both hardware and software problems. Thus, these devices were not considered immediately ready for use in a day-to-day QA program. The equipment, however, has been improved and its reliability has increased. The technology is recommended for use on a control basis but not for acceptance.

- Ultrasonic technology (PSPA) for HMA layers and materials; recommended for use in control and acceptance plans.
    - Test temperature is the main boundary condition for the use of the PSPA. Elevated temperatures during mix placement can result in erratic response measurements. Thus, the gauge may not provide reliable responses to monitor the compaction of HMA layers and define when the rollers are operating within the temperature sensitive zone for the specific mixture.
    - These gauges need to be calibrated to the specific mixture being tested. However, this technology can be used in the laboratory to measure the seismic modulus on test specimens during mixture design or verification prior to measuring the dynamic modulus in the laboratory.
    - A limitation of this technology is that the results (material moduli) do not provide an indication on the durability of the HMA mixture. Density or air void measurements are needed to define durability estimates.
    - The DSPA for testing unbound layers is influenced by the condition of the surface. High modulus values near the surface of the layer will increase the modulus estimated with the DSPA. Thus, the DSPA also needs to be calibrated to the specific material being evaluated.

- Steady-state vibratory technology (GeoGauge) for unbound layers and materials; recommended for use in control and acceptance plans.
    - This technology or device should be used with caution when testing fine-grained soils at high water contents. In addition, it should not be used to test well-graded, non-cohesive sands that are dry; well below the optimum water content.
    - The condition of the surface of the layer is important and should be free of loose particles. A layer of moist sand should also be placed underneath the gague to fill the surface voids and ensure that the gauge’s ring is in contact with about 75 percent of the material’s surface. Placement of this thin, moist layer of sand takes time and does increase the time needed for testing.
    - These gauges need to be calibrated to the specific material being evaluated and are influenced by the underlying layer when testing layers that are less than 8 inches thick.
    - These gauges are not applicable for use in the laboratory during the development of Moisture-Density (M-D) relationships that are used for monitoring compaction. The DSPA technology is applicable for laboratory use to test the samples used to determine the M-D relationship.
    - A relative calibration process is available for use on a day-to-day basis. However, if the gauge does go out of calibration, then it must be returned to the manufacturer for internal adjustments and calibration.

  - These gauges do not determine the density and water content of the material. Alternate devices are necessary to measure the water content and density of the unbound layer.

- Non-nuclear density gauges (electric technology) for HMA layers and materials; recommended for use in control and acceptance plans.
  - Results from these gauges can depend on the condition of the layer's surface—wet versus dry. It is recommended that the gauges be used on relatively dry surfaces until additional data become available pertaining to this limitation. Free water should be removed from the surface to minimize any effect on the density readings. However, water penetrating the surface voids in segregated areas will probably affect the readings—incorrect or high density compared to actual density from a core. The PSPA was able to identify areas with segregation.
  - These gauges need to be calibrated to the specific material under evaluation.

- GPR technology for thickness determination of HMA and unbound layers; recommended for use in acceptance plans.
  - The data analysis or interpretation is a limitation of this technology. The GPR data require some processing time to estimate the material property—the time for layer thickness estimates is much less than for other layer properties.
  - This technology requires the use of cores for calibration purposes. Cores need to be taken periodically to confirm the calibration factors used to estimate the properties.
  - Use of this technology, even to estimate layer thickness, should be used with caution when measuring the thickness of the first lift placed above permeable asphalt treated base (PATB) layers.
  - GPR can be used to estimate the volumetric properties of HMA mats, but that technology has yet to be verified on a global basis.
  - The technology and devices are not applicable to the use of laboratory data for calibration purposes.

- IC rollers; recommended for use in a control plan, but not within an acceptance plan.
  - The instrumented rollers may not identify localized anomalies in the layer being evaluated. These rollers can bridge some defects—insufficient sensitivity to identify defects that are confined to local areas.
  - Temperature is considered an issue with the use of IC rollers for compacting HMA layers. Although most IC rollers measure the surface temperature of the mat, the effect of temperature on the mat stiffness is an issue—as temperature decreases the mat stiffness will increase, not necessarily because of an increase in density of the mat. Delaying the compaction would increase the stiffness of the mat measured under the rollers because of the decrease in temperature.
  - The instrumented rollers also did not properly identify when checking and tearing of the mat occurred during rolling. The non-nuclear density gauges (PaveTracker) successfully identified this detrimental condition.
  - The technology and devices do not support the use of laboratory data for calibration purposes.

5 CONCLUSIONS

5.1 Unbound Layers and Materials

- The GeoGauge is a self-contained NDT device that can be readily incorporated into a QA program for both control and acceptance testing. This conclusion is based on the following reasons:
  - It provides an immediate measure of the resilient modulus of the in-place unbound material.
  - It identified those areas with anomalies at an acceptable success rate (second only to the DSPA).
  - It adequately ranked the relative order of increasing strength or stiffness of the unbound materials.
  - It provided resilient modulus values that were correlated to the dry density over a diverse range of material types.
  - The normalized dispersion is less than for the other NDT devices that provide an estimate of stiffness.
  - The training and technical requirements for this technology are no different than what is required when using a nuclear density gauge.

  Two disadvantages of using this device in a QA program are the need for measuring the water content and density using other methods, which is also the case for the DSPA and other modulus estimating devices, and the need to calibrate the test results to the material and site conditions under evaluation. The latter is the more important issue and is discussed in more detail below.

  The GeoGauge should be calibrated to the project materials and conditions to improve on its accuracy, especially when testing fine-grained soils. This calibration issue requires that laboratory repeated load resilient modulus tests be performed on each unbound layer for judging the quality of construction. Most agencies do not routinely perform resilient modulus tests for design. Eliminating the laboratory resilient modulus tests from the calibration procedure will reduce its accuracy for confirming the design values, but not for identifying construction defects. For those agencies that do not have access to or the capability to perform resilient modulus tests, use of the FHWA-LTPP regression equations is an option that can be used to calculate the target resilient modulus at beginning of construction. The target resilient modulus should be the value used in structural design. For the MEPDG, this is the average value measured in the laboratory.

- The DSPA is also a self-contained unit that was successful in many of the areas noted above for the GeoGauge. It was the device that had the highest success rate in identifying areas with different physical conditions or anomalies. An additional advantage of the DSPA is that the results can be calibrated to the specific unbound material being tested prior to construction—when the M-D relationship is measured in the laboratory. This calibration procedure allows the DSPA to be used to detect volumetric, as well as physical, changes in the materials during construction. In other words, the DSPA modulus is measured on the M-D samples prepared at different water contents and dry densities. In short, the DSPA can be used in day-to-day operations to assist contractor and agency personnel in judging construction and materials quality by itself or in tandem with other geophysical and/or ground truth sampling programs.

Two disadvantages of the DSPA are that it consistently resulted in a higher normalized dispersion measured over a diverse range of conditions and materials, and that it requires more sophisticated training of technicians to correctly interpret the load pulse and responses to ensure that a satisfactory data has been collected by the device.

- The DCP was also successful in many of the areas noted above for the GeoGauge. However, testing takes much more time, especially for stiff materials and layers with large aggregate. In addition, the test results were found to be more dependent on aggregate size than the other NDT devices. The normalized dispersion was also found to be much higher than for the DSPA and GeoGauge.

  Conversely, the DCP does have the capability to readily estimate the strength of thicker unbound layers and can measure the modulus gradient with depth. In fact, it can be used in conjunction with the GeoGauge and DSPA in adjusting the modulus values from those devices to laboratory conditions for fine-grained soils for agencies that do not have a resilient modulus testing capability in the laboratory. Use of the DCP can be considered an option in adjusting the test results for the GeoGauge for those agencies that have no plans to incorporate a resilient modulus testing capability within their design or materials departments.

- The GPR (single antenna method) was found to have a poor success rate in identifying anomalies. In addition, it does not provide a measure of modulus or strength of material. More importantly, using the single antenna method requires that either the density or water content be assumed and the other parameter calculated. Both vary along the project, resulting in higher variations of the property being calculated. Using an inaccurate value can lead to an incorrect finding. For example, the GPR found some of the areas tested to have the highest density, while most other NDT devices found that area to be the softest and least dense. It was successful, however, in measuring the layer thickness of the unbound materials.

  Two other disadvantages of this system are in the training requirements to use this technology and the need to calibrate the dielectric values to physical properties of the in-place material. Samples need to be recovered and tested to determine the water contents and densities of those areas prior to using the results for QC or acceptance. This requires that control strips be used prior to construction, and these calibration factors should be checked periodically during construction. Many agencies are not requiring control strips, or the first day of construction is the control strip. Training is another issue; this system requires more sophisticated training for the operator to interpret the measurements taken with the GPR. Thus, with its current limitations, it is not recommended for future use in testing unbound materials to determine the quality characteristics of the in-place material. However, it is recommended that research with the GPR continue because of its continuous coverage and speed of data collection.

- Similar to the GPR, the EDG was found to have a poor success rate in identifying areas with anomalies. However, this device is believed to have potential to provide volumetric data on the unbound materials for use in a QA program with continued use. The density estimated from this device is definitely related to resilient modulus across a wide range of unbound materials. However, additional data are needed to conclusively make recommendations for improving on the measurements. The variability of the water contents measured with this device was found to be very low. Other agencies are beginning to use this device in their research programs. For example, Texas and Nevada have ongoing programs that could provide improvements to the equipment and procedures in the near future. As a result, it is recommended that this device and technology be evaluated in more detail and that studies be initiated to improve its accuracy.

- The deflection-based methods (LWD and FWD) were found to have limited potential for QC purposes. The LWD devices have greater mobility than the FWD, which is an advantage for their use over the FWD. These devices have more potential for use in acceptance programs of the final structure, and certainly in forensic areas for evaluating the interaction between the pavement layers and foundation. The following summarizes the conclusions reached on these devices:
    - Technology was unable to consistently identify those areas with anomalies.
    - The modulus values can be influenced by the underlying layers, resulting in lower or higher and more variable modulus values.
    - The normalized dispersion was found to be high, relative to the other NDT devices.
    - The relationship between modulus from this technology and dry density was poor.
    - Any error in thickness of the layer being tested can result in large errors and more variability that could lead to wrong decisions being made by the contractor and agency about the construction operation.

5.2 HMA Mixtures

- The PSPA is a self-contained NDT device that can be readily incorporated into a QA program for both control and acceptance testing of HMA mixtures. As noted above for unbound materials, an advantage of this technology is that the device can be calibrated to the specific materials being tested during the mixture design stage for HMA mixtures. This calibration procedure allows the PSPA to be used to detect volumetric, as well as physical, changes in the materials during construction. In short, the PSPA can be used in day-to-day operations to assist contractor and agency personnel in judging construction and materials quality by itself or in tandem with other geophysical and/or ground truth sampling programs. This conclusion is based on the following reasons.
    - The PSPA is the NDT device recommended for QA applications because it adequately identified all areas, but one, with anomalies. The PSPA provides a measure of the dynamic modulus that is needed for pavement structural designs, even before adjusting the PSPA modulus for laboratory conditions. The PSPA modulus was found to be correlated to the dynamic modulus at elevated

temperatures using the master curve developed from laboratory dynamic modulus tests.
  - Similar PSPA modulus values were measured at higher temperatures and corrected for temperature using a master curve in comparison to those measured in the laboratory.
  - An important condition that the NDT device needs to consider is the effect of time and varying moisture content on the properties of the HMA mixture near construction and how those properties will change in-service. There have been various studies completed on using the PSPA to detect stripping in HMA mixtures. For example, the PSPA was used in combination with GPR to successfully locate areas with stripping along selected interstate highways in Georgia (Hammons et al., 2005). The test results from the NCHRP 10-65 study support a similar conclusion.

However, the PSPA does have some limitations regarding full-scale use in QA programs. Use of the PSPA should be delayed after rolling to allow the mix to cool. Dr. Nazarian's recommendation is to delay all testing for one day after HMA placement and compaction. If required, this time restriction is considered a disadvantage for use in QA programs.

A measure of the mixture density or air voids is also required in judging the acceptability of the modulus value or durability of the HMA mixture. The two devices that deserve further evaluation include the GPR and non-nuclear density gauges. The GPR provides full coverage in a short period of time.

- The non-nuclear density gauges are also recommended for QA because they can be readily incorporated into control programs. Some contractors are already using the non-nuclear density gauges in controlling the compaction operation. This technology was also used to identify anomalies at a reasonable rate and can be used to identify tender mixtures and the effects of rolling in the temperature sensitive zone.

  Variations in water have a definite effect on the HMA density measured with the PQI. The manufacturer's recommendation is to measure the density immediately after compaction, prior to allowing any traffic on the HMA surface. Similar to the PSPA, this type of time restriction is considered a disadvantage to the use of the PQI in a day to day practical QA program. This time effect, however, was not found within the Part A test program, but the moisture effect was observed in Part A of the field evaluation. Use of other non-nuclear density gauges (PaveTracker) did not exhibit this moisture sensitivity. However, the effect of water on these gauges was not included in the field evaluation as a primary variable. Measurements were taken after heavy rains in areas where the readings were previously taken prior to the thunderstorms. The same density values were measured, but after removing and drying all free water at the surface. This potential bias of free water on the surface is not considered a limitation but must be considered in taking measurements for control purposes.

- Use of the GPR technology using the single antenna method, even with mixture calibration, requires assumptions on specific volumetric properties that do vary along a project. Using the multi-antenna method is expected to improve on the measurement of the volumetric properties and identification of areas with deficiencies or anomalies. Thus, the GPR is suggested for continued research studies, especially with the multiple antenna system, which is a proprietary analysis system. The proprietary system needs additional validation prior to full-scale implementation into a QA program.

- The FWD is not recommended for use in QA programs, because this technology was unable to identify some of the anomalies. In addition, the FWD has high variation in elastic modulus values, and those values are influenced by the strength of the underlying materials and layers.

6 RECOMMENDATIONS

The research team’s recommendations are based on the evaluation of NDT devices for immediate and practical use in QA programs. The GeoGauge is the device recommended for estimating the modulus of unbound layers, while the PSPA is the device recommended for HMA layers. The PaveTracker is also recommended for use in establishing and confirming the rolling pattern for HMA mixtures. The recommendations do not mean that the other NDT devices do not provide useful data for pavement and materials testing purposes. Each has its own benefits and advantages for evaluating and designing pavements.

The IC or instrumented rollers can be valuable to a contractor in terms of controlling the compaction operation. These rollers that operated without problems were used on too few projects to recommend that they be immediately included in QA programs. Nonetheless, they can assist the contractor in optimizing the compaction of the material. Their disadvantage for HMA layers is the temperature of the mat issue. Decreases in temperature will cause the stiffness of the mat to increase. Thus, other devices still need to be used with the IC rollers for control. The IC rollers are not recommended at this time for acceptance.

Research with the multi-antenna GPR device and proprietary data interpretation system should not be abandoned and should be validated in future studies. This system definitely shows promise in providing the volumetric properties for HMA mixtures. The data can be collected at highway speeds, and the proprietary data interpretation system can provide results on a real-time basis. The disadvantage of this system is that it also needs field cores for calibrating the method to project specific conditions. These cores should be taken periodically to confirm the calibration factors being used in estimating the volumetric properties.

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PART I—INTRODUCTION

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CHAPTER 1

INTRODUCTION

1.1 Background

Good materials and construction practices are important to producing high-quality, long-life pavements. QA programs provide the owner and contractor a means to ensure that the desired results are obtained—that the final product meets with specifications and design requirements.

Traditional flexible pavement construction QC/QA procedures include a variety of laboratory and field test methods that measure volumetric and surface properties of pavement materials. The test methods to measure the volumetric properties have changed little in the past couple of decades. Most QA test methods rely on nuclear density and other volumetric measurements. Although traditional QA tests for bound and unbound materials have been used successfully in the past, these tests do have some major limitations:

- The traditional test methods are time-intensive, and more importantly, lack a sampling frequency that is adequate for highly variable materials that are used in pavement construction, such as soils and unbound aggregate base materials. In general, the required sampling and testing frequency for acceptance was found to be inadequate in some of the earlier work completed for the FHWA based on pavement performance predictions (Von Quintus et al., 1985).

- Many of the traditional QA test methods produce indirect measures of pavement quality. In other words, the values are not used in performance prediction equations. For example, unbound material densities only provide a gross estimate of the modulus and strength of the in-place material. This limitation is a distinct disadvantage in trying to develop performance-related specifications (PRS) or in applying these tests to warranty projects.

- The density and fluids content of an unbound or bound material are not particularly relevant by themselves, but only as they relate to the maximum dry unit weight or maximum density of the material.

NDT has been used in numerous industries involving the evaluation, inspection, and quality control of materials or constructed facilities. Historically, NDT has not been used in the pavements area as extensively as in other industries. Within the past decade, however, the pavement industry has seen a significant increase in the development and application of NDT technology in the control and acceptance of pavement materials.

Nondestructive testing and evaluation of construction quality offers an excellent, high production method of determining the structural and volumetric properties of pavement layers that can be tied directly back to the same properties that are required for both mixture and structural design. This direct relationship to the mixture and structural design methods is important when developing and implementing PRS. The MEPDG developed under NCHRP Project 1-37A and 1-40D as well as the simple performance tests developed under NCHRP Project 9-19 in support of the Superpave volumetric mixture design procedure use modulus and other fundamental engineering properties for characterizing the materials (Applied Research Associates, Inc. [ARA], 2004; 2006, Witczak et al., 2002). Thus, it would be highly advantageous that QA programs use the same tests for estimating construction quality.

Many of the NDT technologies (such as seismic test methods, GPR, FWD, and DCP) have been used to evaluate pavement construction. However, there is a need to more clearly assess the ability of different NDT technologies to evaluate the quality of pavement materials and layers during construction. This project is to identify NDT technologies that have immediate application for routine, practical QA operations to assist agency and contractor personnel in judging the quality of the individual pavement layers and overall pavement structure.

1.2 Definition of Highway Quality Assurance Terms

The Transportation Research Board (TRB) released a circular (TRB, 2005) containing a glossary of highway quality assurance terms to provide a uniform understanding of technical terms that have specific meanings in the highway engineering field. The various terms are introduced through definitions cited from the reference and reflect their usage throughout this document.

QA: *All those planned and systematic actions necessary to provide confidence that a product or facility will perform satisfactorily in service. QA addresses the overall problem of obtaining the quality of a service, product, or facility in the most efficient, economical, and satisfactory manner possible. Within this broad context, QA involves continued evaluation of the activities of planning, design, development of plans and specifications, advertising and awarding of contracts, construction, and maintenance, and the interactions of these activities.*

In summary, QA ensures that the quality of the finished product meets specifications, and is the responsibility of the highway agency. QA process comprises of quality control (QC), acceptance, inspection, and independent assurance (IA).

QC: *QC is also called process control and includes those QA actions and considerations necessary to assess and adjust production and construction processes so as to control the level of quality being produced in the end product.* QC is motivated by QA and acceptance procedures, and typically is the responsibility of the contractor or producer.

Acceptance: *The process of deciding, through inspection, whether to accept or reject a product, including what pay factor to apply. Where contractor test results are used in the agency's acceptance decision, the acceptance process includes contractor testing, agency verification, and possible dispute resolution.*

Quality characteristic*: That characteristic of a unit or product that is actually measured to determine conformance with a given requirement. When the quality characteristic is measured for acceptance purposes, it is an* ***acceptance quality characteristic*** *(AQC).*"

Inspection: *The act of examining, measuring, or testing to determine the degree of compliance with requirements.*

Independent Assurance: *A management tool that requires a third party, not directly responsible for process control or acceptance, to provide an independent assessment of the product or the reliability of test results, or both, obtained from process control and acceptance. The results of independent assurance tests are not to be used as a basis of product acceptance.*

1.3 Research Problem Statement

Test methods used for in-place QC/QA of individual flexible pavement layers and of new and rehabilitated flexible pavement systems have changed little in past decades. Such operations typically rely on nuclear density measurements or the results of testing conducted on pavement cores. Roughness measurements often are used to confirm that the newly constructed pavement has adequate initial smoothness.

More recently, NDT methods, including lasers, ground-penetrating radar, falling weight deflectometers, penetrometers, and infrared and seismic technologies, have been significantly improved and have shown potential for use in QC/QA of flexible pavement construction. Furthermore, the MEPDG uses layer stiffness or modulus as a key material property. This should lead to increased measurement of layer moduli by owner agencies, an activity that currently is not a typical component in the acceptance of a completed project.

This research study investigated the application of existing NDT technologies for measuring the quality of flexible pavement materials and construction workmanship. Promising technologies were assessed on actual field projects for their ability to evaluate the quality of pavement layers during or immediately after placement or to accept the entire pavement at its completion. The study focused on measuring quality characteristics that affect pavement performance and life cycle costs. The results from this project identified NDT technologies ready and appropriate for implementation in routine, practical QC/QA operations.

1.4 Research Objectives

As stated in the research project statement, there were two objectives of this research:

1. Conduct a field evaluation of selected NDT technologies to determine their effectiveness and practicality for QC/QA of flexible pavement construction.
2. Recommend appropriate test protocols, based on the field evaluation results.

Effectiveness and practicality are key words in the first objective. The field experimental plan was developed to determine the effectiveness and practicality of different NDT technologies for use in QA programs. Both terms are defined below, as used in NCHRP Project 10-65:

- Effectiveness of NDT Technology – Ability or capability of the technology and device to detect changes in unbound materials or HMA mixtures that affect the performance and design life of flexible pavements and HMA overlays.
- Practicality of NDT Technology – Capability of the technology and device to collect and interpret data on a real-time basis to assist project construction personnel (quality control and acceptance) in making accurate decisions in controlling and accepting the final product.

1.5 Project Organization

To achieve the research objective, NCHRP Project 10-65 was subdivided into two phases. Phase 1 identified existing NDT technologies with potential for in-place testing of individual flexible pavement layers and of the entire flexible pavement structure at its completion. The flexible pavement layers include HMA, unbound aggregate base material and subgrade soil during new construction, and HMA overlays during rehabilitation. Phase 1 consisted of three tasks, which are listed below:

1. Summarize State of Knowledge of NDT Technologies for Application to Quality Assurance
2. Design Field Experiments to Evaluate NDT Technologies
3. Prepare and Submit Interim Report

Phase 2 was a field evaluation of those NDT technologies judged ready and appropriate for implementation in flexible pavement construction. It also consisted of three tasks as a follow on to phase 1 study, which are listed below:

1. Conduct Field Experiment
2. Conduct Analyses for NDT Technologies from Field Experiment
3. Prepare and Submit Draft Final and Final Reports

Phase 2 was further subdivided into two parts—Parts A and B. Part A was to confirm the applicability and use of different NDT technologies identified from Phase 1 that were judged to be ready and appropriate for implementation into routine, practical, and effective QA programs for measuring the quality of flexible pavement construction and HMA overlays. Part A of the field evaluation also included selecting those NDT technologies and devices that could consistently and accurately identify construction anomalies that were built into the pavement structure or HMA overlay. Part B of Phase 2 used those NDT technologies and devices selected from Part A and refined the test protocols and data interpretation procedures for judging the quality of flexible pavement construction. Part B also included identifying limitations and boundary conditions of the selected NDT test methods.

1.6 Scope of Project Document and Research Report

The final document for NCHRP Project 10-65 has been divided into three major volumes or reports. Volume 1 is the procedural manual for implementing the NDT methods for QA application, Volume 2 (included herein) is the standard NCHRP Research Report, and Volume 3 includes the appendices for the other two parts. Volume 3 also includes the data generated from this project.

This research report in Volume 2 is sectioned into four major parts, including the introduction (Part I) to the project. Part II is a summary of the research findings, Part III presents the interpretation and appraisal of the test results, and Part IV summarizes the research conclusions and recommendations. Part IV is followed by the references to the research report.

The appendices, included in Volume 3, present important information relevant to this study but excluded from the main body of the research report:

- Appendix A lists the topics and questions used in collecting information from agencies on their QA procedures, and application of NDT technologies and devices.
- Appendix B provides a description and summary of the projects that were included in the field evaluation of selected NDT technologies and devices.
- Appendix C includes a summary of the data collected and measured during the project.
- Appendix D contains the recommended NDT test methods in AASHTO standard format.

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PART II—SUMMARY OF FINDINGS

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CHAPTER 2

MATERIAL PROPERTIES FOR CONTROL AND ACCEPTANCE

2.1 Quality Characteristics Used in Previous and Current QA Programs

The specific mixture and/or mat properties used to accept HMA construction, i.e. the AQCs vary from agency to agency. Table 13 lists those material or layer properties that were used by many state agencies prior to adoption of the Performance Graded (PG) asphalt specification and Superpave volumetric mixture design method. The material properties listed in Table 13 do not include those properties that are typically specified by an agency for material source approval and mixture design.

Density, air voids, and fluids content are important volumetric properties related to flexible pavement and HMA overlay performance, which is why the majority of state and federal agencies use these properties as quality characteristics for accepting the pavement layers and materials (refer to Table 13).

Many state agencies have incorporated or are in the process of incorporating smoothness and void in mineral aggregate (VMA) into their acceptance plan and have removed stability and penetration or viscosity after adopting the PG asphalt specification and Superpave mixture design method. Density, air voids, fluids content, and gradation are still included in most agencies' acceptance plans, while engineering properties are excluded from nearly all QA programs in use by state and federal agencies to-date. With the exception of smoothness, all of the properties are determined at a point—either on the roadway or at a specific point in time during mixture production.

2.2 Control and Acceptance Procedures

Of the many process control procedures that can be used in highway construction, process control charts, particularly statistical control charts, are most commonly used by contractors and material producers for verifying that their process is under control. Although there are different approaches that can be taken in implementing NDT technologies to verify that the process is in control, statistical control charts were used within this project. As a result, the NDT test methods must produce results that can be adapted to existing AASHTO procedures in pavement construction. The ASTM *Manual on Presentation of Data and Control Chart Analysis* was used for preparing practical procedures that contractors can use in deciding whether their process is in control (ASTM, 1992).

Table 13. Material Properties Used by State and Federal Agencies for Accepting Flexible Pavement Construction (Von Quintus et al., 1998; Darter et al., 1997)

Pavement Layer	Material-Layer Property	Number of Agencies
HMA Layers; Dense-Graded Mixes	Mat Density/Air Voids	26
	Asphalt Binder Content	18
	Joint Density	14
	Gradation	10
	Smoothness; IRI, Profile Index	10
	Mat Thickness	8
	Mix Density – Laboratory Compacted	*5*
	Voids in Mineral Aggregate	*4*
	Stability – Laboratory Compacted	*10*
	Asphalt Binder Properties; Viscosity or Penetration	*3*
	Voids Filled with Asphalt	*0*
	Strength – Indirect Tensile	0
	Modulus; Dynamic, Resilient, Creep	0
Unbound Layers; Aggregate Base, Embankment	Dry Density	26
	Gradation	12
	Minus 200 Material	8
	Strength; Dynamic Cone Penetrometer, CBR, R-value	6
	Atterberg Limits	0
	Moisture Content	0
	Resilient Modulus	0
NOTE: The material properties that are in italics may not represent the in place materials, if measured on laboratory compacted specimens, asphalt recovered from the storage tank at the plant, or have been replaced by other more recent tests.		

Similarly, there are different acceptance procedures that are used in judging whether the pavement material meets the required specifications. Two methods that have been adopted by most agencies are Percent Within Limits (PWL) and Average Absolute Deviation (AAD). PWL is the procedure used by over 75 percent of the agencies that have adopted statistical-based acceptance specifications. As a result, American Association of State and Highway Transportation Officials (AASHTO) R9 entitled *Acceptance Sampling Plans for Highway Construction* was used for preparing practical but effective procedures that agencies can use in deciding whether the product meets their specifications (AASHTO, 2003).

In summary, statistical control charts is the recommended method for determining whether the construction is in-control or out-of-control, and PWL will be the method used for judging construction quality or acceptability.

2.3 Sampling Plans for Measuring Quality Characteristics

The definition of a lot varies from agency to agency, but generally is a day's production or an amount of material. The sampling frequency for QA tests within a lot is determined assuming that the material property being measured has a normal distribution. The assumption of normality has been found to be adequate for most quality characteristics in use to-date, assuming proper construction procedures are followed. Localized deficiencies, however, can and do occur that are difficult to detect using sampling frequencies defined using the assumption of normality.

Most agencies use 4 to 10 tests per lot for acceptance. The higher frequencies are used for density determinations. These sampling frequencies generally are adequate for estimating the mean and standard deviation of material properties of the population, except when local defects or anomalies occur at random or on a consistent basis. Most acceptance and control sampling and testing frequencies are insufficient to identify these conditions without adequate inspection. It is expected that inspection will be just as important when using NDT methods as for current QA plans.

2.4 Integration of Design and Acceptance Procedures

Historically, most of the pavement design procedures that have been used by state highway agencies in the U.S. require the use of structural layer coefficients. These layer coefficients can be estimated from resilient modulus using charts included in the *1993 AASHTO Guide for the Design of Pavement Structures* (AASHTO, 1993). Currently, there is a move to use the MEPDG structural design procedures that are based on M-E methods (ARA, 2004, 2006). An Interim Manual of Practice for the MEPDG (ARA, 2007) has been prepared and as of data, the MEPDG has been adopted as the AASHTO Interim Design Procedure.[2]

M-E procedures use fundamental pavement material properties such as modulus and strength. Few agencies, however, actually measure resilient modulus or other modulus values of HMA and unbound materials (Darter et al., 1997). Some agencies do not have confidence in these values, while others simply do not have the laboratory equipment.

Using the same mixture properties for accepting the pavement layer that were used for structural and mixture design allows the agency to more precisely estimate the impact that deficient materials and pavement layers have on performance. The focus and approach of NCHRP Project 09-22 is to develop PRS and associated software that is directly tied to the MEPDG by using quality characteristics that are input to that design procedure (Killingsworth, 2003). The material tests that are needed for structural and mixture design using the newer procedures are listed in Table 14.

2.5 Issues with Existing QA Tests for Measuring Quality Characteristics

To improve procedures for measuring the quality of flexible pavement construction and to detect deficiencies in the final product, one must identify some of the limitations, problems, and issues with the current procedures that are used to control and accept construction. This section summarizes the more common issues with current QA programs.

[2] The Manual of Practice for the MEPDG was prepared under NCHRP Project 1-40B and was the official AASHTO ballot for voting on the procedure or MEPDG software.

Most of the QA tests in use by state and federal agencies for flexible pavement construction use location or time specific tests for judging the quality of construction. As noted above, the frequencies of the samples and tests are determined assuming that the layer properties have a normal distribution. This assumption is incorrect in some cases. Anomalies can and do occur during construction. Cold spots and segregation in the HMA mat can be difficult to detect under typical QA programs. In general, the sampling frequencies used by many agencies are inadequate to detect localized areas with defects.

Table 14. Summary of Material and Layer Properties Used for Design and Acceptance of Flexible Pavements and HMA Overlays

Pavement Layer	Material-Layer Property	Property Needed for:		
		Structural Design	Mixture Design	Acceptance
HMA Layers; Dense-Graded Mixtures	Density – Air Voids at Construction	Yes	Yes	Yes
	Voids in Mineral Aggregate	Yes	Yes	Yes
	Effective Asphalt Binder Content	Yes	Yes	Yes
	Voids Filled with Asphalt		Yes	
	Gradation	Yes	Yes	Yes
	Asphalt Binder Properties	Yes	Yes	
	Indirect Tensile Strength and Creep Compliance	Yes	Yes	
	Dynamic Modulus	Yes	Yes	
	Flow Time or Flow Number		Yes	
	Smoothness, Initial	Yes		Yes
Unbound Layers; Dense Graded Granular Base, Embankment Soils	Density	Yes	Yes	Yes
	Moisture Content	Yes	Yes	
	Gradation	Yes	Yes	Yes
	Minus 200 Material	Yes	Yes	Yes
	Resilient Modulus	Yes	Yes	
	Strength, Dynamic Cone Penetrometer	Yes		Yes

Another major issue related to acceptance tests is the time required for obtaining the acceptance test result. Contractors can place a large amount of mixture and materials with today's production and construction equipment. The longer it takes to obtain the results for acceptance criteria, the greater the amount of material and dollars that can be in dispute or penalty. Minimizing the time to obtain accurate test results for acceptance should reduce the magnitude and number of dispute claims. The following summarizes the three major issues with the current QA procedures and tests that were considered in selecting NDT methods for use within this project.

1. Inferior mixtures are defined as those that do not meet the assumptions used in the structural and mixture design process. Density, air voids, and other volumetric properties by themselves do not always detect inferior mixtures or materials. To improve on the process of detecting inferior materials, QA tests need to measure the

same property used in structural and mixture design or at least measure a parameter that is highly correlated to those properties used in design. As previously noted, one of the objectives of NCHRP Project 09-22 is to develop HMA PRS using quality characteristics that are tied to the structural and HMA mixture design procedures. Thus, QA needs to have a similar focus and approach—use fundamental parameters needed to predict performance to assist in developing payment penalties and incentives.[3]

2. The sampling and testing frequency of most location specific tests are inadequate to detect and locate deficiencies in HMA mixtures and other materials. These deficiencies can include random and longitudinal segregation of HMA mixtures and segregated and wet areas of unbound materials. To improve on the detection process, higher sampling and testing frequencies or larger sample sizes within the population are needed, in combination with proper inspection. Another major issue facing state and federal agencies is the reduction in personnel resulting in decreased inspection of construction activities.

3. A large amount of material and mixture can be placed by the contractor within a day's production. The time for obtaining and interpreting the test results for acceptance should be as short as possible. In addition, the tests for accepting the final product are being performed by the contractor for an increasing number of agencies. In other words, using a contractor's QC test results for acceptance is becoming more popular. Thus, the acceptance tests should be applicable for use by the contractor during day-to-day production and the results from the acceptance tests need to be available on a real-time basis (within a day) to minimize the amount of material or funds in dispute.

2.6 Summary of Material Properties Used for QA

The approach taken for this project was to use fundamental properties that are needed for both mixture and structural design for both control and acceptance of flexible pavements and HMA overlays (see table 15). The NDT technologies were evaluated for their ability to estimate these properties accurately. Table 15 lists those properties that were considered for use in the field evaluation study, while Figure 2 illustrates this systems approach. The properties were grouped into three areas—volumetric, structural, and functional. The material properties included traditional QA test methods, fundamental engineering properties needed to predict performance using the MEPDG, and simple performance tests to assist in volumetric mixture design. Structural and mixture design properties are needed to ensure that the NDT technology can quantify construction quality accurately, and that the assumptions used in structural and mixture design have been met. The structural properties that are critical for predicting the performance of flexible pavements and HMA overlays are modulus and thickness.

[3] Although density and air voids are not commonly used in most structural design procedures, both are key material properties for HMA as well as unbound aggregates and soils, as they have a significant effect on the material's strength and modulus.

Field permeability tests have become important since agencies started using coarse-graded Superpave mixtures at the surface and can be considered a nondestructive test. However, none of the agencies contacted or the QA programs reviewed within this project require the use of permeability tests for control or acceptance. The Florida Department of Transportation (DOT) is just about the only agency that has seriously considered using field permeability tests for acceptance. In addition, the field permeability tests take time to perform and require that the roadway be closed to traffic. Although a field permeability test measures an important property of compacted HMA mixtures, the test was not considered in the field evaluation portion of this project because of the time needed to perform the test; furthermore, the results are not needed for both structural and mixture design procedures.

Table 15. Summary of Layer Properties Typically Used in Traditional QA Programs and Material/Pavement Properties Estimated from NDT Methods

Type of Property	Traditional QC/QA Test Methods		NDT Test Methods	
	HMA	Unbound Materials	HMA	Unbound Materials
Volumetric	Density – Mat & joint densities	Density	Density – Mat & joint densities	Density
	Asphalt Binder Content	Moisture Content	Asphalt Binder Content	Moisture Content
	Gradation	Gradation	Gradation: Segregation	---
	VMA	Minus 200 Material	Air Voids, VMA	Percent Saturation
Structural	Thickness	Thickness	Thickness	Thickness
			Elastic (Dynamic & Resilient) Modulus	Resilient Modulus
			Indirect Tensile Creep Compliance	Shear Strength
			Adequate bond or adhesion between HMA layers	NA
Functional	Profile: IRI or Profile Index	NA	IRI & Profile	NA
			Noise	
			Friction	

VMA – Voids in Mineral Aggregate
IRI – International Roughness Index

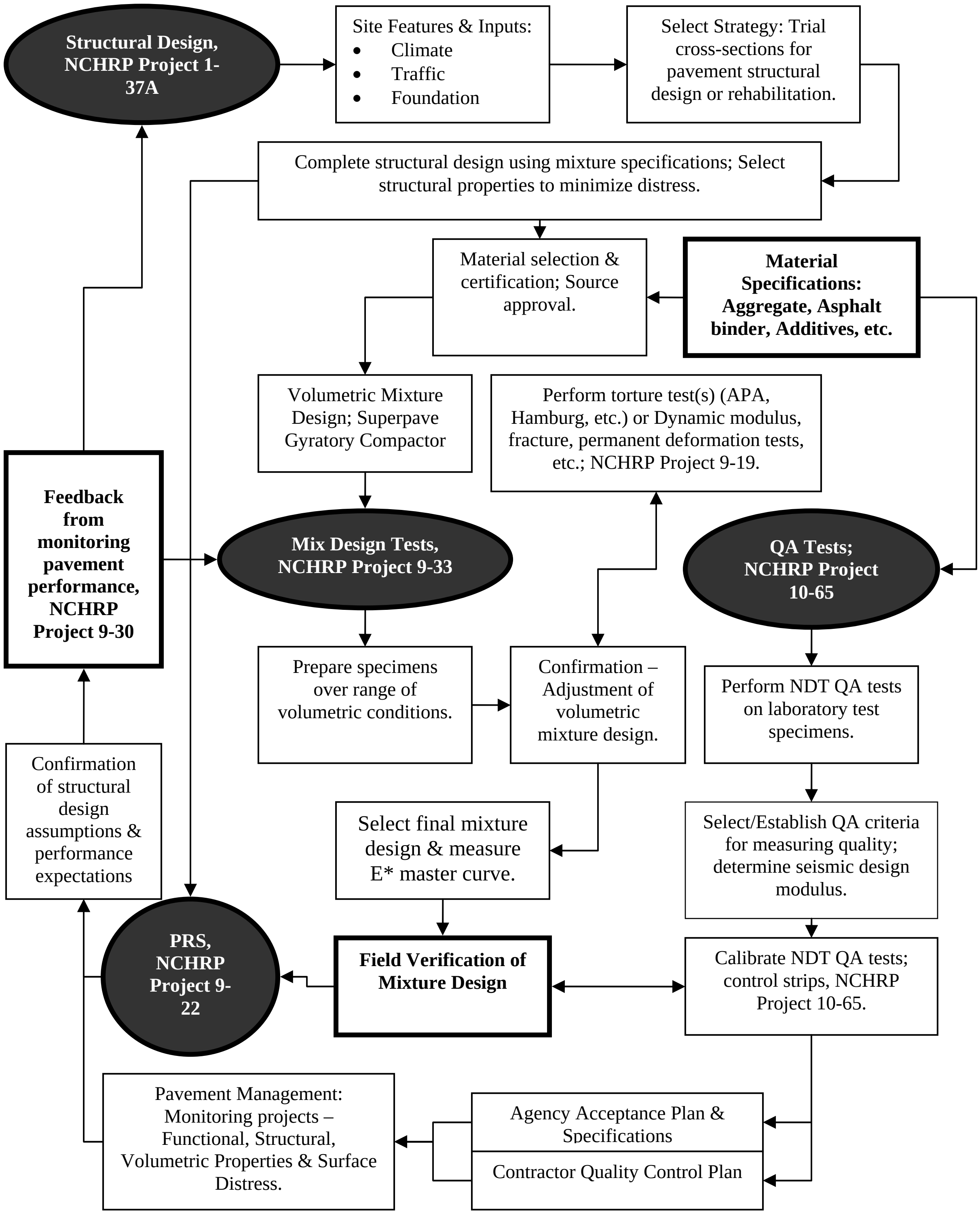

Figure 2. Example Flow Chart for the Systems Approach for Specifying, Designing, and Placing Quality HMA Mixtures

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CHAPTER 3

REVIEW OF NONDESTRUCTIVE TESTING TECHNOLOGIES

Materials are seldom free of defects. Some defects can be difficult to identify, but they can form the basis for rejection or penalty when they occur more frequently or in larger areas. NDT can provide a reliable and cost-effective means to assess the extent of defects in the material or product under evaluation without changing its physical properties.

In the past, NDT has been an after-the-fact technology, used primarily for inspection of parts and components. In contrast, NDT today plays an important role in the examination and evaluation of materials and structures. A number of NDT technologies and inspection systems have been developed that provide data on the quality of the material that do not alter or damage the materials being tested. This chapter provides a discussion and overview on the state-of-practice of selected NDT technologies that have been used for measuring the properties and features of pavements.

3.1 Nondestructive Testing and Evaluation – Definitions and Terminology

NDT is a rather general term used by engineers today to refer to any form of testing that aids in evaluating the strength or perfection of a material without causing any damage or detriment to the material. NDT encompasses several evaluation techniques that are broadly classified as active and passive. An active NDT technique involves the measurement of a response caused by the application of an external force or energy on or through a material or structure without changing the physical character of that material or structure. Ultrasonics, falling weight deflectometer (FWD), and penetration techniques are active NDT techniques. On the other hand, a passive NDT technique involves monitoring or observing the test object in its typical load environment or proof cycle and detecting the presence of a defect by comparing the observed and expected reactions. For instance, visual inspections, acoustic emission, and strain gages are passive techniques. Active NDT techniques are most commonly used in pavement engineering, and all discussion pertaining to NDT techniques in this report refer to active testing methods.

NDT has been in use for a long time in many industries involving the evaluation, inspection, and QC of materials and/or constructed products. In fact, many of the nondestructive examination (NDE) procedures have been standardized. Agencies actively involved in NDT and NDE standardization issues include ASTM (Committee E-7 on Nondestructive Testing) and American Society for Nondestructive Testing (ASNT). ASTM E 1316-95a (Standard Terminology for Nondestructive Examinations) includes definitions for those testing technologies and terms typically used. As a result, ASTM E 1316 will be used as the standard for the terms used within this report. ASTM defines NDT as: "*the development and application of technical methods to examine materials or components in ways that do not impair future usefulness and serviceability in order to detect, locate, measure and evaluate* *discontinuities, defects and other imperfections; to assess integrity, properties and composition; and to measure geometrical characteristics.*"

3.2 Overview of Nondestructive Evaluation Technologies

Using well established, and sometimes fundamental, physical principles, a number of NDT/NDE and/or inspection systems have been developed which provide information on the quality of the material or component. The main techniques used in NDE of pavements are:

- Ultrasonic Techniques
- Acoustic Emission Testing
- Imaging Techniques, including Thermography
- Radar and Microwave Techniques
- Magnetic Flux Leakage Techniques
- Radiographic Techniques

All these NDE systems coexist and, depending on the application, may be used individually or in combination with one another. There obviously is some overlap between the various test methods, but they can be complementary to one another. For example, the fact that ultrasonic testing can reveal both internal and surface flaws and material properties does not necessarily mean that it will be the best method for all inspection applications. Much depends upon the type of flaw or quality characteristic to be measured. Table 16 is a listing of NDE techniques used for evaluating selected non-metallic materials and components, while Table 17 (portions of which were taken from ASTM E 543-02, *Standard Practice for Agencies Performing Nondestructive Testing*) provides a basic comparison of these selected NDE methods.

3.3 NDE Technologies for Evaluating Flexible Pavements

Pavement engineers traditionally have relied on standardized laboratory test procedures to assess material properties and strength parameters. Unfortunately, laboratory tests may not represent the in-place condition of the material and may not provide an accurate condition of the performance characteristics of selected materials under in-service conditions. Furthermore, in pavement diagnostic studies or rehabilitation projects, it becomes imperative to evaluate the existing condition of the pavement, and laboratory tests that are "destructive" are not the preferred option.

A number of NDE technologies and/or inspection systems have been developed that provide information on the quality of the material that do not alter or damage the material being tested. A detailed evaluation of these test methods was completed by Von Quintus et al. (1996) and Saeed et al. (2001) for measuring critical pavement properties and features. Although NDT has been the subject of research for several decades, it is only recently that NDT has seen wide applications in evaluating pavement construction quality. The specific application, the material property to be evaluated, and the obstacles to be overcome in each application dictate the choice of the NDE technique utilized for evaluating a specific material or layer.

Table 16. Key NDE Techniques for Selected Non-Metallic Materials, such as Ceramics and Composites

NDT Techniques	Methods	Example Applications
Dynamic Vibration	Impact & Resonance	Damage, Elastic Moduli
Scanning Ultrasonics	Contact & Non-Contact	Defect Distributions & Damage Assessment
Acoustic Microscopy	Laser & Pulse Echo	Micro-Flaw Detection & Characterization
Analytical Ultrasonics	Velocity & Attenuation	Elastic Moduli, Distributed Flaw Population Statistics
Radiography	Film Radiography	Micro-Flaw Detection, Porosity, Inclusions
X-Ray Tomography	Computed Tomography	Fiber Architecture, Micro-Flaws, Density Variations
Thermography	Thermal Wave	Thermal Conductivity, Densification
Visual-Optical	Laser/Fiber Optics	Stress & Strain, Surface Finish & Roughness

NDT methods saw their first applications in pavement engineering more as a diagnostic and forensic tool rather than a QA tool. NDT for pavement diagnostic studies has been confined primarily to the measurement of peak deflections on the pavement's surface for estimating pavement stiffness for overlay design or for backcalculation of elastic layer modulus. The FWD, the dynamic cone penetrometer (DCP), and more recently, the portable FWD (PFWD) have been the most commonly used deflection-based NDT devices in the pavement industry.

An increased awareness of NDT applications in other fields drew significant attention from pavement engineers, resulting in the adoption of several other NDT techniques for evaluating pavements. Seismic and ground penetrating radar (GPR) methods have been used for determining the modulus and thickness of individual layers in flexible pavements, respectively. The efficiency of infrared thermography, impact-echo, impulse response, and other test methods also has been evaluated for use in pavement engineering (Nazarian et al., 1993; Maser, 1990, 1994, Willoughby, et al., 2003). Acoustic emission has been used to evaluate moisture damage in HMA pavements, while nuclear magnetic resonance techniques and non-nuclear devices have been used for measuring the density of pavement layers (Chang, 1994). Nuclear density gauges represent the current state-of-practice or baseline for QA application and are not discussed or evaluated as part of NCHRP Project 10-65. All discussions and evaluations with regard to density measurements were limited to the newer non-nuclear devices.

Table 17. Comparison of Selected NDE Methods (ASTM E543)

Method	Properties Sensed or Measured	Typical Discontinuities Detected	Advantages	Limitations
Ultrasonic examination	Changes in acoustic impedance.	Cracks, voids, porosity, lamination, delaminations and inclusions.	Excellent penetration; readily automated; good sensitivity and resolution; requires access to only one side; permanent record, if needed.	Requires acoustic coupling to surface; reference standard usually required; highly dependent upon operator skill; relative insensitivity to laminar flaws which are parallel to the sound beam.
Sonic examination	Changes in acoustic impedance.	Disbonds, delaminations, cracks or voids.	Simple to implement; readily automated; portable.	Geometry sensitive; poor definition.
Ultrasonic holography	Same as ultrasonic examination.	Used primarily for evaluation of discontinuities detected by other members.	Produces a viewable image of discontinuities.	Cost; limited to small regions of the structure; poor definition compared to radiography.
Acoustic emission	Stress wave energy generated by growing flaws, areas of high stress, leaks.	Cracks, structural anomalies, leaks, also delamination, fiber fracture and matrix failure in composite materials.	100% volumetric examination in real time, complication geometries, very high sensitivity, permanent record, accurate flaw location.	Structure must be loaded, sensors must be in contact with structure.
X and gamma radiography	Changes in density from voids, inclusions, material variations, placement of internal parts.	Voids, porosity, inclusions and cracks.	Detects internal discontinuities; useful on a wide variety of materials; portable; permanent record.	Cost; relative insensitivity to thin or laminar flaws such as fatigue cracks or delaminations which are perpendicular to the radiation beam; health hazard.
Neutron radiography	Compositional inhomogeneiti es; selectively sensitive to particular atomic nuclei.	Presence, absence, or mislocation of components or variations of suitable composition.	Good penetration of most structural metals; high sensitivity to favorable materials; permanent record.	Cost; relatively portable; health hazard.
Strain gages	Mechanical strains.	Not used for detection or discontinuities.	Low cost; reliable.	Insensitive to preexisting strains; small area coverage; requires bonding to surface.
Brittle coatings	Mechanical strains.	Not commonly used for detection of discontinuities.	Low cost; produces large area map of strain field.	Insensitive to preexisting strains.
Optical holography	Mechanical strains.	Disbonds; delaminations; plastic deformation.	Extremely sensitive; products map of strain field; permanent record if needed.	Cost; complexity; requires considerable skill.
Liquid penetrant examination	Surface openings.	Cracks, porosity, laps and seams.	Inexpensive; easy to apply; portable.	Discontinuity must be open to an accessible surface; false indications often occur.

Method	Properties Sensed or Measured	Typical Discontinuities Detected	Advantages	Limitations
Eddy current examination	Changes in electrical and magnetic properties caused by surface and near-surface discontinuities.	Cracks, seams, laps, voids, and variations in alloy composition and heat treatment	Moderate cost; readily automated; portable; permanent record if needed.	Conductive materials only; shallow penetration; geometry sensitive; reference standards often necessary.
Microwave examination	Anomalies in complex dielectric coefficient; surface anomalies in conductive materials.	In dielectrics: disbonds voids, and cracks; in metal surfaces: surface cracks.	Noncontacting; readily automated; rapid inspection.	No penetration of metals; comparatively poor definition of flaws.
Magnetic particle examination	Leakage in magnetic field flux caused by surface or near-surface discontinuities.	Surface or near-surface cracks, laps, voids, and nonmetallic inclusions.	Stable; inexpensive.	Ferromagnetic materials only; surface preparation may be required; false indications often occur.
Magnetic flux leakage examination	Leakage in magnetic field flux caused by surface or near-surface discontinuities.	Surface or near-surface cracks, laps, voids, and nonmetallic inclusions.	Sensitivity to typical discontinuities; readily automated; moderate depth penetration; permanent record, if needed.	Ferromagnetic materials only; proper magnetization of part sometimes difficult when parts do not have uniform cross section.
Infrared testing	Surface temperature; anomalies in thermal conductivity or surface emissivity, or both.	Voids or disbonds in nonmetallics; location of hot or cold spots in thermally active assemblies.	Produces a viewable thermal map.	Cost; difficult to control surface emissivity; poor definition.
Leak detection	Pressure changes, bubbles, acoustic hiss, or the passage of a tracer fluid through a pressure boundary.	Leaks in closed systems.	Good sensitivity; wide range of instrumentation available.	Requires internal and external access to system; contaminants may interfere; can be costly.

The remaining sections of this chapter provide a discussion on the fundamental principles of physics and engineering concepts used by different NDT technologies that have been used for measuring material properties and features of flexible pavements. Table 18 lists the technologies or methods that have been used to measure the properties and features of flexible pavements. The review provides a summary of the measurement techniques, equipment and output, and identifies those technologies that have been and can be used to measure specific properties.

Table 18. NDT Technologies and Methods Used to Measure Material Properties and Features of Flexible Pavements

Type of Property		
Volumetric	**Structural**	**Functional**
Density-Fluids Content: • Nuclear gauges • Non-nuclear gauges • GPR – ground & air coupled methods	Thickness: • GPR • Impact Echo • DCP	Profile: • ARAN Van • Profilometer • Profilograph
Density: • Pavement Quality Index • PaveTracker gauge • Humboldt nuclear density gauge • Onboard Density Measuring System	Modulus: • Seismic (SASW, Impulse Response, Impact Echo) • Deflection (LWD & FWD)	Noise: • Noise Trailer
Segregation: • Infrared camera • Profile sensor van • R0SAN unit • GPR	Modulus/Shear Strength: • DCP	Friction: • Skid Trailer

3.4 Impact Devices and Technology for Unbound Materials and Layers

Two types of impact testers for measuring the strength of unbound materials are discussed in this section—the DCP and the Clegg Impact Soil Tester.

3.4.1 Dynamic Cone Penetrometer

The DCP is a testing device to estimate the in place strength and deformation characteristics of unbound pavement layers. The DCP was developed in South Africa in 1975 (Kleyn, 1975) and has been used in many parts of the world, including Australia, New Zealand, United Kingdom, Central Africa, Israel, Norway, New Zealand, Germany, Canada, Portugal, and several state and federal agencies in the United States. It is used primarily to measure the structural capacity of unbound pavement layers and embankments, and it can provide an assessment on the uniformity of compaction. It is considered a feasible tool for use in QA during construction because it is amenable to many types of evaluations and is easy to handle.

DCP testing can be performed on unfinished or compacted unbound pavement layers. By ASTM's definition of NDT, the DCP is a quasi-NDT device, because it changes the structure of the material being tested. It also requires that the HMA surface layer be removed to test the supporting unbound materials and soils. Nonetheless, the DCP is considered an NDT device under NCHRP Project 10-65.

The test involves driving a cone shaped probe into the soil or aggregate layer using a dynamic load and measuring the advancement of the device for each applied blow or interval of blows. The factors that have a direct impact on depth of penetration are drop height of the weight, cone size, and cone shape. The strength of the material being tested also has a direct impact on the depth of penetration with each blow. In other words, the resistance to penetration is dependent on the strength of the material. The strength, in turn, is dependent on density, moisture, and material type of the layer evaluated.

Principle of Operation, Equipment, and Software

The DCP is defined by ASTM 6951-03 as a device used to assess the in place strength of soils or compacted materials. The DCP device consists of a0.62 in. (15.8 mm) - diameter steel rod with a standard cone shaped tip, a 17.6-lb (8-kg) hammer that is dropped by a fixed height of 22.6 in (575 mm), a coupler assembly, and a handle. The cone tip has a diameter of 0.79 in (20 mm) with an angle of 60 degrees to reduce side friction. This is accompanied with a sliding rod, 0.62 in (15.8 mm) in diameter, but shorter in length, and attached parallel to the main rod to measure the penetration of the device. Figure 3 shows the manual DCP device in operation. The entire device is made of stainless steel to protect it from corrosion. However, the cone tip is made of hardened tool steel or a similar material to resist wear and tear.

The test is conducted by dropping the weight and measuring the penetration of the cone. The data recorded include the number of blows and the depth of penetration. The rate of penetration is defined as the depth of penetration per blow, and is often referred to as the penetration index or the DCP ratio. The units used are mm/blow or in/blow. The penetration rate is determined as the slope of the curve relating the number of blows to the depth of penetration. The device can be operated manually (see Figure 3) or can be automated by installing it on a trailer, as shown in Figure 4. The automated DCP (ADCP) has a fully developed software tool to determine soil support values.

Application to Flexible Pavement Testing

The use of DCP in pavement evaluation and QA during construction has gained increased popularity mainly because the equipment is simple and easy to handle. It is amenable to many types of evaluations and several material types. It is also an economical device with minimal operator training needs. The information gathered with regard to base/subbase relative thickness and strength is invaluable compared to the resources and time consumed to perform the test.

The DCP penetration rate, *PR*, in in/blow, has been correlated to several engineering properties of the material. It was initially correlated to the California Bearing Ratio (CBR) of the pavement subgrade (Kleyn, 1975; Livneh and Ishai, 1987; Livneh, 1989). These models defined a relationship between the log of CBR and the log of *PR*. Further studies extended a different relationship for fine and coarse-grained soils (Harrison, 1989). More recently, the U.S. Army Corps of Engineers (Webster et al., 1992) developed a relationship based on a wide range of tests on granular and cohesive materials. This relationship, shown as equation 1, is the most widely used one today.

$$Log(CBR) = 2.465 - 1.12Log(PR) \quad (1)$$

Figure 3. Photo of Manual DCP in Operation (courtesy of Minnesota Road Research Section, Office of Materials, Minnesota DOT)

Figure 4. Automated DCP Attached to a Trailer (courtesy of Minnesota Road Research Section, Office of Materials, Minnesota DOT)

This correlation is included in the MEPDG for all unbound materials and soils. Correlations of the *PR* to other engineering properties are accomplished based on the relationship these properties have with CBR. For example, equation 2 is the more common relationship that has been used between resilient modulus (M_R) and CBR (Heukelom and Klomp, 1962).

$$M_R = 1500(CBR) \qquad (2)$$

The particular correlation or regression equation between M_R and CBR that is included in the MEPDG is shown below, as equation 3. The CBR is measured in accordance with AASHTO T193, and provides a direct tie between use of the DCP for QA application and structural design of flexible pavements.

$$M_R = 2555(CBR)^{0.64} \qquad (3)$$

Equations 1 and 2 or 3 can be used to relate the *PR* to M_R values for subgrade soils. This type of correlation was validated by studies that verified the computed modulus to the backcalculated modulus from FWD data (Chen, 2001). Several studies have also correlated the *PR* to the elastic modulus of the subgrade (Chua and Lytton, 1981). In addition, some agencies are developing correlations between resilient modulus and the penetration rate or index.[4] The correlation included in the MEPDG, by combining equations 1 and 3, is shown as equation 4.

$$Log(M_R) = 4.985 - 0.7168 Log(PR) \quad (4)$$

3.4.2 Clegg Impact Soil Tester

The Clegg Impact Soil Tester is an instrument for monitoring and controlling the quality of placing unbound aggregate materials and embankment soils. Generally, it is not used for testing the unbound layers of existing flexible pavements, unless the bound layers can be sawed and removed without disturbing the layers to be tested. The device is manufactured by SDi of Trowbridge. There are three versions of this device—one that uses a 4.5-kg hammer, another using a 2.25-Kg hammer, and a lightweight version that uses a 0.5-Kg hammer. The equipment consists of a compaction hammer operating within a vertical guide tube, as shown in Figure 5.

Figure 5. Photo of the Clegg Impact Soil Tester (courtesy of SDi WebSite)

The hammer falls within the guide tube when it is released and contacts the surface of the material or layer being tested. The hammer then decelerates at a rate determined by the

[4] As an example, the Colorado, Minnesota, Montana, and Ohio DOTs have been collecting DCP and resilient modulus data on a range of soils and materials to develop similar correlations for their own use in pavement design and/or QA activities.

stiffness of the material within the region of impact. A precision accelerometer mounted on the hammer measures the deceleration and provides an output in units of an Impact Value.

The test procedure recommends that five tests or drops of the hammer be used to obtain a reliable Impact Value for each test location. The first two drops take up the surface irregularities, and the final three drops should result in consist readings. The device can be fitted with software for data collection and quality control of the data.

The Impact Value (*IV*) resulting from the tests has been correlated to CBR, much like the penetration rate from the DCP. The relationship that has been developed and included with the literature from SDi is shown as equation 5.

$$CBR = \left(0.24\left[IV\right]+1\right)^2 \quad (5)$$

3.5 Deflection Measuring Devices and Technology

The FWD and heavy weight deflectometer (HWD) are well documented in the literature. These two devices generally are categorized as one device with different maximum load capacities, with the higher-load capacity HWD primarily designed for airfield use. Either device can be used for evaluating the strength and response of pavements using appropriate load levels.

The light weight deflectometer (LWD) operates in a similar fashion to the FWD; however, the LWD is small and light enough to be carried and operated by one person and is mainly used on unbound materials, where lighter loads are required. The LWD is less suitable for deflection tests on thick bound layers. On the other hand, the HWD is not well suited for tests on unbound layers. Of the deflection-based methods, the FWD has the greatest potential range of use for new or rehabilitated pavement structures.

This method of evaluation essentially involves measuring surface deflections to applied loads of known magnitudes. The measured deflections are the pavement's structural response, and an indicator of its structural capacity. This evaluation process has been used in rehabilitation designs, pavement management, forensics, and in determining seasonal load restrictions and overload permits. Deflection-based NDT devices can be grouped into three main categories:

- Static or slow moving load deflection devices, such as the Benkelman beam, California traveling deflectometer, and the LaCroix deflectometer.
- Steady state deflection (vibratory) devices, such as the Road rater and Dynaflect trailer.
- Impact load deflection devices, such as the FWD, HWD, and LWD.

The nature of loading imparted by a moving truck on the pavement is closest to the weight application simulated by the FWD and HWD impact load devices, making them a natural choice over the other deflection testing devices. The percentage of state agencies using the FWD has increased from 10 percent in 1980 to over 80 percent after the Strategic Highway Research Program (SHRP) was completed (Von Quintus et al., 1996; Von Quintus and

Killingsworth, 1998). Thus, the review of deflection-based methods focuses on the impact load devices.

Two other deflection measuring devices recently have been developed that have great potential for use in evaluating, managing, and measuring the quality of flexible pavements. These two devices are the Rolling Dynamic Deflectometer (RDD), developed at the University of Texas, and the Rolling Wheel Deflectometer (RWD), developed by Applied Research Associates (ARA, 2004). Both of these devices are still considered to be in the research and development stage. Thus, they are mentioned but not included in the review of NDT technologies for measuring layer properties and features of flexible pavements and HMA overlays.

3.5.1 Falling Weight Deflectometer

Principle of Operation, Equipment, and Software

The FWD consists of an impact loading mechanism and a set of sensors to measure vertical surface displacements at the load location and at specified offsets from the load. The device delivers a transient load to the pavement surface, and the sensors measure the surface deflection at the specified locations. The system is trailer mounted, as shown in Figure 6.

The loading device consists of a load plate that can apply an impulse load of different magnitudes ranging from1500 to 27000 lb (6.7 to 120 kN). The load can be applied from three standard drop heights resulting in a load pulse of 0.025 to 0.03 seconds. The load plate is circular and has a standard diameter of 6 inches (150 mm). Figure 6 also shows a close up of the FWD loading plate in contact with the pavement surface. A larger loading plate is used to test unbound aggregate layers and subgrade soils prior to placing the HMA or other bound layers.

The vertical deflection response is measured at the surface of the pavement at different sensor locations. The sensor locations are typically chosen to adequately characterize the pavement structure being tested. These deflection measurements are used to characterize the deflection basin of the pavement (see Figure 7). A backcalculation algorithm is used to estimate the modulus of pavement layers based on the measured deflections and the layer thicknesses derived from cores. The HWD works on the same principle but uses a higher level of load. It is designed primarily for airfield use and is not discussed in this study.

Test Procedure

The developmental work for the FWD was conducted mainly at the Technical University of Denmark between 1969 and 1976, and the device has been used in the United States since 1978. ASTM D4695-03, *Standard Guide for General Pavement Deflection Measurements*, provides the guidance and procedural information for measuring pavement surface deflections, directly under, or at locations radially outward (offset) from the load.

Figure 6. Trailer Mounted FWD

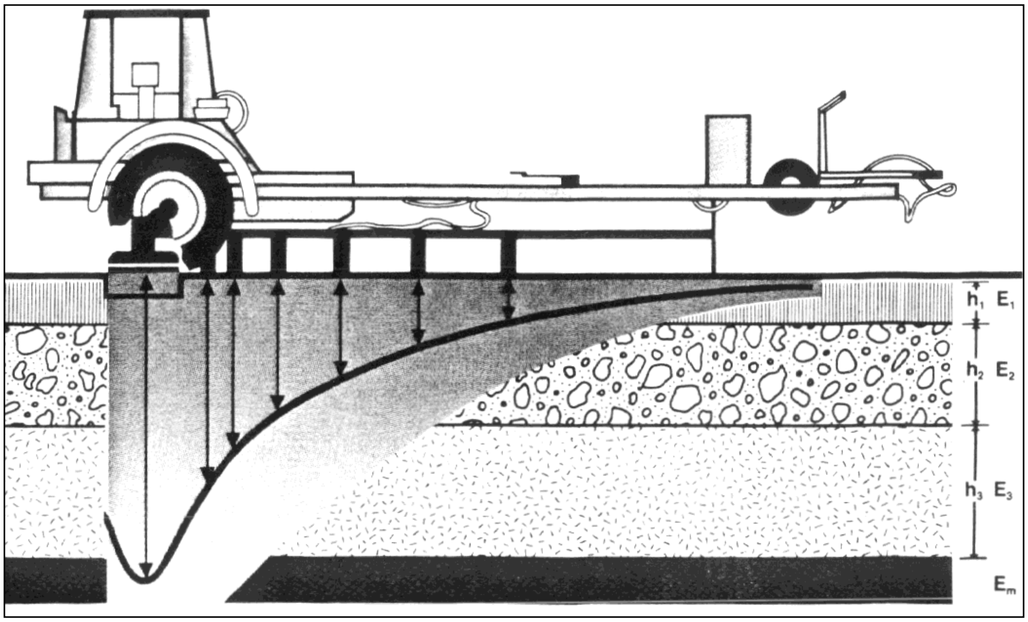


Figure 7. Typical Deflection Basin Measured from FWD (after AASHTO, 1993)

3.5.2 Light Weight Deflectometer or Portable FWD

After successful use of the FWD, the LWD, also known as the PFWD, was developed in the late 1970s to perform deflection based evaluations in a much simplified manner. The PFWD also uses plate bearing test equipment, but the deflection is measured at a single point under the loading plate (although some LWDs also measure the deflection at a few points from the loading plate). The measured deflection is used to calculate or estimate the bearing capacity or composite modulus of the pavement layers. Figure 8 shows a picture of two LWDs. More sophisticated versions of the LWD, with advanced software packages to process the load and deflection readings, were developed in Europe in the early 1990s.

3.5.3 Application to Flexible Pavement Testing

Deflection-based measurements historically have been conducted to assess the bearing capacity of pavements in need of rehabilitation at the project level or for relative bearing capacity assessments at the network level as part of a complete pavement management system. In recent years, however, interest has grown to use deflection measurements (primarily with the FWD, but also with the LWD) to assess the structural properties of pavement layers that are under construction. Many of the same analysis techniques used for evaluating in-service pavements can also be applied to new construction measuring quality characteristics of QA programs (stiffness, modulus, etc.).

The traditional backcalculation techniques have incorporated static-linear analyses to calculate the elastic modulus of the pavement layers. Commonly used programs include BISDEF, ELMOD, ELSDEF, EVERCALC, ISSEM4, MODCOMP, MICHBACK, MODULUS, and WESDEF. However, these programs do not result in unique solutions of layer moduli (Von Quintus and Killingsworth, 1998; ASTM, 1994).

Figure 8. Two Different LWDs

Forward-calculation techniques have been developed and utilized in research studies to obtain unique solutions for layer modulus values for surface courses and the underlying unbound and bound layers (Stubstad, 2002). For forward-calculation of HMA layers, the first three sensors must be placed at 0, 8, and 12 inches (0, 203, and 305 mm), in compliance with LTPP's protocol for testing flexible pavement layers. These techniques have been used in selected agencies (for example, Mississippi).

The FWD test protocol for control or acceptance testing is much the same as the normal test protocols used for pavement rehabilitation design. Test spacing depends on the length of a particular project (for example, 10 meters or 25 feet, per lane), and the applied load has to be adjusted to realistic levels, with lower stress levels applicable to unbound layers. More drops of the FWD weight are needed for testing unbound materials than for bound layers, because of the increased variability associated with unbound material. In any event, a statistically significant sample of test results must be available in order to use PWL or other statistical approaches.

3.6 Ground Penetrating Radar Devices and Technology

GPR is a geophysical nondestructive technique that uses electromagnetic pulses to test, characterize, or detect subsurface materials based on changes in electrical and magnetic properties of the subsurface layers. GPR is also referred to as ground probing radar, georadar, subsurface radar, or earth sounding radar. Literature traces its first use in Austria in 1929. Commercial GPR equipment became available in the 1970s, and wide research was carried out with its application in the pavements area over the next three decades. Both ground coupled and air horned antenna systems are available for multiple applications in the transportation area (see Figure 9.)

Limitations of GPR have included the cost and complexity of the equipment, the need for interpretive expertise, and the requirement for office data processing. Recent developments with GPR hardware have yielded systems which are less expensive and easier to operate, which could overcome equipment complication issues. On the data processing side, prototype software for automated on-site processing has been developed (Maser, 2002 and 2003) to overcome some of the complicated processing issues.

GPR has been used extensively for measuring pavement layer thickness and more recently has been applied to the measurement of pavement density and air content. ASTM D4748-98 (*Standard Test Method for Determining the Thickness of Bound Pavement Layers Using Short-Pulse Radar*) is used for estimating layer thickness; there is no ASTM nor AASHTO standard test method for estimating air voids. GPR layer thickness and air content measurements recently have been used for QA of new HMA pavement layers, as described in the following sections.

3.6.1 Operation Principles

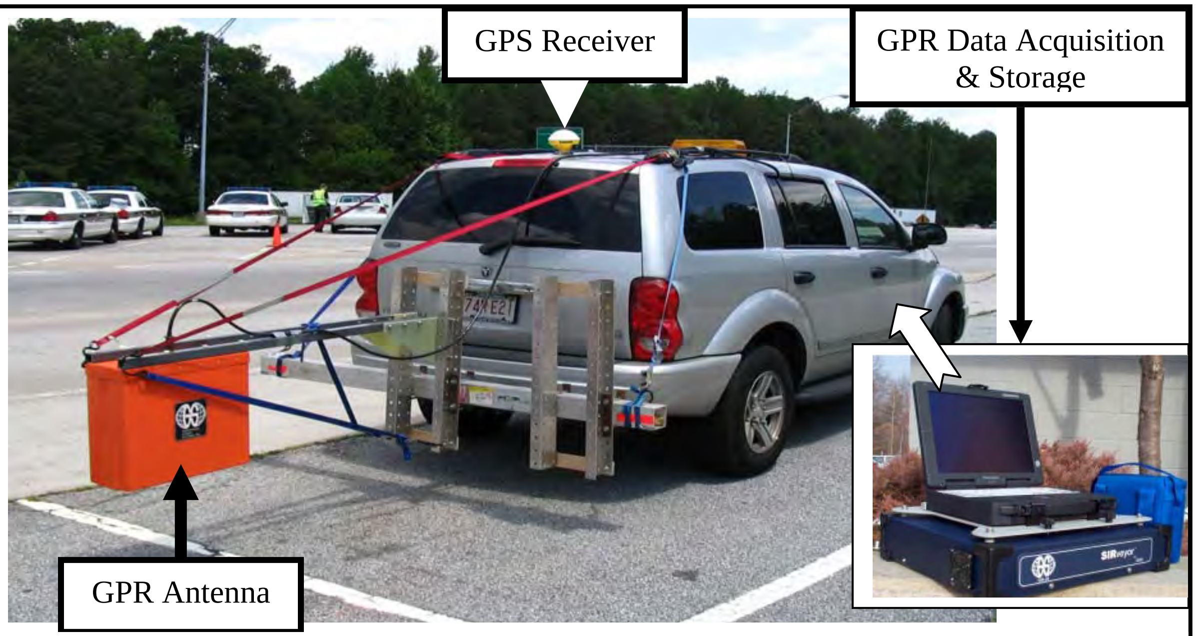
GPR works using short electromagnetic pulses radiated by an antenna which transmit these pulses and receive reflected returns from the pavement layers, as shown in Figure 10.a. The reflected pulses are received by the antenna and recorded as a waveform, as shown in Figure 10.b. As the equipment travels along the pavement, it generates a sequence of waveforms as shown in Figure 10.c. The layer boundary between the HMA and aggregate base is clearly visible in this sequence of waveforms. These waveforms are digitized and interpreted by computing the amplitude and arrival times from each main reflection. The pavement thickness and dielectric permittivity can be computed from these amplitudes and arrival times according to equations 6 and 7 (Maser and Scullion, 1992):

$$Thickness(mm) = \frac{V_{GPR} * t_{GPR}}{2} = \frac{150 * t_{GPR}}{\sqrt{\varepsilon_{a[GPR]}}} \qquad (6)$$

Where:

$$\varepsilon_{a[GPR]} = \left[\frac{Apl + A_{GPR}}{Apl + A_{GPR}}\right]^2 \qquad (7)$$

Where V_{GPR} is the velocity and calculated from $\varepsilon a_{[GPR]}$, the dielectric constant of the HMA; t_{GPR} is the time delay between the reflections from the top and bottom of the HMA layer, computed automatically from each waveform; A_{GPR} is the amplitude of the reflection from the top of the HMA, computed from each waveform; and Apl is the amplitude of the reflection from a metal plate, obtained during calibration.



a. Air-Coupled GPR Antenna Attached to Survey Vehicle

b. Ground-Coupled Antenna Arrays Attached to Survey Vehicle

Figure 9. GPR Antennas Attached to a Standard Survey Vehicle

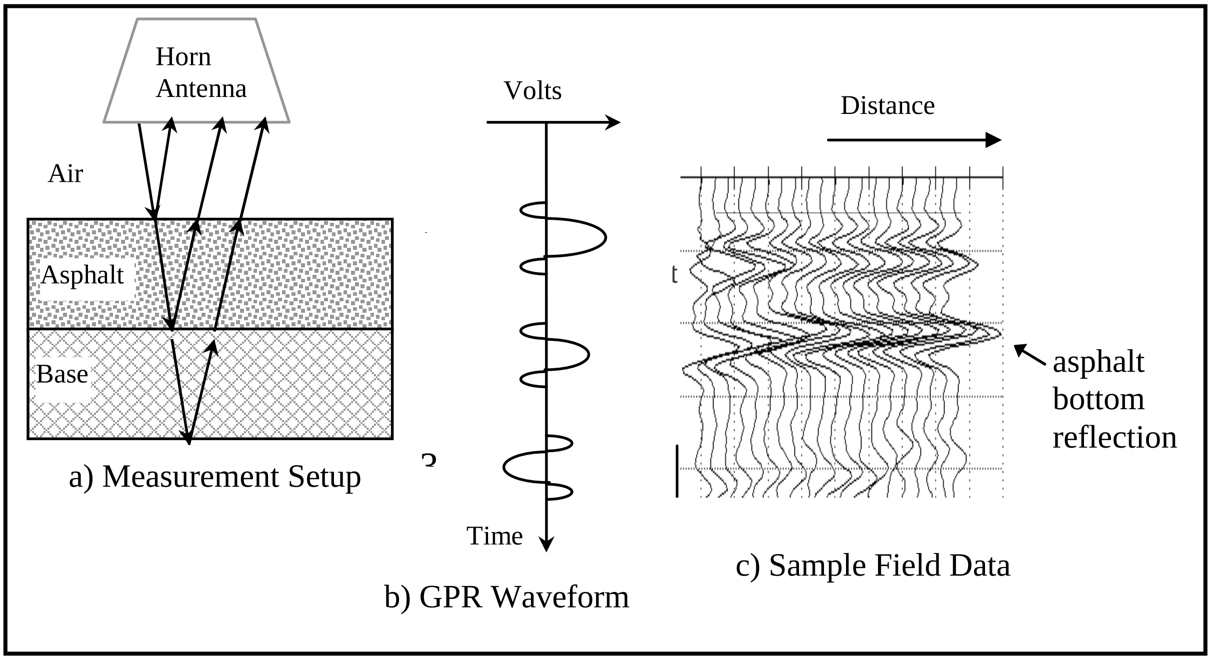


Figure 10. Principle of GPR Operation for Pavement Layer Thickness Evaluation

3.6.2 Equipment and Software

The current GPR technology used in transportation-related applications emerged over 30 years ago through two separate efforts: (a) the development of ground-coupled antenna systems for geological and geotechnical applications and (b) the development of air-coupled horn antennas for mine detection (see Figure 9).

The ground-coupled equipment traditionally has been used for maximum depth penetration and where information is more qualitative rather than quantitative. This technology has been used for a variety of subsurface applications, including mapping of groundwater, bedrock, and soil layers, detecting pipes, buried drums, and subsurface contamination, and locating reinforcement. Antennas are available with center frequencies ranging from 80 MHz to 1.5 GHz, providing a wide range of penetration depths and resolutions. The use of higher frequencies (8-12 GHz) with ground-coupled antenna has been investigated at Iowa State (Jaselskis et al., 1998) for measurement of pavement density. The system incorporated high frequency antennas deployed in front of and behind the roller. A prototype was constructed and initial results showed promise, but problems were encountered and further development of this system has not been reported.

The 1 GHz horn, air-coupled horn antenna equipment is operated 20 to 50 cm (8 to 20 in) above the pavement surface from a moving vehicle and thus allows data collection at highway speed. This antenna has proven to be suitable for pavement and bridge deck applications, where quantitative results are required at high resolution but for shallow penetration. The antenna is non-contact, and the typical 1 GHz horn antenna produces a clear, one-cycle pulse revealing interfaces in the pavement structure as close as 5 cm. Due to the large surface reflection and the high frequencies used, the horn antenna is limited in depth of penetration to about one meter, which is adequate for most QA applications.

Data from ground-coupled equipment generally are analyzed from a graphical display on a computer screens. The analysis seeks to relate arrival patterns from different reflectors to depths, horizontal locations, and qualitative descriptions of subsurface conditions (Ulricksen, 1982). Air horn antenna data generally are processed numerically with custom or commercially available software. Fully automated software has been developed for thickness and density measurement in newly constructed pavements (Scullion and Chen, 1999; Maser, 2002). The automation of thickness calculation is possible for new construction, since the nominal HMA layer thickness should be known for QA application. For pavement thickness evaluation on existing pavements, different software packages are available, but the analysis usually requires user intervention to identify the pavement layers to be analyzed and to ensure that these layers are properly tracked (e.g., Infrasense *PAVLAYER*; Roadscanner *Road DOCTOR*; GSSI *RADACT;* and *Hyper Optics™ Pavement Thickness Analysis*).

Most procedures in use to-date have employed a single antenna in their evaluation method. Electronic Pavement Infrastructure, Inc. (EPIC), however, has a proprietary analysis method that employs multiple antennas. The EPIC proprietary system is referred to under the trade name *Hyper Optics™*. This multiple antenna system includes four major modules that provide an assessment of the pavement: Pavement Thickness Analysis (PTA), Pavement Composition Analysis (PCA), Pavement Voids Analysis (PVA), and Relative Compaction Profile (RCP). The multiple antenna system can provide complete coverage of a lane, while providing multiple volumetric properties. The accuracy of the single or multiple antenna methods for estimating the volumetric properties has not been well established to-date. The accuracy of these methods will be addressed in chapter 4.

3.6.3 Application to Flexible Pavement Testing

The most common application of GPR to pavements has been for thickness measurements associated with rehabilitation design and for pavement structure inventory data input to pavement management systems (Maser, 1999).ASTM D 4748-98 (*Standard Test Method for Determining the Thickness of Bound pavement Layers Using Short-Pulse Radar*) is commonly used for this application. Numerous research evaluations have been conducted to establish and confirm the accuracy of the GPR method for determining the thickness of existing pavements.

The capability of GPR to determine HMA layer thickness has been verified for HMA surface layers and bituminous base layers (Roddis et al., 1992). Investigation of GPR for measurement of unbound aggregate base layer thickness has been limited, and the available data are for existing pavements. Studies in Texas and Florida showed that the average per site deviation between GPR and core measurements ranged from 19 to 25 mm, or 10 to 15% (Maser and Scullion, 1992; Fernando et al., 1994). These studies showed that base layer thickness could not be measured for cement treated bases, since there is inadequate dielectric contrast between the stabilized base and the subgrade. Subsequent studies of existing pavements have shown that the ability to detect the bottom of the base varies considerably, and cannot be predicted in advance. [5] This unpredictability might be due to the "blurring" of the boundary between unbound base and subgrade caused by migration of fine material from the subgrade over time.

The application to QC/QA for new construction is more recent, in part because of stringent accuracy requirements. The ability to detect unbound aggregate base layer thickness in new construction has not been reported. It is likely that the limitations to detect the base/subgrade boundary in older pavements will not be present in new construction.

GPR has also been used to some extent for pavement condition diagnosis, such as detection of voids, segregation, and stripping in HMA (Scullion and Rmeili, 1997). As an example, GPR was used in a Georgia DOT study to identify areas of stripping in thick HMA pavements (Hammons et al., 2005 and 2006). GPR was only partially successful and primarily used to create analysis segments with different dielectric properties for taking cores and conducting seismic tests. As noted above, the accuracy of using GPR to detect stripping, segregation, density, and voids has not been established.

3.6.4 Application to HMA Density and Air Void Content Determinations

Recent work has shown that air horn antenna GPR equipment can accurately characterize the air void content of a newly placed HMA mat. The air content is determined by correlation with the dielectric permittivity measured directly from the GPR signal (see equation 6). Saarenketo and Roimela (1998) demonstrated a correlation between the GPR measured dielectric and newly placed HMA air void content. The developed relationship that was used, shown as equation 8, led to the implementation of the GPR air horn antenna as a standard test method for QC of HMA density in Finland.

$$AirVoids = A_{GPR}(e)^{b_{GPR}\,\varepsilon_{s[GPR]}} \tag{8}$$

Where A_{GPR} and b_{GPR} are determined from calibration cores, and ε is the surface dielectric from GPR data. Results of this data correlation are discussed in chapter 4.

Work in the U.S. confirmed the Finnish approach and demonstrated the ability to map air content variations on a two-dimensional plan view of the newly constructed pavement (Sebesta and Scullion, 2003; see Figure 11). Utilizing the methods developed in Finland for relating the surface dielectric to in-place air voids, probability distributions are generated for the air void content of each control strip or section by using cores to calibrate the equation 8. Air void predictions are made for approximately 5,000 GPR readings within each lot or test section.

Other agencies have also recognized the benefits of applying the GPR technology in their QA program for measuring density or air voids. As an example, Florida DOT is currently sponsoring a project for confirming the use of GPR for evaluating density measurements and

[5] Comments and statements are based on the personnel experience of Dr. Kenneth Maser and based on his extensive experience with the use of GPR.

has already completed some work using the *Hyper Optics*TM technology. As noted above, the EPIC system uses multiple antennas and proprietary software to provide an estimate of the HMA mixture volumetric properties for complete coverage of a lane at highway speeds in real time. Details of this procedure and its reported accuracy are discussed in chapter 4.

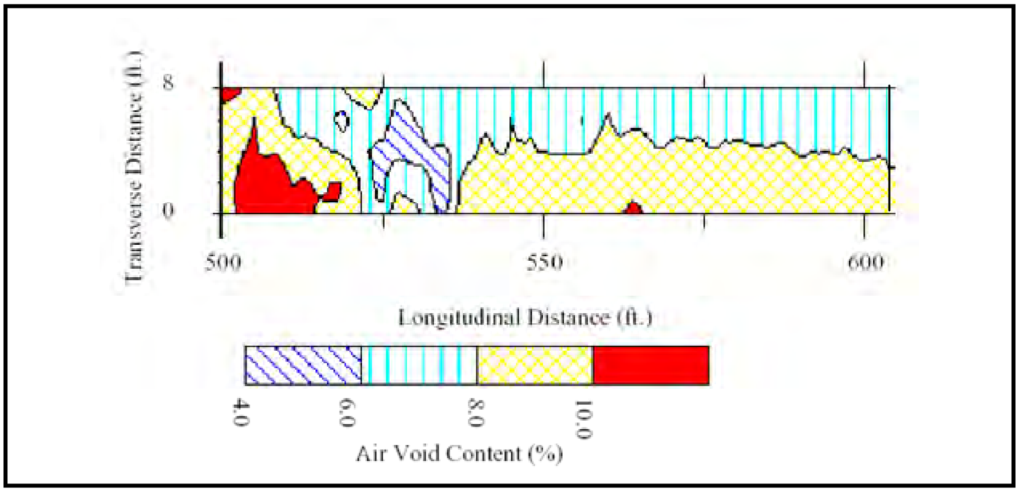


Figure 11. Contours of Air Void Content from GPR Data (Sebesta and Scullion, 2003)

3.7 Infrared Thermography Technology

Infrared (IR) thermography is a diagnostic NDE method which relates changes in surface temperature of a material to subsurface or internal flaws. Thermography simply means the mapping of isotherms, i.e. contours of the equal temperature over the surface of a material or component, and is a method of evaluating materials by measurement of their surface temperature. Basically, heat-sensing materials are used to detect irregularities in temperature contours and such thermal irregularities can be related to defects and/or flaws. Test standards of this type include:

- E 1543-94: Standard Test Methods for Noise Equivalent Temperature Difference of Thermal Imaging Systems
- E 1213-92: Standard Test Method for Minimum Resolvable Temperature Difference for Thermal Imaging Systems

Infrared is a particular implementation of thermography in which an infrared camera is used as the means for making surface temperature measurement. An infrared camera detects the infrared radiation emitted by a material surface. With appropriate calibration for material properties and background radiation, this radiation can be converted into a direct measurement of temperature of the material surface.

IR thermography has been used for the detection of segregation in newly placed HMA, as well as stripping and debonding between HMA layers due to discontinuity in the temperature caused by the difference in voids between two areas (see Figure 11). The effectiveness of IR thermography in identifying segregated areas was recently evaluated in Texas by taking measurements on new HMA overlays at the time of placement, coring, then identifying relationships between changes in the IR data with changes in the measured volumetric and engineering properties of field cores (Sebesta and Scullion, 2003). Analyses of results showed that changes in IR data were significantly related to changes in HMA properties, such as air void content and gradation.

Figure 12. Infrared Camera Attached to Data Collection Vehicle

The potential of IR to serve as a QA tool for evaluating HMA materials or flexible pavement construction has been studied in detail only within the past 5 years or so. It is expected that the use of IR cameras or sensors has potential for newly placed HMA lifts located near the surface, but the technology is less reliable for thicker HMA layers to detect anomalies located below the surface.

Based upon current Texas DOT specifications, significant changes in the HMA are expected if temperature differentials greater than 25 ºF (13.9 ºC) are measured after placement but before breakdown rolling. Work performed in Texas indicates that results from IR imaging are indeed relatable to changes in HMA constituents, and the proposed acceptability limits being used for temperature differentials are reasonable.

Washington DOT has also performed research that uses an IR camera to view the process of placing HMA (Willoughby et al., 2003). Their results show how the temperature changes are depicted with the IR camera, and the correlation between temperature, density, and air void. A similar process was used in Georgia to detect stripping and segregation within thick HMA layers. The results from the Georgia study were less encouraging (Hammons et al., 2005).

3.7.1 Operation Principles

Infrared thermography involves the use of non-contact surface temperature measurement to diagnose subsurface conditions. The basis of the measurement is that the surface temperature at a defect will differ from the "normal" or background surface temperature. In some applications, the object to be tested is artificially heated to produce the desired temperature differentials. In other applications, the heat input is either from solar radiation or from the natural temperature of the material or structure being tested. In either case the infrared sensor detects the infrared radiation emitted from the object, and converts the radiation measurement into a temperature measurement using the Stefan-Boltzmann Law:

$$Q = \sigma E(T^4 - T_0^4) \tag{9}$$

Where:

Q = Radiation emitted from an object (watts/sq.meter).
σ = Stefan-Boltzman constant.
E = Emissivity of the object.
T = Absolute temperature of the object.
T_0 = Absolute temperature of the surroundings.

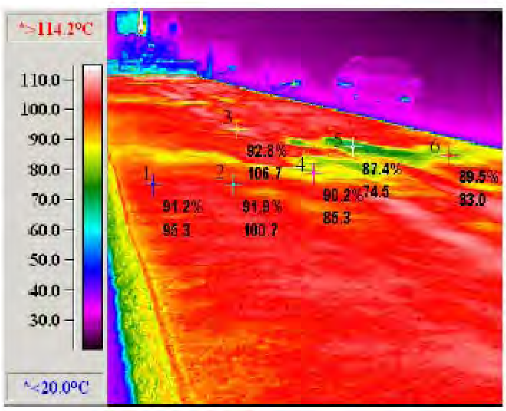
Surface temperature is detected using an infrared sensor or an infrared camera that provide the required infrared radiation. Infrared cameras have been used for civil structures because they provide a two-dimensional image of large surfaces and they operate like a conventional video camera. The main difference is that the intensity levels of the infrared image are related to the infrared radiation (i.e., surface temperature) rather than the intensity of light. For example, where the infrared camera is set to a 50 degree temperature range and provides an eight-bit grey scale image, each pixel of that image provides 256 shades of gray representing the 50 degree range (or a resolution of 0.2 degree). Infrared camera operators often use a pseudo-color scale, in which the gray scale is replaced by a color scale. The use of color can highlight temperature changes that are less obvious in the gray scale image.

An infrared sensor produces an output voltage proportional to the received infrared radiation at a point. These sensors are less expensive than infrared cameras and generally used more in automated manufacturing and QC operations, where the need is to monitor temperature at a fixed point or group of points.

Infrared thermography has been used for the past 15 years as a method for detecting delaminations in bridge decks. The underlying principle is that, with solar radiation, the areas above delaminations will heat up more quickly than the "sound" areas due to the insulating effect of the delamination. These small temperature differentials (about 1 to 2 degrees), or "hot spots," can be observed as bright spots on a high-resolution infrared image. The results, produced by mapping these identified areas onto a plan view of the bridge deck, are used for making rehabilitation decisions, and for scoping and estimating repair projects.

3.7.2 Equipment and Software

Initial work by Washington State DOT and Texas Transportation Institute (TTI) utilized commercial infrared cameras, producing real time video images, such as shown in Figure 13. These cameras allow the user to adjust to the temperature limits so that the appropriate range is being viewed. For example, the selected range for the image in Figure 13 is 20.0 to 114.2 ºC (68 to 238 ºF). These cameras also allow taking snapshots in addition to continuous video, and they provide a cursor that displays numeric temperature values on the image. The low viewing angle required of the video camera creates some distortion of the temperature measurement, due both to the angle and to the range of distances from the pavement surface to the camera. However, temperature differentials associated with segregation seem to be large enough to overcome this distortion. Using the infrared camera, pavement surface locations with temperature anomalies have to be manually marked on the pavement surface while the image is being viewed, since the camera has no distance scale.



Point Density/ Temperature	Temperature (°C)	Percent of Maximum Theoretical Density (%)	Change in Temperature (°C)	Change in Air Voids (%)
1	95.3	91.2	11.4	1.6
2	100.7	91.9	6.0	0.9
3	106.7	92.8	0.0	0.0
4	85.3	90.2	21.4	2.6
5	74.5	87.4	32.2	5.4
6	83.0	89.5	23.7	3.3

Figure 13. Illustration of Variable Density Due to Temperature Differentials (Willoughby et al., 2003)

Subsequent work by TTI and by Auburn University (Stroup-Gardiner and Brown, 2000; Stroup-Gardiner, 2003) has favored the use of an array of infrared sensors mounted behind the screed of a paver in a line transverse to the pavement. With this setup, the collection of infrared data is automated and continuous as the paver moves forward. Distance is monitored using a conventional distance encoder (used by TTI) or a global positioning system (GPS) (used by Auburn). The individual lines of temperature data are contoured to produce a continuous two dimensional strip chart thermal image of the pavement. Figure 14 shows an example of this type of equipment layout and the results. The prototype equipment is separated from the screed itself so as not to interfere with the paving process. Eventually, however, the equipment needs to be attached to the screed for routine use. Custom software has been designed by TTI and Auburn research groups to automate the generation of output of the type shown in Figure 14(b).

A third equipment option is an infrared thermometer, or "infrared gun." This is a hand-held point sensor used to obtain spot temperature measurements. Overall thermal patterns are more difficult to obtain with this equipment, but it is easy to use.

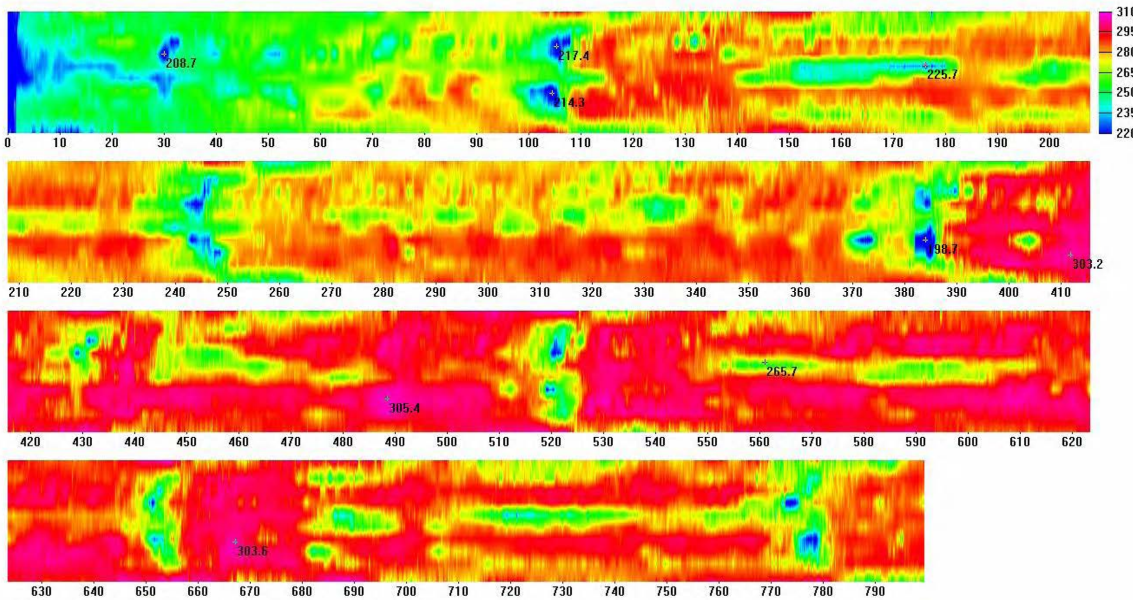
3.7.3 Application to Flexible Pavement Testing

The use of infrared thermography for detecting segregation in newly placed HMA was recommended in NCHRP Report 441, *Segregation in Hot Mix Asphalts* (Stroup-Gardiner and Brown, 2000). The report noted the ability of infrared to detect two types of segregation: (1) temperature segregation (or temperature differences), where the HMA has been unevenly cooled due to uneven exposure to cold surfaces during transport, and (2) gradation segregation, where coarse aggregate segregates, resulting in localized areas with high air voids and thus more rapid cooling. Both of these types of segregation appear to be associated with eventual deficiencies in HMA properties. The infrared measurement, however, cannot distinguish one from the other. The report recommended that the thermal measurement be made prior to the first pass of the roller, since this is where the temperature differentials are greater.

The effectiveness of IR in identifying segregated areas has been evaluated by the Texas and Washington DOTs. The Texas work involved taking measurements on new HMA overlays at the time of placement, coring, then identifying relationships between changes in the IR data with changes in the measured volumetric and engineering properties of field cores (Sebesta and Scullion, 2002 and 2003). Analyses of results showed that changes in IR data were significantly related to changes in HMA properties, such as air void content and gradation.

The Washington DOT research work also used an IR camera to view the process of placing HMA (Willoughby et al., 2003). Figure 13 showed an example of their work. The figure shows temperature changes depicted with the IR camera, and the correlation between temperature fluctuations and density and air void content.

(a) Infrared sensor bar behind paver screed



(b) Sample infrared strip contour plot output showing segregation at 130 foot intervals

Figure 14. TTI Continuous Infrared System (courtesy of Tom Scullion, TTI)

3.8 Ultrasonic/Seismic Devices and Technology

Acoustic velocity, attenuation, and related frequency effects are the primary ultrasonic measurements which have been used in other industries to characterize and inspect materials. Basically, the ultrasonic velocity of surface waves is measured with special electromagnetic-acoustic transducer (EMAT) probes and correlated to Young's modulus and shear modulus of the material. Variations from the modulus values of undamaged materials are used to predict creep damage of in service components. The fundamental theory relates to the fact that wave velocity is sensitive to material condition.

NDT using stress or seismic waves has been used extensively in the geotechnical and soil mechanics area for some time. Some of the tests based on wave propagation that have been standardized include the following:

ASTM D4428 - Test Method for Crosshole Seismic Testing
ASTM D4633 - Test Method for Stress Wave Energy Measurement for Dynamic Penetrometer Testing Systems
ASTM D4945 - Test Method for High Strain Dynamic Testing of Piles

Ultrasonic testing in the pavement area has been in use for many years for void detection by simply dragging a steel chain across the surface of a portland cement concrete (PCC) pavement. However, application of this technology for full-scale pavement evaluation did not begin until the early 1980s. Since then, studies have resulted in the development of sophisticated equipment for use by pavement engineers. Examples include the development of the DOCTOR (Sansalone and Carino, 1986), the application of scanning methods by Olson (Olson et al., 1992), and the development of the Seismic Pavement Analyzer (SPA [Nazarian and Baker, 1993]). Figure 15 is an illustration of the SPA, while Tables 19 and 20 summarize the ultrasonic testing techniques used by the SPA for determining various properties of the pavement structure and distress precursors, respectively. Other selected uses of ultrasonic test methods have included:

- The adhesive and compressive strengths of HMA mixtures.
- Determination of layer/component thicknesses and delaminations.
- QC of compaction of HMA paving mixtures.
- Identification and location of moisture damage and stripping in HMA mixtures at various depths in flexible pavements.
- Determination of the elastic moduli and viscoelastic properties of materials and structures.
- Identification and determination of material degradation due to creep and fatigue and glass-transition temperatures.

The basis for NDT with stress waves is propagation of seismic waves in the material of concern. Seismic wave velocity is the speed at which a wave advances in a medium. It is a direct indication of the stiffness of the material—the higher the wave velocity, the higher the stiffness. Seismic wave methods simply consist of measuring time required for those waves to travel a given distance. Once travel time and distance have been measured, wave velocities are calculated by dividing distance by travel time. Wave motions created by a disturbance on top of a layered system are described as compression (P-), shear (S-), and surface (Rayleigh, R-) waves.

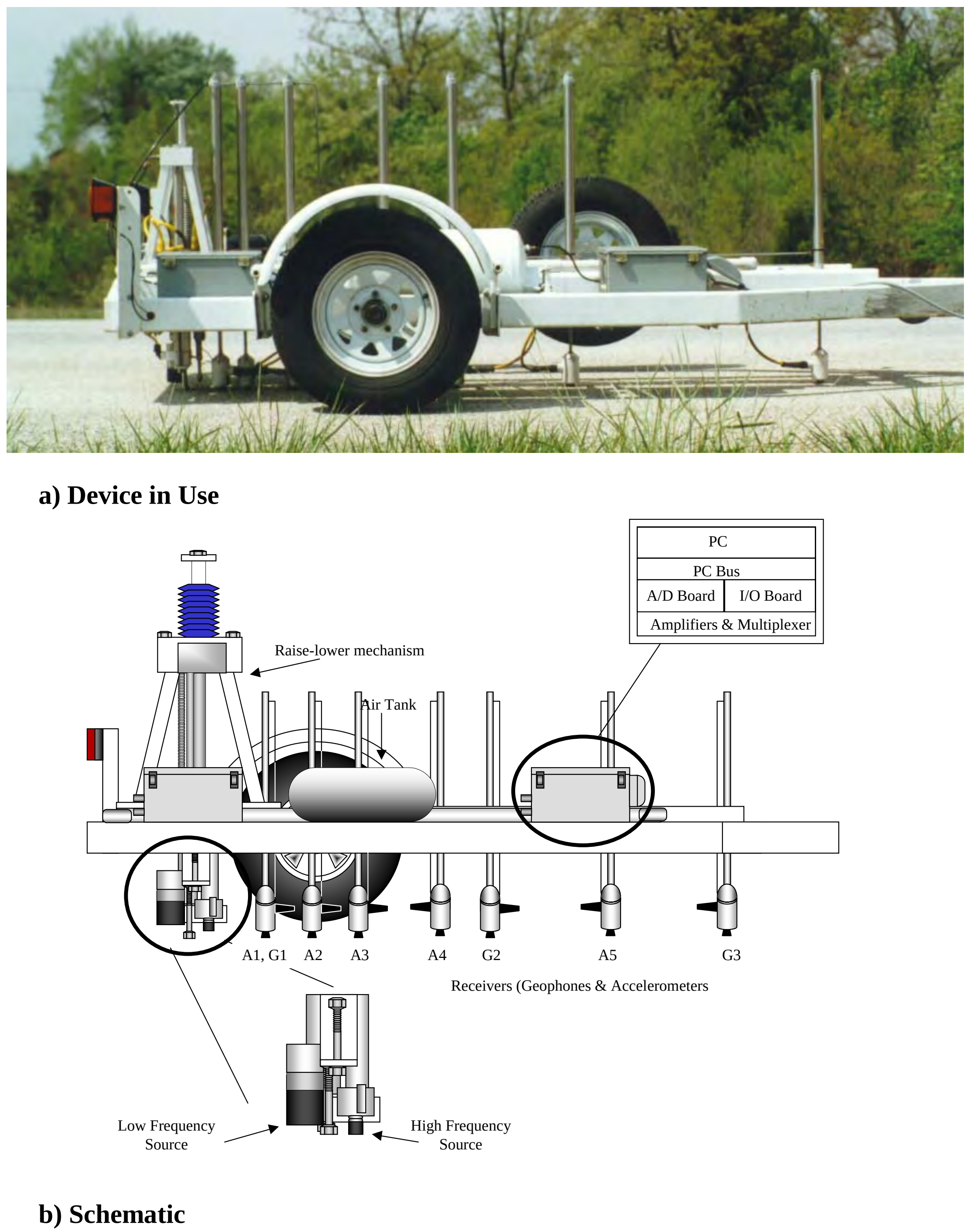


Figure 15. Illustration of the Seismic Pavement Analyzer (SPA)

Table 19. Strengths of Testing Techniques Used by the SPA (Nazarian and Baker, 1993)

Testing Technique	Strengths
Ultrasonic Body Wave	Young's Modulus of top paving layer
Ultrasonic Surface Wave	Shear modulus of top paving layer
Impulse Response	Modulus of subgrade reaction of foundation layers
Spectral Analysis of Surface Waves	Modulus of each layer Thickness of each layer Variation in modulus within each layer
Impact Echo	Thickness of paving layer or depth to delaminated layer

Table 20. Levels and Nature of Measurements for Each Distress Precursor as Used by the SPA (Nazarian and Baker, 1993)

Distress Precursor	Test	Quantity Measured	Pavement Component Evaluated
Moisture in Base	Impulse Response	Change in flexibility due to change in moisture content	Overall pavement system
	Spectral Analysis of Surface Waves (SASW)	Change in Young's modulus due to change in moisture content	Base, subbase and subgrade
Fine Cracking	Impulse Response	Reduction in rigidity of the paving layer due to cracks	Overall pavement system
	Body Wave Velocity	Delay in travel time of compressional wave because of longer travel path and lower rigidity	Paving layer
Voids or Loss of Support	Impulse Response	Significant increase in flexibility of slab due to lack of support under the slab	Supporting layer
	Impact Echo	Return (resonant frequency) associated with the thickness of slab	Upper layer (HMA or concrete)
Overlay Delamination	Impulse Response	Significant increase in flexibility of overlay due to lack of support under the overlay	Overall pavement system
	Impact Echo	Return (resonant) frequency associated with the thickness of overlay	Overlay
Aging	Ultrasonic SASW	Shear wave velocity of HMA layer	HMA layer
	Body Wave Velocity	Poisson's ratio, by measuring compression wave velocity of HMA layer and combining with shear wave velocity	HMA layer

The solution of the equations of motion yields two types of stress waves in an unbonded, isotropic medium. These waves are called body waves, and they propagate with different velocities and generate different particle motions in the medium. The faster wave is called the dilatational, compression, or P-wave. This wave exhibits a push-pull type motion in the direction of wave propagation and is in the same direction of particle motion. The slower wave is called the distortional, shear, or S-wave. The shear wave exhibits rotational motion in which the direction of particle motion is perpendicular to the direction of wave propagation.

The shear wave is sometimes subdivided into two special cases. The first is when both directions of particle motion and wave propagation are contained in a vertical plane. In this case, the shear wave is referred to as a vertically polarized shear wave or SD-wave. The other special case is when particle motion and wave propagation are contained in a horizontal plane. The shear wave in this case is referred to as a horizontally polarized shear wave or SH-wave. In an isotropic elastic medium, the magnitude of the SD-wave and SH-wave velocities are the same.

"Rayleigh waves" are introduced into the pavement by hitting the pavement's surface with a hammer. The velocity of these waves will depend on the mechanical properties of the pavement's surface and to a lesser extent on the properties of the base, subbase, and subgrade materials. The sensitivity to depth is proportional to their wavelength (Seed et al., 1986). More recently, researchers have used wave propagation theory and seismic methods to evaluate different features of pavements (Lee et al., 1993; Lo et al., 1989; Nazarian, 1986-2002; Seed et al., 1986; Hammons et al., 2005 and 2006). Some of these are:

- Fine cracks in a pavement's surface that are not visible, but they will disrupt the local mechanical properties. A surface wave passing through a cracked area should experience high attenuation and a significant delay in arrival. These characteristics can be rapidly detected with geophones or accelerometers placed on the pavement surface.

- Aging of the asphalt results in the hardening of the HMA at the surface layer. This hardening is associated with an increase in elastic modulus. Surface waves with wavelengths less than the pavement thickness will be sensitive to this change in elastic properties. The depth sensitivity noted above will reveal higher velocities for the shorter wavelengths (which are more sensitive to the near surface modulus increase) and lower velocities for the longer wavelengths.

- Identification of moisture damage, stripping, and other forms of damage in HMA mixtures at varying depths in flexible pavements and HMA overlays. Seismic methods (specifically, the PSPA) were used with GPR to identify and locate the damaged areas. The surface waves are affected by the reduced stiffness of the damaged areas. Cores were taken and laboratory wheel load tests were used to confirm the damaged areas identified by the field tests. The seismic-GPR combination was found to be excellent based on the visual observations from the cores and laboratory test results.

- Depending on the soil type, moisture in the subgrade will change the shear wave velocity in the soil. The velocity of surface waves of sufficient wavelength will thus be affected by this moisture. A delaminated or debonded HMA overlay will change the mechanical structure of the pavement, and therefore, change the surface wave velocity. The presence of a subsurface void has a similar effect.

Direct compression or shear waves (in the sonic range) involve propagation of P- or S-waves in the top pavement layer (Kolsky, 1963; Manning, 1985). The waves are initiated with a hammer blow and measured with an array of geophones or accelerometers. Anomalous decreases in wave velocity measured in this fashion will indicate some reduction in the average moduli of the pavement, and are used as an indicator of cracking and other deterioration in the material or layer (e.g., stripping, freeze/thaw damage).

Most ultrasonic analytical methods used in determining material properties from seismic tests make the assumption that the material (or pavement layer) is elastic, isotropic, and homogeneous. This assumption is reasonable for PCC and some granular materials. For HMA and selected fine-grained soils, however, that assumption is inappropriate, especially for low frequencies and/or high temperatures. Corrections or adjustments to load frequency and temperature are required in most cases, when evaluating nonlinear and visco-elastic materials.

The mathematical relationships of wave propagation theory that have been utilized in developing the different methods for determining pavement material properties from various seismic tests are given below.

By employing elastic theory, the compression wave velocity, V_p, can be defined as:

$$V_P = \left(\lambda + 2G \middle/ \rho \right)^{0.5} \tag{10}$$

Where λ, G, and ρ are the Lame's constant, shear modulus, and mass density, respectively. The shear wave velocity, V_s, is equal to:

$$V_S = \left(\frac{G}{\rho} \right)^{0.5} \tag{11}$$

Compression (P-) and shear (S-) wave velocities are interrelated by Poisson's ratio, ν. The ratio of the compressive to shear wave velocities is expressed in terms of Poisson's Ratio as:

$$\frac{V_P}{V_S} = \left(\frac{(1-\upsilon)}{0.5-\upsilon} \right)^{0.5} \tag{12}$$

Rearranging the above equation, results in an expression for Poisson's Ratio.

$$\upsilon = \frac{0.5\left(\frac{V_P}{V_S}\right)^2 - 1}{\left(\frac{V_P}{V_S}\right)^2 - 1} \qquad (13)$$

For a layer having constant properties, surface (Rayleigh or R-) wave and shear (S-) wave velocities are related by Poisson's ratio as well. Although the ratio of R-wave velocity to S-wave velocity increases as Poisson's ratio increases, its change is insignificant. The velocity of Rayleigh waves (V_R) in a material is slightly less than that of the shear waves, and the ratio of the two waves can be expressed by:

$$\frac{V_R}{V_s} = \frac{0.87 + 1.12\upsilon}{(1+\upsilon)} \qquad (14)$$

Wave propagation velocities have limited use in engineering applications, but the calculation of elastic moduli from them has direct application. The velocities of body waves are directly related to the constrained (*M*) and shear (*G*) moduli of an isotropic material by:

$$M = \rho(V_P)^2 \qquad (15)$$

$$G = \rho(V_S)^2 \qquad (16)$$

Young's and shear moduli are related by equation 17.

$$E = 2G(1+\upsilon) \qquad (17)$$

3.8.1 Spectral Analysis of Surface Waves Test Method—SASW

The Spectral-Analysis-of-Surface-Waves (SASW) test is a non-intrusive seismic test method that relies on the measurement of Rayleigh type surface waves. For non-intrusive seismic methods, all instruments are placed on the ground surface. The key point in the SASW method is the measurement of the dispersive nature of the surface waves, which are used to determine the shear wave velocity of the pavement, the base, and the subgrade.

SASW is a powerful NDT method which indicates material modulus (stiffness) versus depth while measuring from one surface and without any coring or other material intrusion required (see Tables 19 and 20). This method for evaluating pavements was largely developed by Nazarian and Stokoe (1983, 1985, and 1986) and significantly improved by Nazarian and Baker (1993). It has been used by the Department of Energy, U.S. Air Force, and Department of Transportation in various capacities to evaluate the strength of subsurface soils and to locate subsurface features in geophysical explorations. It has been used by a few agencies to determine the depth and thickness of soft (loose) fill, depth to rigid layers (limestone), and identification of granular layers that are saturated. SASW is the primary measurement technique employed in the SPA (see Table 19 and Figure 15).

The SASW method is based upon measuring surface waves propagating in layered elastic media. The generation and detection of surface waves are controlled by an impact source and two receivers (or accelerometers) placed on the pavement surface. The two vibration transducers are located at known distances from the source. Typically, one of the distances is kept equal to two times the shorter distance. At the surface, the direction of particles in motion forms a retro-grade ellipse in a uniform material. The amplitude of Rayleigh-wave motion decays with depth and is less than about 10% of the surface amplitude at a depth equal to about 1.5 times the wave length.

Surface wave velocity varies with frequency in a layered system with velocity contrasts, and this frequency dependence of velocity is termed dispersion. A plot of surface wave velocity versus wavelength is called a dispersion curve. The SASW tests and analyses are performed in three phases: 1) collection of data, 2) construction of an experimental dispersion curve from the field data, and 3) inversion (forward modeling) of the theoretical dispersion curve to match the experimental curve and provide the shear wave velocity versus depth profiles.

The ratio of surface wave velocity to shear wave velocity varies slightly with Poisson's ratio (as stated above), but is usually assumed to be equal to 0.90 with an error of less than 5 percent for most materials. Measurement of the surface wave velocity with the SASW method similarly allows calculation of compression wave velocity for use in Impact-Echo (IE) test analysis, discussed in the next subsection. Knowledge of the seismic wave velocities (surface and compression) and mass density of the material layers allows calculation of shear and Young's moduli for low strain amplitudes (Heisey et al., 1982; Kolsky, 1963; Nazarian et al., 1987; Nazarian and Stokoe, 1983; Nazarian and Baker, 1994). The elastic modulus values determined by the SASW method need to be modified to account for higher strain levels when used as inputs to models that include nonlinear constitutive relationships for the material response.

The SASW field tests typically consist of impacting the test surface to generate surface wave energy at various frequencies that are transmitted through the material. For single point stationary SASW, two accelerometer receivers are evenly spaced on the surface in line with the impact point to monitor the passage of the surface wave energy. To obtain increasingly deeper data, several tests with different receiver spacings can be performed by simply doubling the distance between the receivers about the imaginary centerline between the receivers. A PC-based data acquisition system digitizes the analog receiver outputs and records the signals for spectral (frequency) analyses to determine the phase information of the cross power spectrum between the two receivers for each frequency. The dispersion curve is developed by knowing the phase shift (Φ) in degrees at a given frequency (f) and then calculating the travel time (t) between receivers of that frequency/wavelength using equation 18.

$$t = \frac{\phi}{360(f)} \qquad (18)$$

Surface wave velocity (V_R) is obtained by dividing the receiver spacing (X) by the travel time at a specific frequency (f) in accordance with equation 19.

$$V_R = \frac{X}{t} \qquad (19)$$

The wavelength (L_r) of the corresponding surface wave is related to the phase velocity and frequency by equation 20.

$$L_r = \frac{V_R}{f} \qquad (20)$$

By repeating the above procedure for any given frequency, the surface wave velocity corresponding to the given wavelength is evaluated, and the dispersion curve is determined. The phase velocity at wavelengths shorter than the thickness of the pavement layer is indicative of the quality of the material of the surface layer. Changes in the stiffness of the surface layer are manifested by different phase velocities.

To obtain the material properties for layers, a forward modeling process to match the experimental dispersion curve is performed. Forward modeling is the process of determining the "true" shear wave velocity profile from the "apparent" velocity of the dispersion curve. The forward modeling inversion process is iterative and involves assuming a shear wave velocity profile and constructing a theoretical dispersion curve. The experimental (field) and theoretical curves are compared, and the assumed theoretical shear wave velocity profile adjusted until the two curves match. The SASW method and an interactive computer algorithm for both 2-dimensional and 3-dimensional analyses have been developed to compute a theoretical dispersion curve based upon an assumed shear wave velocity and layer thickness profile (Roesset et al., 1990; Stokoe and Hoar, 1978).

The advantage of the SASW method over the IE method (discussed in the next paragraph) is that the thickness and the shear modulus of all layers in a pavement system can be determined with the SASW method, as opposed to only the top layer with the IE method.

3.8.2 Impact-Echo Test Method

The IE test method is an acoustic wave-based method that has long been recognized as a powerful tool for the nondestructive testing of PCC, wood, and other materials. It has the advantage of requiring access to only one side of a test member and is capable of determining thickness as well as flaw depth when used on structures with simple geometries. It is one of the more successful NDE methods for evaluating the internal condition of structural concrete (floors, on-grade walls and decks), and was largely developed and improved at the National Institute of Standards and Technology (NIST) and Cornell University in the mid-1980s

(Sansalone and Carino, 1986; Sansalone et al., 1987). The method has also been used for evaluating HMA overlays on concrete bridge decks and PCC pavements. Nazarian adopted the IE test method in the SPA for measuring the thickness of the surface layer (see Tables 19 and 20).

In an IE test, the surface is impacted with a small instrumented impulse hammer or impactor. From the mechanical impact, a transient stress pulse is generated and introduced into the material (Sansalone, 1993). This pulse travels as pressure waves with spherical wave-fronts, which are reflected by internal cracks, voids, and/or interfaces. The response, reflected wave energy, is measured by an accelerometer or displacement transducer placed on the surface a few inches away from the impact point. Use of a displacement transducer is the preferred response measuring device. The wave form is dominated by the compression or P-wave, as a result of this sensor placement relative to the impact point. Thus, the method relies on reflected compression wave energy from interfaces and/or discontinuities that are present in a pavement system.

These pressure waves are reflected at the free surface back into the material, to be reflected again by the internal interfaces, and so on. Therefore, a transient resonance condition is set up by multiple reflections of pressure waves between the free surface and the internal defects. Resonant conditions are also set up by the plate-like vibrations of thin concrete sections which are delaminated from the total deck structure. These resonant conditions are identified in the accelerometer signal by using the Fast Fourier Transform (FFT) algorithm. Resonant responses are associated with the normal deck dimensions (HMA and PCC thickness) as well as with delaminations. The frequency of these resonances can be analyzed to uniquely distinguish "normal" thickness-related resonant conditions associated with the deck structure, from "abnormal" resonant conditions associated with delamination and concrete deterioration.

In a typical PCC slab supported by soil or crushed stone base material, almost all of the energy is reflected because of the large difference in stiffness between PCC and unbound materials. Thus, the greater the difference in impedance between two adjacent layers, the larger the amplitude of the return resonant frequency. Conversely, if the two materials have similar impedances, little to no energy will be reflected at the interface—diminishing the resonant return frequency from being measured. Separation of the energy related to surface waves from the reflected energy is difficult, especially for thin slabs or low modulus materials, such as HMA in the summer months.

This separation process is made simpler when the signal is Fourier transformed into the frequency domain to obtain the amplitude spectrum. The amplitude of the peak is directly proportional to the difference in impedance between materials on either side of an interface. Thus, the time domain signals are FFT transformed to the frequency domain and a transfer function is calculated. The transfer function between the accelerometer and load is used to determine the resonant frequency. Mathematically, the transfer function is defined as:

$$TF = \frac{Y(f)}{X(f)} \tag{21}$$

Y(f) is the FFT transform of the receiver output in displacement units and *X(f)* is the FFT transform of the hammer input. Dominant peaks in the transfer function plot are resonances resulting from discontinuities such as the interface between the pavement layer and the base layer, delamination of an overlay, or cracks present in the pavement system. The depth of such reflectors is easily calculated from the following equation:

$$D = \frac{V_P}{2(f_r)} \tag{22}$$

Where D is the depth of the reflector, V_P is the velocity of compression waves and f_r is the resonance frequency. However, good contact between the sensor and test surface is essential for obtaining accurate and reliable results.

The IE method can operate effectively on bare concrete and with an HMA overlay. Testing on an HMA overlay is possible because the high frequency impact excites ultrasonic resonant behavior in the PCC below the HMA surface. Traditional sounding methods do not have this capability. Software is available to automatically interpret the IE data, and the system (hardware and software) has been tested in the field and checked against chain drag results when the HMA was removed (Sansalone, 1993). The resulting correlations of delamination locations based on impact-echo and on chain drag were described as excellent.

Olson Engineering has developed test equipment for measuring the thickness of stiff or harder (aged) HMA surfaces. [6] However, using the IE test method on thicker HMA lifts at elevated temperatures after compaction, when the HMA is relatively soft, has yet to be validated for measuring layer thickness.

3.8.3 Impulse Response Test Method

The Impulse Response method (also known as transient dynamic response and mechanical impedance method) is similar to the IE method and historically has been used to evaluate subgrade support conditions. IR involves striking or shaking an object or structure and determining its response versus frequency. The frequency response reflects the material properties of the structure, including modulus, layer thickness, etc. Resonant frequencies are often simple indicators of anomalous structural conditions. The response of a pavement with moisture in the subbase material will be different than for the same pavement without moisture.

For the IR test, the surface of the pavement is impacted to produce a low frequency wave in the surface layer. A portion of the energy is reflected back to the surface at the interface between the surface and base layers and the remainder is transmitted to the bottom layers. The response of the pavement's surface and impacted energy are measured with a geophone and load cell, respectively. The geophone measures particle velocity which is numerically

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[6] Personal communication with Olson Engineering (Dr. Larry Olson), and observing a demonstration of the equipment for testing HMA surfaces.

converted to displacement. Both the force and displacement signals are captured, digitized and processed to develop a flexibility spectrum. The flexibility spectrum is the ratio of the displacement and load as a function of frequency.

The load and displacement time-histories are transformed to the frequency domain using a FFT algorithm. A velocity transducer is used, as compared to an accelerometer in the IE method, to measure the response of a pavement system subjected to an impact source. The method is efficient in evaluating the support conditions under the slab. A smooth transfer function (called a mobility function) with a high dynamic stiffness are expected for good support conditions. A transfer function with peaks manifested at low frequencies and a low dynamic stiffness are indicative of a loss of support/existence of voids.

Based on studies by Reddy (Reddy, 1992), the stiffness obtained by the IR method is also a good representation of the subgrade modulus provided the pavement is rigid with surface layer thicknesses greater than 3 inches. In these cases, the effect of the surface layer on the stiffness values is minimal. Preliminary research has shown that IR scanning should also be possible with the basic scanner approach. Thus, the combination of IE, SASW, and IR scanning with PC-based systems offers the promise for innovative, continuous measurement of pavement system conditions.

3.8.4 Ultrasonic Surface Wave Test Method—USW

The Ultrasonic Surface Wave (USW) method is a variation of the SASW method. With the USW method, the properties of the top layer can be easily and directly determined without the use of a complex inversion algorithm. The USW method was used by Nazarian in developing the SPA (see Table 19) and a PSPA referred to as the "Lunch Box." Figure 16 shows the PSPA in operation and carriage case that was recently developed to facilitate its use in data collection during construction.

To perform the test, a disturbance is applied to the surface to generate stress waves that propagate mostly as surface waves of various wavelengths. The waves are monitored and captured with a data acquisition system (through the receivers). Signal and spectral analyses are then used to determine the phase information of the transfer function (phase spectrum) and the coherence function between the two receivers. This information is used to develop a dispersion curve. A dispersion curve depicts the variation in the velocity of propagation with wavelength. To obtain the dispersion curve, the velocity of wave propagation, V_R, and wavelength, L_r, are determined from the phase spectrum, N, at any frequency, f, (equations 19 and 20).

In a theoretical dispersion curve for a two-layer system, two distinct branches are obvious. First, up to a wavelength approximately equal to the thickness of the uppermost layer, the velocity of propagation is independent of the wavelength. For wavelengths greater than the thickness of the surface layer, the dispersive characteristic of surface waves (i.e., variation of velocity with wavelength) is normally clearly evident. Therefore, if one simply generates high-frequency (short-wavelength) waves and assumes that the properties of the uppermost layer are uniform, the shear modulus of the top layer, G, can be determined using equation 23.

$$G = \gamma\left(k\left(V_R\right)\right)^2 \quad (23)$$

Where:

$$k = 1.13 - 0.16\upsilon \quad (24)$$

γ = Density of surface layer.

Carriage case recently developed for facilitating the use of the PSPA & DSPA in data collection.

Figure 16. PSPA in Operation for Testing HMA Layers, While the DSPA is Used for Testing Unbound Layers

An estimate of the thickness of the surface layer can be made by determining the wavelength above which the surface wave velocity is constant. The methodology can be further simplified by assuming that the stiffness of the top layer is constant. With that assumption, equation 18 can be written as:

$$\phi = \left(\frac{360X}{V_R} \right) f = mf \tag{25}$$

Equation 25 represents a linear relationship between the phase of the transfer function and frequency, provided the phase velocity is constant. Thus, V_R can be easily determined by performing a least-squares linear regression over the high-frequency region of the cross power spectrum and obtaining the slope of the best-fit line.

This method uses the time signals measured with two accelerometers. These two signals are Fourier-transformed, and the ratio of one to the other is calculated in the form of a transfer function. Since this is a complex-valued function, each point can be represented by its magnitude and phase. With this method, only the phase of the transfer function is used.

To ensure high quality results, the source should impart surface wave energy over a wide range of frequencies (in the range of 2 KHz to 40 KHz), and the sensors should be in intimate contact with the pavement. There are two main advantages to using this method (relative to determining the "bulk" surface wave travel time using the time record). First, the variation in velocity with depth (via a dispersion curve) can be determined so that the extent of pavement damage or surface deterioration can be estimated. Second, as the velocity is averaged over the thickness of the HMA (or PCC), the near-surface deterioration does not significantly affect thickness determination, as is the case with the time-domain method.

3.8.5 Ultrasonic Body Wave Method—UBW

According to equation 22, to effectively use the IE method, the compression wave velocity through the HMA (or PCC) must be known. Otherwise, as proven by Sansalone and Carino (1986), large errors will result. For simplicity of the equipment according to Nazarian, the compression wave velocity can be determined using the ultrasonic body wave method. The Ultrasonic Body Wave (UBW) method was also incorporated into developing the SPA and the PSPA (refer to Tables 19 and 20, and Figures 15 and 16).

As indicated before, compression waves travel faster than any other types of seismic wave and are detected first on seismic records. An automated technique for determining the arrival of compression waves, as suggested by Willis and Toksoz (1983), has been implemented in the SPA. With this method, the detection of P-wave arrival is done in two steps: 1) event detection and 2) fine adjustment.

Event detection is carried out by triggering on the first amplitude that falls within a time window satisfying a predetermined amplitude threshold. The threshold value depends on the background noise and anticipated amplitude of the compression wave. This value is typically set as the average of the voltage levels of the background noise and half the anticipated maximum amplitude of the P-wave. The user defines a window within which the compression wave velocity energy is most likely to be concentrated. This is done by defining the most likely value and possible range for the modulus of HMA or PCC. The first point within the window that has a voltage above the threshold is considered a candidate for the arrival of the P-wave.

In the second step, to verify that the arrival of the wave is correctly detected, a semblance correlation is carried out between the peaks selected for different records. The semblance discriminates between amplitude differences and the shape of the signal corresponding to the compression wave energy. This two-step procedure not only yields a robust procedure for detecting the compression wave velocity but also determines if the arrival times were falsely selected because of uncorrelated changes in the background noise level. To clearly detect the arrival of P-waves, the records must be greatly amplified. The compression wave velocity is calculated from the distance between receivers and the difference in travel time.

Practically speaking, an intimate contact between the receiver and surface, a strong source, and extremely low-noise amplifiers are needed to obtain repeatable, interpretable, and reliable signals. To minimize the contamination of the signal with the so-called near-source energy, the source should be able to generate very short-duration impulses. Minor near-surface imperfections and cracks can adversely affect the results (in terms of detecting the compression wave energy or accurately determining the velocity of the material). Even though this sensitivity to minor defects is undesirable for estimating thickness, it can be effectively used to evaluate the quality of the layer or material.

Although the determination of the compressive wave velocity can be carried out with one receiver (through so called "direct measurement"), numerous studies have shown that more reliable results are obtained when the difference in travel time between two receivers (so called "interval measurement") is used. Many problems (such as interval delays) in the system can be avoided when two sensors are used.

When using the PSPA at a given test location and initiating the testing sequence through use of the computer, the high-frequency source is activated. The source is fired at least seven times. For its last three impacts, the output voltages of the receivers are saved and averaged (stacked) in the frequency domain. The other impacts are stacked to determine the arrival of compression waves. The gains are set so that the output of the sensors is optimized. The collection and reduction of data at one point take less than 15 sec when an i-386-20 MHz IBM-PC compatible is used. The data acquisition system for the PSPA can acquire data at a rate of 500 K-sample per channel.

3.8.6 Scanning Test Systems

The ultrasonic testing rate of traditional point-by-point limits the utility of the stress-wave based methods. Thus, IE and SASW scanning systems have been developed and evaluated to fill the need for rapid collection, processing, and display of NDT data from stress-wave based methods.

IE Scanner System. The IE scanner system developed by Olson Engineering is capable of measuring the thickness of a wall or floor slab with an accuracy of typically 5% or better, depending on the accuracy of the velocity used for computing member thickness. The processed data displayed by the system are plots of either frequency peak(s) or member thickness versus position, along with signal energy or amplitude versus position. The IE measured member thickness profile can then be compared to the design thickness for verification of as-built conditions. The IE scanner also shows the locations of defects, such as cracks and delaminations.

To allow rapid scanning with the IE method, the fixed accelerometer or displacement transducer was replaced with a rolling velocity transducer assembly. The hand-held hammer or other manually operated impactor was replaced with an electrically driven solenoid. The impactor drive and the rolling transducer signals are controlled by a digital controller which measures the distance traveled and tests at pre-set distance increments, regardless of speed of motion. The current IE scanning system is capable of testing either 1 or 4 simultaneous lines of points at incremental point spacings of about 3/4 inch (1.9 cm) for 1 channel scanning, or about 3-4 inches (7.6-10 cm) per channel for 4 channel scanning. Testing rates on smooth, open floor slabs have been typically less than 5 minutes for a 50 lineal feet (15 m) scan, during which about 600-800 IE tests will be performed by the 4 scanners.

The system has been found to be sensitive to slab or wall thickness changes of as little as 0.1 inch (2.5 mm), with the absolute accuracy dependent on the accuracy of the measured material velocity. However, the IE scanner has yet to be validated and used on a production basis for testing HMA with rougher surfaces and lower modulus materials.

SASW Scanning System. The IE scanning system was modified at Olson Engineering to allow the performance of SASW scanning. The SASW scanner hardware is based on the IE scanner hardware, modified to allow 2-channel data acquisition from a moving source-receiver-receiver line. The SASW scanner allows near continuous acquisition of data at fixed increments as the unit is rolled across the test surface. A distance wheel controls the impact source that generates the surface wave energy, and tracks the scanner position. The SASW accelerometers are replaced by two rolling displacement transducers, and the impact source consists of an electrically operated solenoid impactor.

The SASW method gives information as to the material properties versus depth, based on the measurement of the surface wave velocity versus wavelength of propagating surface waves. The SASW scanning technology is new and allows rapid acquisition of SASW data, but has yet to become commercially available. Faster data processing software is in the development stage to allow full utilization of this new testing system. Most of the initial data with the use of this scanner has been collected on relatively smooth PCC slabs. The roughness of the surface is also a problem for this method to be applicable on a production basis for flexible pavement testing.

3.8.7 Acoustic Emission Test Method

Acoustic methods are based on monitoring and identifying variations in sound waves emitted by the test specimen to locate flaws in the material. Acoustic emission (AE) qualifies as a passive technique because it involves monitoring or listening to sound waves generated by stresses within a material. AE sensors are piezoelectric transducers that detect out-of-plane displacements created by sound waves. The devices are highly mechanized and automated with sophisticated computerized measurements of resulting voltages.

Most NDT methods, such as ultrasonics, radiography, or infrared thermography, rely on the application of some form of energy to the material and/or structure under tests. The difference between the applied energy and that detected at some later time or distance give an indication of the state of the material. AE, however, relies upon the detection of energy released by the material and/or structure in itself. Although AE has been used to test materials for as long as other ultrasonic tests, it is a relatively new field that only recently is being used as an important research tool for the study of materials.

AE is simply a form of skilled listening to structures and/or materials as changes within the materials occur. It is applicable to a wide variety of materials, including metals, ceramics, polymers, HMA, composites, and wood. The use of AE has been largely confined to a laboratory environment to monitor the failure or damage of specimens under full-scale testing or when specimens are being tested by other methods. Liu and Li (1989) used the total energy of AE to measure the degree of the damage caused by plastic deformation during tensile tests of selected steels. The same techniques have been used in rock mechanics to identify failure plans (or plans of weakness) in testing rock samples for foundations.

AE inspection has several advantages over conventional NDT techniques in that it can access the dynamic response of a flaw to imposed stresses. The following lists some of the standards which are used to test and inspect a variety of materials:

E 976-94:	Standard Guide for Determining the Reproducibility of Acoustic Emission Sensor Response
E 750-88:	Standard Practice for Characterizing Acoustic Emission Instrumentation
E 1106-92:	Standard Method for Primary Calibration of Acoustic Emission Sensors

A typical AE test uses a piezoelectric sensor mounted on a test piece with a couplant (often some type of gel or grease). Because the output signal from the sensor is small, a preamplifier is used to amplify the signal, eliminate some noise, and provide impedance matching with the analysis system. The analysis system usually includes further amplification and the means to measure and record data from the signal.

Conventional AE systems use digital counters to measure parameters of the analog signal, but some of the newer systems use microprocessors to digitize and record the signals. Recent developments and high-speed microcomputers and microprocessor chips have made it feasible to digitize and record the entire AE wave form. This development has led to new analysis techniques and better identification of the sources. Analysis methods have often focused on locating sources of AE and then trying to identify those sources. However, sources are often further inspected using other NDE techniques to determine their size and severity.

The AE technique was employed within Strategic Highway Research Program (SHRP) for monitoring the micro-fracture in the asphalt phase and/or between asphalt and aggregate when the HMA was subjected to mechanical loading (Pearson, 1994). Together with mechanical results, these give a comprehensive indication of the internal structure change of HMA during the loading process. Based on the preliminary test results included in the SHRP, the micro-damage process in HMA can be detected using AE methods. The results from both single-cycle and multi-cycle tests indicate that the deformation of a specimen relates closely to the AE event which is the measurement of damage within the specimen. Other uses of AE tests included in the literature have included:

- QC of HMA mixtures, as related to laboratory compaction.
- Determining the fracture energy (toughness) of PCC mixtures, the fracture-failure planes of rock, the cohesion of asphalt, and the adhesive strength in HMA mixtures.
- Prediction of rock hardness, drillability, and fracture toughness.
- Investigation and monitoring of avalanches, soil stability, retaining walls, earth-dam stability, and foundations.

Currently there is no commercial equipment that can be used to collect, analysis, and interpret AE data for evaluating the in-place condition and quality of HMA mixtures and other pavement layers. The AE method is considered to be in the initial research and development stage.

3.8.8 Laser-Induced Ultrasonic Test Method

One of the problems associated with the conventional use of piezoelectric transducers is that they must be acoustically coupled to the test material. A number of techniques for the non-contact generation and detection of ultrasound are available. Two of these include Electro Magnetic Acoustic Transducer (EMAT) and laser-based interrogation systems. EMAT generally are limited to metals and must be close to the test specimen.

Laser-based ultrasonic interrogation systems are in use to a limited extent for inspections during the manufacturing process. These systems are mainly used to detect the existence of piping and the quality of cast steel. The ultrasonic pulses are produced by focusing a series of light impulses from a laser on the surface of the test specimen. The laser sends out a series of short high-energy light impulses. These impulses are 20 nanoseconds in length and are encountered by thermo-mechanical effects into sound impulses at a frequency of 1MHz to 100 MHz. The advantage of this technique is that no mechanical coupling is required and the acquisition of test results is rapid. The disadvantage is that the sensitivity of the system is lower than that for conventional ultrasonic pulse-echo testing systems (piezoelectric techniques). Thus, these methods are not considered applicable for evaluating the in-place condition and quality of HMA mixtures and flexible pavements.

3.9 Steady-State Vibratory Devices and Technology

The Humboldt Stiffness Gauge (referred to as the GeoGauge and manufactured by Humbolt Manufacturing Company) is a hand-held portable instrument that provides a simple and rapid means of measuring the elastic modulus of compacted soils and aggregate base layers (Humboldt, 2002). Figure 17 shows the GeoGauge in operation. The GeoGauge was developed under a project co-sponsored by the FHWA and the Advanced Research Programs Administration in the late 1990s for potential use as a QA tool in evaluating the quality of unbound aggregate base materials, embankment soils, and HMA mixtures. The GeoGauge has been beta-tested by FHWA and multiple state highway agencies through a pooled fund study that was initiated in the early 2000s.

Figure 17. GeoGauge Used to Estimate the Stiffness and Modulus of Unbound Layers and Soils in Flexible Pavements

Outside of the initial pooled fund study, the GeoGauge has had limited use in measuring the stiffness and modulus of flexible pavement layers. FHWA used the GeoGauge to determine the repeatability of the measurements and to evaluate the unbound materials that had been placed at their accelerated loading facility at Turner-Fairbank Station (FHWA, 2003). A few state agencies have also used the GeoGauge on a limited basis, and there are mixed reports of success. Some of the reports found good repeatability, while other verbal reports found it to be highly variable.

As a result of the beta-testing under the pooled fund study, revisions were made to the gauge and calibration procedure. Some of the revisions included minor mechanical design changes to reduce variability, enclosing the shaker to eliminate the effect of electromagnetic fields on the motion sensor, and fixing errors identified in the signal generation and processing circuit boards. More recent use of the gauge by the FHWA has shown that the variability has been reduced and that the modulus values reported with the gauge are more correlated to the results from other NDT devices (for example, backcalculated modulus values from the deflection basins measured with the FWD).

3.9.1 Principle of Operation

Wang et al. (2003) provides a detailed discussion on the principle of operation and measurements of the GeoGauge. In summary, the GeoGauge measures the impedance at the surface of an unbound layer. It imposes a stress to the surface of a layer and the resulting surface velocity is measured as a function of time. The GeoGauge imparts very small displacements to the soil (< 1.27 x 10^{-6} m or < 0.00005") at 25 steady state frequencies between 100 and 196 Hz.

The stiffness value is determined for each frequency, and the average value is displayed on the surface of the gauge. The entire testing process takes about 1.5 minutes. At the low frequencies, the impedance at the surface is stiffness controlled and is proportional to the shear modulus of the soil. With a Poisson's ratio and the GeoGauge's foot dimensions, shear and Young's modulus are derived.

The GeoGauge weighs about 22 lb (10 kg), is 11 in (28 cm) in diameter, 10 in (25.4 cm) tall, and rests on the soil surface through a circular foot. The foot bears directly on the soil and supports the weight of the GeoGauge through several rubber pads, or what Humbolt calls "isolators." The shaker that drives the gauge is also attached to this foot. The sensors that measure the force and displacement-time history of the foot are also attached to the foot. The connection between the shaker and force sensor of the gauge is manufactured as a rigid column. It is powered by six disposable D-cell batteries.

The GeoGauge is placed on the soil or aggregate base layer. A sand cushion or thin layer is usually placed to ensure that the gauge and surface of the layer are adequately coupled. A slight push or rotation of the GeoGauge is applied to ensure at least 60 percent contact area between the foot and soil. The GeoGauge displays and logs the data in memory. These data can be downloaded to a laptop or PC for more detailed data analysis.

3.9.2 Application to Flexible Pavement Testing

As noted above, outside of the pooled fund study there has been minimal use of the GeoGauge related to flexible pavement evaluation or QA. However, the device has direct application for judging the quality of unbound pavement layers and results in an estimate of the elastic or resilient modulus of the unbound layer.

3.10 Magnetic Imaging or Tomography Technology

Magnetic imaging tools function by emitting and detecting magnetic field in the localized area being scanned for the presence of any magnet-attracting materials. This technology has been applied in pavement evaluation in European countries and more recently in the U.S.

The technology is being used to locate the alignment of dowel bars and tie bars in PCC pavements and for determining the thickness of both HMA and PCC. The device being used in the U.S. for monitoring dowel bars is called the MIT-Scan-2, and for thickness measurements the MIT-Scan-T. Figure 18 shows the MIT-Scan-T being used to measure pavement thickness.

Figure 18. MIT-Scan-T to Measure Flexible Pavement Thickness

3.10.1 Principle of Operation

Magnetic imaging tomography enables users to determine the thickness of flexible or rigid pavements nondestructively, in an accurate and cost-effective manner using data collected from the magnetic field. The response signals of metallic reflectors at the bottom of the layer to be measured induced by short magnetic pulses are recorded and evaluated using magnetic tomography. Consequently, any metallic objects within the proximity of the scan unit will influence the measurements. To obtain reliable results, the surface of the joint to be scanned must be free of any metallic objects (e.g., coins, keys). A standard test procedure has been developed in Germany for this test and is identified as Specification TPD StB99.

3.10.2 Measuring Procedure

The device may be operated in three modes: the service mode, the search mode, and the measuring mode.

1. In the service mode, different data for identification of the measuring place and the type of reflector may be put in.

2. In the search mode, the device is moved meander-like in a distance of 2 to 4 in (5 to 10 cm) above the ground. The unknown location of the reflector is indicated by a four-line bar diagram and, if desired, by an acoustic signal.
3. In the measuring mode, the reflector is crossed by the device. The crossing starts before the reflector and ends about 3.3 ft (1 meter) behind it. The constant given measuring time of 4 seconds prevents subjective measuring errors. The exact localization of the center of the reflector is not necessary, but must be met only within about 7.9 in (20 cm). During measurement, all necessary environmental conditions are recorded, so no calibrations of the device are required.

The magnetic device requires certain conditions and precautions during use:

- Minimum distance between neighbored reflectors: 1.6 ft (0.5 m), from edge to edge
- Distance to guardrails: 3.3 ft (1 m)
- Distance to parking vehicles: 6.6 ft (2 m)
- Measuring temperature: 23 to 112 °F (-5 to 50 °C)

Metallic parts on the pavement must be removed. Safety shoes with metallic caps induce perturbations too. However, no errors are induced by wet pavements, weakly conducting or magnetic additives within the pavement. Reflectors in the device, which are essentially circular sheets of galvanized sheet steel, are 0.04 in (0.6 mm) thick for both PCC and HMA, and have a diameter of 11.8 in (30 cm) and 2.8 in (7 cm) for layer thicknesses up to 18 and 8 in (45 and 20 cm), respectively. The device has a measuring accuracy of 0.04 in (0.1 cm).

3.11 Non-Nuclear Density Estimating Devices and Technology

The acceptance of flexible pavement layers typically is based on in-place density of individual layers. Cores are used by most agencies for acceptance, while nuclear density gauges are used by most contractors for controlling the materials and compaction process. Non-nuclear density gauges are being investigated for use by many agencies. For example, Indiana, Kentucky, Louisiana, Maryland, Nebraska, New York, North Carolina, Ohio, Oklahoma, Pennsylvania, Tennessee, Texas, Utah, Washington, and Wisconsin have obtained different devices and are comparing them to the densities measured by traditional nuclear gauges and cores. The Pavement Quality Indicator (PQI) was used in field studies of NCHRP Project 9-15 and have been used at the National Center for Asphalt Technology (NCAT) test track (Killingsworth, 2002).

Non-nuclear methods have been under development for HMA density testing for many years, but none have proved very successful. The systems can be categorized into two basic types—compactor or roller-mounted and non-roller mounted devices. The early non-roller-mounted systems created interest but failed to become commercially viable. These early systems included the "Density on the Run" system (Seamon, 1988) and the "Rolling Dynamic Deflectometer" (Bay et al., 1995). These systems used some form of acoustic or vibratory waves to estimate density. The focus later changed to electrical current for the non-roller-mounted systems, and systems like the PQI, PaveTracker, and the Electrical Density Gauge (EDG) show promise today.

The roller-mounted density measuring methods are also not a new phenomenon. Since the mid-1970s, attaching a reliable density estimating device to a roller has been tried. The technologies used to achieve the density measurement have included piezo-electric acceleration measurement (the most popular), gamma rays, dielectric probes, GPR, and microwaves. The four most recent attempts have been in the areas of microwaves and piezo-electric acceleration measurement.

Jaselskis et al. (1998 and 2003) used microwaves to measure density with the "Roller-Mountable Asphalt Pavement Quality Indicator." Minchin, Thomas, and Swanson (1999, 2001, and 2003) used piezo-electric acceleration measurement to measure HMA density with the "Onboard Density Measuring System," and BOMAG and Geodynamic have similar systems. BOMAG's system is currently on the American market, while Geodynamic is attempting to translate their success in measuring the density of embankment soils to HMA. Many of these systems do not actually measure density, but rather measure the response of the roller's vibration and translate that response into a density or material stiffness. The status of GPR and laser technologies in the area of densities were covered in an earlier section dealing specifically with those technologies.

3.11.1 Roller-Mounted Density/Stiffness Systems

Some of the roller-mounted systems are being referred to as Intelligent Compaction (IC). IC is an emerging technology that actually monitors layer stiffness during compaction by instruments attached to the roller to measure the reaction of the material being compacted. Many of these rollers are not true intelligent rollers, because they only measure the response of the roller as the material densifies. In other words, the compaction effort is not varied during the rolling process; the roller operator is responsible for discontinuing the rolling operation, once the maximum stiffness has been achieved. Briaud and Seo (2003) provided a thorough overview of the different roller-mounted compaction control processes, including IC rollers.

IC and other roller-mounted systems give the contractor the opportunity to continuously monitor or test and document layer stiffness at the time of compaction, producing more uniformly-compacted material layers and allowing real-time compaction modifications based on response outputs. The output from this technology also provides documentation for owner and contractor management regarding material quality of all pavement layers. Thus, the technology has the potential to improve density and quality, having a positive impact on pavement construction and performance.

IC technology has been in existence for several years and provides real-time, in-place material stiffness data that can be used by roller operators to make better decisions. The use of IC technology as a viable construction quality measure has increased over the past decade. Over 15 state and federal agencies have sponsored demonstration projects or case studies to date. Multiple manufacturers (Ammann, BOMAG, Caterpillar, Geodynamic, and Sakai) now build compaction monitoring or IC equipment with varying outputs and controls (see Figure 19). These manufacturers have fully equipped rollers, but also have instrumentation kits that can be attached to existing vibratory rollers. As noted above, however, not all of these rollers can vary the compaction effort during rolling to account for increasing stiffness of the layer being compacted.

a. BOMAG Asphalt Manager IC Roller

b. AMMANN IC Roller

c. Caterpillar IC Roller

d. Vibratory Roller Instrumented by TTI for Use on Research Projects

Figure 19. Fully Equipped Rollers Measuring the Stiffness of the Material Being Compacted

Most of the instrumented rollers used to control or monitor the compaction process in real-time can be grouped into three categories: relative compaction monitoring equipment, absolute compaction monitoring equipment, and intelligent compaction equipment. Three of the roller-mounted systems that fall within these categories include: the Onboard Density Measuring System (ODMS) patented by Pennsylvania State University—the absolute compaction monitoring equipment; the Continuous Compaction Control (CCC) system marketed by Geodynamik—the relative compaction monitoring equipment; and the Asphalt Manager manufactured by BOMAG—the IC monitoring equipment.

These systems and others offer real-time pavement quality measurement tools and use accelerometers to measure parameters of the compactor's vibratory signature. Other sensors are also used to gain information about the pavement during the compaction process.

Information from all sensors is then used to evaluate pavement density or stiffness and quality. The true test of the "intelligent compaction" system, however, is whether it actually saves time (fewer passes), improves uniformity of the mat, and provides accurate, consistent readings.

Minnesota DOT, FHWA, and NCAT all recently sponsored demonstrations and workshops on the use of IC rollers. Other agencies where case studies have been completed include Alabama, Florida, Iowa, Maine, Oklahoma, Virginia, Texas, and Wisconsin, to name a few. In addition, FHWA has developed a strategic plan (Horan and Ferragut, 2005) to implement IC technology within the U.S., which includes a systematic procedure to encourage state agencies and industry to expedite the implementation process. Several agencies, including Minnesota, Virginia, North Carolina, Louisiana, Iowa, New Jersey, and Wisconsin, are conducting or planning to conduct field and laboratory based studies to evaluate IC technology and to develop specifications for pilot projects.

The Minnesota DOT demonstration at the Minnesota Road Research (MnROAD) test track used the Bomag CCC system and other NDT devices to independently measure soil properties at each test point. The other NDT devices used in the demonstration included the DCP, the Geogauge, and the LWD. In general, it was found that the moisture content in the soil greatly influenced the compaction process and the modulus measurement. The study suggests future demonstration projects on "real-world" construction projects.

NCHRP Project 21-09 was initiated in 2006 to determine the reliability of IC systems and to develop QA specifications for the application of IC in the compaction of unbound materials. The study is ongoing and has included an evaluation of three IC systems for soils using field data—Ammann, BOMAG, and Caterpillar. Based on current progress of this study, the findings suggest smooth drum rollers are more reliable than sheet-foot rollers (Mooney et al., 2007). In addition, a change in displacement amplitude of the roller proved to have a larger effect on soft clays than on granular materials. Soils properties such as modulus and the DCP penetration index are correlated to roller output for both subgrade clays and aggregate materials. The field study was comprehensive, and future tasks to be undertaken will result in the development of construction specifications for embankments and granular bases.

The following paragraphs summarize the operational characteristics of three of the systems currently in existence.

Onboard Density Measuring System

The Onboard Density Measuring System (ODMS), a model patented by Pennsylvania State University, offers density measurements in real time at a rate of one per second during the compaction process, thereby affording the contractor and roller operator the opportunity to recognize and correct compaction problems immediately, while maintaining a permanent record of the entire compaction process.

The ODMS was developed from the rather simple idea that, the denser the material that the vibratory roller is rolling over, the more excited the vibratory response of the roller. This response is measured by an onboard computer connected to a machine milled accelerometer

(MMA) attached to the frame of the roller just inside the roller's damping mechanism. The computer receives the signal from the MMA and uses a FFT to transfer the information into the frequency domain, producing a power spectrum such as the one seen in Figure 20. The computer then integrates the power spectrum into an algorithm that calculates the HMA density at one-second intervals and transports them via radio signal to interested project personnel at a remote computer. Two major aspects of the ODMS separate it from other acoustics-based density gauges.

1. It is the only acoustics-based density gauge that takes physical parameters other than the vibratory response of the roller into account.
2. It does not give a relative density reading, but a direct density reading in pounds-per-cubic-foot.

Principle of Operation of ODMS

The relationships between established vibration parameters are both unique and convenient. The displacement is written as $\Delta(t)$. The velocity of the vibration (V) is the derivative of the displacement (Δ) as a function of time; therefore, velocity can be written as:

$$V(t) = \frac{d\Delta(t)}{dt} \tag{26}$$

Acceleration is defined as the rate of change in velocity at a given point in time. Acceleration is the derivative of velocity; therefore, the acceleration can be written as:

$$a(t) = \frac{dV}{dt} = \frac{d^2\Delta}{dt^2} \tag{27}$$

Thus, these relationships can be derived, as shown in the following equations:

$$Displacement = \Delta(t) = A(\sin(\omega t)) \tag{28}$$

$$Velocity = V(t) = \frac{d\Delta}{dt} = wA(\cos(\omega t)) \tag{29}$$

$$Acceleration = a(t) = \frac{dV}{dt} = \frac{d^2\Delta}{dt^2} = \omega^2 A(\sin(\omega t)) \tag{30}$$

Where:

A = amplitude
t = time
ω = circular frequency (in radians / sec.)

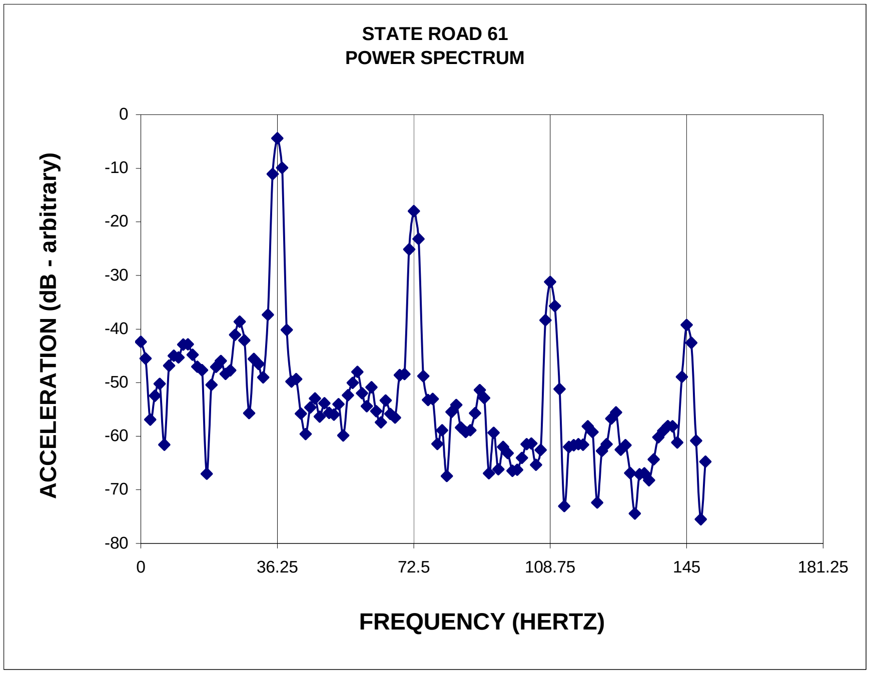

Figure 20. Typical Power Spectrum Produced by the ODMS

As the HMA mat is compacted with each successive pass of the vibratory roller, the density level rises, and the effective stiffness increases. The theory that the system is based upon is that the acceleration level of the vibratory response is affected in a repeatable manner. The fundamental relationship between the displacement, the velocity, and the acceleration of a mechanical system is demonstrated above. These established, fundamental relationships allow the restatement of the theory.

As shown in Figure 21, the concept of mat stiffness and the presence of damping induced by the mat were introduced. The assumption that the mat contains these properties is symbolized by the traditional spring, shown as stiffness, *K*, and dashpot, shown as damping, *C*. The acceleration, *a(t)*, of the compacting vibrations for this study depends on mat stiffness, *K*, and the damping, *C*. At very low frequencies, stiffness *K* is the dominant physical factor affecting *a(t)*. This is shown by equation 31:

$$F_{damping} = CV = CA\omega \sin\omega t \qquad (31)$$

Where:

V = Velocity of the vibration

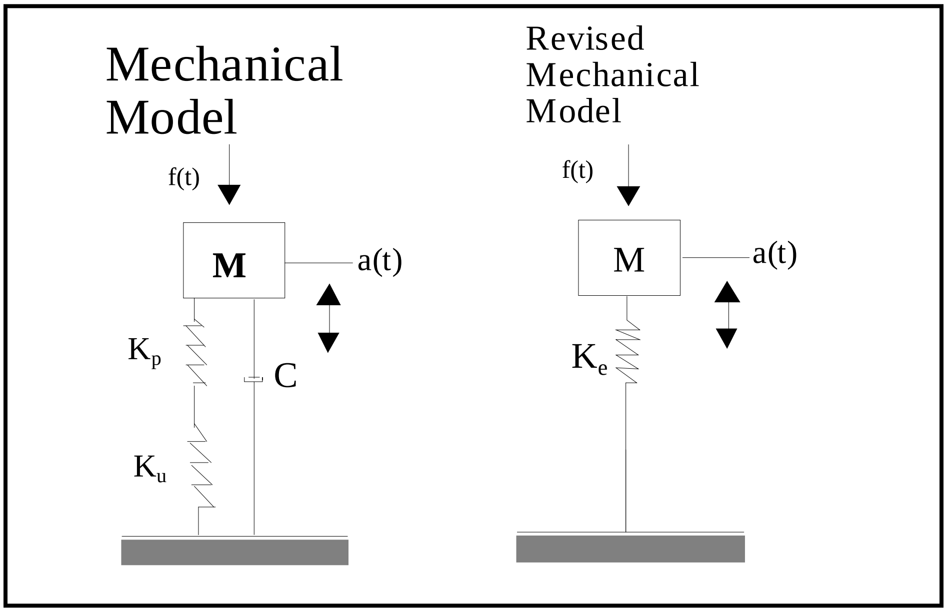

Figure 21. Illustration of the Mechanical Model on which the ODMS was Developed

Equation 31 shows how dependent the damping force is on the frequency. Since the frequencies of the vibratory components studied are in a sufficiently low range, the damping, *C*, can be initially ignored. This theory is a continuation of the original hypothesis, discussed earlier. Mathematically, it can be stated that:

Acceleration, a(t) = f(Stiffness, K)

As material under the roller becomes denser, the reduction of air voids adds structure to the material, resulting in higher densities and mat stiffness. The theoretical relationship for stiffness can be expressed as a function of HMA density, so acceleration can be expressed as a function of density.

Acceleration a(t) = f(Density)

During the developmental phase, the system was tested on twelve highway construction projects in four states. In the validation phase, it was tested on two interstate highway construction projects—one in Florida, and one in New York. Both tests were conducted with the system mounted on an Ingersoll-Rand DD-110 vibratory asphalt roller. The results definitely demonstrated the potential use of these roller-mounted systems. The parameters that have a large impact on the accuracy of the system include the temperature and thickness of the HMA mat, the vibratory frequency and amplitude of the compactor, and the strength of the underlying pavement structure.

BOMAG Asphalt Manager

BOMAG's system, called the Asphalt Manager, was introduced in 2001 and combines VARIOMATIC technology with a new method for HMA compaction and testing to provide an assessment during the compaction process (see Figure 22). BOMAG's system first calculates the stiffness of the HMA and then ties the stiffness to a density, producing a reading of how much the density of the mat has increased in pounds-per-cubic-foot (BOMAG, 2003, Kloubert, 2002). Actually, Asphalt Manager is a total HMA compaction management system. The density measurement is only one component of that, and it is a descendent of the original Hypac Terrameter.

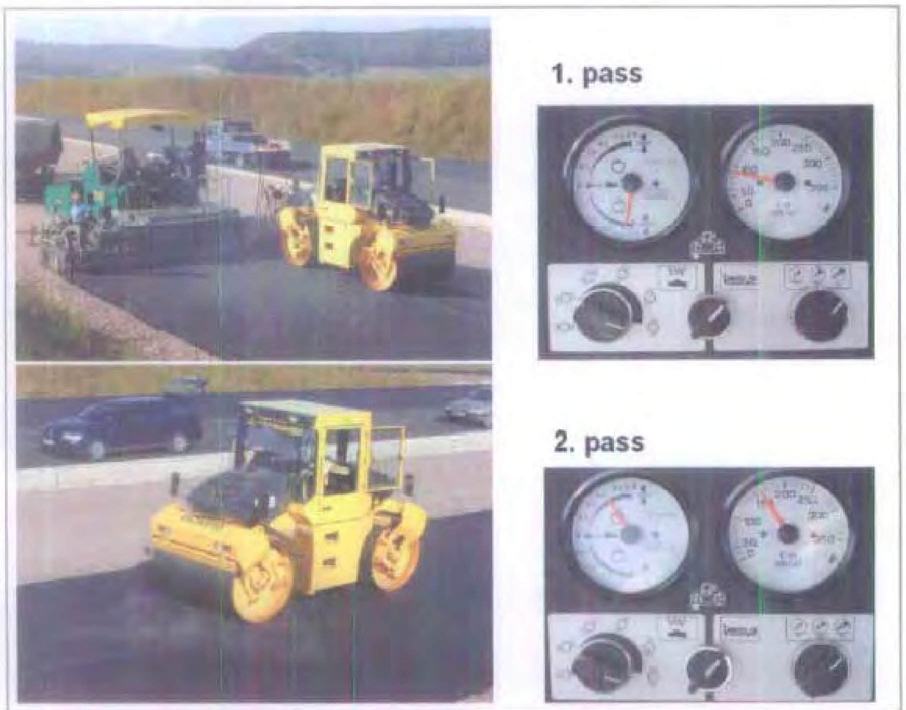

Figure 22. The Asphalt Manager from BOMAG

BOMAG reports and hypothesizes that the dynamic stiffness value calculated by the Asphalt Manager, termed E_{VIB} [MN/m²], can be used as a measure for the level of compaction under uniform subgrade stiffness and under consideration of the HMA temperature. E_{VIB} and the Marshall density have been shown to be related to one another.

The contact force between the HMA and roller drum together with the vibration path is determined by acceleration measurements taken on the vibrating roller drum. When calculating the contact force over the vibration path of the drum each rotation of the eccentric produces a loading and unloading curve in which the enveloped area defines the compaction work done.

As with the plate bearing test used in soils, the dynamic stiffness of the HMA is calculated using the load curve. The cylindrical shape of the drum and the changing contact area of drum and HMA is thereby taken into account. The physical measurement value of HMA stiffness is the vibration modulus, E_{VIB} (BOMAG, 2003).

The roller operator reads the E_{VIB} value on an analogue display. Since HMA stiffness is temperature-related, the surface temperature is sensed by an infrared measuring unit underneath the cab and also displayed on an analogue gauge. Site experience shows that temperature sensitivity of the E_{VIB} value is between 100 and 150°C (212 and 302°F) and is therefore within reasonable limits. The effect of increasing compaction is very distinct and provides an assessment of the compaction progress. Compaction measurements using a nuclear density gauge show a direct correlation between the E_{VIB} vibration modulus and density—given a uniform and stable base under the HMA layer and taking the mat temperature into account.

Continuous Compaction Control

Geodynamik has traditionally focused on embankment density measurements but has initiated operations to service the HMA construction community. Currently, its embankment density measuring system produces a compaction meter value that is a dimensionless unit that measures the compaction state of a material, and its absolute value varies with the material's rigidity. At the end of compaction, a documentation report of both the compaction process and the compaction results is available.

The system consists of an accelerometer, a processor, a compaction meter value (CMV), and a frequency meter. Both meters are fed information by the accelerometer. The accelerometer detects the drum's vertical vibrations and transforms them into electric signals. The signals are amplified, filtered, and then sent to the processor via a cable. In the processor, the signals are analyzed and the CMV is calculated. This CMV signal is then sent to the CMV meter and to the compaction documentation system (CDS). CMV is a measure of how much the vibration signal differs from a pure sinusoidal signal.

The reason the vibration signal differs from a sinusoidal signal is because the drum hits the ground. If the ground is hard, the impact will be very short in duration and very powerful and, consequently, the distortion of the signal from the A-sensor will be very large. This method of measuring compaction can be considered to be a continuous loading test of the material (i.e., while the drum rolls on, a load test for every impact into the ground). In principle, about 25 to 40 load tests per second are obtained. In order to level out the CMV variations from impact to impact, the processor builds up a moving average that is valid over a given period of time. The overall effect is that the CMV values that the processor sends at a given time is the average of the load test results for the last half second.

The system also has an oscillometer. The oscillometer is a patented roller-integrated compaction meter for oscillating rollers. It can be mounted on all types of oscillating rollers of all fabrications. The oscillometer consists of an accelerometer, a processor, an I-sensor (a proximity transducer that produces an electric pulse whenever a metallic object passes by), an OMV (oscillo-meter-value) meter, a roll-speed meter, and an oscillation frequency meter.

The operation of the oscillometer is based on the indirect measurement of the reaction force in the horizontal direction brought about as a result of the drum's contact with the ground. This reaction force accelerates the whole roller horizontally. An A-sensor registers this horizontal acceleration and transforms it into an electrical signal. This signal is then filtered, amplified, and sent to a processor unit via a cable.

In the processor, the signal is analyzed and the OMV is computed and sent to an OMV-meter or to a CDS-system. The analysis includes the computation of the maximum reaction force into the material during the oscillation of the drum. This reaction force increases with increasing rigidity of the ground in a specific way, provided all the other factors affecting the whole system are kept constant.

The friction between the material and the oscillating drum is not big enough to keep the drum and the material in contact during the whole oscillation. Instead, there is always some gliding between the drum and the ground. The processor takes this into consideration and uses only that part of the signal where the gliding between the ground and the drum does not occur. The values produced by this process correspond to the reaction force that would have existed if the friction were big enough to prevent gliding between the drum and the ground.

This method of measurement can be considered as equivalent to a continuous dynamic loading test of the ground while the drum rolls. The compacto-meter analyses loading tests with vertically directed loads, as the oscillometer uses horizontally directed oscillating loads.

In principle, even here, 25 to 40 load tests per second are obtained. In order to level out the variations between cycles, the processor builds up a moving average. The overall effect is that the CMV values that the processor sends at a given time is the average of the load test results for the last half second. The density measurement is a function of the CMV and OMV values.

Before using the continuous compaction control device, it must be calibrated using a traditional density measuring system. Calibration instructions for the system are very detailed and the calibration procedure continues until no considerable rise in compaction occurs or when a double jump occurs for the first time. After the compaction for purposes of calibration is finished, there is a six-step procedure to complete the calibration process.

3.11.2 Non-Roller-Mounted, Non-Nuclear Electric Devices

The four non-roller-mounted systems that show the most promise at this point in time are the PQI, manufactured by TransTech; the PaveTracker manufactured by Troxler; the EDG; and the Purdue Time Domain Reflectometry (TDR) method. The PQI and PaveTracker devices are used for measuring the in place density of HMA, while the EDG and TDR devices are used to measure the in-place density and water content of unbound aggregate base materials and embankment soils.

The use of the non-nuclear density gauges has received much attention over the past 5 years because of the increased regulations and safety issues with the use of nuclear density gauges. Studies conducted by Hausman and Buttlar (2000), Henault (2001), and Romero (2002) found poor correlations between the HMA density devices and the results from cores and nuclear density gauges. Most studies have found that the results from these gauges are related to changes in the material density, but an absolute density value is not reported by any of the gauges. More importantly, the gauges need to be calibrated for the same material being placed. In addition, most studies have recommended that the devices can be used for controlling the materials placement, but that they should not be used for acceptance and establishing payment. A more recent study, (Schmitt et al., 2006), that used significantly upgraded and improved non-nuclear density devices, recommended its use for routine QA and established a procedure for calibrating the device. The recommendations were, however, based on companion nuclear gauge readings, a baseline selected to reflect the agency's current practice.

Unbound Materials and Soils

Electrical Density Gauge—EDG

The EDG was developed for measuring the density and moisture content of soils and other unbound materials using capacitance. This device has not been used to-date for testing HMA layers. The EDG is relatively new and has not been used by many agencies. Nonetheless, those agencies that used the device (for example, Nevada DOT) were satisfied with its performance and recommended it for continued use.[7] The biggest advantage of using the EDG and similar devices is its safety and accompanying lack of regulation and required licenses, as compared to nuclear density gauges.

EDG, LLC has 10 EDG beta units and have made these units available to various highway agencies and consultants. A user's manual is available for this device which describes its operation and calibration.[8] In addition, a draft test standard has been prepared and submitted to ASTM D-18.08 (Soils and Rocks for Engineering Purposes) for balloting purposes.

The unit weighs 11 pounds (5 kg) and is 13.5x12x6 inches (343x305x152 mm) in size. It is placed at the location of interest by the technician. While in operation, the unit emits far less energy than does a cell phone, since the EDG uses radio frequency measurements to measure the density of the material. The current beta units include "soil darts" that are driven into the material and act as probes as well as controlling the sample size. The EDG and all its accessories are shown in Figure 23 (EDG, 2003).

A benchmark or calibration is required for each soil and material being compacted to estimate the density and moisture content of the compacted material. This calibration is a moisture-density relationship prepared in accordance with ASTM D698 or ASTM D1557 or other similar methods. The EDG is then used to determine the electrical conductivity through the different conditions of moisture and density. A relationship is developed between the electrical conductivity and actual volumetric values of the material or soil. The calibration can also be completed during construction by varying the compaction effort (number of roller passes) and measuring the density with the sand-cone method or other devices within each area with different compaction levels and then preparing a relationship between the EDG readings and the actual density and moisture content of the material over the expected range of values encountered in the field.

[7] Density data on a sand/clay soil measured with the Electrical Density Gauge provided by Ali Regimand with Instro Tec, Inc. and Dennis Anderson with Anderson Resource Associates, Inc.
[8] User's Manual, P/N 9093927; Electrical Density Gauge for Compacted Soil, Electrical Density Gauge, LLC; Carson City, Nevada.

Figure 23. Photo of the Electronic Density Gauge

Purdue TDR Device

The Purdue TDR method measures both the density and water content of unbound embankments and other fill materials. The system consists of a TDR device, a coaxial cable, a coaxial head, either a coaxial cylinder or multiple probe arrangement, and a portable computer interface. Figure 24 shows the parts of this system and the gauge in operation. The procedure is currently being marketed by Durham Geo. This system is similar to the EDG, is relatively new, and has yet to be used or evaluated by many agencies.

Other Devices for Estimating Moisture Content

There are other devices where commercial equipment is available for measuring the water content of unbound materials and soils, such as the Field Moisture Oven (FMO 200) that is manufactured by Kessler Soils Engineering Products and the Speedy Moisture Testing Kit manufactured by Humbolt Manufacturing. The Field Moisture Oven measures the water content in accordance with ASTM D 4959 (*Determination of Water (Moisture) Content of Soil by Direct Heating Method*), while the Speedy Moisture Testing kit measures water content in accordance with ASTM D 4944 (*Field Determination of Water (Moisture) Content of Soil by the Calcium Carbide Gas Pressure Tester Method*). Although these devices can be used in the field, they do not actually measure the water content of the in-place soil. Soil must be sampled and removed from the layer, unlike the EDG and Purdue TDR devices that make the measurements in place without physically sampling the soil. Thus, these devices do not meet the definition of NDT devices, as used within this project.

Figure 24. Photo of the Purdue TDR Method (courtesy of Durham Geo Website)

HMA Mixtures

PaveTracker Device

Troxler has long been the leader in nuclear density gauge technology. More recently, Troxler has developed a non-nuclear field density measuring device called the PaveTracker (Model 2701). This particular instrument, unlike Troxler's nuclear gauges and unlike the other non-nuclear gauges covered (PQI and EDG), is not made to be lifted by the operator and placed on the location of interest. The PaveTracker is shown in Figure 25 (Troxler, 2003).

This unit is the lightest of the three models reviewed, at 2 lb (0.9 kg). It gives a reading every second and displays density in pounds-per-cubic-foot. Unlike some non-nuclear, non-mounted gauges, this model needs no moisture or temperature corrections, and the 3-foot (0.9 m) telescoping handle allows the operator to slide the gauge into position and reduces bending. Presently, Troxler recommends this instrument as a QC tool, but in time, it may advance to the point of being considered for acceptance purposes.

Figure 25. Photo of the Troxler PaveTracker

A unique feature of the PaveTracker is its very small size, with dimensions of 3.5x4.5x2.25 inches (89x114x57 mm). Since it is so small, the PaveTracker can be used in the laboratory for calibration by placing it top of a 6-inch (150-mm) gyratory compacted specimen. The instrument is able to probe to depths of 1.75 inches (44.5 mm) and demonstrates a repeatability of +/- 0.5 units.

Pavement Quality Indicator Device—PQI

The PQI is a non-nuclear density gauge for instantaneous, in-situ measurement of asphalt pavement density, invented and manufactured by TransTech Systems, Inc. PQI is a lightweight device (under 16 lb [7.3 kg]), easy to use, no special licensing requirement, and can provide density data in several seconds (see Figure 26).

PQI measures pavement density by measuring the electrical impedance of the material (see Figure 27). A toroidal electrical sensing field is established in the paving material and measured via a flat sensing plate. The measured electrical impedance is a function of the composite dielectric constant, which is further related to the density of the paving material. An embedded computer is used to determine the density of the paving material, and perform calibration and correction functions (TransTech, 2003).

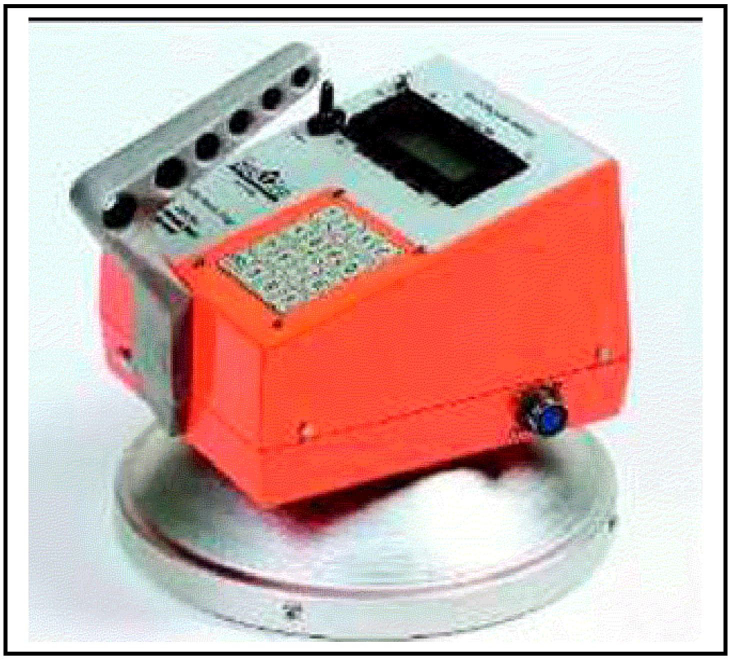

Figure 26. Photo of PQI Device by TransTech

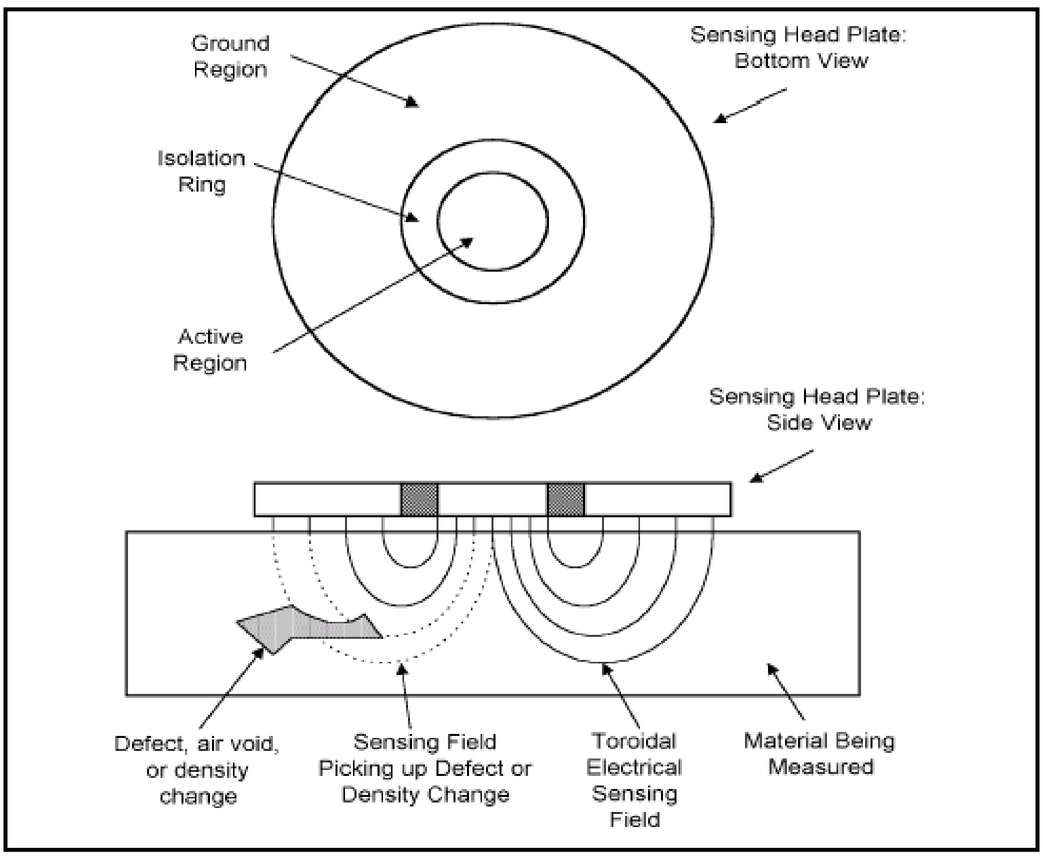

Figure 27. Operational Theory Schematic of the PQI

TransTech started the work on the PQI in 1995 under an agreement with the New York State Energy Research and Development Authority, and later got support from FHWA and AASHTO, delivered through the NCHRP under the IDEA program. Now the PQI Model 300 has been widely evaluated; the latest PQI Model 301, with the ability to compensate for surface water, has been commercially available (TransTech, 2003).

By January 2003, about 400 units of PQI have been sold to more than 10 countries. Many evaluations have been made on the use of PQI. But the conclusions are not consistent. Several research projects reported accurate and reliable results and suggested the use of PQI for QC on asphalt paving (Allen et al., 2003; Rogge et al., 1999; Sully-Miller, 2000). An FHWA five-state pooled fund study provided similar results (TransTech, 2003). But Henault (2001) reported a poor correlation between PQI density and core density, conditioned by the presence of moisture introduced into the asphalt during rolling operations.

One of the most thorough studies performed on the PQI was done by the Kentucky Transportation Center (KTC) at the University of Kentucky. The study took two PQI units and one Troxler thin-lift nuclear density gauge out to an ongoing construction project and let the contractor operate one PQI (HHR PQI), the KTC operate the other PQI (KTC PQI), and the DOT inspector operated the nuclear density gauge (TMTL) and took cores—all on the same project. Results of this study are summarized in Table 21.

Table 21. Summary of Density Comparisons

Density Measurement	HHR PQI	KTC PQI	TMTL	Cores
Number of samples	735	740	453	149
Average (pcf)	144.4	143.4	142.3	144.1
Standard Deviation (pcf)	4.91	3.52	4.15	2.72

The following are quotes from the study's reported conclusions:

- *The standard deviations of the density readings of all the gauges were greater than the standard deviations of the density readings of all the cores. This indicates that there was more scatter in the data from each of the gauges than from the cores.*
- *There was no significant difference between the mean density of the HHR PQI and the mean density of the cores. However, there was a statistically significant difference between the mean density of the TMTL and KTC PQI density gauges and the cores.*
- *The density distribution of the HHR PQI gauge most closely matched the distribution of the cores with an 88% overlap in the distributions. The TMTL gauge and the KTC PQI gauge had overlaps in their density distribution functions with the density distribution function of the cores of 83% and 78%, respectively. This information indicates that the HHR PQI gauge, not only in the mean density, but also in the overall distribution of readings, most closely approximated the results of the cores.*

- *If pay factors were determined from gauge densities, then using the densities provided by the TMTL gauge would have resulted in a five-percent reduction in overall pay for lane densities. One hundred percent overall pay would have resulted from using the two non-nuclear density gauges.*

The report went on to recommend that the PQI gauge be approved for use as a QC device. This is because the ease of operation of the two gauges (Troxler Model 4640-B and PQI) are similar, and because the gauge that most closely approximates the data from the cores (both by comparing the means and the distributions) was the HHR PQI non-nuclear gauge (Allen et al., 2003).

3.12 Surface Condition Measuring Systems and Devices

The quality of the surface condition of the pavement includes the measurement of ride quality or surface profile, surface texture, noise, and friction or skid. Each surface property or characteristic is briefly discussed below in relation to QA applications.

3.12.1 Surface Texture

Several nondestructive methods have been developed to measure pavement texture. The pavement's surface texture is a function of and can be defined by surface wavelengths. The surface wavelengths can be separated into two groups, microtexture and macrotexture. The microtexture wavelengths are defined in a range of 1μm to 0.5 mm, while the macrotexture is defined by wavelengths from 0.5 mm to 50 mm. Microtexture provides a gritty surface to penetrate thin water films and produce good frictional resistance between the tire and the pavement. Macrotexture provides drainage channels for water expulsion between the tire and the pavement, thus allowing better tire contact with the pavement to improve frictional resistance and prevent hydroplaning. Measurements of macrotexture may also indicate pavement uniformity or lack of segregation. This potential use of identifying segregation in HMA mixtures would be applicable to QA use.

Currently there is no system capable of measuring microtexture profiles at highway speeds. Therefore, microtexture can be evaluated by using pavement friction at low speeds as a surrogate. The classic measure of pavement macrotexture is a volumetric method, typically referred to as the "sand patch" method, ASTM E965 (ASTM, 1999). The sand patch method, while historically used, is time intensive and operator dependent (Henry, 2000). Thus, it will not be discussed further.

On the other hand, with the significant advances that have been made in laser technology and data processing, systems are now available to measure macrotexture at traffic speeds. There are three types of laser based systems to measure pavement macrotexture.

- MGPS commercial version of the Road Surface Analyzer (ROSAN).
- Circular track texture meter (CT Meter).
- Various proprietary systems using inertial profilers with laser based sensors.

All three systems use laser range finding technology. As shown in Figure 28, a photosensitive diode measures reflections from a pulsating laser diode source. The MGPS and inertial profiler systems are linked with precision electronic distance measuring systems (McGhee and Flintsch, 2003). Both systems also use accelerometers to account for vehicle body movement. The systems are capable of continuous or semi-continuous measurements at high speeds.

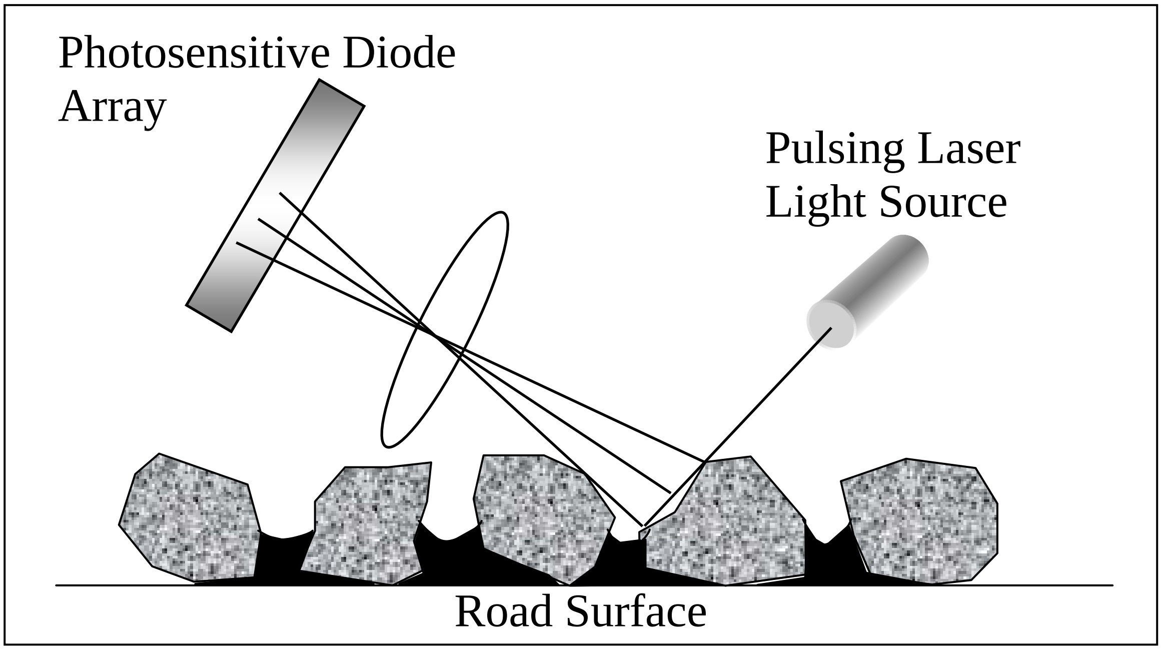

Figure 28. Schematic of Laser Sensor (Stroup-Gardiner and Law, 2000)

The MGPS system is an outgrowth of FHWA's ROSAN project. The MGPS high frequency laser is focused to a smaller diameter, making it more suitable for texture measurements (McGhee et al., 2003). The use of the MGPS system to detect segregation was reported in NCHRP Report 441 (Stroup-Gardiner and Brown, 2000). The MGPS can be mounted on the bumper of most vehicles. The MGPS system measures mean profile depth (MPD) according to ASTM E1845. McGhee and Flintsch (2003) found a good correlation between the MPD measured by the MGPS system and the MTD measured by the sand patch test.

Inertial profilers typically are used for measuring pavement smoothness. However, several companies (ARAN, Australian Road Research Board, Dynatest, Greenwood Engineering, International Cybernetics, and WDM) produce vehicle-mounted inertial profilers with high frequency lasers and software for estimating pavement texture.

The CT Meter is a stationary device with a laser displacement sensor mounted on a rotating arm. The arm rotates in a circular path with a diameter of 284 mm and takes measurements every 0.9 mm (ASTM, 2005). The device calculates a MPD according to ASTM E2157. Several studies have shown good correlation between MPD measurements with the CT Meter and MTD measurements made with the sand patch test (Abe et al., 2000; McGhee and Flintsch, 2003).

Segregation is a major problem in the placement of HMA layers. NCHRP 441 (Stroup-Gardiner and Brown, 2000) defined segregation as: "*a lack of homogeneity in the HMA constituents of the in-place mat of such a magnitude that there is reasonable expectation of accelerated pavement distress*." NCHRP 441 identified both gradation and temperature related segregation. Historically segregation has been identified visually, assuming that segregation is confined to the surface. Visually identified areas could then be cored and the extracted gradations compared with the job mix formula or control areas.

NCHRP 441 proposed using texture ratios determined from the MGPS system to identify segregation (Stroup-Gardiner and Brown, 2000). The ratio of the area in question to a non-segregated area defines the texture ratio. In lieu of identifying a non-segregated area, the texture depth may be estimated from equation 32 (Stroup-Gardiner and Brown, 2000; McGhee et al., 2003):

$$\begin{aligned} ETD &= 0.01980(\max.\, agg.\, size) - 0.004984\,(\%\ pass.\, 4.75\ mm) \\ &+ 0.1038(C_c) + .004861(C_u) \end{aligned} \tag{32}$$

Where:

- *ETD* = Estimated texture depth in mm.
- *Max. Agg. Size* = smallest sieve size with 100 percent passing.
- *% pass. 4.75 mm* = Percent passing the 4.75 mm sieve.
- C_c = Coefficient of curvature = $(D_{30})^2 / (D_{10} D_{60})$.
- C_u = Coefficient of uniformity = D_{60}/D_{1}..
- D_{10} = Sieve size, in mm, with 10 percent passing.
- D_{30} = Sieve size, in mm, with 30 percent passing.
- D_{60} = Sieve size, in mm, with 60 percent passing.

Included with NCHRP Report 441 was a draft AASHTO test method that includes the proposed texture ratios shown in Table 22. Research by McGhee et al. (2003) suggests that these limits may not be applicable to large stone and gap graded mixes, such as Stone Matrix Asphalt (SMA) or Open-Graded Friction Course (OGFC). McGhee et al. (2003) examined two equations for predicting the ideal texture based on the job mix formula, acceptance bands based on the AASHTO Implementation Manual for Quality Assurance and empirically established target standard deviation levels. The authors felt that this last approach could hold some promise for future use in QA application. However, this system and equipment cannot identify segregation at the bottom of an HMA lift.

3.12.2 Noise and Skid

The measurement of noise and skid along a pavement's surface are becoming important regarding the performance of flexible pavements. NCAT recently developed equipment and test procedures to measure both of these parameters. However, these test methods and parameters have yet to be used in any QA format.

Table 22. Proposed Texture Ratios Corresponding to Various Levels of Segregation (Stroup-Gardiner and Brown, 2000)

Level	Upper Limit	Lower Limit
Non-segregated	ETD*1.15	ETD*0.7
Low Segregation	ETD*1.56	ETD*1.16
Medium Segregation	ETD*2.02	ETD*1.57
High Segregation	>ETD*2.02	NA

3.12.3 Ride Quality

Pavement ride quality is the key to user satisfaction. Achieving an appropriate level of smoothness is therefore a strategic goal for highway agencies. Studies have further validated that pavements built smooth remain smooth longer and generally exhibit better performance and serviceability.

ASTM defines pavement roughness as the deviations of a pavement surface from a true planar surface with characteristic dimensions that affect vehicle dynamics, ride quality, dynamic loads, and drainage. Several NDT techniques have been developed to measure the pavement profile to determine pavement roughness and texture. The profile-measuring devices can be classified as:

1. *Response-type road roughness measuring (RTRRM)* devices that measure the movement of an axle with respect to the vehicle or trailer frame.
2. *Inertial profilers* that employ an accelerometer and vertical measuring device to measure the "true" profile of the pavement surface, for a range of wavelengths, at highway speeds.
3. *Profilographs* that record deviations of the pavement surface from the plane of a rolling straightedge.
4. *Inclinometer and manual* devices that measure the slope from one point to the next or the elevation of each point as the unit is moved along the pavement.

During the last decade, FHWA developed the ROSAN, briefly described earlier. This is a laser-based profiler and is capable of measuring longitudinal texture and pavement profiles at highway speeds. More importantly, the inertial profilers, profilometers, and profilographs are already included in many agencies QA programs for acceptance. In addition, none of these devices result in an estimate of the structural or volumetric properties of HMA.

3.13 Summary of NDT Technologies for HMA Pavement Evaluation

Table 23 summarizes those NDT technologies and methods that have been used to measure different properties and features of flexible pavements. Chapter 4 of this report details the evaluation of these methods in regard to their potential for application to QA. As tabulated, the GPR has been used for estimating many more properties than any other NDT technology for the volumetric properties, while the seismic technologies have been used more extensively for estimating the structural properties.

Table 23. Summary of NDT Methods Used to Measure Properties and Features of Flexible Pavements In Place

Type of Property or Feature		NDT Technologies and Methods	
		HMA Layers	Unbound Aggregate Base and Soil Layers
Volumetric	Density	GPR, PQI, PaveTracker, ODMS	GPR, EDG, Purdue TDR
	Air Voids or Percent Compaction	GPR, Infrared, Acoustic Emissions, Roller-Mounted Density Devices	GPR, Roller-Mounted Density Devices
	Fluids Content	GPR	GPR, EDG, Purdue TDR
	Gradation; Segregation	GPR, Infrared, ROSAN	NA
	Voids in Mineral Aggregate	GPR (Proprietary Method)	NA
Structural	Thickness	GPR, Impact Echo, SPA, SASW, Magnetic Tomography	GPR, SASW, SPA
	Modulus; Dynamic or Resilient	PSPA, FWD, LWD, SASW, Asphalt Manager & Other Roller-Mounted Response Systems	DCP, Clegg Hammer, DSPA, SPA, SASW, FWD, LWD, GeoGauge, Roller-Mounted Response Systems
	Bond/Adhesion Between Lifts	SASW, Infrared, Impulse Response	NA
Functional	Profile; IRI	Profilometer, RTRRM, Inertial Profilers	NA
	Noise	Noise Trailers	NA
	Friction	CT Meter, ROSAN	NA

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CHAPTER 4

NDT TECHNOLOGIES FOR APPLICATION TO QUALITY ASSURANCE

Multiple NDT technologies and devices have been used to varying extents by agencies in the U.S. for pavement evaluation, forensic studies, and construction evaluation. Several of these agencies were contacted to ask about their specific use of these NDT devices for potential application within their acceptance plans and the test methods associated with them. These contacts were considered essential to evaluate the various NDT technologies and determine their practical application to QA practices.

Typically, the emergence of a new technology will initiate a research and evaluation effort by an agency before the process is accepted for use as a good engineering tool. This chapter presents an evaluation of the NDT technologies and provides the reasons and justification for selecting specific NDT methods with potential use for judging the quality of flexible pavement construction.

4.1 Evaluation Factors and Topics

As noted in chapter 3, a number of NDT technologies and inspection systems provide information on the quality of the material without altering or damaging the materials being tested. Utility analyses have been completed regarding the potential use of NDT methods and devices for measuring critical pavement properties and features (Von Quintus et al., 1995; Saeed et al., 2001). These analyses were used to rank selected NDT methods and devices for measuring important properties and features of pavements. The factors used in those analyses were considered in this study. However, this evaluation was focused towards specific requirements related to QA programs referred to in the Research Problem Statement, specifically:

> *This will lead to increased **measurement of layer moduli** by owner agencies, an activity that is not at present a typical component in the acceptance of a completed project.*
>
> *The results will identify NDT technologies **ready** and appropriate for implementation in **routine, practical** quality control and acceptance operations.*

Thus, those NDT technologies and methods were evaluated for their ability to accurately measure QA properties that are strongly correlated to performance, including estimates of layer moduli, and can be used in routine, practical QA operations by contractor and agency personnel. Those layer properties that have been found to be strongly correlated to performance and included as inputs to the MEPDG are dynamic and resilient modulus, density, air voids, fluids content, and gradation. Field permeability, although an important characteristic of HMA mixtures, was excluded from this evaluation, as explained in chapter 2 of this report. The following lists the factors used to evaluate specific NDT devices for inclusion into a QA program.

1. Accuracy and precision of the test equipment and protocols in measuring a specific material property—one of the difficulties of this category is defining the target value of some properties for nonlinear and viscoelastic materials. The accuracy and precision of the technology also are tied to the data interpretation procedures.

2. Data collection guidelines and interpretation procedures—this category includes whether there are generalized guidelines and procedures available for performing the tests and analyzing the data to estimate the material properties and/or features.

3. Availability of standardized test procedures (test protocols)—this category includes whether there is a test standard available for use in collecting NDT data to estimate the required material properties and features.

4. Data collection—production rate of the NDT equipment in collecting the data.

5. Data interpretation—time and ancillary equipment/software required to analyze and interpret the data for estimating the specific layer property (see Tables 15 and 23).

6. Cost of the equipment—this category includes the initial cost of the test equipment, additional software and hardware requirements necessary to perform the test, and the operational and maintenance costs, including calibration.

7. Complexity of the equipment or personnel training requirements.

8. Ability of the test method and procedure to quantify the material properties needed for QA, mixture design, and structural design (see Figure 2). In other words, is the NDT test result applicable to mixture and structural design?

9. Relationship between the test result and other traditional and advanced tests used in mixture design and structural design.

Calibration of field and laboratory equipment is important to reduce the error and variability in the test results. However, calibration of the system is often overlooked or confused with equipment calibration in many QA projects. Figure 2 identified some of the calibration steps in the systems approach to ensure that the flexible pavement will meet the design expectations—reducing fracture, distortion, and disintegration distress over the design period. Stated simply, there can be a bias between the structural and mixture design tests, and those tests used for QA. For example, a good modulus (seismic design modulus or dynamic modulus) for one project might be an inferior value for another project under different conditions. Calibration should eliminate or account for this bias for project success and a reduction of contractor disputes.

The advantages and limitations of the equipment and data processing techniques relative to QA application, as well as for measuring material properties needed for forensic studies and rehabilitation design, are included in this chapter. For example, the Florida, Texas, and Washington DOTs routinely use various NDT methods for evaluating flexible pavement construction, but not necessarily for accepting flexible pavement construction.

4.2 Data Sources for Evaluation

Several highway agencies were contacted to collect information on their practices and their experiences with using NDT devices. Research reports of several agencies were also reviewed. These agencies include Arizona, California, Connecticut, Florida, Georgia, Illinois, Maryland, New Hampshire, Minnesota, Mississippi, Missouri, Nevada, Ohio, Oklahoma, Pennsylvania, Texas, Virginia, Washington, and Wisconsin DOTs, the FHWA, FHWA Eastern Federal Lands Division and Central Federal Lands Division, U.S. Air Force, U.S. Army Corps of Engineers Engineer Research and Development Center, Loughborogh University, Nottingham Trent University, TRRL, University of Illinois, University of Mississippi, Louisiana State University, Worcester Polytechnic Institute, and Texas Transportation Institute. Appendix A lists the specific topics and items discussed with these agencies. The following questions were also asked to address important issues and barriers related to the use of NDT technologies for QA. These questions are in addition to the issues already noted in chapter 2:

- What types of NDT methods and devices have been used?
- For what purpose of application have these methods been used?
- How long have these NDT technologies and methods been used?
- What are some of the advantages and disadvantages of the NDT technology?
- What is the operational cost of the equipment?
- Are there test protocols for the specific NDT technologies that have been used?
- What is the repeatability and variability in the measured response?
- What criteria have been used for interpretation of the data collected?
- What properties and features have been used for acceptance?
- What properties have been used for process control?

Some of the equipment manufacturers and suppliers were also contacted to obtain specific information and data on the items listed above. The manufacturers contacted include Olson Engineering, Blackhawk, GSSI, Transtech Systems Inc., and others. In addition, the utility analyses completed by Von Quintus et al. (1995) and Saeed et al. (2001) were reviewed for use in this evaluation.

The agency/contractor contacts and literature reviews were used in the evaluation of those NDT methods that have been used for testing pavements. The information obtained from the surveys and relevant literature for each topic was synthesized and is presented in the remainder of this chapter for each NDT device.

4.3 Deflection-Based Methods—FWD and LWD

The deflection-based device in widespread use in North America is the FWD (see Figure 6 in chapter 3). This device has been used in the U.S. since 1978. Accordingly, it is believed that the FWD is well suited to QA applications, even though its use for QA has only recently begun to emerge. Most of the 150+ FWDs in service today are devoted to pavement rehabilitation design or pavement management purposes.

The other deflection measuring devices discussed in chapter 3, the RDD and RWD, are not suited for QA applications at this point in time, because they are considered to be in the research and development stage. These deflection-based devices are not considered state-of-the art. The LWD is considered to be a manual or portable form of the FWD and was considered for use as a supplemental device to the FWD (see Figure 8 in chapter 3).

Some of the earlier and most recent efforts for using the FWD for QA have used backcalculated and forward-calculated layer moduli because these values can be directly tied to the inputs required by the MEPDG and other M-E based methods for unbound and HMA layers. To demonstrate the practical use and effective application of deflection data for use in control or acceptance plans, the deflections measured with an FWD on a select granular fill material from a construction project in Oklahoma were used. Deflections were measured along a project at random locations along three lines—parallel to the centerline.

For this example, a control chart was prepared using the forward-calculated layer modulus to determine whether the construction process to place and compact the select fill is in control or out of control. Figure 29 illustrates the control chart prepared using the calculated elastic modulus values from the measured deflections. As shown, the elastic modulus is changing from one end of the project to the other, with the stiffer material occurring in a localized area. The design elastic modulus for this project for the select fill was 12,000 psi (82.7 MPa). The control chart would indicate that the agency received a higher quality or modulus-material than assumed in design.

Research conducted under NCHRP Project 10-48 by North Carolina State University (Kim et al., 2000) presented a method for assessing pavement layer condition on the basis of surface deflection data obtained from the FWD. The uniqueness of this study is that it attempted to correlate “along project” variability in deflection basin characteristics (e.g., shapes of basins, magnitudes of deflections) directly with pavement distress parameters (e.g., rutting, cracking). Kim et al. did not use backcalculation programs because of their inherent assumptions and biases, adding subjectivity and complexity to the correlations.

Data from the LTPP program and those collected by state DOTs were used for database development. A sophisticated, commercial finite-element program was used to develop the required pool of theoretical pavement responses. Damage indicators such as the deflection basin parameter (DBP), effective modulus, base curvature index (BCI), subgrade compressive strain, and subgrade stress ratio (SSR) were developed. These indicators, derived from raw deflection data, were deemed to correlate strongly with the pavement layer performance (e.g., subgrade rutting potential is strongly correlated with subgrade effective modulus, BCI, subgrade compressive strain, and SSR).

Models were developed to relate the pavement condition indicators created with surface deflection information available using both regression analysis and artificial neural networks. The entire methodology including processing of raw deflection data, pavement condition indicator calculations, and condition assessment criteria was coded into a software program designated as APLCAP (Asphalt Pavement Layer Condition Analysis Program) for ease of implementation.

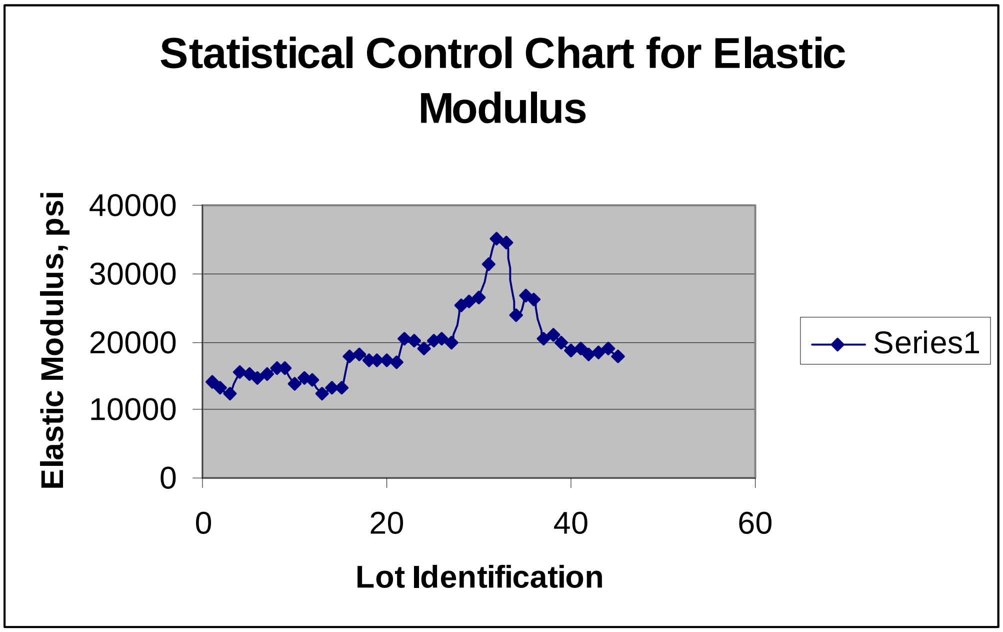

Figure 29. Example of a Control Chart for the Elastic Modulus Calculated from Deflection Basins on an Unbound Granular Embankment (Select Fill) Material

To date, however, the NCHRP Project 10-48 methodology has demonstrated limited success for HMA pavements with granular bases and full-depth HMA pavements. It could not be extended to HMA pavements with cement-treated bases or to HMA overlays of PCC pavements. Even for cases where the methodology was successful, it was only able to establish a relative assessment of condition by comparing the section under evaluation with an “ideal” or “good” section. The methodology, in its present form, does not relate the difference between current and expected performance to specific distress types that may be prevalent in the pavement layer being examined or other reasons.

Agency Use or Adoption

Most states surveyed responded that they use the FWD as an engineering tool for research, forensic studies, and rehabilitation designs. The Mississippi DOT recently sponsored a study to correlate subgrade moduli calculated from FWD deflection basins measured on the subgrade to moduli measured with LTPP TP46 resilient modulus test protocol and DCP tests.

The subgrade moduli were calculated using forward-calculation techniques and correlated to the DCP and laboratory measured values (George et al., 2003). The moduli calculated from FWD deflections were found to be related to moduli estimated from the DCP penetration rate and resilient modulus values measured in the laboratory. The correlation, however, was dependent on soil type. The Mississippi DOT has yet to adopt or include this method into their acceptance plan or QA procedure.

The Florida DOT is tracking subgrade moduli using their own in-house forward-calculation method and the current AASHTO method using FWD tests. These methods use the deflection basins rather than the deflection measured at a single sensor offset from the loading plate. The AASHTO and Florida DOT methods, as well as backcalculation methods, over-estimate laboratory derived resilient modulus values. AASHTO recommends that the subgrade modulus values calculated from deflection basins be adjusted by a C-factor of 0.33 (AASHTO, 1993). Von Quintus and Killingsworth (1998) confirmed the use of the C-factor in relating elastic moduli calculated from deflection basins to those measured in the laboratory at comparable stress states for many of the LTPP test sections. However, they found that the C-factor was not constant, but pavement and layer dependent.

NCHRP Project 20-50(09) (Stubstad, 2002) investigated the efficacy of utilizing FWD tests measured during construction of the Special Pavement Study (SPS)-1 projects within the LTPP program. Deflection basins were measured on the base (unbound or bound) and surface layers during construction. The study showed the potential for QA application using the FWD and forward-calculation techniques (see Figure 29). These results are also applicable to PWL approaches, because so many tests can be conducted within an individual lot.

More recently, the Danish Road Directorate (Road Institute) conducted a study (Hildebrand et al., 2003) evaluating three versions of the LWD and comparing the LWD results with those from the FWD and Static Plate Load (SPL) tests conducted on a cohesive fine-grained (clay) subgrade. Traditional density tests (sand cone and nuclear gauge densities along with moisture-density relationships for compaction control) were also conducted on the subgrade soil. The main goal of this research was to determine whether SPL test equipment and analysis procedure could be replaced by the FWD or LWD. Based on the composite modulus, E_O, as calculated from the center deflection, the results supported the hypothesis that there is a good correlation between the different types of equipment.

This single test section found that the FWD produces E_O-values that were almost identical to those determined through SPL tests, while the three LWDs produced similar results. The test results indicate that the LWD from Keros Technology and, to a lesser degree, the LWD from Loadman, have a reasonable relationship to the FWD and SPL test results conducted on the subgrade soil. The E_O-values from the Zorn LWD were lower than those derived from any other piece of equipment included in the test program. The study concluded that the FWD and LWD can play an active role in QA procedures along new construction projects.

The United Kingdom has conducted substantial research in recent years in their move towards developing PRS for foundations materials (Fleming et al., 2002; Frost et al., 2001).

The research evaluated several in-place testing devices for a direct measurement of stiffness (or resilient modulus) during construction. The devices included in the research studies were the FWD, the German Dynamic Plate (GDP), similar to an LWD, the TRL Foundation Tester (TFT), and the Soil Stiffness Gauge (SSG; now referred to as the GeoGauge). The research found that the stiffness values determined from the various test devices were significantly different, but showed similar trends in the data. A reason for the disparity is the stress dependency of nonlinear, unbound materials. The different devices apply different load levels and load pulse-durations, and use different transducers and mounting devices. Miller (2006) also reported similar results in his master thesis work at the Colorado School of Mines.

The GDP device included in the United Kingdom study consistently predicted lower stiffness than the other devices. The modulus values from each test was verified and correlated to FWD results. Interrelationships between the indices measured from each device were found to be site-specific. TFT test results were comparable to the FWD, being within 20 percent of the FWD results. The data also indicated that the stiffness modulus from the SSG was about 1.3 times that from the GDP, but with more scatter in the data. The data showed less scatter for sections with thick subbase. It was recommended that any specification must account for the expected variability in the stiffness modulus from one point to another.

Test Protocol and Data Collection Guidelines

The FWD test protocol for control or acceptance testing is much the same as the normal test protocols used for pavement rehabilitation design. Test spacing depends on the length of a particular project (for example, 10 meters or 25 feet, per lane), and the applied load has to be adjusted to realistic levels, with lower stress levels applicable to unbound layers. In addition, setting drops must be used prior to collecting the deflection basin data for data analyses. More importantly, a statistically significant sample of test results must be available in order to use PWL or other statistical approaches. The test protocols recommended for initial use in QA operations are those developed in support of the FHWA-LTPP program and standardized through ASTM.

For forward-calculation of HMA layers, the first three sensors must be placed at LTPP's protocol positions of 0, 8, and 12 inches, respectively. In addition, more drops of the FWD weight should be carried out for unbound materials than for bound layers, because of the increased drop-to-drop variability associated with FWD tests on unbound materials.

Interpretation of Test Data and Determination of Material/Mixture Property

FWD load-deflection test data are processed through automated spreadsheet equations or macros. The end result is a set of spatially variable pavement layer moduli, using forward-calculation techniques that are not subject to the "art" of backcalculation procedures. Variables that are subject to input errors are the quality of the FWD data itself (with more testing problems associated with unbound layer tests) and the layer thickness of the bound pavement layer when that layer is under investigation. For HMA pavements and overlays, the mid-depth temperature of the bound layer is also an important factor.

Accuracy, Repeatability, and Reproducibility

Apart from tests on unbound materials, the accuracy, repeatability, and reproducibility of the FWD are well documented in the literature. For tests on unbound materials, the accuracy and precision are somewhat lower, depending on the plate configuration (solid, split, segmented), the drop load, the smoothness or evenness of the tested surface, and the nature of the unbound material (cohesive vs. non-cohesive, etc.).

Calibration Requirements

FWD calibration should be carried out in accordance with the FHWA-LTPP protocols or other equivalent methods and procedures. It is also important, since the entire deflection basin is utilized, to ensure that the sensors are positioned properly for subsequent data analysis. The SLIC program (developed under LTPP) can be used for this purpose. For HMA pavements and overlays it is critical that the infrared sensor mounted on the FWD is calibrated and providing accurate data to produce values that are consistent with the use of surface temperatures determined through the BELLS procedure.

Production Rate

The FWD production rate is between 1 to 2 minutes per test point, plus set-up time. This time is dependent on the pavement being tested, whether the layer is bound or unbound, and the number of drops that are used. Some states report about 5 minutes per test location when accounting for the time to move from one test point location to the next.

Initial Cost, Maintenance, and Complexity of the Equipment and Data Interpretation Procedure – Operator Technical Requirements

The initial cost of an FWD is between $100,000 and $150,000 for a new machine, excluding the tow vehicle. Maintenance can be considered to be between 10 and 20 percent of the initial cost, per year, with increasing costs as the equipment ages. Most states have to arrange for an out-of-state calibration. The equipment is well known and is not complex to operate (although it is somewhat complex to maintain). Data interpretation procedures are very easy, by virtue of newly developed forward-calculation techniques. Results from these forward-calculation techniques, however, have yet to be compared to the values measured in the laboratory, at least for a diverse range of soil types. Results from the back-calculation methods have been correlated to laboratory measured resilient modulus values (Von Quintus and Killingsworth, 1998).

Advantages

The advantages of using the FWD for QA purposes include widespread use, availability, and support from equipment manufacturers. The FWD is also easy to use in a production environment, allowing good coverage for the PWL method to be used for acceptance. In addition, the FWD can be used to test the final flexible pavement structure immediately after construction, rather than just individual layers during construction. It also provides loads that are compatible with the expected range of loads applied by trucks. Conversely, the LWD uses much lighter loads and needs to be adjusted to laboratory values.

The forward-calculation methods developed for QA when using the FWD are easy to use and result in unique layer moduli. Backcalculation procedures traditionally used for pavement evaluation are less likely to be used in acceptance plans because it would be difficult to defend non-unique layer moduli in disputes with the contractor.

Disadvantages and Limitations

Most agencies reported that the analysis of the deflection data can be challenging. The use of forward or backcalculation methods results in composite layer modulus values that are affected by the thickness variations of the layer being tested, as well as non-uniform support conditions. Like any other testing method, data interpretation must be accurate to obtain reliable results, especially under QA operations. Care must also be taken to avoid errors resulting from data normalized to 70 °F or some other standard temperature for HMA mixtures.

A major limitation for QA purposes is the fact that the FWD is not recommended for estimating the modulus of thin layers (bound or unbound layers). The thin layers usually are combined with thicker layers of similar materials, resulting in composite layer modulus values. In addition, the FWD is not widely used for QA to-date, probably because of the thin layer limitation, and universal threshold values and PWL protocols need to be developed.

4.4 Impact Method—DCP

The use of DCP in controlling and accepting unbound layers has gained increased popularity because the equipment is simple and easy to handle (see Figure 3 in chapter 3). It is also an economical device, with minimal operator training needs and little to no equipment maintenance. The information gathered with regard to base/subbase relative thickness and strength is invaluable compared to the resources and time consumed to perform the test. Figure 30 shows the results from the DCP for a set of tests from a site with select fill. These data are for the same site used for the deflection-based example (see Figure 29).

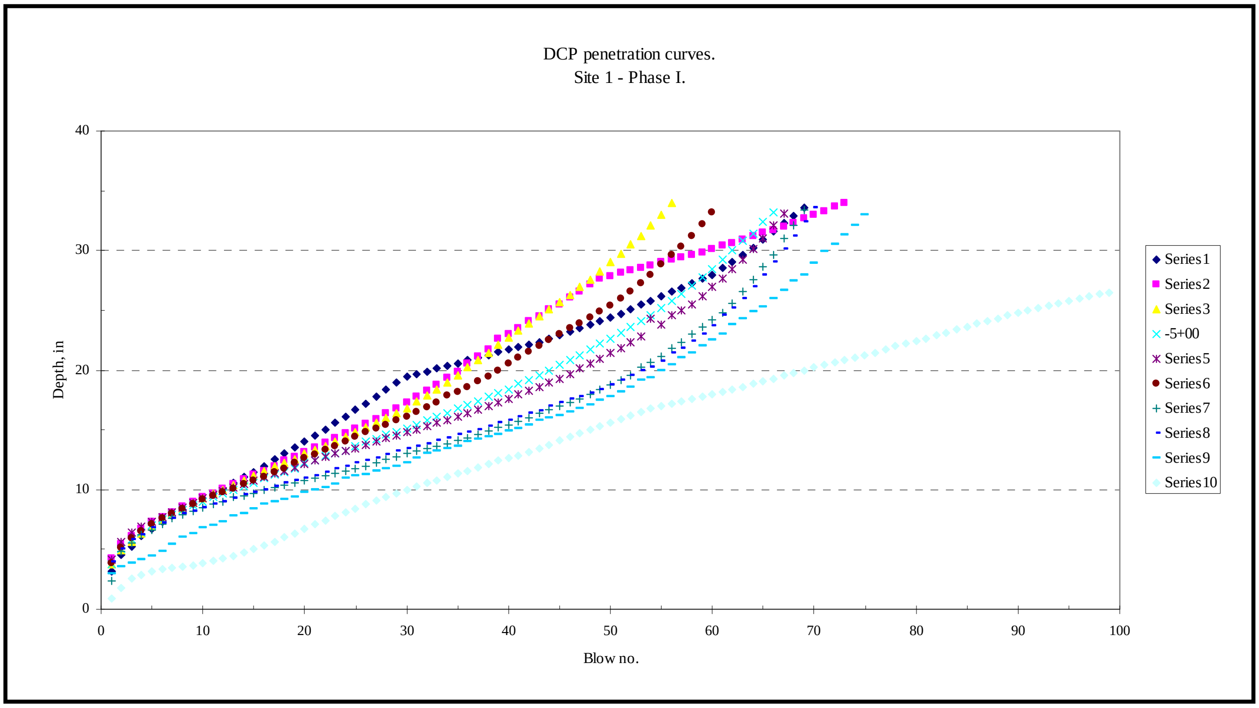

Figure 30. Graphical Presentation of the DCP Test Results on a Granular Select Fill Material

Test data from the DCP were also used to prepare a similar statistical control chart that was prepared for the deflection-based method; see Figure 31. In general, the lower strength material was found where the higher deflections were measured and where the lower elastic modulus values were calculated. The DCP, however, did not show the high elastic modulus values resulting from the deflection basins.

Relationships were provided in chapter 3 between the penetration rate or index and resilient modulus. Thus, these values can be tied back to the structural design values used in the MEPDG and other M-E based design methods.

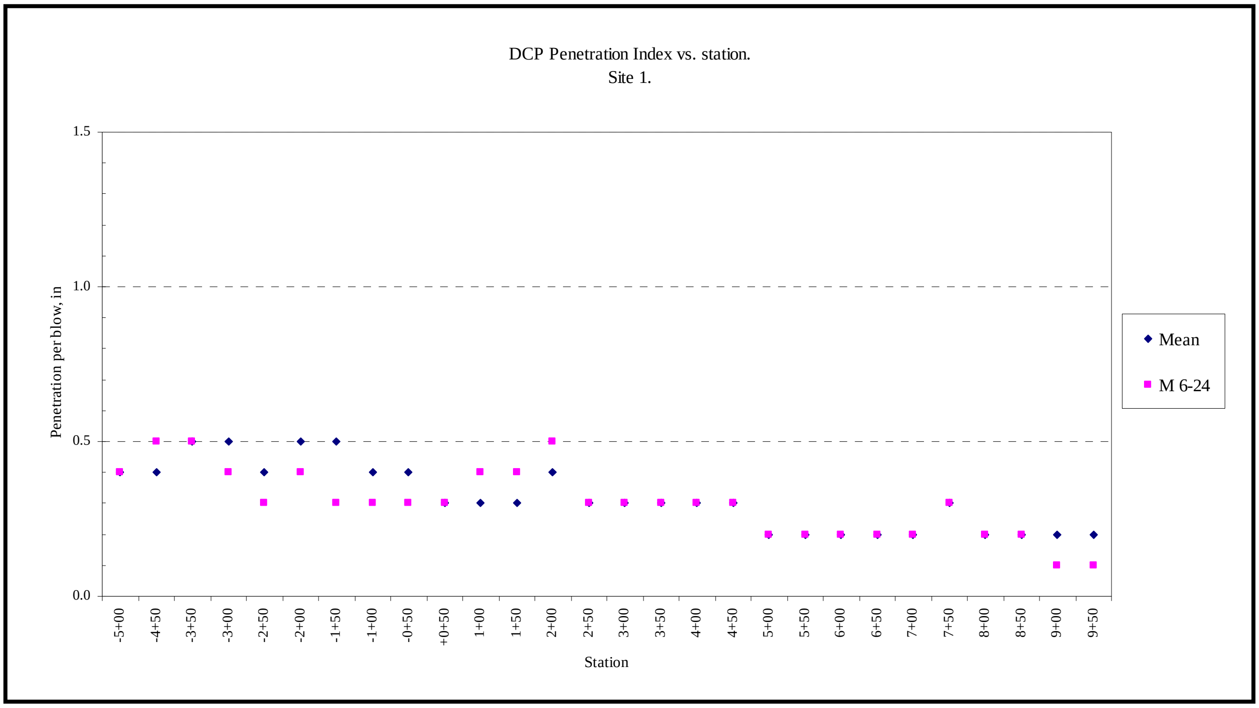

Figure 31. Illustration of the Statistical Control Values for the DCP Being Used to Measure the Strength of the Unbound Aggregate Select Fill Material Used in the Example for the Deflection-Based Method

Agency Use or Adoption

The DCP is used extensively by various agencies for evaluating unbound layers prior for rehabilitation designs. Those agencies with extensive experience include Illinois, Indiana, Louisiana, Minnesota, Mississippi, Oklahoma, Texas, Pennsylvania Turnpike, and the Corp of Engineers. Many other agencies have the DCP but use it on a limited basis. Still others are in the process of evaluating the DCP for use in rehabilitation design and new pavement design through existing and on-going research studies (for example, Montana DOT). These agencies have realized the benefit of using the DCP to provide input data to the new MEPDG, as well as other M-E based pavement design procedures.

CSIR, South Africa has developed a software program, *WinDCP 5.0* (http://asphalt.csir.co.za/DCP/index.htm visited in February 2004), with a user-friendly interface and post-processors. WinDCP5.0 automatically gives average DCP penetration rates in mm/blow. DCP results have also been calibrated with unconfined compressive strength and CBR values (provided in chapter 3). The program estimates the structural capacity of granular and weakly stabilized pavements base materials and classifies the pavement in various categories based on the structural capacity estimations.

Test Protocol and Data Collection Guidelines

ASTM recently standardized a procedure for general use of the DCP, ASTM D 6951. Minnesota, Mississippi, Oklahoma, and other agencies all have test protocols and data collection guidelines for using the DCP for rehabilitation design and forensic studies. No agency contacted uses the DCP as an acceptance tool or device for subgrades to-date. Minnesota DOT, however, uses the DCP in the QA process of aggregate base layers. Testing must be performed within 24 hours of placement of the base layer. A minimum of two tests are conducted within each 1,000 cubic yard (800 cubic meters) volume. The Minnesota DOT specification requires that the compacted base layer has a penetration index less than 10mm/blow. Any layer that exceeds this requirement has to be re-compacted and retested until that rate of penetration is not exceeded. A compacted layer is defined as one with a compacted thickness of at least 3 inches (76 mm) but no more than 6 inches (152 mm) for each lift.

Interpretation of Test Data and Determination of Material/Mixture Property

DCP is easy to interpret, especially for relative comparison of material strengths along a project. The penetration rate or index has been used for design and evaluation. The units used are penetration depth per blow. The more difficult issue is relating the penetration rate or index to the elastic modulus of the material. Regression equations have been developed relating the penetration rate to the CBR value of the material (see chapter 3), but these are believed to be material specific. In addition, any regression equation relating DCP test results to resilient modulus will depend on the pavement type and thickness. It is expected, however, that criteria can be developed for specific type of materials for use in QA programs. The criteria should be tied back to the assumptions used for the elastic modulus of the material during structural design.

The accuracy of the relationships used to develop the criteria noted above is dependent on the number of soil and aggregate types used to develop these regression relationships. The test method can be highly variable, simply because the materials being tested are variable. The variability of the test results is greater for embankment and fill materials, and decreases for processed materials.

Production Rate

The DCP production rate is dependent on the type of material, strength, and thickness of the layer being tested. In general, most DCP tests at a specific location can be completed within 5 to 10 minutes. This time, however, excludes the coring of the HMA surface for testing unbound aggregate base layers, embankments, and subgrade soils. Coring of HMA should not be needed for QA purposes, unless dispute resolution is required after an HMA layer has been placed.

Initial Cost, Maintenance, and Complexity of the Equipment

The DCP is easy to operate and requires minimal training, as compared to most of the other NDT technologies used for testing pavement materials. Maintenance of the equipment is also minimal, even for the automated device. The initial cost of the equipment is less than $30,000 for the automated device and less than $15,000 for the manual device.

Advantages

The advantages of using the DCP for QA include ease of use for testing unbound aggregate and soil layers, the results can be easily understood by field technicians, and the results are related to the modulus of the layer/material being tested. In addition, layers greater than 1 foot thick can be tested, and the results are layer specific, unlike some of the other NDT devices that are influenced by the underlying layers (composite modulus values). The cost and technical support for the equipment are low compared to the cost and support requirements for most of the other NDT technologies.

Disadvantages and Limitations
The major disadvantages of the DCP are the inability to test HMA layers, and that coring is required to remove any HMA layer prior to testing unbound aggregate materials and soils. In addition, no threshold values have been developed that can be used immediately within a QA program for determining the quality of the unbound layers—other than the value being used by the Minnesota DOT for aggregate base layers. Another limitation of the DCP is trying to test embankments with boulders or larger aggregate particles that can result in refusal or low penetration rates at specific points.

4.5 Ground Penetrating Radar Methods—GPR

GPR has been used as part of research, forensics, or evaluation studies. Agencies and organizations that have used GPR include Florida, Illinois, Missouri, Minnesota, Nevada, Oklahoma, Texas, Virginia, Washington, and Wisconsin DOTs. The Corp of Engineers, FHWA, Federal Aviation Administration (FAA), and U.S. Air Force under the Department of Defense have also used GPR for measuring layer thickness and identification of subsurface features for evaluating pavement structures and rehabilitation designs. Some agencies (such as the Georgia and Texas DOTs) are also considering the use of GPR technology in support of their pavement management programs. GPR was used within the FHWA-LTPP program for measuring the layer thickness within the test sections. It was also used for measuring layer thickness and volumetric properties (density and/or air voids) of the HMA layers placed at the WesTrack, MnROAD, and NCAT test tracks.

To demonstrate the practical and effective use of the GPR, the data measured along the WesTrack test sections were used to estimate two quality characteristics: HMA thickness and air voids. The equations and data analyses presented in chapter 3 were used to calculate both properties in accordance with the Finland/Texas DOT correlations. In summary, Figure 32 shows the distribution of the HMA layer thickness, while Figure 33 shows the distribution of air voids. As shown, the HMA layer thickness data set has a normal distribution, while the air void data set has a skewed distribution. The thickness distribution is typical of data measured from other projects where both GPR and a sufficient number of cores were recovered to accurately determine the distributions. The mean thickness from the GPR data at WesTrack closely matched the thickness values measured from cores, but the mean GPR-estimated air voids did not always match the average air voids measured on cores recovered from the test sections.

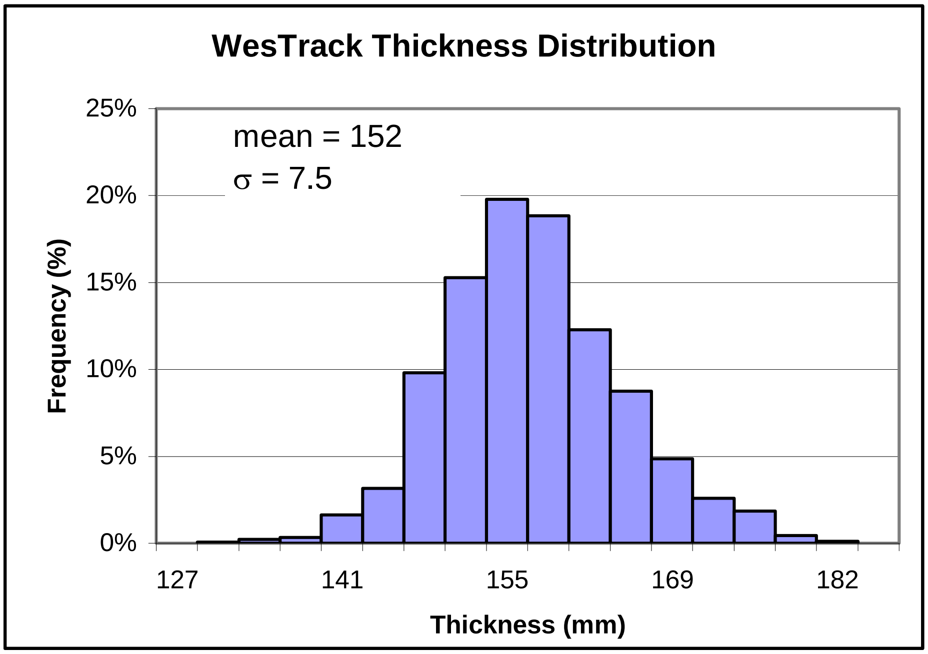

Figure 32. Frequency Distribution of the Variation in HMA Layer Thickness Estimated with GPR Technology at WesTrack

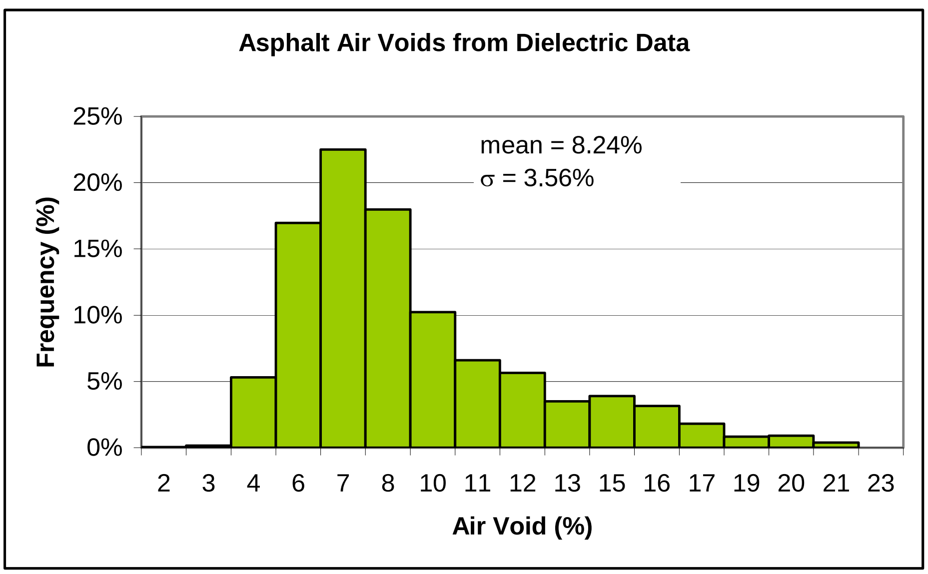

Figure 33. Frequency Distribution of the Variation in HMA Air Voids Estimated with GPR Technology at WesTrack

The distribution of air voids after construction (see Figure 33) also typically has a normal distribution. The skewed distribution resulting from the GPR measurements made at WesTrack could be related to the non-compliance values (high and low air voids) built into some of the test sections along the test track.

The data from each lot at WesTrack are shown in Figure 34, which represents the average air voids between the right wheel path, left wheel path, and centerline using 20 sublots within each lot or test section. As shown, a statistical control chart was prepared for the average air voids that vary down the roadway. A similar statistical chart could also be prepared using the range of values to determine whether the variation in air voids of the population is in control or out of control.

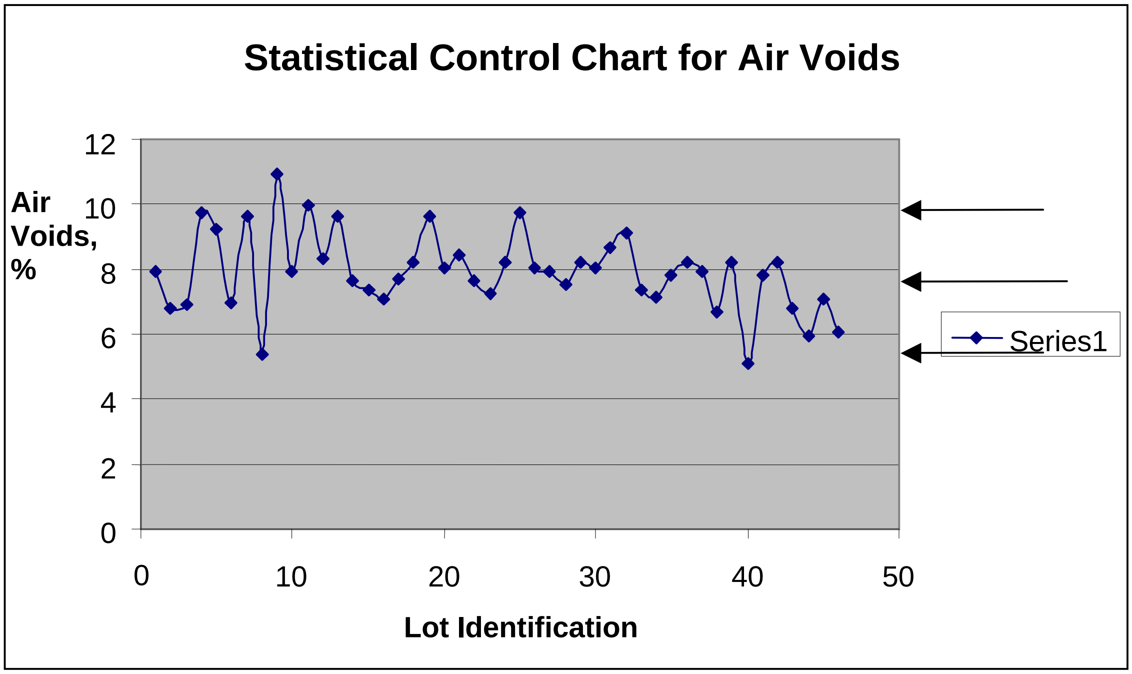

Figure 34. Example of a Statistical Control Chart for the Average Air Voids Estimated Using GPR Technology

The arrows shown in Figure 34 represent typical target air voids for the HMA base layer, and the upper and lower control limits for that specific contractor. As shown, the placement of the HMA layer may be out-of-control in some of the lots. More importantly, there appears to be a drift or uniform decrease in air voids along the project, especially for the higher lot numbers. Although this decrease in air voids was designed into the experimental plan at WesTrack and the lower air voids of some section were not identified in the GPR data, it shows the power of the GPR technology in QA application. The amount of data collected with the GPR is more than sufficient to properly determine the calculated air voids for that population or mat, whereas that would be highly unlikely using the traditional QA sampling and testing programs. Proper calibration of the GPR with at least some cores is essential.

Cores and bulk HMA samples are not normally used to determine the type of distribution because there is an insufficient amount of time to take the required number of samples to ensure that the distribution has been properly described. Normality is assumed for most cases, and a small number of samples are taken to estimate the properties of the population. The GPR technology can take a large number of tests in a short time period to clearly identify the type of distribution and the characteristics of that distribution for the population—rather than for a sample from the population.

As noted in chapter 3, EPIC is promoting the use of a proprietary system that uses multiple antennas and produces different volumetric properties for HMA mixtures, as well as HMA layer thickness. These properties include relative compaction (density) and asphalt content, and a composition analysis of the HMA mixture. The accuracy and reliability of this system has been investigated by an independent organization (Greene, 2006), while some agencies (such as the Florida DOT) are expanding previous investigations of this system. The accuracies that have been reported are provided in the following pertinent paragraphs.

Agency Use or Adoption

Some agencies (for example, the California, Florida, Minnesota, New Hampshire, and Texas DOTs) have their own GPR systems that are used for various purposes. Minnesota and Texas use their devices for forensic analyses and investigations, while Florida uses their system as a rehabilitation design tool. These and other agencies are also considering the GPR technology as a QA tool for supplementing their current acceptance plans for flexible pavement construction.

Since 1999, the New Hampshire DOT has been using the GSSI ground-coupled 1.5 GHz GPR for QA and pay factor calculations for PCC cover over the top rebar on new bridge decks.[9] The method collects data along survey lines parallel to the centerline of each lane. The system uses software to calculate the arrival time of the reflection from each rebar in the scan. The relationship between time and depth is obtained through calibration holes.

The Finnish Road Administration has adopted the GPR technology as a method for assessment of penalties for HMA pavement whose air void content is found to be outside of the specifications.[10] The HMA dielectric constant is calculated from the GPR surface reflection, and calibration cores are used to calibrate the relationship between dielectric constant and air void content. A similar method for using GPR as a tool for QA for new flexible pavement has been developed by TTI, and this method currently is under evaluation by the Texas DOT (Sebesta and Scullion, 2002). The protocol for this method is as follows:

1. Collect a series of parallel GPR survey lines at 2-foot (0.6-m) lateral offsets (5 lines per 12-foot [3.7-m] lane).
2. Process the data to compute the HMA dielectric constant from the GPR surface reflection.
3. Calculate the mean dielectric constant.
4. Plot the GPR data, and identify areas where the dielectric constant is less than the mean by more than 0.8 (for coarse-graded mixtures) or 0.4 (for fine-graded, dense

[9] NHDOT GPR Specification for Concrete Cover; Special Provision—Amendment to Section 520 – Portland Cement Concrete; Subsection 3.1.7 on Quality Assurance.
[10] Finish Road Administration Specification—PANK 4122: Air Void Content of Asphalt Pavement, Ground Penetrating Radar Method.

mixtures). These are areas where the mix properties deviate significantly and where problems are likely to occur.

5. Calibrate the relationship between dielectric constant and air void content using 3 cores and equation 8 (see chapter 3). The result of the correlation is shown in Figure 35.
6. Plot the air void content, and locate areas where the air void content is outside of the specified values. The plot can be linear or a surface contour plot, as shown in Figure 11 in chapter 3.

The same GPR data used for evaluation air void content, listed above, can be used to calculate the variability in pavement thickness, and to identify locations where pavement thickness is outside the specified limits.

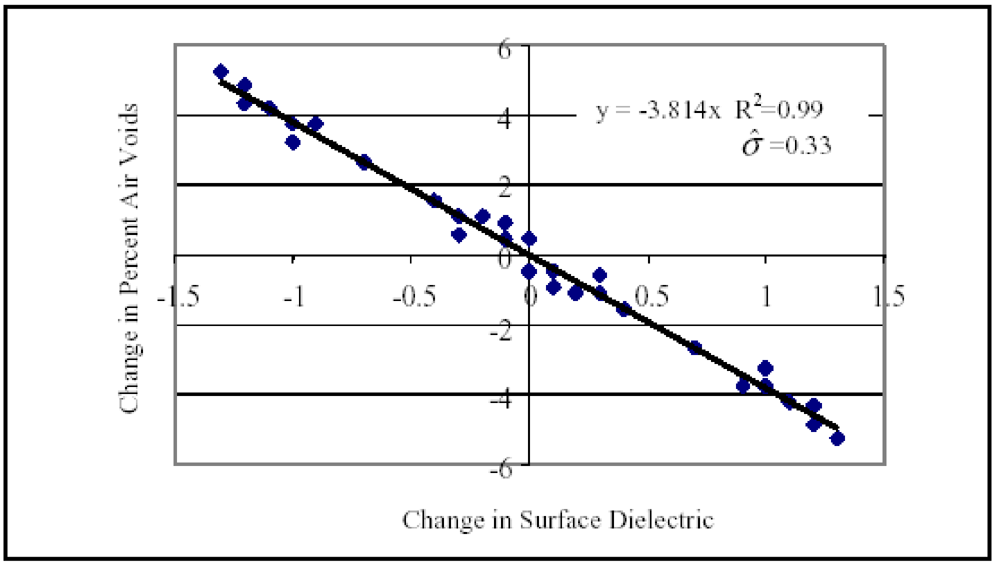

Figure 35. Correlation of Dielectric Values with HMA Air Voids

In 2003, the California DOT (Caltrans) completed an investigation of GPR methods for thickness in their QA program. The objective was to use the method as a basis for pay factors. The Caltrans study showed that GPR using a non-contact, air horn antenna was able to determine the average pavement thickness on a newly constructed segment to within 0.1 inch (2.5 mm) of the value obtained from a sample of 20 cores on that segment (Maser et al., 2002). A protocol for this thickness evaluation was prepared as part of a Caltrans project (Maser, 2003).[11]

Tests were conducted under the Caltrans project on six newly constructed pavement segments, each 1,000 feet (305 m) long representing full depth HMA construction and HMA overlays over existing flexible and rigid pavements. The GPR method was able to cover the

[11] CalTrans Proposed Test Method—Horn Antenna GPR Method for Asphalt Thickness.

pavement section in a small fraction of the time than what was required to take cores. The GPR survey produced thousands of thickness data points, as compared to the limited number of core data points. A recent study by the Virginia DOT using similar equipment produced similar results (Al Qadi et al., 2003).

The capability of GPR to determine HMA layer thickness has been verified for HMA surface and base layers (e.g., Roddis et. al, 1992). Investigation of GPR for measurement of unbound aggregate base layer thickness has been limited. Most of the available data are for existing pavements. Studies in Texas and Florida showed that the average per site deviation between GPR and core measurements ranged from 0.75 to 1 inch (19 to 25 mm), or 10 to 15 percent (Maser and Scullion, 1992; Fernando et al., 1994). These studies showed that base layer thickness could not be measured for cement treated bases, since there was inadequate dielectric contrast between the stabilized base and the subgrade soil.

Subsequent studies of existing flexible pavements (Maser, personal experience) have shown that the ability or accuracy to detect the bottom of the base varies considerably. This unpredictability might be due to the "blurring" of the boundary between unbound base and subgrade caused by migration of fine material from the subgrade over time. The ability to detect unbound aggregate base layer thickness in new construction has not been reported. It is very likely that the limitations to detection of the base/subgrade boundary in existing pavements may not apply to new construction.

Other than the applications described above, the adaptation of GPR by most state agencies in the U.S. has been focused towards forensics or pavement evaluation for rehabilitation purposes. The Texas DOT, with support from TTI, has adapted GPR as a standard tool for project-level pavement evaluation and diagnostics. The Florida DOT acquired a GPR system for layer thickness inventory data in 1996 (Fernando and Maser, 1997). In addition, the New Jersey DOT conducted an evaluation on 1200 lane miles of pavement in 2002-2003 as part of their equipment evaluation process prior to adapting the GPR technology to day-to-day practices.

Accuracy and Repeatability

Air Void Content and Other Volumetric Properties

The Finnish Road Administration reported that the measuring accuracy of the GPR surface reflection technique for estimating air voids is ± 0.9 percent. This statistical analysis result has been achieved through comparison of core sample results and GPR measurements conducted as static shots over each individual measurement points (R=0.9223). Greene completed an independent precision and bias study of the *Hyper Optics*^{TM} technology for EPIC in 2006 and 2007 (Greene, 2007; Greene and Hammons, 2006). The study found good results when the system was calibrated with properties measured on cores recovered from multiple locations along the projects.

In summary, Greene reported a 95 percent precision tolerance of ± 2.32 percent for air voids when outliers were removed from the statistical analyses. Similarly, Greene and Hammons reported a 95 percent precision tolerance of ± 0.36 for asphalt content; ± 0.050 for bulk specific gravity; and ± 2.69 percent for VMA. For the relative compaction module included in *Hyper Optics*^{TM} technology, the percent compaction was within AASHTO T-166 criteria for 61 percent of the time. Although EPIC does not routinely estimate the maximum specific gravity for HMA mixtures, values have been reported for some mixtures or projects. The 95 percent precision tolerance reported by Greene is ± 0.022.

Layer Thickness
The Caltrans study noted above (Maser, 2003) involved six newly constructed test sections, two sections each of the following measurement types: (a) full depth (multiple lift) HMA; (b) HMA overlay on PCC; and (c) single and multiple lift HMA over HMA. The results showed the following accuracy measures based on comparisons to core thickness:

Mean GPR thickness for a section:	std. error = 2.1 mm = 1.6%
Thickness variability for a section: (as measured by the thickness standard deviation)	std. error = 4.3 mm = 3.3%
GPR thickness at a point:	std. error = 8.6 mm = 9.4% (R=0.933)

The local thickness error is reduced when sites representing a new HMA overlay over an old flexible pavement are removed:

GPR thickness at a point: (HMA overlay on HMA excluded)	std. error = 6.5 mm = 7.0%

The Virginia DOT study (Al-Qadi et al., 2003) involved measurements at one full depth HMA construction site at which thickness measurements were made after each lift of HMA was placed. The reported point by point results based on comparison to cores using this cumulative thickness method were as follows:

100 mm HMA Base Layer (at a point)	std. error = 4%
180 mm (HMA Base Layer + 1st HMA Layer)	std. error = 1.7%
250 mm (HMA Base Layer + 2 HMA Layer s)	std. error = 2.2%

The accuracy results suggest that the accuracy estimate is somewhat sensitive to the type of construction (overlay vs. full depth) and the timing of the measurement, similar to the Caltrans study. Measurements after each lift will provide greater accuracy when compared to one measurement after the paving is complete. Greene reported similar values for the *Hyper Optics*^{TM} technology with a 95 percent precision tolerance of ± 0.5 inches using field core thickness measurements.

Unbound Layer Thickness
Previous studies have shown that the error of GPR thickness measurements of unbound base layers below HMA ranges from 10 to 15 percent.

In summary, properly calibrated equipment produces repeatable data, even though there are minimal published repeatability statistics. Repeatability studies carried out by Maser and Scullion (1992) identified the relationship between antenna height calibration and the achievement of repeatable data using identical equipment. This study also showed that using different equipment on the same pavement can produce different results for weak layer boundaries (e.g., base/subgrade boundary) due to differences in the equipment's ability to resolve these boundaries.

Calibration

The GPR equipment should be calibrated each survey day. The daily calibrations consist of static metal plate test and direct wave (air wave) test. Static plate tests should be conducted at the beginning of the survey day after 20 minutes of equipment warm-up, and at the end of the survey day before equipment breakdown. The direct wave test, which requires partial breakdown of the equipment, should be conducted after the second metal plate test at the end of the survey day. The antenna height calibration function (to compensate for vehicle bounce and setup height) should be evaluated periodically, and before any major projects. System time calibrations should be carried out according to ASTM D 4748-9b at the beginning of each survey. The distance-measuring instrument (DMI) should be calibrated at the beginning of each survey and at the end of each week of ongoing surveys.

Production Rate

GPR data collection consists of conducting a series of parallel survey lines with vehicle-mounted equipment driving at normal speeds. Assuming that setup and calibrations are already completed, it is estimated that data collection on 1 mile of new pavement would take less than 30 minutes.

Initial Cost

A single antenna GPR system, including data acquisition and control system, cables, antenna, and mounting, would cost approximately $50,000. An example of the equipment would be a GSSI SIR-20 data acquisition and control system, with a model 4108 1 GHz horn antenna and cable. The survey vehicle would have to be equipped with an electronic DMI so that the data in the survey lines could be coordinated with actual locations on the test pavement. The system would also have to include automated software for calculation of dielectrics and layer thickness. Prototype software of this type has been developed, but none is commercially available. Most of the software that has been developed is proprietary.

Advantages

The advantage of GPR is that it can acquire thousands of measurement points quickly, and by doing so it can provide a complete representation of the variation of thickness and air void content in each layer for the entire population. Some firms that have developed proprietary software report that density (or relative compaction), thickness, asphalt content, and VMA can be extracted from the GPR measurements using multiple antennas.

The tests can be conducted shortly after construction or placement of each layer and lot. Though cores are required for calibration, the number of cores needed is less—and the resulting information far greater—than for any other system.

Disadvantages and Limitations

The required GPR equipment is not simple to operate and generally is operated by well-trained individuals. The software to automate the data analysis has been shown to be feasible for this application, but it is not commercially available and has not been verified to date. As noted above, some of the available software packages are proprietary. In addition, the analysis to review the data and resulting charts takes more time than normally available for QA procedures. This limitation can be overcome with continued use and verification of the results. As an example, EPIC has developed software that can be used on a real-time basis; the limitation of the *Hyper Optics*^{TM} technology is that the software is proprietary.

GPR Status with the FCC – A Potential Limitation of the Equipment

In February 2002, the Federal Communications Commission (FCC) issued a first report and order which severely limited the use of GPR. The order stated that GPR operation would be "*restricted to law enforcement, fire and rescue organizations, to scientific research institutions, to commercial mining companies, and to construction companies.*" The order also stated that "*GPR equipment must be operated below 960 MHz or in the frequency band of 3.1 to 10.6 GHz*" and it specified strict limits for radiation emitted above 960 MHz. After considering some objections raised by the GPR industry, and the fact that no document occurrence of GPR-related interference had ever been reported, the FCC made some amendments.

In July 2002, the FCC ruled that existing GPR operators can continue to operate once they register their operation with the FCC, and that existing equipment used by these operators would be given a blanket waiver. In February 2003, the FCC rules were amended to allow for GPR operation over 960 MHz, and to allow operations "related to" construction (interpreted to mean all highway-related applications). The one remaining issue with the FCC's rules is that the radiation limits above 960 MHz cannot be met by the current manufactured air horn antennas. The GPR industry is working to obtain a waiver for this type of antenna, recognizing its value to highway engineers and its relatively limited use compared to the universe of communications equipment.

4.6 Infrared Tomography Methods and Technology

Infrared tomography has been used by relatively few agencies in their research, forensics, and evaluation studies. The agencies and organizations that have used this technology include the California, Connecticut, Florida, Nevada, Minnesota, Missouri, Texas, Virginia, and Washington DOTs, and the U.S. Army Corps of Engineers, FHWA, and U.S. Air Force through the Department of Defense. The Connecticut, Florida, and Texas DOTs have used infrared cameras to demonstrate temperature anomalies (cold spots) in HMA mats prior to compaction and their effect on mat density. The infrared cameras have not been used extensively in QC operations to date. Washington DOT is the only known agency that uses the infrared cameras (see Figure 13) in their acceptance plan based on density.

Agency Use and Adoption

Washington DOT was an early adapter of the infrared camera as a tool for QC/QA. Their work with infrared began in 1995, and their study and use of infrared to determine variability in density has continued. Washington DOT has concluded that significant density differentials occur when the HMA transport vehicle dumps its load into the paver, leaving a concentrated area of lower temperature HMA with every truckload (see Figures 13 and 14.b in chapter 3). Because of this cyclic nature of density differential, traditional statistically based random sampling for QA of field density does not have the ability to characterize this problem (Willoughby et al., 2003). By investigating the relationship between temperature differentials and density, the Washington DOT has shown that temperature differentials greater than 14ºC (25ºF) correspond to changes in air void content greater than 2 percent.

Washington DOT has implemented a density specification that locates potential areas of low density using the greater than 14ºC (25ºF) temperature differential criterion. These areas are tested for density and must meet a specified minimum. Washington DOT has incorporated these temperature measurements into their nuclear density method specification, prepared special data sheets, and prepared a "Cyclic Density Special Provision" in which the infrared based density results are incorporated as a pay item. At present, Washington DOT has four infrared cameras—three in use by district engineers and one in use by the central office for continued studies (Willoughby, 2004).

The University of Washington, in conjunction with Washington DOT, has set up an infrared image database that has incorporated documented infrared pavement images from states participating in a pooled fund study (Connecticut, Minnesota, Texas, California, and Washington State). A sample entry in this database is shown in Figure 36. The Texas DOT has implemented specifications using the greater than 14ºC (25ºF) temperature differential as an indication of significant problems in the HMA (Scullion, 2003). These differentials are measured after placement but before breakdown rolling.

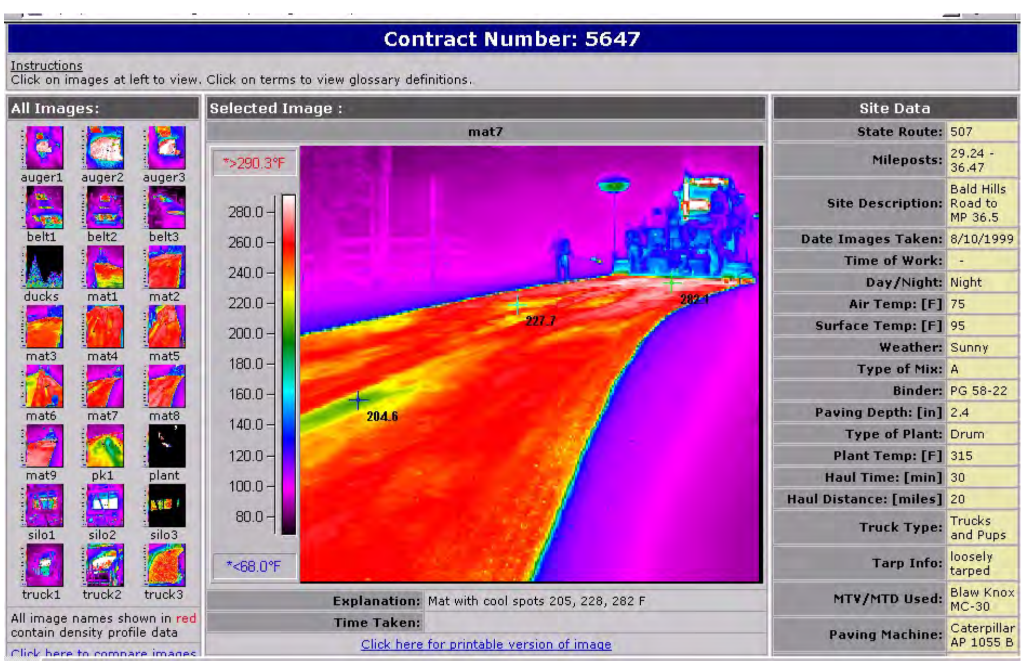

Figure 36. Sample Entry Form in Pooled Fund Study Database

The use of infrared tomography for QC appears to have provided valuable feedback related to problems in the paving process. Both Washington and Texas DOTs report that the infrared data has been extremely valuable in the early stages of the construction process, where inadequate material handling and remixing has led to temperature segregation. Once this information is available, the problem can be isolated and corrected, and the temperature variations no longer appear (Scullion, 2004).

Test Protocol and Data Collection Guidelines

A test protocol for the use of an infrared camera or a hand-held infrared spot thermometer is included in the Washington DOT specification. The Texas DOT system provides automated temperature contour charts, but there is no known evaluation protocol associated with the use of these charts.

Interpretation of Test Data

The infrared data are used as a qualitative QC method for identifying problems in the construction process. For QA, the Washington DOT uses the infrared data to determine the locations of conventional density measurements. They do not use the infrared data as a direct measure of any pavement property. The Texas DOT uses the temperature differential as a direct measure of a pavement deficiency based on previous correlation between temperature differentials and density. However, the Texas DOT does not use the infrared data as a direct measure of a mixture or mat property.

Accuracy, Repeatability, and Reproducibility of the Infrared Measurement

No known documented studies have been conducted dealing with this subject related to measuring temperature differences in an HMA mat and corresponding density measurements.

Calibration Requirements

Standard calibration methods are used for ensuring the proper temperature reading from an infrared camera or sensor. These involve determining the emissivity value of the pavement surface based on either the IR reading from a material of know emissivity (e.g., black tape) or using a surface thermocouple. HMA emissivity is typically between 0.90 and 0.98 (Sebesta and Scullion, 2002).

Production Rate

Both the infrared camera and sensor bar approaches can operate directly behind the paver and have a production rate equivalent to the rate of paving.

Cost, Maintenance, Complexity, Interpretation, Operator Technical Requirements

Infrared Cameras

Infrared cameras sell for anywhere from $20,000 to $50,000. The cameras are reasonably robust, but they need the same care and treatment as a video camera. No regular maintenance is required. After an initial training session (1-2 days), the cameras are easy to operate. The results are directly apparent in the video or still images. A field technician with experience with electronic equipment should be capable of operating an infrared camera.

Infrared Sensor Bar
The infrared sensor bar is a custom built item, so its cost has to be estimated. The primary purchased components are 10 infrared sensors at $250-$350 each, a laptop computer (or dedicated processor) equipped with a 10-channel data acquisition system, a mounting bar for the sensors with an attachment to the screed, an electronic distance encoder, and software to produce the real time temperature contour plots. If manufactured, one might estimate a sales price of $15,000-$20,000.

Advantages

The advantage of infrared tomography is that it provides immediate information on the location of cold spots within the paving process which can be readily understood by all field personnel. This immediate feedback can be used to correct deficiencies in the paving process, as well as to identify locations for density measurements. In some respects, infrared tomography provides information that is already known, such as cyclic temperature differentials (and therefore, density) resulting from transport of HMA and loading of the paver.

These temperature differentials can be minimized by using material transfer devices (MTV). The infrared camera or sensor bar can simply confirm whether such a problem is occurring, and lead to the implementation of a solution. The simple presence of the infrared equipment appears to motivate the contractor to deal proactively with potential material transfer problems (Willoughby, 2004). In summary, the infrared cameras do provide valuable forensic data to a contractor on determining the cause for not being able to obtain adequate densities, and to the agency for selecting bias locations for density tests.

Disadvantages and Limitations

TTI researchers found the camera to be cumbersome and difficult to use on a routine basis, and they went to the automated sensor bar approach. In addition, Connecticut DOT (one of the agencies participating in the pooled fund study) found "no significant correlation between temperature differentials and changes in density" (Sebesta and Scullion, 2002). Thus, the relationship between temperature differentials and density found in Washington and Texas may require more work to improve on the location of the density tests from the temperature differential measured with the cameras. More importantly, the infrared data alone have not been related to fundamental properties of the HMA mixtures that can be used in traditional acceptance programs, and these data do not provide a direct or indirect tie to performance or an input to the MEPDG. Another area of concern for some agencies is the identification of bias sample locations in a statistically-based acceptance program.

4.7 Ultrasonic/Seismic Methods—PSPA and DSPA

A procedure based on seismic techniques to measure the modulus layer-by-layer shortly after placement was developed for the Texas DOT. The procedure measures layer modulus of pavement materials with four inter-related seismic devices. Two of these are laboratory devices: the free-free resonant column device for testing base and subgrade and the ultrasonic device for testing HMA cores and laboratory prepared specimens. The other two are field devices: the PSPA for testing HMA layers and a version of it that works on the base and prepared subgrade layers (called DSPA, for Dirt Seismic Pavement Analyzer).

The proposed QA procedure consists of several steps. The first step consists of selecting the most suitable material or mixture for a given project. The second step is dedicated to determining the variation in modulus with the primary parameter of interest and determining the desired modulus. For base and subgrade materials, this step consists of developing a moisture (water)-modulus curve (similar to an M-D curve). For HMA materials, this step consists of developing voids in total mix (VTM)-modulus curve. In the third step, the variation in modulus with environmental factors is considered. For example, the change in modulus with changes in water content of a base layer can be determined in the laboratory. In the case of HMA, the change in modulus with varying temperature and asphalt content is important. The fourth step consists of determining the desirable or target (design) modulus for the material. The final step is to compare the field modulus with the acceptable laboratory measured modulus.

These procedures allow rapid data collection and interpretation. Thus, any problem during the construction process can be identified and adjusted. Performing the simplified laboratory and field tests along with more traditional tests may result in a database that can be used to confirm the assumptions used for pavement structural design—integrating structural design and acceptance of flexible pavement materials (refer to Figure 2 in chapter 2).

The method has shown promise as a practical tool and is being implemented on a trial basis by the Texas DOT. The key to this procedure is that the NDT is calibrated to the specific mixture in the laboratory. The simplified laboratory tests can also be used to develop the ranges of acceptable properties for a given material. NDT field tests are performed to determine whether the contractor has achieved the minimum specified stiffness that can be related back to the value used for structural design.

The seismic scanners that were discussed in chapter 3 have not been used extensively, with the exception by highly trained consultants that have been involved in the development of the equipment and university personnel for research and forensic purposes. However, these devices have high potential for use in the future because of the extensive coverage of the area tested within a minimal amount of time. These devices are not suggested for use in QA operations until their use become routine in pavement engineering applications.

In addition, there are relatively few of the SPA devices or trailers available for testing and use. The PSPA and DSPA devices can be made easily available for future use and application to QA operations. Thus, the PSPA and DSPA were considered for use in the field evaluation study, while the SPA was not.

<u>Agency Use or Adoption</u>

No agency currently uses seismic technology in routine QA operations. However, Florida, Texas, FHWA, U.S. Army Corp of Engineers, and the U.S. Air Force through the Department of Defense have used this technology for forensic studies of pavement structures.

A few agencies have on-going research projects to develop these methods for use in QA applications.

Accuracy and Repeatability

There is little information available on the accuracy and repeatability of these test methods. The University of Texas at El Paso, through the Texas DOT, has data from selected projects. These laboratory test methods are repeatable considering the variability between test specimens of HMA mixtures and unbound materials and soils. The coefficient of variation measured on similar HMA mixtures tested in the laboratory is less than 5 percent when the test specimens are compacted to the same air void level in a highly controlled manner.

Calibration

Calibration is important to obtain reliable results using seismic test methods. The test methods and test results need to be calibrated for each project or material used to ensure that the results can be related back to the modulus value used in structural design.

Production Rate

Although the SPA and PSPA have not been used in routine pavement evaluation projects, it is estimated that data can be collected on a basis of about 1 test point in 2 minutes for the SPA (trailer mounted device; see Figure 15 in chapter 3), while 1 test in less than a minute can be completed for the manual PSPA (see Figure 16 in chapter 3).

Advantages

The major advantage of seismic methods is that similar results are anticipated from the field and laboratory tests as long as the material is tested under comparable conditions. This unique feature of seismic methods in material characterization is particularly significant in QA operations. In the procedure recommended for use in Texas, simplified field and laboratory tests are suggested that can be performed and interpreted rapidly so that noncompliant materials can be identified during construction. The field and laboratory methods are incorporated in a manner in which the results can be reconciled without any scaling or simplifying assumptions. A major advantage of the DSPA is that it can be used to develop modulus-growth curves to optimize the compaction of unbound materials and soils.

Disadvantages and Limitations

One of the limitations of using seismic technology for QA application is that the mixture modulus value does not represent the stress levels that occur under truck loadings. The modulus values have to be adjusted to account for the design loading frequency and temperature. One of the disadvantages of the equipment is that the HMA mixture must be allowed to cool down to a temperature less than about 160 °F. When the device is placed on HMA at elevated temperatures, the rubber pads of the response detectors begin to melt or become easily damaged. In addition, the wave form usually is not well defined at elevated temperatures. Other disadvantages of the equipment are that it takes highly trained personnel to collect and interpret the data and there is relatively little information available to determine the precision and bias of test output. Training will be an important step in the implementation process for QA application.

4.8 Steady-State Vibratory Response Method—GeoGauge

The GeoGauge is a relatively new device, but it has been recently updated, as discussed in chapter 3. Although the device has significant potential in QA application, it has been used minimally in flexible pavement diagnostic and forensic studies.

Agency Use or Adoption
No agency currently uses the GeoGauge in routine QA operations, nor do any contractors use it in their QC operations. FHWA and other agencies have on-going research projects to investigate the accuracy of the gauge for QA applications.

Accuracy and Repeatability
Information on the accuracy and repeatability of the GeoGauge was obtained during the initial development study and from the pooled fund study that was recently completed. Some of the projects used in those studies used the older gauges. The data collected to-date would suggest that the coefficient of variation for a single operator using a single gauge is between 2 to 5 percent, while for multiple operators and gauges the coefficient of variation increases to a value of 5 to 8 percent.

Calibration
Calibration is important to obtain reliable results using the GeoGauge. It is recommended by the manufacturer that a local calibration be completed at the beginning of each day's use. The GeoGauge comes with a relative calibration procedure and mass verification equipment.

Production Rate
Although the GeoGauge has not been used in routine construction or evaluation projects, it is estimated that data can be collected on a basis of about 1 test in 2 minutes. One test would include clustered tests at a single point, similar to the DSPA.

Advantages
A major advantage of the GeoGauge is that it can be used to develop density and modulus growth curves as the unbound materials and soils are being compacted by the rollers. Another major advantage of GeoGauge is that results from the field tests have been found to be similar to those measured in the laboratory with proper calibration. This unique feature in material characterization is particularly significant in QA operations. In addition, the coefficient of variation is reasonable for clustered testing, and those tests can be performed in a short period of time. The gauge is also easy to use and requires minimal training.

Disadvantages and Limitations
One of the limitations of the GeoGauge is that the material's modulus value does not represent the stress levels that occur under truck loadings. The modulus values have to be adjusted to account for the design loads. Another limitation of the GeoGauge is that the underlying or supporting materials can influence the results of the upper layer when trying to test relatively thin unbound layers (less than 6 inches in depth). Conversely, it cannot be used to accurately measure the modulus of thick unbound layers (greater than 12 inches in thickness).

4.9 Non-Nuclear, Electrical Sensing Methods—PQI, PaveTracker, EDG, and Purdue TDR

Most agencies and contractors consider density as a quality characteristic and include this material property in their acceptance and control plans. The most recent survey conducted to determine the prevalence of NDT methods for HMA density acceptance was the 2002 *Binder Payment Method and Compaction Specification Survey* conducted by the Colorado DOT on behalf of the AASHTO Subcommittee on Materials. The survey was fairly complete in that 41 states and the FHWA participated. The survey showed that 28 states use cores for HMA acceptance, while 22 use the nuclear density gauge for acceptance. While three states were counted as using something other than cores or the nuclear density gauge, these methods were simply a version of the core method or a method specification.

As part of NCHRP Project 10-65, nine states not covered in the Colorado survey were contacted. None of these states use anything other than cores or nuclear density gauges. Since the 2002 survey, however, many agencies are now investigating the non-nuclear electrical sensing NDT devices for both HMA and unbound layers. Some agencies that have on-going research studies of these devices include Alabama, Colorado, Florida, Nevada, Ohio, Texas, and Wisconsin. These methods being investigated include the non-roller-mounted, as well as roller-mounted devices or systems. To date, none of these devices is being used for acceptance, but some contractors have incorporated the non-nuclear density measuring devices (PQI or PaveTracker) into their QC plans for HMA.[12]

The use of non-nuclear density measuring devices for unbound layers has been much more limited. Most agencies and contractors use sand-cone tests and nuclear density gauges for QA. The Colorado, Nevada, and Texas DOTs have on-going research studies that include the use of or are evaluating the EDG device. The following provides supplemental information to that included in chapter 3 on the non-nuclear density gauges for use in QA of flexible pavement construction.

- No state has adopted this technology for acceptance of HMA and unbound materials/soils. Selected contractors, however, are using this technology for controlling the compaction of HMA mixtures. Both the PQI and PaveTracker are being used. The Nevada and Texas DOT studies on the EDG show promising results for monitoring the density and water content of unbound layers.[13]
- Calibration is important to obtain accurate results in terms of material density. Adjustments can be programmed or entered into the HMA devices for measuring density. However, these adjustments need to be periodically checked against cores, similar to the nuclear gauges. The gauges used for measuring density and water content of unbound materials require the development of a soil model between the electrical readings and the density and water content of the in-place soil. The soil

[12] Agencies contacted provided the names of contractors that use these devices for QC operations. These states were considered a high priority for the field evaluation projects (Alabama, Michigan, Minnesota, Texas, and Wisconsin).
[13] Information obtained from the Nevada DOT and University of Texas at Austin (conducting the Texas DOT study) during the survey of NDT devices for use in QA and other applications.

model can be developed in the laboratory but should be periodically checked during construction.
- Data on the accuracy of these gauges is limited, but many agencies have indicated that the accuracy and repeatability of these gauges is equal to or better than that of the nuclear gauges.
- The advantages of the HMA non-nuclear gauges are the speed and safety of the devices, as compared to nuclear density gauges. The disadvantage is that the manufacturers recommend that the gauges be used immediately after compaction—during the same day of paving. Surface water and other contaminates can affect the readings.
- The advantage of the unbound non-nuclear gauges is safety. The disadvantage is that these gauges have had limited use to demonstrate their immediate and practical use in QA programs.

In summary, the material density is an important quality characteristic that deserves additional consideration for further evaluation of NDT techniques that measure this property.

4.10 Non-Nuclear-Roller-Mounted Density/Stiffness Methods—IC Rollers

Although rollers with the IC devices are commercially available, few contractors have purchased these rollers. Some agencies have and are sponsoring demonstration and research projects on the use of this technology for controlling and accepting flexible pavement construction of individual layers. Few projects have included the use of this technology for constructing the entire flexible pavement or all HMA lifts placed on a rehabilitation project. Thus, chapter 3 provided a summary of the information available for review on the roller-mounted systems. It should be noted, however, that NCHRP, Colorado, Ohio, Michigan, Virginia, and Wisconsin are sponsoring or participating in research studies evaluating these systems. Results from many of these studies will be available within the new 2 to 4 years.

4.11 Surface Condition Characteristics

The surface condition factors consist of longitudinal and transverse profiles for determining the ride quality or smoothness of the pavement surface, the texture for determining the noise abatement features of surface layer, and the friction of the surface layer for determining skid resistance.

4.11.1 Smoothness

Most agencies use some measure of smoothness (typically an IRI value) in their specifications. The equipment used to measure smoothness is the profilometer, lightweight profilometer, and profilograph. The lightweight profilometer and profilograph are used by most agencies in their acceptance plan. These devices are readily available for use, but they only provide a measure of the smoothness of the surface layer. In addition, there are numerous manufacturers or suppliers of the lightweight profilometer that can be used. The purpose of the field evaluation study was not to compare and evaluate different lightweight profilometers. Thus, smoothness was not considered in the field study, and the different devices not included.

4.11.2 Noise

Noise is also becoming a significant factor in pavement surface type or rehabilitation strategy selection. However, most of the work completed to-date has been with the NCAT noise trailer. The number of trailers available is limited. In addition, those agencies contacted (for example, Arizona, Michigan, Ohio, Texas) have no plans to incorporate noise into their acceptance procedures.[14] Noise could be included as a factor in an acceptance plan, but only after the tie between mixture properties and noise is developed and verified. In other words, there are no criteria available that can be applied during the HMA mixture design stage. Thus, noise was excluded as a factor in the field study.

4.11.3 Surface Texture

Although macrotexture is an important component in wet weather skid resistance and noise generation (Henry, 2000), agencies have not specified macrotexture levels in relation to skid resistance and identifying surface defects, such as segregation. Surface macrotexture measurements cannot be used to identify segregation beneath the surface. In addition, there is no known HMA mixture design or structural design procedures that use macrotexture. More importantly, none of the DOTs contacted have plans to incorporate surface texture into their acceptance plans. Thus, surface texture was excluded from the field study.

4.11.4 Skid Resistance

Skid resistance testing and its use in acceptance is a concern of many agencies because of a potential liability problem. Excluding Virginia and the FHWA, most state agencies conduct skid resistance testing on an as-needed or requested basis and as required by FHWA policies on federal routes, but have no plans for including friction into their acceptance plans. Due to its limited use, skid resistance was not considered in the field study.

4.12 Summary of Evaluation

Table 24 shows a summary of technologies evaluated or used by different state agencies. Tables 25 through 28 summarize some of the critical points of each NDT technology as they relate to routine QA operations and to inputs needed for the MEPDG. [Note: Tables 24 through 28 are included at the end of this chapter.] The ones selected include those with high to moderate applicability to QA and low to moderate risk for implementation of the technology. Those technologies not selected were those with a low applicability to QA or a high risk for implementation of the technology.

[14] From personal contacts and correspondence: Agencies are considering the use of noise as a factor in their rehabilitation and surface layer selection policy, but do not believe that it should be a part of the acceptance plan. The reasoning for this position is that there is little information that can be used to design “quiet” HMA mixtures.

NDT Devices Included in the Field Evaluation

The following lists the NDT technologies and devices that were selected for use in the field study, in no particular order:

1. **Deflection Based Technologies—**The FWD and LWD were selected for use because of the large number of devices that are being used in the U.S. and the large database that has been created under the FHWA-LTPP program. The LWD will be used to evaluate individual layers, especially unbound layers, while the FWD will be used to evaluate the entire pavement structure at completion to ensure that the flexible pavement structure or HMA overlay have met the overall strength requirements used in the structural design process. Deflection measuring devices are generally readily available within most agencies for their immediate use in QA.

2. **Dynamic Cone Penetrometer—**The DCP was selected for use because of its current use in QA operations in selected agencies and ability to measure the in-place strength of unbound layers and materials. In addition, the DCP does not require extensive support software for evaluating the test results. DCP equipment is being manufactured and marketed by various organizations, so its availability is not a problem.

3. **Ground Penetrating Radar—**GPR was selected for study because of its current use in pavement forensic and evaluation studies for rehabilitation design and for estimating both the thickness and air voids of pavement layers. If proven successful, this will be one of the more important devices used for acceptance of the final product by agencies, assuming that the interpretation of the data can become readily available on a commercial basis. The GPR air-coupled antenna was successfully used within the FHWA-LTPP program to measure the layer thickness within many of the 500-foot test sections.

4. **Seismic Pavement Analyzer—**Both the PSPA and DSPA were selected for use because it provides a measure of the layer modulus and can be used to test thin, as well as thick layers shortly after placement. This technology can also be used in the laboratory to test both HMA and unbound materials compacted to various conditions—different fluids content for unbound materials and soils or temperatures for HMA to evaluate the effect of fluids and temperature on materials.

5. **GeoGauge—**The GeoGauge has had mixed results from its use to test unbound pavement layers. It was selected for use because it is simple to use and provides a measure of the resilient modulus of unbound pavement layers and embankment soils and can be used to test typical lift thicknesses.

6. **Non-Nuclear Electric Gauges; Non-Roller-Mounted Devices**—Non-nuclear density gauges have a definite advantage over the nuclear ones simply from a safety standpoint. These gauges have been used on many projects but with varying results. They were selected for use because many agencies are allowing their use by contractors on a QC basis, and agencies are beginning to use the contractors QC

results for acceptance. They also represent the baseline comparison to the results from the nuclear gauges for measuring density for use in acceptance procedures. Thus, the location specific non-nuclear density gauges were selected. The gauges selected for initial use were the PQI and PaveTracker for HMA mixtures, while the EDG was selected for unbound materials.

NDT Devices Excluded from the Field Evaluation

The following lists some of the basic reasons for excluding specific NDT technologies and devices from the field evaluation study.

- **Roller-Mounted-Density/Stiffness Devices—**Non-nuclear density and stiffness monitoring devices attached to the rollers (Bomag Variocontrol and Onboard Measuring System) were excluded because these devices have not been extensively used for QC, no agency has immediate plans to implement them in their project requirements for future use, and there are a limited number of these rollers available for contractor use. Although the roller-mounted devices were excluded from the experimental plan for the field evaluation study, the roller manufacturers were contacted to determine their availability and use on selected projects. Thus, they were not totally excluded from the field evaluation.

- **Surface Condition Systems—**None of the surface condition measuring systems or devices was recommended for further evaluation under NCHRP Project 10-65. Although the initial IRI is an input to the MEPDG, the smoothness measuring devices used for acceptance of the wearing surface are already included in many agencies QA programs. In addition, none of the devices provide an estimate of the volumetric and structural properties of the wearing surface.

- **Noise and Friction Methods—**Noise and friction measuring devices were excluded from further consideration, because these properties are not needed in the MEPDG. Or any other structural design procedure and no agency is considering their use for acceptance.

- **Infrared Tomography—**The infrared cameras and sensors were excluded from the field evaluation because their output only provides supplemental information to current acceptance plans. In other words, the devices are used to identify “cold spots” or temperature anomalies and other test methods are still used to determine whether the contractor has met the density specification. This statement does not imply that this technology should be abandoned or not used—the infrared cameras and sensors do provide good information and data on the consistency of the HMA being placed by the contractor.

- **Other Ultrasonic Test Methods—**The IE and impulse response methods, as well as the ultrasonic scanners, were excluded because they are perceived to have a high risk of implementation into practical and effective QA operations.

Table 24. Technologies Used by State Agencies as a Research, Forensic, or Evaluation Tool Based on Information Collected During the Project Survey[15]

NDT Technology	State Highway Agencies Using Technology
FWD	Arizona, Alabama, California, Connecticut, Florida, Georgia, Illinois, Minnesota, Mississippi, Missouri, Nevada, Ohio, Oklahoma, Texas, Utah, Virginia, Washington, Wisconsin
DCP	California, Colorado, Florida, Illinois, Iowa, Kansas, Kentucky, Maryland, Michigan, Minnesota, Mississippi, Missouri, Montana, Nevada, New Jersey, North Carolina, North Dakota, Ohio, Oklahoma, Pennsylvania, South Carolina, Texas, Utah, Virginia, Wisconsin
GPR	Florida, Georgia, Illinois, Minnesota, Missouri, Oklahoma, Texas, Nevada, North Dakota, Oklahoma, Virginia, Washington, Wisconsin
PSPA & DSPA	Colorado, Florida, Texas
GeoGauge	FHWA (other agencies have used the device, but only during the pooled fund studies sponsored by FHWA)
IR	Connecticut, Minnesota, Missouri, Nevada, Texas, Washington
Non-nuclear density	Alabama, Connecticut, Florida, Illinois, Minnesota, Mississippi, Missouri, Nevada, New York, Oklahoma, Texas, Washington, Wisconsin
Smoothness	Arizona, Alabama, Colorado, California, Connecticut, Florida, Illinois, Minnesota, Mississippi, Missouri, Nevada, Ohio, Oklahoma, Virginia, Washington, Wisconsin
Skid and Texture	Arizona, Alabama, Colorado, California, Florida, Illinois, Minnesota, Mississippi, Missouri, Nevada, Ohio, Oklahoma, Virginia, Washington, Wisconsin

[15] This summary does not reflect the status of all State DOTs in the U.S., because not all 50 States were consulted in this survey. Detailed information about the DCP was obtained from the Minnesota Road Research Section, Office of Materials, MnDOT, as well as from the Oklahoma and Montana DOTs and consulting organizations.

Table 25. Summary Evaluation Results for DCP, Deflection-Based Methods, GPR, and Infrared Devices for Use in QA

Evaluation Factor		DCP	Deflection		GPR	Infrared
			FWD	LWD		
Test Method Used for QA	Acceptance	No	No	No	No	No
	Process Control	No	No	No	No	No
Material Properties Estimated	HMA Mixes	NA	Layer Modulus	Composite Modulus	Thickness; Density/Voids	NA
	Unbound Layers	Strength Thickness	Layer Modulus	Composite Modulus	Thickness; Density	NA
Modulus Estimated by:		Regression equations	Back-calculation	Forward-calculation	NA	NA
Output Applicable To:	Structural Design	Yes; Strength & Thickness	Yes; Back-Calculated E	No	Yes; Density, Thickness	NA
	Mixture Design	NA	No	No	No	NA
Status of Use		State-of-Practice	State-of-Practice	State-of-Art	State-of-Art	State-of-Art
Test Protocol Used by Agencies		Yes, ASTM Standardized	Yes, ASTM Standardized	No	Yes	Yes, ASTM Standardized
Test Method Applicable To:	Acceptance	Yes	Yes, final structure	Yes	Yes, ASTM Standardized	No
	Process Control	Yes	No	Yes	No	Yes
Test Local		Point Specific	Area Specific	Point Specific	Continuous	Continuous
Identification of Localized Defects		Yes, but requires more testing	No	No	Yes, low density, segregation	Yes; cold spots
Applicability to Test Thin Layers		No	No	Yes	Yes	Yes
Production Rate		1 test/10 min.	1 test/5 min.	1 test/2 min.	High	High
Analysis Effort		Easy	Difficult	Easy	Difficult	Easy
Cost of Equipment		$15,000	$125,000	$20,000	$40,000	$12,000
Practical & Effective QA Operations	Applicability of Device	High	Moderate	Moderate	High	Low for QC; NA for QA
	Risk of Implementation	Low	Moderate	Moderate	Low	Low

Table 26. Summary Evaluation Results for Magnetic Imaging, Density, and Smoothness Devices for Use in QA

Evaluation Factor		Magnetic Imaging	Density			Smoothness, Profilometer
			Non-Nuclear	Humbolt, Nuclear	Roller-Mounted Gauges	
Test Method Currently Used for QA	Acceptance	No	No	No	No	Yes
	Process Control	No	Yes	Yes	No	No
Material Properties Estimated	HMA Mixes	Thickness	Density	Density	Density & Stiffness	IRI, Surface
	Unbound Layers	NA	Density	Density	Density & Stiffness	NA
Modulus Estimated by:		NA	NA	NA	NA	NA
Output Applicable To:	Structural Design	Yes, mat thickness	No	No	No	Yes, initial IRI
	Mixture Design	No	No	No	No	NA
Status of Use		Research & Forensics	Research	Research	Development	State-of-Practice
Test Protocol Used by Agencies		None	Supplier	Supplier	None	Yes; AASHTO Standardized
Test Method Applicable To:	Acceptance	Yes; mat thickness	Yes, density	Yes, density	No	Yes
	Process Control	No	Yes	Yes	Yes	Yes
Test Local		Area Specific	Point Specific	Point Specific	Continuous	Continuous
Identification of Localized Defects		No	Yes, but more testing is needed	Yes, but more testing is needed	No	Yes, bumps
Applicability to Test Thin Layers		Yes	Yes	Yes	Yes	Yes, surface
Production Rate		Based on Location of metallic washers	1 test/2 min.	1 test/ 2 min.	High	High
Analysis Effort		Limited	Easy	Easy	Limited	Extensive
Cost of Equipment		$15,000	$12,000			Van-$100,000 Light-Weight - $35,000
Practical & Effective QA Operations	Applicability of Device	Low	Moderate	Low	Moderate	High
	Risk of Implementation	High	Moderate	Moderate	High	Low

Table 27. Summary Evaluation Results for Seismic and Steady State Vibratory Devices for Use in QA

Evaluation Factor		Seismic			GeoGauge
		SPA; PSPA & DSPA	Impact-Echo	Scanners; I-E, SASW	
Test Method Currently Used for QA	Acceptance	No	No	No	No
	Process Control	No	No	No	No
Material Properties Estimated	HMA Mixes	Thickness, Modulus	Thickness	Thickness, Modulus	No
	Unbound Layers	Thickness, Modulus	NA	NA	Modulus
Modulus Estimated by:		Calibration	NA	Calibration	Direct Reading
Output Applicable To:	Structural Design	Thickness, Modulus	Thickness	Thickness	Modulus
	Mixture Design	Modulus	NA	NA	NA
Status of Use		Limited	R&D	R&D	Limited
Test Protocol Used by Agencies		Forensics	Forensics	No	No
Test Method Applicable To:	Acceptance	Yes	Yes	Yes	Yes
	Process Control	Yes	Yes	Yes	Yes
Test Local		Point Specific	Point Specific	Continuous	Point Specific
Identification of Localized Defects		Yes, but more testing is needed	Yes, but more testing is needed	Yes	Yes, but more testing is needed
Applicability to Test Thin Layers		Yes	Yes	Yes	Yes, to some degree
Production Rate		1 test/2 min.	1 test/5 min.	High	1 test/5 min.
Analysis Effort		Extensive	Extensive	Extensive	Minimal
Cost of Equipment		$25,000	$20,000	$35,000	$25,000
Practical & Effective QA Operations	Applicability of Device	High	Moderate	High	High
	Risk of Implementation	Moderate	High	High	Moderate

Table 28. Summary Evaluation Results for Noise and Skid Devices for Use in QA

Evaluation Factor		Noise	Skid
Test Method Currently Used for QA	Acceptance	No	No
	Process Control	No	No
Material Properties Estimated	HMA Mixes	NA	Friction, surface
	Unbound Layers	NA	NA
Modulus Estimated by:		NA	NA
Output Applicable To:	Structural Design	NA	NA
	Mixture Design	No	No
Status of Use		R&D	State-of-Art
Test Protocol Used by Agencies		Limited	Yes
Test Method Applicable To:	Acceptance	Yes	Yes
	Process Control	No	No
Test Local		Continuous	Continuous
Identification of Localized Defects		No	Yes, surface
Applicability to Test Thin Layers		Yes	Yes
Production Rate		High	High
Analysis Effort		Extensive	Moderate
Cost of Equipment			
Practical & Effective QA Operations	Applicability of Device	Low	Low
	Risk of Implementation	High	High

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CHAPTER 5

FIELD EVALUATION OF NDT DEVICES

As noted in chapter 1, the field evaluation was divided into two parts, referred to as Part A and Part B. Part A was to confirm the applicability of NDT technologies that were judged to be ready and appropriate for implementation into routine, practical, and effective QA programs for flexible pavement construction and HMA overlays. Part A of the field evaluation also included selecting those NDT technologies and devices that can consistently and accurately identify construction anomalies.

Part B of the field study was to use those NDT technologies and devices selected from Part A and refine the test protocols and data interpretation procedures for judging the quality of flexible pavement construction. Part B also included identifying limitations and boundary conditions of selected NDT test methods. This chapter summarizes all testing completed within the field evaluation. The interpretation and analyses of the data are included in Part III of the research report.

5.1 Projects and Materials Included in Field Evaluation

Table 29 summarizes the project and materials included in the field evaluation for Parts A and B. Appendix B provides a discussion of all projects and materials included in the field evaluation. The anomalies included within specific segments or lots are identified and discussed in the following sections of this chapter.

5.2 Field Testing Plan

The NDT technologies and devices recommended for use in the field evaluation were identified in chapter 4. Table 30 lists the specific devices that were used for each project listed in Table 29, while Figure 37 shows the general layout of test points for each section or lot within a project under Part A. Areas with anomalies were included in the test plan to confirm that the NDT devices can estimate at least one quality characteristic and identify areas with anomalous features. The testing plan for the segments included in Part B was similar to Figure 37, but did not purposely include any localized anomalies.

The remainder of this chapter presents the NDT data measured on the projects included within Part A of the field evaluation for identifying the localized anomalies within each project. The NDT data collected on the Part B projects are discussed in more detail in chapters 7 and 8.

5.3 NDT Test Results of Unbound Materials and Soils

This section presents the NDT responses measured on the unbound materials at each project listed in Table 29. It also provides a brief evaluation of the materials based on those measured responses and compares the responses measured by different NDT devices on the same material.

Table 29. Listing of Projects and Material Types Included in the Field Evaluation

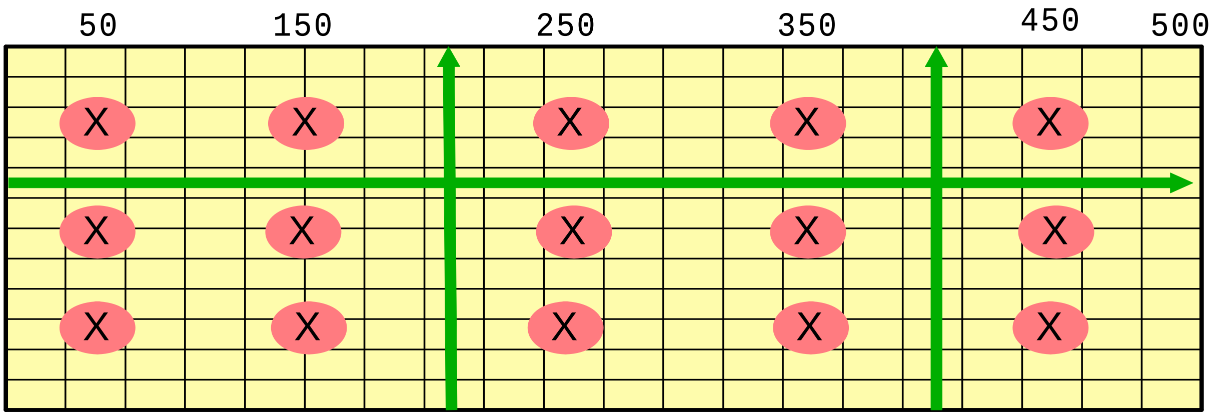
Part	Project Identification & Location		Layer/Material Evaluated	
A	1	MnRoad Demonstration (Note 1)	Embankment	Low Plasticity, Fine-Grained Soil
A	2	TH-23 Reconstruction Project; Wilmar/Spicer Minnesota	HMA	Dense-Graded Base Mixture
			Granular Base	Class 6, Crushed Aggregate
			Class 5 Embankment	Low Plasticity, Improved Soil with Gravel & Large Aggregate Particles
A	3	I-85 Overlay Project; Auburn, Alabama	HMA	12.5mm Stone Matrix Asphalt Mix; PG76-22
A	4	US-280 Reconstruction Project; Opelika, Alabama	HMA	Coarse-Graded Base Mixture; PG67-22
			Granular Base	Crushed Limestone Base
			Embankment	Improved Soil; Aggregate-Soil Mix
A	5	I-85 Ramp Construction Project; Auburn, Alabama	Embankment	Low Plasticity, Fine-Grained Soil
A	6	SH-130 New Construction Project; Georgetown, Texas	HMA	Coarse-Graded 19mm Base Mixture; PG64-22
			Embankment	Coarse-Grained Aggregate/Soil; Improved Soil
A	7	SH-21 Widening Project; Caldwell, Texas	Subgrade	High Plasticity Fine-Grained Soil with Gravel
B	8	US-47 Widening Project; St. Clair, Missouri	HMA	Coarse-Graded Base Mixture
			HMA	Fine-Graded Wearing Surface
			Granular Base	*Crushed Aggregate; In place material*
B	*9*	*US-47 Reconstruction Project; Union, Missouri*	*HMA*	*Coarse-Graded Base Mixture*
			Granular Base	*Crushed Aggregate Base*
B	10	I-75 Rehabilitation Project, Rubblization; Saginaw, Michigan	HMA	Dense-Graded Binder Mixture; Type 3C
			HMA	*Fine-Graded Wearing Surface*
B	11	US-2 New Construction; North Dakota	HMA	Coarse-Graded Base Mix; PG58-28
			Granular Base	Crushed Gravel with Surface Treatment; Class 5
			Embankment	Soil-Aggregate Mixture
B	12	US-53 New Construction; Toledo, Ohio	HMA	Coarse-Graded Binder Mixture
			Granular Base	Crushed Aggregate; Type 304
B	13	I-20 Overlay; Odessa, Texas	HMA	Coarse-Graded Mixture; CMHB
			Granular Base	*Crushed Stone*
B	14	County Road 103; Pecos, Texas	Granular Base	Caliche, Aggregate Base
B	15	NCAT; Alabama Overlay, Section E-5, Opelika, Alabama	HMA	Wearing Surface with 45% RAP; PG67, no modifiers used.
		NCAT; Alabama Overlay, Section E-6, Opelika, Alabama	HMA	Wearing Surface with 45% RAP; PG76 with SBS.
		NCAT; Alabama Overlay, Section E-7, Opelika, Alabama	HMA	Wearing Surface with 45% RAP; PG76 with Sasobit.
B	16	NCAT; Florida; Structural Test Sections N-1 & N-2	HMA	PMA Mixture with SBS; PG76
			HMA	Neat Asphalt Binder Mix; PG67
			Granular Base	Limerock Base
B	17	NCAT; Missouri; Structural Test Section N-10	HMA	Polymer Modified Asphalt Mix; PG76 (SBS)
			HMA	Neat Asphalt Binder Mix; PG64
			Granular Base	Crushed Limestone
B	18	NCAT; Oklahoma; Structural Test Sections N-8 & N-9	Subgrade Soil	High Plasticity Clay with Chert Aggregate
B	19	NCAT; South Carolina; Structural Test Section S-11	HMA	Coarse-Graded Base Mix; PG67; Limestone
			Granular Base	Crushed Granite Base

CMHB – Coarse Matrix, High Binder Content (mixture type term used by the Texas DOT specifications)
PG – Performance Grade
PMA – Polymer Modified Asphalt
RAP – Recycled Asphalt Pavement

NOTE: Shaded cells with italic text in table were excluded from the field evaluation for different reasons; see explanation in Appendix B.

Table 30. NDT Devices Used at Each of the Field Evaluation Projects

Part	Project ID	Material	NDT Technologies						
			Impact (DCP)	Deflect.	Seismic	GeoGauge	GPR	Non-Nuclear Density	Roller Mounted Devices
A	MnRoad Demonstration	Embankment	√	√	---	---	---	---	√
A	TH-23 Project, MN	HMA	NA	---	√	NA	√	√	---
		Crushed Stone	√	√	√	√	√	√	√
		Embankment	√	√	√	√	√	√	---
A	I-85 Overlay, AL	SMA	NA	√	√	NA	√	√	√
A	US-280, AL	HMA	NA	√	√	NA	√	√	√
		Crushed Stone	√	√	√	√	√	√	---
A	I-85 Ramp, AL	Embankment	√	√	√	√	√	√	√
A	SH-130, TX	HMA	NA	√	√	NA	√	√	---
		Embankment	√	√	√	√	√	√	---
A	SH-21, TX	Subgrade Soil	√	√	√	√	---	√	√
B	US-47, MO	HMA	NA	---	√	NA	---	√	---
B	I-75, MI	HMA	NA	---	√	NA	---	√	---
B	US-2; ND	HMA	NA	---	√	NA	---	√	---
		Crushed Stone	√	---	√	√	---	---	---
		Embankment	√	---	√	√	---	---	---
B	US-53, OH	HMA	NA	---	√	NA	---	√	---
		Crushed Stone	√	---	√	√	---	---	---
B	I-20, TX	HMA	NA	---	√	NA	---	√	---
B	Co. Rd. 103, TX	Caliche Base	√	---	---	√	---	---	---
B	NCAT, Alabama	HMA	NA	---	√	NA	√	√	√
B	NCAT, Florida	HMA	NA	---	√	NA	√	√	---
		Limerock Base	√	---	√	√	---	---	---
B	NCAT, Missouri	HMA	NA	---	√	NA	√	√	---
		Crushed Stone	√	---	√	√	---	---	---
B	NCAT, Oklahoma	Subgrade Soil	√	---	√	√	---	---	---
B	NCAT, South Carolina	HMA	NA	---	√	NA	√	√	---
		Crushed Stone	√	---	√	√	---	---	√



NDT Technology (Unbound Layers)	**Frequency of Test**	**Segments or Lots; Localized Anomalies**
• Non-Roller-Mounted Density Devices (EDG) • Steady-State Vibratory (GeoGauge) • Seismic (DSPA) • Deflections (LWD, FWD) • Impact/Penetration Devices (DCP) • GPR, Air Horned Antenna	• Triplicate Tests • Clustered Tests	• Varying density between & within a lot • Varying water content between & within a lot • Material types
NDT Technology (HMA Layers)	**Frequency of Test**	**Segments or Lots; Localized Anomalies**
• Non-Roller-Mounted Density Devices (PQI, PaveTracker) • Seismic (PSPA) • Deflections (FWD) • GPR, Air Horned Antenna	• Triplicate Tests • Clustered Tests	• Varying density between & within lots • Varying asphalt content between lots • Mixture types

Figure 37. General Layout of Test Points and Testing Sequence for Each Section or Lot Included within a Project in Part A of the Field Evaluation

The initial testing under Part A of the field evaluation was to confirm that the NDT technologies can accurately identify differences in construction quality of unbound pavement layers. The specific hypothesis used for this part of the field evaluation was that the NDT technology and device can detect changes in the physical condition of the materials. Table 31 summarizes the anomalies between the unbound materials placed along each project. During nondestructive testing, the NDT operators were not advised of these anomalies. Conversely, no anomalies were planned for the Part B field evaluation projects.

5.3.1 Impact Penetration Test—DCP

The manual DCP was used to estimate the in-place strength of the unbound materials in accordance with ASTM D 6951 (see Figure 3 in chapter 3). However, the sequence of drops and penetration readings were modified based on the layers and thicknesses being evaluated at each project site.

Table 31. Description of the Local Anomalies in the Unbound Materials and Soils Placed Along Each Project Included in Part A

Project Identification	Unbound Sections	Description of Differences Along Project
SH-21 Subgrade, High Plasticity Clay; Caldwell, Texas	Area 2, No IC Rolling	No planned difference between the points tested.
	Area 1, With IC Rolling	With IC rolling, the average density should increase; lane C received more roller passes.
I-85 Embankment, Low Plasticity Clay; Auburn, Alabama	Lane A of Sections 1 & 2	Prior to IC rolling, Lane A (which is further from I-85) had thicker lifts & a lower density.
	All sections tested	After IC rolling, the average density should increase & the variability of density measurements should decrease.
TH-23 Embankment, Silt-Sand-Gravel Mix; Spicer, Minnesota	South Section – Lane C	Construction equipment had disturbed this area. In addition, QA records indicate that this area has a lower density.
	North Section – Lane A	The area with the higher density and lower moisture content – a stronger area.
SH-130, Improved Embankment, Granular; Georgetown, Texas	All sections tested	No planned differences between the areas tested.
TH-23, Crushed Aggregate Base; Spicer, Minnesota	Section 2 (middle section) – Lane C	Curb and gutter section; lane C was wetter than the other two lanes because of trapped water along the curb from previous rains. The water extended into the underlying layers.
	Section 1 (south section) – Lane A	Area with a higher density and lower moisture content; a stronger area.
US-280, Crushed Stone Base; Opelika, Alabama	Section 4	Records indicate that this area was placed with higher moisture contents and is less dense. It is also in an area where water (from previous rains) can accumulate over time.

For each point, the test was begun by using one seating drop from full height. The penetration was recorded for the seating drop. The penetration was then recorded after each drop or five successive drops (depending on its strength) throughout the layer thickness. One DCP test was performed at each test point. At a few test locations, however, refusal of the DCP occurred when large aggregates were encountered (see Figure 38). When refusal occurred, the DCP was moved slightly and the test repeated.

The penetration rate has been correlated to resilient modulus, as presented in the chapter 3. Equation 33 was used to calculate the resilient modulus for each test point. Table 32 lists the average resilient modulus values for each area tested within Part A, while Table 33 lists the average resilient modulus values for the projects included in Part B. The DCP test or penetration of the device was continued into the supporting layer. All incremental penetration rates are provided in Appendix C. The average penetration rates through the test material were used to calculate the average elastic modulus at each test point.

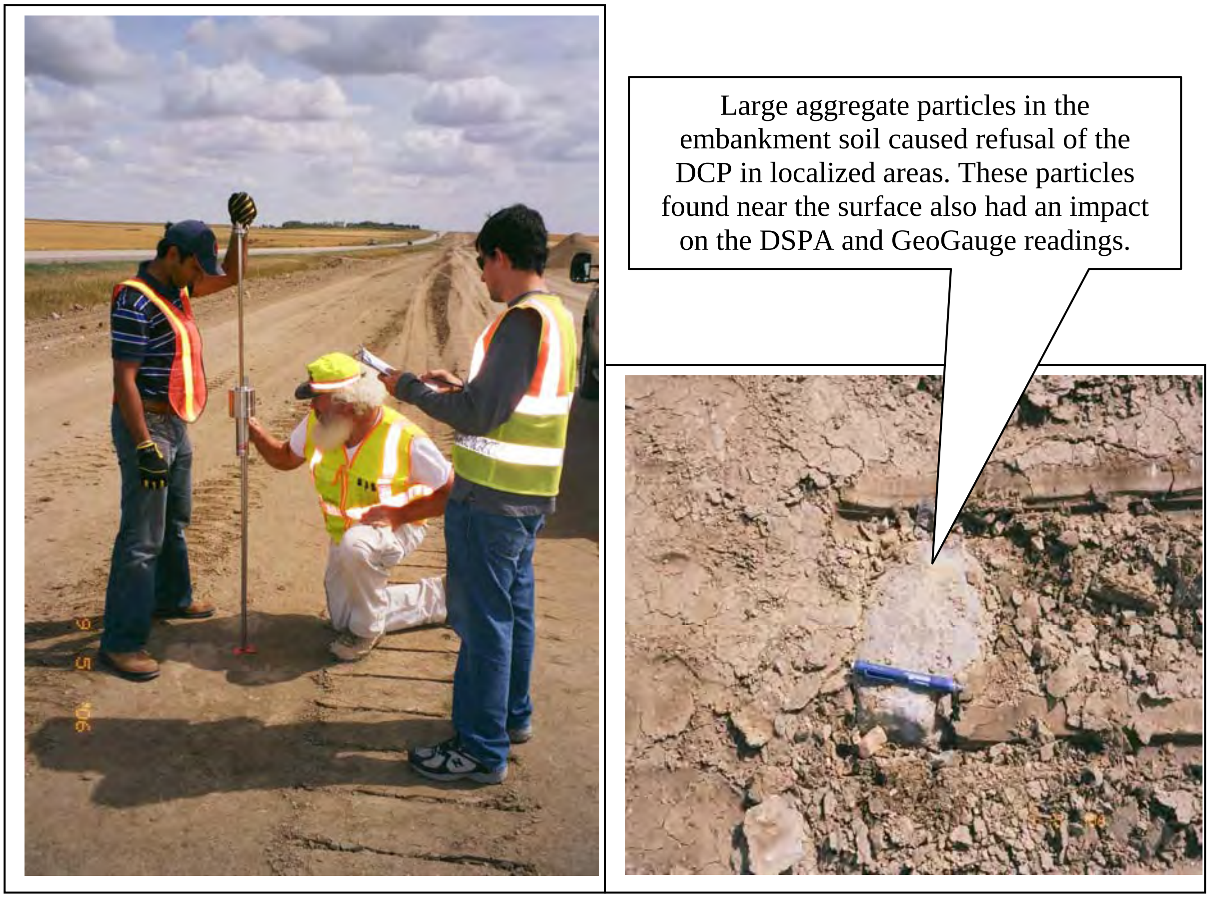


Figure 38. Photo of the DCP Test and Large Aggregate Particles Encountered at Some of the Projects Resulting in Refusal of the Test

$$E_R = 17.6\left(\frac{292}{(DPI)^{1.12}}\right)^{0.64} \tag{33}$$

Where:

E_R = Resilient modulus, MPa.
DPI = Penetration rate or index, mm/blow.

Figure 39 compares the standard deviation to the mean elastic modulus calculated from the DCP penetration rate for both fine and coarse-grained materials. As shown, the standard deviation increases with material strength or increasing elastic modulus. In addition, the coarse-grained materials were found to be consistently stronger than fine-grained soils, as expected.

Table 32. Summary of Resilient Modulus Values Calculated from DCP Test Results Measured Within Specific Sections of the Projects Included in Part A, ksi

Project Identification		Location or Designated Area			
		A	B	C	D
I-85 Low Plasticity Clay; Section 1; Before IC Rolling	Mean, ksi	**5.41**	6.71	6.04	5.47
	COV, %	**13.7**	48.4	29.4	24.3
I-85 Low Plasticity Clay; Section 2; Before IC Rolling	Mean, ksi	**4.98**	5.32	5.44	4.73
	COV, %	**11.9**	25.2	22.7	25.2
I-85 Low Plasticity Clay; Section 1; After IC Rolling	Mean, ksi	6.66	7.74	7.10	6.23
	COV, %	19.5	38.0	24.7	26.6
I-85 Low Plasticity Clay; Section 2; After IC Rolling	Mean, ksi	6.07	6.20	6.54	6.01
	COV	18.5	15.3	12.5	26.5
SH-21, High Plasticity Clay; Area 2, No IC Rolling	Mean, ksi	---	---	---	11.9
	COV, %	---	---	---	16.6
SH-21, High Plasticity Clay; Area 1, With IC Rolling	Mean, ksi	9.1	8.3	9.9	---
	COV, %	40.2	16.8	19.1	---
TH-23 Embankment, Silt-Sand-Gravel Mix; South Section	Mean, ksi	14.77	15.55	**11.47**	---
	COV, %	4.8	14.8	**22.3**	---
TH-23 Embankment, Silt-Sand Gravel Mix; North Section	Mean, ksi	**18.52**	20.22	17.80	---
	COV, %	**21.5**	26.2	28.3	---
SH-130 Granular, Improved Embankment; Section 1	Mean, ksi	20.50	18.65	24.18	---
	COV, %	14.0	25.0	24.0	---
SH-130 Granular, Improved Embankment; Section 2	Mean, ksi	21.31	20.32	18.85	---
	COV, %	43.4	36.8	10.4	---
SH-130 Granular, Improved Embankment; Section 3	Mean, ksi	22.99	23.87	19.18	---
	COV, %	37.5	58.9	40.6	---
TH-23 Crushed Aggregate; Middle Section	Mean, ksi	42.25	33.07	**18.55**	---
	COV, %	46.6	38.3	**20.0**	---
TH-23 Crushed Aggregate; South Section	Mean, ksi	**48.23**	44.66	24.11	---
	COV, %	**50.5**	20.6	16.6	---
US-280, Crushed Stone; Section 1	Mean, ksi	53.79			---
	COV, %	23.8			---
US-280, Crushed Stone; Section 2	Mean, ksi	45.90			---
	COV, %	21.8			---
US-280, Crushed Stone; Section 3	Mean, ksi	51.19			---
	COV, %	8.9			---
US-280, Crushed Stone; Section 4	Mean, ksi	**34.31**			---
	COV, %	**11.9**			---

Note: The shaded cells designate those areas with anomalies (refer to table 31); black cells denote weaker areas, while the gray cells denote stronger areas for a specific project.

Table 33. Summary of Resilient Modulus Values Calculated from DCP Test Results Measured within Projects Included in Part B, ksi

Project Identification	Section and Material	Mean Modulus, ksi	Coefficient of Variation, %	Standard Deviation of Means, ksi
US-2, ND	Crushed Gravel; No prime coat	28.7	2.9	0.095
	Crushed Gravel; Prime Coat	31.7	14.01	4.44
	Embankment, Soil-Aggr.	22.2	15.6	3.45
US-53, OH	Crushed Aggregate	31.9	23.2	7.4
CR-103, TX	Caliche Base	22.5	6.5	2.81
NCAT, Florida	Limerock Base, Sect. N1	43.1	22.8	9.82
	Limerock Base, Sect. N2	49.3	20.2	9.97
NCAT, Missouri	Crushed Limestone, Sect. N10	---	---	---
NCAT, SC	Crushed Granite	---	---	---
NCAT, Oklahoma	High Plasticity Clay, Sect. N8	8.15	27.4	2.23
	High Plasticity Clay, Sect. N9	9.02	21.1	1.91

NOTE: The DCP was excluded from the Missouri and South Carolina test sections because of problems encountered in compacting these base materials that delayed the final completion of these test sections.

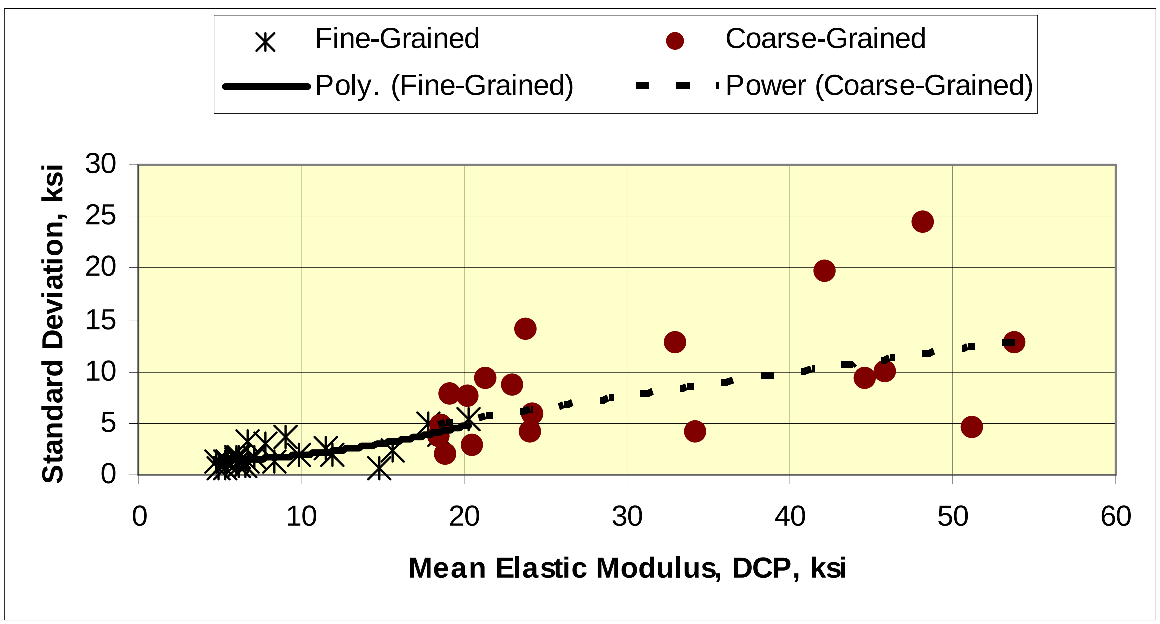


Figure 39. Relationship Between the Standard Deviation and Mean of the Elastic Modulus Values of Unbound Materials Calculated from the DCP Penetration Rate

The cells in Table 32 that correspond to those conditions listed in Table 31 have been shaded. The following list summarizes the results of the DCP tests in accordance with those anomalies identified in Table 31:

- I-85 Low Plasticity Soil Embankment—The DCP found both outside lanes (lanes A and D) to be weaker than the two inside lanes, both before and after IC rolling. The DCP results also indicate a consistent increase in the embankment's strength after IC rolling, but not a reduction in variability of strength.
- SH-21 High Plasticity Clay Soil—The DCP found area 1, with IC rolling and testing, to be weaker than area 2. This observation is inconsistent with construction records. However, area 2 was found to have some gravel mixed in with the high plasticity clay near the surface (top 6 to 8 inches) during the sampling process. This could explain the higher strengths in area 2.
- TH-23 Gravelly, Silty Clay (Silt-Sand Gravel Mix) Embankment—The DCP correctly found lane C of the south section to be the weaker of the areas tested, and found the entire north section to be significantly stronger than the south section. Lane A was not stronger than the other two lanes tested in the north section, which is inconsistent with construction records.
- SH-130 Improved Granular Embankment—The DCP found no significant difference between the areas tested, which was planned.
- TH-23 Crushed Aggregate Base—The DCP found lane C in the middle section to be the weaker and lane A in the south section to be stronger. The paving schedule prevented the north section from being tested with the DCP.
- US-280 Crushed Stone Base—The DCP found area 4 to be softer of the four areas tested. However, its strength is still high and consistent with adequately compacted crushed stone.

5.3.2 Deflection Testing—FWD and LWD

Two types of deflection measuring equipment were used on some of the projects: the trailer-mounted FWD and the portable FWD or LWD.

Falling Weight Deflectometer

Deflection basins were measured with the FWD in accordance with the test protocol being used in the LTPP program (see Figure 6 in chapter 3). The procedure was to use two seating drops, followed by two drops at each drop height. Three drop heights were used at each test point. The deflection basins were recorded for each drop, including the seating drops. After the first set of tests, the FWD was moved forward (where the loading plate would be in contact with a different area) and the test sequence repeated. This sequence of drops and replicate testing was used at each test point. The 18-inch-diameter loading plate was used for all unbound materials testing, and the deflections were measured at seven sensors at the spacing recommended for use in LTPP.

The deflection basins were used to forward-calculate the elastic modulus of the layer being evaluated using the procedure developed by Stubstad et al. (2003). The calculated elastic modulus values are summarized in Table 34 for the US-280 project. Elastic moduli were also backcalculated using other traditional methods and more sophisticated pattern recognition methods. The forward-calculation method resulted in the least variation of elastic moduli within a specific area.

<u>Light Weight Deflectometer</u>

Deflections were also measured with different LWD devices in accordance with the manufacturer's recommendations. One to three LWD devices were used on the Part A projects. These devices are defined as the Loadman, Dynatest Prima 100, and Carl Bro. The Loadman and Dynatest Prima 100 were used to measure the deflection at the center of the loading plate, while the Carl Bro device was used to measure the deflections under the loading plate and at two additional sensors spaced at 8 and 12 inches from the loading plate. Figure 40 shows the LWDs that were used on selected projects.

Table 34. Summary of the Calculated Resilient Modulus Values from the FWD Deflection Basins, ksi

Project Identification	Area	Section of Project			
		A	**B**	**C**	**D**
US-280; Crushed Stone; Section 1	1	18.1	15.7	15.7	---
	2	8.10	6.3	7.2	---
	3	16.7	17.9	20.2	---
	4	27.5	26.8	25.9	---
	5	32.3	35.1	38.3	---
	Mean, ksi	20.794			---
	Std. Dev., ksi	9.979			---
	COV, %	48.0			---
US-280; Crushed Stone; Section 2	1	16.6	13.8	---	---
	2	11.9	8.6	9.2	---
	3	15.5	18.2	14.9	---
	4	26.4	32.1	30.0	---
	5	---	31.4	28.7	---
	Mean, ksi	19.798			---
	Std. Dev., ksi	8.686			---
	COV, %	43.9			---
US-280; Crushed Stone; Section 3	1	32.3	31.7	26.9	---
	2	14.2	11.7	10.6	---
	3	7.8	8.2	9.2	---
	4	22.3	18.5	20.3	---
	5	20.3	18.7	19.6	---
	Mean, ksi	18.166			---
	Std. Dev., ksi	7.969			---
	COV, %	43.9			---
US-280; Crushed Stone; Section 4	1	**5.5**	**5.0**	**5.4**	---
	2	**5.7**	**5.4**	**5.7**	---
	3	**7.3**	**7.2**	**7.5**	---
	4	**7.5**	**6.6**	**7.7**	---
	5	**6.2**	**6.8**	**5.7**	---
	Mean, ksi	**6.352**			---
	Std. Dev., ksi	**0.9196**			---
	COV, %	**14.5**			---

Note: The shaded cells designate those areas with anomalies (refer to table 31); black cells denote weaker areas.


(a) Loadman LWD used on selected projects.


(b) Loading plate for the LWD.


(c) Prima 100 LWD.

Figure 40. LWDs Used for Testing the Unbound Materials and Soils

A seating drop was used to begin the test for each device, and both load and deflection were recorded. The seating drop was followed by five successive drops. Elastic modulus values were calculated from the measured load and deflections for each drop, in accordance with the procedures recommended by the individual manufacturers. The average elastic modulus values, excluding the seating drop, are provided in Table 35 for the Carl Bro device. Table 36 lists the average elastic modulus values calculated from the loads and deflections measured with the other LWD devices (Dynatest Prima 100 and Loadman).

Table 35. Summary of the Elastic Modulus Values Calculated from the Deflections Measured with the CarlBro LWD Device, ksi

Project Identification	Area	Section of Project			
		A	B	C	D
I-85 Low Plasticity Clay; Section 1; Before IC Rolling	Mean, ksi	**---**	---	---	---
	COV, %	**---**	---	---	---
I-85 Low Plasticity Clay; Section 2; Before IC Rolling	Mean, ksi	**---**	---	---	---
	COV, %	**---**	---	---	---
I-85 Low Plasticity Clay; Section 1; After IC Rolling	Mean, ksi	9.767	8.989	13.06	8.145
	COV, %	20.5	31.6	6.5	84.0
I-85 Low Plasticity Clay; Section 2; After IC Rolling	Mean, ksi	11.78			
	COV, %	47.1			
SH-21 High Plasticity Clay, Area 2; No IC Rolling	Mean, ksi	---	---	---	---
	COV, %	---	---	---	---
SH-21 High Plasticity Clay, Area 1; With IC Rolling	Mean, ksi	8.7	7.3	12.9	---
	COV, %	27.9	36.3	45.8	---
TH-23 Embankment, Silt-Sand-Gravel Mix; South Section	Mean, ksi	6.082	5.264	**5.552**	---
	COV, %	14.0	27.6	**14.9**	---
TH-23 Embankment, Silt-Sand-Gravel Mix; North Section	Mean, ksi	**4.685**	4.618	4.800	---
	COV, %	**13.9**	23.6	27.9	---
SH-130 Granular, Improved Embankment, Section 1	Mean, ksi	27.8	23.6	21.7	---
	COV, %	51.2	60.3	22.4	---
SH-130 Granular, Improved Embankment, Section 2	Mean, ksi	23.6	29.7	21.3	
	COV, %	42.7	26.2	28.2	
SH-130 Granular, Improved Embankment, Section 3	Mean, ksi	21.4	30.2	20.7	
	COV, %	65.4	80.5	19.3	
TH-23; Crushed Aggregate, Middle Section	Mean, ksi	15.45	12.80	**7.95**	---
	COV, %	53.6	42.8	**9.0**	---
TH-23 Crushed Aggregate, South Section	Mean, ksi	**17.66**	21.10	8.67	---
	COV, %	**61.1**	42.0	22.5	---
US-280 Crushed Stone; Section 1	Mean, ksi	51.23			---
	COV, %	56.1			---
US-280 Crushed Stone; Section 2	Mean, ksi	37.82			---
	COV, %	44.0			---
US-280 Crushed Stone; Section 3	Mean, ksi	50.334			---
	COV, %	42.2			---
US-280 Crushed Stone; Section 4	Mean, ksi	**18.53**			---
	COV, %	**16.8**			---

Note: The shaded cells designate those areas with anomalies (refer to table 31); black cells denote weaker areas, while the gray cells denote stronger areas within a specific project.

Table 36. Summary of the Elastic Modulus Values Calculated from the Other LWD Test Results, ksi

Project Identification	Area	Loadman LWD Device			Dynatest Prima 100		
		A	B	C	A	B	C
TH-23 Embankment; South Section	Mean, ksi	3.085	3.029	**1.036**	---	---	---
	COV, %	19.9	64.7	**51.6**	---	---	---
TH-23 Embankment; North Section	Mean, ksi	**5.200**	4.488	3.000	---	---	---
	COV, %	**47.1**	44.2	81.8	---	---	---
TH-23 Crushed Aggregate; Middle Section	Mean, ksi	25.922	44.704	**16.026**	---	---	---
	COV, %	46.0	74.4	**31.5**	---	---	---
TH-23 Crushed Aggregate; South Section	Mean, ksi	**35.22**	36.14	20.90	---	---	---
	COV, %	**77.3**	56.6	18.2	---	---	---
US-280 Crushed Stone; Section 1	Mean, ksi	---	---	---	32.87		
	COV, %	---	---	---	41.0		
US-280 Crushed Stone; Section 2	Mean, ksi	---	---	---	14.20		
	COV, %	---	---	---	37.2		
US-280 Crushed Stone; Section 3	Mean, ksi	---	---	---	26.21		
	COV, %	---	---	---	21.5		
US-280 Crushed Stone; Section 4	Mean, ksi	---	---	---	**9.64**		
	COV, %	---	---	---	**20.3**		

Note: The shaded cells designate those areas with anomalies (refer to table 31); black cells denote weaker areas, while the gray cells denote stronger areas tested with a specific project.

Comparison of Test Results from Deflection Based Devices

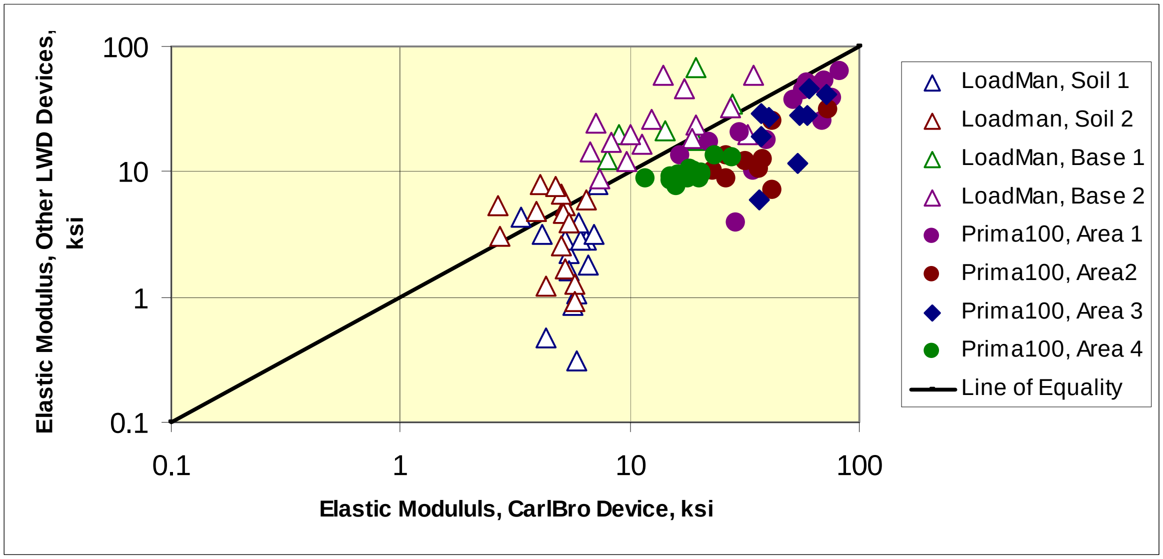
Figure 41 compares the average elastic modulus calculated from the loads and deflections measured with various deflection measuring devices. As shown, the Carl Bro device consistently measured higher elastic modulus values than the Dynatest Prima 100 and FWD. The elastic modulus values from the Loadman are more diverse for the weaker layers and much higher for the stronger layers (Figure 41.a).

Figure 42 presents a cumulative frequency diagram of the standard deviation or repeatability of the deflection based methods. The standard deviations in Figure 42 represent the variability between the five successive drops at the same test point. The repeatability of the LWD devices (excluding the Loadman device) is considered good, with a mean standard deviation less than 0.5 ksi.

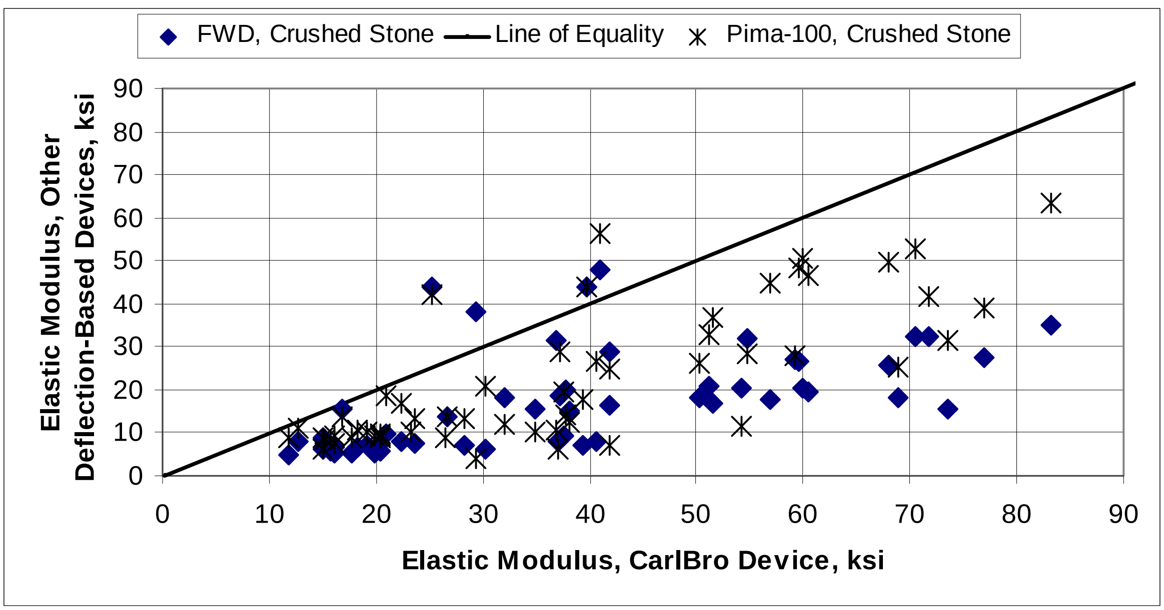
Figure 43 compares the standard deviation of the measurements made within an area to the mean elastic modulus calculated for that area. As shown, the standard deviation continues to increase with increasing elastic modulus. Similar to the DCP, the LWD measured consistently higher elastic modulus values for coarse-grained materials than for fine-grained materials, as expected.

Figure 44 includes a comparison of the coefficient of variation in elastic modulus values determined with each of the deflection measuring devices to normalize differences caused by changes in material strength. The Carl Bro and Dynatest Prima 100 devices measured similar variability, while the Loadman device and FWD consistently measured higher variability.

Thus, test results from the Carl Bro and Dynatest devices were used in comparison to the other NDT technologies.



(a) Other LWD devices, as compared to the CarlBro LWD device.



(b) FWD and Prima 100 devices, as compared to the CarlBro LWD device.

Figure 41. Comparison of the Average Elastic Modulus Calculated from Deflections and Loads Measured with Different LWD Devices

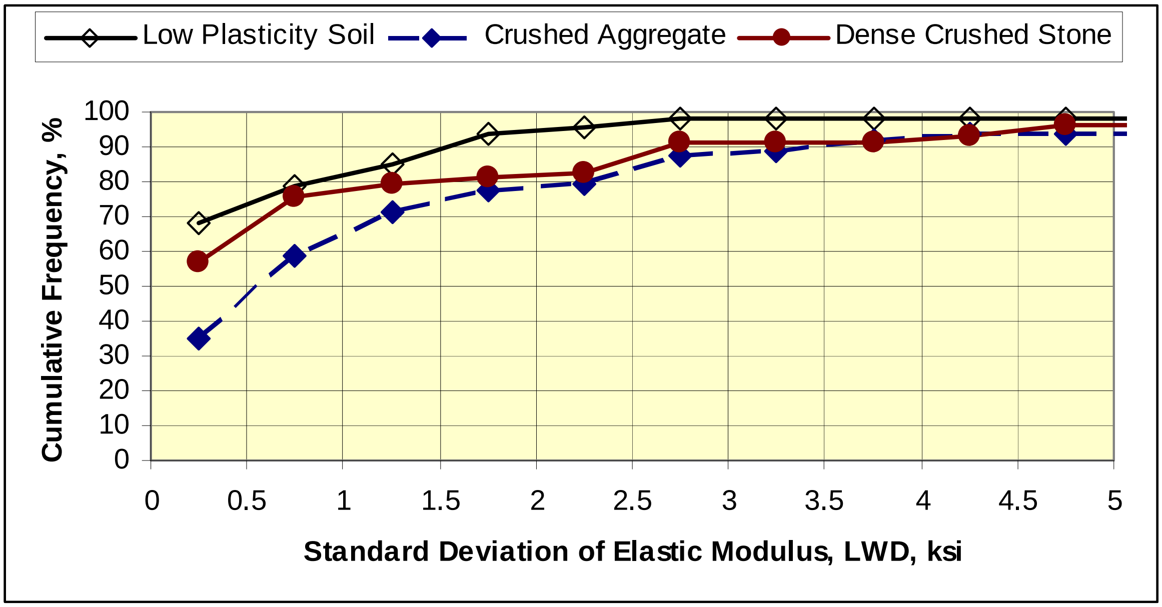


Figure 42. Cumulative Frequency of the Standard Deviation from the Deflection-Based Test Methods

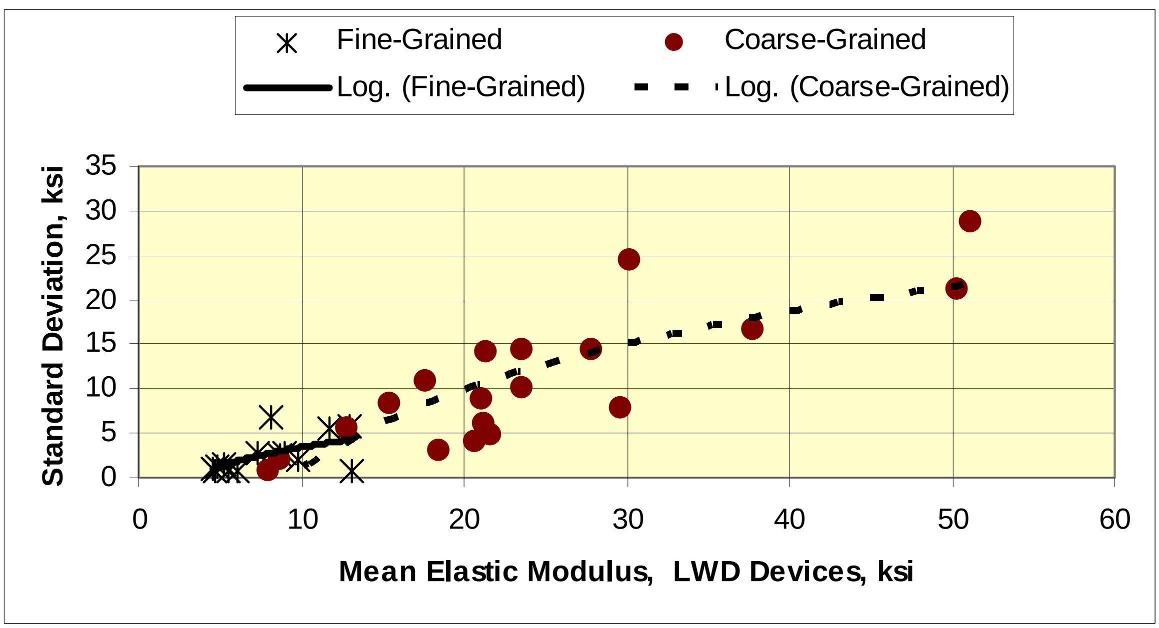


Figure 43. Relationship Between the Standard Deviation and Mean of the Elastic Modulus Values of Unbound Layers Calculated from Deflections

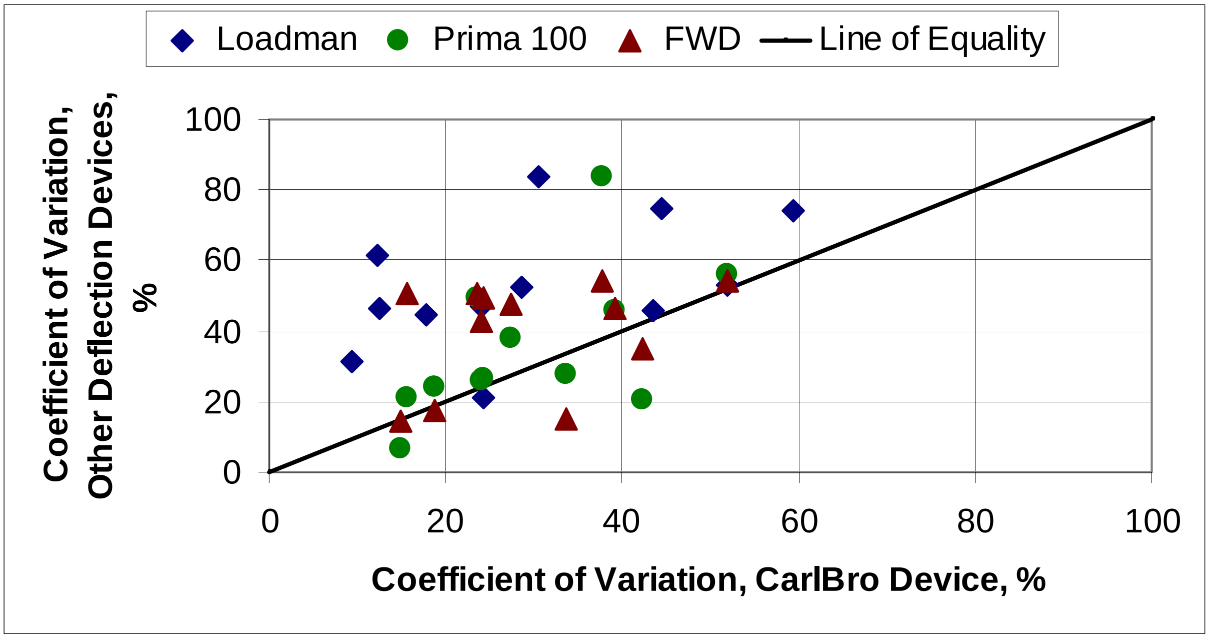


Figure 44. Comparison of the Coefficient of Variations for Calculated Elastic Modulus from Different Deflection Measuring Devices

The cells in Tables 34, 35, and 36 that correspond to those conditions listed in Table 31 have been shaded. The following list summarizes the results of the deflection-based methods in accordance with those conditions listed in Table 31:

- I-85 Low Plasticity Soil Embankment – The deflection-based methods were not used to test the embankment prior to IC rolling. No significant difference in stiffness was found between the areas tested after IC rolling, as planned.
- SH-21 High Plasticity Clay – The deflection-based methods found lane C of area 1 to be stronger than lanes A and B, which is inconsistent with construction records.
- TH-23 Gravelly, Silty Clay Embankment – The deflection-based tests found no significant difference in stiffness between the areas tested in the south section, and found the north section to be weaker than the south section, with the exception of the Loadman device. This finding is inconsistent with QA records and other tests. It is expected that the calculated modulus values are being influenced by the underlying foundation. The Loadman device resulted in low modulus values for the TH-23 embankment that are extremely variable. This result (low modulus values) is questionable based on visual observations of construction traffic using this area. Heavy construction equipment did not cause any visible deformation of the surface.
- SH-130 Improved Granular Soil – The deflection-based methods found no consistent difference between the three areas tested, which was planned.
- TH-23 Crushed Aggregate Base – The deflection-based methods found lane C to be the weakest of all areas tested, similar to the results from the DCP. The paving schedule prevented the north section from being tested with the deflection-based

devices. The deflection-based methods also found the south section to be stronger than the middle section.

- US-280 Crushed Stone Base – The deflection-based methods found area 4 to be the weakest of the four areas tested, similar to the DCP results. However, the modulus values calculated from deflections for area 4 are inconsistent with a good quality crushed stone. It is expected that the calculated modulus values in this area are being influenced (lowered) by the underlying layers.

5.3.3 Ultrasonic Test—DSPA

The DSPA was used to measure the seismic modulus of the unbound materials in accordance with the procedure developed by Nazarian et al. (2002). Triplicate tests were performed at each test point. One test or measurement was taken with the device parallel to the direction of compaction, the second measurement with the device 90 degrees to the first measurement (perpendicular to the direction of compaction), and the final measurement taken 180 degrees to the first measurement. Figure 16 in chapter 3 shows the DSPA in operation, while Tables 37 and 38 provide the average seismic modulus values measured along the Parts A and B projects, respectively. The test results from the DSPA will be discussed with the GeoGauge results in subsection 5.3.5.

5.3.4 Steady-State Vibratory Test—GeoGauge

The GeoGauge was used to measure the resilient modulus of the unbound materials in accordance with the procedure recommended by the manufacturer—with one exception (see Figure 17 in chapter 3). The test was performed with and without a sand cushion below the plate on selected projects (SH-12, TH-23, and US-280), because one of the agencies that hosted a project had been using the gauge without a sand cushion. Triplicate tests were performed at each test point. The gauge was placed and seated on the surface by applying a slight pressure and rotation to ensure uniform contact—making sure that the surface and gauge were coupled. The gauge was then lifted and this sequence repeated.

The sand cushion did make a difference in the measured values for some materials. The resilient modulus values were found to be greater when using the sand cushion on rough surfaces, similar to a crushed aggregate or granular base. A ratio of approximately 2.2 was determined between the two conditions. This ratio or difference (modulus measured with and without a sand cushion) decreased on fine-grained surfaces. In fact, no systematic difference (ratio equal to 1.0) was detected on the SH-21 project with high plasticity clay soil without surface shrinkage cracks. For consistency, however, the sand cushion was used in all testing.

Table 39 summarizes the average resilient modulus values measured with the GeoGauge within each section for the Part A field evaluation projects, while Table 40 lists the average values measured on the Part B projects. The results from these projects are discussed in the next subsection, along with the DSPA test results.

Table 37. Summary of the Seismic Modulus Measured with the DSPA within Specific Sections of the Projects Included in Part A, ksi

Project Identification	Area	A	B	C	D
I-85 Low Plasticity Clay; Section 1, Before IC Rolling	Mean, ksi	**26.2**	31.8	27.9	34.2
	COV, %	**28.4**	7.7	14.1	20.9
I-85 Low Plasticity Clay; Section 2, Before IC Rolling	Mean, ksi	**24.1**	27.2	38.3	44.4
	COV, %	**22.9**	23.9	9.6	21.7
I-85 Low Plasticity Clay; Section 1, After IC Rolling	Mean, ksi	42.5	38.7	37.0	39.5
	COV, %	5.9	22.4	20.0	21.8
I-85 Low Plasticity Clay; Section 2, After IC Rolling	Mean, ksi	33.2	39.7	45.1	43.7
	COV, %	12.8	27.6	10.7	25.8
SH-21 High Plasticity Clay; Area 2, No IC Rolling	Mean, ksi	---	---	---	23.6
	COV, %	---	---	---	7.6
SH-21 High Plasticity Clay; Area 1, With IC Rolling	Mean, ksi	25.8	25.0	30.4	---
	COV, %	18.1	11.3	11.5	---
TH-23 Embankment, Silt-Sand-Gravel Mix; South Section	Mean, ksi	42.00	45.13	**31.12**	---
	COV, %	14.5	20.8	**43.9**	---
TH-23 Embankment, Silt-Sand-Gravel Mix; North Section	Mean, ksi	**51.66**	40.20	31.13	---
	COV, %	**23.2**	23.4	29.7	---
SH-130 Granular, Improved Embankment; Section 1	Mean, ksi	38.4	39.0	34.4	---
	COV, %	9.0	23.0	22.1	---
SH-130 Granular, Improved Embankment; Section 2	Mean, ksi	33.5	38.5	35.3	---
	COV, %	33.1	27.5	18.8	---
SH-130 Granular, Improved Embankment; Section 3	Mean, ksi	29.9	26.7	30.1	---
	COV, %	15.8	21.1	6.6	---
TH-23 Crushed Aggregate; North Section	Mean, ksi	71.87	119.9	61.4	---
	COV, %	41.2	40.4	43.0	---
TH-23 Crushed Aggregate; Middle Section	Mean, ksi	89.47	69.67	**28.0**	---
	COV, %	79.7	48.6	**37.2**	---
TH-23 Crushed Aggregate; South Section	Mean, ksi	**112.8**	108.6	62.8	---
	COV, %	**71.4**	41.1	53.2	---
US-280 Crushed Stone, Section 1	Mean, ksi	233.5			---
	COV, %	13.8			---
US-280 Crushed Stone; Section 2	Mean, ksi	189.0			---
	COV, %	22.0			---
US-280 Crushed Stone; Section 3	Mean, ksi	173.2			---
	COV, %	16.2			---
US-280 Crushed Stone; Section 4	Mean, ksi	**117.4**			---
	COV, %	**12.8**			---

Note: The shaded cells designate those areas with anomalies (refer to table 31); black cells denote weaker areas, while the gray cells denote stronger areas tested within a specific project.

Table 38. Summary of Resilient Modulus Values Estimated from the DSPA within Projects Included in Part B, ksi

Project Identification	Section	Mean Modulus, ksi	Coefficient of Variation, %	Standard Error, ksi
US-2, ND	Crushed Gravel; No Prime Coat	52.0	35.3	18.35
	Crushed Gravel; with Prime	81.9	22.9	18.79
	Embankment, Soil-Aggr.	33.1	21.4	7.08
US-53, OH	Crushed Aggregate	61.3	26.9	16.49
CR-103, TX	Caliche Base	---	---	---
NCAT, Florida	Limerock Base, Sect. N8	80.3	21.2	16.96
	Limerock Base, Sect. N9	96.5	24.1	23.22
NCAT, Missouri	Crushed Limestone, Sect. N10	97.1	22.9	22.20
NCAT, SC	Crushed Granite, Sect. S11	91.5	22.6	20.7
NCAT, Oklahoma	High Plasticity Clay, Sect. N8	43.0	14.1	6.05
	High Plasticity Clay, Sect. N9	40.2	17.6	7.08

5.3.5 Comparison of Test Results from the DSPA and GeoGauge

Figure 45 compares the seismic and resilient modulus values measured with this technology. As shown, the seismic modulus values measured with the DSPA are greater than the resilient modulus values measured with the GeoGauge. The difference between the two values increases with stiffer and coarser materials. There is correspondence between the two seismic devices, but that difference is material dependent.

Figure 46 presents a cumulative frequency diagram of the standard deviation or repeatability of the DSPA and GeoGauge. The standard deviations in Figure 46 represent the triplicate measurements taken at the same test point. The variability of measurements made with the DSPA (Figure 46.a) is higher than for the GeoGauge (Figure 46.b), especially for the stiffer and coarse-grained materials. The repeatability of the GeoGauge devices is considered good but is material dependent. The mean standard deviation of the GeoGauge varies from about 0.5 ksi for the weaker soils to 3.5 ksi for dense base materials. The DSPA has a mean standard deviation varying from about 1.5 ksi to over 21 ksi.

A reason for the higher variability of the DSPA was the rotation of the sensor bar relative to the roller direction. The GeoGauge was not rotated between repeat readings because of the circular loading plate. Another reason for the higher variability is that the DSPA measures the stiffness of the layer evaluated, while the GeoGauge and other NDT devices (excluding the DCP) can be influenced by the supporting layers. More importantly, the moisture gradient is much greater nearer the surface which has a greater influence on those devices that measure material responses closer to the surface—the DSPA. Thus, the mean seismic modulus values and variance of those values should be higher. The measurement and effect of this resilient modulus gradient is discussed in more detail in chapter 7 and at the end of this chapter.

Table 39. Summary of the Resilient Modulus Values Measured with the GeoGauge within Specific Sections of the Part A Projects, ksi

Project Identification	Area	A	B	C	D
I-85 Low Plasticity Clay; Section 1, Before IC Rolling	Mean, ksi	**14.5**	16.3	14.9	15.7
	COV, %	**20.7**	7.4	19.2	12.2
I-85 Low Plasticity Clay; Section 2, Before IC Rolling	Mean, ksi	**10.6**	15.9	17.1	18.1
	COV, %	**26.9**	15.7	7.7	20.8
I-85 Low Plasticity Clay; Section 1, After IC Rolling	Mean, ksi	17.43	16.35	16.633	17.85
	COV, %	11.7	---	27.5	---
I-85 Low Plasticity Clay; Section 2, After IC Rolling	Mean, ksi	18.42	18.50	19.64	19.4
	COV, %	7.6	---	0.4	---
SH-21 High Plasticity Clay; Area 2, No IC Rolling	Mean, ksi	---	---	---	19.6
	COV, %	---	---	---	6.3
SH-21 High Plasticity Clay; Area 1, After IC Rolling	Mean, ksi	24.0	24.7	20.1	---
	COV, %	15.5	24.8	11.5	---
TH-23 Embankment, Silt-Sand-Gravel Mix; South Section	Mean, ksi	10.07	10.86	**7.537**	---
	COV, %	10.2	11.0	**9.4**	---
TH-23 Embankment, Silt-Sand-Gravel Mix; North Section	Mean, ksi	**12.568**	10.00	10.31	---
	COV, %	**15.6**	4.5	22.0	---
SH-130 Granular, Improved Embankment; Section 1	Mean, ksi	28.74	26.82	27.72	---
	COV, %	14.2	15.3	9.0	---
SH-130 Granular, Improved Embankment; Section 2	Mean, ksi	22.92	26.71	25.21	---
	COV, %	17.5	14.4	21.2	---
SH-130 Granular, Improved Embankment; Section 3	Mean, ksi	24.62	22.97	19.21	---
	COV, %	7.7	1.5	17.2	---
TH-23 Crushed Aggregate; North Section	Mean, ksi	13.64	15.16	12.374	---
	COV, %	11.1	10.2	9.1	---
TH-23 Crushed Aggregate; Middle Section	Mean, ksi	12.97	12.55	**9.838**	---
	COV, %	25.0	15.8	**17.6**	---
TH-23 Crushed Aggregate; South Section	Mean, ksi	**15.64**	14.37	11.718	---
	COV, %	**24.3**	14.5	16.2	---
US-280 Crushed Stone; Section 1	Mean, ksi	48.84			---
	COV, %	7.9			---
US-280 Crushed Stone; Section 2	Mean, ksi	49.98			---
	COV, %	5.0			---
US-280 Crushed Stone; Section 3	Mean, ksi	44.96			---
	COV, %	9.9			---
US-280 Crushed Stone; Section 4	Mean, ksi	**35.12**			---
	COV, %	**4.6**			---

Note: The shaded cells designate those areas with anomalies (refer to table 31); black cells denote weaker areas, while the gray cells denote stronger areas tested within a specific project.

Table 40. Summary of Resilient Modulus Values Estimated with the GeoGauge Within Projects Included in Part B, ksi

Project Identification	Section	Mean Modulus, ksi	Coefficient of Variation, %	Standard Error, ksi
US-2, ND	Crushed Gravel, No Prime Coat	17.2	8.61	1.93
	Crushed Gravel, without Prime	26.7	16.9	3.54
	Embankment, Soil-Aggr.	13.1	20.1	2.75
US-53, OH	Crushed Aggregate	23.5	7.01	3.29
CR-103, TX	Caliche Base	26.6	11.9	2.81
NCAT, Florida	Limerock Base, Sect. N1	49.7	11.6	5.95
	Limerock Base, Sect. N2	49.8	13.1	12.86
NCAT, Missouri	Crushed Limestone, Sect. N10	25.7	8.1	5.28
NCAT, SC	Crushed Granite, Sect. S11	15.1	8.31	2.09
NCAT, Oklahoma	High Plasticity Clay, Sect. N8	25.0	8.32	4.36
	High Plasticity Clay, Sect. N9	26.8	7.22	3.62

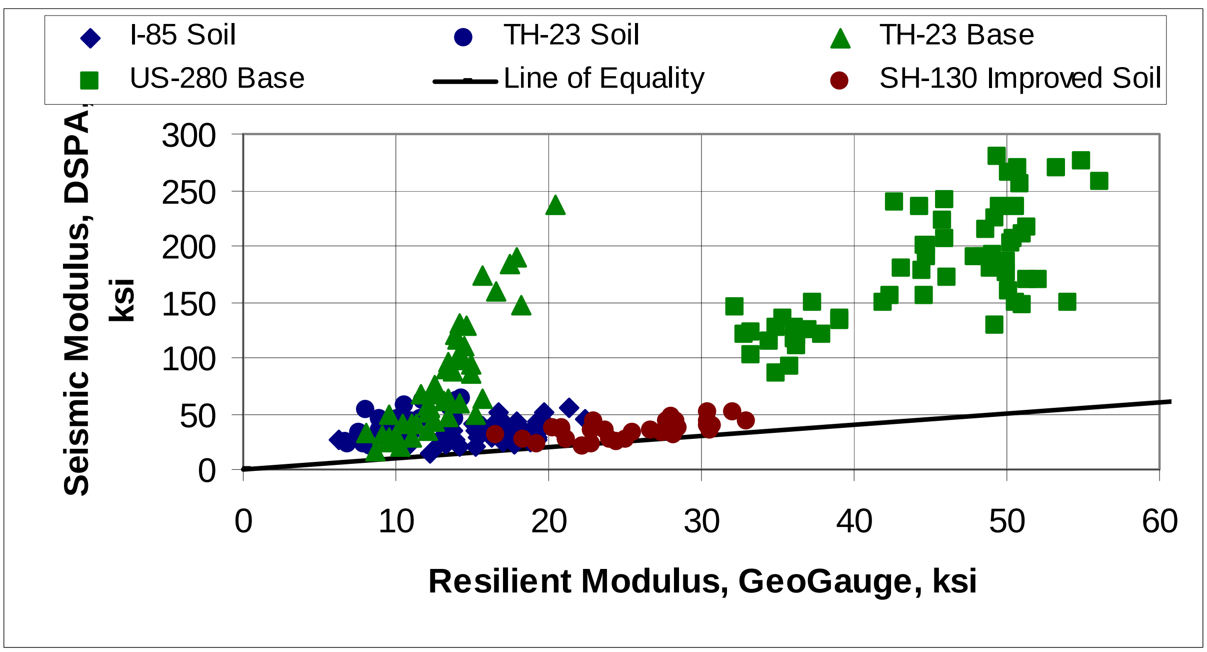
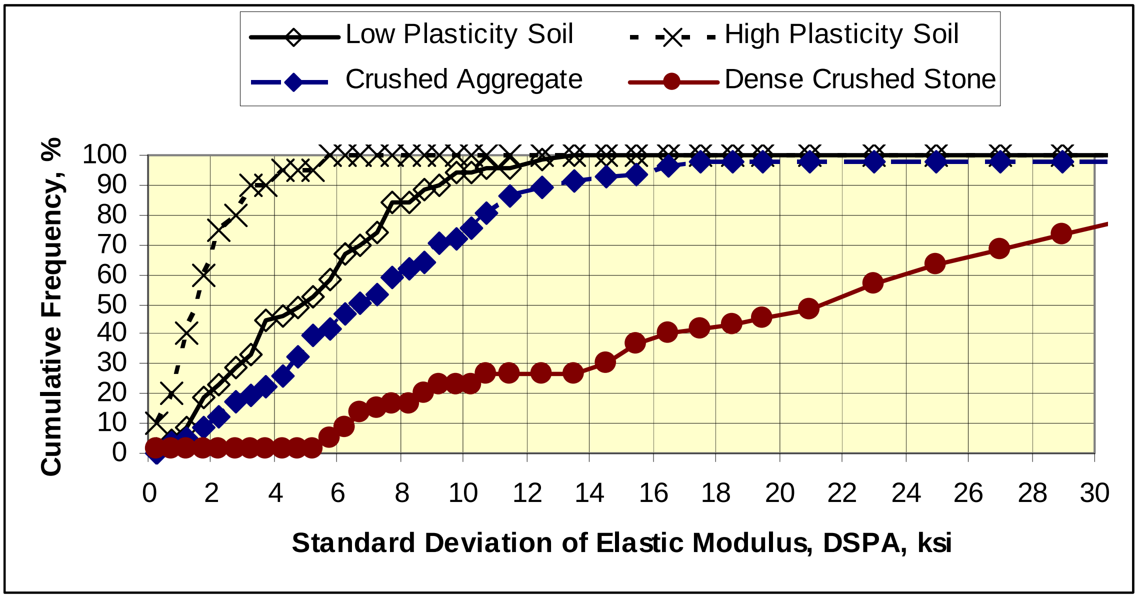
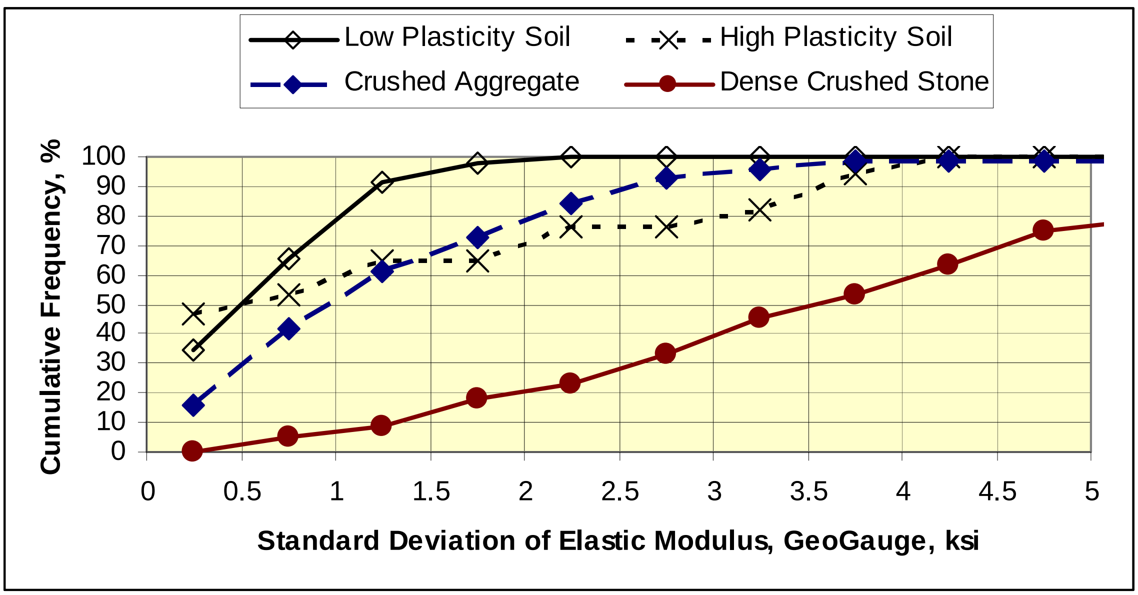


Figure 45. Comparison of the Seismic Modulus Values Measured with the DSPA and Resilient Modulus Values Measured with the GeoGauge



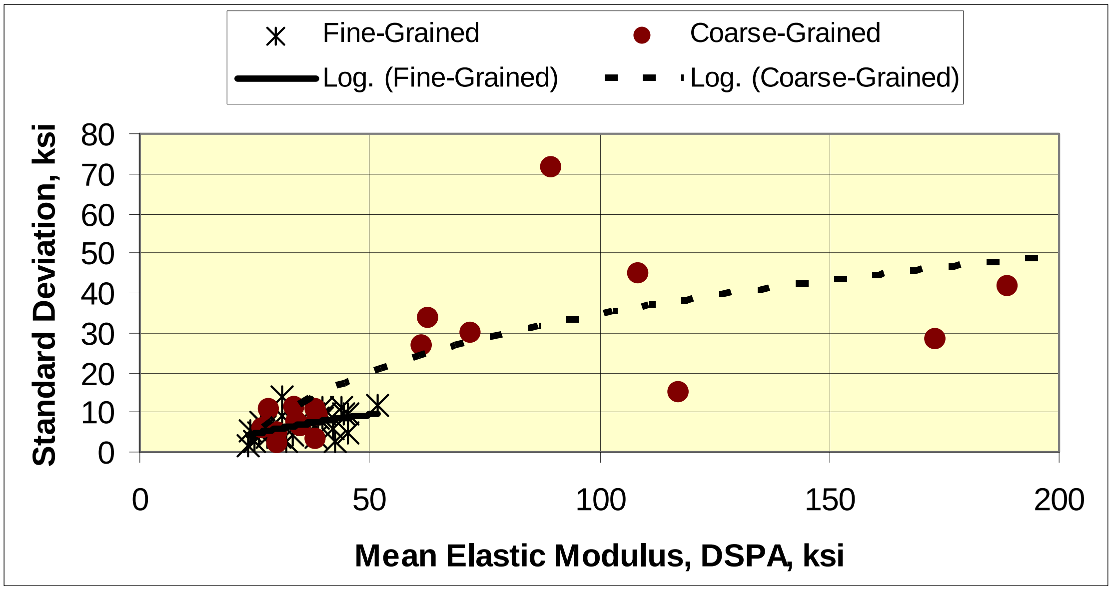
(a) Standard deviation or repeatability for the DSPA.



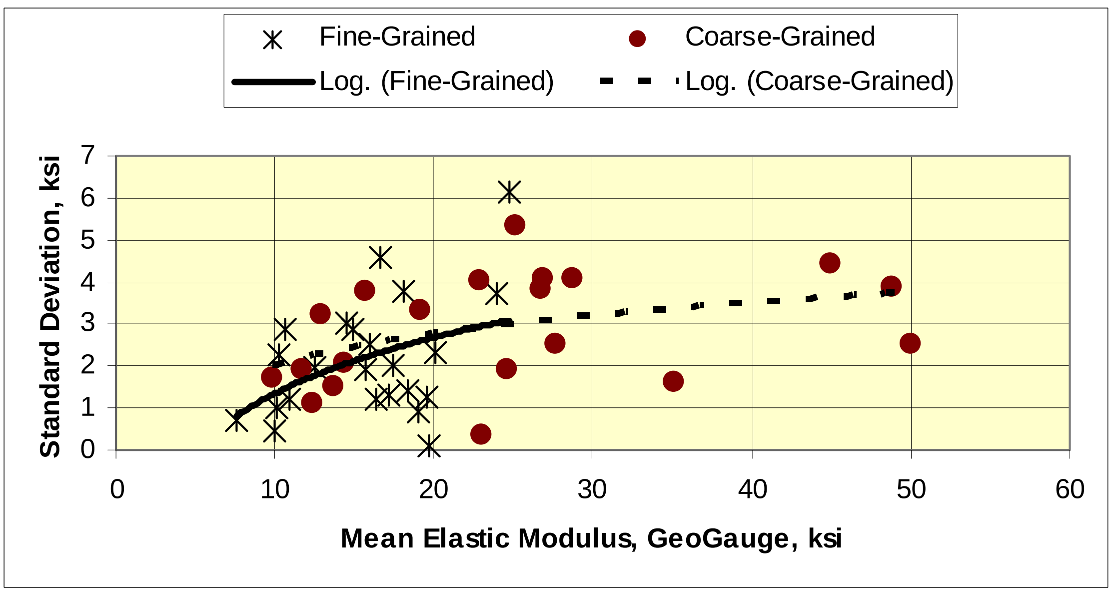
(b) Standard deviation or repeatability for the GeoGauge.

Figure 46. Cumulative Frequency of the Standard Deviation from the DSPA and GeoGauge

Figure 47 compares the standard deviation to the mean of the elastic modulus values determined from the DSPA and GeoGauge for different unbound materials. The standard deviation of the DSPA (Figure 47.a) and GeoGauge (Figure 47.b) slightly increases with increasing elastic modulus values. Figure 47.a does not show all of the DSPA data—it only shows the mean elastic modulus values less than 200 ksi for visual comparison to the other NDT devices.



(a) Standard deviations from the DSPA for all projects; mean elastic modulus values greater than 200 ksi are not shown in the graph.



(b) Standard deviations from the GeoGauge for all projects.

Figure 47. Standard Deviations of the Elastic Modulus Values Resulting from the DSPA and GeoGauge for Testing Unbound Layers

Contrary to the findings from the DCP and deflection-based methods, both the DSPA and GeoGauge found that the elastic modulus values of fine and coarse-grained materials were within the same range for many of the test sections. This difference between the different technologies will be discussed in greater detail in chapter 7 of Part III of the research report.

Figure 48 compares the coefficient of variations determined in different areas of a project with each device. In general, the GeoGauge was found to have the lower variability in modulus values. The coefficient of variation in the TH-23 crushed aggregate base modulus values from the DSPA tests was found to be high. The reason for the high variation is unknown. However, the moisture gradient could be higher along this project because of rains that occurred prior to NDT.

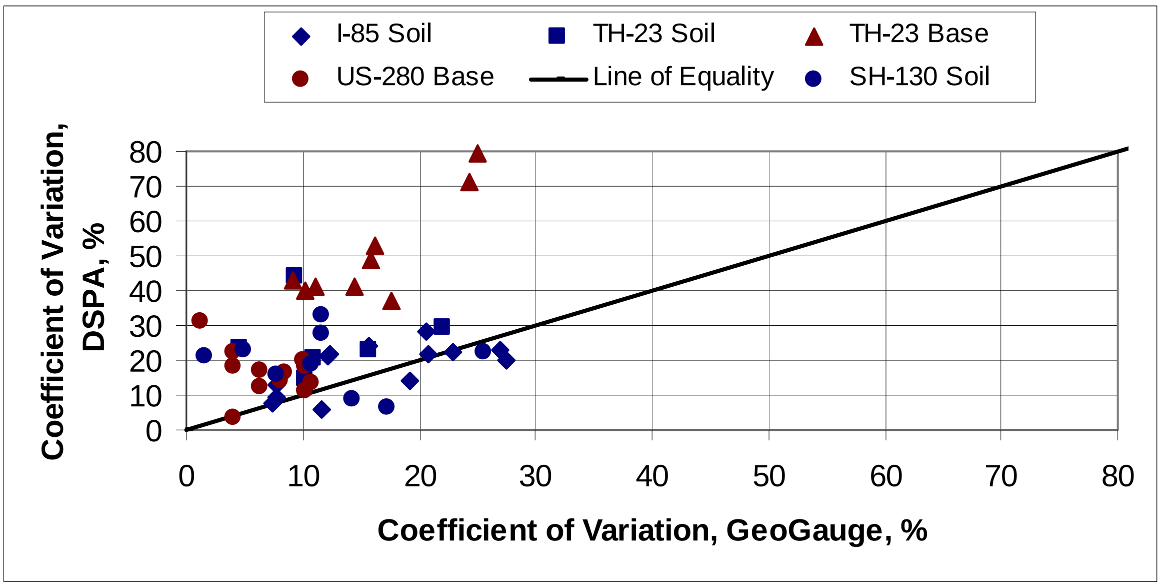


Figure 48. Comparison of the Coefficient of Variations of the Modulus Values Measured with the DSPA and GeoGauge

The cells in Tables 37 and 39 that correspond to those conditions listed in Table 31 have been shaded. The following list summarizes the results of the DSPA and GeoGauge tests in accordance with those conditions listed in Table 31:

- I-85 Low Plasticity Soil Embankment – Both devices found lane A of section 2 to be the weakest, prior to IC rolling. This is the area where thicker lifts had been placed. The results from both devices also indicate an increase in the embankment’s strength after IC rolling, but not a reduction in stiffness variability.
- SH-21 High Plasticity Clay – Both devices found section 2 to be slightly weaker than section 1, which is consistent with construction records. Both devices showed a slight benefit when using the IC roller for testing and compaction.
- TH-23 Gravelly, Silty Clay Embankment – Both devices correctly found lane C of the south section to be the softer (less stiff) of the areas tested, and found lane A of the north section to be stronger.

- SH-130 Improved Granular Embankment – The GeoGauge did not detect any difference between the three areas tested, while the DSPA found section 3 to be consistently weaker, which was not planned.
- TH-23 Crushed Aggregate Base – Both devices found that lane C of the middle section was weaker, and lane A of the south section was the stronger of the areas tested, which is consistent with construction records.
- US-280 Crushed Stone Base – Both devices found area 4 to be weaker of the four areas tested. However, its strength is still high and consistent with adequately compacted crushed stone, similar to the findings with the DCP.

5.3.6 Ground Penetrating Radar Testing—Air Horn Antenna

A GPR, single air-coupled antenna was used to take dielectric measurements of the unbound materials in accordance with ASTM and the procedure outlined by Maser and others (Maser., 2003; see also Figure 9 in chapter 3). Triplicate runs were made for each line of points within a section. Table 42 summarizes the average dielectric values measured at each test point for the other NDT devices for comparison purposes.

One of the key advantages of the GPR is that a continuous profile of the dielectric values can be measured—in contrast to point-based devices. Contours of the dielectric measurements were prepared and used to determine the values at specific points where other tests were performed. Obviously, the increased sampling error between repeat runs will increase the overall variability of the GPR point measurements. Where the measurement lanes were well defined, the coefficient of variation (COV) of the dielectric values was significantly less than for the wider areas. As an example, the COV for the I-85 embankment area was as high as 50 percent, while the COV along the narrow US-280 test lane never exceeded 12 percent (refer to Table 42).

Density contours and profiles were also prepared for each layer. Figures 49 and 50 present examples of contours that were prepared from the dielectric readings. Wet densities were calculated from these dielectric values, assuming a water content for the unbound materials in a specific area. Figure 51 shows an example of the density profile for the TH-23 crushed aggregate base material.

The wet densities were found to be highly variable and generally did not coincide with the actual densities measured from the sand cones and nuclear density gauge readings. As an example, Table 41 lists the average total unit weights (pcf) that were estimated from the GPR data for the crushed aggregate base material placed along the TH-23 project in Minnesota.

Table 41. Density Estimated by GPR on TH-23 Project, pcf.

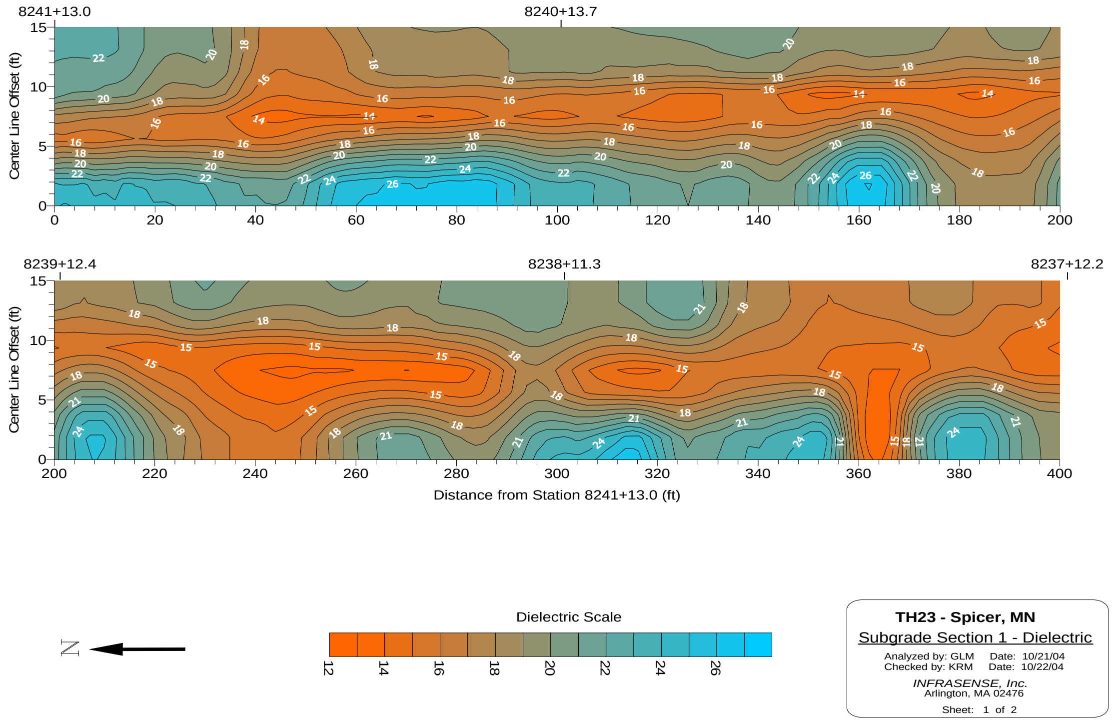
Lane	A	B	C	Comment
North Section	---	129.2	142.4	
Middle Section	---	130.8	150.6	Lane C had the less dense base.
South Section	---	131.0	145.8	Lane A & B had the denser base.

Conversely, all other NDT devices found lanes A and B to be stronger than lane C (refer to Tables 32, 34, 35, 37, and 39). In general, the GPR did not adequately identify those areas with anomalies. As noted above, a reason for this observation is that the water content for a particular area was assumed to be constant to identify changes in density, and vise-versa for water content. Another reason is that the anomaly may have been caused by variations in gradation and other physical properties that would be difficult, at best, to identify with the GPR.

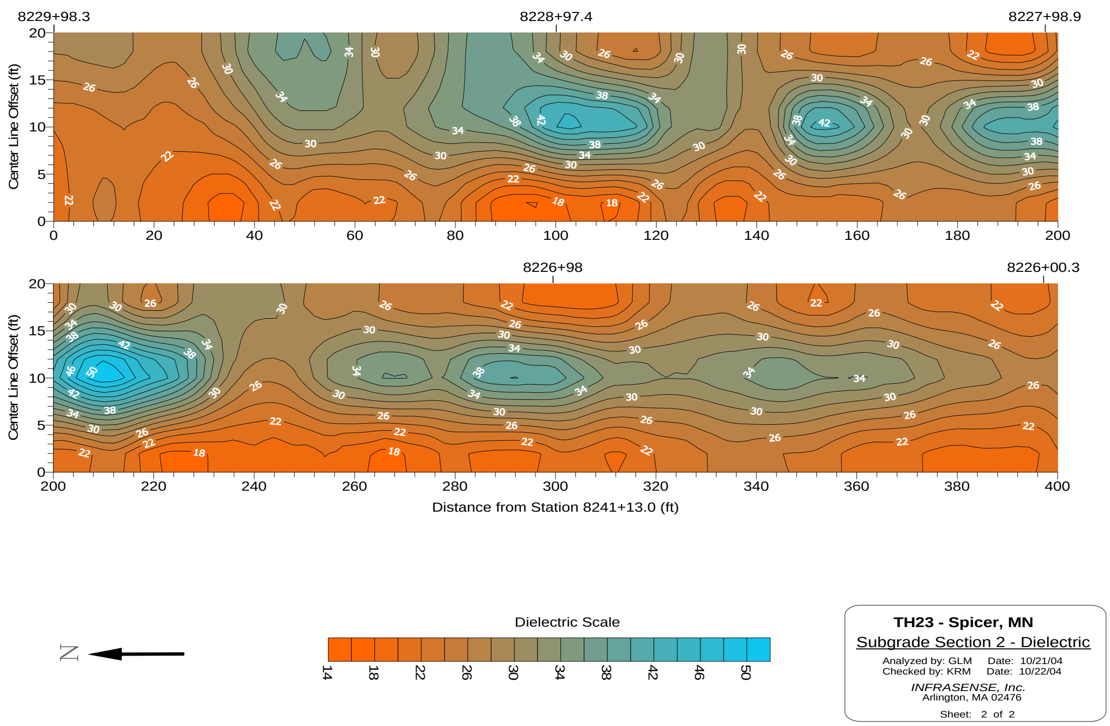
Table 42. Summary of the Dielectric Values Measured with the GPR on the Unbound Layers

Project Identification	Area	A	B	C	D
I-85 Embankment, Silty Clay; Section 1, Before Rolling	Mean	**15.38**	15.79	14.29	15.19
	COV, %	**17.8**	23.3	53.6	25.7
I-85 Embankment, Silty Clay; Section 2, Before IC Rolling	Mean	**13.91**	17.47	16.82	16.38
	COV, %	**29.0**	20.5	30.7	24.1
I-85 Embankment, Silty Clay; Section 1, After IC Rolling	Mean	20.37	21.23	21.61	23.23
	COV, %	15.8	10.6	15.0	12.6
I-85 Embankment, Silty Clay; Section 2; After IC Rolling	Mean	19.13	23.75	23.77	25.36
	COV	10.2	10.7	17.6	8.4
TH-23 Embankment, Silt-Sand-Gravel Mix; South Section	Mean	23.004	13.468	**19.334**	---
	COV, %	11.3	7.0	**14.4**	---
TH-23 Embankment, Silt-Sand-Gravel Mix; North Section	Mean	**20.324**	34.438	23.882	---
	COV, %	**22.2**	32.7	22.7	---
SH-130 Improved Embankment; Section 1	Mean	9.225	10.00	7.65	---
	COV	33.1	42.3	42.9	---
SH-130 Improved Embankment; Section 2	Mean	12.875	8.875	9.825	---
	COV	90.3	47.4	20.1	
SH-130 Improved Embankment; Section 3	Mean	8.775	9.025	11.85	
	COV, %	51.5	50.8	48.7	---
TH-23 Crushed Aggregate; North Section	Mean	---	8.796	10.042	---
	COV, %	---	1.6	5.4	---
TH-23 Crushed Aggregate; Middle Section	Mean	---	8.950	**10.87**	---
	COV, %	---	6.1	**10.9**	---
TH-23 Crushed Aggregate; South Section	Mean	---	9.792	10.378	---
	COV, %	---	8.2	4.3	---
US-280 Crushed Stone; Section 1	Mean	11.723			
	COV, %	8.3			
US-280 Crushed Stone; Section 2	Mean	12.222			
	COV, %	11.4			
US-280 Crushed Stone; Section 3	Mean	11.919			
	COV, %	7.3			
US-280 Crushed Stone; Section 4	Mean	**11.569**			
	COV, %	**7.0**			

Notes:
- The shaded cells designate those areas with anomalies (refer to table 31); the black cells denote the weaker areas, while the gray cells denote the stronger areas tested within a specific project.
- Due to construction sequencing, lane A of the TH-23 crushed aggregate base sections could not be tested with the GPR after it arrived on site.

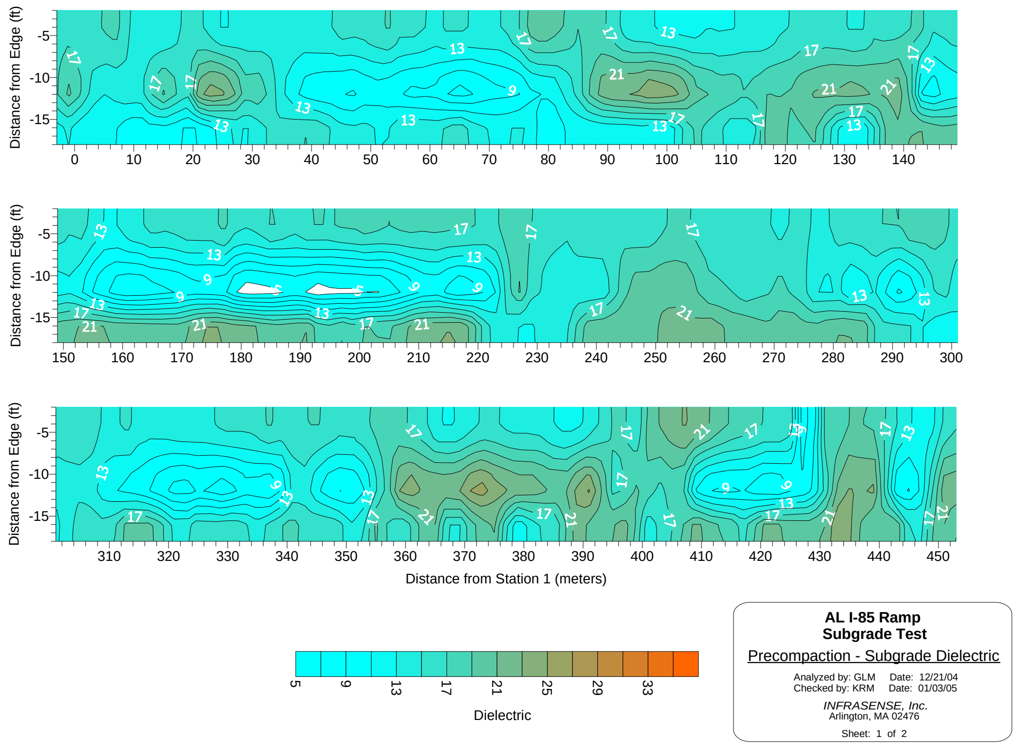


(a) Section 1 of the Embankment.

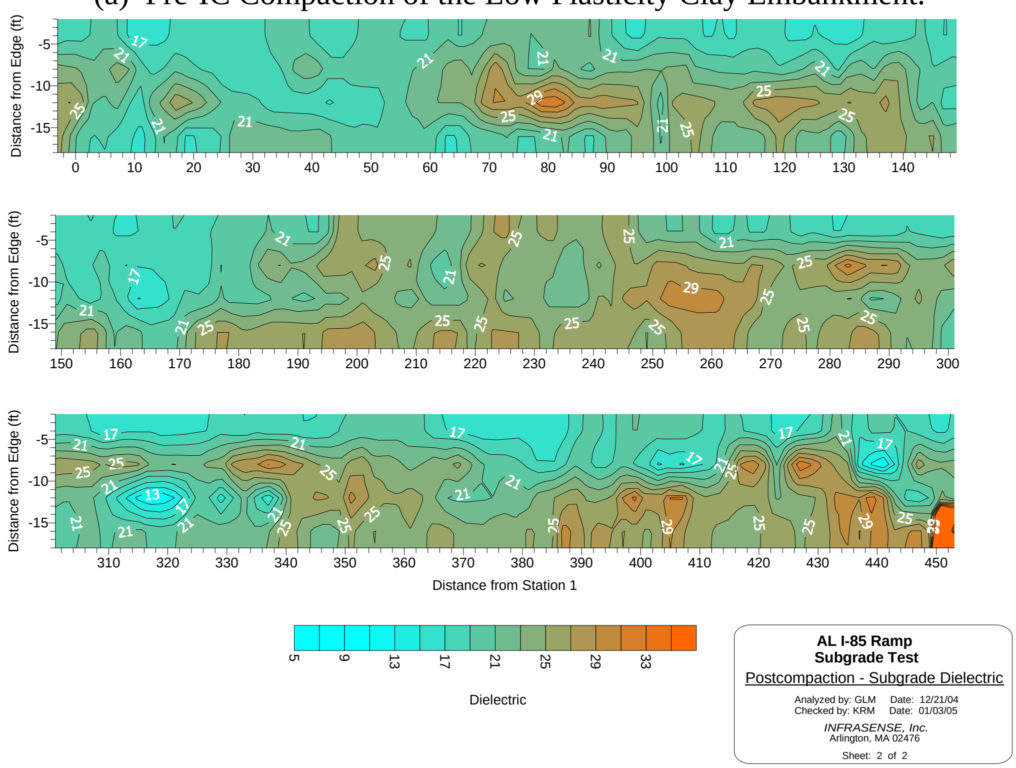


(b) Section 2 of the Embankment.

Figure 49. Dielectric Contours Generated from the GPR Test Results for the Gravelly-Silty Clay Embankment Placed Along the TH-23 Reconstruction Project



(a) Pre-IC Compaction of the Low Plasticity Clay Embankment.



(b) Post-IC Compaction of the Low Plasticity Clay Embankment.

Figure 50. Dielectric Contours Generated from the GPR Test Results for the Low Plasticity Soil Embankment Placed on the I-85 Exit Ramp Reconstruction Project

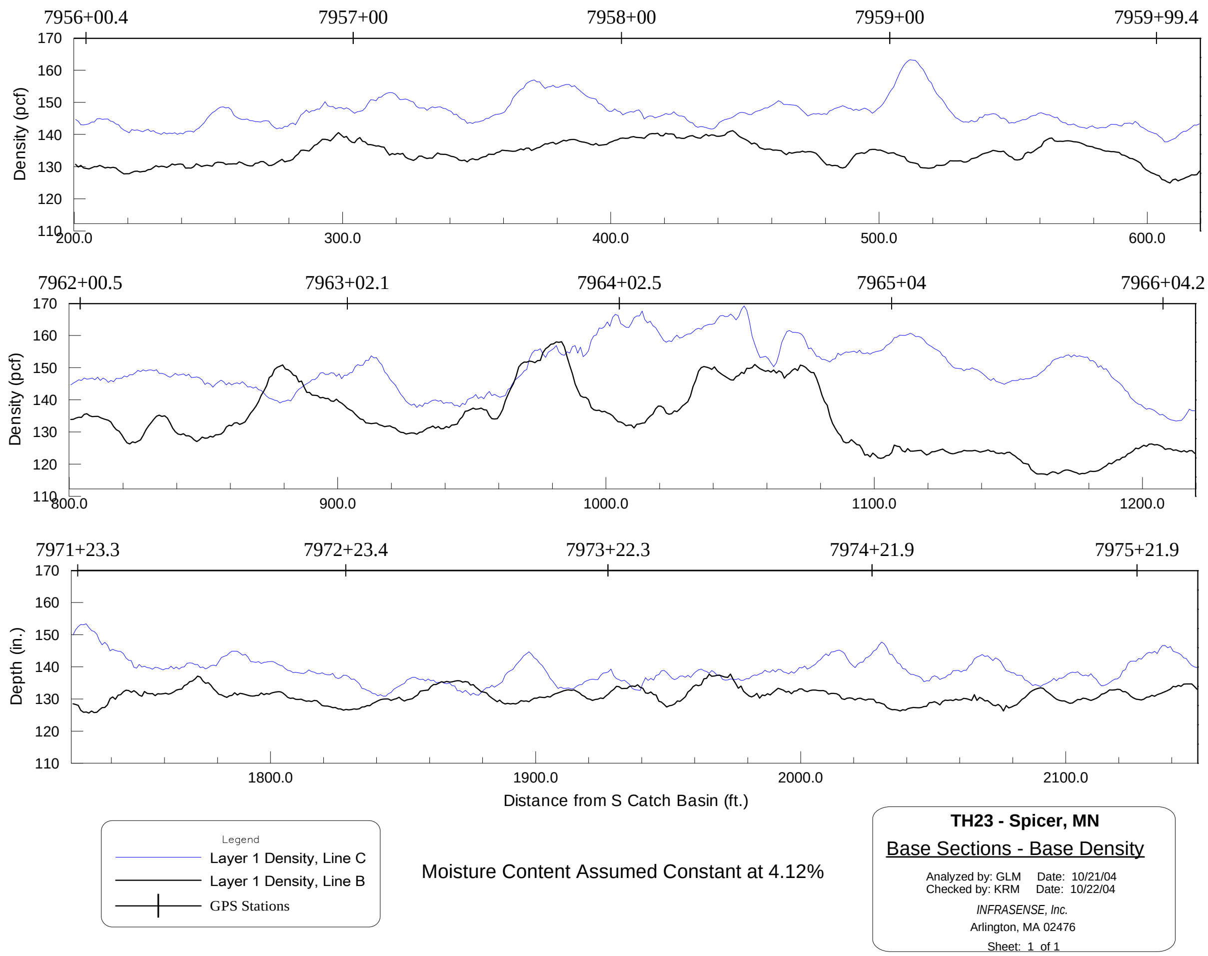


Figure 51. Density Profiles Generated from the GPR Test Results for the Crushed Aggregate Base Layer Placed Along the TH-23 Reconstruction Project

Layer thickness was also determined from the GRP test results, and it concurred with the thickness reported during construction. The thicknesses resulting from the GPR are provided in the appendices. Figure 52 presents an example of the thickness profiles (crushed aggregate base layer for the TH-23 reconstruction project) that were prepared from the dielectric readings. In general, thicknesses estimated with the GPR were within an acceptable error of the thicknesses reported from QC tests and other destructive sampling methods.

5.3.7 Non-Roller-Mounted Density Testing, Non-Nuclear—EDG

The EDG was used to measure the density and water content of the unbound materials placed along each project. Figure 53 shows the EDG and its setup for measuring the density and water content in unbound materials. The test was performed in accordance with the manufacturer's recommendations.

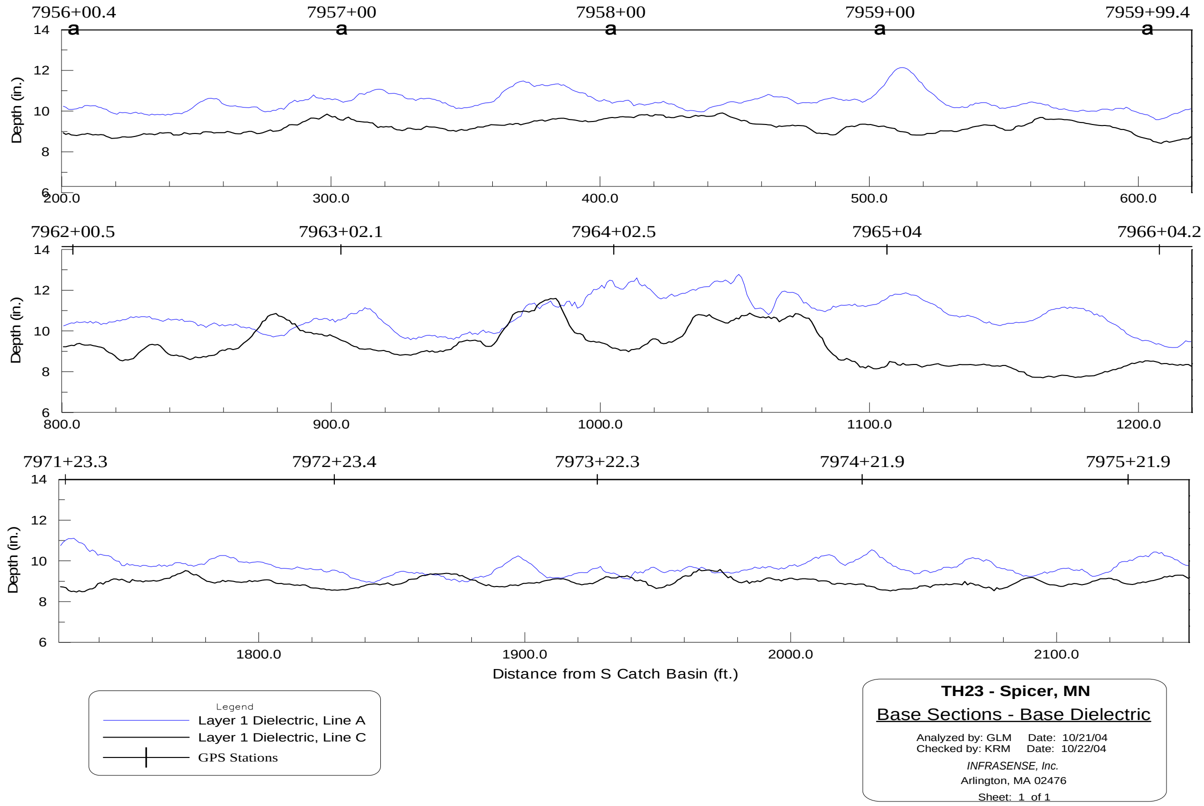


Figure 52. Thickness Profiles Generated from GPR Test Results for the Crushed Aggregate Base Layer Placed Along the TH-23 Reconstruction Project

Triplicate readings were made at each test point without moving the 6-inch probes. The EDG measurements made at each test point were adjusted based on calibration densities obtained from sand cones or nuclear density readings that were suppose to cover the range of values expected for the project. A soil model was developed for each unbound material, and that model was used to determine the actual densities and water contents from the EDG readings. The accuracy of the EDG, as for the GPR, is heavily dependent on the calibration values obtained from other test results. Any error in density or water content from these other tests is included in the EGD values.

Table 43 summarizes the average dry density, while Table 44 provides the average water content measured within each section where the EDG was used. The amount of deviation in the test results was found to be small. The COV of the density readings were generally less than 1 percent, and it was less than 5 percent for water content readings. The water contents listed in Table 44 are generally below the optimum values obtained from construction records and measured in the laboratory. Based on observations at each site, it is expected that the water content of the upper layer materials are less than the optimum values for most of the areas tested, with the exception of the I-85 embankment material.

Table 45 summarizes the maximum dry densities and optimum water contents recovered from construction records in comparison to the average values measured along the project. In some cases, multiple M-D relationships exist for a single layer within the same project.

The values included in Table 45 represent the M-D curve or relationship for the material nearest the location of the specific test section.

Figure 53. EDG Used to Measure the Density and Water Content of the Unbound Layers

The cells in Tables 43 and 44 that correspond to those conditions listed in Table 44 have been shaded. The following list summarizes the results of the EDG tests in accordance with those conditions listed in Table 44:

- I-85 Low Plasticity Soil Embankment –No difference in water content was detected by the EDG between all areas tested. The EDG found both outside lanes to be less dense prior to and after IC rolling, similar to the DCP test results. The variation in dry density and water content was found to be low.
- TH-23 Gravelly, Silty Clay Embankment – Higher water contents and lower dry densities were measured in the south section, but not along lane C. Lane C had the greater variability in water content. The variability of the dry density was found to be low.
- SH-130 Improved Granular Embankment – The EDG found no significant difference in density and water content between all areas tested, which was planned.
- TH-23 Crushed Aggregate Base – The EDG found no significant difference in density and water content between all areas tested, which is inconsistent with construction records.

- US-280 Crushed Stone Base – The EDG found no significant difference in density and water content between all areas tested, also inconsistent with construction records.

Table 43. Summary of the Dry Densities Measured with the EDG, pcf

Project Identification	Area	A	B	C	D
I-85 Embankment, Silty Clay; Section 1, Before IC Rolling	Mean, pcf	**107.92**	108.9	108.6	107.7
	COV, %	**1.3**	0.5	1.1	1.7
I-85 Embankment, Silty Clay; Section 2; Before IC Rolling	Mean, pcf	**107.2**	107.5	108.9	107.2
	COV, %	**0.8**	0.8	1.1	1.9
I-85 Embankment, Silty Clay; Section 1, After IC Rolling	Mean, pcf	108.1	108.2	108.5	108.4
	COV, %	1.0	0.5	0.7	0.3
I-85 Embankment, Silty Clay; Section 2, After IC Rolling	Mean, pcf	107.4	107.7	108.0	107.6
	COV, %	0.5	0.5	0.8	1.3
TH-23 Embankment, Silt-Sand-Gravel Mix; North Section	Mean, pcf	**123.9**	123.7	124.4	---
	COV, %	**0.4**	0.1	1.0	---
TH-23 Embankment, Silt-Sand-Gravel Mix; South Section	Mean, pcf	122.5	122.9	**122.9**	---
	COV, %	1.8	1.8	**0.8**	---
SH-130 Improved Embankment; Section 1	Mean, pcf	123.7	123.7	124.9	---
	COV, %	0.3	0.1	0.6	---
SH-130 Improved Embankment; Section 2	Mean, pcf	122.6	123.1	122.7	---
	COV, %	2.0	2.0	0.8	---
SH-130 Improved Embankment; Section 3	Mean, pcf	123.3	122.3	123.7	
	COV, %	1.4	0.1	0.2	
TH-23 Crushed Aggregate; North Section	Mean, pcf	129.9	129.8	129.8	---
	COV, %	0	0	0	---
TH-23 Crushed Aggregate; Middle Section	Mean, pcf	129.8	129.8	**129.8**	---
	COV, %	0	0	**0**	---
TH-23 Crushed Aggregate; South Section	Mean, pcf	**129.8**	129.9	129.8	---
	COV, %	**0.1**	0.1	0	---
US-280 Crushed Stone; Section 1	Mean, pcf	147.4			
	COV, %	0.7			
US-280 Crushed Stone; Section 2	Mean, pcf	148.8			
	COV, %	0.3			
US-280 Crushed Stone; Section 3	Mean, pcf	145.9			
	COV, %	0.5			
US-280 Crushed Stone; Section 4	Mean, pcf	**148.2**			
	COV, %	**0.3**			

Note: The shaded cells designate those areas with anomalies (refer to table 31); the black cells denote the weaker areas, while the gray cells denote the stronger areas tested within a specific project.

Table 44. Summary of the Water Contents Measured with the EDG, percent

Project Identification	Area	A	B	C	D
I-85 Embankment, Silty Clay; Section 1, Before IC Rolling	Mean, %	**16.9**	16.8	16.9	16.9
	COV, %	**0.8**	0.3	0.3	1.0
I-85 Embankment, Silty Clay; Section 2; Before IC Rolling	Mean, %	**16.9**	16.9	16.8	17.0
	COV, %	**0.7**	0.3	0.3	1.5
I-85 Embankment, Silty Clay; Section 1, After IC Rolling	Mean, %	16.9	16.9	16.9	16.9
	COV, %	0.5	0.3	0.4	0
I-85 Embankment, Silty Clay; Section 2, After IC Rolling	Mean, %	17.0	16.9	16.9	16.9
	COV, %	0.5	0.3	0	0.7
TH-23 Embankment, Silt-Sand-Gravel Mix; North Section	Mean, %	**8.0**	8.0	7.6	
	COV, %	**5.1**	1.1	11.9	
TH-23 Embankment, Silt-Sand-Gravel Mix; South Section	Mean, %	9.8	8.7	**7.6**	
	COV, %	7.5	7.3	**15.8**	
SH-130 Improved Embankment; Section 1	Mean, %	8.1	8.05	7.23	
	COV, %	4.4	1.2	6.8	
SH-130 Improved Embankment; Section 2	Mean, %	8.85	8.43	8.7	
	COV, %	19.8	21.6	8.4	
SH-130 Improved Embankment; Section 3	Mean, %	8.35	9.1	8.05	
	COV, %	14.4	1.6	0.9	
TH-23 Crushed Aggregate; North Section	Mean, %	4.26	4.28	4.34	
	COV, %	1.3	1.0	2.1	
TH-23 Crushed Aggregate; Middle Section	Mean, %	4.24	4.28	**4.30**	
	COV, %	1.3	2.0	**1.6**	
TH-23 Crushed Aggregate; South Section	Mean, %	**4.18**	4.18	4.38	
	COV, %	**3.9**	3.9	1.0	
US-280 Crushed Stone; Section 1	Mean, %	3.92			
	COV, %	3.1			
US-280 Crushed Stone; Section 2	Mean, %	4.18			
	COV, %	2.9			
US-280 Crushed Stone; Section 3	Mean, %	3.77			
	COV, %	2.9			
US-280 Crushed Stone; Section 4	Mean, %	**4.06**			
	COV, %	**2.6**			

Note: The shaded cells designate those areas with anomalies (refer to table 31); the black cells denote weaker areas, while the gray cells denote the stronger areas tested within a specific project.

Table 45. Listing of the Maximum Dry Density and Optimum Water Content for the Unbound Materials and Soils, as Compared to the Average Test Results from the EDG

Project	Material	Maximum Dry Unit Weight, pcf	Optimum Water Content, %	Average Dry Density, pcf	Average Water Content, %
NCAT, Oklahoma	High Plasticity Clay	99.9	21.8	96.7	21.3
SH-21, TX	High Plasticity Clay	108.0	21.9	107.3	18.4
I-85, AL	Low Plasticity Soil; Pre-IC	112.7	13.1	107.98	16.9
	Low Plasticity Soil; Post-IC			107.98	16.9
SH-130, TX	Improved Granular Embankment	122.0	9	123.3	8.32
TH-23, MN	Silt-Sand-Gravel Mix – South Area	122.6	12	122.77	8.69
	Silt-Sand-Gravel Mix – North Area			123.80	7.87
US-2, ND	Soil-Aggregate, Embankment	128.0	9.0	123.1	12.1
NCAT, FL	Limerock Base	116.1	12.5	110.5	13.4
CR-103	Caliche Base	127.5	10.0	125.0	9.5
NCAT, MO	Crushed Limestone	130.0	10.0	124.4	9.0
TH-23, MN	Crushed Aggregate Base	135.3	7.8	129.82	4.3
US-53, OH	Crushed Aggregate Base	134.1	8.5	136.0	9.1
NCAT, SC	Crushed Granite Base	138.1	5.0	130.0	4.7
US-2, ND	Crushed Gravel Base	141.1	6.0	134.4	5.9
US-280, AL	Crushed Stone Base	148.5	6.2	147.58	3.9
NOTE: The maximum dry density and optimum water content for most of the materials and layers were determined using AASHTO T 180. The exception is the high plasticity clay from the Texas project and the North Dakota embankment material.					

5.3.8 Roller-Mounted Density and Stiffness Devices

<u>TH-23 Base Material</u>

The Caterpillar IC roller was used to test the Class 6 crushed aggregate base materials on the TH-23 project in Spicer, Minnesota. The IC roller (shown in Figure 19 in Chapter 3) was set in low amplitude so that the roller would not decompact or damage the existing base material. Figures 54 and 55 show example print outs that were obtained from the IC roller's instrumentation.

The stiffness responses recorded by the IC roller were about the same between both areas tested. Based on the interpretation of the readings by the operator, the IC roller suggests that the crushed aggregate base material is as dense as it can be along these lanes. Further compaction could damage or decompact the aggregate base layer. Table 46 tabulates the results from the stiffness measurements made with the IC roller, which are explained and discussed in the bullets that follow.

Table 46. Stiffness Responses Recorded by the IC Roller, Tabulation of Results

Area	Lanes Tested	A	B	C
1 – South Section	Mean	35.00	24.22	41.80
	Standard Deviation	9.25	9.38	6.78
	COV, %	26.4	38.7	16.2
2 – Middle Section	Mean	38.40	31.78	31.30
	Standard Deviation	13.01	8.70	5.79
	COV, %	33.9	27.4	18.5

- South Section, Area 1 (Figure 54) – Lanes A and C were found to be the stiffer based on the measured responses by the IC roller. The lowest stiffness readings were recorded in the northern part of lane B. Conversely, the other NDT devices found lane C to be weaker (refer to Tables 32, 35, 37, and 39).

- Middle Section, Area 2 (Figure 55) – The IC roller found no consistent difference between the three lanes. The weaker area identified by the DSPA, GeoGauge, DCP, and LWD was found to be along lane C (refer to Tables 32, 35, 37, and 39). Lane C has the lower densities and higher moisture contents. The IC roller may have bridged the less dense area along lane C making it difficult to detect the lower strengths.

I-85 Exit Ramp 51 – Embankment Material

Nondestructive testing was performed on the embankment material prior to final compaction. The Ammann IC roller was used to complete the compaction of the two embankment sections along the I-85 reconstruction of the Exit ramp 51 (refer to Figure 19 in chapter 3). After IC rolling, selected NDT devices were used to re-test each area. The results from this testing were provided in the respective tables for each NDT device, previously discussed in this chapter.

Figure 56 compares the modulus values before and after IC rolling, as measured by the GeoGauge, DSPA, and DCP. As shown, the modulus values consistently increased after IC rolling, with the exception of the DCP device. In general, the test results from those NDT devices suggest increases in density of the embankment. The GRP test results also show a benefit (increased density) of the additional compaction (refer to Table 42). Conversely, the EDG did not show any increase in the embankment density (refer to Table 43).

Figure 57 compares the coefficient of variation of those average modulus values before and after IC rolling. The variability in the modulus values did not decrease. In other words, the uniformity of the stiffness of the embankment did not significantly increase. The GPR test results, however, did show a significant reduction in variability of the dielectric values.

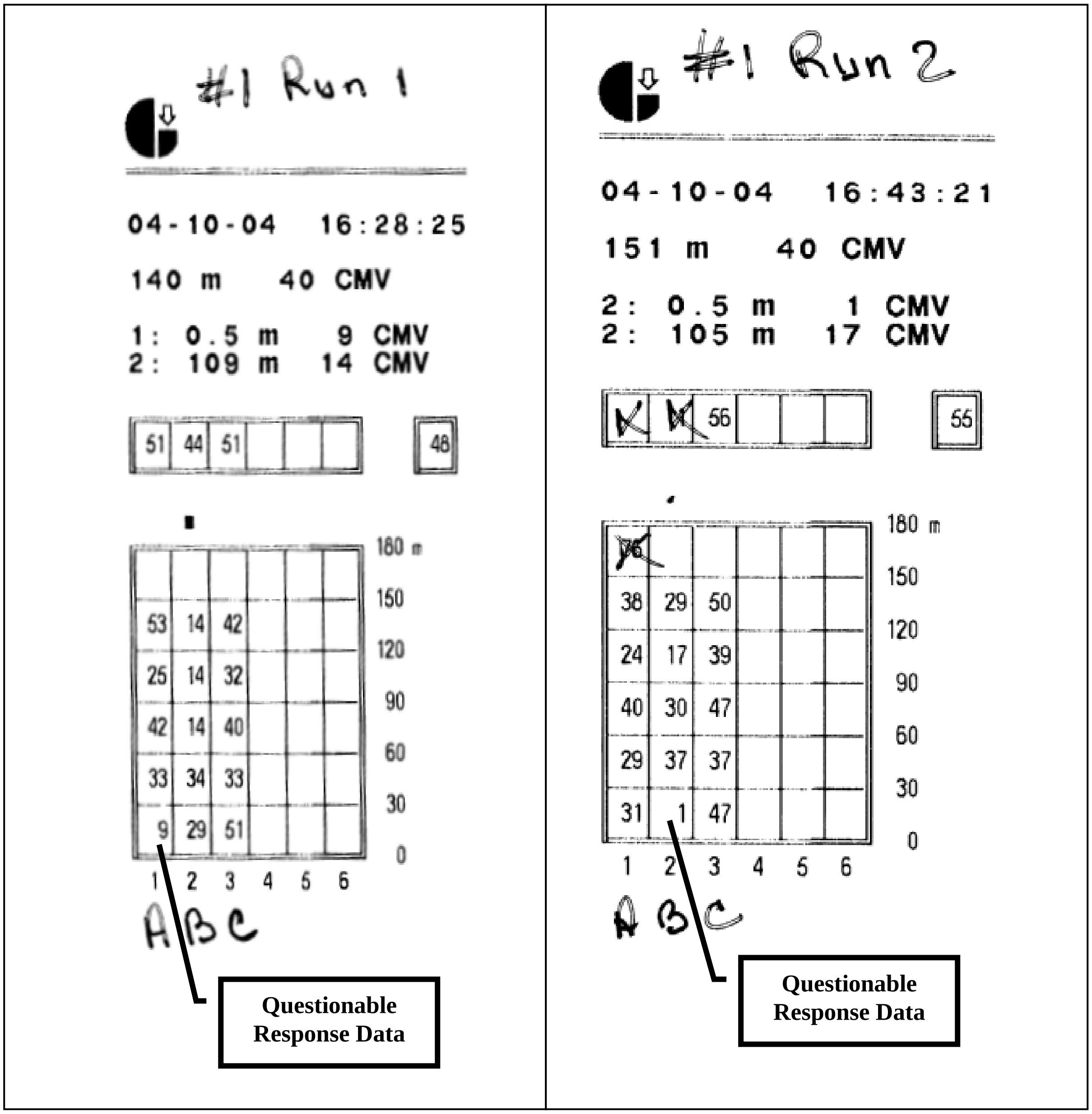


Figure 54. Printouts from the IC Roller Used to Test the Crushed Aggregate Base in Area 1 of the TH-23 Reconstruction Project in Spicer, Minnesota

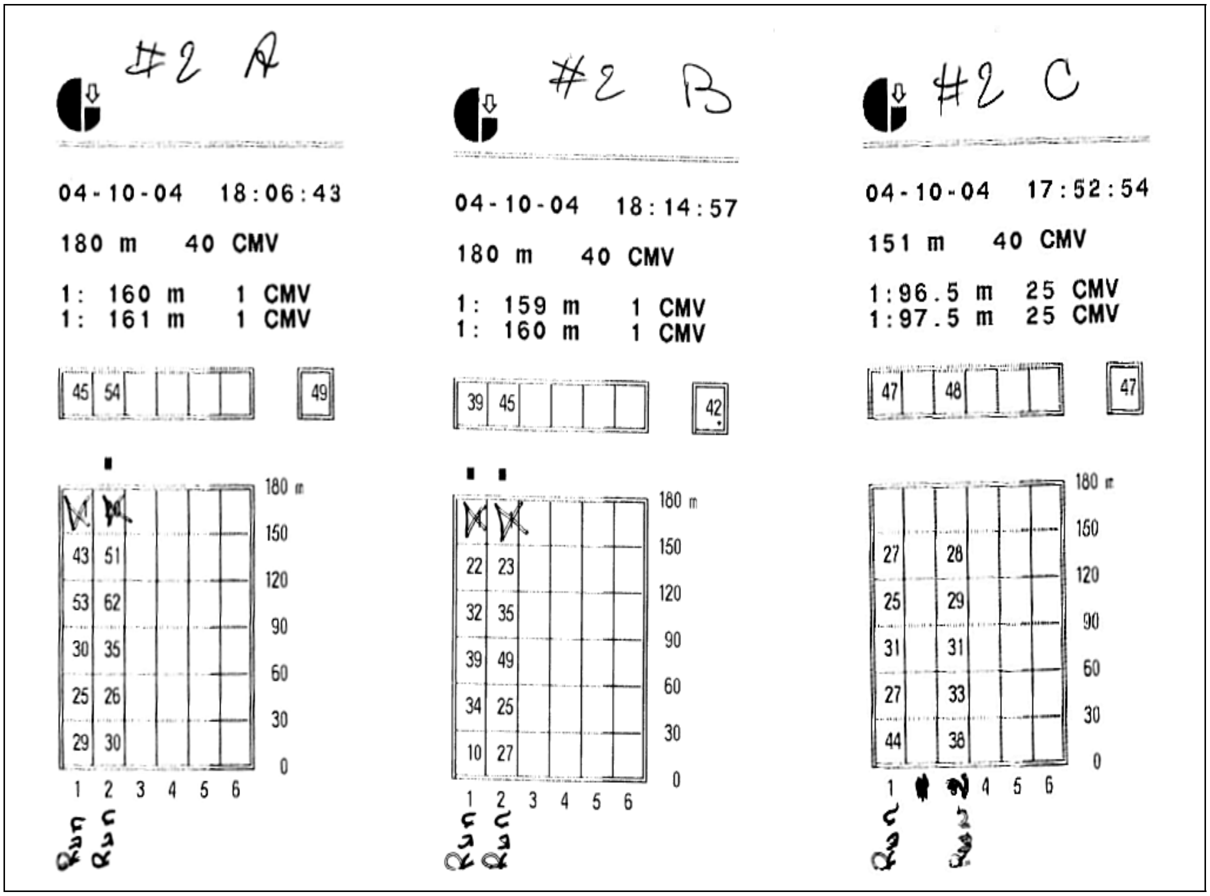


Figure 55. Printouts from the IC Roller Used to Test the Crushed Aggregate Base in Area 2 of the TH-23 Reconstruction Project in Spicer, Minnesota

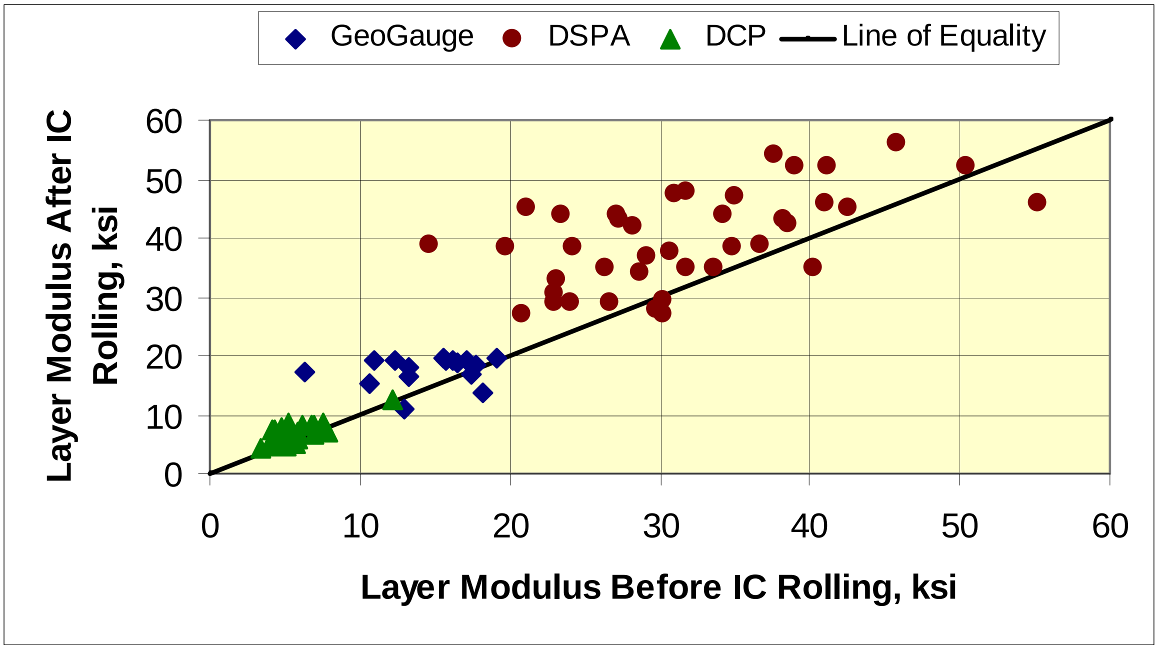


Figure 56. Comparison of Modulus Values Measured with Different NDT Devices Before and After IC Rolling of the I-85 Low Plasticity, Fine-Grained Soil Embankment

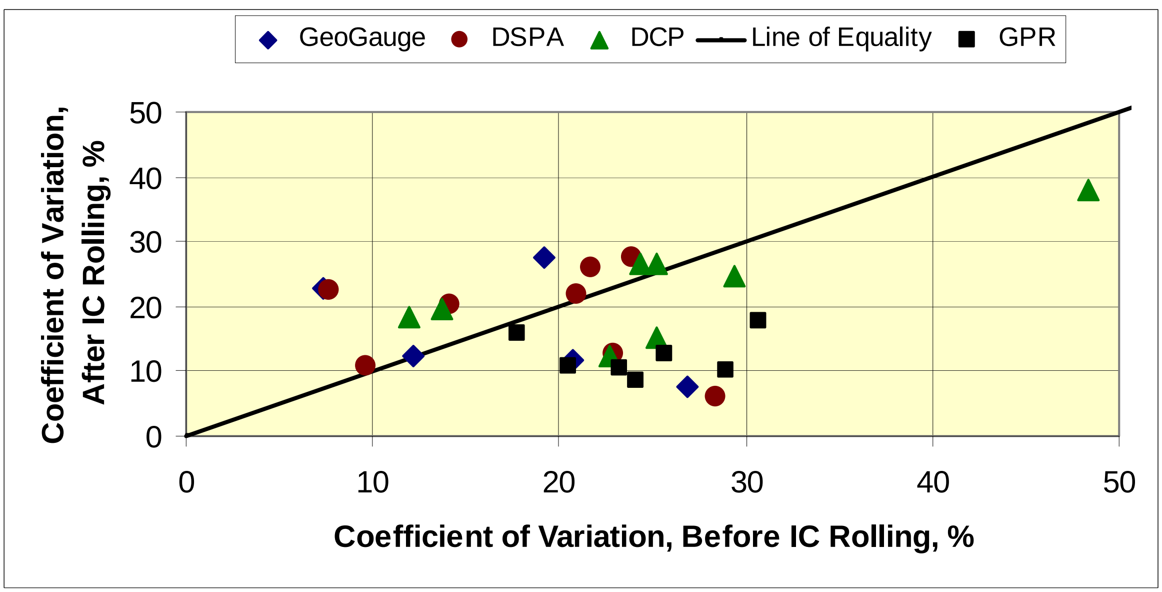


Figure 57. Uniformity of the Embankment Along I-85 Exit 51 Before and After IC Rolling, as Determined Through Modulus Measurements from Different NDT Devices

5.4 NDT Test Results of HMA Mixtures

This section presents the NDT responses measured on HMA mixtures at each project listed above and discussed in Appendix B and identified in Tables 29 and 30. It also provides a brief evaluation of the mixtures based on those measured responses and compares the responses measured by different NDT devices on the same material.

As noted in chapter 1, the initial testing under Part A was to confirm that the NDT technologies can identify differences in construction quality of HMA mixtures. Table 47 summarizes the anomalies between the HMA materials placed along each project. During nondestructive testing, none of the NDT operators were advised of those anomalies or differences.

Table 47. Description of the Different Physical Conditions (Localized Anomalies) of the HMA Mixtures Placed Along Projects within Part A

Project Identification	HMA Sections	Description of Differences Along the Project
TH-23 HMA Base; Spicer, Minnesota	Section 2, Middle or Northeast Section	QA records indicate lower asphalt content in this area – asphalt content was still within the specifications.
I-85 SMA Overlay; Auburn, Alabama	Section 2, Middle; All lanes	QA records indicate higher asphalt content in this area, but it was still within the specifications.
	Lane C, All Sections	This part or lane was the last area rolled using the rolling pattern set by the contractor, and was adjacent to the traffic lane. Densities lower within this area.
US-280 HMA Base Mixture; Opelika, Alabama	Initial Test Sections, defined as A; Section 2, All Lanes	Segregation identified in localized areas. In addition, QA records indicate lower asphalt content in this area of the project. Densities lower within this area.
	Supplemental Test Sections near crushed stone base sections, defined as B.	Segregation observed in limited areas.
	IC Roller Compaction Effort Section, Defined as C.	Higher compaction effort was used along Lane C.
SH-130 HMA Base Mixture; Georgetown, Texas	All Sections	No differences between the different sections tested.

5.4.1 Seismic Testing—PSPA

The PSPA was used to measure the seismic modulus of the HMA materials in accordance with the procedure and software developed by Dr. Nazarian for the Texas DOT (see Figure 16 in chapter 3). Triplicate tests were performed at each test point—similar to what was done for the unbound materials. Table 48 provides the average seismic modulus values measured within each area of the Part A projects, while Table 49 provides the average seismic values measured along the Part B projects. The cells in Table 48 that are shaded correspond to those conditions listed in Table 47.

The sensor bar for the PSPA was rotated relative to roller direction for the repeat readings, similar to the test procedure for unbound materials. Figure 58 compares the differences between the measurements taken parallel and perpendicular to roller direction. No significant difference was found between the measurement directions.

Figure 59 presents the cumulative frequency of the standard deviation or repeatability of the PSPA, while Figure 60 compares the standard deviations to the mean seismic modulus. The standard deviations in Figures 59 and 60 represent the triplicate measurements taken at the same test point. The repeatability of the PSPA is considered good. The mean standard deviation varies from about 10 to 50 ksi and appears to be independent of the mean seismic modulus.

The standard deviation, however, generally decreases with increasing mean seismic modulus for the I-35/SH-130 HMA base, while it increases with increasing mean seismic modulus for the US-280 HMA base. The reason for this disparity between the different projects is unknown. Figure 58.a does show a consistent difference between the seismic modulus measured parallel and perpendicular to the rolling direction for the US-280 project. Figure 58.b also shows more diversity between these two measurements made at a point for the interior of the HMA lane or mat.

The following bullets summarize the results from the PSPA seismic tests in accordance with those conditions listed in Table 47.

- TH-23 HMA Base – The PSPA found that section 2 (northeast section) had the lower seismic modulus values, which could be consistent with a lower asphalt content. The coefficient of variation for all areas tested suggests low variability or uniform construction of the HMA mixture within each area.
- I-85 SMA Overlay – The PSPA found higher seismic modulus in the area with the higher asphalt content; lanes A and B in the middle section. The lowest seismic value measured with the PSPA was in lane C of section 1. The seismic values measured in lane C of the two other areas were similar to the other lanes tested. This observation suggests that the delay in compaction along this lane may have been discontinued with the placement-compaction operations. After section 1, the rollers were able to keep up with the paver.

Table 48. Summary of the Seismic Modulus Measured with the PSPA within the Projects Included in Part A, ksi

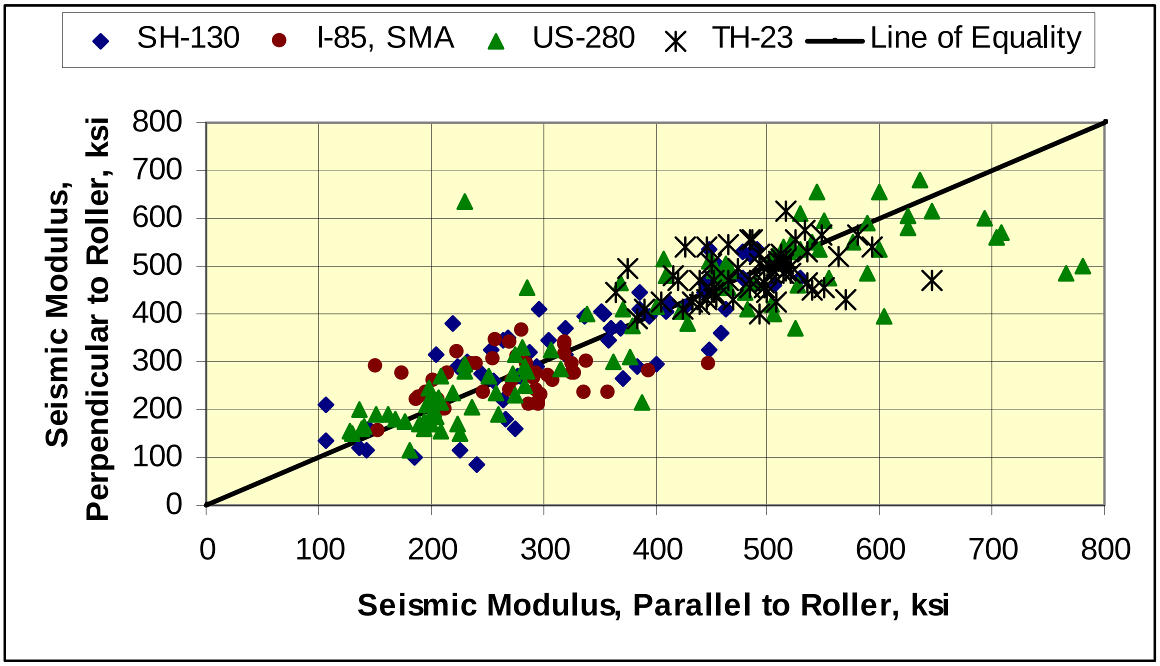
Project ID		Location or Designated Area		
		A	B	C
TH-23 HMA Base, Section 1 – South	Mean, ksi	475.6	505.4	481.8
	COV, %	3.9	2.9	8.9
TH-23 HMA Base, Section 2 – Northeast	Mean, ksi	**454.7**	**447.2**	**461.4**
	COV, %	**9.6**	**8.8**	**6.6**
TH-23 HMA Base, Section 3 – Northwest	Mean, ksi	481.0	501.4	493.6
	COV, %	4.0	6.6	10.1
TH-23 HMA Base, Section 4, North – One Day After Paving	Mean, ksi	472.6	504.4	521.4
	COV, %	3.8	2.3	5.6
I-85 SMA Overlay, Section 1 – North	Mean, ksi	272.4	240.6	**215.4**
	COV, %	32.2	14.1	**9.7**
I-85 SMA Overlay, Section 2 – Middle	Mean, ksi	**290.8**	**279.2**	**278.8**
	COV, %	**9.1**	**7.9**	**16.6**
I-85 SMA Overlay, Section 3 – South	Mean, ksi	269.4	265.4	**298.2**
	COV, %	7.6	6.6	**14.9**
US-280 HMA Base, Section 1, Initial Testing	Mean, ksi	490.0	535.4	474.2
	COV, %	6.9	11.6	10.8
US-280 HMA Base, Section 2, Initial Testing	Mean, ksi	**465.8**	**432.2**	**373.8**
	COV, %	**1.6**	**6.5**	**9.7**
US-280 HMA Base, Joint Measurements, Initial Testing	Mean, ksi	**305.8**		
	COV, %	**29.4**		
US-280 HMA Base, Segregated Areas, Initial Testing	Mean, ksi	**372.0**	**NA**	**287.8**
	COV, %	**3.7**	**NA**	**26.0**
US-280 HMA Base, Section 1, Supplemental Tests	Mean, ksi	550.4	554.4	574.6
	COV, %	15.2	12.8	6.1
US-280 HMA Base, Section 2, Supplemental Tests	Mean, ksi	537.2	559.8	553.5
	COV, %	6.8	11.7	6.6
US-280 HMA Base, Joint Measurements, Supplemental Tests, Section 1	Mean, ksi	**596.0**		
	COV, %	**9.7**		
US-280 HMA Base, Segregated Areas, Supplemental Tests, Section 2	Mean, ksi	**391.3**		
	COV, %	**12.9**		
US-280 HMA Base, Supplemental Testing, IC Roller, One Day After Paving	Mean, ksi	---	238.6	**268.8**
	COV, %	---	15.0	**17.5**
I-35/SH-130 HMA Base, Section 1	Mean, ksi	354.3	427.0	373.4
	COV, %	12.1	10.0	13.4
I-35/SH-130 HMA Base, Section 2	Mean, ksi	260.4	317.4	300.0
	COV, %	3.6	11.6	17.1
I-35/SH-130 HMA Base, Section 3, One Day After Paving	Mean, ksi	441.8	475.9	467.3
	COV, %	12.4	6.5	4.5
I-35/SH-130 HMA Base, Joints, Section 1	Mean, ksi	---	---	**297.5**
	COV, %	---	---	**15.3**

Note: The shaded cells designate those areas with anomalies (refer to table 47).

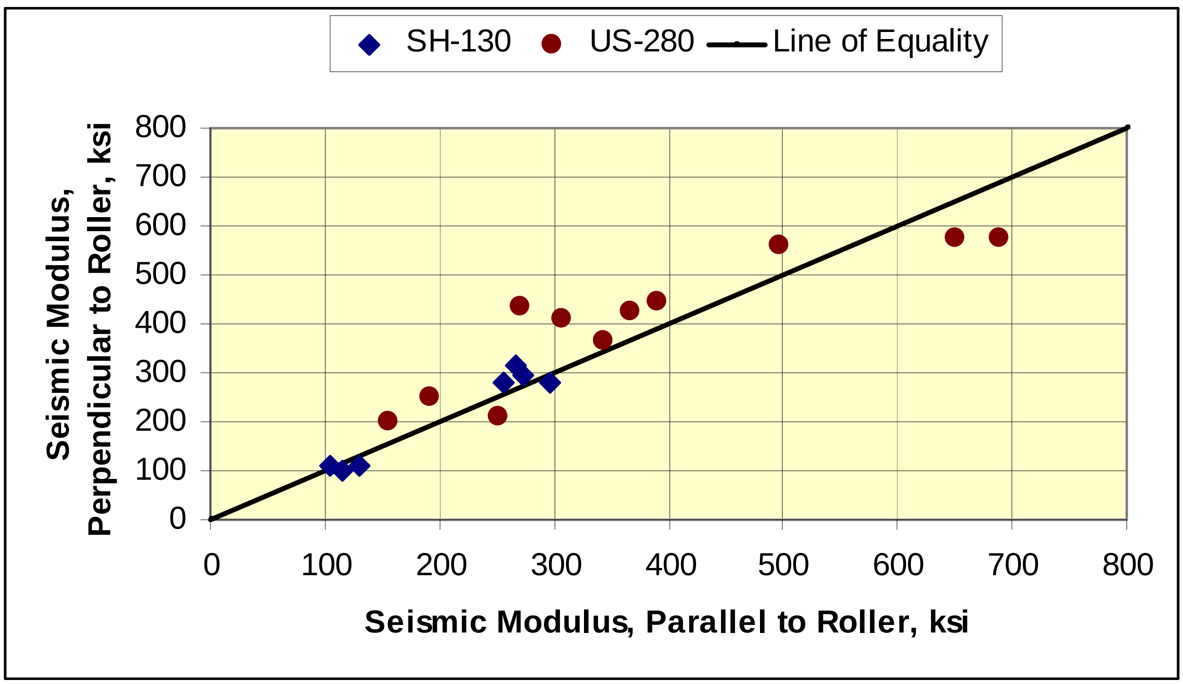
Table 49. Summary of the Seismic Modulus Measured with the PSPA within Projects Included in Part B, ksi

Project Identification	Section and Material	Mean Modulus, ksi	Coefficient of Variation, %	Standard Deviation of Means, ksi
US-47, MO	Coarse-Graded Base	605.3	14.2	85.58
	Fine-Graded Wearing Surface	457.6	18.5	84.7
I-75, MI	Dense-Graded Binder Mix; Type 3-C	676.3	8.9	69.35
US-2, ND	Coarse-Graded Base Mix; PG58-28	344.3	10.6	36.58
US-53, OH	Coarse-Graded Binder Mix	666.7	6.0	40.26
I-20, TX	Coarse-Graded Binder Mix, CMHB	435.5	10.2	44.54
NCAT, Alabama	Surface Mix; 45% RAP, PG67; E-5	510.7	6.5	33.38
	Surface Mixture; 45% RAP, PG76, SBS ; E-6	473.4	12.2	57.79
	Surface Mixture; 45% RAP, PG76, Sasobit ; E-7	444.3	9.1	40.62
NCAT, Florida	Coarse-Graded Base Mix; PG67; N-1	447.1	10.6	47.57
	Coarse-Graded Base Mix; PG76; PMA; N-2	475.8	11.5	54.87
NCAT, Missouri	Dense-Graded Surface Mix; PG76; N-10	528.7	15.1	136.18
NCAT, SC	Coarse-Graded Base Mix; PG67; S-11	495.2	6.6	32.68

- US-280 HMA Base – The PSPA found that section 2 of the project used for the initial testing has lower seismic modulus values than section 1, as expected. Similarly, the PSPA measured lower modulus in the area with lower compaction, as compared to the area compacted with the IC roller for the supplemental sections. The seismic modulus values from the supplemental sections are higher than for the initial sections along this project. The reason for higher values in the supplemental sections is unknown, other than some change in the mixture occurred between the two testing periods. This issue will be discussed in more detail under section 5.5.
- US-280 HMA Base – The seismic modulus values measured at the locations with some minor segregation were found to be lower than for the areas without segregation for both the initial and supplemental sections. Similarly, the seismic modulus values measured along the longitudinal joints were consistently less than those modulus values measured within the interior of the sections.
- I-35/SH-130 HMA Base – The PSPA found section 2 to be weaker or less stiff than the other two sections. This difference was not planned, and the specific reason for the less stiff mixture is unknown.



(b) Seismic modulus measured within interior of the mat.



(a) Seismic modulus measured along a longitudinal joint.

Figure 58. Comparison of the PSPA Seismic Modulus Values Measured Parallel and Perpendicular to Roller Direction

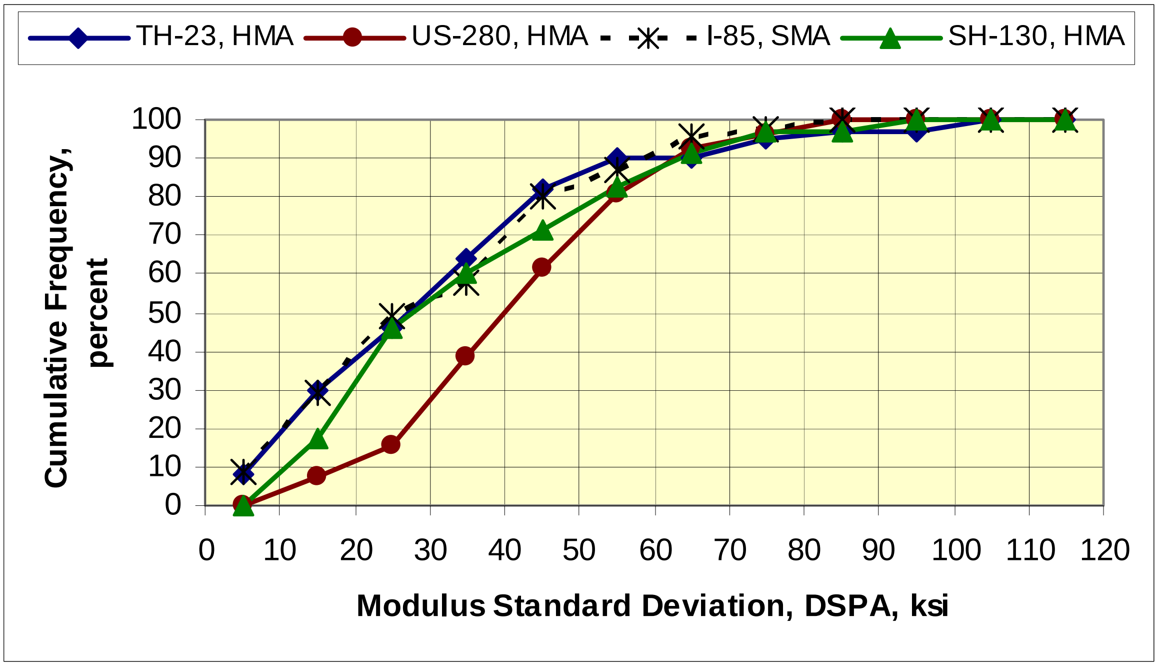


Figure 59. Cumulative Frequency of the Standard Deviation from the PSPA

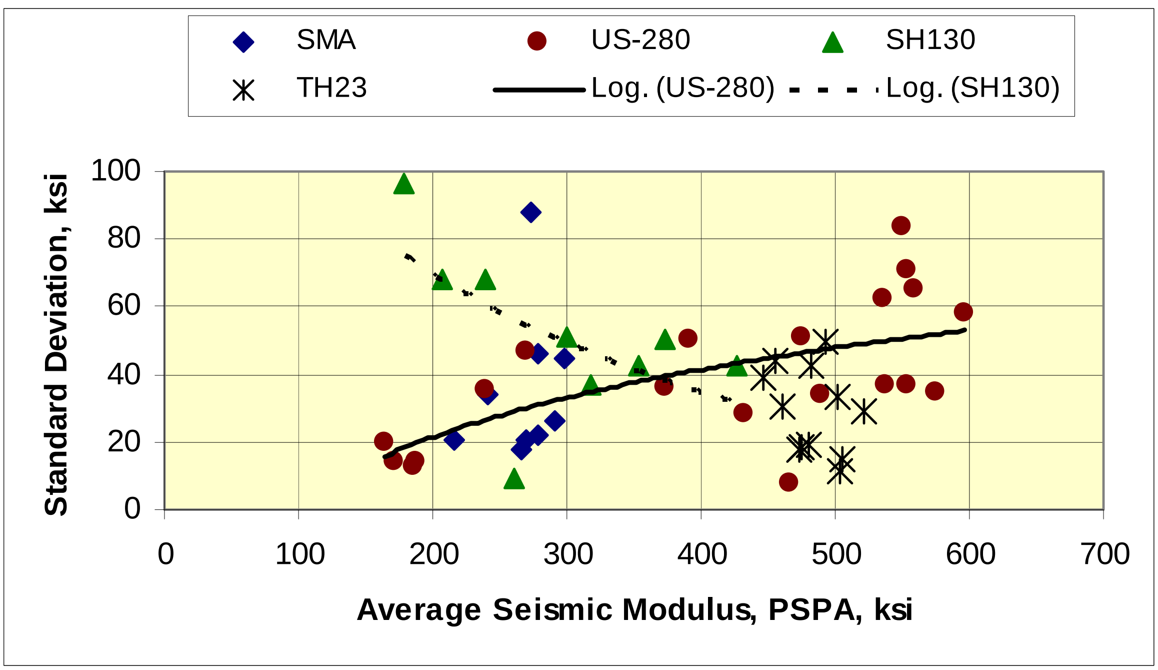


Figure 60. Relationship Between the Standard Deviation and Mean Seismic Modulus Values from the PSPA

NDT devices must be able to identify the quality of joint construction and segregation. Table 50 provides a summary of the seismic modulus measured in areas with different features—along longitudinal joints and within segregated areas. In most areas, the PSPA measured lower seismic modulus values along the longitudinal joints than within the interior of the HMA lane, as expected. The ratios between the joint seismic modulus and interior value are listed in Table 50 and range from 0.54 to 1.05.

Table 50. Summary of the Seismic Modulus Measured with the PSPA Along Longitudinal Joints or in Areas with Limited Segregation

Project	Location/Area		Lane Interior	Area with Feature	Ratio
LONGITUDINAL JOINTS					
US-280 HMA Base; Initial Sections	Multiple Days After Paving	Mean, ksi	499.0	305.8	0.613
		COV, %	10.8	29.4	
US-280 HMA Base; Supplemental Sections	Section 1, During Paving	Mean, ksi	565.2	596.0	1.054
		COV, %	6.2	9.7	
I-35/SH-130 HMA Base	Multiple Days After Paving	Mean, ksi	373.4	297.5	0.797
		COV, %	13.4	25.3	
	During Paving	Mean, ksi	208.0	111.2	0.535
		COV, %	32.9	6.4	
SEGREGATED AREAS					
US-280 HMA Base; Initial Sections	Section 1, Lanes A,B	Mean, ksi	490.0	372.0	0.759
		COV, %	6.9	3.7	
	Section 1, Lane C	Mean, ksi	474.2	287.8	0.607
		COV, %	10.8	26.0	
US-280 HMA Base; Supplemental Sections	Section 2	Mean, ksi	557.2	391.2	0.702
		COV, %	11.5	12.9	

NOTE: The ratio listed above is the mean seismic modulus measured at the feature divided by the seismic modulus measured within the interior of the lane or area.

Similarly, lower seismic modulus values were measured in those areas with limited segregation. The ratio of the seismic modulus measured within the segregated area to non-segregated areas ranged from 0.61 to 0.76. The segregation found in these areas is truck to truck segregation and was not considered severe. The PSPA, however, did detect these areas.

Seismic modulus values were also measured during different times after paving. Table 51 lists the seismic modulus for three different times, when available. These time periods included: (1) during paving or immediately after compaction, (2) the day following placement, and (3) multiple days after placement. As shown, time and temperature of the mixture during testing have a significant effect on the seismic modulus, as expected.

In most cases, one-day after placement resulted in similar mean seismic modulus values to those measured multiple days after placement, adjusting for temperature differences. This was not the case for the US-280 HMA base mixture. More importantly, those areas tested with the PSPA resulting in high variability (COV greater than 15 percent) were tested immediately after compaction or during the same day of placement. The different mat temperatures in combination with other changes in the volumetric properties between test points exaggerate the mixture's variability, as measured by the PSPA.

Table 51. Summary of the Seismic Modulus Measured with the PSPA for Different Times After Paving, Excluding Sections or Areas with Anomalies

Project	Section	Time of Readings	Location	Mean, ksi	COV, %
TH-23 HMA Base		During Paving		---	---
	Section 4	One-Day After Paving	A	472.6	3.8
			B	504.4	2.3
			C	521.4	5.6
	Sections 1,3	Multiple Days After Paving	A	478.6	3.8
			B	503.9	4.8
			C	487.7	9.0
I-85 SMA Overlay	Sections 1,3	During Paving	A	270.9	22.1
			B	253.0	11.3
			C	256.8	21.3
		Multiple Days After Paving		---	---
US-280 HMA Base; Initial Sections	Section 3	During Paving	A	165.0	12.2
			B	185.0	6.8
			C	188.0	7.5
	Section 1	Multiple Days After Paving	A	490.0	6.9
			B	535.4	11.6
			C	474.2	10.8
US-280 HMA Base; Supplemental Sections	Section 3	During Paving	B	171.0	8.3
	IC Roller Section	One Day After Paving	B	238.6	15.0
			C	268.8	17.5
	Sections 1,2	Multiple Days After Paving	A	543.8	11.2
			B	557.2	11.5
			C	565.2	6.2
I-35/SH-130 HMA Base	Section 3	During Paving	A	238.5	28.5
			B	179.0	54.0
			C	208.0	32.9
	Section 3	One Day After Paving	A	441.8	12.4
			B	475.9	6.5
			C	467.3	4.5
	Section 1	Multiple Days After Paving	A	354.3	12.1
			B	427.0	10.0
			C	373.4	13.4

5.4.2 Deflection Testing—FWD

Deflection basins were measured with the FWD in accordance with the test protocol being used in the LTPP program. The procedure was to use two seating drops at a low drop height, followed by two drops at each drop height. Three drop heights were used at each test point. The deflection basins were recorded for each drop, including the seating drops. After the first set of drops, the FWD was moved forward and the test sequence repeated. This sequence of replicate testing was used at each project.

The deflection basins were used to forward-calculate the elastic modulus of the layer being evaluated using the procedure developed by Stubstad and used for evaluating the unbound materials. The calculated elastic modulus values are summarized in Table 52 for those projects where the FWD was used. Elastic modulus values were also backcalculated using other traditional methods. The forward-calculation method resulted in the least variation of elastic modulus values within a specific area, as found for the unbound materials.

Table 52. Summary of the Elastic Modulus Calculated from the Deflection Basins Measured with the FWD

Project Identification		Location or Designated Area		
		A	B	C
I-85 SMA Overlay, Section 1 – North	Mean, ksi	363.9	437.2	---
	COV, %	14.1	27.9	---
I-85 SMA Overlay, Section 2 – Middle	Mean, ksi	**562.8**	**575.0**	---
	COV, %	**14.4**	**9.6**	---
I-85 SMA Overlay, Section 3 – South	Mean, ksi	343.3	477.0	---
	COV, %	24.7	1.9	---
US-280 HMA Base, Section 1, Initial Testing	Mean, ksi	195.8	231.2	183.0
	COV, %	10.6	18.6	27.4
US-280 HMA Base, Section 2, Initial Testing	Mean, ksi	**138**	**143**	**96.6**
	COV, %	**6.0**	**6.3**	**23.0**
US-280 HMA Base, Section 3, Just After Paving, Initial Testing	Mean, ksi	82.8	87.0	73.8
	COV, %	13.9	15.5	8.3
US-280 HMA Base, Joint Measurements, Initial Testing	Mean, ksi	125.2		
	COV, %	23.9		
US-280 HMA Base, Segregated Areas, Initial Testing	Mean, ksi	**149**	**---**	**140**
	COV, %	**16.6**	**---**	**49.1**
US-280 HMA Base, Section 1, Supplemental Tests	Mean, ksi	630	568	509
	COV, %	12.5	10.8	15.8
US-280 HMA Base, Section 2, Supplemental Tests	Mean, ksi	1,324	1,172	1,060
	COV, %	17.6	22.1	28.8
US-280 HMA Base, Joint Measurements, Supplemental Tests	Mean, ksi	379		
	COV, %	53.9		
US-280 HMA Base, Segregated Areas, Supplemental Tests	Mean, ksi	**707**		
	COV, %	**28.2**		
Note: The shaded cells designate those areas with anomalies (refer to table 47).				

Figure 61 presents a cumulative frequency diagram of the standard deviation or repeatability of the FWD, while Figure 62 compares the standard deviations to the mean elastic modulus calculated from the deflection basins. The standard deviations in Figures 61 and 62 represent the triplicate measurements taken at the same test point. The repeatability of the FWD and forward-calculation procedure is considered poor for new construction. The reason for this increased variability is the effect or influence from the supporting layers. More importantly, the standard deviation appears to be more heavily dependent on the elastic modulus—increasing standard deviation with increasing elastic modulus values (refer to Figure 62).

The cells in Table 52 that correspond to those conditions listed in Table 47 have been shaded. The following list summarizes the results from the FWD and forward-calculation procedure in accordance with those conditions listed in Table 47:

- I-85 SMA Overlay – Deflections were not measured along lane C, adjacent to existing traffic, for safety reasons. The FWD found higher elastic modulus in the area with the higher asphalt content, which is consistent with the seismic test results. However, the COV values from the FWD and forward-calculation procedure suggests more construction variability than estimated with the PSPA. The traditional QA test results found the SMA to be within specification. The reason for the higher variability is related to the thickness variations (a constant value was used in the forward-calculation processing of the data) and the variation of the supporting HMA pavement (a constant pavement thickness was also assumed for the underlying structure for overlay placement).
- US-280 HMA Base – The FWD found that section 2 of the project used for the initial testing has lower elastic modulus values, excluding the tests completed immediately after compaction. In addition, the FWD found the HMA base mixture in the supplemental sections to be stiffer than in the initial sections. These observations are consistent with the seismic test results. However, the elastic modulus values calculated from the FWD deflection basins are low and representative of an inferior mixture. These elastic modulus values are believed to be influenced by the supporting layers and are not representative of the in-place material. Similar to the findings from testing the I-85 SMA overlay, the FWD estimate of construction variability is greater than estimated with the PSPA.
- US-280 HMA Base – The elastic modulus values calculated at the locations with some minor segregation were higher than some of the other areas tested without segregation. This finding is contrary to the PSPA results and previous experience. A potential reason for this discrepancy between the two devices is that the FWD measures response from a much larger area than for the PSPA. Placing the FWD loading plate over a small area with segregation would bridge the coarse aggregate particles having little to no effect on the measured deflection basin. The PSPA measures responses that are more localized.
- US-280 HMA Base – The elastic modulus calculated from the FWD deflection basins measured along the longitudinal joints is lower than within the interior of the lanes. This observation is consistent with the findings from the PSPA. The difference between the two results, however, is the magnitude of the differences. The PSPA

found the joint to interior seismic modulus ratios to be in the range of 0.54 to 1.054, while the FWD found ratios to average 0.62 for the supplemental sections and 0.43 for the initial sections. It is believed that the FWD is measuring a more structural response along the longitudinal joints, while the PSPA is more of a mixture response in localized areas.

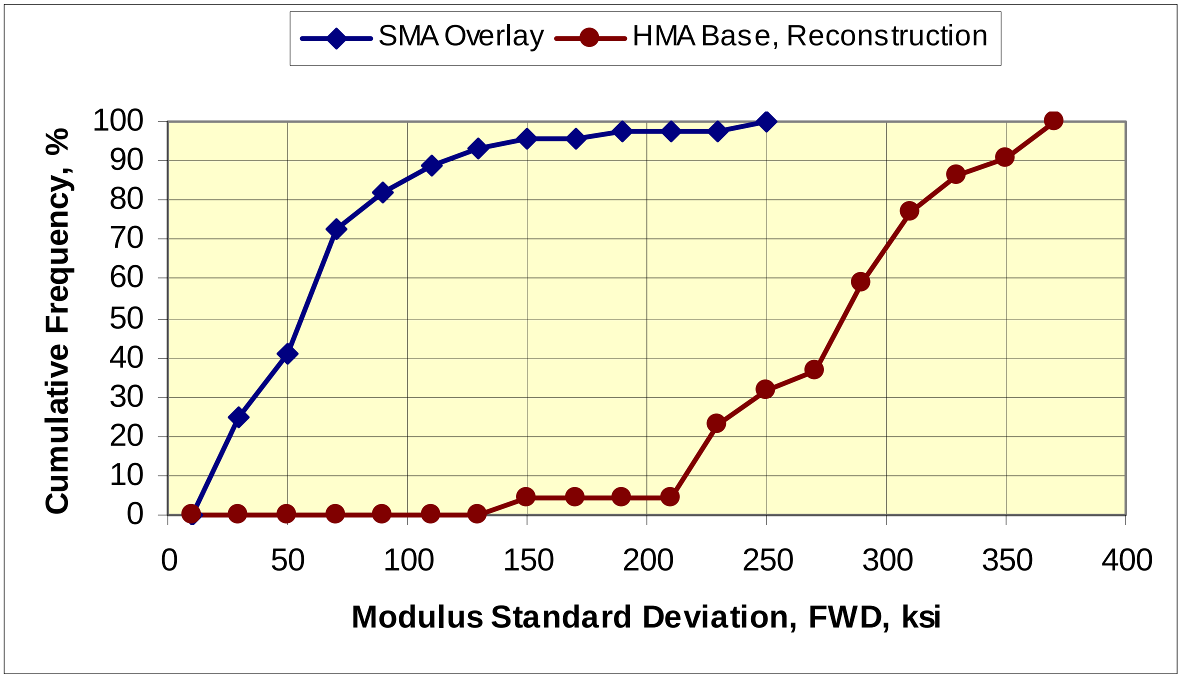


Figure 61. Cumulative Frequency of the Standard Deviation from the Deflection-Based Test Methods, FWD

5.4.3 Ground Penetrating Radar Testing—Air Horn Antenna

A GPR, single air-coupled antenna was used to take dielectric measurements of the HMA materials in accordance with ASTM and the procedure outlined by Maser (2003). Replicate or triplicate runs were made for each line of points within a section of a project. The data were analyzed by software written by Dr. Maser for use in QA applications.

Table 53 summarizes the average air voids calculated from the dielectric values measured at each test point for the other NDT devices and technologies for comparative purposes. The cells in Table 53 that correspond to those conditions listed in Table 47 have been shaded.

As noted in chapter 3, one of the advantages of the GPR is that a continuous profile can be measured for different properties. Contours of the dielectric measurements were prepared and used to determine the values at specific points where other point-based nondestructive tests were performed. Figure 63 presents the contours of the dielectric values measured within section 1 of the TH-23 HMA base project. In addition, contour plots of the HMA air voids and base thickness were also prepared by the software. Examples are provided in

Figures 64 and 65. These contour plots can be beneficial for evaluating in more detail areas that appear to be deficient, strategically locating areas with different dielectric properties (a key benefit of GPR).

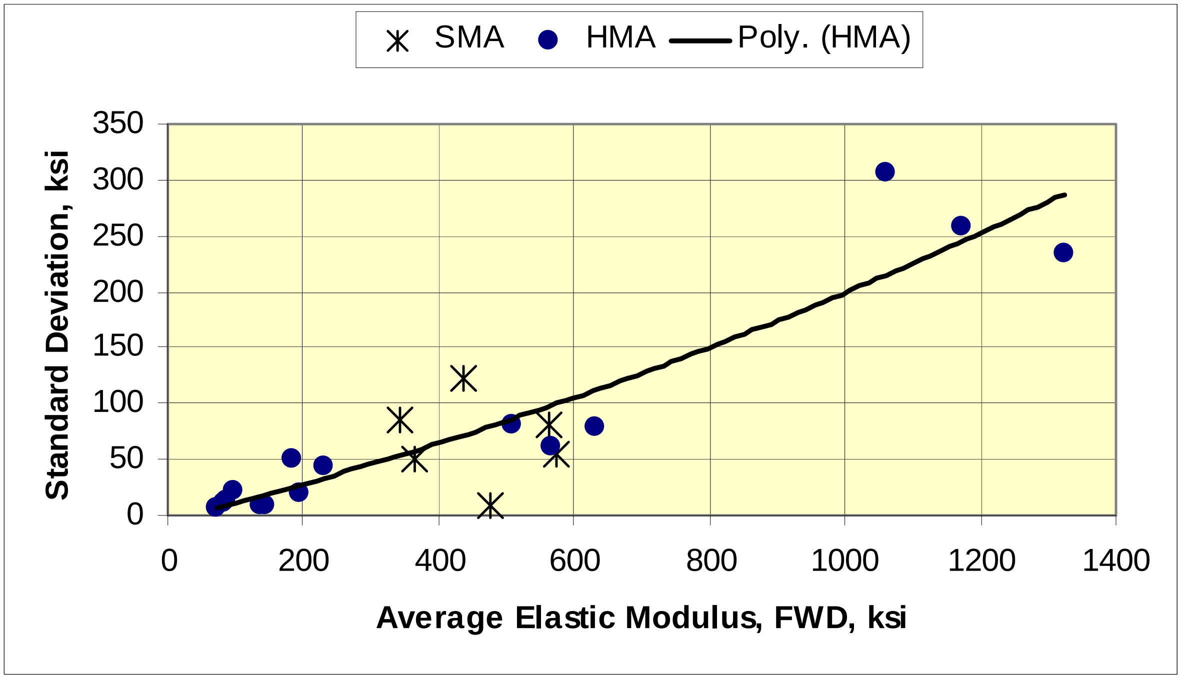


Figure 62. Relationship Between the Standard Deviation and Mean Elastic Modulus Calculated from Deflection Basins

Table 53. Summary of the Air Voids Calculated from the Dielectric Values Measured with the GPR

Project ID		Location or Designated Area		
		A	B	C
TH-23 HMA Base, Section 1 – South	Mean, %	5.80	6.58	6.62
	COV, %	5.1	1.3	3.9
TH-23 HMA Base, Section 2 – Northeast	Mean, %	**8.34**	**7.24**	**5.52**
	COV, %	**3.8**	**3.6**	**3.5**
TH-23 HMA Base, Section 3 – Northwest	Mean, %	7.02	6.90	6.90
	COV, %	10.7	9.3	7.0
I-85 SMA Overlay, Section 1 – North	Mean, %	6.72	10.00	**8.62**
	COV, %	15.6	6.6	**4.1**
I-85 SMA Overlay, Section 2 – Middle	Mean, %	**5.71**	**6.64**	**8.76**
	COV, %	**16.9**	**5.7**	**24.3**
I-85 SMA Overlay, Section 3 – South	Mean, %	13.11	10.74	**8.25**
	COV, %	12.5	13.0	**15.3**
US-280 HMA Base, Section 1, Initial Testing	Mean, %	7.02	6.80	7.27
	COV, %	7.1	8.2	13.8
US-280 HMA Base, Section 2, Initial Testing	Mean, %	**7.12**	**6.59**	**6.72**
	COV, %	**6.3**	**10.3**	**11.8**
US-280 HMA Base, Joint Measurements, Initial Testing	Mean, %		7.70	
	COV, %		11.1	
US-280 HMA Base, Segregated Areas, Initial Testing	Mean, %	**7.51**	**NA**	**7.04**
	COV, %	**8.8**	**NA**	**9.3**
US-280 HMA Base, Section 1, Supplemental Tests	Mean, %	5.76	5.48	5.42
	COV, %	2.7	2.4	2.0
US-280 HMA Base, Section 2, Supplemental Tests	Mean, %	5.36	5.44	5.54
	COV, %	3.7	3.3	3.3
US-280 HMA Base, Joint Measurements, Supplemental Tests	Mean, %		5.78	
	COV, %		2.2	
US-280 HMA Base, Segregated Areas, Supplemental Tests	Mean, %		**5.64**	
	COV, %		**2.2**	
I-35/SH-130 HMA Base, Section 1	Mean, %	5.60	6.19	6.05
	COV, %	1.1	3.4	1.1
I-35/SH-130 HMA Base, Section 2	Mean, %	5.13	5.70	6.01
	COV, %	---	1.3	2.7
I-35/SH-130 HMA Base, Joints, Section 1	Mean, %	---	---	5.19
	COV, %	---	---	1.6
I-35/SH-130 HMA Base, Joints, Section 2	Mean, %	---	---	4.97
	COV, %	---	---	---

Note: The shaded cells designate those areas with anomalies (refer to table 47).

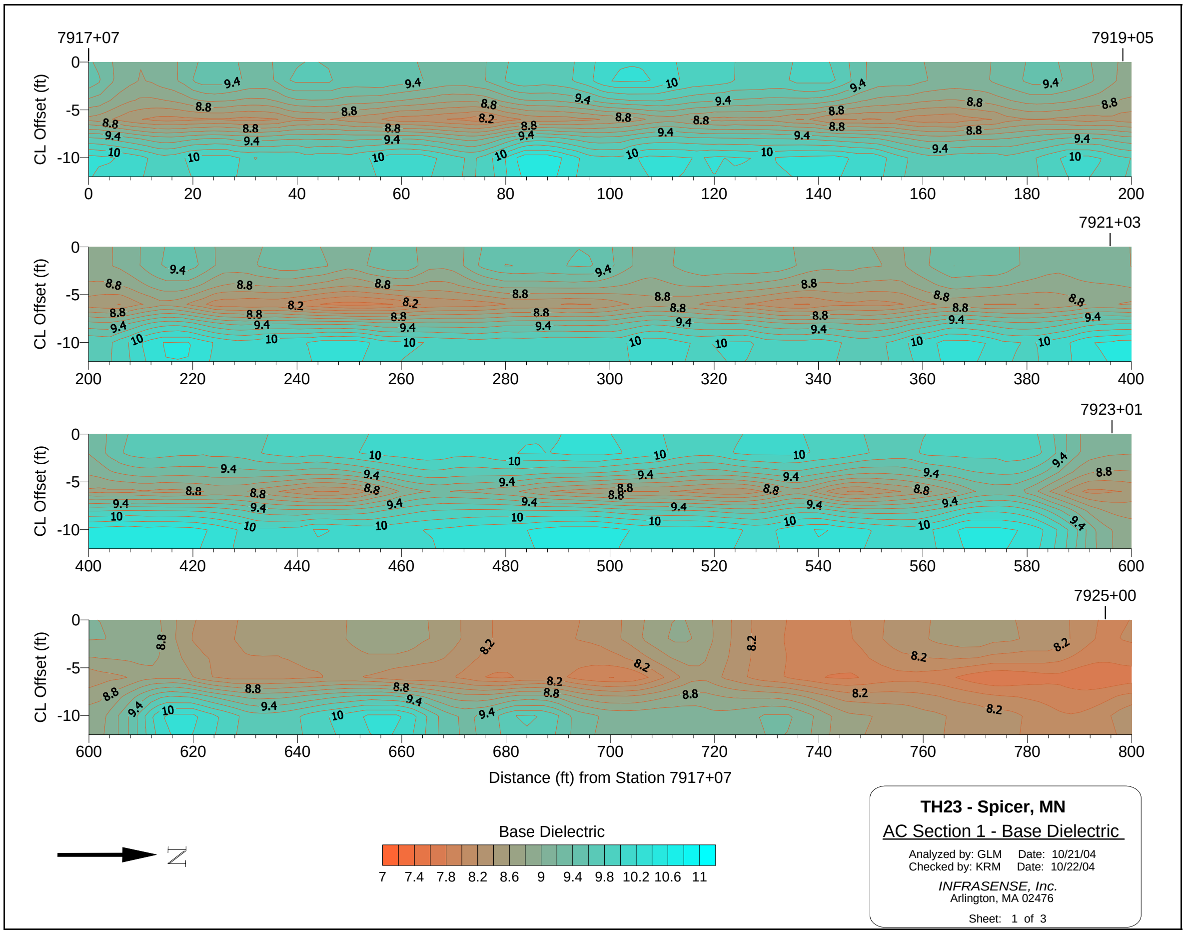


Figure 63. Contours of the Dielectric Values Measured with GPR; Section 1, TH-23 HMA Base Layer

The repeatability of the GPR was found to be higher when testing HMA mixtures than when testing unbound materials. Cumulative frequency plots were not prepared because the variation between repeat runs was low for both air voids and thickness estimates. One reason for these lower standard deviations, in comparison to unbound materials, is that the driving lines and test points within a section were always well defined for the HMA surfaces, which was not always the case for unbound layers. Table 54 summarizes the GPR repeatability for testing HMA mixtures.

Table 54. Summary of the GPR Repeatability for Testing HMA Mixtures

Mixture	Standard Deviation in Air Voids, percent			Standard Deviation in Layer Thickness, inches		
	Mean	Median	Range	Mean	Median	Range
US-180, HMA	0.54	0.38	0.0 to 2.10	0.057	0.04	0.0 to 0.28
I-35/SH-130, HMA	0.087	0.08	0.0 to 0.33	0.045	0.03	0.0 to 0.14
I-85 SMA	1.37	1.29	0.05 to 1.37	0.036	0.03	0.0 to 0.34

As shown, the lowest repeatability or higher standard deviations was found for the SMA mixture along I-85 in Auburn, Alabama. The reason for this higher variation between repeat measurements is unknown. However, the SMA did have the thinner layer tested, as well as a higher fluids content. Most of the COV values for estimating air voids within an area were less than 10 percent. Overall, the repeatability for the GPR is considered very good for both air voids and layer thickness.

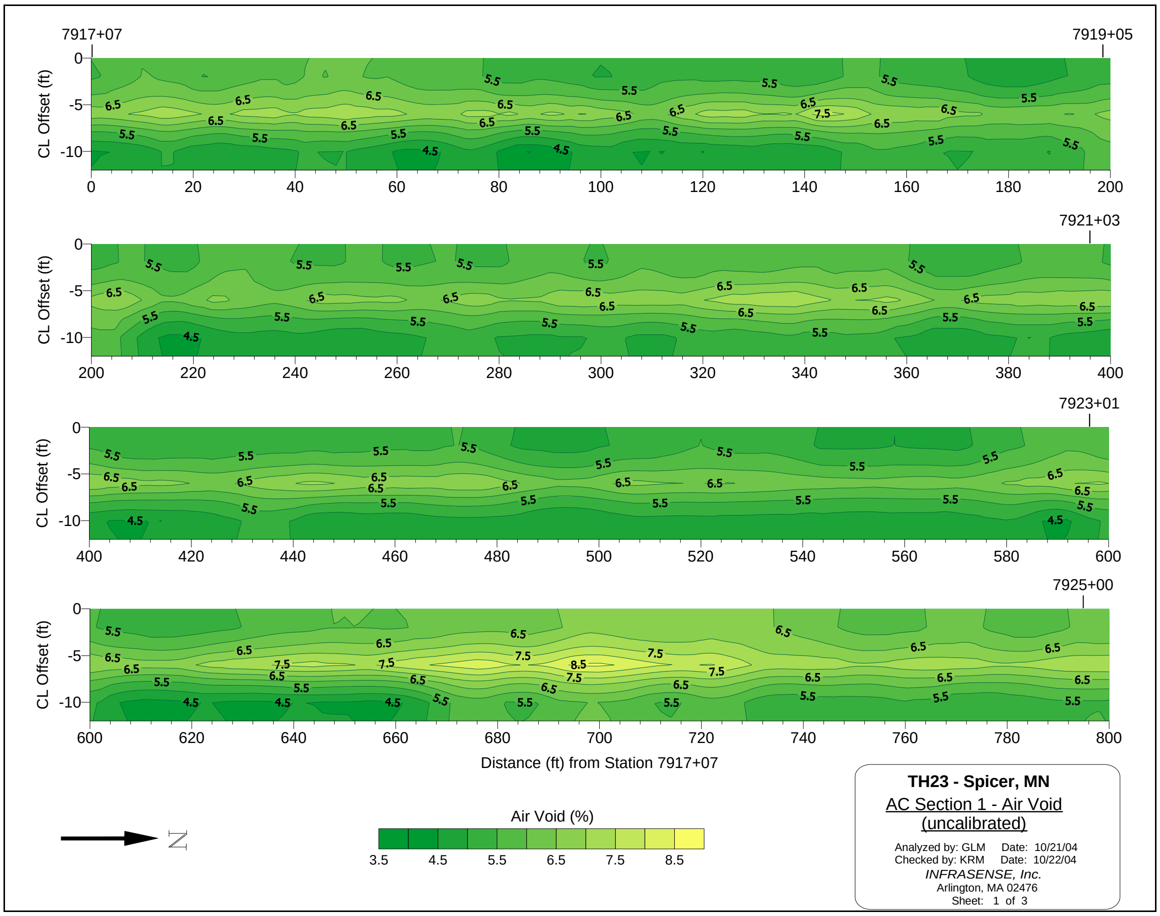


Figure 64. Contours of Air Voids Calculated from the Dielectric Values Measured Along Section 1 of TH-23 for the HMA Base Layer

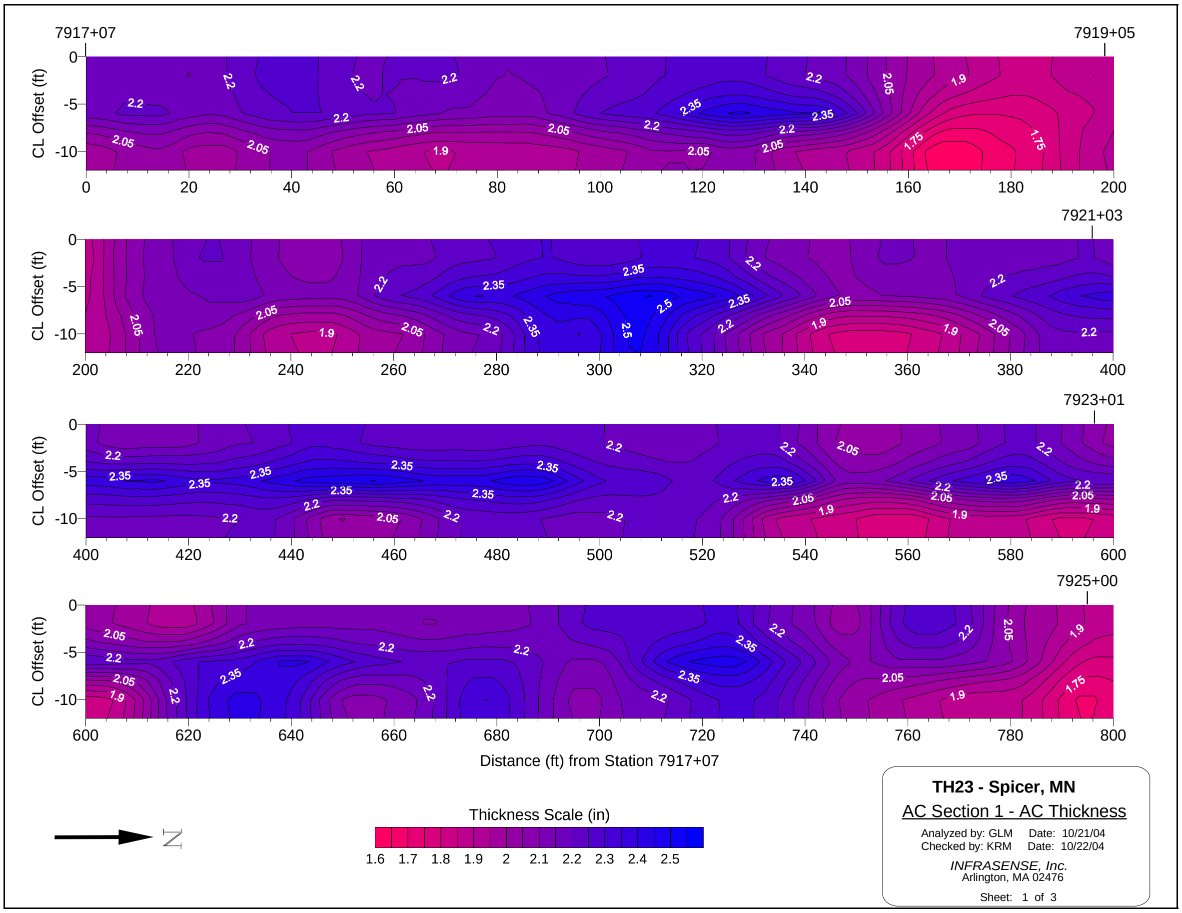


Figure 65. Contours of the Layer Thickness Determined from Dielectric Values Measured Along Section 1 of TH-23 HMA Base Layer

The following list summarizes the results from the GPR measurements in accordance with those conditions listed in Table 47:

- TH-23 HMA Base – The GPR found that section 2 (northeast section) had the higher air voids, which would be consistent with a lower asphalt content. This observation is also similar to that from the PSPA test results. The coefficient of variation for all areas tested suggests low variability of the HMA mixture within each area, which is also consistent with the PSPA test results.
- I-85 SMA Overlay – The GPR found lower air voids in the area with the higher asphalt content, which is consistent with the PSPA and FWD results. The mean air voids measured in lane C were consistent between all sections, and lower than the air voids calculated for lane B in sections 1 and 3 and lane A in section 3. Section 3 was found to have high air voids with the mean exceeding 10 percent in lanes A and B. In fact, the highest air voids were measured in lane A of section 3, which suggests inadequate compaction of the SMA mixture within this area. This observation is not believed to be the case, based on the test results from field cores and other nondestructive tests.

- US-280 HMA Base – The GPR found no consistent difference in air voids between the initial sections tested a couple of days after placement. This finding is inconsistent with construction records and results from the PSPA and FWD. In addition, the GPR did not distinguish any difference between the initial and supplemental sections, while both the PSPA and FWD found the supplemental sections to have higher stiffness. It should be noted that the differences picked up by the PSPA and FWD were not planned. This issue will be addressed in more detail in chapter 7 of Part III.
- US-280 HMA Base – No consistent difference in air voids was measured between the longitudinal joints and interior of the lanes. More importantly, the GPR air voids measured at the locations with some minor segregation were found to be the same or less than the other areas without segregation, which is inconsistent with previous experience and the results from the PSPA.
- I-35/SH-130 HMA Base – The GPR found no difference in air voids between the sections tested. The lower air voids were measured within section 2. Conversely, the PSPA found the less stiff mixture to be in section 2. More importantly, the GPR found the air voids along the longitudinal joints to be lower than within the interior of the area tested—directly in contrast to the results from the other NDT devices.
- Lift Thickness for all Projects – The GPR estimated the thickness for the first lift of the HMA base placed along the TH-23 project in Minnesota to be about 2.2 inches (see Figure 65)—the average thickness of the limited cores recovered for QA purposes. The GPR also provided an accurate estimate of the lift thickness in comparison to the cores recovered from the I-85 SMA overlay (1.7 inches) and SH-130 base mixture (2.9 inches). The GPR results for the US-280 HMA base mixture, however, did have a negative bias of about 0.5 inches. This project was the only one included in the field evaluation where a 4-inch permeable asphalt treated base (PATB) layer was used. The HMA base mixture included in the project was placed directly above the PATB layer. All cores removed from the 3.5-inch HMA base lift for volumetric property determination and QA purposes did not include the PATB layer. It is possible that the PATB may have been less than the design thickness or the high air voids and moisture in that layer could have caused the bias in the HMA base layer placed above the PATB.

5.4.4 Non-Roller-Mounted Density Testing, Non-Nuclear—PQI and PaveTracker

Two non-nuclear density gauges were used to measure the density of the HMA mixtures: the PQI and the PaveTracker. Figure 66 shows both devices used on the project. The tests were performed in accordance with the manufacturer's recommendation. Five readings were made at each point. Density readings were made directly over the marked test point, and four additional reading were made at 90 degree deviations around the test point with the edge of the gauge's base adjacent to the test point. Repeatability with the non-nuclear gauges was found to be very good. As an example, in Part B tests, the COV of cluster readings taken at each point was 1.32% and 99 percent of the test points had a COV of less than 5%.. This is in agreement with the results from a study sponsored by Wisconsin DOT on the evaluation of nonnuclear gauges (Schmitt et al., 2006, Rao et al., 2007).

Tables 55 and 56 summarize the average densities for each area tested in the Part A evaluation with the PQI and PaveTracker, respectively. During the testing sequence, it was noticed that the PaveTracker device started going out of calibration and malfunctioned during the testing along the US-280 project. It was returned to the manufacturer, and thus, fewer tests were performed with the PaveTracker device. Tables 57 and 58 summarize the average densities measured along the projects included in Part B.

Figure 67 presents a cumulative frequency diagram of the standard deviation or repeatability of the non-nuclear density gauges. The standard deviations represent the five readings taken at each point. The repeatability for both gauges is considered very good. Figure 68 shows the cumulative frequency diagram of the standard deviation in density measured with a nuclear density gauge. With the exception of the readings taken on the HMA base mixture placed along US-280, both devices resulted in comparable, if not lower standard deviations than the nuclear density gauge.

Figure 69 shows a comparison of the density readings made with each device at the same test points. As shown, there is a significant bias or difference between the two non-nuclear density measuring devices. The PaveTracker measured significantly lower densities. These low values, however, are not believed to be representative of the in-place mixture.

(a) PQI device ***(b) Pavetracker device***

Figure 66. Non-Nuclear Density Measuring Devices for HMA Mixtures

One reason for this observation is that the PaveTracker device was not calibrated to local materials at the beginning of the test program, while the PQI device was calibrated to the specific mixture prior to testing. Conversely, Figure 70 shows the results from the Wisconsin study referred (Schmitt et al., 2006, Rao et al., 2007). On that project, the PaveTracker device was calibrated to local mixtures, and the PQI device was used as received. As shown, the PQI resulted in significantly lower densities, which was not representative of the in-place HMA mixture.

Table 55. Summary of the Densities Measured with the Non-Nuclear PQI Along the Projects Included in Part A

Project Identification		Location or Designated Area		
		A	B	C
TH-23 HMA Base, Section 1 – South	Mean, pcf	148.2	147.6	147.0
	COV, %	0.5	1.0	0.6
TH-23 HMA Base, Section 2 – Northeast	Mean, pcf	**146.2**	**145.2**	**144.1**
	COV, %	**0.5**	**0.8**	**0.6**
TH-23 HMA Base, Section 3 – Northwest	Mean, pcf	145.5	145.6	145.9
	COV, %	0.7	0.3	0.6
TH-23 HMA Base, Section 4, North – Just after paving and compaction	Mean, pcf	143.4	144.7	143.6
	COV, %	0.7	0.6	0.7
I-85 SMA Overlay, Section 1 – North	Mean, pcf	144.4	146.9	**140.3**
	COV, %	1.9	1.4	**1.1**
I-85 SMA Overlay, Section 2 – Middle	Mean, pcf	**148.3**	**151.5**	**140.9**
	COV, %	**2.0**	**1.9**	**1.4**
I-85 SMA Overlay, Section 3 – South	Mean, pcf	144.8	150.3	**142.3**
	COV, %	2.1	2.4	**3.2**
US-280 HMA Base, Section 1, Initial Testing	Mean, pcf	148.3	149.4	146.3
	COV, %	0.4	1.0	0.9
US-280 HMA Base, Section 2, Initial Testing	Mean, pcf	**156.0**	**157.0**	**150.4**
	COV, %	**1.0**	**2.3**	**2.7**
US-280 HMA Base, Section 3, Just After Paving, Initial Testing	Mean, pcf	141.5	141.3	140.9
	COV, %	1.5	1.1	1.8
US-280 HMA Base, Joint Measurements, Initial Testing	Mean, pcf		145.7	
	COV, %		2.9	
US-280 HMA Base, Segregated Areas, Initial Testing	Mean, pcf	**147.6**	**NA**	**146.6**
	COV, %	**4.8**	**NA**	**2.6**
US-280 HMA Base, Section 1, Supplemental Tests	Mean, pcf	141.6	140.2	139.3
	COV, %	1.8	1.2	1.4
US-280 HMA Base, Section 2, Supplemental Tests	Mean, pcf	139.5	140.6	141.4
	COV, %	1.6	1.1	2.6
US-280 HMA Base, Section 3, Supplemental Tests, Just after paving	Mean, pcf		142.9	
	COV, %		1.2	
US-280 HMA Base, Joint Measurements, Supplemental Tests	Mean, pcf		135.8	
	COV, %		4.3	
US-280 HMA Base, Segregated Areas, Supplemental Tests	Mean, pcf		**136.6**	
	COV, %		**1.2**	
US-280 HMA Base, IC Roller	Mean, pcf		140.8	**141.2**
	COV, %		1.4	**1.5**
I-35/SH-130 HMA Base, Section 1	Mean, pcf	127.2	126.9	125.4
	COV, %	0.6	0.5	1.1
I-35/SH-130 HMA Base, Section 2	Mean, pcf	123.4	124.1	124.6
	COV, %	1.1	1.1	1.6
I-35/SH-130 HMA Base, Section 3	Mean, pcf	124.8	125.3	125.2
	COV, %	0.9	0.6	1.0
I-35/SH-130 HMA Base, Joints, Section 1	Mean, pcf	---	---	118.8
	COV, %	---	---	1.4
I-35/SH-130 HMA Base, Joints, Section 3	Mean, pcf	---	---	120.1
	COV, %	---	---	1.2
Note: The shaded cells designate those areas with anomalies (refer to table 47).				

Table 56. Summary of the Densities Measured with the Non-Nuclear PaveTracker Along Projects Included in Part A

Project ID		Location or Designated Area		
		A	B	C
TH-23 HMA Base, Section 1 - South	Mean, pcf	132.6	132.6	132.7
	COV, %	0.4	0.6	1.5
TH-23 HMA Base, Section 2 – Northeast	Mean, pcf	**130.2**	**131.6**	**131.0**
	COV, %	**0.8**	**0.6**	**0.4**
TH-23 HMA Base, Section 3 – Northwest	Mean, pcf	130.6	131.8	132.4
	COV, %	0.3	0.4	0.7
TH-23 HMA Base, Section 4, North – After Paving	Mean, pcf	131.6	132.1	131.9
	COV, %	0.6	0.7	1.0
I-85 SMA Overlay, Section 1 - North	Mean, pcf	134.6	137.1	**133.4**
	COV, %	1.8	2.2	**2.0**
I-85 SMA Overlay, Section 2 - Middle	Mean, pcf	**137.82**	**140.2**	**131.9**
	COV, %	**2.4**	**2.3**	**2.8**
I-85 SMA Overlay, Section 3 - South	Mean, pcf	132.8	136.6	**132.1**
	COV, %	1.7	2.0	**2.7**
US-280 HMA Base, Section 1, Initial Testing	Mean, pcf	127.2	131.6	128.8
	COV, %	2.8	1.4	0.7
US-280 HMA Base, Section 2, Initial Testing	Mean, pcf	NA	NA	NA
	COV, %	NA	NA	NA
US-280 HMA Base, Section 3, Just After Paving, Initial Testing	Mean, pcf	NA	NA	NA
	COV, %	NA	NA	NA
US-280 HMA Base, Joint Measurements, Initial Testing	Mean, pcf	126.5		
	COV, %	NA		
US-280 HMA Base, Segregated Areas, Initial Testing	Mean, pcf	NA	NA	NA
	COV, %	NA	NA	NA
I-35/SH-130 HMA Base, Section 1	Mean, pcf	142.4	142.0	139.9
	COV, %	1.2	3.0	1.4
I-35/SH-130 HMA Base, Section 2	Mean, pcf	---	---	---
	COV, %	---	---	---

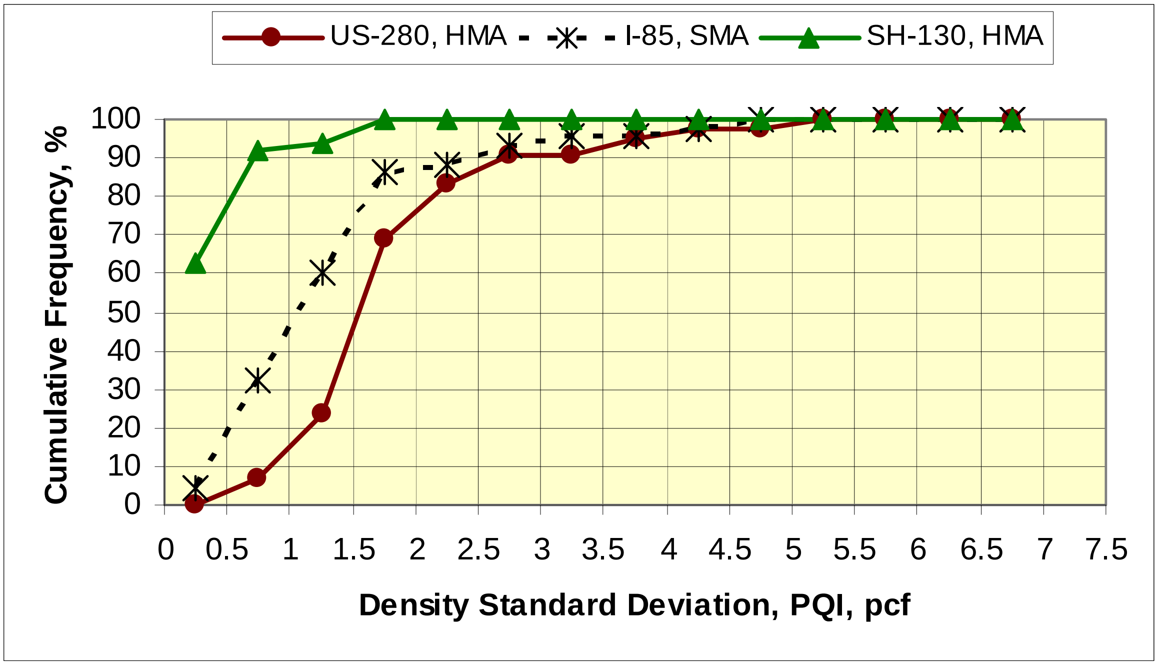
Note: The shaded cells designate those areas with anomalies (refer to table 47).

Table 57. Summary of the Densities Measured with the Non-Nuclear PaveTracker Along Projects Included in Part B

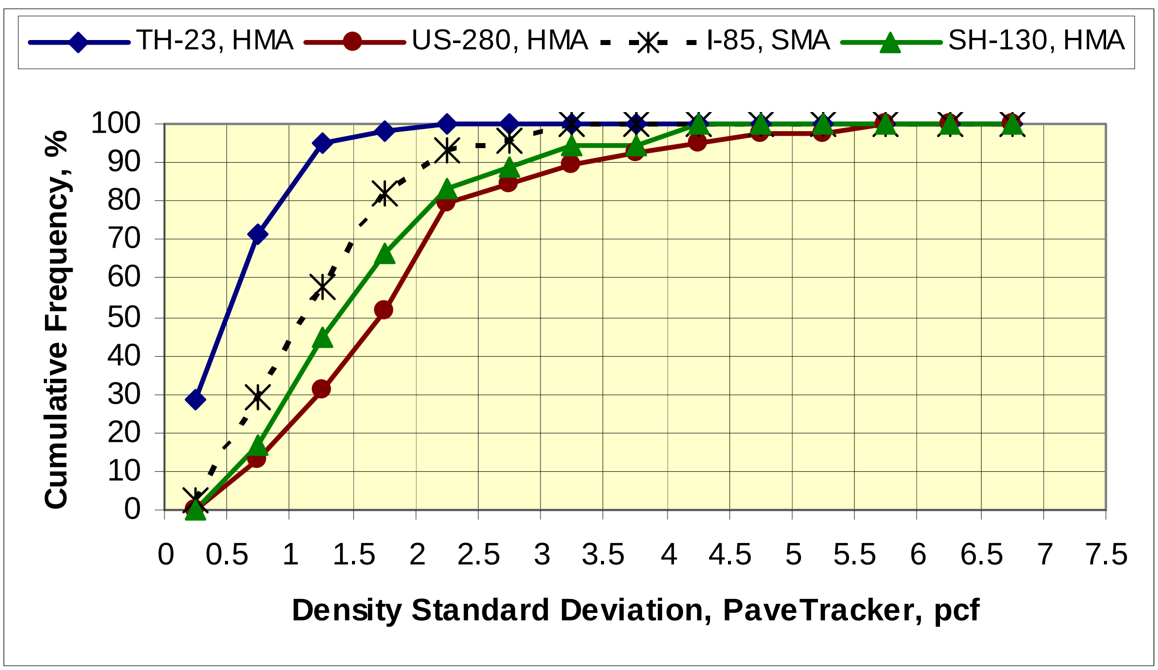
Project Identification	Section and Material	Mean Density, pcf	Coefficient of Variation, %	Standard Deviation of Means, pcf
US-47, MO	Coarse-Graded Base	131.3	3.2	4.22
	Fine-Graded Wearing Surface	136.3	2.0	2.77
I-75, MI	Dense-Graded Surface Mix; Type 3-C	156.0	2.3	3.60
	Dense-Graded Base Mix	145.5	2.5	3.66
US-2, ND	Coarse-Graded Base Mix; PG58-28	132.8	1.1	1.44
US-53, OH	Coarse-Graded Binder Mix	158.0	1.3	2.04
I-20, TX	Coarse-Graded Binder Mix, CMHB	122.7	1.6	2.01
NCAT, Alabama	Surface Mix; 45% RAP, PG67; E-5	124.5	0.9	1.13
	Surface Mixture; 45% RAP, PG76, SBS ; E-6	125.0	1.3	1.46
	Surface Mixture; 45% RAP, PG76, Sasobit ; E-7	124.9	1.0	1.25
NCAT, Florida	Coarse-Graded Base Mix; PG67; N-1	130.9	1.3	1.78
	Coarse-Graded Base Mix; PG76; PMA; N-2	131.5	1.0	1.28
NCAT, Missouri	Dense-Graded Surface Mix; PG76; N-10	139.9	1.4	1.97
NCAT, SC	Coarse-Graded Base Mix; PG67; S-11	134.1	0.7	0.98

Figure 71 shows a comparison of the measured densities with different devices when proper calibration procedures are followed closely. As shown, both non-nuclear devices resulted in densities similar to those measured with a nuclear density gauge. These test results note the importance of calibration to local materials for both devices to be considered for use in a QA program. Figure 72 shows the distribution of the standard deviation between the PaveTracker and PQI. Both result in similar variability when testing the same mixtures. Results from the PQI device will be used in comparison to the other NDT test results, because of this calibration and more extensive use of the device on the projects where the other NDT devices were used.

Table 58 summarizes the densities in areas with anomalies or features—along longitudinal joints and in areas with segregation. As shown, the PQI generally measured lower densities along the longitudinal joints, as expected. However, the densities measured in the segregated areas were generally similar to those measured in those areas without segregation. A confounding factor related to the initial testing along US-280 is that wet weather in the form of a light drizzle occurred about halfway through the test program. Without question, some of the surface voids contained water below the surface when the test program was resumed. In fact, the operator made note that the densities began to consistently increase along the roadway after the wet weather began.



(a) PQI Gauge.



(b) PaveTracker Gauge.

Figure 67. Cumulative Frequency of the Standard Deviation for the Non-Nuclear Density Gauges

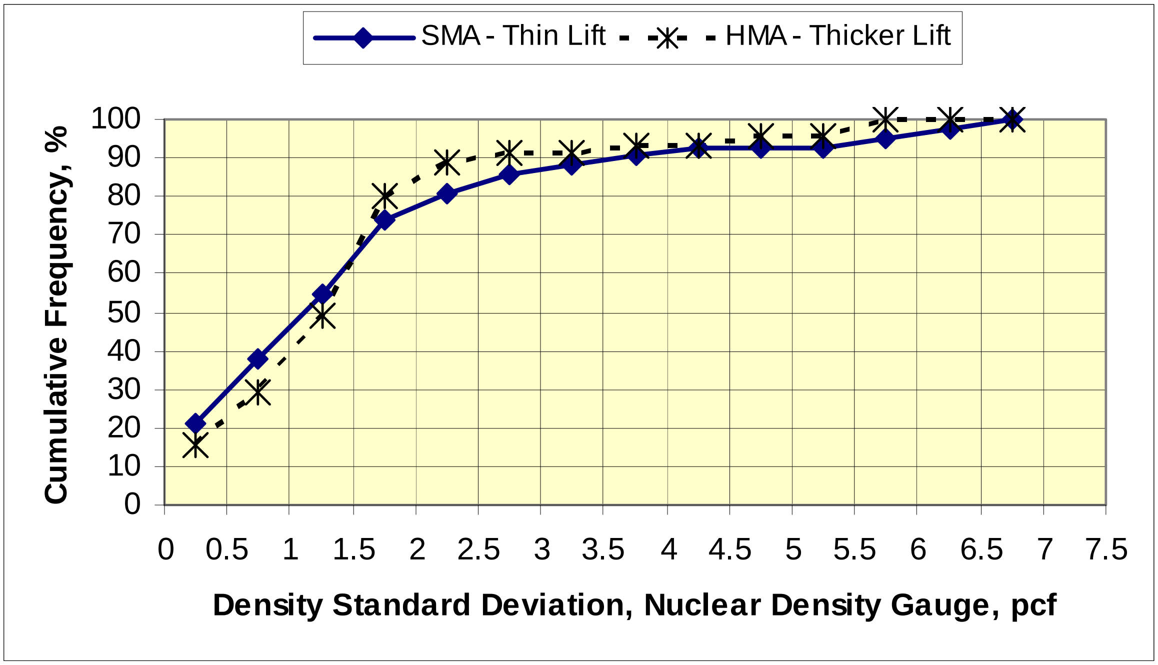


Figure 68. Cumulative Frequency of the Standard Deviation for the Nuclear Density Gauges

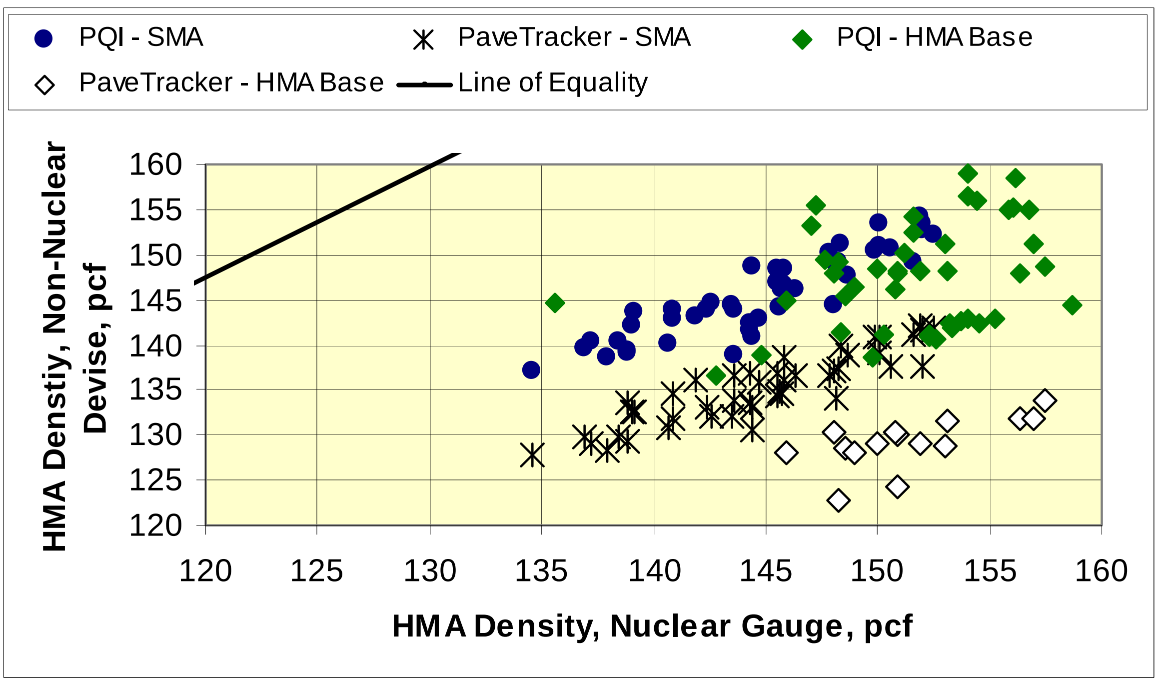


Figure 69. Comparison of Densities Measured with the PQI and PaveTracker (without Proper Calibration) Devices to Those Measured with a Nuclear Density Gauge

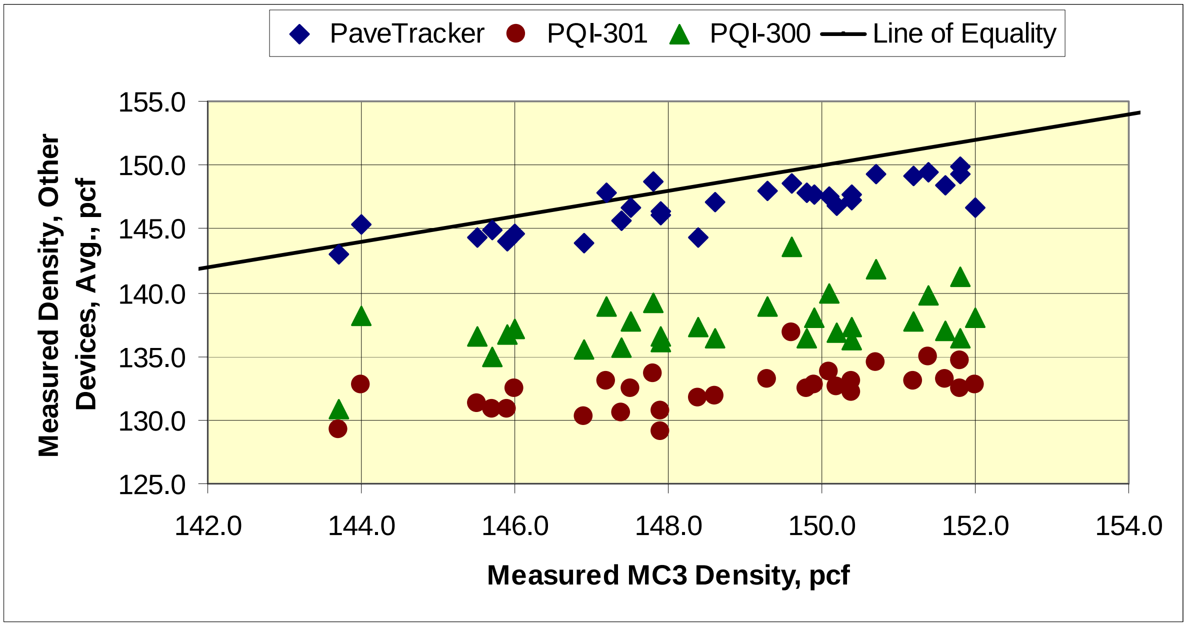


Figure 70. Comparison of Densities Measured with the PQI (<u>without Proper Calibration</u>) and PaveTracker Devices to Those Values Measured with a Nuclear Density Gauge (courtesy of the Wisconsin DOT)

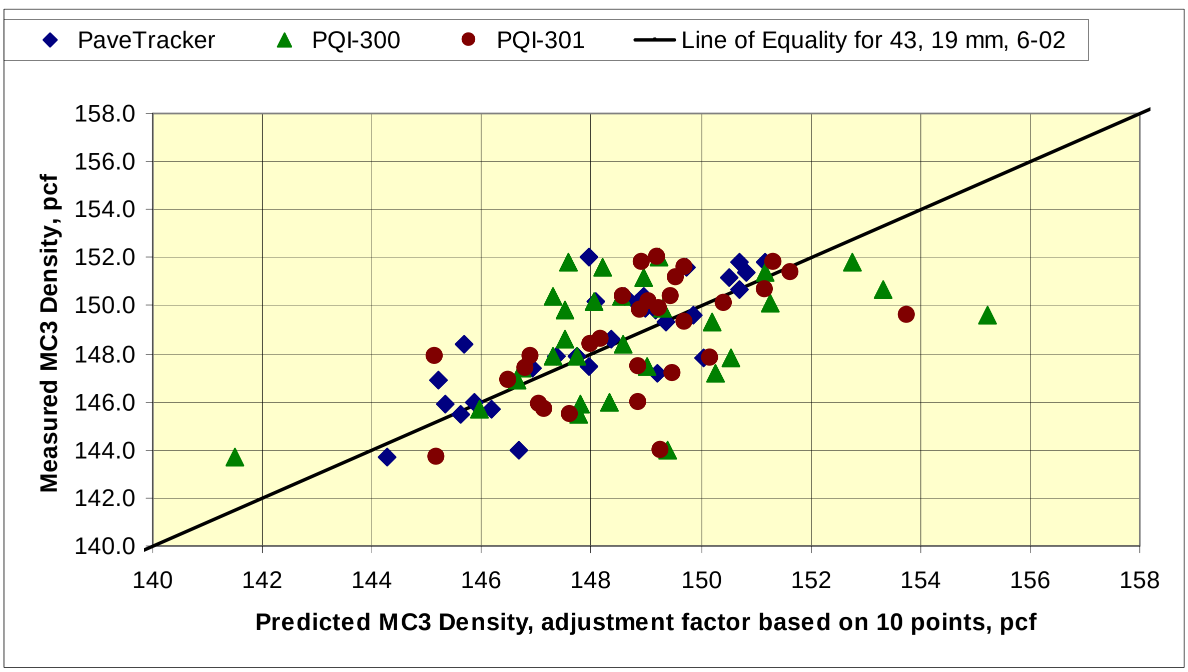


Figure 71. Comparison of Densities Measured with a <u>Properly Calibrated PQI and PaveTracker</u> to Those Values Measured with a Nuclear Density Gauge (courtesy of the Wisconsin DOT)

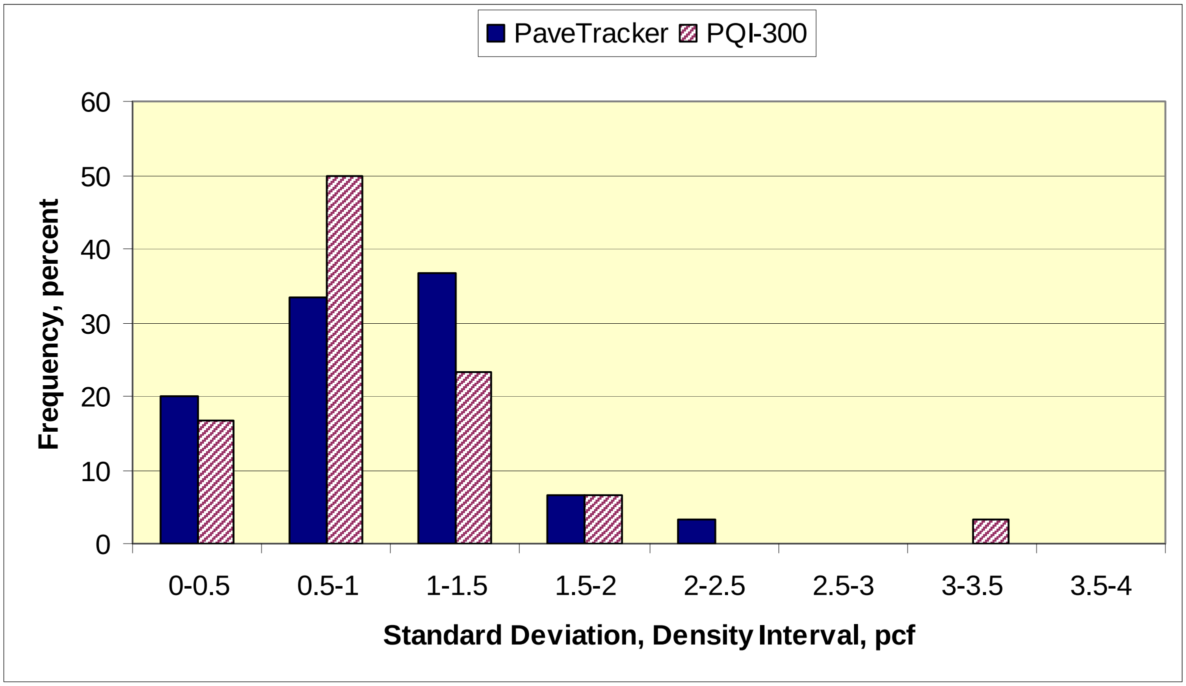


Figure 72. Comparison of the Standard Deviations for Each of the Non-Nuclear Density Gauges Resulting from the Wisconsin Project (courtesy Wisconsin DOT)

Table 58. Summary of the Densities Measured with the PQI Along Longitudinal Joints and in Areas with Limited Segregation

Project	Location/Area		Lane Interior	Area with Feature	Ratio
LONGITUDINAL JOINTS					
US-280 HMA Base; Initial Sections	Multiple Days After Paving	Mean, pcf	148.0	145.7	0.984
		COV, %	1.20	2.9	
US-280 HMA Base; Supplemental Sections	Section 1, During Paving	Mean, pcf	139.6	135.8	0.973
		COV, %	1.42	4.3	
I-35/SH-130 HMA Base	Multiple Days After Paving	Mean, pcf	126.4	118.8	0.940
		COV, %	0.93	1.4	
	During Paving	Mean, pcf	125.1	120.1	0.960
		COV, %	0.80	1.2	
SEGREGATED AREAS					
US-280 HMA Base; Initial Sections	Section 1, Lanes A,B	Mean, pcf	148.9	147.6	0.991
		COV, %	0.83	4.8	
	Section 1, Lane C	Mean, pcf	146.3	146.6	1.002
		COV, %	0.95	2.6	
US-280 HMA Base; Supplemental Sections	Section 2	Mean, pcf	139.5	136.6	0.979
		COV, %	2.78	1.2	
NOTE: The ratio listed above is the mean density measured at the feature divided by the density measured within the interior of the lane or area.					

The cells in Tables 55 and 56 that correspond to those conditions listed in Table 47 have been shaded. The following list summarizes the results of the non-nuclear density gauges in accordance with those conditions listed in Table 47:

- TH-23 HMA Base – The non-nuclear density gauges found that the higher densities were from section 1, while sections 2 and 3 had similar densities. The lower density was measured along lane C within section 2. Lower densities would be expected in areas with the lower asphalt content. However, construction records only indicate that section 2 had the lower asphalt content.
- I-85 SMA Overlay – The PQI definitely measured higher densities in lanes A and B of section 2 with the higher asphalt content. In addition, the PQI found the lower densities consistently along lane C of all areas tested. This finding is consistent with the visual observations made during paving.
- US-280 HMA Base – The PQI found that section 2 of the project used for the initial testing had the highest density. This finding is consistent with the GPR test results, but inconsistent the seismic results. This finding or observation is discussed in greater detail in the next paragraph.
- US-280 HMA Base – The PQI found that the density in the segregated areas was slightly lower in most cases than in the areas without segregation. This difference was much less than expected based on previous experience. Conversely, the PQI measured large differences between the density along the longitudinal joints and interior of the lane tested. However, the densities measured along I-35/SH-130 project are low for both the interior and joint readings. It is believed that the measured densities are not representative of the in place values. Low densities were measured for both multiple days after placement as well as for immediately after compaction. The reason for this finding is unknown.

As noted above, lower densities are expected in areas with lower asphalt content. However, the PQI found a much higher density in the area with lower asphalt content. The reason for these higher densities and lower air voids is believed to be related to moisture, as noted above. During the test program, the HMA surface became wet from earlier rains in the area. Water may have filled some of the permeable voids, especially in some of the segregated areas. Figure 69 showed the PQI density in comparison to those measured with a nuclear gauge. As shown, the density measurements made on the SMA are related and linear. However, there is extensive scatter for the HMA base mixture (the US-280 project). This scatter is believed to be related to moisture in the mixture from previous rains.

More importantly, two groups of PQI HMA base density data are shown in the figure: one from the initial sections and the other from the supplemental sections. The initial sections have the higher densities, as measured by the PQI. Table 59 shows the average densities, seismic modulus values, and air voids measured on the mixture placed between these two time periods. The density was found to be much lower on the mixture placed after initial testing. Conversely, the air voids were found to be lower and the seismic modulus higher. The density and seismic modulus are different enough to suggest a change in material, even though the results contradict one another. Thus, dynamic modulus tests were performed on samples from both testing areas (presented in section 5.5).

Table 59. Summary of HMA Properties Measured on Mixtures Placed During Different Time Periods

NDT Device	Mixture Property	HMA Mixture Placed:	
		Initial Area Used for Testing	Supplemental Area; After Initial Testing
PQI	Density, pcf	149.7	139.3
PSPA	Seismic Modulus, ksi	415	540
GPR	Air Voids, %	6.2	5.6

5.4.5 Roller-Mounted-Density and Stiffness Measuring Devices

The Bomag Asphalt Manager IC roller was scheduled to be used to compact the SMA overlay in the areas where other NDT tests were planned as a demonstration. The IC roller was transported to the I-85 project (refer to Figure 22 in chapter 3), but the demonstration was postponed because of a problem that occurred with one of the roller's components.

The IC roller was used to compact the HMA base along US-280, north of Opelika, Alabama, after the component had been repaired. In summary, a nuclear density gauge and the PQI were used to measure the HMA density after each pass of the IC roller. These data were used to prepare densification curves and evaluate the changes in the measured responses of the IC roller to increases in density of the HMA layer.

The density measurements made with each device were compared to the E_{vib} readings from the IC roller. Figures 73 and 74 compare the density and E_{vib} readings, while Figure 89 is an example of one of the densification curves that were prepared during this demonstration. The IC roller was able to adequately compact the HMA base mixture to a density of 153 pcf using the nuclear density gauge (Figure 74) or a value of 144 pcf using the PQI. The densities measured with the nuclear density gauge in this area, but without use of the IC roller, averaged about 151 pcf, while those measured with the PQI averaged about 142 pcf. Both gauges showed an increase in density of about 2 pcf with just the IC roller (no other roller was used). The contractor's compaction operation included the use of two rollers to achieve the same density level.

Figure 75 shows the benefit of using the E_{vib} to determine when the correct number of passes has been used to reach density. The density gauges and the IC roller, through monitoring the E_{vib} value, showed no additional increase in density of the mixture with continued passes of the IC roller. This additional information during lift compaction would be a benefit to most roller operators to ensure that an adequate density or stiffness of the HMA mixture had been reached.

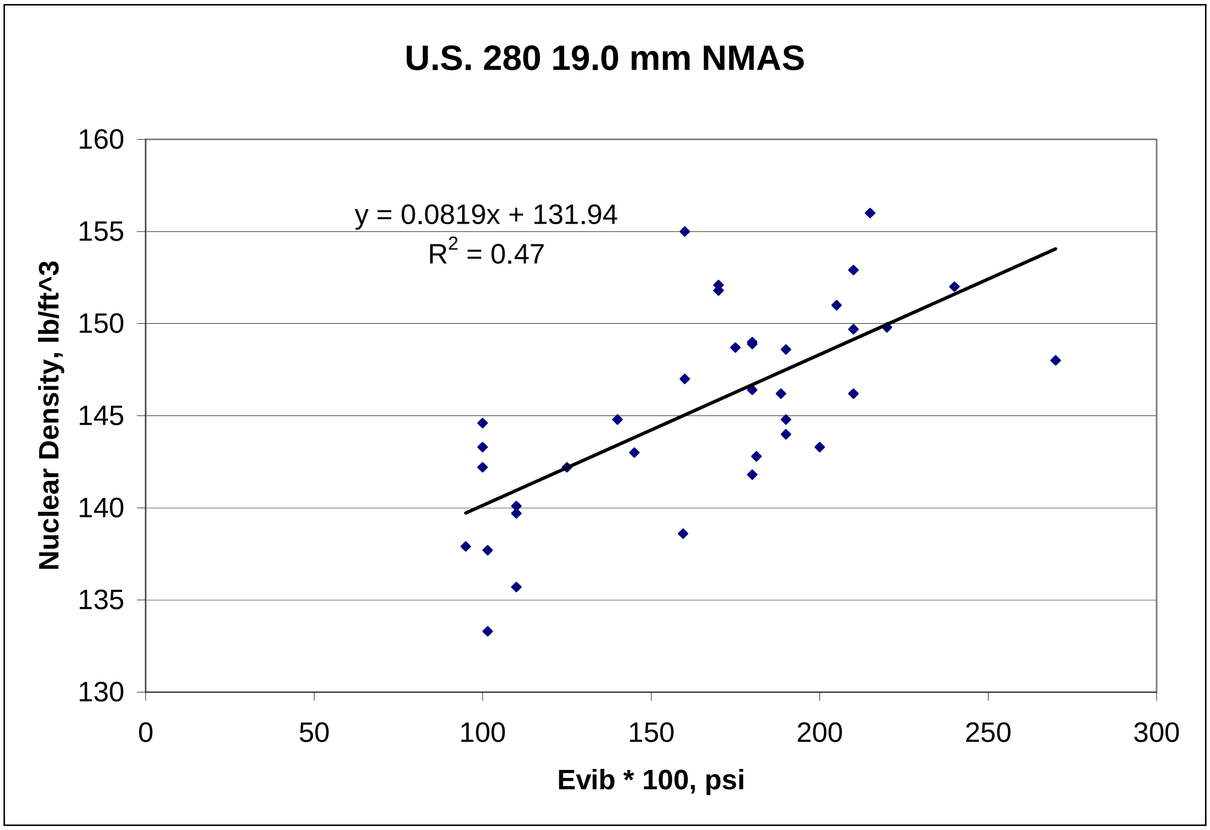


Figure 73. Comparison of the Nuclear Density Gauge Readings to the E_{vib} Values Measured with the IC Roller

As shown in Figures 73 and 74, both the nuclear and PQI gauges resulted in a large amount of data scatter. It should be noted that only 1 density measurement was taken at each of the 12 points along the compaction control strip, whereas 5 density readings were taken at each test point for the other areas tested. It is expected that the fewer density readings caused some of this scatter in the data. The reason for taking one density reading was not to delay the IC roller in compacting the HMA lift, because of mixture cooling with time. Although there is scatter in the data, this demonstration clearly showed the relationship between the density gauge readings and the E_{vib} value measured with the IC roller.

The PSPA was also used to measure the seismic modulus of the HMA mixture at the same points used to prepare the densification curves. The average values from this area are included in Table 48. The average seismic modulus measured in this area (the control strip) was 269 ksi, as compared to an average value of 239 ksi without the use of the IC roller. The seismic tests suggest a definite increase in the stiffness of the mixture, in addition to the increase in density. This demonstration clearly identified the potential benefit of using the IC roller for compacting HMA mixtures. The one major issue that has yet to be resolved is correctly taking into account the effect of decreases in temperature on the increase in E_{vib} during compaction of the HMA lift.

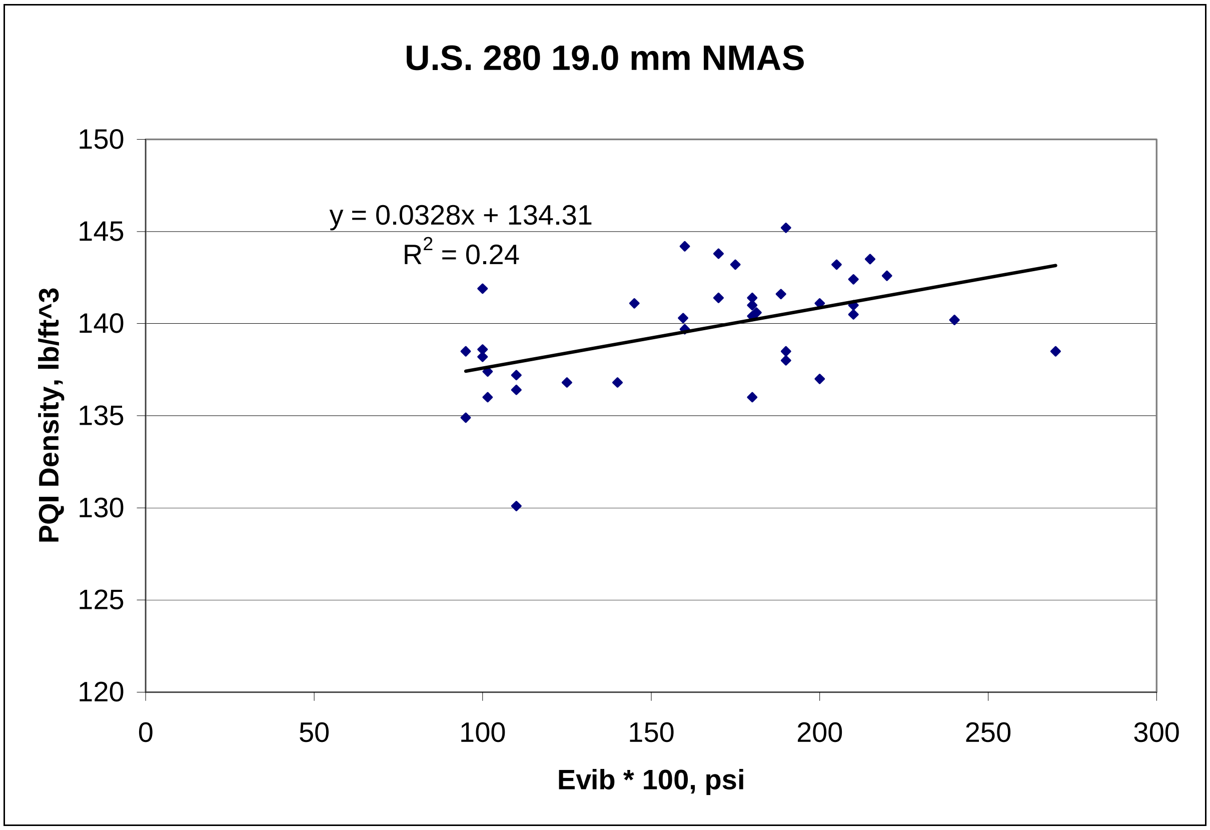


Figure 74. Comparison of the PQI Density Readings to the E_{vib} Values Measured with the IC Roller

5.5 Laboratory Measured Modulus

Dynamic modulus tests were conducted on all HMA mixtures, while repeated load resilient modulus tests were conduced on all unbound granular base materials and subgrade soils included in the field evaluation. The test results from these laboratory tests are included in Appendix C and discussed further in the following paragraphs for each material.

5.5.1 Unbound Aggregate Materials/Embankments and Subgrade Soils—Resilient Modulus Values

Laboratory repeated load resilient modulus tests were completed for all of the unbound materials at the average in-place densities and moisture contents. The resilient modulus tests were performed in accordance with the provisional test procedure that resulted from NCHRP 1-28A. Twelve resilient modulus values were measured for each test specimen and are provided in Appendix B. However, only one stress state was used for consistency in comparing the field estimated elastic modulus values from each NDT device to values measured in the laboratory. Table 60 summarizes the resilient modulus values measured in the laboratory at a low stress state for the unbound aggregate base materials and embankment soils included in the field evaluation (Parts A and B).

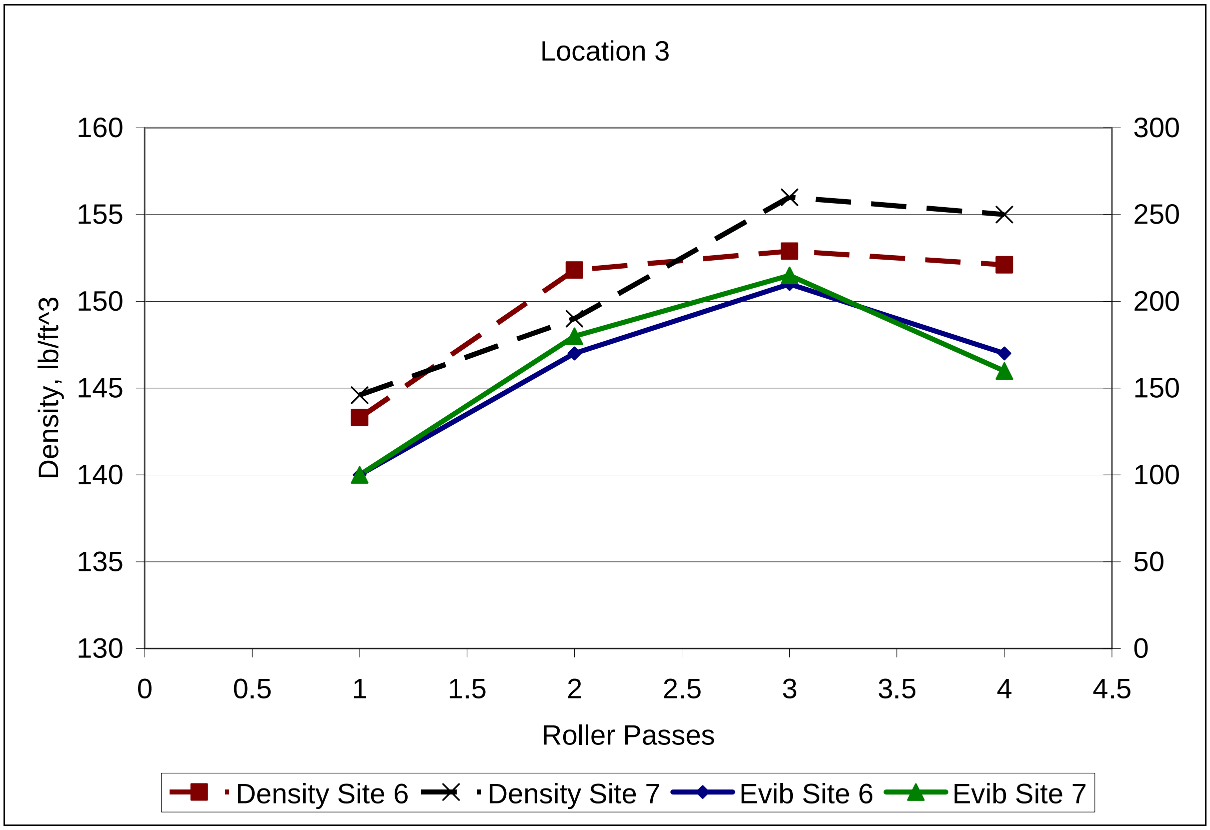


Figure 75. Example of a Density Growth Curve Prepared from the IC Roller Demonstration and NDT Results

As noted above, the test specimens were compacted to the average dry density and moisture content reported from the construction records. The dry density, moisture content, and percent compaction that apply to each area tested are also summarized in Table 60. Table 45 listed the optimum moisture contents and maximum dry densities resulting from M-D relationships for each material.

In general, the resilient modulus values measured in the laboratory increase with the quality of the material. The dense crushed stone base material placed along US-280 has the highest resilient modulus, while the I-85 low plasticity silty-clay soil embankment prior to IC rolling had the lowest resilient modulus.

The high plasticity clay subgrade along SH-21 has a much higher resilient modulus than expected based on previous testing experience with this soil (Von Quintus, 1980 to 1996). Two potential reasons for the larger values are that the average water content at testing (18.4 percent) was below the optimum water content (21.9 percent) and some gravel was mixed in with the upper subgrade soil. Water contents below the optimum value and approaching the plastic limit of the soil can significantly increase the resilient modulus. Similarly, the improved granular embankment placed along SH-130 was found to have a larger value than expected. It is believed that the higher in-place densities (above the maximum dry unit weight) account for the higher modulus values. In addition, lime was used on this project to stabilize some of the subgrade soils. Visual observations of the material suggest that lime may have also been used in the improved embankment layer.

Conversely, the South Carolina crushed granite base placed at the NCAT test track (test section S-11) had a much lower resilient modulus (14.3 ksi) than expected. One possible reason for this low value is that the density during NDT was well below the maximum dry density, in addition to the water content also being below the optimum value for this material (AASHTO T 180).

Table 60. Summary of Average Repeated Load Resilient Modulus Values Measured in the Laboratory at a Specific Stress State

Project & Materials	Area		Dry Density, pcf	Moisture Content, %	Percent Maximum Density, %	Laboratory Resilient Modulus, ksi
I-85 Low Plasticity Clay Embankment	Before IC Rolling	Section 1, Lanes B,C,D	103.0	21.6	0.91	2.5
	After IC Rolling	Section 1, Lanes B,C,D	108.0	16.9	0.96	4.0
NCAT; Oklahoma High Plasticity Clay			96.7	21.3	0.97	6.9
NCAT; South Caroline Crushed Granite Base			130.0	4.7	0.94	14.3
TH-23 Embankment, Silt-Sand-Gravel Mix	South Section	Lanes A,B	121.0	8.2	0.98	16.0
	North Section	Lane B,C	122.4	9.1	1.00	16.4
US-2 Embankment; Soil-Aggregate Mix			123.1	12.1	0.96	19.0
NCAT; Missouri Crushed Limestone Base			124.4	9.0	0.96	19.2
SH-21 High Plasticity Clay	Area 1, with IC rolling	Lanes A,B	107.3	18.4	0.99	26.8
TH-23 Crushed Aggregate Base	Middle Area	Lane B	139.4	4.3	1.04	24.0
	South Area	All Lanes	141.1	4.2	1.03	24.6
US-53 Crushed Aggregate Base, Type 304			136.0	9.1	1.01	27.5
NCAT; Florida Limerock Base			110.5	13.4	0.95	28.6
US-2 Class 5 Crushed Aggregate Base			134.4	5.9	0.95	32.4
SH-130 Improved Granular	Sections 2, 3	Lanes A,B	128.7	9.1	1.05	35.3
US-280 Crushed Stone	Areas 1,2,3		150.6	3.2	1.01	48.4

NOTES:

- Resilient modulus values for the fine-grained soils and embankments are for a low confining pressure (2 psi) and repeated stress of 4 psi, while a confining pressure of 6 psi and repeated stress of 6 psi was used for the granular base materials. These low stress conditions are not based on any theoretical analysis. One stress state for the embankment soils and one for aggregate base layers were selected for consistency in comparing the field estimated elastic modulus values from each NDT device to values measured in the laboratory, which were considered the target values.
- Percent maximum density is based on the maximum dry unit weight or density from the moisture-density relationship (the maximum dry densities were included in table 45 for each material tested).

5.5.2 HMA Mixtures—Dynamic Modulus Values

Laboratory dynamic modulus tests were performed on all HMA mixtures sampled during construction in accordance with the provisional standard recommended for the MEPDG. The dynamic modulus was measured without confinement for five test temperatures (14, 40, 70, 100, and 140 F) and six loading frequencies (0.1, 0.5, 1.0 5.0, 10.0, and 25.0 Hz.). All dynamic modulus data measured on test specimens compacted to the in-place air voids and density are provided in Appendix C. Table 61 summarizes the dynamic modulus measured at temperatures of 70 and 130 F and a loading frequency of 5.0 Hz. These values were used for relative comparison purposes between the mixtures.

Samples were recovered from the US-280 HMA base mixture for the two testing periods along the US-280 reconstruction project. As listed in Table 61, the dynamic modulus measured on bulk mixture recovered from both time periods is significantly different. The results from the laboratory dynamic modulus tests confirmed the NDT results that identified significant differences between the mixtures placed for the initial and supplemental sections. Thus, these two areas were treated as separate projects or mixtures in the analyses. The reason for this difference is unknown.

Table 61. Summary of Dynamic Modulus Values Measured in the Laboratory

Part	Project Identification	Layer/Mixture	Dynamic Modulus, ksi	
			130 °F & 5 Hz	70 °F & 5 Hz
B	I-75, Michigan	Dense-Graded Binder; Type 3-C	190	611
B	NCAT, Florida	Base, Mix, Sect. N-1; PG67	203	1,163
B	NCAT, S. Carolina	Base Mixture; Sect. S-11; PG67	214	1,228
B	I-75, Michigan	Fine-Graded Surface; Type E10	255	780
A	I-85, Alabama	Wearing Surface; SMA Mixture	230	1,485
B	NCAT, Alabama	Surface; 45% RAP; Sect. E-5, PG67	250	1,414
B	US-47, Missouri	Fine-Graded Surface	276	770
A	TH-23, Minnesota	HMA Base Mixture	319	1,848
A	US-280, Alabama	HMA Base; Initial Area	330	1,950
B	US-47, Missouri	Coarse-Graded Base; Shoulder	344	1,076
B	US-2, N. Dakota	Coarse-Graded Base; PG58-28	356	1,052
B	NCAT, Florida	Base Mix, SBS, Sect. N-2, PG76	366	1,614
B	NCAT, Alabama	Surface; 45% RAP, Sect. E-7; PG76 (Sasobit)	421	1,813
B	NCAT, Alabama	Surface; 45% RAP, Sect. E-6; PG76 (SBS)	427	1,836
B	US-53, Ohio	Coarse-graded Binder Mix	479	1,053
B	I-20, Texas	HMA Base Mixture, Type CMHB	520	1,600
A	US-280, Alabama	HMA Base; Supplemental Area	613	2,668
A	SH-130, Texas	HMA Base	965	4,271

5.5.3 Comparison of Laboratory Measured Modulus to NDT Measured Values

Resilient Modulus of Unbound Materials

Table 62 summarizes the laboratory resilient modulus and average modulus values estimated from the different NDT devices of each area tested within Part A. As shown, the GeoGauge and DSPA provided a reasonable ranking of each area tested, followed by the DCP. The deflection measuring devices did a poor job. This correspondence between the NDT and laboratory determined values would not change if a different stress state was used.

Table 62. Elastic Modulus Values Estimated from the NDT Technologies and Devices, Without Adjustments, in Comparison to Resilient Modulus Values Measured in the Laboratory

Project	Material	Area	Modulus, ksi				
			Lab.*	GeoGage	DSPA	DCP	LWD
I-85 Embankment Before IC Rolling	Low Plasticity Clay	Section 2, Lane A	2.2	10.6	24.1	5.0	---
		Section 1, All Lanes	2.5	15.4	30.0	5.9	---
		Section 2, Lanes B, C, D	2.5	17.0	36.6	5.2	---
I-85 Embankment After IC Rolling	Low Plasticity Clay	Section 1	4.0	16.8	30.4	6.9	9.99
		Section 2	4.5	19.0	40.4	6.2	11.78
TH-23 Embankment	Silt-Sand-Gravel Mix	So. Section, Lane C	15.0	13.2	31.1	11.5	5.6
		So. Sect., Lanes A,B	16.0	18.3	43.6	15.2	5.7
		No. Sect., Lanes B,C	16.4	17.8	35.7	19.0	4.7
		No. Sect., Lane A	17.0	22.0	51.7	18.5	4.7
SH-21 Subgrade	High Plastic Clay	No IC Rolling	22.0	19.6	23.6	11.9	---
		After IC Rolling	26.8	22.9	27.1	8.8	9.6
TH-23 Base	Crushed Aggregate Base	Middle Sect., Lane C	19.5	21.6	28.0	18.6	8.0
		North Section, All Lanes; Middle Section Lanes A, B	24.6	28.2	79.3	33.1	12.3
		South Section, Lanes A, B	26.0	33.0	110.7	46.4	19.4
SH-130 Improved Embankment	Granular	Section 3	34.5	19.4	33.3	20.7	24.1
		Sections 1, 2	35.3	26.4	34.3	21.3	24.6
US-280 Base	Crushed Stone	Area 4	40.0	35.1	117.4	34.3	18.5
		Areas 1, 2, 3	48.4	47.9	198.6	50.3	46.5

NOTES:
* - The repeated load resilient modulus values measured in the laboratory, but corrected to the actual dry density and moisture content measured for the specific section, in accordance with the LTPP procedure and regression equations.

Figure 76 compares the NDT results and those values measured in the laboratory. As shown, the GeoGauge provided a reasonable estimate of the laboratory values across all materials included in the Part A field study (fine-grained soils to crushed stone), with the exception of the I-85 fine-grained, low-plasticity embankment. The DCP also provided a reasonable estimate of the laboratory resilient modulus values. The elastic modulus values estimated from both the DSPA and LWD devices increase with increasing values measured in the laboratory but have a significant bias. The DSPA has a positive bias or over-estimates the laboratory values, while the LWD has a negative bias or under-estimates those values and has the greater dispersion.

Dynamic Modulus of HMA Mixtures

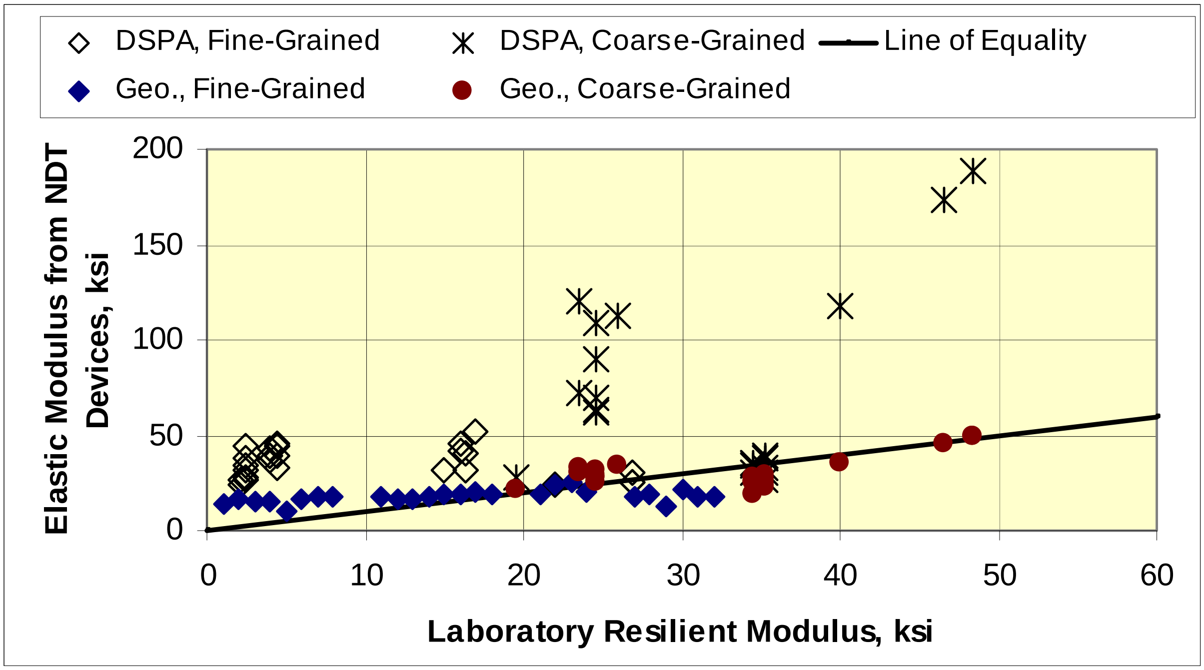
Unlike for unbound materials, the modulus of HMA mixtures is affected significantly by temperature and frequency. The PSPA values can be adjusted to a temperature and load frequency selected for design. The internal adjustments are included in the software and initially based on global default values. However, these default adjustments can be determined in the laboratory by measuring the seismic modulus on test specimens prepared during the mixture design process, on bulk mixture compacted to the density or air void level expected during construction, or on field cores recovered during construction.

Global default values initially were used to calculate the seismic modulus at a load frequency of 5 Hz for the field evaluation projects. Table 63 compares the seismic and deflection-based moduli to values measured in the laboratory. The in-place temperatures for the laboratory values included in Table 63 were measured with multiple devices during NDT. An average mix temperature was used to estimate the laboratory dynamic moduli listed in Table 63. The FWD deflection-based moduli were calculated from the deflection basins using a forward-calculation program. Figure 77 compares the PSPA and laboratory measured HMA modulus values. As shown, the PSPA moduli appear to correlate to the laboratory measured values. The FWD moduli are significantly different than those measured in the laboratory.

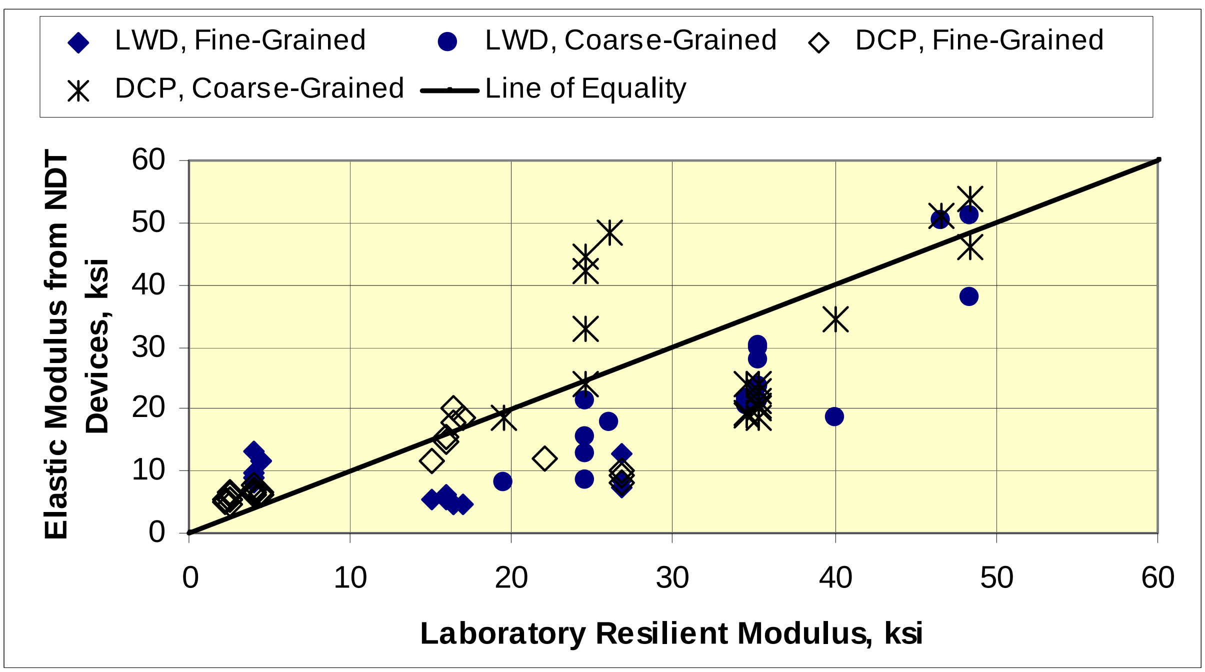
Two factors, however, have a significant effect on the use of global adjustments. The first is that asphalt binders have different temperature susceptibilities, so the use of a constant global adjustment can result in a significant error. The second is that laboratory compacted test specimens for the dynamic modulus testing do not have checking and mat tears, while field tests are subjected to these fractures which can have a significant effect on the NDT measurements. These issues will be evaluated and discussed in greater detail in chapter 7 of Part III of the research report.

5.6 Summary of Field Projects

A diverse range of HMA mixtures and unbound materials/soils were included in the field evaluation of NDT devices (see Table 29). Appendix B provides a summary of each project. Tables 31 and 47, within this chapter, listed the anomalies that exist along those projects included in the Part A field evaluation. Although no anomalies were planned for the Part B projects, construction defects were observed on some of the projects. At the end of this chapter is a listing of those defects and material issues that should have an impact on the quality characteristics measured by the QA tests. The effectiveness of the NDT devices in measuring these defects is discussed in Part III of the research report.



(a) DSPA and the GeoGauge.

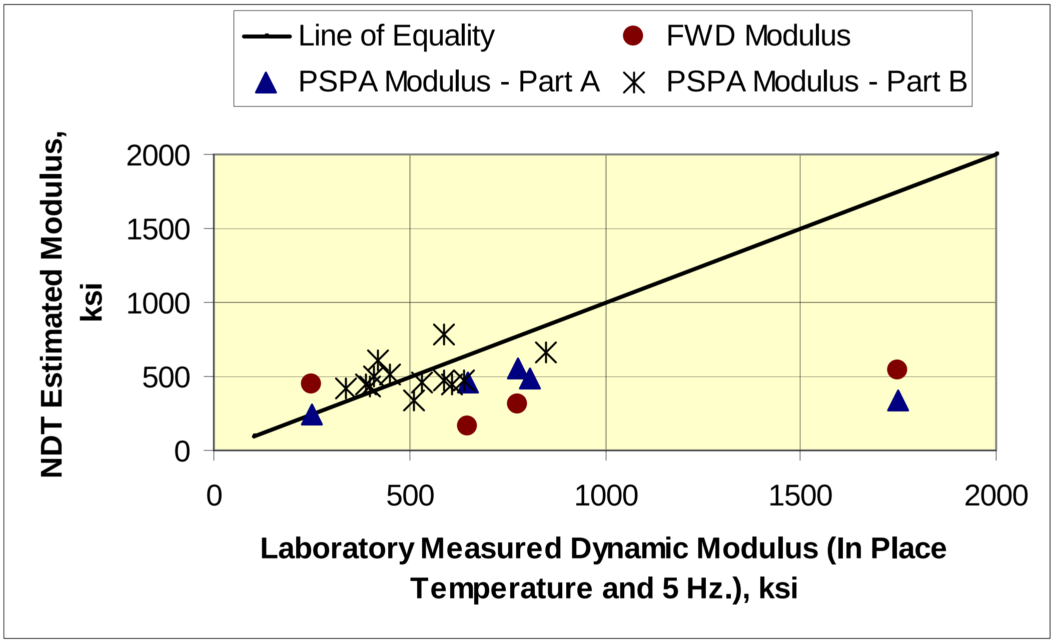


(b) Deflection-Based and DCP methods.

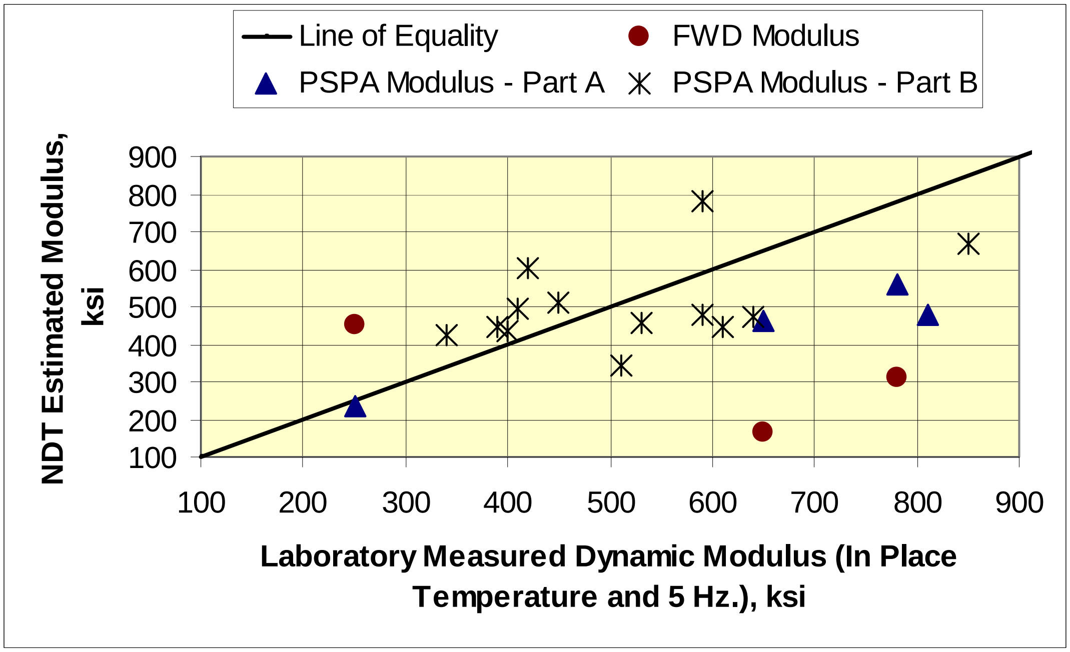
Figure 76. Comparison of Laboratory Resilient Modulus and the Elastic Modulus Values Estimated with Different NDT Technologies and Devices

Table 63. Elastic Modulus Values Estimated from NDT Devices, Without Any Adjustments, in Comparison to Dynamic Modulus Values Measured in the Laboratory

Part	Project Identification	Layer/Mixture	Laboratory Values, ksi		NDT Values, ksi	
			130 °F & 5 Hz	In Place Temp. & 5 Hz	PSPA	FWD
B	I-75, Michigan	Dense-Graded; Type 3-C	190	400	435.2	---
B	NCAT, Florida	Base, Mix; PG67	203	390	447.1	---
B	NCAT, S. Carolina	Base Mix; PG67	214	410	495.2	---
B	I-75, Michigan	Fine-Graded Surface; Type E10	255	590	676.3	---
A	I-85, Alabama	SMA Mixture	230	250	237	450
B	NCAT, Alabama	45% RAP; Sect. E-5, PG67	250	450	510.7	---
B	US-47, Missouri	Fine-Graded Surface	276	530	457.6	---
A	TH-23, Minnesota	HMA Base Mixture	319	810	480	---
A	US-280, Alabama	HMA Base; Initial Area	330	650	462	165
B	US-47, Missouri	Coarse-Graded Base	344	420	605.3	---
B	US-2, N. Dakota	Coarse-Graded Base; PG58-28	356	510	344.3	---
B	NCAT, Florida	Base Mix, SBS, PG76	366	590	475.8	---
B	NCAT, Alabama	45% RAP, Sect. E-7; PG76 (Sasobit)	421	610	444.3	---
B	NCAT, Alabama	45% RAP, Sect. E-6; PG76 (SBS)	427	640	473.4	---
B	US-53, Ohio	Coarse-graded Binder Mix	479	850	666.7	---
B	I-20, Texas	HMA Base, CMHB	520	340	435.5	---
A	US-280, Alabama	HMA Base; Supplemental Area	613	780	558	310
A	SH-130, Texas	HMA Base	965	1,750	342	725



(a) Entire data set.



(b) Excludes data point for very stiff HMA mixture placed along SH-130.

Figure 77. Comparison of Laboratory Dynamic Modulus and the Elastic Modulus Values Estimated with Different NDT Technologies and Devices

Unbound Materials and Embankments:	No construction defect was observed in any of the Parts A and B projects. As listed in Table 44, however, there were differences in the condition of the base materials and embankments that were planned to ensure that the NDT devices would identify those differences.
HMA Mixtures:	
• US-280 HMA Base	Truck-to-truck segregation observed in some areas. Cores were taken in these areas, but some of the cores disintegrated during the wet coring process. In addition, a significant difference in dynamic modulus was found between the initial and supplemental sections included in the test program. The supplemental section was found to have much higher dynamic modulus values. This difference was not planned.
• I-85 SMA Overlay	No defects noted.
• TH-23 HMA Base	No defects noted.
• SH-130 HMA Base	No defects noted during the time of testing, but there was controversy on the mixture because it had been exhibiting checking during the compaction process. Changes were made to the mixture during production. The change made and the time that the change was made were unclear relative to the time that the NDT evaluation.
• US-47 HMA Base	The mixture was tender; and shoved under the rollers.
• US-47 Wearing Surface	Portions of this mixture were rejected by the agency in other areas of the project.
• I-75 HMA Base, Type 3-C	No defects noted, but mixture was tender – placed along the shoulder.
• I-75 HMA, Type E3 & E10	No defects noted, but portions of this mixture were rejected by the agency in other areas of the project.
• US-2 HMA Base	Checking and mat tears observed under the rollers.
• US-53 HMA Base	No defects noted.
• I-20 HMA CHMB Base	No defects noted.
• NCAT – Alabama HMA RAP; with & without modifiers	No defects noted on any of the test sections.
• NCAT – South Carolina HMA Base	No defects noted.
• NCAT – Missouri HMA Base	No defects noted.
• NCAT Florida – PMA Base	No defects noted.
• NCAT Florida – HMA Base, no modification	Checking and mat tears observed under the rollers.

Sponsor Agency	Missouri DOT
Project Location	St. Clair & Union, Missouri
Project Identification	Two-lane widening project – shoulder reconstruction and HMA Overlay across entire width of roadway. The HMA base was 4 inches in thickness, while the HMA overlay was 1.75 inches in thickness.
Materials Tested	HMA Base and HMA Wearing Surface
Special Features	Tender HMA base mixture placed along the shoulder.
Issues	Rain occurred during the shoulder placement or construction. The wet weather did not affect placement of the HMA mixture.
Positive Aspects	1. The contractor rolled the HMA mixture placed along the shoulder. The confined edge of the HMA was being rolled using the cold-side pitch method. It was observed that the HMA mixture was being pushed away from the cold joint. The PaveTracker was used to measure the density along the confined joint. The densities were low. The contractor was encouraged to change the rolling pattern – roll from the hot side of the joint. Densities were measured with both the PaveTracker and nuclear density gauge along the confined joint. The densities increased by about 5 to 8 pcf between the two rolling patterns. The contractor changed the rolling pattern to increase the joint density. 2. Another positive aspect is that the PSPA did identify the soft HMA mixture after placement through problems with obtaining a smooth waveform from the PSPA. It was originally believed that the PSPA had been damaged during transport; however, the PSPA was identifying the mixture to be tender. 3. The initial wearing surface/overlay was found to have low air voids and was rejected by the DOT. The PSPA and PaveTracker did identify these differences during construction and placement. The test results for the new mixture placed were found to be statistically different.
Negative Aspects	1. Rains resulted in delays and scheduling conflicts. The rain caused the contractor to move off of the job and return weeks later. Thus, the test equipment was not left with the contractor nor agency personnel. However, both the contractor and agency personnel did use the equipment on site during initial testing when the shoulder was being placed with positive results and comments. 2. The HMA mixture being placed along the shoulders was a soft mixture. In fact, the mixture was so soft that indentations could be observed from light loads on the mix after it had cooled down to 160F. The PSPA was used to test the HMA mixture being placed along the shoulder. This point could also be a positive aspect of the project. 3. The unbound aggregate base course was planned to be tested along the shoulder areas after the surface material had been removed, the base material scarified and compacted or removed and replaced. However, the unbound aggregate base along the shoulder area was found to be in excellent structural condition and was able to support the construction equipment. Thus, the unbound aggregate base layer was left in place without any additional compaction and work. Use of the GeoGauge, DSPA, and DCP were excluded from the field testing plan.

Sponsor Agency	Missouri DOT
Project Location	NCAT Test Track
Project Identification	New construction of two structural sections placed at the NCAT test track facility. Both test sections were instrumented by NCAT.
Materials Tested	Crushed limestone base layer and an HMA binder layer
Special Features	None. However, the pavement structure did include a high binder content base mix or crack resistant layer. This layer was not tested under the NCHRP Project 10-65.

Issues	None. However, the crushed limestone layer was compacted at a water content that was below the optimum water content. This required many more passes or coverages of the roller than expected or planned.
Positive Aspects	1. Density and modulus growth curves were measured using both the GeoGauge and DSPA devices. Two DCPs were used to measure the in place strength of the base material. 2. Density growth curves were also measured using the PaveTracker for the HMA binder mixture.
Negative Aspects	None.

Sponsor Agency	Michigan DOT
Project Location	Saginaw, Michigan; I-75
Project Identification	I-75 rehabilitation included PCC rubblization in the northbound lanes and milling and overlaying the existing HMA surface in the southbound direction with 7 inches of HMA, consisting of a 3 inch HMA base, 2 inch HMA Binder layer, 2 inch Wearing surface. The portion included in NCHRP Project 10-65 was confined to the southbound lanes.
Materials Tested	HMA 4-C base and HMA 3-C binder layers. Included both Superpave designed mixtures along the main lanes and Marshall designed mix placed along the shoulders.
Special Features	None.
Issues	Rain occurred during the testing period that delayed the paving operation, but it is believed that the rain had no impact on the HMA mixtures being placed.
Positive Aspects	Density growth curves were developed for the HMA base and binder layers.
Negative Aspects	During the testing operation, the DOT rejected about 2 miles of HMA that had been previously placed. The contractor ceased paving operations until the cause of the rejected material could be determined. The equipment was not left with the agency and contractor personnel because of this problem and dispute of test results in the DOT’s day-to-day acceptance plan. In addition, the wearing surface was not tested as part of NCHRP Project 10-65.

Sponsor Agency	North Dakota DOT
Project Location	Williston, North Dakota
Project Identification	Realignment and new construction of US-2 between Minot and Williston.
Materials Tested	HMA base layer (PG58-28); Crushed Gravel – Class 5 Base; Fine-grained embankment (soil-aggregate mix)
Special Features	The crushed aggregate base layer was tested in two conditions; the first area had been placed over a year ago, while the second area had been placed a couple of weeks prior to arrival at the project site. The surface of the crushed stone base that had been placed the previous construction season received a prime coat to protect it from construction traffic. The test equipment was left with the DOT and contractor personnel for use in testing other areas of the project as the paving materials were placed.
Issues	Rain and tornados occurred during the week of testing. The unbound materials were tested prior to the rainfall and the HMA layer was tested prior to and after the storm.
Positive Aspects	Both the DOT and contractor personnel used all gauges during and after the testing under NCHRP Project 10-65.
Negative Aspects	The HMA base mixture checked and tore during one day’s production. The checking and mat tears occurred under the finish roller – after the density had been obtained by the contractor using the breakdown and intermediate rollers. The PaveTracker and

	PSPA were used to test the area with checking. The checking and tears were found to be severe in localized areas. This is also considered to be a positive aspect of this project, in terms of using the NDT devices.

Sponsor Agency	Ohio DOT
Project Location	Freemont, Ohio
Project Identification	Realignment and widening of SR-53, near Freemont, Ohio; between Toledo and Columbus, Ohio.
Materials Tested	HMA 19 mm base mixture and crushed stone base layer (304 base material).
Special Features	None.
Issues	Rain and wet weather occurred during the week of testing. The contractor also had problems with the plant which delayed another project in the area. Thus, the contractor did not move the paving equipment and rollers back on the project until the testing under NCHRP Project 10-65 had been completed. The test equipment, however, was left with the DOT personnel for use and continued testing for the following weeks. The DOT retained the test equipment for more than two weeks.
Positive Aspects	1. Water from the recent rains had accumulated in areas with insufficient drainage to remove the rainfall from the pavement area. The DCP, GeoGauge and DSPA measured low modulus values in the areas where water had been standing and allowed to penetrate the base layer. 2. The PSPA and PaveTracker were used to test the HMA base mixture in all areas where the DOT had taken cores for acceptance testing.
Negative Aspects	No HMA paving and placement of the unbound aggregate base material was completed during the initial week of testing. Thus, density and modulus growth curves could be obtained from this project for the HMA base mixture and aggregate base layer.

Sponsor Agency	Alabama DOT
Project Location	NCAT Test Track
Project Identification	Mill and HMA overlay of three test sections along the test track.
Materials Tested	HMA wearing surface with 45 percent RAP and different asphalt binders. The asphalt used in the three sections included a PG 67-22, a PG76-22 with Sasobit, and a PG-76-22 with SBS.
Special Features	High amount of RAP in the HMA overlay and different asphalt binders.
Issues	None.
Positive Aspects	None, with the exception of comparing the density and seismic modulus for mixtures with high amounts of RAP and varying asphalt grades, as compared to mixtures without RAP.
Negative Aspects	None; however, the HMA overlay was placed a week prior to the testing under NCHRP Project 10-65. Thus, density growth curves were not obtained.

Sponsor Agency	Florida DOT
Project Location	NCAT Test Track
Project Identification	New construction; two structural sections that were constructed side by side; one with a neat asphalt mix and the other with a polymer modified asphalt mix. Both of these test sections were instrumented by NCAT.
Materials Tested	Limerock base material; a high binder content HMA base mix considered a crack resistant layer; HMA binder layer with a neat asphalt; an HMA binder layer with a

	modified asphalt.
Special Features	Pavement cross section included a 3-inch high binder base layer to resist fatigue crack initiation at the bottom of the pavement. This layer or mixture was tested. Two other HMA mixtures were tested – Florida's standard neat asphalt type mixture and another with a polymer modified asphalt.
Issues	1. The temperature of the HMA neat asphalt mix was low at the time of placement. The low temperature made getting density difficult and caused the mixture to check and tear under the rollers. 2. The HMA mixture with the neat asphalt checked during compaction in localized areas. The checking was considered severe in a localized area. The PMA and high binder content base layer did not check or team under the rollers, or at least the checking and tears were not observed during placement.
Positive Aspects	A comparison of a neat HMA mix to that of a PMA mix. The HMA neat mix did check while the PMA mix did not check. Two DCPs were used to test the limerock base layer.
Negative Aspects	None. However, the contractor had a lot difficulty in getting the required density for both the HMA neat asphalt mix and the PMA mix. A rubber tired roller was used to continue the compaction operation for many hours. The density did finally reach the required value. PaveTrack and PSPA tests were completed on the mix with the low densities, as well as with the required or specific density.

Sponsor Agency	Oklahoma DOT
Project Location	NCAT Test Track
Project Identification	New construction; two structural test sections that were built side-by-site. It was originally designed that these two sections would be full-depth HMA pavements placed over a high plasticity subgrade soil imported from Oklahoma. Both of these sections were instrumented by NCAT.
Materials Tested	High plasticity clay soil was in a relatively dry condition (with extensive and wide shrinkage cracks), and high plasticity clay soil compacted to the optimum dry density (without the shrinkage cracks that could be observed at the surface); HMA binder layer.
Special Features	Wide shrinkage cracks existed in the high plasticity clay soil at the time of initial testing for NCHRP Project 10-65.
Issues	None.
Positive Aspects	1. The effects of wide shrinkage cracks in a high plasticity clay soil can be assessed in terms of their effect on the test results from the GeoGauge and DSPA. 2. Two DCPs were also used to test the subgrade soil in different conditions. 3. Density and modulus growth curves were measured during the original compaction of the clay soil.
Negative Aspects	The surface of the high plasticity clay soil was removed, the lower soil scarified, reworked, and re-compacted, and a 6-inch layer of local chert aggregate was placed. A misunderstanding of the cross section for these structural sections had occurred. The Oklahoma DOT wanted an intermediate layer of aggregate placed between the HMA base and high plasticity clay. Thus, the NCHRP Project 10-65 tests on the high plasticity clay were performed twice.

Sponsor Agency	South Carolina DOT
Project Location	NCAT Test Track
Project Identification	New construction of a structural section at the NCAT test facility. This section was instrumented by NCAT.

Materials Tested	Crushed granite base layer; HMA base mixture and HMA binder layer.
Special Features	None
Issues	Contractor tried to use a smaller roller for compacting the crushed granite layer. The water content of the crushed granite base layer was about half of the water moisture content. Contractor could not get density. Tried using the BOMAG Asphalt Manager – which was a problem by disturbing (decompacted) the surface of that base layer.
Positive Aspects	Density and modulus growth curves were measured for the crushed granite base material.
Negative Aspects	The water content of the crushed granite base was about half of the optimum water content, and the roller that was available could not densify this material past a specific density. A heavier roller had to be brought to the test section to get the required density. The DSPA and GeoGauge did detect the lower density levels.

Sponsor Agency	Texas DOT
Project Location	Odessa, Texas
Project Identification	Reconstruction of I-20 main lanes, due to construction of overpass, and reconstruction of frontage roads. HMA was placed in two 2-inch lifts.
Materials Tested	HMA Coarse Matrix High Binder Content Base Layer (CMHB) under new DOT specification; the crushed stone base course material was not tested. A surface treatment had already been placed on top of the crushed stone base layer at the time of testing.
Special Features	None
Issues	None
Positive Aspects	1. Contractor and DOT were already using the PaveTrack for setting the rolling pattern and DOT was already using the PSPA for acceptance confirmation. Density growth curves were measured by both the contractor's and NCHRP Project 10-65 PaveTracker devices. Contractor was positive towards using the non-nuclear density gauges and did use the PSPA. Results from the PSPA demonstrated that the HMA mixture was meeting all minimum requirements of the mixture. 2. Multiple PSPAs were used on this project; the one being used under NCHRP 10-65 and by the Odessa district office. The Texas DOT had already used the PSPA for use as a forensic tool in evaluating the failure, prior to the contractor finishing the paving, on a 7-mile section of I-20 through Odessa. The DOT and UTEP agreed to provide that data for use on NCHRP 10-65.
Negative Aspects	1. Plant breakdown that significantly delayed paving operation during the week scheduled for the testing under NCHRP Project 10-65. 2. High winds and sand storm occurred during paving that resulted in contractor ceasing paving operations during the week selected for testing under NCHRP Project 10-65. 3. The crushed stone base layer with typical aggregate in west Texas (similar to a caliche) was planned for testing. However, crushed stone base materials had already been covered with a surface treatment prior to NCHRP 10-65 testing. Thus, the DCP, DSPA, and GeoGauge were not used on this project.

Sponsor Agency	Texas DOT
Project Location	Odessa, Texas
Project Identification	Mill and overlay main lanes along Loop 338.
Materials Tested	---
Special Features	HMA overlay was a modified asphalt mixture with rubber.
Issues	Project was cancelled, as noted below.

Positive Aspects	---
Negative Aspects	Contractor was delayed from another project and plant breakdown further delayed the paving operation. Contractor's new schedule was to place the HMA modified asphalt mix with rubber after Thanksgiving. Thus, project was cancelled relative to NCHRP Project 10-65.

Sponsor Agency	Pecos Research and Test Center
Project Location	Pecos, Texas
Project Identification	New construction of the entrance roadway to a private facility located near Pecos, Texas.
Materials Tested	Caliche base typically used for county roads in west Texas.
Special Features	Salcido Sand and Gravel Company was placing a caliche base without time restrictions. Material was used to measure the increase in material strength with successive passes of a static steel drum roller.
Issues	None.
Positive Aspects	Modulus growth curves were developed using two devices; the DCP and GeoGauge.
Negative Aspects	None.

PART III—DATA INTERPRETATION AND APPLICATION

Part III of the research report describes the physical characteristics and process for using each NDT technology and device on construction projects to define construction quality. Each system was evaluated in two parts: 1) the systems' potential to be integrated into the flexible pavement construction process (level of process impact), and 2) the reliability and accuracy of the system (system accuracy and reliability). Chapter 6 focuses on the level of process impact on construction. In other words, what impact will the device have on the contractor's progress, and will agencies need substantially more manpower to use the technology? Chapters 7 and 8 focus on the system accuracy and reliability of the different technologies and devices included in the field evaluation study.

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CHAPTER 6

APPLICABILITY OF NDT TECHNOLOGIES ON CONSTRUCTION PROJECTS

Some NDT devices initially were operated by a representative of the manufacturer and then used by field technicians or engineers. Those devices that were found to have a reasonable success rate in identifying anomalies were used by the contractor and agency staff in their daily QA operations, in accordance with manufacturers' guidelines. Clustered tests were performed using each NDT device to determine the repeatability and accuracy of each system in evaluating its effectiveness in defining construction quality. The time and personnel requirements to perform each test were recorded. This information was considered in rating the level of impact that each device may have on construction. Since the technology was of primary interest (not a particular system or manufacturer), reports on each system are presented under the heading of the technology utilized by the system.

6.1 Ultrasonic—PSPA and DSPA

This system is applicable to HMA, unbound aggregate base, and embankment soils. The PSPA is used to test HMA, while the DSPA is used for unbound materials and soils. Both devices consist of a stand linearly connected by a stiff arm to a source and two receivers and by wire to a computer, as shown in Figure 16 in chapter 3. The source contains a hammer which is dropped several times at regular intervals. The receivers, containing quartz-crystal accelerometers, measure the acceleration of the Rayleigh waves induced by the dropping of the hammer and report the resulting electrical charge to the data acquisition system. A FFT transforms the electrical charge or data into the frequency domain. There is also a temperature sensor in the system. Roughness of the laptop is an important feature.

The PSPA test can be and was performed on cold material one or multiple days after placement, as well as on surfaces at elevated temperatures, immediately after compaction. The system's temperature gauge is used to incorporate the temperature into the calculation of the material's modulus. The rubber pads beneath the receivers deteriorate more rapidly when used on surfaces at elevated temperatures. In fact, they have been known to melt when used on HMA surfaces shortly after placement. The operator needs to check these periodically to ensure adequate coupling between the receivers and surface. These pads are easily replaced.

Both devices work properly as long as all points are in firm contact (coupled) with the surface being tested. Adequate coupling is the system's primary limitation. The speed of data collection makes this technology a good candidate for QC applications, assuming that the temperature of the material is properly considered by the modulus calculation process. None of the PSPA and DSPA devices (including the laptops) used exhibited any problems. The main operational issue was inspecting and replacing the rubber pads of the receivers to ensure good contact with the surface being tested.

The data interpretation program that comes with the PSPA and DSPA devices uses this information to provide the output in the form of the mean Young's modulus to a particular depth. The spacing of the receivers determines the depth of measurement. The operator needs to be trained to visually inspect the load pulse and response data on the output screen for judging the suitability of an individual test (see Figure 78). This training is considered more sophisticated than what is required for a nuclear density gauge. The operator also needs to ensure that the spring-loaded receivers are in contact with the surface between each test. If one of the receivers gets stuck, the result will be a data anomaly or "false" reading. False readings are easily identified by the operator viewing the shape of the load pulse and receiver response with proper training. The shapes of the load pulse and receiver response are visually displayed on the laptop screen for each reading.

The PSPA is used to test HMA mixtures, while the DSPA is used to test crushed aggregate base layers, embankments, and prepared subgrades. The DSPA was used on the shoulders of the US-280 reconstruction project instead of on the main roadway because the roadway base layer had been chip-sealed. This type of surface reduces the repeatability of the ultrasonic device, as well as other NDT devices, because the points of the receivers and source are not always in good contact with the surface tested. Ensuring good contact with the surface being evaluated is important for both the PSPA and DSPA.

The system initially converts the readings of the load pulse and response to a seismic modulus of the material. The seismic modulus is internally adjusted to a modulus at a specific condition (temperature and load frequency for HMA). Each test location requires three to five tests for this system. Each test took 10 to 20 seconds to complete. Therefore, the entire process (3 to 5 readings at a point) takes only slightly longer than the system currently used for QC, the nuclear density gauge, which is generally set for one 60-second reading.

This system can also be used to estimate the elastic properties parallel and perpendicular to the direction of the rollers (refer to chapters 7 and 8). Measuring the seismic properties in different directions actually increases the perceived variability of the device. The variability can be reduced slightly by always taking the readings in one direction. All other NDT devices result in an average or equivalent value at a test point. The spacing of the receivers can also be changed easily for testing thin and thick layers. Layer thickness variation that occurs along a construction project can have less of an impact on the resulting seismic modulus values than on the resulting values from other NDT technologies.

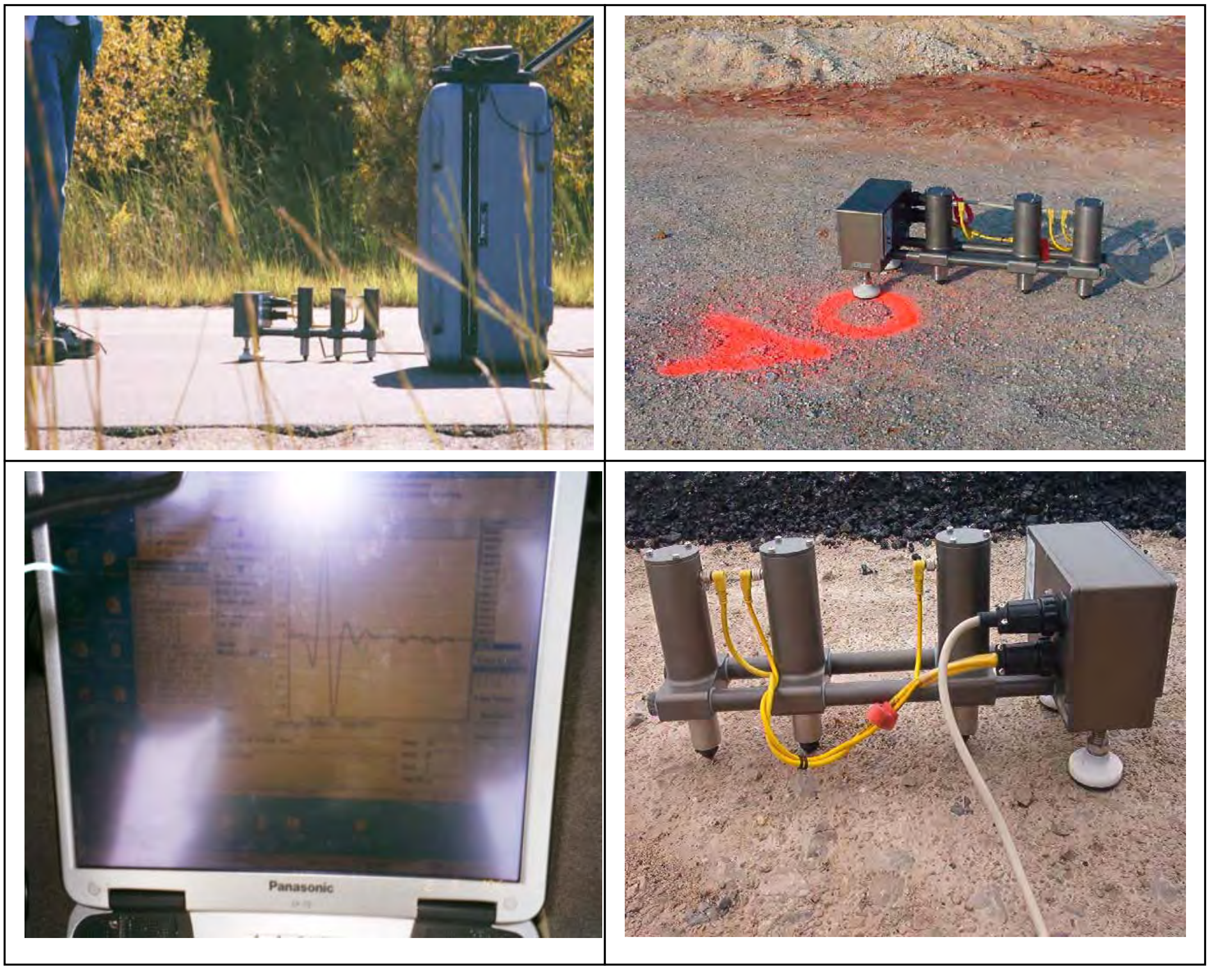

Figure 78. DSPA and PSPA Being Used to Test Different Materials

Another advantage of this technology is that the system can be calibrated easily to the specific materials being tested during the mixture design stage for HMA materials or in developing M-D relationships for unbound materials. This calibration procedure allows the PSPA and DSPA to be used to detect volumetric, as well as physical, changes in the materials during construction.

The DSPA can be used to develop modulus growth with compaction relationships during the first day of construction for the unbound layers and periodically during the project. Use of the PSPA to develop HMA modulus growth relationships can be problematic because of the elevated temperature. It is more applicable to warm-mix projects.

The equipment (including the laptop) was found to be durable, and it does not require more personnel than are now being used for control or acceptance of flexible pavement construction. In fact, the same technician using the nuclear density gauges or taking cores from the HMA layer could also operate the PSPA and DSPA at the same time. Its main disadvantage is training the operators for determining a “false” reading.

In summary, the ultrasonic technology can be used in day-to-day QA operations to assist contractor and agency personnel in judging construction and materials quality by itself or in tandem with other geophysical and/or ground truth sampling programs.

6.2 Steady-State Vibratory—GeoGauge

This system is applicable to HMA and unbound materials and soils, and is similar to the roller-mounted-devices that are discussed at the end of this section of chapter 6. The GeoGauge, however, is only used for testing unbound materials and soils. The GeoGauge provides elastic modulus values that are displayed on the gauge or the readings can be stored in the device and downloaded to a computer at a later date. The resulting values were found to be similar to the resilient modulus values measured in the laboratory or calculated from the resilient modulus regression equations developed through the FHWA-LTPP program (Yau and Von Quintus, 2002). The elastic modulus values from the GeoGauge were found to be a function of the materials moisture content and density. Stiffness readings are also reported by the test equipment and are a function of the structure.

The process followed by the GeoGauge operator is almost identical to that followed by an operator of the current state-of-the-art nuclear density gauge, except that the GeoGauge operator spreads a thin layer of sand on the pavement surface to set the instrument on before taking the reading (see Figure 79). The operator clears the surface to be tested with a small broom or other device to remove loose surface particles (see Figure 79). A thin layer of moist sand is used on rough surfaces to fill in surface voids to ensure that the ring under the gauge is in contact with at least 75 percent with the test surface. Moist sand should be used because the gauge vibrations will cause dry sand particles to relocate under the gauge and disturb the reading. The layer of moist sand should only be thick enough to fill the surface voids of the material being tested. A light pressure and rotation of the GeoGauge was also used to ensure good contact with the test surface.

Each test takes 75 seconds, as compared to the nuclear density gauge’s 60 seconds. Thus, this test takes about twice as long as the nuclear density gauge, including the time for spreading the sand. The test procedure is still quick enough not to be a hindrance to the contractor’s progress and does not require more personnel now being used for control and acceptance. As for the DSPA, the same technician using the nuclear density gauge or running sand-cone tests could also operate the GeoGauge at the same time. The training and technical capability of the operator is no more than what would be required for operating a nuclear density gauge.

The GeoGauge can be easily used to develop modulus growth with compaction effort relationships of unbound layers at the start of the project with periodically throughout the project, similar to the DSPA. This feature becomes advantageous when the water content is significantly varying from the optimum value measured in the laboratory.

Figure 79. Humboldt GeoGauge

The GeoGauge should be calibrated to the project materials and conditions to improve on its accuracy, because of the potential influence from the supporting materials (refer to chapters 3 and 4). This calibration issue requires that laboratory repeated load resilient modulus tests be performed on each unbound layer for judging the quality of construction. Most agencies do not routinely perform resilient modulus tests for design or for forensic evaluations, even though the 1993 AASHTO Design Guide suggests that they be performed (AASHTO, 1993). Eliminating the laboratory resilient modulus tests from the calibration procedure will reduce its accuracy for confirming the design values, but not for identifying construction defects. As a replacement to repeated load resilient modulus test, the regression equations developed from repeated load resilient modulus tests included in the LTPP program (Von Quintus and Yau, 2001) or use of the DCP is permissible.

The disadvantage of the GeoGauge is that it will result in high variability when testing non-cohesive, well-graded sands or similar soils. In addition, the elastic modulus readings from the gauge represent an equivalent modulus for the upper 10 to 12 inches of the layer. Thus, the gauge in its current form should not be used to test thin (less than 4 inches) or thick (greater than 12 inches) layers without proper material calibration adjustments or changing the diameter of the ring under the gauge.

In summary, the GeoGauge has potential use in day-to-day QA programs by both the contractor and agency personnel.

6.3 Deflection-Based Methods

6.3.1 Falling Weight Deflectometer

The FWD is a large, expensive apparatus that is mounted on a trailer and pulled behind a tow vehicle from where the operator works a computer and locates the apparatus for testing (see Figure 6 in chapter 3). This system is capable of applying dynamic loads to the pavement surface, similar in magnitude and duration to that of a single heavy moving wheel load. It is being used within the LTPP program, and most state agencies have access to at least one FWD. Thus, it is already being used in most agencies day-to-day practice.

The response of the pavement system is measured in terms of vertical deformation, or deflection, over a given area using seismometers or geophones. The use of a FWD enables the user to determine a deflection basin caused by a controlled load. These results make it possible to determine the stiffness of existing pavement structures for use in M-E based rehabilitation design methods.

The falling weight strikes a set of rubber buffers mounted to a 300 mm circular foot plate, which transmits the force to the pavement (refer to Figure 6 in chapter 3). A thin-ribbed rubber pad is always mounted under the footplate. By varying the mass or the drop height or both, the impulse load can be varied. This load may be varied between 10 kN and 140 kN. Sensors measure the surface deflections caused by the impulse load.

Most agencies use seven sensors at the spacing recommended by LTPP. However, fewer or more sensors can be used, and those can be spaced uniformly or at some other spacing selected by the user. Peak deflections are recorded, stored, and displayed. In some cases, one of the geophones or sensors can be incorrectly placed on the test surface by the sensor bar, especially on rough surfaces. The data acquisition software will identify this anomaly, notifying the operator that the test should be rejected and redone.

The test takes about 2 minutes to complete, including the use of seating drops. Seating drops are important and should be used at each test point. This does not include time to configure the trailer and set up the data acquisition system, which should only have to be done once per day for each project. It takes about 30 minutes to configure the trailer and 2-3 minutes to set up the data acquisition program. Similar to the PSPA, the operator requires more technical and sophisticated training in setting up the equipment and visually interpreting the deflection basin data.

A separate data interpretation system or software is required for producing elastic modulus values from the measured deflection basins—Young's modulus for each layer. The calculated elastic modulus values are structure dependent. Most data interpretation or analysis programs used backcalculation techniques for calculating layered elastic modulus values. Backcalculation programs do not determine unique modulus values for each layer and are sensitive to layer thickness variations. Forward-calculation procedures have been developed that result in unique layer modulus values for a particular deflection basin, but these values are thickness dependent. Any errors in the layer thickness will increase the error and variability of the processed data.

Its use for acceptance of individual layers by the agency should be limited to the use of the forward-calculation procedure. Because the backcalculation procedures do not result in unique layer modulus values, it would be difficult to defend in contractor disputes where material has been rejected or payment penalties issued to the contractor. The device can be used to check or confirm the final flexible pavement for new construction or HMA overlays of existing pavements, but would probably create many disputes with contractor when the entire pavement structure is rejected at the end of the project.

In addition, the resulting values for the upper layer are dependent on the stiffness and variability of the supporting layers. More importantly, calculating the elastic modulus of layers is generally restricted to those that are thicker than 3 inches. The FWD may also require one addition field technician and tow vehicle.

The expense, size of the system, time needed to perform each test, and data interpretation software make this system less practical for QC and acceptance. Thus, the FWD is believed to be less practical and effective for the QA uses upon which this study is focused.

6.3.2 Lightweight Deflectometer

The LWDs use the same theory as the FWD described above, but offer an advantage of being much more portable. In addition, the training and technical requirements for the LWD operators are no different than for nuclear density gauges, with one exception—the operator needs to understand and be aware of the factors and physical features that affect layer modulus calculated from the measured deflections. Results from the LWDs were significantly influenced by the supporting materials on some of the projects.

As noted in chapter 5, all three LWD devices used on selected projects have similar features, so only the Dynatest and Carl Bro devices are discussed in the following paragraphs.

Dynatest Prima 100 LWD Device

The Prima 100 is manufactured by Dynatest and consists of the weight (hammer) on a pole and the sensors (geophones) in a plate on the ground, all encompassed in one, connected, portable structure (see Figure 80). The sensors were connected to a hand-held computer by wireless remote technology.

Figure 80. The Dynatest Prima 100 LWD

The unit tested was somewhat flexible and the frame came apart on multiple occasions. Besides slowing down the process, this resulted in questionable data because the wireless remote would sense the jolt resulting from the frame coming apart as a separate test—resulted in a deflection and modulus value for that anomaly.

The wireless remote was troublesome and kept losing contact with the apparatus. This happened anytime the technician carrying the apparatus became closer than a few feet from the technician holding the computer. This was an additional source of aggravation that also slowed down the operation because the computer had to be re-started each time it occurred.

When using the system on particularly stiff base material, the hammer can bounce high enough, such that it can strike the apparatus again—resulting in an appreciable rebound load. The rebound load can cause the remote to mistake that rebound as a second or separate test. The software, as written, causes the actual test results to be deleted and replaced by a reading of the rebound.

The system, however, is fast. One test takes about 10 seconds, so the five tests conducted (and averaged) at each location take approximately the same amount of time that a nuclear density reading takes at one location. Conversely, the apparatus is bulky to handle, so the time that most non-nuclear systems gain by not having to deal with the steps of transporting the nuclear device are lost.

Carl Bro LWD Device

The Carl Bro system looks exactly like the Dynatest system, except that it has additional sensors that are not attached to the frame. These extended geophones do not change the theory and applications. Although, the algorithms are slightly different to include input from the additional sensors, the theory and application appear to be the same.

The geophones are arranged linearly at set distances from the plate. Since the sensors are connected to each other by a bar, but separate from the loading plate, connecting and placing them at a specific distance from the plate for each test becomes problematical. It is expected, however, that these perceived disadvantages can be resolved in future modifications to the equipment, similar to the Prima 100 device.

From beginning the process of setting the plate through the last of the five drops, takes on average about 5.5 minutes. The procedure followed for using the system is listed below.

1. Locate test point (surface must be even (flat) and must be cleared of anything that could cause part of the plate to lose contact with the surface).
2. Set the loading plate on the surface to be tested (plate must be flat on the surface).
3. Measure for geophone location.
4. Set the geophone arm and line up the sensors.
5. Set data acquisition key for collecting the deflection data.
6. Drop hammer (first drop “seats” the plate and is not read).
7. Repeat last two steps for five drops at each location (including the one to “seat” the plate).

This system had a wired connection to a laptop computer and is more cumbersome to set up due to the additional geophones. More importantly, the seating drop of the plate sometimes moved the plate. This increased the variability in the data gathered from the geophones and increased the number of anomalies. The system is comparable in cost to the Prima 100.

Summary

This technology was tested on crushed aggregate base material, embankments, and prepared subgrades. However, there should be no difference between the procedures and the device’s reaction to a hard base material and those of HMA mixtures. A key advantage of this technology is that it gives the operator a reading of the elastic modulus in about the same time required to obtain a nuclear density gauge reading. The disadvantages are that the devices have limited reliability because of the range and reliability of the wireless remote and its software logic. In addition, the resulting values for the upper layer are dependent on the stiffness and variability of the supporting layer.

It is expected that these disadvantages of the equipment can be easily resolved with future modifications. These devices will likely make the technology and device more expensive. It does, however, provide the agency with elastic modulus values that can be used to confirm design assumptions with proper calibration. In summary, the LWDs are believed to be less practical and effective for the uses upon which this study was focused, similar to the FWD.

6.4 Dynamic Cone Penetrometer

The DCP is used to estimate the strength and modulus of unbound materials and soils. The DCP is much like the LWD in appearance (see Figure 81) but uses a 15-lb (6.8-kg) steel mass falling 20 in (50.8 cm) that strikes the anvil to cause penetration of a 1.5-in (3.8-cm) diameter cone (45° vertex angle) that has been seated at the surface or in the bottom of a hand augured hole (see Figure 3 in chapter 3). The blows required to drive the embedded cone a depth of 1-3/4 in. have been correlated by others to N values derived from the Standard Penetration Test (SPT). Experience has shown that the DCP can be used effectively in augered holes to depths of 15 to 20 ft (4.6 to 6.1 m). The system has been used in the past for the testing of soils more than anything else.

Figure 81. The DCP Before Assembly for Use in Measuring the In-Place Strength of Unbound Materials and Layers

The technical skills and training requirements for the DCP operator are no different than for a nuclear density gauge. Advantages of the DCP include its simplicity, low maintenance (using disposable tips, making sure that the allen screws are kept tight, etc.), mobility, and low cost. It can also be used to test thick embankment layers, unlike some of the other NDT technologies and devices.

Conversely, the manual apparatus is slow (tests took 5 to 10 minutes at each location), its use is physically demanding, and the test is actually destructive to bases and pavements in that a test results in a hole in the material. Use of the device can also be dangerous, if the operator's hand gets caught between the hammer and base for the hammer. Furthermore, soils or materials with boulders or large aggregate particles (refer to Figure 38 in chapter 5) can cause refusal of the device. When this occurs, the test point should be moved and the test redone. An automated trailer mounted DCP is available, but is more expensive (see Figure 4 in chapter 3). Only the manual DCP was used within the field evaluation of NCHRP Project 10-65.

The manual DCP is considered to have potential for QC use on a day-to-day basis, but an additional contractor and agency staff person would probably need to be assigned to using the DCP under normal practices. However, the training and maintenance of this device is considered minimal.

6.5 Ground Penetrating Radar

GPR is a pulse echo method for measuring pavement layer thickness' and properties. GPR uses radio waves to penetrate the pavement by transmitting the wave energy into the pavement from a moving antenna. These waves travel through the pavement structure and echoes are created at boundaries of dissimilar materials. An air-coupled horn antenna attached to the back of a small SUV (see Figure 9 in chapter 3) was used in the field evaluation of NCHRP Project 1065 to evaluate HMA, unbound aggregate base, and embankment soils.
The speed of data collections is one of the biggest advantages of GPR technology. There should be no impact to the contractor's operation, because this system collects the same information regardless of material temperature and is capable of taking measurements at speeds of up to 40 miles per hour. Higher speeds have been used on more recent projects through enhancements made to the equipment and data acquisition systems. The disadvantages of the technology are the interpretation of the dielectric values that are measured and personnel requirements for calibrating and maintaining the equipment and data interpretation software.

The system is simple to operate and provides results immediately, at least in terms of dielectric values. The results are in the form of a "picture" of the pavement system, much like an X-ray. Although the transducer is located above the surface, aimed downward, the picture can be viewed from "plan" or "elevation" ("profile") perspective. Another huge advantage of this technology is that a continuous profile of the dielectric values is available. In fact, layer thickness profiles or complete contours of the layer can be developed in a short time period.

Currently, the technology requires operators with special technical skills to interpret the data that have physical meaning to the quality of construction. Software programs are available that provide color coded charts and contours of the material. This system has been used to determine layer thickness at a reasonable accuracy—when layers with different dielectric values are tested. The accuracy of the analysis programs require cores to accurately measure the in place thickness and other volumetric properties.

Most of the data reduction-presentation programs, however, still require some volumetric properties to be assumed in estimating density, air voids, and other volumetric properties. These assumptions result in error of the properties that are calculated from the dielectric values. The assumptions are believed to be a reason why the GPR's analysis and interpretation from the Part A projects did not coincide with some of the other NDT devices (refer to chapter 5 in Part II). There are programs available that do not require many assumptions, but all of the known programs are proprietary. These proprietary programs were no used in the Part A field evaluations, but were included in the Part B summary at a few facilities. Data from some one of these proprietary programs is presented and discussed in chapter 7.

Calibration is another issue that is important to the success of GPR antennas in estimating volumetric properties of materials. Cores have to be recovered and the physical properties of those cores determined and correlated to the dielectric values measured by the GPR prior to and during construction. This requires that control strips be used at the beginning of a project and the correlations periodically confirmed during construction. Many agencies are eliminating or not requiring the contractor to use control strips, especially for small projects. Thus, this technology has limited use in QC applications, but has greater potential for use in acceptable programs—especially those for which thickness is included in the price adjustments or pay factors.

6.6 Electric Current/Electronic

This family of systems includes those that rely on technology such as electrical sensing fields, impedance, electric current, and radio waves to determine the quality of HMA pavement, base, or embankment (see Figures 23 and 24 in chapter 3). The training and technical skills required to operate this technology are no different than required for nuclear density gauges. In addition, the calibration requirements to improve on the accuracy of testing specific materials with the non-nuclear gauges are similar in detail and extent for nuclear density gauges.

6.6.1 Electrical Density Gauge

An electrical density gauge was used in the Part A field evaluation projects, because of the equipment's perceived ease of use and application to a diverse set of unbound materials and soils. The specific gauge used was the one manufactured by EDG, which is confined for use on aggregate base layers, embankments and subgrades, or any unbound layer (see Figure 82). The system uses 6-inch darts that are driven into the soil within a 1.8 square foot area. This allows the system to measure a 1.0 cubic foot volume of material.

The system uses a 3-MHz radio signal, producing a current of a certain voltage and phase, which allows measurements of the capacitance, resistance, and impedance. The connected data acquisition program uses algorithms and ratios of the measured parameters to determine the density and water content of an unbound layer (refer to Figure 82).

Figure 82. Electric Density Gauge

This test takes several minutes to perform, but it appears to have huge potential for use in replacing the nuclear density gauges and other traditional QA tests, such as the sand-cone tests. This technology does not require more personnel than are now being used for QC/QA of unbound layers. The system and devices should be easier to maintain and the operators of the equipment can be easily trained in its use—similar to a nuclear density gauge.

The most time-consuming but critical part of the system is developing a proper soil-model for density and moisture content measurements. To date, other more traditional tests (such as sand cones) are performed in specific locations that cover the range in density and water contents. A regression model is then developed based on correlations between the EDG values and the density and water contents measured from other tests. It is expected that this test will be improved with time, but at present, its use as a practical device for controlling construction of unbound layers is limited.

6.6.2 Pavement Quality Indicator—PQI

The PQI (see Figure 83.a) uses a constant voltage, radio frequency, electrical impedance approach, in which a toroidal electrical sensing field is established in the material being tested. This allows the PQI to make quick, in-situ measurements of pavement density. The sensor consists of a set of flat plates that are interconnected to form the electrodes of a planar capacitor. Variations in density are determined through changes in the dielectric constant of the medium between the capacitor plates.

(a) PQI Non-Nuclear Density Gauge

(b) PaveTracker Non-Nuclear Density Gauge

Figure 83. Non-Nuclear, Non-Roller-Mounted Devices Used to Measure the Density of HMA Layers

Using this technology, the PQI can be used like the nuclear density gauge, with the exception that it has the capability to adjust for moisture variations and mix type. The device also has an on-board, real-time system that takes the readings and keeps a record of them, allowing it to be integrated seamlessly into the paving process.

6.6.3 PaveTracker

The PaveTracker (see Figure 83.b) is a lightweight non-nuclear device for measuring the uniformity of HMA mixtures. The measurements are practically instantaneous when the device is placed on an HMA surface. Areas of segregation, lower density levels along longitudinal joints or other non-uniformity areas can be detected by the PaveTracker Plus, which allows the operator to correct the problem before construction is complete.

The advanced software, built-in reference plate and enlarged display screen are some of the features offered by the PaveTracker. The large display screen is an advantage, because the device is compact and close to the ground. Like the PQI, the PaveTracker can be used exactly like the nuclear density gauge, without the use of any nuclear device. The PaveTracker also has an on-board, real-time system that takes the density readings and keeps a record of them for future use, allowing the device to be easily integrated into the paving process.

6.7 Intelligent Compactors/Rollers with Mounted Response Measuring Devices

These systems offer real-time pavement quality measurement with no negative impact to the contractor's progress. They use accelerometers to measure parameters of the compactor's vibratory signature. Other sensors are also used to gain information about the pavement. Information from the sensors is then used to make decisions about pavement quality. Although these roller-mounted systems have been shown to be beneficial to a contractor from a control standpoint, they have not been used for acceptance and confirmation of the design-modulus values. Two of these systems were used in the demonstrations sponsored by FHWA at the NCAT and MnROAD facilities and included in the NCHRP Project 10-65 field evaluations. Thus, they are discussed in the following paragraphs.

6.7.1 Asphalt Manager and Vari-Control System

This system, developed by Bomag, contains an onboard pavement analysis system based on the electrical charge generated by strategically-mounted quartz-crystal accelerometers that measure the acceleration of the vibratory drums of the compactor. An onboard computer transforms the data from the sensors using a FFT into the frequency domain. This transformation allows the computer to calculate the material's modulus. There is also a temperature sensor in the system, which feeds data into the computer for use in modulus calculations. In addition, the system takes this reading and alters the compaction effort of the roller to avoid the damaging effects of over-compaction. Stiffness readings are taken continuously and presented as a modulus value developed by Bomag and called E_{vib}, in the form of MN/m^2.

The E_{vib} value should be related to the dynamic modulus of the material being compacted. However, this computed value is expected to be affected by the underlying support conditions. To-date, the E_{vib} value has not been evaluated or checked against dynamic modulus values measured in the laboratory or estimated through other NDT devices.

The system is fully integrated into a vibratory roller that is part of an operational paving train (see Figure 19 in chapter 3). The true test of this "intelligent compaction" system is whether it actually saves time (fewer passes), improves uniformity of the mat, and renders accurate, consistent readings. As for this part of the analysis (impact on the contractor's progress), assuming that the system does what it claims, it can only help the contractor's progress.

6.7.2 Ammann Compaction Expert

Ammann-America, the U.S. branch of the Swiss manufacturer Ammann Compaction, Ltd., has introduced the Ammann Compaction Expert (ACE) to the U.S. market. The goal of the ACE is the same as for the Asphalt Manage. The major difference is that the ACE seems to take the paving environment into account more than does the Asphalt Manager does in an automated fashion. The computer in the ACE system is capable of receiving information such as lift thickness, number of passes, mix or soil type, etc., which is used in the calculation of the material's stiffness or modulus. Just as with the Asphalt Manager, the system is fully integrated into a vibratory roller that is part of an operational paving train.

6.7.3 Summary

The true test of this "intelligent compaction" system is whether it actually saves time (fewer passes), improves uniformity of the mat, and results in accurate, consistent readings. As for this part of the analysis (impact on the contractor's progress), aAssuming that the roller-mounted devices do what they claim, they can only help the contractor's progress and in making better decisions in real-time regarding compaction of pavement layers.

6.8 Summary of Process Impact

Table 64 provides a summary of the level of process impact on flexible pavement construction for different NDT technologies and devices regarding their use in QA programs.

Table 64. Summary of Process Impact of Different NDT Technologies and Devices on QA Programs

Impact Topics or Issues	NDT Technologies								
	Ultrasonic Gauges	Steady-State Vibratory	Deflection-Based		DCP		GPR	Non-Nuclear Devices	
			Trailer	Portable	Manual	Automated		Non-Roller-Mounted	Roller-Mounted
Easily used to develop density or modulus growth curves?	**HMA-No** Unbound-Yes	Yes	**No**	Yes	**No**	**No**	**No**	Yes	Yes
Resulting Value	Seismic Modulus	Elastic Modulus	Deflection	Deflection & Elastic Modulus	Penetration Rate or Index	Penetration Rate or Index	Dielectric Values	Density & Water Content	Stiffness or Density
Conversion required to adjust readings?	**Yes**	No	No	No	No	No	Yes	No	No
Requires calibration to specific materials or soils?	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**	No
Can readily test thin layers (<3 inches)	Yes	**No**	**No**	**No**	Yes	Yes	Yes	Yes	Yes
Can readily test thick layers (>12 inches)	Yes	**No**	Yes	Yes	Yes	Yes	Yes	**No**	**No**
Readily applicable to control?	Yes	Yes	**No**	Yes	Yes	Yes	**No**	Yes	Yes
Readily applicable to acceptance?	Yes	Yes	**No**; Only final structure	Yes	Yes	Yes	Yes	Yes	**No**
Additional auxiliary equipment needed?	No	No	**Yes**, tow vehicle	No	No	**Yes**	**Yes,** vehicle	No	No
Additional man power needed?	No	No	**Yes,** operator	No	No	**Yes**	**Yes**	No	No
Equipment readily available on commercial basis?	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Software readily available on commercial basis?	Yes	NA	Yes	Yes	NA	NA	**No**; for Proprietary	NA	NA

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CHAPTER 7

MATERIALS TESTING FOR CONSTRUCTION QUALITY DETERMINATION

This chapter focuses on the effectiveness of the NDT technology and device for measuring or judging the quality of construction of unbound materials and HMA mixtures. As described in chapter 1, "effectiveness" is defined as the ability or capability of the NDT technology or device to detect changes in unbound materials or HMA mixtures. The research problem statement noted that, with the development of the MEPDG, layer modulus will become a more important property and should be considered a quality characteristic. Thus, the emphasis of the interpretation of data presented in chapter 5 was on identifying those NDT devices that can consistently and accurately determine when changes occur within the construction process, as well as confirm the assumptions used in pavement structural design.

7.1 Identification of Material Anomalies and Differences

The testing under the Part A field evaluation was to confirm that the NDT technologies can identify differences in construction quality of unbound pavement layers and HMA mixtures. The specific hypothesis used for this part of the field evaluation was that the NDT technology and device can detect changes in the physical condition of pavement materials and soils that affect flexible pavement performance. Tables 31 and 47 in chapter 5 summarize the anomalies and different conditions placed along each project.

A standard t-test and the Student-Newman-Keuls (SNK) mean separation procedure using a 95 percent confidence level were used to determine whether the areas with anomalies were significantly different from the other areas tested. The following subsections summarize the results from the statistical analyses of the data collected within Part A of the field evaluation.

7.1.1 Unbound Layers

Table 66 tabulates the results for checking the hypothesis for the unbound material layers. The shaded cells in Table 66 designate those where the hypothesis was incorrectly rejected or accepted. The DSPA accurately identified most of the areas with anomalies or material differences. The GeoGauge did a reasonable identification of the areas, followed by the DCP and LWD. The EDG and GPR devices did a poor job in identifying the different areas. Table 65 demonstrates the success rate by each device in identifying the physical differences of the unbound material within a project.

Table 65. Success Rate Demonstrated by each Device in Identifying the Physical Differences of the Unbound Material

NDT Device	DSPA	GeoGauge	DCP	LWD	GPR	EDG
Success Rate, %	86	79	64	64	33	25

Table 66. Summary on the Effectiveness of NDT Devices to Identify Areas of Unbound Layers With Anomalies or Different Physical Conditions

Project	Hypothesis		NDT Device: GPR	EDG, pcf	Geo., ksi	DSPA, ksi	DCP, ksi	Defl., ksi
I-85 Low Plasticity Soil Embankment	Pre-IC Rolling	Lane A	**14.65**	107.6	12.6	25.2	**5.20**	---
		Lanes B,C,D	**15.99**	108.1	16.3	34.0	**5.62**	---
	Lane A is weaker		**No**	Yes	Yes	Yes	**No**	---
	Post-IC	Area 1	21.61	**108.3**	**17.1**	39.4	6.93	**9.99**
		Area 2	23.00	**107.7**	**19.0**	40.4	6.21	**11.78**
	No Planned Difference		Yes	**No**	**No**	Yes	Yes	**No**
	All areas	Pre-IC	15.65	**108.0**	15.4	31.8	5.51	---
		Post-IC	22.31	**108.0**	17.7	39.9	6.57	---
	Post-IC area is stronger		Yes	**No**	Yes	Yes	Yes	---
SH-21 High Plasticity Clay	Area 2	No IC	---	---	19.6	23.6	**11.9**	---
	Area 1	With IC	---	---	22.9	27.1	**9.1**	---
	Area 1 is stronger		---	---	Yes	Yes	**No**	---
	With IC Rolling	Lane C	---	---	**20.1**	30.4	**9.9**	12.9
		Lanes A,B	---	---	**24.4**	25.4	**8.7**	8.00
	Lane C is stronger		---	---	**No**	Yes	**No**	Yes
TH-23 Silt-Sand-Gravel Mix Embankment	So. Area	Laanes A,B	**18.24**	**122.7**	10.5	**43.6**	**15.16**	**5.65**
	No. Area	Lanes B,C	**29.16**	**124.1**	10.1	**35.7**	**19.01**	**4.77**
	No Planned Difference		**No**	**No**	Yes	**No**	**No**	**No**
	So. Area	Lane C	**19.33**	**122.9**	7.5	31.1	11.47	**5.58**
		Lanes A,B	**18.24**	**122.7**	10.5	43.6	15.16	**5.65**
	Lane C is weaker		**No**	**No**	Yes	Yes	Yes	**No**
	No. Area	Lane A	**20.32**	**123.9**	12.6	51.7	**18.52**	**4.69**
		Lanes B,C	**29.16**	**124.1**	10.1	35.7	**19.01**	**4.77**
	Lane A is stronger		**No**	**No**	Yes	Yes	**No**	**No**
SH-130 Granular Improved Embankment	All lanes	Lane A	10.29	123.2	25.4	33.9	21.60	**24.2**
		Lane B	9.30	123.0	25.5	34.7	20.95	**27.8**
		Lane C	9.78	123.8	24.77	33.3	20.74	**21.2**
	No Planned Difference		Yes	Yes	Yes	Yes	Yes	**No**
	All areas	Area 1,2	9.74	123.5	**26.3**	**36.5**	20.64	24.6
		Area 3	9.88	123.1	**22.3**	**28.9**	22.01	24.1
	No Planned Difference		Yes	Yes	**No**	**No**	Yes	Yes
TH-23 Crushed Aggregate Base	South & Middle Sections	Lanes A,B	**9.37**	**129.8**	14.4	100.4	42.05	16.75
		Lane C	**10.62**	**129.8**	10.8	50.7	21.33	8.31
	Lane C is weaker		**No**	**No**	Yes	Yes	Yes	Yes
	So. Area	Lanes A,B	**9.79**	**129.9**	15.0	110.7	46.45	19.38
	Middle Section	Lane C	**10.38**	**129.8**	9.8	28.0	18.55	7.95
	All other areas		**9.54**	**129.8**	12.8	75.0	33.14	12.31
	Lane C, middle section, is weaker		**No**	**No**	Yes	Yes	Yes	Yes
	Lanes A & B, south section, are stronger		**No**	**No**	Yes	Yes	Yes	Yes
US-280 Crushed Stone Base	All areas	Lane 4	**11.57**	**148.2**	35.1	117.4	34.31	18.53
		Lanes 1,2,3	**11.95**	**147.4**	47.9	198.6	50.29	46.46
	Lane 4 is weaker		**No**	**No**	Yes	Yes	Yes	Yes

NOTE: The shaded or black cells are those areas were the hypothesis was rejected based on a 95 percent confidence interval, and are inconsistent with the construction records and experimental plan.

The DSPA and GeoGauge have acceptable success rates, while the EDG and GPR have unacceptable rates. More importantly, the modulus measuring devices (DSPA, GeoGauge, DCP, and LWD) found all of the hypotheses to be true for the crushed aggregate materials (TH-23 and US-280 projects), while the volumetric devices (GPR and EDG) rejected all of the hypotheses. This observation suggests systematic differences between the technologies. Some of the important differences observed between the technologies and devices and the reason for the higher success rates for the DSPA and GeoGauge are listed below.

- The DSPA and GeoGauge induce small dynamic stress waves into the material being tested. These small responses emphasize the effect of changes in the density and moisture content of the material being tested. More importantly, both devices measure the responses in a relatively limited area and depth. In fact, the sensors for the DSPA (refer to Figures 16 and 78) were spaced so the measured responses would be confined to the layer being tested. The GeoGauge measurements have a deeper influence, so its results can be influenced by the supporting layer. The depth of influence depends on the thickness and stiffness of the material being tested.

- The DCP is a point-based test and estimates the modulus of the material from the average penetration rate through the material. The penetration rate is dependent on the dry density of the material. However, there are other physical properties that have a greater effect on the penetration rate. The amount and size of the aggregate particles can have a larger effect on the estimated modulus than for the DSPA or GeoGauge, especially for fine-grained soils with some aggregates. For example, the DCP found all of the hypotheses to be true for the coarse-grained materials and rejected many of the hypotheses for the fine-grained embankment materials with varying amounts of coarse aggregate.

- The LWD induces larger strains into the underlying materials. The measured deflections or responses are affected by a much larger area and depth than for the DSPA, GeoGauge, and DCP. The modulus calculated from the deflections is dependent on the thickness and stiffness of the material being tested, as well as the thickness and stiffness of the supporting layers. In fact, some resulting modulus values were lower than expected for the type of material being tested (TH-23 embankment and areas of the US-280 crushed stone). More importantly, the LWD found all of the hypotheses to be true were the layer thicknesses were well defined, but rejected many of the hypotheses for the materials where the layer thickness was less defined—the embankments.

- Both the GPR and EDG devices are dependent on the density and water content measurements made with other traditional test methods. Any errors within those traditional methods are included in the GPR and EDG results. More importantly, average water contents were assumed for each area in calculating the wet densities from the dielectric values measured with the GPR. Obviously, water contents are not constant within a specific area. Errors in the water content will be reflected in the wet density for a specific test. More importantly, varying plasticity of the fines and in the gradation of the material is difficult to identify with the GPR and EDG by themselves.

- Variability of the measurements is another reason for the outcome. The GeoGague had lower variability, followed by the DSPA and DCP. The deflection-based methods had the greatest variability. The lower the variability, the higher the probability to identify a difference, if a difference exists, given the same number of tests (refer to section 7.3).

In summary, the DSPA and GeoGauge are considered acceptable in identifying localized differences in the physical condition of unbound materials.

7.1.2 HMA Layers

Table 68 tabulates the results for checking the hypotheses for the HMA layers. The shaded cells in Table 68 designate those areas where the hypothesis was incorrectly rejected. Another difference that was found but not planned (so it was excluded from Table 68) was the difference between the initial and supplemental sections of the US-280 project (see chapter 5). All NDT devices found a significant difference between these two areas—the supplemental section had the higher dynamic modulus, which was confirmed with laboratory dynamic modulus tests. Both the PSPA and FWD resulted in higher modulus values and the GPR estimated lower air voids, but the PQI resulted in much lower densities.

The PSPA did identify all but one of the areas with anomalies or differences. The non-nuclear density gauge did a reasonable job, while the GPR and FWD only identified slightly more than 50 percent of the areas with differences. The GPR, however, did measure the HMA lift thickness placed that was confirmed through field cores. Table 67 summarizes the success rates for identifying the physical differences of the HMA mixtures within a project.

Table 67. Summary of the Success Rates for Identifying the Physical Differences of the HMA Mixtures Within a Project

NDT Device	PSPA	PQI	GPR	FWD
Success Rate, %	93	71	54	56

The PSPA had an excellent success rate, while the PQI had an acceptable rate. The GPR and FWD had lower rates that are considered unacceptable. Some of the important differences observed between the technologies and devices and the reasons for the lower success rates of the GPR and FWD are listed below.

- The FWD is believed to have been influenced by the supporting layers creating noise and additional variability making it more difficult to identify the localized areas. In addition, its loading plate probably bridged some of the localized anomalies making it difficult to detect differences near the surface of the layer evaluated (e.g., segregation).

- The dielectric values measured by the GPR are minimally affected by some of the properties that can change within a project, and its success is heavily dependent on the number of cores taken for calibration purposes—similar to that for unbound materials.

In summary, the PSPA and non-nuclear density gauges (PQI) are considered acceptable in identifying localized differences in the physical condition of HMA mixtures.

Table 68. Summary of the Effectiveness of NDT Devices to Identify Areas of HMA Layers With Anomalies or Different Physical Conditions

Project	Hypothesis		NDT Device			
			PSPA	FWD	GPR	PQI
I-85 SMA Overlay	Section 2	Lanes A,B	285.0	568.9	6.18	149.9
	Sections 1,3	Lanes A,B	262.0	405.4	10.14	146.6
	Section 2 is Stronger or Stiffer		Yes	Yes	Yes	Yes
	Lane C	Section 2,3	288.5	NA	**8.51**	141.6
	Lane C	Sections 1	215.4	NA	**8.62**	140.3
	Section 1 is Weaker/Less Dense		Yes	NA	**No**	Yes
TH-23 HMA Base	Section 2	All Lanes	454.4	NA	7.04	145.2
	Sections 1,3	All Lanes	489.8	NA	6.64	146.6
	Section 2 is Weaker		Yes	NA	Yes	Yes
	Section 4	All Lanes	499.5	NA	NA	**143.9**
	No Planned Difference; Sections 1,3,4		Yes	NA	NA	**No**
US-280 HMA Base	Initial Sections	Section 1	499.9	203.3	7.03	**148.0**
	Supplemental Sections	Sections 1,2	555.0	877.2	5.50	**140.4**
	Supplemental Area is Stronger/Denser		Yes	Yes	Yes	**No**
US-280 HMA Base, Initial Sections	Section 1	All Lanes	499.9	203.3	**7.03**	**148.0**
	Section 2	All Lanes	423.9	125.9	**6.81**	**154.5**
	Section 1 is Stronger/Denser		Yes	Yes	**No**	**No**
	Longitudinal Joints	Confined Joint	305.8	**125.5**	7.70	145.7
	Joints are Less Dense/Weaker		Yes	**No**	Yes	Yes
	Segregated Areas	All Lanes	329.9	**144.5**	**7.28**	147.1
	Segregated Areas are Less Dense/Stiff		Yes	**No**	**No**	Yes
US-280 HMA Base, Supplemental Sections	Section 1	All Lanes	559.8	**569.0**	5.55	140.4
	Section 2	All Lanes	550.2	**1185.3**	5.45	140.5
	No Planned Difference		Yes	**No**	Yes	Yes
	Longitudinal Joints	All Lanes	**596.0**	379.0	**5.78**	135.8
	Joints are Les Dense/Weaker		**No**	Yes	**No**	Yes
	Segregated Areas	All Lanes	391.3	**707.0**	**5.64**	136.6
	Segregated Areas are Less Dense/Stiff		Yes	**No**	**No**	Yes
I-35/SH-130 HMA Base	Section 1	All Lanes	384.9	NA	5.95	126.5
	Section 2	All Lanes	292.6	NA	5.61	124.0
	Section 3	All Lanes	461.7	NA	NA	125.1
	Section 2 is Weaker/Less Dense		Yes	NA	Yes	Yes
	Joints	All Lanes	297.5	NA	**5.08**	118.8
	Joints are Less Dense/Stiff		Yes	NA	**No**	Yes

7.2 Estimating Target Modulus Values

Laboratory measured modulus of a material is an input parameter for all layers in the MEPDG. Resilient modulus is the input for unbound layers and soils, while the dynamic modulus is used for all HMA layers. As discussed in chapter 5, none of the NDT devices accurately predicted the modulus values that were measured in the laboratory for the unbound materials and HMA mixtures (see Figures 76 and 77 in chapter 5). All of the modulus estimating NDT devices, however, did show a trend of increasing moduli with increasing laboratory measured moduli. The following subsections discuss the use of adjustment factors for confirming the assumptions used for structural design.

7.2.1 Unbound Layers

It has been previously reported that layer moduli calculated from deflection basins must be adjusted (multiplied) by a factor for pavement structural design procedures that are based on laboratory derived values at the same stress state (AASHTO, 1993; Von Quintus and Killingsworth, 1998). In the 1993 AASHTO Pavement Design Manual, the adjustment factor is referred to as the “C-factor,” and the value recommended for use is 0.33. Thus, there are differences between the field and laboratory conditions that can cause significant bias when using NDT modulus values.

Von Quintus and Killingsworth (1998) found that this adjustment factor was structure or layer dependent but not material type dependent. Adjustment factors were determined for different types of structures. The C-factor found for embankment or subgrade soils ranged from 0.35 to 0.75 and averaged 0.62 for aggregate base materials. However, none of the deflection basins measured in this study was measured on the surface of the unbound layers themselves. Conversely, all testing under this study was directly on the surface of the layer being evaluated.

To compensate for differences between the laboratory and field conditions, an adjustment procedure was used to estimate the laboratory resilient modulus from the different NDT technologies for making relative comparisons. The adjustment procedure assumes that the NDT response and modulus of laboratory prepared test specimens are directly related and proportional to changes in density and water content of the material. Figures 84 to 86 compare the seismic (PSPA) modulus measured on the samples used in preparing an M-D relationship. The PSPA modulus-water content relationship follows the M-D relationship. Thus, the assumption is believed to be valid.

For simplicity, the adjustment factors were derived using the same methodology within the FHWA-LTPP study, with the exception that a constant, low stress state was used to determine the adjustment factor. In other words, the average laboratory measured modulus (triplicate repeated load resilient modulus tests were performed) was divided by the average moduli estimated with each NDT device.

Table 69 summaries the adjustment factors equating the NDT moduli to the resilient modulus measured in the laboratory (see Tables 60 and 62 in chapter 5) for the Part A field evaluation projects. The adjustment factors do not appear to be related to the percent compaction, percent of optimum water content, or material type. The adjustment factors for the deflection-based devices are approximately the inverse of the values reported from the FHWA-LTPP study. Thus, the adjustment factors derived from testing on bound pavement surfaces should not be used when testing directly on the unbound layer being evaluated.

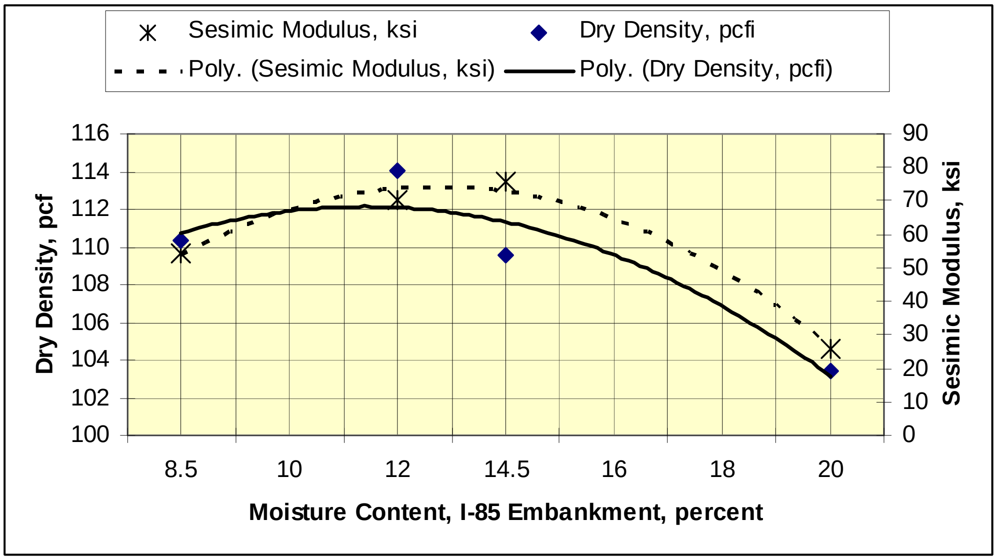


Figure 84. Comparison of the PSPA Moduli to the M-D Relationship for the I-85 Low Plasticity Soil Embankment

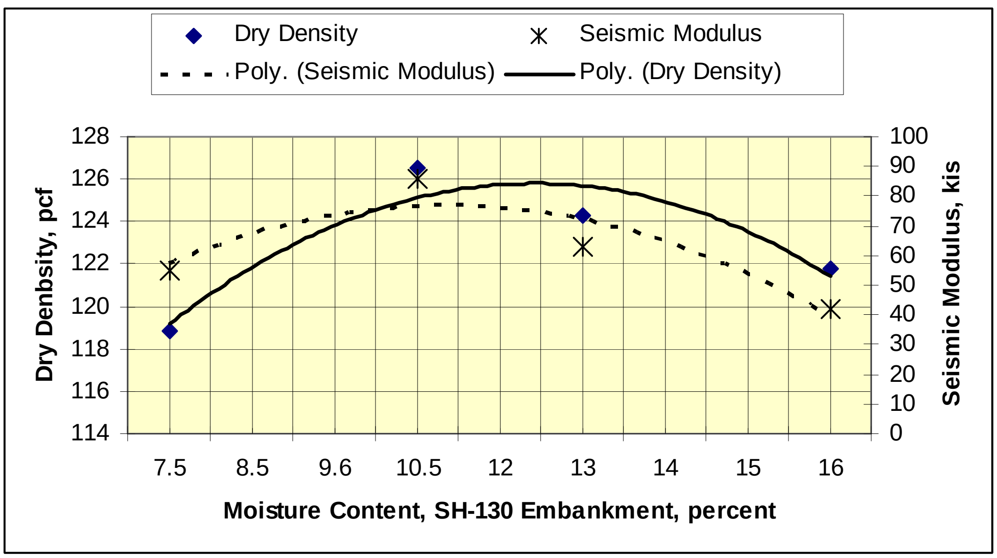


Figure 85. Comparison of the PSPA Moduli to the M-D Relationship for the SH-130 Improved Granular Embankment

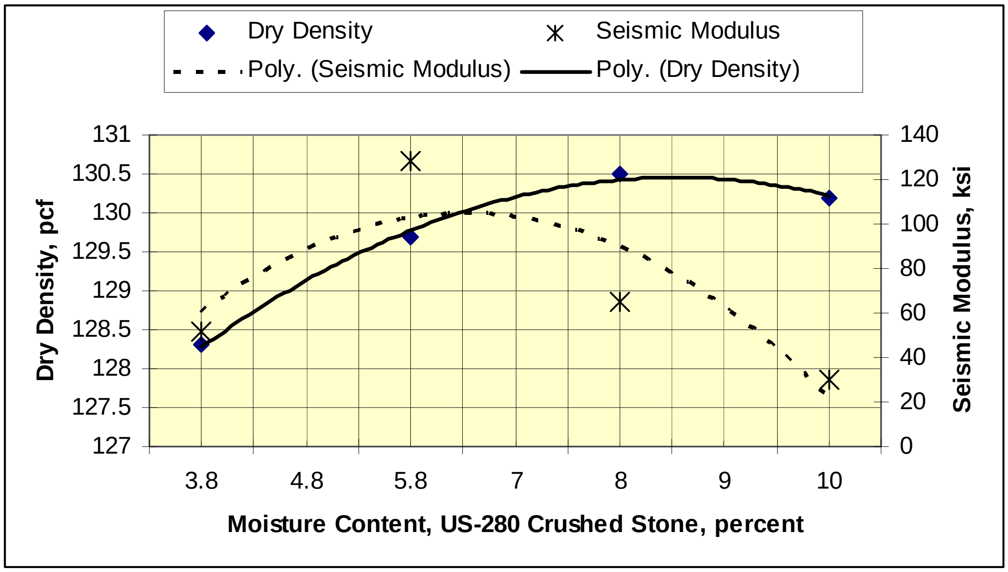


Figure 86. Comparison of the PSPA Modulus to the M-D Relationship for the US-280 Crushed Stone Base

Table 69. Adjustment Factors or Ratios Applied to the NDT Modulus Values to Represent Laboratory Conditions or Values at Low Stress States; Part A Projects

Project	Material	Percent Compaction	Percent of Optimum Moisture	Ratio or Adjustment Factor			
				Geo.	DSPA	DCP	LWD
I-85 Embankment	Low Plasticity Clay	91	165	0.19	0.087	0.53	0.39
TH-23 Embankment	Silt-Sand-Gravel Mix	100	132	0.90	0.41	0.95	3.13
SH-21 Subgrade	High Plastic Clay	99	84	1.16	0.99	2.94	2.78
TH-23 Base	Crushed Aggregate	104	55	0.71	0.30	0.68	1.69
SH-130 Embankment	Improved Granular Mix	105	101	1.39	1.04	1.67	1.43
US-280 Base	Crushed Stone	101	52	1.01	0.24	0.96	1.04
The adjustment ratio or factor was determined by dividing the average resilient modulus measured in the laboratory (for a specific stress state, see table 60) by the average modulus from the NDT device.							

Another important observation from the Part A projects is that the adjustment factors for all NDT devices for the I-85 low plasticity clay embankment prior to IC rolling are significantly lower than for any of the other materials. This observation suggests that the resilient moduli measured in the laboratory are much lower than for any of the other soils and materials. The reason for the low values is unknown. This embankment soil had the lowest dry density and highest water content relative to its maximum dry density and optimum water content also see Tables 60, in chapter 5). However, these data were excluded from developing the adjustment factors and selection of an NDT device that can be used to confirm the structural design parameters because they were consistent across all NDT devices.

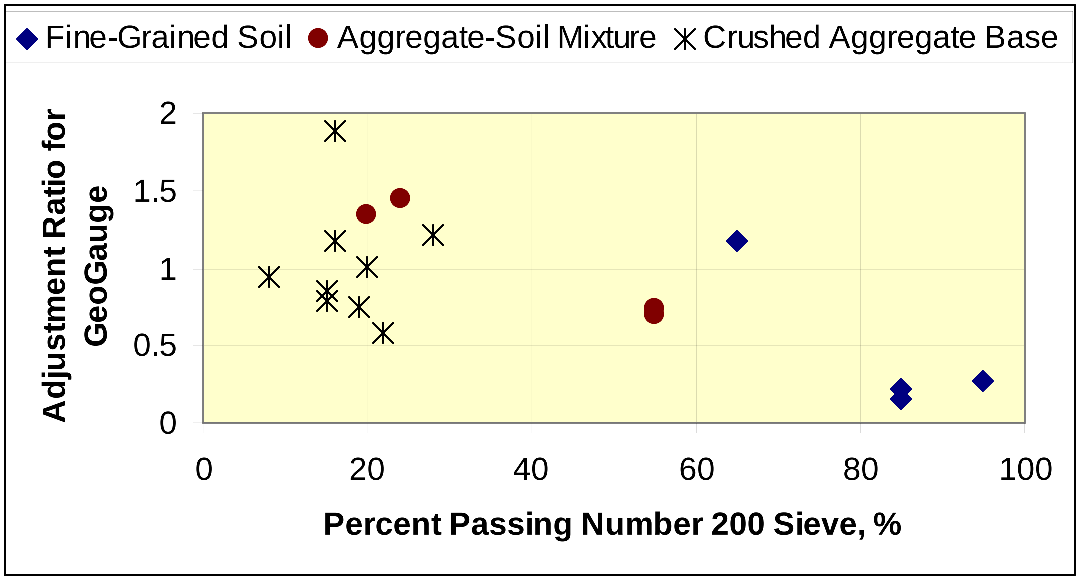
Table 70 summarizes the adjustment factors for all projects included in the field evaluation (Parts A and B). The LWD is not included in Table 70 because it was excluded from the Part B projects. On the average, the GeoGauge and DCP provided a reasonable estimate to the laboratory measured values, with the exception of the fine-grained, clay soils. The GeoGauge deviated significantly from the laboratory values for the fine-grained soils. The results also show that both the GeoGauge and DCP over- or under-predicted the laboratory measured values for the same material, with a few exceptions.

Table 70. Adjustment Factors Applied to the NDT Modulus Values to Represent Laboratory Conditions or Values at Low Stress States, All Projects

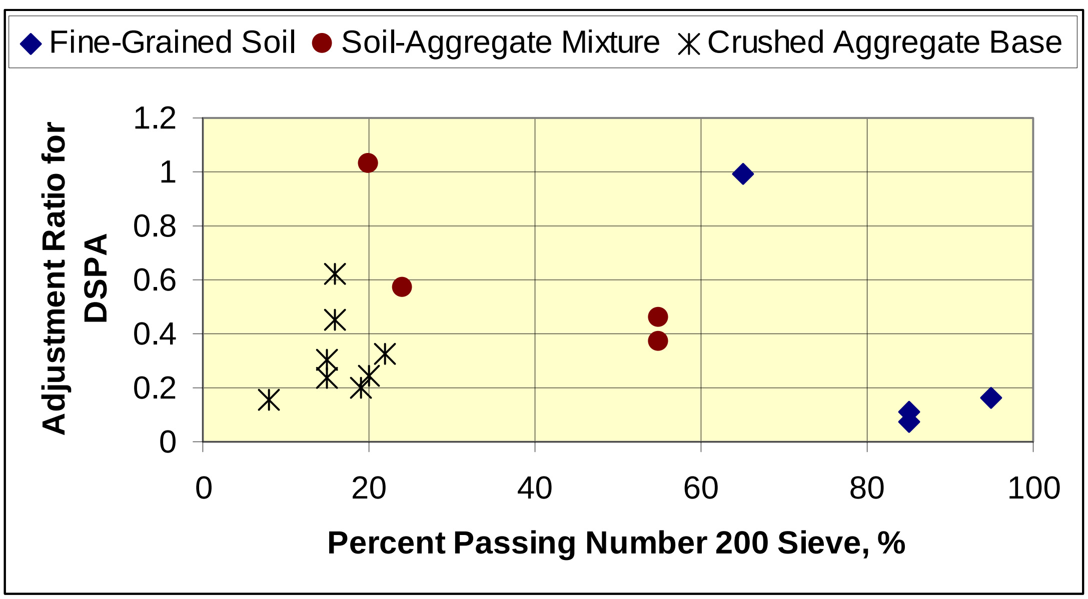
Project Identification		Resilient Modulus, ksi		Adjustment Factors Relating Laboratory Values to NDT Values		
		Laboratory Measured Value	Predicted with LTPP Equations	Geo Gauge	DSPA	DCP
Fine-Grained Clay Soils						
I-85 Low-Plastic Soil	Before IC Rolling	2.5	10.5	0.154	.0751	0.446
	After IC Rolling	4.0	13.1	0.223	0.113	0.606
NCAT; OK	High Plastic Clay	6.9	19.7	0.266	0.166	0.802
SH-21, TX	High Plastic Clay	26.8	19.6	1.170	0.989	3.045
Average Ratios for Fine-Grained Soil				**0.454**	**0.336**	**1.225**
Embankment Materials; Soil-Aggregate Mixture						
TH-23, MN	South Embankment	16.0	15.7	0.696	0.367	1.053
	North Embankment	16.4	16.3	0.735	0.459	0.863
US-2, ND	Embankment	19.0	19.5	1.450	0.574	0.856
SH-130, TX	Improved Soil	35.3	21.9	1.337	1.029	1.657
Average Ratios for Soil-Aggregate Mixtures; Embankments				**1.055**	**0.607**	**1.107**
Aggregate Base Materials						
Co. 103, TX	Caliche Base	---	32.3	1.214	---	1.436
NCAT, SC	Crushed Granite	14.3	36.1	0.947	0.156	---
NCAT, MO	Crushed Limestone	19.2	40.9	0.747	0.198	---
TH-23, MN	Crushed Stone, Middle	24.0	29.9	0.851	0.303	0.725
	Crushed Stone, South	26.0	35.6	0.788	0.235	0.560
US-53, OH	Crushed Stone	27.5	38.3	1.170	0.449	0.862
NCAT, FL	Limerock	28.6	28.1	0.574	0.324	0.619
US-2, ND	Crushed Aggregate	32.4	39.8	1.884	0.623	1.129
US-280, AL	Crushed Stone	48.4	49.3	1.010	0.244	0.962
Average Ratios for Aggregate Base Materials				**1.021**	**0.316**	**0.899**
Overall Average Values				**0.942**	**0.422**	**1.084**

NOTES:
1. The adjustment ratio is determined by dividing the resilient modulus measured in the laboratory at a specific stress state by the NDT estimated modulus.
2. The average ratios listed above exclude the data from the I-85 low plasticity clay prior to IC rolling. The resilient modulus regression equations are provided in equations 34 to 48.

These ratios were compared to the percent compaction, percent of optimum water content, and material type, but no relationship could be found. The GeoGauge and DSPA adjustment ratios appear to be related to the amount of fines in the material (percent passing number 200 sieve), as shown in Figure 87.



(a) GeoGauge



(b) DSPA

Figure 87. Effect of the Amount of Fines of the Adjustment Ratio for the GeoGauge and DSPA Devices

In summary, the GeoGauge can be used to estimate the resilient modulus measured in the laboratory for aggregate base materials and coarse-graded soil-aggregate embankments, while the DCP provided a closer estimate for the fine-grained soils. However, the ratios for both of these devices were variable—even within the same soil or material group. The DSPA resulted in a positive bias (over-predicted the laboratory resilient modulus) with variable ratios. It is suggested that repeated load resilient modulus tests be performed to determine the target or design value and those results be used to calibrate the NDT devices for a specific soil or aggregate base, because of the variability of these ratios. The resilient modulus test should be performed on bulk material sampled from the stockpiles or the roadway during construction (control strips).

Most state agencies do not have a resilient modulus testing capability, so other procedures will need to be used to establish the design or target value during construction (Darter et al., 1997). The resilient modulus was calculated at the same stress state shown in Table 60 using the regression equations that were developed from an FHWA-LTPP study (Von Quintus and Yau, 2001). The regression equations used are provided in equations 34 to 48.

$$M_R = k_1(p_a)\left(\frac{\theta}{p_a}\right)^{k_2}\left(\frac{\tau_{oct}}{p_a}+1\right)^{k_3} \quad (34)$$

Where:

θ = Bulk Stress, psi

$$\theta = \sigma_1 + \sigma_2 + \sigma_3 \quad (35)$$

τ = Octahedral shear stress, psi

$$\tau = \frac{\left((\sigma_1-\sigma_2)^2+(\sigma_2-\sigma_3)^2+(\sigma_3-\sigma_1)^2\right)^{0.5}}{3} \quad (36)$$

p_a = Atmospheric pressure, 14.7 psi.

$\sigma_{1,2,3}$ = Principal stress, psi.

$k_{1,2,3}$ = Regression constants from laboratory resilient modulus test results.

The *k* regression constants are material specific. The following defines the regression constants for the different materials that were tested within the field evaluation projects. These relationships for these regression constants were developed from the FHWA-LTPP study (Von Quintus and Killingsworth, 1998)

Crushed Stone Base Materials:

$$k_1 = 0.7632 + 0.008(P_{3/8}) + 0.0088(LL) - 0.037(w_s) - 0.0001(\gamma_{dry}) \quad (37)$$

$$k_2 = 2.2159 - 0.0016(P_{3/8}) + 0.0008(LL) - 0.038(w_s) - 0.0006(\gamma_{dry}) + 0.00000024\left(\frac{\gamma_{dry}^2}{P_{\#40}}\right) \quad (38)$$

$$k_3 = -1.1720 - 0.0082(LL) - 0.0014(w_s) + 0.0005\gamma_{dry} \quad (39)$$

Embankments, Soil-Aggregate Mixture, Coarse-Grained

$$k_1 = 0.5856 + 0.0130(P_{3/8}) - 0.0174(P_{\#4}) + 0.0027(P_{\#200}) + 0.0149(PI) + 0.0000016(\gamma_{Max}) - 0.0426(w_S) + 1.6456\left(\frac{\gamma_{dry}}{\gamma_{Max}}\right) + 0.3932\left(\frac{w_s}{w_{Max}}\right) - 0.00000082\left(\frac{\gamma_{Max}^2}{P_{\#40}}\right) \quad (40)$$

$$k_2 = 0.7833 - 0.0060(P_{\#200}) - 0.0081(PI) + 0.0001(\gamma_{Max}) - 0.1483\left(\frac{w_s}{w_{opt}}\right) + 0.00000027\left(\frac{\gamma_{dry}^2}{P_{\#40}}\right) \quad (41)$$

$$k_3 = -0.1906 - 0.0026(P_{\#200}) + 0.00000081\left(\frac{\gamma_{opt}^2}{P_{\#40}}\right) \quad (42)$$

Embankments, Soil-Aggregate Mixture, Fine-Grained

$$k_1 = 0.7668 + 0.0051(P_{\#4}) + 0.0128(P_{\#200}) + 0.0030(LL) - 0.051(w_{opt}) + 1.179\left(\frac{\gamma_{dry}}{\gamma_{Max}}\right) \quad (43)$$

$$k_2 = 0.4951 - 0.0141(P_{\#4}) - 0.0061(P_{\#200}) + 1.3941\left(\frac{\gamma_{dry}}{\gamma_{Max}}\right) \quad (44)$$

$$k_3 = 0.9303 + 0.0293(P_{3/8}) + 0.0036(LL) - 3.8903\left(\frac{\gamma_{dry}}{\gamma_{Max}}\right) \quad (45)$$

Fine-Grained Clay Soil

$$k_1 = 1.3577 + 0.0106(Clay) - 0.0437(w_s) \quad (46)$$

$$k_2 = 0.5193 - 0.0073(P_{\#4}) + 0.0095(P_{\#40}) - 0.0027(P_{\#200}) - 0.0030(LL) - 0.0049(w_s) \quad (47)$$

$$k_3 = 1.4258 - 0.0288(P_{\#4}) + 0.0303(P_{\#40}) - 0.0521(P_{\#200}) + 0.025(Silt) + 0.0535(LL) - 0.0672(w_{opt}) - 0.0026(\gamma_{\max}) + 0.0025(\gamma_{dry}) - 0.6055\left(\frac{w_s}{w_{opt}}\right) \quad (48)$$

Figure 88 compares the laboratory measured resilient modulus values and those calculated from the regression equations (see Table 70). Use of the regression equations, on the average, resulted in a reasonable prediction of the laboratory measured values. Von Quintus and Yau (2001), however, reported that the regression equations can result in significant error and recommended that repeated load resilient modulus tests be performed.

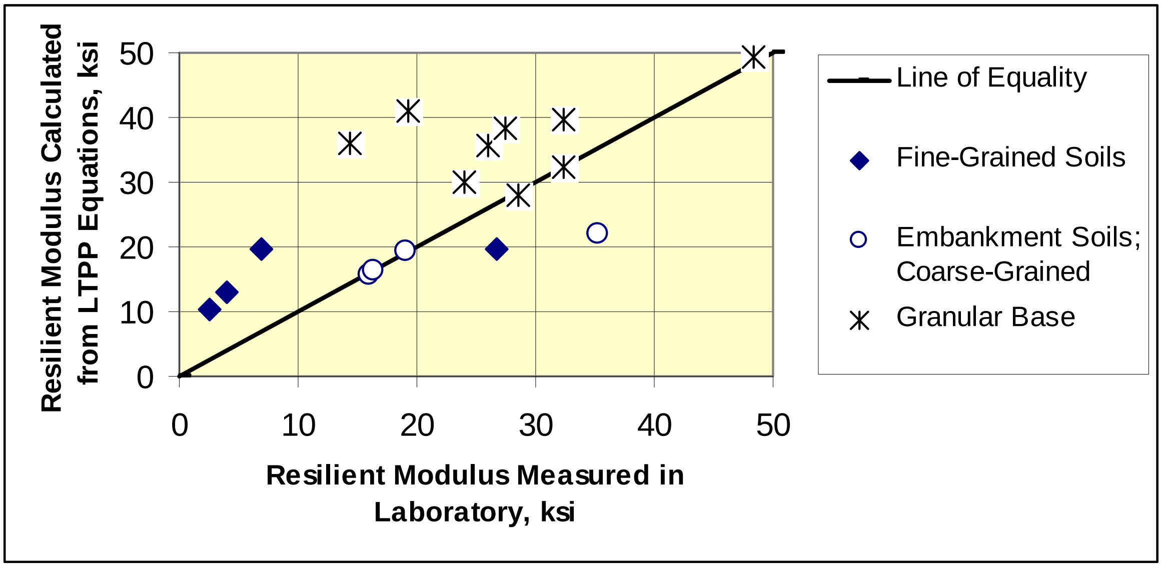


Figure 88. Comparison of the Resilient Modulus Values Measured in the Laboratory to the Resilient Modulus Values Predicted with the LTPP Regression Equations

7.2.2 HMA Layers

Table 63 in chapter 5 listed the laboratory dynamic moduli measured at a loading frequency of 5.0 Hz for the in-place average mixture temperature measured during NDT. As for the unbound materials, it is expected that the modulus values determined from the deflection-based methods are affected by the supporting materials. To compensate for differences between the laboratory and field conditions, an adjustment procedure was used to estimate the modulus values from the PSPA and FWD for making relative comparisons. This field adjustment procedure is the same as used for the unbound materials. The adjustment ratios were determined for the areas without any anomalies or physical differences from the target properties and are given in Table 71.

The PSPA adjustment ratios were found to be relatively close to unity, with the exception of the I-35/SH-130 HMA base mixture. This HMA base mixture is a very stiff mixture in the laboratory but was estimated to be similar to the US-2 HMA base with the PSPA (see Table 63 in chapter 5). The reason for the large difference between the laboratory and field or deviation from unity for this one mixture is unknown. Conversely, the FWD adjustment factors are significantly different from unity. The FWD over estimated the SMA modulus for the overlay project and under estimated the HMA base modulus for the reconstruction projects suggesting that the calculated values from the deflection basins are being influenced by the supporting materials.

On the average, the PSPA can be used to estimate the dynamic modulus measured in the laboratory HMA mixtures, while the FWD was found to be extremely variable. The PSPA ratios are variable, but that variability is less than the ratios for the unbound materials. These ratios were compared to the binder type, gradation, and other volumetric properties but no relationship was found. It is suggested that dynamic modulus tests be performed to determine the target or design value and those results be used to calibrate the PSPA for a specific mixture. The dynamic modulus test can be performed on bulk mixture compacted to the expected in-place density during the mixture verification process or during construction of a control strip.

Table 71. Summary of Dynamic Modulus Values Measured in the Laboratory and Adjustment Factors for the Modulus Estimating NDT Devices

Project/Mixture	Dynamic Modulus, ksi	Ratio or Adjustment Factor	
		PSPA	FWD
I-85 AL, SMA Overlay	250	1.055	0.556
TH-23 MN, HMA Base	810	1.688	NA
US-280 AL, HMA Base; Initial Area	650	1.407	3.939
US-280 AL, HMA Base; Supplemental Area	780	1.398	2.516
I-35/SH-130 TX, HMA Base	1,750	5.117	3.253
I-75 MI, Dense-Graded Type 3-C	400	0.919	NA
I-75 MI, Dense-Graded Type E-10	590	0.756	NA
US-47 MO, Fine-Graded Surface	530	1.158	NA
US-47 MO, Coarse-Graded Base Mix	420	0.694	NA
I-20 TX, HMA Base, CMHB	340	0.799	NA
US-53 OH, Coarse-Graded Base	850	1.275	NA
US-2 ND, Coarse-Graded Base, PG58-28	510	1.482	NA
NCAT SC, PG67 Base Mix	410	0.828	NA
NCAT FL, PG67 Base Mix	390	0.872	NA
NCAT FL, PG76 Base Mix	590	1.240	NA
NCAT AL, PG76 with RAP and Sasobit	610	1.3760	NA
NCAT AL, PG76 with RAP and SBS	640	1.352	NA
NCAT AL, PG67 with RAP	450	0.881	NA
Overall Average Ratio or Adjustment Factor		**1.128**	**2.566**

NOTES:
1. The adjustment factor or ratio was determined by dividing the dynamic modulus measured in the laboratory for the in place temperature and at a loading frequency of 5 Hz by the modulus estimated with the NDT device.
2. The laboratory dynamic modulus values listed above are for a test temperature of a loading frequency of 5.0 Hz at the temperature of the mixture when the NDT was performed (see table 63).
3. The overall average adjust factor excludes the SH-130 mixture because it was found to be significantly different than any other mixture tested in the laboratory; which has been shaded.

7.3 Accuracy and Precision

Important parameters in QA are the accuracy and precision of a test method. The higher precision of a test method, the fewer tests need to be completed at some confidence level for estimating properties of the population or lot and making the "right" decision regarding the quality of the lot. This section evaluates and compares the variability measured within the field evaluation projects with different NDT devices. The more precise the result, however, does not automatically imply that the test method can identify physical differences or information about the population related to performance.

7.3.1 NDT Devices for Unbound Layers

Variability of Response Measurements

Figures 89 through 92 compare the COV to the average modulus measured by each device. All COV point comparisons were for the same test area. Thus, the material variance should be the same between the different NDT devices.

The GeoGauge consistently has the lower COV, and that value decreases with increasing material stiffness (Figure 92). The variations of the GeoGauge measurements were found to be less dependent of type and size of aggregate, as well as less dependent on the underlying materials for the thicker layers tested. The reason for the higher COV values for the other devices is that the DCP penetration rate is dependent on the amount and size of coarse aggregate particles, while the LWD modulus values are more dependent on the underlying materials. The DSPA is dependent on the water content variations nearer the surface (water content-density gradients), and the amount of fines in coarse-gained materials.

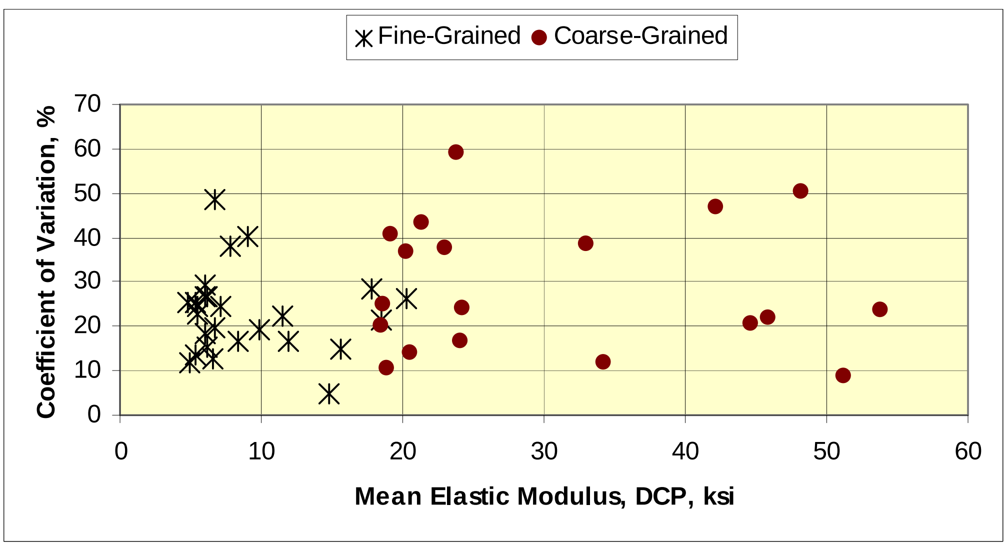


Figure 89. Coefficient of Variation versus the Mean Modulus Calculated from the DCP Penetration Rates

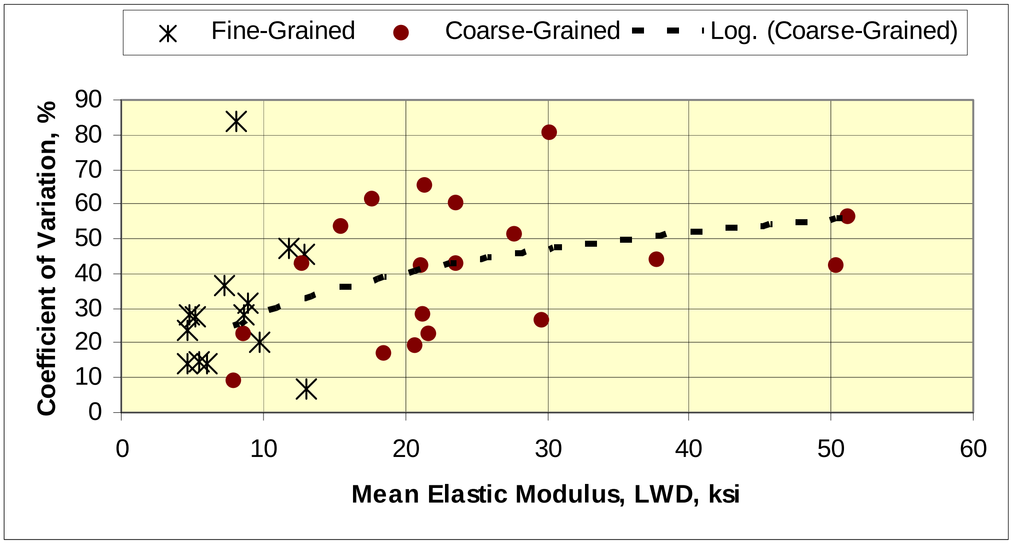


Figure 90. Coefficient of Variation versus the Mean Modulus Calculated from the LWD Deflections

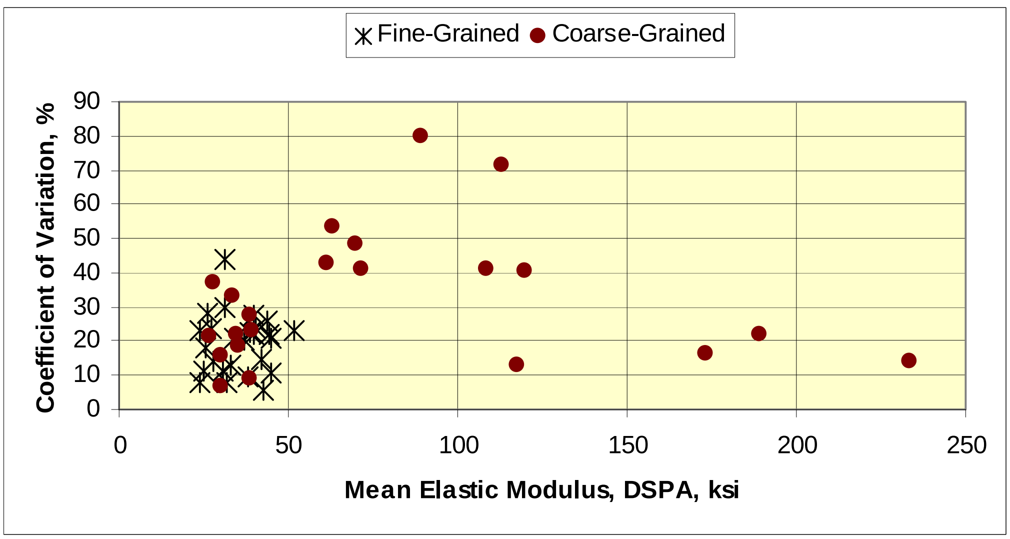


Figure 91. Coefficient of Variation versus the Mean Modulus Determined from the DSPA Responses

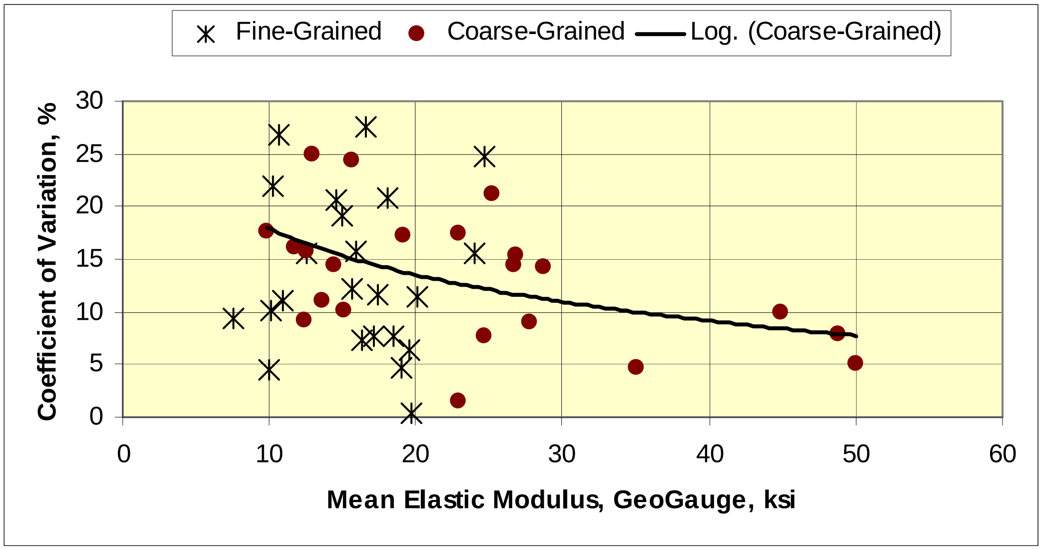
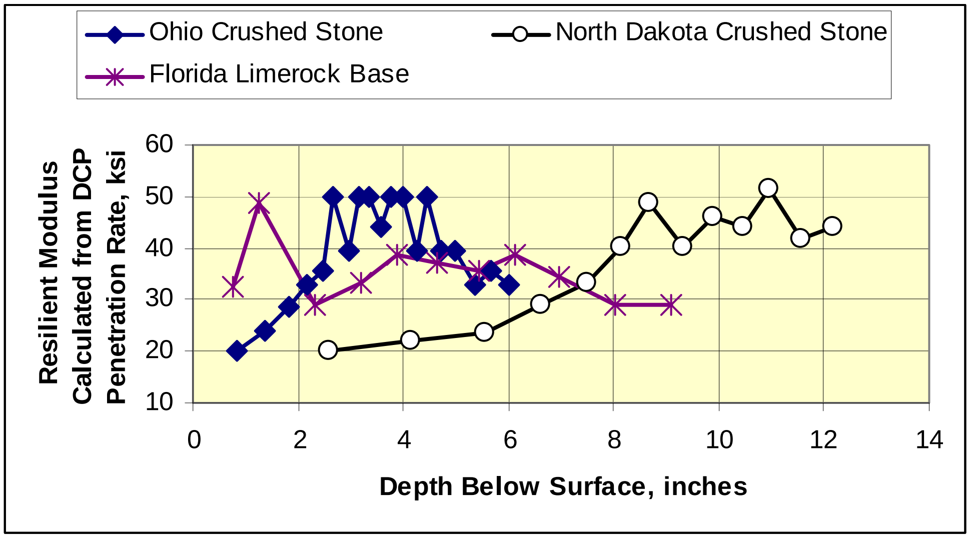


Figure 92. Coefficient of Variation versus the Mean Modulus Determined from the GeoGauge Responses

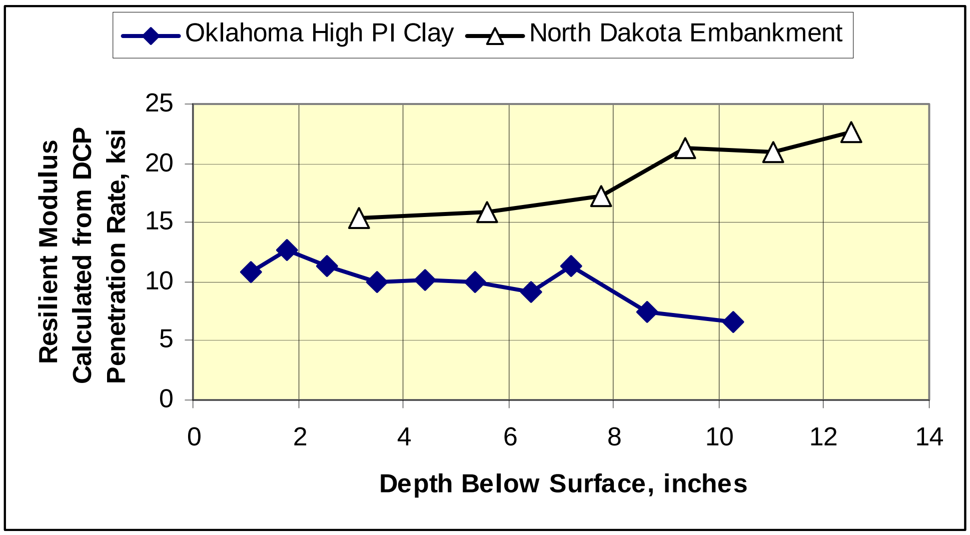
The DSPA had higher variability when testing stiff materials that had water contents significantly below the optimum value or where the surface had been primed. Some layers tested had a significant modulus gradient near the surface, which has a much larger effect on the DSPA responses. Some sites had a positive gradient (modulus increases with depth), while other sites had a negative gradient. Those sites with positive modulus gradients generally had higher adjustment ratios, while those with negative gradients had lower ratios. These modulus gradients were confirmed with the DCP—the only device that could readily measure these gradients in real-time. Figure 92 shows some examples of the change in modulus with depth, as calculated from the penetration rate (see equation 33 in chapter 5).

The DSPA was also placed in different directions relative to the roller direction for measuring modulus, while the other NDT devices do not have this capability—only an equivalent or average modulus value is reported for all directions. Figure 93 compares the difference between the modulus values parallel and perpendicular to the roller's direction to the modulus measured parallel to roller direction. For less stiff materials (especially fine-grained materials) there is no difference between the two readings. For stiffer, coarse-grained materials, however, there is a slight bias. The moduli measured parallel to roller direction were slightly higher, on the average. This difference and bias result in a higher COV for the clustered measurements.

The LWD had the higher variability in test results and lower success rates. The higher COV value is related to the variability in the underlying layers and their influence on the measured response with the deflection measuring devices, as well as thickness variations of the layer being evaluated—a constant layer thickness and subsurface condition were used.



(a) Aggregate Base Materials/Layers



(b) Subgrade and Embankment Materials/Layers

Figure 93. Modulus Gradients in Unbound Layers, as Determined with the DCP

The variability of the GPR and EDG for measuring the volumetric properties (density and fluids content) were found to be significantly different from each other, as well as from the agencies' QA data, when available. Both of these devices had very poor success rates in identifying physical differences between different sections. The EDG resulted in very low variability in its estimates of dry density and water content within a specific area or test section. Most of the COV values for both properties were less than 2 percent (see Tables 43 and 44 in chapter 5). Thus, the average values determined at a test point and within a test section did not deviate significantly from the project average that was determined from nuclear density gauges and/or sand-cone tests.

Conversely, the GPR resulted in high variability of the dielectric values (see Table 42 in chapter 5), as well as for the dry densities. More importantly, the dry densities determined in some areas exceeded 160 pcf (see Figure 51 in chapter 5)—an unlikely value. The reasons for the improbable high as well as low values within a project is the assumption used to convert the dielectric values to dry densities—a constant water content for all areas within a lot was assumed. As a result, the GPR data interpretation technique needs to be improved and determine the dry density and water content along the project prior to day-to-day use in QA programs.

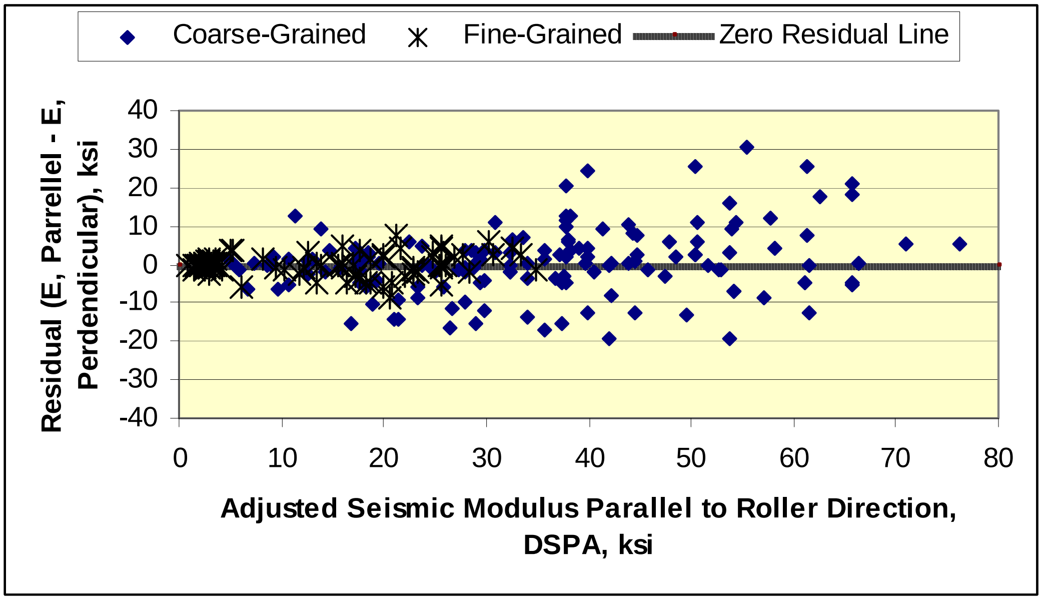


Figure 94. DSPA Modulus Values Measured Parallel to Roller Direction versus the Difference Between Modulus Values Parallel and Perpendicular to Roller Direction

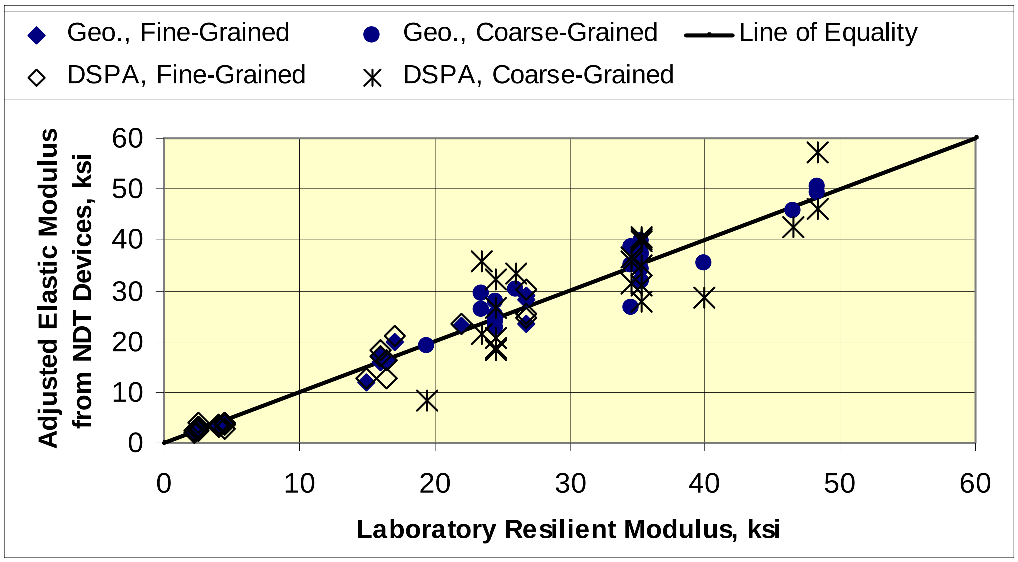
Standard Error

Another reason for using the adjustment ratios in evaluating each NDT device is to eliminate or reduce bias in assuming that the target value is the laboratory resilient modulus measured at a specific stress state. Figure 95 compares the laboratory measured resilient modulus values to those estimated with different NDT devices but adjusted to laboratory conditions, while Figure 96 presents the residuals (laboratory resilient modulus minus the NDT modulus), assuming that the laboratory value is the target value. On the average, the adjusted elastic modulus from all devices compare reasonably well with the laboratory measured resilient modulus. Table 72 tabulates the mean of the residuals and standard error for the NDT devices that provide a direct measure of material stiffness.

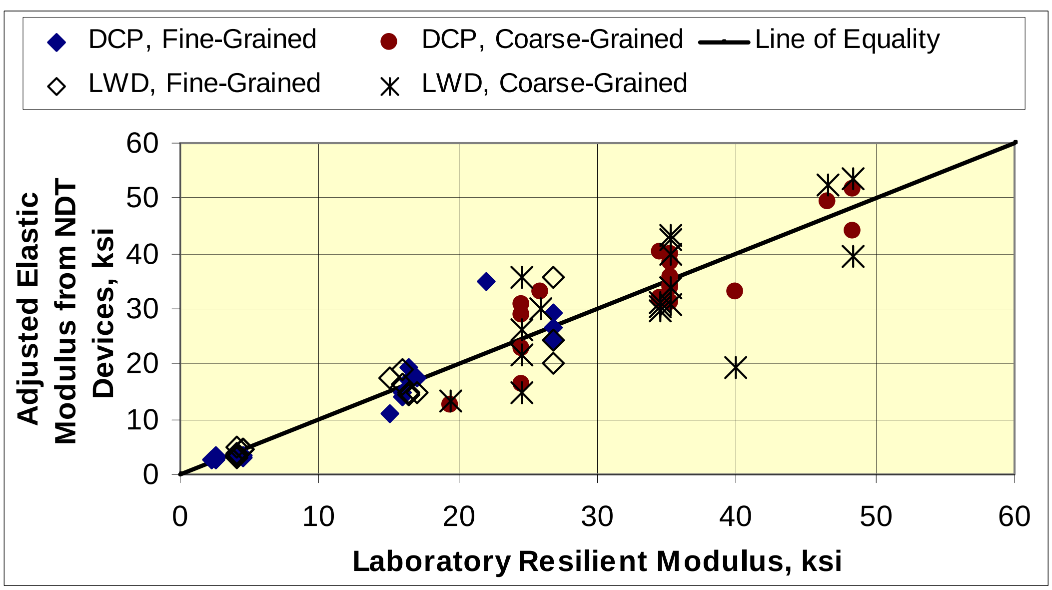
Table 72. Tabulation of Mean of the Residuals and Standard Error for NDT Devices

NDT Device	GeoGauge	DSPA	DCP	LWD
Mean Residual, ksi	-0.117	0.149	-0.078	0.614
Standard Error, ksi	2.419	4.486	3.768	5.884

In summary, the GeoGauge, DSPA, and DCP all provide good estimates with negligible bias (effect of adjustment ratios) of the laboratory measured resilient modulus values. The GeoGauge has the lower standard error. The LWD has a higher bias and over two times the standard error, in comparison to the GeoGauge.

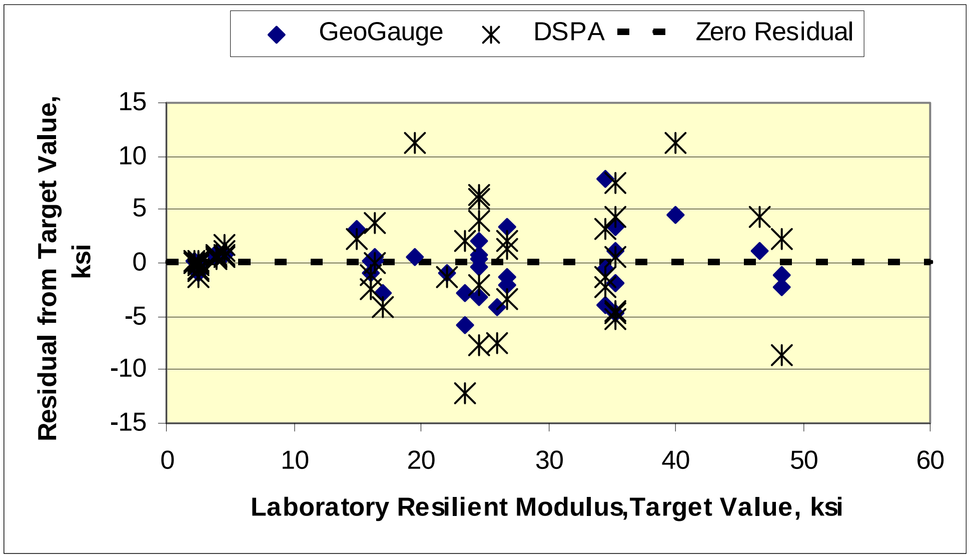


(a) DSPA and the GeoGauge.

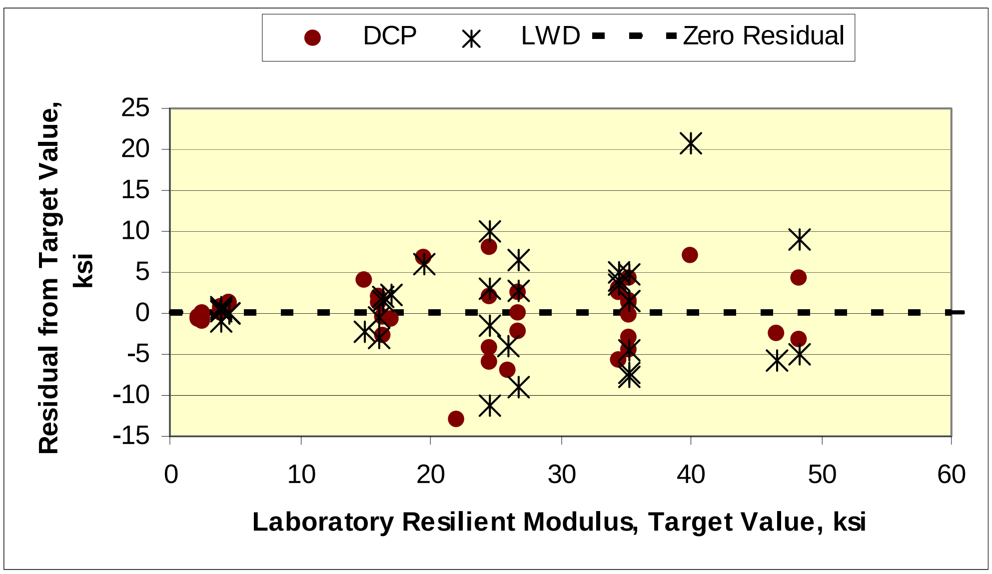


(b) Deflection-Based and DCP methods.

Figure 95. Laboratory Resilient Modulus versus Adjusted NDT Modulus



(a) GeoGauge and DSPA.



(b) DCP and LWD.

Figure 96. Residuals (Laboratory Minus NDT Modulus Values) versus Adjusted NDT Modulus

7.3.2 NDT Devices for HMA Mixtures

Variability of Response Measurements

Figure 97 compares the COV between different technologies and devices (PSPA, FWD, PQI, and GPR). The PQI consistently had a low COV relative to the other devices, while the FWD has the largest value. It should be noted that a low COV does not necessarily mean that the device is providing an accurate measure of the HMA mixture property and variability. One reason for the lower COV values for the PQI relative to the other devices is that five tests were performed at each test point. In other words, the testing and sampling error or differences get averaged out through the testing sequence.

Two versions of the GPR air-coupled antennas were used. The first version was a single-antenna method and only used in Part A of the field evaluation. The second version included the use of multiple antennas and the EPIC *Hyper Optics*^{TM} proprietary data interpretation system. The EPIC GPR system was supposed to be used along the NCAT, Missouri (US-47), and Texas (I-20) sections; however, weather delays and equipment/plant problems resulted in changes to the testing schedule. These schedule changes resulted in conflicts with other projects, so ultimately, this system was used only on the NCAT test sections, at a later date.

Data were made available for use from other projects built in Florida, which were not included in the original field evaluation (Greene, 2007; Greene and Hammons, 2006). The EPIC system is reported to have much more accurate and repeatable estimates of the HMA volumetric properties. One reason for this increased accuracy and precision is that it does not rely on the assumptions that were included in the single antenna method used along the Part A projects. The precision and bias for both devices and systems is provided in the next section.

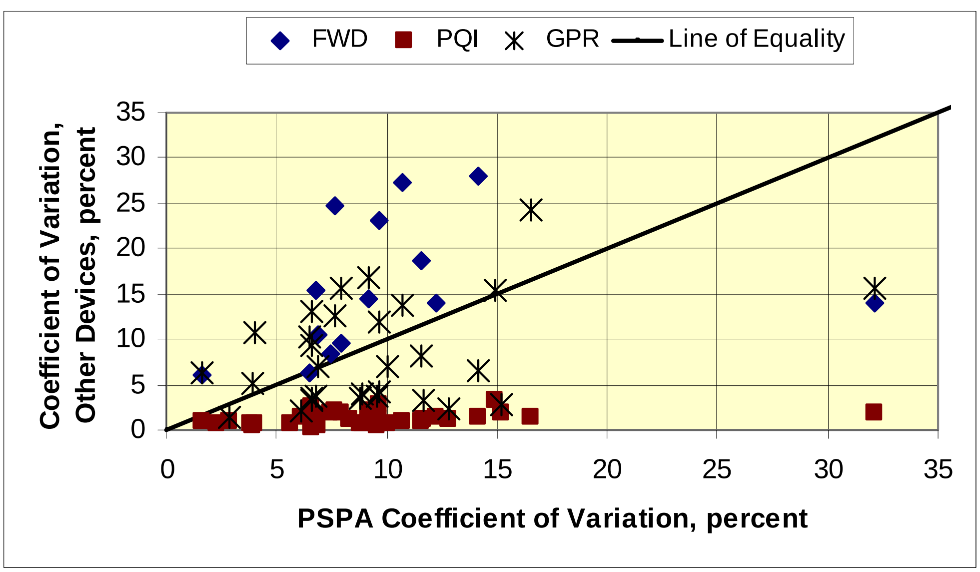


Figure 97. Comparison of Coefficient of Variations of Different NDT Devices

Standard Error

As for the unbound materials, the adjustment ratios were used in evaluating the PSPA and FWD to reduce bias in assuming that the target value is the laboratory dynamic modulus measured at a specific load frequency and average in place mix temperature. Figure 98 compares the PSPA and FWD modulus values that have been adjusted to laboratory conditions using the factors or ratios listed in Table 71. On the average, the adjusted modulus values compare reasonably well to one another. Table 73 tabulates the mean of the residuals (laboratory dynamic modulus minus the NDT modulus) and standard error from the expected laboratory value—excluding all measurements taken in areas with anomalies, segregation, and along longitudinal joints.

Table 73. Tabulation of Mean of the Residuals and Standard Error for NDT Devices From the Expected Laboratory Value

NDT Device	PSPA	FWD
Mean Residual, ksi	13.5	39.0
Standard Error, ksi	76	87

While the difference between the two NDT devices is small, the PSPA had the lower residual and standard error.

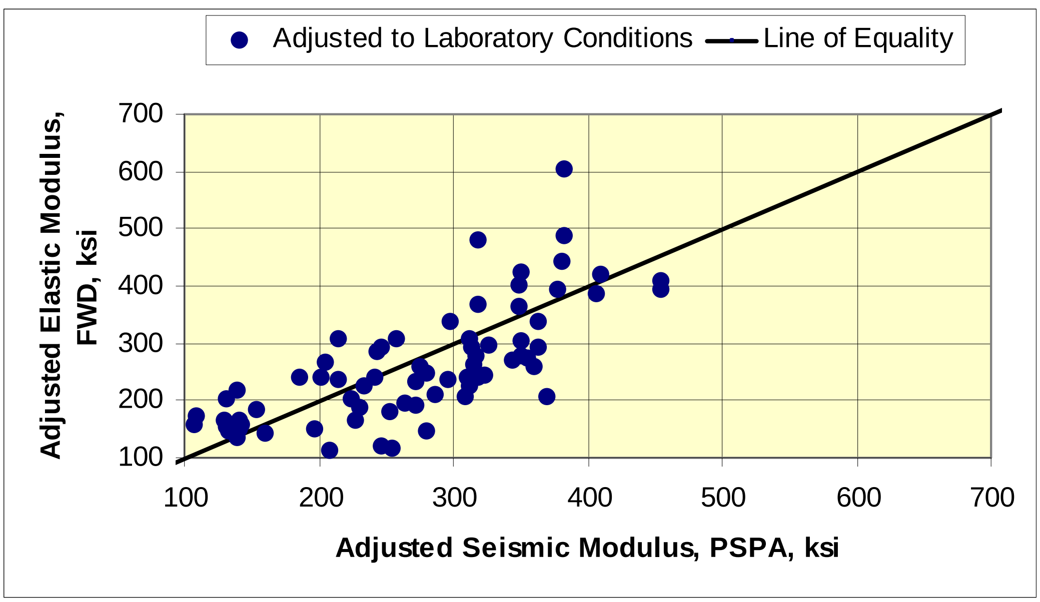


Figure 98. Comparison of the PSPA and FWD Modulus Values Adjusted to Laboratory Conditions

7.3.3. Summary

Table 74 summarizes the statistical analyses of the NDT devices included in the field evaluation projects. This information is grouped into two areas—those NDT devices with an acceptable to excellent success rate and those with poor success rates in identifying material/layer differences.

Table 74. NDT Device and Technology Variability Analysis Summary; Standard Error

Material	NDT Devices	Material/Layer Property				
		Structural		Volumetric		
		Thickness, in.	Modulus, ksi	Density, pcf	Air Voids, %	Fluids Content
NDT Devices with Good Success Rates Based on Modulus or Volumetric Properties; see section 7.1.1						
Fine-Grained Soils	GeoGauge	NA	**2.5**	NA	NA	NA
	DSPA	NA	**4.5**	NA	NA	NA
Coarse-Grained Soils & Aggregate Base	GeoGauge	NA	**2.5**	NA	NA	NA
	DSPA	NA	**4.5**	NA	NA	NA
HMA Mixtures	PSPA	NA	**76**	NA	NA	NA
	PQI & PT	NA	**NA**	**1.7**	NA	NA
NDT Devices with Poor Success Rates Based on Modulus or Volumetric Properties; see section 7.1.2						
Fine-Grained Soils	DCP	NA	**3.8**	NA	NA	NA
	LWD	NA	**5.9**	NA	NA	NA
	GPR	NA	NA	NA	NA	NA
	EDG	NA	NA	**0.8**	NA	**0.2**
Coarse-Grained Soils & Aggregate Base	DCP	NA	**3.8**	NA	NA	NA
	LWD	NA	**5.9**	NA	NA	NA
	GPR	**0.8**	NA	**3.4**	NA	NA
	EDG	NA	NA	**1.0**	NA	**0.2**
HMA	FWD	NA	**87**	NA	NA	NA
	GPR; Single	**0.25**	NA	NA	**0.40**	NA
	GPR; Multiple	**0.27**	NA	**1.6**	**0.22**	**0.18**

NOTES:
1. The standard error for the modulus estimating devices is based on the adjusted modulus values that have been adjusted to laboratory conditions.
2. The US-280 project with the PATB was removed for the GPR (single antenna) thickness data – it was the only site that resulted in a significant bias of layer thickness and the only one with a PATB layer directly beneath the layer tested.

Table 75. NDT Device and Technology Variability Analysis Summary; 95 Percent Precision Tolerance

Material	NDT Devices	Material/Layer Property				
		Structural		Volumetric		
		Thickness, in.	Modulus, ksi	Density, pcf	Air Voids, %	Fluids Content
NDT Devices with Good Success Rates Based on Modulus or Volumetric Properties; see section 7.1.1						
Fine-Grained Soils	GeoGauge	NA	**4.9**	NA	NA	NA
	DSPA	NA	**8.8**	NA	NA	NA
Coarse-Grained Soils & Aggregate Base	GeoGauge	NA	**4.9**	NA	NA	NA
	DSPA	NA	**8.8**	NA	NA	NA
HMA Mixtures	PSPA	NA	**150**	NA	NA	NA
	PQI & PT	NA	NA	**3.4**	NA	NA
NDT Devices with Poor Success Rates Based on Modulus or Volumetric Properties; see section 7.1.2						
Fine-Grained Soils	DCP	NA	**7.4**	NA	NA	NA
	LWD	NA	**11.6**	NA	NA	NA
	GPR	NA	NA	NA	NA	NA
	EDG	NA	NA	**1.6**	NA	**0.4**
Coarse-Grained Soils & Aggregate Base	DCP	NA	**7.4**	NA	NA	NA
	LWD	NA	**11.6**	NA	NA	NA
	GPR	**1.5**	NA	**6.7**	NA	NA
	EDG	NA	NA	**2.0**	NA	**0.4**
HMA	FWD	NA	**170.5**	NA	NA	NA
	GPR; Single	**0.49**	NA	NA	**0.8**	NA
	GPR; Multiple	**0.55**	NA	**3.1**	**0.4**	**0.36**

NOTES:
1. The precision tolerance for the modulus estimating devices is based on the adjusted modulus values that have been adjusted to laboratory conditions.
2. The US-280 project with the PATB was removed for the GPR (single antenna) thickness data – it was the only site that resulted in a significant bias of layer thickness and the only one with a PATB layer directly beneath the layer tested.

7.4 Comparison of Results—Between NDT Technologies

This section provides a brief evaluation and comparison of the test results between different technologies to determine the reasons for the low success rates of the DCP, LWD, GPR, and EDG.

7.4.1 NDT Modulus Comparisons

Figure 99 compares the NDT modulus values used to identify areas with physical differences in the unbound layers, except that the NDT values have been adjusted to laboratory conditions with the adjustment ratios listed in Table 70. Figure 99.a includes a comparison of the individual test points, while Figure 99.b compares the data on a project basis. Figure 98 compared the adjusted PSPA and FWD modulus for the HMA layers using the adjustment ratios listed in Table 71.

Table 76. NDT Device and Technology Variability Analysis Summary; Combined or Pooled Standard Deviation

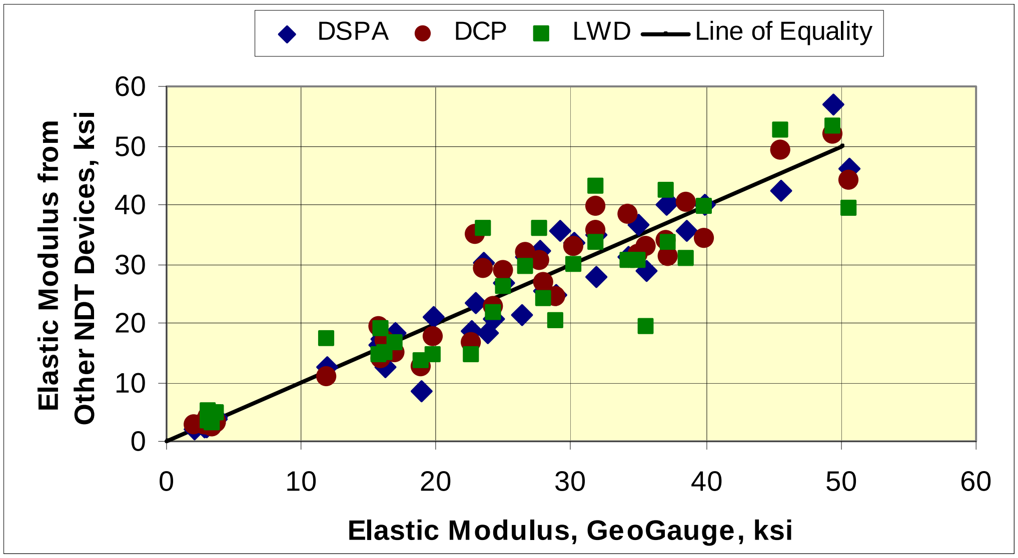
Material	NDT Devices	Material/Layer Property				
		Structural		Volumetric		
		Thickness, in.	Modulus, ksi	Density, pcf	Air Voids, %	Fluids Content
NDT Devices with Good Success Rates Based on Modulus or Volumetric Properties; see section 7.1.1						
Fine-Grained Soils	GeoGauge	NA	**1.1**	NA	NA	NA
	DSPA	NA	**1.2**	NA	NA	NA
Coarse-Grained Soils & Aggregate Base	GeoGauge	NA	**1.8**	NA	NA	NA
	DSPA	NA	**1.5**	NA	NA	NA
HMA Mixtures	PSPA	NA	**56**	NA	NA	NA
	PQI & PT	NA	NA	**2.5**	NA	NA
NDT Devices with Poor Success Rates Based on Modulus or Volumetric Properties; see section 7.1.2						
Fine-Grained Soils	DCP	NA	**1.9**	NA	NA	NA
	LWD	NA	**2.0**	NA	NA	NA
	GPR	NA	NA	**4.2**	NA	NA
	EDG	NA	NA	**0.7**	NA	**0.5**
Coarse-Grained Soils & Aggregate Base	DCP	NA	**5.3**	NA	NA	NA
	LWD	NA	**2.0**	NA	NA	NA
	GPR	**0.6**	**NA**	**3.0**	NA	NA
	EDG	NA	**NA**	**0.8**	NA	**0.6**
HMA	FWD	NA	**55**	NA	NA	NA
	GPR; Single	**0.3**	**NA**	NA	**2.1**	NA
	GPR; Multiple	NA	NA	NA	NA	NA

NOTES:
1. The pooled standard deviations for the modulus estimating devices are based on the adjusted modulus values that have been adjusted to laboratory conditions.
2. The US-280 project with the PATB was removed for the GPR (single antenna) thickness data – it was the only site that resulted in a significant bias of layer thickness and the only one with a PATB layer directly beneath the layer tested.

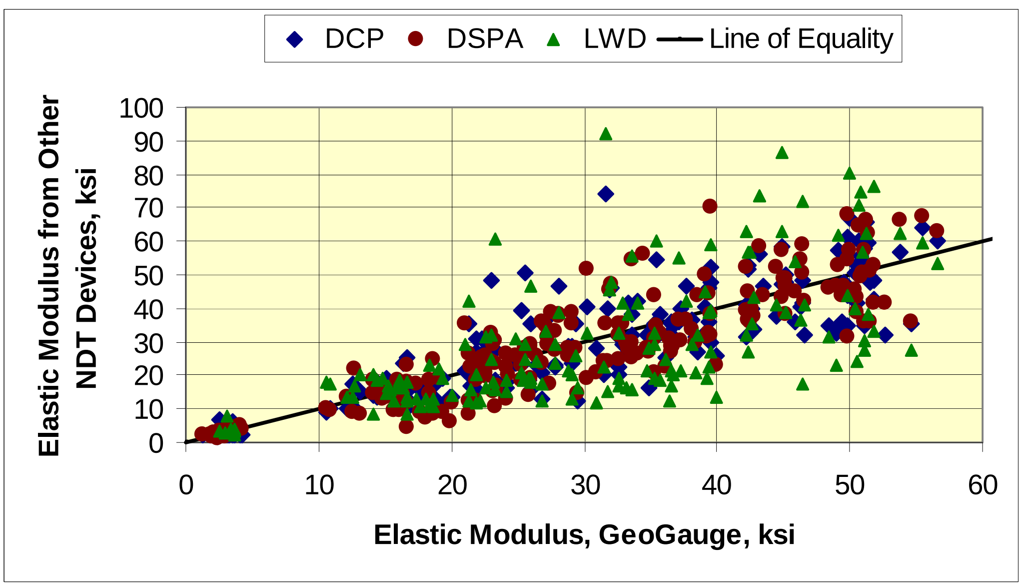
As noted in the previous section, the adjustment procedure reduced the bias between the different devices, but not the dispersion. Thus, any of these NDT modulus estimating devices can be used to estimate the resilient modulus of the material with proper calibration at the beginning of the project, with some exceptions.

- Deflection-Based Devices: The calculated modulus values from the deflection-based devices can be affected greatly by the underlying materials and soils. For example, the crushed stone base material placed in area 4 along US-280 near Opelika, Alabama, is a stiff and dense material, even though the deflection-based devices found it to be weaker than the other areas tested with a value less than 20 ksi. All other NDT devices estimated the modulus for area 4 to be about 35 ksi or higher. An in place modulus of 20 ksi for this material is too low. Thus, variations in the subsurface layers or materials/soils can incorrectly result in significant bias in the resilient modulus.
- DSPA: The DSPA can significantly over-estimate the laboratory measured resilient modulus values. The US-280 crushed stone base was dry or significantly below the

optimum water content during testing in some areas. It is believed that the surface of this dense-dry crushed stone is responding like a bound layer—resulting in a much higher modulus of the entire layer. In fact, the surface of this material actually exhibited radial cracks during the seating drop of the DCP. Figure 100 shows the estimated modulus with depth from the DCP.



(b) Comparison of adjusted modulus values on a project basis



(a) Comparison of adjusted modulus values on a point-by-point basis

Figure 99. Comparison of Adjusted Modulus Values Determined from Different NDT Devices

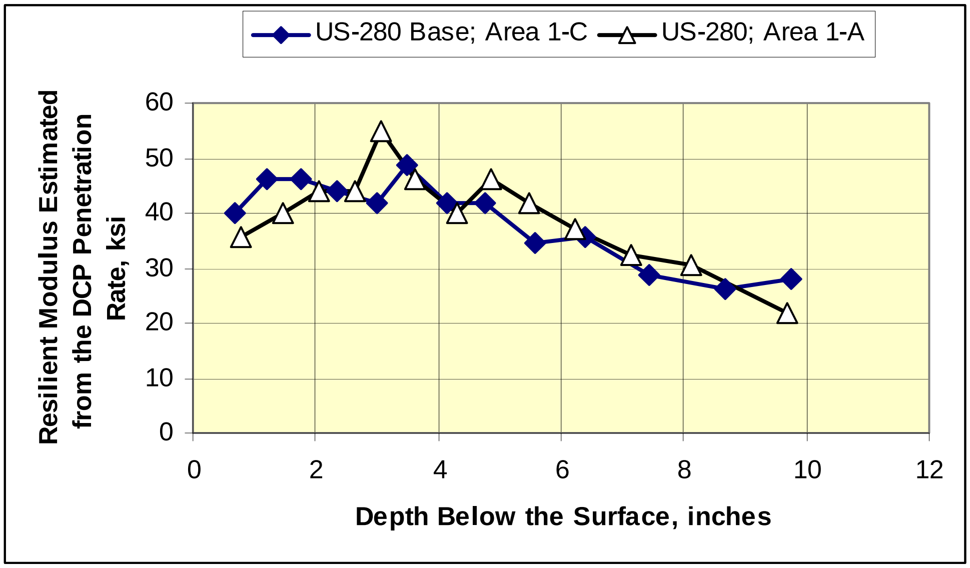


Figure 100. Modulus Gradient Measured with the DCP for the US-280 Crushed Stone Base Material

7.4.2 NDT Volumetric Property Comparisons

Unbound Layers

The EDG and GPR were used to estimate the volumetric properties of the unbound materials. The following provides a summary of the response measurements to the dry densities obtained from construction records and traditional volumetric tests.

- Figure 101 compares the dielectric values to the dry densities measured with the EDG. No good correlation was found between the different materials tested. In addition, no defined relationship was found between the two response measurements for the same material. This observation suggests that there are different properties affecting the EDG and GPR results—none of which could identify the physical differences at a reasonable success rate.
- Figure 102 compares the GPR dielectric values to the dry density measured with different devices—the EDG, nuclear density gauges, and sand-cone tests. No good correlation was found; only a trend was identified between the GPR results and the densities obtained from construction records. As the dry density increased, the GPR dielectric values decreased, but across significantly different materials. Changes in material density along the same project were poorly correlated to changes in the dielectric value.
- Figure 103 compares the dry densities measured with the EDG to those measured with a traditional nuclear density gauge. As shown, there are two definite groups of data—one for fine-grained soils and the other for crushed aggregate base materials. As the dry density increased between different materials, the density from the EDG also increased. Within each group, however, no reasonable relationship was found.

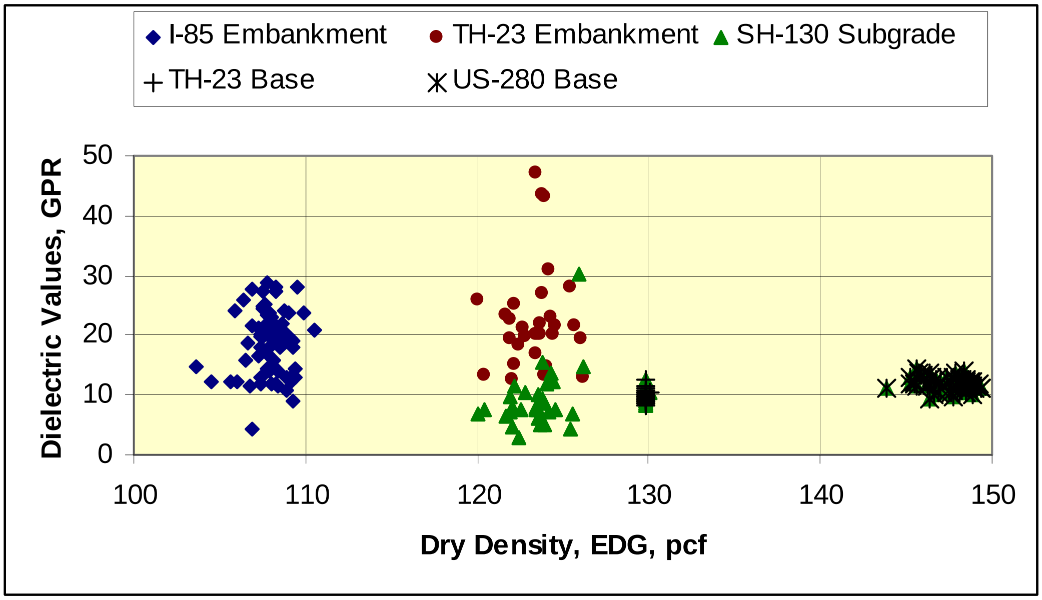


Figure 101. GPR Dielectric Values versus the EDG Dry Densities Measured along Different Projects

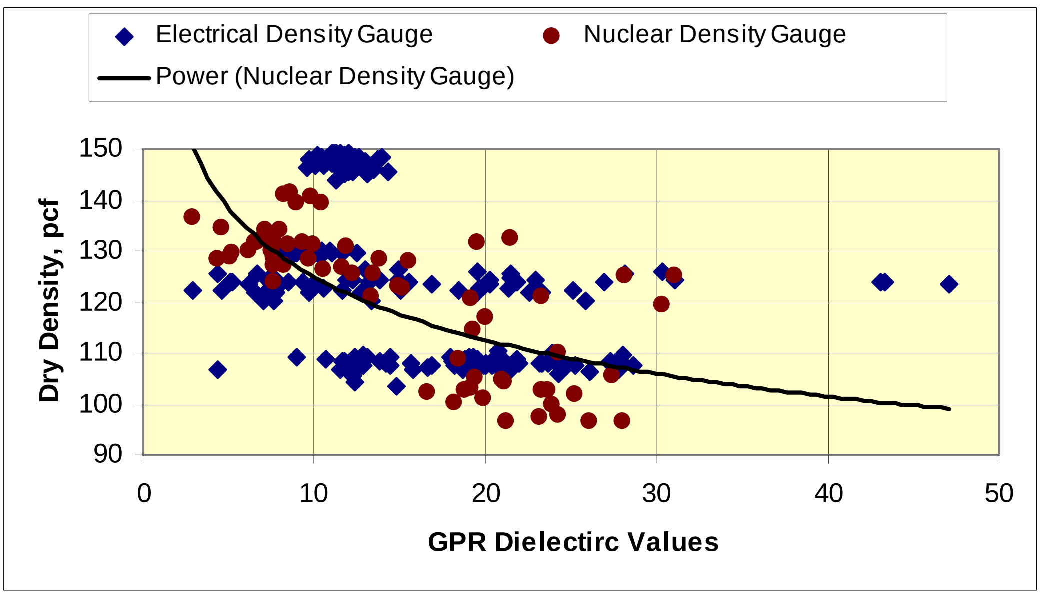


Figure 102. GPR Dielectric Values versus Dry Densities Measured with Nuclear and Non-Nuclear Density Gauges

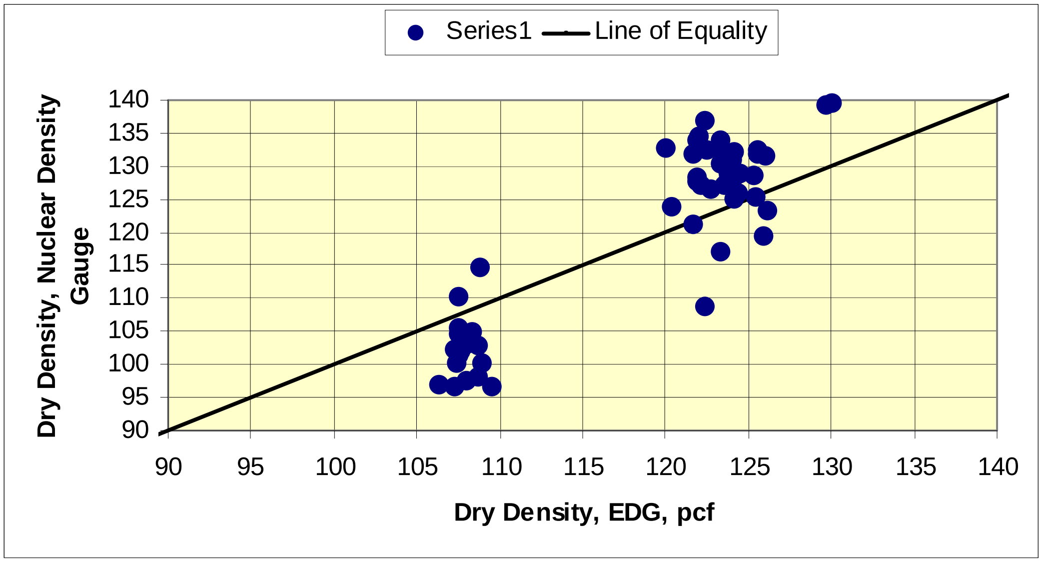


Figure 103. Dry Densities Measured with the EDG and Nuclear Density Gauges

HMA Layers

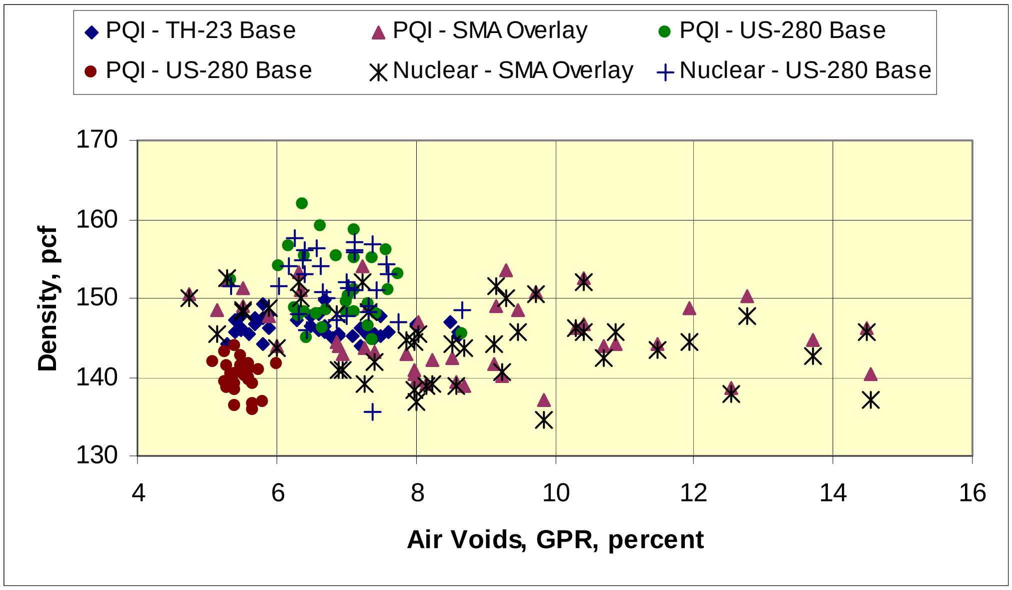
Figure 104 compares the air voids measured with the GPR to the results from other devices and methods. Figure 104.a compares the densities measured directly with the nuclear density gauge and PQI. There is a general trend between the air void measurements and densities—as air voids increase, the density decreases, but any correlation is poor. There are significant differences between the volumetric properties measured with these different devices. Figure 104.b compares the air voids calculated from the maximum theoretical density provided for each mixture to the air voids estimated from the GPR dielectric values. As shown, no correlation exists between the devices from the field evaluation projects included in this study.

Figure 105 compares the densities measured with the nuclear density gauge and the PQI along the longitudinal joints and in areas with localized segregation. These densities are compared with the values measured away from the joints and outside any noticeable segregation. There is a greater variation in density measured with the nuclear device than with the PQI. As noted previously, however, the wet surface may have affected the PQI readings when the measurements were recorded.

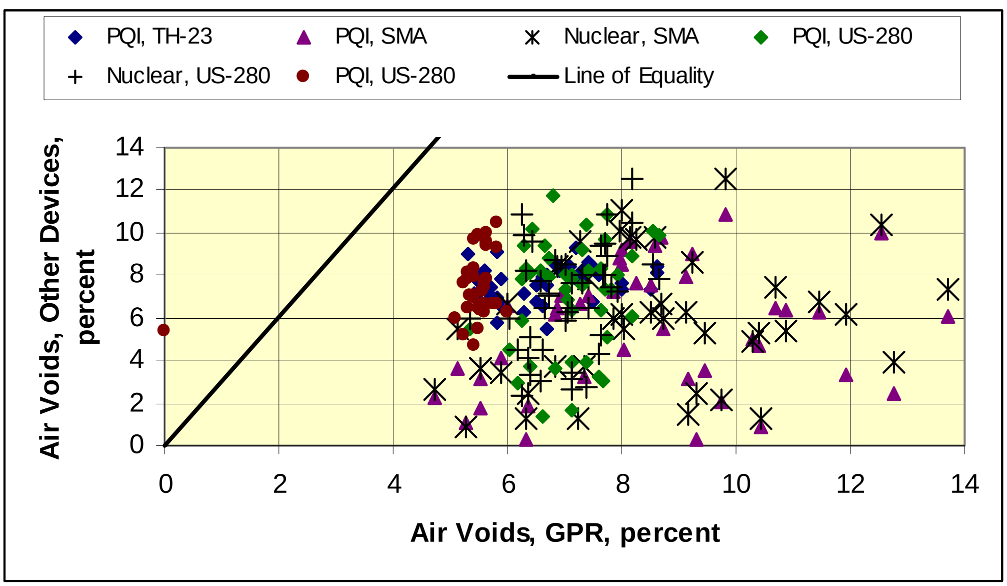
7.4.3 Volumetric—Modulus Comparisons

Unbound Layers

The in-place modulus of the unbound materials is dependent on its density. The FHWA-LTPP study reported that the laboratory resilient modulus was dependent on dry density for all unbound materials (Von Quintus and Yau, 2001). In fact, density and water content are two volumetric properties that have a significant affect on the modulus of the material. Thus, it follows that the NDT devices resulting in a material modulus should be related to the density and/or water content of the material. Dry densities and water contents were extracted from the QA reports for the different projects included in the field evaluation.



(a) Density measured with the different devices.



(b) Air voids calculated from the maximum theoretical density for the mixture.

Figure 104. Air Voids Measured with the GPR versus Densities Measured with the PQI and Nuclear Density Gauges for Different HMA Mixtures

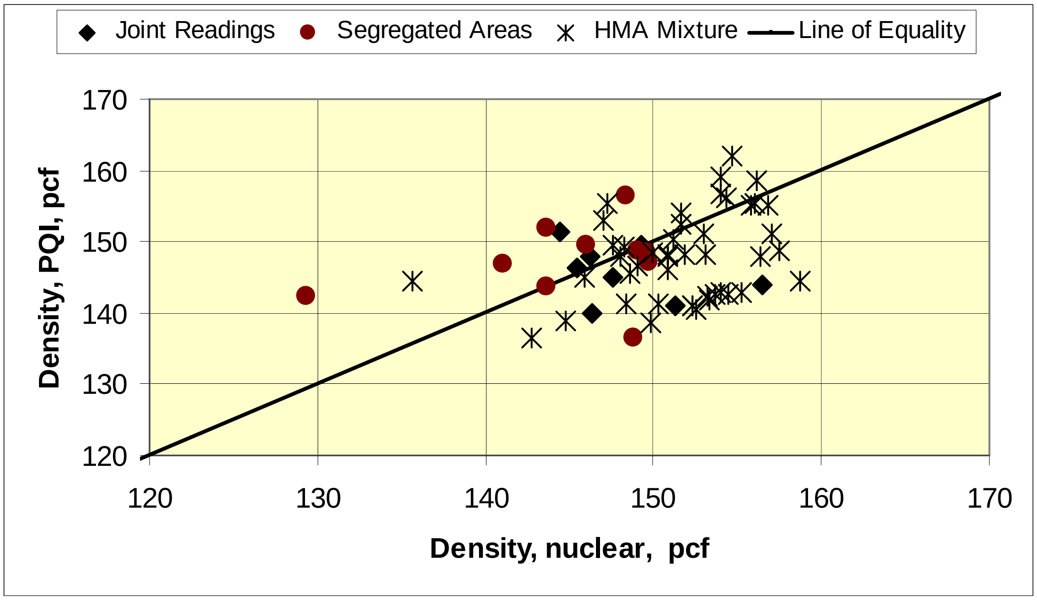
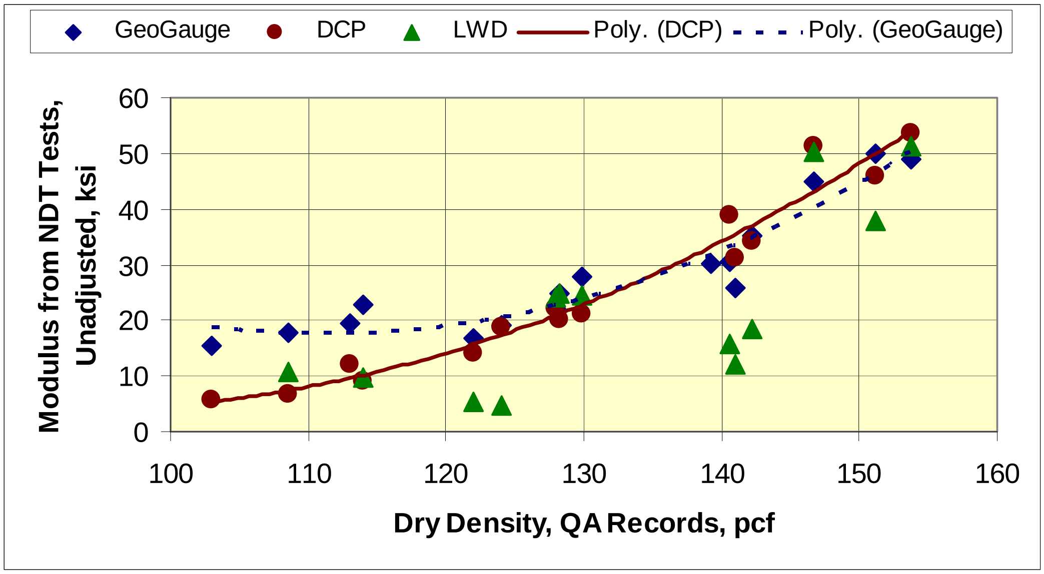


Figure 105. Nuclear Density Gauge Measurements Compared to the PQI Values Along Longitudinal Joints and in Areas with Segregation

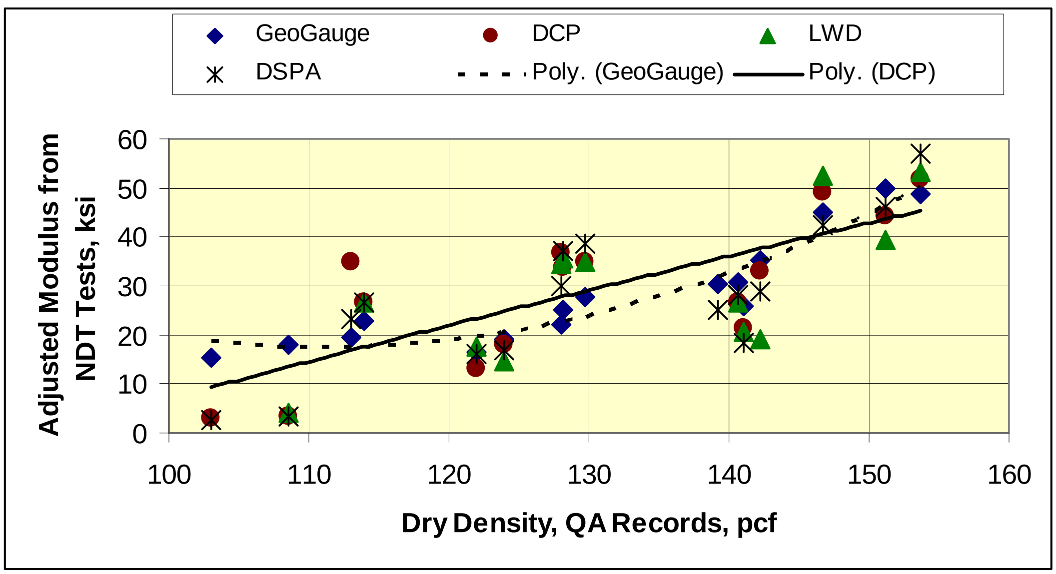
Figure 106 compares the average modulus values estimated from the different NDT devices and dry densities reported by the individual agencies during construction. The important observation from this comparison is that there is a good relationship between dry density and the DCP estimated modulus, prior to adjusting the modulus values to laboratory conditions (Figure 106.a). The resilient modulus from the GeoGauge is also related to the dry density of the material, but appears to be become insensitive to dry density for less dense, fine-grained soils with high water contents. The resilient modulus from the LWD is related to dry density but has the greatest variation because of the influence of the underlying materials.

Figure 106.b graphically presents the same comparison included in Figure 106.a, but using the adjusted modulus values. The GeoGauge and DSPA have similar relationships to dry density for both conditions. Conversely, the relationship for the DCP becomes less defined while it is improved for the LWD. Overall, the modulus values resulting from each NDT device are related to the dry density across a wide range material. The GeoGauge has the better correlation to dry density using the adjusted values, followed by the DSPA and DCP. Thus, the GeoGauge was the primary device used in comparing the elastic modulus to the EDG and GPR results.

The dry density and water contents from the QA records were fairly dispersed and were not taken at each NDT test location or individual area. As such, the QA data can only be used to evaluate the results for different types of materials, rather than actual density variations within a project or lot. The EDG was used to measure the density and water contents at specific test locations for the other NDT devices.



(a) Unadjusted modulus values.



(b) Modulus values adjusted to laboratory conditions.

Figure 106. Dry Density versus NDT Adjusted Modulus Values for Different Materials

Figure 107 compares the dry densities measured with the EDG and modulus values estimated from the GeoGauge and DCP. The NDT modulus increases with increasing dry density over a wide range of material types, which is consistent with previous experience. However, there are clusters of data for the EDG that correspond to similar unbound materials that were tested. Within each data cluster, the correspondence between dry density and NDT modulus is poor for both devices.

This observation suggests that there are other factors that impact the modulus within a specific area; for example, water content and amount of coarse aggregate varying within each data cluster. The EDG did not measure large variations in water content within each area. In summary, the within-project area variation of the modulus values appears to be more dependent on properties other than dry density (e.g., water content, gradation)—assuming that the EDG is providing an accurate estimate of the in-place dry density. That assumption is questionable based on the data accumulated to-date.

Figure 108 compares the GeoGauge modulus to the GPR dielectric values. No clear correspondence was found between the dielectric values and modulus values. Specifically, a wide range of dielectric values and moduli were measured, but no consistent relationship was found between the two properties. Thus, material/layer properties that affect modulus within an area have little effect on the dielectric values.

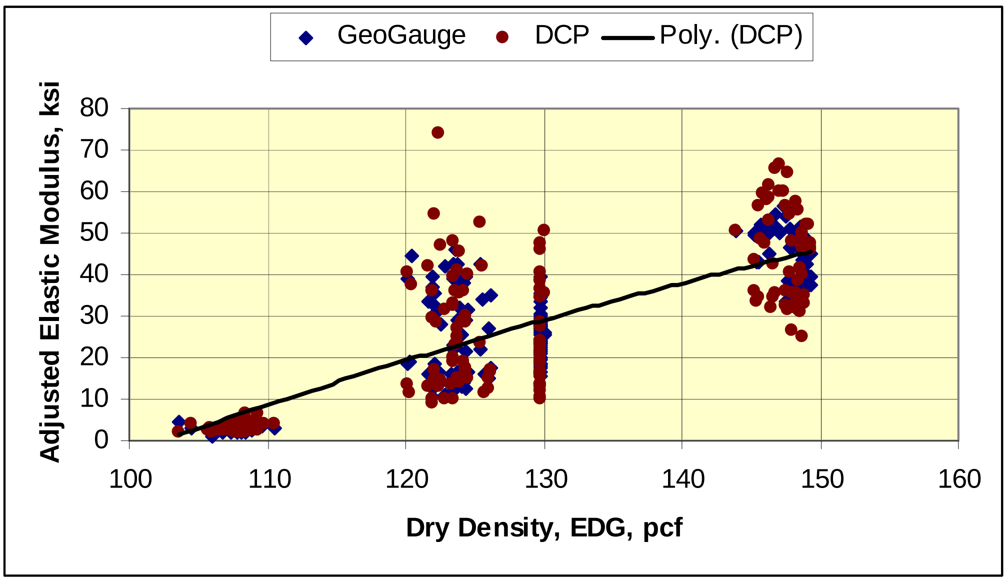


Figure 107. NDT Modulus Values versus Dry Density Measured by the EDG

HMA Layers

Figure 109 compares the PSPA modulus and the GPR air voids. There is a general trend within this data set—decreasing air voids and increasing PSPA modulus, but no good correlation. All NDT devices did correctly identify the difference between the US-280 initial and supplemental sections, with the exception of the PQI. This difference was not planned but was confirmed through the use of laboratory dynamic modulus tests. The state agency's and contractor's QA data did not identify any difference between these two areas or time periods.

Figure 110 compares the PSPA modulus and the PQI density. A general trend exists for a specific mixture, but no correlation exists between these devices that can be used in day-to-day construction operations for control or acceptance. A more important observation is that the volumetric measuring devices are not being influenced by those properties that affect the modulus measuring NDT devices. As an example, changes in the asphalt content and gradation in relation to density, air voids, and stiffness changes within an area. This finding or conclusion is applicable to all of the NDT devices used to test the HMA mixtures.

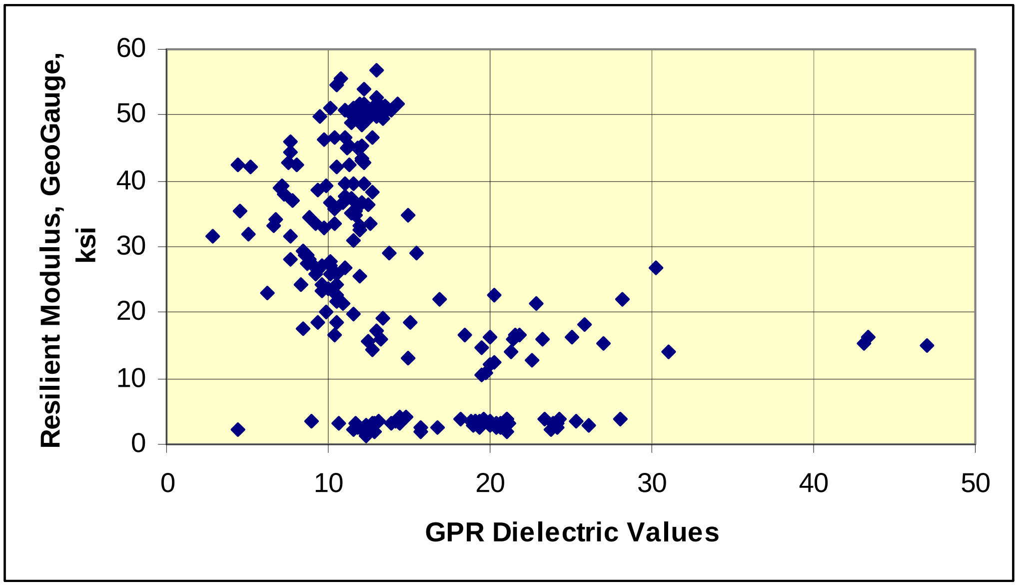


Figure 108. GPR Dielectric Values versus the GeoGauge Modulus

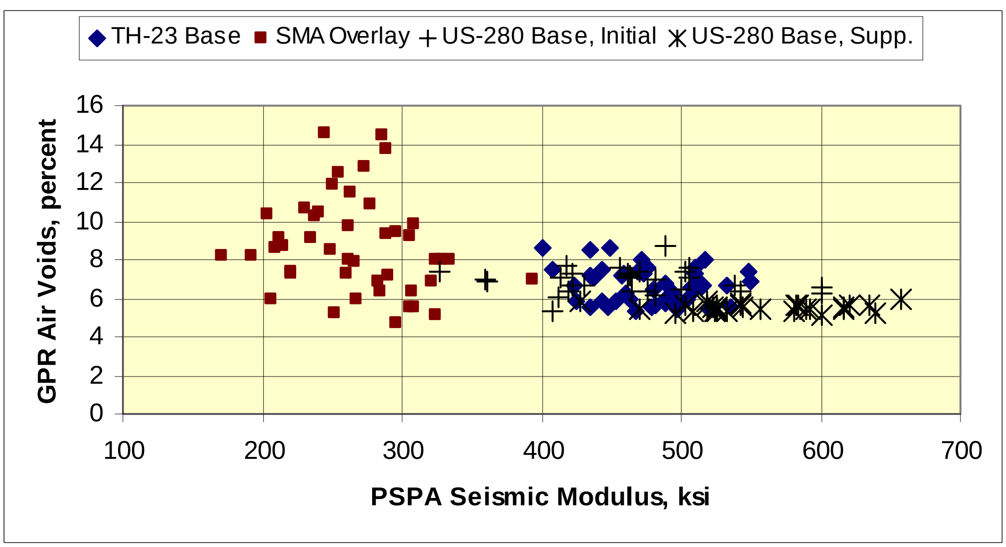


Figure 109. PSPA Modulus versus GPR Air Voids

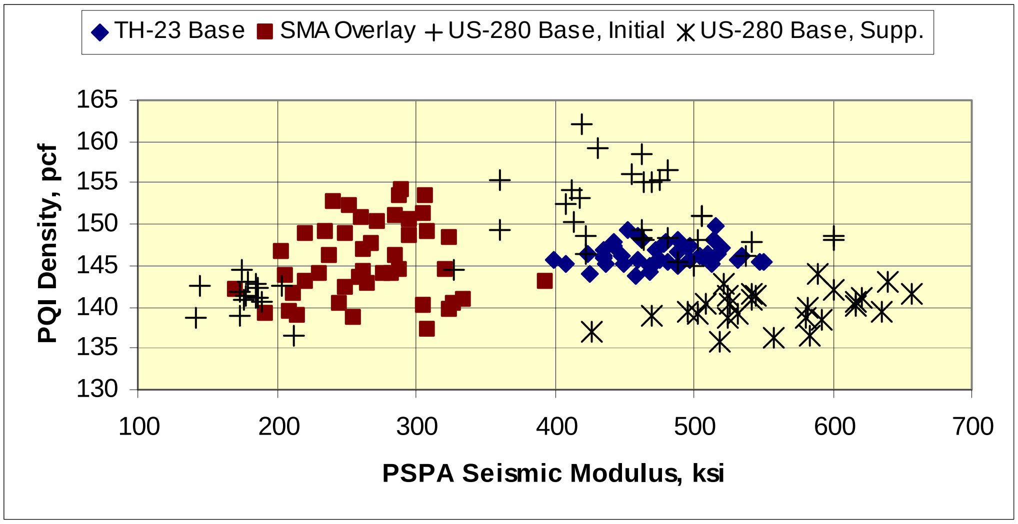


Figure 110. PSPA Modulus versus PQI Density of HMA Mixtures

7.5 Supplemental Comparisons

This section provides an overview of three areas of supplementary information and data that were collected during the Part B field evaluation projects: use of multiple gauges, development of modulus and density-growth relationships, and contractor-agency personnel use of selected NDT devices.

7.5.1 Modulus and Density-Growth Relationships for Monitoring the Rolling Operation

Instrumented rollers were used on projects to monitor the increase in density and stiffness of the unbound and HMA layers, where the rollers could be scheduled for use. In a couple of cases, the Asphalt Manager was on the project site but exhibited hardware or software problems. In other cases, the unbound base layer had already been compacted by the contractor, and the instrumented roller was only used to test the surface. The contractor did not want to take the risk of potentially disturbing the aggregate base, requiring it to be re-compacted and tested. Figures 73 to 75 in chapter 5 presented some of the IC roller data, as related to HMA densities measured with other devices. Overall, the densities and stiffness measured with other devices compared with the output from the instrumented rollers in the areas without localized anomalies. The instrumented rollers did not identify differences caused by localized anomalies (i.e., anomalies significantly less than the width of the roller).

Different NDT devices were also used to monitor the compaction operation of HMA and unbound layers to demonstrate the value of these devices in real-time. The PSPA, DSPA, GeoGauge, and PaveTracker devices were used on some of the Part A and most of the Part B field evaluation projects. The following summarizes important observations from the use of selected NDT devices for controlling the placement and compaction of both unbound and HMA layers in real-time.

<u>Unbound Materials and Layers</u>

Overall, the GeoGauge, DCP, and DSPA were successful in monitoring the build-up of modulus with the number of roller passes for the unbound materials placed within the field evaluation, and they were beneficial in assisting the contractor in making decisions on the compaction operation used along the project. Some examples are noted below.

- Figure 111 presents data collected on a caliche base material placed along an entrance roadway from County Road 103 near Pecos, Texas. Both the GeoGauge and DCP were used to determine the increase in material modulus with compaction. The DCP was used along this project because it was on a private facility and delaying the compaction of this base material was not an issue. Both devices found an increase in modulus with increasing number of roller passes.

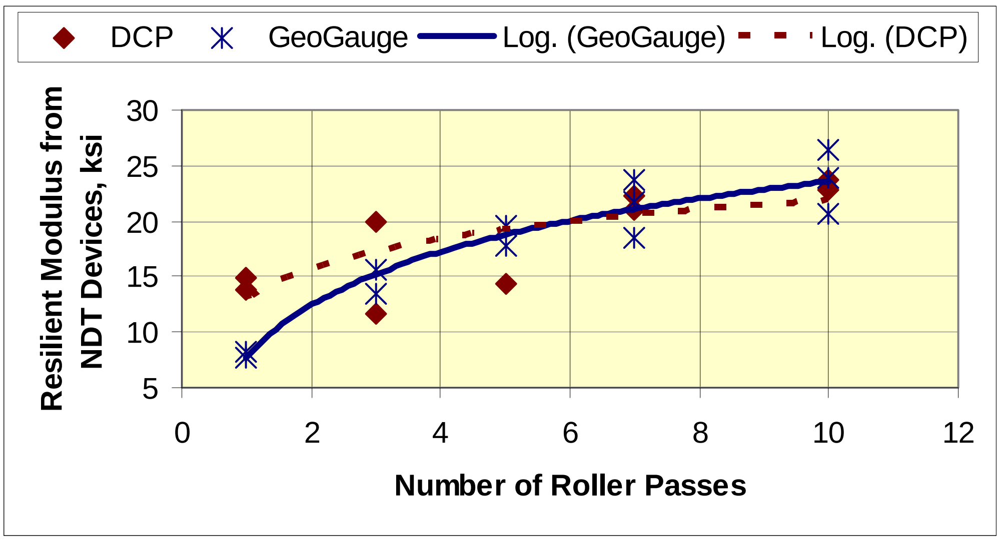


Figure 111. Modulus-Growth Relationships for a Caliche Base Along an Entrance Roadway to a Facility from County Road 103 near Pecos, Texas

- Figure 112 presents data collected during the compaction of a Missouri crushed limestone base material. The first roller pass within this figure is after the material had been preliminary compacted from other construction equipment and roller passes. The maximum modulus for this material was achieved at about eight passes of the roller over a specific area. The number of passes obviously is dependent on the water content of the in-place material; for the Missouri crushed limestone, the in-place water content was just below the optimum value.

- Figure 113 presents data collected during the compaction of a South Carolina crushed granite base material. This crushed granite base material was difficult to compact with the roller on the project site when compaction was initiated. In addition, the water content of this base material was well below the optimum value. As shown, both the DSPA and GeoGauge modulus values did not increase with the number of roller passes. A nuclear density gauge was also used along the project, and it also showed no increase in density with the number of roller passes. Thus, rather than waste additional compaction effort, the contractor had to use a heavier roller, but more importantly, increase the water content of the material to obtain the specified density. This example shows the benefit and advantage of using the GeoGauge or DSPA to make decisions in real-time.

These examples show the benefit of developing modulus-growth curves using the DSPA or GeoGauge during construction for monitoring and optimizing the rolling pattern.

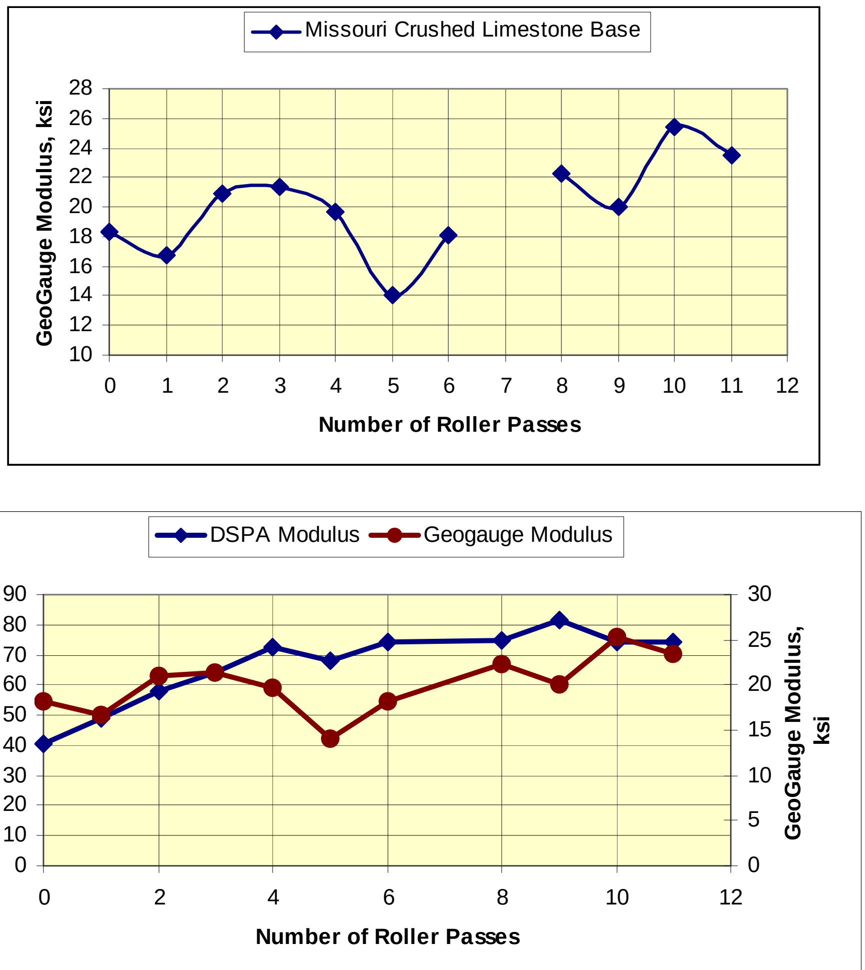


Figure 112. Modulus-Growth Relationships for a Missouri Crushed Limestone Base Material for Two Different Areas

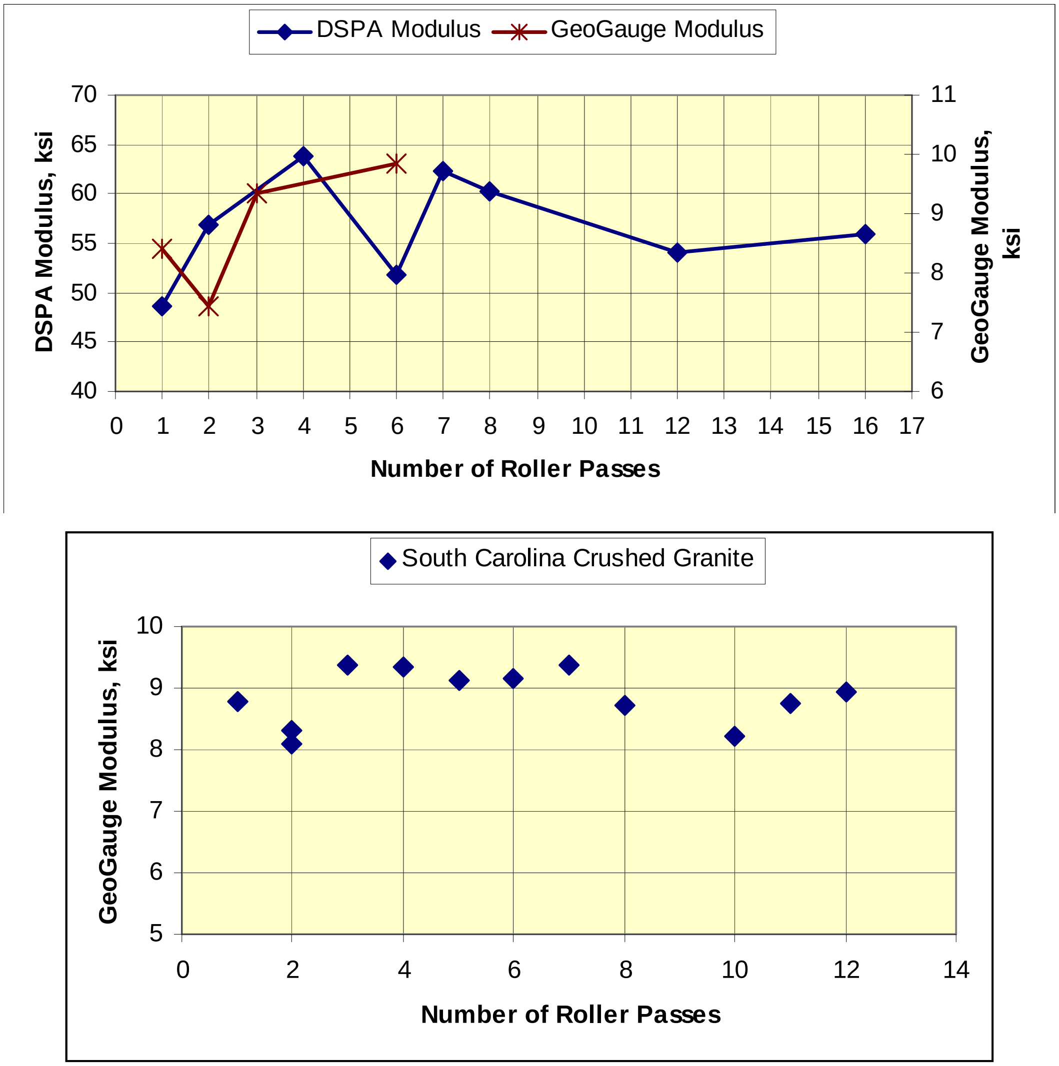


Figure 113. Modulus-Growth Relationships for a South Carolina Crushed Granite Base Material for Two Different Areas

HMA Mixtures and Layers

Overall, the PSPA and PaveTracker were successful in monitoring the build up of modulus and density with the number of roller passes for the HMA layers placed within the field evaluation projects. Some examples are noted below.

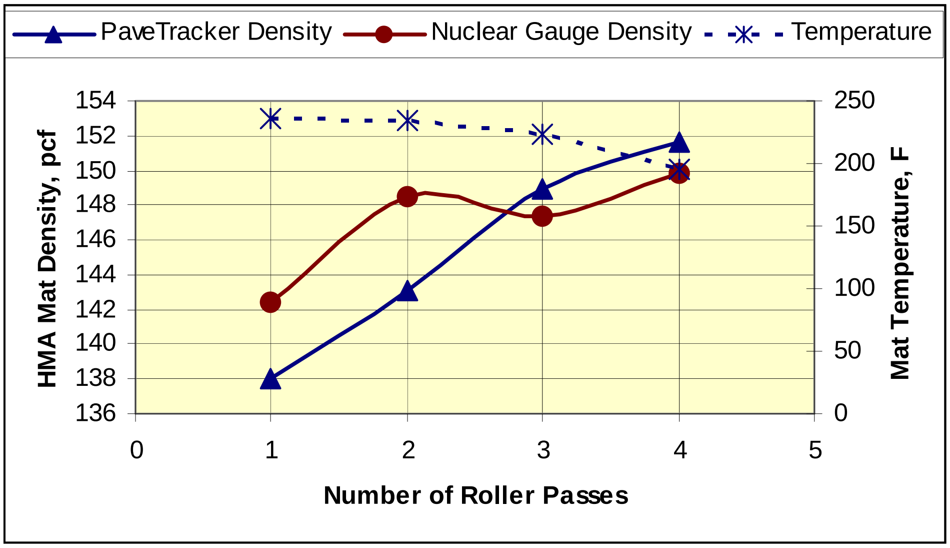
- Figure 114 presents data collected along the Missouri widening project (US-47) for two different areas. Figure 114.a compares the densities measured with the contractor's nuclear density gauge being used on site for QC to those values measured with the PaveTracker. The densities from the nuclear gauge were related to the non-nuclear density gauge values with mixture specific calibration values. The contractor was using one-test point readings with the nuclear gauge, while four readings at a test point were made with the PaveTracker within the same time.

More importantly, the contractor was using the cold-side pinch method for compacting the longitudinal joint adjacent to the old pavement. This HMA was tender based on visual observations of its behavior under the roller—shoving of the mat was observed in front of, as well as across, the roller's direction. Rollers marks were also present after the last pass of the finish roller. The HMA was being pushed away from the confined longitudinal joint, rather than being pushed down into the joint. Joint densities were made with both the nuclear and non-nuclear density gauges along the joint, and the densities were found to be very low—about 5 to 10 pcf below the densities measured within the center of mat. The contractor was asked to change the rolling pattern for the confined longitudinal joint using the hot-side method. Using the hot-side method, the first pass of the roller is along the confined longitudinal joint, with about a 6-inch overhang off the hot mat. Densities were measured with both devices after changing the rolling pattern. Figure 114.b shows the densities along the longitudinal joint, as compared to those in the center of the mat. As shown, the densities significantly increased by eliminating the roller pass on the cold side of the joint. Thus, the contractor was able to use the non-nuclear density gauge in real-time to significantly increase the joint density by slightly revising the rolling pattern of the joint.

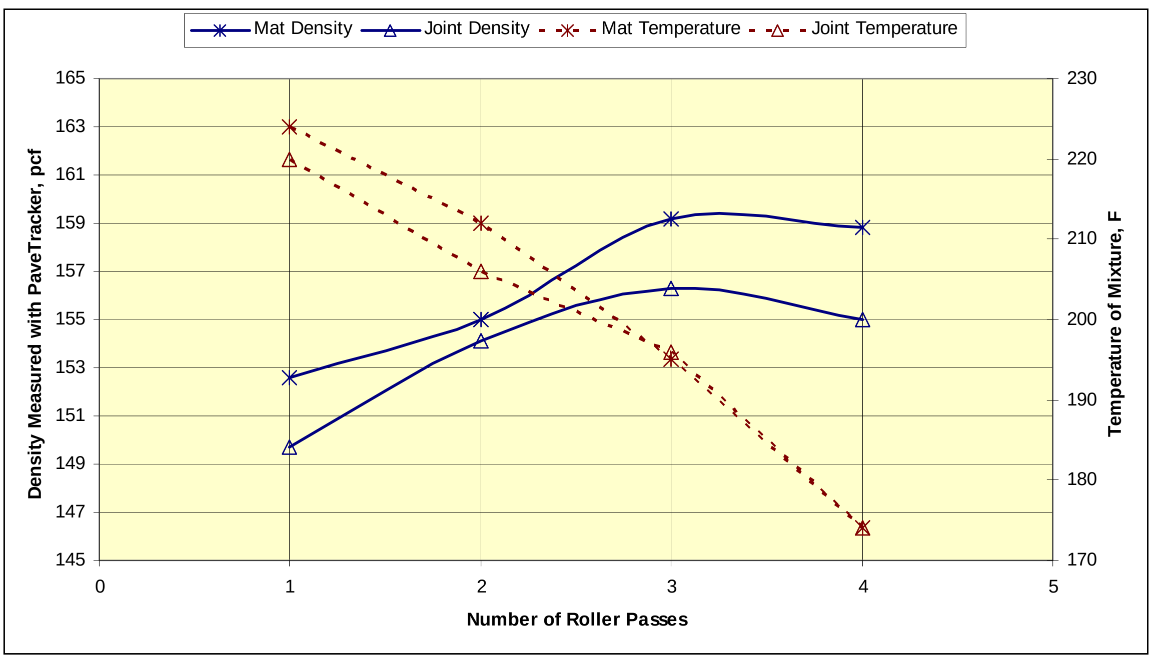
The PSPA was also used along this project, but the results were erratic during or immediately after compaction of the mat—the wave form was not consistent with HMA mixtures. The mixture was found to be too tender to obtain reliable readings, until the mix cooled below about 150 °F. This HMA mixture was being used as the base for the shoulder or in a non-critical area. It was initially believed that the PSPA had been damaged in transport, but that was found to be incorrect from latter testing of the HMA after it had cooled down. At lower temperatures, the PSPA provided reasonable results. Thus, its use would have been a benefit in identifying a tender mix, if this mix had been used in a critical area under heavy traffic. The PSPA was attempted to be used on a couple of other projects, but the temperature of those mixtures was too high to obtain reliable results. Mix temperature is a limitation on testing HMA mixtures during rolling.

- Figure 115 presents density data collected on a Missouri HMA base mixture that was not tender, but was rolled within the temperature sensitive zone. As shown, the first pass of the rubber-tired roller increased the density, but additional passes of that roller significantly decreased the density of the mat. The nuclear density gauge being used on site for QC gave the same results. The nuclear gauge, however, was not being used after each roller pass. This mixture did not exhibit the traditional mix "checking" or tearing under the rollers, but the non-nuclear density gauge did identify the detrimental effect of rolling within the temperature sensitive zone. More roller passes were required to regain the density that was lost by rolling within the temperature sensitive zone. Many of the other HMA mixtures that were included within the field evaluation projects also exhibited this temperature sensitivity under the rollers.

Selecting HMA mixtures that checked and tore for the field evaluation was not planned.

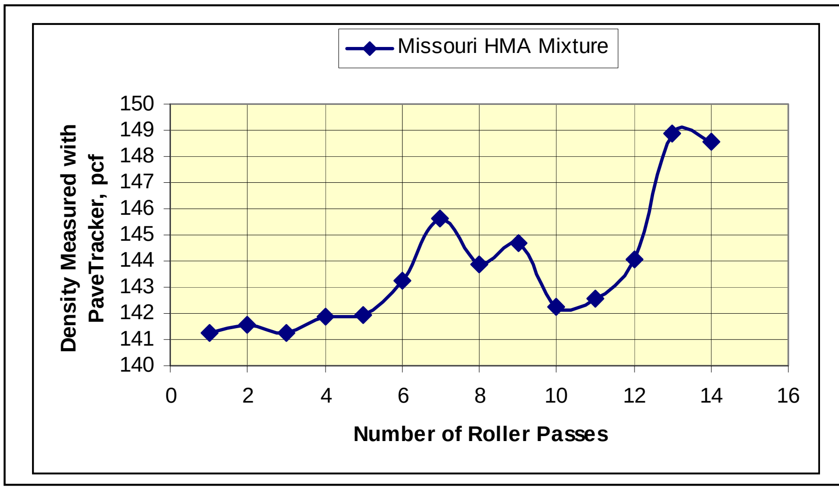


(a). PaveTrack versus nuclear gauge density measurements



(b) PaveTracker density measurements made along a confined joint and within the center of the mat.

Figure 114. Typical Density-Growth Curve Measured with PaveTracker and Nuclear Density Gauge for the Missouri US-47 Project



Compaction Operation:
Pass 1-2; Vibratory Roller
Pass 3-4; Static Steel Wheel
Pass 5-6; Vibratory Roller
Pass 7-11; Rubber Tired
Pass 11-14; Finish Roller

Figure 115. Density-Growth Relationship for an HMA Base Mixture from Missouri

- The I-75 Michigan overlay project was another project where a HMA mixture was rolled within its temperature sensitive zone. With three passes of a SAKAI vibratory roller in the primary roller position, the HMA mixture density was greater than the specified value (see Figure 116). However, an intermediate roller continued to roll the mix, and was followed by two additional rollers. The use of the PaveTracker determined that the contractor was rolling in the temperature sensitive zone—the density began to decrease. By monitoring the density of the mat during rolling, the result was that the contractor could eliminate two of the rollers and use fewer passes to obtain the required density, as long as the rollers stayed out of the temperature sensitive zone.

- Figure 117 shows another example, but for polymer modified asphalt (PMA) and conventional neat asphalt mixtures. These mixtures were placed during the same time period. The conventional neat asphalt mixture exhibited the traditional checking and tearing of the mat when it is rolled within the temperature sensitive zone (photographs are included in Appendix B), while the PMA mixture did not exhibit tearing or checking. As shown, after pass 3 for the neat asphalt mix and after pass 5 for the PMA mix, the densities decreased. The mix tearing and checking was observed under the roller, to confirm that the mix was rolled within the temperature zone. Thus, the mat had to be rolled much more to increase density to the specified value for both mixtures.

Similar to the benefit for unbound layers, the non-nuclear density gauges provide significant benefit to a contractor to optimize the rolling pattern within the center of the mat, as well as along longitudinal joints. The non-nuclear gauges can be also used to determine when the rollers are being operated within the temperature sensitive zone, so a contractor does not waste compaction effort or time, but more importantly, does not tear or damage the HMA mix by operating the rollers within the temperature sensitive zone.

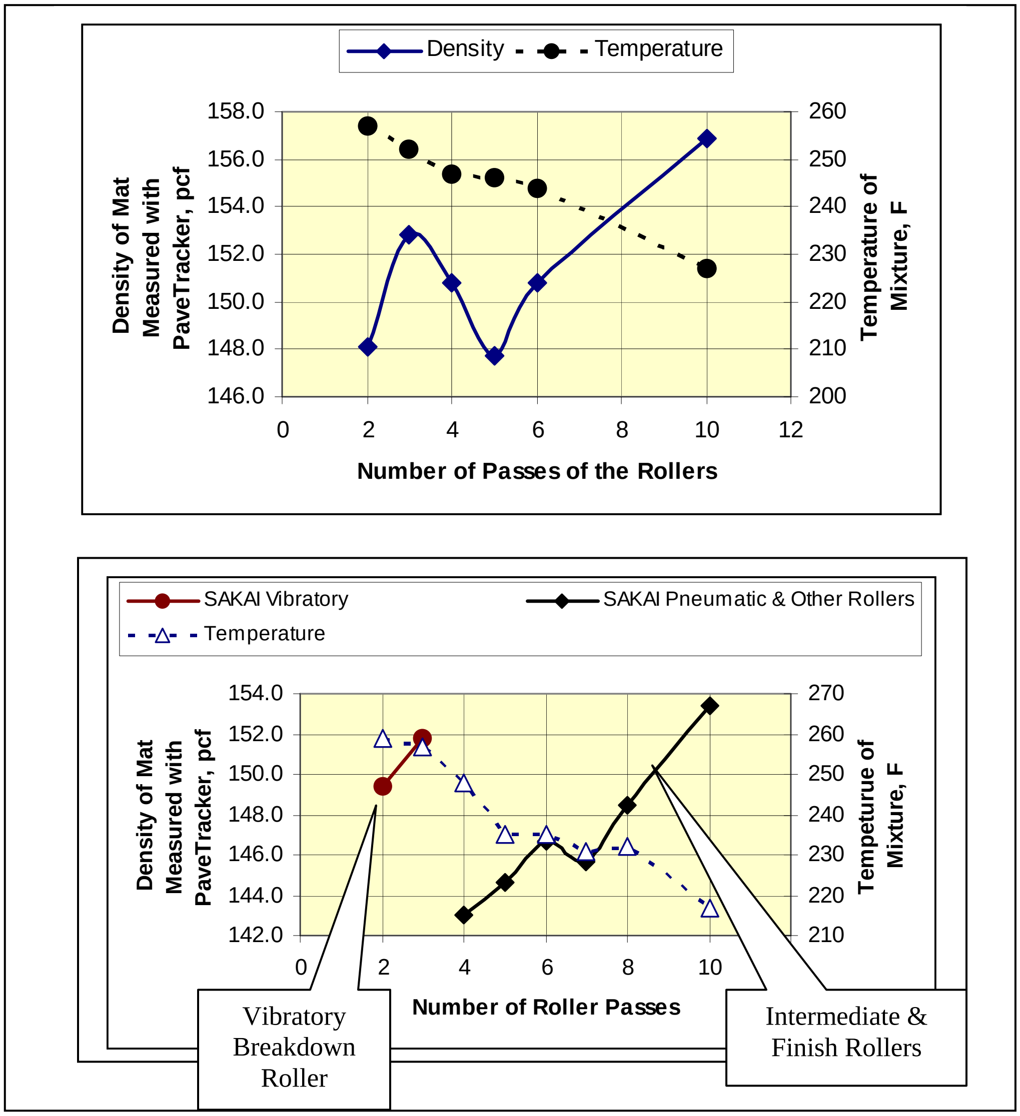
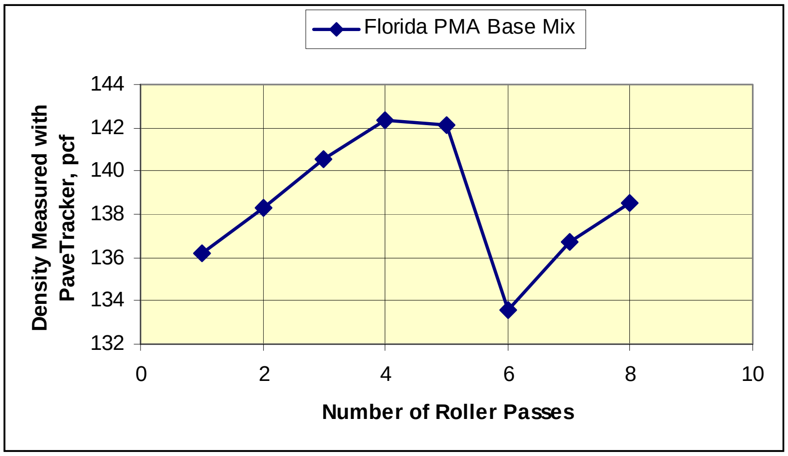
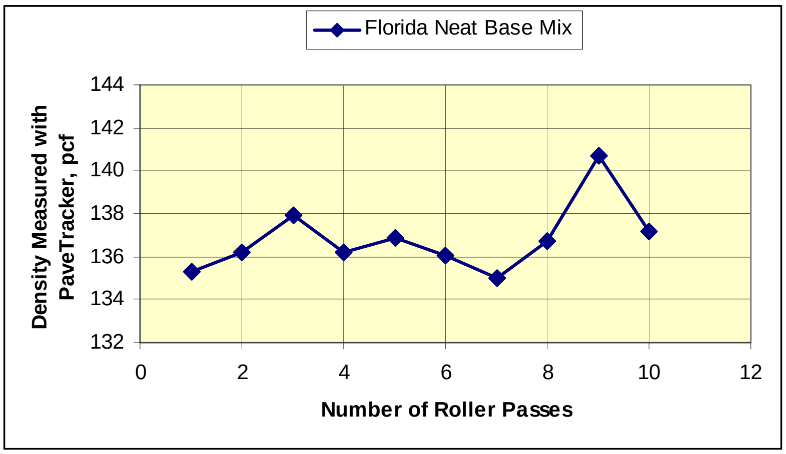


Figure 116. Density-Growth Curves for the Michigan Mixture Measured with PaveTracker and Effects of Rolling within the Temperature Sensitive Zone; Two Different Areas of Project



Compaction Operation:
Pass 1-4; Vibratory Roller
Pass 5; Static Steel Drum
Pass 6-8; Vibratory Roller
Pass 9- ; Finish Roller

(b) PMA Mixture



Compaction Operation:
Pass 1-4; Static Steel Drum
Pass 5-7; Rubber Tired Roller
Pass 8-10; Finish Roller

(a) Conventional Neat HMA Mixture

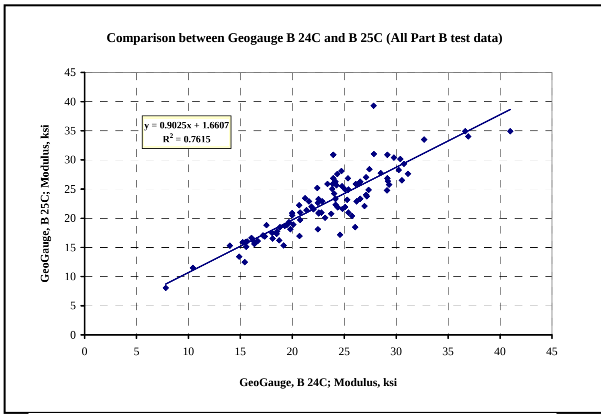
Figure 117. Density-Growth Curves for Two Florida Mixtures Measured with PaveTracker and Effects of Rolling within the Temperature Sensitive Zone

7.5.2 Multiple Operators and NDT Gauges

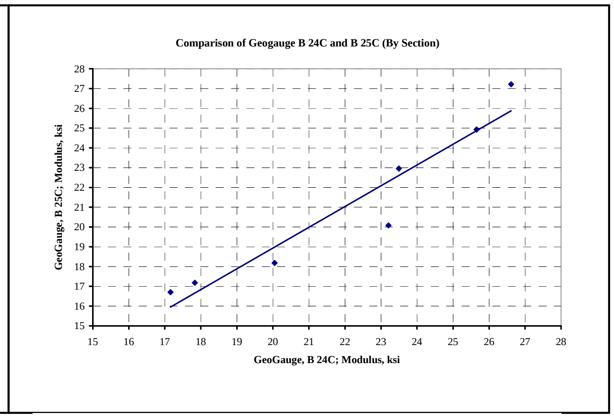
For most of the Part B projects, multiple GeoGauges and PaveTrackers were used by different operators to determine the effects of multiple operators on the variability of the devices. Figure 118 compares the measured responses from the two GeoGauges that were used for testing unbound materials, while Figure 119 compares the measured densities from the two PaveTracker devices used to monitor HMA mixtures. At the end of the field evaluation testing for each project, one of each device was left with the agency and contractor personnel. The following summarizes observations from this comparative testing.

- Use of different GeoGauges and operators resulted in some bias that was modulus dependent for some materials; more bias was exhibited for the higher modulus values or stiffer material. It is recommended that material specific calibration or adjustment factors be determined and used for each material tested (see Table 70). This material specific calibration with a sufficient number of replicate tests should minimize the bias between the different gauges. The variability between different gauges, however, will still exist.

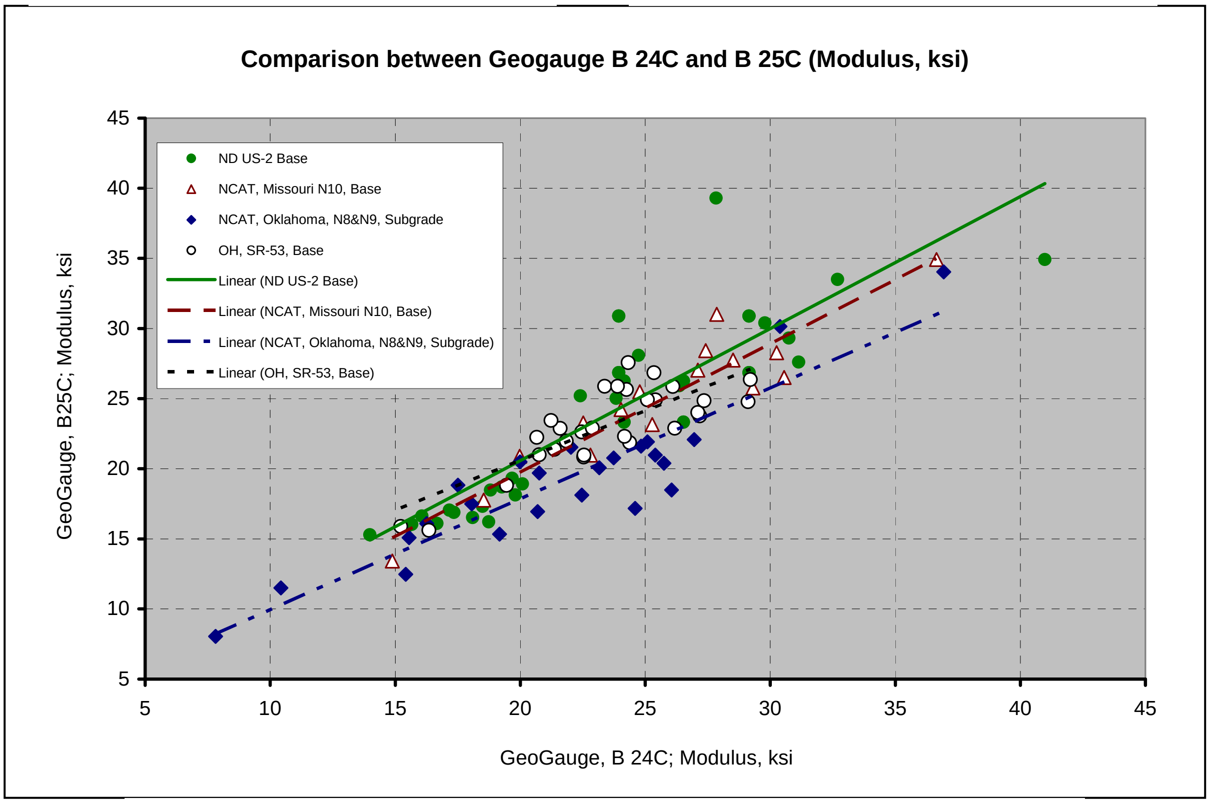
- Use of different PaveTrackers and operators resulted in almost no bias between the two gauges, with the exception of dense or high specific gravity mixtures. It is also recommended for these devices that material specific adjustments be determined for each mixture tested. The mixture specific factors should minimize bias, but the variability between different gauges will still exist.



(a) Comparison on a point-by-point basis.

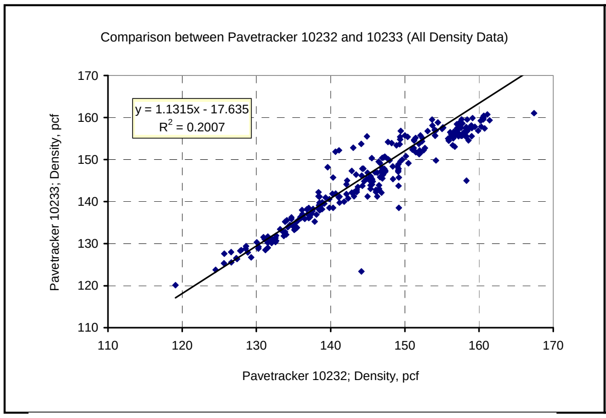


(b) Comparison on a project basis.

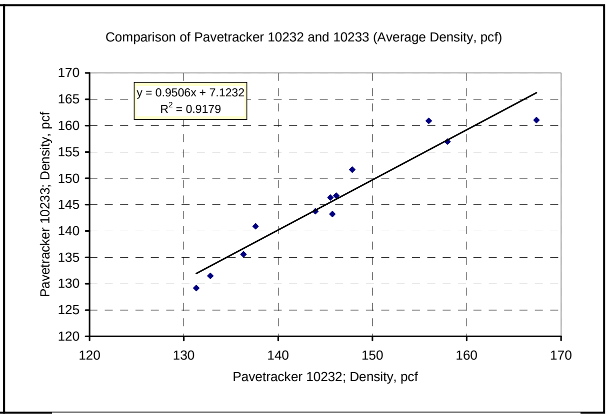


(c) Comparison on a material basis

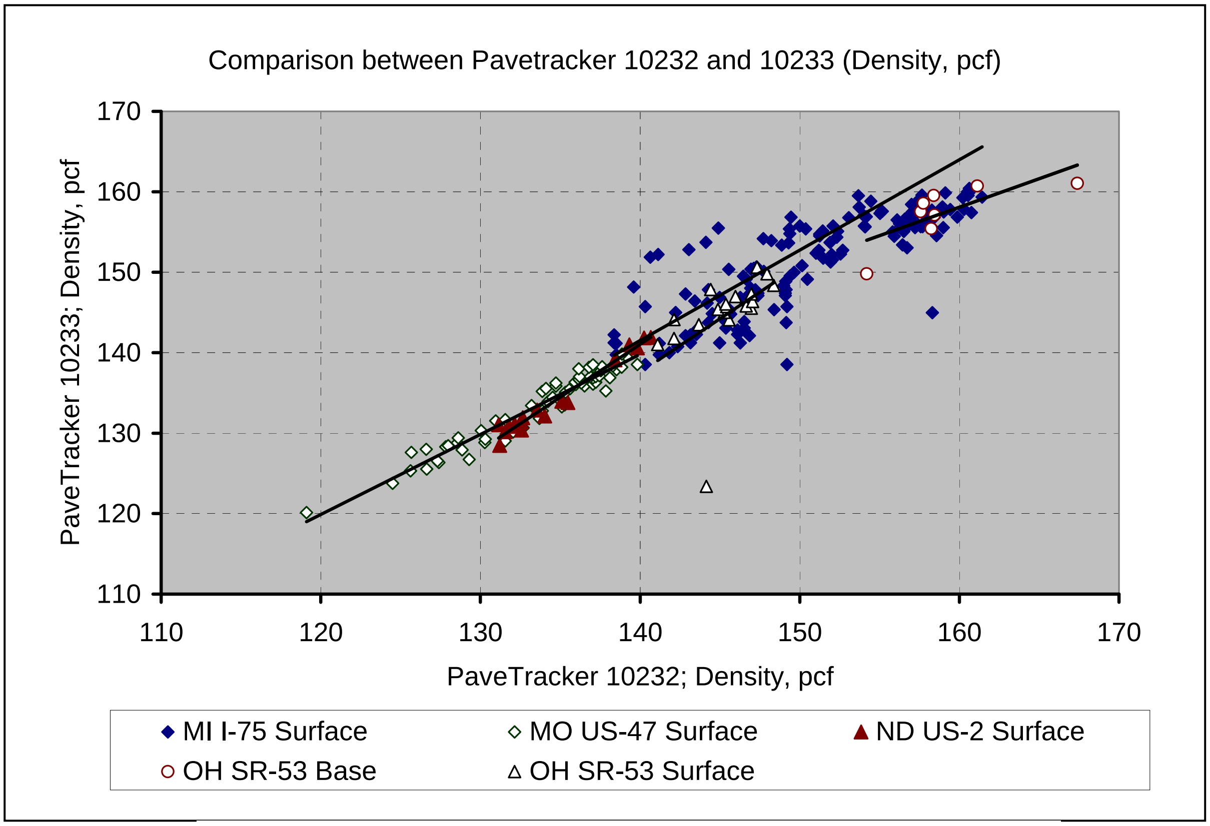
Figure 118. Comparison of Modulus Measurement with Two Independent GeoGauges



(a) Comparison on a point-by-point basis



(b) Comparison on a project basis



(c) Comparison on a material or mixture basis

Figure 119. Comparison of the Density Measurements with Two Non-Nuclear PaveTracker Devices Used Within the Part B Field Evaluation

7.5.3 Agency and Contractor Use of NDT Devices

During Part B of the field evaluation, one of the multiple gauges being used on a project was left with agency and contractor construction personnel for continued use on a day-to-day QA bases. Those NDT devices left with the construction personnel included the GeoGauge, PSPA, and PaveTracker. Data from this additional use were included in the comparison of multiple operators and devices at specific project sites. This information was used in the evaluation described in chapter 8, in determining the parameters needed to set up control and acceptance plans when using these NDT devices.

The projects where construction personnel continued to use the devices included Missouri, North Dakota, and Texas. The NDT devices were going to be left at the Michigan I-75 project, but issues with the HMA mixture resulted in the project being stopped for a short term, so the construction personnel did not actually use the devices. For the Missouri project, weather delays resulted in the contractor moving to a different project so the devices were not used on the same project, as included in the Part B field evaluation. The devices were used for more than 2 weeks on the North Dakota and Texas projects. In actuality, the contractor had already been using the PaveTracker and PSPA on the Texas I-20 project. The PaveTracker was a part of the contractor's standard or day-to-day QC plan, while the PSPA had been used on a research basis.

7.6 Summary of Evaluations

In summary, the steady-state vibratory (GeoGauge) and seismic (DSPA) technologies are recommended for use in judging the quality of unbound layers, while the seismic (PSPA) and non-nuclear density gauges (the PaveTracker was used in Part B) are recommended for use of HMA layers. The GPR is recommended for layer thickness acceptance, while the IC rollers are recommended for use on a control basis for compacting unbound and HMA layers. The following identifies and lists some of the reasons for these recommendations.

7.6.1 NDT Devices for Unbound Layers and Materials

- The DSPA and GeoGauge devices had the highest success rates for identifying an area with anomalies with rates of 86 and 79 percent, respectively. The DCP and LWD identified about two-thirds of the anomalies, while the GPR and EDG had unacceptable rates below 50 percent.

- Three to five repeat measurements were made at each test point with the NDT devices, with the exception of the DCP.
    - The LWD exhibited low standard deviations that were less dependent on material stiffness with a pooled standard deviation less than 0.5 ksi. One reason for the low values is that the moduli were less than for the other devices. The COV, however, was higher. It is expected that the supporting layers had an effect on the results by reducing the modulus.
    - The GeoGauge had a standard deviation for repeatability measurements varying from 0.3 to3.5 ksi and are material dependent.

- The DSPA had the lowest repeatability with a standard deviation varying from 1.5 to 21.5 ksi. The reason for this higher variation in repeat readings is that the DSPA sensor bar was rotated relative to the direction of the roller, while the other devices were kept stationary or do not have the capability to detect anisotropic conditions. No significant difference was found relative to the direction of testing for fine-grained soils, but there was a slight bias for the stiffer coarse-grained materials.
- The EDG was highly repeatable with a standard deviation in density measurements less than 1 pcf, while the GPR had poor repeatability—based on point measurements. Triplicate runs of the GPR were made over the same area or sublot. For comparison to the other NDT devices, the values measured at a specific point, as close as possible, were used. Use of point specific values from successive runs could be a reason for the lower repeatability, which are probably driver specific. One driver was used for all testing with the GPR.

- The COV was used to compare the normalized dispersion measured with different NDT devices. The EDG consistently had the lowest COV with values less than 1 percent. The GeoGauge had a value of 15 percent, followed by the DSPA, LWD, DCP, and GPR. The GPR and EDG are dependent on the accuracy of other tests in estimating volumetric properties (density and moisture contents). Any error in the calibration of these devices for the specific material is directly reflected in the resulting values. A probable reason why the GPR and EDG devices did not consistently identify the areas with anomalies or physical differences.

- Repeated load resilient modulus tests were performed in the laboratory for characterizing and determining the target resilient modulus for each material. Adjustment ratios were determined based on uniform conditions. The overall average ratio for the GeoGauge for the stiffer coarse-grained materials was near unity (1.05). For the fine-grained, less stiff soils, the ratio was about 0.5. After adjusting for laboratory conditions, all NDT devices that estimate resilient modulus resulted in low residuals (laboratory resilient modulus minus the NDT elastic modulus). However, the GeoGauge and DCP resulted in the lowest standard error. The LWD had the highest residuals and standard error.

- The DSPA and DCP measured responses represent the specific material being tested. The DCP, however, can be significantly affected by the varying amounts of aggregate particles in fine-grained soils and the size of the aggregate in coarse-grained soils. The GeoGauge measured responses are minimally affected by the supporting materials, while the LWD can be significantly affected by the supporting materials and thickness of the layer being tested. Thickness deviations and variable supporting layers are reasons that the LWD had a low success rate in identifying areas with anomalies or physical differences.

- No good or reasonable correlation was found between the NDT devices that estimate modulus and those devices that estimate volumetric properties.

- The instrumented rollers were used on too few projects for a detailed comparison to the other NDT devices. The rollers were used to monitor the increase in density and stiffness with increasing number of roller passes. One potential disadvantage with these rollers is that they may bridge localized soft areas. These rollers are believed to be worth future investment in monitoring the compaction of unbound materials.

- The GPR resulted in reasonably accurate estimates to the thickness of aggregate base layers. None of the other NDT devices have the capability or same accuracy to determine the thickness of the unbound layer.

7.6.2 NDT Devices for HMA Mixtures and Layers

- The PSPA had the highest success rate for identifying an area with anomalies with a rate of 93 percent. The PQI identified about three-fourths of the anomalies, while the FWD and GPR identified about half of those areas. The seismic and non-nuclear gauges were the only technologies that consistently identified differences between the areas with and without segregation. These two technologies also consistently found differences between the longitudinal joint and interior of the mat.

- The non-nuclear density gauges (PaveTracker) was able to identify and measure the detrimental effect of rolling the HMA mat within the temperature sensitive zone. This technology was beneficial on some of the Part B projects to optimize the rolling pattern initially used by the contractor.

- Three to four repeat measurements were made at each test point with the NDT devices.
    - The PSPA had a repeatability value, a median or pooled standard deviation, of about 30 ksi for most mixtures, with the exception of the US-280 supplemental mixture that was much higher.
    - The FWD resulted in comparable value for the SMA mixture (55 ksi), but a higher value for the US-280 mixture (275 ksi).
    - The non-nuclear density gauges had repeatability values similar to nuclear density gauges with a value less than 1.5 pcf.
    - The repeatability for the GPR device was found to be good and repeatable, with a value of 0.5 percent for air voids and 0.05 inches for thickness.

- The PSPA moduli were comparable to the dynamic moduli measured in the laboratory on test specimens compacted to the in place density at a loading frequency of 5 Hz and the in place mixture temperature, with the exception of one mixture—the US-280 supplemental mixture. In fact, the overall average ratio or adjustment factor for the PSPA was close to unity (1.1). This was not the case for the FWD. More importantly, without making any corrections for volumetric differences to the laboratory dynamic modulus values, the standard error for the PSPA was 76 ksi (laboratory values assumed to be the target values). The PSPA was used on HMA surfaces after compaction and the day following placement. The PSPA modulus values measured immediately following compaction were found to be similar to the values one or two days after placement—making proper temperature corrections in accordance with the master curves measured in the laboratory.

- A measure of the mixture density or air voids is required in judging the acceptability of the modulus value from a durability stand point. The non-nuclear gauges were found to be acceptable, assuming that the gauges have been properly calibrated to the specific mixture—as for the PSPA.

- Use of the GPR single antenna method, even with mixture calibration, requires assumptions on specific volumetric properties that do vary along a project. As the mixture properties change, the dielectric values may or may not be affected. Use of the proprietary GPR analysis method on other projects was found to be acceptable for the air void or relative compaction method. This proprietary and multiple antenna system, however, was not used within Part A of the field evaluation to determine its success rate in identifying localized anomalies and physical differences between different areas. Both GPR systems were found to be very good for measuring layer thickness along the roadway.

- Water can have a definite affect on the HMA density measured with the non-nuclear density gauges (PQI). The manufacturer's recommendation is to measure the density immediately after compaction, prior to allowing any traffic on the HMA surface. Within this project, the effect of water was observed on the PQI readings, as compared to dry surfaces. The measured density of wet surfaces did increase, as compared to dry surfaces. From the limited testing completed with wet and dry surfaces, the PaveTracker was less affected by surface conditions. However, wet versus dry surfaces were not included in the field evaluation plan for different devices—only the technology. Based on the data collected within the field evaluation, wet surfaces did result in a bias of the density measurements with this technology.

- Another important condition is the effect of time and varying water content on the properties of the HMA mixture during construction. There have been various studies completed on using the PSPA to detect stripping and moisture damage in HMA mixtures. For example, Hammons et al. used the PSPA (in combination with GPR) to locate areas with stripping along selected interstate highways in Georgia (Hammons et al., 2005). The testing completed within this study also supports the use of the seismic-based technology to identify such anomalies.

- The instrumented rollers used to establish the increase in stiffness with number of passes was correlated to the increases in density, as measured by different devices. These rollers were used on too few projects to develop or confirm any correlation between the NDT response and the instrumented roller's response. One issue that will need to be addressed is the effect of decreasing temperature on the stiffness of the mixture and how the IC roller perceives that increase in stiffness related to increases in density of the mat. A potential disadvantage with these rollers is that they will bridge segregated areas and may not accurately identify cold spots in the HMA mat. These rollers are believed to be worth future investments in monitoring the compaction of HMA mixtures.

7.6.3 Limitations and Boundary Conditions

The following lists the limitations and boundary conditions observed during the field evaluation for the NDT devices recommended for QA application on an immediate, effective, and practical basis.

- All NDT devices recommended for QA application, with the exception of the GPR and IC rollers, are point-specific tests. Point-specific tests are considered a limitation because of the number of samples that would be required to identify localized anomalies that deviate from the population distribution.
    - Ultrasonic scanners are currently under development so that relatively continuous measurements can be made with this technology. These scanners are still considered in the research and development stage and are not ready for immediate and practical use in a QA program.
    - GPR technology to estimate the volumetric properties of HMA mixtures is available for use on a commercial basis, but the proprietary system has only had limited verification of its potential use in QA applications and validation of all volumetric properties determined with the system.
    - Similarly, the IC rollers take continuous measurements of density or stiffness of the material being compacted. During the field evaluation, some of these rollers had both hardware and software problems. Thus, these devices were not considered immediately ready for use in a day-to-day QA program. The equipment, however, has been improved and its reliability has increased. The technology is recommended for use on a control basis but not for acceptance.
- Ultrasonic technology (PSPA) for HMA layers and materials are recommended for use in control and acceptance plans.
    - Test temperature is the main boundary condition for the use of the PSPA. Elevated temperatures during mix placement can result in erratic response measurements. Thus, the gauge may not provide reliable responses to monitor the compaction of HMA layers and define when the rollers are operating within the temperature sensitive zone for the specific mixture.
    - These gauges need to be calibrated to the specific mixture being tested. However, this technology can be used in the laboratory to measure the seismic modulus on test specimens during mixture design or verification prior to measuring the dynamic modulus in the laboratory.
    - A limitation of this technology is that the results (material moduli) do not provide an indication on the durability of the HMA mixture. Density or air void measurements are needed to define durability estimates.
    - The DSPA for testing unbound layers is influenced by the condition of the surface. High modulus values near the surface of the layer will increase the modulus estimated with the DSPA. Thus, the DSPA also needs to be calibrated to the specific material being evaluated.
- Steady-state vibratory technology (GeoGauge) for unbound layers and materials; recommended for use in control and acceptance plans.

- This technology or device should be used with caution when testing fine-grained soils at high water contents. In addition, it should not be used to test well-graded, non-cohesive sands that are dry.
- The condition of the surface of the layer is important and should be free of loose particles. A layer of moist sand should also be placed to fill the surface voids and ensure that the gauge's ring is in contact with about 75 percent of the material's surface. Placing this thin layer of moist sand takes time and does increase the time needed for testing.
- These gauges need to be calibrated to the specific material being evaluated, and are influenced by the underlying layer when testing layers that are less than 8 inches thick.
- These gauges are not applicable for use in the laboratory during the preparation of M-D relationships that are used for monitoring compaction. The DSPA technology is applicable for laboratory use to test the samples used to determine the M-D relationship.
- A relative calibration process is available for use on a day-to-day basis. However, if the gauge does go out calibration, it must be returned to the manufacturer for internal adjustments and calibration.
- These gauges do not determine the density and water content of the material. The water content and density of the unbound layer should be measured with other devices.

- Non-nuclear density gauges (electric technology) for HMA layers and materials; recommended for use in control and acceptance plans.
  - The results from these non-nuclear density gauges can be dependent on the condition of the layer's surface—wet versus dry conditions. It is recommended that the gauges be used on relatively dry surfaces until additional data become available relative to this limitation. Free water should be removed from the surface to minimize any affect on the density readings. However, water penetrating the surface voids in a segregated areas will probably affect the readings—incorrect or high density reading, in comparison to the actual density from a core. The PSPA was able to identify areas with segregation.
  - These gauges need to be calibrated to the specific material under evaluation.
- GPR technology for thickness determination of HMA and unbound layers are recommended for use in acceptance plans.
  - The data analysis or interpretation is a limitation of this technology. The GPR data requires some time to estimate the material property—the time for layer thickness estimates is much less than for other layer properties.
  - This technology requires the use of cores for calibration purposes. Cores need to be taken periodically to confirm the calibration factors used to estimate the properties.
  - Use of this technology, even to estimate layer thickness, should be used with caution when measuring the thickness of the first lift placed above PATB layers.
  - GPR can be used to estimate the volumetric properties of HMA mats, but that technology has yet to be verified on a global basis.
  - The technology and devices are not applicable to the use of laboratory data for calibration purposes.

- IC rollers are recommended for use in a control plan, but not within an acceptance plan.
    - The instrumented rollers may not identify localized anomalies in the layer being evaluated. These rollers can bridge some defects—insufficient sensitivity to identify defects that are confined to local areas.
    - Temperature is an issue with the use of IC rollers for compacting HMA layers. Although most of these rollers have a capability to measure the surface temperature of the mat, the effect of temperature on the mat stiffness is an issue—as temperature decreases the mat stiffness will increase, not necessarily because of an increase in density of the mat. Delaying the compaction would increase the stiffness of the mat measured under the rollers because of the decrease in temperature.
    - The instrumented rollers also did not properly identify when checking and tearing of the mat occurred during rolling. The non-nuclear density gauges (PaveTracker) did identify this detrimental condition.
    - The technology and devices are not applicable to the use of laboratory data for calibration purposes.

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CHAPTER 8

CONSTRUCTION QUALITY DETERMINATION

The approach taken for this project is to use fundamental properties needed for mixture and structural design for the control and acceptance of flexible pavements and HMA overlays. The NDT technologies included in the field evaluation were evaluated for their ability to determine these properties accurately on a practical and effective QA program. Basically, the NDT technology or QA tests are used to confirm the design assumptions for the materials placed.

Chapter 5 presented the test results measured using each technology, and chapter 7 identified those devices that were able to identify or discriminate areas with different material properties or conditions. This chapter presents the evaluation of the NDT devices recommended for further use (chapters 5 and 7) to determine the quality of the unbound and HMA mixtures placed on some of the projects discussed in Appendix B. These devices include the GeoGauge for unbound materials and the PSPA for HMA mixtures. Other devices can also be used, such as the DCP, but these were not as successful in identifying anomalies. In addition, the intent of this chapter is to show the use of NDT devices that estimate modulus for defining construction quality.

8.1 Quality Control and Acceptance Application

As stated earlier in the report, of the many process control procedures that can be used in highway construction, process control charts, particularly statistical control charts, are most commonly used by contractors and material producers for verifying that their process is under control. Although there are different approaches that can be taken in implementing NDT technologies to verify that the process is in control, statistical control charts are being used within this project. As a result, the NDT test methods must produce results that can be adapted to existing AASHTO procedures in pavement construction. The ASTM *Manual on Presentation of Data and Control Chart Analysis* was used for preparing practical procedures that contractors can use in deciding whether their process is in control (ASTM, 1992).

Similarly, there are different acceptance procedures that are used in judging whether the pavement material meets the required specifications. Two of the more common methods that have been used and adopted by most agencies are PWL and AAD. PWL is the procedure used by over 75 percent of the agencies that have adopted statistical-based acceptance specifications. As a result, AASHTO R9 entitled *Acceptance Sampling Plans for Highway Construction* was used for preparing practical but effective procedures that agencies can use in deciding whether the product meets their specifications (AASHTO, 2003).

In summary, statistical control charts are the primary method for determining whether the construction is in-control or out-of-control, and PWL is the primary method for judging the acceptability of construction. To demonstrate the use of the NDT technology for use in QA program, specific projects were selected to cover the range of conditions encountered during construction. The following lists the steps recommended for use in setting up a QA program for using NDT devices to judge the quality of construction of unbound materials and HMA mixtures using the material modulus.

Unbound Materials	HMA Mixtures
1. Develop M-D relationships in the laboratory prior to construction for the unbound material to determine the maximum dry unit weight. Select the target density and water content for compacting the unbound layer.	1. Conduct an HMA mixture design to determine the target gradation and asphalt content. Select the target density and job mix formula for the project mixture or lift being tested. The target job mix formula will likely be revised based on plant produced and placed material.
2. Prepare and compact test specimens at the average water content and dry density expected during construction; based on the project specifications.	2. Prepare and compact test specimens at the target asphalt content and the average density expected during construction; based on the project specifications.
3. Measure the repeated load resilient modulus in accordance with the agency's procedure (AASHTO T307 or NCHRP 1-28A, as required by the MEPDG). Determine the resilient modulus at a selected stress state. The resilient modulus should equal or exceed the value used during design. If the agency does not have a resilient modulus testing capability, the FHWA-LTPP regression equations can be used to estimate the target value, until the laboratory resilient modulus test has been completed (see equations 34 to 48).	3. Measure the dynamic modulus in accordance with the agency's procedure or the test protocol in accordance with the MEPDG. Determine the dynamic modulus for the test temperature expected during acceptance testing. Two values should be extracted from the test results or master curve; one for the day of paving (an elevated temperature expected after compaction) and the other for one or multiple days following placement. This target value for one or more days following placement will need to be adjusted back to a standard temperature depending on the actual pavement temperature.
4. Define the adjustment factor or ratio for the unbound material to laboratory conditions. Low stress states were used in establishing the ratios for this project.	4. Define the adjustment factor for the HMA mixtures to laboratory conditions. A load frequency of 5 Hz was used in establishing the adjustment ratios for this project.
5. Determine the combined or pooled standard deviation of the modulus for setting up the control limits of the unbound layer for the contractor (see section 8.3). Establish the action, as well as warning, limits for the statistical control charts; upper and lower control limits (see section 8.2.	5. Determine the combined or pooled standard deviation of the seismic modulus for setting up the control limits of the HMA mixture for the contractor (see section 8.3). Establish the action, as well as warning limits for the statistical control charts; upper and lower control limits (see section 8.2).
6. Determine the upper and lower specification limits (see section 8.3) for the resilient modulus of the unbound material. This includes the upper and lower specification limits for the resilient modulus of the unbound layer.	6. Determine the upper and lower specification limits (see section 8.3) for the dynamic modulus of the HMA mixture. This includes the upper and lower specification limits for the dynamic modulus of the HMA mixture.
7. Prepare the statistical control charts	7. Prepare the statistical control charts.
8. Determine the PWL criteria for different conditions.	8. Determine the PWL criteria for different conditions.

8.2 Control Limits for Statistical Control Charts

The upper and lower control or action limits are calculated from the NDT modulus tests in accordance with the following equations.

$$UCL_{\overline{X}} = \overline{\overline{X}} + (A_3)(\overline{s}) \quad (49)$$

$$LCL_{\overline{X}} = \overline{\overline{X}} - (A_3)(\overline{s}) \quad (50)$$

Where:

$UCL_{\overline{X}}$ = Upper control limit for the sample means.

$LCL_{\overline{X}}$ = Lower control limit for the sample means.

$\overline{\overline{X}}$ = Target value for a project.

$\bar{s}$ = Pooled standard deviation that represents the process variance.

The target value of the control chart for each material is the average value measured in the laboratory in accordance with AASHTO T 307 or the test protocol used by the agency. Both action and warning limits are normally included on the statistical control charts. The upper and lower action limits are set at three standard deviations from the target value, while the warning limits are set at two standard deviations from the target.

8.2.1 Target Modulus or Critical Value

As noted above, the target value of the control chart for each material and project is the modulus measured in the laboratory. This average laboratory value should be the same as the input to the MEPDG for structural design. Tables 77 and 78 list the target values for the unbound and HMA layers included in the field evaluation projects, respectively. The repeated load resilient modulus (low stress state) and dynamic modulus (5 Hz load frequency) test results are provided in Appendix B and summarized in chapter 5.

Table 77. Parameters Used to Prepare Statistical Control Charts for the Unbound Layers Included in the Field Evaluation Projects

Project Identification	Material	Target Modulus, ksi	Pooled Standard Deviation, ksi	Action Warning Limits, ksi	
				UCL	LCL
I-85, AL	Low Plasticity Clay	4.0	0.8	5.6	2.4
NCAT, OK	High Plasticity Clay	6.9	2.0	10.8	3.00
SH-21, TX	High Plasticity Clay	26.8	2.5	30.4	23.2
TH-23, MN	Soil-Aggregate Embankment	16.4	1.0	17.8	15.0
US-2, ND	Soil-Aggregate Embankment	19.0	2.6	22.7	15.3
SH-130, TX	Improved Soil Embankment	35.3	2.8	39.3	31.3
NCAT, SC	Crushed Granite Base	36.1	2.7	41.4	30.8
NCAT, MO	Crushed Limestone Base	19.2	2.7	24.5	13.9
TH-23, MN	Crushed Stone Base	24.0	2.6	27.7	20.3
US-53, OH	Crushed Stone Base	27.5	1.6	30.6	24.4
NCAT, FL	Limerock Base	28.6	3.5	35.4	25.5
US-2, ND	Crushed Aggregate Base	32.4	4.5	38.8	26.0
US-280, AL	Crushed Limestone Base	48.4	10.0	62.7	33.7
NOTE: The target modulus for the South Carolina crushed granite base was determined using the FHWA-LTPP regression equation, because the densities were significantly below the maximum dry unit weight of the material during NDT testing. The pooled standard deviation for this project was assumed to be equal to the Missouri limestone base because the same contractor placed both materials.					

Table 78. Parameters Used to Prepare Statistical Control Charts for the HMA Layers Included in the Field Evaluation Projects

Project Identification	Material	Target Modulus, ksi	Pooled Standard Deviation, ksi	Action Warning Limits, ksi	
				UCL	LCL
I-85, AL	SMA	250	14	270	230
TH-23, MN	HMA Base	810	35	860	760
US-280, AL	HMA Base	650	45	715	585
I-35, TX	HMA Base	800	57	910	690
I-75, MI	Type 3-C	400	86	520	280
I-75, MI	Type E-10	590	86	715	465
US-47, MO	Surface Mix	530	60	615	445
US-47, MO	Base Mix	420	36	470	370
I-20, TX	CMHB Base	340	40	420	260
US-53, OH	HMA Base	850	44	915	785
US-2, ND	HMA Base	510	33	555	465
NCAT, SC	HMA Base	410	58	525	295
NCAT, FL	HMA Base	390	40	470	310
NCAT, FL	PMA Base	590	45	675	505
NCAT, AL	PG76-Sasobit	610	40	690	530
NCAT, AL	PG76-SBS	640	45	725	555
NCAT, AL	HMA Base	450	50	550	350

NOTE: The Texas SH-130 target modulus was determined from Witczak's regression equation because changes were made to mixture just prior to NDT testing.

8.2.2 Combined or Pooled Standard Deviation

The pooled standard deviation was calculated in accordance with the AASHTO R 9-03, *Standard Recommended Practice for Acceptance Sampling Plans for Highway Construction*. The pooled standard deviation was determined for each project and unbound material using the NDT results for the areas without anomalies or physical differences included at the end chapter 5. The pooled standard deviations for each project and material are listed in Tables 77 and 78 for the unbound and HMA layers, respectively. These values were used to determine whether the projects were in-control or out-of-control, using the action limits or upper control limit (UCL) and lower control limit (LCL) provided in Tables 77 and 78.

8.3 Parameters for Determining PWL

8.3.1 Determining Quality Indices

The upper and lower quality indices are calculated in accordance with equations 51 and 52, respectively. The upper and lower specification limits were determined using data from all projects with similar materials.

$$Q_L = \frac{\overline{X} - LSL}{s} \quad (51)$$

$$Q_L = \frac{USL - \overline{X}}{s} \quad (52)$$

Where:

Q_L = Lower quality index.
Q_U = Upper quality index.
USL = Upper specification limit.
LSL = Lower specification limit.
s = Sample standard deviation of the lot.
$\overline{X}$ = Sample mean of a lot.

The upper and lower quality indices are used to determine the total PWL for each lot of material using equation 53. The upper and lower PWL values are then determined from the Q-tables provided in the AASHTO QC/QA Guide Specification.

$$PWL = PWL_L + PWL_U - 100 \quad (53)$$

Where:

PWL = Percent Within Limits.
PWL_L = Percent Within Limits from the lower specification limit.
PWL_U = Percent Within Limits from the upper specification limit.

8.3.2 Determining Specification Limits

Tables 79 and 80 list the target values for the unbound and HMA layers included in the field evaluation projects, respectively. These values were used to determine the PWL for the different materials used in the field evaluation projects and compared to the control limits determined for each project.

Table 79. Upper and Lower Specification Limits for the Unbound Layers and Materials Included in the Field Evaluation Projects

Project Identification	Material	Median Standard Deviation, ksi	Specification Tolerance, (-) ksi
I-85, AL	Low Plasticity Clay	2.0	3.3
NCAT, OK	High Plasticity Clay		
SH-21, TX	High Plasticity Clay		
TH-23, MN	Soil-Aggregate Embankment	2.1	3.5
US-2, ND	Soil-Aggregate Embankment		
SH-130, TX	Improved Soil Embankment		
NCAT, SC	Crushed Granite Base	3.0	5.0
NCAT, MO	Crushed Limestone Base		
TH-23, MN	Crushed Stone Base		
US-53, OH	Crushed Stone Base		
NCAT, FL	Limerock Base		
US-2, ND	Crushed Aggregate Base		
US-280, AL	Crushed Limestone Base		

Table 80. Upper and Lower Specification Limits for the HMA Layers and Mixtures Included in the Field Evaluation Projects

Project Identification	Material	Median Standard Deviation, ksi	Specification Tolerance, ± ksi
I-85, AL	SMA	15	30
TH-23, MN	HMA Base	50	100
US-280, AL	HMA Base		
I-35, TX	HMA Base		
I-75, MI	Type 3-C		
I-75, MI	Type E-10	70	140
US-47, MO	Surface Mix		
US-47, MO	Base Mix	50	100
I-20, TX	CMHB Base		
US-53, OH	HMA Base		
US-2, ND	HMA Base		
NCAT, SC	HMA Base		
NCAT, FL	HMA Base		
NCAT, FL	PMA Base		
NCAT, AL	PG76-Sasobit	45	90
NCAT, AL	PG76-SBS		
NCAT, AL	HMA Base	50	100

PART IV – CONCLUSIONS AND RECOMMENDATIONS

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CHAPTER 9

CONCLUSIONS AND RECOMMENDATIONS

The overall objective of NCHRP 10-65 was to identify NDT technologies that have immediate application for routine, practical QA operations to assist agency and contractor personnel in judging the quality of HMA overlays and flexible pavement construction. This chapter provides a summary of the conclusions and recommendations resulting from the study.

9.1 Conclusions

9.1.1 Unbound Materials

- The GeoGauge is a self-contained NDT device that can be readily incorporated into a QA program for both control and acceptance testing, based on the fact that:
    - It provides an immediate measure of the resilient modulus of the in-place unbound material.
    - It identified those areas with anomalies at an acceptable success rate; second only to the DSPA.
    - It adequately ranked the relative order of increasing strength or stiffness of the unbound materials.
    - It provided resilient modulus values that were correlated to the dry density over a diverse range of material types.
    - The normalized dispersion is less than for the other NDT devices that provide an estimate of stiffness.
    - The training and technical requirements for the technical are no different than what is required when using a nuclear density gauge.

  Two disadvantages of using this device in a QA program are the need for measuring the water content and density using other methods, which is also the case for the DSPA and other modulus estimating devices, and the need to calibrate the test results to the material and site conditions under evaluation. The latter is more important and is discussed in more detail below.

  The GeoGauge should be calibrated to the project materials and conditions to improve on its accuracy, especially when testing fine-grained soils. This calibration issue requires that laboratory repeated load resilient modulus tests be performed on each unbound layer for judging the quality of construction. Most agencies do not routinely perform resilient modulus tests for design. Eliminating the laboratory resilient modulus tests from the calibration procedure will reduce its accuracy for confirming the design values, but not for identifying construction defects. For those agencies that do not have access to or the capability to perform resilient modulus tests, the FHWA-LTPP regression equations can be used to calculate the target resilient modulus at beginning of construction. The target resilient modulus should be the value used in structural design. For the MEPDG, this is the average value measured in the laboratory.

- The DSPA is also a self-contained unit that was successful in many of the areas noted above for the GeoGauge. It was the device that had the highest success rate in identifying areas with different physical conditions or anomalies. An additional advantage of the DSPA is that the results can be calibrated to the specific unbound material being tested prior to construction—when the M-D relationship is measured in the laboratory. This calibration procedure allows the DSPA to be used to detect volumetric, as well as physical, changes in the materials during construction. In other words, the DSPA modulus is measured on the M-D samples prepared at different water contents and dry densities. In short, the seismic technology can be used in day-to-day operations to assist contractor and agency personnel in judging construction and materials quality by itself or in tandem with other geophysical and/or ground truth sampling programs.

  Two disadvantages of the DSPA are that it consistently resulted in a higher normalized dispersion measured over a diverse range of conditions and materials, and it requires more sophisticated training of technicians to correctly interpret the load pulse and responses to ensure that a suitable test has been collected by the device.

- The DCP was also successful in many of the areas noted above for the GeoGauge. However, more much more time is needed to conduct the test, especially for stiff materials and layers with large aggregate. The test results were found to be more dependent on aggregate size. The normalized dispersion was also found to be much higher than for the DSPA and GeoGauge. However, the DCP does have the capability to easily test the strength of thicker layers of unbound materials. In fact, it can be used in conjunction with the GeoGauge and DSPA in adjusting the modulus values from those devices to laboratory conditions for fine-grained soils for agencies that do not have a resilient modulus testing capability in the laboratory. Use of the DCP can be considered an option in adjusting the test results for the DSPA for those agencies that have no plans to incorporate a resilient modulus testing capability within their design or materials departments.

- The GPR (single antenna method) was found to have a poor success rate in identifying anomalies. In addition, it does not provide a measure of modulus or strength of the material. More importantly, using the single antenna method requires that either the density or water content be assumed and the other parameter calculated. Both vary along the project, resulting in higher variations of the property being calculated. Using an inaccurate value can lead to an incorrect finding. For example, the GPR found some of the areas tested to have the highest density, while most other NDT devices found that area to be the softest and least dense. It was successful, however, in measuring the layer thickness of the unbound materials.

  Two other disadvantages of this system are in the training area and the need to calibrate the dielectric values to physical properties of the in-place material. Samples need to be recovered and tested to determine the water contents and densities of those areas prior to using the results for QC or acceptance. This requires that control strips be used prior to construction, and these calibration factors should be checked periodically during construction. Many agencies are not requiring control strips, or the first day of construction is the control strip. Training is another issue; this system requires more sophisticated training for the operator to interpret the measurements taken with the GPR. Thus, it is not recommended for future use in testing unbound materials to determine the quality characteristics of the in-place material. However, it is recommended that research with the GPR continue because of its continuous coverage and speed of data collection.

- Similar to the GPR, the EDG was found to have a poor success rate in identifying areas with anomalies. However, this device is believed to have potential to provide volumetric data on the unbound materials for use in a QA program with continued use. The density estimated from this device is definitely related to resilient modulus across a wide range of unbound materials. However, additional data are needed to make conclusive recommendations for improving on the measurements. The variability of the water contents measured with this device was found to be very low. Other agencies are beginning to use this device in their research programs. For example, Texas and Nevada have ongoing programs that could provide improvements to the equipment and procedures in the near future. As a result, it is recommended that this device and technology be evaluated in more detail and that studies be initiated to improve its accuracy.

- The LWD and FWD are believed to have limited potential for QC purposes. The LWD These devices have more potential for use in acceptance programs of the final structure, and certainly in forensic areas for evaluating the interaction between the pavement layers and foundation. The following summarizes the conclusions reached on these devices.
  - This technology was unable to consistently identify those areas with anomalies.
  - The modulus values can be influenced by the underlying layers, resulting in lower or higher and more variable modulus values.
  - The normalized dispersion was found to be high, relative to the other NDT devices.
  - The relationship between modulus from this technology and dry density was poor.
  - Any error in thickness of the layer being tested can result in large errors and more variability that could lead to wrong decisions being made by the contractor and agency about the construction operation.

9.1.2 HMA Mixtures

- The PSPA is a self-contained NDT device that can be readily incorporated into a QA program for both control and acceptance testing of HMA mixtures. As noted above for unbound materials, an advantage of this technology is that the device can be calibrated to the specific materials being tested during the mixture design stage for HMA mixtures. This calibration procedure allows the PSPA to be used to detect volumetric, as well as physical, changes in the materials during construction. In short, the PSPA can be used in day-to-day operations to assist contractor and agency personnel in judging construction and materials quality by itself or in tandem with other geophysical and/or ground truth sampling programs.

- The PSPA is the NDT device recommended for QA applications because it adequately identified all areas, but one, with anomalies. The PSPA provides a measure of the dynamic modulus that is needed for pavement structural designs, even before adjusting the PSPA modulus for laboratory conditions.
- Similar PSPA modulus values were measured at higher temperatures when corrected for temperature using a master curve in comparison to those measured in the laboratory.
- An important condition that the NDT device needs to consider is the effect of time and varying moisture content on the properties of the HMA mixture near construction and how those properties will change over time. There have been various studies completed on using the PSPA to detect stripping in HMA mixtures. For example, Hammons et al. used the PSPA (in combination with GPR) to locate areas with stripping along selected interstate highways in Georgia (Hammons et al., 2005). The test results from the Part A and B studies support a similar decision.

The PSPA, however, does have some limitations regarding full-scale use in QA programs. Use of the PSPA should be delayed after rolling to allow the mix to cool. Dr. Nazarian's recommendation is to delay all testing for one day after HMA placement and compaction. If required, this time restriction is considered a disadvantage for use in QA program. As noted above, the seismic modulus was found to be correlated to the dynamic modulus at elevated temperatures using the master curve developed from laboratory dynamic modulus tests.

- A measure of the mixture density or air voids will also be required in judging the acceptability of the modulus value. However, none of the NDT methods has clear advantages for use in day-to-day construction operations. The two that deserve further evaluation include the GPR, because of full coverage in a short period of time, and the non-nuclear PQI for of safety reasons (in relation to nuclear density gauges).

- The non-nuclear density gauges are also recommended for QA because they can be incorporated into control programs readily. Some contractors are already using the non-nuclear density gauges in controlling the compaction operation. This technology was also used to identify anomalies at a reasonable rate and can be used to identify tender mixtures and the effects of rolling in the temperature sensitive zone.

Variations in water have a definite affect on the HMA density measured with the PQI. The manufacturer's recommendation is to measure the density immediately after compaction, prior allowing any traffic on the HMA surface. Similar to the PSPA, this type of time restriction is considered a disadvantage to the use of the PQI in a day-to-day practical QA program. This time effect was not found within the Part A test program, but the moisture effect was observed within Parts A of the field evaluation. Use of other non-nuclear density gauges (PaveTracker) did not exhibit this moisture sensitivity. However, the effect of water on these gauges was not included in the field evaluation as a primary variable. Measurements were taken after heavy rains in areas where the readings were previously taken prior to the thunderstorms. The same density values were measured, but after removing and drying all free water at the surface. This potential bias of free water on the surface is not considered a limitation but must be considered in taking measurements for control purposes.

- Use of the GPR technology using the single antenna method, even with mixture calibration, requires assumptions on specific volumetric properties that vary along a project. Using the multi-antenna method is expected to improve on the measurement of the volumetric properties and identification of areas with deficiencies or anomalies. Thus, the GPR is suggested for continued research studies, especially with the multiple antenna system, which is a proprietary analysis system. The proprietary system needs additional validation prior to full-scale implementation into a QA program.

- The FWD is not recommended for use in QA programs, because this technology was unable to identify some of the anomalies. In addition, the FWD has high variation in elastic modulus values, and those values are influenced by the strength of the underlying materials and layers.

9.2 Recommendations

1. It is recommended that a project be procured and developed to sponsor the production of continued improvements to the steady-state vibratory and ultrasonic technologies.

2. The IC or instrumented rollers can be valuable to a contractor in terms of controlling the compaction operation. These rollers that operated without problems were used on too few projects to recommend that they be immediately included in QA programs. However, their use can assist the contractor in optimizing the compaction of the material. Their disadvantage for HMA layers is the temperature of the mat issue. Decreases in temperature will cause the stiffness of the mat to increase. Thus, other devices still need to be used with the IC rollers for control. The IC rollers are not recommended at this time for acceptance.

3. Research with the multi-antenna GPR device and proprietary data interpretation system should not be abandoned and should be validated in future studies. This system definitely shows promise in providing the volumetric properties for HMA mixtures. The data can be collected at highway speeds and the proprietary data interpretation system can provide results on a real-time basis. The disadvantage of this system is that it also needs field cores for calibrating the method to project specific conditions. These cores should be taken periodically to confirm the calibration factors being used in estimating the volumetric properties.

9.3 Impediments to Implementation of Recommended Technologies

Initially, the availability of the NDT equipment can be an impediment to implementing the recommended QC/QA results, although this is a relatively minor obstacle. A more challenging impediment is adequately training personnel in the use of the equipment and data interpretation procedures. Some of the devices will be easy to implement (for example, the DCP), while others will require additional work (for example, interpretation of the GRP data). To address this challenge quickly, it will be necessary to coordinate with training agencies such as the National Highway to develop training programs to accelerate implementation of these products.

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APPENDIX A

TOPICS COVERED AND QUESTIONS USED DURING THE REVIEW OF NDT TECHNOLOGIES THAT HAVE BEEN USED BY DIFFERENT STATE AND FEDERAL AGENCIES

Appendix A is a listing of the questions and topics that were used during the review of the different NDT technologies that have been used by state and federal agencies for evaluating, controlling, and accepting flexible pavement construction and HMA overlay placement.

General Information and Expertise with NDT Methods

1. What types of NDT methods and devices have been used by the agency?
    a. Dynamic Cone Penetrometer
    b. Deflection-Based Methods
    c. Seismic
    d. Ultrasonic
    e. Density Measurement
        i. Bomag Asphalt Manager
        ii. PQI – Transtec
        iii. PaveTracker – Troxler
        iv. Humbolt Density Gauge
    f. Ground Penetrating Radar
        i. PERES II – Precision Electromagnetic Roadway Evaluation System; Lawrence Livermore National Laboratories
        ii. HERMES II
    g. MIT-Scan T
    h. Infrared
    i. Smoothness
    j. Skid
    k. Noise
2. For what purpose or application have they been used?
    a. Pavement forensic studies – limited use
    b. Pavement evaluation and rehabilitation design studies – routine use for design and evaluation
    c. Construction evaluation to identify or explain non-compliance
    d. Quality acceptance of HMA____ or unbound materials____
    e. Quality control of HMA___ or unbound materials___
3. How long have these NDT technologies and methods been used within the agency?

4. What comments does the agency have on the use of NDT methods for each specific purpose?
    a. Effectiveness of the NDT technology and equipment and analysis procedures
    b. Advantages of the NDT technology
    c. Disadvantages of the NDT technology
5. What is the operational cost of the equipment:
    a. Initial cost
    b. Maintenance requirements and costs
    c. Production rates of the equipment
    d. Time required for data analysis
    e. Complexity of the equipment and data acquisition system – software requirements and support
    f. Accuracy and repeatability of the equipment
    g. Calibration requirements

NDT Protocols and Guidelines:

6. Has the agency prepared test protocols for the specific NDT devices used or has the agency developed test protocols or guidelines that are being used?
7. Does the agency have any repeatability data to determine the variability in the use of the equipment and methods?
8. Does the agency have criteria for interpretation of the data collected?

NDT and Quality Assurance Procedures:

If the NDT equipment has not been used for quality control and/or acceptance:

9. What is the agency's opinion on the use of NDT for quality control and/or acceptance?
10. Does the agency believe that it can be used successfully at the present state of the art, or how do they believe that it can be used in a quality assurance plan?

If the NDT equipment has been used for quality control and/or acceptance:

11. What properties have been measured?
12. What is the variability of the methods and equipment?
    a. Single operator variability
    b. Multi-operator variability
    c. General comment on its use in QA
13. How was the acceptance methods and criteria developed, and can a copy be obtained for use in NCHRP Project 10-65?

Control Testing and Procedures:

14. What types of quality control tests are typically used by contractors within the organization for HMA and unbound materials and soils?
    a. Volumetric Properties
        i. Density/Air Voids
        ii. VMA
        iii. VFA

iv. Gradation
v. Asphalt Content
b. Structural Properties
i. Thickness
ii. Modulus (Dynamic and Resilient)
iii. IDT Strength
c. Functional Properties
i. Surface Profile, Smoothness
ii. Skid Resistance and Texture
iii. Texture and noise

15. What procedure is used in the quality control process?
    a. Statistical Control Charts
    b. Run Charts
    c. Others

Acceptance Testing and Procedures:

16. What types of tests and properties are used within your organization for HMA and unbound materials and soils?
    a. Volumetric Properties
        i. Density/Air Voids
        ii. VMA
        iii. VFA
        iv. Gradation
        v. Asphalt Content
    b. Structural Properties
        i. Thickness
        ii. Modulus (Dynamic and Resilient)
        iii. IDT Strength
    c. Functional Properties
        i. Surface Profile, Smoothness
        ii. Skid Resistance and Texture
        iii. Texture and noise
17. What type of procedure is used for acceptance?
    a. Percent Within Limits
    b. Absolute Average Deviation
    c. Others

APPENDIX B

DESCRIPTION OF FIELD TESTING PROJECTS IN PHASE 2

Appendix B describes the projects included in the field evaluation of NCHRP Project 10-65. As noted in the main body of the research report, the field evaluation was divided into two parts, referred to as Part A and Part B. The objective of Part A was to confirm the applicability and use of different NDT technologies and equipment identified from Phase 1 of the project. Findings from Part A formed the basis for selecting technologies and devices most suitable to determine construction quality. Part B focused on evaluating those technologies and test procedures selected at the end of Part A for further verification and refinement.

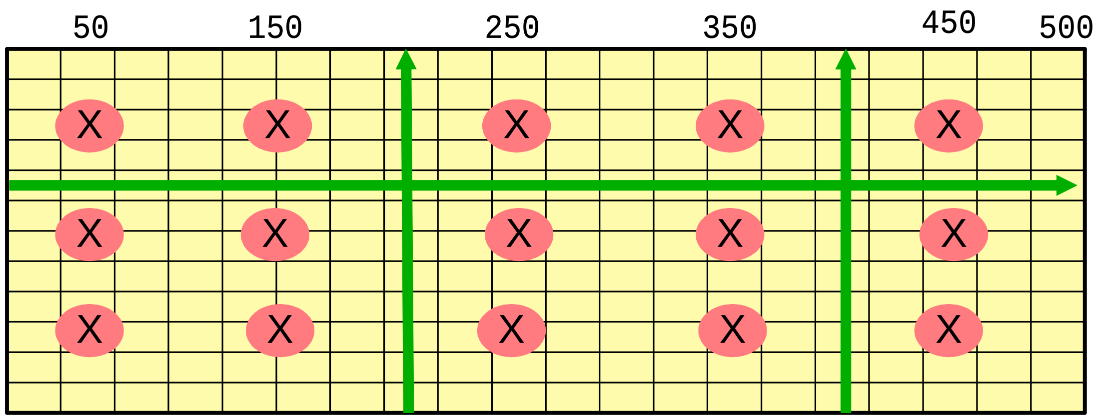
B.1 – Projects Included in Part A

Table B.1 lists the projects included in the Part A field testing plan, each of which is described in the following sections. Figure B.1 shows the general layout of test points for each section or lot within a project used for Part A testing. As noted in the body of the research report, most of the projects included in Part A had some type of anomalies built into the project for confirming that the NDT technologies and devices were able to identify those anomalies consistently. Table B.2 summarizes the anomalies within each of the Part A projects; this information was included in chapter 5 of the research report but is repeated here for completeness.

Table B.1. Projects Included in Part A of the Field Evaluation

Project Identification		Material Evaluated	NDT Technologies					
			DCP	Deflect.	Seismic	GPR	Density	IC
1	MnRoad Demonstration	Embankment	√	√	---	---	---	√
2	TH-23 Reconstruction Project; Wilmar, MN.	HMA – Surface	NA	---	√	√	√	√
		Aggregate Base	√	√	√	√	√	√
		Embankment	√	√	√	√	√	---
3	I-85 Overlay; Auburn	SMA Overlay	NA	√	√	√	√	√
4	US-280 Reconstruction Project; Opelika, AL	HMA – Base	NA	√	√	√	√	√
		Aggregate Base	√	√	√	√	√	---
5	I-85 Ramp; Auburn, AL.	Embankment	√	√	√	√	√	√
6	SH-130 New Construction; Austin, TX.	HMA Base	NA	---	√	√	√	---
		Embankment	√	√	√	√	√	---
7	SH-21 Widening Project; Caldwell, TX.	High Plasticity Clay	√	√	√	---	---	√

NA – Not Applicable
DCP = Dynamic Cone Penetrometer, manual.
Deflect. = Deflections measured with the Falling Weight Deflectometer or Light Weight Deflectometer.
Seismic = Responses measured with the DSPA, PSPA, or GeoGauge.
GPR = Ground Penetrating Radar, air-coupled antenna.
Density = Non-Nuclear density measurements with PaveTracker, Pavement Quality Indicator, or Electrical Density Gauge.
IC = Intelligent Compaction.



NDT Technology (Unbound Layers)	Frequency of Test	Segments or Lots
• Density • Moisture • Seismic • LWD • DCP • GPR	• Triplicate Tests • Clustered Tests	• Varying density, between & within a lot • Varying moisture, between & within a lot • Material types
NDT Technology (HMA Layer)	**Frequency of Test**	**Segments or Lots**
• Density • Seismic • GPR	• Triplicate Tests • Clustered Tests	• Varying density, between & within lots • Varying asphalt content between lots • Mixture types

Figure B.1. General Layout of Test Points and Testing Sequence for Each Section or Lot Included Within a Project

B.1.1 MnROAD Intelligent Compaction and NDT Demonstration

The IC demonstration project was sponsored by the Minnesota DOT and held at the MnROAD facility. In summary, this demonstration project included use of the BOMAG VariControl IC roller to compact a fine-grained soil, and companion testing with NDT devices—LWD, DCP, and GeoGauge. Other traditional in-place tests were also performed during construction. All testing was performed by Minnesota DOT personnel. No laboratory repeated load resilient modulus tests were planned or completed as part of this demonstration project.

The IC roller that was used at this site to compact the embankment soil is shown in Figure B.2. After each lift reached the minimum stiffness requirement, as measured by the IC roller, the NDT devices were used to measure the properties of that lift. A report was prepared by the Minnesota DOT and shared with NCHRP Project 10-65.

Table B.2. Description of the Local Anomalies of the Unbound Materials and Soils and HMA Mixtures Placed Along Each Project Included in Part A

Project Identification	Unbound Sections	Description of Differences Along Project
Unbound Material and Soil Layers		
SH-21 Subgrade, High Plasticity Clay; Caldwell, Texas	Area 2, No IC Rolling	No planned difference between the points tested.
	Area 1, With IC Rolling	With IC rolling, the average density should increase; lane C received more roller passes.
I-85 Embankment, Low Plasticity Clay; Auburn, Alabama	Lane A of Sections 1 & 2	Prior to IC rolling, Lane A (which is further from I-85) had thicker lifts & a lower density.
	All sections tested	After IC rolling, the average density should increase & the variability of density measurements should decrease.
TH-23 Embankment, Silt-Sand-Gravel Mix; Spicer, Minnesota	South Section – Lane C	Construction equipment had disturbed this area. In addition, QA records indicate that this area has a lower density.
	North Section – Lane A	The area with the higher density and lower moisture content – a stronger area.
SH-130, Improved Embankment, Granular; Georgetown, Texas	All sections tested	No planned differences between the areas tested.
TH-23, Crushed Aggregate Base; Spicer, Minnesota	Section 2 (middle section) – Lane C	Curb and gutter section; lane C was wetter than the other two lanes because of trapped water along the curb from previous rains. The water extended into the underlying layers.
	Section 1 (south section) – Lane A	Area with a higher density and lower moisture content; a stronger area.
US-280, Crushed Stone Base; Opelika, Alabama	Section 4	Records indicate that this area was placed with higher moisture contents and is less dense. It is also in an area where water (from previous rains) can accumulate over time.
HMA Mixtures and Layers		
TH-23 HMA Base; Spicer, Minnesota	Section 2, Middle or Northeast Section	QA records indicate that a lower asphalt content was used in this area – asphalt content is still within the specifications.
I-85 SMA Overlay; Auburn, Alabama	Section 2, Middle; All lanes	QA records indicate a higher asphalt content was used in this area, but it is still within the specifications.
	Lane C, All Sections	This part or lane was the last area rolled using the pattern set by the contractor, and is adjacent to the traffic lane. Densities expected to be lower.
US-280 HMA Base Mixture; Opelika, Alabama	Initial Test Sections, defined as A; Section 2, All Lanes	Segregation identified in localized areas. In addition, QA records indicate lower asphalt content in this area of the project. Densities expected to be lower within this area.
	Supplemental Test Sections near crushed stone base sections, defined as B.	Segregation observed in limited areas.
	IC Roller Compaction Effort Section, Defined as C.	Higher compaction effort was used along Lane C.
SH-130 HMA Base Mixture; Georgetown, Texas	All Sections	No differences between the different sections tested.

Figure B.2. Embankment Soil at MnROAD Facility Being Compacted with the BOMAG VariControl Device/Roller

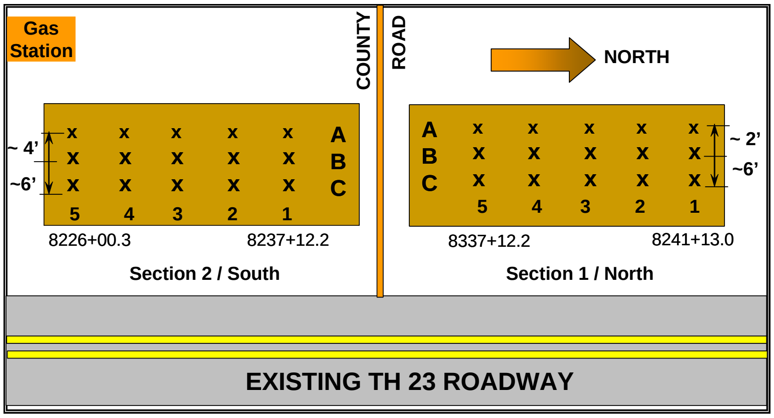
B.1.2 NCAT Intelligent Compaction Demonstration

The NCAT hosted an Intelligent Compaction Symposium and Demonstration in December 2004. As part of the symposium, various IC rollers were used to compact unbound fine-grained materials and HMA mixtures in the Auburn, Alabama, area. The projects on which the IC devices were demonstrated included the embankment on I-85 exit ramp 51 and the HMA layer on US-280 reconstruction. As part of the NCHRP Project 10-65 study, other NDT technologies were used to measure the in place properties of the pavement layers along these projects. The IC rollers used and test results obtained from this demonstration are presented in sections B.1.5 and B.1.6 of this appendix.

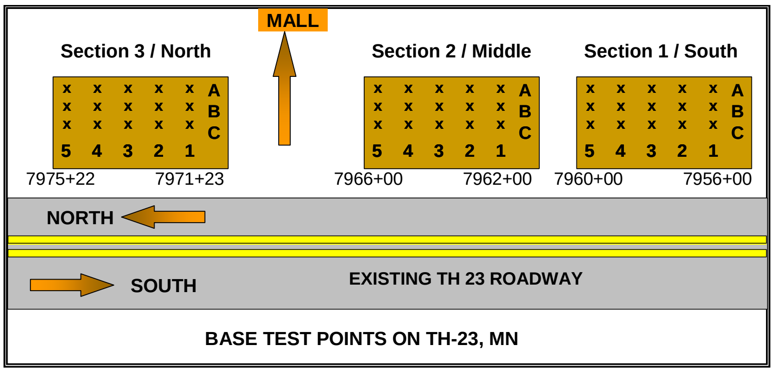
B.1.3 TH-23 Project; Spicer, Minnesota

This 13-mile project is along Highway 23 (TH-23) just north of Willmar, Minnesota. Dunnick Brothers was the contractor for the project. TH-23 was being reconstructed and expanded to a four-lane divided highway during 2004 construction season. The pavement cross section for this project included a 6-inch HMA layer, a 6-inch Class 6 aggregate base layer, and a Class 5 embankment over the subgrade. The Class 5 embankment was a gravelly-silty clay material with varying amounts of larger aggregate, and the thickness of this material varied over the project limits.

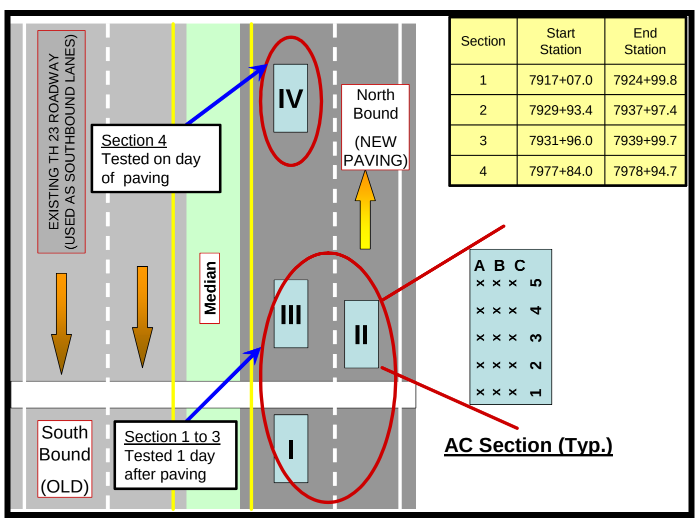
The NCHRP Project 10-65 sections along TH-23 were located between the towns of New London and Spicer, and all tests were conducted between October 4 and 8, 2004.



(a) Embankment sections tested along TH-23.



(b) Class 6, crushed aggregate base material tested along TH-23.



(c) HMA base mixture tested along TH-23.

[Note: Some of the physical properties of the HMA layer could not be varied as originally included in the test plan. The contractor for the TH-23 project had placed the HMA base mix a couple of days prior to the field testing. HMA mixture was being placed during the field testing, but this mix was in a critical area of the roadway (intersections), and NDT tests were not possible. The shoulders, considered to be in a non-critical area, were not paved during the NDT testing operations.]

Figure B.3. Section Layout on TH-23 Expansion Project at Spicer, Minnesota

Three separate locations were selected for testing three materials: the first lift of the HMA base mixture, the Class 6 aggregate base, and the Class 5 embankment material. Each layer tested was divided into sections or lots as shown in Figure B.3. The NDT technologies used along this project are listed in Table B.3.

Table B.3. Nondestructive Technologies Used for the TH-23 Project in Spicer, Minnesota

NDT Technology	Gravelly-Silty Clay Embankment	Base, Class 6 Crushed Aggregate	HMA Base
FWD	—	—	—
LWD 1 (Loadmann)*	✓	✓	—
LWD 2 (Dynatest)*	✓	✓	—
LWD 3 (Carl Bro)*	✓	✓	—
DCP	✓	✓	—
GeoGauge (stiffness)*	✓	✓	—
Seismic – PSPA for HMA, DSPA for soils*	✓	✓	✓
GPR (thickness, AC voids; soil density)**	✓	✓	✓
Non-nuclear HMA density 1 (PQI)*	—	—	✓
Non-nuclear HMA density 2 (Troxler)*	—	—	✓
Field Soil Moisture Tester (Preliminary evaluation)	✓	—	—
Electrical Density Gauge; Density & Moisture Content*	✓	✓	—
Intelligent Compaction Device-Caterpillar Roller	—	✓	—
Other Traditional Tests			
HMA mixture design test data	—	—	✓
HMA cores for densities & volumetric properties	—	—	✓
Sand cone tests; density & moisture content	✓	✓	—
Moisture-density relationship tests	✓	✓	—
Bulk material for laboratory modulus tests	✓	✓	✓

* - Clustered tests performed at each test point – refer to figure B.1.
** - Triplicate runs used within each lot or section.

The Caterpillar IC roller was brought to the project by the manufacturer after the crushed stone base and embankment material had already been compacted. As such, the vibratory setting on the roller was set at low amplitude and used to test the uniformity in the stiffness of the base section. The low amplitude setting was used so that the compacted base would not be disturbed or de-compacted just prior to placing the HMA base.

Bulk samples for laboratory testing of the embankment, Class 6 base, and HMA mixture were taken during construction. Minnesota DOT personnel provided the moisture-density curves for the unbound materials and performed sand-cone tests at specific points for calibrating the electrical density gauge and other NDT devices. Copies of the mixture design data sheets and QA test results were also provided by Minnesota DOT for the areas tested under NCHRP Project 10-65. HMA cores were recovered at specific locations to measure lift thicknesses, bulk specific gravity, and maximum specific gravity. These cores are also used for measuring the seismic modulus in the laboratory for calibration purposes.

Embankment Layer: The embankment section, about 1500 feet in length, was a Class 5 subbase material with some large aggregate particles. This section was at the north end of the project near New London, Minnesota. The soil appeared uniform along this section, so the area was divided into two separate 500-foot-long lots (refer to Figure B.3a). Five test locations, 100 feet apart, were marked longitudinally. At each station, three test points were marked transversely to perform triplicate tests along the width of the section. At each of the 15 points in the section, clustered tests were performed with the point measurement devices to assess the repeatability of the specific NDT devices. Figure B.4 shows the condition of the embankment section during testing of the lots.

Base Layer: The base layer assigned for testing was approximately 2,000 feet in length and divided into three areas, each about 500 feet in length. Each area was further divided into 15 sublots similar to the test layout shown in Figure B.3b. Figure B.5 shows the Class 6 base material and its condition during testing.

HMA Layer: The first 3-inch lift of the HMA section assigned for this study was paved on October 1, 2004, 3 days prior to nondestructive testing (October 4, 2004). Three sections were selected for testing this layer over a length of about 3,000 feet (refer to Figure B.3c). The test layout was similar to that of the embankment and base layer, however, the stationing between each sublot was about 200 feet.

B.1.4 I-85 Rehabilitation Project with SMA Overlay; Auburn, Alabama

This rehabilitation project is along I-85 between Auburn and Montgomery, Alabama. In summary, the rehabilitation strategy included milling the existing HMA surface and placing a 1.5-inch SMA overlay. Figure B.6 shows the paving operation at the time of testing on this project, while Figure B.7 shows the compacted SMA mixture that was tested using the NDT technologies listed in Table B.4. Part A tests were conducted on October 26 through 28, 2004.

Three test sections, each with test points located on a 5x3 grid pattern, were used for this project (refer to Figure B.1). Figure B.8 shows the specific section layout for this project, which includes 200-foot spacing between lots. Each lot was further divided into five sublots at 100-foot intervals. No specific tests for segregation and joint locations were included within this project, because of traffic in the adjacent lane during overlay placement. All testing was performed immediately after paving (refer to Table B.4 for the tests used on this project).

Bulk samples and cores for laboratory testing were recovered during construction. Nuclear gauge density readings were also collected on the overlay at all test points. Cores were taken at specific test points to measure lift thickness, bulk specific gravity, and maximum specific gravity of the SMA mixture. These cores were also used for measuring the seismic modulus in the laboratory for calibration purposes.

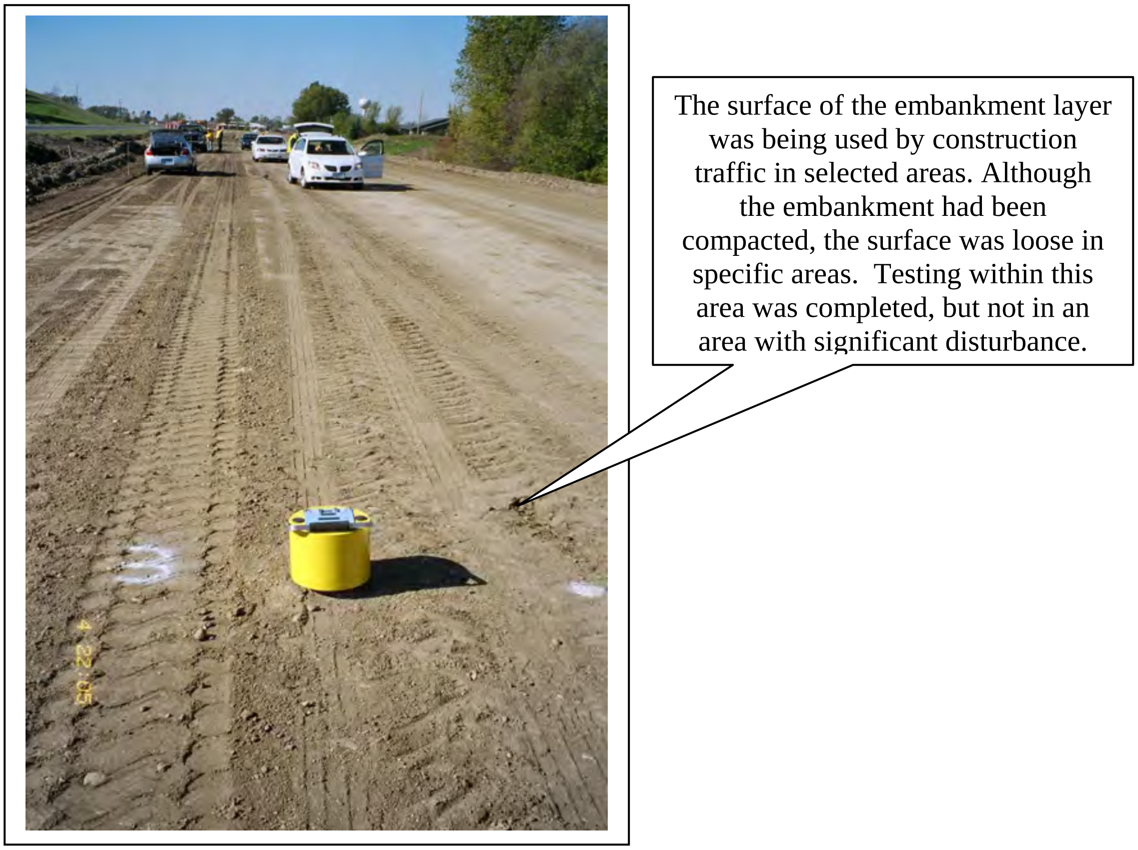


Figure B.4. Embankment Material Placed and Tested Along the TH-23 Project Near Spicer, Minnesota (refer to Figure B.3a)

Figure B.5. Caterpillar IC Roller Used to Test the Stiffness and Uniformity of the Class 6 Base Material Along the TH-23 Project Near Spicer, Minnesota (refer to Figure B.3b)

Figure B.6. Placement of the 1.5-inch SMA Overlay Tested During the I-85 Rehabilitation Project Near Auburn, Alabama (refer to Figure B.8)

Figure B.7. Compacted SMA Overlay and Ground Penetrating Radar Testing Along the SMA Overlay Project Near Auburn, Alabama (refer to Figure B.8)

Table B.4. Nondestructive Technologies Used for the I-85 Overlay Project; Auburn, Alabama

NDT Technology	Subgrade	Aggregate Base	SMA Overlay
FWD	NA		✓
Seismic (modulus)*			✓
GPR (thickness and AC voids)**			✓
Non-nuclear density 1 (PQI)*			✓
Non-nuclear density 2 (Troxler)*			✓
Intelligent compaction for HMA			✓ (No results)
Other Traditional Tests			
HMA mixture design test data	NA		✓
Nuclear gauge testing for density			✓
HMA cores for thickness, densities & other volumetric properties			✓
Bulk material for laboratory modulus tests			✓
* - Clustered tests performed at each test point; refer to figure B.1. ** - Triplicate runs used within each section.			

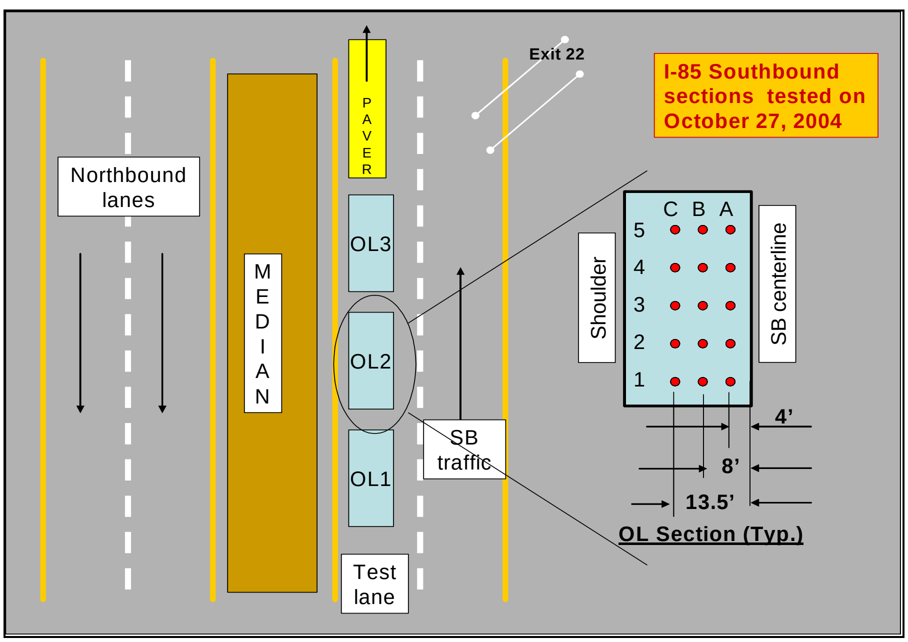


Figure B.8. Section Layout for Nondestructive Testing Along the I-85 Overlay Project, West of Auburn, Alabama

The BOMAG Asphalt Manager IC roller was intended for use on this project as an initial demonstration. However, a software-related problem occurred at the time of paving and caused the IC system to malfunction. Thus, the roller was not used for the test. The evaluation of intelligent compaction operations for HMA paving was therefore moved to the demonstration project conducted in December 2004.

B.1.5 US-280 Expansion Project; Opelika, Alabama

The US-280 expansion project was selected for testing HMA, crushed aggregate base material, an improved subgrade, and a soil with moderate plasticity that was used in fill areas. The contractor for this project was East Alabama Paving. The pavement section consists of a 6-inch aggregate subbase or improved subgrade, a 6-inch crushed aggregate base, a 4-inch permeable asphalt treated base, a 4-inch HMA base, and a 2-inch HMA wearing surface. The sections tested were located on US-280 at the intersection with Rt. 121, about 20 miles west of the Auburn/Opelika area. NDT was conducted along this project on separate occasions, which are defined as the initial project testing, supplemental project testing, and IC Demonstration. The testing conducted during each time is discussed in the following subsections of this chapter.

Initial Project Testing

The initial testing for the project was limited to the crushed aggregate base material and the first lift of the HMA base mixture. The tests were conducted on October 26 through 28, 2004. Bulk samples of the base and HMA materials for laboratory modulus testing were recovered. Nuclear gauge density readings were collected on both the base and HMA layers. HMA cores were removed at specific test points to measure lift thickness, bulk specific gravity, and maximum specific gravity. These cores were also used for measuring the seismic modulus in the laboratory for calibration purposes. Each layer tested was divided into sections or lots as shown in Figure B.1. NDT technologies used for testing each layer on this project are shown in Table B.5.

The 6-inch improved subgrade had to be excluded from the field study because of construction traffic operations and traffic activity in one area and the embankment soil was too wet in another area. The improved subgrade was in a critical area with continuous construction and truck traffic. It was abandoned after some initial attempts were made to block traffic for a sufficient time period for the NDT measurements with minimal success. The fine-grained, moderate plasticity soil was also abandoned in the areas that were accessible after repeated efforts to locate the NDT test points—only to have construction traffic remove the paint marks for the test point locations and to deform the surface enough such that NDT could not be properly performed with all devices.

<u>Base Layer</u>: The crushed aggregate base layer was tested in four sections along the shoulders in the westbound and eastbound lanes of US-280. Figure B.9 shows the section layout for the unbound aggregate base. The material placed along the shoulders had to be tested, because a chip seal had already been placed along the main lanes of the roadway (refer to Figure B.10). Both the east and westbound directions had two sections each. As shown in Figure B.10, each of the four sections was divided into five sublots 40 meters apart.

Each sublot consisted of three points, making a total of 60 test points for the base layer. Placement of the DSPA, LWDs, and GeoGauge on the chip seal surface was believed to be problematical because of the potential concentrated point loads on the aggregate.

Table B.5. Nondestructive Technologies Used Along the US-280 Expansion Project Near Opelika, Alabama

NDT Technology	Granular Embankment	Crushed Aggregate Base	HMA Base	
			3-days After Paving	Just After Paving
FWD	—	✓	✓	✓
LWD 1 (Loadmann)*	—	—	—	—
LWD 2 (Dynatest)*	—	✓	—	—
LWD 3 (Carl Bro)*	—	✓	—	—
GeoGauge (stiffness)*	—	✓	—	—
DCP	—	✓	—	—
Seismic – PSPA for HMA, DSPA for soils (modulus)*	—	✓	✓	✓
GPR (thickness and AC voids)**	—	✓	✓	✓
Non-nuclear density 1 (PQI)*	—	—	✓	✓
Non-nuclear density 2 (Troxler)*	—	—	✓	—
Electrical Density Gauge; Density & Moisture Content*	—	✓	—	—
Other Traditional Tests				
HMA mixture design test data	—	—	✓	✓
HMA cores for densities & other volumetric properties	—	—	✓	✓
Nuclear density gauge results	—	✓	✓	✓
Moisture-density relationship tests	—	✓	—	—
Bulk material for laboratory modulus tests	—	✓	✓	✓

* - Clustered tests performed at each test point; refer to figure B.1.
** - Triplicate runs within each section or lot.

HMA Layer: Three sections were marked, totaling 2,500 feet. The first lift of the HMA base mixture was included in the field evaluation (refer to Figure B.11). The test layout for these sections is shown in Figure B.12. The HMA mixture in two of the sections was tested 3 days after paving. For the third section, testing was completed on the same day of paving and then repeated the day after paving. Segregation was also identified in some localized areas along these sections, and those areas were marked for testing. Both density and modulus values were measured at joint locations and in designated areas where mix segregation was evident using each of the NDT technologies. Cores were taken in some of the segregated areas to confirm the segregation.

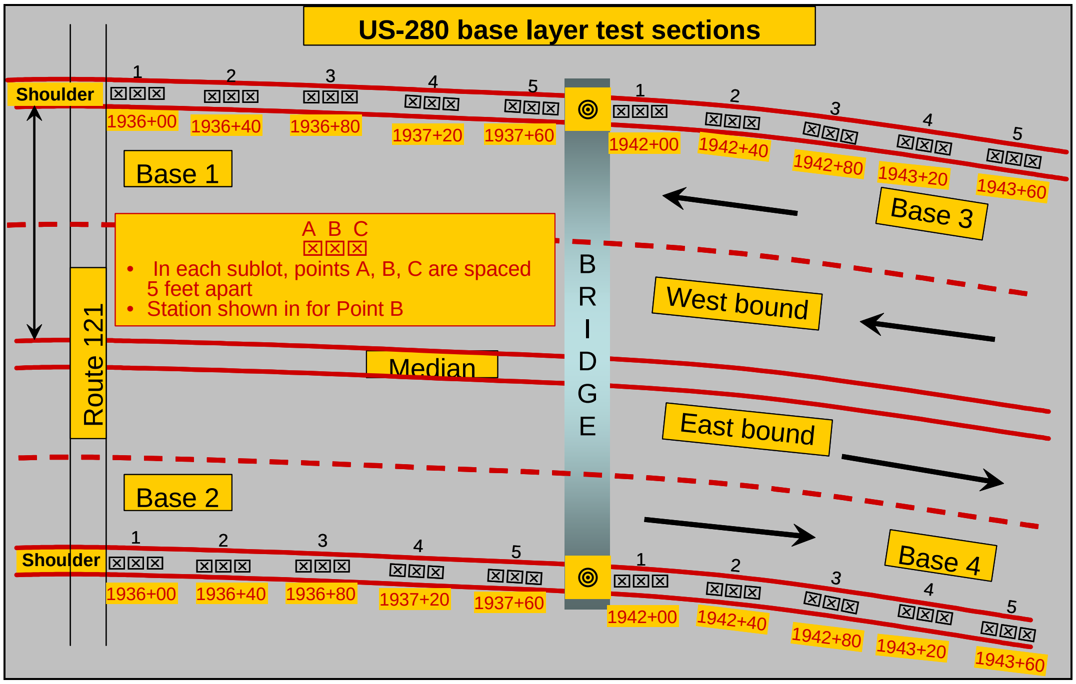


Figure B.9. Crushed Aggregate Base Sections Tested Along US-280, North of Opelika, Alabama

Figure B.10. Crushed Aggregate Base Placed Along US-280 and Used in Part A of the Field Evaluation (refer to Figure B.9); US-280 Viewing East

Figure B.11. Placing the HMA Base Mixture Within Section 3 on Top of the Permeable Asphalt Base Layer Along US-280; North of Opelika, Alabama (refer to Figure B.12)

Figure B.13 shows the segregation along the face of the core taken in one of these localized areas. Other cores disintegrated during the coring process—confirming the segregation. GPR tests were made both longitudinally down the roadway (parallel to the centerline) and diagonally across longitudinal joints. The transverse measurements were made to evaluate joint density and mixture condition along those joint.

Supplemental Project Testing

Additional HMA layer tests along US-280 were completed in December 2004, during the same time period of the IC demonstration workshops at NCAT. This segment of the HMA layer tested was located at the same stations as the crushed stone base layer initially tested. HMA layer tests were conducted on December 15 and 16, 2004, at this same location.

Three HMA test sections were laid out as shown in Figure B.14. Sections 1 and 2 were paved 1 day prior to testing. Section 3 was paved on the day of testing, and the tests were performed immediately after paving. Some tests were also performed on Section 3 one day later, to assess how the test results would change with time after paving. The sections were again divided into a 5x3 grid, and in addition, sections 1 and 2 included points on the longitudinal joint between the two lanes. Figure B.15 shows the HMA that was tested and Table B.6 lists the nondestructive tests performed at these three sections. As with the previous projects, bulk samples were collected for laboratory testing and cores were recovered for determining lift thickness, specific gravity measurements, seismic testing in the laboratory, and calibration purposes.

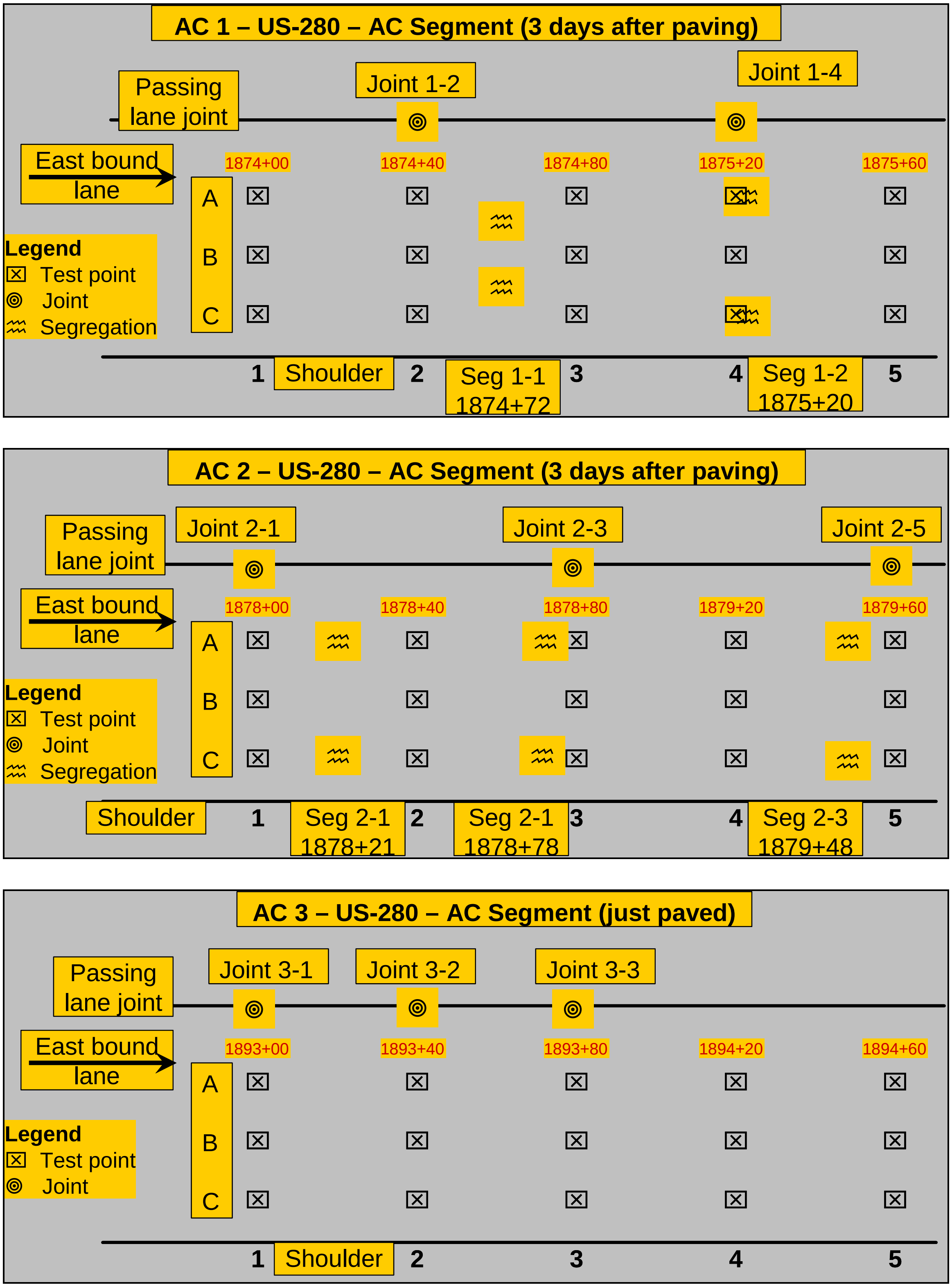


Figure B.12. HMA Base Mixture Sections Along US-280; North of Opelika, Alabama

(a) Core Taken in area without segregation. *(b) Core taken in segregated area.*

Figure B.13. Face of Mixture Where a Core Was Taken from US-280; North of Opelika, Alabama

Intelligent Compaction Demonstration

A separate section of the HMA layer was tested on the US-280 project where the IC equipment for asphalt was demonstrated on December 16, 2004. The tests were performed on the day of paving and in a location where the BOMAG Asphalt Manger had been used for the compacting the HMA layer. Bulk samples were collected for laboratory testing, and cores were recovered for determining the lift thickness, specific gravity determinations, and seismic modulus measurements in the laboratory for calibration purposes.

Test points were laid out, as shown in Figure B.16, and density tests were performed during compaction using the BOMAG Asphalt Manager. The test section was divided into an 11x2 grid, as shown in the Figure B.16. A Troxler nuclear density gauge and the PQI non-nuclear density gauge were the two NDT devices used to measure density. These NDT data were used to prepare density growth curves and compare the increase in density with an increase in HMA stiffness as measured by the Asphalt Manager. It is expected that the data can be used to correlate the output from the IC device to the measured density on the field.

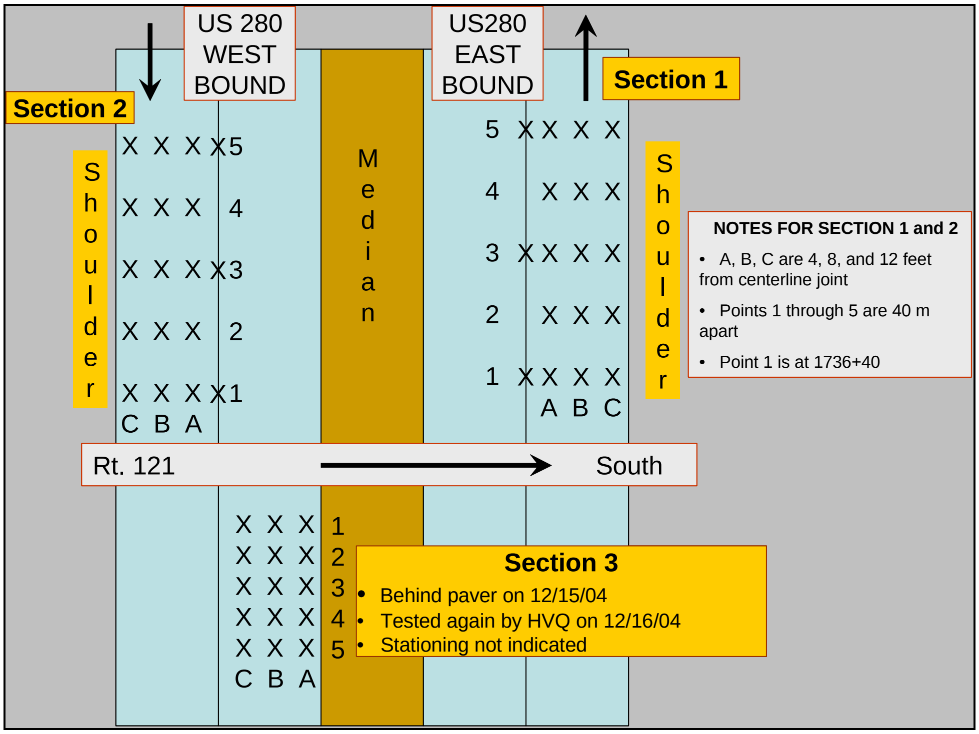


Figure B.14. Section Layout for HMA Base Mixture Testing Along the US-280 Expansion Project; North of Opelika, Alabama

Figure B.15. Eastbound Lanes of US-280 HMA Base Mixture Testing (refer to Figure B.14)

Table B.6. Nondestructive Technologies Used for the HMA Testing on US-280 Without Compaction Using the IC Roller

NDT Technology	Subgrade	Aggregate Base	HMA Base	
			Sections 1, 2, 3	Section 3 After Paving
FWD	—	—	✓	—
LWD 1 (Loadmann) – not available	—	—	—	—
LWD 2 (Dynatest) – not available	—	—	—	—
LWD 3 (Carl Bro)*	—	—	—	—
GeoGauge (stiffness)*	—	—	—	—
DCP	—		—	—
Seismic PSPA for HMA (modulus)*	—	—	✓	✓
GPR (thickness, HMA voids; soil density)**	—	—	✓	✓
Non-nuclear HMA density 1 (PQI)*	—	—	✓	✓
Non-nuclear HMA density 2 (Troxler)*	—	—	✓	—
Other Traditional Tests				
Nuclear gauge density measurements	—	—	✓	—
Core for thickness, bulk specific gravity & air voids	—	—	✓	
Bulk material for laboratory modulus tests	—	—	✓	
* - Clustered tests performed at each test point – refer to figure B.1. ** - Triplicate runs used within each lot or section.				

B.1.6 I-85, Exit 51 Ramp Reconstruction; Auburn, Alabama

The US-29 entrance and exit ramps along I-85 in Auburn, Alabama, were being reconstructed as part of the I-85 rehabilitation project. The contractor for this project was Scott Bridge Company. The northbound exit ramp along I-85 was used in the IC demonstration workshop hosted by NCAT in December 2004 (refer to section B.1.2). Most manufacturers of automated compaction equipment participated in this workshop and symposium. This same section was also included in NCHRP Project 10-65. Specifically, the 600-foot length of the prepared subgrade as part of the expansion of Exit 51 ramp on I-85 northbound lanes was selected for this testing. The project location is shown in Figure B.17.

Testing of this low plasticity embankment soil location was conducted on December 14 and 15, 2004. NDT was completed in this area, both prior to and after compaction with the IC rollers. On December 14, 2004, the test section was laid out and NDT tests were performed. On December15, 2004, several roller passes were made by the AMMANN intelligent roller for soils in an operational mode that resulted in uniform compaction of the entire area as perceived by this particular IC model (refer to Figure B.18). Tests were repeated at the same locations using the same devices to assess the change in material properties as a result of the additional roller passes. Bulk samples of the soil were collected for laboratory testing. Nuclear gauge density readings were also made on the embankment soil both before and after the IC rolling.

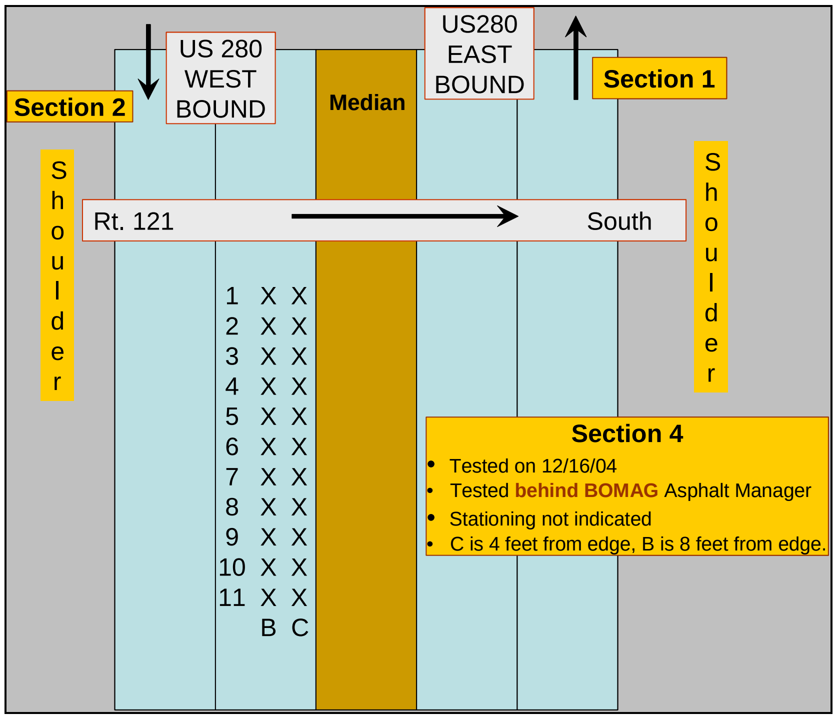


Figure B.16. Section Layout for US-280 HMA Base Mixture Testing with BOMAG's Asphalt Manager IC Roller

The soil placed in the embankment area was relatively wet (high moisture content) and variable at the time of testing. More importantly, the depth or thickness of the embankment varied across this area for widening the exit ramp area. The number of roller passes or compaction effort being used was the same for the entire area within a specific section. Two test sections, each with test points located on a 5x4 grid pattern, were used for this project. A total of 40 test points were used in the project and were located in areas with different lift thicknesses. Figure B.17 shows the project and section layout for this area. Table B.7 lists the nondestructive technologies that were used on this project before and after IC rolling.

B.1.7 Texas SH-130 Construction; Georgetown, Texas

State Highway (SH) 130 is a project undertaken by the Texas DOT, and is one of the largest projects of this magnitude in recent times. SH 130 is planned to serve as a tollway that runs nearly parallel to and east of Interstate 35 to ease traffic congestion issues in the Metropolitan Austin area, and is expected to be completed by December 2007. The project extends from the north of Georgetown southward to the southeast of Austin, through Williamson and Travis Counties. The approximate location of the NCHRP Project 10-65 sections is shown in Figure B.19.

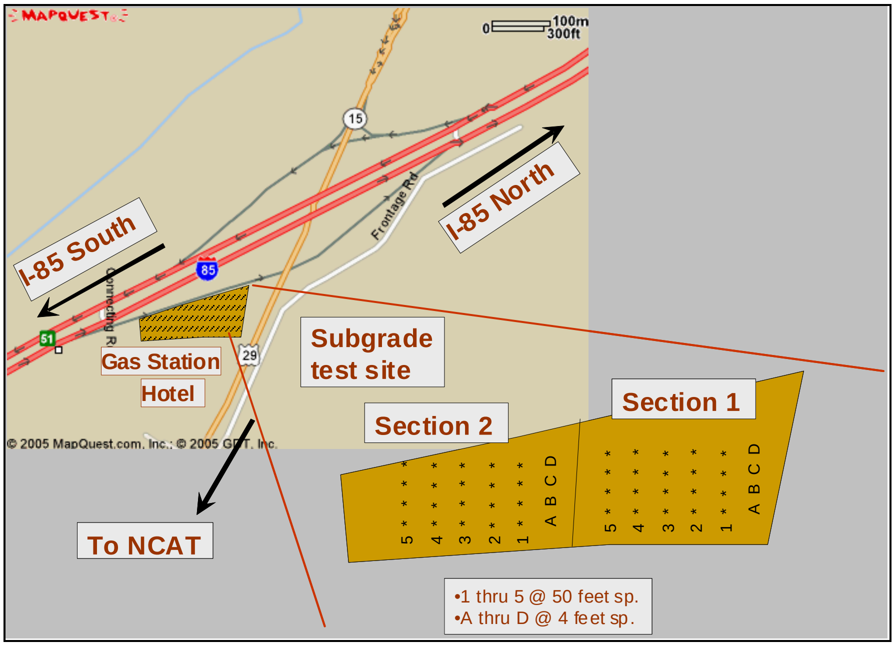


Figure B.17. Embankment Test Locations and Section Layout for Exit 51 Ramp of I-85 North; Near Auburn, Alabama (Map courtesy Mapquest™)

Figure B.18. Intelligent Compaction Roller of the Embankment Soil at Exit 51 Ramp – I-85 Improvements (refer to Figure B.17)

Table B.7. Nondestructive Technologies Used for Embankment Testing on the I-85 Exit 51 Ramp in Auburn, Alabama

NDT Technology	Low Plasticity Soil Embankment		Aggregate Base	HMA Base
	Before IC	After IC		
FWD	—	—	—	—
LWD 1 (Loadmann) – not available	—	—	—	—
LWD 2 (Dynatest) – not available	—	—	—	—
LWD 3 (Carl Bro)*	—	✓	—	—
GeoGauge (stiffness)*	✓	✓	—	—
DCP	✓	✓	—	—
Seismic DSPA for soils (modulus)*	✓	✓	—	—
GPR (thickness, AC voids; soil density)**	✓	✓	—	—
Non-nuclear HMA density 1 (PQI)	—	—	—	—
Non-nuclear HMA density 2 (Troxler)	—	—	—	—
Field Soil Moisture Tester (Preliminary evaluation)	—	—	—	—
Electrical Density Gauge; Density & Moisture Content*	✓	✓	—	—
Intelligent compaction-Caterpillar	—	✓	—	—
Other Traditional Tests				
Nuclear gauge density measurements	✓	✓	—	—
Moisture-density relationship tests	✓		—	—
Bulk material for laboratory modulus tests	✓		—	—

* - Clustered tests conducted at each test point, refer to figure B.1.
** - Triplicate runs within each section.

LoneStar Infrastructure is the prime contractor on this project, and project management is provided by HDR, Inc. Aviles Engineering serves as a subcontractor to HDR to assist in managing the construction of this project. Dr. Weng On Tam of Aviles Engineering was the primary contact for NCHRP Project 10-65. Dr. Tam also coordinated with the Texas DOT to provide on-site escort for NCHRP Project 10-65 personnel throughout the testing phase.

The project was under various stages of construction because of recent rainfall in the central Texas area at the time of testing. The testing was limited to the embankment and HMA base layer, and conducted on April 12 through 14, 2005. The contractor provided a fairly large area of an improved granular embankment material that had been compacted and accepted by the owner. HMA layer tests were conducted on the same day of paving along a segment of I-35. The NDT technologies used for testing each layer on this project are shown in Table B.8.

Bulk samples of the embankment and HMA base mixture were collected for laboratory testing. Densities were collected on the embankment and HMA layer with a nuclear density gauge. HMA cores were removed at specific test points to measure core thicknesses, bulk specific gravity, and air voids.

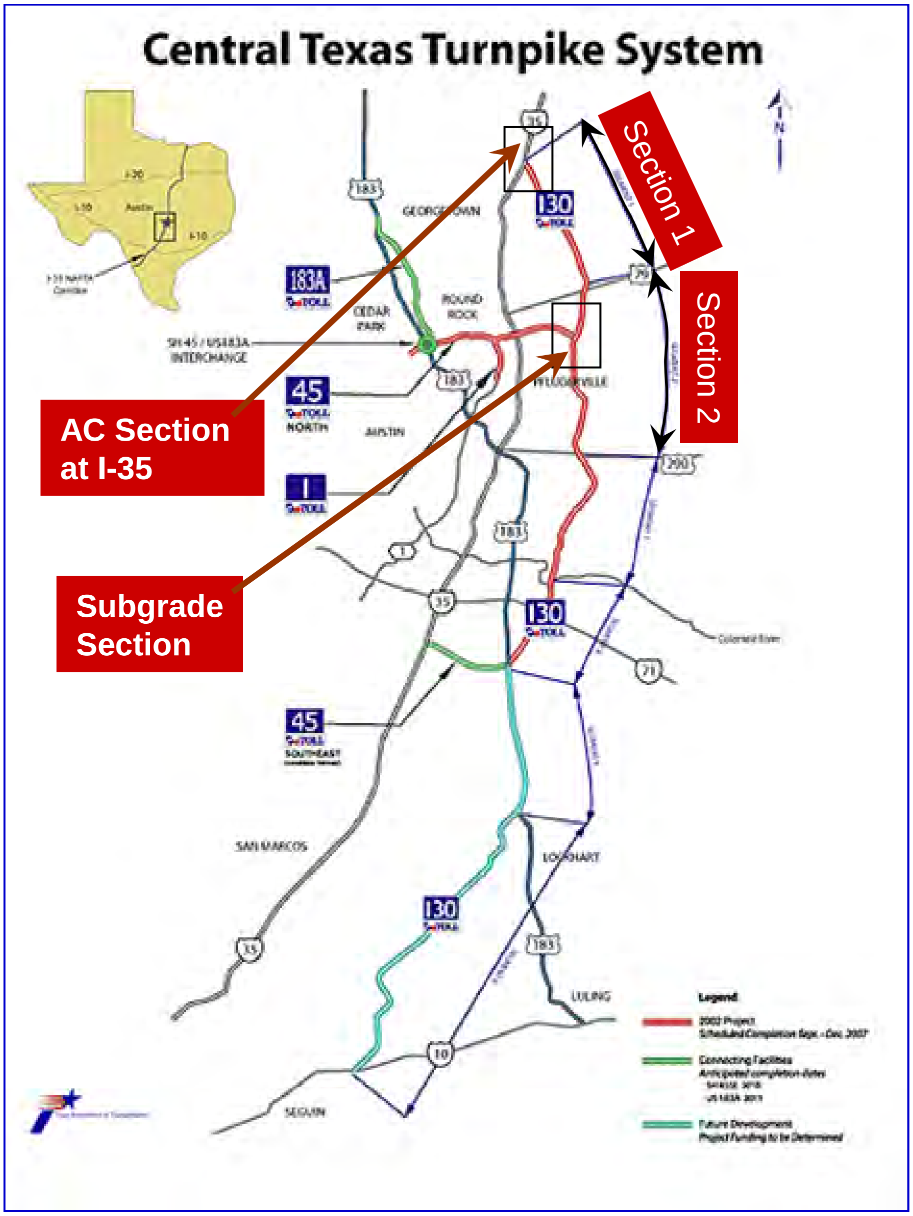


Figure B.19. State Highway 130 Construction Sections and Test Locations for the Improved Granular Embankment and HMA Base Mixture (Courtesy LoneStar Infrastructure™)

Table B.8. Nondestructive Technologies Used for the Texas SH-130 Project, Near Georgetown, Texas

NDT Technology	Granular Embankment	Aggregate Base	HMA Base
FWD	—	—	—
LWD 1 (Loadmann)*	—	—	—
LWD 2 (Dynatest)*	—	—	—
LWD 3 (Carl Bro)*	✓	—	—
DCP	✓	—	—
GeoGauge (stiffness)*	✓	—	—
Seismic – PSPA for HMA, DSPA for soils (modulus)*	✓	—	✓
GPR (thickness, AC voids; soil density)**	✓	—	✓
Non-nuclear HMA density 1 (PQI)*	—	—	✓
Non-nuclear HMA density 2 (Troxler)*	—	—	✓
Electrical Density Gauge; Density & Moisture Content*	✓	—	—
Intelligent Compaction Device-Caterpillar Roller	—	—	—
Other Traditional Tests			
HMA mixture design test data	—	—	✓
HMA cores for densities & other volumetric properties	—	—	✓
Nuclear density tests; density & moisture content	✓	—	—
Moisture-density relationship tests	✓	—	—
Bulk material for laboratory modulus tests	✓	—	✓
* - Clustered tests performed at each test point – refer to figure B.1. ** - Triplicate runs used within each lot or section.			

Improved Embankment Layer: The improved granular embankment material that was tested consisted of 30-inch fill material on top of the existing subgrade. Figure B.20 shows the section layout for the embankment testing, while Figure B.21 shows the condition of that material prior to testing. As noted on the figure, each embankment section was divided into four sublots, about 40 meters apart. Each sublot consisted of three points, making a total of 36 test points for the embankment.

HMA Layer: The contractor provided access to about 1,500 feet of HMA section that was paved during the ongoing construction and just prior to testing. Three HMA sections were marked for testing (AC1, AC2, and AC3), as shown in Figure B.22. AC1 and AC2 were tested about 16 hours after paving, while section AC 3 was tested immediately after compaction. Grid patterns similar to previous tests were maintained for the current tests. In addition, test points were laid out along the transverse and longitudinal construction joints. The HMA base mixture had exhibited checking during the rolling process prior to any NDT tests being completed under NCHRP Project 10-65. Changes were made to the HMA mixture which eliminated the checking. Those changes made were unknown during the day of testing.

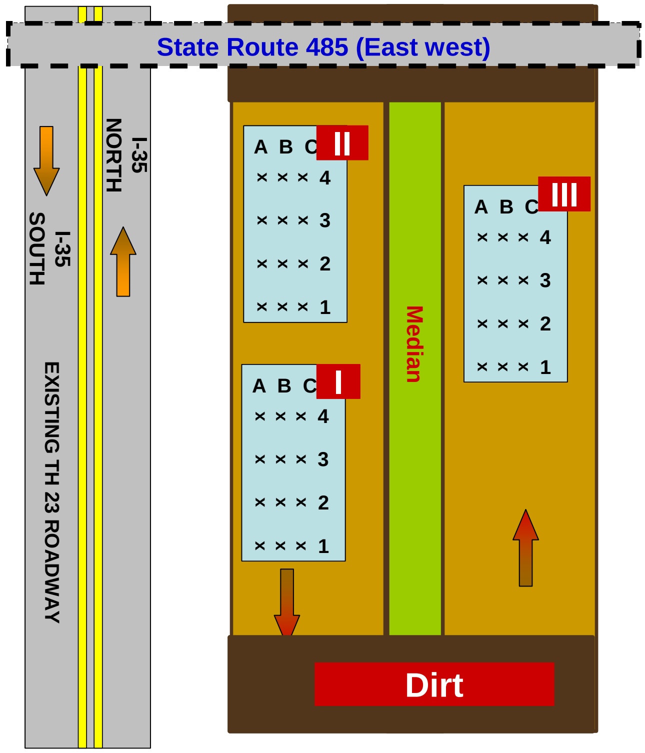


Figure B.20. Improved Granular Embankment Sections Tested Along SH-130 Near Georgetown, Texas

Figure B.21. Surface Condition of the Thick Improved Granular Embankment Tested Along SH-130, Near Georgetown, Texas

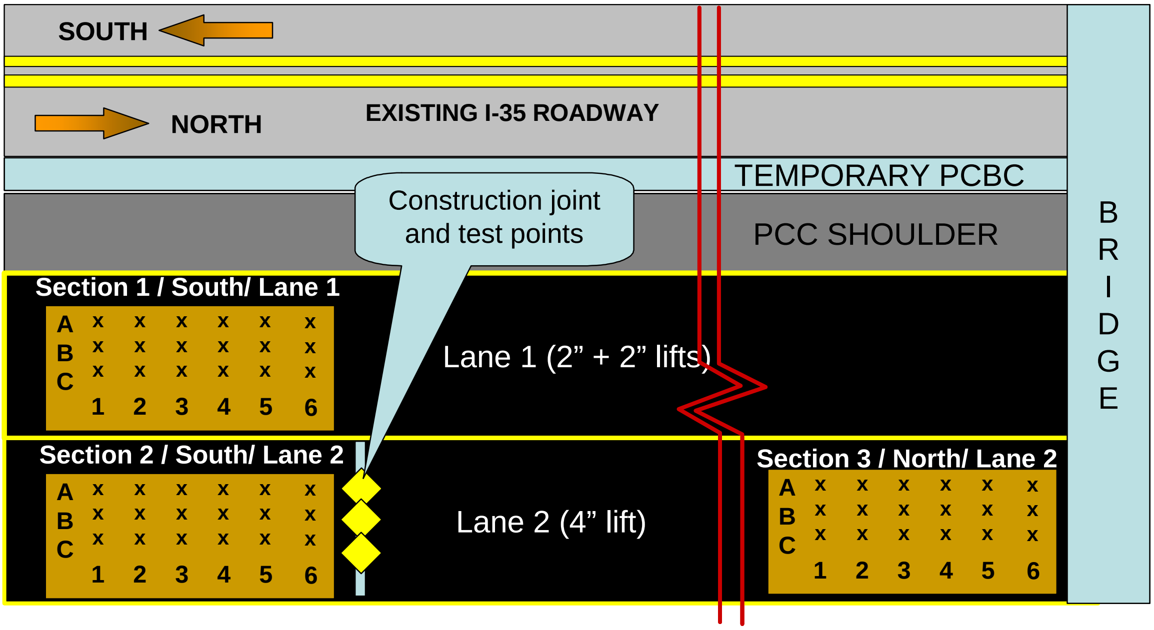


Figure B.22. HMA Section Layout for Testing Along SH-130 Near Georgetown, Texas (NOT TO SCALE)

B.1.8 Texas SH-21 Widening Project; Caldwell, Texas

SH-21 was widened in 2005 to a four-lane divided highway just east of Caldwell, Texas. The subgrade or existing soil along this project consists of high plasticity clay. The Texas Transportation Institute (TTI) used portions of this widening project for a research study related to intelligent compaction of unbound materials. Mr. Tom Scullion was TTI's Principal Investigator for the project.

Two areas of the part being used by TTI were included as part of NCHRP Project 10-65 (refer to Figure B.23). Testing of the high plasticity clay soil was conducted on August 18 and 19, 2005, after compaction and testing with the instrumented roller. Figure B.24 shows the roller equipped with testing equipment and used to compact the subgrade soil, as a part of the TTI research project.

Table B.9 lists the nondestructive technologies that were used along this project. Test points were located within the first area on a 5x3 grid, while the second area included equally-spaced test points along a longitudinal line. Figure B.23 shows the test plan layout for this area, while Figure B.25 shows the general area and condition of the subgrade that was included as a part of NCHRP Project 10-65. The high plasticity clay was relatively dry near the surface and shrinkage cracks where observed during testing in area 2, without any IC rolling. These shrinkage cracks were not present in the area after IC rolling.

Bulk samples of the subgrade soil were collected for laboratory testing. Densities and water content data were collected on the subgrade with a nuclear density gauge.

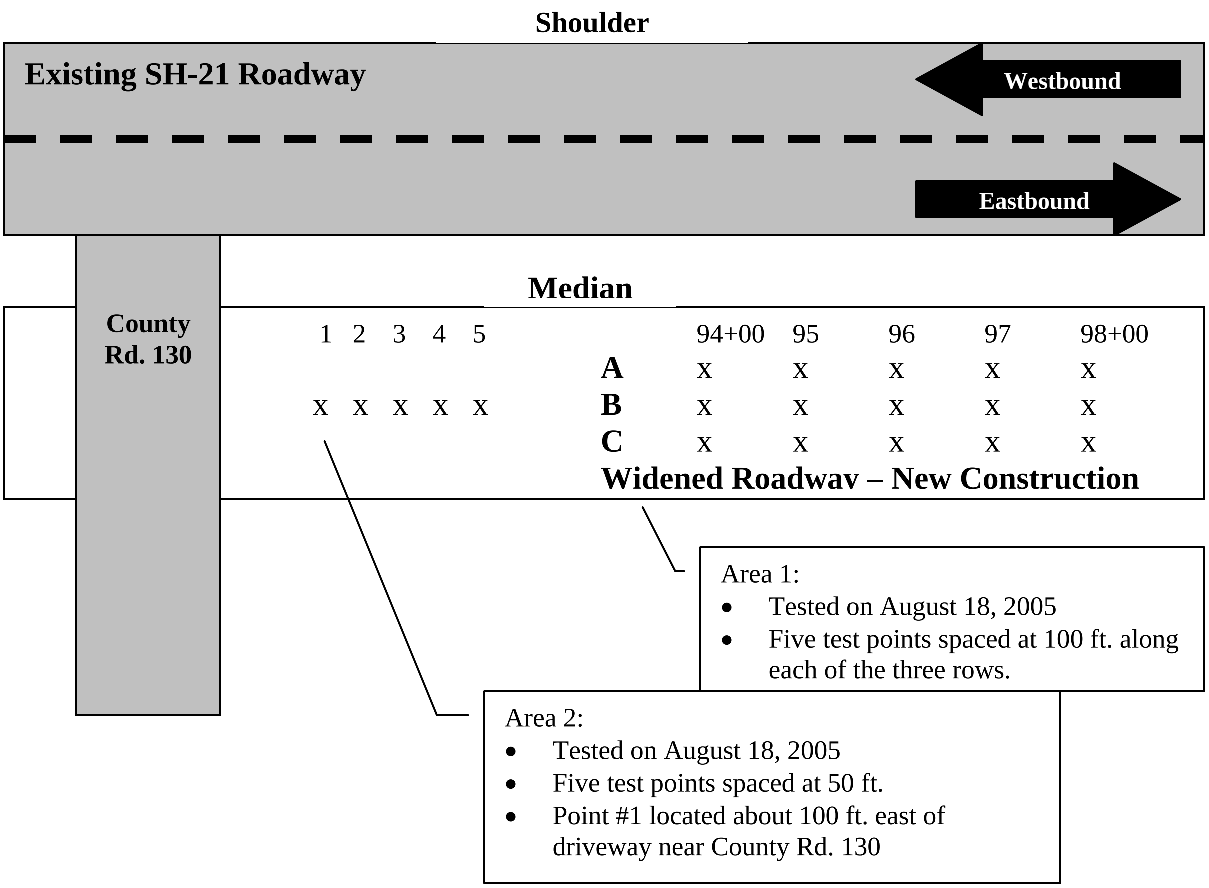


Figure B.23. Layout for the High Plasticity Clay Soil Tested Along the Texas SH-21 Widening Project, East of Caldwell, Texas (Not to Scale)

B.2 – Projects Included in Part B

As noted above and documented in the research report, Part B testing was designed based on results from Part A. The NDT devices that were selected for Part B of the field evaluation were those that were capable of detecting changes in the material or workmanship, while providing real-time data to assist project construction and/or inspection personnel on the job. The PSPA and GeoGauge were recommended for measuring the modulus of HMA and unbound layers, respectively. However, the DSPA and DCP were also used on several of the Part B projects to test unbound layers. The DSPA was used because that device had a higher success rate than the GeoGauge, and the DCP was used to assist in determining the target resilient modulus of the unbound material. The non-nuclear density gauges were also used to measure the density of the HMA layers.

Figure B.24. Roller Used to Compact and Test the Soil Prior to the Use of other NDT Technologies along the Texas SH-21 Widening Project; East of Caldwell, Texas

Figure B.25. Overview of the Area and Condition of the Subgrade that was Tested along the Texas SH-21 Widening Project, East of Caldwell, Texas

Table B.9. Nondestructive Technologies Used for the Texas SH-21 Widening Project, East of Caldwell, Texas

NDT Technology	High Plasticity Clay Subgrade	Aggregate Base	HMA Mix
FWD	—	—	—
LWD 1 (Loadmann)*	—	—	—
LWD 2 (Dynatest)*	—	—	—
LWD 3 (Carl Bro)*	✓	—	—
DCP; Two devices used	✓	—	—
GeoGauge (stiffness)*	✓	—	—
Seismic – DSPA for soils (modulus)*	✓	—	—
GPR (thickness, AC voids; soil density)**	—	—	—
Non-nuclear HMA density 1 (PQI)*	—	—	—
Non-nuclear HMA density 2 (Troxler)*	—	—	—
Electrical Density Gauge; Density & Moisture Content*	—	—	—
Intelligent Compaction Device	✓	—	—
Other Traditional Tests			
HMA mixture design test data	—	—	✓
HMA cores for densities & other volumetric properties	—	—	✓
Nuclear density tests; density & moisture content	✓	—	—
Moisture-density relationship tests	✓	—	—
Bulk material for laboratory modulus tests	✓	—	✓
* - Clustered tests performed at each test point – refer to figure B.1. ** - Triplicate runs used within each lot or section.			

The layout of test points for each lot within the Part B field evaluation was developed for each project. A random set of test points or a test grid similar to that illustrated in Figure B.1 was followed for most projects. HMA layers were tested at two different times: right after paving and 24 hours after paving to monitor the increases in seismic modulus. Samples were collected of the HMA and unbound materials for laboratory testing, similar to Part A.

Six sites were included in Part B testing, with multiple visits and materials covered for several test sites. Table B.10 lists the projects included in the Part B field evaluation, each of which is described in the following sections. The following provides a tabulated summary of the special features and positive and negative points of each project included in Part B.

Sponsor Agency	Missouri DOT
Project Location	St. Clair & Union, Missouri
Project Identification	Two-lane widening project – shoulder reconstruction and HMA Overlay across entire width of roadway. The HMA base was 4 inches in thickness, while the HMA overlay was 1.75 inches in thickness.
Materials Tested	HMA Base and HMA Wearing Surface
Special Features	Tender HMA base mixture placed along the shoulder.
Issues	Rain occurred during the shoulder placement or construction. The wet weather did not affect placement of the HMA mixture.
Positive Aspects	1. The contractor rolled the HMA mixture placed along the shoulder. The confined edge of the HMA was being rolled using the cold-side pitch method. It was observed that the HMA mixture was being pushed away from the cold joint. The PaveTracker was used to measure the density along the confined joint. The densities were low. The contractor was encouraged to change the rolling pattern – roll from the hot side of the joint. Densities were measured with both the PaveTracker and nuclear density gauge along the confined joint. The densities increased by about 5 to 8 pcf between the two rolling patterns. The contractor changed the rolling pattern to increase the joint density. 2. Another positive aspect is that the PSPA did identify the soft HMA mixture after placement through problems with obtaining a smooth waveform from the PSPA. It was originally believed that the PSPA had been damaged during transport; however, the PSPA was identifying the mixture to be tender. 3. The initial wearing surface/overlay was found to have low air voids and was rejected by the DOT. The PSPA and PaveTracker did identify these differences during construction and placement. The test results for the new mixture placed were found to be statistically different.
Negative Aspects	1. Rains resulted in delays and scheduling conflicts. The rain caused the contractor to move off of the job and return weeks later. Thus, the test equipment was not left with the contractor nor agency personnel. However, both the contractor and agency personnel did use the equipment on site during initial testing when the shoulder was being placed with positive results and comments. 2. The HMA mixture being placed along the shoulders was a soft mixture. In fact, the mixture was so soft that indentations could be observed from light loads on the mix after it had cooled down to 160F. The PSPA was used to test the HMA mixture being placed along the shoulder. This point could also be a positive aspect of the project. 3. The unbound aggregate base course was planned to be tested along the shoulder areas after the surface material had been removed, the base material scarified and compacted or removed and replaced. However, the unbound aggregate base along the shoulder area was found to be in excellent structural condition and was able to support the construction equipment. Thus, the unbound aggregate base layer was left in place without any additional compaction and work. Use of the GeoGauge, DSPA, and DCP were excluded from the field testing plan.

Sponsor Agency	Missouri DOT
Project Location	NCAT Test Track
Project Identification	New construction of two structural sections placed at the NCAT test track facility. Both test sections were instrumented by NCAT.
Materials Tested	Crushed limestone base layer and an HMA binder layer
Special Features	None. However, the pavement structure did include a high binder content base mix or crack resistant layer. This layer was not tested under the NCHRP Project 10-65.
Issues	None. However, the crushed limestone layer was compacted at a water content that was below the optimum water content. This required many more passes or coverages of the roller than expected or planned.
Positive Aspects	1. Density and modulus growth curves were measured using both the GeoGauge and DSPA devices. Two DCP's were used to measure the in place strength of the base material. 2. Density growth curves were also measured using the PaveTracker for the HMA binder mixture.
Negative Aspects	None.

Sponsor Agency	Michigan DOT
Project Location	Saginaw, Michigan; I-75
Project Identification	I-75 rehabilitation included PCC rubblization in the northbound lanes and milling and overlaying the existing HMA surface in the southbound direction with 7 inches of HMA, consisting of a 3 inch HMA base, 2 inch HMA Binder layer, 2 inch Wearing surface. The portion included in NCHRP Project 10-65 was confined to the southbound lanes.
Materials Tested	HMA 4-C base and HMA 3-C binder layers. Included both Superpave designed mixtures along the main lanes and Marshall designed mix placed along the shoulders.
Special Features	None.
Issues	Rain occurred during the testing period that delayed the paving operation, but it is believed that the rain had no impact on the HMA mixtures being placed.
Positive Aspects	Density growth curves were developed for the HMA base and binder layers.
Negative Aspects	During the testing operation, the DOT rejected about 2 miles of HMA that had been previously placed. The contractor ceased paving operations until the cause of the rejected material could be determined. The equipment was not left with the agency and contractor personnel because of this problem and dispute of test results in the DOT's day-to-day acceptance plan. In addition, the wearing surface was not tested as part of NCHRP Project 10-65.

Sponsor Agency	North Dakota DOT
Project Location	Williston, North Dakota
Project Identification	Realignment and new construction of US-2 between Minot and Williston.
Materials Tested	HMA base layer (PG58-28); Crushed Gravel – Class 5 Base; Fine-grained embankment (soil-aggregate mix)
Special Features	The crushed aggregate base layer was tested in two conditions; the first area had been placed over a year ago, while the second area had been placed a couple of weeks prior to arrival at the project site. The surface of the crushed stone base that had been placed the previous construction season received a prime coat to protect it from construction traffic. The test equipment was left with the DOT and contractor personnel for use in testing other areas of the project as the paving materials were placed.
Issues	Rain and tornados occurred during the week of testing. The unbound materials were tested prior to the rainfall and the HMA layer was tested prior to and after the storm.
Positive Aspects	Both the DOT and contractor personnel used all gauges during and after the testing under NCHRP Project 10-65.
Negative Aspects	The HMA base mixture checked and tore during one day's production. The checking and mat tears occurred under the finish roller – after the density had been obtained by the contractor using the breakdown and intermediate rollers. The PaveTracker and PSPA were used to test the area with checking. The checking and tears were found to be severe in localized areas. This is also considered to be a positive aspect of this project, in terms of using the NDT devices.

Sponsor Agency	Ohio DOT
Project Location	Freemont, Ohio
Project Identification	Realignment and widening of SR-53, near Freemont, Ohio; between Toledo and Columbus, Ohio.
Materials Tested	HMA 19 mm base mixture and crushed stone base layer (304 base material).
Special Features	None.
Issues	Rain and wet weather occurred during the week of testing. The contractor also had problems with the plant which delayed another project in the area. Thus, the contractor did not move the paving equipment and rollers back on the project until the testing under NCHRP Project 10-65 had been completed. The test equipment, however, was left with the DOT personnel for use and continued testing for the following weeks. The DOT retained the test equipment for more than two weeks.
Positive Aspects	1. Water from the recent rains had accumulated in areas with insufficient drainage to remove the rainfall from the pavement area. The DCP, GeoGauge and DSPA measured low modulus values in the areas where water had been standing and allowed to penetrate the base layer. 2. The PSPA and PaveTracker were used to test the HMA base mixture in all areas where the DOT had taken cores for acceptance testing.
Negative Aspects	No HMA paving and placement of the unbound aggregate base material was completed during the initial week of testing. Thus, density and modulus growth curves could be obtained from this project for the HMA base mixture and aggregate base layer.

Sponsor Agency	Alabama DOT
Project Location	NCAT Test Track
Project Identification	Mill and HMA overlay of three test sections along the test track. Test Sections E-5, E-6, and E-7 were used in the NCHRP Project 10-65 field evaluation.
Materials Tested	HMA wearing surface with 45 percent RAP and a PG76-22 that included Sasobit in Section E-7. The asphalt used in the other two sections included a PG 67-22 without any modification (Section E-5), and a PG76-22 with SBS (Section E-6).
Special Features	High amount of RAP with and without asphalt modification using Sasobit and SBS in the HMA overlay.
Issues	None.
Positive Aspects	None, with the exception of comparing the density and seismic modulus for mixtures with high amounts of RAP and varying asphalt grades and different asphalt modifiers, as compared to mixtures without RAP.
Negative Aspects	None; however, the HMA overlay was placed a week prior to the testing under NCHRP Project 10-65. Thus, density growth curves were not obtained.

Sponsor Agency	Florida DOT
Project Location	NCAT Test Track
Project Identification	New construction; two structural sections that were constructed; one with a neat asphalt mix (Section N-1) and the other with a polymer modified asphalt mix (Section N-2). Both of these test sections were instrumented by NCAT.
Materials Tested	Limerock base material; a high binder content HMA base mix considered a crack resistant layer; HMA binder layer with neat asphalt; an HMA binder layer with modified asphalt.
Special Features	Pavement cross section included a 3-inch high binder base layer to resist fatigue crack initiation at the bottom of the pavement. This layer or mixture was tested. Two other HMA mixtures were tested – Florida's standard neat asphalt type mixture and another with a polymer modified asphalt.
Issues	1. The temperature of the HMA neat asphalt mix was low at the time of placement. The low temperature made getting density difficult and caused the mixture to check and tear under the rollers. 2. The HMA mixture with the neat asphalt checked during compaction in localized areas. The checking was considered severe in a localized area. The PMA and high binder content base layer did not check or tear under the roller or at least the mat checking and tears were not observed during mixture placement and compaction.
Positive Aspects	A comparison of a neat HMA mix to that of a PMA mix. The HMA neat mix did check while the PMA mix did not check. Two DCPs were used to test the limerock base layer.
Negative Aspects	None. However, the contractor had a lot difficulty in getting the required density for both the HMA neat asphalt mix and the PMA mix. A rubber tired roller was used to continue the compaction operation for many hours. The density did finally reach the required value. PaveTrack and PSPA tests were completed on the mix with the low densities, as well as with the required or specific density.

Sponsor Agency	Oklahoma DOT
Project Location	NCAT Test Track
Project Identification	New construction; two structural test sections that were built side-by-site. It was originally designed that these two sections would be full-depth HMA pavements placed over a high plasticity subgrade soil imported from Oklahoma. Both of these sections were instrumented by NCAT. Sections N-8 and N-9 included neat asphalt within the lower layers, while Section N-9 included SPS in the upper layers.
Materials Tested	High plasticity clay soil was in a relatively dry condition (with extensive and wide shrinkage cracks), and high plasticity clay soil compacted to the optimum dry density (without the shrinkage cracks that could be observed at the surface); HMA binder layer with a PG67-22 and a dense graded granite aggregate.
Special Features	Wide shrinkage cracks existed in the high plasticity clay soil at the time of initial testing for NCHRP Project 10-65.
Issues	None, other than the wide shrinkage cracks. The GeoGauge was used with and without the thin sand layer.
Positive Aspects	1. The effects of wide shrinkage cracks in a high plasticity clay soil can be assessed in terms of their effect on the test results from the GeoGauge and DSPA. 2. Two DCPs were also used to test the subgrade soil in different conditions. 3. Density and modulus growth curves were measured during the original compaction of the clay soil.
Negative Aspects	The surface of the high plasticity clay soil was removed, the lower soil scarified, reworked, and re-compacted, and a 6-inch layer of local chert aggregate was placed. A misunderstanding of the cross section for these structural sections had occurred. The Oklahoma DOT wanted an intermediate layer of aggregate placed between the HMA base and high plasticity clay. Thus, the NCHRP Project 10-65 tests on the high plasticity clay were performed twice.

Sponsor Agency	South Carolina DOT
Project Location	NCAT Test Track
Project Identification	New construction of a structural section at the NCAT test facility. This section was instrumented by NCAT.
Materials Tested	Crushed granite base layer; HMA base mixture and HMA binder layer with a PG67-22 asphalt and limestone aggregate.
Special Features	None
Issues	The water content of the crushed granite base layer was about half of the optimum water moisture content. Contractor had difficulty compacting the aggregate base to the specified density. Multiple rollers were tried for compacting the crushed granite layer; including the BOMAG Asphalt Manager. The Asphalt Manager created a problem by disturbing (decompacted) the surface of that base layer.
Positive Aspects	Density and modulus growth curves were measured for the crushed granite base material using relatively dry material, as noted above.
Negative Aspects	The water content of the crushed granite base was about half of the optimum water content, and the roller that was available could not densify this material past a specific density. A heavier roller had to be brought to the test section to get the required density, but after the NCHRP Project 10-65 tests had been completed. The DSPA and GeoGauge did detect the lower density levels.

Sponsor Agency	Texas DOT
Project Location	Odessa, Texas
Project Identification	Reconstruction of I-20 main lanes, due to construction of overpass, and reconstruction of frontage roads. HMA was placed in two 2-inch lifts.
Materials Tested	HMA Coarse Matrix High Binder Content Base Layer (CMHB) under new DOT specification; the crushed stone base course material was not tested. A surface treatment had already been placed on top of the crushed stone base layer at the time of testing.
Special Features	None
Issues	None
Positive Aspects	1. Contractor and DOT were already using the PaveTrack for setting the rolling pattern and DOT was already using the PSPA for acceptance confirmation. Density growth curves were measured by both the contractor's and NCHRP Project 10-65 PaveTracker devices. Contractor was positive towards using the non-nuclear density gauges and did use the PSPA. Results from the PSPA demonstrated that the HMA mixture was meeting all minimum requirements of the mixture. 2. Multiple PSPAs were used on this project; the one being used under NCHRP 10-65 and by the Odessa district office. The Texas DOT had already used the PSPA for use as a forensic tool in evaluating the failure, prior to the contractor finishing the paving, on a 7-mile section of I-20 through Odessa. The DOT and UTEP agreed to provide that data for use on NCHRP 10-65.
Negative Aspects	1. Plant breakdown that significantly delayed paving operation during the week scheduled for the testing under NCHRP Project 10-65. 2. High winds and sand storm occurred during paving that resulted in contractor ceasing paving operations during the week selected for testing under NCHRP Project 10-65. 3. The crushed stone base layer with typical aggregate in west Texas (similar to a caliche) was planned for testing. However, crushed stone base materials had already been covered with a surface treatment prior to NCHRP 10-65 testing. Thus, the DCP, DSPA, and GeoGauge were not used on this project.

Sponsor Agency	Texas DOT
Project Location	Odessa, Texas
Project Identification	Mill and overlay main lanes along Loop 338.
Materials Tested	---
Special Features	HMA overlay was a modified asphalt mixture with rubber.
Issues	Project was cancelled, as noted below.
Positive Aspects	---
Negative Aspects	Contractor was delayed from another project and plant breakdown further delayed the paving operation. Contractor's new schedule was to place the HMA modified asphalt mix with rubber after Thanksgiving. Thus, project was cancelled relative to NCHRP Project 10-65.

Sponsor Agency	Pecos Research and Test Center
Project Location	Pecos, Texas
Project Identification	New construction of the entrance roadway to a private facility located near Pecos, Texas.
Materials Tested	Caliche base typically used for county roads in west Texas.
Special Features	Salcido Sand and Gravel Company was placing a caliche base without time restrictions. Material was used to measure the increase in material strength with successive passes of a static steel drum roller.
Issues	None.
Positive Aspects	Modulus growth curves were developed using two devices; the DCP and GeoGauge.
Negative Aspects	None.

B.2.1 US-47, Missouri

The US-47 project consisted of reconstructing the shoulder and overlaying the two-lane state route in St. Clair, Missouri (see Figure B.26). The project was south of St. Louis, just north of I-44 and south of US Highway 50E. The mainline and shoulders in both directions were being paved, and the contractor was N.B. West. This project was paved during nighttime hours (Figure B.27). Testing on this project was conducted in two phases to cover the shoulder and mainline paving operations. Two different HMA mixture designs were used, one for the shoulder and one for main line paving. Two independent set of tests were conducted for the two areas, and are referred to as preliminary and supplemental tests.

Table B.10. Listing of Project Sites and the NDT Devices Used Within the Part B Field Evaluation

Project Identification		Material Evaluated	NDT Technologies				
			Unbound Materials			HMA	
			Geogauge	DCP	DSPA	PSPA	NNDG
1	US-47, Missouri – July 9-12, Aug 16-17, 2006	HMA	NA			√	√*
2	I-75 Michigan, July 25-27, 2006	HMA	NA			√	√*
3	US-2, North Dakota Aug 23-31, 2006	Subgrade	√*	√	√	NA	
		Granular Base	√*	√	√		
		HMA	NA			√	√*
4	NCAT Test Track, Alabama Sep 25-29, Oct 9-11, 2006	Subgrade	√*	√	√	NA	
		Granular Base	√*	√	√		
		HMA	NA			√	√
5	US-53, Ohio Oct 17-20, 2006	Granular Base	√*	√	√	NA	
		HMA	NA			√	√*
6	I-20, Texas Nov 13-16, 2006	HMA	NA			√	√

NA – Not Applicable
DCP = Dynamic Cone Penetrometer, manual.
DSPA = Dirt Seismic Pavement Analyzer.
Density = Non-Nuclear density measurements with PaveTracker
* - Multiple gauges used to evaluate variability between two devices with the same NDT technology and underlying software.

a) Should Condition Before Paving

b) Should After Paving

Figure B.26. Shoulder Paved on US-47, Missouri, and Used in the Part B Evaluation

Figure B.27. Nighttime Paving Along US-47, Missouri

The original plan was to test the unbound crushed stone base along the shoulders as that material was being scarified and recompacted. After the existing surface was removed, the crushed stone base was found to be in good condition. The Missouri DOT field personnel made a decision to leave that material in place without any other work. Thus, no work was completed on the crushed stone base, other than measuring the in-place density of that material, so the NDT field evaluation was eliminated from this project.

Preliminary HMA Testing on Shoulder

The shoulder, paved between stations 45+00 and 105+13, was tested in the preliminary phase between July 9 and July 12, 2006. As noted above, the existing shoulder in this location contained an aggregate base layer that was determined to be suitable and left in place. No NDT was performed on the base layer. The paving operation followed the milling operation. The test points selected were along the centerline of the shoulder and along the longitudinal edge (confined edge) in both the northbound and southbound directions, as shown in Figure B.28. A set of tests were conducted on July 9 and July 11, 2006, during the paving operations. An additional set of readings were taken on July 12, 2006, on a section of the southbound shoulder paved on July 9 (see Figure B.29).

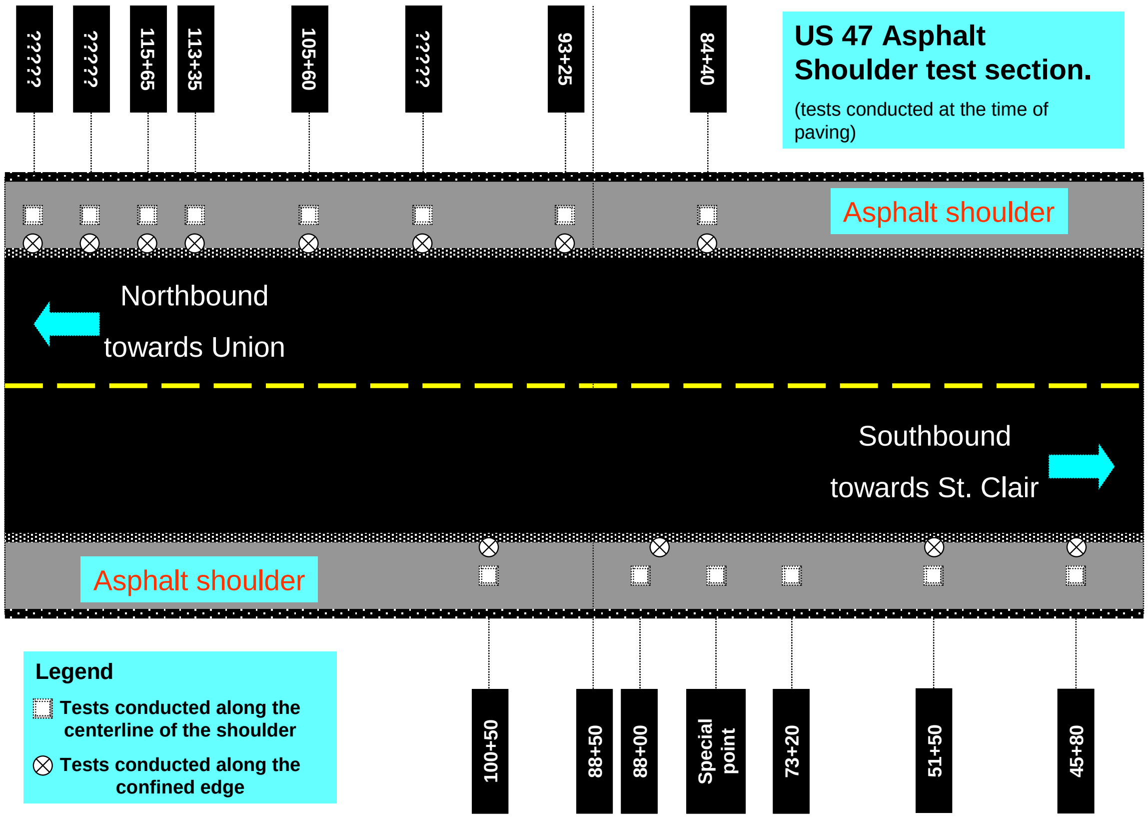


Figure B.28. Layout of Test Points on the Shoulder Paved on US-47, Missouri

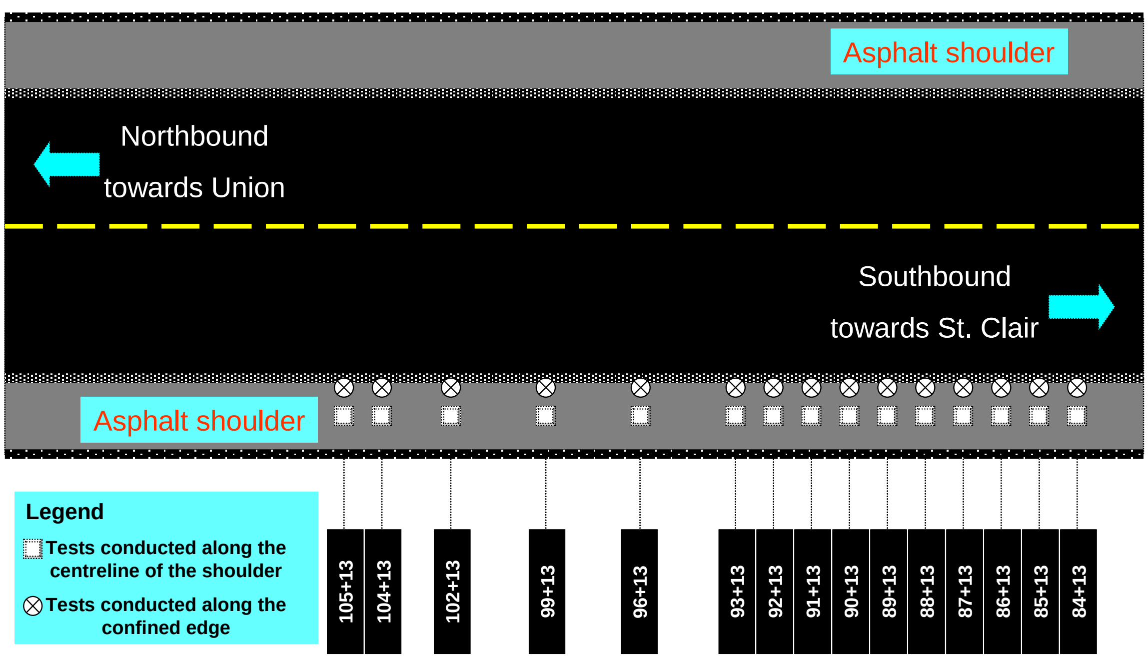


Figure B.29. Layout of Points for Tests Conducted Three Days After Paving on the Shoulder Paved in the Southbound Direction on US-47, Missouri

The PSPA and non-nuclear density gauge (Troxler model) were used for this project. Two Troxler devices were used, to determine the variability between these devices (Figure B.30). Density and modulus tests were also conducted on the HMA layer with each roller pass to develop a density growth curve. HMA cores and bulk material samples were also collected for laboratory testing. A summary of testing conducted and the data collected is shown in Table B.11. An important feature of this project was that the contractor used the non-nuclear density gauge to change the rolling pattern that was being used to compact the HMA along the longitudinal, confined joint with the traffic lane. The contractor used the non-nuclear gauge to check the density of the shoulders in real-time to optimize the rolling operation, while maximizing the density along that longitudinal joint.

Supplemental HMA Testing on Mainline and Shoulder

NDT was conducted during subsequent paving of the mainline and shoulder in the southbound direction on August 16-17, 2006. The lots selected for NCHRP Project 10-65 testing were north of the shoulder sections tested in July 2006, and spanned between stations 189+00 and 255+01. The contractor and agency discovered a problem with the HMA overlay mixture during the second day of paving and discontinued the paving operation. Thus, data were limited during the second day of paving over the shoulder sections to compare differences in NDT measurements. The section layouts for the two days of paving are shown in Figures B.31 and B.32.

Figure B.30. Multiple Non-nuclear Density Gauge and PSPA Testing on US-47, Missouri

Table B.11. Nondestructive Test Devices Used for the US-47 Project, Near St. Clair, Missouri

NDT Technology	Subgrade	Aggregate Base	HMA[††]
GeoGauge (stiffness)*[, †]	—	—	—
Seismic – PSPA for HMA, DSPA for soils (modulus) *[, #,]	—	—	✓
Non-nuclear HMA density (Troxler)*[, #, †]	—	—	✓
Other Traditional Tests			
HMA mixture design test data	—	—	✓
HMA cores for densities & other volumetric properties	—	—	✓
Nuclear density tests	—	—	✓
Moisture-density relationship tests	—	—	—
Bulk material for laboratory modulus tests	—	—	✓

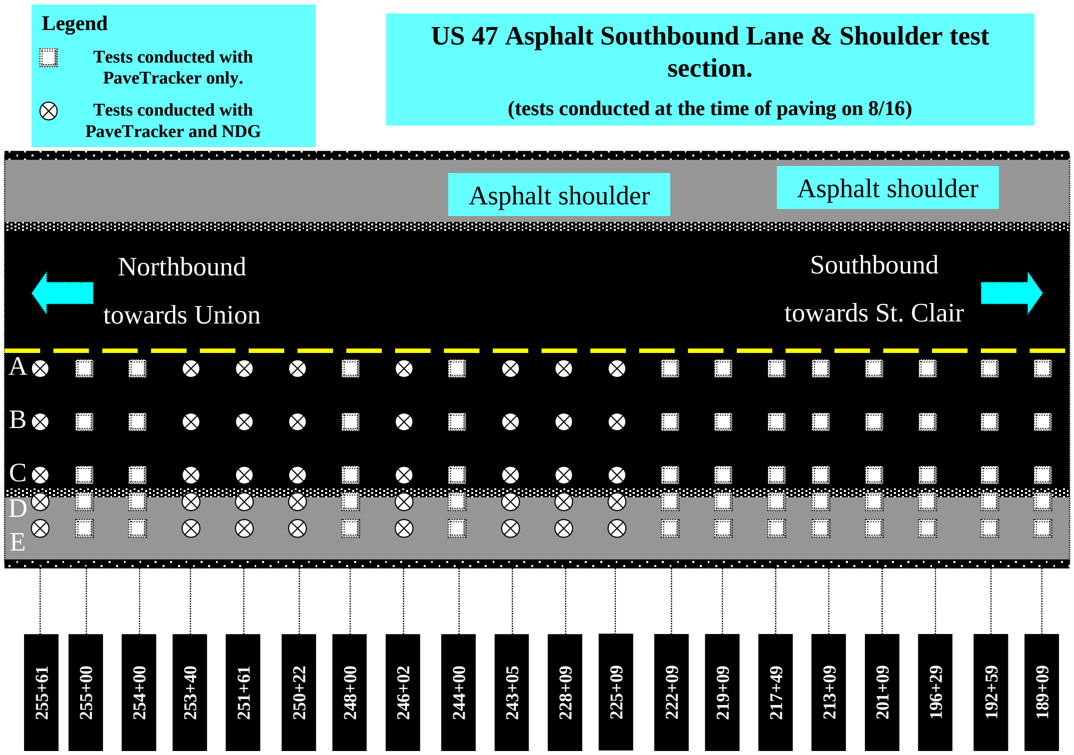
* - Clustered tests performed at each test point – refer to figure B.1.
[†] - Multiple gauges to assess variability between devices
[††] - Testing performed behind paver and 36 hours after paving
[#] - Testing included measurements to develop a density growth curve

B.2.2 I-75 Rehabilitation Project, Michigan

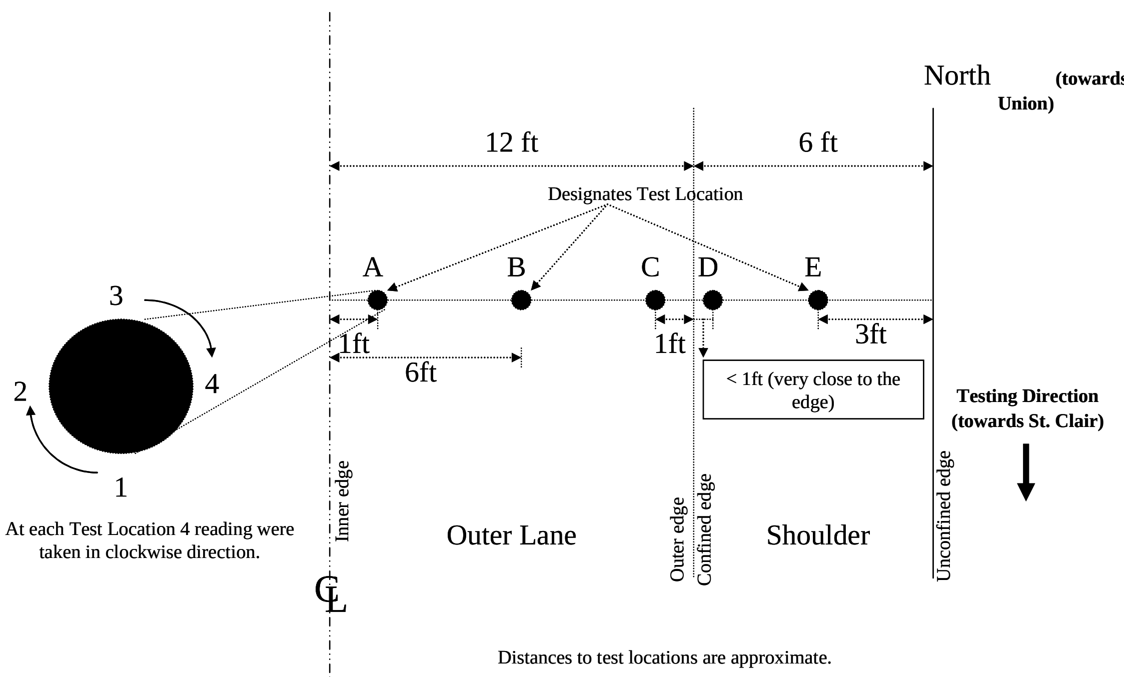
The rehabilitation of the I-75 southbound lanes just north of Saginaw, Michigan, was included in Part B. This project included milling the existing HMA surface and overlaying the traffic and passing lanes with multiple lifts of HMA. The shoulder and outer lane were tested from stations 2751+00 to 3170+00, and 3112+87 and 3219+14, respectively. All paving was performed during daytime hours, and the Michigan 3C Marshall-design was used on this project. A summary of all NDT performed is presented in Table B.12.

The shoulder and mainlines were each divided into two sections. The test point layouts for sections 1 through 4 are shown in Figures B.33 through B.36. The shoulder sections were tested on July 25 and 26, 2006. Section 1 of the shoulder testing was performed on HMA that had been paved on July 19 to 21, 2006, while Section 2 was tested immediately after paving (see Figures B.37 and B.38). Sections 3 and 4 along the traffic or outer lane were tested immediately after paving on July 25 to 27, 2006.

The pattern of the breakdown or primary vibratory roller used on the shoulder and the outer lane is shown in Figure B.39. This vibratory roller was followed by three additional rollers along the traffic lane, for a total of about 12 to 14 passes. The intermediate, pneumatic, and static steel drum rollers were being used within the temperature sensitive zone and damaged or decompacted the HMA base mixture. The number of passes was increased to rebuild the density obtained by the primary roller. Use of the PaveTracker non-nuclear density gauge clearly showed this condition in real-time. The contractor was made aware of this observation, but did not take corrective action during the initial paving.

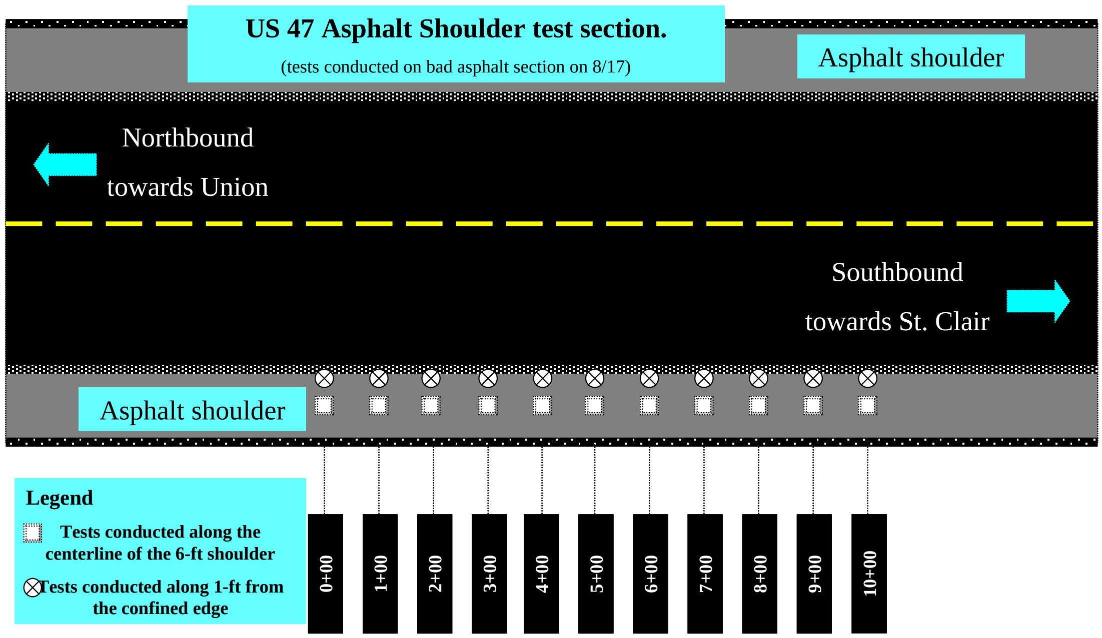


a) Test points in US-47 mainline testing

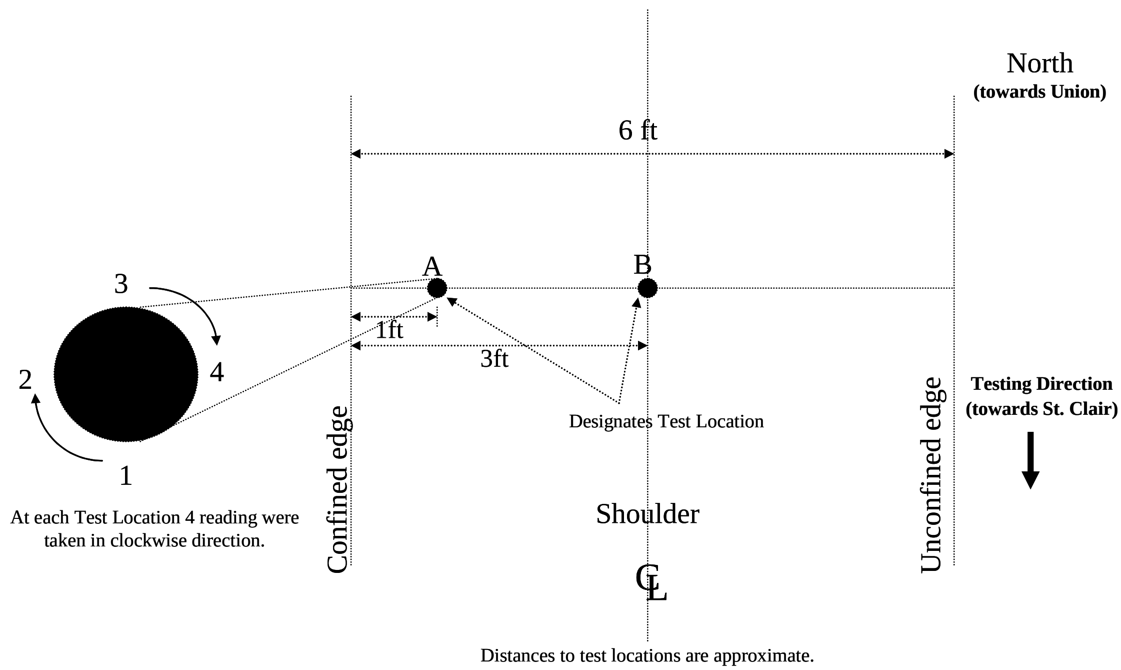


b) Test points layout at each test station

Figure B.31. Layout of Points for Tests Conducted During Mainline and Shoulder Paving in the Southbound Direction on US-47, Missouri



a) Test points layout along section



b) Test points layout at each test station

Figure B.32. Layout of Points for Supplemental Testing of the HMA Mixture that Was Rejected Along US-47, Missouri

Table B.12. Nondestructive Devices Used for the I-75 Overlay Rehabilitation Project Near Saginaw, Michigan

NDT Technology	Subgrade	Aggregate Base	HMA[††]
GeoGauge (stiffness)*, †	—	—	—
Seismic – PSPA for HMA, DSPA for soils (modulus) *, #,	—	—	✓
Non-nuclear HMA density (Troxler)*, #, †	—	—	✓
Other Traditional Tests			
HMA mixture design test data	—	—	✓
HMA cores for densities & other volumetric properties	—	—	✓
Nuclear density tests[##]	—	—	✓
Moisture-density relationship tests	—	—	—
Bulk material for laboratory modulus tests	—	—	✓

* - Clustered tests performed at each test point – refer to figure B.1.
† - Multiple gauges to assess variability between devices
†† - Testing performed behind paver and 36 hours after paving
\# - Testing included measurements to develop a density growth curve
\## - Nuclear density readings were not collected on cold asphalt

B.2.3 US Route 2, New Construction; Minot, North Dakota

The construction of Route 2 between the cities of Williston and Minot in North Dakota was selected for the Part B field evaluation. The pavement cross section for this project included 8 inches of different layers of HMA over a 15-inch crushed aggregate base layer over the existing subgrade. Segments of this project were under different levels of completion with respect to the construction of the subgrade, base, and HMA layers during the 2006 construction season. Thus, segments of each layer under different conditions were tested. The general location of the test sections for each material type along Route 2 is shown in Figure B.40.

Test dates were selected to coincide with the HMA paving operation. The subgrade and base layers on the west end of the project near Ray, North Dakota, were completed a few weeks prior to the dates of testing. HMA paving was performed in the vicinity of Stanley, where the base layer had been previously placed in the fall of 2005. A prime coat was placed on the base layer in this area. HMA layer testing was conducted during the paving operation on August 23. In addition, a portion of the base layer placed in 2005 (over which HMA was being placed) was also tested on the same day. The HMA section tested on August 23 was retested 24 hours after a rain event. On August 25, two additional sections of HMA, one additional section of the base, and a section of the subgrade were tested. Details of all section are given below for each layer, while Table B.13 provides a summary of NDT devices and field tests conducted along Route 2 in North Dakota.

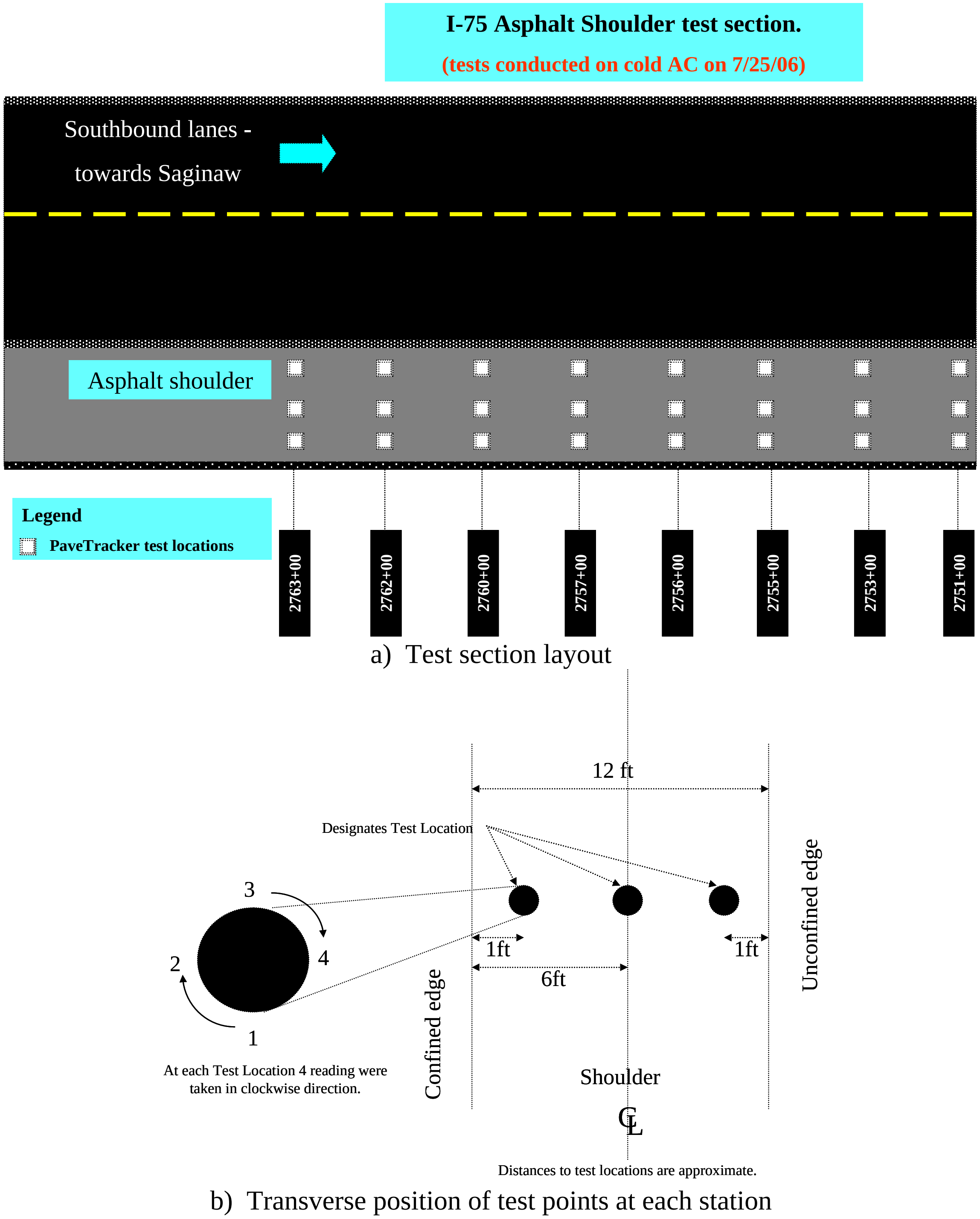
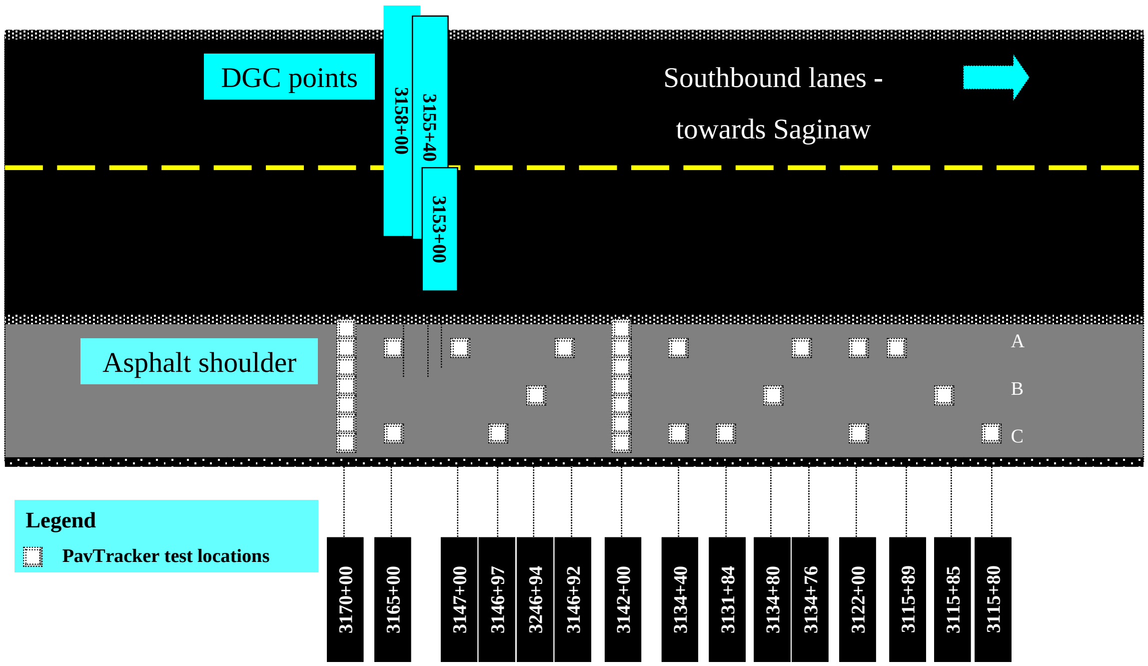
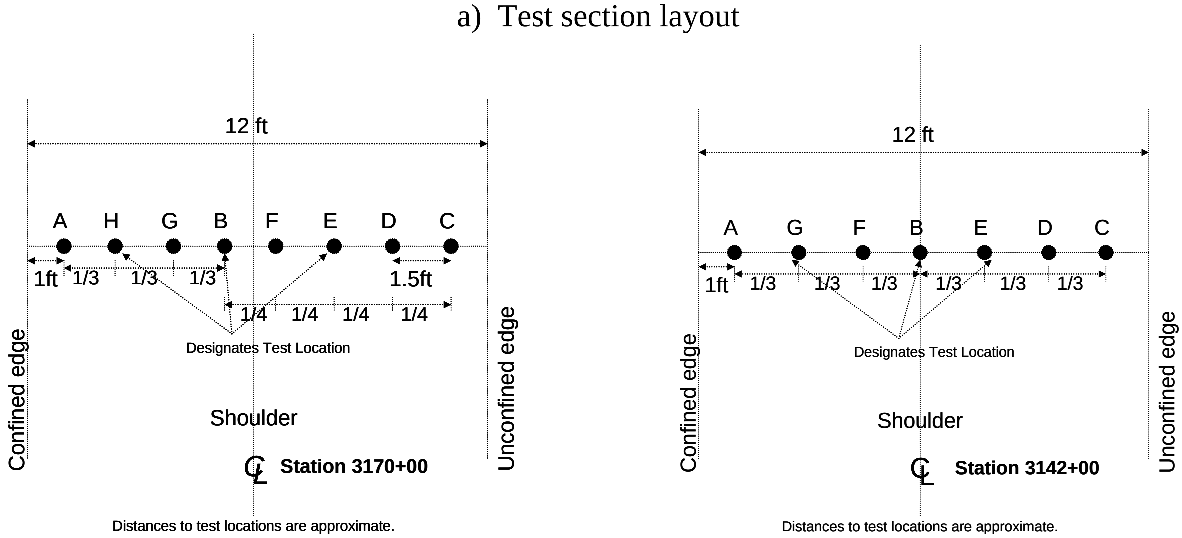


Figure B.33. General Layout of Test Points Along Shoulder for Section 1; I-75, Saginaw, Michigan; HMA Paved on July 19 to 21 and Tested on July 25, 2006

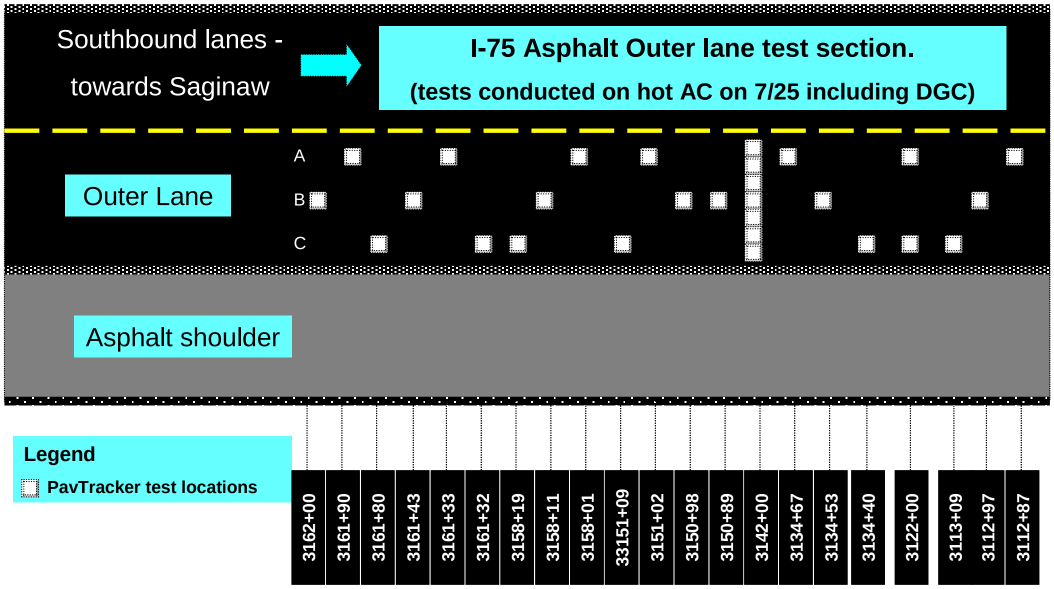


a) Test section layout

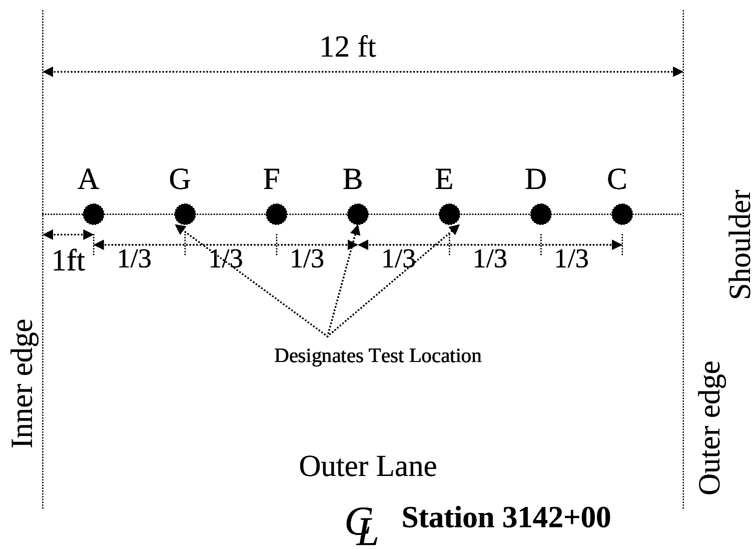


b) Layout for stations 3170+00 and 3142+00
Note: All other points on test section were more or less centered and evenly distributed across width of the section

Figure B.34. General Layout of Test Points Along Shoulder for Section 2; I-75, Saginaw, Michigan; Testing Performed Immediately After Paving on July 25, 2006



a) Test section layout

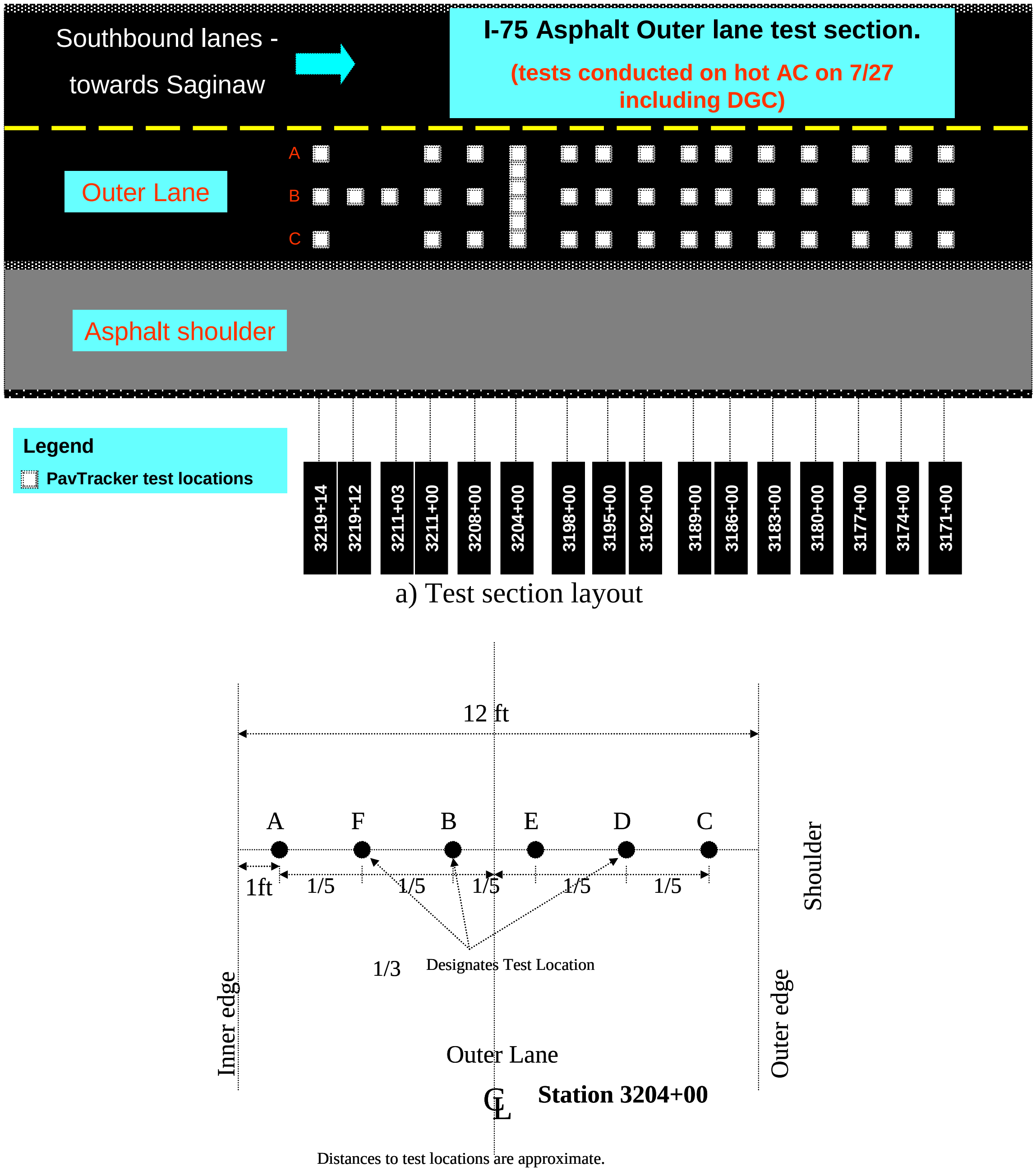


Distances to test locations are approximate.

b) Layout for stations 3142+00

Note: All other points on test section were more or less centered and evenly distributed across width of the section

Figure B.35. General Layout of Test Points Along Section 3, Outer Lane; I-75, Saginaw, Michigan; Testing Performed Immediately After Paving on July 25, 2006



a) Test section layout

b) Layout for stations 3204+00

Note: All other points on test section were more or less centered and evenly distributed across width of the section

Figure B.36. General Layout of Test Points Along Section 4, Outer Lane; I-75, Saginaw, Michigan; Testing Performed Immediately After Paving on July 27, 2006

Figure B.37. General View of the Paving Operation Along I-75 of the Traffic Lane and Shoulder Near Saginaw, Michigan

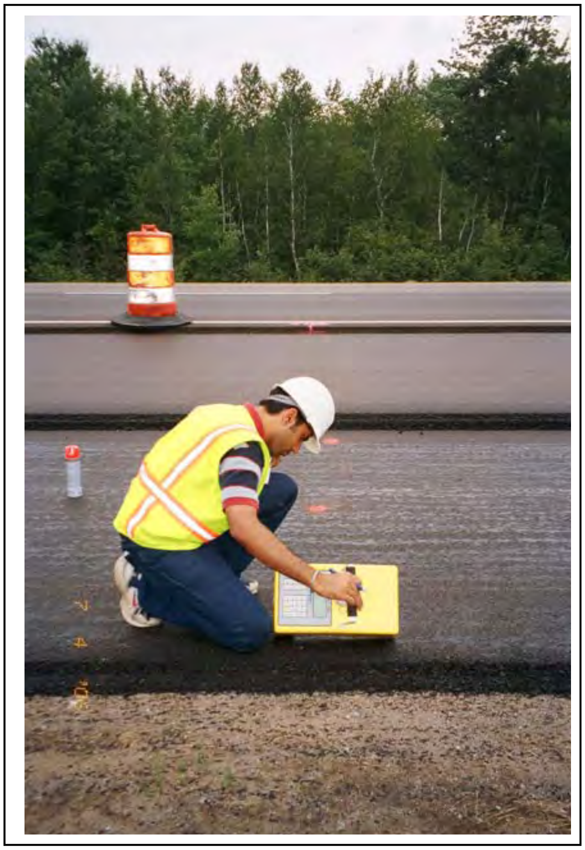


Figure B.38. PaveTracker Non-Nuclear Density Gauge Being Used Along the Shoulder of the I-75 Rehabilitation Project, Near Saginaw, Michigan

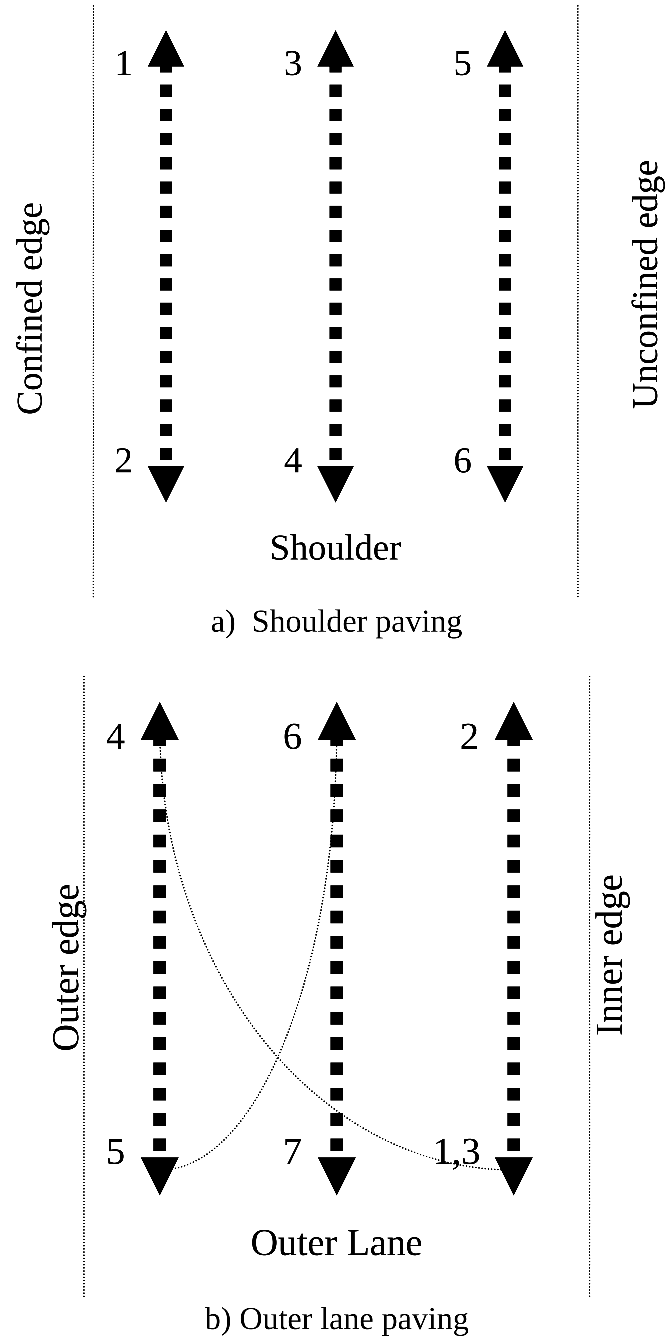


Figure B.39. Rolling Pattern of the Primary or Breakdown Vibratory Roller Used for the HMA Paved Along Shoulder and Outer Lanes, I-75 Rehabilitation; Saginaw, Michigan

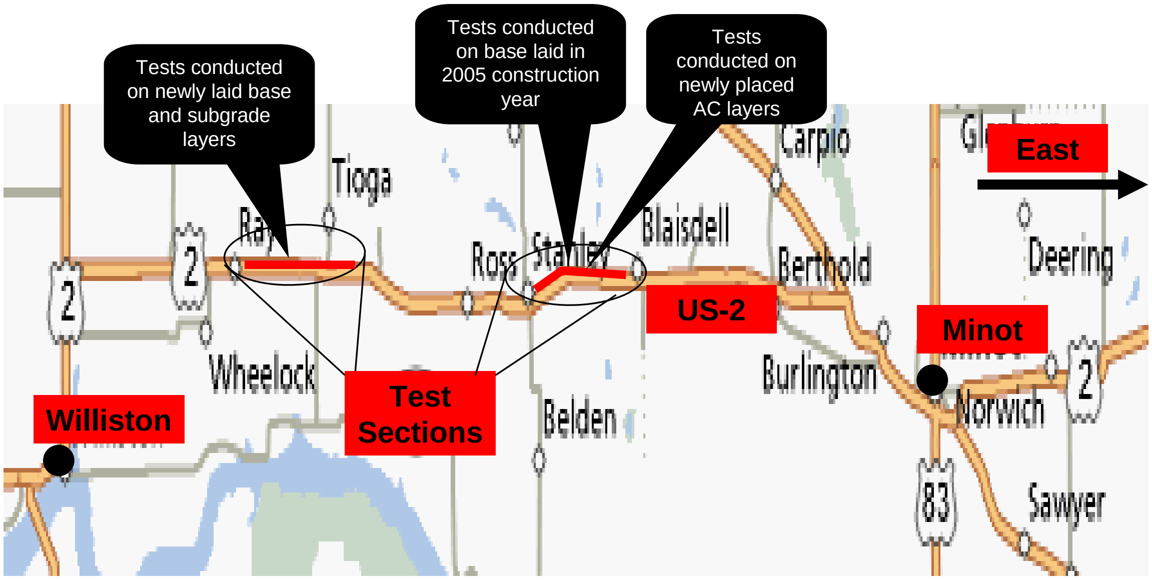


Figure B.40. Location of HMA, Crushed Stone Base, and Subgrade Test Sections Along Route 2 in North Dakota

Table B.13. Nondestructive Devices Used for the US Route 2 Project at Ray and Stanley, North Dakota

NDT Technology	Subgrade	Aggregate Base	HMA[††]
GeoGauge (stiffness)*, †, ^^	✓	✓	—
DCP	✓	✓	—
Seismic – PSPA for HMA, DSPA for soils (modulus) *, #, ^^	✓	✓	✓
Non-nuclear HMA density (Troxler)*, #, †, ^^	—	—	✓
Other Traditional Tests			
HMA mixture design test data	—	—	✓
HMA cores for densities & other volumetric properties	—	—	✓
Nuclear density tests[##]	—	—	✓
Moisture-density relationship tests	✓	—	—
Bulk material for laboratory modulus tests	✓	✓	✓

* - Clustered tests performed at each test point – refer to figure B.38 – 44.
[†] - Multiple gauges to assess variability between devices
[††] - Testing performed behind paver and 24 hours after paving
[#] - Testing included measurements to develop a density growth curve
[##] - Nuclear density readings were not collected on cold asphalt
[^^] - Devices used in contractor testing

Subgrade Layer: The embankment or subgrade section, about 2000 feet in length, was defined as silty clay with sand and gravel (#5 Proctor). The selected section was located in the inner lane at the west end of the project near Ray, North Dakota. Test points were marked 200 feet apart and were located at mid-width of the lane. Figure B.41 shows the test point layout of the subgrade section. Balloon density tests were conducted along with DCP tests for some areas, and bulk samples of the soil were collected for laboratory resilient modulus testing. Figure B.42 shows the condition of the subgrade layer that was tested. This layer did contain large aggregate particles that definitely had an influence on the NDT results when using the DCP and GeoGauge (see Figure B.43).

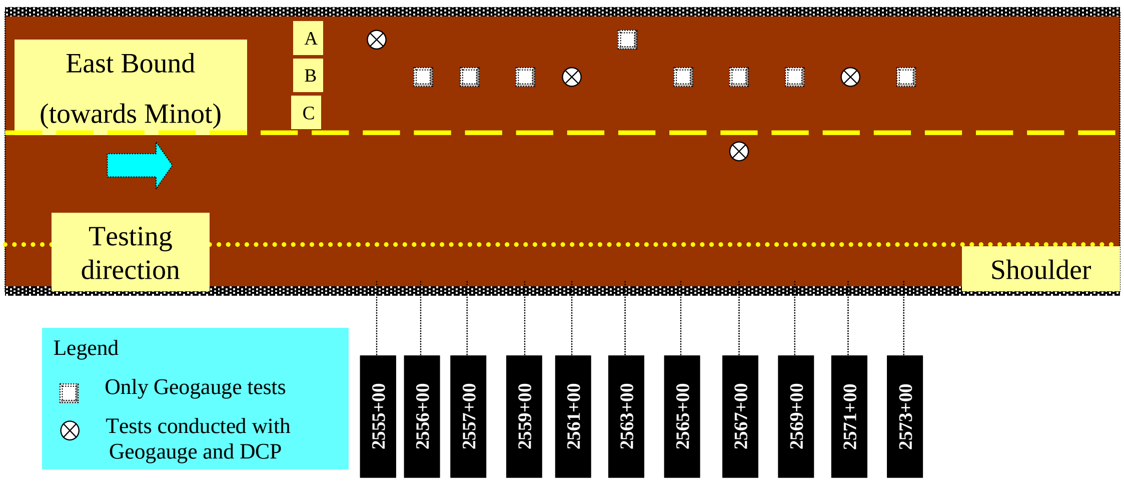


Figure B.41. General Layout of Test Points on Test Section on Subgrade Along Route 2 Near Ray, North Dakota

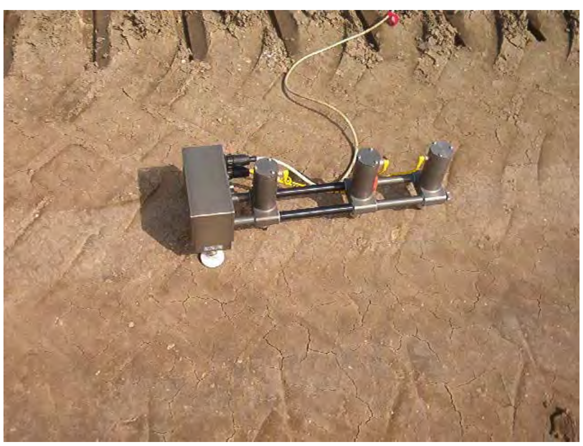


Figure B.42. Condition of Subgrade Layer Tested Along Route 2 Near Ray, North Dakota

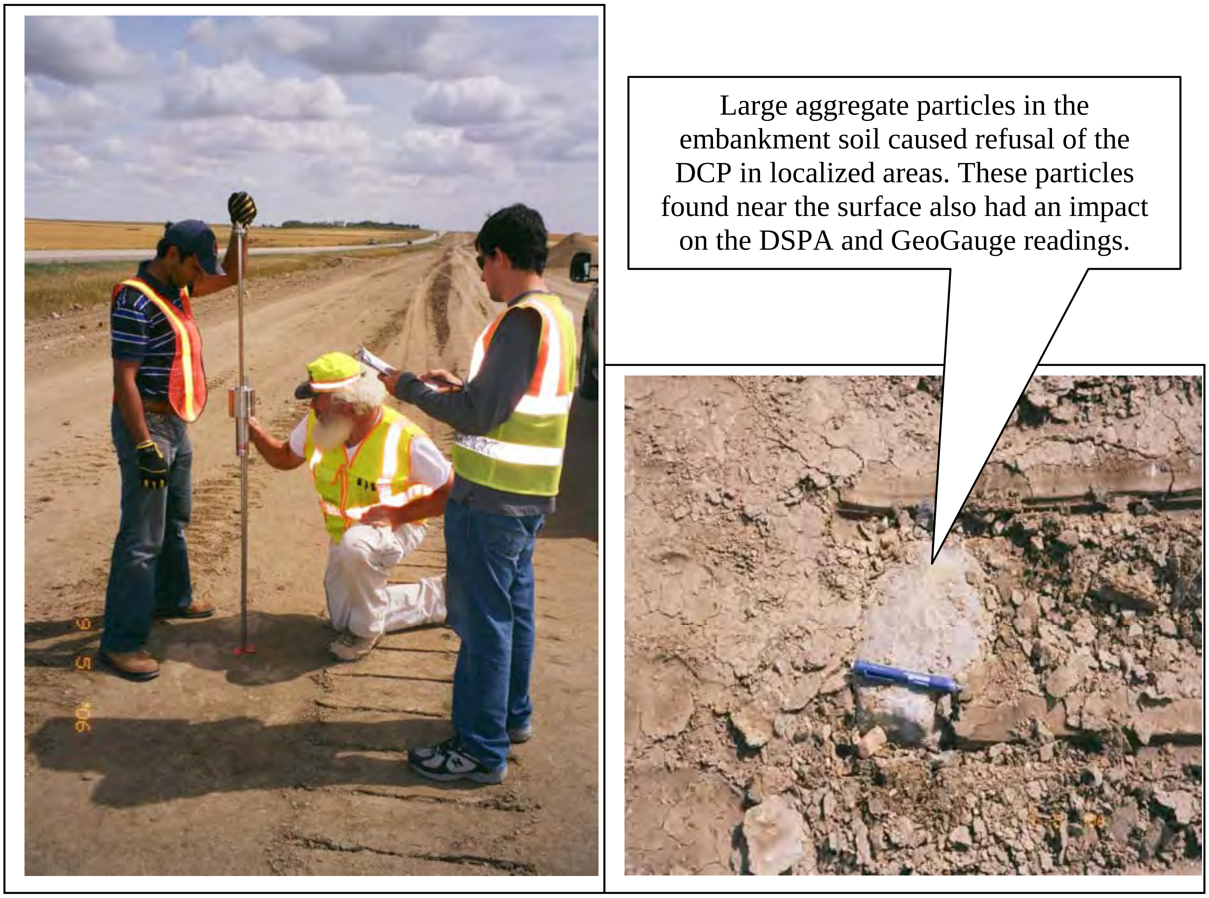
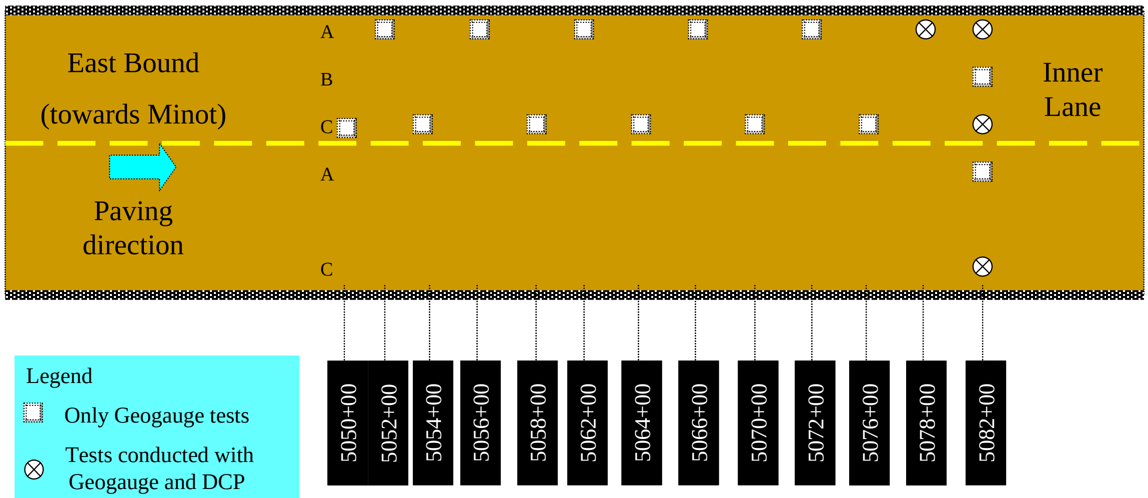


Figure B.43. Photo Showing the Large Aggregate Particles Encountered During Testing of the Subgrade Soil

Base Layer: The base layer on this project was a Class 5 crushed gravel material. As stated earlier, the base layer was tested at two locations, nearly Stanley and Ray on August 23 and 25, 2006, respectively. These are referred to as Sections 1 and 2 and represent the base layer prepared in 2005 and 2006. Section 1 was primed shortly after the DOT had accepted the layer during the previous construction season, while Section 2 consisted of the crushed gravel base that had just been placed. The test point layout of Sections 1 and 2 are shown in Figures B.44 and B.45, while Figures B.46 and 47 show pictures of the test section.

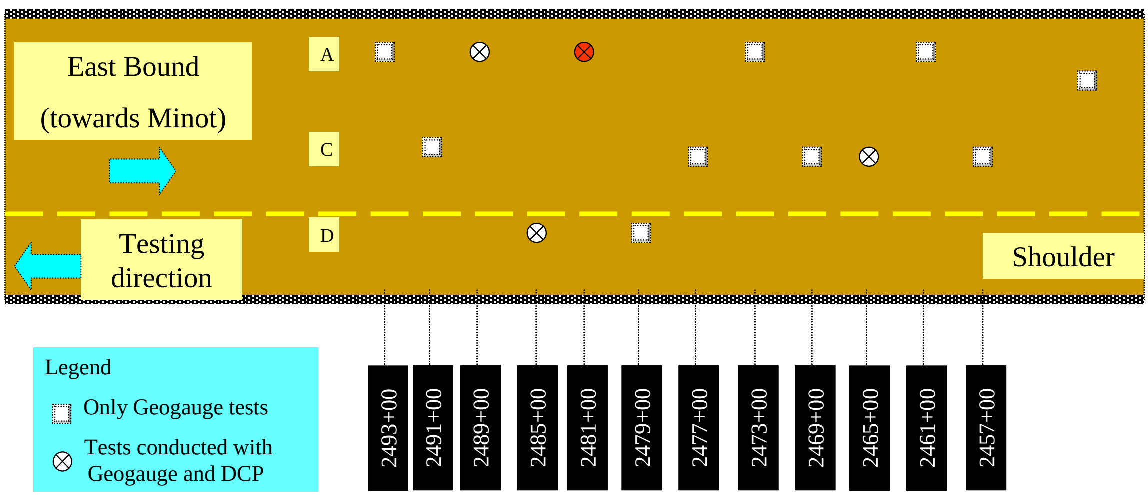
The crushed gravel has very low cohesion and is a non-plastic material. The aggregate particles on the surface become easily disturbed under construction traffic. Prior to testing with the DSPA and GeoGauge the surface of the crushed aggregate base layer that had yet to be primed was swept to remove the loose particles (see Figure B.48). Those loose particles reduced the resilient modulus values estimated with the DSPA and GeoGauge.

The North Dakota DOT does not have a specified density for granular bases. For acceptance, the DOT requires ordinary compaction of the base layer. Bulk samples of the aggregate base were taken from stockpiles of the crushed gravel that had yet to be used for repeated load resilient modulus testing and determining the M-D relationship for this material. An M-D relationship was unavailable for the Class 5 base material during the dates of testing.



Note: Constructed in Fall 2005, and tests conducted on Aug 23, 2006 with a tack coat. **C** is 4-ft from outer edge, **B** is 3-ft from C and **A** is 3-ft from B.

Figure B.44. General Layout of Test Points on Section 1 of Base Layer of Route 2 Near Stanley, North Dakota (refer to Figure B. 46)



Note: Constructed in July 2006, and tests conducted on Aug 25, 2006.

Figure B.45. General Layout of Test Points on Section 2 of Base Layer of Route 2 Near Ray, North Dakota (refer to Figure B.47)

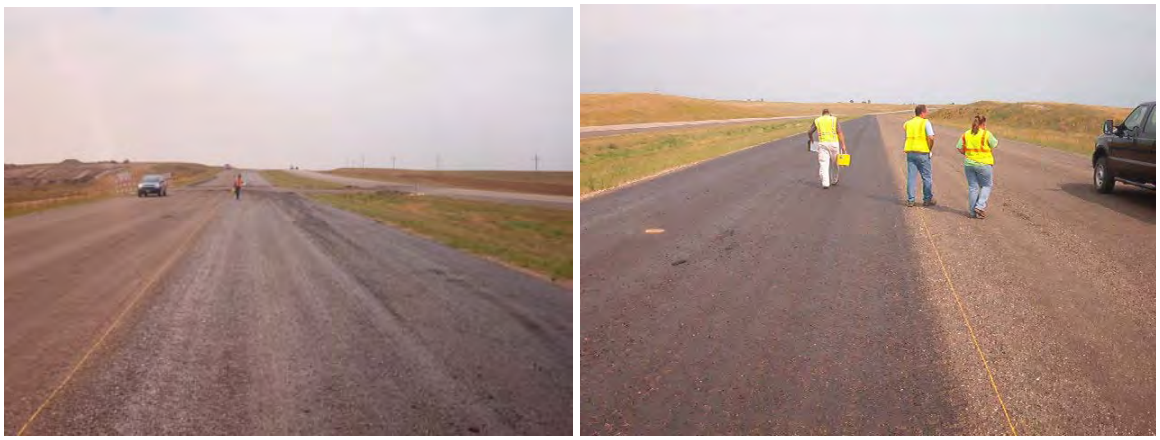
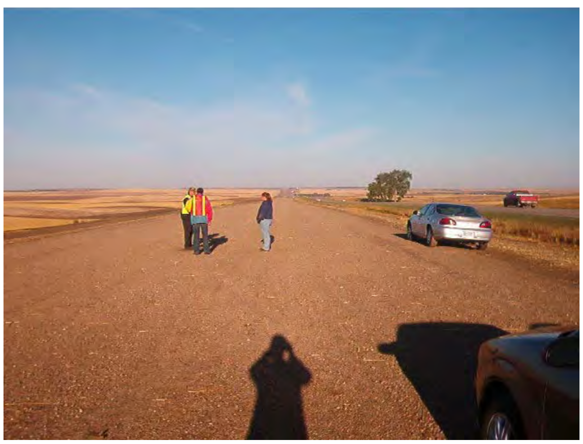


Figure B.46. Section 1 of the Crushed Aggregate Base that Had Been Primed Along Route 2 Near Stanley, North Dakota (refer to Figure B. 44)



a) Section selected for testing

b) Close-up view of Class 5 base

c) Geogauge testing using multiple devices

d) PSPA testing on base material

Figure B.47. Section 2 of the Crushed Aggregate Base that Had Yet to be Primed Along Route 2 Near Stanley, North Dakota (refer to Figure B. 45)

Figure B.48. Surface Preparation of the Crushed Gravel to Remove the Loose Aggregate Prior to NDT Testing; US Route 2, North Dakota

HMA Layer: The HMA layer was paved in 2-inch lifts with a PG 58-28 binder mixture and tests were conducted on three sections. As stated earlier, the first section was tested on August 23, 2006, and retested on August 24, after a rain event. Section 1 was located along the inner lanes of eastbound direction. Figure B.49 shows the segment of Section 1 used for testing immediately after paving, while Figure B.50 shows the condition of the HMA tested the following day. All free water was removed prior to density testing with the non-nuclear density gauges (see Figure B.50.c). Test points along this section were spaced every 400 feet and staggered at three points along the width of the lane, as shown in Figure B.51.

Sections 2 and 3 were located along the inner lanes in the eastbound direction and were tested on August 25, 2006, immediately after the paving. Figure B.52 shows the condition of the HMA layer within Section 2, while Figures B.53 and 54 provide the test point layout for Sections 2 and 3, respectively. A few areas were found along Section 3 where the HMA base mixture was rolled within the temperature sensitive zone and had left checking cracks and tears in the surface. The NDT devices were used to test the HMA mixture in these areas.

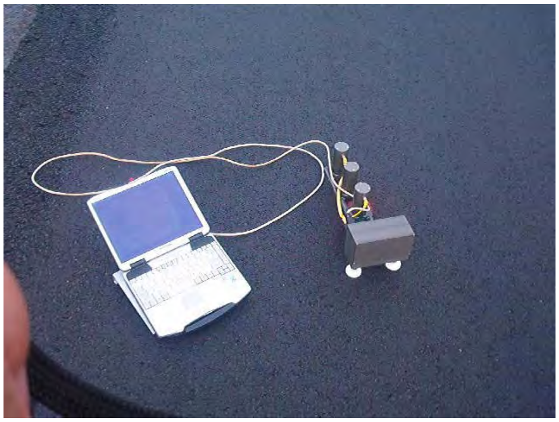
The test points were spaced at 200 feet longitudinally and staggered transversely in Section 2, while test points were spaced successively at 200 and 400 feet in Section 3 along the centerline of the lane. NDT readings were also taken at one station in Section 2 after each roller pass to develop density growth curves for the mixture. Mixture design details and the JMF were provided by the DOT for this mixture. NDT readings were also taken at those locations within Sections 1 through 4 where the DOT and contractor had taken cores for QA purposes (see Figure B.55).

The contractor and DOT personnel were trained to use the NDT devices. They used these gauges over about a 2-week period following the testing dates included in NCHRP Project

10-65. The test data and observations were provided from the contractor and DOT personnel using the devices.

a) Section 1 material tested

b) Non-nuclear device for HMA density



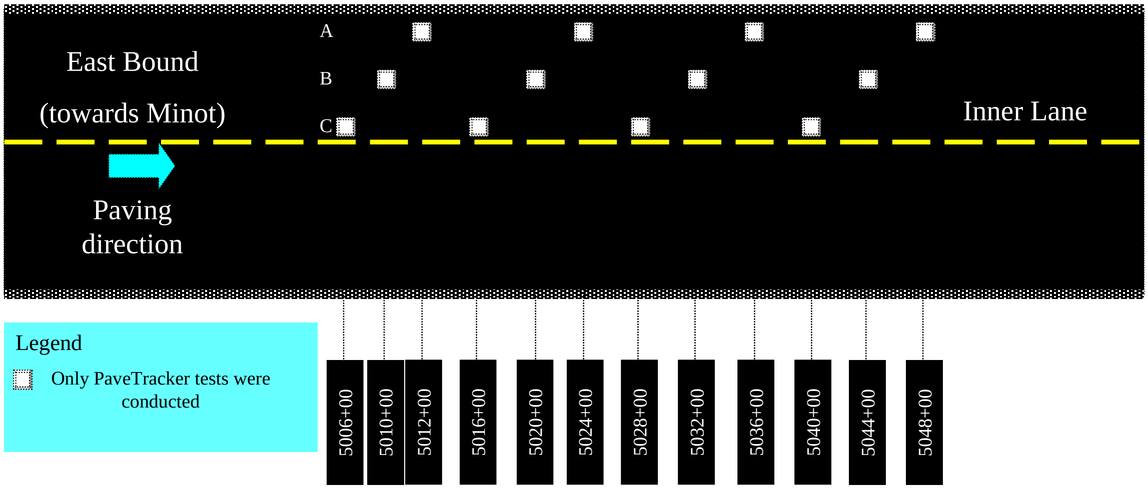
c) PSPA device for HMA modulus

Figure B.49. Section 1 of HMA Along Route 2 Near Stanley, North Dakota; Testing Conducted Immediately After Paving (refer to Figure B.51)

a) Section 1 after rain in 24 hours b) Close-up view of Section 1 after rain

c) and d) Non-nuclear density testing with multiple devices after rain in 24 hours

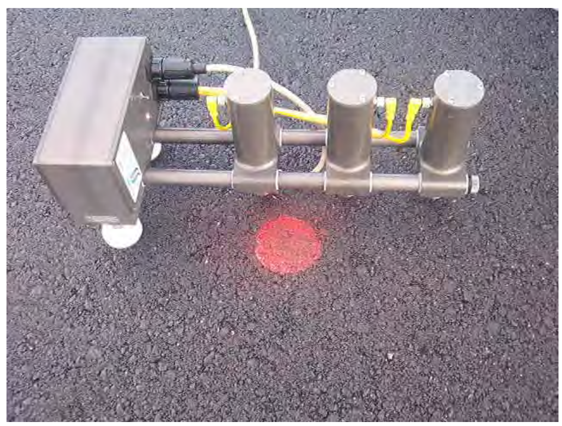
Figure B.50. Section 1 of HMA Along Route 2 Near Stanley, North Dakota; Testing Conducted 24 Hours After Paving and Rain Event (refer to Figure B. 51)



Note: Tests conducted during paving on August 23, 2006 and also on cold pavement on August 24, 2006 after a rain event.

Figure B.51. General Layout of Test Points Along Section 1 of HMA Layer Along Route 2 Near Stanley, North Dakota

a) HMA paved material for testing



b) Seismic testing example for Section 2

Figure B.52. Section 2 of HMA Testing Along Route 2 Near Stanley, North Dakota (refer to Figure B. 53)

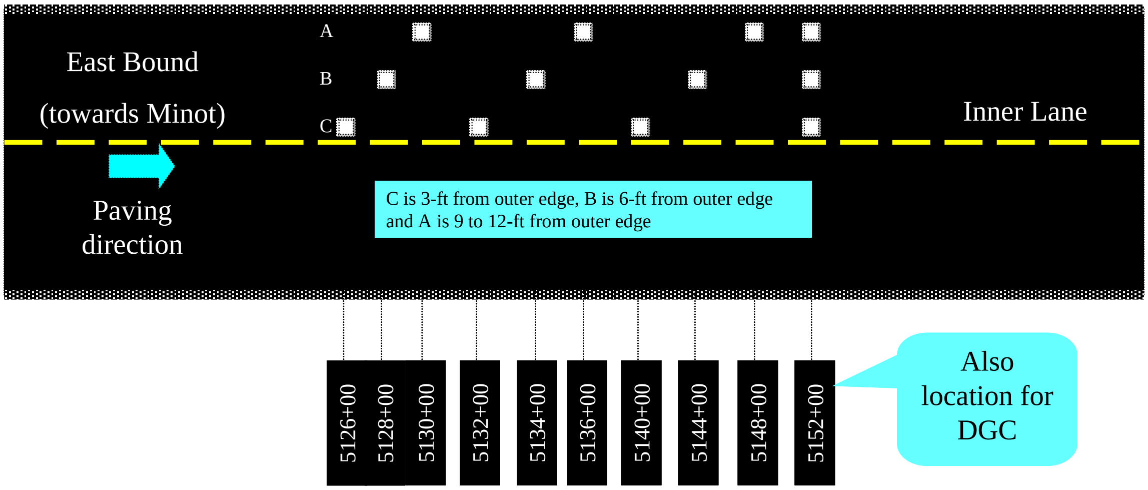


Figure B.53. General Layout of Test Points Along Section 2 of HMA Layer; Route 2 Near Stanley, North Dakota

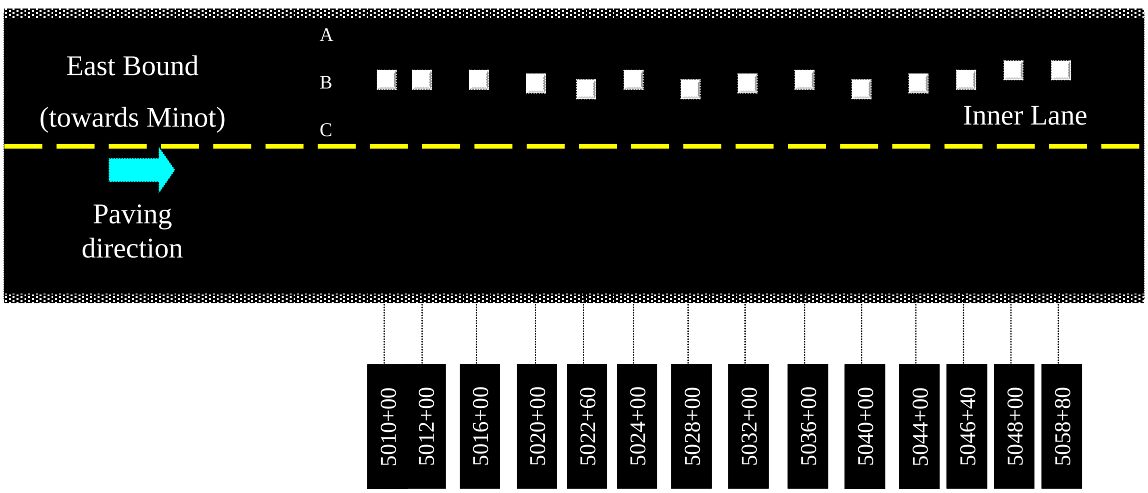


Figure B.54. General Layout of Test Points Along Section 3 of HMA Layer; Route 2 Near Stanley, North Dakota

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Figure B.55. The PSPA and Non-Nuclear Density Gauges Were Used to Test the HMA Base and Other Mixtures in the Areas Where the North Dakota DOT and Contractor Took Cores for QA Purposes

B.2.4 NCAT Test Track, Opelika, Alabama

Several sections of the NCAT pavement test track were included in the Part B field evaluation. Figure B.56 shows a schematic of the test track and indicates specific sections that were used within the Part B field study. The 2006 test sections were reconstructed in the fall of 2006, and the contractor was East Alabama Paving. For all test sections included n NCHRP Project 10-65, a significant amount of material data was made available by NCAT. For example, mixture design and gradation test results were provided for use during the data interpretation process and bulk material samples were made available to perform the laboratory tests.

Two trips were made to the test track for Part B from September 25 to 29, 2006, and October 8 to 12, 2006. The sections that were incorporated into Part B tests, the date of construction and testing, and the NDT devices used are summarized in Table B.14. In addition, Table B.15 summarizes the NDT in a format consistent with the tables provided for all other test sites.

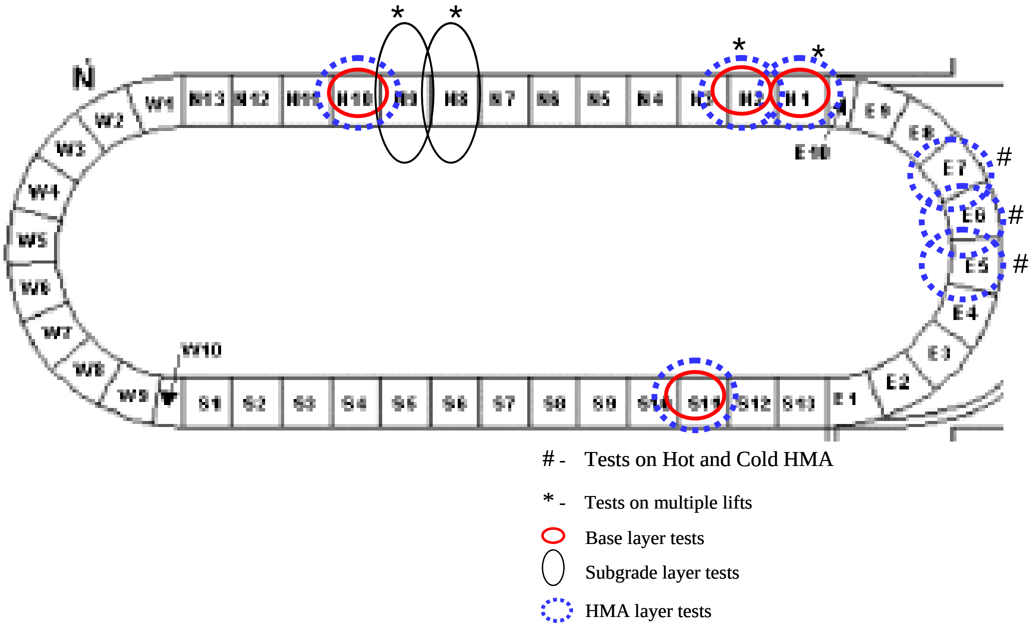


Figure B.56. NCAT Test Track Sections Used in the Part B Field Evaluation that Were Overlaid or Reconstructed in 2006

Table B.14. Summary of the Materials Tested Within Each Test Section at NCAT

NCAT Test section ID	Test date	Granular Base/Subgrade					HMA			
		Layer	Geogauge	DCP	DSPA	NDG	Troxler	PSPA	NDG	Cores
E5-7 (AL)	26-Sep	NA					✓	✓	✓	Yes
E5-7 (AL)	27-Sep	NA					✓ ††	✓††		
N1 & N2 (FL)	26-Sep	Base	✓	✓	✓	✓				
N1 & N2 (FL)	27-Sep	NA					✓*	✓	✓	Yes
N1 & N2 (FL)	28-Sep	Base	✓	✓	✓	✓	✓*, #	✓,#	✓,#	Yes
N8 & N9 (OK)	28-Sep	Subgrade	✓	✓	✓	✓				
N8 & N9 (OK)	9-Oct	Subgrade	✓,#	✓#	✓#	✓#				
N10 (MO)	9-Oct	Base	✓†*	✓	✓	✓				
N10 (MO)	10-Oct	NA					✓*	✓	✓	Yes
S11 (SC)	9-Oct	Base	✓†*	✓	✓	✓				
S11 (SC)	11-Oct	Base	✓*	✓	✓	✓	✓*	✓	✓	Yes

* Testing included measurements to develop a density growth curve.
[#] Multiple lifts tested.
[†] Multiple devices used for the NDT technology.
[††] Cold HMA tested.

Table B.15. Nondestructive Devices Used to Test the Different Test Sections Along the NCAT Test Track

NDT Technology	Subgrade	Aggregate Base	HMA††
GeoGauge (stiffness)* , †, #	✓	✓	—
Seismic – PSPA for HMA, DSPA for soils (modulus) *, #,	✓	✓	✓
DCP	✓	✓	
Non-nuclear HMA density (Troxler)*, #, †	—	—	✓
Other Traditional Tests			
HMA mixture design test data	—	—	NCAT
HMA cores for densities & other volumetric properties	—	—	NCAT
Nuclear density tests##	NCAT	NCAT	NCAT
Moisture-density relationship tests	✓	✓	—
Bulk material for laboratory modulus tests	✓	✓	✓

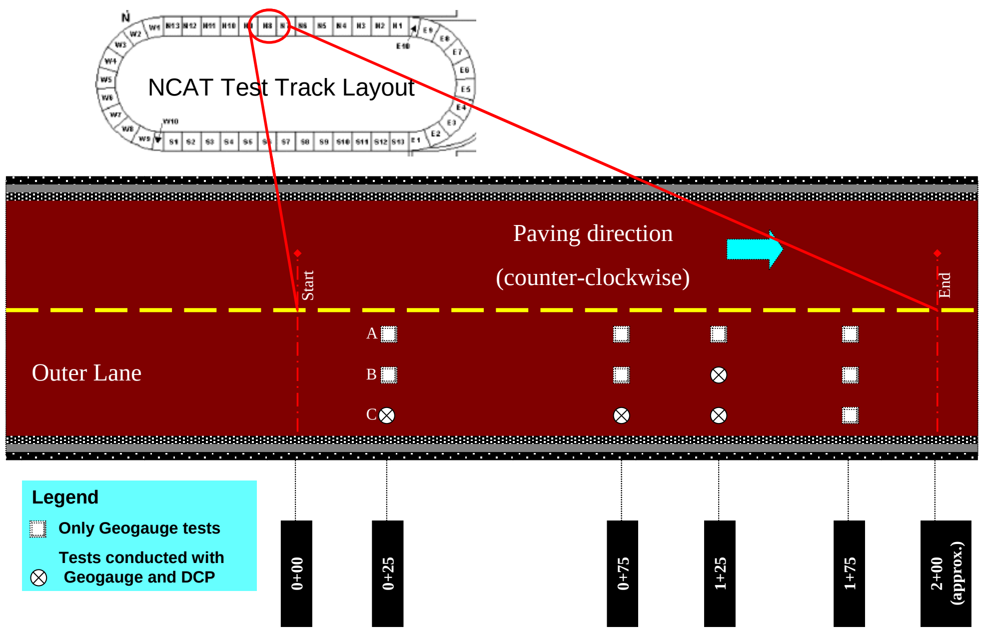
* - Clustered tests performed at each test point – refer to figure B.1.
† - Multiple gauges to assess variability between devices
†† - Testing performed behind paver and 24 hours after paving
# - Testing included measurements to develop a density growth curve
- Nuclear density readings were not collected on cold asphalt
NCAT – Data provided by NCAT.

Laboratory test data, as well as QA data, were made available to NCHRP Project 10-65 by NCAT. Bulk material was sampled for resilient modulus testing, and HMA cores were drilled to determine mix volumetrics. A brief description of each test section is provided below for each material type.

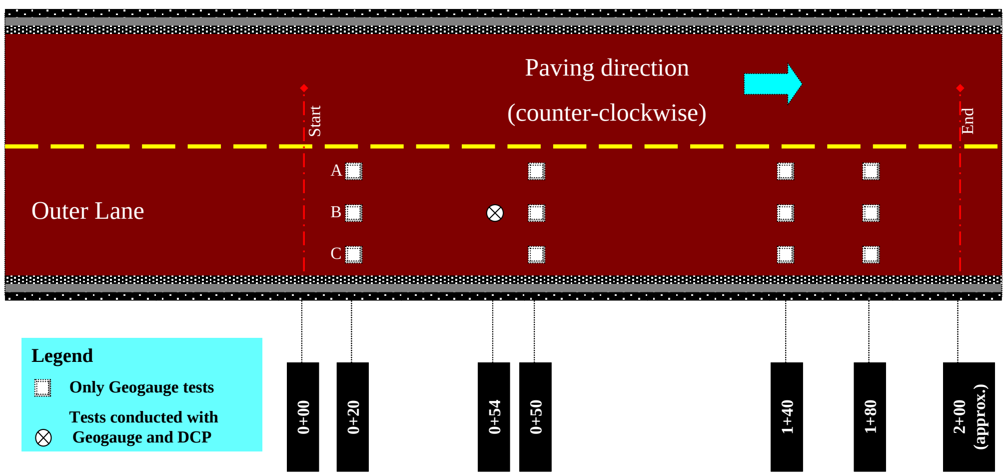
Subgrade Layer: Subgrade in the Oklahoma Sections N-8 and N-9 were tested during the construction of the first lift and the final lift in September and October 2006. Test points were marked 50 feet apart in the longitudinal direction, and three test points were selected in the transverse direction at each station tested. Figure B.57 and B.58 show the test layout of the Oklahoma N-8 and N-9 subgrade sections.

The embankment material used on the Oklahoma N-8 and N-9 sections was a high plasticity clay soil with chert. The clay had a Plasticity Index of 28 and 75 percent fines (minus 200 material). Nuclear density and DCP tests were conducted in some areas where the NDT devices were used. Bulk samples of the soil were collected for laboratory resilient modulus testing. In addition, a few points within this section were used to measure the density and modulus growth curves during compaction.

The surface of the high plasticity clay soil was relatively dry and exhibited extensive shrinkage cracks at the time of testing. The shrinkage cracks did affect the GeoGauge readings, even when using the thin layer of sand for leveling and ensuring good contact between the GeoGauge and surface of the clay soil. Figure B.59 shows the subgrade layer being constructed and tested.

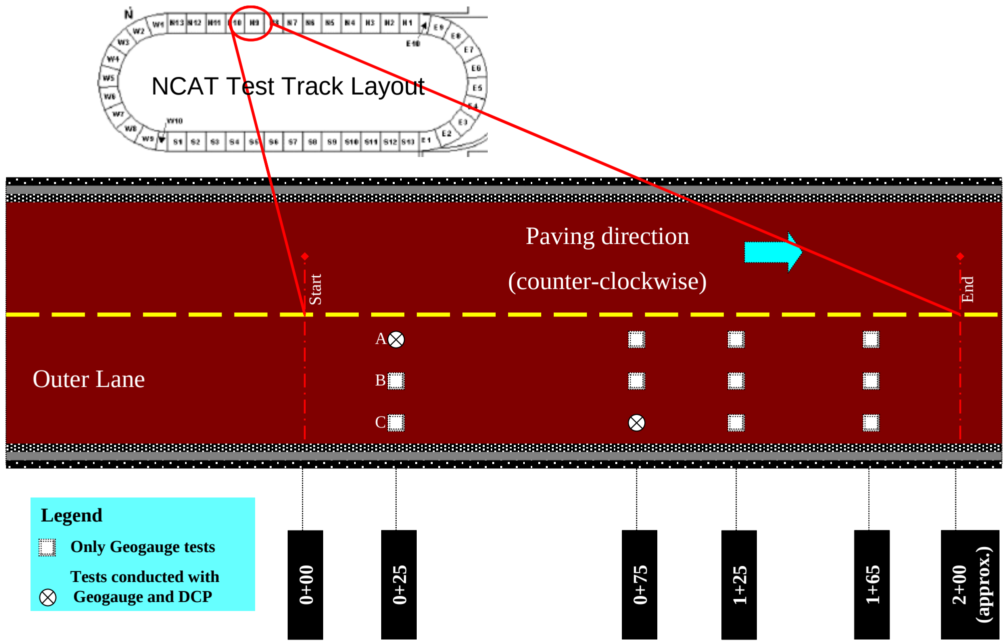


a) Layout for first lift in September, 2006

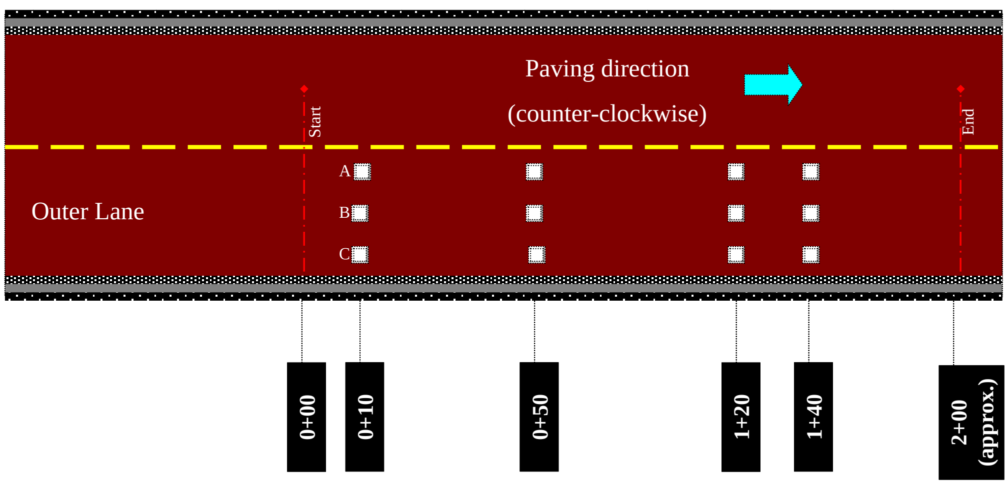


b) Layout for last lift in October 2006

Figure B.57. Layout of Test Points on Subgrade Section N-8 at NCAT (refer to Tables B.14 and B.15)



b) Layout for first lift in September 2006



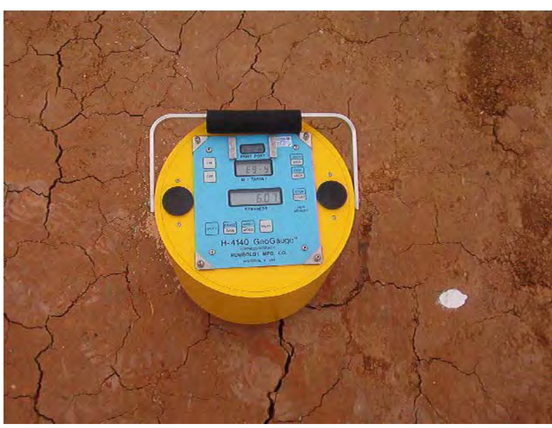
b) Layout for last lift in October 2006

Figure B.58. Layout of Test Points on Subgrade Section N-9 at NCAT (refer to Tables B.14 and B.15)

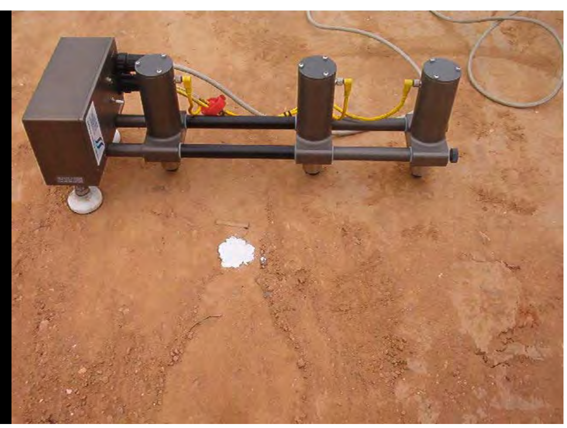
a) View of section Oklahoma section N-9.

b) Subgrade compaction

c) Field instrumentation by NCAT



d) Geogauge testing on subgrade soil



e) DSPA testing on subgrade soil

Figure B.59. Oklahoma Subgrade Section Tested at NCAT Test Track

Base Layer: Three different base types were tested at the NCAT test track. The Florida limerock base placed in Sections N-1 and N-2 were tested in September 2006, the Missouri Class 5 base material placed in section N-10 was tested in October 2006, and the South Carolina Vulcan crushed granite base placed in Section S-11 was tested in October 2006. Figures B.60 through B.63 show the test point layout for these test sections. These test sections were paved with HMA the next day after the base layer testing had been completed, and were also included as part of the HMA tests under NCHRP Project 10-65. A second lift of the Florida DOT sections was placed within 48 hours and included in the test program as well.

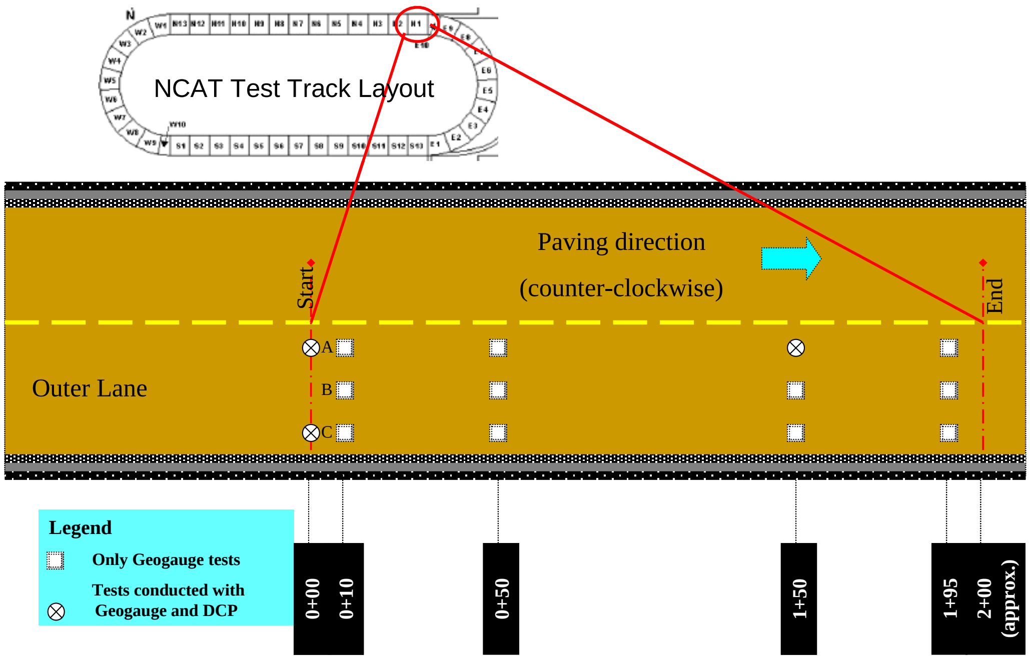


Figure B.60. Layout of Test Points Along the Florida Limerock Base Placed in Section N-1 at the NCAT Test Track (refer to Tables B.14 and B.15)

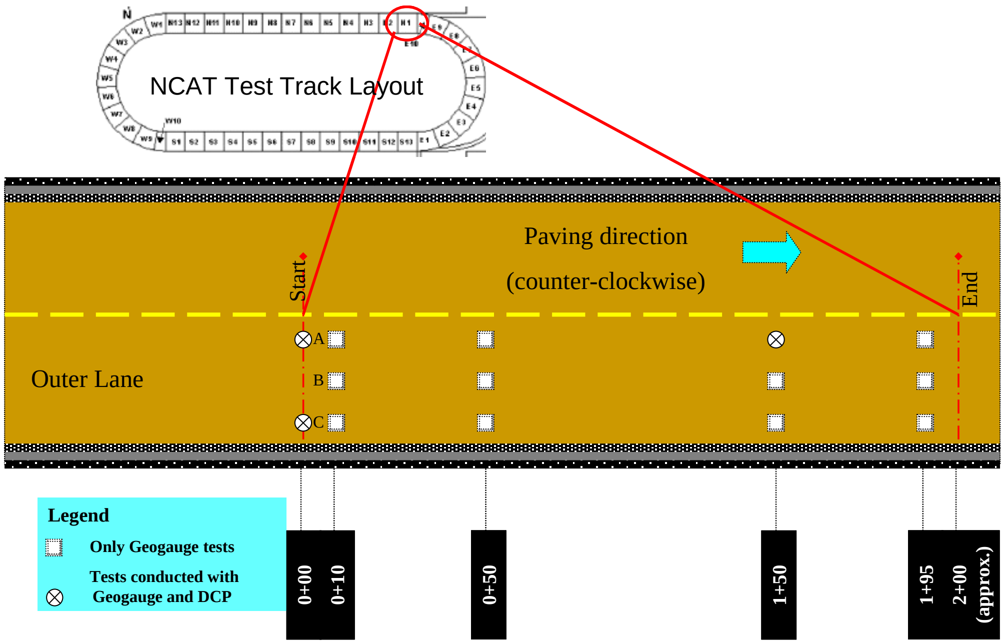


Figure B.61. Layout of Test Points Along the Florida DOT Limerock Base Placed in Section N-2 at the NCAT Test Track (refer to Tables B.14 and B.15)

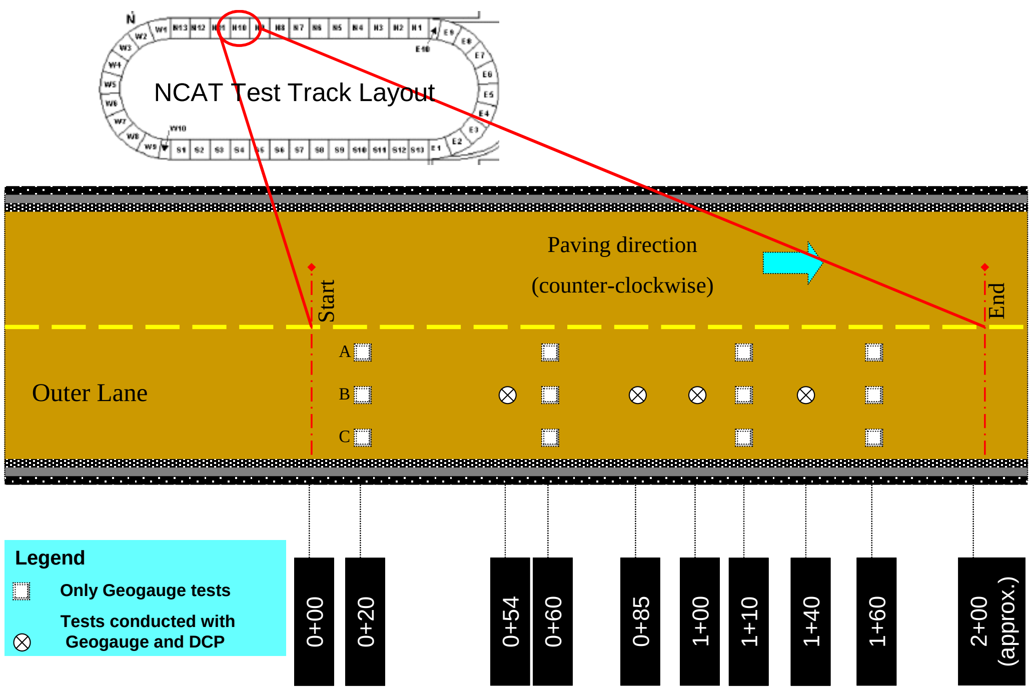


Figure B.62. Layout of Test Points Along the Missouri Crushed Limestone Base Placed in Section N-10 at the NCAT Test Track (refer to Tables B.14 and B.15)

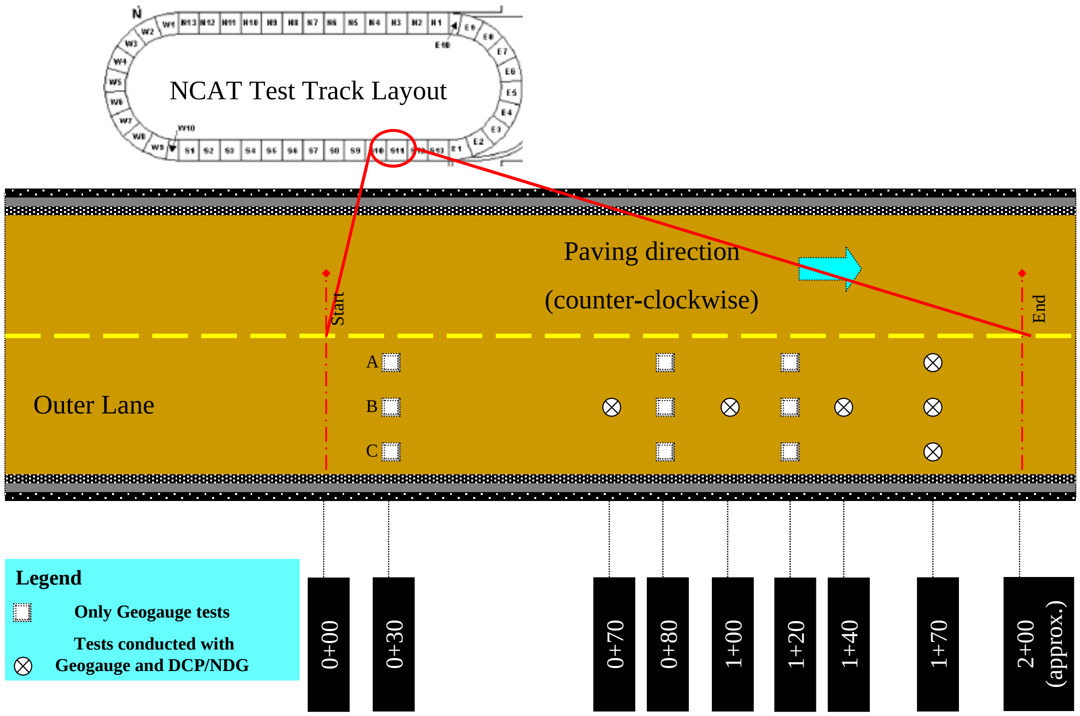


Figure B.63. Layout of Test Points Along the South Carolina Crushed Granite Base Placed in Section S-11 at the NCAT Test Track (refer to Tables B.14 and B.15)

The DSPA and Geogauge devices were used to test these materials at all points. DCP tests were performed at selected points. In addition, the non-nuclear density gauges, DSPA, and GeoGauge were used within N-10 and S-11 test sections to measure the increase in density and modulus of the base materials under specific intervals of the roller. Multiple GeoGauges and the DSPA were used to test all of the base materials and to develop modulus-growth curves during compaction (see Figure B.64).

The Florida limerock base in Sections N-1 and N-2 is a good quality nonplastic base material with a maximum dry density of 116.1 pcf, an optimum water content of 12.5 percent, and a LBR value of 147.0. The Class 5 crushed aggregate base placed in the Missouri N-10 section is also a good quality aggregate with a maximum dry density of 130 pcf and an optimum water content of 10 percent. The Vulcan crushed granite base material placed in the South Carolina S-11 section has a maximum dry density of 138.1 pcf and an optimum water content of 5 percent. Figures B.65, B.66, and B.67 include photos of the surface condition of the Florida limerock, Missouri crushed limestone, and South Carolina crushed granite base, respectively.

Bulk samples of these base materials were collected for laboratory resilient modulus testing and confirming the M-D relationships obtained from NCAT for controlling the placement of these base materials.

Figure B.64. Multiple GeoGauges Being Used to Test the Missouri Crushed Stone Base and Determine the Modulus-Growth Curve During Compaction

Figure B.65. Florida Limerock Base Placed in NCAT Test Sections N-1 and N-2

HMA Layer: Seven different HMA sections were tested within the Part B field investigations at the NCAT test track. These included the following:

- Alabama Sections E-5, E-6, and E-7; During paving and 24 hours after paving
- Florida Sections N-1 and N-2; Lift 1 and lift 2
- Missouri N-10; First lift of paving
- South Carolina S-11; First lift of paving

The Alabama E-5 to 7 sections and Florida sections were tested in September 2006, while the Missouri and South Carolina sections were tested in October 2006.

Figures B.68 through B.70 show the test layout of the Alabama sections. The HMA mixture placed in these sections included a high percentage of RAP and different asphalt binders with and without asphalt modification. A PG67 asphalt was used in the HMA mix placed on Section E-5, a PG76 with SBS was used in Section E-6, and a PG76 with Sasobit was used in Section E-7.


a) Section view b) Rolling operation


c) Close-up view of compacted base d) NDT testing

Figure B.66. Missouri Crushed Limestone Base Placed in NCAT Test Section N-10

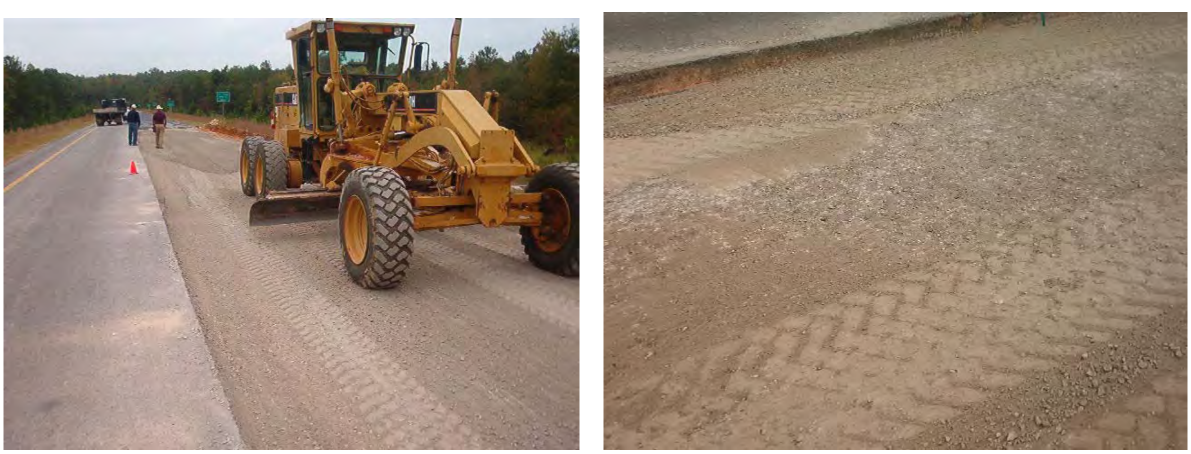


Figure B.67. South Carolina Crushed Granite Base Placed in NCAT Section S-11

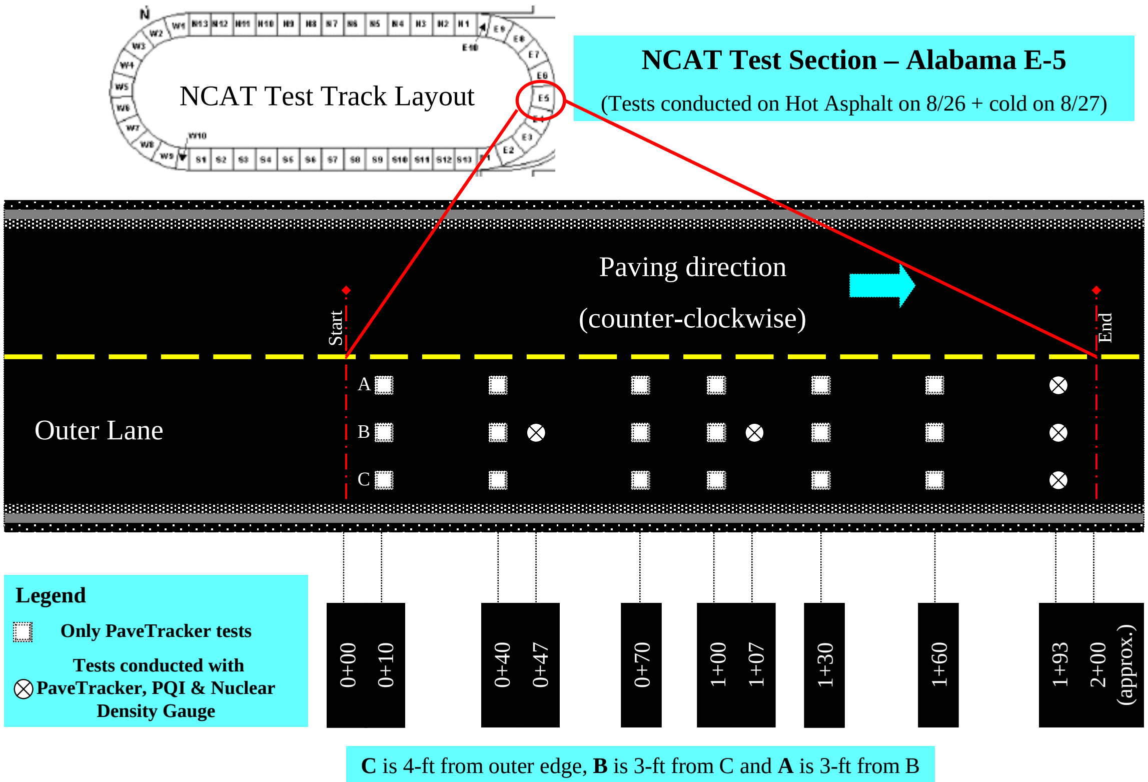


Figure B.68. Test Point Layout Along the Alabama E-5 Test Section at NCAT (refer to Tables B.14 and B.15)

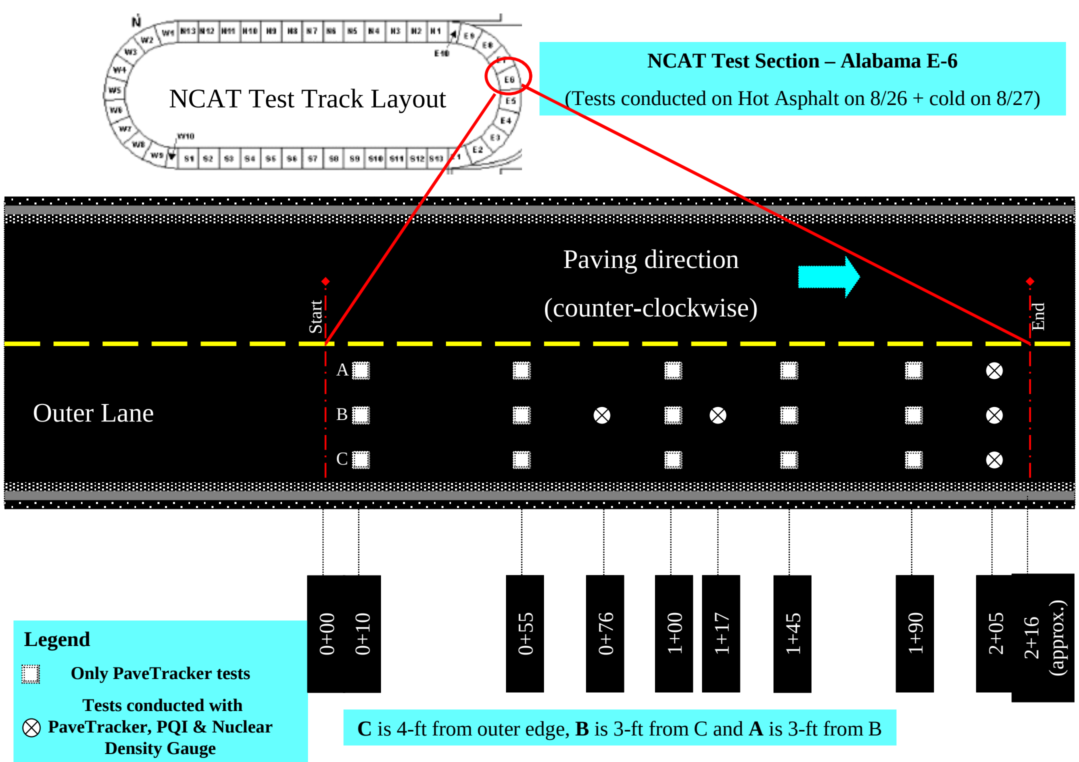


Figure B.69. Test Point Layout Along the Alabama E-6 Test Section at NCAT (refer to Tables B.14 and B.15)

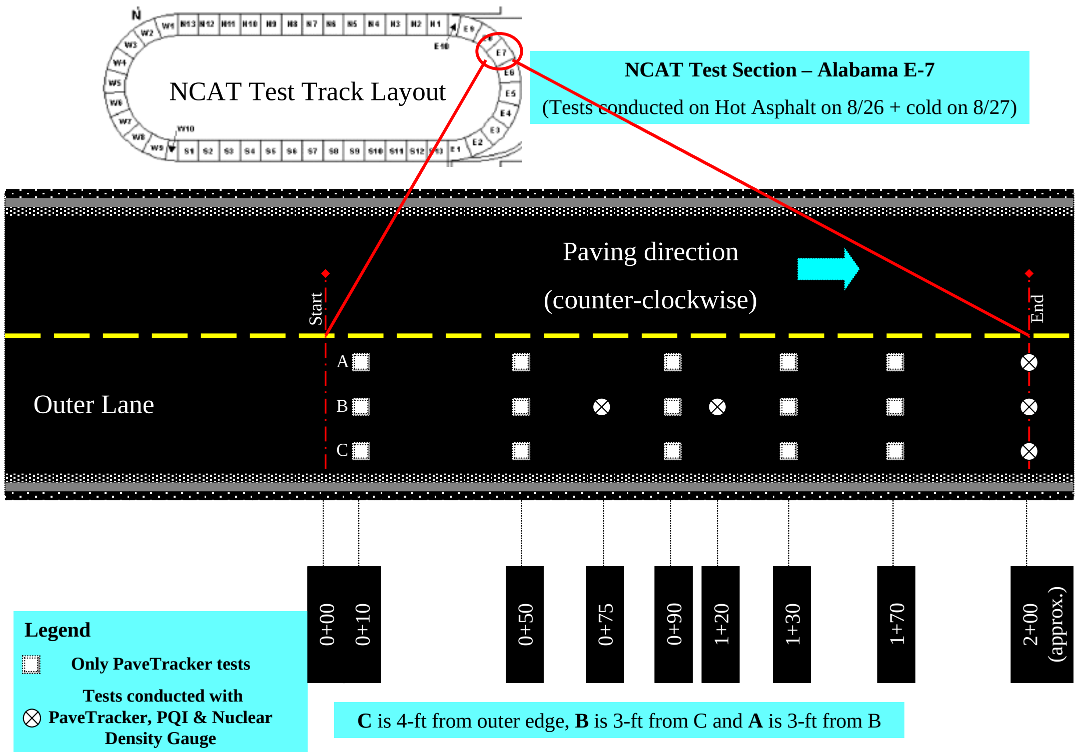


Figure B.70. Test Point Layout Along the Alabama E-7 Test Section at NCAT (refer to Tables B.14 and B.15)

These Alabama test sections were tested soon after paving and 24 hours after paving to evaluate the effect of temperature drop on modulus gain. As shown in the figures, the test points were laid out in a grid pattern. PSPA and the PQI non-nuclear density measurements were recorded at all points. A nuclear gauge was also used within these test sections to measure the density of the in-place mixture. Figure B.71 shows a picture of the finished section and NDT.

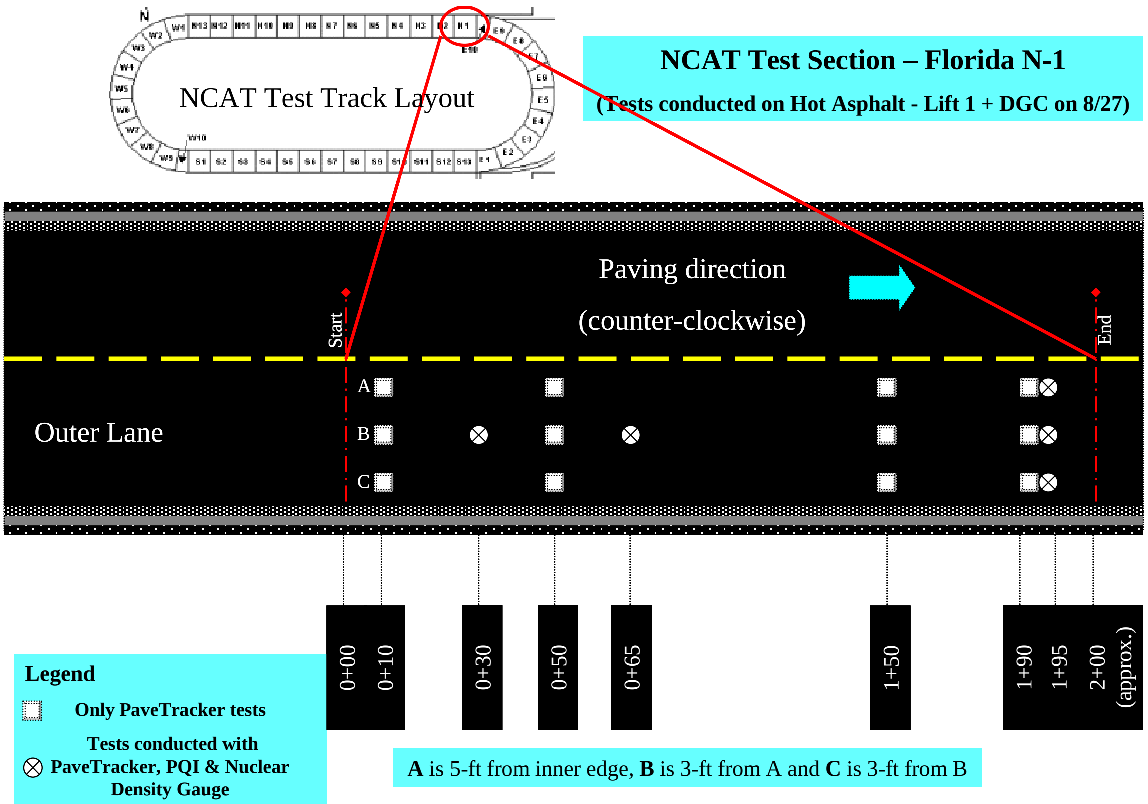
Figures B.72 and B.73 show the test point layout of the Florida N-1 and N-2 HMA sections that were tested in September 2006. Tests were performed on two lifts that were paved on consecutive days within each test section. The first HMA lift was 3 inches thick, and the second lift was 2 inches thick. The HMA placed was a 19-mm mixture with limestone aggregate. This first lift was a high binder content, crack resistant layer compacted to an air void level of 3 percent. The target density for the second lift was 145 pcf and target air void level was 7 percent. A PG 64-22 was used in the layers placed along Section N-1, while polymer modified asphalt with SBS was used in the mixtures placed along Section N-2.

During both days of testing, density growth readings were recorded after each roller pass at specific locations. Multiple devices were used for non-nuclear density measurement to evaluate variability between their readings. Figure B.74 shows the paving and testing of these sections. As with some of the other projects included in Part B, the Florida N-1 section at NCAT exhibited checking and mat tears during the compaction (see Figure B.75).

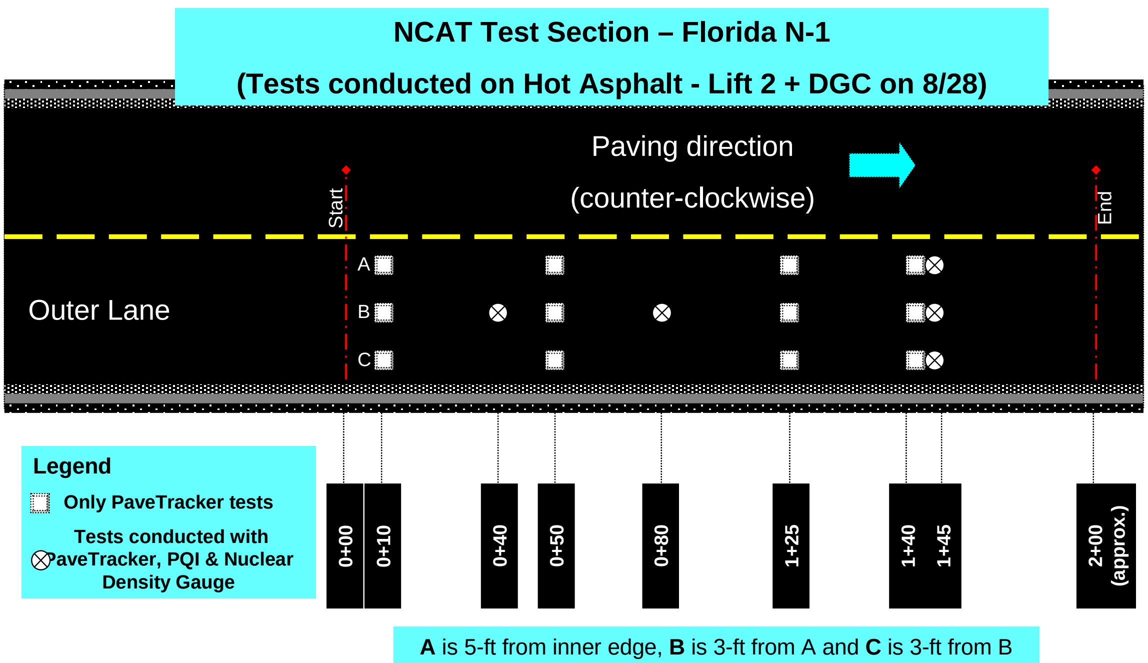
a) Paving of Alabama sections at NCAT test track

b) NDT testing immediately after paving

Figure B.71. Paving and General Surface Condition of the Alabama E-5, E-6, and E-7 Test Sections Placed NCAT



a) Lift 1 tested on August 28, 2006



b) Lift 2 tested on August 29, 2006

Figure B.72. Test Point Layout Along Florida Test Section N-1 at NCAT (refer to Tables B.14 and B.15)

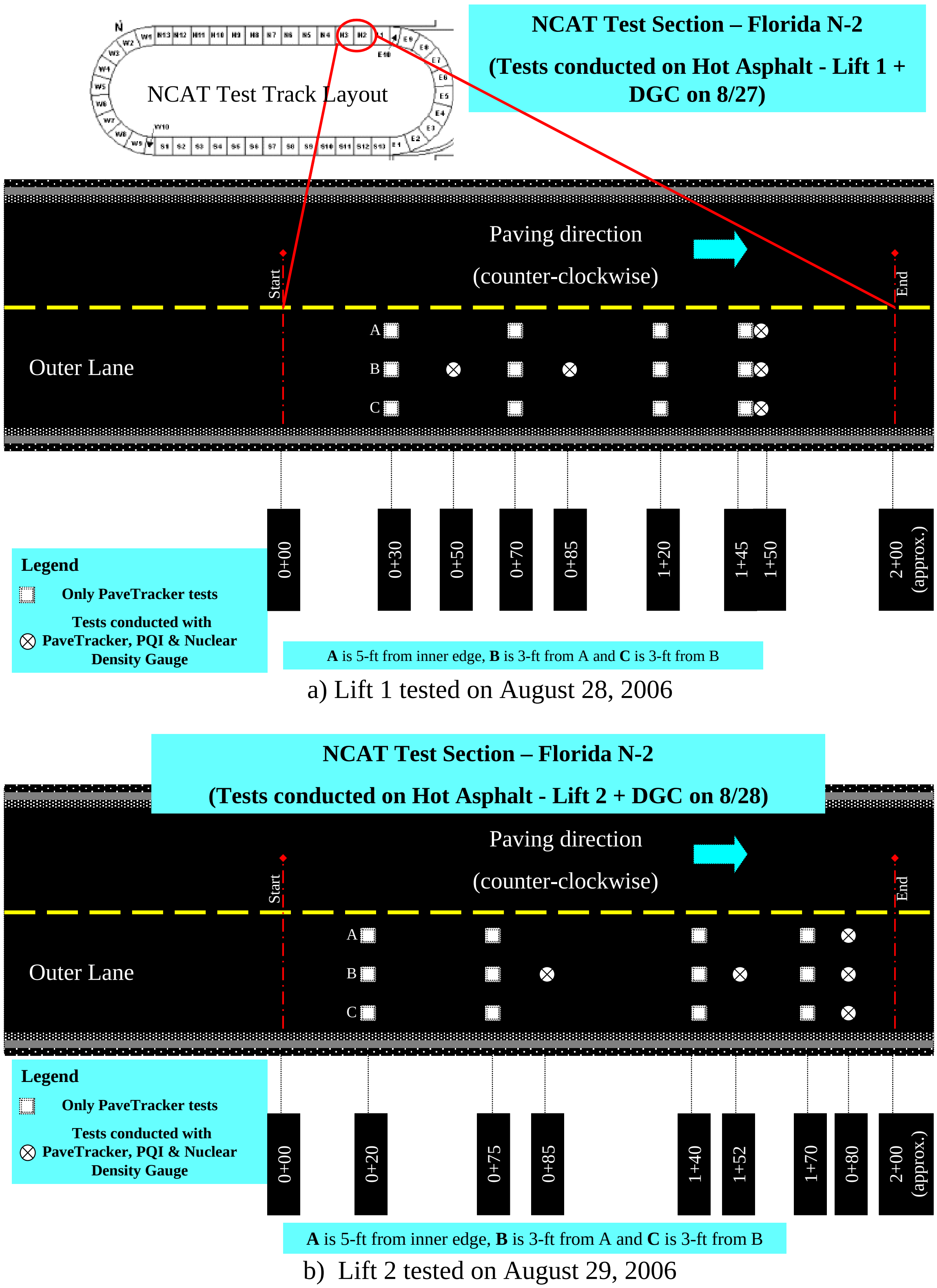


Figure B.73. Test Point Layout Along Florida N-2 Test Section at NCAT (refer to Tables B.14 and B.15)

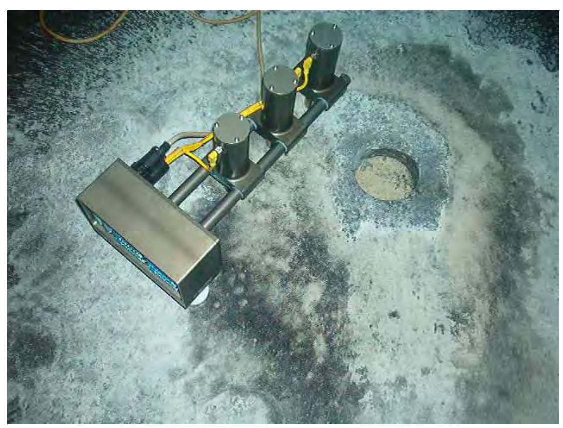
a) Paving first lift

b) Finished surface with first lift

c) Two lift completed

d) Finished surface; checking & mat tears

e) NDT testing – Nonnuclear density gage



f) NDT seismic testing and core

Figure B.74. Paving and NDT Measurements in Florida N-1 and N-2 Test Sections

Figure B.75. Checking and Mat Tears Exhibited Along the Florida Section N-1

Figure B.76 shows the test layout for the Missouri N-10 section. A 2-inch lift was paved using a PG64-22 asphalt mixture. The first lift was included in Part B. A grid pattern was adopted for this section and density growth readings were recorded as well. Readings from two non-nuclear Troxler gauges were obtained for this section. Nuclear density readings were also measured along this section.

Figures B.77 and B.78 include the test layout and the paving operations for the South Carolina section S-11 at NCAT. Data was collected during the paving of the first HMA lift of this section. The lift thickness for that layer was 2 inches. A grid pattern with three test points in the transverse direction at four stations within the section was used as the testing plan.

B.2.5 SR-53 New Construction; Fremont, Ohio

The SR 53 project selected for the Part B field evaluation was just south of the Ohio Turnpike and east of Toledo. The pavement design included two layers of HMA over a 6-inch aggregate base over a cement treated embankment layer placed on the natural subgrade. During the testing dates selected for this project, about 1800 feet of HMA was being paved in a specific area and several finished base layers were available (see Figure B.79). All tests were complete on October 18 and 19, 2006. The NDT devices that were used on all previous projects were used on this project and summarized in Table B.16. A brief description of the base and HMA test section is provided below.

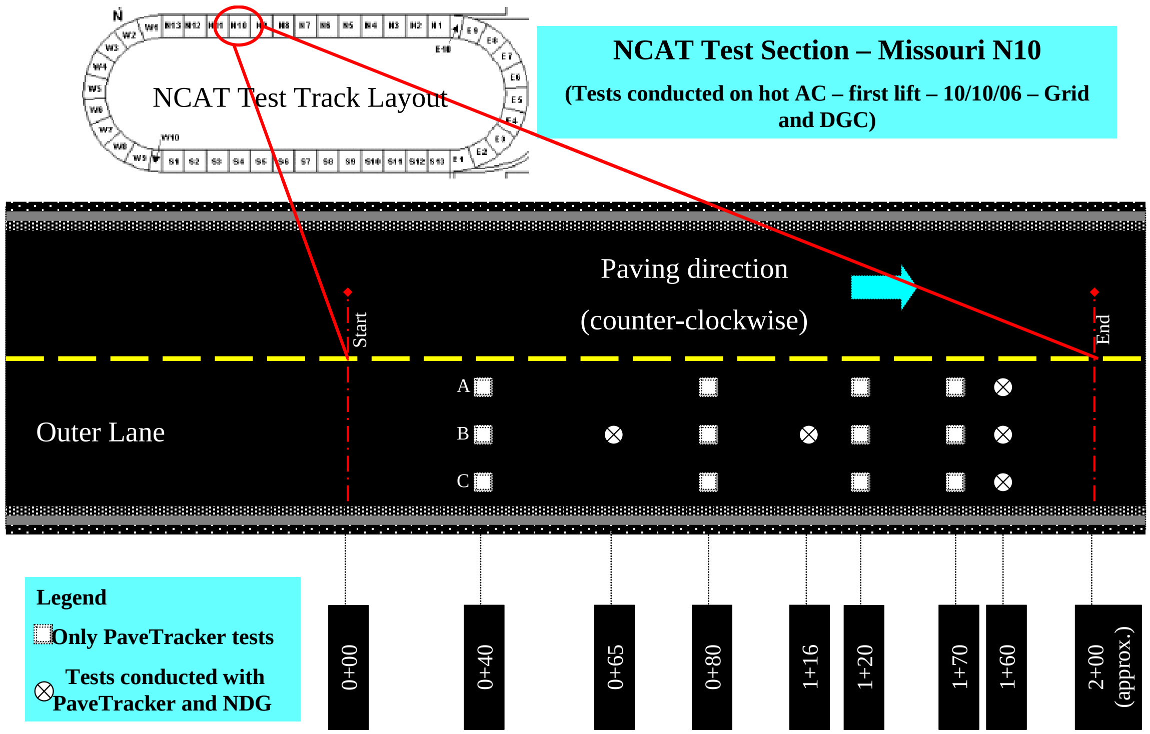


Figure B.76. Test Point Layout Along Missouri N-10 Test Section at NCAT (refer to Tables B.14 and B.15)

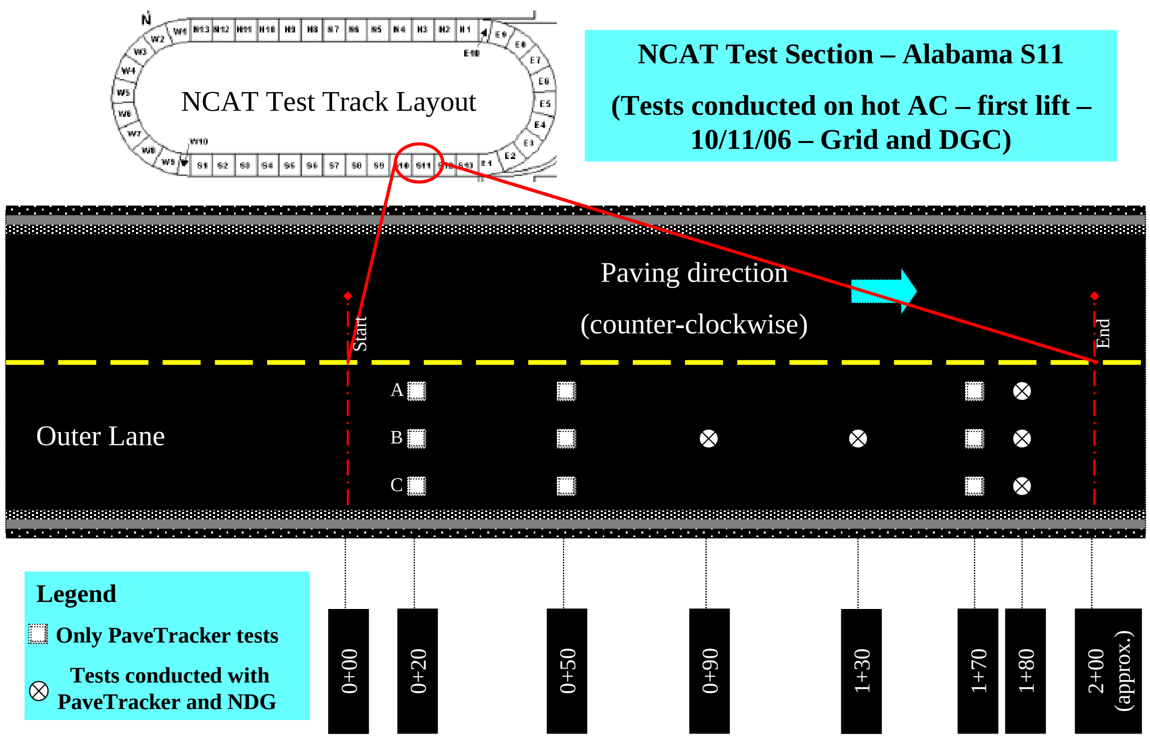


Figure B.77. Test Point Layout Along the South Carolina S-11 Test Section at NCAT (refer to Tables B.14 and B.15)

Figure B.78. HMA Compacted Using a Pneumatic Roller in the South Carolina Section S-11 at NCAT

Figure B.79. New Construction Project Along SR-53 Near Toledo, Ohio Included in the Part B Field Evaluation

Table B.16. Nondestructive Devices Used for the Ohio SR-53 Project in Ohio

NDT Technology	Subgrade	Aggregate Base	HMA††
GeoGauge (stiffness)*, †,	—	✓	—
Seismic – PSPA for HMA, DSPA for soils (modulus) *, #,	—	✓	✓
DCP	—	✓	
Non-nuclear HMA density (Troxler)*, †,	—	—	✓
Other Traditional Tests			
HMA mixture design test data	—	—	✓
HMA cores for densities & other volumetric properties	—	—	✓
Nuclear density tests	—	✓	✓
Moisture-density relationship tests	—	✓	—
Bulk material for laboratory modulus tests	—	✓	✓

* - Clustered tests performed at each test point – refer to figure B.1.
† - Multiple gauges to assess variability between devices
†† - Testing performed behind paver and weeks after paving

Base Layer: The base layer on the SR 53 project was a crushed stone base classified as Ohio 304 base material. It had rained within the 24-hour period preceding the base testing, and the base material was relatively damp at the surface. A cement treated subgrade material was used underneath the base layer tested. The aggregate base layer had a laboratory maximum dry density of 135.2 pcf and an optimum moisture content of 8.5 percent. Bulk material samples were collected for laboratory resilient modulus testing and M-D relationships confirmation that were provided during construction.

Figure B.80 shows the test point layout of the base section. All test points were located in the southbound lanes, and were roughly at 200 feet staggered transversely. GeoGauge and DSPA tests were performed at each test point along with DCP tests at selected points. Figures B.81 to B.83 include photos of the condition of the base and the NDT devices used to test the crushed stone base along SR-53 new construction project.

HMA Layer: The HMA mixture tested within NCHRP Project 10-65 for the field evaluation was classified as a 19-mm HMA base mixture and was the first lift placed above the crushed stone base layer. Tests were conducted on the newly placed HMA base mixture over a length of about 3000 feet. Test points were randomly chosen along the project width and at the selected locations where cores were taken for QA purposes. All tests were conducted in the shoulder, inner or outer lanes in the southbound direction. Figure B.84 shows the test point layout of the HMA test section.

Test data were collected behind the paver in the inner lane as shown in Figure B.85. Bulk material as well as core samples were collected for laboratory testing. DOT personnel provided details on the mixture design, and QA testing data.

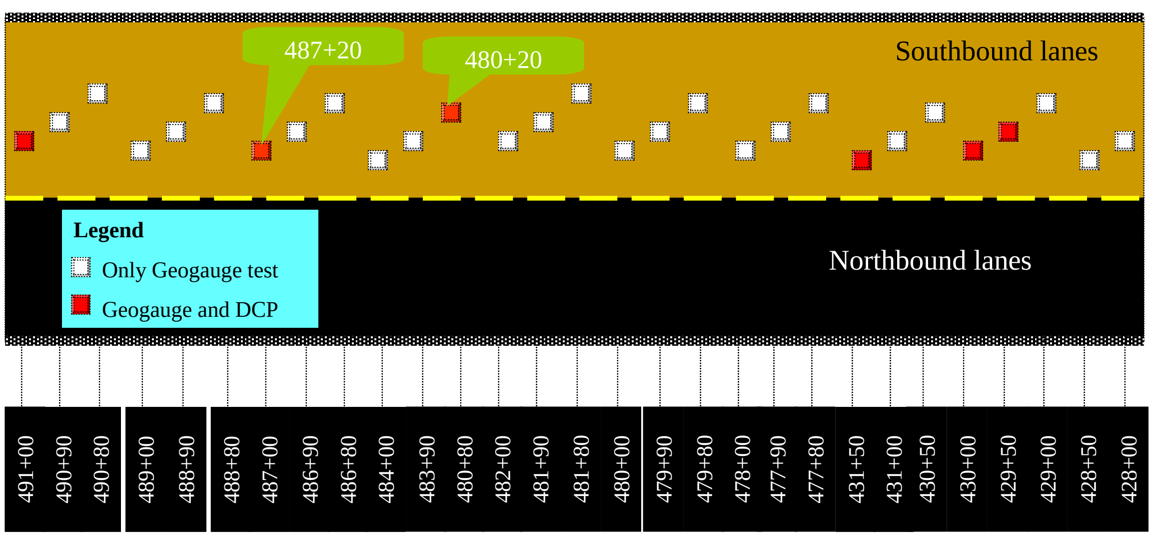


Figure B.80. Test Point Layout Along the Crushed Stone Base Section of SR-53 New Construction at Fremont, Ohio

Figure B.81. Crushed Stone Base Section Tested Along US-53 at Fremont, Ohio

Figure B.82. NDT Testing of the Crushed Stone Base with Multiple GeoGauges and the DSPA Along SR-53 in Ohio

Figure B.83. Seismic Testing of the Crushed Stone Base Layer Along SR-53 New Construction Project in Fremont, Ohio

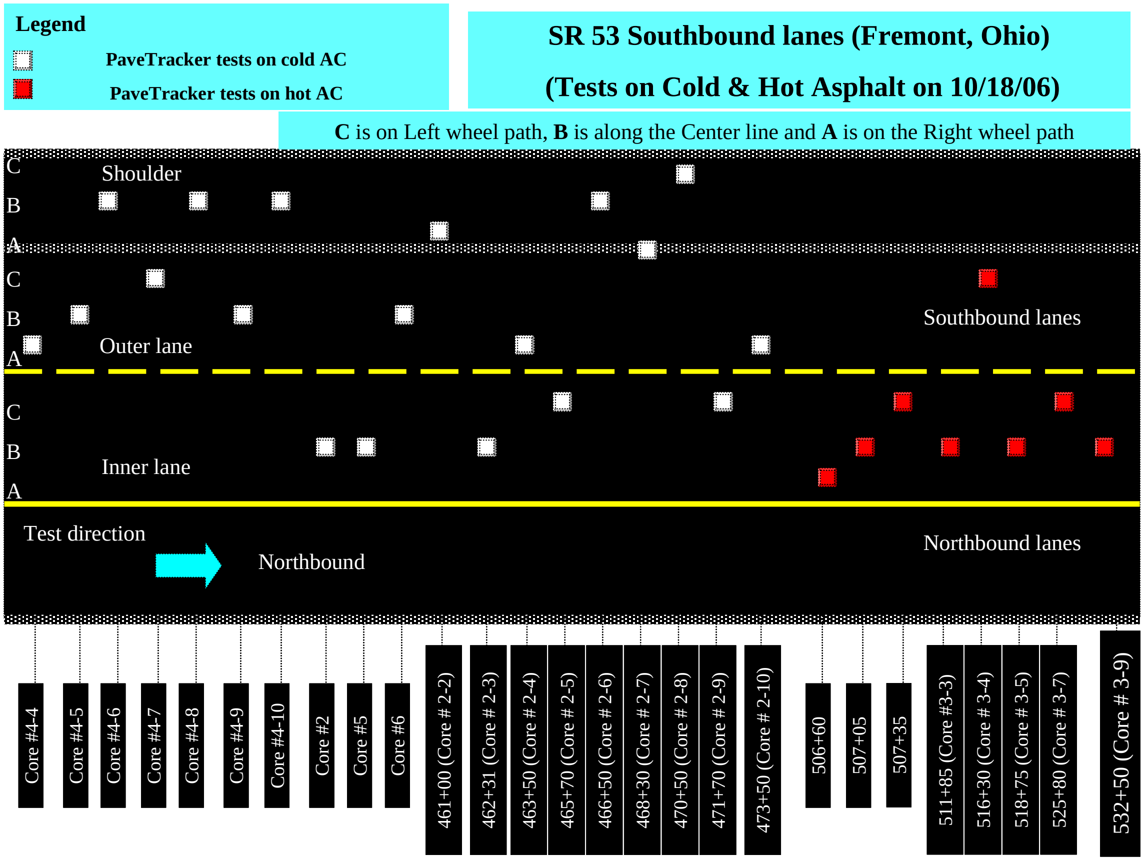


Figure B.84. Test Point Layout Along SR53 in Ohio

Figure B.85. HMA Paving and NDT Along SR 53 in Ohio

B.2.6 I-20, Caldwell, Texas

The reconstruction of the I-20 frontage road in Odessa, Texas, was included within the Part B field evaluation. Tests were conducted from November 13 through17, 2006. The HMA mixture included in the study was paved in a 2.5-inch-thick lift. Tests were done along the outer and middle lanes in the eastbound direction. Two test sections were established. Section 1 included test points from 5000 feet of paving along the outside lane of the three lane frontage road. Section 2 included test points within the same stationing but within the middle lane. Figures B.86 and B.87 include the test point and section layout for both sections.

Section 1 was paved and tested on November 14, 2006. Cores were taken from this section the following day. Section 2 was paved and tested on November 16, 2006. The test sections were divided into sublots every 50 to 100 feet, and the points were evenly distributed across the width of the test section. The NDT devices used on this project are summarized in Table B.17.

The difference between this project and the others included in Part B was that the contractor was already using the PaveTrack for controlling the compaction process. This contractor already had experience in using the PaveTrack and PSPA within a QA program. Thus, the gauges were not left with this contractor. Figure B.88 shows pictures of the paving and testing on the I-20 project. Non-nuclear density test results were collected in the vicinity of the cores.

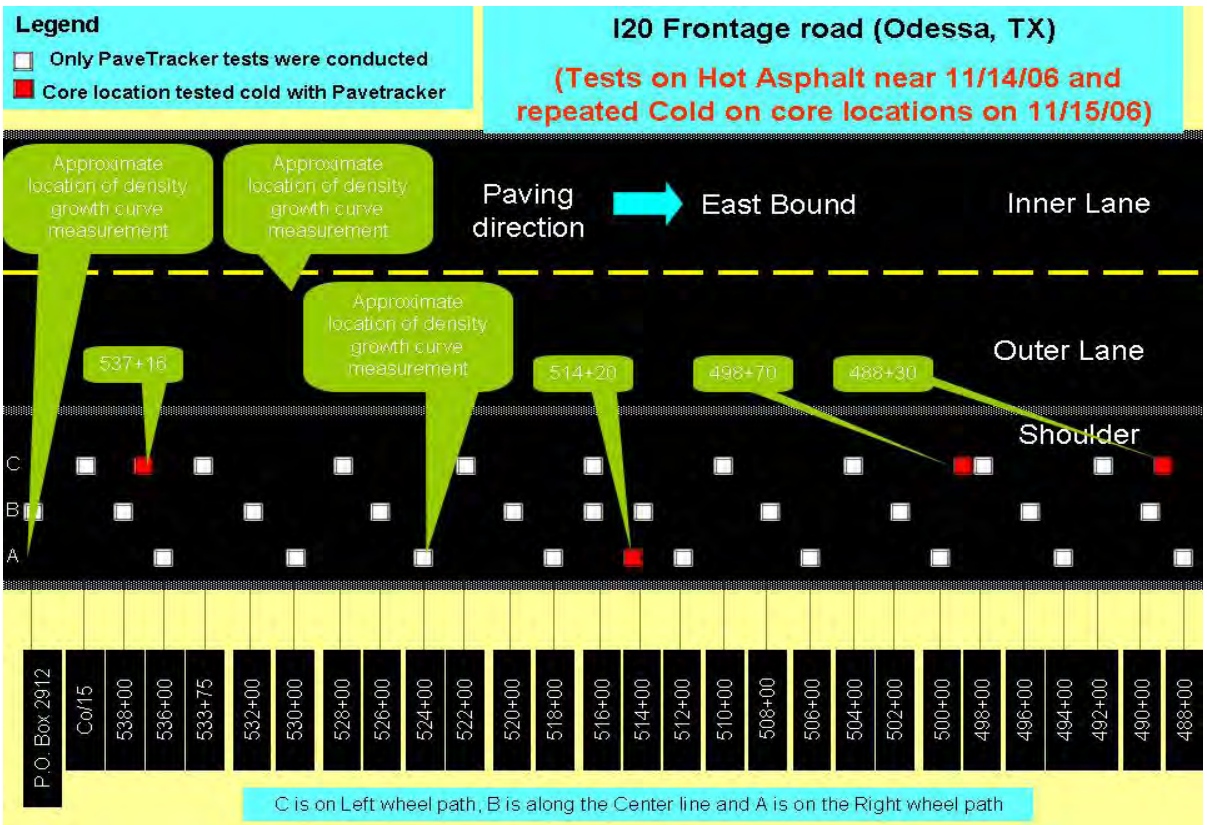


Figure B.86. Test Point Layout of Section 1 for HMA Testing Along the I-20 Frontage Road in Odessa, Texas

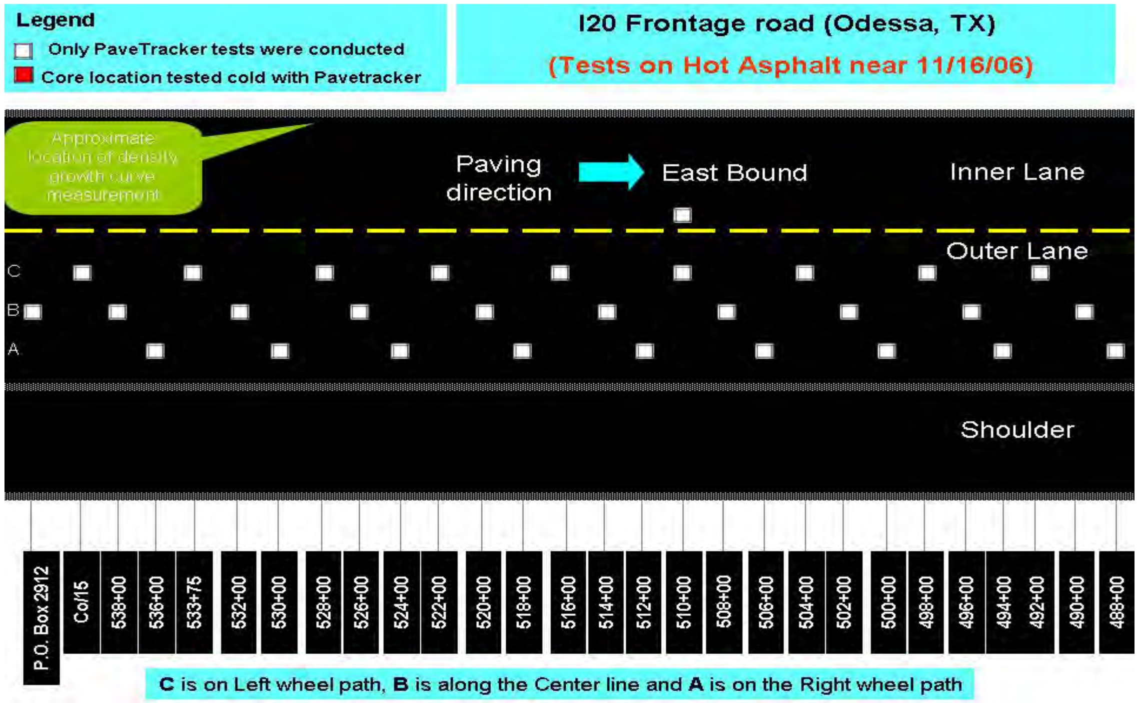


Figure B.87. Test Point Layout of Section 2 for HMA Testing Along the I-20 Frontage Road in Odessa, Texas

Table B.17. Nondestructive Devices Used Along the I-20 Frontage Road in Odessa, Texas

NDT Technology	Subgrade	Aggregate Base	HMA††
GeoGauge (stiffness)	—	—	—
Seismic – PSPA for HMA, DSPA for soils (modulus) *	—	—	✓
DCP	—	—	
Non-nuclear HMA density (Troxler)*’	—	—	✓
Other Traditional Tests			
HMA mixture design test data	—	—	✓
HMA cores for densities & other volumetric properties	—	—	✓
Nuclear density tests	—	—	—
Moisture-density relationship tests	—	—	—
Bulk material for laboratory modulus tests	—	—	✓

* - Clustered tests performed at each test point – refer to figure B.1.
† - Multiple gauges to assess variability between devices
†† - Testing performed behind paver and weeks after paving

a) and b) Paving on I-20 frontage road

c) Compacted lift

d) Finished surface

e) Non-nuclear density test

f) Seismic testing

Figure B.88. Paving and Testing of the Test Sections Along the I-20 Frontage Road in Odessa, Texas

APPENDIX C

DATA COLLECTED FROM THE FIELD EVALUATIONS

Appendix C is a listing of all data collected from the field and laboratory tests. The data have been written to a CD that is attached to this appendix. The first part of the appendix contains the measurements made by each of the NDT devices used within NCHRP Project 10-65. The processed data also are included in those sections of the CD (e.g., the resilient modulus values calculated from the DCP penetration indices and the forward- and backcalculated elastic modulus values from the deflections measured along each project section and lot).

The repeated load resilient modulus test results from laboratory tests on unbound materials and soils and the dynamic modulus results are included in the second part of the CD. The third part of the CD includes the standard or traditional volumetric and mixture design tests that were obtained from the agencies building the projects.

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PART A TESTING

UNBOUND MATERIAL TEST DATA

TH23, MN SUBGRADE TESTING

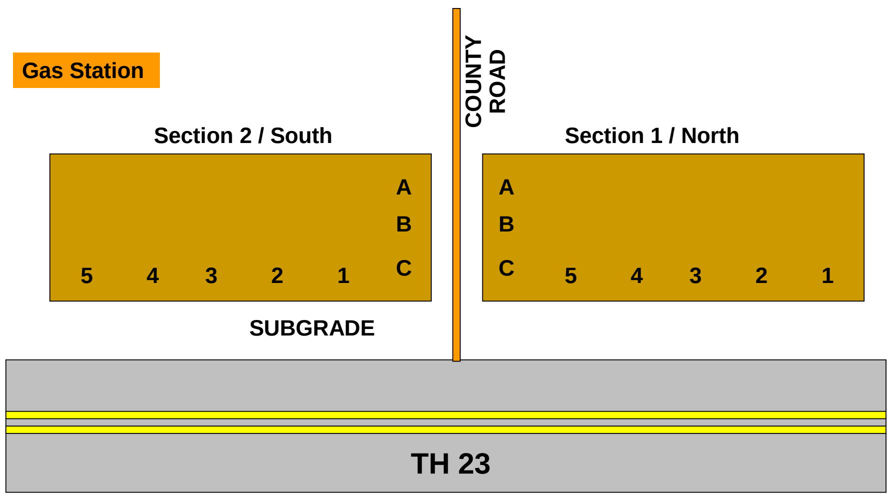


Table 1. Test point station information

Lot	Sublot	Point	GPS station	GPS Offset
North	1	A	8241+13.0	1.9RT
North	1	B	8241+13.0	5.9RT
North	1	C	8241+13.0	9.3RT
North	2	A	8240+13.7	2.7RT
North	2	B	8240+13.7	7.9RT
North	2	C	8240+13.7	11.1RT
North	3	A	8239+12.4	3.2RT
North	3	B	8239+12.4	9.8RT
North	3	C	8239+12.4	12.7RT
North	4	A	8238+11.3	1.4RT
North	4	B	8238+11.3	6.4RT
North	4	C	8238+11.3	11.1RT
North	5	A	8237+12.2	4.1RT
North	5	B	8237+12.2	8.1RT
North	5	C	8237+12.2	13.1RT
South	1	A	8229+98.3	2.5RT
South	1	B	8229+98.3	9.7RT
South	1	C	8229+98.3	16.6RT
South	2	A	8228+97.4	2.3RT
South	2	B	8228+97.4	11.3RT
South	2	C	8228+97.4	17.6RT
South	3	A	8227+98.9	2.7RT
South	3	B	8227+98.9	10.2RT
South	3	C	8227+98.9	17.1RT
South	4	A	8226+98	1.9RT
South	4	B	8226+98	10.3RT
South	4	C	8226+98	17.6RT
South	5	A	8226+00.3	3.8RT
South	5	B	8226+00.3	11.9RT
South	5	C	8226+00.3	17.6RT

Table 2. ***Penetration Index*** measured by ***DCP*** in ***TH-23, MN Subgrade, mm/blow***
Note: Test data for number of blows vs penetration is shown in Table 3

Lot #	Sublot	A	B	C	Average	Lot Average
1 (North)	1	5.6	5.5	6.7	5.9	
	2	7.4	6.3	7.5	7.1	
	3	10.7	5.2	7.1	7.7	
	4	11.9	14.1	15.1	13.7	
	5	14.8	12.7	18.2	15.2	9.9
2 (South)	1	14.4	17.8	21.9	18.0	
	2	15.1	14.2	21.6	16.9	
	3	13.4	12.3	25.1	16.9	
	4	12.6	10.6	22.0	15.0	
	5	11.5	9.0	11.7	10.7	15.5
Average lot 1 by row		10.1	8.8	10.9		
Average lot 2 by row		13.4	12.8	20.4		
Average project by row		11.7	10.8	15.7		
Average project						12.7

Table 3. ***Penetration Index*** measured by ***DCP*** in ***TH-23, MN Subgrade, mm/blow***
Note: Summary is shown in Table 2

Lot		Penetration, mm			PI, mm/blow			Penetration, mm			PI, mm/blow		
		North	North	North	North	North	North	North	North	North	North	North	North
Sublot		1	1	1	1	1	1	2	2	2	2	2	2
Point		A	B	C	A	B	C	A	B	C	A	B	C
Number of blows	1	8	13	14				22	20	11			
	5	51	45	39	8.6	6.4	5.0	81	92	49	11.8	14.4	7.6
	10	84	78	82	7.6	6.5	6.8	113	122	114	9.1	10.2	10.3
	15	109	117	131	6.7	6.9	7.8	136	139	168	7.6	7.9	10.5
	20	132	126	158	6.2	5.7	7.2	162	153	193	7.0	6.7	9.1
	25	154	141	180	5.8	5.1	6.6	183	167	210	6.4	5.9	8.0
	30	177	157	211	5.6	4.8	6.6	211	182	225	6.3	5.4	7.1
	35	194	166	255	5.3	4.4	6.9	240	197	244	6.2	5.1	6.7
	40	214	169	290	5.2	3.9	6.9	268	213	258	6.2	4.8	6.2
	45	230	(refused)	309	4.9		6.6	305	226	272	6.3	4.6	5.8
	50	244			4.7				246	286		4.5	5.5
	55	258			4.5				264	302		4.4	5.3
	60	273			4.4				281			4.4	
	65	285			4.3				300			4.3	
	70	301			4.2								
Average at point					5.6	5.5	6.7				7.4	6.3	7.5

Table 3 Continued, ***Penetration Index*** measured by ***DCP*** in ***TH-23, MN Subgrade, mm/blow***
Note: Summary is shown in Table 2

Lot		Penetration, mm			PI, mm/blow			Penetration, mm			PI, mm/blow		
		North	North	North	North	North	North	North	North	North	North	North	North
Sublot		3	3	3	3	3	3	4	4	4	4	4	4
Point		A	B	C	A	B	C	A	B	C	A	B	C
Number of blows	1	37	35	9				11	14	32			
	5	101	80	79	12.8	9.0	14.0	71	86	104	12.0	14.4	14.4
	10	140	109	124	10.3	7.4	11.5	146	171	194	13.5	15.7	16.2
	15	192	127	151	10.3	6.1	9.5	209	247	260	13.2	15.5	15.2
	20	239	147	168	10.1	5.6	8.0	251	274	320	12.0	13.0	14.4
	25	284	168	184	9.9	5.3	7.0	282	316		10.8	12.1	
	30	359	189	200	10.7	5.1	6.4	301			9.7		
	35		207	216		4.9	5.9						
	40		221	230		4.7	5.5						
	45		240	246		4.6	5.3						
	50		254	258		4.4	5.0						
	55		269	274		4.3	4.8						
	60		282	295		4.1	4.8						
	65		296	331		4.0	5.0						
	70		314			4.0							
Average at point					10.7	5.2	7.1				11.9	14.1	15.1

Table 3 Continued, ***Penetration Index*** measured by ***DCP*** in ***TH-23, MN Subgrade, mm/blow***
Note: Summary is shown in Table 2

Lot		**Penetration, mm**			**PI, mm/blow**			**Penetration, mm**			**PI, mm/blow**		
		North	**North**	**North**	**North**	**North**	**North**	**South**	**South**	**South**	**South**	**South**	**South**
Sublot		**5**	**5**	**5**	**5**	**5**	**5**	**1**	**1**	**1**	**1**	**1**	**1**
Point		**A**	**B**	**C**	**A**	**B**	**C**	**A**	**B**	**C**	**A**	**B**	**C**
Number of blows	1	22	25	33				8	18	65			
	5	89	88	131	13.4	12.6	19.6	88	130	202	16.0	22.4	27.4
	10	176	132	239	15.4	10.7	20.6	182	201	274	17.4	18.3	20.9
	15	264	230	296	16.1	13.7	17.5	222	259	325	14.3	16.1	17.3
	20	308	302	337	14.3	13.9	15.2	259	306		12.6	14.4	
	25							300			11.7		
	30												
	35												
	40												
	45												
	50												
	55												
	60												
	65												
	70												
Average at point					14.8	12.7	18.2				14.4	17.8	21.9

Table 3 Continued, ***Penetration Index*** measured by ***DCP*** in ***TH-23, MN Subgrade, mm/blow***
Note: Summary is shown in Table 2

Lot		**Penetration, mm**			**PI, mm/blow**			**Penetration, mm**			**PI, mm/blow**		
		South	**South**	**South**	**South**	**South**	**South**	**South**	**South**	**South**	**South**	**South**	**South**
Sublot		**2**	**2**	**2**	**2**	**2**	**2**	**3**	**3**	**3**	**3**	**3**	**3**
Point		**A**	**B**	**C**	**A**	**B**	**C**	**A**	**B**	**C**	**A**	**B**	**C**
Number of blows	1	16	11	59				10	7	18			
	5	76	94	190	12.0	16.6	26.2	79	63	180	13.8	11.2	32.4
	10	181	172	265	16.5	16.1	20.6	158	153	256	14.8	14.6	23.8
	15	266	220	328	16.7	13.9	17.9	213	207	303	13.5	13.3	19.0
	20	319	264		15.2	12.7		269	255		13.0	12.4	
	25		302			11.6		307	292		11.9	11.4	
	30								330			10.8	
	35												
	40												
	45												
	50												
	55												
	60												
	65												
	70												
Average at point					15.1	14.2	21.6				13.4	12.3	25.1

Table 3 Continued, ***Penetration Index*** measured by ***DCP*** in ***TH-23, MN Subgrade, mm/blow***
Note: Summary is shown in Table 2

Lot		**Penetration, mm**			**PI, mm/blow**			**Penetration, mm**			**PI, mm/blow**		
		South	**South**	**South**	**South**	**South**	**South**	**South**	**South**	**South**	**South**	**South**	**South**
Sublot		**4**	**4**	**4**	**4**	**4**	**4**	**5**	**5**	**5**	**5**	**5**	**5**
Point		**A**	**B**	**C**	**A**	**B**	**C**	**A**	**B**	**C**	**A**	**B**	**C**
Number of blows	1	32	16	59				24	26	47			
	5	121	67	171	17.8	10.2	22.4	120	93	140	19.2	13.4	18.6
	10	181	141	289	14.9	12.5	23.0	165	144	184	14.1	11.8	13.7
	15	216	180	366	12.3	10.9	20.5	197	181	209	11.5	10.3	10.8
	20	251	212		11.0	9.8		225	213	235	10.1	9.4	9.4
	25	280	259		9.9	9.7		251	244	269	9.1	8.7	8.9
	30	316	332		9.5	10.5		279	264	306	8.5	7.9	8.6
	35							305	277		8.0	7.2	
	40								291			6.6	
	45								300			6.1	
	50								(possibly a rock under the cone)				
	55												
	60												
	65												
	70												
Average at point					12.6	10.6	22.0				11.5	9.0	11.7

Table 4. ***Wet density*** measured by ***EDG*** in ***TH-23, MN Subgrade, pcf***
Note: Test repetitions were not performed at individual points

Lot #	Sublot	A	B	C	Average	Lot Average
1 (North)	1	133.62	133.59	133.97	133.73	
	2	133.6	133.55	133.71	133.62	
	3	133.77	133.68	133.89	133.78	
	4	133.87	133.73	122.41	130.00	
	5	133.67	133.68	134.12	133.82	132.99
2 (South)	1	132.98	133.02	133.15	133.05	
	2	133.17	133.26	133.38	133.27	
	3	133.36	133.52	133.23	133.37	
	4	133.32	133.31	133.55	133.39	
	5	134.21	134.21	133.65	134.02	133.42
Average lot 1 by row		10.6	133.71	133.65	131.62	
Average lot 2 by row		13.8	133.41	133.46	133.39	
Average project by row		12.2	133.56	133.56	132.51	
Average project						133.21

Table 5. ***Percent Moisture*** measured by **EDG** in **TH-23, MN Subgrade**
Note: Test repetitions were not performed at individual points

Lot #	Sublot	A	B	C	Average	Lot Average
1 (North)	1	8.1	8	6.8	7.6	
	2	8.3	8.2	7.7	8.1	
	3	7.6	8.0	7.6	7.7	
	4	7.5	8.0	9.0	8.2	
	5	8.4	8.0	6.8	7.7	7.9
2 (South)	1	10.7	10.5	9.2	10.1	
	2	9.4	9.2	8.6	9.1	
	3	8.8	7.7	9.3	8.6	
	4	9.2	9.2	8.1	8.8	
	5	6.5	6.3	7.7	6.8	8.7
Average lot 1 by row		10.6	8.0	8.0	7.6	
Average lot 2 by row		13.8	8.9	8.6	8.6	
Average project by row		12.2	8.4	8.3	8.1	
Average project						8.3

Table 6. ***Modulus*** measured by ***GEOGAUGE*** in ***TH-23, MN Subgrade, psi***
Note: Test repetitions were performed at individual points as shown in Table 7

Lot #	**Sublot**	**A**	**B**	**C**	**Average**	**Lot Average**
1 (North)	1	14293	10580	13920	12931	
	2	14017	9560	8943	10840	
	3	13647	10383	7937	10656	
	4	10580	9790	10553	10308	
	5	10303	9683	10180	10056	10958
2 (South)	1	11603	12103	8063	10590	
	2	10110	9167	6923	8733	
	3	8933	10210	6697	8613	
	4	10330	11797	7670	9932	
	5	9373	11027	8330	9577	9489
Average lot 1 by row		12568	9999	10307		
Average lot 2 by row		10070	10861	7537		
Average project by row		11319	10430	8922		
Average project						10224

Table 7. Repeatability in ***Modulus*** measurements by ***Geogauge*** in ***TH-23, MN Subgrade, psi***

Note: Summary of test results are shown in Table 6.

Lot	Sublot	Point	Trial 1	Trial 2	Trial 3	Average at point	Std deviation at point
North	1	A	12160	16400	14320	14293	**2120**
North	1	B	8980	10620	12140	10580	**1580**
North	1	C	15560	12940	13260	13920	**1429**
North	2	A	14560	14360	13130	14017	**774**
North	2	B	8840	10720	9120	9560	**1014**
North	2	C	8880	8740	9210	8943	**241**
North	3	A	14940	13510	12490	13647	**1231**
North	3	B	11600	10190	9360	10383	**1132**
North	3	C	8840	7880	7090	7937	**876**
North	4	A	10240	9730	11770	10580	**1062**
North	4	B	9550	10200	9620	9790	**357**
North	4	C	9290	11450	10920	10553	**1126**
North	5	A	10780	9770	10360	10303	**507**
North	5	B	8590	10260	10200	9683	**947**
North	5	C	10210	10380	9950	10180	**217**
South	1	A	10900	12070	11840	11603	**620**
South	1	B	10920	11340	14050	12103	**1699**
South	1	C	7440	7360	9390	8063	**1150**
South	2	A	10990	8750	10590	10110	**1195**
South	2	B	9310	9210	8980	9167	**169**
South	2	C	6550	6590	7630	6923	**612**
South	3	A	8370	9600	8830	8933	**621**
South	3	B	8750	9620	12260	10210	**1828**
South	3	C	6430	6760	6900	6697	**241**
South	4	A	9730	10680	10580	10330	**522**
South	4	B	10830	11410	13150	11797	**1207**
South	4	C	7140	7420	8450	7670	**690**
South	5	A	7850	9740	10530	9373	**1377**
South	5	B	11390	10310	11380	11027	**621**
South	**5**	**C**	**7090**	**8150**	**9750**	**8330**	**1339**

Table 8. ***Dielectric*** measured by ***GPR*** in ***TH-23, MN Subgrade***
Note: Test repetitions were not performed at individual points

Lot #	Sublot	A	B	C	Average	Lot Average
1 (North)	1	25.8	13.3	22.6	20.6	
	2	23.2	12.7	19.7	18.6	
	3	21.3	13.3	19.5	18.0	
	4	25.1	15.1	20.0	20.1	
	5	19.5	12.9	14.9	15.8	18.6
2 (South)	1	20.3	21.8	28.1	23.4	
	2	16.9	47.0	31.0	31.6	
	3	22.9	43.4	20.3	28.8	
	4	21.5	43.1	18.5	27.7	
	5	20.1	27.0	21.5	22.8	26.9
Average lot 1 by row		12568	23.00	13.47	19.33	
Average lot 2 by row		10070	20.32	36.44	23.88	
Average project by row		11319	21.7	25.0	21.6	
Average project						22.7

Table 9. ***Modulus*** measured by ***LWD 1*** in ***TH-23, MN Subgrade, psi***
Note: Test repetitions were performed at individual points as shown in Table 10

Lot #	**Sublot**	**A**	**B**	**C**	**Average**	**Lot Average**
1 (North)	1	4879	3532	6073	4828	
	2	8196	7698	5252	7049	
	3	6547	4765	1374	4229	
	4	4770	2424	1345	2846	
	5	1607	4021	957	2195	4229
2 (South)	1	4176	1819	908	2301	
	2	2816	312	832	1320	
	3	2933	4120	1172	2742	
	4	2755	5255	410	2807	
	5	2744	3637	1857	2746	2383
Average lot 1 by row		12568	5200	4488	3000	
Average lot 2 by row		10070	3085	3029	1036	
Average project by row		11319	4142	3758	2018	
Average project						3306

Table 10. Repeatability in ***Modulus*** measurements by ***LWD 1*** in ***TH-23, MN Subgrade, psi***
Note: Summary of test results are shown in Table 9

Lot	Sublot	Point A			Point B			Point C		
		Load, kN	**Deflection, mm**	**Modulus, psi ***	**Load, kN**	**Deflection, mm**	**Modulus, psi**	**Load, kN**	**Deflection, mm**	**Modulus, psi**
North	1	6.5	0.25	3531	3.7	0.32	1402	7.5	0.27	**3368**
		9.5	0.2	6450	4.2	0.32	1591	10.3	0.23	**5430**
		7	0.26	3656	6.7	0.28	2901	11.1	0.21	**6409**
		9.3	0.23	5491	8.5	0.26	3964	10.8	0.23	**5693**
		9.3	0.23	5491	8	0.26	3731	11.1	0.22	**6118**
			Average	4879			3532			**6073**
			Std. dev	1059			558			**360**
North	2	8	0.24	4042	6.7	0.27	3009	5	0.33	**1837**
		11.1	0.2	6729	12.1	0.2	7336	10.3	0.23	**5430**
		12.3	0.18	8285	10.6	0.21	6120	9.3	0.24	**4698**
		11.8	0.19	7530	12.9	0.18	8690	8.3	0.25	**4025**
		12.3	0.17	8773	12.3	0.18	8285	11.6	0.2	**7032**
			Average	8196			7698			**5252**
			Std. dev	626			1382			**1578**
North	3	8.3	0.26	3871	7.5	0.31	2933	1.1	0.5	**267**
		11.8	0.21	6813	9	0.27	4042	2.9	0.43	**818**
		9.5	0.23	5008	9	0.27	4042	2.4	0.43	**677**
		11.8	0.21	6813	10.1	0.25	4898	4.7	0.37	**1540**
		12.9	0.2	7821	10.6	0.24	5355	5.5	0.35	**1905**
			Average	6547			4765			**1374**
			Std. dev	1425			667			**631**

Lot	Sublot	Point A			Point B			Point C		
		Load, kN	Deflection, mm	Modulus, psi *	Load, kN	Deflection, mm	Modulus, psi	Load, kN	Deflection, mm	Modulus, psi
North	4	4.7	0.32	1781	2.9	0.37	950	19.8	0.65	**3693**
		9.3	0.24	4698	6.7	0.29	2801	2.9	0.36	**977**
		9.3	0.24	4698	5	0.32	1895	4.2	0.33	**1543**
		9.8	0.23	5166	6	0.31	2347	3.2	0.34	**1141**
		8.8	0.24	4446	7	0.28	3031	3.9	0.35	**1351**
			Average	4770			2424			**1345**
			Std. dev	366			572			**201**
North	5	0.4	0.36	135	2.4	0.35	831	25.2	0.49	**6236**
		4.7	0.29	1965	7.5	0.25	3637	2.7	0.38	**862**
		4.2	0.29	1756	6.2	0.27	2784	3.2	0.38	**1021**
		4.7	0.29	1965	8	0.24	4042	2.9	0.38	**925**
		2.9	0.32	1099	9.5	0.22	5236	2.9	0.38	**925**
			Average	1607			4021			**957**
			Std. dev	452			1226			**55**
South	1	2.9	0.29	1212	23.4	0.3	9457	23.2	0.49	**5741**
		6	0.24	3031	1.9	0.24	960	1.4	0.36	**472**
		6.7	0.22	3693	3.2	0.24	1617	2.9	0.33	**1066**
		7.5	0.21	4330	3.4	0.24	1718	2.9	0.31	**1134**
		7.8	0.21	4504	4.2	0.24	2122	1.6	0.37	**524**
			Average	4176			1819			**908**
			Std. dev	427			267			**334**

Lot	Sublot	Point A			Point B			Point C		
		Load, kN	**Deflection, mm**	**Modulus, psi ***	**Load, kN**	**Deflection, mm**	**Modulus, psi**	**Load, kN**	**Deflection, mm**	**Modulus, psi**
South	2	2.7	0.34	963	20.9	0.63	4022	24.4	0.52	**5689**
		1.6	0.34	571	1.1	0.42	318	3.2	0.39	**995**
		5	0.3	2021	1.4	0.4	424	2.9	0.4	**879**
		6.2	0.26	2891	0.6	0.43	169	1.6	0.41	**473**
		7	0.24	3536	1.1	0.39	342	3.4	0.36	**1145**
			Average	2816			312			**832**
			Std. dev	761			130			**338**
South	3	25.5	0.37	8356	4.4	0.3	1778	24.2	0.54	**5434**
		5.5	0.25	2667	7.5	0.26	3498	2.4	0.4	**727**
		6.7	0.23	3532	8	0.24	4042	3.4	0.58	**711**
		5.5	0.27	2470	8.5	0.24	4294	4.2	0.36	**1415**
		6	0.26	2798	8.3	0.25	4025	3.9	0.34	**1391**
			Average	2933			4120			**1172**
			Std. dev	544			151			**400**
South	4	0.4	0.42	115	7.8	0.25	3783	24.7	0.63	**4754**
		6.5	0.27	2919	4.2	0.34	1498	2.4	0.46	**633**
		4.2	0.3	1697	8.8	0.23	4639	2.7	0.43	**761**
		6.5	0.26	3031	9.3	0.24	4698	1.1	0.44	**303**
		7	0.24	3536	10.6	0.2	6426	0.6	0.44	**165**
			Average	2755			5255			**410**
			Std. dev	950			1015			**312**
South	5	3.7	0.33	1359	3.7	0.33	1359	25.5	0.45	**6871**

Lot	Sublot	Point A			Point B			Point C		
		Load, kN	**Deflection, mm**	**Modulus, psi ***	**Load, kN**	**Deflection, mm**	**Modulus, psi**	**Load, kN**	**Deflection, mm**	**Modulus, psi**
South		7	0.26	3264	4.2	0.3	1697	4.2	0.33	**1543**
South		8	0.24	4042	8.8	0.22	4850	3.4	0.33	**1249**
		4.2	0.32	1591	8	0.24	4042	5.5	0.29	**2300**
		6	0.28	2598	5	0.3	2021	5	0.3	**2021**
			Average	2744			3637			**1857**
			Std. dev	**1232**			**1457**			**544**

* Average modulus values are calculated using load-deflection data for drops 3, 4, and 5. Drops 1 and 2 are considered seating drops.
Calibration factors for load and deflection were 0.7 and 4.0 for this LWD device
Modulus is determined from the following expression:

$$E(psi) = 2\left(1-\nu^2\right) * a * \frac{P}{Area} * \frac{1000}{\delta} * 0.145$$

ν is the Poisson's ration (recommended value is 0.4 for this device)
a is radius of the load plate in mm (100 mm in this project)
P is the contact pressure kPa
δ is the deflection measured by the LWD in mm
0.145 is the conversion factor to express modulus in psi

Table 11. ***Modulus*** measured by ***LWD 2*** in ***TH-23, MN Subgrade, psi***
Note: Test repetitions were performed at individual points as shown in Table 12

Lot #	Sublot	A	B	C	Average	Lot Average
1 (North)	1	5203	2719	6453	4792	
	2	4041	4752	2671	3821	
	3	5035	5128	4292	4819	
	4	3914	5023	5767	4901	
	5	5231	5466	5806	5501	4767
2 (South)	1	7289	6936	5456	6560	
	2	5386	5881	5659	5642	
	3	6479	5960	5829	6090	
	4	5185	3379	4272	4279	
	5	6073	4164	6544	5594	5633
Average lot 1 by row		12568	4685	4618	4998	
Average lot 2 by row		10070	6083	5264	5552	
Average project by row		11319	5384	4941	5275	
Average project						5200

Table 12. Repeatability in ***Modulus*** measurements by ***LWD 2*** in ***TH-23, MN Subgrade, psi***
Note: Summary of test results are shown in Table 11

Lot	Sublot	Point A			Point B			Point C		
		Load, kN	**Deflection, μm**	**Modulus, psi ***	**Load, kN**	**Deflection, μm**	**Modulus, psi ***	**Load, kN**	**Deflection, μm**	**Modulus, psi ***
North	1	8.22	505	5610	8.21	499	5670	8.07	420	**6622**
		8.73	763	3943	8.86	1208	2528	8.39	565	**5118**
		8.71	689	4357	8.84	1138	2677	8.83	496	**6135**
		8.61	441	6728	8.83	1118	2722	8.84	494	**6167**
		8.6	655	4525	8.96	1119	2759	8.54	417	**7058**
			Average	5203			2719			**6453**
			Std. dev	1323			41			**524**
North	2	8.93	537	5731	8.78	529	5720	8.45	1230	**2368**
		9.05	781	3993	8.94	690	4465	8.91	1131	**2715**
		8.84	737	4134	8.9	613	5004	8.68	1105	**2707**
		8.7	721	4158	8.83	630	4830	8.82	1125	**2702**
		8.67	780	3831	8.38	653	4423	8.68	1149	**2603**
			Average	4041			4752			**2671**
			Std. dev	183			298			**58**
North	3	8.52	871	3371	8.3	459	6232	7.15	825	**2987**
		8.72	626	4801	8.83	621	4900	7.55	604	**4308**
		8.65	616	4839	8.89	737	4157	7.97	657	**4181**
		8.83	606	5021	8.86	734	4160	7.85	596	**4539**
		8.6	565	5246	8.49	414	7067	7.83	649	**4158**
			Average	5035			5128			**4292**

Lot	Sublot	Point A			Point B			Point C		
		Load, kN	**Deflection, µm**	**Modulus, psi ***	**Load, kN**	**Deflection, µm**	**Modulus, psi ***	**Load, kN**	**Deflection, µm**	**Modulus, psi ***
			Std. dev	204			1679			**214**
North	4	8.01	433	6375	7.68	581	4555	7.29	550	**4568**
		8.66	1022	2920	7.96	514	5337	7.83	420	**6425**
		8.56	1328	2221	7.98	575	4783	7.76	409	**6539**
		7.98	407	6757	7.86	534	5073	7.86	482	**5620**
		8.18	1020	2764	7.88	521	5212	7.55	506	**5142**
			Average	3914			5023			**5767**
			Std. dev	2477			219			**710**
North	5	7.3	535	4702	7.27	463	5411	7.32	374	**6745**
		7.64	463	5687	7.76	497	5381	7.53	345	**7522**
		7.59	569	4597	7.89	495	5493	7.62	393	**6682**
		7.71	468	5677	7.92	504	5416	7.52	436	**5944**
		7.58	482	5420	8.06	506	5489	7.26	522	**4793**
			Average	5231			5466			**5806**
			Std. dev	564			44			**952**
South	1	7.48	417	6182	8.09	392	7112	6.44	531	**4180**
		7.78	448	5985	8.38	327	8832	7.46	632	**4068**
		8.28	384	7431	8.6	614	4827	7.64	516	**5103**
		8.27	422	6754	8.27	348	8190	7.9	494	**5511**
		8.27	371	7682	8.32	368	7791	7.93	475	**5753**
			Average	7289			6936			**5456**
			Std. dev	480			1837			**329**

Lot	Sublot	Point A			Point B			Point C		
		Load, kN	**Deflection, µm**	**Modulus, psi ***	**Load, kN**	**Deflection, µm**	**Modulus, psi ***	**Load, kN**	**Deflection, µm**	**Modulus, psi ***
South	2	8.18	518	5442	7.14	429	5736	6.48	652	**3425**
		8.25	548	5188	7.65	431	6117	7.07	474	**5140**
		8.22	514	5511	7.57	419	6226	7.42	434	**5892**
		8.15	491	5720	7.52	486	5332	7.39	473	**5384**
		8.19	573	4926	7.52	426	6083	7.28	440	**5702**
			Average	5386			5881			**5659**
			Std. dev	412			480			**256**
South	3	7.88	533	5095	7.41	500	5107	6.23	423	**5076**
		8.36	629	4580	8.15	518	5422	7.43	419	**6111**
		8.25	482	5899	7.94	441	6205	7.65	427	**6174**
		8.37	405	7122	7.9	458	5944	7.67	487	**5428**
		8.23	442	6417	8.05	484	5732	7.55	442	**5887**
			Average	6479			5960			**5829**
			Std. dev	614			237			**377**
South	4	7.64	652	4038	7.88	500	5431	6.98	595	**4043**
		8.22	551	5141	8.5	874	3352	7.49	403	**6405**
		8.31	540	5303	8.44	866	3359	7.38	622	**4089**
		8.35	558	5157	8.51	870	3371	7.46	606	**4242**
		8.31	562	5096	8.45	855	3406	7.42	570	**4486**
			Average	5185			3379			**4272**
			Std. dev	107			25			**200**

Lot	Sublot	Point A			Point B			Point C		
		Load, kN	**Deflection, μm**	**Modulus, psi ***	**Load, kN**	**Deflection, μm**	**Modulus, psi ***	**Load, kN**	**Deflection, μm**	**Modulus, psi ***
South	5	7.75	588	4542	8.14	853	3289	7.85	643	**4207**
		8.44	413	7043	8.52	619	4743	8.21	424	**6673**
		8.42	432	6717	8.3	644	4442	8.07	437	**6364**
		8.48	658	4441	8.17	705	3994	8.2	425	**6649**
		8.36	408	7061	8.31	706	4056	8.22	428	**6619**
			Average	6073			4164			**6544**
			Std. dev	**1424**			**243**			**157**

* Average modulus values are calculated using load-deflection data for drops 3, 4, and 5. Drops 1 and 2 are considered seating drops. Modulus is determined from the following expression:

$$E(MPa) = 2\left(1-\nu^2\right) * a * \frac{p}{\delta}$$

ν is the Poisson's ration (recommended value is 0.4 for this device)
a is radius of the load plate in mm (100 mm in this project)
p is the contact pressure kPa
d is measured deflection μm
The calculations used a conversion factor of 145 to express modulus in psi

Table 13. ***Modulus*** measured by ***DSPA*** in ***TH-23, MN Subgrade, psi***
Note: Test repetitions were performed at individual points as shown in Table 14

Lot #	Sublot	A	B	C	Average	Lot Average
1 (North)	1	63333	56667	45000	55000	
	2	60333	33000	35333	42889	
	3	55667	35667	22667	38000	
	4	44667	37667	29000	37111	
	5	34333	38000	23667	32000	41000
2 (South)	1	45000	46333	54000	48444	
	2	45333	36667	23333	35111	
	3	45667	39333	24667	36556	
	4	42667	60667	33333	45556	
	5	31333	42667	20333	31444	39422
Average lot 1 by row		12568	51667	40200	31133	
Average lot 2 by row		10070	42000	45133	31133	
Average project by row		11319	46833	42667	31133	
Average project						40211

Table 14. Repeatability in ***Modulus*** measurements by ***DSPA*** in ***TH-23, MN Subgrade, psi***

Note: Summary of test results are shown in Table 13

Lot	Sublot	Point	Trial 1	Trial 2	Trial 3	Average at point	Std deviation at point
North	1	A	63000	76000	51000	63333	**12503**
North	1	B	63000	53000	54000	56667	**5508**
North	1	C	46000	57000	32000	45000	**12530**
North	2	A	63000	65000	53000	60333	**6429**
North	2	B	38000	39000	22000	33000	**9539**
North	2	C	39000	38000	29000	35333	**5508**
North	3	A	56000	59000	52000	55667	**3512**
North	3	B	39000	41000	27000	35667	**7572**
North	3	C	23000	25000	20000	22667	**2517**
North	4	A	53000	43000	38000	44667	**7638**
North	4	B	38000	39000	36000	37667	**1528**
North	4	C	30000	32000	25000	29000	**3606**
North	5	A	34000	35000	34000	34333	**577**
North	5	B	33000	45000	36000	38000	**6245**
North	5	C	25000	28000	18000	23667	**5132**
South	1	A	40000	51000	44000	45000	**5568**
South	1	B	49000	44000	46000	46333	**2517**
South	1	C	49000	63000	50000	54000	**7810**
South	2	A	46000	43000	47000	45333	**2082**
South	2	B	39000	27000	44000	36667	**8737**
South	2	C	15000	29000	26000	23333	**7371**
South	3	A	43000	52000	42000	45667	**5508**
South	3	B	43000	34000	41000	39333	**4726**
South	3	C	31000	24000	19000	24667	**6028**
South	4	A	52000	33000	43000	42667	**9504**
South	4	B	63000	52000	67000	60667	**7767**
South	4	C	33000	32000	35000	33333	**1528**
South	5	A	29000	35000	30000	31333	**3215**
South	5	B	49000	43000	36000	42667	**6506**
South	**5**	**C**	**20000**	**17000**	**24000**	**20333**	**3512**

Table 15. Summary of ***Sandcone Test Results*** in ***TH-23, MN Subgrade, psi***

Test #	Station	Moisture Content, % by dry weight	Optimum Moisture Content, %	Dry Density, pcf	Max Density, pcf	Wet Density, pcf	Moisture Density Curve #
914	8226+761	5.2	9.6	131.5	128.2	138.34	52
916	8229+93	8.2	13.1	121.0	121.0	130.92	18
919	8235+39.4	11.1	9.8	116.9	127.2	129.86	41
912	8238+01	8.8	13.1	125.3	121.0	136.33	18
918	8238+09	9.1	9.8	132.3	127.2	144.34	41
911	8240+08	10.6	16.7	108.7	111.5	120.22	9
910	8240+19	7.4	12.8	125.0	118.5	134.25	14
	Average	8.6		123.0			

Table 16. Summary of ***Resilient Modulus Test Results*** in ***TH-23, MN Subgrade***

Sequence	σ_1 psi	σ_2 psi	σ_3 psi	θ psi	τ_{oct} psi	$\sigma_1 - \sigma_3$ psi	M_R psi	Pred. M_R psi
Repetition 1								
1	13.2	8.0	8.0	29.2	2.5	5.2	32210	32929
2	10.9	6.0	6.0	22.9	2.3	4.9	29000	28645
3	8.5	4.0	4.0	16.5	2.1	4.5	24320	23671
4	6.1	2.0	2.0	10.1	1.9	4.1	17863	17615
5	16.1	8.0	8.0	32.1	3.8	8.1	29527	30319
6	13.7	6.0	6.0	25.7	3.6	7.7	26591	26769
7	11.4	4.0	4.0	19.4	3.5	7.4	22874	22694
8	8.9	2.0	2.0	13.0	3.3	6.9	17806	17869
9	19.0	8.0	8.0	35.0	5.2	11.0	27965	28064
10	16.6	6.0	6.0	28.6	5.0	10.6	24990	25071
11	14.2	4.0	4.0	22.2	4.8	10.2	21598	21682
12	11.8	2.0	2.0	15.9	4.6	9.8	17383	17736
13	22.9	8.0	8.0	38.9	7.0	14.9	26308	25443
14	20.5	6.0	6.0	32.5	6.9	14.5	23489	23009
15	18.1	4.0	4.0	26.2	6.7	14.1	20363	20310
16	15.7	2.0	2.0	19.7	6.5	13.7	16753	17235
Repetition 2								
1	13.3	8.0	8.0	29.3	2.5	5.3	32954	33749
2	10.9	6.0	6.0	22.9	2.3	4.9	29422	28969
3	8.5	4.0	4.0	16.5	2.1	4.5	23451	23484
4	6.1	2.0	2.0	10.1	1.9	4.1	17381	16994
5	16.1	8.0	8.0	32.2	3.8	8.1	30850	31240
6	13.7	6.0	6.0	25.8	3.7	7.7	27226	27245
7	11.4	4.0	4.0	19.4	3.5	7.4	22720	22724
8	9.0	2.0	2.0	13.0	3.3	7.0	17477	17488
9	19.0	8.0	8.0	35.1	5.2	11.0	29038	29036
10	16.6	6.0	6.0	28.6	5.0	10.6	25801	25669
11	14.2	4.0	4.0	22.2	4.8	10.2	21844	21875
12	11.9	2.0	2.0	15.9	4.6	9.9	17352	17555
13	22.9	8.0	8.0	38.9	7.0	14.9	27151	26491
14	20.6	6.0	6.0	32.6	6.9	14.5	24091	23728
15	18.2	4.0	4.0	26.2	6.7	14.2	20648	20684
16	15.8	2.0	2.0	19.8	6.5	13.8	16777	17269

Sequence	σ_1	σ_2	σ_3	θ	τ_{oct}	$\sigma_1 - \sigma_3$	M_R	Pred. M_R
	psi	**psi**	**psi**	**psi**	**psi**	**psi**	**psi**	**psi**
Repetition 3								
1	13.2	8.0	8.0	29.2	2.5	5.2	31541	32603
2	10.9	6.0	6.0	22.9	2.3	4.9	27915	27890
3	8.5	4.0	4.0	16.5	2.1	4.5	23193	22545
4	6.1	2.0	2.0	10.1	1.9	4.1	16579	16225
5	16.1	8.0	8.0	32.1	3.8	8.1	29209	29999
6	13.7	6.0	6.0	25.8	3.7	7.7	26133	26103
7	11.3	4.0	4.0	19.3	3.5	7.3	22049	21721
8	8.9	2.0	2.0	13.0	3.3	6.9	16555	16639
9	19.0	8.0	8.0	35.0	5.2	11.0	27656	27750
10	16.6	6.0	6.0	28.6	5.0	10.6	24667	24474
11	14.2	4.0	4.0	22.2	4.8	10.2	20932	20819
12	11.8	2.0	2.0	15.8	4.6	9.8	16185	16648
13	22.9	8.0	8.0	38.9	7.0	14.9	26034	25194
14	20.5	6.0	6.0	32.5	6.8	14.5	23094	22541
15	18.1	4.0	4.0	26.1	6.6	14.1	19671	19598
16	15.7	2.0	2.0	19.7	6.4	13.7	15600	16310

Calculated Mr coefficients

	Rep 1	Rep 2	Rep 3
K_1	1,923.7	1,897.1	1,838.1
K_2	0.644	0.702	0.714
K_3	-1.877	-1.879	-1.961

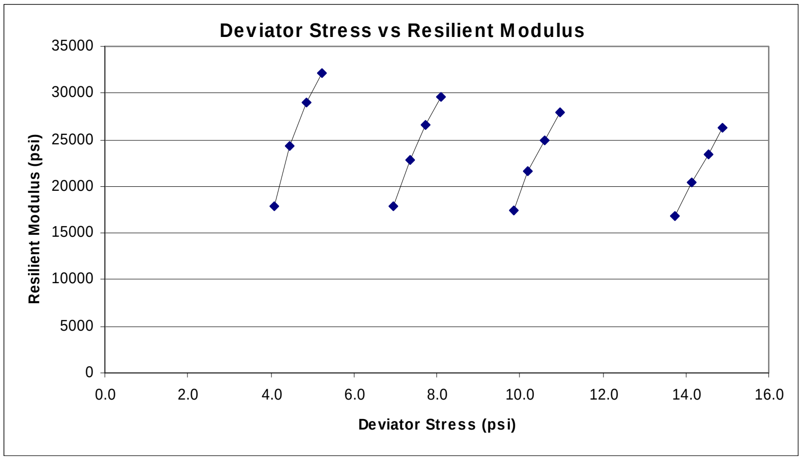


Figure 1. ***Resilient Modulus vs. Deviator Stress*** in ***TH-23, MN Subgrade – Rep 1***

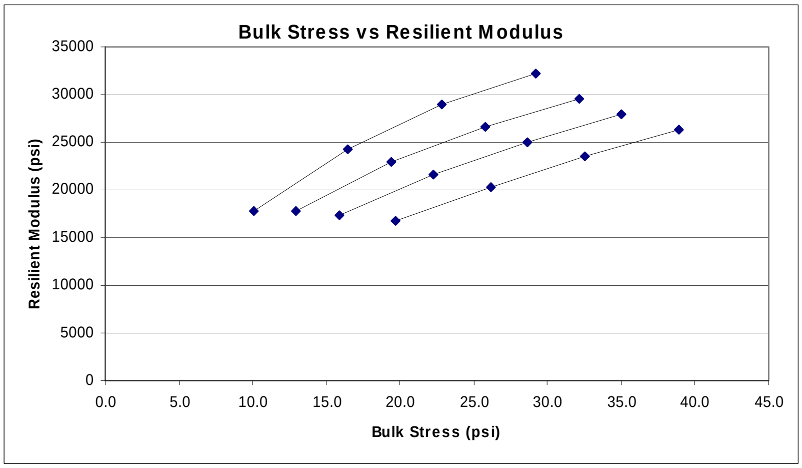


Figure 2. ***Bulk stress vs. Resilient Modulus*** in ***TH-23, MN Subgrade – Rep 1***

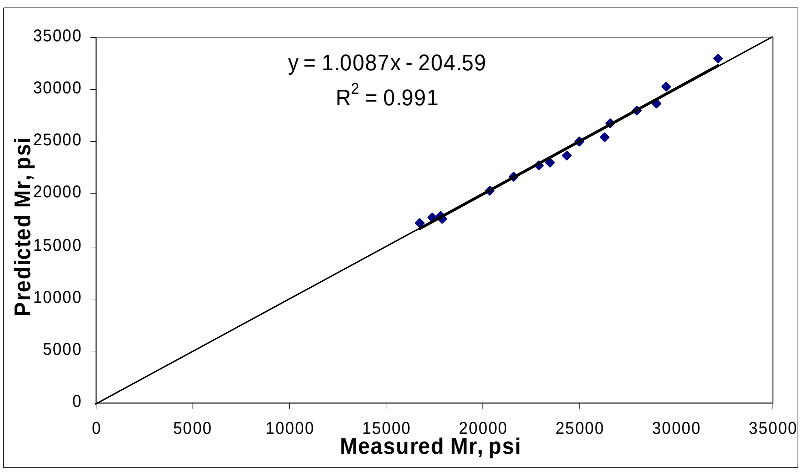


Figure 3. ***Predicted vs Measured Resilient Modulus*** in ***TH-23, MN Subgrade – Rep 1***

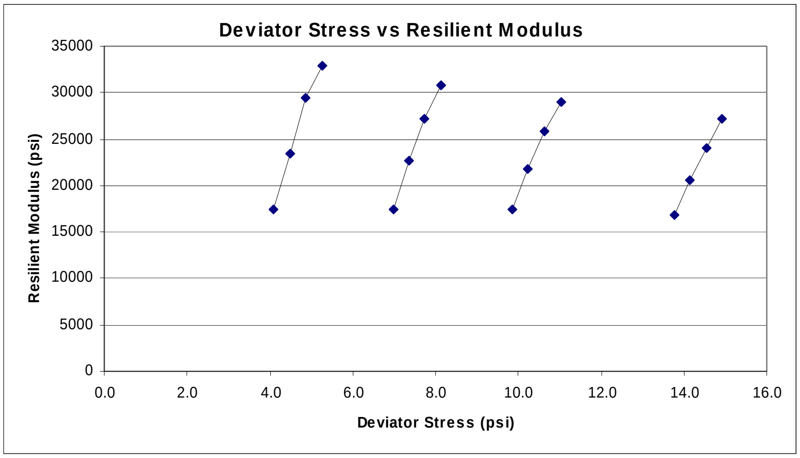


Figure 4. ***Resilient Modulus vs. Deviator Stress*** in ***TH-23, MN Subgrade – Rep 2***

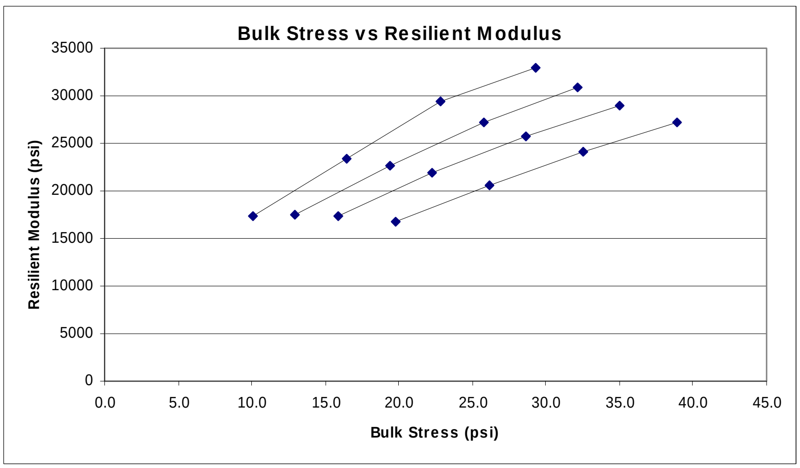


Figure 5. ***Bulk stress vs. Resilient Modulus*** in ***TH-23, MN Subgrade – Rep 2***

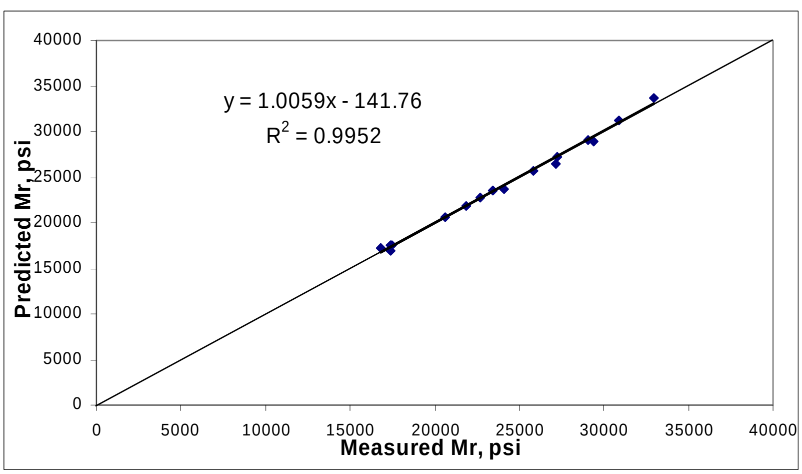


Figure 6. ***Predicted vs Measured Resilient Modulus*** in ***TH-23, MN Subgrade – Rep 2***

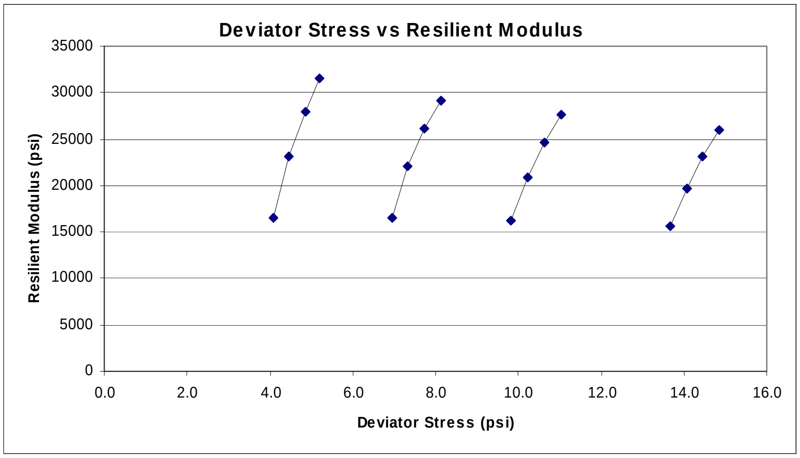


Figure 7. ***Resilient Modulus vs. Deviator Stress*** in ***TH-23, MN Subgrade – Rep 3***

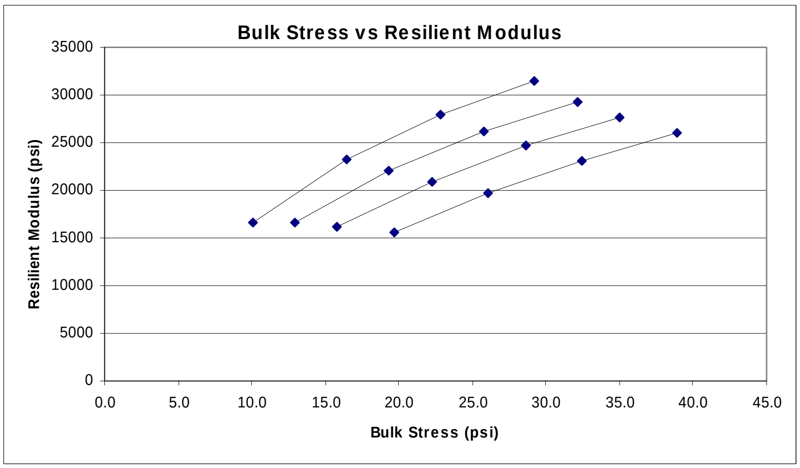


Figure 8. ***Bulk stress vs. Resilient Modulus*** in ***TH-23, MN Subgrade – Rep 3***

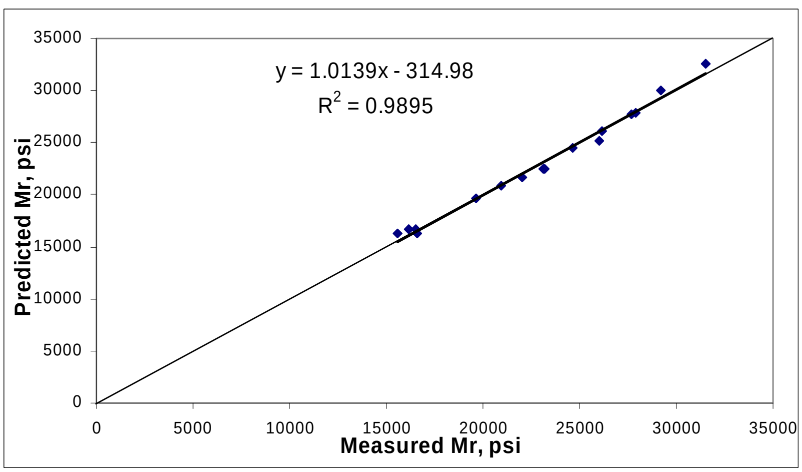


Figure 9. ***Predicted vs Measured Resilient Modulus*** in ***TH-23, MN Subgrade – Rep 3***

TH23, MN GRANULAR BASE TESTING

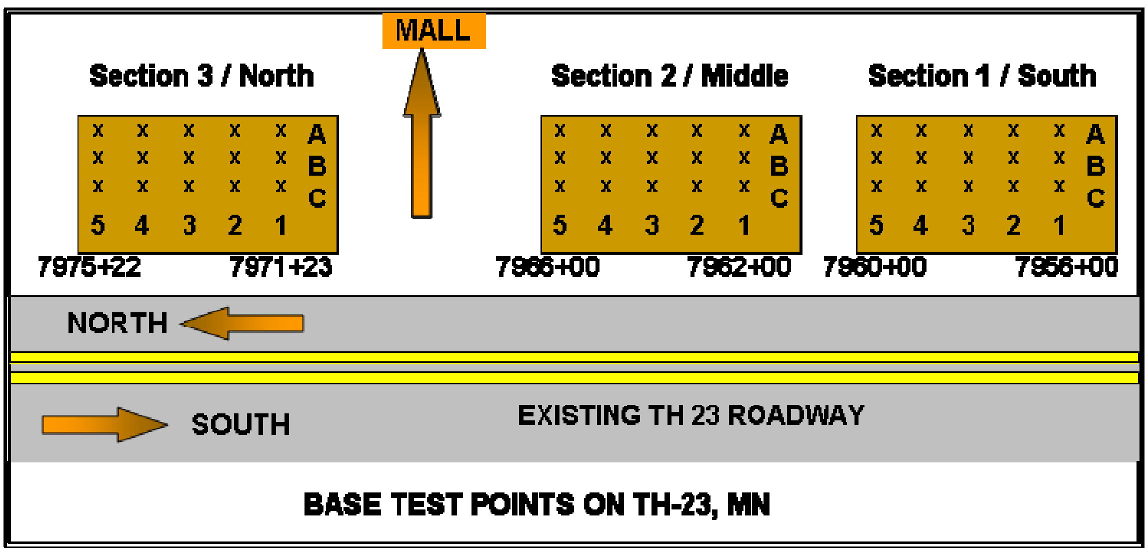


Table 17. Test point station information for Base section test at TH-23, MN

Lot	Sublot	GPS station	GPS Offset		
			A	B	C
South	1	7956+00.4	6.1LT	7.9RT	11.9RT
South	2	7957+00.0	6.0LT	8.0RT	12.0RT
South	3	7958+00.0	5.9LT	8.1RT	12.0RT
South	4	7959+00.0	6.0LT	4.0RT	7.9RT
South	5	7959+99.4	6.1LT	3.9RT	7.9RT
Middle	1	7962+00.5	6.0LT	3.9RT	7.9RT
Middle	2	7963+02.1	6.0LT	4.0RT	7.9RT
Middle	3	7964+02.5	6.3LT	3.7RT	7.7RT
Middle	4	7965+04.0	5.9LT	4.3RT	8.1RT
Middle	5	7966+04.2	5.8LT	4.1RT	8.1RT
North	1	7971+23.3	6.0LT	3.9RT	8.0RT
North	2	7972+23.4	6.0LT	3.9RT	7.9RT
North	3	7973+22.3	6.0LT	3.9RT	7.9RT
North	4	7974+21.9	6.1LT	3.9RT	7.9RT
North	5	7975+21.9	6.1LT	4.0RT	7.9RT

Table 18. ***Penetration Index*** measured by ***DCP*** in ***TH-23, MN Base, mm/blow***
Note: Test data for number of blows vs penetration is shown in Table 19.

Lot #	Sublot	A	B	C	Average	Lot Average
1 (South)	1	0.7	6.1	7.9	4.9	
	2	6.1	4.0	8.3	6.1	
	3	2.6	3.2	8.1	4.6	
	4	2.1	2.8	4.9	3.3	
	5	3.5	4.3	10.0	5.9	5.0
2 (Middle)	1	2.8	5.7	12.4	7.0	
	2	2.3	3.1	8.2	4.6	
	3	5.6	7.3	12.2	8.4	
	4	7.3	6.4	11.0	8.2	
	5	8.7	10.9	10.1	9.9	7.6
3 (North) NOT TESTED	1	*	*	*	*	
	2	*	*	*	*	
	3	*	*	*	*	
	4	*	*	*	*	
	5	*	*	*	*	*
Average lot 1 by row		3.0	4.1	7.8		
Average lot 2 by row		5.3	6.7	10.8		
Average lot 3 by row		NOT TESTED				
Average project by row		4.2	5.4	9.3		
Average project						6.3

Table 19. ***Penetration Index*** measured by ***DCP*** in ***TH-23, MN Base, mm/blow***

Lot		**Penetration, mm**			**PI, mm/blow**		
		South	**South**	**South**	**South**	**South**	**South**
Sublot		**1**	**1**	**1**	**1**	**1**	**1**
Point		**A**	**B**	**C**	**A**	**B**	**C**
Number of blows	1	8.1	21.0	49.0			
	5	9.5	66.0	72.0	0.4	14.5	16.0
	10	10.6	89.0	100.0	0.3	9.0	10.2
	15	28.8	103.0	122.0	1.5	6.8	8.1
	20	30.7	115.0	146.0	1.2	5.6	7.3
	25	32.6	129.0	171.0	1.0	5.0	6.8
	30	34.1	139.0	186.0	0.9	4.5	6.1
	35	35.6	154.0	202.0	0.8	4.3	5.7
	40	36.5	165.0	225.0	0.7	4.0	5.6
	45	38.2	175.0	228.0	0.7	3.8	5.0
	50	39.8	185.0		0.6	3.6	
	55						
	60	43.0			0.6		
	65						
	70	45.2			0.5		
	75						
	80	48.4			0.5		
	85						
	90	52.8			0.5		
	95						
	100	57.8			0.5		
	105						
	110	61.7			0.5		
	120	65.1			0.5		
	130	68.3			0.5		
	140	72.0			0.5		
	150	76.2			0.5		
Average at point				Average	0.7	6.1	7.9

Table 19 Continued, ***Penetration Index*** measured by ***DCP*** in ***TH-23, MN Base, mm/blow***

Lot		Penetration, mm			PI, mm/blow		
		South	South	South	South	South	South
Sublot		2	2	2	2	2	2
Point		A	B	C	A	B	C
Number of blows	1	18	10	22			
	5	49	36	64	10.2	7.0	14.0
	10	72	56	91	7.1	5.3	9.2
	15	91	74	118	5.9	4.7	7.9
	20	114	89	146	5.6	4.3	7.3
	25	137	103	177	5.4	4.0	7.0
	30	155	115	200	5.1	3.7	6.6
	35	184	127	227	5.2	3.5	6.4
	40	208	141		5.1	3.4	
	45	225	154		4.9	3.3	
	50		168			3.3	
	55						
	60		182			2.9	
	65						
	70		201			2.8	
	75						
	80						
	85						
	90						
	95						
	100						
	105						
	110						
	120						
	130						
	140						
	150						
Average at point					6.1	4.0	8.3

Table 19 Continued, ***Penetration Index*** measured by ***DCP*** in ***TH-23, MN Base, mm/blow***

Lot		**Penetration, mm**			**PI, mm/blow**		
		South	**South**	**South**	**South**	**South**	**South**
Sublot		**3**	**3**	**3**	**3**	**3**	**3**
Point		**A**	**B**	**C**	**A**	**B**	**C**
Number of blows	1	14	9	19			
	5	48	37	62	10.0	7.2	13.5
	10	57	57	94	5.4	5.4	9.5
	15	70	66	115	4.4	4.1	7.6
	20	76	78	140	3.6	3.7	6.9
	25	80	88	166	3.0	3.3	6.6
	30	86	98	191	2.7	3.1	6.3
	35	90	110	216	2.4	3.0	6.1
	40	96	119		2.3	2.8	
	45	103	128		2.2	2.7	
	50	114	136		2.2	2.6	
	55						
	60	119	143		1.9	2.3	
	65						
	70	131	153		1.8	2.1	
	75						
	80	137	159		1.6	1.9	
	85						
	90	143	167		1.5	1.8	
	95						
	100	146	175		1.4	1.7	
	105						
	110	157			1.4		
	120	168			1.3		
	130	176			1.3		
	140	185			1.3		
	150	194			1.2		
Average at point					2.6	3.2	8.1

Table 19 Continued, ***Penetration Index*** measured by ***DCP*** in ***TH-23, MN Base, mm/blow***

Lot		**Penetration, mm**			**PI, mm/blow**		
		South	**South**	**South**	**South**	**South**	**South**
Sublot		**4**	**4**	**4**	**4**	**4**	**4**
Point		**A**	**B**	**C**	**A**	**B**	**C**
Number of blows	1	3	7	4			
	5	23	39	28	3.7	7.7	5.0
	10	38	46	56	3.3	4.2	5.3
	15	50	58	80	3.0	3.6	5.1
	20	61	72	103	2.8	3.4	5.0
	25	71	79	125	2.6	3.0	4.9
	30	80	85	149	2.5	2.7	4.9
	35	86	98	169	2.3	2.6	4.7
	40	94	106	188	2.2	2.5	4.6
	45	102	114		2.1	2.4	
	50	109	119		2.1	2.3	
	55	116	126		2.0	2.2	
	60	122	132		1.9	2.1	
	65	126	140		1.8	2.1	
	70	128	149		1.7	2.0	
	75	131	152		1.7	1.9	
	80	139	157		1.7	1.9	
	85	142	165		1.6	1.9	
	90	148	169		1.6	1.8	
	95	150			1.5		
	100	154			1.5		
	105	162			1.5		
	110						
	120						
	130						
	140						
	150						
Average at point					2.1	2.8	4.9

Table 19 Continued, ***Penetration Index*** measured by ***DCP*** in ***TH-23, MN Base, mm/blow***

Lot		**Penetration, mm**			**PI, mm/blow**		
		South	**South**	**South**	**South**	**South**	**South**
Sublot		**5**	**5**	**5**	**5**	**5**	**5**
Point		**A**	**B**	**C**	**A**	**B**	**C**
Number of blows	1	4	8	18			
	5	45	41	65	9.2	8.2	14.2
	10	62	61	104	6.0	5.9	10.7
	15	76	76	139	4.9	4.9	9.4
	20	88	93	167	4.2	4.5	8.4
	25	96	113	187	3.7	4.4	7.5
	30	106	115		3.4	3.7	
	35	115	126		3.1	3.5	
	40	121	139		2.9	3.4	
	45	128	144		2.7	3.1	
	50	136	157		2.6	3.0	
	55	144	165		2.5	2.9	
	60	148			2.4		
	65	156			2.3		
	70	164			2.3		
	75	168			2.2		
	80	171			2.1		
	85						
	90						
	95						
	100						
	105						
	110						
	120						
	130						
	140						
	150						
Average at point					3.5	4.3	10.0

Table 19 Continued, ***Penetration Index*** measured by ***DCP*** in ***TH-23, MN Base, mm/blow***

Lot		Penetration, mm			PI, mm/blow		
		Middle	Middle	Middle	Middle	Middle	Middle
Sublot		**1**	**1**	**1**	**1**	**1**	**1**
Point		**A**	**B**	**C**	**A**	**B**	**C**
Number of blows	1	12	7	40			
	5	37	54	114	7.2	11.5	26.5
	10	56	71	135	5.3	7.0	14.1
	15	67	91	158	4.2	5.9	10.7
	20	77	108	176	3.6	5.3	8.8
	25	88	122	190	3.3	4.7	7.6
	30	95	135	205	3.0	4.4	6.8
	35	102	150		2.8	4.2	
	40	110	165		2.6	4.0	
	45	118	181		2.5	3.9	
	50	123			2.3		
	55	129			2.2		
	60	134			2.1		
	65	139			2.0		
	70	143			2.0		
	75	149			1.9		
	80	152			1.8		
	85	157			1.8		
	90	160			1.7		
	95	165			1.7		
	100	165			1.6		
	105						
	110						
	120						
	130						
	140						
	150						
Average at point					2.8	5.7	12.4

Table 19 Continued, ***Penetration Index*** measured by ***DCP*** in ***TH-23, MN Base, mm/blow***

Lot		**Penetration, mm**			**PI, mm/blow**		
		Middle	**Middle**	**Middle**	**Middle**	**Middle**	**Middle**
Sublot		**2**	**2**	**2**	**2**	**2**	**2**
Point		**A**	**B**	**C**	**A**	**B**	**C**
Number of blows	1	6	6	18			
	5	27	32	59	4.7	6.0	12.7
	10	41	52	90	3.7	4.9	9.1
	15	55	66	115	3.4	4.1	7.6
	20	65	77	141	3.0	3.6	7.0
	25	73	88	167	2.7	3.3	6.6
	30	85	98	193	2.7	3.1	6.4
	35	90	109		2.4	3.0	
	40	95	120		2.2	2.9	
	45	103	128		2.2	2.7	
	50	110	133		2.1	2.5	
	55	116	137		2.0	2.4	
	60	120	142		1.9	2.3	
	65	126	149		1.8	2.2	
	70	131	154		1.8	2.1	
	75	136	160		1.7	2.1	
	80	140			1.7		
	85	145			1.6		
	90	149			1.6		
	95	155			1.6		
	100	161			1.5		
	105	169			1.5		
	110						
	120						
	130						
	140						
	150						
Average at point					2.3	3.1	8.2

Table 19 Continued, ***Penetration Index*** measured by ***DCP*** in ***TH-23, MN Base, mm/blow***

Lot		Penetration, mm			PI, mm/blow		
		Middle	Middle	Middle	Middle	Middle	Middle
Sublot		3	3	3	3	3	3
Point		A	B	C	A	B	C
Number of blows	1	16	16	35			
	5	56	61	110	12.0	13.2	25.5
	10	72	87	134	7.1	8.8	14.0
	15	92	107	155	6.0	7.1	10.5
	20	104	125	174	5.0	6.2	8.7
	25	118	146	191	4.6	5.7	7.6
	30	134	161	210	4.3	5.3	7.0
	35	146	181		4.1	5.1	
	40	163			4.0		
	45	174			3.8		
	50						
	55						
	60						
	65						
	70						
	75						
	80						
	85						
	90						
	95						
	100						
	105						
	110						
	120						
	130						
	140						
	150						
Average at point					5.6	7.3	12.2

Table 19 Continued, ***Penetration Index*** measured by ***DCP*** in ***TH-23, MN Base, mm/blow***

Lot		**Penetration, mm**			**PI, mm/blow**		
		Middle	**Middle**	**Middle**	**Middle**	**Middle**	**Middle**
Sublot		**4**	**4**	**4**	**4**	**4**	**4**
Point		**A**	**B**	**C**	**A**	**B**	**C**
Number of blows	1	31	17	32			
	5	77	65	82	17.2	14.2	18.5
	10	97	88	109	9.9	8.9	11.2
	15	117	107	140	7.8	7.1	9.4
	20	132	119	166	6.5	5.8	8.3
	25	142	131	196	5.6	5.1	7.8
	30	154	142		5.0	4.6	
	35	166	151		4.6	4.2	
	40	181	165		4.4	4.0	
	45	192	176		4.2	3.8	
	50						
	55						
	60						
	65						
	70						
	75						
	80						
	85						
	90						
	95						
	100						
	105						
	110						
	120						
	130						
	140						
	150						
Average at point					7.3	6.4	11.0

Table 19 Continued, ***Penetration Index*** measured by ***DCP*** in ***TH-23, MN Base, mm/blow***

Lot		Penetration, mm			PI, mm/blow		
		Middle	Middle	Middle	Middle	Middle	Middle
Sublot		5	5	5	5	5	5
Point		A	B	C	A	B	C
Number of blows	1	40	26	49			
	5	86	95	90	19.5	21.7	20.5
	10	111	120	116	11.4	12.4	12.0
	15	131	144	140	8.8	9.7	9.4
	20	151	160	161	7.5	8.0	8.0
	25	164	179	184	6.5	7.1	7.3
	30	179	191	206	5.9	6.3	6.8
	35	191		225	5.4		6.4
	40	201			4.9		
	45						
	50						
	55						
	60						
	65						
	70						
	75						
	80						
	85						
	90						
	95						
	100						
	105						
	110						
	120						
	130						
	140						
	150						
Average at point					8.7	10.9	10.1

Table 20. ***Wet density*** measured by ***EDG*** in ***TH-23, MN Base, pcf***
Note: Test repetitions were not performed at individual points

Lot #	Sublot	A	B	C	Average	Lot Average
1 (South)	1	146.32	146.37	146.44	146.38	
	2	146.33	146.34	146.48	146.38	
	3	146.15	146.14	146.54	146.28	
	4	146.40	146.34	146.52	146.42	
	5	146.38	146.35	146.50	146.41	146.37
2 (Middle)	1	146.33	146.42	146.49	146.41	
	2	146.34	146.35	146.37	146.35	
	3	146.31	146.29	146.42	146.34	
	4	146.38	146.35	146.45	146.39	
	5	146.43	146.52	146.34	146.43	146.39
3 (North)	1	146.35	146.31	146.31	146.32	
	2	146.41	146.44	146.46	146.44	
	3	146.32	146.42	146.50	146.41	
	4	146.40	146.40	146.51	146.44	
	5	146.30	146.40	146.47	146.39	146.40
Average lot 1 by row		146.32	146.31	146.50		
Average lot 2 by row		146.36	146.39	146.41		
Average lot 3 by row		146.36	146.39	146.45		
Average project by row		146.34	146.36	146.45		
Average project						146.39

Table 21. ***Percent Moisture*** measured by **EDG** in **TH-23, MN Base**
Note: Test repetitions were not performed at individual points

Lot #	Sublot	A	B	C	Average	Lot Average
1 (South)	1	4.2	4.3	4.3	4.27	
	2	4.2	4.2	4.4	4.27	
	3	3.9	3.9	4.4	4.07	
	4	4.3	4.2	4.4	4.30	
	5	4.3	4.3	4.4	4.33	4.25
2 (Middle)	1	4.2	4.3	4.4	4.30	
	2	4.2	4.3	4.3	4.27	
	3	4.2	4.2	4.3	4.23	
	4	4.3	4.2	4.3	4.27	
	5	4.3	4.4	4.2	4.30	4.27
3 (North)	1	4.3	4.2	4.2	4.23	
	2	4.3	4.3	4.3	4.30	
	3	4.2	4.3	4.4	4.30	
	4	4.3	4.3	4.4	4.33	
	5	4.2	4.3	4.4	4.30	4.29
Average lot 1 by row		4.18	4.18	4.38		
Average lot 2 by row		4.24	4.28	4.30		
Average lot 3 by row		4.26	4.28	4.34		
Average project by row		4.23	4.25	4.34		
Average project						4.27

Table 22. ***Modulus*** measured by ***GEOGAUGE*** in ***TH-23, MN Base, psi***
Note: Test repetitions were performed at individual points as shown in Table 23

Lot #	Sublot	A	B	C	Average	Lot Average
1 (South)	1	15260	14423	13463	14382	
	2	11013	11687	11313	11338	
	3	13207	13443	9530	12060	
	4	20457	17390	13893	17247	
	5	18273	14893	10403	14523	13910
2 (Middle)	1	15687	13660	8640	12662	
	2	16600	14017	12537	14384	
	3	13137	13363	8093	11531	
	4	10043	12590	10303	10979	
	5	9360	9143	9623	9376	11786
3 (North)	1	12103	14223	11037	12454	
	2	12137	14923	12493	13184	
	3	14150	14223	12027	13467	
	4	15650	17870	14130	15883	
	5	14173	14560	12183	13639	13726
Average lot 1 by row		15642	14367	11721		
Average lot 2 by row		12965	12555	9839		
Average lot 3 by row		13643	15160	12374		
Average project by row		14083	14027	11311		
Average project						13141

Table 23. Repeatability in ***Modulus*** measurements by ***Geogauge*** in ***TH-23, MN Base, psi***

Note: Summary of test results are shown in Table 22

Lot	Sublot	Point	Trial 1	Trial 2	Trial 3	Average at point	Std deviation at point
South	1	A	17020	13980	14780	15260	**1576**
South	1	B	14950	13390	14930	14423	**895**
South	1	C	14930	10970	14490	13463	**2170**
South	2	A	10590	12070	10380	11013	**921**
South	2	B	10020	10750	14290	11687	**2284**
South	2	C	10870	12700	10370	11313	**1227**
South	3	A	13560	14380	11680	13207	**1384**
South	3	B	12340	12620	15370	13443	**1674**
South	3	C	9400	10400	8790	9530	**813**
South	4	A	17790	22190	21390	20457	**2344**
South	4	B	17140	17010	18020	17390	**549**
South	4	C	13020	12260	16400	13893	**2204**
South	5	A	17420	20640	16760	18273	**2076**
South	5	B	13750	17190	13740	14893	**1989**
South	5	C	11580	10820	8810	10403	**1431**
Middle	1	A	13260	18770	15030	15687	**2813**
Middle	1	B	13360	11900	15720	13660	**1928**
Middle	1	C	8460	8940	8520	8640	**262**
Middle	2	A	15050	17170	17580	16600	**1358**
Middle	2	B	15610	11860	14580	14017	**1937**
Middle	2	C	11950	12800	12860	12537	**509**
Middle	3	A	12470	14730	12210	13137	**1386**
Middle	3	B	14290	13020	12780	13363	**811**
Middle	3	C	8910	7930	7440	8093	**748**
Middle	4	A	8870	10160	11100	10043	**1120**
Middle	4	B	12360	11590	13820	12590	**1133**
Middle	4	C	10120	10270	10520	10303	**202**
Middle	5	A	8870	9630	9580	9360	**425**
Middle	5	B	8260	9930	9240	9143	**839**
Middle	5	C	9110	9910	9850	9623	**446**

Lot	**Sublot**	**Point**	**Trial 1**	**Trial 2**	**Trial 3**	**Average at point**	**Std deviation at point**
North	1	A	12530	12790	10990	12103	**973**
North	1	B	14080	17950	10640	14223	**3657**
North	1	C	12160	9340	11610	11037	**1495**
North	2	A	11870	12120	12420	12137	**275**
North	2	B	12210	16620	15940	14923	**2374**
North	2	C	12760	11170	13550	12493	**1212**
North	3	A	15060	14520	12870	14150	**1141**
North	3	B	14820	13270	14580	14223	**834**
North	3	C	12680	11390	12010	12027	**645**
North	4	A	14710	15800	16440	15650	**875**
North	4	B	21490	16870	15250	17870	**3238**
North	4	C	13360	15370	13660	14130	**1084**
North	5	A	13390	15150	13980	14173	**896**
North	5	B	12450	13650	17580	14560	**2683**
North	**5**	**C**	**11780**	**14210**	**10560**	**12183**	**1858**

Table 24. ***Dielectric*** measured by ***GPR*** in ***TH-23, MN Base***
Note: Test repetitions were not performed at individual points

Lot #	Sublot	A	B	C	Average	Lot Average
1 (South)	1	No test	10.1	10.1	10.1	
	2	No test	10.5	10.5	10.5	
	3	No test	10.5	10.5	10.5	
	4	No test	9.2	11.0	10.1	
	5	No test	8.7	9.8	9.3	10.1
2 (Middle)	1	No test	9.3	10.4	9.8	
	2	No test	9.6	10.5	10.0	
	3	No test	9.2	12.5	10.8	
	4	No test	8.3	11.6	9.9	
	5	No test	8.5	9.4	8.9	9.9
3 (North)	1	No test	8.7	10.9	9.8	
	2	No test	8.6	9.6	9.1	
	3	No test	8.9	9.6	9.3	
	4	No test	8.9	10.2	9.5	
	5	No test	8.9	10.0	9.4	9.4
Average lot 1 by row		No test	9.8	10.4		
Average lot 2 by row		No test	8.9	10.9		
Average lot 3 by row		No test	8.8	10.0		
Average project by row		No test	9.2	10.4		
Average project		No test				9.8

Table 25. ***Modulus*** measured by ***LWD 1*** in ***TH-23, MN Base, psi***
Note: Test repetitions were performed at individual points as shown in Table 26

Lot #	Sublot	A	B	C	Average	Lot Average
1 (South)	1	14739	70918	21626	35761	
	2	9963	22392	25700	19352	
	3	50979	38683	16580	35414	
	4	74771	21062	23020	39617	
	5	25669	27653	17592	23638	30756
2 (Middle)	1	175004	20889	14737	70210	
	2	54158	88159	21196	54504	
	3	No Data	No Data	No Data		
	4	No Data	No Data	No Data		
	5	No Data	No Data	No Data		62357
3 (North)	1	No Data	No Data	No Data		
	2	No Data	No Data	No Data		
	3	No Data	No Data	No Data		
	4	No Data	No Data	No Data		
	5	No Data	No Data	No Data		
Average lot 1 by row		35224	36142	20904		
Average lot 2 by row		114581	54524	17967		
Average lot 3 by row		No Data	No Data	No Data		
Average project by row		57897	41394	20064		
Average project						39785

Table 26. Repeatability in ***Modulus*** measurements by ***LWD 1*** in ***TH-23, MN Base, psi***
Note: Summary of test results are shown in Table 25

Lot	Sublot	Point A			Point B			Point C		
		Load, kN	**Deflection, mm**	**Modulus, psi ***	**Load, kN**	**Deflection, mm**	**Modulus, psi**	**Load, kN**	**Deflection, mm**	**Modulus, psi**
South	1	3.9	0.14	3783	6	0.14	5820	6.7	0.17	**5352**
		5.7	0.15	5160	11.3	0.03	51151	7.6	0.12	**8601**
		10.6	0.07	20564	12.3	0.03	55678	12.3	0.08	**20879**
		10.3	0.12	11656	13.1	0.03	59299	14.4	0.1	**19555**
		10.6	0.12	11996	14.4	0.02	97776	14.4	0.08	**24444**
			Average	14739			70918			**21626**
			Std dev	5048			23330			**2529**
South	2	2.4	0.21	1386	6.2	0.19	3957	12.1	0.12	**12226**
		5.5	0.14	4763	9	0.18	6062	14.4	0.09	**19400**
		9.3	0.1	11276	13.1	0.13	12218	15.9	0.07	**27541**
		8.3	0.15	6709	14.1	0.04	42741	16.4	0.07	**28407**
		10.8	0.11	11905	13.1	0.13	12218	15.7	0.09	**21151**
			Average	9963			22392			**25700**
			Std dev	2836			17622			**3963**
South	3	5.7	0.16	4320	8.5	0.13	7928	12.1	0.12	**12226**
		11.1	0.04	33647	12.3	0.1	14914	9.8	0.17	**6990**
		13.6	0.03	54967	14.4	0.03	58200	13.1	0.1	**15884**
		13.9	0.05	33707	12.3	0.13	11472	15.2	0.08	**23037**
		15.9	0.03	64262	15.3	0.04	46378	11.6	0.13	**10819**
			Average	50979			38683			**16580**
			Std dev	15663			24296			**6139**

Lot	Sublot	Point A			Point B			Point C		
		Load, kN	Deflection, mm	Modulus, psi *	Load, kN	Deflection, mm	Modulus, psi	Load, kN	Deflection, mm	Modulus, psi
South	4	12.1	0.13	11286	10.6	0.16	8033	11.3	0.15	**9134**
		13.1	0.12	13236	12.9	0.1	15641	13.1	0.15	**10589**
		12.6	0.14	10912	17.3	0.09	23307	15.7	0.1	**19036**
		17.2	0.02	104275	13.9	0.09	18726	16.4	0.1	**19885**
		18	0.02	109125	15.7	0.09	21151	17.4	0.07	**30139**
			Average	74771			21062			**23020**
			Std dev	55356			2292			**6180**
South	5	8	0.11	8818	4.2	0.2	2546	9.5	0.16	**7199**
		12.1	0.09	16301	12.3	0.05	29827	12.1	0.09	**16301**
		13.6	0.04	41225	11.3	0.13	10539	11.8	0.13	**11006**
		13.6	0.09	18322	12.9	0.11	14219	15.2	0.1	**18430**
		14.4	0.1	17460	14.4	0.03	58200	15.4	0.08	**23341**
			Average	25669			27653			**17592**
			Std dev	13479			26518			**6210**
Middle	1	10.1	0.12	10205	10.6	0.18	7140	12.1	0.14	**10479**
		14.4	0.01	174600	16.4	0.09	22094	9.3	0.2	**5638**
		16.2	0.01	196424	14.9	0.13	13897	15.2	0.11	**16754**
		18.2	0.02	110337	17.2	0.09	23172	16.2	0.1	**19642**
		18	0.01	218249	19	0.09	25597	11.6	0.18	**7814**
			Average	175004			20889			**14737**
			Std dev	57056			6175			**6167**

Lot	Sublot	Point A			Point B			Point C		
		Load, kN	**Deflection, mm**	**Modulus, psi ***	**Load, kN**	**Deflection, mm**	**Modulus, psi**	**Load, kN**	**Deflection, mm**	**Modulus, psi**
Middle	2	8.5	0.19	5424	7.2	0.11	7936	11.3	0.11	**12456**
		14.4	0.12	14550	9	0.13	8394	13.4	0.11	**14770**
		13.4	0.03	54158	12.1	0.08	18339	15.2	0.09	**20478**
					13.6	0.01	164900	15.2	0.08	**23037**
					13.4	0.02	81237	14.9	0.09	**20074**
			Average	54158			88159			**21196**
			Std dev	0			73525			**1607**
Middle	3	No data			No data			No data		
North	**1-5**	**No data**			**No data**			**No data**		

* Average modulus values are calculated using load-deflection data for drops 3, 4, and 5. Drops 1 and 2 are considered seating drops.
Calibration factors for load and deflection were 0.7 and 4.0 for this LWD device
Modulus is determined from the following expression:

$$E(psi) = 2\left(1-\nu^2\right) * a * \frac{P}{Area} * \frac{1000}{\delta} * 0.145$$

ν is the Poisson's ration (recommended value is 0.4 for this device)
a is radius of the load plate in mm (100 mm in this project)
P is the contact pressure kPa
δ is the deflection measured by the LWD in mm
0.145 is the conversion factor to express modulus in psi

Table 27. ***Modulus*** measured by ***LWD 2*** in ***TH-23, MN Base, psi***
Note: Test repetitions were performed at individual points as shown in Table 28

Lot #	Sublot	A	B	C	Average	Lot Average
1 (South)	1	9629	14001	11210	11613	
	2	7398	18510	7099	11003	
	3	17205	27640	6676	17174	
	4	34798	32926	10133	25952	
	5	19282	12434	8248	13321	15813
2 (Middle)	1	19211	14132	7950	13764	
	2	28140	19439	8956	18845	
	3	11033	11290	7364	9896	
	4	11258	No Data	No Data	11258	
	5	7594	6324	7538	7152	12325
3 (North)	1	No Data	No Data	No Data		
	2	No Data	No Data	No Data		
	3	No Data	No Data	No Data		
	4	No Data	No Data	No Data		
	5	No Data	No Data	No Data		
Average lot 1 by row		17662	21102	8673		
Average lot 2 by row		15447	12796	7952		
Average lot 3 by row		No Data	No Data	No Data		
Average project by row		16555	17411	8353		
Average project						14194

Table 28. Repeatability in ***Modulus*** measurements by ***LWD 2*** in ***TH-23, MN Base, psi***
Note: Summary of test results are shown in Table 27

Lot	Sublot	Point A			Point B			Point C		
		Load, kN	**Deflection, mm**	**Modulus, psi ***	**Load, kN**	**Deflection, mm**	**Modulus, psi**	**Load, kN**	**Deflection, mm**	**Modulus, psi**
South	1	9.1	116	27035	7.76	238	11236	7.86	196	**13820**
		7.89	223	12193	7.83	236	11434	8.24	282	**10070**
		8.25	332	8564	8.09	186	14989	8.23	244	**11624**
		8.02	258	10713	8.24	205	13852	8.21	264	**10717**
		8.17	293	9609	8.25	216	13163	8.19	250	**11290**
			Average	9629			14001			**11210**
			Std dev	1075			922			**459**
South	2	8.49	801	3653	8.23	230	12332	7.77	617	**4340**
		8.25	368	7726	8.05	196	14154	8.14	368	**7623**
		8.15	359	7824	7.95	120	22831	8.23	343	**8269**
		8.21	377	7505	8.2	172	16430	7.83	513	**5260**
		7.97	400	6867	8.12	172	16269	8.25	366	**7768**
			Average	7398			18510			**7099**
			Std dev	487			3743			**1612**
South	3	7.77	171	15659	8.09	104	26808	7.72	398	**6685**
		8.19	153	18447	8.32	88	32583	7.99	364	**7565**
		8.07	178	15624	8.12	96	29149	7.94	563	**4860**
		7.83	156	17297	7.98	97	28352	8.15	375	**7490**
		8.19	151	18692	8.04	109	25420	8.11	364	**7678**
			Average	17205			27640			**6676**

Lot	Sublot	Point A			Point B			Point C		
		Load, kN	Deflection, mm	Modulus, psi *	Load, kN	Deflection, mm	Modulus, psi	Load, kN	Deflection, mm	Modulus, psi
			Std dev	1536			1964			**1575**
South	4	7.9	97	28067	8.01	67	41201	8.07	271	**10262**
		8.21	84	33683	8.17	75	37541	8.01	253	**10911**
		8.26	83	34296	8.15	90	31208	7.89	301	**9033**
		8.11	83	33673	8.09	80	34850	8.09	263	**10601**
		8.35	79	36425	8.07	85	32719	8.06	258	**10766**
			Average	34798			32926			**10133**
			Std dev	1443			1830			**956**
South	5	8.28	100	28535	7.71	164	16202	7.88	513	**5294**
		8.21	100	28294	8.16	141	19944	7.57	571	**4569**
		8.18	173	16295	7.98	219	12558	7.59	324	**8073**
		8.17	133	21170	7.94	723	3785	8.06	303	**9167**
		8.28	140	20382	8.15	134	20960	8.1	372	**7504**
			Average	19282			12434			**8248**
			Std dev	2617			8588			**845**
Middle	1	8.14	169	16599	9.93	265	12914	7.78	399	**6720**
		8.18	154	18305	8.48	205	14256	7.87	396	**6849**
		8.77	163	18542	8.32	202	14194	8.09	380	**7337**
		8.77	152	19884	8.3	201	14231	8.18	337	**8365**
		8.75	157	19207	8.31	205	13970	8.11	343	**8148**
			Average	19211			14132			**7950**
			Std dev	671			141			**542**

Lot	Sublot	Point A			Point B			Point C		
		Load, kN	Deflection, mm	Modulus, psi *	Load, kN	Deflection, mm	Modulus, psi	Load, kN	Deflection, mm	Modulus, psi
Middle	2	8.15	123	22835	7.95	166	16505	8.17	331	**8506**
		8.23	103	27536	8.19	152	18569	8.17	321	**8771**
		8.49	115	25442	8.1	145	19251	8.12	308	**9086**
		7.95	88	31134	8.17	140	20111	8.07	318	**8746**
		8.08	100	27846	7.7	140	18954	8.13	310	**9038**
			Average	28140			19439			**8956**
			Std dev	2857			601			**184**
Middle	3	8.32	351	8169	7.84	378	7148	7.86	481	**5631**
		8.14	260	10789	8.21	267	10597	7.96	319	**8599**
		8.28	250	11414	8.17	251	11217	8.16	308	**9130**
		8.32	263	10902	8.09	249	11197	7.61	562	**4667**
		8.23	263	10784	8.21	247	11455	7.99	332	**8294**
			Average	11033			11290			**7364**
			Std dev	335			143			**2373**
Middle	4	8.08	262	10628	NO Data			No Data		
		8.25	253	11238						
		8.18	251	11231						
		8.2	255	11082						
		8.18	246	11459						
			Average	11258						
			Std dev	190						

Lot	Sublot	Point A			Point B			Point C		
		Load, kN	**Deflection, mm**	**Modulus, psi ***	**Load, kN**	**Deflection, mm**	**Modulus, psi**	**Load, kN**	**Deflection, mm**	**Modulus, psi**
Middle	5	7.72	379	7020	8.1	559	4993.7	8.16	642	**4380**
		8.16	357	7877	7.92	564	4839.4	7.94	395	**6927**
		8.28	359	7948	8.02	467	5918.4	8.02	345	**8011**
		8.16	336	8369	8.15	433	6486.6	8.04	365	**7591**
		9.51	507	6464	8.08	424	6567.4	8.14	400	**7013**
			Average	7594			6324			**7538**
			Std dev	**1001**			**354**			**501**

* Average modulus values are calculated using load-deflection data for drops 3, 4, and 5. Drops 1 and 2 are considered seating drops. Modulus is determined from the following expression:

$$E(MPa) = 2\left(1 - \nu^2\right) * a * \frac{p}{\delta}$$

ν is the Poisson's ration (recommended value is 0.4 for this device)
a is radius of the load plate in mm (100 mm in this project)
p is the contact pressure kPa
d is measured deflection μm
The calculations used a conversion factor of 145 to express modulus in psi

Table 29. ***Modulus*** measured by ***DSPA*** in ***TH-23, MN Base, psi***
Note: Test repetitions were performed at individual points as shown in Table 30

Lot #	Sublot	A	B	C	Average	Lot Average
1 (South)	1	50333	111333	64167	75278	
	2	41167	67167	41167	49833	
	3	89833	95500	48667	78000	
	4	236000	183167	120333	179833	
	5	146667	85833	39667	90722	94733
2 (Middle)	1	173000	86667	15833	91833	
	2	158667	116667	43333	106222	
	3	61500	47167	31833	46833	
	4	30000	68000	20667	39556	
	5	24167	29833	27833	27278	62344
3 (North)	1	34667	58500	27667	40278	
	2	56833	93833	75000	75222	
	3	104833	130833	51000	95556	
	4	63833	188833	98167	116944	
	5	99167	127500	55333	94000	84400
Average lot 1 by row		112800	108600	62800		
Average lot 2 by row		89467	69667	27900		
Average lot 3 by row		71867	119900	61433		
Average project by row		91378	99389	50711		
Average project						80493

Table 30. Repeatability in ***Modulus*** measurements by ***DSPA*** in ***TH-23, MN Base, psi***
Note: Summary of test results are shown in Table 29

Lot	Sublot	Point	Trial 1	Trial 2	Trial 3	Average at point	Std deviation at point
South	1	A	59000	48000	44000	50333	**7767**
South	1	B	125000	117000	92000	111333	**17214**
South	1	C	62000	52000	78500	64167	**13382**
South	2	A	42500	39000	42000	41167	**1893**
South	2	B	79500	63000	59000	67167	**10867**
South	2	C	32500	55000	36000	41167	**12107**
South	3	A	100500	88000	81000	89833	**9878**
South	3	B	97500	97000	92000	95500	**3041**
South	3	C	48000	55000	43000	48667	**6028**
South	4	A	207000	250000	251000	236000	**25120**
South	4	B	183000	146000	220500	183167	**37250**
South	4	C	114500	114000	132500	120333	**10540**
South	5	A	147500	146000	146500	146667	**764**
South	5	B	96000	83500	78000	85833	**9224**
South	5	C	44000	40000	35000	39667	**4509**
Middle	1	A	177500	182000	159500	173000	**11906**
Middle	1	B	78000	98000	84000	86667	**10263**
Middle	1	C	17000	14000	16500	15833	**1607**
Middle	2	A	154000	159000	163000	158667	**4509**
Middle	2	B	109000	109000	132000	116667	**13279**
Middle	2	C	36000	54000	40000	43333	**9452**
Middle	3	A	53000	56500	75000	61500	**11822**
Middle	3	B	42000	51000	48500	47167	**4646**
Middle	3	C	22500	45000	28000	31833	**11730**
Middle	4	A	31000	24500	34500	30000	**5074**
Middle	4	B	59000	75500	69500	68000	**8352**
Middle	4	C	19000	22500	20500	20667	**1756**
Middle	5	A	24500	23500	24500	24167	**577**
Middle	5	B	29000	29000	31500	29833	**1443**
Middle	5	C	30500	31000	22000	27833	**5058**
North	1	A	36000	32000	36000	34667	**2309**

North	1	B	59000	64500	52000	58500	**6265**
North	1	C	20000	25000	38000	27667	**9292**
North	2	A	57500	54000	59000	56833	**2566**
North	2	B	92000	97500	92000	93833	**3175**
North	2	C	65000	79500	80500	75000	**8675**
North	3	A	100500	114000	100000	104833	**7943**
North	3	B	136000	142500	114000	130833	**14936**
North	3	C	58000	43000	52000	51000	**7550**
North	4	A	65500	65000	61000	63833	**2466**
North	4	B	177000	182500	207000	188833	**15971**
North	4	C	94000	100500	100000	98167	**3617**
North	5	A	100500	88000	109000	99167	**10563**
North	5	B	133000	132000	117500	127500	**8675**
North	**5**	**C**	**59000**	**57000**	**50000**	**55333**	**4726**

Table 31. Moisture Density determined from ***Sand Cone Test*** in ***TH-23, MN Base***

Lot-Sublot Point	Moisture Content, % by dry weight	Optimum Moisture Content, %	Dry Density, pcf	Max Density, pcf	Wet Density, pcf	Moisture Density Curve Used for Determination
1-1C	4.4	7.8	139.4	135.3	145.5	38
1-2C	4.3	7.8	140.7	135.3	146.8	38
3-2C	4.4	7.8	139.2	135.3	145.32	38
2-5C	4.3	7.8	141.0	135.3	147.06	38
1-5C	4.0	7.8	141.6	135.3	147.3	38
	4.3	7.8	140.4	135.3	146.4	

Table 32. Summary of ***Resilient Modulus Test Results*** in ***TH-23, MN Base***

Sequence	σ_1	σ_2	σ_3	θ	τ_{oct}	$\sigma_1 - \sigma_3$	M_R	Pred. M_R
	psi	**psi**	**psi**	**psi**	**psi**	**psi**	**psi**	**psi**
Repetition 1								
1	4.8	3.0	3.0	10.8	0.9	1.8	13564	10638
2	9.8	6.0	6.0	21.8	1.8	3.8	20400	19980
3	16.7	10.0	10.0	36.7	3.2	6.7	29361	31017
4	25.2	15.0	15.0	55.2	4.8	10.2	41365	42965
5	33.5	20.0	20.0	73.5	6.4	13.5	53826	53399
6	6.3	3.0	3.0	12.3	1.5	3.3	13100	11609
7	12.8	6.0	6.0	24.8	3.2	6.8	20411	21235
8	21.6	10.0	10.0	41.6	5.5	11.6	30317	31879
9	32.4	15.0	15.0	62.4	8.2	17.4	43162	42767
10	43.1	20.0	20.0	83.1	10.9	23.1	56040	51782
11	9.2	3.0	3.0	15.2	2.9	6.2	13635	13397
12	18.8	6.0	6.0	30.8	6.0	12.7	22340	23368
13	31.2	10.0	10.0	51.2	10.0	21.2	33663	33363
14	46.8	15.0	15.0	76.8	15.0	31.8	46560	42828
15	62.4	20.0	20.0	102.4	20.0	42.4	56568	50173
16	12.2	3.0	3.0	18.2	4.3	9.2	14613	15010
17	24.6	6.0	6.0	36.6	8.8	18.6	23865	25117
18	40.9	10.0	10.0	60.9	14.6	30.9	34393	34619
19	61.2	15.0	15.0	91.2	21.8	46.2	44551	43175
20	81.5	20.0	20.0	121.5	29.0	61.5	54098	49585
21	18.1	3.0	3.0	24.1	7.1	15.1	15819	17758
22	36.1	6.0	6.0	48.1	14.2	30.1	24931	27865
23	58.1	10.0	10.0	78.1	22.7	48.1	33621	36494
24	90.0	15.0	15.0	120.0	35.4	75.0	44141	44149
25	119.9	20.0	20.0	159.9	47.1	99.9	54656	49553
26	23.5	3.0	3.0	29.5	9.7	20.5	16816	19816
27	47.6	6.0	6.0	59.6	19.6	41.6	27406	30044
28	79.2	10.0	10.0	99.2	32.6	69.2	36487	38361
29	118.6	15.0	15.0	148.6	48.8	103.6		
30	157.5	20.0	20.0	197.5	64.8	137.5		50076
Repetition 2								
1	4.8	3.0	3.0	10.8	0.8	1.8	11210	9685
2	9.9	6.0	6.0	22.0	1.9	3.9	17380	18802

Sequence	σ_1 psi	σ_2 psi	σ_3 psi	θ psi	τ_{oct} psi	$\sigma_1 - \sigma_3$ psi	M_R psi	Pred. M_R psi
3	16.7	10.0	10.0	36.7	3.2	6.7	27038	29704
4	25.2	15.0	15.0	55.2	4.8	10.2	40178	41880
5	33.6	20.0	20.0	73.6	6.4	13.6	53635	52722
6	6.3	3.0	3.0	12.3	1.6	3.3	11429	10706
7	12.9	6.0	6.0	24.9	3.2	6.9	18684	20119
8	21.6	10.0	10.0	41.6	5.5	11.6	29305	30845
9	32.4	15.0	15.0	62.4	8.2	17.4	43144	42185
10	43.1	20.0	20.0	83.1	10.9	23.1	56544	51845
11	9.3	3.0	3.0	15.3	3.0	6.3	13132	12517
12	18.8	6.0	6.0	30.8	6.0	12.8	21976	22429
13	31.3	10.0	10.0	51.2	10.0	21.3	33876	32824
14	46.8	15.0	15.0	76.8	15.0	31.8	46865	43078
15	62.3	20.0	20.0	102.3	19.9	42.3	57194	51336
16	12.3	3.0	3.0	18.3	4.4	9.3	14666	14153
17	24.6	6.0	6.0	36.6	8.8	18.6	24026	24365
18	40.9	10.0	10.0	60.9	14.6	30.9	34847	34540
19	61.2	15.0	15.0	91.2	21.8	46.2	45392	44116
20	81.6	20.0	20.0	121.6	29.0	61.6	55281	51600
21	18.1	3.0	3.0	24.1	7.1	15.1	16465	16948
22	36.0	6.0	6.0	48.1	14.2	30.0	25495	27558
23	58.2	10.0	10.0	78.2	22.7	48.2	34584	37158
24	90.1	15.0	15.0	120.0	35.4	75.1	45867	46233
25	119.9	20.0	20.0	159.9	47.1	99.9	56501	52921
26	23.4	3.0	3.0	29.4	9.6	20.4	17708	19098
27	47.6	6.0	6.0	59.7	19.6	41.6	28113	30189
28	79.4	10.0	10.0	99.4	32.7	69.4	37456	39829
29	118.7	15.0	15.0	148.7	48.9	103.7	45939	48227
30	157.5	20.0	20.0	197.5	64.8	137.5		54519
Repetition 3								
1	4.9	3.0	3.0	10.9	0.9	1.9	17011	13361
2	9.9	6.0	6.0	21.9	1.8	3.9	22830	23548
3	16.7	10.0	10.0	36.7	3.1	6.7	31454	34973
4	25.2	15.0	15.0	55.2	4.8	10.2	44963	47049
5	33.5	20.0	20.0	73.5	6.4	13.5	60398	57377
6	6.4	3.0	3.0	12.4	1.6	3.4	16571	14506
7	12.8	6.0	6.0	24.8	3.2	6.8	22819	24935

Sequence	σ_1	σ_2	σ_3	θ	τ_{oct}	$\sigma_1 - \sigma_3$	M_R	Pred. M_R
	psi	psi	psi	psi	psi	psi	psi	psi
8	21.6	10.0	10.0	41.6	5.5	11.6	32889	36076
9	32.4	15.0	15.0	62.4	8.2	17.4	47971	47222
10	43.4	20.0	20.0	83.4	11.0	23.4	62775	56332
11	9.2	3.0	3.0	15.2	2.9	6.2	17223	16492
12	18.7	6.0	6.0	30.7	6.0	12.7	25575	27329
13	31.3	10.0	10.0	51.2	10.0	21.3	38049	37946
14	46.9	15.0	15.0	76.9	15.0	31.9	52504	47888
15	62.6	20.0	20.0	102.6	20.1	42.6	62410	55594
16	12.1	3.0	3.0	18.1	4.3	9.1	18146	18284
17	24.5	6.0	6.0	36.5	8.7	18.5	27557	29322
18	40.8	10.0	10.0	60.8	14.5	30.8	39755	39534
19	61.2	15.0	15.0	91.2	21.8	46.2	51549	48710
20	81.6	20.0	20.0	121.6	29.0	61.6	61403	55632
21	18.0	3.0	3.0	24.0	7.1	15.0	19802	21383
22	36.1	6.0	6.0	48.1	14.2	30.1	30297	32539
23	58.1	10.0	10.0	78.1	22.7	48.1	40853	41953
24	89.9	15.0	15.0	119.9	35.3	74.9	51169	50461
25	119.8	20.0	20.0	159.8	47.1	99.8	61074	56539
26	23.3	3.0	3.0	29.3	9.6	20.3	20356	23694
27	47.6	6.0	6.0	59.6	19.6	41.6	31901	35099
28	79.2	10.0	10.0	99.2	32.6	69.3	42081	44380
29	118.6	15.0	15.0	148.5	48.8	103.6	48093	52136
30	157.3	20.0	20.0	197.3	64.7	137.3		57770
1	4.9	3.0	3.0	10.9	0.9	1.9	17011	13361
2	9.9	6.0	6.0	21.9	1.8	3.9	22830	23548

Calculated Mr coefficients

	Rep 1	Rep 2	Rep 3
K_1	1,014.3	933.9	1,223.3
K_2	0.964	0.996	0.863
K_3	-0.765	-0.716	-0.637

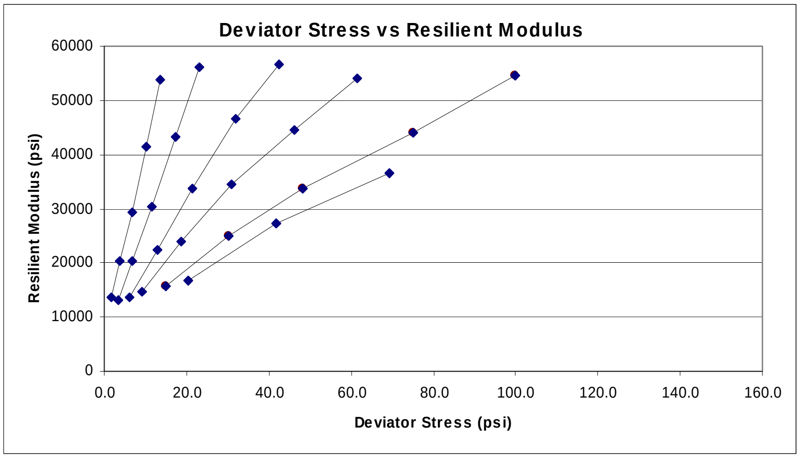


Figure 10. ***Resilient Modulus vs. Deviator Stress*** in ***TH-23, MN Base Rep 1***

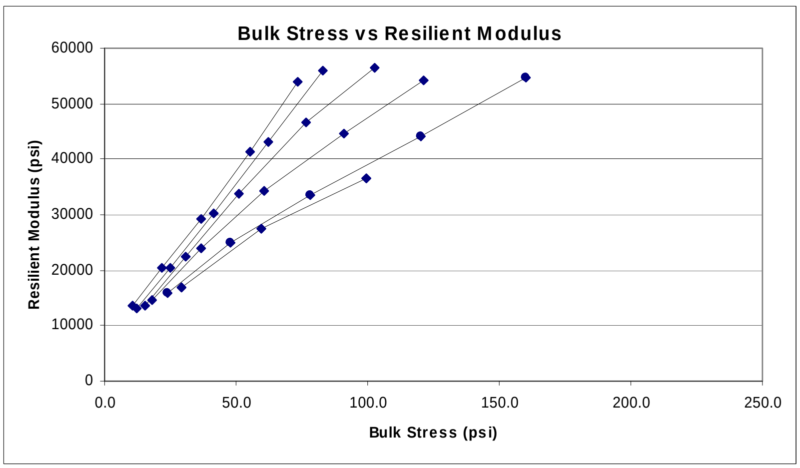


Figure 11. ***Bulk stress vs. Resilient Modulus*** in ***TH-23, MN Base – Rep 1***

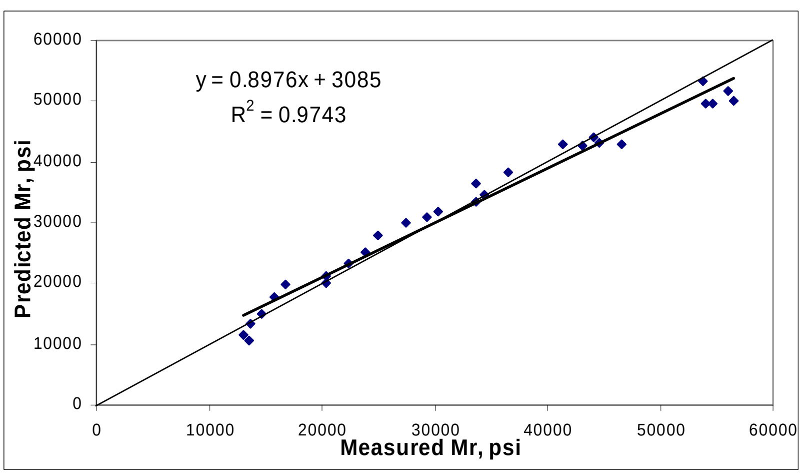


Figure 12. ***Predicted vs Measured Resilient Modulus*** in ***TH-23, MN Base – Rep 1***

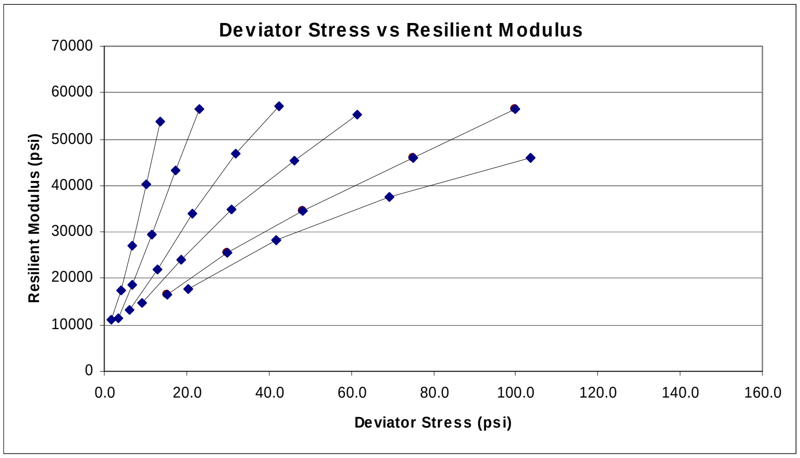


Figure 13. ***Resilient Modulus vs. Deviator Stress*** in ***TH-23, MN Base – Rep 2***

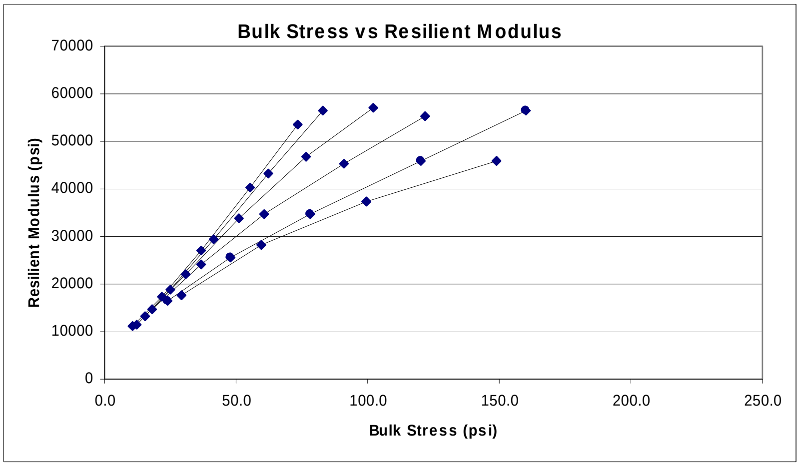


Figure 14. ***Bulk stress vs. Resilient Modulus*** in ***TH-23, MN Base – Rep 2***

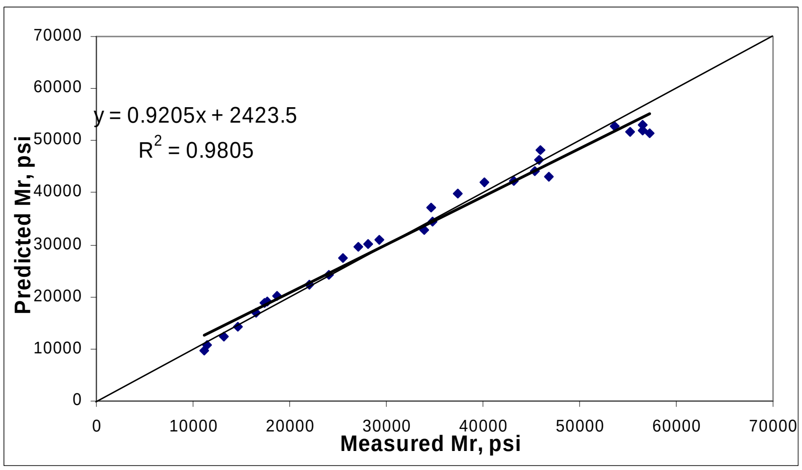


Figure 15. ***Predicted vs Measured Resilient Modulus*** in ***TH-23, MN Base – Rep 2***

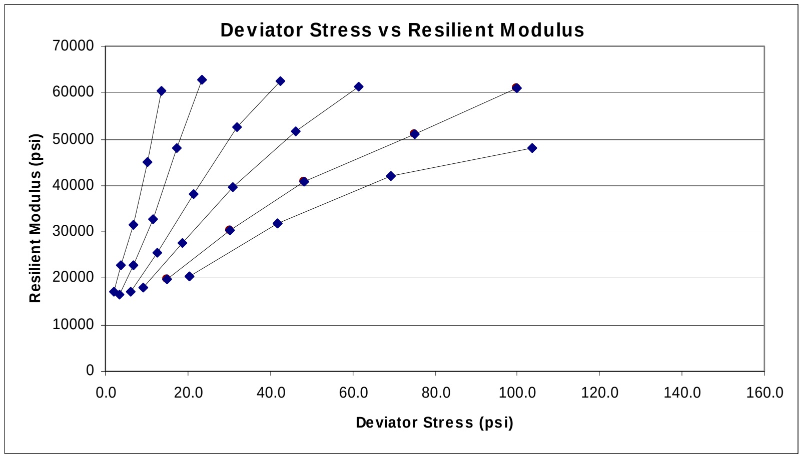


Figure 16. ***Resilient Modulus vs. Deviator Stress*** in ***TH-23, MN Base – Rep 3***

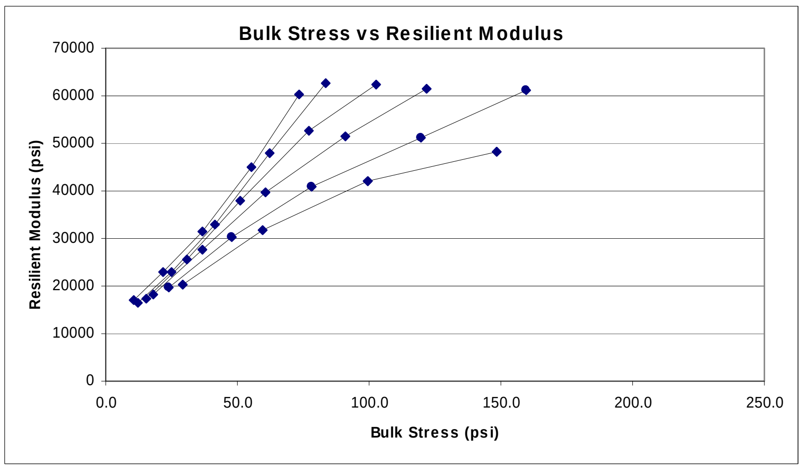


Figure 17. ***Bulk stress vs. Resilient Modulus*** in ***TH-23, MN Base – Rep 3***

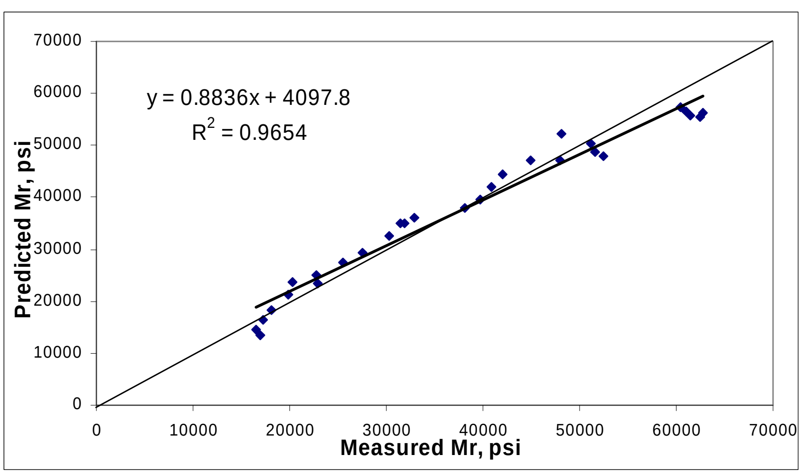


Figure 18. ***Predicted vs Measured Resilient Modulus*** in ***TH-23, MN Base – Rep 3***

US-280, AL GRANULAR BASE TESTING

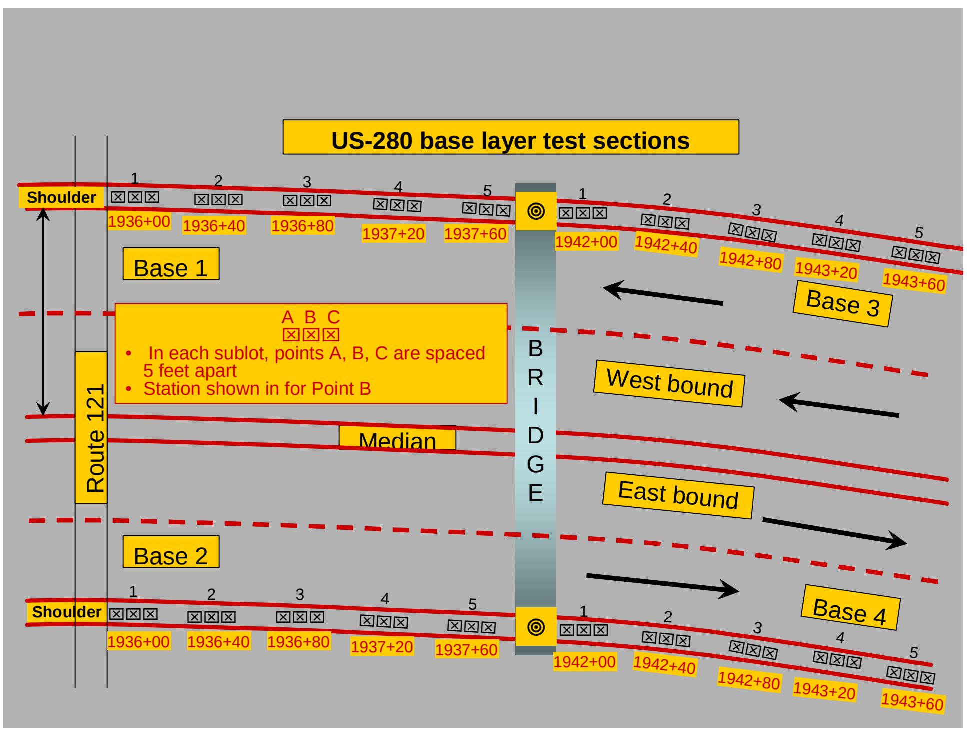


Table 33. Test point station information for Base section test at US-280, AL

Lot	Sublot	Station and Offset		
		A	B	C
Base 1	1	1935+95 L	1936+00 L	1936+05 L
Base 1	2	1936+35 L	1936+40 L	1936+45 L
Base 1	3	1936+75 L	1936+80 L	1936+85 L
Base 1	4	1937+15 L	1937+20 L	1937+25 L
Base 1	5	1937+55 L	1937+60 L	1937+65 L
Base 2	1	1935+95 R	1936+00 R	1936+05 R
Base 2	2	1936+35 R	1936+40 R	1936+45 R
Base 2	3	1936+75 R	1936+80 R	1936+85 R
Base 2	4	1937+15 R	1937+20 R	1937+25 R
Base 2	5	1937+55 R	1937+60 R	1937+65 R
Base 3	1	1941+95 L	1942+00 L	1942+05 L
Base 3	2	1942+35 L	1942+40 L	1942+45 L
Base 3	3	1942+75 L	1942+80 L	1942+85 L
Base 3	4	1943+15 L	1943+20 L	1943+25 L
Base 3	5	1943+55 L	1943+60 L	1943+65 L
Base 4	1	1941+95 R	1942+00 R	1942+05 R
Base 4	2	1942+35 R	1942+40 R	1942+45 R
Base 4	3	1942+75 R	1942+80 R	1942+85 R
Base 4	4	1943+15 R	1943+20 R	1943+25 R
Base 4	5	1943+55 R	1943+60 R	1943+65 R

Table 34. ***Penetration Index*** measured by ***DCP*** in ***US-280, AL Base, mm/blow***
Note: Test data for number of blows vs penetration is shown in Table 35.

Lot #	Sublot	A	B	C	Average	Lot Average
1	1	2.75	1.52	1.48	1.92	
	2	4.42	1.89	3.84	3.38	
	3	2.19	0.97	1.02	1.39	
	4	1.81	0.96	1.00	1.25	
	5	2.08	1.01	0.87	1.32	1.85
2	1	3.97	1.64	1.82	2.48	
	2	4.31	1.67	1.66	2.55	
	3	3.04	1.10	1.11	1.75	
	4	No Data	No Data	No Data		
	5	No Data	No Data	No Data		2.26
3	1	2.31	1.23	1.03	1.52	
	2	2.58	1.18	1.23	1.67	
	3	3.07	1.32	1.20	1.86	
	4	2.84	1.57	1.31	1.91	
	5	2.76	1.39	1.35	1.83	1.76
4	1	3.80	2.25	1.92	2.66	
	2	3.60	1.59	1.56	2.25	
	3	4.05	1.78	2.33	2.72	
	4	4.26	2.03	2.09	2.79	
	5	4.58	2.08	2.40	3.02	2.69
Average lot 1 by row		2.65	1.27	1.64		
Average lot 2 by row		3.77	1.47	1.53		
Average lot 3 by row		2.71	1.34	1.22		
Average lot 4 by row		4.06	1.95	2.06		
Average project by row		3.25	1.51	1.62		
Average project						2.13

Table 35. ***Penetration Index*** measured by ***DCP*** in ***US-280, AL Base, mm/blow***

Lot		**Penetration, mm**			**PI, mm/blow**		
		Base 1	**Base 1**	**Base 1**	**Base 1**	**Base 1**	**Base 1**
Sublot		**1**	**1**	**1**	**1**	**1**	**1**
Point		**A**	**B**	**C**	**A**	**B**	**C**
Number of blows	0	0	0	0			
	5	20	20	17	4.00	1.18	1.00
	10	34	37	31	3.40	1.95	1.63
	15	47	52	45	3.13	1.21	1.05
	20	59	67	60	2.95	1.26	1.13
	25	68	78	76	2.72	1.26	1.23
	30	74	92	89	2.47	1.31	1.27
	35	83	109	105	2.37	1.40	1.35
	40	93	123	121	2.33	1.46	1.44
	45	104	139	142	2.31	1.58	1.61
	50	119	158	162	2.38	1.63	1.67
	55	135	181	189	2.45	1.71	1.78
	60	150	206	220	2.50	1.79	1.91
	65	166	246	248	2.55	2.08	2.10
	70	189			2.70		
	75	211			2.81		
	80	232			2.90		
	85						
	90						
	95						
	100						
	105						
	110						
Average at point					2.75	1.52	1.48

Table 35 Continued, ***Penetration Index*** measured by ***DCP*** in ***US-280, AL Base, mm/blow***

Lot		Penetration, mm			PI, mm/blow		
		Base 1	Base 1	Base 1	Base 1	Base 1	Base 1
Sublot		2	2	2	2	2	2
Point		A	B	C	A	B	C
Number of blows	0	3	3	0			
	5	28	30	28	5.00	1.59	1.65
	10	43	53	46	4.00	2.63	2.42
	15	58	71	66	3.67	1.58	1.53
	20	80	87	86	3.85	1.58	1.62
	25	102	102	107	3.96	1.60	1.73
	30	128	122	132	4.17	1.70	1.89
	35	159	138	155	4.46	1.73	1.99
	40	208	165	182	5.13	1.93	2.17
	45	252	192	2003	5.53	2.15	22.76
	50		209	219		2.12	2.26
	55		220	237		2.05	2.24
	60		230			1.97	
	65						
	70						
	75						
	80						
	85						
	90						
	95						
	100						
	105						
	110						
Average at point					4.42	1.89	3.84

Table 35 Continued, ***Penetration Index*** measured by ***DCP*** in ***US-280, AL Base, mm/blow***

Lot		Penetration, mm			PI, mm/blow		
		Base 1	Base 1	Base 1	Base 1	Base 1	Base 1
Sublot		3	3	3	3	3	3
Point		A	B	C	A	B	C
Number of blows	0	3	0	0			
	5	22	16	15	3.80	0.94	0.88
	10	35	25	26	3.20	1.32	1.37
	15	45	39	38	2.80	0.91	0.88
	20	53	50	47	2.50	0.94	0.89
	25	61	57	57	2.32	0.92	0.92
	30	68	67	66	2.17	0.96	0.94
	35	74	72	77	2.03	0.92	0.99
	40	80	80	88	1.93	0.95	1.05
	45	84	82	95	1.80	0.93	1.08
	50	93	94	102	1.80	0.97	1.05
	55	102	101	113	1.80	0.95	1.07
	60	108	107	121	1.75	0.93	1.05
	65	118	115	125	1.77	0.97	1.06
	70	127	120	136	1.77		
	75	136	128	150	1.77		
	80	152	135	164	1.86		
	85	178	142	187			
	90	203	150	205			
	95	228	163	227			
	100		186				
	105		210				
	110		250				
Average at point					2.19	0.97	1.02

Table 35 Continued, ***Penetration Index*** measured by ***DCP*** in ***US-280, AL Base, mm/blow***

Lot		Penetration, mm			PI, mm/blow		
		Base 1	Base 1	Base 1	Base 1	Base 1	Base 1
Sublot		4	4	4	4	4	4
Point		A	B	C	A	B	C
Number of blows	0	0	1	0			
	5	15	17	17	3.00	0.94	1.00
	10	22	28	19	2.20	1.42	1.00
	15	31	42	43	2.07	0.95	1.00
	20	38	48	53	1.90	0.89	1.00
	25	49	56	62	1.96	0.89	1.00
	30	53	63	70	1.77	0.89	1.00
	35	61	69	78	1.74	0.87	1.00
	40	66	81	84	1.65	0.95	1.00
	45	72	84	88	1.60	0.94	1.00
	50	78	92	97	1.56	0.94	1.00
	55	88	98	106	1.60	0.92	1.00
	60	95	107	115	1.58	0.92	1.00
	65	104	108	118	1.60	0.91	1.00
	70	112	116	125	1.60		
	75	117	122	136	1.56		
	80	123	128	146	1.54		
	85	131	137	161			
	90	143	146	183			
	95	163	155	206			
	100	199	173	226			
	105	235	191				
	110		207				
Average at point					1.81	0.96	1.00

Table 35 Continued, ***Penetration Index*** measured by ***DCP*** in ***US-280, AL Base, mm/blow***

Lot		Penetration, mm			PI, mm/blow		
		Base 1	Base 1	Base 1	Base 1	Base 1	Base 1
Sublot		5	5	5	5	5	5
Point		A	B	C	A	B	C
Number of blows	0	0	2	0			
	5	17	19	12	3.40	1.00	0.71
	10	26	33	25	2.60	1.63	1.32
	15	38	45	33	2.53	1.00	0.77
	20	41	50	43	2.05	0.91	0.81
	25	49	58	48	1.96	0.90	0.77
	30	59	64	55	1.97	0.89	0.79
	35	64	74	63	1.83	0.92	0.81
	40	75	82	71	1.88	0.95	0.85
	45	82	91	78	1.82	1.01	0.89
	50	90	99	84	1.80	1.00	0.87
	55	98	105	95	1.78	0.97	0.90
	60	110	112	105	1.83	0.96	0.91
	65	120	122	117	1.85	1.02	0.99
	70	134	132	127	1.91		
	75	151	143	145	2.01		
	80	160	153	164	2.00		
	85	173	171	183			
	90	191	182	201			
	95	213	196	218			
	100	241	212	238			
	105						
	110						
Average at point					2.08	1.01	0.87

Table 35 Continued, ***Penetration Index*** measured by ***DCP*** in ***US-280, AL Base, mm/blow***

Lot		Penetration, mm			PI, mm/blow		
		Base 2	Base 2	Base 2	Base 2	Base 2	Base 2
Sublot		1	1	1	1	1	1
Point		A	B	C	A	B	C
Number of blows	0	13	11	8			
	5	35	30	34	4.40	1.12	1.53
	10	56	51	52	4.30	2.11	2.32
	15	72	70	67	3.93	1.37	1.37
	20	93	87	83	4.00	1.43	1.42
	25	108	102	100	3.80	1.47	1.48
	30	125	117	117	3.73	1.51	1.56
	35	144	134	139	3.74	1.58	1.68
	40	163	152	159	3.75	1.68	1.80
	45	182	182	207	3.76	1.94	2.26
	50	228	227	280	4.30	2.23	2.80
	55						
	60						
	65						
	70						
	75						
	80						
	85						
	90						
	95						
	100						
	105						
	110						
Average at point					3.97	1.64	1.82

Table 35 Continued, ***Penetration Index*** measured by ***DCP*** in ***US-280, AL Base, mm/blow***

Lot		Penetration, mm			PI, mm/blow		
		Base 2	Base 2	Base 2	Base 2	Base 2	Base 2
Sublot		2	2	2	2	2	2
Point		A	B	C	A	B	C
Number of blows	0	8	2	13			
	5	29	21	32	4.20	1.12	1.12
	10	50	38	52	4.20	1.89	2.05
	15	70	53	64	4.13	1.19	1.19
	20	88	68	80	4.00	1.25	1.26
	25	111	87	98	4.12	1.37	1.37
	30	133	105	121	4.17	1.47	1.54
	35	157	128	139	4.26	1.62	1.62
	40	185	151	165	4.43	1.77	1.81
	45	217	180	191	4.64	2.02	2.02
	50	257	222	216	4.98	2.27	2.09
	55		260	249		2.43	2.23
	60						
	65						
	70						
	75						
	80						
	85						
	90						
	95						
	100						
	105						
	110						
Average at point					4.31	1.67	1.66

Table 35 Continued, ***Penetration Index*** measured by ***DCP*** in ***US-280, AL Base, mm/blow***

Lot		Penetration, mm			PI, mm/blow		
		Base 2	Base 2	Base 2	Base 2	Base 2	Base 2
Sublot		3	3	3	3	3	3
Point		A	B	C	A	B	C
Number of blows	0	5	0	0			
	5	22	11	15	3.40	0.65	0.88
	10	37	23	30	3.20	1.21	1.58
	15	50	38	39	3.00	0.88	0.91
	20	63	48	49	2.90	0.91	0.92
	25	75	58	60	2.80	0.94	0.97
	30	89	70	73	2.80	1.00	1.04
	35	103	83	80	2.80	1.06	1.03
	40	116	95	92	2.78	1.13	1.10
	45	133	109	101	2.84	1.24	1.15
	50	156	119	113	3.02	1.23	1.16
	55	188	136	126	3.33	1.28	1.19
	60	220	148	140	3.58	1.29	1.22
	65		180	159		1.53	1.35
	70		204	179			
	75		238	201			
	80			222			
	85			243			
	90						
	95						
	100						
	105						
	110						
Average at point					3.04	1.10	1.11

Sublots 4 and 5 in Lot Base 2 were not tested

Table 35 Continued, ***Penetration Index*** measured by ***DCP*** in ***US-280, AL Base, mm/blow***

Lot		Penetration, mm			PI, mm/blow		
		Base 3	Base 3	Base 3	Base 3	Base 3	Base 3
Sublot		1	1	1	1	1	1
Point		A	B	C	A	B	C
Number of blows	0	1	0	10			
	5	20	23	31	3.80	1.35	1.24
	10	30	39	41	2.90	2.05	1.63
	15	42	48	52	2.73	1.12	0.98
	20	53	58	61	2.60	1.09	0.96
	25	60	71	69	2.36	1.15	0.95
	30	67	79	78	2.20	1.13	0.97
	35	75	87	82	2.11	1.12	0.92
	40	84	98	88	2.08	1.17	0.93
	45	94	105	95	2.07	1.19	0.97
	50	101	112	104	2.00	1.15	0.97
	55	106	122	112	1.91	1.15	0.96
	60	118	131	116	1.95	1.14	0.92
	65	130	139	124	1.98	1.18	0.97
	70	143	147	133	2.03		
	75	156	156	147	2.07		
	80	171	173	159	2.13		
	85	190	194	170			
	90	210	218	185			
	95			205			
	100			235			
	105						
	110						
Average at point					2.31	1.23	1.03

Table 35 Continued, ***Penetration Index*** measured by ***DCP*** in ***US-280, AL Base, mm/blow***

Lot		Penetration, mm			PI, mm/blow		
		Base 3	Base 3	Base 3	Base 3	Base 3	Base 3
Sublot		2	2	2	2	2	2
Point		A	B	C	A	B	C
Number of blows	0	0	0	0			
	5	20	18	18	4.00	1.06	1.06
	10	34	32	34	3.40	1.68	1.79
	15	45	45	46	3.00	1.05	1.07
	20	55	56	54	2.75	1.06	1.02
	25	62	63	69	2.48	1.02	1.11
	30	70	75	77	2.33	1.07	1.10
	35	81	82	87	2.31	1.05	1.12
	40	89	93	99	2.23	1.11	1.18
	45	99	106	109	2.20	1.20	1.24
	50	110	117	123	2.20	1.21	1.27
	55	121	132	136	2.20	1.25	1.28
	60	134	146	152	2.23	1.27	1.32
	65	147	160	168	2.26	1.36	1.42
	70	170	178	194	2.43		
	75	195	197	218	2.60		
	80	217	208	236	2.71		
	85	235	223				
	90						
	95						
	100						
	105						
	110						
Average at point					2.58	1.18	1.23

Table 35 Continued, ***Penetration Index*** measured by ***DCP*** in ***US-280, AL Base, mm/blow***

Lot		Penetration, mm			PI, mm/blow		
		Base 3	Base 3	Base 3	Base 3	Base 3	Base 3
Sublot		3	3	3	3	3	3
Point		A	B	C	A	B	C
Number of blows	0	0	6	2			
	5	23	25	23	4.60	1.12	1.24
	10	48	43	36	4.80	1.95	1.79
	15	52	57	49	3.47	1.19	1.09
	20	65	72	59	3.25	1.25	1.08
	25	74	83	71	2.96	1.24	1.11
	30	87	90	79	2.90	1.20	1.10
	35	96	97	90	2.74	1.17	1.13
	40	108	113	99	2.70	1.27	1.15
	45	122	122	105	2.71	1.32	1.17
	50	131	135	115	2.62	1.33	1.16
	55	144	146	125	2.62	1.32	1.16
	60	161	162	135	2.68	1.36	1.16
	65	176	179	145	2.71	1.47	1.21
	70	186	206	162	2.66		
	75	205	233	174	2.73		
	80	238		190	2.98		
	85			210			
	90			232			
	95						
	100						
	105						
	110						
Average at point					3.07	1.32	1.20

Table 35 Continued, ***Penetration Index*** measured by ***DCP*** in ***US-280, AL Base, mm/blow***

Lot		Penetration, mm			PI, mm/blow		
		Base 3	Base 3	Base 3	Base 3	Base 3	Base 3
Sublot		4	4	4	4	4	4
Point		A	B	C	A	B	C
Number of blows	0	5	1	0			
	5	28	24	23	4.60	1.35	1.35
	10	41	42	36	3.60	2.16	1.89
	15	56	57	50	3.40	1.30	1.16
	20	67	71	60	3.10	1.32	1.13
	25	75	81	76	2.80	1.29	1.23
	30	87	99	83	2.73	1.40	1.19
	35	95	110	96	2.57	1.40	1.23
	40	104	122	102	2.48	1.44	1.21
	45	113	139	115	2.40	1.57	1.31
	50	121	161	127	2.32	1.65	1.31
	55	132	183	138	2.31	1.72	1.30
	60	142	211	152	2.28	1.83	1.32
	65	156	243	170	2.32	2.05	1.44
	70	175		202	2.43		
	75	203		234	2.64		
	80	285			3.50		
	85						
	90						
	95						
	100						
	105						
	110						
Average at point					2.84	1.57	1.31

Table 35 Continued, ***Penetration Index*** measured by ***DCP*** in ***US-280, AL Base, mm/blow***

Lot		Penetration, mm			PI, mm/blow		
		Base 3	**Base 3**	**Base 3**	**Base 3**	**Base 3**	**Base 3**
Sublot		**5**	**5**	**5**	**5**	**5**	**5**
Point		**A**	**B**	**C**	**A**	**B**	**C**
Number of blows	0	1	2	0			
	5	22	25	20	4.20	1.35	1.18
	10	38	48	39	3.70	2.42	2.05
	15	53	59	55	3.47	1.33	1.28
	20	62	69	65	3.05	1.26	1.23
	25	73	78	77	2.88	1.23	1.24
	30	79	88	86	2.60	1.23	1.23
	35	90	95	98	2.54	1.19	1.26
	40	98	104	110	2.43	1.21	1.31
	45	105	114	116	2.31	1.27	1.32
	50	113	127	128	2.24	1.29	1.32
	55	123	140	142	2.22	1.30	1.34
	60	133	162	154	2.20	1.39	1.34
	65	146	185	178	2.23	1.55	1.51
	70	164	225	210	2.33		
	75	203		262	2.69		
	80	245			3.05		
	85						
	90						
	95						
	100						
	105						
	110						
Average at point					2.76	1.39	1.35

Table 35 Continued, ***Penetration Index*** measured by ***DCP*** in ***US-280, AL Base, mm/blow***

Lot		Penetration, mm			PI, mm/blow		
		Base 4	Base 4	Base 4	Base 4	Base 4	Base 4
Sublot		1	1	1	1	1	1
Point		A	B	C	A	B	C
Number of blows	0	7	0	7			
	5	27	23	30	4.00	1.35	1.35
	10	46	98	51	3.90	5.16	2.32
	15	62	66	72	3.67	1.53	1.51
	20	78	88	91	3.55	1.66	1.58
	25	98	103	112	3.64	1.66	1.69
	30	113	128	136	3.53	1.83	1.84
	35	134	155	165	3.63	1.99	2.03
	40	154	192	202	3.68	2.29	2.32
	45	184	242	241	3.93	2.75	2.66
	50	230			4.46		
	55						
	60						
	65						
	70						
	75						
	80						
	85						
	90						
	95						
	100						
	105						
	110						
Average at point					3.80	2.25	1.92

Table 35 Continued, ***Penetration Index*** measured by ***DCP*** in ***US-280, AL Base, mm/blow***

Lot		Penetration, mm			PI, mm/blow		
		Base 4	Base 4	Base 4	Base 4	Base 4	Base 4
Sublot		2	2	2	2	2	2
Point		A	B	C	A	B	C
Number of blows	0	4	2	0			
	5	23	25	21	3.80	1.35	1.24
	10	39	42	39	3.50	2.11	2.05
	15	55	56	59	3.40	1.26	1.37
	20	71	70	70	3.35	1.28	1.32
	25	88	83	88	3.36	1.31	1.42
	30	109	100	96	3.50	1.40	1.37
	35	128	117	112	3.54	1.47	1.44
	40	149	137	127	3.63	1.61	1.51
	45	164	161	146	3.56	1.81	1.66
	50	195	189	165	3.82	1.93	1.70
	55	232	214	187	4.15	2.00	1.76
	60			220			1.91
	65						
	70						
	75						
	80						
	85						
	90						
	95						
	100						
	105						
	110						
Average at point					3.60	1.59	1.56

Table 35 Continued, ***Penetration Index*** measured by ***DCP*** in ***US-280, AL Base, mm/blow***

Lot		Penetration, mm			PI, mm/blow		
		Base 4	Base 4	Base 4	Base 4	Base 4	Base 4
Sublot		3	3	3	3	3	3
Point		A	B	C	A	B	C
Number of blows	0	0	2	2			
	5	21	28	35	4.20	1.53	1.94
	10	41	45	54	4.10	2.26	2.74
	15	57	63	72	3.80	1.42	1.63
	20	78	80	103	3.90	1.47	1.91
	25	98	97	154	3.92	1.53	2.45
	30	119	114	189	3.97	1.60	2.67
	35	137	135	232	3.91	1.71	2.95
	40	155	161		3.88	1.89	
	45	188	190		4.18	2.14	
	50	230	218		4.60	2.23	
	55						
	60						
	65						
	70						
	75						
	80						
	85						
	90						
	95						
	100						
	105						
	110						
Average at point					4.05	1.78	2.33

Table 35 Continued, ***Penetration Index*** measured by ***DCP*** in ***US-280, AL Base, mm/blow***

Lot		Penetration, mm			PI, mm/blow		
		Base 4	Base 4	Base 4	Base 4	Base 4	Base 4
Sublot		4	4	4	4	4	4
Point		A	B	C	A	B	C
Number of blows	0	2	3	0			
	5	24	29	26	4.40	1.53	1.53
	10	44	51	49	4.20	2.53	2.58
	15	63	69	73	4.07	1.53	1.70
	20	79	91	89	3.85	1.66	1.68
	25	99	112	115	3.88	1.76	1.85
	30	122	140	133	4.00	1.96	1.90
	35	153	168	168	4.31	2.12	2.15
	40	185	205	208	4.58	2.40	2.48
	45	230	245	256	5.07	2.75	2.91
	50						
	55						
	60						
	65						
	70						
	75						
	80						
	85						
	90						
	95						
	100						
	105						
	110						
Average at point					4.26	2.03	2.09

Table 35 Continued, ***Penetration Index*** measured by ***DCP*** in ***US-280, AL Base, mm/blow***

Lot		Penetration, mm			PI, mm/blow		
		Base 4	Base 4	Base 4	Base 4	Base 4	Base 4
Sublot		5	5	5	5	5	5
Point		A	B	C	A	B	C
Number of blows	0	0	0	2			
	5	22	27	31	4.40	1.59	1.71
	10	38	46	55	3.80	2.42	2.79
	15	68	66	92	4.53	1.53	2.09
	20	85	89	109	4.25	1.68	2.02
	25	106	111	144	4.24	1.79	2.29
	30	131	135	194	4.37	1.93	2.74
	35	165	168	246	4.71	2.15	3.13
	40	209	218		5.23	2.60	
	45	257	270		5.71	3.07	
	50						
	55						
	60						
	65						
	70						
	75						
	80						
	85						
	90						
	95						
	100						
	105						
	110						
Average at point					4.58	2.08	2.40

Table 36. ***Wet density*** measured by ***EDG*** in ***US-280, AL Base, pcf***

Lot #	Sublot	A	B	C	Average	Lot Average
	1	153.9	154.5	153.6	154.0	
1	2	155.0	154.5	154.4	154.6	
	3	153.2	153.5	153.4	153.3	
	4	152.7	152.4	152.7	152.6	
	5	151.0	151.9	151.8	151.5	153.2
	1	150.9	152.4	152.3	151.9	
2	2	152.0	150.7	151.0	151.3	
	3	152.3	151.1	149.2	150.9	
	4	151.3	150.7	151.5	151.2	
	5	151.9	151.4	152.0	151.8	151.4
	1	154.5	153.8	154.3	154.2	
3	2	154.9	155.0	155.0	155.0	
	3	155.9	155.9	155.6	155.8	
	4	154.8	154.6	154.6	154.6	
	5	155.4	155.7	155.3	155.5	155.0
	1	154.0	154.4	153.5	153.9	
4	2	153.3	154.6	154.9	154.2	
	3	155.0	154.3	154.9	154.7	
	4	154.3	154.8	154.1	154.4	
	5	153.4	154.4	153.9	153.9	154.2
Average lot 1 by row		153.1	153.3	153.2		
Average lot 2 by row		151.7	151.3	151.2		
Average lot 3 by row		155.1	155.0	155.0		
Average lot 4 by row		154.0	154.5	154.2		
Average project by row		153.5	153.5	153.4		
Average project						153.5

Table 37. ***Percent Moisture*** measured by **EDG** in **US-280, AL Base**
Note: Test repetitions were not performed at individual points

Lot #	Sublot	A	B	C	Average	Lot Average
1	1	96.11	96.43	95.95	96.16	
	2	96.64	96.40	96.39	96.48	
	3	95.73	95.91	95.83	95.82	
	4	95.46	95.28	95.45	95.40	
	5	94.48	94.99	94.94	94.80	95.73
2	1	94.46	95.33	95.24	95.01	
	2	95.10	94.34	94.53	94.66	
	3	95.24	94.59	93.41	94.41	
	4	94.66	94.32	94.79	94.59	
	5	95.03	94.73	95.04	94.93	94.72
3	1	96.38	96.03	96.28	96.23	
	2	96.56	96.60	96.64	96.60	
	3	97.00	97.00	96.87	96.96	
	4	96.53	96.44	96.43	96.47	
	5	96.78	96.93	96.79	96.83	96.62
4	1	96.12	96.28	95.90	96.10	
	2	95.75	96.40	96.56	96.24	
	3	96.65	96.31	96.57	96.51	
	4	96.28	96.51	96.19	96.33	
	5	95.83	96.36	96.08	96.09	96.25
Average lot 1 by row		95.68	95.80	95.71		
Average lot 2 by row		94.90	94.66	94.60		
Average lot 3 by row		96.65	96.60	96.60		
Average lot 4 by row		96.13	96.37	96.26		
Average project by row		95.84	95.86	95.79		
Average project						95.83

Table 36. ***Wet density*** measured by ***EDG*** in ***US-280, AL Base, pcf***
Note: Test repetitions were not performed at individual points

Lot #	Sublot	A	B	C	Average	Lot Average
1	1	153.9	154.5	153.6	154.0	
	2	155.0	154.5	154.4	154.6	
	3	153.2	153.5	153.4	153.3	
	4	152.7	152.4	152.7	152.6	
	5	151.0	151.9	151.8	151.5	153.2
2	1	150.9	152.4	152.3	151.9	
	2	152.0	150.7	151.0	151.3	
	3	152.3	151.1	149.2	150.9	
	4	151.3	150.7	151.5	151.2	
	5	151.9	151.4	152.0	151.8	151.4
3	1	154.5	153.8	154.3	154.2	
	2	154.9	155.0	155.0	155.0	
	3	155.9	155.9	155.6	155.8	
	4	154.8	154.6	154.6	154.6	
	5	155.4	155.7	155.3	155.5	155.0
4	1	154.0	154.4	153.5	153.9	
	2	153.3	154.6	154.9	154.2	
	3	155.0	154.3	154.9	154.7	
	4	154.3	154.8	154.1	154.4	
	5	153.4	154.4	153.9	153.9	154.2
Average lot 1 by row		153.1	153.3	153.2		
Average lot 2 by row		151.7	151.3	151.2		
Average lot 3 by row		155.1	155.0	155.0		
Average lot 4 by row		154.0	154.5	154.2		
Average project by row		153.5	153.5	153.4		
Average project						153.5

Table 39. ***Stiffness*** measured by ***GEOGAUGE*** in ***US-280, AL Base, psi***
Note: Test repetitions were performed at individual points as shown in

Lot #	Sublot	A	B	C	Average	Lot Average
1	1	208.80	208.56	207.84	208.40	
	2	219.82	217.35	209.15	215.44	
	3	254.41	249.10	241.47	248.33	
	4	224.51	230.00	227.42	227.31	
	5	193.68	201.34	229.33	208.12	221.52
	5 – no sand	148.62	135.12	144.92	142.89	
2	1	192.29	245.13	229.24	222.22	
	2	236.50	221.98	223.54	227.34	
	3	232.80	232.63	226.61	230.68	
	4	231.37	223.53	222.67	225.86	
	5	226.78	231.02	223.80	227.20	226.66
3	1	227.99	227.75	220.66	225.47	
	2	195.26	202.37	203.11	200.25	
	3	169.46	177.08	177.59	174.71	
	4	202.77	227.13	231.61	220.50	
	5	190.27	202.58	201.76	198.20	203.83
	5 – no sand	138.57	144.85	139.92	141.11	
4	1	164.36	163.63	172.23	166.74	
	2	164.10	160.32	167.60	164.01	
	3	164.63	158.23	162.22	161.69	
	4	156.04	158.42	151.00	155.15	
	5	150.94	146.51	149.13	148.86	159.29
Average lot 1 by row		220.24	221.27	223.04		
Average lot 2 by row		223.95	230.86	225.17		
Average lot 3 by row		197.15	207.38	206.95		
Average lot 4 by row		160.01	157.42	160.44		
Average project by row		200.34	204.23	203.90		
Average project						202.82

Table 40. Repeatability in ***Modulus*** measurements by ***Geogauge*** in ***US-280, AL Base, psi***
Note: Summary of test results are shown in Table 38

Lot	Sublot	Point	Trial 1	Trial 2	Trial 3	Average	Std deviation
Base 1	1	A	53770	43860	40480	46037	**6907**
Base 1	1	B	51860	48260	37840	45987	**7281**
Base 1	1	C	49860	44020	43600	45827	**3499**
Base 1	2	A	50320	42150	52940	48470	**5628**
Base 1	2	B	46600	46690	50490	47927	**2220**
Base 1	2	C	45110	43640	49610	46120	**3111**
Base 1	3	A	60540	56340	51420	56100	**4565**
Base 1	3	B	58180	52830	53760	54923	**2858**
Base 1	3	C	55560	50820	53350	53243	**2372**
Base 1	4	A	54430	49520	44560	49503	**4935**
Base 1	4	B	50310	53620	48150	50693	**2755**
Base 1	4	C	51530	52900	46000	50143	**3653**
Base 1	5	A	40380	39550	48180	42703	**4761**
Base 1	5	B	45680	39940	47570	44397	**3974**
Base 1	5	C	50640	48640	52420	50567	**1891**
Base 1	5*	A	26150	31700	40470	32773	**7220**
Base 1	5*	B	25550	31140	32690	29793	**3756**
Base 1	5*	C	27270	30210	38380	31953	**5757**
Base 2	1	A	40430	43610	43160	42400	**1721**
Base 2	1	B	58200	54410	49550	54053	**4336**
Base 2	1	C	54420	50540	46690	50550	**3865**
Base 2	2	A	46620	57480	52350	52150	**5433**
Base 2	2	B	41900	56240	48700	48947	**7173**
Base 2	2	C	47510	50410	49950	49290	**1559**
Base 2	3	A	52040	44940	57020	51333	**6071**
Base 2	3	B	50940	42670	60280	51297	**8810**
Base 2	3	C	51530	42540	55770	49947	**6756**
Base 2	4	A	50740	51600	50710	51017	**505**
Base 2	4	B	51020	49700	47140	49287	**1973**
Base 2	4	C	48280	51390	47620	49097	**2013**
Base 2	5	A	51860	54960	43180	50000	**6106**
Base 2	5	B	47610	56920	48290	50940	**5190**
Base 2	5	C	48090	50720	49220	49343	**1319**
Base 3	1	A	55100	46110	49600	50270	**4532**

Lot	Sublot	Point	Trial 1	Trial 2	Trial 3	Average	Std deviation
Base 3	1	B	56840	44930	49680	50483	**5996**
Base 3	1	C	50270	45570	50170	48670	**2685**
Base 3	2	A	43430	42030	43710	43057	**900**
Base 3	2	B	46530	39710	47630	44623	**4290**
Base 3	2	C	50180	41370	42800	44783	**4728**
Base 3	3	A	40450	37080	34570	37367	**2950**
Base 3	3	B	39980	38050	39100	39043	**966**
Base 3	3	C	39170	36580	41730	39160	**2575**
Base 3	4	A	57120	39190	37810	44707	**10772**
Base 3	4	B	55490	52300	42450	50080	**6798**
Base 3	4	C	57600	51260	44350	51070	**6627**
Base 3	5	A	43110	42550	40200	41953	**1544**
Base 3	5	B	49910	43390	40710	44670	**4732**
Base 3	5	C	48240	41370	43850	44487	**3479**
Base 3	5*	A	22540	28500	40620	30553	**9213**
Base 3	5*	B	34590	30770	30450	31937	**2303**
Base 3	5*	C	38220	25690	28640	30850	**6551**
Base 4	1	A	39930	33660	35120	36237	**3281**
Base 4	1	B	40780	32330	35130	36080	**4304**
Base 4	1	C	42180	34180	37560	37973	**4016**
Base 4	2	A	40440	36100	32010	36183	**4216**
Base 4	2	B	39580	34220	32250	35350	**3793**
Base 4	2	C	40000	37030	33840	36957	**3081**
Base 4	3	A	39530	33390	35980	36300	**3082**
Base 4	3	B	36210	34210	34250	34890	**1143**
Base 4	3	C	37500	34280	35530	35770	**1623**
Base 4	4	A	36890	35070	31260	34407	**2873**
Base 4	4	B	39980	33970	30850	34933	**4641**
Base 4	4	C	34600	35840	29440	33293	**3394**
Base 4	5	A	29030	36830	33790	33217	**3931**
Base 4	5	B	25470	36850	34590	32303	**6025**
Base 4	**5**	**C**	**28140**	**36760**	**33740**	**32880**	**4374**

* NO sand used underneath the test device during test measurement

Table 41. Repeatability in ***Stiffness*** measured by ***Geogauge*** in ***US-280, AL Base, klb/in***
Note: Summary of test results are shown in Table 39

Lot	Sublot	Point	Trial 1	Trial 2	Trial 3	Average	Std deviation
Base 1	1	A	243.88	198.90	183.61	208.80	**31.33**
Base 1	1	B	235.20	218.88	171.59	208.56	**33.04**
Base 1	1	C	226.13	199.64	197.74	207.84	**15.87**
Base 1	2	A	228.22	191.16	240.09	219.82	**25.52**
Base 1	2	B	211.33	211.75	228.97	217.35	**10.07**
Base 1	2	C	204.56	197.90	224.98	209.15	**14.11**
Base 1	3	A	274.55	255.49	233.20	254.41	**20.70**
Base 1	3	B	263.87	239.59	243.83	249.10	**12.97**
Base 1	3	C	251.97	230.49	241.96	241.47	**10.75**
Base 1	4	A	246.84	224.59	202.11	224.51	**22.37**
Base 1	4	B	228.45	243.20	218.36	230.00	**12.49**
Base 1	4	C	233.72	239.93	208.62	227.42	**16.58**
Base 1	5	A	183.12	179.39	218.52	193.68	**21.60**
Base 1	5	B	207.17	181.12	215.74	201.34	**18.03**
Base 1	5	C	229.67	220.58	237.74	229.33	**8.59**
Base 1	5*	A	118.58	143.75	183.54	148.62	**32.75**
Base 1	5*	B	115.89	141.21	148.26	135.12	**17.02**
Base 1	5*	C	123.68	137.00	174.07	144.92	**26.11**
Base 2	1	A	183.36	197.79	195.73	192.29	**7.80**
Base 2	1	B	263.94	246.75	224.70	245.13	**19.67**
Base 2	1	C	246.80	229.20	211.73	229.24	**17.54**
Base 2	2	A	211.42	260.68	237.41	236.50	**24.64**
Base 2	2	B	190.01	255.04	220.88	221.98	**32.53**
Base 2	2	C	215.49	228.61	226.53	223.54	**7.05**
Base 2	3	A	236.01	203.80	258.58	232.80	**27.53**
Base 2	3	B	231.01	193.53	273.36	232.63	**39.94**
Base 2	3	C	233.97	192.92	252.93	226.61	**30.68**
Base 2	4	A	230.13	234.01	229.98	231.37	**2.28**
Base 2	4	B	231.39	225.42	213.78	223.53	**8.96**
Base 2	4	C	218.98	233.07	215.97	222.67	**9.13**
Base 2	5	A	235.22	249.26	195.85	226.78	**27.69**
Base 2	5	B	215.91	258.14	219.00	231.02	**23.54**
Base 2	5	C	218.11	230.04	223.25	223.80	**5.98**
Base 3	1	A	249.88	209.13	224.95	227.99	**20.54**

Lot	Sublot	Point	Trial 1	Trial 2	Trial 3	Average	Std deviation
Base 3	1	B	254.16	203.77	225.33	227.75	**25.28**
Base 3	1	C	228.00	206.46	227.53	220.66	**12.30**
Base 3	2	A	196.96	190.60	198.23	195.26	**4.09**
Base 3	2	B	211.02	180.10	216.00	202.37	**19.45**
Base 3	2	C	227.58	187.62	194.12	203.11	**21.44**
Base 3	3	A	183.44	168.17	156.77	169.46	**13.38**
Base 3	3	B	181.34	172.58	177.32	177.08	**4.38**
Base 3	3	C	177.64	165.90	189.24	177.59	**11.67**
Base 3	4	A	259.06	177.75	171.49	202.77	**48.85**
Base 3	4	B	251.64	237.21	192.54	227.13	**30.81**
Base 3	4	C	261.24	232.46	201.13	231.61	**30.06**
Base 3	5	A	195.51	192.99	182.32	190.27	**7.00**
Base 3	5	B	226.34	196.77	184.62	202.58	**21.46**
Base 3	5	C	218.78	187.61	198.88	201.76	**15.78**
Base 3	5*	A	102.22	129.27	184.22	138.57	**41.78**
Base 3	5*	B	156.87	139.56	138.12	144.85	**10.43**
Base 3	5*	C	173.36	116.52	129.88	139.92	**29.72**
Base 4	1	A	181.11	152.68	159.28	164.36	**14.88**
Base 4	1	B	184.94	146.64	159.32	163.63	**19.51**
Base 4	1	C	191.31	155.03	170.35	172.23	**18.21**
Base 4	2	A	183.40	163.72	145.17	164.10	**19.12**
Base 4	2	B	179.51	155.19	146.26	160.32	**17.21**
Base 4	2	C	181.42	167.94	153.45	167.60	**13.99**
Base 4	3	A	179.26	151.43	163.19	164.63	**13.97**
Base 4	3	B	164.23	155.15	155.32	158.23	**5.19**
Base 4	3	C	170.07	155.46	161.14	162.22	**7.37**
Base 4	4	A	167.29	159.04	141.79	156.04	**13.01**
Base 4	4	B	181.31	154.05	139.9	158.42	**21.05**
Base 4	4	C	156.93	162.54	133.53	151.00	**15.39**
Base 4	5	A	131.65	167.02	154.16	150.94	**17.90**
Base 4	5	B	115.50	167.15	156.89	146.51	**27.34**
Base 4	**5**	**C**	**127.64**	**166.73**	**153.01**	**149.13**	**19.83**

* NO sand used underneath the test device during test measurement

Table 42. **Thickness** measured by ***GPR*** in ***US-280, AL Base, inch***
Note: Repeatability results are shown in Table 48

Lot #	Sublot	A	B	C	Average	Lot Average
1	1	6.09	5.91	6.37	6.13	
	2	5.56	5.04	5.61	5.40	
	3	5.45	6.29	5.55	5.76	
	4	5.50	5.40	5.81	5.57	
	5	4.77	4.52	4.65	4.65	5.50
2	1	6.09	5.91	6.94	6.31	
	2	4.91	5.08	5.12	5.04	
	3	4.72	4.18	5.04	4.65	
	4	4.45	4.31	4.40	4.39	
	5	5.08	5.43	6.29	5.60	5.20
3	1	5.22	5.32	5.45	5.33	
	2	5.99	5.98	6.06	6.01	
	3	6.49	6.86	6.68	6.68	
	4	6.34	6.27	5.75	6.12	
	5	6.43	6.16	6.08	6.22	6.07
4	1	5.89	5.41	5.35	5.55	
	2	6.86	6.56	6.26	6.56	
	3	6.61	5.84	5.64	6.03	
	4	5.94	5.59	5.56	5.70	
	5	6.02	5.11	5.07	5.40	5.85
Average lot 1 by row		5.47	5.43	5.60		
Average lot 2 by row		5.05	4.98	5.56		
Average lot 3 by row		6.09	6.12	6.00		
Average lot 4 by row		6.26	5.70	5.58		
Average project by row		5.72	5.56	5.69		
Average project						5.65

Table 43. ***Dielectric*** measured by ***GPR*** in ***US-280, AL Base***
Note: Repeatability results are shown in Table 48

Lot #	Sublot	A	B	C	Average	Lot Average
1	1	11.04	10.40	9.69	10.37	
	2	11.49	12.10	12.68	12.09	
	3	12.96	10.77	12.22	11.99	
	4	12.27	12.70	11.09	12.02	
	5	12.95	11.96	11.53	12.15	11.72
2	1	12.20	10.58	10.10	10.96	
	2	13.04	11.79	11.64	12.16	
	3	12.16	14.35	11.31	12.61	
	4	13.49	13.05	13.38	13.31	
	5	13.52	13.19	9.53	12.08	12.22
3	1	13.90	13.68	12.36	13.32	
	2	12.10	11.77	12.10	11.99	
	3	11.03	11.08	11.56	11.22	
	4	11.25	11.52	12.01	11.59	
	5	11.24	12.01	11.18	11.48	11.92
4	1	12.02	12.42	12.79	12.41	
	2	10.87	10.41	11.43	10.91	
	3	10.14	11.40	11.81	11.12	
	4	11.74	11.64	12.55	11.98	
	5	10.37	11.99	11.95	11.44	11.57
Average lot 1 by row		12.14	11.59	11.44		
Average lot 2 by row		12.88	12.59	11.19		
Average lot 3 by row		11.90	12.01	11.84		
Average lot 4 by row		11.03	11.57	12.11		
Average project by row		11.99	11.94	11.65		
Average project						11.86

Table 44. Repeatability in ***GPR Thickness and Dielectric measurements*** in ***US-280, AL***
Note: Summary of test results are shown in Table 42 and Table 43

Lot	Sublot	Point	Thickness, inch			Dielectric		
			Trial 1	Trial 2	Average	Trial 1	Trial 2	Average
Base 1	1	A	6.30	5.89	6.09		10.45	**11.62**
Base 1	1	B	5.90	5.91	5.91		10.39	**10.40**
Base 1	1	C	6.46	6.29	6.37		9.43	**9.95**
Base 1	2	A	5.37	5.75	5.56		11.98	**11.01**
Base 1	2	B	4.94	5.13	5.04		12.48	**11.73**
Base 1	2	C	5.34	5.87	5.61		13.70	**11.67**
Base 1	3	A	5.23	5.67	5.45		13.96	**11.97**
Base 1	3	B	6.14	6.44	6.29		11.27	**10.28**
Base 1	3	C	5.54	5.57	5.55		12.39	**12.06**
Base 1	4	A	5.55	5.45	5.50		12.11	**12.43**
Base 1	4	B	5.24	5.56	5.40		13.44	**11.96**
Base 1	4	C	5.71	5.92	5.81		11.48	**10.71**
Base 1	5	A	4.81	4.73	4.77		12.73	**13.17**
Base 1	5	B	4.37	4.67	4.52		12.72	**11.20**
Base 1	5	C	4.69	4.60	4.65		11.32	**11.74**
Base 2	1	A	5.54	6.64	6.09		11.72	**12.69**
Base 2	1	B	5.55	6.27	5.91		11.60	**9.56**
Base 2	1	C	6.65	7.24	6.94		10.05	**10.15**
Base 2	2	A	5.09	4.73	4.91		12.14	**13.93**
Base 2	2	B	5.10	5.06	5.08		11.74	**11.85**
Base 2	2	C	5.09	5.16	5.12		11.74	**11.55**
Base 2	3	A	4.40	5.03	4.72		12.62	**11.69**
Base 2	3	B	4.26	4.09	4.18		13.17	**15.53**
Base 2	3	C	5.04	5.05	5.04		10.67	**11.94**
Base 2	4	A	4.38	4.51	4.45		13.06	**13.92**
Base 2	4	B	4.08	4.54	4.31		13.20	**12.90**
Base 2	4	C	4.25	4.56	4.40		12.81	**13.95**
Base 2	5	A	5.05	5.12	5.08		13.50	**13.55**
Base 2	5	B	5.45	5.41	5.43		13.29	**13.09**
Base 2	5	C	6.28	6.30	6.29		9.58	**9.49**
Base 3	1	A	5.35	5.10	5.22		13.44	**14.37**

Lot	Sublot	Point	Thickness, inch			Dielectric		
			Trial 1	Trial 2	Average	Trial 1	Trial 2	Average
Base 3	1	B	5.08	5.55	5.32		14.69	**12.68**
Base 3	1	C	5.15	5.75	5.45		13.72	**11.01**
Base 3	2	A	5.85	6.13	5.99		12.70	**11.49**
Base 3	2	B	6.11	5.85	5.98		11.26	**12.27**
Base 3	2	C	5.98	6.15	6.06		12.44	**11.77**
Base 3	3	A	6.52	6.46	6.49		11.25	**10.82**
Base 3	3	B	6.64	7.07	6.86		12.01	**10.15**
Base 3	3	C	6.58	6.78	6.68		12.02	**11.10**
Base 3	4	A	6.05	6.63	6.34		12.24	**10.27**
Base 3	4	B	6.03	6.51	6.27		12.34	**10.69**
Base 3	4	C	5.65	5.84	5.75		12.33	**11.69**
Base 3	5	A	6.24	6.61	6.43		11.76	**10.72**
Base 3	5	B	5.88	6.44	6.16		13.06	**10.97**
Base 3	5	C	6.25	5.91	6.08		11.71	**10.66**
Base 4	1	A	5.66	6.12	5.89		12.88	**11.16**
Base 4	1	B	5.54	5.29	5.41		11.86	**12.99**
Base 4	1	C	5.37	5.33	5.35		12.72	**12.86**
Base 4	2	A	6.69	7.04	6.86		11.15	**10.60**
Base 4	2	B	6.62	6.50	6.56		10.24	**10.59**
Base 4	2	C	6.34	6.19	6.26		11.19	**11.67**
Base 4	3	A	6.69	6.52	6.61		10.06	**10.22**
Base 4	3	B	5.70	5.98	5.84		12.45	**10.34**
Base 4	3	C	5.54	5.75	5.64		12.52	**11.10**
Base 4	4	A	5.96	5.91	5.94		11.87	**11.60**
Base 4	4	B	5.30	5.88	5.59		13.08	**10.20**
Base 4	4	C	5.17	5.96	5.56		14.33	**10.77**
Base 4	5	A	5.80	6.25	6.02		11.19	**9.54**
Base 4	5	B	5.07	5.16	5.11		12.17	**11.82**
Base 4	**5**	**C**	**5.02**	**5.13**	**5.07**		**12.21**	**11.69**

Table 45. ***Modulus**** measured by ***LWD 2*** in ***US-280, AL Base, psi***
Note: Test repetitions were performed at individual points as shown in Table 46

Lot #	Sublot	A	B	C	Average	Lot Average
1	1	68890	16770	34848	40169	
	2	22371	30294	39427	30698	
	3	51501	56952	59917	56124	
	4	76966	59647	67949	68188	
	5	70466	83167	29067	60900	51216
2	1	41796	26618	26462	31625	
	2	No Data	No Data	No Data		
	3	73570	32043	38074	47896	
	4	No Data	No Data	No Data		
	5	54274	37253	60554	50694	43405
3	1	16186	11772	19800	15919	
	2	20334	17794	20428	19519	
	3	19165	28211	23649	23675	
	4	20437	18184	15181	17934	
	5	15115	16017	15741	15625	18534
4	1	No Data	No Data	No Data		
	2	No Data	No Data	No Data		
	3	No Data	No Data	No Data		
	4	No Data	No Data	No Data		
	5	No Data	No Data	No Data		
Average lot 1 by row		58039	49366	46242		
Average lot 2 by row		56547	31971	41697		
Average lot 3 by row		18247	18396	18960		
Average lot 4 by row						
Average project by row		42390	33440	34700		
Average project						36843

* Modulus reported in the table is determined from first sensor deflection measurement.
Table 46 shows deflection readings and modulus predictions from other sensors.

Table 46. Repeatability in ***Modulus*** measurements by ***LWD 1*** in ***US-280, AL Base, psi***
Note: Summary of test results are shown in Table 25

Lot	Sublot	Point A									
		Load, kN	Deflection, µm			Modulus, Mpa			Modulus, psi		
		Load	δ 1	δ 2	δ 3	E1	E2	E3	E1	E2	E3
Base 1	1	8.91	59	50	33	562.71	2.26	2.18	81592	327	315
		9.11	74	55	38	458.71	2.05	1.89	66514	297	274
		9.17	64	53	35	533.88	2.13	2.05	77413	309	297
		9.26	78	58	39	442.36	1.95	1.84	64142	282	267
		9.28	77	57	39	449.07	1.98	1.84	65115	287	267
					Average	475.10	2.02	1.91	68890	293	277
					Stdev	51.015	0.098	0.121	7397	14	18
Base 1	2	8.74	322	150	96	101.14	0.75	0.75	14665	109	108
		9.12	226	107	78	150.36	1.05	0.92	21803	153	133
		9.09	219	105	76	154.66	1.07	0.94	22426	156	137
		9.01	213	108	80	157.62	1.04	0.90	22854	151	130
		8.89	220	117	78	150.57	0.96	0.92	21832	140	133
					Average	154.28	1.03	0.92	22371	149	134
					Stdev	3.539	0.057	0.024	513	8	3
Base 1	3	8.92	165	103	44	201.44	1.10	1.63	29208	159	237
		9.14	97	55	34	351.10	2.05	2.11	50909	297	306
		9.16	92	51	33	370.99	2.21	2.18	53794	321	315

Lot	Sublot	Point A									
		Load, kN	Deflection, μm			Modulus, Mpa			Modulus, psi		
		Load	δ 1	δ 2	δ 3	E1	E2	E3	E1	E2	E3
		9.17	99	51	33	345.14	2.21	2.18	50045	321	315
		9.19	98	51	33	349.42	2.21	2.18	50666	321	315
					Average	355.18	2.21	2.18	51501	321	315
					Stdev	13.858	0.000	0.000	2009	0	0
Base 1	4	9.21	68	31	22	504.67	3.64	3.26	73177	528	473
		9.14	67	29	22	508.31	3.89	3.26	73705	564	473
		9.11	67	29	22	506.64	3.89	3.26	73463	564	473
		9.11	67	29	21	506.64	3.89	3.42	73463	564	496
		9.17	59	29	22	579.13	3.89	3.26	83973	564	473
					Average	530.80	3.89	3.32	76966	564	481
					Stdev	41.850	0.000	0.090	6068	0	13
Base 1	5	9.19	61	44	6	561.36	2.56	11.97	81397	372	1735
		9.3	62	45	22	558.92	2.51	3.26	81043	364	473
		9.26	71	44	5	485.97	2.56	14.36	70466	372	2082
						No data	No data	No data	No data	No data	No data
						No data	No data	No data	No data	No data	No data
					Average	485.97	2.56	14.36	70466	372	2082
					Stdev	N/A	N/A	N/A	N/A	N/A	N/A

Lot	Sublot	Point A									
		Load, kN	Deflection, μm			Modulus, Mpa			Modulus, psi		
		Load	δ 1	δ 2	δ 3	E1	E2	E3	E1	E2	E3
Base 2	1	8.92	127	65	42	261.71	1.74	1.71	37948	252	248
		9.09	122	61	41	277.63	1.85	1.75	40256	268	254
		9.07	118	62	42	286.41	1.82	1.71	41529	264	248
		9.03	117	61	41	287.58	1.85	1.75	41699	268	254
		9.13	117	61	41	290.76	1.85	1.75	42161	268	254
					Average	288.25	1.84	1.74	41796	267	252
					Stdev	2.255	0.017	0.024	327	2	3
Base 2	2	NO DATA									
Base 2	3	9.17	74	37	8	461.74	3.05	8.97	66952	442	1301
		9.15	64	37	27	532.72	3.05	2.66	77244	442	386
		9.1	67	37	27	506.08	3.05	2.66	73382	442	386
		9.17	67	37	27	509.98	3.05	2.66	73947	442	386
		9.1	67	37	27	506.08	3.05	2.66	73382	442	386
					Average	507.38	3.05	2.66	73570	442	386
					Stdev	2.248	0.000	0.000	326	0	0
Base 2	4	NO DATA									

Lot	Sublot	Point A									
		Load, kN	Deflection, µm			Modulus, Mpa			Modulus, psi		
		Load	δ 1	δ 2	δ 3	E1	E2	E3	E1	E2	E3
Base 2	5	9.09	134	50	27	252.76	2.26	2.66	36651	327	386
		9.13	143	50	27	237.90	2.26	2.66	34495	327	386
		9.11	141	50	27	240.74	2.26	2.66	34908	327	386
		9.04	141	49	27	238.89	2.30	2.66	34640	334	386
									0	0	0
					Average	239.82	2.28	2.66	23183	220	257
					Stdev	1.308	0.033	0.000	20077	191	223
Base 3	1	7.6	73	27	17	387.92	4.18	4.22	56249	606	612
		9.27	71	27	20	486.49	4.18	3.59	70542	606	521
		9.33	72	27	20	482.84	4.18	3.59	70012	606	521
		9.44	70	29	21	502.49	3.89	3.42	72862	564	496
		9.38	70	29	20	499.30	3.89	3.59	72398	564	521
					Average	494.88	3.99	3.53	71757	578	512
					Stdev	10.545	0.166	0.099	1529	24	14
Base 3	2	NO DATA									
	3	9.23	120	94	67	286.60	1.20	1.07	41557	174	155
		9.32	118	96	66	294.30	1.18	1.09	42673	170	158

Lot	Sublot	Point A									
		Load, kN	Deflection, µm			Modulus, Mpa			Modulus, psi		
		Load	δ 1	δ 2	δ 3	E1	E2	E3	E1	E2	E3
		9.31	118	97	67	293.98	1.16	1.07	42628	169	155
		9.18	125	96	66	273.65	1.18	1.09	39679	170	158
		9.26	126	97	67	273.84	1.16	1.07	39707	169	155
					Average	280.49	1.17	1.08	40671	169	156
					Stdev	11.687	0.007	0.009	1695	1	1
Base 3	4	NO DATA									
Base 3	5	9.22	96	38	29	357.86	2.97	2.48	51890	431	359
		9.26	94	39	29	367.06	2.89	2.48	53224	419	359
		9.26	94	38	29	367.06	2.97	2.48	53224	431	359
		9.23	92	39	29	373.83	2.89	2.48	54205	419	359
		9.33	91	40	29	382.03	2.82	2.48	55394	409	359
					Average	374.31	2.89	2.48	54274	420	359
					Stdev	7.495	0.074	0.000	1087	11	0
Base 4	1	8.84	321	163	109	102.61	0.69	0.66	14879	100	96
		8.91	352	159	109	94.32	0.71	0.66	13676	103	96
		8.88	314	154	105	105.38	0.73	0.68	15279	106	99
		8.9	292	152	105	113.57	0.74	0.68	16468	108	99
		8.93	287	151	104	115.94	0.75	0.69	16811	108	100

Lot	Sublot	Point A									
		Load, kN	Deflection, μm			Modulus, Mpa			Modulus, psi		
		Load	δ 1	δ 2	δ 3	E1	E2	E3	E1	E2	E3
					Average	111.63	0.74	0.69	16186	107	99
					Stdev	5.543	0.007	0.004	804	1	1
Base 4	2	9.13	260	142	100	130.84	0.79	0.72	18972	115	104
		9.16	249	148	104	137.07	0.76	0.69	19876	111	100
		9.12	241	146	102	141.00	0.77	0.70	20446	112	102
		9.13	244	145	102	139.42	0.78	0.70	20216	113	102
		9.11	242	145	103	140.27	0.78	0.70	20339	113	101
					Average	140.23	0.78	0.70	20334	113	102
					Stdev	0.791	0.003	0.004	115	0	1
Base 4	3	9.11	275	119	80	123.44	0.95	0.90	17898	137	130
		9.09	266	117	79	127.33	0.96	0.91	18463	140	132
		9.16	259	116	78	131.78	0.97	0.92	19108	141	133
		9.14	258	115	78	132.00	0.98	0.92	19140	142	133
		9.19	258	116	78	132.72	0.97	0.92	19245	141	133
					Average	132.17	0.98	0.92	19165	141	133
					Stdev	0.494	0.005	0.000	72	1	0
Base 4	4	9.03	244	135	88	137.90	0.84	0.82	19995	121	118
		9.1	243	134	88	139.54	0.84	0.82	20233	122	118

Lot	Sublot	Point A									
		Load, kN	Deflection, μm			Modulus, Mpa			Modulus, psi		
		Load	δ 1	δ 2	δ 3	E1	E2	E3	E1	E2	E3
		9.11	242	134	88	140.27	0.84	0.82	20339	122	118
		9.08	239	132	87	141.56	0.85	0.83	20526	124	120
		9.12	241	134	88	141.00	0.84	0.82	20446	122	118
					Average	140.94	0.85	0.82	20437	123	119
					Stdev	0.649	0.007	0.005	94	1	1
Base 4	5	9.04	530	211	129	63.55	0.53	0.56	9215	78	81
		9.14	365	157	104	93.31	0.72	0.69	13529	104	100
		9.16	324	152	102	105.34	0.74	0.70	15275	108	102
		9.15	332	148	101	102.69	0.76	0.71	14890	111	103
		9.16	326	148	101	104.70	0.76	0.71	15181	111	103
					Average	104.24	0.76	0.71	15115	110	103
					Stdev	1.382	0.012	0.004	200	2	1

Lot	Sublot	Point B									
		Load, kN	Deflection, μm			Modulus, Mpa			Modulus, psi		
		Load	δ 1	δ 2	δ 3	E1	E2	E3	E1	E2	E3
Base 1	1	9.09	314	390	171	107.87	0.29	0.42	15641	42	61
		9.07	322	178	108	104.96	0.63	0.66	15219	92	96
		9.12	301	168	105	112.90	0.67	0.68	16370	97	99

Lot	Sublot	Point B									
		Load, kN	Deflection, µm			Modulus, Mpa			Modulus, psi		
		Load	δ 1	δ 2	δ 3	E1	E2	E3	E1	E2	E3
		8.99	288	163	102	116.31	0.69	0.70	16865	100	102
		9.07	287	181	105	117.76	0.62	0.68	17075	90	99
					Average	115.65	0.66	0.69	16770	96	100
					Stdev	2.495	0.035	0.012	362	5	2
Base 1	2	9.34	282	209	170	123.41	0.54	0.42	17895	78	61
		9.11	164	129	23	206.98	0.87	3.12	30012	127	453
		9.1	163	125	30	208.02	0.90	2.39	30163	131	347
		9.08	162	124	21	208.85	0.91	3.42	30283	132	496
		9.07	161	123	23	209.91	0.92	3.12	30437	133	453
					Average	208.93	0.91	2.98	30294	132	432
					Stdev	0.947	0.007	0.528	137	1	77
Base 1	3	9.43	66	66	40	532.38	1.71	1.79	77195	248	260
		9.15	86	43	32	396.44	2.62	2.24	57484	380	325
		9.21	87	45	32	394.45	2.51	2.24	57196	364	325
		9.14	86	45	32	396.01	2.51	2.24	57421	364	325
		9.16	88	45	34	387.85	2.51	2.11	56239	364	306
					Average	392.77	2.51	2.20	56952	364	319
					Stdev	4.329	0.000	0.076	628	0	11

Lot	Sublot	Point B									
		Load, kN	Deflection, µm			Modulus, Mpa			Modulus, psi		
		Load	δ 1	δ 2	δ 3	E1	E2	E3	E1	E2	E3
Base 1	4	9.24	85	44	26	405.05	2.56	2.76	58732	372	400
		9.25	87	43	25	396.17	2.62	2.87	57444	380	416
		9.22	86	42	24	399.47	2.69	2.99	57924	390	434
		9.23	82	42	25	419.42	2.69	2.87	60815	390	416
		9.36	84	41	25	415.20	2.75	2.87	60203	399	416
					Average	411.36	2.71	2.91	59647	393	422
					Stdev	10.509	0.038	0.069	1524	5	10
Base 1	5	9.13	70	39	24	485.99	2.89	2.99	70469	419	434
		9.17	70	40	24	488.12	2.82	2.99	70778	409	434
		9.2	60	41	26	571.34	2.75	2.76	82844	399	400
		9.2	58	40	25	591.04	2.82	2.87	85701	409	416
		9.29	62	40	24	558.32	2.82	2.99	80956	409	434
					Average	573.56	2.80	2.87	83167	406	417
					Stdev	16.475	0.040	0.115	2389	6	17
Base 2	1	9.14	194	79	52	175.55	1.43	1.38	25455	207	200
		9.14	192	79	51	177.38	1.43	1.41	25720	207	204
		9.15	184	77	51	185.29	1.47	1.41	26868	212	204
		9.13	187	77	51	181.92	1.47	1.41	26379	212	204
		9.16	186	75	51	183.50	1.50	1.41	26608	218	204

Lot	Sublot	Point B									
		Load, kN	Deflection, µm			Modulus, Mpa			Modulus, psi		
		Load	δ 1	δ 2	δ 3	E1	E2	E3	E1	E2	E3
					Average	183.57	1.48	1.41	26618	214	204
					Stdev	1.687	0.023	0.000	245	3	0
Base 2	2										
Base 2	3	9.17	156	75	38	219.03	1.50	1.89	31759	218	274
		9.04	156	76	39	215.92	1.48	1.84	31309	215	267
		9.22	156	75	39	220.22	1.50	1.84	31932	218	267
		9.06	152	74	38	222.10	1.52	1.89	32204	221	274
		9.06	153	75	38	220.64	1.50	1.89	31993	218	274
					Average	220.99	1.51	1.87	32043	219	272
					Stdev	0.983	0.012	0.028	142	2	4
Base 2	4										
Base 2	5	9.06	150	40	25	225.06	2.82	2.87	32633	409	416
		9.11	144	41	24	235.73	2.75	2.99	34181	399	434
		9.2	140	42	24	244.86	2.69	2.99	35505	390	434
		9.2	135	43	24	253.93	2.62	2.99	36820	380	434
		9.31	132	42	24	262.80	2.69	2.99	38107	390	434
					Average	253.86	2.67	2.99	36810	386	434

Lot	Sublot	Point B									
		Load, kN	Deflection, µm			Modulus, Mpa			Modulus, psi		
		Load	δ 1	δ 2	δ 3	E1	E2	E3	E1	E2	E3
					Stdev	8.973	0.036	0.000	1301	5	0
Base 3	1	7.59	99	39	22	285.67	2.89	3.26	41422	419	473
		9.34	94	41	27	370.23	2.75	2.66	53684	399	386
		9.37	92	39	27	379.50	2.89	2.66	55027	419	386
		9.31	93	39	26	373.01	2.89	2.76	54087	419	400
		9.27	91	39	26	379.57	2.89	2.76	55038	419	400
					Average	377.36	2.89	2.73	54717	419	395
					Stdev	3.766	0.000	0.059	546	0	9
Base 3	2										
	3	9.13	146	84	58	233.01	1.34	1.24	33786	195	179
		9.46	140	85	61	251.78	1.33	1.18	36508	192	171
		9.35	140	86	61	248.85	1.31	1.18	36083	190	171
		9.34	135	85	61	257.79	1.33	1.18	37380	192	171
		9.28	134	85	61	258.05	1.33	1.18	37417	192	171
					Average	254.90	1.32	1.18	36960	192	171
					Stdev	5.237	0.009	0.000	759	1	0
Base 3	4	NO DATA									

Lot	Sublot	Point B									
		Load, kN	Deflection, µm			Modulus, Mpa			Modulus, psi		
		Load	δ 1	δ 2	δ 3	E1	E2	E3	E1	E2	E3
Base 3	5	9.26	139	59	36	248.23	1.91	1.99	35993	277	289
		7.41	107	45	28	258.04	2.51	2.56	37416	364	372
		9.38	153	59	35	228.44	1.91	2.05	33123	277	297
		9.31	134	62	37	258.88	1.82	1.94	37538	264	281
		9.28	122	62	34	283.43	1.82	2.11	41097	264	306
					Average	256.92	1.85	2.03	37253	268	295
					Stdev	27.548	0.053	0.087	3995	8	13
Base 4	1	9.03	474	183	123	70.98	0.62	0.58	10293	89	85
		8.87	439	172	119	75.29	0.66	0.60	10916	95	87
		9.03	450	175	119	74.77	0.64	0.60	10842	93	87
		9.04	418	170	117	80.58	0.66	0.61	11685	96	89
		9.09	384	168	116	88.20	0.67	0.62	12790	97	90
					Average	81.19	0.66	0.61	11772	96	89
					Stdev	6.737	0.014	0.008	977	2	1
Base 4	2	9.18	305	169	113	112.15	0.67	0.64	16262	97	92
		9.02	297	163	111	113.16	0.69	0.65	16409	100	94
		9.12	281	162	111	120.93	0.70	0.65	17535	101	94
		9.12	278	165	112	122.24	0.68	0.64	17725	99	93

Lot	Sublot	Point B									
		Load, kN	Deflection, µm			Modulus, Mpa			Modulus, psi		
		Load	δ 1	δ 2	δ 3	E1	E2	E3	E1	E2	E3
		9.09	271	164	112	124.98	0.69	0.64	18123	100	93
					Average	122.72	0.69	0.64	17794	100	93
					Stdev	2.067	0.006	0.003	300	1	0
Base 4	3	9.37	185	89	63	188.72	1.27	1.14	27365	184	165
		9.27	178	91	63	194.05	1.24	1.14	28137	180	165
		9.17	176	90	67	194.14	1.25	1.07	28150	182	155
		9.27	177	90	66	195.15	1.25	1.09	28296	182	158
		9.13	175	90	66	194.40	1.25	1.09	28188	182	158
					Average	194.56	1.25	1.08	28211	182	157
					Stdev	0.524	0.000	0.009	76	0	1
Base 4	4	9.05	298	159	101	113.16	0.71	0.71	16408	103	103
		9.06	274	159	99	123.21	0.71	0.73	17865	103	105
		9.08	273	155	99	123.93	0.73	0.73	17970	106	105
		9.16	268	153	98	127.36	0.74	0.73	18467	107	106
		9.02	269	151	98	124.94	0.75	0.73	18117	108	106
					Average	125.41	0.74	0.73	18184	107	106
					Stdev	1.759	0.010	0.004	255	1	1
Base 4	5	9.12	338	155	100	100.54	0.73	0.72	14578	106	104

Lot	Sublot	Point B									
		Load, kN	Deflection, µm			Modulus, Mpa			Modulus, psi		
		Load	δ 1	δ 2	δ 3	E1	E2	E3	E1	E2	E3
		9.13	319	150	98	106.64	0.75	0.73	15463	109	106
		9.09	310	148	97	109.26	0.76	0.74	15843	111	107
		9.06	308	147	97	109.61	0.77	0.74	15893	111	107
		9.09	301	146	97	112.53	0.77	0.74	16316	112	107
					Average	110.46	0.77	0.74	16017	111	107
					Stdev	1.794	0.005	0.000	260	1	0

Lot	Sublot	Point C									
		Load, kN	Deflection, µm			Modulus, Mpa			Modulus, psi		
		Load	δ 1	δ 2	δ 3	E1	E2	E3	E1	E2	E3
Base 1	1	8.66	219	136	79	147.34	0.83	0.91	21365	120	132
		9.2	149	82	56	230.07	1.38	1.28	33360	200	186
		9.23	143	80	55	240.50	1.41	1.31	34873	204	189
		9.16	141	78	55	242.07	1.45	1.31	35099	210	189
		9.15	143	79	55	238.42	1.43	1.31	34571	207	189
					Average	240.33	1.43	1.31	34848	207	189
					Stdev	1.829	0.018	0.000	265	3	0
Base 1	2	9.84	289	297	136	126.87	0.38	0.53	18396	55	77
		9.26	131	123	83	263.39	0.92	0.87	38191	133	125

Lot	Sublot	Point C									
		Load, kN	Deflection, μm			Modulus, Mpa			Modulus, psi		
		Load	δ 1	δ 2	δ 3	E1	E2	E3	E1	E2	E3
		9.21	125	118	55	274.54	0.96	1.31	39808	139	189
		9.17	123	117	85	277.79	0.96	0.84	40280	140	122
		9.19	130	117	1	263.41	0.96	71.80	38194	140	10410
					Average	271.91	0.96	24.65	39427	139	3574
					Stdev	7.544	0.005	40.831	1094	1	5921
Base 1	3	9.39	210	57	37	166.61	1.98	1.94	24159	287	281
		9.18	82	38	28	417.14	2.97	2.56	60486	431	372
		9.15	82	38	30	415.78	2.97	2.39	60288	431	347
		9.16	82	38	28	416.23	2.97	2.56	60354	431	372
		9.19	84	38	28	407.65	2.97	2.56	59110	431	372
					Average	413.22	2.97	2.51	59917	431	364
					Stdev	4.828	0.000	0.099	700	0	14
Base 1	4	9.3	69	60	31	502.22	1.88	2.32	72821	273	336
		9.2	69	56	31	496.82	2.01	2.32	72038	292	336
		9.24	69	52	30	498.98	2.17	2.39	72351	315	347
		9.17	69	56	31	495.20	2.01	2.32	71803	292	336
		9.17	83	50	30	411.67	2.26	2.39	59692	327	347
					Average	468.61	2.15	2.37	67949	311	343
					Stdev	49.352	0.122	0.045	7156	18	6

Lot	Sublot	Point C									
		Load, kN	Deflection, µm			Modulus, Mpa			Modulus, psi		
		Load	δ 1	δ 2	δ 3	E1	E2	E3	E1	E2	E3
Base 1	5	9.22	197	162	47	174.39	0.70	1.53	25287	101	221
		9.21	188	138	24	182.54	0.82	2.99	26468	119	434
		9.22	173	130	41	198.58	0.87	1.75	28794	126	254
		9.19	169	129	41	202.62	0.87	1.75	29380	127	254
		9.23	168	129	41	204.71	0.87	1.75	29684	127	254
					Average	201.97	0.87	1.75	29286	126	254
					Stdev	3.117	0.004	0.000	452	1	0
Base 2	1	9.03	194	79	57	173.44	1.43	1.26	25148	207	183
		9.08	192	81	58	176.21	1.39	1.24	25551	202	179
		9.12	187	81	58	181.72	1.39	1.24	26350	202	179
		9.09	185	80	57	183.08	1.41	1.26	26547	204	183
		9.07	185	82	59	182.68	1.38	1.22	26489	200	176
					Average	182.50	1.39	1.24	26462	202	180
					Stdev	0.699	0.017	0.021	101	2	3
Base 2	2										
Base 2	3	9.12	134	71	41	253.60	1.59	1.75	36772	230	254
		9.1	129	70	41	262.85	1.61	1.75	38113	234	254

Lot	Sublot	Point C									
		Load, kN	Deflection, μm			Modulus, Mpa			Modulus, psi		
		Load	δ 1	δ 2	δ 3	E1	E2	E3	E1	E2	E3
		9.13	129	68	41	263.72	1.66	1.75	38239	241	254
		9.1	131	68	40	258.84	1.66	1.79	37531	241	260
		9.11	128	67	40	265.19	1.68	1.79	38453	244	260
					Average	262.58	1.67	1.78	38074	242	258
					Stdev	3.327	0.014	0.025	482	2	4
Base 2	4										
Base 2	5	9.13	123	56	29	276.58	2.01	2.48	40104	292	359
		9.12	103	54	29	329.92	2.09	2.48	47839	303	359
		9.22	121	53	28	283.92	2.13	2.56	41169	309	372
		9.23	118	51	28	291.46	2.21	2.56	42261	321	372
		9.12	117	51	28	290.45	2.21	2.56	42115	321	372
					Average	288.61	2.18	2.56	41848	317	372
					Stdev	4.089	0.048	0.000	593	7	0
Base 3	1	9.3	87	57	41	398.31	1.98	1.75	57755	287	254
		9.3	98	58	41	353.60	1.95	1.75	51272	282	254
		9.34	87	60	42	400.02	1.88	1.71	58003	273	248
		9.31	82	61	42	423.05	1.85	1.71	61342	268	248
		9.21	85	62	43	403.74	1.82	1.67	58542	264	242

Lot	Sublot	Point C									
		Load, kN	Deflection, µm			Modulus, Mpa			Modulus, psi		
		Load	δ 1	δ 2	δ 3	E1	E2	E3	E1	E2	E3
					Average	408.94	1.85	1.70	59296	268	246
					Stdev	12.364	0.030	0.023	1793	4	3
Base 3	2										
	3	9.32	135	68	54	257.24	1.66	1.33	37300	241	193
		9.17	133	71	55	256.91	1.59	1.31	37251	230	189
		9.14	136	71	55	250.42	1.59	1.31	36310	230	189
		9.14	132	72	55	258.01	1.57	1.31	37411	227	189
		9.21	128	72	55	268.11	1.57	1.31	38875	227	189
					Average	258.84	1.57	1.31	37532	228	189
					Stdev	8.874	0.013	0.000	1287	2	0
Base 3	4	NO DATA									
Base 3	5	9.12	80	47	34	424.78	2.40	2.11	61593	348	306
		9.21	82	48	36	418.51	2.35	1.99	60683	341	289
		9.09	81	48	35	418.15	2.35	2.05	60632	341	297
		9.24	82	49	36	419.87	2.30	1.99	60881	334	289
		9.24	83	50	36	414.81	2.26	1.99	60148	327	289
					Average	417.61	2.30	2.01	60554	334	292

Lot	Sublot	Point C									
		Load, kN	Deflection, µm			Modulus, Mpa			Modulus, psi		
		Load	δ 1	δ 2	δ 3	E1	E2	E3	E1	E2	E3
					Stdev	2.572	0.047	0.033	373	7	5
Base 4	1	9.05	244	199	105	138.20	0.57	0.68	20039	82	99
		9.06	221	196	108	152.75	0.58	0.66	22149	83	96
		9.1	229	194	108	148.07	0.58	0.66	21470	84	96
		9.08	247	186	108	136.98	0.61	0.66	19862	88	96
		9.13	273	182	107	124.61	0.62	0.67	18069	90	97
					Average	136.55	0.60	0.67	19800	87	97
					Stdev	11.733	0.019	0.004	1701	3	1
Base 4	2	8.92	244	153	112	136.22	0.74	0.64	19751	107	93
		8.96	243	161	112	137.39	0.70	0.64	19922	102	93
		9.03	241	162	113	139.61	0.70	0.64	20244	101	92
		9.02	240	161	113	140.04	0.70	0.64	20306	102	92
		8.98	234	161	113	142.99	0.70	0.64	20734	102	92
					Average	140.88	0.70	0.64	20428	101	92
					Stdev	1.841	0.002	0.000	267	0	0
Base 4	3	9.07	221	98	71	152.92	1.15	1.01	22174	167	147
		9.09	213	100	71	159.02	1.13	1.01	23057	164	147
		9.11	211	100	71	160.88	1.13	1.01	23327	164	147

Lot	Sublot	Point C									
		Load, kN	Deflection, µm			Modulus, Mpa			Modulus, psi		
		Load	δ 1	δ 2	δ 3	E1	E2	E3	E1	E2	E3
		9.1	207	100	70	163.81	1.13	1.03	23752	164	149
		9.1	206	100	71	164.60	1.13	1.01	23867	164	147
					Average	163.09	1.13	1.02	23649	164	147
					Stdev	1.961	0.000	0.008	284	0	1
Base 4	4	9.02	344	138	91	97.70	0.82	0.79	14167	119	114
		8.95	325	138	90	102.61	0.82	0.80	14879	119	116
		9.1	324	136	90	104.65	0.83	0.80	15175	120	116
		9.05	324	139	92	104.08	0.81	0.78	15091	118	113
		9.02	319	136	90	105.36	0.83	0.80	15277	120	116
					Average	104.70	0.82	0.79	15181	119	115
					Stdev	0.642	0.010	0.010	93	1	1
Base 4	5	9.09	322	165	119	105.19	0.68	0.60	15252	99	87
		9.11	322	163	117	105.42	0.69	0.61	15286	100	89
		9.26	314	163	117	109.88	0.69	0.61	15933	100	89
		9.12	317	161	115	107.20	0.70	0.62	15544	102	91
		9.18	315	160	116	108.59	0.71	0.62	15745	102	90
					Average	108.56	0.70	0.62	15741	101	90
					Stdev	1.343	0.007	0.005	195	1	1

* Average modulus values are calculated using load-deflection data for drops 3, 4, and 5. Drops 1 and 2 are considered seating drops.

Modulus is determined from the following expression:

$$E_0(MPa) = 2(1-\nu^2) * a * \frac{p}{\delta_0}$$ and $$E(MPa) = (1-\nu^2) * a^2 * \frac{1}{\delta_x} * \frac{1}{R_x}$$

where

ν is the Poisson's ration (recommended value is 0.4 for this device)
a is radius of the load plate in mm (100 mm in this project)
p is the contact pressure kPa
δ_x is measured deflection at distance 'x' μm
R_x is the radial distance of the deflection sensor from the load
The calculations used a conversion factor of 145 to express modulus in psi

Table 47. ***Modulus*** measured by ***LWD 3*** in ***US-280, AL Base, psi***
Note: Test repetitions were performed at individual points as shown in Table 48

Lot #	Sublot	A	B	C	Average	Lot Average
1	1	25287	13583	10001	16290	
	2	17108	20791	17710	18537	
	3	36855	44871	50323	44016	
	4	38809	48117	49662	45529	
	5	52636	63518	3973	40042	32883
2	1	24986	13641	8917	15848	
	2	14716	10567	14962	13415	
	3	31429	12132	12500	18687	
	4	13833	13186	14515	13844	
	5	10054	10493	7056	9201	14199
3	1	41680	28560	27909	32716	
	2	25091	29001	21491	25195	
	3	26730	6009	19392	17377	
	4	19506	41692	18967	26721	
	5	11573	28877	46626	29026	26207
4	1	9340	8868	9471	9226	
	2	8692	8786	9354	8944	
	3	10024	13149	13249	12141	
	4	9805	10425	8630	9620	
	5	8998	7531	8225	8251	9636
Average lot 1 by row		34139	38176	26334		
Average lot 2 by row		19004	12004	11590		
Average lot 3 by row		24916	26828	26877		
Average lot 4 by row		9372	9752	9786		
Average project by row		21858	21690	18647		
Average project						20731

Table 48. Repeatability in ***Modulus*** measurements by ***LWD 3*** in ***US-280, AL Base, psi***
Note: Summary of test results are shown in Table 47

Lot	Sub-lot	Point A				Point B				Point C			
		Load	δ	Modulus	Modulus	Load	δ	Modulus	Modulus	Load	δ	Modulus	Modulus
		kN	µm	MPa	psi	kN	µm	MPa	psi	kN	µm	MPa	psi
Base 1	1	9.1	96	177	25616	9.3	268	65	9354	9.4	500	35	5086
		9.6	105	171	24800	9.8	209	87	12674	9.8	611	30	4337
		9.6	104	173	25089	10.0	306	61	8830	9.8	257	71	10308
		9.8	104	174	25259	9.8	127	144	20860	9.8	237	77	11156
		9.8	104	176	25513	10.0	244	76	11058	9.8	311	59	8538
			Average	174	25287	10	226	94	13583	10	268	69	10001
			Stdev	1.47	213.06	0.11	90.98	44.14	6400.01	0.00	38.28	9.21	1335.54
Base 1	2	8.2	178	86	12504	8.6	126	127	18352	8.5	135	117	16938
		8.6	147	109	15800	8.6	114	139	20213	8.6	133	121	17512
		8.6	138	116	16772	8.6	113	142	20572	8.5	131	121	17578
		8.6	136	118	17059	8.6	112	143	20750	8.6	130	123	17864
		8.6	136	118	17108	8.6	112	143	20791	8.5	130	122	17689
			Average	117	16980	9	112	143	20704	9	130	122	17710
			Stdev	1.25	181.25	0.02	0.89	0.80	116.53	0.03	0.55	0.99	143.98
Base 1	3	8.5	67	238	34484	8.6	60	265	38417	8.5	55	288	41710
		8.6	63	253	36668	8.7	53	305	44175	8.7	45	361	52295
		8.6	63	255	37010	8.7	52	308	44614	8.6	47	344	49881
		8.6	63	255	36961	8.7	52	308	44717	8.7	46	353	51177

Lot	Sub-lot	Point A				Point B				Point C			
		Load	δ	Modulus	Modulus	Load	δ	Modulus	Modulus	Load	δ	Modulus	Modulus
		kN	µm	MPa	psi	kN	µm	MPa	psi	kN	µm	MPa	psi
		8.5	62	252	36592	8.8	53	312	45281	8.7	47	344	49910
			Average	254	36855	9	52	309	44871	9	47	347	50323
			Stdev	1.58	228.44	0.08	0.06	2.48	358.97	0.04	0.75	5.10	739.85
Base 1	4	8.1	503	30	4326	8.3	82	189	27435	8.5	184	86	12406
		8.6	60	270	39097	8.6	49	326	47246	8.7	48	338	49011
		8.6	59	271	39326	8.7	49	332	48146	8.7	47	343	49692
		8.6	60	267	38775	8.7	48	335	48539	8.7	47	343	49664
		8.7	61	264	38326	8.6	49	329	47665	8.7	47	342	49629
			Average	268	38809	9	49	332	48117	9	47	342	49662
			Stdev	3.45	500.44	0.04	0.34	3.02	437.84	0.02	0.08	0.22	31.59
Base 1	5	8.9	50	335	48519	8.2	37	416	60382	8.3	4541	3	494
		8.7	43	373	54130	8.6	36	441	63974	8.8	597	27	3986
		8.7	44	367	53261	8.7	37	444	64402	8.6	784	20	2967
		8.7	45	359	52095	8.7	37	434	62907	8.8	516	32	4582
		8.7	44	362	52550	8.6	37	436	63243	8.7	535	30	4370
			Average	363	52636	9	37	438	63518	9	612	27	3973
			Stdev	4.05	587.56	0.05	0.35	5.41	784.28	0.08	149.70	6.05	877.81
Base 2	1	8.4	95	163	23659	8.0	257	58	8396	7.6	5514	3	371
		1.7	29	110	15966	8.7	199	81	11758	6.4	1666	7	1041

Lot	Sub-lot	Point A				Point B				Point C			
		Load	δ	Modulus	Modulus	Load	δ	Modulus	Modulus	Load	δ	Modulus	Modulus
		kN	µm	MPa	psi	kN	µm	MPa	psi	kN	µm	MPa	psi
		8.4	112	140	20332	8.4	172	91	13242	6.8	4006	3	459
		8.4	85	184	26707	8.7	169	95	13840	8.3	143	107	15579
		8.5	82	193	27921	8.5	166	95	13842	8.6	216	74	10713
			Average	172	24986	9	169	94	13641	8	1455	61	8917
			Stdev	28.11	4076.54	0.12	2.95	2.38	345.63	0.94	####	53.23	7718.34
Base 2	2	8.4	137	114	16572	7.9	838	17	2531	8.3	229	68	9828
		1.2	419	5	747	8.6	390	41	5960	8.8	171	95	13835
		8.6	109	147	21270	8.8	303	54	7861	8.7	159	102	14738
		8.4	236	66	9589	8.6	222	72	10479	8.7	157	103	14960
		8.6	175	92	13291	8.7	175	92	13363	8.8	156	105	15188
			Average	101	14716	9	234	73	10567	9	157	103	14962
			Stdev	41.17	5969.52	0.11	64.81	18.98	2752.31	0.03	1.93	1.55	224.72
Base 2	3	8.0	261	57	8251	7.8	541	27	3892	7.9	730	20	2906
		7.8	142	102	14838	8.6	252	63	9172	8.7	208	78	11317
		8.7	73	221	32108	8.5	187	84	12238	8.6	190	84	12185
		8.7	75	217	31405	8.1	197	77	11166	8.5	182	87	12653
		8.7	76	212	30773	8.3	173	90	12992	8.1	173	87	12661
			Average	217	31429	8	186	84	12132	8	182	86	12500
			Stdev	4.61	667.84	0.16	12.05	6.33	917.76	0.25	8.38	1.88	272.90

Lot	Sub-lot	Point A				Point B				Point C			
		Load	δ	Modulus	Modulus	Load	δ	Modulus	Modulus	Load	δ	Modulus	Modulus
		kN	µm	MPa	psi	kN	µm	MPa	psi	kN	µm	MPa	psi
Base 2	4	7.8	288	50	7322	7.8	307	47	6862	8.5	181	88	12752
		8.2	231	66	9635	8.6	188	85	12322	8.6	166	96	13985
		8.6	175	91	13222	8.5	175	90	13029	8.7	167	97	14091
		8.6	178	90	13001	8.5	176	90	13050	8.6	158	102	14749
		8.4	149	105	15277	8.5	170	93	13478	8.6	158	101	14704
			Average	95	13833	8	173	91	13186	9	161	100	14515
			Stdev	8.66	1255.01	0.02	3.38	1.75	253.13	0.05	4.93	2.54	367.81
Base 2	5	7.9	525	28	4069	8.2	2496	6	886	8.5	504	31	4538
		8.2	238	64	9319	8.6	159	100	14553	8.5	411	39	5607
		8.4	228	68	9917	8.6	227	71	10235	8.5	221	72	10420
		8.4	223	70	10159	8.7	111	145	21091	8.6	405	39	5720
		8.4	224	70	10085	1.2	2070	1	155	8.5	456	35	5028
			Average	69	10054	6	803	72	10493	9	361	49	7056
			Stdev	0.86	124.18	4.30	####	72.21	#####	0.04	123.89	20.23	2933.90
Base 3	1	8.4	297	53	7661	8.0	256	58	8440	8.2	94	162	23454
		8.7	106	152	22051	8.6	97	167	24144	8.7	75	214	31096
		8.7	57	284	41178	1.1	8	236	34168	8.7	74	219	31762
		8.7	56	288	41773	8.6	92	175	25387	3.4	49	130	18810
		8.6	55	290	42090	8.7	89	180	26124	8.7	71	229	33156
			Average	287	41680	6	63	197	28560	7	65	192	27909

Lot	Sub-lot	Point A				Point B				Point C			
		Load	δ	Modulus	Modulus	Load	δ	Modulus	Modulus	Load	δ	Modulus	Modulus
		kN	µm	MPa	psi	kN	µm	MPa	psi	kN	µm	MPa	psi
			Stdev	3.19	463.09	4.38	47.52	33.60	4871.32	3.04	13.33	54.56	7910.88
Base 3	2	8.0	300	50	7199	8.2	102	150	21769	7.9	1050	14	2026
		8.6	96	168	24383	8.7	82	197	28615	8.5	133	118	17113
		8.6	95	170	24586	8.9	82	200	29066	8.4	107	146	21226
		8.7	94	172	24947	8.7	82	199	28797	8.5	109	145	21089
		8.7	91	178	25740	8.9	82	201	29140	8.7	106	153	22160
			Average	173	25091	9	82	200	29001	9	108	148	21491
			Stdev	4.07	590.18	0.08	0.26	1.25	180.75	0.16	1.43	4.02	582.73
Base 3	3	8.2	100	152	22112	8.0	1412	11	1523	7.7	195	73	10640
		8.5	95	168	24348	8.5	552	29	4182	8.7	134	121	17514
		3.1	28	205	29778	8.5	367	43	6293	8.6	121	133	19297
		8.5	92	173	25035	8.6	371	43	6228	8.7	120	134	19466
		8.7	92	175	25376	8.5	418	38	5506	8.6	120	134	19413
			Average	184	26730	9	385	41	6009	9	120	134	19392
			Stdev	18.24	2645.13	0.02	28.43	3.01	436.56	0.02	0.44	0.60	86.75
Base 3	4	8.0	195	76	11044	8.3	56	277	40098	8.5	150	105	15267
		8.6	135	118	17119	8.6	51	313	45457	8.6	82	196	28441
		8.6	123	130	18836	8.4	53	296	42887	8.6	143	112	16238
		8.5	117	136	19725	8.4	59	267	38655	8.6	141	113	16368

Lot	Sub-lot	Point A				Point B				Point C			
		Load	δ	Modulus	Modulus	Load	δ	Modulus	Modulus	Load	δ	Modulus	Modulus
		kN	µm	MPa	psi	kN	µm	MPa	psi	kN	µm	MPa	psi
		8.7	117	138	19956	8.4	52	300	43534	8.5	94	168	24294
			Average	135	19506	8	55	288	41692	9	126	131	18967
			Stdev	4.08	591.14	0.02	3.67	18.28	2649.98	0.07	27.78	31.82	4613.90
Base 3	5	8.3	287	54	7850	8.4	85	184	26636	8.2	604	25	3658
		8.7	147	110	15903	8.6	82	195	28249	8.6	126	127	18384
		8.6	183	88	12707	8.6	86	187	27062	8.3	47	331	47938
		8.5	207	76	11084	8.7	78	207	30023	8.4	48	329	47668
		8.5	210	75	10929	8.6	78	204	29548	8.2	50	305	44272
			Average	80	11573	9	81	199	28877	8	48	322	46626
			Stdev	6.79	984.55	0.05	4.36	10.97	1590.25	0.13	1.54	14.09	2043.28
Base 4	1	7.8	400	36	5237	7.8	396	37	5346	7.4	928	15	2161
		8.4	260	60	8661	8.5	275	57	8304	8.2	251	61	8882
		8.4	248	63	9107	8.5	262	60	8733	8.4	243	65	9374
		8.4	240	65	9419	8.3	254	61	8814	8.5	241	66	9508
		8.4	239	65	9494	8.3	249	62	9056	8.4	237	66	9532
			Average	64	9340	8	255	61	8868	8	240	65	9471
			Stdev	1.42	205.32	0.10	6.74	1.16	168.48	0.06	3.10	0.59	85.16
Base 4	2	7.6	526	27	3888	8.3	395	39	5646	7.9	473	31	4502
		8.5	298	53	7675	8.4	282	55	8043	8.5	284	56	8062

Lot	Sub-lot	Point A				Point B				Point C			
		Load	δ	Modulus	Modulus	Load	δ	Modulus	Modulus	Load	δ	Modulus	Modulus
		kN	µm	MPa	psi	kN	µm	MPa	psi	kN	µm	MPa	psi
		8.3	266	58	8447	8.4	263	60	8678	8.6	256	62	9027
		8.5	262	60	8727	8.5	264	60	8665	8.6	245	66	9499
		8.5	258	61	8902	8.4	253	62	9014	8.5	240	66	9536
			Average	60	8692	8	260	61	8786	9	247	65	9354
			Stdev	1.58	229.36	0.02	6.06	1.37	198.04	0.06	8.17	1.96	283.58
Base 4	3	7.5	386	36	5259	8.1	207	73	10571	7.7	366	39	5667
		8.5	244	64	9337	8.5	167	95	13788	8.4	185	85	12327
		8.4	235	67	9702	8.6	159	100	14569	8.4	170	92	13351
		8.5	227	69	10040	8.6	157	102	14724	8.5	181	87	12626
		8.6	224	71	10331	8.5	226	70	10154	8.4	166	95	13769
			Average	69	10024	9	181	91	13149	8	172	91	13249
			Stdev	2.17	314.66	0.05	39.05	17.89	2594.72	0.04	8.03	3.99	578.20
Base 4	4	7.8	442	33	4754	7.9	408	36	5222	7.7	672	21	3108
		8.4	244	64	9261	8.3	237	66	9526	8.4	284	55	7960
		8.5	241	66	9555	8.4	225	70	10082	8.3	271	57	8297
		8.4	232	68	9800	8.5	220	72	10487	8.5	263	60	8711
		8.5	228	69	10059	8.6	216	74	10707	8.5	257	61	8882
			Average	68	9805	9	220	72	10425	8	263	60	8630
			Stdev	1.74	251.98	0.09	4.62	2.19	316.87	0.09	6.81	2.08	300.94

Lot	Sub-lot	Point A				Point B				Point C			
		Load	δ	Modulus	Modulus	Load	δ	Modulus	Modulus	Load	δ	Modulus	Modulus
		kN	μm	MPa	psi	kN	μm	MPa	psi	kN	μm	MPa	psi
Base 4	5	8.3	462	33	4857	8.2	692	22	3188	8.1	1023	15	2144
		8.5	278	57	8250	8.6	340	47	6815	8.6	315	51	7407
		8.6	263	61	8813	8.6	317	51	7331	8.6	289	56	8086
		8.6	260	62	8997	8.6	304	53	7686	8.4	279	56	8181
		8.6	254	63	9182	8.7	309	52	7575	8.7	278	58	8408
			Average	62	8998	9	310	52	7531	9	282	57	8225
			Stdev	1.27	184.16	0.03	6.58	1.25	181.32	0.12	5.86	1.14	165.12

Table 49. ***Modulus*** measured by ***DSPA*** in ***US-280, AL Base, psi***
Note: Test repetitions were performed at individual points as shown in Table 50

Lot #	Sublot	A	B	C	Average	Lot Average
1	1	241000	205667	223333	223333	
	2	189667	189000	172000	183556	
	3	258333	275333	270000	267889	
	4	235000	270000	265167	256722	
	5	237667	235167	235167	236000	233500
2	1	155000	147500	148000	150167	
	2	169667	179333	128333	159111	
	3	217000	169500	184500	190333	
	4	209500	224000	191333	208278	
	5	176333	255167	279333	236944	188967
3	1	203333	207000	214667	208333	
	2	180167	198667	198833	192556	
	3	148833	133667	132333	138278	
	4	189500	159333	147333	165389	
	5	150000	156167	178000	161389	173189
4	1	111000	126667	121167	119611	
	2	117000	134333	124333	125222	
	3	118333	126000	91667	112000	
	4	114333	85667	103333	101111	
	5	122000	144667	121333	129333	117456
Average lot 1 by row		232333	235033	233133		
Average lot 2 by row		185500	195100	186300		
Average lot 3 by row		174367	170967	174233		
Average lot 4 by row		116533	123467	112367		
Average project by row		177183	181142	176508		
Average project						178278

Table 50. Repeatability in ***Modulus*** measurements by ***DSPA*** in ***US-280, AL Base, psi***
Note: Summary of test results are shown in Table 49

Lot	Sublot	Point	Trial 1	Trial 2	Trial 3	Average at point	Std deviation at point
Base 1	1	A	234000	269000	220000	241000	**25239**
Base 1	1	B	172000	251000	194000	205667	**40772**
Base 1	1	C	269000	194000	207000	223333	**40079**
Base 1	2	A	207000	183000	179000	189667	**15144**
Base 1	2	B	221000	183000	163000	189000	**29462**
Base 1	2	C	172000	172000	172000	172000	**0**
Base 1	3	A	271000	269000	235000	258333	**20232**
Base 1	3	B	269000	288000	269000	275333	**10970**
Base 1	3	C	220000	300000	290000	270000	**43589**
Base 1	4	A	251000	220000	234000	235000	**15524**
Base 1	4	B	290000	269000	251000	270000	**19519**
Base 1	4	C	269000	290500	236000	265167	**27451**
Base 1	5	A	250000	269000	194000	237667	**38991**
Base 1	5	B	221500	250000	234000	235167	**14286**
Base 1	5	C	221500	250000	234000	235167	**14286**
Base 2	1	A	163000	155000	147000	155000	**8000**
Base 2	1	B	155000	146000	141500	147500	**6874**
Base 2	1	C	183000	152000	109000	148000	**37162**
Base 2	2	A	207000	163000	139000	169667	**34487**
Base 2	2	B	183000	172000	183000	179333	**6351**
Base 2	2	C	132000	133000	120000	128333	**7234**
Base 2	3	A	194000	206000	251000	217000	**30050**
Base 2	3	B	152500	173000	183000	169500	**15548**
Base 2	3	C	251000	147500	155000	184500	**57713**
Base 2	4	A	236000	186500	206000	209500	**24935**
Base 2	4	B	269000	183000	220000	224000	**43139**
Base 2	4	C	206000	195000	173000	191333	**16803**
Base 2	5	A	220000	155000	154000	176333	**37820**
Base 2	5	B	252000	252000	261500	255167	**5485**
Base 2	5	C	312000	290000	236000	279333	**39107**
Base 3	1	A	220000	207000	183000	203333	**18771**

Lot	Sublot	Point	Trial 1	Trial 2	Trial 3	Average at point	Std deviation at point
Base 3	1	B	238000	220000	163000	207000	**39154**
Base 3	1	C	182000	234000	228000	214667	**28449**
Base 3	2	A	139000	195000	206500	180167	**36112**
Base 3	2	B	206000	195000	195000	198667	**6351**
Base 3	2	C	163000	213500	220000	198833	**31202**
Base 3	3	A	139000	155000	152500	148833	**8607**
Base 3	3	B	155000	114000	132000	133667	**20551**
Base 3	3	C	132000	139000	126000	132333	**6506**
Base 3	4	A	146000	215500	207000	189500	**37911**
Base 3	4	B	173000	172000	133000	159333	**22811**
Base 3	4	C	114000	155000	173000	147333	**30238**
Base 3	5	A	155000	175000	120000	150000	**27839**
Base 3	5	B	163000	146000	159500	156167	**8977**
Base 3	5	C	173000	206000	155000	178000	**25865**
Base 4	1	A	114000	99000	120000	111000	**10817**
Base 4	1	B	120000	114000	146000	126667	**17010**
Base 4	1	C	155000	104000	104500	121167	**29302**
Base 4	2	A	120000	139000	92000	117000	**23643**
Base 4	2	B	155000	109000	139000	134333	**23352**
Base 4	2	C	109000	155000	109000	124333	**26558**
Base 4	3	A	126000	114000	115000	118333	**6658**
Base 4	3	B	146000	132000	100000	126000	**23580**
Base 4	3	C	92000	69000	114000	91667	**22502**
Base 4	4	A	102000	109000	132000	114333	**15695**
Base 4	4	B	76000	67000	114000	85667	**24947**
Base 4	4	C	100000	100000	110000	103333	**5774**
Base 4	5	A	132000	120000	114000	122000	**9165**
Base 4	5	B	132000	139000	163000	144667	**16258**
Base 4	**5**	**C**	**114000**	**118000**	**132000**	**121333**	**9452**

Table 51. ***Modulus*** measured by ***FWD*** in ***US-280, AL Base, psi***
Note: Test repetitions were not performed at individual points;

Sublot-Point	**Composite Base + Subgrade Stiffness from Center Defl.**	**Subgrade Stiffness from 12"-36" Offset Defl.**	**Hogg Mr from Forward calculation ***	**Composite Base + Subgrade Stiffness from Center Defl.**	**Subgrade Stiffness from 12"-36" Offset Defl.**	**Hogg Mr from Forward-calculation***
	Lot – Base 1			**Lot Base 2**		
0	33,088	24,482	17,163	34,547	22,917	**16,612**
1-A	35,102	24,988	18,147	22,860	19,973	**13,829**
1-B	31,414	21,950	15,738	6825*	15,708	**error**
1-C	30,158	20,664	15,722			
Average	32,441	23,021	16,693	28,703	19,533	**15,221**
Stdev	2,142	2,058	1,182	8,264	3,624	**1,968**
2-A	18,717	12,308	8,130	21,616	18,480	**11,900**
2-B	17,554	10,127	6,260	18,572	14,055	**8,602**
2-C	18,036	11,153	7,159	20,656	16,947	**9,232**
Average	18,102	11,196	7,183	20,282	16,494	**9,912**
Stdev	585	1,091	935	1,556	2,247	**1,751**
3-A	39,748	21,711	16,655	31,336	35,140	**15,481**
3-B	39,147	24,372	17,922	25,895	33,383	**18,156**
3-C	43,675	28,016	20,210	21,103	28,206	**14,862**
Average	40,856	24,700	18,262	26,111	32,243	**16,166**
Stdev	2,459	3,165	1,802	5,120	3,605	**1,751**
4-A	52,057	45,582	27,526	36,072	46,720	**26,444**
4-B	54,487	45,358	26,779	43,591	49,506	**32,122**
4-C	52,660	43,691	25,914	44,295	47,417	**30,026**
Average	53,068	44,877	26,739	41,319	47,881	**29,531**
Stdev	1,265	1,033	807	4,558	1,450	**2,871**
5-A	58,036	51,238	32,322	24565*	49,891	**error**
5-B	61,723	55,383	35,101	45,775	50,736	**31,367**
5-C	60,276	57,685	38,332	41,904	50,295	**28,742**
Average	60,011	54,769	35,252	43,839	50,307	**30,054**
Stdev	1,857	3,267	3,008	2,738	423	**1,856**
Lot avg	40,367	31,169	20,567	31,402	33,291	**19,798**
stdev	15,094	16,085	9,683	10,200	14,618	**8,686**

Sublot-Point	Composite Base + Subgrade Stiffness from Center Defl.	Subgrade Stiffness from 12"-36" Offset Defl.	Hogg Mr from Forward calculation *	Composite Base + Subgrade Stiffness from Center Defl.	Subgrade Stiffness from 12"-36" Offset Defl.	Hogg Mr from Forward-calculation*
	Lot – Base 3			**Lot – Base 4**		
1-A	54,681	38,264	32,303	13,735	8,584	**5,502**
1-B	53,653	37,502	31,691	12,883	7,744	**4,972**
1-C	49,336	32,146	26,903	13,561	8,357	**5,429**
Average	52,557	35,970	30,299	13,393	8,228	**5,301**
Stdev	2,836	3,334	2,957	450	434	**287**
2-A	24,606	26,845	14,202	14,851	9,365	**5,699**
2-B	25,096	16,972	11,711	14,659	9,247	**5,406**
2-C	23,666	15,797	10,614	14,705	9,384	**5,704**
Average	24,456	19,871	12,176	14,738	9,332	**5,603**
Stdev	727	6,068	1,839	100	74	**171**
3-A	18,482	11,106	7,811	14,573	11,054	**7,281**
3-B	19,830	11,224	8,198	14,387	11,189	**7,201**
3-C	21,396	12,300	9,235	14,241	10,995	**7,452**
Average	19,902	11,543	8,415	14,401	11,079	**7,311**
Stdev	1,458	658	737	166	99	**128**
4-A	42,285	26,543	22,321	15,089	12,868	**7,505**
4-B	27,066	23,161	18,461	12,697	12,369	**6,601**
4-C	32,557	25,176	20,328	15,746	13,177	**7,699**
Average	33,969	24,960	20,370	14,511	12,805	**7,268**
Stdev	7,708	1,701	1,931	1,605	408	**586**
5-A	37,368	28,201	20,349	14,187	9,876	**6,230**
5-B	29,734	26,961	18,739	14,478	12,903	**6,844**
5-C	37,551	25,894	19,630	12,591	10,350	**5,749**
Average	34,884	27,019	19,573	13,752	11,043	**6,274**
Stdev	4,461	1,154	807	1,016	1,628	**549**
Lot avg	33,154	23,873	18,166	14,202	10,650	**6,418**
stdev	12,172	8,789	7,969	925	1,722	**917**
Project Average				29,781	24,746	**16,237**
Project Stdev				**11,087**	**10,226**	**6,623**

* Modulus determined from center and offset deflections are considered more accurate as the Hogg model might not be applicable for unbound layer tests

Table 52. ***Density (pcf) and Percent Moisture Content (MC)*** measured by ***Nuclear Gauge*** in ***US-280, AL Base***

Note: Test repetitions data is shown in Table 53

Lot #	**Sublot**	**A**	**B**		**C**	**Average**		**Lot Average**	
			Density	**MC**	*	**Density**	**MC**		
1	1	*	160.5	3.6	*	160.5	3.6		
	5	*	159.3	4.5		159.3	4.5	159.9	4.0
					*				
2	1	*	152.1	2.9	*	152.1	2.9		
	5	*	158.6	2.5		158.6	2.5	155.3	2.7
					*				
3	1	*	148.7	3.4	*	148.7	3.4		
	5	*	153.9	3.0		153.9	3.0	151.3	3.2
					*				
4	1	*	148.1	3.8	*	148.1	3.8		
	5	*	147.4	3.8		147.4	3.8	147.7	3.8
					*				
Average lot 1		*	159.9	4.0	*				
Average lot 2		*	155.3	2.7	*				
Average lot 3		*	151.3	3.2	*				
Average lot 4		*	147.7	3.8					
					*				
Average project		*	153.5	3.4	*				

Table 53. ***Density and Moisture Content*** using ***Nuclear Gauge*** in ***US-280, AL Base***
Note: Summary of results is presented in

Lot 1 - Westbound, west side of bridge		
Point	Density, lbs/ft^3	Moisture Content, %
1-B-1	158.1	3.4
1-B-2	162.8	3.7
Average	160.5	3.6
5-B-1	155.8	4.9
5-B-2	162.8	4.1
Average	159.3	4.5
Lot 2 - Eastbound, west side of bridge		
Point	Density, lbs/ft^3	Moisture Content, %
5-B-1	159.3	2.7
5-B-2	159.4	2.8
5-B-3	157.0	2.0
Average	158.6	2.5
1-B-1	154.7	3.0
1-B-2	149.5	2.8
Average	152.1	2.9
Lot 3 - Westbound, east side of bridge		
Point	Density, lbs/ft^3	Moisture Content, %
1-B-1	148.1	3.5
1-B-2	149.3	3.3
Average	148.7	3.4
5-B-1	154.6	2.9
5-B-2	153.1	3.0
Average	153.9	3.0
Lot 4 - Eastbound, east side of bridge		
Point	Density, lbs/ft^3	Moisture Content, %
1-B-1	151.4	4.0
1-B-2	144.7	3.5
Average	148.1	3.8
5-B-1	144.4	3.7
5-B-2	150.3	3.8
Average	147.4	3.8

Table 54. Summary of ***Resilient Modulus Test Results*** in ***US-280, MN Base***

Sequence	σ_1 psi	σ_2 psi	σ_3 psi	θ psi	τ_{oct} psi	$\sigma_1 - \sigma_3$ psi	M_R psi	Pred. M_R psi
Repetition 1								
1	4.9	3.0	3.0	10.9	0.9	1.9	55245	36626
2	10.0	6.0	6.0	22.0	1.9	4.0	61503	54516
3	16.7	10.0	10.0	36.7	3.2	6.7	71132	70822
4	25.2	15.0	15.0	55.2	4.8	10.2	89915	84883
5	33.2	20.0	20.0	73.2	6.2	13.2	105235	95429
6	6.4	3.0	3.0	12.4	1.6	3.4	46559	38147
7	12.8	6.0	6.0	24.8	3.2	6.8	51383	54797
8	21.3	10.0	10.0	41.3	5.3	11.3	62790	68552
9	32.3	15.0	15.0	62.3	8.2	17.3	78397	78981
10	43.3	20.0	20.0	83.3	11.0	23.3	90944	85402
11	9.3	3.0	3.0	15.3	2.9	6.3	40306	40505
12	18.6	6.0	6.0	30.6	5.9	12.5	46202	54872
13	31.1	10.0	10.0	51.1	9.9	21.1	59165	64656
14	47.0	15.0	15.0	77.0	15.1	32.0	72720	70509
15	61.9	20.0	20.0	101.9	19.7	41.9		
16	12.1	3.0	3.0	18.1	4.3	9.1	38425	42226
17	24.4	6.0	6.0	36.4	8.7	18.4	44699	54570
18	40.9	10.0	10.0	60.9	14.6	30.9	56794	61544
19	60.9	15.0	15.0	90.9	21.6	45.9	67863	64988
20	81.4	20.0	20.0	121.4	28.9	61.4	83823	65905
21	17.8	3.0	3.0	23.8	7.0	14.8	36902	44487
22	35.9	6.0	6.0	47.9	14.1	29.9	45713	53490
23	57.9	10.0	10.0	77.9	22.6	47.9	55636	57368
24	89.5	15.0	15.0	119.5	35.1	74.5	68828	57505
25	119.4	20.0	20.0	159.4	46.9	99.4		
26	23.0	3.0	3.0	29.0	9.4	20.0	37379	45671
27	47.3	6.0	6.0	59.3	19.5	41.3	48517	52218
28	78.9	10.0	10.0	98.8	32.5	68.9		
29	118.2	15.0	15.0	148.2	48.6	103.2		
30	20.0	20.0	20.0	60.0	0.0	0.0		
Repetition 2								
1	4.9	3.0	3.0	10.9	0.9	1.9	33954	30128
2	9.9	6.0	6.0	22.0	1.9	3.9	42045	47786
3	16.8	10.0	10.0	36.8	3.2	6.8	67598	65436

Sequence	σ_1	σ_2	σ_3	θ	τ_{oct}	$\sigma_1 - \sigma_3$	M_R	Pred. M_R
	psi	psi	psi	psi	psi	psi	psi	psi
4	25.1	15.0	15.0	55.1	4.8	10.2	87513	82323
5	33.4	20.0	20.0	73.4	6.3	13.4	108758	95697
6	6.4	3.0	3.0	12.4	1.6	3.4	39951	32008
7	12.9	6.0	6.0	24.9	3.3	6.9	47613	49303
8	21.5	10.0	10.0	41.5	5.4	11.5	60646	65451
9	32.2	15.0	15.0	62.2	8.1	17.2	80035	79877
10	43.2	20.0	20.0	83.2	10.9	23.2	96945	90376
11	9.3	3.0	3.0	15.3	3.0	6.3	35443	35105
12	18.7	6.0	6.0	30.7	6.0	12.6	43942	51597
13	31.0	10.0	10.0	51.0	9.9	21.0	59463	65434
14	47.0	15.0	15.0	77.0	15.1	32.0	78004	76455
15	62.1	20.0	20.0	102.1	19.8	42.1	84116	83966
16	12.2	3.0	3.0	18.2	4.3	9.2	34185	37623
17	24.4	6.0	6.0	36.4	8.7	18.4	45059	53305
18	40.9	10.0	10.0	60.9	14.6	30.9	62086	65382
19	61.2	15.0	15.0	91.2	21.8	46.2	75340	74327
20	81.1	20.0	20.0	121.1	28.8	61.1	82212	80043
21	18.0	3.0	3.0	24.0	7.1	15.0	34883	41580
22	36.0	6.0	6.0	48.0	14.1	30.0	48361	55681
23	58.1	10.0	10.0	78.1	22.7	48.1	63104	65260
24	89.5	15.0	15.0	119.5	35.1	74.5	75463	71683
25	117.9	20.0	20.0	157.9	46.2	97.9	88100	75564
26	23.2	3.0	3.0	29.2	9.5	20.2	35227	44263
27	47.6	6.0	6.0	59.6	19.6	41.6	48730	57231
28	79.0	10.0	10.0	99.0	32.5	69.0	67032	65103
29	117.4	15.0	15.0	147.4	48.3	102.4	79191	70098
30	20.0	20.0	20.0	60.0	0.0	0.0		107854
Repetition 3								
1	4.9	3.0	3.0	10.9	0.9	1.9	55947	40258
2	10.0	6.0	6.0	22.0	1.9	4.0	66632	57614
3	16.7	10.0	10.0	36.6	3.1	6.7	80474	73472
4	24.9	15.0	15.0	54.9	4.7	9.9	99239	87791
5	33.1	20.0	20.0	73.1	6.2	13.1	117617	98588
6	6.4	3.0	3.0	12.4	1.6	3.4	50553	42122
7	12.9	6.0	6.0	24.9	3.2	6.9	58262	58884
8	21.4	10.0	10.0	41.4	5.4	11.4	71493	73272

Sequence	σ_1 psi	σ_2 psi	σ_3 psi	θ psi	τ_{oct} psi	$\sigma_1 - \sigma_3$ psi	M_R psi	Pred. M_R psi
9	32.5	15.0	15.0	62.5	8.2	17.5	88274	85257
10	43.3	20.0	20.0	83.3	11.0	23.3	97941	93637
11	9.3	3.0	3.0	15.3	3.0	6.3	44994	45184
12	18.6	6.0	6.0	30.6	5.9	12.6	53254	60801
13	31.2	10.0	10.0	51.2	10.0	21.2	67722	72881
14	46.9	15.0	15.0	76.9	15.1	31.9	79173	81929
15	62.4	20.0	20.0	102.4	20.0	42.4	80893	87735
16	12.2	3.0	3.0	18.2	4.3	9.2	43829	47600
17	24.3	6.0	6.0	36.3	8.6	18.3	51913	62178
18	40.9	10.0	10.0	60.8	14.5	30.9	65451	72532
19	61.1	15.0	15.0	91.1	21.7	46.1	74143	79739
20	81.9	20.0	20.0	121.9	29.2	61.9	77784	83980
21	17.9	3.0	3.0	23.9	7.0	14.9	43210	51287
22	36.0	6.0	6.0	48.0	14.1	30.0	53330	64011
23	58.1	10.0	10.0	78.1	22.7	48.1	65965	71988
24	89.3	15.0	15.0	119.3	35.0	74.3	78217	76928
25	119.7	20.0	20.0	159.7	47.0	99.7	86814	79594
26	23.1	3.0	3.0	29.1	9.5	20.1	45274	53726
27	47.6	6.0	6.0	59.6	19.6	41.6	56418	65115
28	78.8	10.0	10.0	98.8	32.4	68.8	72546	71443
29	117.1	15.0	15.0	147.1	48.2	102.2	85558	75158
30	155.6	20.0	20.0	195.6	63.9	135.6	99626	77078

Calculated Mr coefficients for

	Rep 1	Rep 2	Rep 3
K_1	3,199.8	2,658.1	3,358.1
K_2	0.650	0.722	0.563
K_3	-0.951	-0.742	-0.604

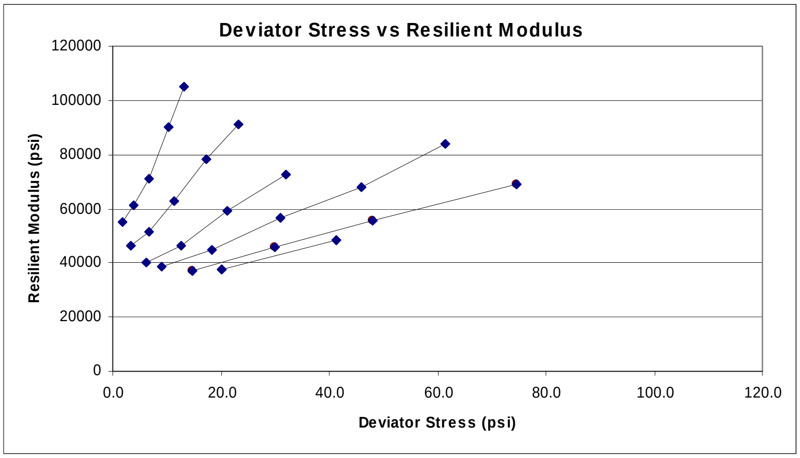


Figure 19. ***Resilient Modulus vs. Deviator Stress*** in ***US-280, MN Base Rep 1***

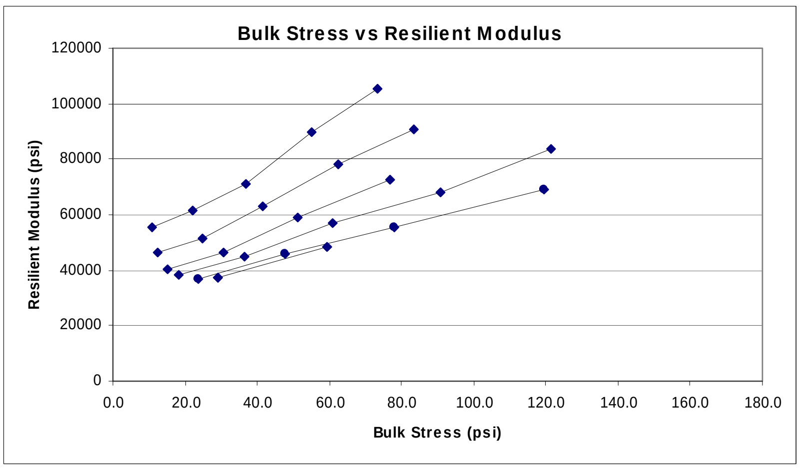


Figure 20. ***Bulk stress vs. Resilient Modulus*** in ***US-280, MN Base – Rep 1***

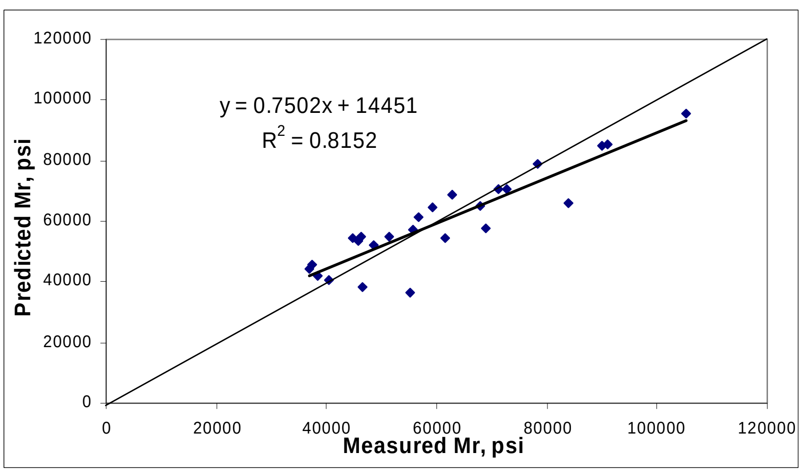


Figure 21. ***Predicted vs Measured Resilient Modulus*** in ***US-280, MN Base – Rep 1***

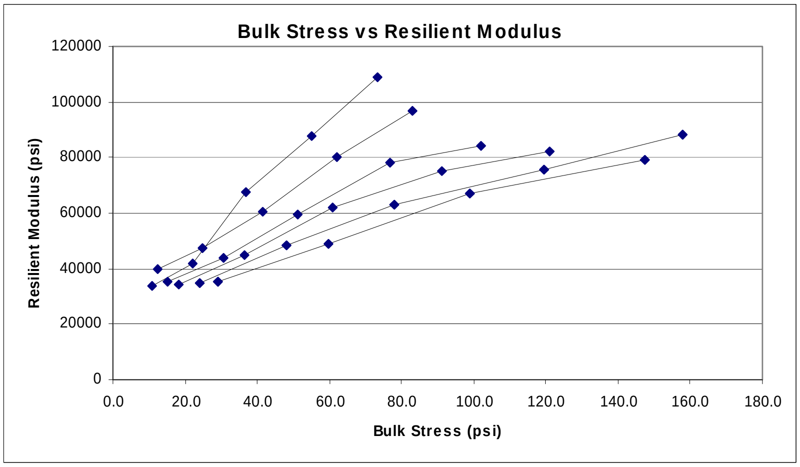


Figure 22. ***Resilient Modulus vs. Deviator Stress*** in ***US-280, MN Base – Rep 2***

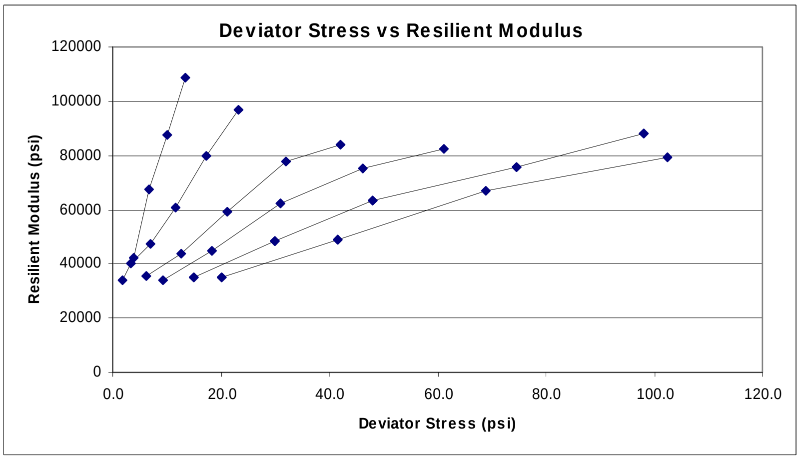


Figure 23. ***Bulk stress vs. Resilient Modulus*** in ***US-280 MN Base – Rep 2***

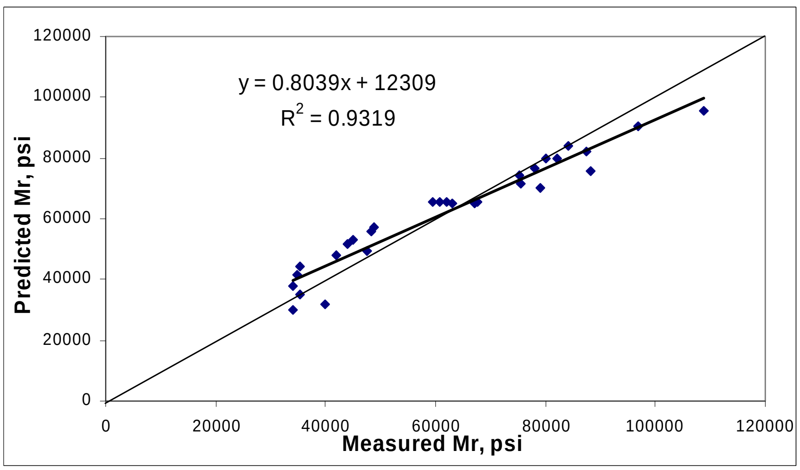


Figure 24. ***Predicted vs Measured Resilient Modulus*** in ***US-280, MN Base – Rep 2***

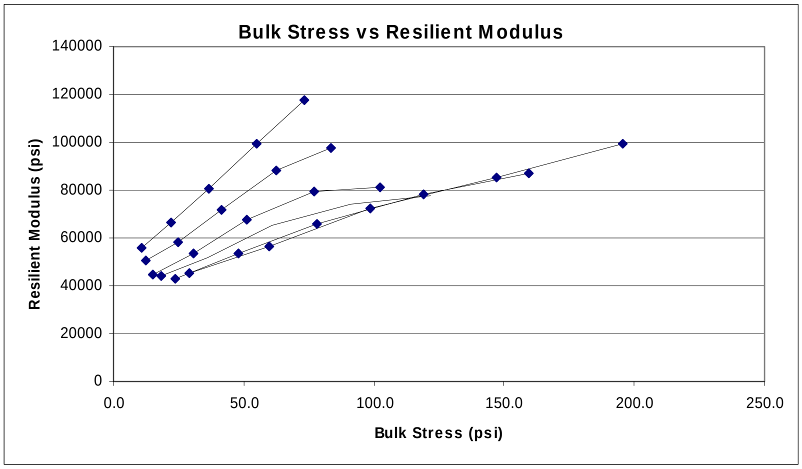


Figure 25. ***Resilient Modulus vs. Deviator Stress*** in ***US-280, MN Base – Rep 3***

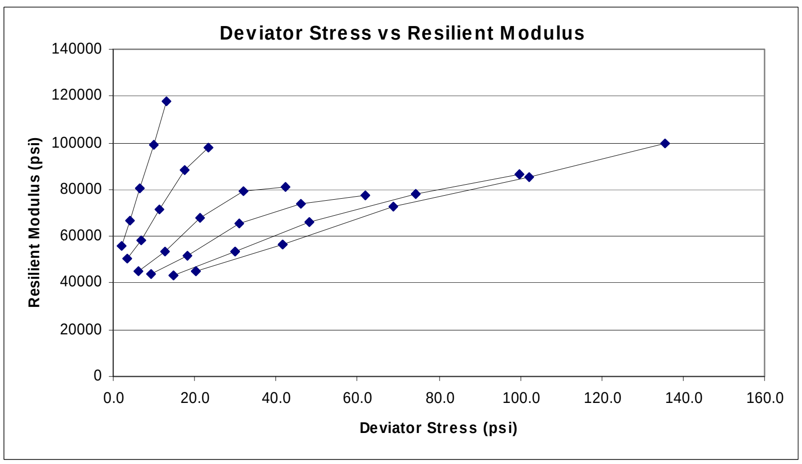


Figure 26. ***Bulk stress vs. Resilient Modulus*** in ***US-280, MN Base – Rep 3***

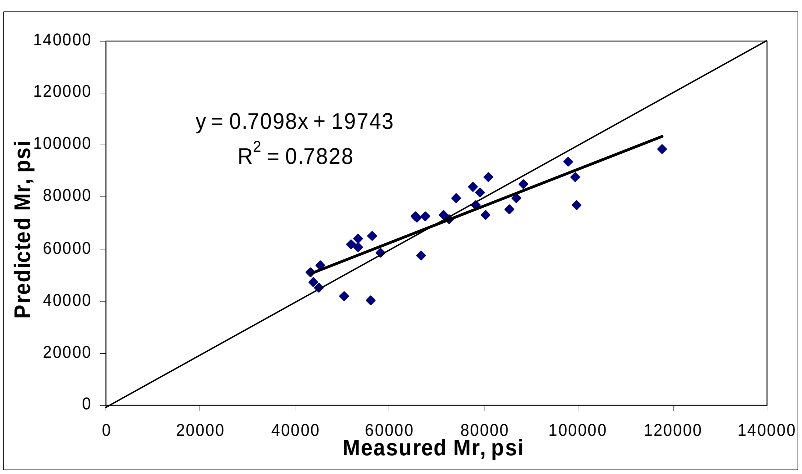
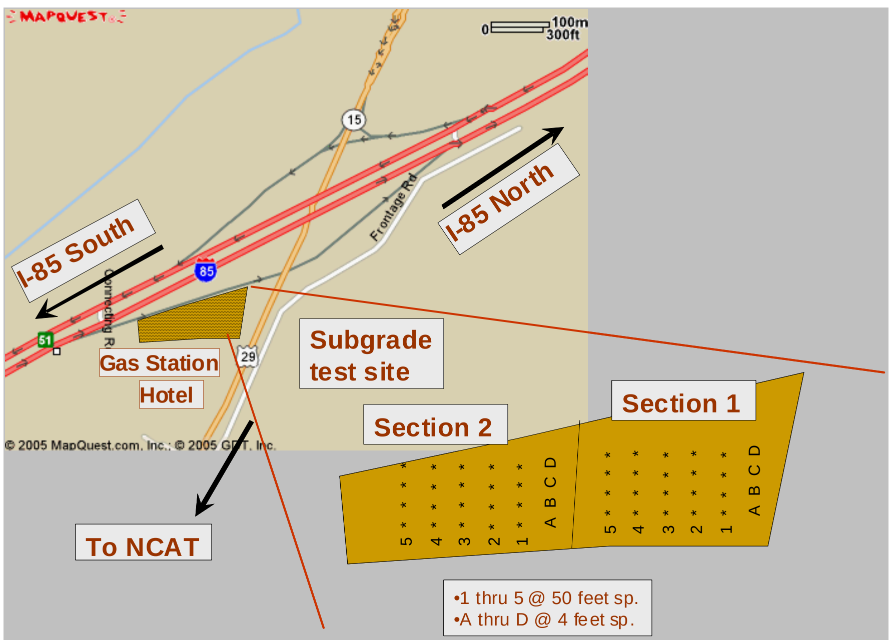


Figure 27. ***Predicted vs Measured Resilient Modulus*** in ***US-280, MN Base – Rep 3***

I-85, AL SUBGRADE TESTING
PRIOR TO INTELLIGENCE COMPACTION



Note: No station information was available for these sections

Table 55. ***Penetration Index*** measured by ***DCP*** in ***I-85 Ramp, AL, Subgrade, Pre-IC, mm/blow***

Note: Test data for number of blows vs penetration is shown in Table 56.

Lot	Sublot	A	B	C	D	Average	Lot Average
1	1	59.03	46.58	45.69	41.26	48.14	
	2	46.63	14.00	36.57	43.22	35.11	
	3	61.17	54.12	75.10	64.65	63.76	
	4	59.39	47.50	32.12	50.96	47.49	
	5	43.31	63.03	42.09	56.03	51.11	49.12
2	1	59.93	45.35	29.76	36.77	42.95	
	2	55.77	54.85	40.63	49.43	50.17	
	3	62.43	43.09	44.84	59.15	52.38	
	4	59.46	77.65	62.03	62.67	65.45	
	5	69.60	57.35	75.88	73.13	68.99	55.99
Average lot 1 by row		53.90	45.05	46.32	51.22		
Average lot 2 by row		61.44	55.66	50.63	56.23		
Average by row		57.67	50.35	48.47	53.73		
Project average							52.56

Table 56. ***Penetration Index*** measured by ***DCP*** in ***I-85 Ramp, AL, Subgrade, Pre-IC, mm/blow***

Lot		**Penetration, mm**				**PI, mm/blow**			
		1	**1**	**1**	**1**	**1**	**1**	**1**	**1**
Sublot		**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**
Point		**A**	**B**	**C**	**D**	**A**	**B**	**C**	**D**
Number of blows	1	280	310	270	285				
	2	370	385	310	325	90.00	75.00	40.00	40.00
	3	430	440	410	395	75.00	65.00	70.00	55.00
	4	470	465	440	450	63.33	51.67	56.67	55.00
	5	485	485	465	470	51.25	43.75	48.75	46.25
	6	510	510	490	495	46.00	40.00	44.00	42.00
	7	540	535	515	525	43.33	37.50	40.83	40.00
	8	590	560	540	535	44.29	35.71	38.57	35.71
	9		595	565	560		35.63	36.88	34.38
	10		625	590	580		35.00	35.56	32.78
	11				600				31.50
	12								
	13								
	14								
	15								
	16								
	17								
	18								
	End								
		580	610	570	585				
Average PI at point						59.03	46.58	45.69	41.26

Table 56 Continued, ***Penetration Index*** measured by ***DCP*** in ***I-85 Ramp, AL, Subgrade, Pre-IC, mm/blow***

Lot		Penetration, mm				PI, mm/blow			
		1	1	1	1	1	1	1	1
Sublot		2	2	2	2	2	2	2	2
Point		A	B	C	D	A	B	C	D
Number of blows	1	280	285	300	280				
	2	335	300	345	320	55.00	15.00	45.00	40.00
	3	375	315	380	365	47.50	15.00	40.00	42.50
	4	420	330	410	400	46.67	15.00	36.67	40.00
	5	475	340	435	450	48.75	13.75	33.75	42.50
	6	520	350	470	520	48.00	13.00	34.00	48.00
	7	550	360	500	560	45.00	12.50	33.33	46.67
	8	575	370	550	580	42.14	12.14	35.71	42.86
	9	600	380	590		40.00	11.88	36.25	
	10		395	610			12.22	34.44	
	11		405				12.00		
	12		415				11.82		
	13		430				12.08		
	14		455				13.08		
	15		490				14.64		
	16		535				16.67		
	17		560				17.19		
	18		575				17.06		
	End		590				16.94		
		580	585	600	580				
Average PI at point						46.63	14.00	36.57	43.22

Table 56 Continued, ***Penetration Index*** measured by ***DCP*** in ***I-85 Ramp, AL, Subgrade, Pre-IC, mm/blow***

Lot		Penetration, mm				PI, mm/blow			
		1	1	1	1	1	1	1	1
Sublot		3	3	3	3	3	3	3	3
Point		A	B	C	D	A	B	C	D
Number of blows	1	290	280	320	310				
	2	355	340	390	380	65.00	60.00	70.00	70.00
	3	415	390	455	425	62.50	55.00	67.50	57.50
	4	465	460	565	490	58.33	60.00	81.67	60.00
	5	530	500	645	585	60.00	55.00	81.25	68.75
	6	590	535		645	60.00	51.00		67.00
	7		580				50.00		
	8		615				47.86		
	9								
	10								
	11								
	12								
	13								
	14								
	15								
	16								
	17								
	18								
	End								
		590	580	620	610				
Average PI at point						61.17	54.12	75.10	64.65

Table 56 Continued, ***Penetration Index*** measured by ***DCP*** in ***I-85 Ramp, AL, Subgrade, Pre-IC, mm/blow***

Lot		**Penetration, mm**				**PI, mm/blow**			
		1	**1**	**1**	**1**	**1**	**1**	**1**	**1**
Sublot		**4**	**4**	**4**	**4**	**4**	**4**	**4**	**4**
Point		**A**	**B**	**C**	**D**	**A**	**B**	**C**	**D**
Number of blows	1	315	275	300	370				
	2	380	310	330	420	65.00	35.00	30.00	50.00
	3	430	360	370	480	57.50	42.50	35.00	55.00
	4	505	415	410	520	63.33	46.67	36.67	50.00
	5	555	485	450	565	60.00	52.50	37.50	48.75
	6	605	550	470	630	58.00	55.00	34.00	52.00
	7	630	595	485	670	52.50	53.33	30.83	50.00
	8			500				28.57	
	9			530				28.75	
	10			575				30.56	
	11			610				31.00	
	12			635				30.45	
	13								
	14								
	15								
	16								
	17								
	18								
	End								
		615	575	600	670				
Average PI at point						59.39	47.50	32.12	50.96

Table 56 Continued, ***Penetration Index*** measured by ***DCP*** in ***I-85 Ramp, AL, Subgrade, Pre-IC, mm/blow***

Lot		Penetration, mm				PI, mm/blow			
		1	1	1	1	1	1	1	1
Sublot		5	5	5	5	5	5	5	5
Point		A	B	C	D	A	B	C	D
Number of blows	1	360	320	315	315				
	2	425	385	360	375	65.00	65.00	45.00	60.00
	3	450	440	390	435	45.00	60.00	37.50	60.00
	4	470	505	425	485	36.67	61.67	36.67	56.67
	5	495	570	470	525	33.75	62.50	38.75	52.50
	6	535	650	520	575	35.00	66.00	41.00	52.00
	7	625		585	645	44.17		45.00	55.00
	8	665		670		43.57		50.71	
	9								
	10								
	11								
	12								
	13								
	14								
	15								
	16								
	17								
	18								
	End								
		650	620	615	615				
Average PI at point						43.31	63.03	42.09	56.03

Table 56 Continued, ***Penetration Index*** measured by ***DCP*** in ***I-85 Ramp, AL, Subgrade, Pre-IC, mm/blow***

Lot		**Penetration, mm**				**PI, mm/blow**			
		2	**2**	**2**	**2**	**2**	**2**	**2**	**2**
Sublot		**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**
Point		**A**	**B**	**C**	**D**	**A**	**B**	**C**	**D**
Number of blows	1	335	350	340	320				
	2	395	380	365	350	60.00	30.00	25.00	30.00
	3	455	420	390	395	60.00	35.00	25.00	37.50
	4	505	480	420	440	56.67	43.33	26.67	40.00
	5	575	535	455	485	60.00	46.25	28.75	41.25
	6	650	625	495	510	63.00	55.00	31.00	38.00
	7		725	530	540		62.50	31.67	36.67
	8			570	570			32.86	35.71
	9			600	610			32.50	36.25
	10			625	640			31.67	35.56
	11			665				32.50	
	12								
	13								
	14								
	15								
	16								
	17								
	18								
	End								
		635	650	640	620				
Average PI at point						59.93	45.35	29.76	36.77

Table 56 Continued, ***Penetration Index*** measured by ***DCP*** in ***I-85 Ramp, AL, Subgrade, Pre-IC, mm/blow***

Lot		**Penetration, mm**				**PI, mm/blow**			
		2	**2**	**2**	**2**	**2**	**2**	**2**	**2**
Sublot		**2**	**2**	**2**	**2**	**2**	**2**	**2**	**2**
Point		**A**	**B**	**C**	**D**	**A**	**B**	**C**	**D**
Number of blows	1	310	320	315	290				
	2	380	375	350	340	70.00	55.00	35.00	50.00
	3	465	455	395	370	77.50	67.50	40.00	40.00
	4	490	505	435	415	60.00	61.67	40.00	41.67
	5	510	540	470	500	50.00	55.00	38.75	52.50
	6	535	570	515	605	45.00	50.00	40.00	63.00
	7	580	610	615		45.00	48.33	50.00	
	8	610	645			42.86	46.43		
	9								
	10								
	11								
	12								
	13								
	14								
	15								
	16								
	17								
	18								
	End								
		610	620	615	590				
Average PI at point						55.77	54.85	40.63	49.43

Table 56 Continued, ***Penetration Index*** measured by ***DCP*** in ***I-85 Ramp, AL, Subgrade, Pre-IC, mm/blow***

Lot		**Penetration, mm**				**PI, mm/blow**			
		2	**2**	**2**	**2**	**2**	**2**	**2**	**2**
Sublot		**3**	**3**	**3**	**3**	**3**	**3**	**3**	**3**
Point		**A**	**B**	**C**	**D**	**A**	**B**	**C**	**D**
Number of blows	1	300	290	290	290				
	2	375	350	330	345	75.00	60.00	40.00	55.00
	3	440	415	385	405	70.00	62.50	47.50	57.50
	4	495	455	420	470	65.00	55.00	43.33	60.00
	5	535	475	480	535	58.75	46.25	47.50	61.25
	6	575	490	525	600	55.00	40.00	47.00	62.00
	7	605	510	560		50.83	36.67	45.00	
	8		530	595			34.29	43.57	
	9		550				32.50		
	10		580				32.22		
	11		605				31.50		
	12								
	13								
	14								
	15								
	16								
	17								
	18								
	End								
		600	590	590	590				
Average PI at point						62.43	43.09	44.84	59.15

Table 56 Continued, ***Penetration Index*** measured by ***DCP*** in ***I-85 Ramp, AL, Subgrade, Pre-IC, mm/blow***

Lot		**Penetration, mm**				**PI, mm/blow**			
		2	**2**	**2**	**2**	**2**	**2**	**2**	**2**
Sublot		**4**	**4**	**4**	**4**	**4**	**4**	**4**	**4**
Point		**A**	**B**	**C**	**D**	**A**	**B**	**C**	**D**
Number of blows	1	320	305	325	305				
	2	390	395	385	360	70.00	90.00	60.00	55.00
	3	440	485	465	415	60.00	90.00	70.00	55.00
	4	490	545	530	510	56.67	80.00	68.33	68.33
	5	545	570	565	585	56.25	66.25	60.00	70.00
	6	610	615	615	630	58.00	62.00	58.00	65.00
	7	655		660		55.83		55.83	
	8								
	9								
	10								
	11								
	12								
	13								
	14								
	15								
	16								
	17								
	18								
	End								
		620	605	625	605				
Average PI at point						59.46	77.65	62.03	62.67

Table 56 Continued, ***Penetration Index*** measured by ***DCP*** in ***I-85 Ramp, AL, Subgrade, Pre-IC, mm/blow***

Lot		Penetration, mm				PI, mm/blow			
		2	2	2	2	2	2	2	2
Sublot		5	5	5	5	5	5	5	5
Point		A	B	C	D	A	B	C	D
Number of blows	1	300	310	300	290				
	2	385	375	385	360	85.00	65.00	85.00	70.00
	3	455	420	465	445	77.50	55.00	82.50	77.50
	4	530	490	530	535	76.67	60.00	76.67	81.67
	5	575	525	585	580	68.75	53.75	71.25	72.50
	6	590	595	620	610	58.00	57.00	64.00	64.00
	7	610	630			51.67	53.33		
	8								
	9								
	10								
	11								
	12								
	13								
	14								
	15								
	16								
	17								
	18								
	End								
		600	610	600	590				
Average PI at point						69.60	57.35	75.88	73.13

Table 57. ***Wet density*** measured by ***EDG*** in ***I-85 Ramp, AL, Subgrade, Pre-IC, pcf***
Note: Test repetitions were not performed at individual points

Lot	Sublot	A	B	C	D	Average	Lot Average
1	1	127.18	127.19	127.54	122.51	126.11	
	2	127.64	127.67	127.19	126.7	127.30	
	3	123.78	127.4	39.13	126.56	104.22	
	4	125.96	127.76	127.76	126.65	127.03	
	5	126.31	126.25	124.99	127.12	126.17	122.16
2	1	124.12	125.55	129.15	127.11	126.48	
	2	125.62	126.13	126.03	126.59	126.09	
	3	124.91	125.62	127.63	121.66	124.96	
	4	126.64	126.27	127.27	125.94	126.53	
	5	125.6	124.68	125.92	125.77	125.49	125.91
Average lot 1 by row		126.17	127.25	109.32	125.91		
Average lot 2 by row		125.38	125.65	127.20	125.41		
Average by row		125.78	126.45	118.26	125.66		
Project average							124.04

Table 58. ***Percent Moisture*** measured by **EDG** in **I-85 Ramp, AL, Subgrade, Pre-IC**
Note: Test repetitions were not performed at individual points

Lot	Sublot	A	B	C	D	Average	Lot Average
1	1	16.8	16.8	16.8	17.2	16.9	
	2	16.8	16.8	16.8	16.8	16.8	
	3	17.1	16.8	86.2	16.8	34.2	
	4	16.9	16.8	16.8	16.9	16.9	
	5	16.8	16.9	17.0	16.8	16.9	20.3
2	1	17.1	16.9	16.8	16.8	16.9	
	2	16.9	16.9	16.9	16.8	16.9	
	3	17.0	16.9	16.8	17.4	17.0	
	4	16.8	16.9	16.8	16.9	16.9	
	5	16.9	17.0	16.9	16.9	16.9	16.9
Average lot 1 by row		16.9	16.8	30.7	16.9		
Average lot 2 by row		16.9	16.9	16.8	17.0		
Average by row		16.9	16.9	23.8	16.9		
Project average							18.6

Table 59. ***Modulus*** measured by ***GEOGAUGE*** in ***I-85 Ramp, AL, Subgrade, Pre-IC, psi***

Note: Test repetitions were not performed at individual points.

Lot	Sublot	A	B	C	D	Average	Lot Average
1	1	15700	16300	17500	15300	16200	
	2	18800	18200	16100	16200	17325	
	3	13200	15200	12900	15000	14075	
	4	14200	16500	17000	13300	15250	
	5	10700	15300	10900	18500	13850	15340
2	1	6300	15200	15600	13100	12550	
	2	10500	17700	17600	17100	15725	
	3	12300	19300	19100	22400	18275	
	4	10000	13800	16600	21300	15425	
	5	13900	13600	16700	16700	15225	15440
Average lot 1 by row		14520	16300	14880	15660		
Average lot 2 by row		10600	15920	17120	18120		
Average by row		12560	16110	16000	16890		
Project average							15390

Table 60. ***Stiffness*** measured by ***GEOGAUGE*** in ***I-85 Ramp, AL, Subgrade, Pre-IC, klb/in***

Note: Test repetitions were not performed at individual points.

Lot	Sublot	A	B	C	D	Average	Lot Average
1	1	70.9	74.1	79.5	69.4	73	
	2	85.04	82.4	73.1	73.5	79	
	3	59.7	68.9	58.4	68	64	
	4	64.2	74.7	76.9	60.3	69	
	5	48.3	69.6	49.3	83.9	63	70
		0	0	0	0		
		0	0	0	0		
2	1	28.5	68.9	70.8	59.3	57	
	2	47.5	80.1	80	77.3	71	
	3	55.7	87.7	86.4	101.8	83	
	4	45.1	62.6	75.2	96.6	70	
	5	63	61.5	75.8	75.9	69	70
Average lot 1 by row		66	74	67	71		
Average lot 2 by row		48	72	78	82		
Average by row		47	61	60	64		
Project average							58

Table 61. ***Dielectric*** measured by ***GPR*** in ***I-85 Ramp, AL, Subgrade, Pre-IC***
Note: Test repetitions were not performed at this site prior to IC rolling

Lot	**Sublot**	**A**	**B**	**C**	**D**	**Average**	**Lot Average**
1	1	19.02	12.78	19.32	12.32	15.86	
	2	13.13	19.05	10.71	13.89	14.20	
	3	12.27	12.37	24.15	11.77	15.14	
	4	16.81	14.39	12.88	20.42	16.12	
	5	15.66	20.36	4.40	19.07	14.87	15.24
2	1	12.28	19.98	20.80	20.59	18.41	
	2	12.86	20.04	14.19	11.69	14.70	
	3	11.50	19.65	8.94	14.75	13.71	
	4	21.06	11.95	19.54	14.46	16.75	
	5	11.84	15.75	20.65	20.43	17.17	16.15
Average lot 1 by row		15.38	15.79	14.29	15.49		
Average lot 2 by row		13.91	17.47	16.82	16.39		
Average by row		14.64	16.63	15.56	15.94		
Project average							15.69

Note: NO LWD TESTS WERE CONDUCTED PRIOR TO INTELLIGENT COMPACTION ROLLING OPERATIONS

Table 62. ***Modulus*** measured by ***DSPA*** in ***I-85 Ramp, AL, Subgrade, Pre-IC, psi***
Note: Test repetitions were performed at individual points as shown in Table 63

Lot	Sublot	A	B	C	D	Average	Lot Average
1	1	38167	31000	30667	38500	34583	
	2	23500	33667	31667	36667	31375	
	3	28167	35000	23167	41167	31875	
	4	21167	30167	24167	23000	24625	
	5	19833	29167	29833	31833	27667	30025
2	1	26333	20833	34167	30333	27917	
	2	24000	23000	34833	40167	30500	
	3	14667	27167	39000	45833	31667	
	4	28667	27333	42500	55167	38417	
	5	26667	37667	41000	50500	38958	33492
Average lot 1 by row		26167	31800	27900	34233		
Average lot 2 by row		24067	27200	38300	44400		
Average by row		25117	29500	33100	39317		
Project average							31758

Table 63. Repeatability in ***Modulus*** measurements by ***DSPA*** in ***I-85 Ramp, AL, Subgrade, Pre-IC, psi***
Note: Summary of test results are shown in Table 62

Lot	Sublot	Point	Thickness, inch			
			Trial 1	Trial 2	Trial 3	Average
1	1	A	39000	34500	41000	**38167**
1	1	B	28000	42000	23000	**31000**
1	1	C	38000	31000	23000	**30667**
1	1	D	29000	39000	47500	**38500**
1	2	A	30500	18000	22000	**23500**
1	2	B	28000	40000	33000	**33667**
1	2	C	41500	26500	27000	**31667**
1	2	D	38000	35000	37000	**36667**
1	3	A	28500	27000	29000	**28167**
1	3	B	33000	43000	29000	**35000**
1	3	C	22500	23000	24000	**23167**
1	3	D	38500	43000	42000	**41167**
1	4	A	21500	26000	16000	**21167**
1	4	B	29000	30500	31000	**30167**
1	4	C	23000	22000	27500	**24167**
1	4	D	21000	25000	23000	**23000**
1	5	A	18000	21000	20500	**19833**
1	5	B	31000	31500	25000	**29167**
1	5	C	30000	28000	31500	**29833**
1	5	D	34000	28000	33500	**31833**
2	1	A	33000	18000	28000	**26333**
2	1	B	18500	26000	18000	**20833**
2	1	C	32500	34000	36000	**34167**
2	1	D	34500	27000	29500	**30333**
2	2	A	28000	28000	16000	**24000**
2	2	B	20500	25500	23000	**23000**
2	2	C	33500	40000	31000	**34833**
2	2	D	35000	40500	45000	**40167**
2	3	A	10000	11000	23000	**14667**
2	3	B	28500	23000	30000	**27167**

Lot	**Sublot**	**Point**	**Thickness, inch**			
			Trial 1	**Trial 2**	**Trial 3**	**Average**
2	3	C	36000	38000	43000	**39000**
2	3	D	33500	62000	42000	**45833**
2	4	A	17000	31000	38000	**28667**
2	4	B	28000	28000	26000	**27333**
2	4	C	42000	42500	43000	**42500**
2	4	D	47500	63000	55000	**55167**
2	5	A	23000	23000	34000	**26667**
2	5	B	38000	29000	46000	**37667**
2	5	C	40000	39000	44000	**41000**
2	**5**	**D**	**47000**	**54500**	**50000**	**50500**

Table 64. Summary of ***Resilient Modulus Test Results*** in ***US-280, MN Base***

Sequence	σ_1 psi	σ_2 psi	σ_3 psi	θ psi	τ_{oct} psi	$\sigma_1 - \sigma_3$ psi	M_R psi	Pred. M_R psi
Repetition 1								
1	12.9	8.0	8.0	28.9	2.3	4.9	5345	5263
2	10.6	6.0	6.0	22.6	2.1	4.6	4933	4806
3	8.1	4.0	4.0	16.1	1.9	4.1	4206	4214
4	5.6	2.0	2.0	9.6	1.7	3.6	3546	3340
5	15.5	8.0	8.0	31.5	3.5	7.5	3736	3791
6	13.0	6.0	6.0	25.0	3.3	7.0	3355	3533
7	10.5	4.0	4.0	18.5	3.1	6.5	2946	3172
8	8.0	2.0	2.0	12.0	2.8	6.0	2498	2649
9	17.9	8.0	8.0	33.9	4.7	9.9	2941	2830
10	15.4	6.0	6.0	27.5	4.5	9.4	2699	2647
11	12.9	4.0	4.0	20.9	4.2	8.9	2440	2413
12	10.3	2.0	2.0	14.3	3.9	8.3	2158	2093
13	22.8	8.0	8.0	38.8	7.0	14.8	-	-
14	20.5	6.0	6.0	32.5	6.8	14.4	-	-
15	18.3	4.0	4.0	26.3	6.7	14.3	-	-
16	16.0	2.0	2.0	20.0	6.6	14.0	-	-
Repetition 2								
1	13.0	8.0	8.0	29.0	2.3	5.0	5356	5249
2	10.6	6.0	6.0	22.6	2.2	4.6	5015	4831
3	8.2	4.0	4.0	16.2	2.0	4.1	4313	4283
4	5.7	2.0	2.0	9.7	1.7	3.7	3656	3458
5	15.5	8.0	8.0	31.5	3.5	7.5	3707	3825
6	13.1	6.0	6.0	25.1	3.3	7.0	3381	3583
7	10.6	4.0	4.0	18.6	3.1	6.6	2996	3242
8	8.0	2.0	2.0	12.0	2.8	6.0	2545	2753
9	17.9	8.0	8.0	33.9	4.7	9.9	2967	2885
10	15.5	6.0	6.0	27.5	4.5	9.5	2792	2711
11	13.0	4.0	4.0	21.0	4.2	9.0	2556	2492
12	10.4	2.0	2.0	14.4	4.0	8.4	2274	2179
13	21.2	8.0	8.0	37.2	6.2	13.2	-	-
14	18.8	6.0	6.0	30.8	6.1	12.8	-	-
15	16.4	4.0	4.0	24.4	5.8	12.4	-	-
16	13.9	2.0	2.0	17.9	5.6	11.9	-	-

Sequence	σ_1	σ_2	σ_3	θ	τ_{oct}	$\sigma_1 - \sigma_3$	M_R	Pred. M_R
	psi	psi	psi	psi	psi	psi	psi	psi
Repetition 3								
1	13.0	8.0	8.0	29.0	2.3	5.0	4841	4740
2	10.6	6.0	6.0	22.6	2.1	4.6	4495	4362
3	8.1	4.0	4.0	16.1	1.9	4.1	3864	3842
4	5.6	2.0	2.0	9.6	1.7	3.6	3292	3077
5	15.5	8.0	8.0	31.5	3.5	7.5	3498	3577
6	13.0	6.0	6.0	25.0	3.3	7.0	3150	3346
7	10.5	4.0	4.0	18.5	3.1	6.5	2759	3016
8	7.9	2.0	2.0	12.0	2.8	5.9	2344	2533
9	17.9	8.0	8.0	33.9	4.6	9.9	2891	2783
10	15.4	6.0	6.0	27.4	4.4	9.4	2677	2608
11	12.9	4.0	4.0	20.9	4.2	8.9	2432	2383
12	10.3	2.0	2.0	14.3	3.9	8.3	2161	2075
13	21.1	8.0	8.0	37.1	6.2	13.1	-	-
14	18.7	6.0	6.0	30.7	6.0	12.7	-	-
15	16.2	4.0	4.0	24.2	5.8	12.2	-	-
16	13.6	2.0	2.0	17.7	5.5	11.6	-	-

Calculated Mr coefficients for

	Rep 1	Rep 2	Rep 3
K_1	540.3	541.2	454.5
K_2	0.600	0.561	0.561
K_3	-5.571	-5.383	-4.891

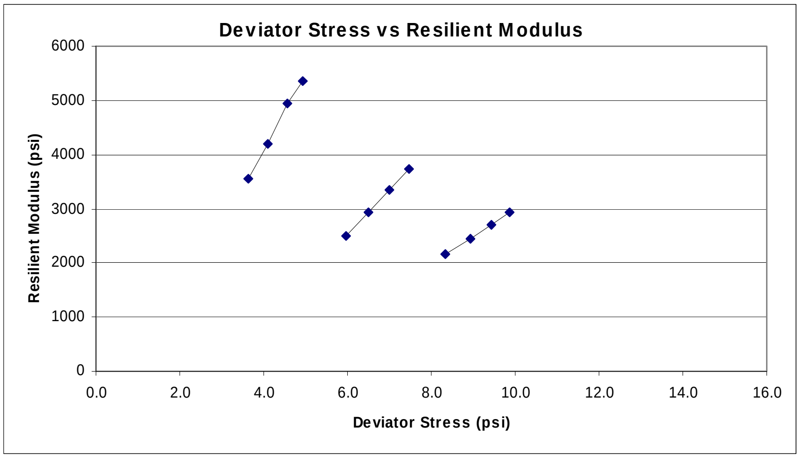


Figure 28. ***Resilient Modulus vs. Deviator Stress*** in ***US-280, MN Base Rep 1***

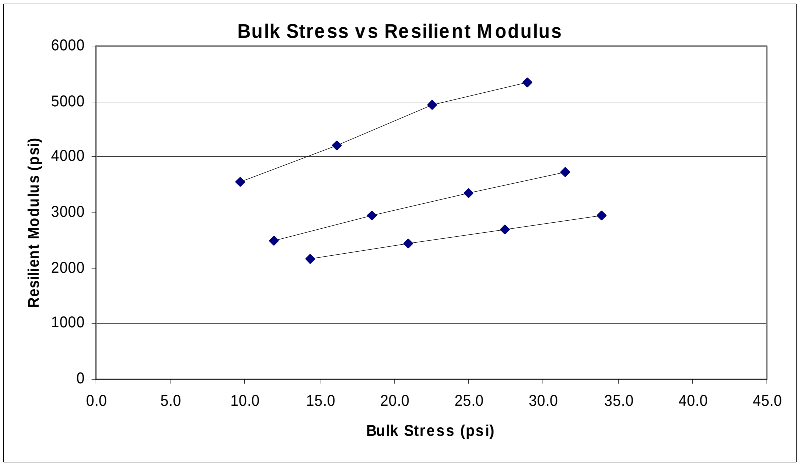


Figure 29. ***Bulk stress vs. Resilient Modulus*** in ***US-280, MN Base – Rep 1***

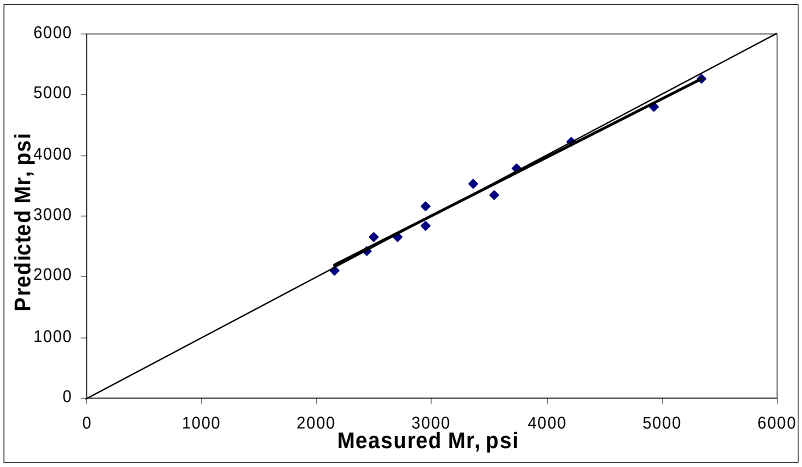


Figure 30. ***Predicted vs Measured Resilient Modulus*** in ***US-280, MN Base – Rep 1***

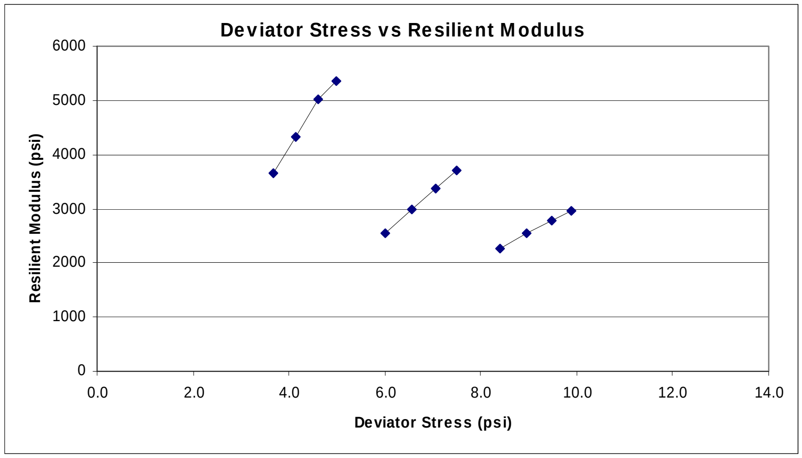


Figure 31. ***Resilient Modulus vs. Deviator Stress*** in ***US-280, MN Base – Rep 2***

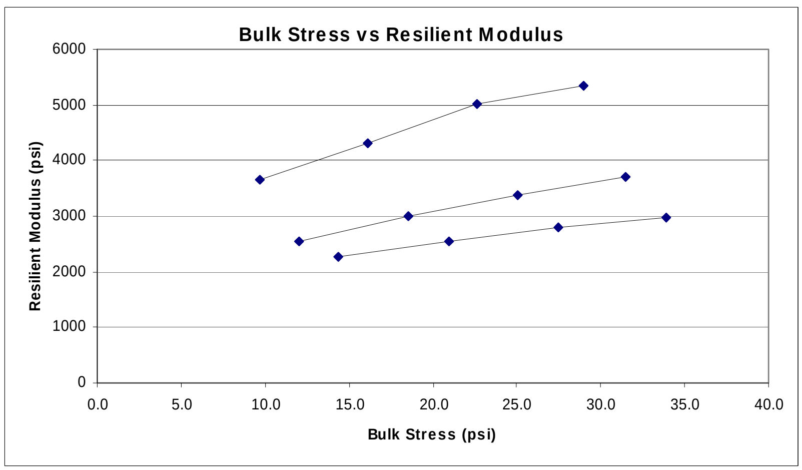


Figure 32. ***Bulk stress vs. Resilient Modulus*** in ***US-280 MN Base – Rep 2***

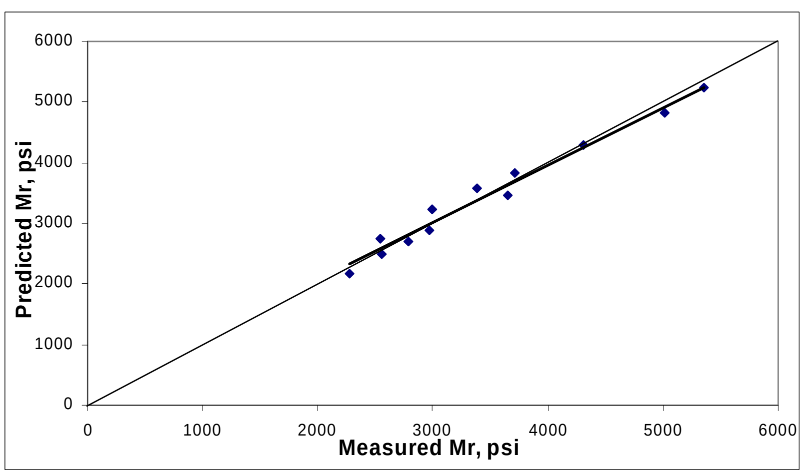


Figure 33. ***Predicted vs Measured Resilient Modulus*** in ***US-280, MN Base – Rep 2***

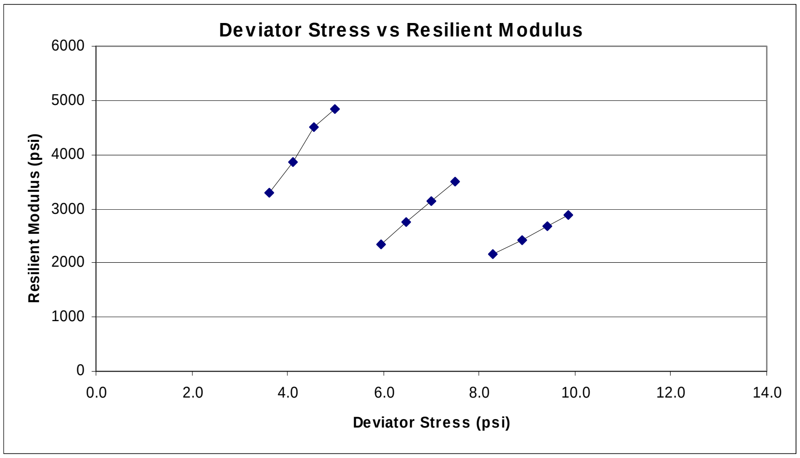


Figure 34. ***Resilient Modulus vs. Deviator Stress*** in ***US-280, MN Base – Rep 3***

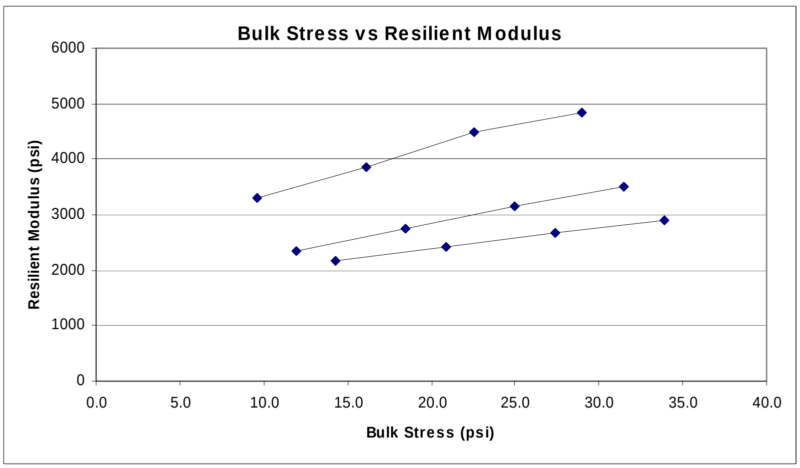


Figure 35. ***Bulk stress vs. Resilient Modulus*** in ***US-280, MN Base – Rep 3***

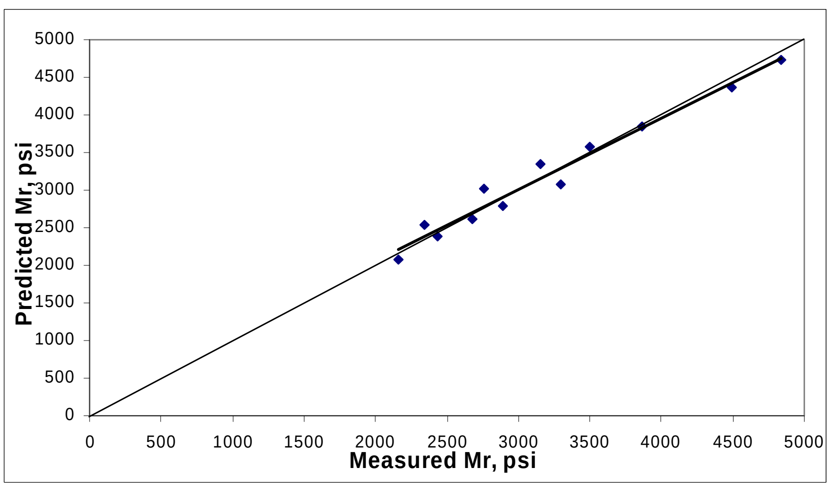
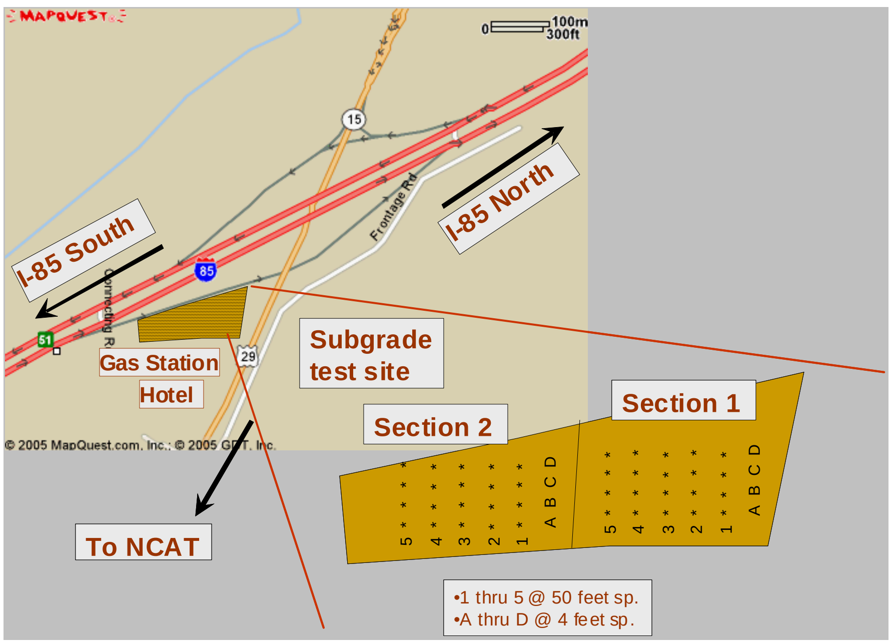


Figure 36. ***Predicted vs Measured Resilient Modulus*** in ***US-280, MN Base – Rep 3***

I-85, AL SUBGRADE TESTING
AFTER INTELLIGENT COMPACTION



Note: No station information was available for these sections

Table 65. ***Penetration Index*** measured by ***DCP*** in ***I-85 Ramp, AL, Subgrade, Post-IC, mm/blow***

Note: Test data for number of blows vs penetration is shown in Table 66.

Lot	Sublot	A	B	C	D	Average	Lot Average
1	1	38.28	29.85	29.85	23.93	30.48	
	2	24.94	11.30	24.96	28.85	22.51	
	3	23.72	34.01	45.81	43.64	36.79	
	4	31.55	24.93	28.72	46.12	32.83	
	5	35.45	41.84	15.62	36.43	32.33	30.99
2	1	35.01	39.77	27.29	29.80	32.97	
	2	39.52	39.66	30.39	35.21	36.19	
	3	33.72	28.86	28.41	34.65	31.41	
	4	34.49	37.61	24.78	22.17	29.76	
	5	48.56	28.28	39.76	45.20	40.45	34.16
Average lot 1 by row		30.79	28.39	28.99	35.79		
Average lot 2 by row		38.26	34.83	30.12	33.40		
Average by row		34.52	31.61	29.56	34.60		
Project average							32.57

Table 66. ***Penetration Index*** measured by ***DCP*** in ***I-85 Ramp, AL, Subgrade, Post-IC, mm/blow***

Lot		Penetration, mm				PI, mm/blow			
		1	1	1	1	1	1	1	1
Sublot		1	1	1	1	1	1	1	1
Point		A	B	C	D	A	B	C	D
Number of blows	1	112	7	6	3				
	2	200	37	33	28	44.00	15.00	13.50	12.50
	3	232	95	96	50	40.00	29.33	30.00	15.67
	4	265	147	155	77	38.25	35.00	37.25	18.50
	5	312	182	182	110	40.00	35.00	35.20	21.40
	6	368	210	208	182	42.67	33.83	33.67	29.83
	7	392	233	234	218	40.00	32.29	32.57	30.71
	8	410	255	250	230	37.25	31.00	30.50	28.38
	9	425	275	272	254	34.78	29.78	29.56	27.89
	10	445	295	290	277	33.30	28.80	28.40	27.40
	11	470	320	312	300	32.55	28.45	27.82	27.00
	12	505	350		323	32.75	28.58		26.67
	13		388				29.31		
	14								
	15								
	16								
	17								
	18								
	19								
Average PI at point						38.28	29.85	29.85	23.93

Table 66 Continued, ***Penetration Index*** measured by ***DCP*** in ***I-85 Ramp, AL, Subgrade, Post-IC, mm/blow***

Lot		Penetration, mm				PI, mm/blow			
		1	1	1	1	1	1	1	1
Sublot		2	2	2	2	2	2	2	2
Point		A	B	C	D	A	B	C	D
Number of blows	1	10	10	12	18				
	2	38	26	32	50	14.00	8.00	10.00	16.00
	3	66	40	56	88	18.67	10.00	14.67	23.33
	4	99	55	98	122	22.25	11.25	21.50	26.00
	5	130	68	136	158	24.00	11.60	24.80	28.00
	6	170	80	180	208	26.67	11.67	28.00	31.67
	7	212	92	226	285	28.86	11.71	30.57	38.14
	8	250	105	288	295	30.00	11.88	34.50	34.63
	9	275	120	333	315	29.44	12.22	35.67	33.00
	10	292	133			28.20	12.30		
	11	311	146			27.36	12.36		
	12		158				12.33		
	13		168				12.15		
	14		182				12.29		
	15		196				12.40		
	16		220				13.13		
	17		256				14.47		
	18		293				15.72		
	19		318				16.21		
Average PI at point						24.94	11.30	24.96	28.85

Table 66 Continued, ***Penetration Index*** measured by ***DCP*** in ***I-85 Ramp, AL, Subgrade, Post-IC, mm/blow***

Lot		Penetration, mm				PI, mm/blow			
		1	1	1	1	1	1	1	1
Sublot		3	3	3	3	3	3	3	3
Point		A	B	C	D	A	B	C	D
Number of blows	1	10	13	18	16				
	2	40	51	73	72	15.00	19.00	27.50	28.00
	3	65	106	142	136	18.33	31.00	41.33	40.00
	4	83	148	230	191	18.25	33.75	53.00	43.75
	5	120	196	325	274	22.00	36.60	61.40	51.60
	6	140	265		345	21.67	42.00		54.83
	7	190	305			25.71	41.71		
	8	240				28.75			
	9	300				32.22			
	10	325				31.50			
	11								
	12								
	13								
	14								
	15								
	16								
	17								
	18								
	19								
Average PI at point						23.72	34.01	45.81	43.64

Table 66 Continued, ***Penetration Index*** measured by ***DCP*** in ***I-85 Ramp, AL, Subgrade, Post-IC, mm/blow***

Lot		Penetration, mm				PI, mm/blow			
		1	1	1	1	1	1	1	1
Sublot		4	4	4	4	4	4	4	4
Point		A	B	C	D	A	B	C	D
Number of blows	1	14	7	10	25				
	2	44	25	54	96	15.00	9.00	22.00	35.50
	3	82	48	93	155	22.67	13.67	27.67	43.33
	4	126	80	134	215	28.00	18.25	31.00	47.50
	5	178	125	152	278	32.80	23.60	28.40	50.60
	6	232	175	174	347	36.33	28.00	27.33	53.67
	7	294	240	213		40.00	33.29	29.00	
	8	332	302	260		39.75	36.88	31.25	
	9	355	338	308		37.89	36.78	33.11	
	10								
	11								
	12								
	13								
	14								
	15								
	16								
	17								
	18								
	19								
Average PI at point						31.55	24.93	28.72	46.12

Table 66 Continued, ***Penetration Index*** measured by ***DCP*** in ***I-85 Ramp, AL, Subgrade, Post-IC, mm/blow***

Lot		Penetration, mm				PI, mm/blow			
		1	1	1	1	1	1	1	1
Sublot		5	5	5	5	5	5	5	5
Point		A	B	C	D	A	B	C	D
Number of blows	1	25	20	7	12				
	2	72	71	26	58	23.50	25.50	9.50	23.00
	3	106	129	48	110	27.00	36.33	13.67	32.67
	4	158	187	61	157	33.25	41.75	13.50	36.25
	5	214	246	75	209	37.80	45.20	13.60	39.40
	6	271	312	90	262	41.00	48.67	13.83	41.67
	7	376	395	110	331	50.14	53.57	14.71	45.57
	8			134				15.88	
	9			169				18.00	
	10			211				20.40	
	11			261				23.09	
	12			317				25.83	
	13			390				29.46	
	14								
	15								
	16								
	17								
	18								
	19								
Average PI at point						35.45	41.84	15.62	36.43

Table 66 Continued, ***Penetration Index*** measured by ***DCP*** in ***I-85 Ramp, AL, Subgrade, Post-IC, mm/blow***

Lot		Penetration, mm				PI, mm/blow			
		2	2	2	2	2	2	2	2
Sublot		1	1	1	1	1	1	1	1
Point		A	B	C	D	A	B	C	D
Number of blows	1	12	23	16	35				
	2	59	71	68	81	23.50	24.00	26.00	23.00
	3	93	116	100	117	27.00	31.00	28.00	27.33
	4	142	177	120	165	32.50	38.50	26.00	32.50
	5	187	226	140	204	35.00	40.60	24.80	33.80
	6	239	314	171	231	37.83	48.50	25.83	32.67
	7	311	415	204	253	42.71	56.00	26.86	31.14
	8	384		233	274	46.50		27.13	29.88
	9			272	296			28.44	29.00
	10			311	323			29.50	28.80
	11			350	364			30.36	29.91
	12								
	13								
	14								
	15								
	16								
	17								
	18								
	19								
Average PI at point						35.01	39.77	27.29	29.80

Table 66 Continued, ***Penetration Index*** measured by ***DCP*** in ***I-85 Ramp, AL, Subgrade, Post-IC, mm/blow***

Lot		**Penetration, mm**				**PI, mm/blow**			
		2	**2**	**2**	**2**	**2**	**2**	**2**	**2**
Sublot		**2**	**2**	**2**	**2**	**2**	**2**	**2**	**2**
Point		**A**	**B**	**C**	**D**	**A**	**B**	**C**	**D**
Number of blows	1	22	23	18	15				
	2	73	77	57	51	25.50	27.00	19.50	18.00
	3	151	128	98	92	43.00	35.00	26.67	25.67
	4	206	195	130	145	46.00	43.00	28.00	32.50
	5	242	251	165	231	44.00	45.60	29.40	43.20
	6	249	282	208	355	37.83	43.17	31.67	56.67
	7	312	315	268		41.43	41.71	35.71	
	8	333	360	352		38.88	42.13	41.75	
	9								
	10								
	11								
	12								
	13								
	14								
	15								
	16								
	17								
	18								
	19								
Average PI at point						39.52	39.66	30.39	35.21

Table 66 Continued, ***Penetration Index*** measured by ***DCP*** in ***I-85 Ramp, AL, Subgrade, Post-IC, mm/blow***

Lot		**Penetration, mm**				**PI, mm/blow**			
		2	**2**	**2**	**2**	**2**	**2**	**2**	**2**
Sublot		**3**	**3**	**3**	**3**	**3**	**3**	**3**	**3**
Point		**A**	**B**	**C**	**D**	**A**	**B**	**C**	**D**
Number of blows	1	21	17	22	23				
	2	62	48	51	58	20.50	15.50	14.50	17.50
	3	100	94	80	94	26.33	25.67	19.33	23.67
	4	154	141	109	143	33.25	31.00	21.75	30.00
	5	201	182	162	227	36.00	33.00	28.00	40.80
	6	255	207	243	308	39.00	31.67	36.83	47.50
	7	300	232	298	362	39.86	30.71	39.43	48.43
	8	350	268	334		41.13	31.38	39.00	
	9		287				30.00		
	10		320				30.30		
	11		340				29.36		
	12								
	13								
	14								
	15								
	16								
	17								
	18								
	19								
Average PI at point						33.72	28.86	28.41	34.65

Table 66 Continued, ***Penetration Index*** measured by ***DCP*** in ***I-85 Ramp, AL, Subgrade, Post-IC, mm/blow***

Lot		**Penetration, mm**				**PI, mm/blow**			
		2	**2**	**2**	**2**	**2**	**2**	**2**	**2**
Sublot		**4**	**4**	**4**	**4**	**4**	**4**	**4**	**4**
Point		**A**	**B**	**C**	**D**	**A**	**B**	**C**	**D**
Number of blows	1	32	32	23	32				
	2	97	94	56	67	32.50	31.00	16.50	17.50
	3	153	130	72	84	40.33	32.67	16.33	17.33
	4	194	172	94	101	40.50	35.00	17.75	17.25
	5	220	231	136	119	37.60	39.80	22.60	17.40
	6	240	291	196	151	34.67	43.17	28.83	19.83
	7	265	340	263	209	33.29	44.00	34.29	25.29
	8	281		320	276	31.13		37.13	30.50
	9	304			322	30.22			32.22
	10	334				30.20			
	11								
	12								
	13								
	14								
	15								
	16								
	17								
	18								
	19								
Average PI at point						34.49	37.61	24.78	22.17

Table 66 Continued, ***Penetration Index*** measured by ***DCP*** in ***I-85 Ramp, AL, Subgrade, Post-IC, mm/blow***

Lot		Penetration, mm				PI, mm/blow			
		2	2	2	2	2	2	2	2
Sublot		5	5	5	5	5	5	5	5
Point		A	B	C	D	A	B	C	D
Number of blows	1	35	21	30	31				
	2	106	51	81	81	35.50	15.00	25.50	25.00
	3	169	86	155	146	44.67	21.67	41.67	38.33
	4	250	121	196	241	53.75	25.00	41.50	52.50
	5	312	157	246	311	55.40	27.20	43.20	56.00
	6	356	213	292	356	53.50	32.00	43.67	54.17
	7		286	331			37.86	43.00	
	8		335				39.25		
	9								
	10								
	11								
	12								
	13								
	14								
	15								
	16								
	17								
	18								
	19								
Average PI at point						48.56	28.28	39.76	45.20

Table 67. ***Wet density*** measured by ***EDG*** in ***I-85 Ramp, AL, Subgrade, Post-IC, pcf***
Note: Test repetitions were not performed at individual points

Lot	Sublot	A	B	C	D	Average	Lot Average
1	1	127.12	126.44	127.42	127.01	127.00	
	2	127.34	126.79	126.89	126.35	126.84	
	3	126.53	126.21	126.09	126.41	126.31	
	4	126.36	127.26	127.73	127.13	127.12	
	5	124.54	125.80	125.86	126.65	125.71	126.60
2	1	125.54	126.57	128.08	128.35	127.14	
	2	124.83	125.92	125.96	126.03	125.69	
	3	125.64	125.83	125.81	124.05	125.33	
	4	126.53	126.23	125.97	125.73	126.12	
	5	125.49	125.07	125.73	125.08	125.34	125.92
Average lot 1 by row		126.38	126.50	126.80	126.71		
Average lot 2 by row		125.61	125.92	126.31	125.85		
Average by row		125.99	126.21	126.55	126.28		
Project average							126.26

Table 68. ***Percent Moisture*** measured by **EDG** in **I-85 Ramp, AL, Subgrade, Post-IC**
Note: Test repetitions were not performed at individual points

Lot	Sublot	A	B	C	D	Average	Lot Average
1	1	16.90	16.90	16.90	16.90	16.90	
	2	16.90	16.90	16.90	16.90	16.90	
	3	16.90	16.90	16.90	16.90	16.90	
	4	16.90	16.90	16.80	16.90	16.88	
	5	17.10	17.00	17.00	16.90	17.00	16.92
2	1	17.00	16.90	16.90	16.80	16.90	
	2	17.10	16.90	16.90	16.90	16.95	
	3	16.90	16.90	16.90	17.10	16.95	
	4	16.90	16.90	16.90	16.90	16.90	
	5	16.90	17.00	16.90	17.00	16.95	16.93
Average lot 1 by row		16.94	16.92	16.90	16.90		
Average lot 2 by row		16.96	16.92	16.90	16.94		
Average by row		16.95	16.92	16.90	16.92		
Project average							16.92

Table 69. ***Modulus*** measured by ***GEOGAUGE*** in ***I-85 Ramp, AL, Subgrade, Post-IC, psi***

Note: Repeatability data is shown in Table 71

Lot	Sublot	A	B	C	D	Average	Lot Average
1	1	19.20		16.67		17.93	
	2		13.67		19.37	16.52	
	3	17.87		10.93		14.40	
	4		18.97		16.30	17.63	
	5	15.23		19.27		17.25	16.75
2	1	17.43		19.57		18.50	
	2		18.50		19.40	18.95	
	3	19.40		19.70	0.00	13.03	
	4						
	5						16.29
Average lot 1 by row		17.43	16.32	15.62	17.83		
Average lot 2 by row		18.42	18.50	19.63	9.70		
Average by row		17.83	17.04	17.23	13.77		
Project average							16.56

Table 70. ***Stiffness*** measured by ***GEOGAUGE*** in ***I-85 Ramp, AL, Subgrade, Post-IC, klb/in***
Note: Note: Repeatability data is shown in Table 72

Lot	Sublot	A	B	C	D	Average	Lot Average
1	1	87.20		75.50		75.50	
	2		61.90		87.87	74.88	
	3	81.07		49.40		65.23	
	4		86.07		73.87	79.97	
	5	68.87		87.43		78.15	74.66
2	1	79.03		88.67		83.85	
	2		83.93		87.80	85.87	
	3	88.10		89.37	0.00	59.16	
	4						
	5						73.84
Average lot 1 by row		79.04	73.98	70.78	80.87		
Average lot 2 by row		83.57	83.93	89.02	43.90		
Average by row		80.85	77.30	78.07	62.38		
Project average							75.06

Table 71. Repeatability in ***Modulus*** measurements by ***Geogauge*** in ***I-85 Ramp, AL, Subgrade, Post-IC, psi***

Lot	Sublot	Point	Trial 1	Trial 2	Trial 3	Average	Std deviation
1	1	A	19300	18600	19700	19200.00	**556.78**
1	1	B					
1	1	C	16700	16700	16600	16666.67	**57.74**
1	1	D					
1	2	A					
1	2	B	13600	14100	13300	13666.67	**404.15**
1	2	C					
1	2	D	19400	20300	18400	19366.67	**950.44**
1	3	A	17700	17900	18000	17866.67	**152.75**
1	3	B					
1	3	C	10700	11200	10900	10933.33	**251.66**
1	3	D					
1	4	A					
1	4	B	18700	19200	19000	18966.67	**251.66**
1	4	C					
1	4	D	15900	16400	16600	16300.00	**360.56**
1	5	A	15500	15100	15100	15233.33	**230.94**
1	5	B					
1	5	C	20000	17800	20000	19266.67	**1270.17**
1	5	D					
2	1	A	17300	17700	17300	17433.33	**230.94**
2	1	B					
2	1	C	20000	19100	19600	19566.67	**450.92**
2	1	D					
2	2	A					
2	2	B	18200	18900	18400	18500.00	**360.56**
2	2	C					
2	2	D	19800	19900	18500	19400.00	**781.02**
2	3	A	18900	19500	19800	19400.00	**458.26**
2	3	B					
2	**3**	**C**	**19800**	**19100**	**20200**	**19700.00**	**556.78**

* Limited test points were used for modulus measurements

Table 72. Repeatability in ***Stiffness*** measurements by ***Geogauge*** in ***I-85 Ramp, AL, Subgrade, Post-IC, klb/in***

Lot	Sublot	Point	Trial 1	Trial 2	Trial 3	Average	Std deviation
1	1	A	87.70	84.50	89.40	87.20	**2.49**
1	1	B					
1	1	C	75.50	75.60	75.40	75.50	**0.10**
1	1	D					
1	2	A					
1	2	B	61.40	63.90	60.40	61.90	**1.80**
1	2	C					
1	2	D	88	92.3	83.3	87.87	**4.50**
1	3	A	80.40	81.40	81.40	81.07	**0.58**
1	3	B					
1	3	C	48.60	50.10	49.50	49.40	**0.75**
1	3	D					
1	4	A					
1	4	B	85.00	87.10	86.10	86.07	**1.05**
1	4	C					
1	4	D	72	74.5	75.1	73.87	**1.64**
1	5	A	70.10	68.20	68.30	68.87	**1.07**
1	5	B					
1	5	C	90.60	80.70	91.00	87.43	**5.83**
1	5	D					
2	1	A	78.30	80.40	78.40	79.03	**1.18**
2	1	B					
2	1	C	90.50	86.70	88.80	88.67	**1.90**
2	1	D					
2	2	A					
2	2	B	82.70	85.50	83.60	83.93	**1.43**
2	2	C					
2	2	D	89.6	90.1	83.7	87.80	**3.56**
2	3	A	85.80	88.60	89.90	88.10	**2.10**
2	3	B					
2	**3**	**C**	**89.90**	**86.60**	**91.60**	**89.37**	**2.54**

* Limited test points were used for stiffness measurements

Table 73. ***Dielectric*** measured by ***GPR*** in ***I-85 Ramp, AL, Subgrade, Post-IC***
Note: Repeatability results are shown in Table 74

Lot	Sublot	A	B	C	D	Average	Lot Average
1	1	18.80	21.93	23.92	21.90	21.64	
	2	19.46	19.39	18.14	21.06	19.51	
	3	19.12	20.73	23.71	21.02	21.14	
	4	18.39	19.33	17.98	24.22	19.98	
	5	26.06	24.78	24.29	27.93	25.77	21.61
2	1	21.23	27.33	27.98	23.92	25.11	
	2	18.70	25.29	21.38	23.32	22.17	
	3	18.16	21.49	20.99	24.25	21.22	
	4	20.95	23.11	28.63	27.45	25.04	
	5	16.61	21.49	19.85	27.85	21.45	23.00
Average lot 1 by row		20.37	21.23	21.61	23.22		
Average lot 2 by row		19.13	23.74	23.77	25.36		
Average by row		19.75	22.49	22.69	24.29		
Project average							22.30

Table 74. Repeatability in ***GPR Thickness and Dielectric measurements*** in ***I-85 Ramp, AL , Post-IC***

Note: Summary of test results are shown in Table 73

Lot	Sublot	Point	Dielectric			
			Trial 1	Trial 2	Average	Std dev
1	1	A	17.80	19.81	18.80	**1.42**
1	1	B	23.20	20.66	21.93	**1.80**
1	1	C	27.36	20.47	23.92	**4.87**
1	1	D	21.13	22.66	21.90	**1.08**
1	2	A	20.21	18.71	19.46	**1.06**
1	2	B	21.02	17.75	19.39	**2.31**
1	2	C	16.89	19.38	18.14	**1.76**
1	2	D	20.23	21.89	21.06	**1.18**
1	3	A	18.84	19.40	19.12	**0.40**
1	3	B	22.82	18.64	20.73	**2.96**
1	3	C	21.29	26.13	23.71	**3.42**
1	3	D	21.47	20.56	21.02	**0.64**
1	4	A	17.39	19.39	18.39	**1.41**
1	4	B	19.21	19.45	19.33	**0.17**
1	4	C	19.44	16.52	17.98	**2.07**
1	4	D	24.75	23.69	24.22	**0.75**
1	5	A	25.16	26.97	26.06	**1.28**
1	5	B	25.68	23.88	24.78	**1.28**
1	5	C	24.52	24.07	24.29	**0.32**
1	5	D	28.29	27.57	27.93	**0.51**
2	1	A	21.26	21.20	21.23	**0.04**
2	1	B	28.00	26.67	27.33	**0.94**
2	1	C	27.68	28.29	27.98	**0.43**
2	1	D	23.24	24.59	23.92	**0.95**
2	2	A	17.20	20.19	18.70	**2.11**
2	2	B	26.46	24.12	25.29	**1.65**
2	2	C	21.39	21.37	21.38	**0.01**
2	2	D	20.16	26.47	23.32	**4.46**
2	3	A	19.26	17.06	18.16	**1.56**
2	3	B	24.03	18.95	21.49	**3.59**

Lot	Sublot	Point	Dielectric			
			Trial 1	**Trial 2**	**Average**	**Std dev**
2	3	C	28.32	13.67	20.99	**10.36**
2	3	D	24.95	23.55	24.25	**0.99**
2	4	A	20.84	21.06	20.95	**0.16**
2	4	B	18.32	27.91	23.11	**6.78**
2	4	C	30.09	27.18	28.63	**2.06**
2	4	D	25.70	29.21	27.45	**2.48**
2	5	A	15.93	17.29	16.61	**0.96**
2	5	B	23.56	19.42	21.49	**2.93**
2	5	C	19.62	20.08	19.85	**0.32**
2	**5**	**D**	**26.14**	**29.56**	**27.85**	**2.42**

Table 75. ***Modulus*** measured by ***LWD 2*** in ***I-85 Ramp, AL, Subgrade, Post-IC***
Note: Repeatability results are shown in Table 76

Lot	Sublot	A	B	C	D	Average	Lot Average
1	1	9503	12675		5115	9098	
	2	12171	8894	13655	9260	10995	
	3	9942	8642		4301	7628	
	4	10552	5744	12455	19546	12074	
	5	6669	-	-	2501	4585	9477
2	1	-	-	8582	19668	14125	
	2	4875	-	-	-	4875	
	3	-	12463	-	13306	12884	
	4	-	-	-	-	-	
	5	-	-	-	-	-	11779
Average lot 1 by row		9767	8989	13055	8145		
Average lot 2 by row		4875	12463	8582	16487		
Average by row		8952	9684	11564	10528		
Project average							10025

Table 76. Repeatability in ***LWD 2*** measurements in ***I-85 Ramp, AL, Subgrade, Post-IC***

Lot	Sublot	Point A					Point B				
		Load kN	δ 1 (μm)	δ 2 (μm)	δ 3 (μm)	E (Psi)	Load kN	δ 1 (μm)	δ 2 (μm)	δ 3 (μm)	E (Psi)
Subgrade 1	1	8.26	535	259	59	8342	8.42	389	222	14	11695
		8.5	465	214	63	9876	8.57	350	181	19	13229
		8.63	499	225	66	9344	8.68	362	163	20	12955
		8.67	490	223	65	9560	8.55	369	169	20	12519
		8.57	482	222	67	9606	8.48	365	158	20	12552
					Avg	9503				Avg	12675
					Stdv	139.9				Stdv	242.7
Subgrade 1	2	8.49	470	205	56	9760	8.31	555	319	60	8090
		8.58	394	185	56	11766	8.51	560	210	58	8210
		8.55	384	182	55	12030	8.54	522	197	57	8839
		8.72	381	184	56	12366	8.51	525	196	57	8758
		8.59	383	183	56	12118	8.56	509	193	57	9086
					Avg	12171				Avg	8894
					Stdv	174.1				Stdv	171.0
Subgrade 1	3	4.16	350	696	27	6422	8.18	418	719	25	10573
		8.35	585	476	42	7712	8.32	462	397	31	9730
		8.47	425	436	46	10768	8.35	495	379	31	9114
		8.42	560	429	46	8124	8.37	525	384	32	8614
		8.38	414	420	46	10936	8.36	551	369	31	8197
					Avg	9942				Avg	8642
					Stdv	1577.5				Stdv	458.9
Subgrade 1	4	8.15	268	474	27	16430	8.35	253	553	14	17832
		8.39	678	348	33	6686	8.49	807	415	34	5684
		8.41	786	332	33	5781	8.55	798	408	36	5789
		8.39	518	321	33	8751	8.52	806	405	37	5711
		8.43	266	304	33	17123	8.57	808	405	37	5731
					Avg	10552				Avg	5744
					Stdv	5881.3				Stdv	40.4
rade 1	5	8.25	665	438	36	6703	NO DATA				

Lot	Sublot	Point A					Point B				
		Load kN	δ 1 (μm)	δ 2 (μm)	δ 3 (μm)	E (Psi)	Load kN	δ 1 (μm)	δ 2 (μm)	δ 3 (μm)	E (Psi)
		8.39	681	427	38	6656					
		8.3	690	409	40	6499					
		8.26	690	398	41	6468					
		5.72	439	240	28	7040					
					Avg	6669					
					Stdv	321.6					
Subgrade 2	1	NO DATA					NO DATA				
Subgrade 2	2	8.02	183	379	3	23678	NO DATA				
		8.32	486	348	1	9249					
		8.5	866	355	2	5303					
		8.42	980	362	5	4642					
		8.47	978	364	6	4679					
					Avg	4875					
					Stdv	371.4					
Subgrade 2	3	NO DATA					8.08	563	453	21	7754
							7.99	331	247	27	13042
							8.3	353	235	28	12704
							8.1	347	240	27	12612
					Avg					Average	12786
					Stdv					stdev	226.5

Table 76 Continued. Repeatability in ***LWD 2*** measurements in ***I-85 Ramp, AL, Subgrade, Post-IC***

Lot	Sublot	Point C					Point D				
		Load kN	δ 1 (μm)	δ 2 (μm)	δ 3 (μm)	E (Psi)	Load kN	δ 1 (μm)	δ 2 (μm)	δ 3 (μm)	E (Psi)
Subgrade 1	1	NO DATA					8.03	200	276	18	21693
							8.57	947	217	25	4889
							8.59	921	222	27	5039
							8.58	908	223	28	5105
							8.54	887	224	29	5202
										Avg	5115
										Stdv	81.8
Subgrade 1	2	8.2	419	294	34	10574		318	841	27	0
		8.5	341	220	37	13468	8.53	536	443	34	8598
		8.51	342	217	38	13444	8.54	508	411	35	9083
		8.58	334	221	38	13879	8.54	502	385	35	9191
		8.56	339	221	38	13643	8.55	486	356	35	9505
					Avg	13655				Avg	9260
					Stdv	217.9				Stdv	219.3
Subgrade 1	3	NO DATA					8.22	999	819	59	4446
							8.18	1008	723	59	4384
							8.22	1017	713	60	4367
							8.2	1035	727	62	4281
							8.23	1045	658	60	4255
										Avg	4301
										Stdv	58.6
Subgrade 1	4	8.17	199	526	10	22182	8.71	265	296	0	17758
		8.27	445	362	33	10041	8.07	265	235	16	16453
		8.46	369	239	27	12387	8.18	244	188	14	18113
		8.48	366	246	27	12518	8.24	236	209	16	18864
		8.44	366	240	27	12459	8.58	214	212	17	21662
					Avg	12455				Avg	19546
					Stdv	65.6				Stdv	1870.3

Lot	Sublot	Point C					Point D				
		Load kN	δ 1 (μm)	δ 2 (μm)	δ 3 (μm)	E (Psi)	Load kN	δ 1 (μm)	δ 2 (μm)	δ 3 (μm)	E (Psi)
Subgrade 1	5	NO DATA					NO DATA				
Subgrade 2	1	8.5	617	239	34	7443	8.35	175	144	17	25779
		8.47	583	240	37	7849	8.32	251	155	23	17909
		8.43	585	242	39	7786	8.38	246	156	25	18405
		8.28	438	259	40	10214	8.11	193	162	27	22703
		8.33	581	244	40	7746	8.48	256	151	27	17897
					Avg	8582				Avg	19668
					Stdv	1413.3				Stdv	2640.5
Subgrade 2	2	NO DATA					NO DATA				
Subgrade 2	3	NO DATA					8.17	324	321	80	13624
							8.28	349	319	81	12818
										Avg	12818
										Stdv	N/A

Table 77. ***Modulus*** measured by ***DSPA*** in ***I-85 Ramp, AL, Subgrade, Post-IC, psi***
Note: Test repetitions were not performed for Post-IC measurements

Lot	Sublot	A	B	C	D	Average	Lot Average
1	1	43000	47500	37500	42500	42625	
	2	44000	35000	48000	39000	41500	
	3	42000	47000	33000	52000	43500	
	4	45000	27000	38500	29000	34875	
	5	38500	37000	28000	35000	34625	39425
2	1	35000	27000	44000	29333	33833	
	2	29000	30500	38500	35000	33250	
	3	39000	44000	52000	56000	47750	
	4	34000	43000	45000	46000	42000	
	5	29000	54000	46000	52000	45250	40417
Average lot 1 by row		42500	38700	37000	39500		
Average lot 1 by row		33200	39700	45100	43667		
Average by row		37850	39200	41050	41583		
Project average							39921

Table 78. ***Density*** measured by ***Nuclear Gauge*** in ***I-85, AL, Subgrade, Post-IC, pcf***
Note: Test repetition measurements are shown in Table 80

Lot	Sublot	A	B	C	D	Average	Lot Average
1	1	124.05		122.90		123.48	
	2		127.35		126.90	127.13	
	3	124.90		124.90		124.90	
	4		136.25		121.05	128.65	
	5	120.20		133.85		127.03	126.24
2	1	121.90		122.35		122.13	
	2		124.30		124.45	124.38	
	3	121.30		128.50		124.90	
	4		122.80		129.40	126.10	
	5	125.25		123.90		124.58	124.42
Average lot 1 by row		123.05	131.80	127.22	123.98		
Average lot 1 by row		122.82	123.55	124.92	126.93		
Average by row		122.93	127.68	126.07	125.45		
Project average							125.33

Table 79. ***Moisture*** measured by ***Nuclear Gauge*** in ***I-85, AL, Subgrade, Post-IC, psi***
Note: Test repetition measurements are shown in Table 80

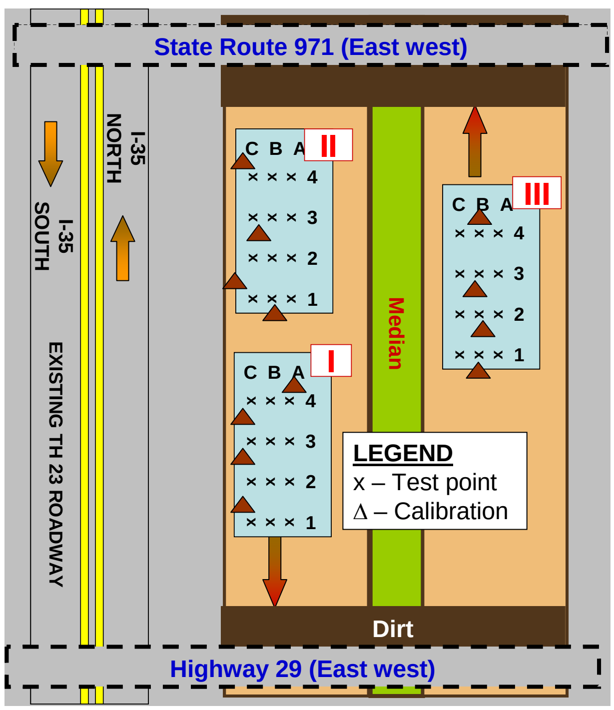
Lot	Sublot	A	B	C	D	Average	Lot Average
1	1	20.95		22.85		21.90	
	2		21.50		21.55	21.53	
	3	21.05		21.75		21.40	
	4		18.90		23.70	21.30	
	5	24.25		21.65		22.95	21.82
2	1	26.45		26.85		26.65	
	2		22.10		21.25	21.68	
	3	21.10		22.95		22.03	
	4		25.95		22.65	24.30	
	5	22.65		22.60		22.63	23.46
Average lot 1 by row		22.08	20.20	22.08	22.63		
Average lot 1 by row		23.40	24.03	24.13	21.95		
Average by row		22.74	22.11	23.11	22.29		
Project average							22.64

Table 80. ***Density and Moisture*** measured by ***Nuclear Density Gauge I-85 Ramp, AL, Subgrade, Post-IC, psi***
Note: Test repetitions are reported within this table, summaries are provided in Table 78 and Table 79

Section	Sublot and point	Replicate 1		Replicate 2		Average	
		Density, lbs/ft^3	Moisture Content, %	Density, lbs/ft^3	Moisture Content, %	Density, lbs/ft^3	Moisture Content, %
1	1A	122.3 (121.8)	20.3 (24.8)	125.8 (122.0)	21.6 (21.8)	124.1	21.0
1	1C	122.7 (122.9)	22.4 (26.4)	123.1 (121.8)	23.3 (27.3)	122.9	22.9
1	2B	128.8 (124.1)	21.5 (21.1)	125.9 (124.5)	21.5 (23.1)	127.4	21.5
1	2D	127.0 (127.3)	21.5 (21.1)	126.8 (126.6)	21.6 (21.4)	126.9	21.6
1	3A	125.9 (118.4)	20.8 (22.6)	123.9 (124.2)	21.3 (19.6)	124.9	21.1
1	3C	126.6	21.2	123.2	22.3	124.9	21.8
1	4B	125.5	21.7	147.0	16.1	136.3	18.9
1	4D	120.6	24.2	121.5	23.2	121.1	23.7
1	5A	118.4	23.5	122.0	25.0	120.2	24.3
1	5C	141.6	20.8	126.1	22.5	133.9	21.7
2	1A	121.8	24.8	122.0	28.1	121.9	26.5
2	1C	122.9	26.4	121.8	27.3	122.4	26.9
2	2B	124.1	21.1	124.5	23.1	124.3	22.1
2	2D	122.3	21.1	126.6	21.4	124.5	21.3
2	3A	118.4	22.6	124.2	19.6	121.3	21.1
2	3C	129.0	24.2	128.0	21.7	128.5	23.0
2	4B	122.8	25.6	122.8	26.3	122.8	26.0
2	4D	129.2	23.6	129.6	21.7	129.4	22.7
2	5A	125.1	23.0	125.4	22.3	125.3	22.7
2	5C	125.6	23.5	122.2	21.7	123.9	22.6
					Average	**125.3**	**22.6**

* Numbers in parenthesis represent test values prior to IC rolling operation

SH-130, TX SUBGRADE TESTING (FILL MATERIAL ON NATURAL SUBGRADE TEST)



Note: No station information was available for these sections

Table 81. ***Penetration Index*** measured by ***DCP*** in ***SH-130, TX, Subgrade, mm/blow***
Note: Test data for number of blows vs penetration is shown in Table 82.

Lot	Sublot	A	B	C	Average	Lot Average
1	1	7.6	5.2	4.4	5.7	
	2	8.0	9.9	7.3	8.4	
	3	13.8	15.5	12.2	13.8	
	4	7.5	9.4	6.7	7.9	9.0
2	1	7.0	7.7	9.7	8.1	
	2	6.6	7.8	10.5	8.3	
	3	7.6	5.1	7.2	6.6	
	4	30.3	14.9	11.9	19.1	10.5
3	1	7.7	11.6	8.5	9.3	
	2	4.6	2.9	6.2	4.6	
	3	7.6	8.3	19.2	11.7	
	4	15.2	13.3	13.5	14.0	9.9
Average lot 1 by row		9.2	10.0	7.7		
Average lot 2 by row		12.9	8.9	9.8		
Average lot 3 by row		8.8	9.0	11.8		
Average by row		10.3	9.3	9.8		
Project average						9.8

Table 82. ***Penetration Index*** measured by ***DCP*** in ***SH-130, TX, Subgrade, mm/blow***

Lot		**Penetration, mm**			**PI, mm/blow**			**Penetration, mm**			**PI, mm/blow**		
		1	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**
Sublot		**1**	**1**	**1**	**1**	**1**	**1**	**2**	**2**	**2**	**2**	**2**	**2**
Point		**A**	**B**	**C**	**A**	**B**	**C**	**A**	**B**	**C**	**A**	**B**	**C**
Number of blows	1	9	7	9				8	18	10			
	5	48	32	44	7.80	5.00	7.00	51	75	55	8.60	11.40	9.00
	10	85	59	73	7.60	5.20	6.40	81	110	86	7.30	9.20	7.60
	15	124	101	93	7.67	6.27	5.60	119	155	129	7.40	9.13	7.93
	20	170	155	113	8.05	7.40	5.20	194	225	170	9.30	10.35	8.00
	25	215	175	135	8.24	6.72	5.04	235	265	207	9.08	9.88	7.88
	30	255	188	154	8.20	6.03	4.83	257	302	230	8.30	9.47	7.33
	35	278	198	175	7.69	5.46	4.74	274		248	7.60		6.80
	40	290	212	185	7.03	5.13	4.40	293		267	7.13		6.43
	45	302	225	205	6.51	4.84	4.36	320		288	6.93		6.18
	50		237	20		4.60	0.22			316			6.12
	55		251	235		4.44	4.11						
	60		265	250		4.30	4.02						
	65		277	260		4.15	3.86						
	70		286	275		3.99	3.80						
	75		298	288		3.88	3.72						
	80			300			3.64						
Average PI at point					7.64	5.16	4.43				7.96	9.91	7.33

Table 82 Continued, ***Penetration Index*** measured by ***DCP*** in ***SH-130, TX, Subgrade, Post-IC, mm/blow***

Lot		**Penetration, mm**			**PI, mm/blow**			**Penetration, mm**			**PI, mm/blow**		
		1	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**
Sublot		**3**	**3**	**3**	**3**	**3**	**3**	**4**	**4**	**4**	**4**	**4**	**4**
Point		**A**	**B**	**C**	**A**	**B**	**C**	**A**	**B**	**C**	**A**	**B**	**C**
Number of blows	1	25	23	34				9	15	15			
	5	82	108	112	11.40	17.00	15.60	43	75	63	6.80	12.00	9.60
	10	137	171	138	11.20	14.80	10.40	76	136	100	6.70	12.10	8.50
	15	240	264	193	14.33	16.07	10.60	109	200	120	6.67	12.33	7.00
	20	390	307	275	18.25	14.20	12.05	150	222	153	7.05	10.35	6.90
	25			340			12.24	213	243	177	8.16	9.12	6.48
	30							270	257	196	8.70	8.07	6.03
	35							297	271	212	8.23	7.31	5.63
	40								290	234		6.88	5.48
	45								311	264		6.58	5.53
	50									304			5.78
Average PI at point					13.80	15.52	12.18				7.47	9.42	6.69

Table 82 Continued, ***Penetration Index*** measured by ***DCP*** in ***SH-130, TX, Subgrade, Post-IC, mm/blow***

Lot		Penetration, mm			PI, mm/blow			Penetration, mm			PI, mm/blow		
		2	2	2	2	2	2	2	2	2	2	2	2
Sublot		1	1	1	1	1	1	2	2	2	2	2	2
Point		A	B	C	A	B	C	A	B	C	A	B	C
Number of blows	1	13	8	15				9	10	18			
	5	54	41	45	8.20	6.60	6.00	49	46	72	8.00	7.20	10.80
	10	86	69	82	7.30	6.10	6.70	76	94	122	6.70	8.40	10.40
	15	115	106	175	6.80	6.53	10.67	97	135	163	5.87	8.33	9.67
	20	197	161	270	9.20	7.65	12.75	130	171	214	6.05	8.05	9.80
	25	182	232	320	6.76	8.96	12.20	173	205	318	6.56	7.80	12.00
	30	205	284		6.40	9.20		205	230		6.53	7.33	
	35	225	306		6.06	8.51		244	266		6.71	7.31	
	40	253			6.00			273	337		6.60	8.18	
	45	290			6.16			302			6.51		
	50	375			7.24								
Average PI at point					7.01	7.65	9.66				6.62	7.83	10.53

Table 82 Continued, ***Penetration Index*** measured by ***DCP*** in ***SH-130, TX, Subgrade, Post-IC, mm/blow***

Lot		**Penetration, mm**			**PI, mm/blow**			**Penetration, mm**			**PI, mm/blow**		
		2	**2**	**2**	**2**	**2**	**2**	**2**	**2**	**2**	**2**	**2**	**2**
Sublot		**3**	**3**	**3**	**3**	**3**	**3**	**4**	**4**	**4**	**4**	**4**	**4**
Point		**A**	**B**	**C**	**A**	**B**	**C**	**A**	**B**	**C**	**A**	**B**	**C**
Number of blows	1	13	7	9				43	30	17			
	5	65	34	35	10.40	5.40	5.20	215	151	72	34.40	24.20	11.00
	10	96	52	55	8.30	4.50	4.60	305	220	127	26.20	19.00	11.00
	15	115	70	84	6.80	4.20	5.00		245	184		14.33	11.13
	20	136	92	171	6.15	4.25	8.10		265	274		11.75	12.85
	25	155	147	216	5.68	5.60	8.28		290	358		10.40	13.64
	30	181	181	256	5.60	5.80	8.23		328			9.93	
	35	268	203	395	7.29	5.60	11.03						
	40	430	220		10.43	5.33							
	45		244			5.27							
	50		265			5.16							
	55		286			5.07							
	60		307			5.00							
Average PI at point					7.58	5.10	7.21				30.30	14.94	11.92

Table 82 Continued, ***Penetration Index*** measured by ***DCP*** in ***SH-130, TX, Subgrade, Post-IC, mm/blow***

Lot		Penetration, mm			PI, mm/blow			Penetration, mm			PI, mm/blow		
		3	**3**	**3**	**3**	**3**	**3**	**3**	**3**	**3**	**3**	**3**	**3**
Sublot		**1**	**1**	**1**	**1**	**1**	**1**	**2**	**2**	**2**	**2**	**2**	**2**
Point		**A**	**B**	**C**	**A**	**B**	**C**	**A**	**B**	**C**	**A**	**B**	**C**
Number of blows	1	12	18	11				7	6	9			
	5	45	96	60	6.60	15.60	9.80	42	32	88	7.00	5.20	15.80
	10	78	132	97	6.60	11.40	8.60	66	45	107	5.90	3.90	9.80
	15	110	187	132	6.53	11.27	8.07	82	62	126	5.00	3.73	7.80
	20	152	233	176	7.00	10.75	8.25	100	80	143	4.65	3.70	6.70
	25	224	280	223	8.48	10.48	8.48	124	94	153	4.68	3.52	5.76
	30	337	321	255	10.83	10.10	8.13	146	105	170	4.63	3.30	5.37
	35			309			8.51	159	115	187	4.34	3.11	5.09
	40							187	125	196	4.50	2.98	4.68
	45							214	135	212	4.60	2.87	4.51
	50							235	150	226	4.56	2.88	4.34
	55							248	168	243	4.38	2.95	4.25
	60							262	18	262	4.25	0.20	4.22
	65							274	196	282	4.11	2.92	4.20
	70							282	215	298	3.93	2.99	4.13
	75							290	220		3.77	2.85	
	80							301	228		3.68	2.78	
	85								236			2.71	
	90								246			2.67	
	95								257			2.64	

Lot		Penetration, mm			PI, mm/blow			Penetration, mm			PI, mm/blow		
		3	3	3	3	3	3	3	3	3	3	3	3
Sublot		1	1	1	1	1	1	2	2	2	2	2	2
Point		A	B	C	A	B	C	A	B	C	A	B	C
	100								265			2.59	
	105								275			2.56	
	110								283			2.52	
	120								287			2.34	
	130								291			2.19	
	140								297			2.08	
	150												
Average PI at point					7.67	11.60	8.55				4.62	2.89	6.19

Table 82 Continued, ***Penetration Index*** measured by ***DCP*** in ***SH-130, TX, Subgrade, Post-IC, mm/blow***

Lot		**Penetration, mm**			**PI, mm/blow**			**Penetration, mm**			**PI, mm/blow**		
		3	**3**	**3**	**3**	**3**	**3**	**3**	**3**	**3**	**3**	**3**	**3**
Sublot		**3**	**3**	**3**	**3**	**3**	**3**	**4**	**4**	**4**	**4**	**4**	**4**
Point		**A**	**B**	**C**	**A**	**B**	**C**	**A**	**B**	**C**	**A**	**B**	**C**
Number of blows	1	6	14	26				26	15	20			
	5	43	54	145	7.40	8.00	23.80	155	60	93	25.80	9.00	14.60
	10	80	93	227	7.40	7.90	20.10	213	174	151	18.70	15.90	13.10
	15	125	145	287	7.93	8.73	17.40	252	251	235	15.07	15.73	14.33
	20	151	185	332	7.25	8.55	15.30	266	290	277	12.00	13.75	12.85
	25	187	240		7.24	9.04		284	315	330	10.32	12.00	12.40
	30	246	273		8.00	8.63		304			9.27		
	35	286	291		8.00	7.91							
	40	324	316		7.95	7.55							
Average PI at point					7.65	8.29	19.15				15.19	13.28	13.46

Table 83. ***Wet density*** measured by ***EDG*** in ***SH-130, TX, Subgrade, pcf***
Note: Test repetitions were not performed at individual points

Lot	Sublot	A	B	C	Average	Lot Average
1	1	141.67	143.73	143.57	142.99	
	2	141.92	145.13	143.40	143.48	
	3	144.08	143.12	141.88	143.03	
	4	140.05	143.72	143.70	142.49	143.00
2	1	No data	No data	No data	No data	No data
	2	No data	No data	No data	No data	No data
	3	No data	No data	No data	No data	No data
	4	No data	No data	No data	No data	No data
3	1	No data	No data	No data	No data	No data
	2	No data	No data	No data	No data	No data
	3	No data	No data	No data	No data	No data
	4	No data	No data	No data	No data	No data
Average lot 1 by row		141.93	143.93	143.14		
Average lot 2 by row		No data	No data	No data		
Average lot 3 by row		No data	No data	No data		
Average by row		-	-	-		
Project average						-

Table 84. ***Percent Moisture*** measured by **EDG** in **SH-130, TX, Subgrade**
Note: Test repetitions were not performed at individual points

Lot	Sublot	A	B	C	Average	Lot Average
1	1	8.5	7.1	7.3	7.63	
	2	8.3	6.6	7.2	7.37	
	3	7.0	7.2	7.9	7.40	
	4	9.7	7.1	6.9	7.92	7.58
2	1	No data	No data	No data	No data	No data
	2	No data	No data	No data	No data	No data
	3	No data	No data	No data	No data	No data
	4	No data	No data	No data	No data	No data
3	1	No data	No data	No data	No data	No data
	2	No data	No data	No data	No data	No data
	3	No data	No data	No data	No data	No data
	4	No data	No data	No data	No data	No data
Average lot 1 by row		8.40	7.01	7.34		
Average lot 2 by row		No data	No data	No data		
Average lot 3 by row		No data	No data	No data		
Average by row		-	-	-		
Project average		-	-	-	-	-

Table 85. ***Modulus*** measured by ***GEOGAUGE*** in ***SH-130, TX, Subgrade, psi***
Note: Repeatability data is shown in Table 87

Lot	Sublot	A	B	C	Average	Lot Average
1	1	32988	30428	30467	31294	
	2	30588	28235	27453	28759	
	3	20889	20907	28472	23422	
	4	30685	27721	24494	27633	27777
2	1	28122	32024	23712	27953	
	2	24010	26713	30382	27035	
	3	20257	23006	28372	23878	
	4	19303	25114	18383	20934	24950
3	1	No Data	No Data	No Data	No Data	
	2	No Data	No Data	No Data	No Data	
	3	No Data	No Data	No Data	No Data	
	4	No Data	No Data	No Data	No Data	No Data
Average lot 1 by row		28787	26823	27721		
Average lot 2 by row		22923	26714	25212		
Average lot 3 by row		No Data	No Data	No Data		
Average by row		25855	26768	26467		
Project average						26364

Table 86. ***Stiffness*** measured by ***GEOGAUGE*** in ***SH-130, TX, Subgrade, klb/in***
Note: Note: Repeatability data is shown in Table 88

Lot	Sublot	A	B	C	Average	Lot Average
1	1	149.6	138.0	138.2	141.9	
	2	138.7	128.1	124.5	130.4	
	3	94.7	94.8	129.1	106.2	
	4	139.2	125.7	111.1	125.3	126.0
2	1	127.5	145.2	107.5	126.8	
	2	108.9	121.1	137.8	122.6	
	3	91.9	104.3	128.7	108.3	
	4	87.5	113.9	83.4	94.9	113.2
3	1	No Data	No Data	No Data	No Data	
	2	No Data	No Data	No Data	No Data	
	3	No Data	No Data	No Data	No Data	
	4	No Data	No Data	No Data	No Data	No Data
Average lot 1 by row		130.6	121.6	125.7		
Average lot 2 by row		104.0	121.2	114.3		
Average lot 3 by row		No Data	No Data	No Data		
Average by row		117.3	121.4	120.0		
Project average						119.6

Table 87. Repeatability in ***Modulus*** measurements by ***Geogauge*** in ***SH-130, TX, Subgrade, psi***

Lot	Sublot	Point	Trial 1	Trial 2	Trial 3	Average	Std deviation
Sub1	1	A	28817	35086	35060	32988	**3612**
Sub1	1	B	32522	28524	30237	30428	**2006**
Sub1	1	C	27761	33406	30235	30467	**2830**
Sub1	2	A	28996	31406	31364	30588	**1380**
Sub1	2	B	28641	29569	26495	28235	**1577**
Sub1	2	C	27990	25843	28526	27453	**1420**
Sub1	3	A	20480	21556	20630	20889	**583**
Sub1	3	B	18855	22191	21675	20907	**1796**
Sub1	3	C	24689	31091	29635	28472	**3355**
Sub1	4	A	27893	30980	33181	30685	**2656**
Sub1	4	B	30863	27408	24892	27721	**2998**
Sub1	4	C	21852	24211	27419	24494	**2795**
Sub2	1	A	28453	27865	28048	28122	**301**
Sub2	1	B	31840	41057	23175	32024	**8943**
Sub2	1	C	21183	25715	24237	23712	**2311**
Sub2	2	A	24425	24436	23170	24010	**728**
Sub2	2	B	27073	27113	25953	26713	**658**
Sub2	2	C	30369	30350	30427	30382	**40**
Sub2	3	A	20348	20379	20046	20257	**184**
Sub2	3	B	22899	23247	22870	23006	**210**
Sub2	3	C	28484	27818	28813	28372	**507**
Sub2	4	A	19014	19550	19347	19303	**271**
Sub2	4	B	24542	25245	25556	25114	**520**
Sub2	**4**	**C**	**18412**	**18491**	**18246**	**18383**	**125**

Note: Sublot 3 was not tested with the Geogauge

Table 88. Repeatability in ***Stiffness*** measurements by ***Geogauge*** in ***SH-130, TX, Subgrade, klb/in***

Lot	Sublot	Point	Trial 1	Trial 2	Trial 3	Average	Std deviation
Sub1	1	A	130.69	159.12	159	149.6	**16.4**
Sub1	1	B	147.49	129.36	137.13	138.0	**9.1**
Sub1	1	C	125.9	151.5	137.12	138.2	**12.8**
Sub1	2	A	131.5	142.43	142.24	138.7	**6.3**
Sub1	2	B	129.89	134.1	120.16	128.1	**7.1**
Sub1	2	C	126.94	117.2	129.37	124.5	**6.4**
Sub1	3	A	92.88	97.76	93.56	94.7	**2.6**
Sub1	3	B	85.51	100.64	98.3	94.8	**8.1**
Sub1	3	C	111.97	141	134.4	129.1	**15.2**
Sub1	4	A	126.5	140.5	150.48	139.2	**12.0**
Sub1	4	B	139.97	124.3	112.89	125.7	**13.6**
Sub1	4	C	99.1	109.8	124.35	111.1	**12.7**
Sub2	1	A	129.04	126.37	127.2	127.5	**1.4**
Sub2	1	B	144.4	186.2	105.1	145.2	**40.6**
Sub2	1	C	96.07	116.62	109.92	107.5	**10.5**
Sub2	2	A	110.77	110.82	105.08	108.9	**3.3**
Sub2	2	B	122.78	122.96	117.7	121.1	**3.0**
Sub2	2	C	137.73	137.64	137.99	137.8	**0.2**
Sub2	3	A	92.28	92.42	90.91	91.9	**0.8**
Sub2	3	B	103.85	105.43	103.72	104.3	**1.0**
Sub2	3	C	129.18	126.16	130.67	128.7	**2.3**
Sub2	4	A	86.23	88.66	87.74	87.5	**1.2**
Sub2	4	B	111.3	114.49	115.9	113.9	**2.4**
Sub2	**4**	**C**	**83.5**	**83.86**	**82.75**	**83.4**	**0.6**

Table 89. ***Dielectric*** measured by ***GPR*** in ***SH-130, TX, Subgrade***
Note: Repeatability results are shown in Table 91

Lot	Sublot	A	B	C	Average	Lot Average
1	1	10.8	9.8	10.5	10.4	
	2	10.4	9.5	9.1	9.7	
	3	9.2	10.6	7.7	9.2	
	4	9.8	9.1	8.0	9.0	9.6
2	1	8.8	9.7	8.2	8.9	
	2	8.4	9.3	8.8	8.8	
	3	9.4	10.0	8.6	9.3	
	4	9.5	10.1	7.9	9.2	9.1
3	1	7.6	7.8	7.5	7.7	
	2	7.1	7.6	7.6	7.5	
	3	7.9	8.0	8.9	8.3	
	4	8.8	8.3	8.1	8.4	8.0
Average lot 1 by row		10.1	9.8	8.8	10.1	
Average lot 2 by row		9.0	9.8	8.4	9.0	
Average lot 3 by row		7.9	7.9	8.0	7.9	
Average by row		9.0	9.2	8.4	8.9	
Project average						9.0

Table 90. ***Moisture**** measured by ***GPR*** in ***SH-130, TX, Subgrade***
Note: Repeatability results are shown in Table 91

Lot	Sublot	A	B	C	Average	Lot Average
1	1	11.0	10.8	10.9	10.9	
	2	10.9	10.8	10.7	10.8	
	3	10.8	10.9	10.5	10.7	
	4	10.8	10.7	10.6	10.7	10.9
2	1	9.5	10.4	8.9	9.6	
	2	9.1	10.0	9.5	9.5	
	3	10.1	10.7	9.3	10.0	
	4	10.2	10.8	8.6	9.9	9.7
3	1	10.3	11.0	10.1	10.5	
	2	8.5	10.3	10.3	9.7	
	3	11.5	11.9	15.0	12.8	
	4	14.8	13.0	12.1	13.3	11.3
Average lot 1 by row		10.9	10.8	10.7	10.8	
Average lot 2 by row		9.7	10.5	9.1	9.8	
Average lot 3 by row		11.3	11.6	11.9	11.6	
Average by row		10.6	11.0	10.5		
Project average						10.7

* Moisture data was determined from dielectric values assuming a constant density

Table 91. Repeatability in ***GPR Thickness and Dielectric measurements*** in ***SH-130, TX***
Note: Summary of test results are shown in Table 89

Lot	Sublot	Point	Thickness, inch				Dielectric			
			Trial 1	Trial 2	Average	Std dev	Trial 1	Trial 2	Average	Std dev
Sub1	1	A	11.11	10.54	10.8	0.4	11.02	10.94	11.0	**0.1**
Sub1	1	B	10.52	9.16	9.8	1.0	10.93	10.74	10.8	**0.1**
Sub1	1	C	10.47	10.44	10.5	0.0	10.93	10.92	10.9	**0.0**
Sub1	2	A	10.24	10.61	10.4	0.3	10.89	10.95	10.9	**0.0**
Sub1	2	B	10.02	8.95	9.5	0.8	10.86	10.71	10.8	**0.1**
Sub1	2	C	9.40	8.84	9.1	0.4	10.77	10.70	10.7	**0.1**
Sub1	3	A	9.24	9.23	9.2	0.0	10.75	10.75	10.8	**0.0**
Sub1	3	B	11.32	9.87	10.6	1.0	11.05	10.84	10.9	**0.1**
Sub1	3	C	7.74	7.70	7.7	0.0	10.54	10.53	10.5	**0.0**
Sub1	4	A	10.12	9.53	9.8	0.4	10.88	10.79	10.8	**0.1**
Sub1	4	B	9.76	8.45	9.1	0.9	10.83	10.64	10.7	**0.1**
Sub1	4	C	8.83	7.26	8.0	1.1	10.69	10.47	10.6	**0.2**
Sub2	1	A	9.49	8.04	8.8	1.0	10.19	8.74	9.5	**1.0**
Sub2	1	B	9.41	9.93	9.7	0.4	10.11	10.63	10.4	**0.4**
Sub2	1	C	7.93	8.57	8.2	0.5	8.63	9.27	8.9	**0.5**
Sub2	2	A	8.50	8.30	8.4	0.1	9.20	9.00	9.1	**0.1**
Sub2	2	B	9.29	9.33	9.3	0.0	9.99	10.03	10.0	**0.0**
Sub2	2	C	8.78	8.78	8.8	0.0	9.48	9.48	9.5	**0.0**
Sub2	3	A	9.60	9.13	9.4	0.3	10.30	9.83	10.1	**0.3**
Sub2	3	B	10.56	9.53	10.0	0.7	11.26	10.23	10.7	**0.7**
Sub2	3	C	9.09	8.03	8.6	0.7	9.79	8.73	9.3	**0.7**
Sub2	4	A	10.97	7.96	9.5	2.1	11.67	8.66	10.2	**2.1**
Sub2	4	B	10.81	9.37	10.1	1.0	11.51	10.07	10.8	**1.0**
Sub2	4	C	7.87	7.99	7.9	0.1	8.57	8.69	8.6	**0.1**
Sub3	1	A	7.67	7.55	7.6	0.1	10.52	10.08	10.3	**0.3**
Sub3	1	B	7.68	7.93	7.8	0.2	10.56	11.50	11.0	**0.7**
Sub3	1	C	7.64	7.45	7.5	0.1	10.41	9.73	10.1	**0.5**
Sub3	2	A	6.86	7.40	7.1	0.4	7.53	9.54	8.5	**1.4**
Sub3	2	B	7.69	7.51	7.6	0.1	10.60	9.95	10.3	**0.5**
Sub3	2	C	7.98	7.26	7.6	0.5	11.68	8.99	10.3	**1.9**

Lot	Sublot	Point	Thickness, inch				Dielectric			
			Trial 1	Trial 2	Average	Std dev	Trial 1	Trial 2	Average	Std dev
Sub3	3	A	7.69	8.19	7.9	0.4	10.60	12.45	11.5	**1.3**
Sub3	3	B	8.34	7.75	8.0	0.4	13.03	10.84	11.9	**1.5**
Sub3	3	C	8.88	8.84	8.9	0.0	15.05	14.87	15.0	**0.1**
Sub3	4	A	8.42	9.23	8.8	0.6	13.33	16.33	14.8	**2.1**
Sub3	4	B	8.26	8.42	8.3	0.1	12.72	13.33	13.0	**0.4**
Sub3	**4**	**C**	**8.18**	**8.00**	**8.1**	**0.1**	**12.43**	**11.74**	**12.1**	**0.5**

Table 92. ***Modulus*** measured by ***LWD 2*** in ***SH-130, TX, Subgrade***
Note: Repeatability results are shown in Table 93

Lot	Sublot	A	B	C	Average	Lot Average
1	1	37893	44032	18705	33543	
	2	39827	13533	20348	24569	
	3	9038	14258	18947	14081	
	4	24602	22475	28952	25343	24384
2	1	31417	28758	29290	29822	
	2	26922	38377	22378	29226	
	3	27260	31803	15902	24988	
	4	8797	19672	17497	15322	24839
3	1	10537	8362	18125	12341	
	2	41953	64332	17352	41212	
	3	17690	29338	26148	24392	
	4	15612	18753	21073	18479	24106
Average lot 1 by row		27840	23575	21738		
Average lot 2 by row		23599	29653	21267		
Average lot 3 by row		21448	30196	20675		
Average by row		24296	27808	21226		
Project average						24443

Table 93. Repeatability in ***LWD 2*** measurements in ***SH-130, TX, Subgrade***

Lot / Sublot	**Force (kN)**	**Pressure (kPa)**	**Pulse (ms)**	**δ 1 (µm)**	**δ 2 (µm)**	**δ 3 (µm)**	**E(1) Mpa**	**E(2) Mpa**	**E(3) Mpa**	**E(1) psi**	**E(2) psi**	**E(3) psi**
A1	8.35	118.2	19.1	197	64	22	158	206	379	22910	29870	54955
Lot 1	8.43	119.3	19.3	121	47	16	260	283	518	37700	41035	75110
	8.58	121.4	20	121	48	16	265	282	525	38425	40890	76125
	8.73	123.5	25.6	126	49	17	259	281	526	37555	40745	76270
									Avg	37893	40890	75835
									Std dev	466.1	145.0	632.0
B1	8.56	121	19	98	79	22	324	169	382	46980	24505	55390
Lot 1	8.65	122.4	19.1	111	78	23	290	173	383	42050	25085	55535
	8.61	121.9	19.1	108	78	23	297	174	379	43065	25230	54955
									Avg	44032	24940	55293
									Std dev	2603.3	383.6	301.8
C1	8.72	123.3	18.9	258	121	20	126	113	446	18270	16385	64670
Lot 1	8.78	124.2	19	253	103	19	129	134	458	18705	19430	66410
	8.78	124.3	19	247	97	19	132	142	464	19140	20590	67280
									Avg	18705	18802	66120
									Std dev	435.0	2171.8	1328.9
A2	8.83	124.9	19	121	79	26	272	174	335	39440	25230	48575
Lot 1	8.91	126.1	19	120	75	26	276	186	338	40020	26970	49010
	8.95	126.6	19	121	73	26	276	192	338	40020	27840	49010

Lot / Sublot	Force (kN)	Pressure (kPa)	Pulse (ms)	δ 1 (μm)	δ 2 (μm)	δ 3 (μm)	E(1) Mpa	E(2) Mpa	E(3) Mpa	E(1) psi	E(2) psi	E(3) psi
									Avg	39827	26680	48865
									Std dev	334.9	1328.9	251.1
B2	8.74	123.6	19	372	179	59	88	77	149	12760	11165	21605
Lot 1	8.84	125	19	352	130	58	94	107	153	13630	15515	22185
	8.87	125.4	19.1	337	123	58	98	113	154	14210	16385	22330
									Avg	13533	14355	22040
									Std dev	729.8	2796.7	383.6
C2	6.76	95.6	19.8	230	72	24	109	147	278	15805	21315	40310
Lot 1	8.85	125.3	19	217	69	33	152	202	267	22040	29290	38715
	8.94	126.5	19	209	64	32	160	220	278	23200	31900	40310
									Avg	20348	27502	39778
									Std dev	3977.2	5514.4	920.9
A3	8.88	125.7	19.3	533	378	81	62	37	109	8990	5365	15805
Lot 1	8.93	126.3	19.7	536	372	81	62	38	110	8990	5510	15950
	8.91	126	19.3	526	370	81	63	38	110	9135	5510	15950
									Avg	9038	5462	15902
									Std dev	83.7	83.7	83.7
B3	8.75	123.7	19.2	328	176	36	99	78	243	14355	11310	35235
Lot 1	8.78	124.2	19.3	337	172	38	97	80	234	14065	11600	33930

Lot / Sublot	Force (kN)	Pressure (kPa)	Pulse (ms)	δ 1 (μm)	δ 2 (μm)	δ 3 (μm)	E(1) Mpa	E(2) Mpa	E(3) Mpa	E(1) psi	E(2) psi	E(3) psi
	8.91	126.1	19.7	337	171	38	99	82	237	14355	11890	34365
									Avg	14258	11600	34510
									Std dev	167.4	290.0	664.5
C3	8.92	126.1	19.2	256	260	49	130	54	184	18850	7830	26680
Lot 1	8.92	126.2	19.1	247	205	49	134	68	183	19430	9860	26535
	8.92	126.2	19.2	259	184	48	128	76	187	18560	11020	27115
									Avg	18947	9570	26777
									Std dev	443.0	1614.7	301.8
A4	8.88	125.6	19.3	196	208	52	169	67	169	24505	9715	24505
Lot 1	8.91	126.1	19.1	188	162	43	177	86	209	25665	12470	30305
	8.98	127.1	19.1	205	156	40	163	90	226	23635	13050	32770
									Avg	24602	11745	29193
									Std dev	1018.4	1781.8	4243.2
B4	9.04	127.8	19.3	197	42	26	171	341	347	24795	49445	50315
Lot 1	9.12	129	19.6	254	40	25	134	354	358	19430	51330	51910
	9.18	129.8	19.3	213	41	26	160	353	351	23200	51185	50895
									Avg	22475	50653	51040
									Std dev	2755.0	1049.0	807.3
C4	9.01	127.5	19.3	174	79	35	193	180	257	27985	26100	37265
Lot 1	9.08	128.5	19.2	169	72	35	201	197	261	29145	28565	37845

Lot / Sublot	Force (kN)	Pressure (kPa)	Pulse (ms)	δ 1 (μm)	δ 2 (μm)	δ 3 (μm)	E(1) Mpa	E(2) Mpa	E(3) Mpa	E(1) psi	E(2) psi	E(3) psi
	9.12	129	19.2	166	72	34	205	199	267	29725	28855	38715
									Avg	28952	27840	37942
									Std dev	886.0	1513.8	729.8
A1	9.13	129.1	19.4	108	55	26	314	261	348	45530	37845	50460
Lot 2	9.07	128.3	19.1	106	52	26	318	273	349	46110	39585	50605
	9.12	129.1	19.2	102	56	26	332	255	351	48140	36975	50895
	0	0	0	0	0	0	0	0	0	0	0	0
									Avg	31417	25520	33833
									Std dev	27226.6	22139.5	29300.9
B1	7.37	104.3	19.8	169	52	23	162	221	321	23490	32045	46545
Lot 2	9.12	129.1	19.2	156	53	30	218	269	307	31610	39005	44515
	9.18	129.8	19.2	159	54	30	215	265	301	31175	38425	43645
									Avg	28758	36492	44902
									Std dev	4567.7	3861.8	1488.2
C1	9.17	129.8	19.2	168	158	52	203	91	178	29435	13195	25810
Lot 2	9.21	130.4	19.1	171	136	52	201	106	178	29145	15370	25810
	9.23	130.5	19.1	170	134	52	202	108	178	29290	15660	25810
									Avg	29290	14742	25810
									Std dev	145.0	1347.3	0.0
A2	9.17	129.8	19.3	189	134	41	181	107	223	26245	15515	32335

Lot / Sublot	Force (kN)	Pressure (kPa)	Pulse (ms)	δ 1 (μm)	δ 2 (μm)	δ 3 (μm)	E(1) Mpa	E(2) Mpa	E(3) Mpa	E(1) psi	E(2) psi	E(3) psi
Lot 2	9.13	129.1	19.3	182	150	41	187	95	223	27115	13775	32335
	9.1	128.8	19.1	180	165	41	189	87	220	27405	12615	31900
									Avg	26922	13968	32190
									Std dev	603.7	1459.6	251.1
B2	9.11	128.9	19.2	130	81	36	261	176	251	37845	25520	36395
Lot 2	9.26	131	19.1	130	83	37	266	176	251	38570	25520	36395
	9.32	131.8	19.1	130	81	37	267	180	252	38715	26100	36540
									Avg	38377	25713	36443
									Std dev	466.1	334.9	83.7
C2	9.04	127.9	19.2	228	166	24	148	85	377	21460	12325	54665
Lot 2	8.97	127	19.2	213	147	24	157	96	368	22765	13920	53360
	9.07	128.4	19.4	214	139	25	158	103	360	22910	14935	52200
									Avg	22378	13727	53408
									Std dev	798.6	1315.7	1233.2
A3	9.2	130.2	19	183	155	52	187	93	178	27115	13485	25810
Lot 2	9.19	130	19.2	183	159	53	187	90	174	27115	13050	25230
	9.21	130.3	19.1	181	156	51	190	93	182	27550	13485	26390
									Avg	27260	13340	25810
									Std dev	251.1	251.1	580.0
B3	8.98	127.1	19.2	149	116	44	225	122	204	32625	17690	29580

Lot / Sublot	Force (kN)	Pressure (kPa)	Pulse (ms)	δ 1 (μm)	δ 2 (μm)	δ 3 (μm)	E(1) Mpa	E(2) Mpa	E(3) Mpa	E(1) psi	E(2) psi	E(3) psi
Lot 2	9.15	129.5	19.3	162	114	46	210	126	201	30450	18270	29145
	9.17	129.8	19.1	153	113	46	223	127	200	32335	18415	29000
									Avg	31803	18125	29242
									Std dev	1181.0	383.6	301.8
C3	9.2	130.1	19.6	292	160	77	117	90	119	16965	13050	17255
Lot 2	9.23	130.6	19.1	330	155	75	104	94	124	15080	13630	17980
	9.2	130.1	19.1	317	151	74	108	96	124	15660	13920	17980
									Avg	15902	13533	17738
									Std dev	965.5	443.0	418.6
A4	8.97	126.9	19.2	480	410	41	70	34	220	10150	4930	31900
Lot 2	8.99	127.2	19.1	597	474	44	56	30	206	8120	4350	29870
	9.03	127.7	19.8	599	538	47	56	26	194	8120	3770	28130
									Avg	8797	4350	29967
									Std dev	1172.0	580.0	1886.9
B4	9.04	127.9	19.1	251	122	19	134	116	475	19430	16820	68875
Lot 2	9.06	128.2	19.2	253	119	20	133	119	458	19285	17255	66410
	9.06	128.2	19.1	241	120	20	140	119	448	20300	17255	64960
									Avg	19672	17110	66748
									Std dev	549.0	251.1	1979.3
C4	9.08	128.4	19.3	281	150	21	120	95	432	17400	13775	62640

Lot / Sublot	Force (kN)	Pressure (kPa)	Pulse (ms)	δ 1 (μm)	δ 2 (μm)	δ 3 (μm)	E(1) Mpa	E(2) Mpa	E(3) Mpa	E(1) psi	E(2) psi	E(3) psi
Lot 2	9.14	129.4	19.1	283	141	22	120	102	415	17400	14790	60175
	9.11	128.9	19.1	277	136	23	122	105	397	17690	15225	57565
									Avg	17497	14597	60127
									Std dev	167.4	744.1	2537.8
SUBGRADE LOT 3												
A1	8.93	126.4	19.3	457	283	83	73	49	108	10585	7105	15660
Lot 3	8.98	127.1	19.3	466	264	84	72	53	107	10440	7685	15515
	8.98	127.1	19.3	461	263	84	73	54	107	10585	7830	15515
									Avg	10537	7540	15563
									Std dev	83.7	383.6	83.7
B1	9.04	127.8	19.2	542	381	77	62	37	118	8990	5365	17110
Lot 3	9.05	128.1	19.3	545	351	67	62	40	136	8990	5800	19720
	7.23	102.3	20.4	550	350	51	49	32	141	7105	4640	20445
									Avg	8362	5268	19092
									Std dev	1088.3	586.0	1754.0
C1	9.19	130	19.2	279	179	22	123	80	415	17835	11600	60175
Lot 3	9.24	130.8	19.2	274	164	22	126	88	426	18270	12760	61770
	9.17	129.7	19.2	270	170	22	126	84	417	18270	12180	60465
									Avg	18125	12180	60803
									Std dev	251.1	580.0	849.6
A2	9.19	129.9	19.2	118	52	14	289	275	669	41905	39875	97005

Lot / Sublot	Force (kN)	Pressure (kPa)	Pulse (ms)	δ 1 (μm)	δ 2 (μm)	δ 3 (μm)	E(1) Mpa	E(2) Mpa	E(3) Mpa	E(1) psi	E(2) psi	E(3) psi
Lot 3	9.33	132	19.2	122	42	12	285	345	790	41325	50025	114550
	9.31	131.7	19	118	43	12	294	336	769	42630	48720	111505
									Avg	41953	46207	107687
									Std dev	653.8	5522.1	9375.0
B2	9.23	130.6	18.9	74	25	13	465	583	717	67425	84535	103965
Lot 3	9.22	130.5	19	82	22	12	421	649	761	61045	94105	110345
	9.35	132.3	19.2	78	22	12	445	653	766	64525	94685	111070
									Avg	64332	91108	108460
									Std dev	3194.4	5700.1	3909.6
C2	9.24	130.7	19.1	307	86	19	112	168	478	16240	24360	69310
Lot 3	9.3	131.6	19.1	285	68	19	121	215	495	17545	31175	71775
	9.32	131.8	19	275	64	18	126	229	506	18270	33205	73370
									Avg	17352	29580	71485
									Std dev	1028.7	4633.2	2045.5
A3	9.07	128.3	19.2	283	49	28	119	291	322	17255	42195	46690
Lot 3	9.11	128.9	19.1	282	41	27	120	345	338	17400	50025	49010
	9.07	128.3	19	266	39	26	127	368	346	18415	53360	50170
									Avg	17690	48527	48623
									Std dev	632.0	5731.3	1771.9
B3	9.17	129.8	19	190	73	25	180	198	370	26100	28710	53650

Lot / Sublot	**Force (kN)**	**Pressure (kPa)**	**Pulse (ms)**	**δ 1 (μm)**	**δ 2 (μm)**	**δ 3 (μm)**	**E(1) Mpa**	**E(2) Mpa**	**E(3) Mpa**	**E(1) psi**	**E(2) psi**	**E(3) psi**
Lot 3	9.23	130.6	19	162	63	25	212	228	376	30740	33060	54520
	9.08	128.4	19	157	60	25	215	238	368	31175	34510	53360
									Avg	29338	32093	53843
									Std dev	2812.9	3018.4	603.7
C3	9.08	128.4	19.2	183	115	23	185	124	398	26825	17980	57710
Lot 3	9.08	128.5	19	182	125	28	186	114	328	26970	16530	47560
	9.05	128	19	198	122	28	170	117	326	24650	16965	52635
									Avg	26148	17158	7177.1
									Std dev	1299.6	744.1	5075.0
A4	9.07	128.4	19.2	315	96	15	107	148	594	15515	21460	86130
Lot 3	9.05	128	19.1	315	96	15	107	148	598	15515	21460	86710
	9.14	129.3	19.1	312	98	15	109	146	591	15805	21170	85695
									Avg	15612	21363	86178
									Std dev	167.4	167.4	509.2
B4	9.08	128.4	19.5	267	100	20	127	142	446	18415	20590	64670
Lot 3	9.05	128.1	19.1	260	102	22	130	139	405	18850	20155	58725
	9.23	130.6	19.3	262	76	20	131	191	468	18995	27695	67860
									Avg	18753	22813	63752
									Std dev	301.8	4233.2	4636.2
C4	9.13	129.2	19.2	251	181	29	136	79	316	19720	11455	45820

Lot / Sublot	Force (kN)	Pressure (kPa)	Pulse (ms)	δ 1 (μm)	δ 2 (μm)	δ 3 (μm)	E(1) Mpa	E(2) Mpa	E(3) Mpa	E(1) psi	E(2) psi	E(3) psi
Lot 3	9.11	128.9	19.2	237	159	28	143	90	321	20735	13050	46545
	9.21	130.4	19	219	158	29	157	91	319	22765	13195	46255
									Avg	21073	12567	46207
									Std dev	1550.4	965.5	364.9

Table 94. ***Modulus*** measured by ***DSPA*** in ***SH-130, TX, Subgrade, psi***
Note: Test repetitions are shown in Table 95

Lot	Sublot	A	B	C	Average	Lot Average
1	1	43063	50175	43333	45524	
	2	34728	30059	32419	32402	
	3	37442	33768	36687	35966	
	4	38484	41859	25185	35176	37267
2	1	47814	50129	33956	43966	
	2	27022	34904	37990	33305	
	3	36184	43440	42370	40664	
	4	22809	25696	26786	25097	35758
3	1	23420	20145	27147	23571	
	2	33641	33887	31421	32983	
	3	33120	25976	30888	29995	
	4	29305	26894	31078	29092	28910
Average lot 1 by row		38429	38965	34406		
Average lot 2 by row		33457	38542	35275		
Average lot 3 by row		29872	26725	30133		
Average by row		33919	34744	33272		
Project average						33978

Table 95. Repeatability in ***Modulus*** measured by ***DSPA*** in ***SH-130, TX, Subgrade, psi***
Note: Summary of results is shown in Table 94

Lot	Sublot	Point	Trial 1	Trial 2	Trial 3	Average	Std deviation
Sub1	1	A	53262	24000	51926	43063	**16522**
Sub1	1	B	49803	49835	50887	50175	**617**
Sub1	1	C	36000	51000	43000	43333	**7506**
Sub1	2	A	35404	38797	29982	34728	**4446**
Sub1	2	B	36658	30519	23000	30059	**6841**
Sub1	2	C	20613	34644	42000	32419	**10866**
Sub1	3	A	48581	24210	39537	37442	**12320**
Sub1	3	B	36852	33414	31038	33768	**2924**
Sub1	3	C	36516	31014	42530	36687	**5760**
Sub1	4	A	28660	40346	46445	38484	**9038**
Sub1	4	B	42578	35000	48000	41859	**6530**
Sub1	4	C	24852	30702	20000	25185	**5359**
Sub2	1	A	60239	43202	40000	47814	**10879**
Sub2	1	B	47765	60181	42443	50129	**9102**
Sub2	1	C	36394	16474	49000	33956	**16399**
Sub2	2	A	32447	25678	22940	27022	**4894**
Sub2	2	B	27954	42658	34099	34904	**7385**
Sub2	2	C	37658	33782	42530	37990	**4383**
Sub2	3	A	42308	32575	33667	36184	**5332**
Sub2	3	B	46210	40341	43768	43440	**2948**
Sub2	3	C	46790	44915	35404	42370	**6105**
Sub2	4	A	16153	30816	21458	22809	**7424**
Sub2	4	B	27975	24939	24174	25696	**2010**
Sub2	4	C	20210	34058	26089	26786	**6950**
Sub3	1	A	18116	28099	24046	23420	**5021**
Sub3	1	B	17620	23353	19461	20145	**2927**
Sub3	1	C	38416	15085	27939	27147	**11686**
Sub3	2	A	39886	31038	30000	33641	**5433**
Sub3	2	B	25500	41161	35000	33887	**7890**
Sub3	2	C	20591	29710	43963	31421	**11780**

Lot	Sublot	Point	Trial 1	Trial 2	Trial 3	Average	Std deviation
Sub3	3	A	36207	39153	24000	33120	**8034**
Sub3	3	B	27751	28616	21560	25976	**3849**
Sub3	3	C	36837	24826	31000	30888	**6006**
Sub3	4	A	29720	19017	39179	29305	**10087**
Sub3	4	B	22424	30500	27757	26894	**4107**
Sub3	**4**	**C**	**31402**	**25000**	**36832**	**31078**	**5923**

Table 96. ***Wet Density*** measured by ***Nuclear Gage*** in ***SH-130, TX, Subgrade, psi***

Lot	Sublot	A	B	C	Average	Lot Average
1	1	138.2	140.8	139.4	139.5	
	2	143.4	142.8	142.5	142.9	
	3	140.5	138.7	138.7	139.3	
	4	140.7	141.3	141.9	141.3	140.7
2	1	141.3	142.8	137.2	140.4	
	2	140.2	138.3	136.9	138.5	
	3	142.2	137.1	142.5	140.6	
	4	130.7	135.3	139.5	135.2	138.7
3	1	140.9	136.5	142.8	140.1	
	2	142.7	145.7	140.8	143.1	
	3	140.7	138.3	137.0	138.7	
	4	136.4	133.8	139.1	136.4	139.6
Average lot 1 by row		140.7	140.9	140.6		
Average lot 2 by row		138.6	138.4	139.0		
Average lot 3 by row		140.2	138.6	139.9		
Average by row		139.8	139.3	139.9		
Project average						139.7

Table 97. ***Percent Moisture*** measured by ***Nuclear Gage*** in ***SH-130, TX, Subgrade, psi***

Lot	Sublot	A	B	C	Average	Lot Average
1	1	8.8	8.7	8.5	8.7	
	2	7.1	8.7	8.0	7.9	
	3	9.3	8.5	10.3	9.4	
	4	8.0	7.3	7.8	7.7	8.4
2	1	6.6	15.4	7.1	9.7	
	2	6.5	8.3	8.2	7.7	
	3	7.4	6.5	6.4	6.8	
	4	9.7	9.8	6.7	8.7	8.2
3	1	9.4	7.6	8.9	8.6	
	2	6.2	6.7	8.1	7.0	
	3	7.1	8.8	13.6	9.8	
	4	11.4	10.6	10.7	10.9	9.1
Average lot 1 by row		8.3	8.3	8.7		
Average lot 2 by row		7.6	10.0	7.1		
Average lot 3 by row		8.5	8.4	10.3		
Average by row		8.1	8.9	8.7		
Project average						8.6

Table 98. Summary of ***Resilient Modulus Test Results*** in ***SH-130, TX Subgrade***

Sequence	σ_1 psi	σ_2 psi	σ_3 psi	θ psi	τ_{oct} psi	$\sigma_1 - \sigma_3$ psi	M_R Psi	Pred. M_R psi
Repetition 1								
1	12.9	8.0	8.0	28.9	2.3	4.9		69442
2	10.8	6.0	6.0	22.8	2.3	4.8	58930	61001
3	8.5	4.0	4.0	16.5	2.1	4.5	55339	51605
4	6.2	2.0	2.0	10.2	2.0	4.2	41930	39964
5	15.3	8.0	8.0	31.3	3.4	7.3		64539
6	13.8	6.0	6.0	25.8	3.7	7.8	53258	56503
7	11.4	4.0	4.0	19.4	3.5	7.4	48772	49014
8	8.9	2.0	2.0	12.9	3.2	6.9	37861	39840
9	18.0	8.0	8.0	34.0	4.7	10.0	62611	59620
10	16.6	6.0	6.0	28.6	5.0	10.6	50276	52613
11	14.3	4.0	4.0	22.3	4.8	10.3	46137	46372
12	11.9	2.0	2.0	15.9	4.7	9.9	37956	38981
13	21.8	8.0	8.0	37.9	6.5	13.8	55444	53717
14	20.6	6.0	6.0	32.6	6.9	14.6	48038	47898
15	18.2	4.0	4.0	26.2	6.7	14.2	43896	42990
16	15.8	2.0	2.0	19.8	6.5	13.8	37465	37295
Repetition 2								
1	13.2	8.0	8.0	29.2	2.5	5.2	67126	69138
2	10.9	6.0	6.0	22.9	2.3	4.9	62896	61848
3	8.5	4.0	4.0	16.5	2.1	4.5	53094	53172
4	6.1	2.0	2.0	10.1	1.9	4.1	42727	42103
5	16.2	8.0	8.0	32.2	3.9	8.2	63870	64723
6	13.8	6.0	6.0	25.8	3.7	7.8	59364	58638
7	11.5	4.0	4.0	19.5	3.5	7.5	51868	51471
8	9.1	2.0	2.0	13.1	3.3	7.0	42136	42640
9	19.1	8.0	8.0	35.1	5.2	11.1	60791	60978
10	16.7	6.0	6.0	28.7	5.1	10.7	56658	55731
11	14.4	4.0	4.0	22.4	4.9	10.4	50167	49689
12	12.0	2.0	2.0	16.0	4.7	10.0	41784	42429
13	23.0	8.0	8.0	39.0	7.1	15.0	56497	56504
14	20.7	6.0	6.0	32.7	6.9	14.6	52949	52184
15	18.3	4.0	4.0	26.3	6.7	14.3	47455	47278
16	15.9	2.0	2.0	19.9	6.5	13.9	40660	41530

Sequence	σ_1 psi	σ_2 psi	σ_3 psi	θ psi	τ_{oct} psi	$\sigma_1 - \sigma_3$ psi	M_R Psi	Pred. M_R psi
Repetition 3								
1	13.3	8.0	8.0	29.3	2.5	5.3	44281	45059
2	10.9	6.0	6.0	22.9	2.3	4.9	37904	39086
3	8.5	4.0	4.0	16.5	2.1	4.5	31859	32245
4	6.1	2.0	2.0	10.1	1.9	4.1	26126	24009
5	16.2	8.0	8.0	32.2	3.8	8.2	44673	43966
6	13.8	6.0	6.0	25.8	3.7	7.8	38381	38704
7	11.4	4.0	4.0	19.4	3.5	7.4	31639	32760
8	9.0	2.0	2.0	13.0	3.3	7.0	25920	25803
9	19.1	8.0	8.0	35.1	5.2	11.1	44147	42932
10	16.8	6.0	6.0	28.8	5.1	10.7	38567	38248
11	14.3	4.0	4.0	22.4	4.9	10.3	32375	33026
12	11.9	2.0	2.0	15.9	4.7	9.9	26142	27033
13	23.0	8.0	8.0	39.0	7.1	15.0	43550	41654
14	20.7	6.0	6.0	32.7	6.9	14.6	38406	37585
15	18.3	4.0	4.0	26.3	6.7	14.3	32765	33114
16	15.9	2.0	2.0	19.9	6.5	13.9	26984	28085

Calculated Mr coefficients for

	Rep 1	Rep 2	Rep 3
K_1	4,218.5	4,154.2	2,362.5
K_2	0.565	0.510	0.624
K_3	-1.846	-1.465	-1.089

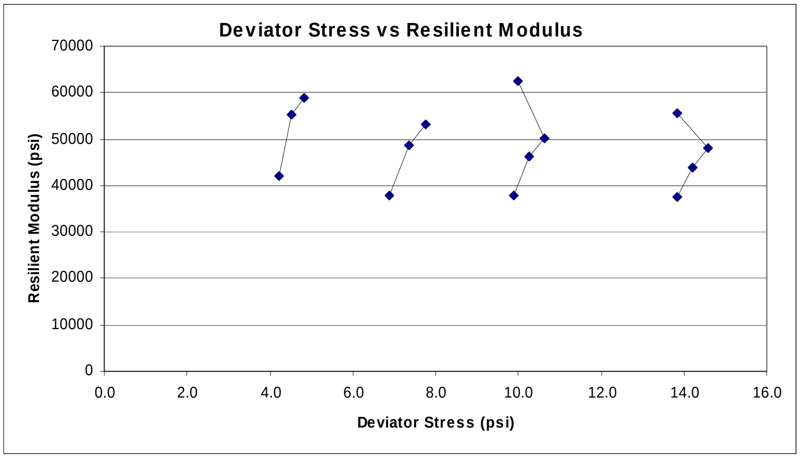


Figure 37. ***Resilient Modulus vs. Deviator Stress*** in ***SH-130, TX Subgrade Rep 1***

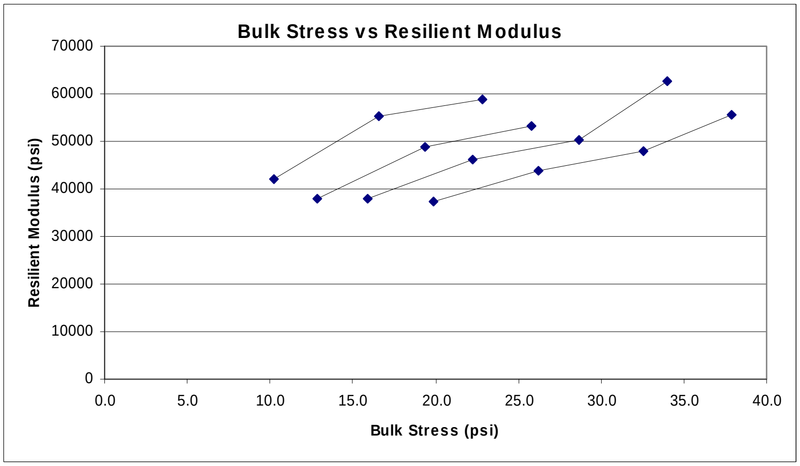


Figure 38. ***Bulk stress vs. Resilient Modulus*** in ***SH-130, TX Subgrade – Rep 1***

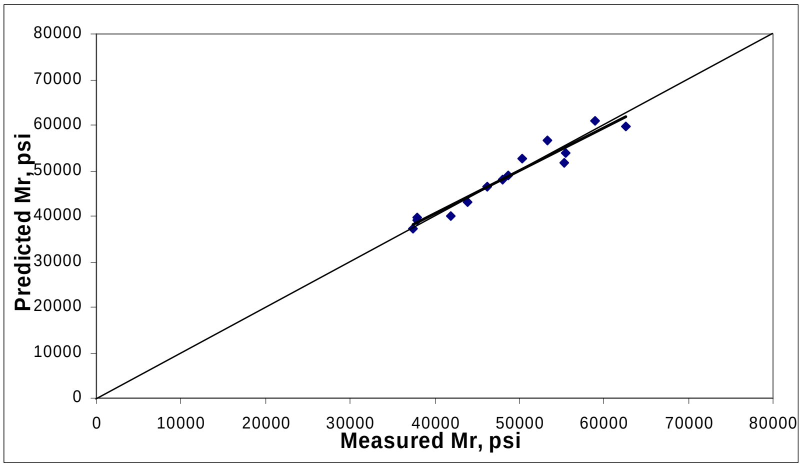


Figure 39. ***Predicted vs Measured Resilient Modulus*** in ***SH-130, TX Subgrade – Rep 1***

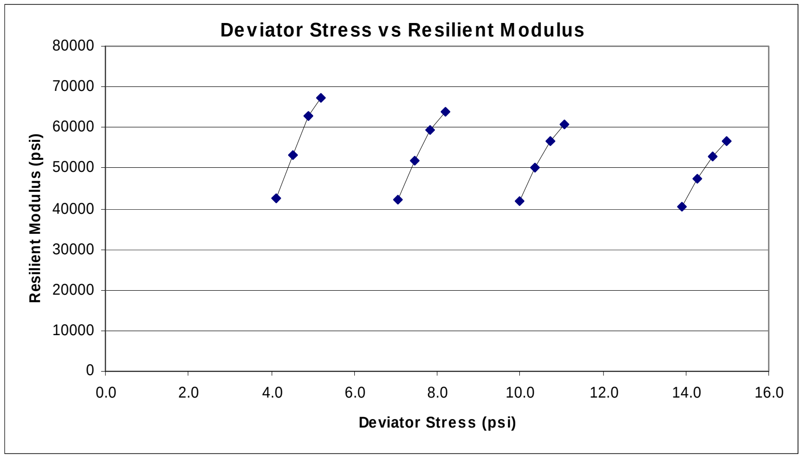


Figure 40. ***Resilient Modulus vs. Deviator Stress*** in ***SH-130, TX Subgrade – Rep 2***

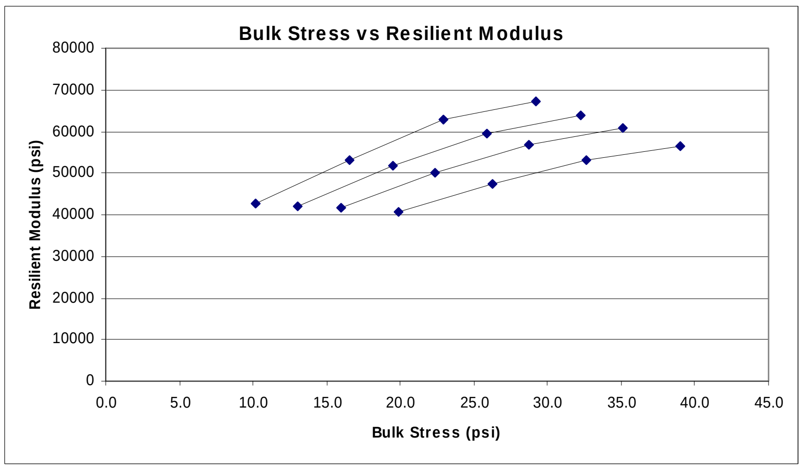


Figure 41. ***Bulk stress vs. Resilient Modulus*** in ***SH-130, TX Subgrade – Rep 2***

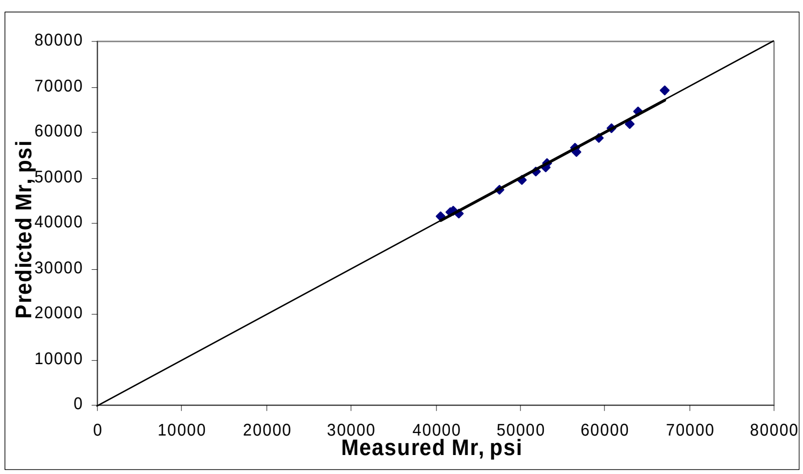


Figure 42. ***Predicted vs Measured Resilient Modulus*** in ***SH-130, TX Subgrade– Rep 2***

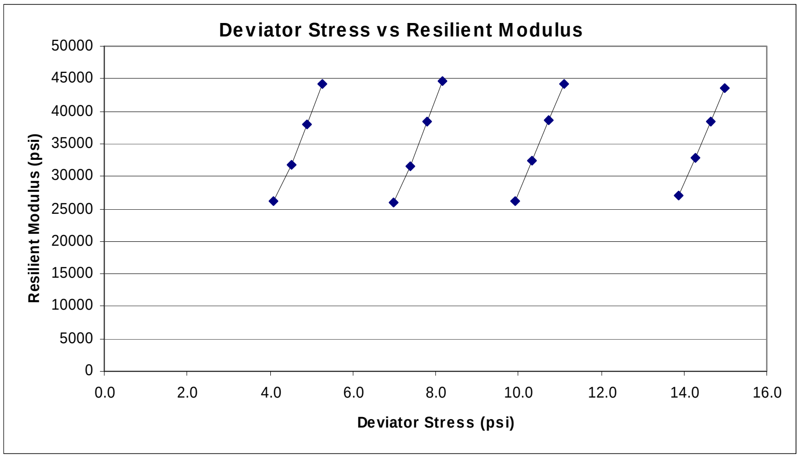


Figure 43. ***Resilient Modulus vs. Deviator Stress*** in ***SH-130, TX Subgrade – Rep 3***

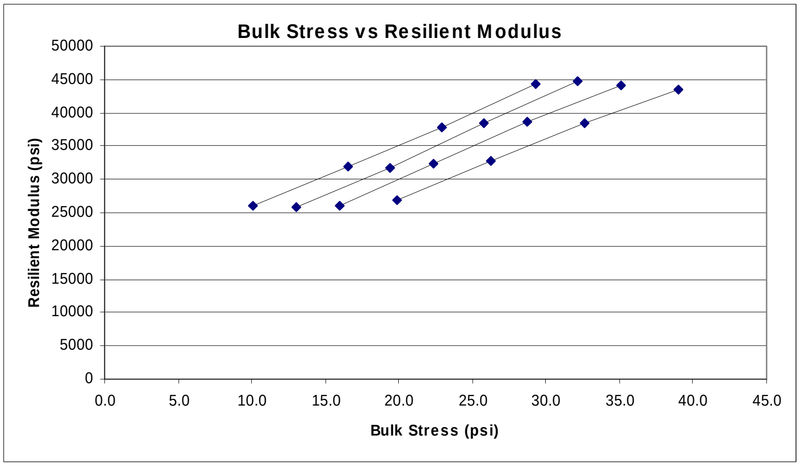


Figure 44. ***Bulk stress vs. Resilient Modulus*** in ***SH-130, TX Subgrade – Rep 3***

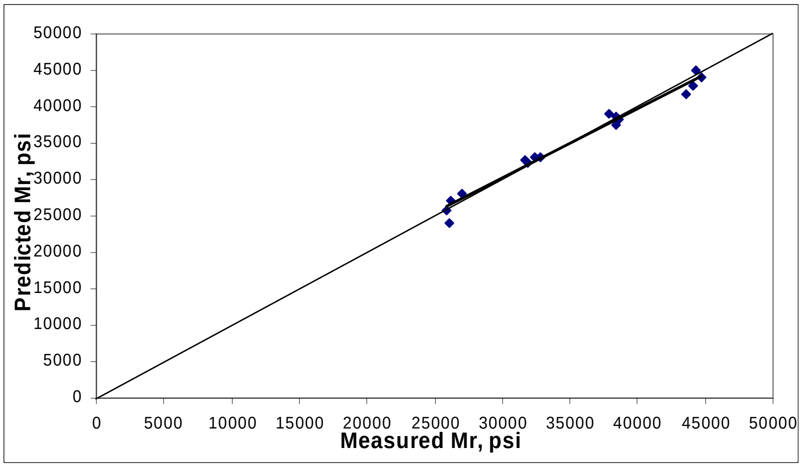
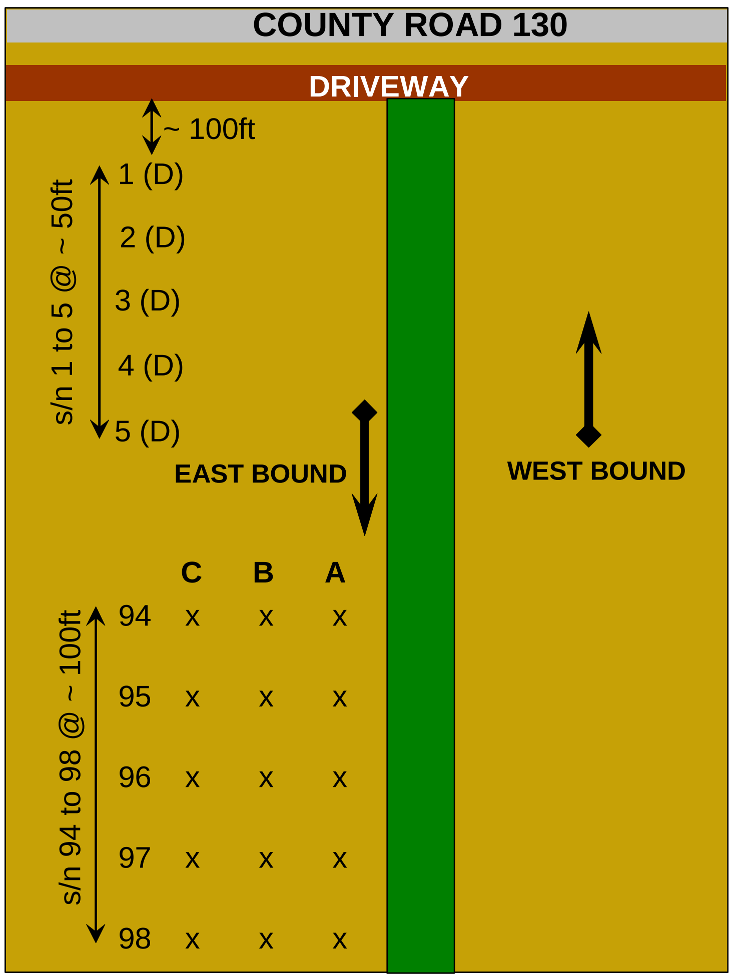


Figure 45. ***Predicted vs Measured Resilient Modulus*** in ***SH-130, TX Subgrade– Rep 3***

CALDWELL, TX SUBGRADE TESTING (HIGH PLASTICITY SOIL TEST)



Note: Precise station information was not available for this section
A is LWP, B is Center and C is RWP

Table 99. ***Modulus*** measured by ***Geogauge*** in ***Caldwell, TX, Subgrade, psi***
Note: Test repetitions are shown in Table 100

Lot	Sublot	A	B	C	C*	Average **	Lot Statistics
1	94	21735	22324	19938	19699	21333	
	95	28083	34324	18361	19956	26923	
	96	20759	20023	23911	19317	21564	
	97	21381	19774	19998	19869	20384	
	98	28035	27075	18153	19782	24421	
Average lot 1 by row		23999	24704	20072	19725		22925
Standard Dev lot 1 by row		3723	4528	2311	247		2695
		D	**-**	**-**	**D***		
2	1	18781	No Data	No Data	19577		
	2	19137	No Data	No Data	19358		
	3	18793	No Data	No Data	19472		
	4	21716	No Data	No Data	19472		
	5	19475	No Data	No Data	25467		
Average lot 2 by row		19580			20669		19580
Standard Dev lot 2 by row		1228			2683		1228
Project average							22089
Project standard dev							4212

* Point measurement without sand pad.
** Value does not include reading without sand.

Table 100. Repeatability in ***Modulus*** measured by ***Geogauge*** in ***Caldwell, TX, Subgrade, psi***
Note: Summary of results is shown in Table 99

Lot	Sublot	Point	Trial 1	Trial 2	Trial 3	Average	Std deviation
Sub1	94	A	24166	19562	21478	21735	**2313**
Sub1	94	B	26539	20964	19469	22324	**3726**
Sub1	94	C	19654#	19838	20322	19938	**345**
Sub1	94	C*	19699	0	0	6566	
Sub1	95	A	34900#	24000	25350	28083	**5942**
Sub1	95	B	38240	34551	30180	34324	**4035**
Sub1	95	C	18198	18669	18216	18361	**267**
Sub1	95	C*	19956	0	0	6652	
Sub1	96	A	21402	20124	20751	20759	**639**
Sub1	96	B	20126	20084	19859	20023	**144**
Sub1	96	C	25785	19910	26037	23911	**3467**
Sub1	96	C*	19317	0	0	6439	
Sub1	97	A	20047	24096	20001	21381	**2351**
Sub1	97	B	19902	19640	19779	19774	**131**
Sub1	97	C	19836	20199	19960	19998	**184**
Sub1	97	C*	19869	0	0	6623	
Sub1	98	A	19304	41673#	23128	28035	**11965**
Sub1	98	B	18739	42939#	19547	27075	**13744**
Sub1	98	C	18026	17731	18702	18153	**498**
Sub1	98	C*	19782	0	0	6594	
Sub2	1	D	19003	19131	18209	18781	**499**
Sub2	1	D*	19577	0	0	6526	
Sub2	2	D	19514	18850	19046	19137	**341**
Sub2	2	D*	19358	0	0	6453	
Sub2	3	D	20192	18015#	18171	18793	**1214**
Sub2	3	D*	19472	0	0	6491	
Sub2	4	D	19543	19581	26024	21716	**3731**
Sub2	4	D*	19472	0	0	6491	
Sub2	5	D	18209	19943	20274	19475	**1109**
Sub2	**5**	**D***	**25467**	**0**	**0**	**8489**	

* Test point without sand bed;
\# Reading taken while rolling operation in proximity

Table 101. ***Modulus*** measured by ***DSPA*** in ***Caldwell, TX, Subgrade, psi***
Note: Test repetitions are shown in Table 102

Lot	Sublot	A	B	C	Average	Standard deviaton	Lot Statistics
1	94	18880	29767	29506	26051	6212	
	95	24964	23372	26558	24964	1593	
	96	26755	23755	27712	26074	2064	
	97	26196	24349	30825	27123	3336	
	98	32446	24242	35826	30838	5957	
Average lot 1 by row		25848	25097	30085			27010
Standard Dev lot 1 by row		4843	2640	3603			4191
		D					
2	1	24349					
	2	25705					
	3	23768					
	4	23355					
	5	20823					
Average lot 2 by row		23600					23600
Standard Dev lot 2 by row		1788					1788
Project average							**26157**
Project standard dev							**3989**

Table 102. Repeatability in ***Modulus*** measured by ***DSPA*** in ***Caldwell, TX, Subgrade, psi***
Note: Summary of results is shown in Table 101

Lot	Sublot	Point	Trial 1	Trial 2	Average	Std deviation
Sub1	94	A	17422	20337	18880	**2062**
Sub1	94	B	30937	28596	29767	**1655**
Sub1	94	C	28632	30381	29506	**1237**
Sub1	95	A	20745	29183	24964	**5967**
Sub1	95	B	20900	25843	23372	**3496**
Sub1	95	C	26310	26805	26558	**350**
Sub1	96	A	27915	25594	26755	**1641**
Sub1	96	B	22285	25225	23755	**2079**
Sub1	96	C	30607	24816	27712	**4094**
Sub1	97	A	27236	25156	26196	**1471**
Sub1	97	B	23520	25178	24349	**1173**
Sub1	97	C	32936	28715	30825	**2985**
Sub1	98	A	33796	31096	32446	**1910**
Sub1	98	B	25069	23415	24242	**1170**
Sub1	98	C	35237	36414	35826	**832**
Sub2	1	D	23128	25570	24349	**1727**
Sub2	2	D	25727	25683	25705	**31**
Sub2	3	D	23231	24305	23768	**759**
Sub2	4	D	24993	21716	23355	**2317**
Sub2	**5**	**D**	**18376**	**23270**	**20823**	**3461**

Table 103. ***Penetration Index*** measured by ***DCP*** in ***Caldwell, TX, Subgrade, mm/blow***
Note: Penetration readings for each blow is shown in Table 104

Lot	**Sublot**	**A**	**B**	**C**	**Average**	**Standard deviaton**	**Lot Statistics**
1	94	16.1	26.3	23.8	22.0	5.3	
	95	38.3	34.8	18.9	30.7	10.4	
	96	42.6	43.5	32.6	39.6	6.1	
	97	31.7	29.0	25.1	28.6	3.3	
	98	32.6	37.6	33.7	34.6	2.6	
Average lot 1 by row		32.3	34.2	26.8			31.1
Standard Dev lot 1 by row		10.1	6.9	6.2			8.0
		D					
2	1	26.4					
	2	22.9					
	3	22.7					
	4	16.5					
	5	23.3					
Average lot 2 by row		22.3					22.3
Standard Dev lot 2 by row		3.6					3.6
Project average							28.9
Project standard dev							8.0

Table 104. ***Penetration Index*** measured by ***DCP*** in ***Caldwell, TX, Subgrade, mm/blow***

Lot		Penetration, mm			PI, mm/blow			Penetration, mm			PI, mm/blow		
		1	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**
Sublot		**94**	**94**	**94**	**94**	**94**	**94**	**95**	**95**	**95**	**95**	**95**	**95**
Point		**A**	**B**	**C**	**A**	**B**	**C**	**A**	**B**	**C**	**A**	**B**	**C**
Number of blows	0	19	30	36				27	68	24			
	1	31	74	70	12	44	34	54	109	52	27	41	28
	2	59	103	104	28	29	34	82	139	79	28	30	27
	3	91	131	126	32	28	22	115	165	96	33	26	17
	4	116	152	143	25	21	17	165	183	112	50	18	16
	5	137	177	159	21	25	16	230	209	127	65	26	15
	6	153	195	175	16	18	16			144			17
	7	164	210	192	11	15	17			158			14
	8	175		214	11		22			174			16
	9	183			8					187			13
	10	190			7					208			21
	11	198			8								
	12	209			11								
Average at point					15.8	25.7	22.3				40.6	28.2	18.4

Table 104 Continued, ***Penetration Index*** measured by ***DCP*** in ***Caldwell, TX, Subgrade, mm/blow***

Lot		**Penetration, mm**			**PI, mm/blow**			**Penetration, mm**			**PI, mm/blow**		
		1	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**
Sublot		**96**	**96**	**96**	**96**	**96**	**96**	**97**	**97**	**97**	**97**	**97**	**97**
Point		**A**	**B**	**C**	**A**	**B**	**C**	**A**	**B**	**C**	**A**	**B**	**C**
Number of blows	0	22	34	21				32	18	20			
	1	50	64	47	28	30	26	59	42	42	27	24	22
	2	89	100	69	39	36	22	86	72	69	27	30	27
	3	141	141	96	52	41	27	114	99	85	28	27	16
	4	213	196	132	72	55	36	146	127	105	32	28	20
	5		261	177		65	45	181	162	129	35	35	24
	6			228			51	222	203	155	41	41	26
	7									187			32
	8									226			39
	9												
	10												
	11												
	12												
Average at point					47.8	45.4	34.5				31.7	30.8	25.8

Table 104 Continued, ***Penetration Index*** measured by ***DCP*** in ***Caldwell, TX, Subgrade, mm/blow***

Lot		Penetration, mm			PI, mm/blow			Penetration, mm					PI, mm/blow				
		1	1	1	1	1	1	2	2	2	2	2	2	2	2	2	2
Sublot		98	98	98	98	98	98	1	2	3	4	5	1	2	3	4	5
Point		A	B	C	A	B	C	D	D	D	D	D	D	D	D	D	D
Number of blows	0	22	20	12				26	32	29	25	24					
	1	61	47	30	39	27	18	65	71	68	69	62	39	39	39	44	38
	2	89	74	55	28	27	25	105	96	102	82	96	40	25	34	13	34
	3	115	104	82	26	30	27	134	115	127	92	120	29	19	25	10	24
	4	146	142	120	31	38	38	162	131	141	100	143	28	16	14	8	23
	5	180	196	171	34	54	51	184	147	152	109	164	22	16	11	9	21
	6	228	263	236	48	67	65	198	163	166	117	184	14	16	14	8	20
	7							211	181	183	130	199	13	18	17	13	15
	8								206	204	149	210		25	21	19	11
	9										164					15	
	10										182					18	
	11										201					19	
	12										214					13	
Average at point					34.3	40.5	37.3						26.4	21.8	21.9	15.8	23.3

Table 105. Summary of ***Resilient Modulus Test Results*** in ***Caldwell, TX Subgrade***

Sequence	σ_1	σ_2	σ_3	θ	τ_{oct}	$\sigma_1 - \sigma_3$	M_R	Pred. M_R
	psi	**psi**	**psi**	**psi**	**psi**	**psi**	**Psi**	**psi**
Repetition 1								
1	13.1	8.0	8.0	29.1	2.4	5.1	38046	38745
2	10.8	6.0	6.0	22.8	2.3	4.8	36740	36190
3	8.5	4.0	4.0	16.5	2.1	4.5	32921	32995
4	6.1	2.0	2.0	10.1	1.9	4.1	27595	28554
5	16.1	8.0	8.0	32.1	3.8	8.0	35821	36107
6	13.7	6.0	6.0	25.7	3.6	7.7	34654	34015
7	11.3	4.0	4.0	19.3	3.4	7.3	32156	31425
8	8.9	2.0	2.0	12.9	3.3	6.9	27820	27963
9	19.0	8.0	8.0	35.0	5.2	11.0	33588	33837
10	16.6	6.0	6.0	28.6	5.0	10.6	32555	32078
11	14.2	4.0	4.0	22.2	4.8	10.2	30816	29938
12	11.7	2.0	2.0	15.8	4.6	9.7	27528	27159
13	22.8	8.0	8.0	38.8	7.0	14.8	30381	31226
14	20.4	6.0	6.0	32.4	6.8	14.4	29528	29816
15	18.0	4.0	4.0	26.0	6.6	14.0	28142	28085
16	15.6	2.0	2.0	19.6	6.4	13.6	25837	25933
Repetition 2								
1	13.3	8.0	8.0	29.3	2.5	5.3	43092	44485
2	10.9	6.0	6.0	22.9	2.3	4.9	41050	40282
3	8.6	4.0	4.0	16.6	2.1	4.6	35817	35229
4	6.2	2.0	2.0	10.2	2.0	4.2	28380	28765
5	16.2	8.0	8.0	32.2	3.9	8.2	42869	43696
6	13.8	6.0	6.0	25.8	3.7	7.8	40287	39986
7	11.4	4.0	4.0	19.4	3.5	7.4	36103	35589
8	9.1	2.0	2.0	13.1	3.3	7.1	30454	30156
9	19.1	8.0	8.0	35.1	5.2	11.1	42772	42961
10	16.7	6.0	6.0	28.7	5.1	10.7	40090	39628
11	14.4	4.0	4.0	22.4	4.9	10.4	36035	35770
12	11.9	2.0	2.0	15.9	4.7	9.9	30703	31095
13	23.0	8.0	8.0	39.0	7.0	15.0	42109	42031
14	20.6	6.0	6.0	32.6	6.9	14.6	39649	39124
15	18.2	4.0	4.0	26.2	6.7	14.2	36069	35808
16	15.8	2.0	2.0	19.8	6.5	13.8	31060	31909

Sequence	σ_1 psi	σ_2 psi	σ_3 psi	θ psi	τ_{oct} psi	$\sigma_1 - \sigma_3$ psi	M_R Psi	Pred. M_R psi
Repetition 3								
1	13.1	8.0	8.0	29.1	2.4	5.1	35196	36528
2	10.8	6.0	6.0	22.8	2.3	4.8	32635	31928
3	8.5	4.0	4.0	16.5	2.1	4.5	26852	26634
4	6.0	2.0	2.0	10.1	1.9	4.0	20091	20186
5	16.1	8.0	8.0	32.1	3.8	8.1	35166	35805
6	13.8	6.0	6.0	25.8	3.7	7.8	32644	31745
7	11.4	4.0	4.0	19.4	3.5	7.4	27585	27137
8	9.0	2.0	2.0	13.0	3.3	7.0	21384	21686
9	19.0	8.0	8.0	35.0	5.2	11.0	34652	35136
10	16.6	6.0	6.0	28.6	5.0	10.6	32287	31509
11	14.3	4.0	4.0	22.3	4.8	10.3	27870	27432
12	11.8	2.0	2.0	15.8	4.6	9.8	22282	22693
13	22.8	8.0	8.0	38.8	7.0	14.8	33659	34303
14	20.5	6.0	6.0	32.5	6.8	14.5	31523	31129
15	18.1	4.0	4.0	26.1	6.6	14.1	28085	27616
16	15.7	2.0	2.0	19.7	6.5	13.7	23187	23632

Calculated Mr coefficients for

	Rep 1	Rep 2	Rep 3
K_1	2,574.9	2,526.4	1,931.3
K_2	0.323	0.436	0.585
K_3	-1.303	-0.769	-0.974

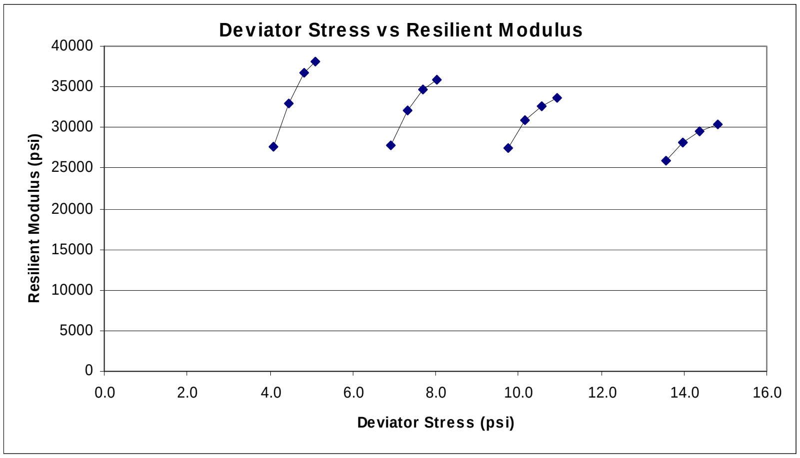


Figure 46. ***Resilient Modulus vs. Deviator Stress*** in ***Caldwell, TX Subgrade Rep 1***

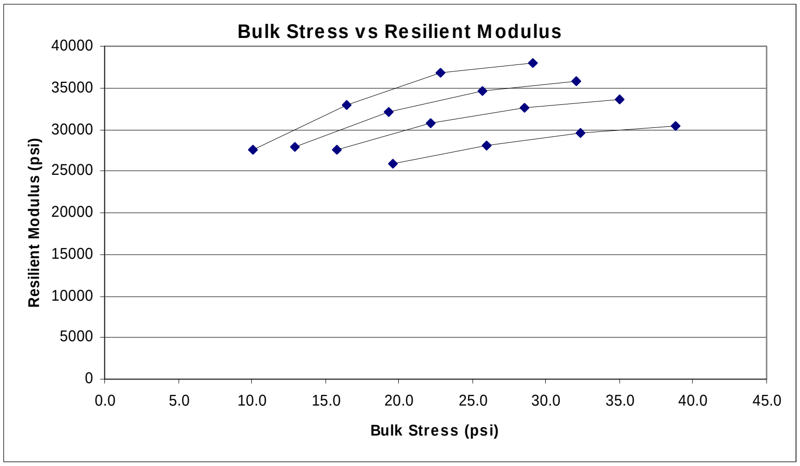


Figure 47. ***Bulk stress vs. Resilient Modulus*** in ***Caldwell,TX Subgrade – Rep 1***

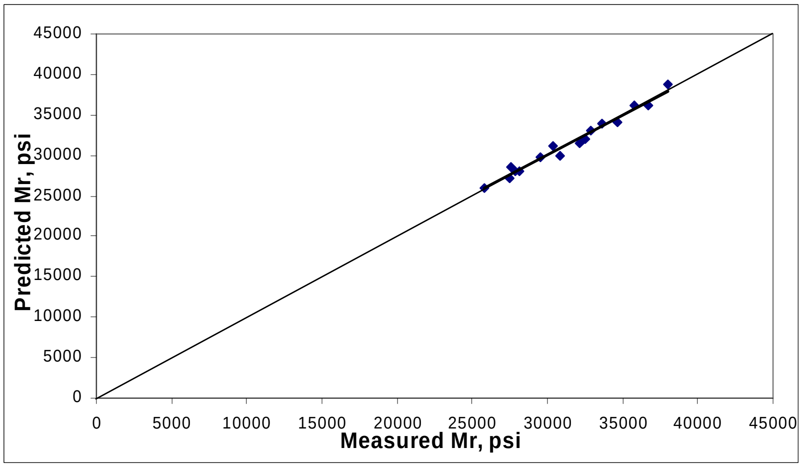


Figure 48. ***Predicted vs Measured Resilient Modulus*** in ***Caldwell, TX Subgrade–Rep 1***

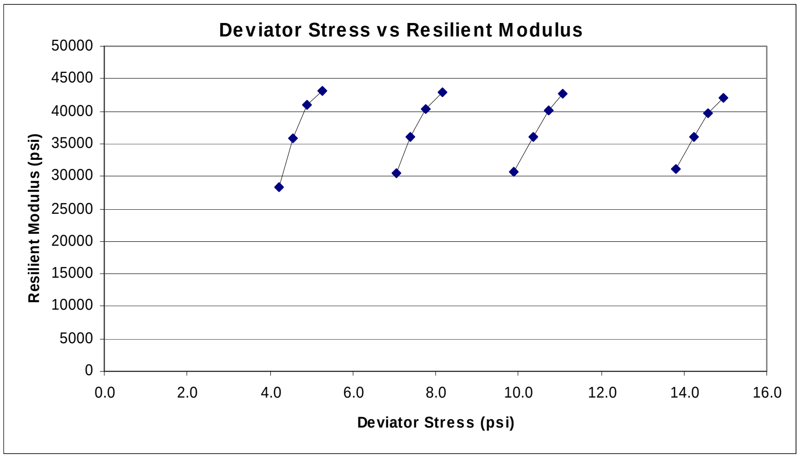


Figure 49. ***Resilient Modulus vs. Deviator Stress*** in ***Caldwell, TX Subgrade – Rep 2***

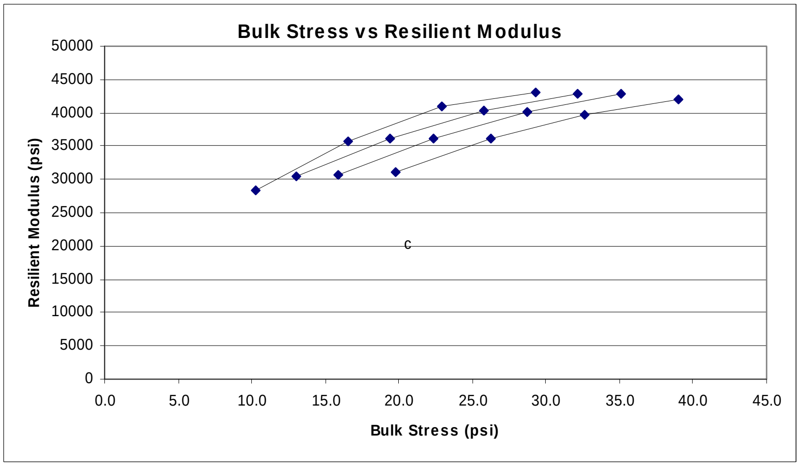


Figure 50. ***Bulk stress vs. Resilient Modulus*** in ***Caldwell, TX Subgrade – Rep 2***

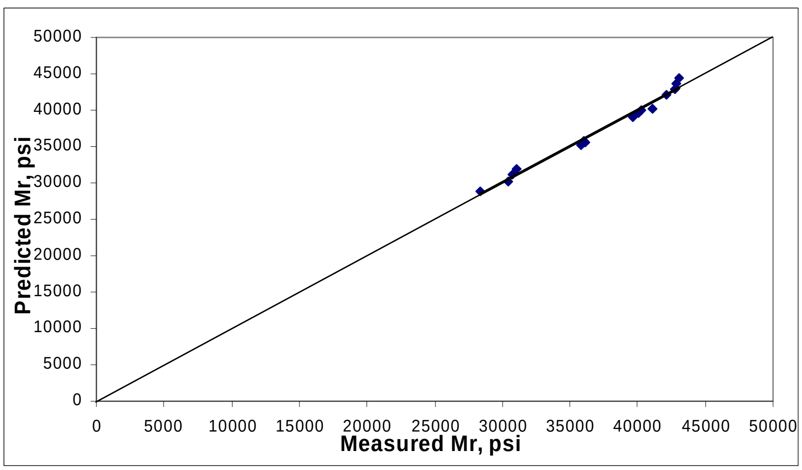


Figure 51. ***Predicted vs Measured Resilient Modulus Caldwell, TX Subgrade–Rep 2***

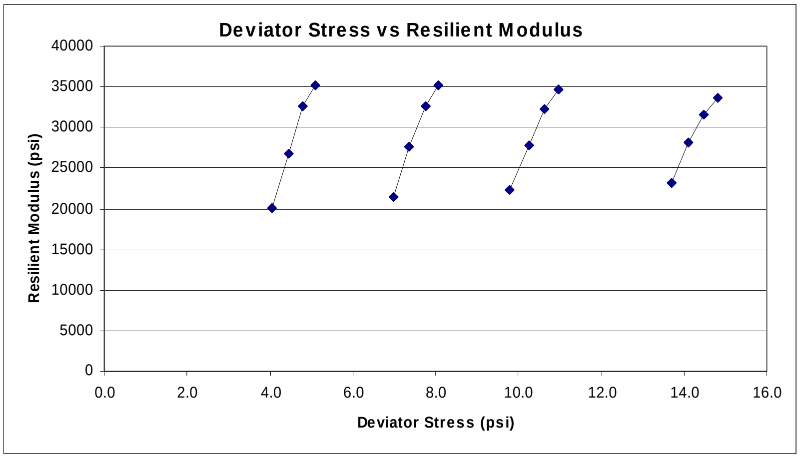


Figure 52. ***Resilient Modulus vs. Deviator Stress*** in ***Caldwell, TX Subgrade – Rep 3***

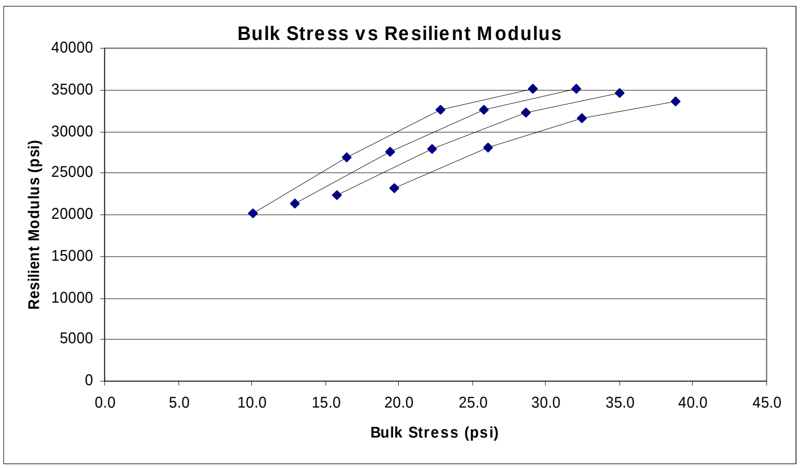


Figure 53. ***Bulk stress vs. Resilient Modulus*** in ***Caldwell, TX Subgrade – Rep 3***

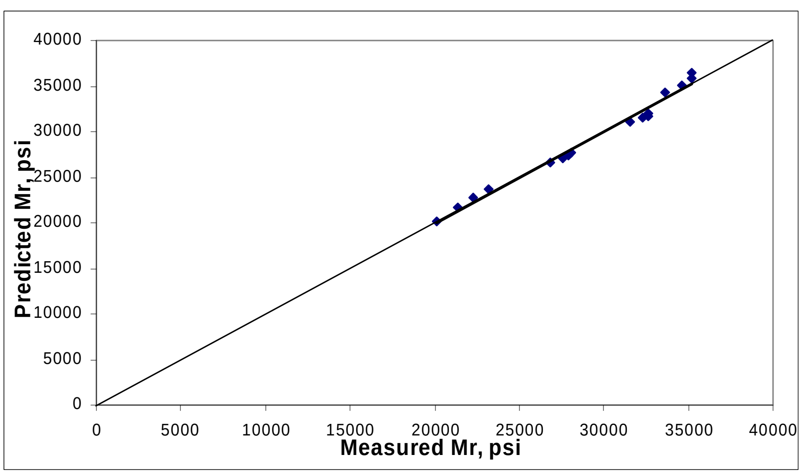


Figure 54. ***Predicted vs Measured Resilient Modulus Caldwell, TX Subgrade– Rep3***

PART A TESTING

HMA MATERIAL TEST DATA

TH23, MN HMA SECTIONS

Section	Start Station	End Station
1	7917+07.0	7924+99.8
2	7929+93.4	7937+97.4
3	7931+96.0	7939+99.7
4	7977+84.0	7978+94.7

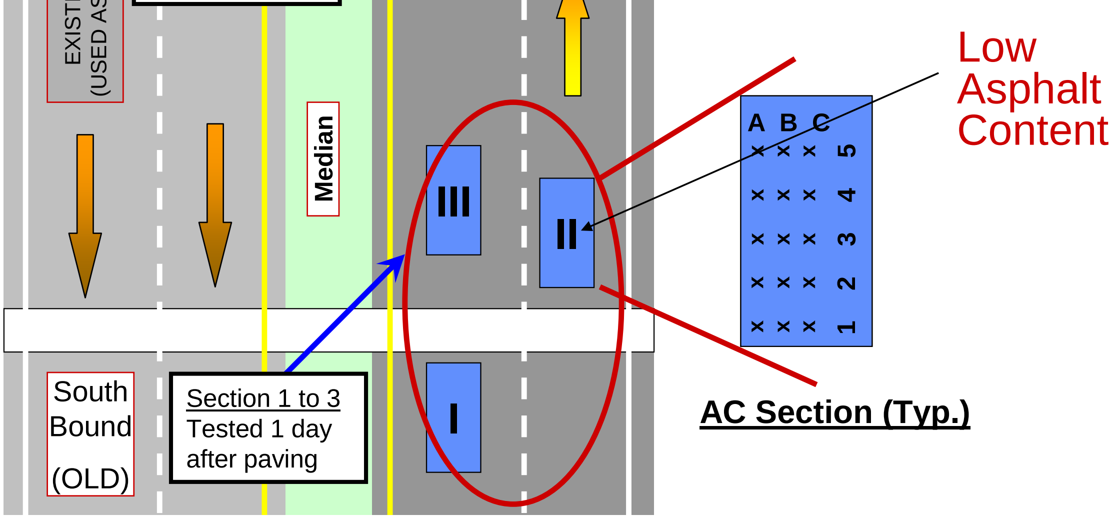


Table 106. Test point station information

Lot	Sublot	GPS station	GPS Offset		
			A	B	C
South - I	1	7917+07.0	2.6RT	6.0RT	9.6RT
South - I	2	7919+05.2	2.6RT	6.0RT	9.4RT
South - I	3	7921+03.3	2.7RT	6.2RT	9.7RT
South - I	4	7923+01.3	2.3RT	5.8RT	9.4RT
South - I	5	7924+99.8	2.5RT	6.0RT	9.5RT
Northeast - II	1	7929+93.4	2.5RT	5.8RT	8.7RT
Northeast - II	2	7931+95.7	2.4RT	5.7RT	8.7RT
Northeast - II	3	7933+96.4	2.3RT	5.6RT	8.6RT
Northeast - II	4	7935+97.3	2.6RT	5.8RT	8.8RT
Northeast - II	5	7937+97.4	2.6RT	5.7RT	8.7RT
Northwest - III	1	7931+96.0	12.3LT	8.1LT	3.5LT
Northwest - III	2	7933+97.0	12.7LT	8.2LT	3.7LT
Northwest - III	3	7935+97.4	12.3LT	7.9LT	3.3LT
Northwest - III	4	7937+98.0	12.6LT	8.2LT	3.7LT
Northwest - III	5	7939+99.7	12.6LT	8.2LT	3.7LT
North - IV(new)	1	7977+84.0	9.97LT	7.3LT	3.6LT
North - IV(new)	2	7978+12.2	10.0LT	7.1LT	3.9LT
North - IV(new)	3	7978+40.1	9.8LT	6.3LT	3.6LT
North - IV(new)	4	7978+67.0	9.3LT	6.8LT	4.0LT
North - IV(new)	5	7978+94.7	8.6LT	5.7LT	3.1LT

Table 107. ***Calibrated Thickness*** measured by ***GPR*** on ***TH-23, MN, inch***
Note: Repeatability data is not available for GPR Testing in this section

Lot #	Sublot	A	B	C	Average	Lot Average
1	1	2.08	2.09	1.85	2.01	
	2	1.77	1.77	1.82	1.79	
	3	2.11	2.27	2.10	2.16	
	4	1.98	2.18	1.70	1.95	
	5	1.82	1.72	1.60	1.71	1.92
2	1	2.24	2.19	2.08	2.17	
	2	2.30	2.02	1.69	2.00	
	3	2.39	2.38	2.23	2.33	
	4	2.33	2.29	2.32	2.31	
	5	2.18	2.30	2.33	2.27	2.22
	1	2.52	2.39	2.34	2.42	
	2	2.32	2.28	2.28	2.29	
	3	2.16	2.13	2.25	2.18	
	4	2.22	2.08	2.10	2.13	2.26
	5	1.92	1.97	2.00		
4	1	No Data	No Data	No Data		
	2	No Data	No Data	No Data		
	3	No Data	No Data	No Data		
	4	No Data	No Data	No Data		
	5	No Data	No Data	No Data		
Average lot 1 by row		1.95	2.01	1.81		
Average lot 2 by row		2.29	2.24	2.13		
Average lot 3 by row		2.23	2.17	2.20		
Average lot 4 by row		No Data	No Data	No Data		
Average project by row		2.15	2.14	2.05		
Average project						2.11

Table 108. ***Dielectric*** measured by ***GPR*** in ***TH-23, MN***
Note: Test repetitions were not performed at individual points

Lot #	Sublot	A	B	C	Average	Lot Average
1	1	6.67	6.22	7.01	6.64	
	2	6.68	6.32	6.55	6.52	
	3	6.61	6.21	6.87	6.56	
	4	6.53	6.19	6.85	6.52	
	5	6.45	6.10	6.67	6.41	6.53
2	1	5.93	6.18	6.75	6.29	
	2	5.93	6.23	6.75	6.31	
	3	5.85	6.18	6.71	6.25	
	4	5.93	6.31	6.79	6.34	
	5	5.96	6.23	6.59	6.26	6.29
	1	6.13	6.09	6.33	6.18	
	2	6.18	6.23	6.04	6.15	
	3	6.08	6.26	6.18	6.17	
	4	6.11	6.34	6.24	6.23	
	5	6.14	6.17	6.09	6.13	6.17
4	1	No Data	No Data	No Data		
	2	No Data	No Data	No Data		
	3	No Data	No Data	No Data		
	4	No Data	No Data	No Data		
	5	No Data	No Data	No Data		
Average lot 1 by row		6.59	6.21	6.79		
Average lot 2 by row		5.92	6.23	6.72		
Average lot 3 by row		6.13	6.22	6.17		
Average lot 4 by row		No Data	No Data	No Data		
Average project by row		6.21	6.22	6.56		
Average project						6.33

Table 109. ***Density*** measured by Pavetracker – Non-nuclear Gage on ***TH-23, MN, pcf***
Note: Test repetitions are shown in Table 110

Lot #	Sublot	A	B	C	Average	Lot Average
1	1	133.0	133.5	133.4	133.3	
	2	132.7	131.6	131.9	132.1	
	3	132.9	132.1	133.2	132.7	
	4	132.9	133.4	135.0	133.8	
	5	131.7	132.3	129.8	131.3	132.6
2	1	130.9	132.1	131.4	131.5	
	2	130.1	130.2	130.6	130.3	
	3	128.4	131.8	131.6	130.6	
	4	130.5	132.4	130.6	131.2	
	5	131.2	131.5	130.7	131.1	130.9
	1	131.2	131.9	132.8	132.0	
	2	130.3	131.5	131.5	131.1	
	3	130.4	131.2	131.9	131.2	
	4	130.7	132.5	133.8	132.3	
	5	130.6	131.9	132.1	131.5	131.6
4	1	132.1	132.3	131.5	132.0	
	2	131.3	133.2	132.5	132.3	
	3	130.5	132.5	132.4	131.8	
	4	132.1	130.6	133.2	132.0	
	5	132.2	131.9	129.7	131.3	131.9
Average lot 1 by row		132.6	132.6	132.7		
Average lot 2 by row		130.2	131.6	131.0		
Average lot 3 by row		130.6	131.8	132.4		
Average lot 4 by row		131.6	132.1	131.9		
Average project by row		131.3	132.0	132.0		
Average project						131.8

Table 110. Repeatability in ***Density*** measured by ***Pavetracker*** on ***TH-23, MN, pcf***
Note: Summary of results is shown in Table 109

Lot	Sublot	Point	Trial 1	Trial 2	Trial 3	Average at point	Std deviation at point
1	1	A	133.4	132	133.6	133.0	**0.87**
1	1	B	132.5	133.6	134.3	133.5	**0.91**
1	1	C	134.3	132.4	133.5	133.4	**0.95**
1	2	A	133.4	131	133.7	132.7	**1.48**
1	2	B	131.4	132	131.5	131.6	**0.32**
1	2	C	133.4	130.3	131.9	131.9	**1.55**
1	3	A	132	133.6	133.1	132.9	**0.82**
1	3	B	130.7	133	132.6	132.1	**1.23**
1	3	C	133	134.6	132	133.2	**1.31**
1	4	A	133.5	132.6	132.6	132.9	**0.52**
1	4	B	134.2	134.3	131.8	133.4	**1.42**
1	4	C	134.2	136.2	134.5	135.0	**1.08**
1	5	A	132.3	132.1	130.6	131.7	**0.93**
1	5	B	132	132.7	132.1	132.3	**0.38**
1	5	C	129.7	130.8	129	129.8	**0.91**
2	1	A	130.4	130.4	131.9	130.9	**0.87**
2	1	B	133	132.1	131.2	132.1	**0.90**
2	1	C	130.8	132.6	130.8	131.4	**1.04**
2	2	A	129.7	130	130.7	130.1	**0.51**
2	2	B	130.3	129.3	131	130.2	**0.85**
2	2	C	130.5	130.3	130.9	130.6	**0.31**
2	3	A	128.4	127.1	129.6	128.4	**1.25**
2	3	B	130.9	132.2	132.4	131.8	**0.81**
2	3	C	131.4	131.8	131.7	131.6	**0.21**
2	4	A	130.4	130.5	130.7	130.5	**0.15**
2	4	B	132.3	131.4	133.4	132.4	**1.00**
2	4	C	130.8	130	130.9	130.6	**0.49**
2	5	A	131.2	132	130.4	131.2	**0.80**
2	5	B	131.4	131.9	131.2	131.5	**0.36**
2	5	C	131.1	130.5	130.5	130.7	**0.35**
3	1	A	130	131.4	132.3	131.2	**1.16**

3	1	B	132.5	131.4	131.8	131.9	**0.56**
3	1	C	134.2	131.6	132.6	132.8	**1.31**
3	2	A	130.3	130.7	129.9	130.3	**0.40**
3	2	B	131.4	131.5	131.5	131.5	**0.06**
3	2	C	129.3	131.9	133.3	131.5	**2.03**
3	3	A	130.8	130.1	130.2	130.4	**0.38**
3	3	B	130.9	131.8	130.9	131.2	**0.52**
3	3	C	132.5	131.1	132.2	131.9	**0.74**
3	4	A	130.9	130.9	130.3	130.7	**0.35**
3	4	B	131.6	131.7	134.1	132.5	**1.42**
3	4	C	133.8	134.2	133.4	133.8	**0.40**
3	5	A	131.4	130.5	130	130.6	**0.71**
3	5	B	133.3	130.8	131.5	131.9	**1.29**
3	5	C	131.5	132	132.7	132.1	**0.60**
4	1	A	133.2	132.6	130.5	132.1	**1.42**
4	1	B	132.7	132.1	132.2	132.3	**0.32**
4	1	C	133.1	130.5	130.8	131.5	**1.42**
4	2	A	132.1	130.8	131.1	131.3	**0.68**
4	2	B	132.8	133	133.7	133.2	**0.47**
4	2	C	131.6	132.6	133.3	132.5	**0.85**
4	3	A	130.6	129.9	130.9	130.5	**0.51**
4	3	B	131.6	133.1	132.8	132.5	**0.79**
4	3	C	132.5	133.1	131.7	132.4	**0.70**
4	4	A	131.7	132.5	132.1	132.1	**0.40**
4	4	B	129.3	130	132.6	130.6	**1.74**
4	4	C	133.4	133.3	132.8	133.2	**0.32**
4	5	A	132.4	133.5	130.8	132.2	**1.36**
4	5	B	131.2	131.9	132.5	131.9	**0.65**
4	**5**	**C**	**130.2**	**129.1**	**129.9**	**129.7**	0.57

Table 111. ***Density*** measured by PQI – Non-nuclear Gage on **TH-23, MN, pcf**
Note: Test repetitions were not recorded, but were averaged internally by the device

Lot #	Sublot	A	B	C	Average	Lot Average
1	1	148.0	148.1	146.2	147.4	
	2	147.6	147.8	147.5	147.6	
	3	147.4	146.0	146.2	146.5	
	4	149.3	146.5	147.2	147.7	
	5	148.5	149.8	148.1	148.8	147.6
2	1	146.9	147.8	145.5	146.7	
	2	145.6	146.1	145.7	145.8	
	3	145.1	145.2	145.9	145.4	
	4	146.8	145.2	144.3	145.4	
	5	146.4	145.2	144.1	145.2	145.7
	1	146.7	146.1	147.1	146.6	
	2	143.8	144.3	146.5	144.9	
	3	145.5	145.3	144.9	145.2	
	4	145.6	145.1	145.7	145.5	
	5	146.0	145.8	145.5	145.8	145.6
4	1	144.2	144.4	142.7	143.8	
	2	144.1	145.7	144.2	144.7	
	3	143.6	145.5	144.7	144.6	
	4	143.4	144.1	143.8	143.8	
	5	141.7	143.9	142.5	142.7	143.9
Average lot 1 by row		148.2	147.6	147.0		
Average lot 2 by row		146.2	145.9	145.1		
Average lot 3 by row		145.5	145.3	145.9		
Average lot 4 by row		143.4	144.7	143.6		
Average project by row		145.8	145.9	145.4		
Average project						145.7

Table 112. ***Modulus*** measured by PSPA on **TH-23, MN, ksi**

Lot #	Sublot	A	B	C	Average	Lot Average
1	1	489	514	535	513	
	2	479	480	443	467	
	3	497	507	448	484	
	4	453	510	520	494	
	5	460	516	463	480	488
2	1	435	443	482	453	
	2	400	435	497	444	
	3	449	408	435	430	
	4	472	513	468	484	
	5	517	437	425	460	454
	1	488	504	495	496	
	2	458	489	424	457	
	3	473	459	469	467	
	4	476	550	532	519	
	5	510	510	548	523	492
4	1	489	503	524	505	
	2	450	489	492	477	
	3	484	504	567	519	
	4	456	504	524	495	
	5	484	522	500	502	499
Average lot 1 by row		476	506	482		
Average lot 2 by row		454	447	461		
Average lot 3 by row		481	502	494		
Average lot 4 by row		473	504	521		
Average project by row		471	490	490		
Average project						483

Table 113. Repeatability in ***Modulus*** measured by ***PSPA*** on ***TH-23, MN, ksf***
Note: Summary of results is shown in Table 112

Lot	Sublot	Point	Trial 1	Trial 2	Trial 3	Average at point	Std deviation at point
1	1	A	450	503	515	489	**34**
1	1	B	503	485	555	514	**36**
1	1	C	517	617	471	535	**75**
1	2	A	474	497	465	479	**17**
1	2	B	535	465	441	480	**49**
1	2	C	439	468	424	443	**22**
1	3	A	570	430	491	497	**70**
1	3	B	503	485	532	507	**24**
1	3	C	453	447	444	448	**4**
1	4	A	493	402	465	453	**47**
1	4	B	524	555	450	510	**54**
1	4	C	513	517	528	520	**8**
1	5	A	485	471	423	460	**33**
1	5	B	507	501	542	516	**22**
1	5	C	452	469	469	463	**10**
2	1	A	420	472	412	435	**32**
2	1	B	446	429	455	443	**13**
2	1	C	540	449	457	482	**51**
2	2	A	364	446	390	400	**42**
2	2	B	406	423	475	435	**36**
2	2	C	549	566	376	497	**105**
2	3	A	383	389	575	449	**109**
2	3	B	390	408	425	408	**17**
2	3	C	376	494	434	435	**59**
2	4	A	469	431	515	472	**42**
2	4	B	492	503	543	513	**27**
2	4	C	500	446	457	468	**29**
2	5	A	486	556	509	517	**36**
2	5	B	439	421	452	437	**16**
2	5	C	425	412	438	425	**13**
3	1	A	516	517	432	488	**49**

3	1	B	550	454	507	504	**48**
3	1	C	515	505	466	495	**26**
3	2	A	507	424	444	458	**44**
3	2	B	446	540	480	489	**47**
3	2	C	432	427	412	424	**10**
3	3	A	426	540	454	473	**59**
3	3	B	450	451	477	459	**15**
3	3	C	484	456	465	469	**14**
3	4	A	466	469	492	476	**14**
3	4	B	535	530	584	550	**30**
3	4	C	533	575	489	532	**43**
3	5	A	515	485	530	510	**23**
3	5	B	484	553	494	510	**37**
3	5	C	647	471	525	548	**90**
4	1	A	492	527	448	489	**40**
4	1	B	520	484	504	503	**18**
4	1	C	592	542	437	524	**79**
4	2	A	416	480	454	450	**32**
4	2	B	465	547	454	489	**51**
4	2	C	512	527	438	492	**48**
4	3	A	498	467	487	484	**15**
4	3	B	509	509	495	504	**8**
4	3	C	581	563	557	567	**13**
4	4	A	454	434	481	456	**23**
4	4	B	517	488	508	504	**15**
4	4	C	563	522	486	524	**38**
4	5	A	498	457	498	484	**24**
4	5	B	502	498	565	522	**38**
4	**5**	**C**	**520**	**498**	**481**	**500**	**20**

Table 114. ***Dynamic Modulus*** Test results for ***TH-23, MN, HMA,*** psi

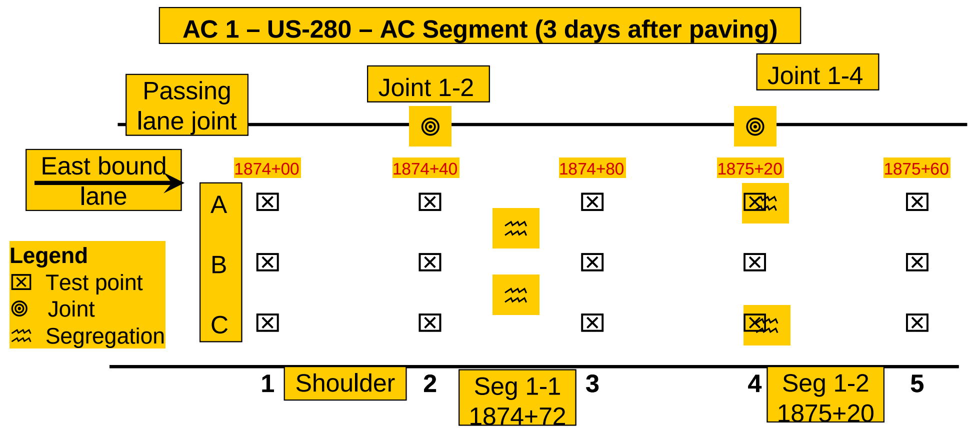
Temperature,°F	Replicate	E* Measured at Frequency					
		25	10	5	1	0.5	0.1
14	**1**	10,559,675	0,589,254	10,171,630	8,967,668	8,695,672	6,864,817
	3	11,123,813	10,681,196	10,276,205	9,075,958	8,521,134	6,974,867
	4	8,610,348	8,242,807	7,675,660	6,676,098	5,232,621	5,025,535
	Average	10,097,945	9,837,752	9,374,499	8,239,908	7,483,142	6,288,406
40	**1**	6,355,097	5,695,992	5,266,064	4,061,422	3,612,232	2,481,663
	3	7,207,175	6,355,583	5,665,391	4,334,882	3,679,686	2,390,404
	4	5,941,348	5,179,542	4,880,206	3,671,705	3,478,291	2,248,990
	Average	6,501,207	5,743,706	5,270,554	4,022,670	3,590,070	2,373,686
70	**1**	2,831,602	2,258,411	1,931,969	1,175,306	892,087	514,564
	3	2,990,658	2,406,219	2,012,065	1,219,222	974,587	595,768
	4	1,097,308	879,514	726,809	512,669	432,691	320,193
	Average	2,306,523	1,848,048	1,556,947	969,066	766,455	476,842
100	**1**	1,082,699	786,794	658,849	426,958	345,945	247,008
	3	875,334	645,458	536,582	339,268	286,991	201,575
	4	1,097,308	879,514	726,809	512,669	432,691	320,193
	Average	1,018,447	770,589	640,747	426,298	355,209	256,259
130	**1**	445,101	345,442	319,410	249,098	227,026	200,882
	3	334,450	244,490	224,612	162,838	128,984	22,565
	4	555,538	397,575	434,572	353,668	338,445	311,703
	Average	445,030	329,169	326,198	255,201	231,485	178,383

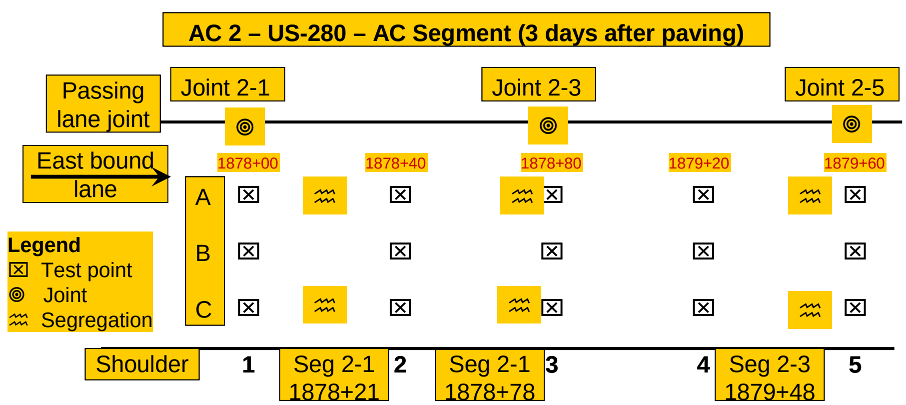
Table 115. ***Repeated load*** Test results for ***TH-23, MN, HMA,*** psi

Replicate	**Repeated Load @ 136 deg F**			
	Flow time, cycles	**Applied stress, psi**	**Maximum LVDT slope**	**Minimum LVDT slope**
1	452	68.7		
2	100	33.7		
3	176	52		
Average		51.5	N/A	**N/A**
CV, %		**34.01**		

NOTE: Samples failed quickly and did not reach secondary flow.

US-280, AL HMA SECTIONS
(TESTED IN OCTOBER 2004)





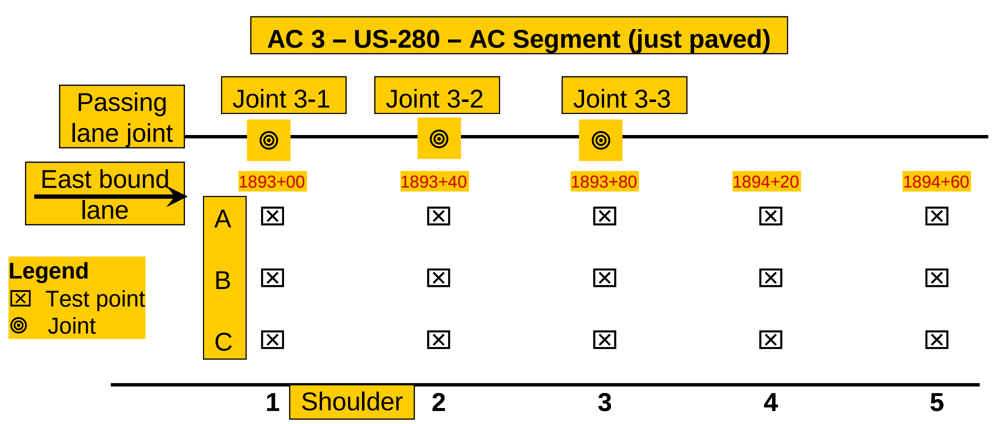


Table 116. Test point station information

Lot	Sublot	Point	Station	Offset*
AC 1	1	A	1874+00	Left*
AC 1	1	B	1874+00	Center
AC 1	1	C	1874+00	Right
AC1	2	A	1874+40	Left
AC1	2	B	1874+40	Center
AC1	2	C	1874+40	Right
AC1	2	Joint 1-2	1874+41	Left joint
AC1	seg 1-1	A	1874+72	Left
AC1	seg 1-1	C	1874+72	Right
AC1	3	A	1874+80	Left
AC1	3	B	1874+80	Center*
AC1	3	C	1874+80	Right
AC1	4, seg 1-2	A	1875+20	Left
AC1	4, seg 1-2	B	1875+20	Center
AC1	4, seg 1-2	C	1875+20	Right
AC1	4	Joint 1-4	1875+20	Left joint
AC1	5	A	1875+60	Left
AC1	5	B	1875+60	Center
AC1	5	C	1875+60	Right
AC2	1	A	1878+00	Left
AC2	1	B	1878+00	Center
AC2	1	C	1878+00	Right*
AC2	1	Joint 2-1	1878+00	Left joint
AC2	seg 2-1	A	1878+21	Left
AC2	seg 2-1	C	1878+21	Right
AC2	2	A	1878+40	Left
AC2	2	B	1878+40	Center
AC2	2	C	1878+40	Right
AC2	seg 2-2	A	1878+78	Left*
AC2	seg 2-2	C	1878+78	Right
AC2	3	A	1878+80	Left
AC2	3	B	1878+80	Center*

Lot	Sublot	Point	Station	Offset*
AC2	3	C	1878+80	Right
AC2	3	Joint 2-3	1878+80	Left joint
AC2	4	A	1879+20	Left
AC2	4	B	1879+20	Center
AC2	4	C	1879+20	Right
AC2	seg 2-2	A	1879+60	Left
AC2	seg 2-2	C	1879+60	Right*
AC2	5	A	1879+60	Left*
AC2	5	B	1879+60	Center
AC2	5	C	1879+60	Right
AC2	5	Joint 2-5	1879+60	Left joint
AC3	1	A	1893+00	Left
AC3	1	B	1893+00	Center*
AC3	1	C	1893+00	Right
AC3	1	Joint 3-1	1893+00	Left joint
AC3	2	A	1893+40	Left
AC3	2	B	1893+40	Center
AC3	2	C	1893+40	Right
AC3	2	Joint 3-2	1893+40	Left joint
AC3	3	A	1893+80	Left*
AC3	3	B	1893+80	Center
AC3	3	C	1893+80	Right
AC3	3	Joint 3-3	1893+80	Left joint
AC3	4	A	1894+20	Left
AC3	4	B	1894+20	Center
AC3	4	C	1894+20	Right
AC3	5	A	1894+60	Left
AC3	5	B	1894+60	Center
AC3	5	C	1894+60	Right*

* Core location

Table 117. ***Calibrated Thickness*** measured by ***GPR*** on ***US-280, AL, inch***
Note: Repeatability in measurements is shown in Table 119

Lot	Sublot	A	B	C	J	Average	Average by lot
AC1	1	3.85	3.99	4.64		4.16	
	2	3.76	4.03	4.47	2.69	3.74	
	3	3.32	3.64	4.10		3.69	
	5	3.00	3.46	3.97		3.48	3.76
AC2	1	2.51	2.42	2.62	2.85	2.60	
	2	2.75	2.63	2.70		2.69	
	3	2.53	2.40	2.66	2.88	2.62	
	4	2.89	2.61	2.83		2.78	
	5	2.90	2.54	2.72	3.10	2.82	2.70
AC3	1	No Data	No Data	No Data	No Data		
	2	No Data	No Data	No Data	No Data		
	3	No Data	No Data	No Data	No Data		
	4	No Data	No Data	No Data	No Data		
	5	No Data	No Data	No Data	No Data		
Segregated	seg 1-1	3.19		3.63		3.41	
	4, seg 1-2	3.01	3.47	3.61	2.30	3.10	
	seg 2-1	2.32		2.49		2.40	
	seg 2-2	2.42		2.47		2.45	
	seg 2-3	2.50		1.97		2.24	2.78
Average lot 1 by row		3.48	3.78	4.29	2.69		
Average lot 2 by row		2.72	2.52	2.71	2.94		
Average lot 3 by row		No Data	No Data	No Data	No Data		
Average lot 4 by row		2.69	3.47	2.83	2.30		
Average by row		2.93	3.12	3.21	2.77		
Average project							3.04

Table 118. ***Percent Air voids*** measured by ***GPR*** in ***US-280, AL***
Note: Repeatability in measurements is shown in Table 119

Lot	**Sublot**	**A**	**B**	**C**	**J**	**Average**	**Average by lot**
AC1	1	6.32	6.41	6.44		6.39	
	2	7.43	6.26	6.67	6.30	6.66	
	3	7.02	6.59	8.67		7.43	
	5	7.31	7.62	7.31		7.41	6.95
	1	7.11	6.04	7.04	7.83	7.01	
	2	7.37	6.17	5.34		6.29	
AC2	3	7.59	7.74	7.38	8.17	7.72	
	4	6.40	6.63	7.00		6.68	
	5	7.13	6.38	6.85	8.56	7.23	7.03
AC3	1	No Data	No Data	No Data	No Data		
	2	No Data	No Data	No Data	No Data		
	3	No Data	No Data	No Data	No Data		
	4	No Data	No Data	No Data	No Data		
	5	No Data	No Data	No Data	No Data		
Segregated	seg 1-1	7.72		7.68		7.70	
	4, seg 1-2	7.11	7.11	6.71	7.65	7.14	
	seg 2-1	6.58		6.24		6.41	
	seg 2-2	8.20		7.74		7.97	
	seg 2-3	7.94		6.81		7.37	7.30
Average lot 1 by row		7.02	6.72	7.27	6.30		
Average lot 2 by row		7.12	6.59	6.72	8.19		
Average lot 3 by row		No Data	No Data	No Data	No Data		
Average lot 4 by row		7.51	7.11	7.04	7.65		
Average by row		7.23	6.69	6.99	7.70		
Average project							7.08

Table 119. Repeatability measurements for ***Percent Air voids and Thickness*** measured by ***GPR*** on ***US-280, AL***
Note: Summary of results are shown in Table 117 and Table 118

Lot	Sublot	Test Point	Thickness (calibrated)					Air Voids			
			Trial 1	Trial 2	Average	Std dev		Trial 1	Trial 2	Average	Std dev
			(in)	(in)	(in)	(in)		percent	percent	percent	percent
AC 1	1	A	4.05	3.65	3.85	0.28		7.81	4.84	6.32	2.10
AC 1	1	B	3.95	4.02	3.99	0.05		5.69	7.13	6.41	1.02
AC 1	1	C	4.64	4.64	4.64	0.00		6.44	6.44	6.44	0.00
AC1	2	A	3.87	3.65	3.76	0.16		8.83	6.03	7.43	1.98
AC1	2	B	4.06	3.99	4.03	0.05		5.94	6.58	6.26	0.46
AC1	2	C	4.47	4.47	4.47	0.00		6.67	6.67	6.67	0.00
AC1	2	Joint 1-2	x	2.69	2.69	x		x	6.30	6.30	x
AC1	seg 1-1	A	3.06	3.31	3.19	0.18		8.54	6.90	7.72	1.16
AC1	seg 1-1	C	3.63	3.63	3.63	0.00		7.68	7.68	7.68	0.00
AC1	3	A	3.41	3.23	3.32	0.13		7.71	6.33	7.02	0.98
AC1	3	B	3.56	3.72	3.64	0.11		6.15	7.02	6.59	0.62
AC1	3	C	4.10	4.10	4.10	0.00		8.67	8.67	8.67	0.00
AC1	4, seg 1-2	A	2.90	3.13	3.01	0.16		7.68	6.53	7.11	0.81
AC1	4, seg 1-2	B	3.56	3.37	3.47	0.14		7.66	6.55	7.11	0.78
AC1	4, seg 1-2	C	3.61	3.61	3.61	0.00		6.71	6.71	6.71	0.00
AC1	4	Joint 1-4	x	2.30	2.30	x		x	7.65	7.65	x
AC1	5	A	2.96	3.05	3.00	0.06		8.06	6.56	7.31	1.06
AC1	5	B	3.46	3.47	3.46	0.01		7.05	8.18	7.62	0.80
AC1	5	C	3.97	3.97	3.97	0.00		7.31	7.31	7.31	0.00
AC2	1	A	2.48	2.54	2.51	0.04		6.90	7.33	7.11	0.30

Lot	Sublot	Test Point	Thickness (calibrated)					Air Voids			
			Trial 1	Trial 2	Average	Std dev		Trial 1	Trial 2	Average	Std dev
			(in)	(in)	(in)	(in)		percent	percent	percent	percent
AC2	1	B	2.44	2.41	2.42	0.02		6.28	5.79	6.04	0.35
AC2	1	C	2.62	2.62	2.62	0.00		6.84	7.24	7.04	0.28
AC2	1	Joint 2-1	2.85	x	2.85	x		7.83	x	7.83	x
AC2	seg 2-1	A	2.31	2.33	2.32	0.02		6.60	6.56	6.58	0.03
AC2	seg 2-1	C	2.53	2.44	2.49	0.06		6.08	6.40	6.24	0.23
AC2	2	A	2.70	2.80	2.75	0.07		7.79	6.94	7.37	0.60
AC2	2	B	2.68	2.58	2.63	0.07		6.59	5.75	6.17	0.60
AC2	2	C	2.70	2.70	2.70	0.00		5.49	5.18	5.34	0.22
AC2	seg 2-2	A	2.38	2.47	2.42	0.06		7.58	8.81	8.20	0.87
AC2	seg 2-2	C	2.48	2.47	2.47	0.01		7.48	8.01	7.74	0.37
AC2	3	A	2.50	2.56	2.53	0.04		7.30	7.89	7.59	0.42
AC2	3	B	2.34	2.47	2.40	0.09		7.17	8.31	7.74	0.81
AC2	3	C	2.66	2.66	2.66	0.00		7.62	7.14	7.38	0.34
AC2	3	Joint 2-3	2.88	x	2.88	x		8.17	x	8.17	x
AC2	4	A	2.89	2.89	2.89	0.00		6.58	6.23	6.40	0.24
AC2	4	B	2.60	2.63	2.61	0.02		6.90	6.36	6.63	0.38
AC2	4	C	2.85	2.81	2.83	0.03		7.59	6.41	7.00	0.84
AC2	seg 2-3	A	2.47	2.53	2.50	0.05		7.80	8.08	7.94	0.20
AC2	seg 2-3	C	2.35	1.60	1.97	0.53		6.58	7.04	6.81	0.32
AC2	5	A	2.88	2.92	2.90	0.03		6.97	7.29	7.13	0.23
AC2	5	B	2.55	2.53	2.54	0.02		6.38	6.38	6.38	0.00
AC2	5	C	2.79	2.66	2.72	0.09		6.36	7.35	6.85	0.69
AC2	5	Joint 2-5	3.10	x	3.10	x		8.56	x	8.56	x

Table 120. ***Density*** measured by Pavetracker – Non-nuclear Gage on ***US-280, AL, pcf***
Note: Test repetitions are shown in Table 121

Lot	Sublot	A	B	C	J	Average	Average by lot
AC1	1	130.3	131.6	128.1		130.0	
	2	124.2	133.9	130.2	128.4	129.2	
	3	129.0	131.7	128.5		129.7	
	5	122.7	128.8	128.1		126.5	128.9
	1	No Data	No Data	No Data	No Data		
	2	No Data	No Data	No Data	No Data		
AC2	3	No Data	No Data	No Data	No Data		
	4	No Data	No Data	No Data	No Data		
	5	No Data	No Data	No Data	No Data		
AC3	1	No Data	No Data	No Data	No Data		
	2	No Data	No Data	No Data	No Data		
	3	No Data	No Data	No Data	No Data		
	4	No Data	No Data	No Data	No Data		
	5	No Data	No Data	No Data	No Data		
Segregated	seg 1-1	126.1		117.7		121.9	
	4, seg 1-2	129.9	131.9	126.6	124.6	128.2	
	seg 2-1	No Data	No Data	No Data	No Data		
	seg 2-2	No Data	No Data	No Data	No Data		
	seg 2-3	No Data	No Data	No Data	No Data		126.1
Average lot 1 by row		126.5	131.5	128.7	128.4		
Average lot 2 by row		No Data	No Data	No Data	No Data		
Average lot 3 by row		No Data	No Data	No Data	No Data		
Average lot 4 by row		128.0	131.9	122.1	124.6		
Average by row		127.0	131.6	126.5	126.5		
Average project							128.0

Table 121. Repeatability in ***Density*** measured by ***Pavetracker*** on ***US-280, AL, pcf***
Note: Summary of results is shown in Table 120

Section	Location	Point	Density, pcf					
			Trial 1	Trial 2	Trial 3	Trial 4	Average	Stdev
AC 1	**1**	**A**	131.6	130.7	130.9	128.1	130.3	1.5
AC 1	**1**	**B**	132.5	130.3	130.1	133.6	131.6	1.7
AC 1	**1**	**C**	129.4	127.0	128.0	127.9	128.1	1.0
AC1	**2**	**A**	128.5	125.3	119.7	123.2	124.2	3.7
AC1	**2**	**B**	135.7	134.7	132.1	132.9	133.9	1.6
AC1	**2**	**C**	130.3	129.2	129.5	131.7	130.2	1.1
AC1	**2**	**Joint 1-2**	129.8	127.8	129.8	126.3	128.4	1.7
AC1	**seg 1-1**	A	124.8	124.2	131.7	123.5	126.1	3.8
AC1	**seg 1-1**	C	120.0	118.6	113.3	118.7	117.7	3.0
AC1	**3**	**A**	130.8	129.4	127.7	128.1	129.0	1.4
AC1	**3**	**B**	133.3	129.9	131.8	131.9	131.7	1.4
AC1	**3**	**C**	125.0	131.0	128.9	129.1	128.5	2.5
AC1	**4, seg 1-2**	**A**	130.6	131.1	125.5	132.2	129.9	3.0
AC1	**4, seg 1-2**	**B**	129.4	132.3	134.1	131.8	131.9	1.9
AC1	**4, seg 1-2**	**C**	126.0	127.5	125.5	127.4	126.6	1.0
AC1	**4**	**Joint 1-4**	128.5	120.9	124.9	123.9	124.6	3.1
AC1	**5**	**A**	125.5	123.6	121.4	120.1	122.7	2.4

Section	Location	Point	Density, pcf					
			Trial 1	Trial 2	Trial 3	Trial 4	Average	Stdev
AC1	**5**	**B**	127.7	128.3	129.8	129.4	128.8	1.0
AC1	**5**	**C**	127.1	127.6	126.9	130.8	128.1	1.8

Table 122. ***Density*** measured by PQI – Non-nuclear Gage on **US-280, AL, pcf**
Note: Test repetitions are shown in Table 126

Lot	**Sublot**	**A**	**B**	**C**	**J**	**Average**	**Average by lot**
AC1	1	147.8	148.2	144.9	146.2	146.8	
	2	148.0	148.7	146.1	150.1	148.2	
	3	148.3	148.0	145.4		147.2	
	5	149.2	151.1	146.5		148.9	147.7
	1	155.0	154.1	150.2	149.5	152.2	
	2	155.0	156.6	152.4		154.7	
AC2	3	156.1	153.1	144.6	151.5	151.3	
	4	155.3	159.1	149.4		154.6	
	5	No Data	No Data	No Data	No Data		153.0
AC3	1	138.6	138.9	141.4	140.0	139.7	
	2	140.9	140.6	143.0	141.1	141.4	
	3	144.5	142.8	141.2	143.9	143.1	
	4	142.6	142.5	142.3		142.5	
	5	141.1	141.9	136.6		139.9	141.3
Segregated	seg 1-1	149.5		146.9		148.2	
	4, seg 1-2	148.6	152.1	148.5	147.8	149.3	
	seg 2-1	156.4		151.9		154.2	
	seg 2-2	147.1		143.7		145.4	
	seg 2-3	No Data	No Data	No Data	No Data		149.2
Average lot 1 by row		148.3	149.0	145.7	148.2		
Average lot 2 by row		155.4	155.7	149.1	150.5		
Average lot 3 by row		141.5	141.4	140.9	141.7		
Average lot 4 by row		150.4	152.1	147.7	147.8		
Average by row		148.5	148.4	145.6	146.3		
Average project							147.3

Table 123. Repeatability in ***Density*** measured by ***PQI*** on ***US-280, AL, pcf***
Note: Summary of results is shown in Table 125

Lot	Sublot	Point	Density, pcf							Comments
			Trial 1	Trial 2	Trial 3	Trial 4	Trial 5	Average	Stdev	
AC 1	1	A	149.7	150.1	143.7	147.2	148.4	147.8	2.6	Foggy, light rain previous day
AC 1	1	B	148.7	147.1	150.2	147.3	147.7	148.2	1.3	
AC 1	1	C	145.1	144.3	141.4	145.4	148.3	144.9	2.5	
			148.1	144.8	144.9	152.3	141.0	146.2	4.2	
AC1	2	A	144.1	148.2	149.0	149.2	149.3	148.0	2.2	
AC1	2	B	148.7	149.1	148.4	147.1	150.1	148.7	1.1	
AC1	2	C	147.4	147.9	144.2	144.7	146.2	146.1	1.6	
AC1	2	Joint 1-2	147.0	151.5	150.7	150.6	150.7	150.1	1.8	
AC1	seg 1-1	A	144.3	150.7	150.8	151.6	149.9	149.5	2.9	
AC1	seg 1-1	C	148.2	148.6	147.1	143.6	146.8	146.9	2.0	
AC1	3	A	151.3	148.9	144.6	147.5	149.2	148.3	2.5	
AC1	3	B	147.3	149.0	146.2	147.2	150.1	148.0	1.6	
AC1	3	C	143.5	144.2	147.6	146.2	145.6	145.4	1.6	
AC1	4, seg 1-2	A	143.9	142.8	153.9	150.3	152.2	148.6	5.0	
AC1	4, seg 1-2	B	153.4	153.4	153.6	153.1	147.1	152.1	2.8	
AC1	4, seg 1-2	C	149.8	149.0	147.0	146.3	150.3	148.5	1.8	
AC1	4	Joint 1-4	150.7	146.5	146.9	147.0	148.0	147.8	1.7	
AC1	5	A	152.1	147.8	147.5	149.5	149.3	149.2	1.8	
AC1	5	B	151.3	150.5	147.9	152.6	153.2	151.1	2.1	
AC1	5	C	147.4	147.4	145.1	148.2	144.3	146.5	1.7	
AC2	1	A	155.2	152.7	155.7	157.1	154.3	155.0	1.6	

Lot	Sublot	Point	Density, pcf							Comments
			Trial 1	Trial 2	Trial 3	Trial 4	Trial 5	Average	Stdev	
AC2	1	B	155.8	154.2	153.4	153.9	153.4	154.1	1.0	
AC2	1	C	150.4	153.7	149.7	146.3	150.9	150.2	2.7	Surface wet shoulder core
AC2	1	Joint 2-1	149.7	146.7	149.7	151.7	149.8	149.5	1.8	
AC2	seg 2-1	A	154.9	158.1	156.6	158.2	154.4	156.4	1.8	
AC2	seg 2-1	C	152.6	146.0	152.2	153.0	155.7	151.9	3.6	
AC2	2	A	157.0	155.7	153.9	153.0	155.5	155.0	1.6	
AC2	2	B	158.6	157.8	157.4	155.2	154.2	156.6	1.9	
AC2	2	C	154.7	151.4	151.4	150.2	154.2	152.4	2.0	
AC2	seg 2-2	A	139.1	156.4	145.9	147.7	146.3	147.1	6.2	Overcast, 81.7F
AC2	seg 2-2	C	143.2	143.7	144.2	140.6	146.8	143.7	2.2	Showing corner aggregate
AC2	3	A	155.9	155.1	156.3	156.7	156.4	156.1	0.6	
AC2	3	B	148.0	158.6	151.2	153.2	154.5	153.1	3.9	
AC2	3	C	141.5	148.3	147.1	136.8	149.5	144.6	5.3	
AC2	3	Joint 2-3	148.5	153.5	153.8	147.9	153.8	151.5	3.0	Joint appears to be confined jt
AC2	4	A	154.1	158.3	154.9	153.7	155.7	155.3	1.8	Sunny and partly cloudy, 89.8F
AC2	4	B	160.5	158.4	157.4	159.7	159.4	159.1	1.2	
AC2	4	C	150.8	150.3	148.7	150.1	146.9	149.4	1.6	
AC2	seg 2-3	A	No data	No data	No data	No data	No data	No data	No data	
AC2	seg 2-3	C	No data	No data	No data	No data	No data	No data	No data	
AC2	5	A	No data	No data	No data	No data	No data	No data	No data	
AC2	5	B	No data	No data	No data	No data	No data	No data	No data	
AC2	5	C	No data	No data	No data	No data	No data	No data	No data	
AC2	5	Joint 2-5	No data	No data	No data	No data	No data	No data	No data	

Lot	Sublot	Point	Density, pcf							Comments
			Trial 1	Trial 2	Trial 3	Trial 4	Trial 5	Average	Stdev	
AC3	1	A	137.3	136.9	140.7	139.4	138.8	138.6	1.6	126.25F
AC3	1	B	137.5	139.5	137.9	139.5	140.3	138.9	1.2	112.5F
AC3	1	C	142.5	142.0	140.2	139.1	143.4	141.4	1.8	107.1F
AC3	1	Joint 3-1	137.7	140.4	141.0	142.4	138.3	140.0	1.9	
AC3	2	A	142.6	138.1	141.2	142.5	140.0	140.9	1.9	
AC3	2	B	140.6	140.2	139.8	140.1	142.5	140.6	1.1	
AC3	2	C	142.4	145.3	142.6	141.8	143.0	143.0	1.3	
AC3	2	Joint 3-2	141.8	140.3	141.2	139.6	142.8	141.1	1.3	
AC3	3	A	145.1	145.4	144.1	143.6	144.2	144.5	0.7	127 F
AC3	3	B	142.9	143.1	142.0	142.0	144.0	142.8	0.8	
AC3	3	C	143.2	141.3	138.9	139.1	143.5	141.2	2.2	
AC3	3	Joint 3-3	144.1	140.9	147.3	147.8	139.6	143.9	3.7	
AC3	4	A	141.2	142.7	145.0	142.2	141.8	142.6	1.5	Unconfined
AC3	4	B	139.0	142.6	142.7	144.0	144.3	142.5	2.1	
AC3	4	C	143.4	142.2	140.1	141.0	144.6	142.3	1.8	139 F, much segregation (only C)
AC3	5	A	139.4	142.1	144.8	141.8	137.6	141.1	2.8	Unconfined
AC3	5	B	141.5	144.5	141.7	139.6	142.0	141.9	1.8	
AC3	5	C	137.4	139.2	134.9	135.7	135.7	136.6	1.7	Temp = 133F

Other notes from testing
Density slope=1.001; H20 offset -1.6; Density offset 0.01
Gage set for 19mm mix, 3" lift; After test point B changed mix type to13 mm mix

Table 124. ***FWD Modulus*** on ***US-280, AL, psi***

Lot	Sublot	A			B			C			Joint		
		Subgrade	Base	HMA	Subgrade	Base	HMA	Subgrade	Base	HMA	Subgrade	Base	HMA
AC1	1	20,410	47,179	220,478	22,828	52,768	269,241	12,337	28,517	215,410			
		16,222	37,499	210,783	19,644	45,409	234,930	10,781	24,920	169,156			
		14,293	33,040	194,989	17,914	41,408	227,804	10,023	23,168	168,524			
	2	18,654	43,121	245,598	20,986	48,510	378,388	13,570	31,369	287,057	15,625	36,118	113,773
		14,338	33,142	212,955	17,008	39,316	265,601	11,215	25,925	214,876	12,540	28,987	118,177
		12,669	29,285	200,729	14,285	33,021	259,826	9,997	23,109	218,105	11,000	25,426	127,441
	seg 1-1	20,196	46,684	192,755				15,301	35,368	96,484			
		17,074	39,467	176,084				14,475	33,461	99,223			
		15,611	36,087	185,291				14,166	32,745	109,608			
	3	24,475	56,576	171,731	27,491	63,548	216,386	16,448	38,021	193,003			
		21,595	49,919	167,891	23,974	55,417	199,364	14,757	34,113	179,101			
		20,853	48,203	167,225	22,064	51,002	198,035	14,219	32,869	178,834			
	4, seg 1-2	23,929	55,313	161,342	22,030	50,924	215,322	12,613	29,157	219,889	24,702	57,100	165,981
		19,816	45,806	155,228	18,200	42,069	192,844	10,210	23,600	183,815	20,348	47,036	169,703
		17,825	41,205	157,578	15,658	36,194	178,787	8,946	20,679	173,004	18,390	42,510	171,048
	5	13,413	31,005	197,249	14,304	33,065	229,908	10,084	23,309	217,390			
		9,780	22,607	170,893	10,432	24,114	201,188	7,791	18,009	192,914			
		8,135	18,804	174,593	8,757	20,242	200,680	6,669	15,416	181,124			
AC2	1	25,388	58,685	156,919	23,969	55,406	142,641	15,292	35,350	95,998	20,329	46,992	114,769
		20,546	47,494	146,141	20,498	47,382	132,269	13,112	30,310	92,021	16,382	37,868	112,514
		18,120	41,885	150,079	18,407	42,550	138,427	11,789	27,250	95,963	14,338	33,144	120,346

Lot	Sublot	A			B			C			Joint		
		Subgrade	Base	HMA	Subgrade	Base	HMA	Subgrade	Base	HMA	Subgrade	Base	HMA
	seg 2-1	25,244	58,353	150,669				11,204	25,898	92,039			
		20,956	48,442	148,496				9,567	22,115	87,532			
		18,457	42,664	151,275				8,842	20,440	90,139			
	2	31,267	72,277	135,586	32,903	76,058	155,761	17,202	39,764	110,778			
		28,095	64,943	132,088	30,466	70,424	142,156	14,645	33,853	110,945			
		26,798	61,947	140,359	29,318	67,771	143,022	13,920	32,177	123,536			
	seg 2-2	8,561	19,789	133,438				7,300	16,875	88,817	8,666	20,032	157,660
		6,180	14,286	119,010				5,542	12,810	98,269	6,322	14,614	145,293
		5,411	12,508	116,760				4,709	10,885	102,459	5,473	12,650	148,766
	3	9,060	20,944	141,149	8,292	19,167	141,384	5,680	13,130	57,673			
		6,691	15,467	129,438	6,148	14,211	125,849	4,414	10,204	59,190			
		5,824	13,462	130,686	5,420	12,528	121,764	3,925	9,072	61,913			
	4	31,274	72,292	132,419	25,649	59,289	157,608	14,630	33,818	96,392			
		27,394	63,322	124,344	22,817	52,743	142,255	13,295	30,733	102,559			
		24,813	57,356	130,474	21,511	49,725	139,379	12,475	28,838	106,651			
	seg 2-3	22,794	52,690	151,338				10,623	24,556	89,047			
		17,356	40,120	120,916				8,493	19,631	91,930			
		14,862	34,354	115,189				7,541	17,431	85,896			
	5	19,263	44,528	144,725	17,709	40,937	158,321	10,859	25,102	105,356	18,558	42,898	119,152
		14,783	34,172	135,001	13,900	32,131	150,460	9,585	22,157	116,042	14,618	33,790	115,754
		12,701	29,360	137,712	12,154	28,094	151,535	8,466	19,570	116,112	12,401	28,666	126,258
AC3	1	8,826	20,402	70,549	8,826	20,402	74,133	7,718	17,842	64,778	10,514	24,304	146,564

Lot	Sublot	A			B			C			Joint		
		Subgrade	Base	HMA	Subgrade	Base	HMA	Subgrade	Base	HMA	Subgrade	Base	HMA
		6,022	13,919	76,661	6,022	13,919	78,956	5,356	12,381	69,805	8,227	19,018	151,070
		5,105	11,801	86,057	5,105	11,801	90,258	4,505	10,414	81,859	6,906	15,964	156,295
	2	12,672	29,293	68,777	12,672	29,293	70,115	10,961	25,338	66,958	14,244	32,927	94,370
		8,954	20,697	71,161	8,954	20,697	74,233	7,649	17,680	72,590	10,170	23,509	89,012
		7,654	17,692	83,290	7,654	17,692	87,946	6,322	14,613	96,425	8,608	19,899	97,725
	3	12,878	29,769	99,765	12,878	29,769	106,459	9,879	22,837	58,315	13,497	31,199	76,631
		9,162	21,178	95,467	9,162	21,178	103,344	7,134	16,491	63,656	9,813	22,683	77,674
		7,705	17,810	109,934	7,705	17,810	115,581	6,268	14,490	77,284	8,402	19,421	89,716
	4	15,270	35,297	82,681	15,270	35,297	86,481	13,780	31,854	73,800			
		11,288	26,093	84,100	11,288	26,093	88,400	9,899	22,882	79,153			
		9,632	22,265	91,961	9,632	22,265	101,078	8,615	19,913	90,999			
	5	15,512	35,856	67,463	15,512	35,856	67,463	13,159	30,417	63,659			
		10,932	25,271	70,494	10,932	25,271	73,800	9,495	21,948	68,702			
		9,220	21,312	84,663	9,220	21,312	87,189	8,260	19,094	78,413			

Table 125. ***Modulus*** measured by PSPA on **US-280, AL, ksi**
Note: Repeatability data is presented in Table 126

Lot	**Sublot**	**A**	**B**	**C**	**J**	**Average**	**Average by lot**
AC1	1	542	464	500		502	
	2	503	601	538	396	509	
	3	481	600	489		523	
	5	462	506	422		463	500
	1	464	412	413	383	418	
	2	470	481	408		453	
AC2	3	456	418	327	325	382	
	4	476	431	360		423	
	5	463	419	361	362	402	413
AC3	1	142	173	177	167	165	
	2	176	189	179	213	189	
	3	175	185	185	226	193	
	4	145	204	187		178	
	5	187	174	212		191	183
Segregated	seg 1-1	374		290		332	
	4, seg 1-2	367	482	404	374	407	
	seg 2-1	390		300		345	
	seg 2-2	352		212		282	
	seg 2-3	377		233		305	346
Average lot 1 by row		497	543	487	396		
Average lot 2 by row		466	432	374	357		
Average lot 3 by row		165	185	188	202		
Average lot 4 by row		372	482	288	374		
Average by row		369	383	326	306		
Average project							351

Table 126. Repeatability in ***Modulus*** measured by ***PSPA*** on ***US-280, AL, ksf***
Note: Summary of results is shown in Table 125

Lot	Sublot	Point	Trial 1	Trial 2	Trial 3	Average	Stdev
AC 1	1	A	518	530	580	542	**32.8**
AC 1	1	B	524	369	499	464	**83.2**
AC 1	1	C	462	505	533	500	**35.9**
AC1	2	A	465	457	586	503	**72.1**
AC1	2	B	530	611	663	601	**67.1**
AC1	2	C	539	552	524	538	**14.0**
AC1	2	Joint 1-2	390	446	350	396	**48.2**
AC1	seg 1-1	A	362	383	376	374	**11.1**
AC1	seg 1-1	C	257	302	312	290	**29.2**
AC1	3	A	452	490	502	481	**25.8**
AC1	3	B	545	657	598	600	**55.8**
AC1	3	C	449	511	505	489	**34.1**
AC1	4, seg 1-2	A	378	332	390	367	**31.0**
AC1	4, seg 1-2	B	477	432	536	482	**52.1**
AC1	4, seg 1-2	C	403	446	364	404	**41.1**
AC1	4	Joint 1-4	344	366	412	374	**34.8**
AC1	5	A	467	491	427	462	**32.5**
AC1	5	B	555	475	486	506	**43.4**
AC1	5	C	402	414	452	422	**26.1**
AC2	1	A	407	514	470	464	**53.9**
AC2	1	B	372	410	454	412	**41.1**
AC2	1	C	379	374	486	413	**63.4**
AC2	1	Joint 2-1	366	424	360	383	**35.7**
AC2	seg 2-1	A	405	390	374	390	**15.6**
AC2	seg 2-1	C	340	256	306	300	**42.3**
AC2	2	A	410	480	521	470	**55.8**
AC2	2	B	505	524	413	481	**59.1**
AC2	2	C	369	464	391	408	**49.5**
AC2	seg 2-2	A	331	376	350	352	**22.2**
AC2	seg 2-2	C	186	172	278	212	**57.4**

Lot	Sublot	Point	Trial 1	Trial 2	Trial 3	Average	Stdev
AC2	3	A	483	410	476	456	**40.5**
AC2	3	B	429	378	448	418	**36.1**
AC2	3	C	316	283	381	327	**50.1**
AC2	3	Joint 2-3	308	411	257	325	**78.5**
AC2	4	A	506	401	521	476	**65.3**
AC2	4	B	459	456	379	431	**45.8**
AC2	4	C	340	401	340	360	**35.5**
AC2	seg 2-3	A	404	390	336	377	**35.8**
AC2	seg 2-3	C	277	141	280	233	**79.5**
AC2	5	A	479	443	469	463	**18.5**
AC2	5	B	423	405	430	419	**12.6**
AC2	5	C	378	308	397	361	**47.1**
AC2	5	Joint 2-5	270	433	384	362	**83.5**
AC3 *	1	A	127	153	146	142	**13.6**
AC3 *	1	B	169	179	169	173	**5.6**
AC3 *	1	C	199	168	166	177	**18.3**
AC3 *	1	Joint 3-1	156	199	146	167	**27.7**
AC3 *	2	A	195	159	173	176	**17.9**
AC3 *	2	B	204	186	177	189	**13.5**
AC3 *	2	C	195	177	166	179	**14.5**
AC3 *	2	Joint 3-2	252	208	177	213	**37.8**
AC3 *	3	A	176	174	174	175	**1.3**
AC3 *	3	B	201	168	188	185	**16.9**
AC3 *	3	C	223	172	161	185	**33.4**
AC3 *	3	Joint 3-3	192	250	237	226	**30.4**
AC3 *	4	A	131	149	154	145	**12.4**
AC3 *	4	B	261	191	158	204	**53.0**
AC3 *	4	C	210	154	196	187	**29.2**
AC3 *	5	A	141	164	257	187	**61.1**
AC3 *	5	B	190	172	159	174	**15.5**
AC3 *	**5**	**C**	**226**	**151**	**258**	**212**	**54.6**

* Tested soon after paving on new section one day after testing AC1 and AC2
** Note: Modulus determined based on HMA thickness of 3 inch

Table 127. ***Density*** measured by Nuclear Gauge on **US-280, AL, pcf**
Note: Repeatability data is presented in Table 128

Lot	Sublot	A	B	C	J	Average	Average by lot
AC1	1	148.0	153.1	145.9		149.0	
	2	150.9	157.5	150.8	145.4	151.1	
	3	151.9	156.4	148.6		152.3	
	5	148.3	153.0	149.0		150.1	150.7
	1	155.8	151.6	151.2	149.3	151.9	
	2	156.8	154.0	151.6		154.1	
AC2	3	154.4	147.0	135.6	144.4	145.4	
	4	156.0	154.0	147.6		152.5	
	5	156.2	154.7	147.2	147.6	151.4	150.8
AC3	1	149.8	144.8	148.4	146.3	147.3	
	2	152.3	152.6	154.0	151.2	152.5	
	3	158.7	155.2	150.3	156.5	155.1	
	4	153.7	154.5	153.2		153.8	
	5	152.3	153.3	142.8		149.4	151.6
Segregated	seg 1-1	146.0		141.4		143.7	
	4, seg 1-2	149.0	157.0	149.6	146.2	150.4	
	seg 2-1	148.4		143.7		146.1	
	seg 2-2	149.7		143.7		146.7	
	seg 2-3	148.8		129.3		139.0	146.0
Average lot 1 by row		497	543	487	396		
Average lot 2 by row		466	432	374	357		
Average lot 3 by row		165	185	188	202		
Average lot 4 by row		372	482	288	374		
Average by row		369	383	326	306		
Average project							351

Table 128. Repeatability data for ***Density*** measured by Nuclear Gauge on **US-280, AL, pcf**
Note: Summary of test results is presented in Table 127

Lot	Sublot	Point	Trial 1	Trial 2	Average	Stdev
AC 1*	1	A	147.6	148.3	148.0	**0.49**
AC 1	1	B	152.4	153.7	153.1	**0.92**
AC 1	1	C	147.3	144.5	145.9	**1.98**
AC1	2	A	149.9	151.8	150.9	**1.34**
AC1	2	B	156.7	158.3	157.5	**1.13**
AC1	2	C	155.4	146.1	150.8	**6.58**
AC1	2	Joint 1-2	146.2	144.6	145.4	**1.13**
AC1	seg 1-1	A	146.4	145.6	146.0	**0.57**
AC1	seg 1-1	C	139.0	143.7	141.4	**3.32**
AC1	3	A	151.3	152.4	151.9	**0.78**
AC1*	3	B	157.3	155.5	156.4	**1.27**
AC1	3	C	148.2	148.9	148.6	**0.49**
AC1	4, seg 1-2	A	148.7	149.2	149.0	**0.35**
AC1	4, seg 1-2	B	157.1	156.8	157.0	**0.21**
AC1	4, seg 1-2	C	151.4	147.8	149.6	**2.55**
AC1	4	Joint 1-4	145.7	146.7	146.2	**0.71**
AC1	5	A	148.6	148.0	148.3	**0.42**
AC1	5	B	153.3	152.7	153.0	**0.42**
AC1	5	C	150.5	147.5	149.0	**2.12**
AC2	1	A	155.6	156.0	155.8	**0.28**
AC2	1	B	151.4	151.7	151.6	**0.21**
AC2*	1	C	149.4	152.9	151.2	**2.47**
AC2	1	Joint 2-1	147.0	151.5	149.3	**3.18**
AC2	seg 2-1	A	149.6	147.2	148.4	**1.70**
AC2	seg 2-1	C	139.7	147.7	143.7	**5.66**
AC2	2	A	157.1	156.4	156.8	**0.49**
AC2	2	B	152.2	155.7	154.0	**2.47**
AC2	2	C	152.5	150.6	151.6	**1.34**
AC2*	seg 2-2	A	150.0	149.3	149.7	**0.49**
AC2	seg 2-2	C	139.7	147.7	143.7	**5.66**

Lot	Sublot	Point	Trial 1	Trial 2	Average	Stdev
AC2	3	A	154.0	154.8	154.4	**0.57**
AC2*	3	B	145.9	148.1	147.0	**1.56**
AC2	3	C	134.2	137.0	135.6	**1.98**
AC2	3	Joint 2-3	145.6	143.2	144.4	**1.70**
AC2	4	A	155.3	156.7	156.0	**0.99**
AC2	4	B	154.8	153.1	154.0	**1.20**
AC2	4	C	146.2	149.0	147.6	**1.98**
AC2	seg 2-3	A	148.9	148.6	148.8	**0.21**
AC2*	seg 2-3	C	130.6	128.0	129.3	**1.84**
AC2*	5	A	156.0	156.3	156.2	**0.21**
AC2	5	B	154.0	155.3	154.7	**0.92**
AC2	5	C	148.4	146.0	147.2	**1.70**
AC2	5	Joint 2-5	145.5	149.6	147.6	**2.90**
AC3	1	A	149.0	150.5	149.8	**1.06**
AC3*	1	B	145.9	143.7	144.8	**1.56**
AC3	1	C	151.2	145.6	148.4	**3.96**
AC3	1	Joint 3-1	147.3	145.3	146.3	**1.41**
AC3	2	A	153.7	150.9	152.3	**1.98**
AC3	2	B	154.5	150.6	152.6	**2.76**
AC3	2	C	155.0	153.0	154.0	**1.41**
AC3	2	Joint 3-2	150.4	151.9	151.2	**1.06**
AC3*	3	A	156.4	160.9	158.7	**3.18**
AC3	3	B	154.0	156.3	155.2	**1.63**
AC3	3	C	154.7	145.8	150.3	**6.29**
AC3	3	Joint 3-3	157.6	155.3	156.5	**1.63**
AC3	4	A	153.3	154.1	153.7	**0.57**
AC3	4	B	154.4	154.5	154.5	**0.07**
AC3	4	C	156.3	150.0	153.2	**4.45**
AC3	5	A	148.2	156.3	152.3	**5.73**
AC3	5	B	152.6	154.0	153.3	**0.99**
AC3*	**5**	**C**	**144.7**	**140.8**	**142.8**	**2.76**

* Core location

Table 129. Core height measurements on **US-280, AL, inch**

Specimen, lot-sublot point	**Height Measurements**				
	1	**2**	**3**	**4**	Average
1-1A	3.67	3.70	3.72	3.71	3.70
1-3B	3.91	3.89	3.91	3.97	3.92
2-5A	2.34	2.41	2.41	2.34	2.38
2-3B	2.02	1.99	2.01	2.05	2.02
2-1C	2.49	2.43	2.49	2.57	2.49
3-3A	3.13	3.39	3.54	3.53	3.40
3-1B	2.74	2.73	3.06	3.03	2.89
3-5C	2.95	2.87	2.96	2.90	2.92
2-SEG-2	2.47	2.38	2.35	2.35	2.39
2-SEG-3	2.44	2.45	2.39	2.14	2.36

Table 130. Air voids from cores on **US-280, AL**

Specimen, lot-sublot point	**Dry Weight, gm**	**Submerged Weight, gm**	**SSD Weight, gm**	**Bulk Specific Gravity Gmb**	**Theor. Max Spec gravity, Gmm**	**Percent Air Voids**
1-1A	3947.4	2357.4	3962.2	2.460	2.595	5.2
1-3B	4139.6	2485.8	4176.2	2.449	2.595	5.6
2-5A	2466.7	1462.3	2475.8	2.434	2.595	6.2
2-3B	1947.7	1144.9	1971.4	2.357	2.595	9.2
2-1C	2554.1	1503.1	2576.1	2.380	2.595	8.3
2-SEG-2A (seg 2-1)	2426.7	1442.1	2452.9	2.401	2.595	7.5
2-SEG-3C (seg 2-2)	2090.5	1259.4	2141.0	2.371	2.595	8.6
3-3A	3681.0	2209.6	3689.4	2.487	2.595	4.1
3-1B	2803.7	1673.6	2848.5	2.386	2.595	8.0
3-5C	2972.7	1781.2	3015.2	2.409	2.595	7.2

Table 131. ***Dynamic Modulus*** Test results for ***US-280, AL, HMA,*** psi

Temperature, °F	Replicate	E* Measured at Frequency					
		25	10	5	1	0.5	0.1
14	**1**	13,009,380	11,924,665	11,139,959	9,635,259	7,409,783	**7,022,192**
	3	6,375,896	5,540,466	5,060,779	3,869,095	2,280,320	**2,194,288**
	4	9,425,734	8,966,325	8,380,664	7,369,893	6,020,622	**5,762,810**
	Average	9,603,670	8,810,486	8,193,800	6,958,082	5,236,908	**4,993,097**
	CV, %	34.57	36.26	37.15	41.75	50.66	**50.16**
40	**1**	4,865,976	4,245,618	3,897,675	3,050,351	2,791,658	**1,948,051**
	3	6,274,929	5,549,240	5,194,577	4,104,199	3,797,716	**2,666,990**
	4	7,113,378	6,149,527	5,851,215	4,636,901	4,545,273	**3,273,767**
	Average	6,084,761	5,314,795	4,981,156	3,930,483	3,711,549	**2,629,603**
	CV, %	18.66	18.31	19.96	20.54	23.71	**25.24**
70	**1**	2,281,738	1,765,079	1,504,751	1,040,928	835,337	**546,458**
	3	2,711,620	2,286,282	2,017,255	1,402,998	1,156,730	**855,111**
	4	3,142,792	2,516,690	2,197,275	1,546,222	1,294,956	**883,390**
	Average	2,712,050	2,189,350	1,906,427	1,330,049	1,095,674	**761,653**
	CV, %	15.87	17.59	18.85	19.58	21.52	**24.54**
100	**1**	827,113	651,153	513,820	339,058	276,406	**189,701**
	3	1,466,890	1,142,896	982,989	689,435	576,676	**426,914**
	4	1,307,978	1,050,057	860,544	582,136	484,894	**334,130**
	Average	1,200,660	948,035	785,784	536,876	445,992	**316,915**
	CV, %	27.74	27.56	30.97	33.44	34.50	**37.72**

Temperature, °F	Replicate	E* Measured at Frequency					
		25	10	5	1	0.5	0.1
130	**1**	322,602	247,715	219,758	156,174	118,091	**94,048**
	3	691,771	542,453	463,773	330,405	277,505	**208,337**
	4	447,302	364,616	287,319	196,150	158,994	**115,581**
	Average	487,225	384,928	323,617	227,576	184,863	**139,322**
	CV, %	**38.54**	**38.56**	**38.93**	**40.10**	**44.79**	**43.59**

Table 132. ***Repeated load*** test results for ***US-280, AL, HMA,*** psi

Replicate	Repeated Load @ 147 deg F			
	Flow time, cycles	Applied stress, psi	Maximum LVDT slope	Minimum LVDT slope
1	10000	72.5	0.563	**0.572**
2	10000	74.8	0.180	**0.179**
3				
Average		73.7	0.372	**0.376**
CV, %		**2.21**	**72.90**	**74.01**

NOTE: Sample 3 was damaged during testing.

I-85, AL HMA OVERLAY SECTIONS (TESTED IN OCTOBER 2004)

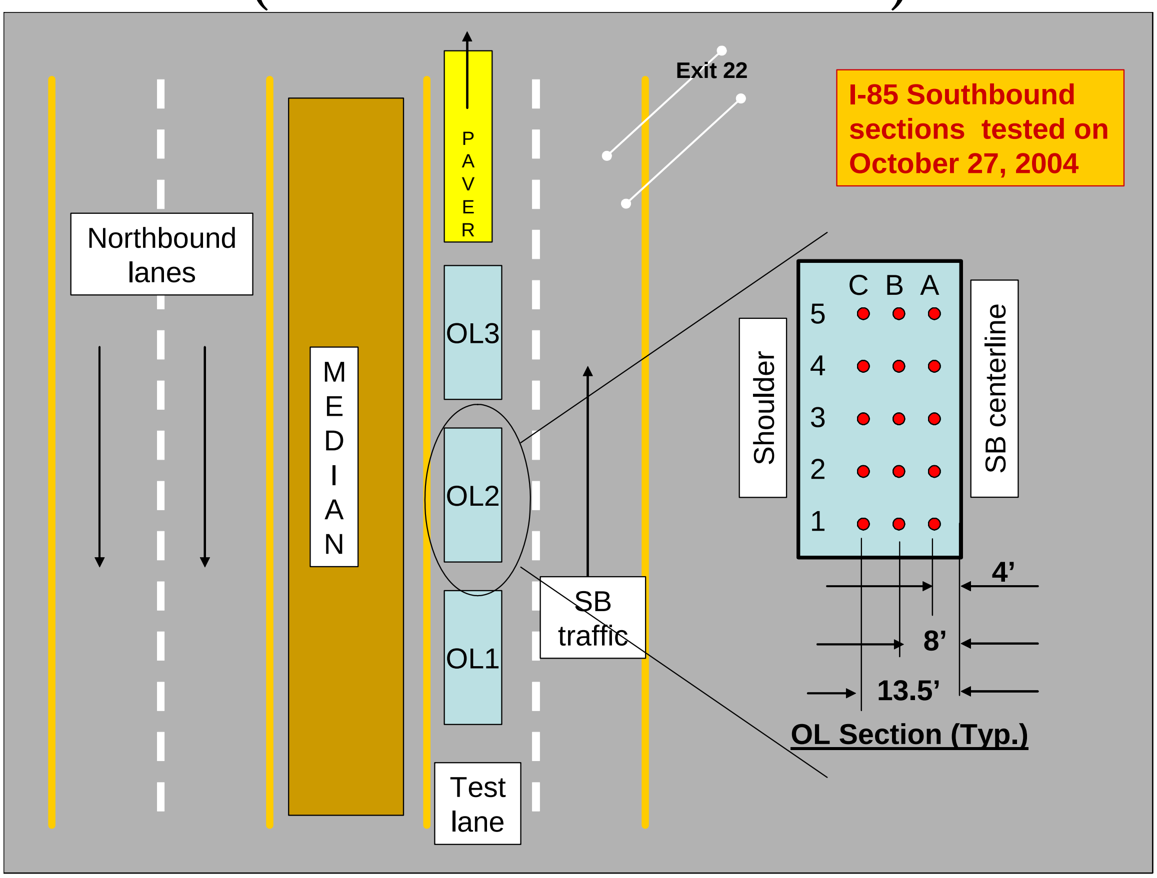


Table 133. Test point station information for I-85, AL HMA sections

Lot	Sublot	Point	Station	Offset		
				A	B	C
OL1	1	A	72+00	R*	C	L
OL1	2	A	71+00	R	C	L
OL1	3	A	70+00	R	C	L
OL1	4	A	69+00	R	C*	L
OL1	5	A	68+00	R	C	L*
OL2	1	A	64+00	R	C	L
OL2	2	A	63+00	R	C*	L
OL2	3	A	62+00	R	C	L*
OL2	4	A	61+00	R*	C	L
OL2	5	A	60+00	R	C	L
OL3	1	A	56+00	R	C	L
OL3	2	A	55+00	R	C	L*
OL3	3	A	54+00	R	C*	L
OL3	4	A	53+00	R	C	L
OL3	5	A	52+00	R*	C	L

* Core location

Table 134. ***Calibrated Thickness*** measured by ***GPR*** on ***I-85, AL, inch***
Note: Repeatability in measurements is shown in Table 136

Lot	Sublot	A	B	C	Average	Average by lot
OL1	1	1.46	2.09	2.46	2.01	
	2	1.23	1.31	1.43	1.32	
	3	1.20	1.19	1.35	1.25	
	4	1.14	1.45	1.80	1.46	
	5	1.32	1.34	1.57	1.41	1.49
OL2	1	1.17	1.10	1.09	1.12	
	2	1.06	0.97	1.46	1.16	
	3	1.01	0.93	1.27	1.07	
	4	0.96	1.03	1.39	1.13	
	5	1.02	1.05	1.31	1.13	1.12
OL3	1	1.19	1.21	0.95	1.12	
	2	1.08	1.03	1.12	1.08	
	3	1.23	1.13	1.07	1.14	
	4	1.16	1.08	0.81	1.01	
	5	1.28	1.27	1.04	1.20	1.11
Average lot 1 by row		1.27	1.47	1.72		
Average lot 2 by row		1.05	1.02	1.30		
Average lot 3 by row		1.19	1.15	1.00		
Average by row		1.17	1.21	1.34		
Average project						1.24

Table 135. ***Percent Air voids*** measured by ***GPR*** in ***I-85, AL***
Note: Repeatability in measurements is shown in Table 136

Lot	**Sublot**	**A**	**B**	**C**	**Average**	**Average by lot**
OL1	1	5.51	10.30	8.52	8.11	
	2	8.25	10.70	9.14	9.37	
	3	6.89	9.46	8.57	8.31	
	4	6.94	10.41	8.16	8.50	
	5	6.00	9.15	8.70	7.95	8.45
OL2	1	5.90	5.28	7.87	6.35	
	2	5.52	7.23	7.98	6.91	
	3	4.74	6.31	8.00	6.35	
	4	5.14	6.35	7.40	6.30	
	5	7.26	8.04	12.53	9.28	7.04
OL3	1	11.94	10.42	6.85	9.74	
	2	10.86	9.30	7.33	9.16	
	3	14.48	9.73	7.99	10.73	
	4	13.72	12.77	9.23	11.91	
	5	14.54	11.47	9.83	11.94	10.70
Average lot 1 by row		6.72	10.00	8.62		
Average lot 2 by row		5.71	6.64	8.76		
Average lot 3 by row		13.11	10.74	8.24		
Average by row		8.51	9.13	8.54		
Average project						8.73

Table 136. Repeatability measurements for ***Percent Air voids and Thickness*** measured by ***GPR*** on ***I-85, AL***
Note: Summary of results are shown in Table 134 and Table 135

Lot	Sublot	Test Point	Thickness (calibrated)					Air Voids			
			Trial 1	Trial 2	Average	Std dev		Trial 1	Trial 2	Average	Std dev
			(in)	(in)	(in)	(in)		percent	percent	percent	percent
OL1	1	A	1.46	1.45	1.46	0.00		5.05	5.97	5.51	0.46
OL1	1	B	2.03	2.16	2.09	0.07		9.18	11.42	10.30	1.12
OL1	1	C	2.48	2.45	2.46	0.01		7.23	9.81	8.52	1.29
OL1	2	A	1.16	1.30	1.23	0.07		5.00	11.51	8.25	3.26
OL1	2	B	1.27	1.34	1.31	0.04		11.07	10.34	10.70	0.37
OL1	2	C	1.39	1.47	1.43	0.04		9.22	9.07	9.14	0.07
OL1	3	A	1.20	1.20	1.20	0.00		5.97	7.80	6.89	0.91
OL1	3	B	1.19	1.19	1.19	0.00		8.54	10.38	9.46	0.92
OL1	3	C	1.39	1.32	1.35	0.03		8.98	8.17	8.57	0.40
OL1	4	A	1.12	1.16	1.14	0.02		5.24	8.63	6.94	1.70
OL1	4	B	1.41	1.49	1.45	0.04		8.77	12.06	10.41	1.64
OL1	4	C	1.74	1.87	1.80	0.07		7.55	8.77	8.16	0.61
OL1	5	A	1.26	1.37	1.32	0.06		4.08	7.93	6.00	1.92
OL1	5	B	1.34	1.34	1.34	0.00		7.51	10.78	9.15	1.63
OL1	5	C	1.62	1.52	1.57	0.05		9.67	7.73	8.70	0.97
OL2	1	A	1.19	1.15	1.17	0.02		6.94	4.86	5.90	1.04
OL2	1	B	1.19	1.01	1.10	0.09		6.97	3.58	5.28	1.69
OL2	1	C	1.09	1.10	1.09	0.00		7.73	8.01	7.87	0.14
OL2	2	A	1.07	1.05	1.06	0.01		6.49	4.55	5.52	0.97
OL2	2	B	0.96	0.99	0.97	0.01		8.67	5.79	7.23	1.44
OL2	2	C	1.11	1.80	1.46	0.34		6.95	9.02	7.98	1.03

Lot	Sublot	Test Point	Thickness (calibrated)					Air Voids			
			Trial 1	Trial 2	Average	Std dev		Trial 1	Trial 2	Average	Std dev
			(in)	(in)	(in)	(in)		percent	percent	percent	percent
OL2	3	A	1.03	1.00	1.01	0.02		5.54	3.95	4.74	0.80
OL2	3	B	0.95	0.91	0.93	0.02		8.52	4.10	6.31	2.21
OL2	3	C	1.27	1.28	1.27	0.00		7.62	8.38	8.00	0.38
OL2	4	A	0.98	0.94	0.96	0.02		5.70	4.58	5.14	0.56
OL2	4	B	1.08	0.99	1.03	0.05		8.09	4.61	6.35	1.74
OL2	4	C	1.43	1.35	1.39	0.04		8.46	6.34	7.40	1.06
OL2	5	A	1.07	0.97	1.02	0.05		9.04	5.49	7.26	1.77
OL2	5	B	1.07	1.03	1.05	0.02		9.35	6.73	8.04	1.31
OL2	5	C	1.36	1.25	1.31	0.05		14.68	10.37	12.53	2.15
OL3	1	A	1.16	1.21	1.19	0.03		10.01	13.86	11.94	1.92
OL3	1	B	1.20	1.23	1.21	0.02		10.37	10.47	10.42	0.05
OL3	1	C	0.91	0.98	0.95	0.03		4.97	8.74	6.85	1.89
OL3	2	A	1.05	1.10	1.08	0.03		8.46	13.26	10.86	2.40
OL3	2	B	1.03	1.03	1.03	0.00		9.07	9.54	9.30	0.24
OL3	2	C	1.13	1.12	1.12	0.01		5.49	9.16	7.33	1.83
OL3	3	A	1.18	1.28	1.23	0.05		11.11	17.84	14.48	3.36
OL3	3	B	1.09	1.17	1.13	0.04		9.93	9.53	9.73	0.20
OL3	3	C	1.03	1.11	1.07	0.04		6.01	9.97	7.99	1.98
OL3	4	A	1.09	1.22	1.16	0.06		9.88	17.57	13.72	3.84
OL3	4	B	1.08	1.08	1.08	0.00		11.87	13.66	12.77	0.89
OL3	4	C	0.79	0.82	0.81	0.02		7.37	11.09	9.23	1.86
OL3	5	A	1.24	1.32	1.28	0.04		11.97	17.10	14.54	2.56
OL3	5	B	1.28	1.27	1.27	0.01		12.52	10.42	11.47	1.05
OL3	5	C	1.02	1.05	1.04	0.02		7.73	11.93	9.83	2.10

Table 137. ***Modulus*** backcalculated from FWD Data on ***I-85, AL, pcf***

Lot	Sublot	A			B		
		Subgrade	Base	HMA	Subgrade	Base	HMA
OL1	1	55,322	128,518	254,246	46,812	108,749	386,736
		47,590	110,557	322,320	40,810	94,805	462,426
		45,203	105,012	379,858	40,030	92,994	502,149
	2	55,882	129,820	282,214	53,888	125,188	456,868
		46,481	107,979	359,608	46,626	108,316	498,334
		45,272	105,171	421,750	error	error	error
	3	45,293	105,219	353,003	44,288	102,884	304,274
		38,250	88,858	458,472	37,444	86,986	404,392
		error	error	error	36,992	85,935	452,227
	4	57,567	133,733	203,673	51,463	119,553	350,369
		48,931	113,672	277,342	44,342	103,011	450,871
		47,176	109,595	322,289	43,056	100,024	493,886
	5	54,858	127,441	270,033	57,982	134,697	165,766
		47,928	111,342	306,499	50,471	117,249	211,526
		45,987	106,832	345,900	49,311	114,553	243,890
OL2	1	51,870	120,499	505,027	51,962	120,713	503,541
		44,115	102,483	503,461	43,086	100,092	569,575
		41,988	97,543	545,798	24,641	57,243	631,422
	2	52,744	122,529	399,507	55,902	129,866	346,011
		45,709	106,185	423,952	46,448	107,904	440,467
		42,179	97,987	475,143	43,615	101,322	502,494
	3	47,150	109,534	648,999	52,164	121,181	463,310
		26,215	60,900	650,282	43,726	101,580	548,649
		25,412	59,036	726,115	24,821	57,662	610,574
	4	46,006	106,877	380,073	55,030	127,839	494,519
		51,838	120,424	255,754	43,384	100,784	605,875
		38,631	89,743	511,419	25,022	58,129	634,834
	5				51,095	118,699	526,813
					42,447	98,609	534,854
					40,556	94,216	587,238

Lot	Sublot	A			B		
		Subgrade	Base	HMA	Subgrade	Base	HMA
OL2	1	47,478	92,805	417,299	error	error	error
		42,624	83,316	498,950	29,761	51,845	416,742
		25,613	50,065	856,618	28,883	50,316	480,905
	2	59,810	116,910	498,838	error	error	error
		52,512	102,644	548,922	26,464	46,102	484,141
		49,593	96,938	662,093	26,395	45,981	471,219
	3	49,710	97,168	461,227	error	error	error
		46,216	90,338	586,938	27,628	48,129	450,850
		46,206	90,318	696,857	27,063	47,145	494,551
	4	56,355	110,156	573,029	41,259	71,875	398,109
		49,425	96,610	575,162	38,724	67,459	380,937
		48,049	93,920	748,133	25,723	44,810	453,476
	5	52,410	102,445	270,717			
		49,000	95,778	384,269			
		47,953	93,732	490,332			

Table 138. ***Density*** measured by Pavetracker – Non-nuclear Gage on ***I-85, AL, pcf***
Note: Test repetitions are shown in Table 139

Lot	Sublot	A	B	C	Average	Average by lot
OL1	1	137.3	136.5	133.6	135.8	
	2	132.7	133.0	136.8	134.2	
	3	134.6	138.5	133.6	135.5	
	4	131.8	136.1	129.2	132.4	
	5	136.6	141.2	133.9	137.2	135.0
OL2	1	138.9	141.8	135.8	138.8	
	2	139.9	142.1	129.8	137.2	
	3	140.7	141.6	129.8	137.4	
	4	136.9	140.9	136.0	137.9	
	5	132.5	134.4	128.3	131.7	136.6
OL3	1	133.2	137.5	137.2	135.9	
	2	134.8	139.1	134.1	136.0	
	3	134.6	137.5	130.6	134.2	
	4	132.1	136.7	130.9	133.2	
	5	129.1	132.0	127.8	129.6	133.8
Average lot 1 by row		134.6	137.1	133.4		
Average lot 2 by row		137.8	140.1	131.9		
Average lot 3 by row		132.7	136.6	132.1		
Average by row		135.0	137.9	132.5		
Average project						135.1

Table 139. Repeatability in ***Density*** measured by ***Pavetracker*** on ***I-85, AL, pcf***
Note: Summary of results is shown in Table 137and Table 138

Section	Location	Point	Density, pcf					
			Trial 1	**Trial 2**	**Trial 3**	**Trial 4**	**Average**	**Stdev**
OL1	1	A	133.9	137.9	140.2	137.2	137.3	2.60
OL1	1	B	137.0	134.8	136.6	137.7	136.5	1.24
OL1	1	C	134.5	131.6	133.0	135.1	133.6	1.57
OL1	2	A	130.5	134.2	132.1	134.0	132.7	1.75
OL1	2	B	131.1	132.9	135.2	132.9	133.0	1.68
OL1	2	C	136.6	137.2	136.2	137.1	136.8	0.46
OL1	3	A	137.4	132.8	135.4	132.9	134.6	2.21
OL1	3	B	138.5	137.0	138.9	139.4	138.5	1.03
OL1	3	C	134.4	133.6	132.1	134.1	133.6	1.02
OL1	4	A	131.6	134.6	131.2	129.9	131.8	1.99
OL1	4	B	136.2	135.2	137.5	135.5	136.1	1.02
OL1	4	C	126.2	127.2	130.5	132.8	129.2	3.04
OL1	5	A	139.0	135.0	136.4	135.9	136.6	1.72
OL1	5	B	139.9	141.6	141.1	142.1	141.2	0.94
OL1	5	C	133.7	133.3	133.0	135.6	133.9	1.17
OL2	1	A	139.1	139.5	137.7	139.4	138.9	0.83
OL2	1	B	140.2	141.2	141.7	143.9	141.8	1.56
OL2	1	C	135.8	134.5	135.8	137.2	135.8	1.10
OL2	2	A	140.6	141.4	139.0	138.4	139.9	1.39
OL2	2	B	141.8	142.2	143.4	140.8	142.1	1.08
OL2	2	C	129.8	129.1	130.7	129.6	129.8	0.67

Section	Location	Point	Density, pcf					
			Trial 1	Trial 2	Trial 3	Trial 4	Average	Stdev
OL2	3	A	138.7	141.1	142.5	140.4	140.7	1.58
OL2	3	B	140.3	142.6	142.1	141.3	141.6	1.00
OL2	3	C	128.4	130.5	131.0	129.3	129.8	1.17
OL2	4	A	140.3	136.0	135.0	136.2	136.9	2.34
OL2	4	B	138.8	140.6	141.5	142.6	140.9	1.61
OL2	4	C	136.3	135.5	135.3	137.0	136.0	0.78
OL2	5	A	129.5	132.6	133.8	134.3	132.5	2.15
OL2	5	B	132.8	135.7	134.2	134.8	134.4	1.22
OL2	5	C	128.4	126.9	129.1	128.7	128.3	0.96
OL3	1	A	133.3	131.7	134.1	133.5	133.2	1.02
OL3	1	B	136.9	138.8	137.2	137.2	137.5	0.86
OL3	1	C	138.0	137.7	137.3	135.6	137.2	1.07
OL3	2	A	132.5	135.5	134.4	136.7	134.8	1.78
OL3	2	B	139.6	138.3	138.3	140.2	139.1	0.96
OL3	2	C	132.9	133.7	136.4	133.5	134.1	1.55
OL3	3	A	132.0	136.4	134.9	134.9	134.6	1.84
OL3	3	B	138.3	138.9	138.9	134.0	137.5	2.37
OL3	3	C	130.4	131.5	130.2	130.1	130.6	0.65
OL3	4	A	133.0	131.7	132.6	131.1	132.1	0.86
OL3	4	B	137.6	136.8	136.6	135.7	136.7	0.78
OL3	4	C	133.3	131.9	128.9	129.5	130.9	2.06
OL3	5	A	129.0	128.9	128.0	130.5	129.1	1.04
OL3	5	B	131.0	131.4	132.5	133.1	132.0	0.97
OL3	5	C	124.9	130.8	130.1	125.4	127.8	3.08

Table 140. ***Density*** measured by PQI – Non-nuclear Gage on **I-85, AL, pcf**
Note: Test repetitions are shown in Table 141

Lot	**Sublot**	**A**	**B**	**C**	**J**	**Average**	**Average by lot**
OL1	1	149.1	146.2	142.3	145.9		149.1
	2	142.1	143.9	141.7	142.6		142.1
	3	144.0	148.5	139.4	144.0		144.0
	5	143.0	146.6	139.1	142.9		143.0
		143.8	149.1	138.9	143.9	143.8	143.8
	1						
	2	147.6	152.3	142.8	147.6		147.6
OL2	3	151.2	154.1	140.3	148.5		151.2
	4	150.5	153.4	139.7	147.9		150.5
	5	148.4	151.0	143.1	147.5		148.4
		143.6	146.9	138.6	143.0	146.9	143.6
OL3	1						
	2	148.8	152.6	144.4	148.6		148.8
	3	144.1	153.5	148.9	148.8		144.1
	4	146.1	150.8	140.8	145.9		146.1
	5	144.6	150.2	140.1	145.0		144.6
Average lot 1 by row		144.4	146.8	140.3			
Average lot 2 by row		148.3	151.5	140.9			
Average lot 3 by row		184.8	150.3	142.3			
Average by row		159.2	149.5	141.2			159.2
Average project							150.0

Table 141. Repeatability in ***Density*** measured by ***PQI*** on ***I-85, AL, pcf***
Note: Summary of results is shown in Table 140

Lot	Sublot	Point	Density, pcf						
			Trial 1	Trial 2	Trial 3	Trial 4	Trial 5	Average	Stdev
OL1	1	A	150.2	149.4	148.1	148.8	148.9	149.1	0.8
OL1	1	B	145.8	147.1	145.7	147.7	144.6	146.2	1.2
OL1	1	C	143.2	141.6	141.5	142.1	143.1	142.3	0.8
OL1	2	A	142.3	144.4	142.8	139.0	142.2	142.1	2.0
OL1	2	B	143.5	143.6	144.1	144.0	144.3	143.9	0.3
OL1	2	C	142.4	141.2	140.7	141.9	142.2	141.7	0.7
OL1	3	A	143.1	145.6	143.4	142.2	145.5	144.0	1.5
OL1	3	B	149.6	147.6	148.6	148.3	148.4	148.5	0.7
OL1	3	C	141.6	142.1	142.2	139.1	132.2	139.4	4.2
OL1	4	A	143.4	140.7	141.8	145.0	144.2	143.0	1.8
OL1	4	B	147.6	146.8	146.6	146.0	145.8	146.6	0.7
OL1	4	C	139.1	140.1	137.6	139.6	139.0	139.1	0.9
OL1	5	A	144.3	143.8	142.8	142.3	145.6	143.8	1.3
OL1	5	B	150.5	149.0	147.0	149.1	149.9	149.1	1.3
OL1	5	C	135.8	137.0	138.2	140.8	142.6	138.9	2.8
OL2	1	A	147.6	148.3	147.4	147.4	147.5	147.6	0.4
OL2	1	B	152.0	154.4	152.1	150.1	152.8	152.3	1.6
OL2	1	C	142.1	144.2	142.6	141.5	143.7	142.8	1.1
OL2	2	A	150.9	152.9	149.0	150.5	152.6	151.2	1.6
OL2	2	B	156.7	151.5	154.2	154.8	153.4	154.1	1.9
OL2	2	C	139.5	139.2	141.6	142.6	138.5	140.3	1.7
OL2	3	A	151.5	149.0	149.4	151.6	151.2	150.5	1.2
OL2	3	B	155.6	152.5	156.4	149.0	153.3	153.4	2.9
OL2	3	C	135.8	136.7	144.5	145.5	136.1	139.7	4.8
OL2	4	A	148.3	147.9	150.0	148.4	147.4	148.4	1.0
OL2	4	B	152.6	151.0	149.8	150.7	150.8	151.0	1.0
OL2	4	C	143.0	142.4	146.8	143.5	140.0	143.1	2.4
OL2	5	A	142.6	143.3	143.1	142.9	146.1	143.6	1.4
OL2	5	B	147.8	147.0	147.5	145.2	146.9	146.9	1.0
OL2	5	C	137.6	138.8	140.0	138.9	137.8	138.6	1.0
OL3	1	A	145.7	147.4	154.1	147.9	149.0	148.8	3.2
OL3	1	B	152.2	152.3	152.2	154.3	151.8	152.6	1.0
OL3	1	C	143.8	141.3	145.1	146.5	145.3	144.4	2.0
OL3	2	A	143.6	143.3	143.5	146.0	143.9	144.1	1.1
OL3	2	B	155.5	151.5	154.3	154.3	152.1	153.5	1.7

Lot	Sublot	Point	Density, pcf						
			Trial 1	Trial 2	Trial 3	Trial 4	Trial 5	Average	Stdev
OL3	2	C	147.1	150.1	150.1	147.8	149.4	148.9	1.4
OL3	3	A	146.8	146.4	143.9	146.8	146.7	146.1	1.3
OL3	3	B	153.2	148.6	149.8	151.1	151.5	150.8	1.7
OL3	3	C	141.4	140.0	141.3	141.3	140.2	140.8	0.7
OL3	4	A	144.1	146.1	144.1	143.6	145.1	144.6	1.0
OL3	4	B	150.5	148.1	152.6	151.1	148.5	150.2	1.9
OL3	4	C	140.0	139.3	142.2	140.8	138.2	140.1	1.5
OL3	5	A	1140.1	141.9	139.3	137.7	142.9	340.4	447.1
OL3	5	B	145.1	143.4	143.9	145.7	143.3	144.3	1.1
OL3	5	C	138.0	136.0	138.9	138.4	134.9	137.2	1.7

Table 142. ***Modulus*** measured by PSPA on **I-85, AL, ksi**
Note: Repeatability data is presented in Table 143

Lot	Sublot	A	B	C	J	Average	Average by lot
OL1	1	249	238	309	266		249
	2	212	231	171	205		212
	3	209	296	283	262		209
	5	192	203	393	263		192
		215	235	206	219	243	215
	1						
	2	268	252	266	262		268
OL2	3	306	290	328	308		306
	4	296	307	324	309		296
	5	324	285	221	277		324
		260	262	255	259	283	260
OL3	1						
	2	250	241	321	270		250
	3	277	289	221	262		277
	4	286	261	334	294		286
	5	289	273	306	290		289
Average lot 1 by row		215	241	273			
Average lot 2 by row		291	279	279			
Average lot 3 by row		269	265	298			
Average by row		259	262	283			259
Average project						268	

Table 143. Repeatability in ***Modulus*** measured by ***PSPA*** on ***I-85, AL, ksf***
Note: Summary of results is shown in Table 142

Lot	Sublot	Point	Trial 1	Trial 2	Trial 3	Average	Stdev
OL1	1	A	242	294	212	249	**41**
OL1	1	B	216	276	222	238	**33**
OL1	1	C	337	237	354	309	**63**
OL1	2	A	214	202	221	212	**10**
OL1	2	B	187	221	285	231	**50**
OL1	2	C	153	157	204	171	**28**
OL1	3	A	207	220	199	209	**10**
OL1	3	B	271	340	278	296	**38**
OL1	3	C	358	236	253	283	**66**
OL1	4	A	200	170	205	192	**19**
OL1	4	B	189	226	194	203	**20**
OL1	4	C	448	296	435	393	**84**
OL1	5	A	175	276	194	215	**53**
OL1	5	B	152	292	259	235	**73**
OL1	5	C	196	234	188	206	**24**
OL2	1	A	233	285	285	268	**30**
OL2	1	B	273	261	221	252	**27**
OL2	1	C	310	259	229	266	**41**
OL2	2	A	327	275	317	306	**27**
OL2	2	B	292	267	310	290	**22**
OL2	2	C	321	333	331	328	**7**
OL2	3	A	286	294	308	296	**11**
OL2	3	B	326	294	302	307	**16**
OL2	3	C	281	365	326	324	**42**
OL2	4	A	340	300	333	324	**22**
OL2	4	B	329	277	248	285	**41**
OL2	4	C	203	261	200	221	**34**
OL2	5	A	294	242	244	260	**29**
OL2	5	B	297	209	279	262	**47**
OL2	5	C	237	294	234	255	**34**
OL3	1	A	271	240	240	250	**18**

Lot	Sublot	Point	Trial 1	Trial 2	Trial 3	Average	Stdev
OL3	1	B	211	201	310	241	**60**
OL3	1	C	394	278	289	321	**64**
OL3	2	A	257	303	271	277	**23**
OL3	2	B	299	229	338	289	**55**
OL3	2	C	289	210	166	221	**62**
OL3	3	A	294	274	289	286	**11**
OL3	3	B	305	269	210	261	**48**
OL3	3	C	321	340	342	334	**11**
OL3	4	A	277	309	281	289	**18**
OL3	4	B	225	319	276	273	**47**
OL3	4	C	259	343	318	306	**43**
OL3	5	A	247	235	252	245	**9**
OL3	5	B	296	213	279	263	**44**
OL3	**5**	**C**	**319**	**316**	**291**	**309**	**16**

Table 144. ***Density*** measured by Nuclear Gauge on **I-85, AL, pcf**
Note: Repeatability data is presented in Table 145

Lot	**Sublot**	**A**	**B**	**C**	**Average**	**Average by lot**
OL1	1	146.9	144.9	142.9	144.9	
	2	137.6	141.0	142.9	140.5	
	3	139.5	144.4	137.4	140.4	
	4	139.5	144.4	137.4	140.4	
	5	142.2	150.2	142.2	144.9	142.2
	1	147.3	151.1	143.3	147.2	
	2	147.0	150.5	137.0	144.8	
OL2	3	148.5	150.6	135.5	144.9	
	4	144.1	148.7	140.5	144.5	
	5	137.7	144.1	136.5	139.4	144.2
OL3	1	143.0	150.6	146.7	146.8	
	2	144.2	148.7	146.8	146.6	
	3	144.3	149.2	143.0	145.5	
	4	141.2	146.4	139.3	142.3	
	5	135.8	142.1	133.2	137.1	143.6
Average lot 1 by row		141.1	145.0	140.6		141.1
Average lot 2 by row		144.9	149.0	138.6		144.9
Average lot 3 by row		141.7	147.4	141.8		141.7
Average by row		142.6	147.1	140.3		142.6
Average project					143.3	

Table 145. Repeatability data for ***Density*** measured by Nuclear Gauge on **I-85, AL, pcf**
Note: Summary of test results is presented in Table 144

Lot	Sublot	Point	Trial 1	Trial 2	Trial 3	Trial 4	Average	Stdev
OL1	1	A	146.3	149.3	148.2	143.8	146.9	**2.41**
OL1	1	B	146.5	145.0	142.2	145.7	144.9	**1.87**
OL1	1	C	142.8	142.7	142.3	143.8	142.9	**0.64**
OL1	2	A	133.7	143.1	136.2	137.3	137.6	**3.98**
OL1	2	B	141.2	141.1	141.4	140.4	141.0	**0.43**
OL1	2	C	143.4	144.8	141.8	141.7	142.9	**1.47**
OL1	3	A	139.3	142.1	138.4	138.1	139.5	**1.82**
OL1	3	B	143.7	142.8	144.8	146.1	144.4	**1.42**
OL1	3	C	137.1	139.8	136.9	135.7	137.4	**1.73**
OL1	4	A	139.3	142.1	138.4	138.1	139.5	**1.82**
OL1	4	B	143.7	142.8	144.8	146.1	144.4	**1.42**
OL1	4	C	137.1	139.8	136.9	135.7	137.4	**1.73**
OL1	5	A	141.1	144.7	142.1	140.8	142.2	**1.77**
OL1	5	B	150.3	149.9	150.0	150.5	150.2	**0.28**
OL1	5	C	142.3	140.7	145.0	140.9	142.2	**1.98**
OL2	1	A	148.0	148.2	146.2	146.8	147.3	**0.96**
OL2	1	B	152.2	152.5	150.5	149.0	151.1	**1.63**
OL2	1	C	143.0	145.6	143.3	141.3	143.3	**1.77**
OL2	2	A	148.2	148.7	147.8	143.3	147.0	**2.49**
OL2	2	B	151.1	150.3	150.1	150.4	150.5	**0.43**
OL2	2	C	133.8	134.3	135.8	144.0	137.0	**4.76**
OL2	3	A	149.5	149.1	147.2	148.0	148.5	**1.05**
OL2	3	B	150.2	149.8	152.2	150.3	150.6	**1.07**
OL2	3	C	132.6	132.3	133.0	144.0	135.5	**5.69**
OL2	4	A	141.0	145.2	146.1	144.2	144.1	**2.22**
OL2	4	B	148.1	149.3	148.4	149.1	148.7	**0.57**
OL2	4	C	135.9	141.9	136.0	148.0	140.5	**5.76**
OL2	5	A	134.8	141.5	136.3	138.3	137.7	**2.90**
OL2	5	B	143.0	143.5	143.9	145.9	144.1	**1.27**
OL2	5	C	135.9	134.9	138.9	136.2	136.5	**1.71**
OL3	1	A	145.5	140.9	143.3	142.2	143.0	**1.95**

Lot	Sublot	Point	Trial 1	Trial 2	Trial 3	Trial 4	Average	Stdev
OL3	1	B	150.1	150.7	150.8	150.7	150.6	**0.32**
OL3	1	C	147.4	145.5	144.4	149.3	146.7	**2.16**
OL3	2	A	144.0	145.1	144.4	143.2	144.2	**0.79**
OL3	2	B	149.5	147.8			148.7	**1.20**
OL3	2	C	145.8	147.8			146.8	**1.41**
OL3	3	A	143.3	145.2			144.3	**1.34**
OL3	3	B	150.3	148.1			149.2	**1.56**
OL3	3	C	142.9	143.0			143.0	**0.07**
OL3	4	A	142.3	140.0			141.2	**1.63**
OL3	4	B	146.3	146.5			146.4	**0.14**
OL3	4	C	139.8	138.8			139.3	**0.71**
OL3	5	A	136.4	135.2			135.8	**0.85**
OL3	5	B	143.5	140.7			142.1	**1.98**
OL3	**5**	**C**	**132.9**	**133.5**			**133.2**	**0.42**

Table 146. Core height measurements on **I-85, AL, inch**

Specimen, lot-sublot point	Height Measurements					
	1	2	3	4	Average	Stdev
1-1A	1.12	1.16	1.18	1.19	1.16	0.03
1-4B	1.43	1.45	1.49	1.44	1.45	0.03
1-5C	2.15	2.12	2.05	2.02	2.08	0.06
2-2B	2.52	2.48	2.41	2.54	2.49	0.05
2-3C	1.98	1.90	1.95	1.95	1.95	0.03
2-4A	0.93	0.92	0.90	0.89	0.91	0.02
3-2C	1.38	1.37	1.36	1.36	1.37	0.01
3-3B	2.29	2.31	2.39	2.31	2.32	0.04
3-5A	1.18	1.24	1.21	1.14	1.19	0.04

Table 147. Air voids from cores on **I-85, AL**

Specimen, lot-sublot point	Dry Weight, gm	Submerged Weight, gm	SSD Weight, gm	Bulk Specific Gravity Gmb	Theor. Max Spec gravity, Gmm	Percent Air Voids
1-1A	1131.1	653.6	1136.3	2.3	2.5	6.2
1-4B	1407.5	810.1	1421.2	2.3	2.5	7.8
1-5C	2044.8	1170.8	2060	2.3	2.5	7.9
2-2B	2582.3	1535.1	2586.3	2.5	2.5	1.7
2-3C	1825.7	1036	1854.4	2.2	2.5	10.7
2-4A	894.7	512.8	905.6	2.3	2.5	8.8
3-2C	1416.2	824.6	1419.6	2.4	2.5	4.7
3-3B	2477.5	1472.5	2481.4	2.5	2.5	1.7
3-5A	1090.2	616.9	1110.6	2.2	2.5	11.6
1-1A	1131.1	653.6	1136.3	2.3	2.5	6.2

Table 148. ***Dynamic Modulus*** Test results for ***I-85, AL, Overlay HMA,*** psi

Temperature, °F	Replicate	E* Measured at Frequency					
		25	**10**	**5**	**1**	**0.5**	**0.1**
14	**1**	4,329,082	3,664,874	3,251,890	2,433,493	1,448,113	**1,386,289**
	3	7,644,260	7,073,887	6,445,040	5,456,337	4,087,247	**3,968,102**
	4	3,877,611	3,396,086	2,982,038	2,268,410	1,430,087	**1,386,294**
	Average	5,283,651	4,711,616	4,226,323	3,386,080	2,321,816	**2,246,895**
	CV, %	38.93	43.51	45.58	53.01	65.85	**66.34**
40	**1**	4,865,976	4,245,618	3,897,675	3,050,351	2,791,658	**1,948,051**
	3	5,016,686	4,401,057	3,971,567	3,193,611	2,881,184	**2,032,153**
	4	4,646,644	4,187,456	3,900,846	2,897,860	2,625,292	**1,821,054**
	Average	4,843,102	4,278,043	3,923,362	3,047,274	2,766,045	**1,933,753**
	CV, %	3.84	2.58	1.06	4.85	4.69	**5.50**
70	**1**	2,281,738	1,765,079	1,504,751	1,040,928	835,337	**546,458**
	3	2,101,666	1,679,867	1,423,833	998,127	803,759	**519,869**
	4	2,001,340	1,625,991	1,399,582	932,307	770,135	**504,367**
	Average	2,128,248	1,690,312	1,442,722	990,454	803,077	**523,564**
	CV, %	6.68	4.15	3.82	5.52	4.06	**4.07**
100	**1**	827,113	651,153	513,820	339,058	276,406	**189,701**
	3	703,750	611,220	497,784	334,995	291,459	**208,810**
	4	778,633	632,715	522,165	347,524	294,005	**230,279**
	Average	769,832	631,696	511,256	340,526	287,290	**209,597**
	CV, %	8.07	3.16	2.42	1.88	3.31	**9.69**

Temperature, °F	Replicate	E* Measured at Frequency					
		25	10	5	1	0.5	0.1
130	1	322,602	247,715	219,758	156,174	118,091	**94,048**
	3	303,173	230,350	215,461	158,925	140,971	**109,833**
	4	356,723	275,884	252,218	195,410	178,499	**146,729**
	Average	327,499	251,316	229,145	170,170	145,854	**116,870**
	CV, %	**8.28**	**9.14**	**8.77**	**12.87**	**20.91**	**23.13**

Table 149. ***Repeated load*** test results for ***I-85, AL, HMA***

Replicate	Repeated Load @ 147 deg F			
	Flow time, cycles	Applied stress, psi	Maximum LVDT slope	Minimum LVDT slope
1	3,000	68.8	N/A	**N/A**
2	1,000	65.7		
3	701	69.1		
Average		67.9		
CV, %		**2.77**	**N/A**	**N/A**

NOTE: The samples failed very quickly. None of the samples reached secondary flow.

US-280, AL HMA SECTIONS WITHOUT INTELLIGENT COMPACTION DURING PAVING

(TESTED IN DECEMBER 2004)

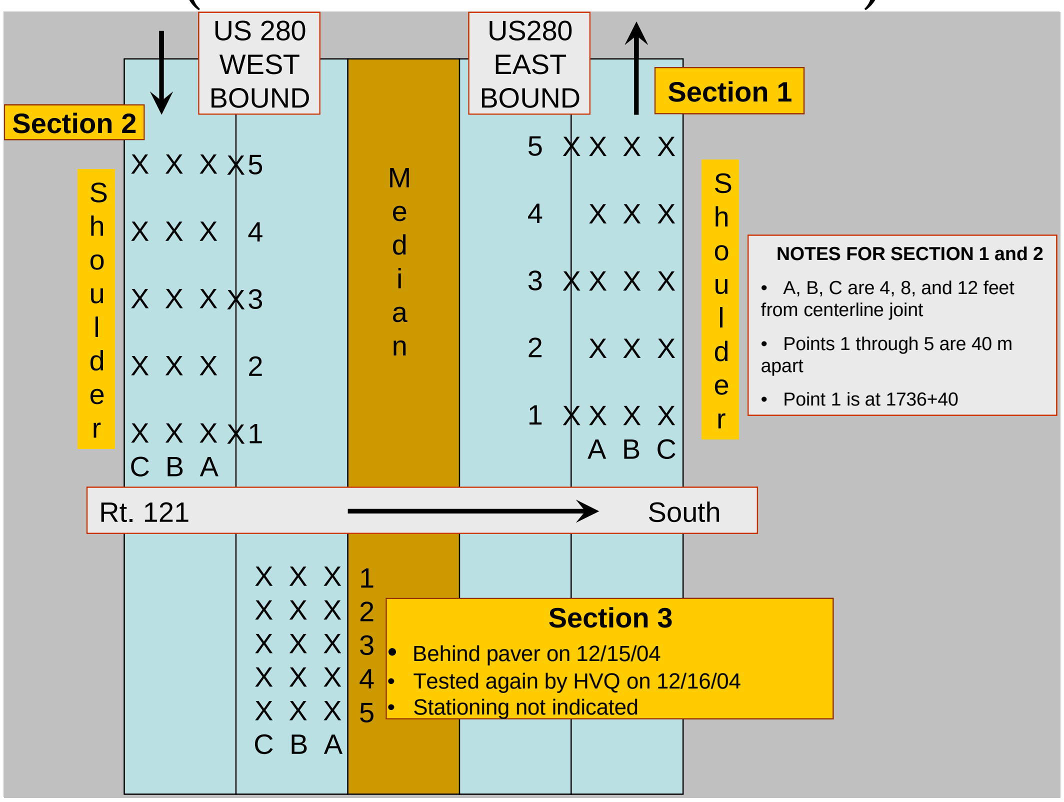


Table 150. Test point station information for ***US-280 (Without IC), AL*** HMA sections

Lot	Sublot	Station	Offset for points		
			A	B	C
AC 1	1	1736 + 40	4 - R	8 - R	12 - R
AC 1	2	1736 + 80	4 - R	8 - R	12 - R
AC 1	3	1737 + 20	4 - R	8 - R	12 - R
AC 1	4	1737 + 60	4 - R	8 - R	12 - R
AC 1	5	1738 + 00	4 - R	8 - R	12 - R
AC 2	1	1736 + 40	4 - L	8 - L	12 - L
AC 2	2	1736 + 80	4 - L	8 - L	12 - L
AC 2	3	1737 + 20	4 - L	8 - L	12 - L
AC 2	4	1737 + 60	4 - L	8 - L	12 - L
AC 2	5	1738 + 00	4 - L	8 - L	12 - L
AC 3	1	un known	-	-	-
AC 3	2	un known	-	-	-
AC 3	3	un known	-	-	-
AC 3	4	un known	-	-	-
AC 3	5	un known	-	-	-

Table 151. ***Calibrated Thickness*** measured by ***GPR*** on ***US-280 (Without IC), AL, inch***
Note: Repeatability in measurements is shown in Table 153

Lot	Sublot	A	B	C	J	Average	Average by lot
AC1	1	4.70	4.53	4.37	4.35	4.49	
	2	4.62	4.59	4.85		4.69	
	3	3.99	4.34	4.55	4.15	4.26	
	4	4.37	4.22	4.53		4.37	
	5	4.99	4.80	4.88	4.55	4.80	4.52
AC2	1	4.43	4.24	4.06	No Data	4.24	
	2	5.00	4.70	4.42	No Data	4.71	
	3	4.64	4.19	4.00	No Data	4.28	
	4	4.73	4.54	4.11	No Data	4.46	
	5	4.51	3.91	3.68	No Data	4.03	4.34
AC3	1	No Data	No Data	No Data	No Data	No Data	
	2	No Data	No Data	No Data	No Data	No Data	
	3	No Data	No Data	No Data	No Data	No Data	
	4	No Data	No Data	No Data	No Data	No Data	
	5	No Data	No Data	No Data	No Data	No Data	No Data
Average lot 1 by row		4.53	4.50	4.64	4.35		
Average lot 2 by row		4.66	4.32	4.05	No data		
Average lot 3 by row		No Data	No Data	No Data	No Data		
Average by row		4.60	4.41	4.34	4.35		
Average project							4.44

Table 152. ***Percent Air voids*** measured by ***GPR US-280 (Without IC), AL***
Note: Repeatability in measurements is shown in Table 136

Lot	**Sublot**	**A**	**B**	**C**	**J**	**Average**	**Average by lot**
AC1	1	4.88	5.83	5.76	8.66	6.28	
	2	4.93	5.39	5.02		5.11	
	3	4.46	5.17	5.05	8.38	5.76	
	4	4.84	5.52	4.88		5.08	
	5	6.07	6.76	5.84	7.21	6.47	5.81
AC2	1	4.83	4.55	4.98	No Data	4.79	
	2	5.93	4.91	6.34	No Data	5.73	
	3	6.08	5.63	5.90	No Data	5.87	
	4	5.83	5.70	5.69	No Data	5.74	
	5	6.01	5.06	6.34	No Data	5.80	5.59
AC3	1	No Data	No Data	No Data	No Data	No Data	
	2	No Data	No Data	No Data	No Data	No Data	
	3	No Data	No Data	No Data	No Data	No Data	
	4	No Data	No Data	No Data	No Data	No Data	
	5	No Data	No Data	No Data	No Data	No Data	No Data
Average lot 1 by row		5.04	5.73	5.31	8.08		
Average lot 2 by row		5.74	5.17	5.85	No data		
Average lot 3 by row		No Data	No Data	No Data	No Data		
Average by row		5.39	5.45	5.58	8.08		
Average project							5.71

Table 153. Repeatability measurements for ***Percent Air voids and Thickness*** measured by ***GPR*** on ***US-280 (Without IC), AL***
Note: Summary of results are shown in Table 134 and Table 135

Lot	Sublot	Test Point	Thickness (calibrated)					Air Voids			
			Trial 1	Trial 2	Average	Std dev		Trial 1	Trial 2	Average	Std dev
			(in)	(in)	(in)	(in)		percent	percent	percent	percent
AC 1	1	A	4.7	4.7	4.7	0.03		4.5	5.2	4.9	0.51
AC 1	1	B	4.6	4.5	4.5	0.06		5.9	5.8	5.8	0.03
AC 1	1	C	4.4	4.3	4.4	0.02		5.9	5.6	5.8	0.25
AC 1	1	joint	4.4	-	4.4	-		8.7	-	8.7	-
AC 1	2	A	4.6	4.7	4.6	0.06		4.5	5.3	4.9	0.56
AC 1	2	B	4.7	4.5	4.6	0.14		5.3	5.5	5.4	0.16
AC 1	2	C	5.0	4.7	4.8	0.16		5.4	4.7	5.0	0.48
AC 1	3	A	3.9	4.0	4.0	0.06		4.0	4.9	4.5	0.60
AC 1	3	B	4.3	4.4	4.3	0.07		5.1	5.3	5.2	0.14
AC 1	3	C	4.6	4.5	4.5	0.07		5.1	4.9	5.0	0.14
AC 1	3	joint	4.1	-	4.1	-		8.4	-	8.4	-
AC 1	4	A	4.3	4.5	4.4	0.12		4.5	5.1	4.8	0.43
AC 1	4	B	4.2	4.2	4.2	0.00		5.5	5.6	5.5	0.05
AC 1	4	C	4.6	4.5	4.5	0.05		5.1	4.7	4.9	0.27
AC 1	5	A	4.8	5.1	5.0	0.21		5.4	6.7	6.1	0.93
AC 1	5	B	4.8	4.8	4.8	0.06		6.6	6.9	6.8	0.26
AC 1	5	C	4.9	4.8	4.9	0.08		6.2	5.5	5.8	0.54
AC 1	5	joint	4.5	-	4.5	-		7.2	-	7.2	-
AC 2	1	A	4.4	4.5	4.4	0.06		4.6	5.1	4.8	0.36
AC 2	1	B	4.3	4.2	4.2	0.12		4.7	4.4	4.5	0.20
AC 2	1	C	4.0	4.1	4.1	0.04		4.9	5.1	5.0	0.18

Lot	Sublot	Test Point	Thickness (calibrated)					Air Voids			
			Trial 1 (in)	Trial 2 (in)	Average (in)	Std dev (in)		Trial 1 percent	Trial 2 percent	Average percent	Std dev percent
AC 2	1	joint		-	-	-		-	-	-	-
AC 2	2	A	4.9	5.1	5.0	0.12		5.6	6.3	5.9	0.46
AC 2	2	B	4.8	4.6	4.7	0.13		5.2	4.6	4.9	0.41
AC 2	2	C	4.4	4.4	4.4	0.00		6.1	6.6	6.3	0.40
AC 2	3	A	4.7	4.6	4.6	0.04		5.9	6.3	6.1	0.27
AC 2	3	B	4.3	4.1	4.2	0.10		6.0	5.3	5.6	0.45
AC 2	3	C	4.0	4.0	4.0	0.06		5.8	6.0	5.9	0.09
AC 2	3	joint	-	-	-	-		-	-	-	-
AC 2	4	A	4.6	4.8	4.7	0.15		5.4	6.2	5.8	0.56
AC 2	4	B	4.6	4.5	4.5	0.03		6.3	5.1	5.7	0.85
AC 2	4	C	4.1	4.1	4.1	0.00		6.0	5.4	5.7	0.42
AC 2	5	A	4.6	4.4	4.5	0.12		5.6	6.4	6.0	0.56
AC 2	5	B	4.0	3.8	3.9	0.11		5.4	4.8	5.1	0.42
AC 2	5	C	3.7	3.7	3.7	0.01		6.1	6.6	6.3	0.30
AC 2	5	joint	-	-	-	-		-	-	-	-

Table 154. ***Density*** measured by Pavetracker – Non-nuclear Gage on ***US-280 (Without IC), AL, pcf***

Note: Test repetitions are shown in Table 155

Lot	Sublot	A	B	C	J	Average	Average by lot
AC1	1	128.0	128.1	128.4	99.8	121.1	
	2	124.8	132.7	133.9		130.5	
	3	131.2	132.9	127.6	128.9	130.2	
	4	119.8	130.3	127.2		125.8	
	5	136.0	132.8	132.3	130.1	132.8	128.0
AC2	1	128.4	128.6	127.5	115.8	125.1	
	2	127.3	127.1	135.6		130.0	
	3	130.4	128.2	127.2		128.6	
	4	124.3	130.1	122.6		125.6	
	5	129.2	128.6	133.3	129.4	130.1	127.8
AC3	1	No Data	No Data	No Data	No Data		
	2	No Data	No Data	No Data	No Data		
	3	No Data	No Data	No Data	No Data		
	4	No Data	No Data	No Data	No Data		
	5	No Data	No Data	No Data	No Data		-
Average lot 1 by row		128.0	131.3	129.9	119.6		
Average lot 2 by row		127.9	128.5	129.2	122.6		
Average lot 3 by row		-	-	-	-		
Average by row		127.9	129.9	129.5	120.8		
Average project							127.9

Table 155. Repeatability in ***Density*** measured by ***Pavetracker*** on ***US-280 (Without IC), AL, pcf***
Note: Summary of results is shown in Table 137and Table 138

Section	Location	Point	Density, pcf					
			Trial 1	**Trial 2**	**Trial 3**	**Trial 4**	**Average**	**Stdev**
AC 1	1	A	126.4	126.4	130.8	128.3	128.0	2.1
AC 1	1	B	127.6	131.3	127.1	126.2	128.1	2.2
AC 1	1	C	122.0	132.7	134.1	124.6	128.4	6.0
AC 1	1	joint	98.3	99.6	97.9	103.5	99.8	2.6
AC 1	2	A	126.4	127.3	122.7	122.8	124.8	2.4
AC 1	2	B	129.5	130.4	134.1	136.6	132.7	3.3
AC 1	2	C	133.9	138.0	132.7	131.1	133.9	2.9
AC 1	3	A	129.9	133.2	129.6	132.2	131.2	1.8
AC 1	3	B	133.4	133.8	133.2	131.3	132.9	1.1
AC 1	3	C	121.4	129.9	130.6	128.4	127.6	4.2
AC 1	3	joint	132.7	131.3	129.7	122.0	128.9	4.8
AC 1	4	A	117.7	120.6	119.0	121.8	119.8	1.8
AC 1	4	B	130.9	129.9	131.3	129.2	130.3	1.0
AC 1	4	C	124.1	127.6	127.1	129.9	127.2	2.4
AC 1	5	A	136.9	133.9	134.1	139.0	136.0	2.4
AC 1	5	B	133.9	132.7	130.6	133.9	132.8	1.6
AC 1	5	C	132.6	132.5	130.6	133.4	132.3	1.2
AC 1	5	joint	126.7	131.1	134.1	128.6	130.1	3.2
AC 2	1	A	126.5	127.9	128.3	130.9	128.4	1.8
AC 2	1	B	126.1	130.6	126.7	131.1	128.6	2.6
AC 2	1	C	129.4	128.5	129.4	122.7	127.5	3.2
AC 2	1	joint	115.8	121.4	115.3	110.7	115.8	4.4

Section	Location	Point	Density, pcf					
			Trial 1	Trial 2	Trial 3	Trial 4	Average	Stdev
AC 2	2	A	126.7	126.1	130.8	125.5	127.3	2.4
AC 2	2	B	125.5	130.6	125.1	127.1	127.1	2.5
AC 2	2	C	134.1	134.1	139.2	134.9	135.6	2.4
AC 2	3	A	131.1	129.5	131.3	129.8	130.4	0.9
AC 2	3	B	130.9	126.9	126.7	128.1	128.2	1.9
AC 2	3	C	125.5	127.8	129.9	125.4	127.2	2.1
AC 2	3	joint						#DIV/0!
AC 2	4	A	121.8	124.2	126.9	124.1	124.3	2.1
AC 2	4	B	131.1	133.1	127.8	128.3	130.1	2.5
AC 2	4	C	119.1	124.3	122.8	124.2	122.6	2.4
AC 2	5	A	129.8	128.5	130.2	128.3	129.2	0.9
AC 2	5	B	128.3	131.3	127.8	127.1	128.6	1.9
AC 2	5	C	134.1	133.6	134.1	131.3	133.3	1.3
AC 2	5	joint	130.4	130.6	127.3		129.4	1.9

Table 156. ***Density*** measured by PQI – Non-nuclear Gage on I***US-280 (Without IC), AL*, pcf**
Note: Test repetitions are shown in Table 157

Lot	**Sublot**	**A**	**B**	**C**	**J**	**Average**	**Average by lot**
AC1	1	136.5	138.7	140.5	136.8	138.1	
	2	136.9	142.7	141.3		140.3	
	3	140.9	139.5	138.4	141.0	139.9	
	4	136.2	139.0	136.3		137.2	
	5	141.6	141.0	139.8	129.5	138.0	138.7
AC2	1	139.1	141.3	139.1	No data	139.8	
	2	142.0	143.1	143.9	No data	143.0	
	3	140.4	139.4	136.0	No data	138.6	
	4	135.9	139.2	135.2	No data	136.8	
	5	140.3	140.1	138.8	No data	139.7	139.6
AC3	1	No data	143.1	No data	No data	143.1	
	2	No data	143.3	No data	No data	143.3	
	3	No data	144.7	No data	No data	144.7	
	4	No data	140.5	No data	No data	140.5	
	5	No data	0.0	No data	No data	0.0	142.9
AC 3	1	No data	140.6	No data	No data	140.6	
Repeat	2	No data	140.1	No data	No data	140.1	
After	3	No data	141.1	No data	No data	141.1	
24 hr	4	No data	139.6	No data	No data	139.6	
	5	No data	140.0	No data	No data	140.0	140.3
Average lot 1 by row		138.4	140.2	139.3	135.8		
Average lot 2 by row		139.5	140.6	138.6	No data		
Average lot 3 by row		No data	114.3	No data	No data		
Average lot 4 by row		No data	140.3	No data	No data		
Average by row		139.0	133.9	138.9	135.8		
Average project							139.6

Table 157. Repeatability in ***Density*** measured by ***PQI*** on ***US-280 (Without IC), AL, pcf***
Note: Summary of results is shown in Table 156

Lot	Sublot	Point	Density, pcf						
			Trial 1	Trial 2	Trial 3	Trial 4	Trial 5	Average	Stdev
AC 1	1	A	139.3	132.9	136.0	136.7	137.4	136.5	2.34
AC 1	1	B	140.6	138.9	135.9	139.3	138.9	138.7	1.72
AC 1	1	C	138.8	142.1	139.4	140.8	141.4	140.5	1.37
AC 1	1	joint	137.9	136.0	136.6	136.6	136.9	136.8	0.70
AC 1	2	A	134.7	140.5	136.1	138.1	135.1	136.9	2.40
AC 1	2	B	143.7	141.4	143.2	142.6	142.6	142.7	0.86
AC 1	2	C	141.8	142.4	140.1	139.2	143.0	141.3	1.60
AC 1	3	A	140.6	140.6	140.7	141.1	141.5	140.9	0.39
AC 1	3	B	139.4	140.8	137.8	137.4	141.9	139.5	1.92
AC 1	3	C	138.5	138.1	137.1	139.7	138.5	138.4	0.93
AC 1	3	joint	139.6	139.7	142.1	140.6	142.9	141.0	1.47
AC 1	4	A	135.8	136.9	133.9	138.5	136.1	136.2	1.68
AC 1	4	B	141.0	141.0	135.9	138.5	138.6	139.0	2.12
AC 1	4	C	136.9	139.6	135.1	136.9	133.0	136.3	2.45
AC 3	1	A							
AC 3	1	B	143.8	144.5	142.4	142.0	142.7	143.1	1.04
AC 3	1	C							
AC 3	2	A							
AC 3	2	B	144.3	143.4	142.0	144.5	142.1	143.3	1.18
AC 3	2	C							
AC 3	3	A							
AC 3	3	B	145.3	145.7	144.1	143.8	144.7	144.7	0.79
AC 3	3	C							
AC 3	4	A							
AC 3	4	B	139.7	139.3	142	142.2	139.5	140.5	1.43
AC 3	4	C							
AC 3	5	A							
AC 3	5	B							
AC 3	5	C							
AC 3*	1	A							
AC 3*	1	B	140.4	142.4	141.4	139.3	139.4	140.6	1.33
AC 3*	1	C							
AC 3*	2	A							
AC 3*	2	B	142.9	136.1	139.1	142.3	140.1	140.1	2.72
AC 3*	2	C							

Lot	Sublot	Point	Density, pcf						
			Trial 1	Trial 2	Trial 3	Trial 4	Trial 5	Average	Stdev
AC 3*	3	A							
AC 3*	3	B	140.8	139	143.4	141.7	140.5	141.1	1.62
AC 3*	3	C							
AC 3*	4	A							
AC 3*	4	B	138.6	138.2	141.5	140.6	138.9	139.6	1.418802312
AC 3*	4	C							
AC 3*	5	A							
AC 3*	5	B	140.2	141.2	139	139.7	140.1	140.0	0.801872808
AC 3*	5	C							

* Test repeated after 24 hours

Table 158. ***Modulus*** measured by PSPA on ***US-280 (Without IC), AL*****, ksi**
Note: Repeatability data is presented in Table 159

Lot	Sublot	A	B	C	J	Average	Average by lot
AC1	1	584	524	617	536	565	
	2	427	522	525		491	
	3	542	635	592	600	592	
	4	377	470	557		468	
	5	657	621	582	652	628	557
AC2	1	532	544	432	No Data	503	
	2	601	639	589	No Data	610	
	3	526	496	430	No Data	484	
	4	518	503	326	No Data	449	
	5	509	617	581	No Data	569	523
AC3	1	No Data	159	No Data	No Data	159	
	2	No Data	180	No Data	No Data	180	
	3	No Data	161	No Data	No Data	161	
	4	No Data	165	No Data	No Data	165	
	5	No Data	192	No Data	No Data	192	172
Average lot 1 by row		518	554	574	596		
Average lot 2 by row		537	560	472			
Average lot 3 by row			172				
Average by row		527	429	523	596		
Average project							493

Table 159. Repeatability in ***Modulus*** measured by ***PSPA*** on ***US-280 (Without IC), ksf***
Note: Summary of results is shown in Table 158

Lot	Sublot	Point	Trial 1	Trial 2	Trial 3	Average	Stdev
AC 1	1	A	600	536	615	584	**41.9**
AC 1	1	B	515	542	515	524	**15.7**
AC 1	1	C	635	680	535	617	**74.6**
AC 1	1	joint	497	560	549	536	**33.5**
AC 1	2	A	503	419	360	427	**71.6**
AC 1	2	B	520	547	500	522	**23.3**
AC 1	2	C	547	536	491	525	**29.6**
AC 1	3	A	529	534	565	542	**19.2**
AC 1	3	B	694	600	612	635	**51.3**
AC 1	3	C	635	603	538	592	**49.3**
AC 1	3	joint	650	576	573	600	**43.3**
AC 1	4	A	286	455	390	377	**85.5**
AC 1	4	B	458	479	473	470	**10.7**
AC 1	4	C	625	580	468	557	**80.8**
AC 1	5	A	600	655	717	657	**58.2**
AC 1	5	B	704	560	597	621	**74.8**
AC 1	5	C	588	588	570	582	**10.6**
AC 1	5	joint	689	573	695	652	**69.0**
AC 2	1	A	465	502	628	532	**85.6**
AC 2	1	B	588	484	561	544	**54.3**
AC 2	1	C	604	397	296	432	**157.0**
AC 2	1	joint	No test	No test	No test	-	**-**
AC 2	2	A	551	597	655	601	**52.2**
AC 2	2	B	646	616	655	639	**20.8**
AC 2	2	C	766	487	514	589	**153.6**
AC 2	3	A	577	552	449	526	**67.8**
AC 2	3	B	521	546	421	496	**66.0**
AC 2	3	C	231	636	424	430	**202.7**
AC 2	3	joint	No test	No test	No test	-	**-**
AC 2	4	A	489	464	600	518	**72.2**
AC 2	4	B	451	511	546	503	**47.9**

AC 2	4	C	388	215	376	326	**96.8**
AC 2	5	A	527	458	543	509	**45.1**
AC 2	5	B	709	571	571	617	**79.7**
AC 2	5	C	781	502	461	581	**174.1**
AC 2	5	joint	No test	No test	No test	-	**-**
AC 3	1	A	No test	No test	No test	-	**-**
AC 3	1	B	151	190	137	159	**27.7**
AC 3	1	C	No test	No test	No test	-	**-**
AC 3	2	A	No test	No test	No test	-	**-**
AC 3	2	B	136	199	206	180	**38.4**
AC 3	2	C	No test	No test	No test	-	**-**
AC 3	3	A	No test	No test	No test	-	**-**
AC 3	3	B	139	161	183	161	**21.8**
AC 3	3	C	No test	No test	No test	-	**-**
AC 3	4	A	No test	No test	No test	-	**-**
AC 3	4	B	162	189	145	165	**22.1**
AC 3	4	C	No test	No test	No test	-	**-**
AC 3	5	A	No test	No test	No test	-	**-**
AC 3	5	B	196	212	167	192	**22.7**
AC 3	**5**	**C**	**No test**	**No test**	**No test**	**-**	**-**

Table 160. Core height measurements on ***US-280 (Without IC), AL*, inch**

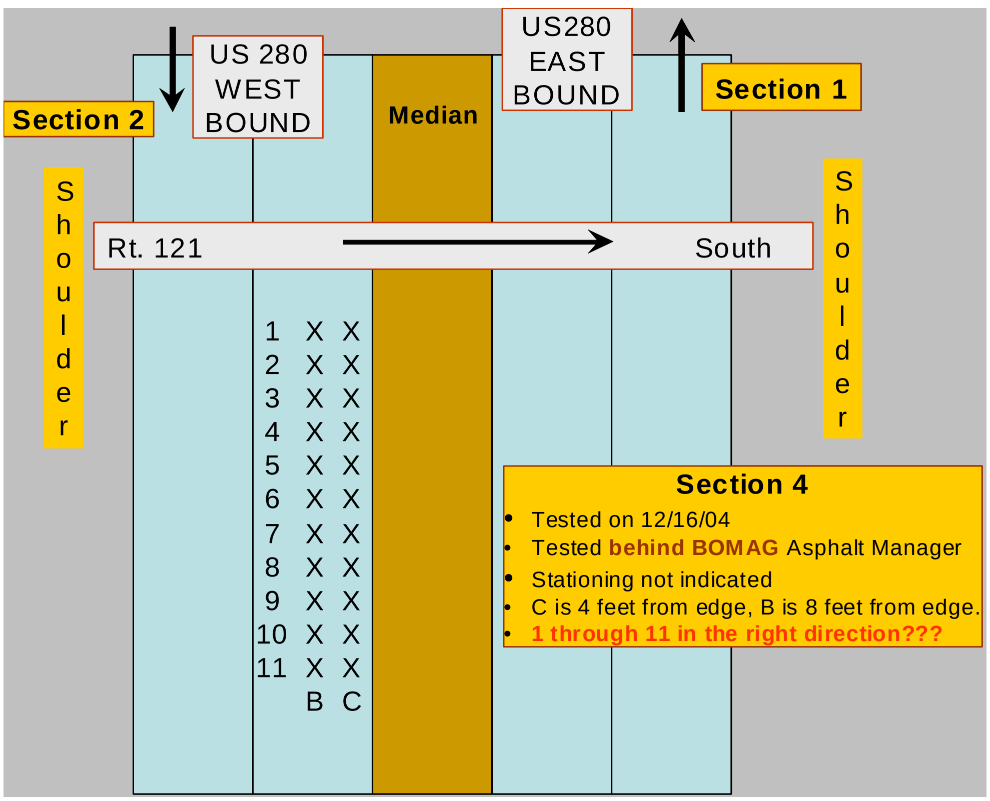
Specimen, lot-sublot point	**Height Measurements**				
	1	**2**	**3**	**4**	**Average**
AC 1-1A	3.12	3.10	3.07	3.10	3.10
AC 1-2B	3.09	3.07	3.17	3.17	3.12
AC 2-2C	3.31	3.34	3.20	3.20	3.26
AC 2-4C	2.83	2.92	2.81	2.86	2.85

Table 161. Air voids from cores on ***US-280 (Without IC), AL***

Specimen, lot-sublot point	Dry Weight, gm	Submerged Weight, gm	SSD Weight, gm	Bulk Specific Gravity Gmb	Theor. Max Spec gravity, Gmm	Percent Air Voids
1-1A	3280.3	1931.8	3297.6	2.402	2.592	7.3
1-2B	3330.4	1972.6	3343.4	2.4	2.592	6.3
2-2C	3485.1	2104.1	3505.7	2.487	2.592	4.1-
2-4C	2702.4	1633	2762.9	2.392	2.592	7.7

US-280, AL HMA SECTIONS WITH INTELLIGENT COMPACTION DURING PAVING

(TESTED IN DECEMBER 2004)



Note: Stationing and offsets of test points are not shown for this test site

Table 162. ***Density*** measured by PQI – Non-nuclear Gage on **I*US-280 (With IC), AL,* pcf**
Note: Test repetitions are shown in Table 163

Lot	Sublot	Test Point			Average	Average by lot
		A	B	C		
AC4	1	-	141.0	142.3	141.7	
	2	-	141.1	142.2	141.7	
	3	-	144.3	144.3	144.3	
	4	-	137.7	139.1	138.4	
	5	-	0.0	138.5	69.2	
	6	-	141.2	141.6	141.4	
	7	-	143.2	144.3	143.8	
	8	-	139.3	138.9	139.1	
	9	-	141.0	139.3	140.2	
	10	-	139.1	141.4	140.3	
	11	-	140.5	141.0	140.8	134.6
		-				
Average lot 1 by row		-	128.0	141.2	134.6	
Average by row		-	128.0	141.2	134.6	
Average project		-				134.6

Table 163. Repeatability in ***Density*** measured by ***PQI*** on ***US-280 (With IC), AL, pcf***
Note: Summary of results is shown in Table 162

Lot	Sublot	Point	Density, pcf				
			Trial 1	Trial 2	Trial 3	Average	Stdev
AC 4	1	B	140.0	142.3	140.7	141.0	1.2
AC 4	1	C	141.5	141.5	144.0	142.3	1.4
AC 4	2	B	141.3	140.5	141.6	141.1	0.6
AC 4	2	C	142.9	140.7	143.0	142.2	1.3
AC 4	3	B	142.9	146.4	143.5	144.3	1.9
AC 4	3	C	145.5	143.2	144.2	144.3	1.2
AC 4	4	B	137.1	138.6	137.5	137.7	0.8
AC 4	4	C	140.0	137.5	139.9	139.1	1.4
AC 4	5	B	137.9			137.9	*
AC 4	5	C	136.1	140.2	139.1	138.5	2.1
AC 4	6	B	140.9	142.0	140.7	141.2	0.7
AC 4	6	C	141.8	143.0	140.1	141.6	1.5
AC 4	7	B	144.9	142.2	142.5	143.2	1.5
AC 4	7	C	145.5	143.2	144.3	144.3	1.2
AC 4	8	B	139.0	139.9	139.1	139.3	0.5
AC 4	8	C	137.7	138.8	140.1	138.9	1.2
AC 4	9	B	140.5	141.0	141.6	141.0	0.6
AC 4	9	C	138.4	143.0	136.6	139.3	3.3
AC 4	10	B	138.6	139.4	139.3	139.1	0.4
AC 4	10	C	141.9	137.3	145.1	141.4	3.9
AC 4	11	B	142.5	137.9	141.1	140.5	2.4
AC 4	11	C	142.4	142.2	138.4	141.0	2.3

Table 164. ***Modulus*** measured by PSPA on ***US-280 (With IC), AL***, **ksi**
Note: Repeatability data is presented in Table 165

Lot	Sublot	Test Point			Average	Average by lot
		A	B	C		
AC4	1	-	207	222	215	
	2	-	261	289	275	
	3	-	319	340	330	
	4	-	174	299	236	
	5	-	260	283	272	
	6	-	216	302	259	
	7	-	230	222	226	
	8	-	219	247	233	
	9	-	258	238	248	
	10	-	226	254	240	
	11	-	255	229	242	252
		-				
Average lot 1 by row		-	239	266	252	
Average by row		-	239	266	252	
Average project		-				252

Table 165. Repeatability in ***Modulus*** measured by ***PSPA*** on ***US-280 (Without IC), ksf***
Note: Summary of results is shown in Table 164

Lot	Sublot	Point	Density, pcf				
			Trial 1	Trial 2	Trial 3	Average	Stdev
AC 4	1	B	308	323	326	319	9.9
AC 4	1	C	286	282	301	289	10.1
AC 4	2	B	220	233	212	222	10.9
AC 4	2	C	203	199	220	207	11.0
AC 4	3	B	251	270	240	254	15.2
AC 4	3	C	236	203	218	219	16.9
AC 4	4	B	210	214	243	222	17.9
AC 4	4	C	284	292	321	299	19.3
AC 4	5	B	283	250	250	261	19.4
AC 4	5	C	275	232	257	255	21.5
AC 4	6	B	276	315	315	302	22.1
AC 4	6	C	206	223	257	229	26.0
AC 4	7	B	273	277	230	260	26.4
AC 4	7	C	200	225	254	226	26.8
AC 4	8	B	198	247	202	216	26.9
AC 4	8	C	231	279	231	247	28.0
AC 4	9	B	208	270	237	238	31.0
AC 4	9	C	259	234	196	230	31.5
AC 4	10	B	231	294	250	258	32.1
AC 4	10	C	362	300	359	340	35.3
AC 4	11	B	282	328	240	283	44.0
AC 4	11	C	182	117	222	174	53.4

Table 166. Core height measurements on ***US-280 (With IC), AL*, inch**

Specimen, lot-sublot point	**Height Measurements**					
	1	**2**	**3**	**4**	**Average**	**Stdev**
AC 4-6C	3.39	3.50	3.36	3.34	3.40	0.069
AC 4-8	2.03	2.04	1.99	2.05	2.03	0.026
AC 4-10C	2.32	2.31	2.54	2.40	2.39	0.105

Table 167. Air voids from cores on ***US-280 (With IC), AL***

Specimen, lot-sublot point	Dry Weight, gm	Submerged Weight, gm	SSD Weight, gm	Bulk Specific Gravity Gmb	Theor. Max Spec gravity, Gmm	Percent Air Voids
AC 4-6C	3677.7	2191.8	3689.7	2.455	2.592	5.3
AC 4-8	1988.1	1166.2	1997.5	2.392	2.592	7.7
AC 4-10C	2473.7	1456.5	2483.7	2.408	2.592	7.1

Table 168. ***Dynamic Modulus*** Test results for ***US-280, AL, Overlay HMA,*** psi

Temperature, °F	**Replicate**	**E* Measured at Frequency**					
		25	**10**	**5**	**1**	**0.5**	**0.1**
14	**1**	9,781,924	9,180,398	8,676,910	7,678,442	6,281,545	**6,107,647**
	3	8,343,293	7,989,861	7,658,621	6,982,878	6,191,835	**5,863,909**
	4	6,539,737	6,057,287	5,789,861	5,133,463	4,235,248	**4,161,028**
	Average	8,221,651	7,742,515	7,375,130	6,598,261	5,569,543	**5,377,528**
	CV, %	19.8	20.4	19.9	19.9	20.8	**19.7**
40	**1**	7,360,668	6,489,224	5,935,064	4,933,740	4,612,265	**3,452,698**
	3	6,118,143	5,650,802	5,677,432	4,687,536	4,496,473	**3,561,312**
	4	5,052,739	4,678,519	4,579,046	3,770,004	3,507,511	**2,907,589**
	Average	6,177,183	5,606,181	5,397,181	4,463,760	4,205,416	**3,307,200**
	CV, %	18.7	16.2	13.3	13.7	14.4	**10.6**
70	**1**	4,284,976	3,539,574	2,967,974	1,939,033	1,565,085	**1,063,793**
	3	3,347,060	3,016,982	2,658,984	2,040,414	1,725,602	**1,224,126**
	4	2,644,338	2,239,551	2,005,672	1,514,402	1,279,328	**919,137**
	Average	3,425,458	2,932,035	2,544,210	1,831,283	1,523,338	**1,069,018**
	CV, %	24.03	22.31	19.31	15.24	14.84	**14.27**
100	**1**	1,920,961	1,633,961	1,399,018	951,689	827,147	**602,082**
	3	2,011,967	1,661,103	1,433,099	981,886	832,204	**567,619**
	4	1,407,231	1,131,060	961,023	673,827	559,733	**389,707**
	Average	1,780,053	1,475,375	1,264,380	869,134	739,694	**519,803**
	CV, %	18.3	20.2	20.8	19.5	21.1	**21.9**

Temperature, °F	Replicate	E* Measured at Frequency					
		25	10	5	1	0.5	0.1
130	**1**	886,377	732,890	627,549	445,154	396,222	**298,563**
	3	1,036,305	811,429	716,247	513,147	441,346	**324,072**
	4	705,974	572,885	479,151	348,879	305,609	**238,277**
	Average	876,218	705,735	607,649	435,726	381,059	**286,971**
	CV, %	**18.9**	**17.2**	**19.7**	**18.9**	**18.1**	**15.4**

Table 169. ***Repeated load*** test results for ***US-280, AL, HMA***

Replicate	Repeated Load @ 147 deg F			
	Flow time, cycles	Applied stress, psi	Maximum LVDT slope	Minimum LVDT slope
1	10000	73.4	0.178	**0.185**
2		75	0.154	**0.151**
3		74.8	0.196	**0.197**
Average		74.4	0.176	**0.178**
CV, %		**1.17**	**11.97**	**13.43**

I-35, TX HMA SECTIONS

(TESTED IN APRIL 2005)

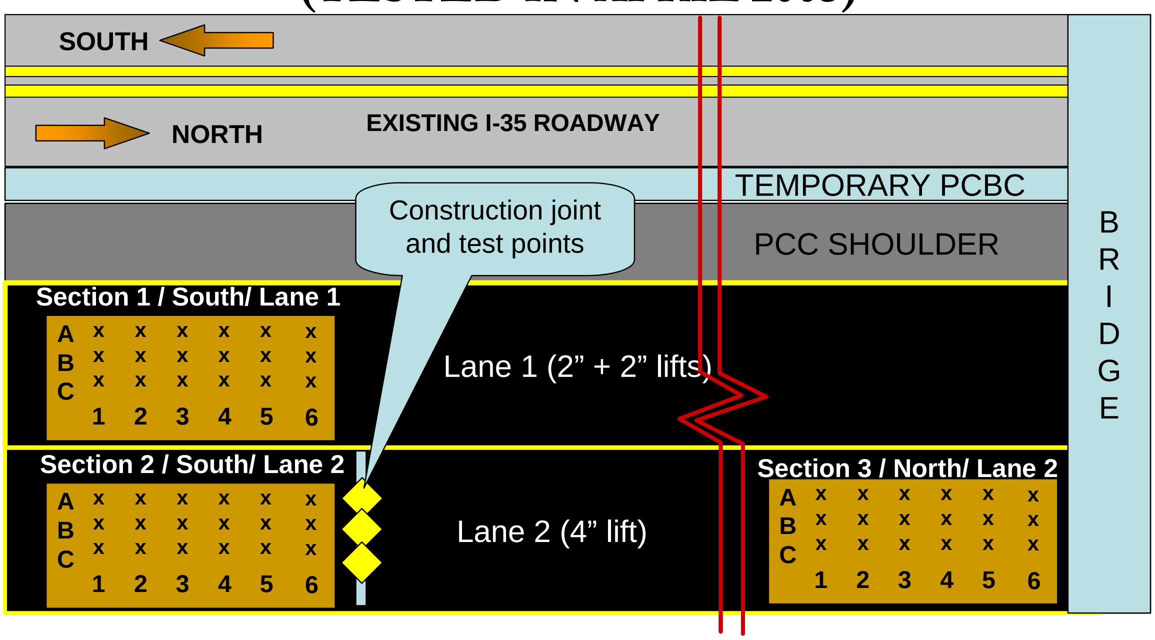


Table 170. ***Uncalibrated Thickness*** measured by ***GPR*** on ***I-35, TX inch***
Note: Repeatability in measurements is shown in Table 172

Lot	**Sublot**	**A**	**B**	**C**	**J**	**Average**	**Average by lot**
Lane 1	1	5.03	4.34	4.21	4.35	4.48	
	2	4.41	3.95	4.08	4.03	4.12	
	3	4.12	3.92	3.95	4.00	4.00	
	4	4.25	4.08	4.08	4.14	4.14	
	5	4.85	4.24	4.22	No data	4.43	
	6	4.73	4.53	4.33	4.25	4.46	4.26
Lane 2	1	-	4.52	4.28	-	4.40	
	2	-	4.45	4.13	-	4.29	
	3	-	4.33	3.95	-	4.14	
	4	-	4.50	4.33	-	4.42	
	5	-	4.09	4.08	4.44	4.20	
	6	4.25	4.18	4.33	-	4.25	4.28
	Const Jt.	No data	No data	No data	No data	No data	
Lane 3*	1	No data	No data	No data	No data	No data	
Average lot 1 by row		4.56	4.18	4.14	4.15		
Average lot 2 by row		4.25	4.34	4.18	4.44		
Average lot 3 by row		NO data					
Average by row		4.41	4.26	4.16	4.30		
Average project							4.27

Table 171. ***Uncalibrated Percent Air voids*** measured by ***GPR I-35, TX***
Note: Repeatability in measurements is shown in Table 172

Lot	**Sublot**	**A**	**B**	**C**	**J**	**Average**	**Average by lot**
Lane 1	1	5.55	6.30	6.11	5.16	5.78	
	2	5.70	6.40	6.00	5.24	5.84	
	3	5.63	6.29	6.04	5.11	5.77	
	4	5.54	6.16	6.03	5.31	5.76	
	5	5.56	6.20	6.16	No data	5.97	
	6	5.59	5.79	5.98	5.13	5.62	5.78
Lane 2	1	-	5.62	6.09	-	5.86	
	2	-	5.72	6.18	-	5.95	
	3	-	5.82	6.17	-	6.00	
	4	-	5.61	5.87	-	5.74	
	5	-	5.70	5.89	4.97	5.52	
	6	5.13	5.71	5.83	-	5.55	5.74
	Const Jt.	No data	No data	No data	No data	No data	
Lane 3*	1	No data	No data	No data	No data	No data	
Average lot 1 by row		5.59	6.19	6.05	5.19		
Average lot 2 by row		5.13	5.70	6.00	4.97		
Average lot 3 by row		NO data					
Average by row		5.36	5.94	6.03	5.08		
Average project							5.76

Table 172. Repeatability measurements for ***Percent Air voids and Thickness*** measured by ***GPR*** on ***I-35, TX***
Note: Readings were not calibrated with actual core data; Summary of results are shown in Table 170 and Table 171

Lot	Sublot	Test Point	Thickness (calibrated)					Air Voids			
			Trial 1 (in)	Trial 2 (in)	Average (in)	Std dev (in)		Trial 1 percent	Trial 2 percent	Average percent	Std dev percent
LANE 1	1	A	4.98	5.08	5.03	0.07		5.53	5.58	5.55	0.03
LANE 1	1	B	4.32	4.35	4.34	0.02		6.34	6.25	6.30	0.06
LANE 1	1	C	4.23	4.20	4.21	0.02		6.11	6.11	6.11	0.00
LANE 1	1	J	4.36	4.34	4.35	0.01		5.13	5.19	5.16	0.04
LANE 1	2	A	4.44	4.38	4.41	0.04		5.58	5.83	5.70	0.17
LANE 1	2	B	3.94	3.96	3.95	0.01		6.44	6.36	6.40	0.05
LANE 1	2	C	4.13	4.02	4.08	0.07		5.88	6.12	6.00	0.17
LANE 1	2	J	4.11	3.94	4.03	0.12		5.11	5.38	5.24	0.19
LANE 1	3	A	4.15	4.08	4.12	0.05		5.55	5.71	5.63	0.11
LANE 1	3	B	3.93	3.92	3.92	0.01		6.27	6.30	6.29	0.02
LANE 1	3	C	3.97	3.92	3.95	0.04		5.99	6.09	6.04	0.08
LANE 1	3	J	4.10	3.90	4.00	0.14		5.00	5.22	5.11	0.15
LANE 1	4	A	4.28	4.23	4.25	0.04		5.46	5.62	5.54	0.11
LANE 1	4	B	4.06	4.11	4.08	0.03		6.24	6.08	6.16	0.11
LANE 1	4	C	4.09	4.06	4.08	0.02		6.00	6.05	6.03	0.03
LANE 1	4	J	4.14	4.14	4.14	0.01		5.35	5.26	5.31	0.06
LANE 1	5	A	4.92	4.77	4.85	0.11		5.45	5.68	5.56	0.16
LANE 1	5	B	4.22	4.25	4.24	0.02		6.20	6.19	6.20	0.01
LANE 1	5	C	4.23	4.21	4.22	0.02		6.14	6.18	6.16	0.03
LANE 1	6	A	4.77	4.70	4.73	0.05		5.53	5.64	5.59	0.08
LANE 1	6	B	4.53	4.52	4.53	0.00		5.79	5.79	5.79	0.00
LANE 1	6	C	4.29	4.36	4.33	0.05		6.07	5.89	5.98	0.13

Lot	Sublot	Test Point	Thickness (calibrated) Trial 1 (in)	Trial 2 (in)	Average (in)	Std dev (in)		Air Voids Trial 1 percent	Trial 2 percent	Average percent	Std dev percent
LANE 1	6	J	4.32	4.18	4.25	0.10		5.01	5.24	5.13	0.16
LANE 2	1	A	-	-	-	-		-	-	-	-
LANE 2	1	B	4.46	4.58	4.52	0.08		5.73	5.51	5.62	0.16
LANE 2	1	C	4.31	4.24	4.28	0.05		6.05	6.13	6.09	0.05
LANE 2	2	A	-	-	-	-		-	-	-	-
LANE 2	2	B	4.42	4.48	4.45	0.04		5.83	5.62	5.72	0.15
LANE 2	2	C	4.12	4.14	4.13	0.01		6.19	6.17	6.18	0.01
LANE 2	3	A	-	-	-	-		-	-	-	-
LANE 2	3	B	4.28	4.37	4.33	0.06		5.87	5.77	5.82	0.07
LANE 2	3	C	3.96	3.94	3.95	0.01		6.15	6.20	6.17	0.04
LANE 2	4	A	-	-	-	-		-	-	-	-
LANE 2	4	B	4.46	4.54	4.50	0.06		5.68	5.53	5.61	0.11
LANE 2	4	C	4.31	4.35	4.33	0.03		5.90	5.85	5.87	0.04
LANE 2	5	A	-	-	-	-		-	-	-	-
LANE 2	5	B	4.08	4.10	4.09	0.01		5.76	5.63	5.70	0.09
LANE 2	5	C	4.06	4.09	4.08	0.02		5.93	5.85	5.89	0.05
LANE 2	5	J	4.44	4.43	4.44	0.01		5.00	4.94	4.97	0.04
LANE 2	6	A	4.32	4.18	4.25	0.10		5.01	5.24	5.13	0.16
LANE 2	6	B	4.10	4.25	4.18	0.11		5.94	5.48	5.71	0.33
LANE 2	6	C	4.36	4.31	4.33	0.04		5.89	5.76	5.83	0.09
LANE 2	CJ*	A	-	-	-	-		-	-	-	-
LANE 2	CJ*	B	-	-	-	-		-	-	-	-
LANE 2	CJ*	C	-	-	-	-		-	-	-	-

* Transverse Construction Joint

Table 173. ***Density*** measured by Pavetracker – Non-nuclear Gage on ***I-35, TX, pcf***
Note: Test repetitions are shown in Table 174

Lot	Sublot	A	B	C	J	Average	Average by lot
Lane 1	1	141.6	135.6	137.8	131.2	136.5	
	2	143.7	145.3	141.5	123.4	138.5	
	3	144.2	143.3	142.5	125.2	138.8	
	4	142.5	139.7	138.3	123.5	136.0	
	5	139.8	145.9	139.6	126.3	137.9	
	6*	145.8	144.8	142.25	125.8	144.3	137.9
Average lot 1 by row		142.9	142.4	140.3	125.9		
Average lot 2 by row		-	-	-	-		
Average lot 3 by row		-	-	-	-		
Average by row		142.9	142.4	140.3	125.9		
Average project							137.9

Table 174. Repeatability in ***Density*** measured by ***Pavetracker*** on ***I-35, TX, pcf***
Note: Summary of results is shown in Table 173

Section	Location	Point	Density, pcf					
			Trial 1	**Trial 2**	**Trial 3**	**Trial 4**	**Average**	**Stdev**
LANE 1	1	A	141.3	140.8	140.5	143.6	141.6	1.4
LANE 1	1	B	137.0	133.9	136.9	134.5	135.6	1.6
LANE 1	1	C	135.7	138.0	139.1	138.2	137.8	1.4
LANE 1	1	J	132.0	131.6	134.0	127.1	131.2	2.9
LANE 1	2	A	144.9	142.5	144.1	143.1	143.7	1.1
LANE 1	2	B	143.8	144.5	149.0	143.9	145.3	2.5
LANE 1	2	C	140.7	142.4	141.2	141.6	141.5	0.7
LANE 1	2	J	125.6	120.1	125.4	122.6	123.4	2.6
LANE 1	3	A	142.6	144.9	144.3	145.0	144.2	1.1
LANE 1	3	B	146.9	142.0	142.7	141.6	143.3	2.4
LANE 1	3	C	141.0	144.5	138.7	145.8	142.5	3.2
LANE 1	3	J	127.4	126.9	122.4	124.1	125.2	2.4
LANE 1	4	A	144.1	142.1	143.7	140.2	142.5	1.8
LANE 1	4	B	142.8	137.6	139.9	138.6	139.7	2.3
LANE 1	4	C	137.4	139.0	138.5	138.4	138.3	0.7
LANE 1	4	J	126.6	121.6	125.4	120.3	123.5	3.0
LANE 1	5	A	141.8	142.1	136.9	138.4	139.8	2.6
LANE 1	5	B	146.0	146.0	146.4	145.1	145.9	0.6
LANE 1	5	C	141.3	134.8	144.7	137.5	139.6	4.3
LANE 1	5	J	131.3	127.7	128.6	117.6	126.3	6.0
LANE 1	6	A	143.8	147.5	145.4	146.4	145.8	1.6

Section	Location	Point	Density, pcf					
			Trial 1	Trial 2	Trial 3	Trial 4	Average	Stdev
LANE 1	6	B	146.6	143.7	143.9	144.9	144.8	1.3
LANE 1	6	C	142.5	143.9	142.6	140.0	142.3	1.6
LANE 1	6	J	128.0	122.5	128.4	124.4	125.8	2.9

Table 175. ***Density*** measured by PQI – Non-nuclear Gage on **I-35, TX, pcf**
Note: Test repetitions are shown in Table 176

Lot	Sublot	A	B	C	J	Average	Average by lot
Lane 1	1	126.7	125.9	123.1	121.1	124.2	
	2	127.4	127.5	126.0	117.7	124.7	
	3	127.5	126.7	125.4	119.9	124.9	
	4	126.2	127.2	125.7	117.1	124.0	
	5	128.0	127.3	126.9	118.1	125.0	
	6*	127.3	127.9	127.3	118.3	125.2	125.0
Lane 2	1	123.2	125.5	122.4		123.7	
	2	121.9	124.3	125.9		124.0	
	3	122.4	123.9	127.3		124.5	
	4	125.0	121.9	124.0		123.6	
	5	124.4	125.0	123.5		124.3	
	6	124.9	130.1	122.1		125.7	
	Cons. Jt.	124.6	121.4	123.2		123.1	124.1
Lane 3	1	125.9	124.3	126.8	120.2	124.3	
	2	125.5	125.3	124.6	120.7	124.0	
	3	123.8	126.5	124.9	121.5	124.1	
	4	125.5	125.3	126.0	120.8	124.4	
	5	123.5	125.3	123.7	118.6	122.8	123.9
Average lot 1 by row		127.2	127.1	125.7	118.7		
Average lot 2 by row		123.8	124.6	124.0			
Average lot 3 by row		124.8	125.3	125.2	120.3		
Average by row		125.2	125.6	124.9	119.4		
Average project							124.3

Table 176. Repeatability in ***Density*** measured by ***PQI*** on ***I-35, TX, pcf***
Note: Summary of results is shown in Table 175

Lot/ Lane	Sublot	Point	Density, pcf						
			Trial 1	Trial 2	Trial 3	Trial 4	Trial 5	Avg	Stdev
LANE 1	1	A	125.7	127.2	127.0	127.0	-	126.7	0.69
LANE 1	1	B	125.6	125.9	126.0	126.0	-	125.9	0.19
LANE 1	1	C	122.7	122.6	123.4	123.7	-	123.1	0.54
LANE 1	1	J	120.0	122.0	121.0	121.2	-	121.1	0.82
LANE 1	2	A	127.4	127.9	127.6	126.8	-	127.4	0.46
LANE 1	2	B	127.8	126.8	127.5	128.0	-	127.5	0.53
LANE 1	2	C	126.3	126.2	125.5	125.8		126.0	0.37
LANE 1	2	J	116.6	116.9	119.0	118.4	-	117.7	1.16
LANE 1	3	A	127.9	127.9	127.3	126.9	-	127.5	0.49
LANE 1	3	B	126.6	126.9	126.9	126.5	-	126.7	0.21
LANE 1	3	C	125.1	125.1	125.7	125.7	-	125.4	0.35
LANE 1	3	J	120.5	121.3	118.0	119.8	-	119.9	1.41
LANE 1	4	A	126.5	126.4	125.9	125.9	-	126.2	0.32
LANE 1	4	B	127.3	127.2	126.8	127.3	-	127.2	0.24
LANE 1	4	C	125.5	125.8	125.5	125.8	-	125.7	0.17
LANE 1	4	J	117.1	117.2	117.5	116.6	-	117.1	0.37
LANE 1	5	A	128.1	127.7	128.2	127.8	-	128.0	0.24
LANE 1	5	B	127.2	127.1	127.4	127.4	-	127.3	0.15
LANE 1	5	C	128.9	126.5	126.3	125.7	-	126.9	1.41
LANE 1	6	A	127.0	127.7	127.5	127.1	-	127.3	0.33
LANE 1	6	B	128.3	127.8	127.8	127.5	-	127.9	0.33
LANE 1	6	C	126.7	127.9	126.8	127.9	-	127.3	0.67
LANE 1	6	J	118.1	119.2	117.7	118.2	-	118.3	0.64
LANE 2	1	A	123.2	123.2	123.9	122.3	-	123.2	0.66
LANE 2	1	B	125.5	125.5	124.8	126.0	-	125.5	0.49
LANE 2	1	C	125.1	120.6	121.5	122.3	-	122.4	1.94
LANE 2	2	A	122.3	121.7	121.8	121.9	-	121.9	0.26
LANE 2	2	B	124.0	124.2	124.3	124.5	-	124.3	0.21
LANE 2	2	C	126.1	125.8	125.3	126.4	-	125.9	0.47
LANE 2	3	A	121.7	122.2	123.1	122.4	-	122.4	0.58
LANE 2	3	B	121.4	125.0	124.5	124.6		123.9	1.66
LANE 2	3	C	127.5	127.6	127.3	126.7	-	127.3	0.40
LANE 2	4	A	125.2	125.0	124.5	125.4	-	125.0	0.39
LANE 2	4	B	121.1	121.9	122.1	122.5	-	121.9	0.59
LANE 2	4	C	123.1	123.5	124.5	124.7	-	124.0	0.77

Lot/ Lane	Sublot	Point	Density, pcf						
			Trial 1	Trial 2	Trial 3	Trial 4	Trial 5	Avg	Stdev
LANE 2	5	A	124.2	124.8	124.9	123.8	-	124.4	0.52
LANE 2	5	B	122.3	125.6	125.9	126.0	-	125.0	1.77
LANE 2	5	C	123.6	123.5	123.2	123.5	-	123.5	0.17
LANE 2	5	J	117.8	118.3	118.4	117.7	-	118.1	0.35
LANE 2	6	A	125.1	125.4	124.7	124.2	-	124.9	0.52
LANE 2	6	B	130.4	128.6	130.6	130.7	-	130.1	0.99
LANE 2	6	C	122.1	122.0	122.3	121.8	-	122.1	0.21
LANE 2	CJ	A	125.0	124.6	124.8	123.9	-	124.6	0.48
LANE 2	CJ	B	121.6	121.5	121.3	121.2	-	121.4	0.18
LANE 2	CJ	C	122.9	122.6	123.3	123.9	-	123.2	0.56
LANE 3	1	A	125.6	126.3	126.2	125.6	-	125.9	0.38
LANE 3	1	B	124.4	124.3	124.1	124.4	-	124.3	0.14
LANE 3	1	C	126.7	126.8	126.7	126.9	-	126.8	0.10
LANE 3	1	J	121.5	120.3	120.0	118.8	-	120.2	1.11
LANE 3	2	A	125.4	125.6	125.4	125.7	-	125.5	0.15
LANE 3	2	B	124.6	125.2	125.4	126.1	-	125.3	0.62
LANE 3	2	C	124.7	124.9	124.5	124.2	-	124.6	0.30
LANE 3	2	J	120.8	119.7	121.2	121.0	-	120.7	0.67
LANE 3	3	A	124.2	124.0	122.9	124.0	-	123.8	0.59
LANE 3	3	B	126.6	125.8	127.0	126.4	-	126.5	0.50
LANE 3	3	C	125.2	124.3	125.0	124.9	-	124.9	0.39
LANE 3	3	J	121.3	121.8	120.7	122.0	-	121.5	0.58
LANE 3	4	A	125.8	125.6	125.7	124.9	-	125.5	0.41
LANE 3	4	B	125.3	125.2	125.0	125.5	-	125.3	0.21
LANE 3	4	C	126.3	126.4	124.7	126.6	-	126.0	0.88
LANE 3	4	J	120.6	122	121.2	119.2	-	120.8	1.18
LANE 3	5	A	123.9	122.0	124.2	123.9	-	123.5	1.01
LANE 3	5	B	125.3	125.2	125.0	125.5	-	125.3	0.21
LANE 3	5	C	123.6	123.6	124.1	123.6	-	123.7	0.25
LANE 3	5	J	118.5	119.1	118.7	117.9	-	118.6	0.50

Table 177. ***Modulus*** measured by PSPA on ***I-35, TX*, ksi**
Note: Repeatability data is presented in Table 178

Lot	**Sublot**	**A**	**B**	**C**	**J**	**Average**	**Average by lot**
Lane 1	1	412.8	472.8	444.1	282.7	403.1	
	2	361.9	461.6	396.4	243.0	365.7	
	3	320.7	369.8	348.4	272.2	327.8	
	4	304.6	401.3	311.5	344.7	340.5	
	5	371.6	429.6	366.5	0.0	389.2	
	6*	No data	No data	No data	No data	No data	364.0
Lane 2	1	274.0	296.2	325.7	No data	298.6	
	2	250.2	382.4	345.3	No data	326.0	
	3	254.1	303.3	340.5	No data	299.3	
	4	259.8	311.2	243.5	No data	271.5	
	5	264.0	294.1	245.0	No data	267.7	
	6	No data	No data	No data	No data	No data	
	Const. Jt.	No data	No data	No data	No data	No data	292.6
Lane 3*	1	303.7	169.9	274.8	106.8	213.8	
	2	305.0	127.8	290.5	No data	241.1	
	3	223.4	348.3	162.5	119.4	213.4	
	4	217.5	129.0	159.1	No data	168.5	
	5	143.1	119.8	153.1	107.3	130.9	192.3
Lane 3**	1	513.5	518.4	487.8	No data		
	2	464.4	493.2	491.9	No data		
	3	453.6	475.7	454.9	No data		
	4	407.2	447.2	456.6	No data		
	5	370.5	445.1	445.1	No data		461.7
Average lot 1 by row		354.3	427.0	373.4	285.6		
Average lot 2 by row		260.5	317.5	300.0	*		
Average lot 3* row		238.6	179.0	208.0	111.2		
Average lot 3** row		441.8	475.9	467.2	*		
Average by row		284.4	307.8	293.8	210.9		
Average project							284.0* 372.1**

* One hour after construction; ** 18 hours after construction

Table 178. Repeatability in ***Modulus*** measured by ***PSPA*** on ***I-35, TX, ksf***
Note: Summary of results is shown in Table 177

Lot	Sublot	Point	Trial 1	Trial 2	Trial 3	Average	Stdev
LANE 1	1	A	387	443	409	412.8	**28.3**
LANE 1	1	B	443	465	510	472.8	**34.4**
LANE 1	1	C	458	480	394	444.1	**44.8**
LANE 1	1	J	296	281	270	282.7	**13.2**
LANE 1	2	A	353	407	326	361.9	**41.0**
LANE 1	2	B	457	499	430	461.6	**34.8**
LANE 1	2	C	386	409	395	396.4	**11.6**
LANE 1	2	J	274	297	157	243.0	**75.1**
LANE 1	3	A	306	346	310	320.7	**21.9**
LANE 1	3	B	355	399	355	369.8	**25.1**
LANE 1	3	C	321	369	355	348.4	**24.4**
LANE 1	3	J	257	280	280	272.2	**13.1**
LANE 1	4	A	319	317	278	304.6	**23.4**
LANE 1	4	B	410	404	390	401.3	**10.6**
LANE 1	4	C	269	350	315	311.5	**40.5**
LANE 1	4	J	267	315	452	344.7	**95.7**
LANE 1	5	A	296	409	409	371.6	**65.4**
LANE 1	5	B	411	425	453	429.6	**21.1**
LANE 1	5	C	337	396	366	366.5	**29.4**
LANE 1	6	A	x	x	x	x	**x**
LANE 1	6	B	x	x	x	x	**x**
LANE 1	6	C	x	x	x	x	**x**
LANE 1	6	J	x	x	x	x	**x**
LANE 2	1	A	232	302	288	274.0	**37.4**
LANE 2	1	B	220	379	290	296.2	**79.6**
LANE 2	1	C	385	290	302	325.7	**51.3**
LANE 2	2	A	223	289	239	250.2	**34.8**
LANE 2	2	B	449	326	372	382.4	**62.3**
LANE 2	2	C	360	368	308	345.3	**33.0**
LANE 2	3	A	204	314	244	254.1	**55.4**
LANE 2	3	B	278	270	362	303.3	**51.2**

Lot	Sublot	Point	Trial 1	Trial 2	Trial 3	Average	Stdev
LANE 2	3	C	358	343	320	340.5	**19.1**
LANE 2	4	A	246	275	259	259.8	**14.5**
LANE 2	4	B	290	281	362	311.2	**44.1**
LANE 2	4	C	264	221	246	243.5	**21.3**
LANE 2	5	A	295	292	205	264.0	**50.7**
LANE 2	5	B	371	266	246	294.1	**67.2**
LANE 2	5	C	255	261	219	245.0	**22.8**
LANE 2	5	J	x	x	x	x	**x**
LANE 2	6	A	x	x	x	x	**x**
LANE 2	6	B	x	x	x	x	**x**
LANE 2	6	C	x	x	x	x	**x**
LANE 2	CJ	A	x	x	x	x	**x**
LANE 2	CJ	B	x	x	x	x	**x**
LANE 2	CJ	C	x	x	x	x	**x**
LANE 3*	1	A	287	321	N/A	303.7	**23.9**
LANE 3*	1	B	227	113	N/A	169.9	**80.1**
LANE 3*	1	C	280	270	N/A	274.8	**6.8**
LANE 3*	1	J	116	98	N/A	106.8	**12.6**
LANE 3*	2	A	265	345	N/A	305.0	**57.1**
LANE 3*	2	B	137	119	N/A	127.8	**12.7**
LANE 3*	2	C	253	327	N/A	290.5	**52.3**
LANE 3*	2	J	x	x	x	x	**x**
LANE 3*	3	A	266	181	N/A	223.4	**60.3**
LANE 3*	3	B	402	295	N/A	348.3	**76.1**
LANE 3*	3	C	240	85	N/A	162.5	**109.2**
LANE 3*	3	J	131	108	N/A	119.4	**16.6**
LANE 3*	4	A	275	160	N/A	217.5	**81.2**
LANE 3*	4	B	143	115	N/A	129.0	**20.0**
LANE 3*	4	C	107	211	N/A	159.1	**73.2**
LANE 3*	4	J	x	x	x	x	**x**
LANE 3*	5	A	186	100	N/A	143.1	**61.2**
LANE 3*	5	B	107	133	N/A	119.8	**18.8**
LANE 3*	5	C	145	161	N/A	153.1	**11.8**

Lot	Sublot	Point	Trial 1	Trial 2	Trial 3	Average	Stdev
LANE 3*	5	J	105	110	N/A	107.3	**3.5**
LANE 3**	1	A	514	501	525	513.5	**11.9**
LANE 3**	1	B	485	527	544	518.4	**30.3**
LANE 3**	1	C	448	534	481	487.8	**43.5**
LANE 3**	1	J	x	x	x	x	**x**
LANE 3**	2	A	506	460	428	464.4	**39.4**
LANE 3**	2	B	490	534	456	493.2	**39.3**
LANE 3**	2	C	478	532	466	491.9	**35.3**
LANE 3**	2	J	x	x	x	x	**x**
LANE 3**	3	A	459	361	541	453.6	**89.9**
LANE 3**	3	B	529	474	423	475.7	**52.9**
LANE 3**	3	C	427	414	524	454.9	**59.8**
LANE 3**	3	J	x	x	x	x	**x**
LANE 3**	4	A	394	396	432	407.2	**21.1**
LANE 3**	4	B	450	482	409	447.2	**36.7**
LANE 3**	4	C	477	473	420	456.6	**31.5**
LANE 3**	4	J	x	x	x	x	**x**
LANE 3**	5	A	370	372	370	370.5	**1.1**
LANE 3**	5	B	444	444	448	445.1	**2.1**
LANE 3**	5	C	462	411	462	445.1	**29.9**
LANE 3**	**5**	**J**	**x**	**x**	**x**	**x**	**x**

* One hour after construction; ** 18 hours after construction

Table 179. Comparison of Laboratory measured and PSPA Modulus on ***I-35, TX*****, psi**
Note: Summary of results is shown in Table 177 and Repeatability data in Table 178

Specimen ID	**Modulus**		
	Lab	**PSPA**	**Difference**
Section 1. Core 1A	356000	413000	**16%**
Section 1. Core 3A	369983	321000	**13%**
Section 1. Core 5B	379415	430000	**13%**
Section 2. Core 3C	346000	340000	**2%**
Section 2. Core 4A-1	285000	260000	**9%**
Section 2. Core 4B	358875	311000	**13%**
Section 3. Core 1C	492000	483000	**2%**
Section 3. Core 2B	433000	493000	**14%**
Section 3. Core 4C	**440423**	**457000**	**4%**

Table 180. ***Density*** measured by **Nuclear Gauge** on ***I-35, TX*, pcf**
Note: Single measurements were made at each point

Lot	Sublot	A	B	C	J	Average	Average by lot
Lane 1	1	145.5	143.5	138.5	128.1	138.9	
	2	147.6	146.4	142.9	132.1	142.3	
	3	146.5	146.1	144.2	130.0	141.7	
	4	142.2	144.1	140.3	129.9	139.1	
	5	147.8	147.3	141.8	131.5	142.1	
	6*	147.1	146.8	143.2	125.7	140.7	140.8
Lane 2	1	128.0	130.5	146.5	*	135.0	
	2	142.6	140.8	147.0	*	143.5	
	3	141.6	143.4	150.5	*	145.2	
	4	145.6	139.5	139.3	*	141.5	
	5	141.4	138.5	140.1	*	140.0	
	6	143.8	144.4	140.7	*	143.0	
	Const Jt.	138.6	135.8	138.3	*	137.6	140.8
Lane 3*	1	143.6	128.1	139.8	129.3	135.2	
	2	143.0	139.8	136.0	124.3	135.8	
	3	136.0	139.5	140.1	124.3	135.0	
	4	140.9	138.3	136.2	128.9	136.1	
	5	135.7	137.6	126.5	120.5	130.1	134.4
Average lot 1 by row		146.1	145.7	141.8	129.6		
Average lot 2 by row		140.2	139.0	143.2	*		
Average lot 3 by row		139.8	136.7	135.7	125.5		
Average by row		142.1	140.6	140.7	127.7		
Average project							138.8

Table 181. Core height measurements on ***I-35, TX*, inch**

Specimen, lot-sublot point	**Height Measurements**				
	1	**2**	**3**	**4**	**Average**
Lane 1 – 1A	x	x	x	x	3.33
Lane 1 – 3A	x	x	x	x	x
Lane 1 – 5B	x	x	x	x	3.45
Lane 2 – 4A	x	x	x	x	x
Lane 2 – 4B	x	x	x	x	x
Lane 2 – 3C	x	x	x	x	x
Lane 3 – 1C	x	x	x	x	x
Lane 3 – 2B	x	x	x	x	x
Lane 3 – 4C	x	x	x	x	x

Table 182. Air voids from cores on ***I-35, TX*, inch**

Specimen, lot-sublot point	Dry Weight, gm	Submerged Weight, gm	SSD Weight, gm	Bulk Specific Gravity Gmb	Theor. Max Spec gravity, Gmm	Percent Air Voids
Lane 1 – 1A	-	-	-	-	-	-
Lane 1 – 3A	3261	1847.7	3263.7	2.303	2.462	6.5
Lane 1 – 5B	3249.1	1836.8	3260.8	2.282	2.462	7.3
Lane 2 – 4A	2359.9	1334.6	2365.4	2.289	2.462	7.0
Lane 2 – 4B	2625	1490.6	2632	2.300	2.462	6.6
Lane 2 – 3C	2864.5	1650.9	2865.4	2.359	2.462	4.2
Lane 3 – 1C	-	-	-	-	-	-
Lane 3 – 2B	-	-	-	-	-	-
Lane 3 – 4C	3085.4	1745.4	3097.3	2.282	2.462	7.3

Table 183. ***Dynamic Modulus*** Test results for ***I-35, TX, HMA,*** psi

Temperature, °F	Replicate	E* Measured at Frequency					
		25	**10**	**5**	**1**	**0.5**	**0.1**
14	**1**	11,751,234	11,114,097	10,552,517	9,433,055	7,909,937	**7,482,062**
	2	10,874,108	10,378,841	9,553,877	8,458,348	6,748,046	**6,382,897**
	3	9,469,871	8,850,972	8,580,794	7,426,643	6,088,080	**5,787,464**
	Average	10,698,404	10,114,637	9,562,396	8,439,349	6,915,354	**6,550,808**
	CV, %	10.76	11.41	10.31	11.89	13.34	**13.12**
40	**1**	10,036,405	9,171,859	9,078,787	7,324,681	6,994,478	**5,215,454**
	2	8,848,540	8,589,329	8,226,239	6,839,080	6,546,194	**5,039,292**
	3	8,533,549	8,036,650	7,851,198	6,649,232	6,331,697	**5,010,286**
	Average	9,139,498	8,599,279	8,385,408	6,937,664	6,624,123	**5,088,344**
	CV, %	8.67	6.60	7.50	5.02	5.11	**2.18**
70	**1**	5,414,297	4,764,000	4,164,730	3,142,821	2,634,981	**1,845,000**
	2	4,824,896	4,196,728	3,690,083	2,618,905	2,181,193	**1,514,874**
	3	5,543,182	4,943,922	4,489,297	3,467,926	3,057,037	**2,205,774**
	Average	5,260,792	4,634,883	4,114,704	3,076,551	2,624,404	**1,855,216**
	CV, %	7.28	8.41	9.77	13.92	16.69	**18.63**
100	**1**	2,928,299	2,459,924	2,111,651	1,486,457	1,230,034	**855,449**
	2	2,930,915	2,459,418	2,036,833	1,323,791	1,120,203	**791,363**
	3						
	Average	2,929,607	2,459,671	2,074,242	1,405,124	1,175,118	**823,406**
	CV, %	0.06	0.01	2.55	8.19	6.61	**5.50**

Temperature, °F	Replicate	E* Measured at Frequency					
		25	10	5	1	0.5	0.1
130	1	1,370,126	1,093,234	948,880	708,449	617,503	**496,747**
	2	1,463,116	1,143,621	981,316	697,912	615,765	**464,824**
	3						
	Average	1,416,621	1,118,428	965,098	703,181	616,634	**480,786**
	CV, %	**4.64**	**3.19**	**2.38**	**1.06**	**0.20**	**4.70**

Table 184. ***Repeated load*** test results for ***I-35, TX, HMA***

Replicate	Repeated Load @ 147 deg F			
	Flow time, cycles	Applied stress, psi	Maximum LVDT slope	Minimum LVDT slope
1	10,000	77.1	0.110	**0.109**
2				
3				
Average		77.1	0.110	**0.109**
CV, %		**N/A**	**N/A**	**N/A**

Table 185. Indirect Tensile Strength Results Summary for HMA Projects under Part A

Sample	% Air Voids	Test Temp, °C	Peak Load, kgf
Minnesota 1	7.4	19	1155.4
Minnesota 3	6.9	19	1181.5
Minnesota 4	6.6	19	1314.1
Average			***1217.0***
CV, %			***7.0***
I85 SMA 1	7.7	25	804.2
I85 SMA 2	7.5	25	769.8
I85 SMA 3	7.4	25	889.6
Average			***821.2***
CV, %			***7.5***
US280 10/29/2004 1	6.4	25	1033.7
US280 10/29/2004 2	7.1	25	1092.3
US280 10/29/2004 3	6.4	25	1150.5
Average			***1092.2***
CV, %			***5.3***
US280 12/16/2004 1	7.0	25	975.8
US280 12/16/2004 6	6.7	25	1158.7
US280 12/16/2004 8	6.5	25	1316.6
Average			***1150.4***
CV, %			***14.8***
Texas 1	6.4	22	1575.6
Texas 2	6.5	22	1735.4
Texas 3	7.0	22	1405.1
Average			***1572.0***
CV, %			***10.5***

PART B TESTING

UNBOUND MATERIAL TEST DATA

US-2, ND SUBGRADE TESTING

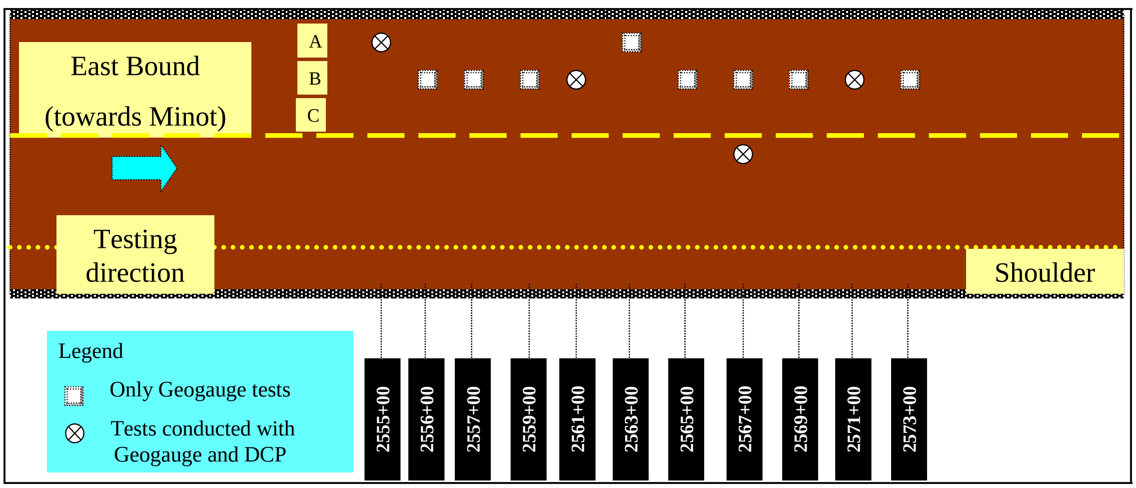


Table 186. ***Modulus*** measured by ***Geogauge B25C*** in ***US-2, ND Subgrade, ksi***

Station	Trial	Modulus	Average	Std Dev
2555+00	1	10.46		
2555+00	2	11.38		
2555+00	3	10.56	10.8	0.5
2556+00	1	17.25		
2556+00	2	13.08		
2556+00	3	15.63	15.32	2.1
2557+00	1	10.85		
2557+00	2	13.96		
2557+00	3	12.41	12.41	1.56
2559+00	1	13.89		
2559+00	2	14.11		
2559+00	3	13.53	13.84	0.29
2561+00	1	15.78		
2561+00	2	13.78		
2561+00	3	14.04	14.53	1.09
2563+00	1	11.07		
2563+00	2	9.87		
2563+00	3	7.62	9.52	1.75
2565+00	1	14.95		
2565+00	2	15.97		
2565+00	4	8.54	9.28	1.51
2567+00	1	10.97		
2567+00	2	12.23		
2567+00	3	17.12	16.01	1.09
2567+00	1	16.09		
2567+00	2	17.43		
2567+00	3	15.14	16.22	1.15
2569+00	1	12.5		
2569+00	2	12.83		
2569+00	3	11.91	12.41	0.47
2571+00	1	12.04		
2571+00	2	12.72		
2571+00	3	14.12	12.96	1.06
2573+00	1	8.63		
2573+00	2	10.72		
2573+00	3	9.37	9.57	1.06

Table 187. ***Modulus*** measured by ***Geogauge B24C*** in ***US-2, ND Subgrade, ksi***

Station	Trial	Modulus	Average	Std Dev
2555+00	1	10.09	1.02	
2555+00	2	11.78	1.11	
2555+00	3	10.44	1.02	10.77
2556+00	1	11.11	1.04	
2556+00	2	13.58	1.06	
2556+00	3	12.9	1.03	12.53
2557+00	1	8.58	1.03	
2557+00	2	10.09	1.04	
2557+00	3	11.79	1.11	10.15
2559+00	1	14.94	1.02	
2559+00	2	13.7	1.04	
2559+00	3	13.37	1.05	14.00
2561+00	1	13.46	1.04	
2561+00	2	10.57	1.03	
2561+00	3	12.67	1.03	12.23
2563+00	1	10.67	1.21	
2563+00	2	10.38	1.07	
2563+00	3	8.36	1.35	9.80
2565+00	1	14.01	1.04	
2565+00	2	12.63	1.02	
2565+00	4	12.71	1.02	13.12
2567+00	1	11.83	1.02	
2567+00	2	12.96	1.02	
2567+00	3	14.35	1.02	13.05
2567+00	1	21.42	1.14	
2567+00	2	21.89	1.18	
2567+00	3	24.3	1.15	22.54
2569+00	1	not tested		
2569+00	2	not tested		
2569+00	3	not tested	-	-
2571+00	1	14.93	1.03	
2571+00	2	11.56	1.1	
2571+00	3	13.94	1.02	13.48
2573+00	1	12.93	1.03	
2573+00	2	9.42	1.05	
2573+00	3	11.94	1.04	11.43

Table 188. ***Penetration Index*** measured by ***DCP*** in ***US-2, ND Subgrade, mm/blow***

Station	# of Blows	mm/blow	Average
2555+00	5	10.2	
2555+00	10	9.2	
2555+00	15	9	
2555+00	20	8.7	
2555+00	25	8.08	
2555+00	30	7.53	
2555+00	35	7.26	
2555+00	40	7.03	8.37
2561+00	5	15.2	
2561+00	10	12.5	
2561+00	15	11	
2561+00	20	10	
2561+00	25	9.28	
2561+00	30	8.33	
2561+00	35	7.71	10.58
2567+00	5	13	
2567+00	10	12.7	
2567+00	15	12.13	
2567+00	20	11.15	
2567+00	25	10.6	
2567+00	30	10.1	11.61
2571+00	5	11.8	
2571+00	10	11.8	
2571+00	15	10.87	
2571+00	20	9.8	
2571+00	25	9.56	
2571+00	30	9.67	10.58

Table 189. ***Modulus*** measured by ***DSPA*** in ***US-2, Subgrade, ksi***

Station	Trial	Average
2555+00	3	24
2556+00	3	39
2557+00	3	36
2559+00	3	37
2561+00	3	32
2563+00	3	34
2565+00	2	38
2567+00	2	19
2567+00	3	44
2569+00	3	-
2571+00	3	39
2573+00	3	32

Table 190. Summary of ***Resilient Modulus Test Results*** in ***US-2, ND Subgrade***

Sequence	σ_1 psi	σ_2 psi	σ_3 psi	θ psi	τ_{oct} psi	$\sigma_1 - \sigma_3$ psi	M_R psi	Pred. M_R psi
Repetition 1								
1	13.9	7.9	7.9	29.7	2.8	6.0	24933	25721
2	11.3	5.9	5.9	23.1	2.5	5.4	23623	23647
3	9.0	3.9	3.9	16.8	2.4	5.1	20241	20611
4	6.5	1.9	1.9	10.3	2.2	4.6	16739	16739
5	16.9	7.9	7.9	32.7	4.2	9.0	22306	22238
6	14.3	5.9	5.9	26.1	4.0	8.4	21001	20645
7	12.0	3.9	3.9	19.8	3.8	8.1	18647	18347
8	9.5	1.9	1.9	13.3	3.6	7.6	15499	15550
9	19.8	7.9	7.9	35.6	5.6	11.9	19664	19500
10	17.4	5.9	5.9	29.2	5.4	11.5	18567	18090
11	15.0	3.9	3.9	22.8	5.2	11.1	16886	16381
12	12.6	1.9	1.9	16.4	5.0	10.7	14367	14245
13	23.8	7.9	7.9	39.6	7.5	15.9	16379	16479
14	21.4	5.9	5.9	33.2	7.3	15.5	15244	15424
15	18.9	3.9	3.9	26.7	7.1	15.0	14010	14221
16	16.6	1.9	1.9	20.4	6.9	14.7	12356	12648
Repetition 2								
1	13.8	7.9	7.9	29.6	2.8	5.9	26954	28158
2	11.4	5.9	5.9	23.2	2.6	5.5	26080	26311
3	9.0	3.9	3.9	16.8	2.4	5.1	23785	23846
4	6.6	1.9	1.9	10.4	2.2	4.7	19950	20339
5	16.8	7.9	7.9	32.6	4.2	8.9	24215	24094
6	14.4	5.9	5.9	26.2	4.0	8.5	23262	22689
7	12.0	3.9	3.9	19.8	3.8	8.1	21536	20864
8	9.5	1.9	1.9	13.3	3.6	7.6	18865	18449
9	19.7	7.9	7.9	35.5	5.6	11.8	20941	20936
10	17.3	5.9	5.9	29.1	5.4	11.4	20200	19833
11	14.9	3.9	3.9	22.7	5.2	11.0	18778	18433
12	12.7	1.9	1.9	16.5	5.1	10.8	16627	16474
13	23.8	7.9	7.9	39.6	7.5	15.9	17582	17417
14	21.4	5.9	5.9	33.2	7.3	15.5	16533	16611
15	19.0	3.9	3.9	26.8	7.1	15.1	15327	15613
16	16.5	1.9	1.9	20.3	6.9	14.6	13804	14397

Sequence	σ_1 psi	σ_2 psi	σ_3 psi	θ psi	τ_{oct} psi	$\sigma_1 - \sigma_3$ psi	M_R psi	Pred. M_R psi
Repetition 3								
1	13.8	7.9	7.9	29.6	2.8	5.9	28533	29477
2	11.4	5.9	5.9	23.2	2.6	5.5	26161	27039
3	9.0	3.9	3.9	16.8	2.4	5.1	22952	23857
4	6.6	1.9	1.9	10.4	2.2	4.7	20330	19483
5	16.9	7.9	7.9	32.7	4.2	9.0	24360	23995
6	14.5	5.9	5.9	26.3	4.1	8.6	22599	22234
7	12.0	3.9	3.9	19.8	3.8	8.1	20226	20107
8	9.6	1.9	1.9	13.4	3.6	7.7	17671	17116
9	19.8	7.9	7.9	35.6	5.6	11.9	20527	20055
10	17.4	5.9	5.9	29.2	5.4	11.5	19164	18725
11	15.0	3.9	3.9	22.8	5.2	11.1	17072	17067
12	12.6	1.9	1.9	16.4	5.0	10.7	14940	14939
13	23.7	7.9	7.9	39.5	7.4	15.8	16633	16033
14	21.7	5.9	5.9	33.5	7.4	15.8	14956	14775
15	18.9	3.9	3.9	26.7	7.1	15.0	13364	13944
16	16.7	1.9	1.9	20.5	7.0	14.8	11671	12401

Calculated Mr coefficients for

	Rep 1	Rep 2	Rep 3
K_1	1,913.6	2,244.4	2,458.3
K_2	0.496	0.389	0.496
K_3	-2.490	-2.487	-3.178

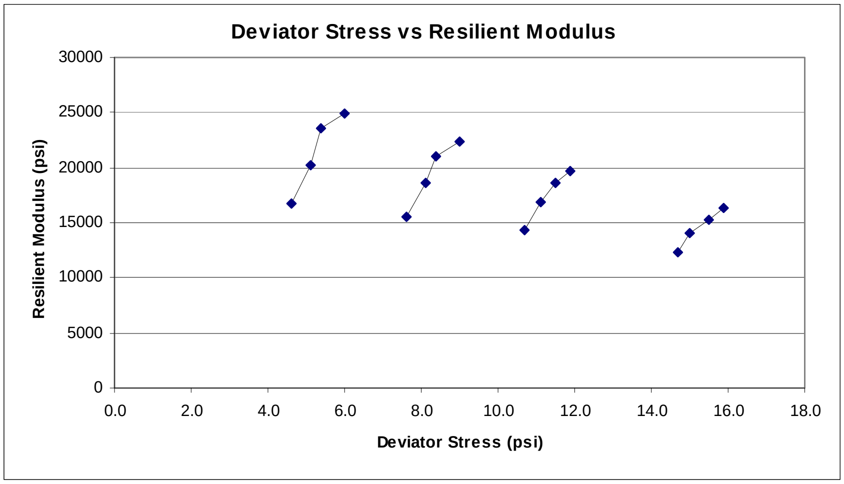


Figure 55. ***Resilient Modulus vs. Deviator Stress*** in ***US-2, ND Subgrade Rep 1***

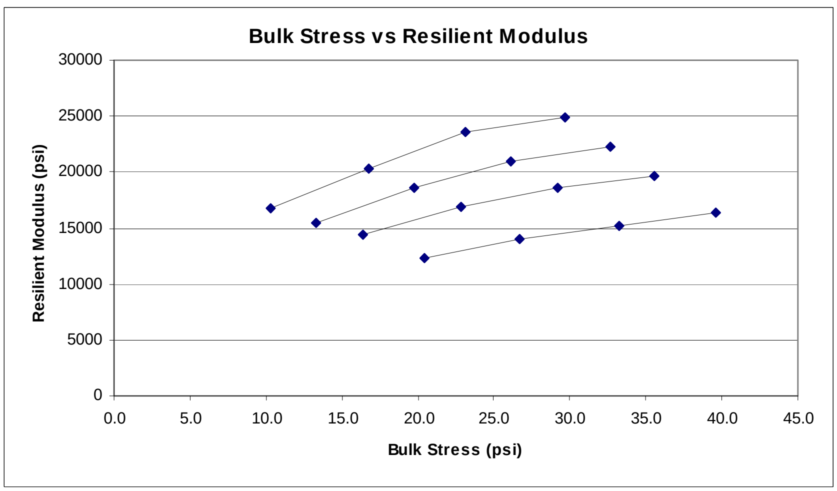


Figure 56. ***Bulk stress vs. Resilient Modulus*** in ***US-2, ND Subgrade – Rep 1***

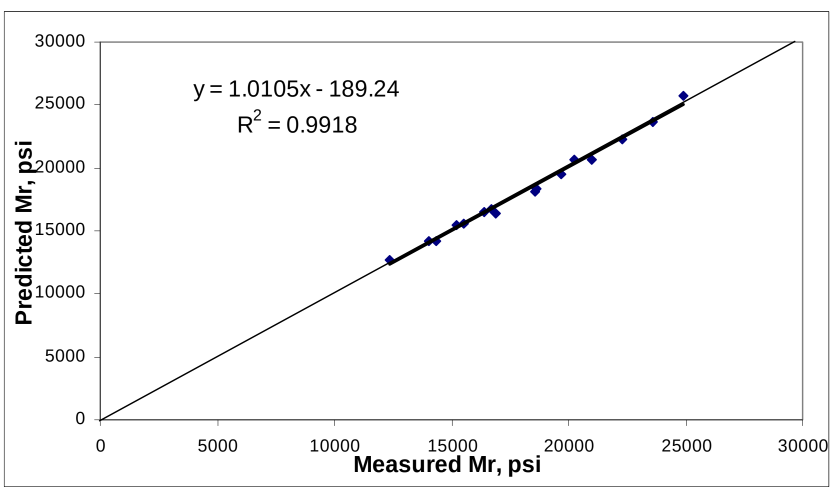


Figure 57. ***Predicted vs Measured Resilient Modulus*** in ***US-2, ND Subgrade–Rep 1***

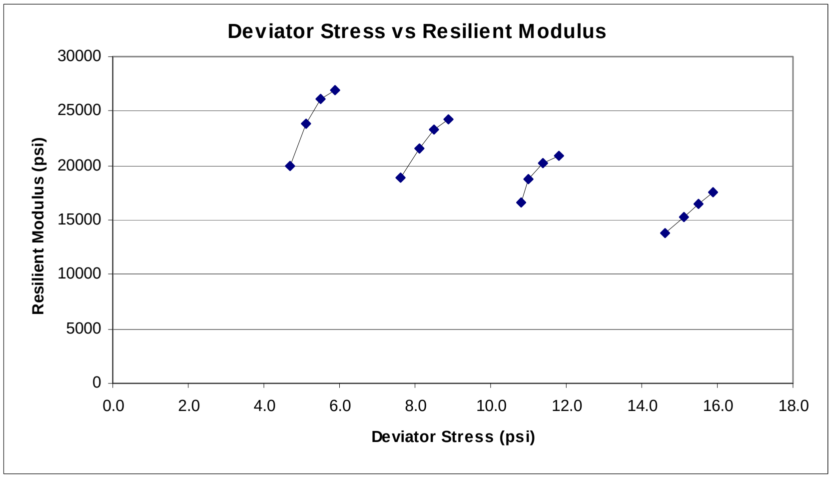


Figure 58. ***Resilient Modulus vs. Deviator Stress*** in ***US-2, ND Subgrade – Rep 2***

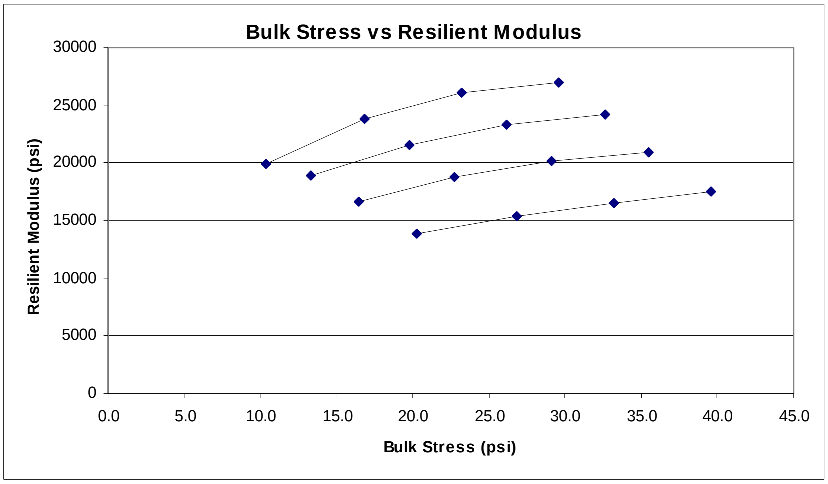


Figure 59. ***Bulk stress vs. Resilient Modulus*** in ***US-2, ND Subgrade – Rep 2***

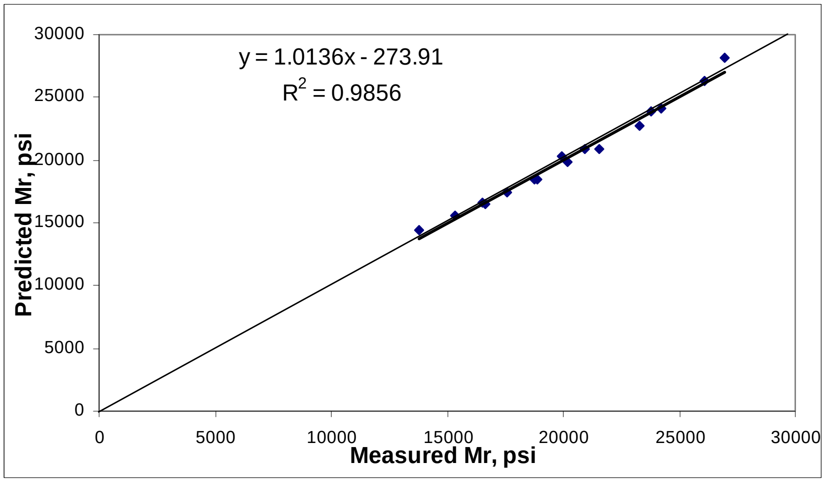


Figure 60. ***Predicted vs Measured Resilient Modulus US-2, ND Subgrade–Rep 2***

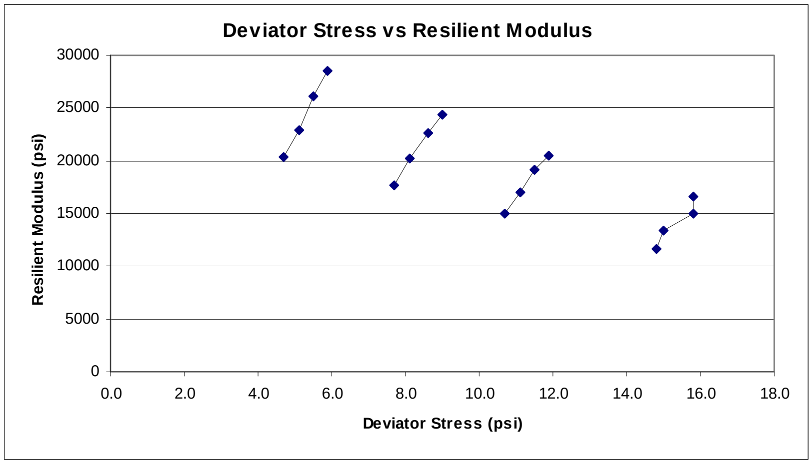


Figure 61. ***Resilient Modulus vs. Deviator Stress*** in ***US-2, ND Subgrade – Rep 3***

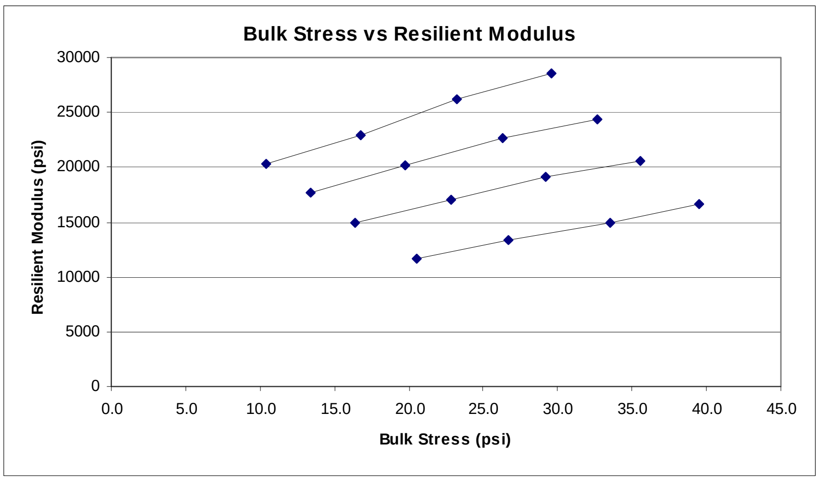


Figure 62. ***Bulk stress vs. Resilient Modulus*** in ***US-2, ND Subgrade – Rep 3***

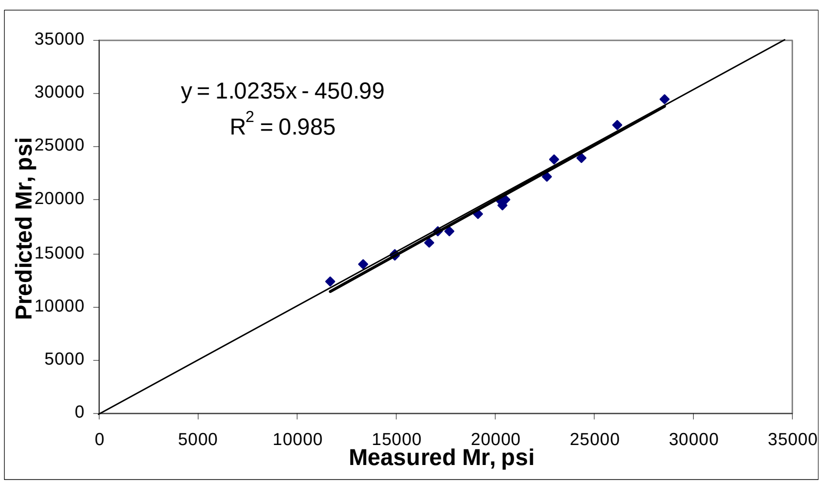
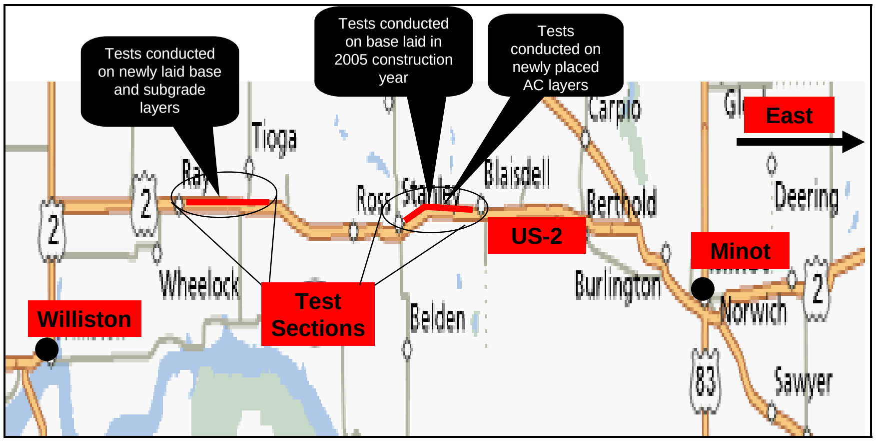
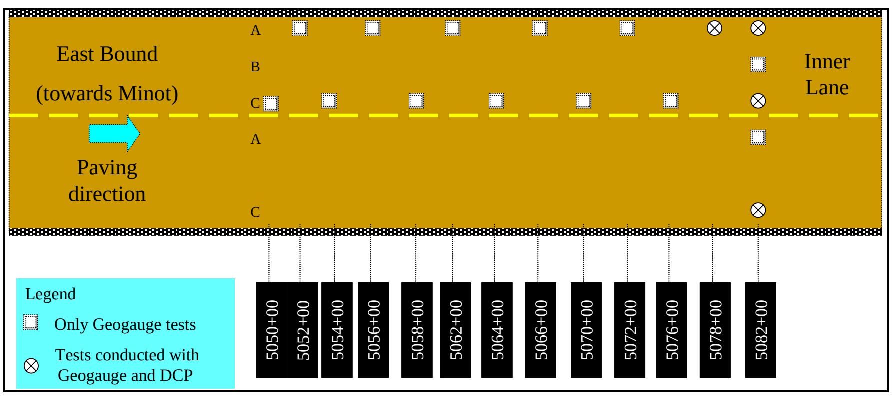


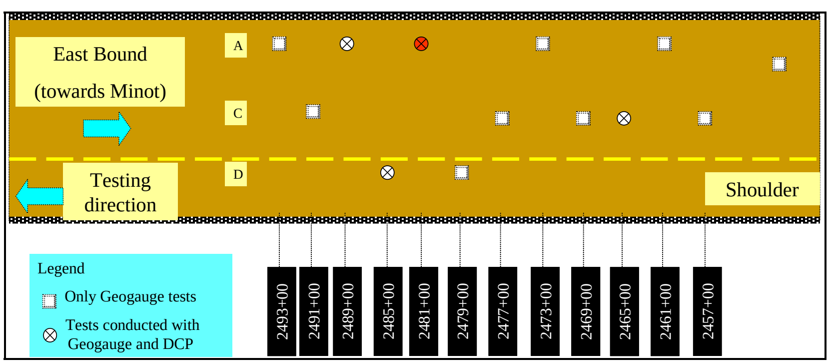
Figure 63. ***Predicted vs Measured Resilient Modulus US-2, ND Subgrade– Rep 3***

US-2, ND BASE TESTING





Section 1 of Base Layer of Route 2 Near Stanley, North Dakota



Section 2 of Base Layer of Route 2 Near Ray, North Dakota

Table 191. ***Modulus*** measured by ***Geogauge B25C*** in ***US-2 Section 1, ND Base, ksi***

Station	Point	Trial .	Modulus	Average	Std Dev
5050+00	C	1	34.37		
5050+00	C	2	26.78		
5050+00	C	3	38.08		
5050+00	C	4	34.71	33.49	4.77
5052+00	A	1	18.79		
5052+00	A	2	19.21		
5052+00	A	3	18.09	18.7	0.57
5054+00	C	1	37.67		
5054+00	C	2	37.38		
5054+00	C	3	28.52		
5054+00	C	4	36.09	34.92	4.32
5056+00	A	1	17.9		
5056+00	A	2	19.1		
5056+00	A	3	18.45	18.48	0.6
5058+00	C	1	45.04		
5058+00	C	2	39.18		
5058+00	C	3	31.37		
5058+00	C	4	41.6	39.3	5.81
5062+00	A	1	28.63		
5062+00	A	2	30.33		
5062+00	A	3	32.22	30.39	1.8
5064+00	C	1	23.05		
5064+00	C	2	26.7		
5064+00	C	3	28.17		
5064+00	C	4	22.89	25.2	2.65
5066+00	A	1	24.93		
5066+00	A	2	26.24		
5066+00	A	3	26.6	25.92	0.88
5070+00	C	1	21.04		
5070+00	C	2	26.71		
5070+00	C	3	27.64		
5070+00	C	4	24.68	25.02	2.93
5072+00	A	1	33.06		
5072+00	A	2	18.68		
5072+00	A	3	31.71		
5072+00	A	4	26.98	27.61	6.5
5076+00	C	1	28.71		
5076+00	C	2	31.56		
5076+00	C	3	27.68	29.32	2.01
5078+00	A	1	17.71		

Table 191. ***Modulus*** measured by ***Geogauge B25C*** in ***US-2 Section 1, ND Base, ksi***
Continued

Station	Point	Trial	Modulus	Average	Std Dev
5078+00	A	2	19.5		
5078+00	A	3	19.54	18.92	1.05
5082+00	A	1	23.43		
5082+00	A	2	21.05		
5082+00	A	3	25.52	23.33	2.24
5082+00	A	1	26.66		
5082+00	A	2	25.03		
5082+00	A	3	27.06	26.25	1.08
5082+00	B	1	21.68		
5082+00	B	2	32.53		
5082+00	B	3	28.97		
5082+00	B	4	29.16	28.09	4.57
5082+00	C	1	26.25		
5082+00	C	2	26.23		
5082+00	C	3	28.06	26.85	1.05
5082+00	C	1	33.46		
5082+00	C	2	29.99		
5082+00	C	3	26.75		
5082+00	C	4	33.3	30.88	3.18

Table 192. ***Modulus*** measured by ***Geogauge B25C*** in ***US-2 Section 2, ND Base, ksi***

Station	Point	Trial	Modulus	Average	Std Dev
2493+00	A	1	17.77		
2493+00	A	2	15.56		
2493+00	A	3	15.3	16.21	1.35724
2491+00	C	1	17.54		
2491+00	C	2	16.61		
2491+00	C	3	17.79	17.3133	0.6218
2489+00	A	1	15.89		
2489+00	A	2	15.05		
2489+00	A	3	14.93	15.29	0.52307
2485+00	D	1	19.45		
2485+00	D	2	19.76		
2485+00	D	3	18.77	19.3267	0.50639
2481+00	A	1	15.83		
2481+00	A	2	15.73		
2481+00	A	3	16.18	15.9133	0.23629
2479+00	D	1	15.8		
2479+00	D	2	18		
2479+00	D	3	17.34	17.0467	1.12895
2477+00	C	1	16.72		
2477+00	C	2	16.4		
2477+00	C	3	16.46	16.5267	0.1701
2473+00	A	1	17.05		
2473+00	A	2	17.75		
2473+00	A	3	13.49	16.0967	2.28441
2469+00	C	1	19.8		
2469+00	C	2	16.64		
2469+00	C	3	17.93	18.1233	1.58885
2465+00	C	1	16.08		
2465+00	C	2	17.48		
2465+00	C	3	17.07	16.8767	0.71975
2461+00	A	1	17		
2461+00	A	2	16		
2461+00	A	3	15.07	16.0233	0.96521
2457+00	C	1	17.02		
2457+00	C	2	15.98		
2457+00	C	3	16.88	16.6267	0.56439

Table 193. ***Modulus*** measured by ***Geogauge B24C*** in ***US-2 Section 1, ND Base, ksi***

Station	Point	Trial	Modulus	Average	Std Dev
5050+00	C	1	32.1		
5050+00	C	2	27.83		
5050+00	C	3	37.78		
5050+00	C	4	33.06	32.69	4.08
5052+00	A	1	18.12		
5052+00	A	2	19.16		
5052+00	A	3	20.54	19.27	1.21
5054+00	C	1	41.28		
5054+00	C	2	42.56		
5054+00	C	2a	43.83		
5054+00	C	4	36.25	40.98	3.32
5056+00	A	1	18.14		
5056+00	A	2	19.66		
5056+00	A	3	18.62	18.81	0.78
5058+00	C	1	32.97		
5058+00	C	2	18.66		
5058+00	C	2a	26.14		
5058+00	C	3	24.37	27.83	4.54
5062+00	A	1	25.89		
5062+00	A	2	32.9		
5062+00	A	3	30.58	29.79	3.57
5064+00	C	1	20.76		
5064+00	C	2	24.14		
5064+00	C	3	22.3	22.4	1.69
5066+00	A	1	28.36		
5066+00	A	2	23.25		
5066+00	A	3	18.16		
5066+00	A	4	27.51	26.37	2.74
5070+00	C	1	27.47		
5070+00	C	2	22.72		
5070+00	C	2a	20.87		
5070+00	C	3	21.86		
5070+00	C	3a	26.26	23.84	2.87
5072+00	A	1	34.71		
5072+00	A	2	28.86		
5072+00	A	3	29.84	31.14	3.13
5076+00	C	1	29.56		
5076+00	C	2	31.67		
5076+00	C	3	26.3		

Table 193. ***Modulus*** measured by ***Geogauge B24C*** in ***US-2 Section 1, ND Base, ksi***
Continued

Station	Point	Trial	Modulus	Average	Std Dev
5076+00	C	3a	31.03	30.75	1.08
5078+00	A	1	19.81		
5078+00	A	2	19.98		
5078+00	A	3	20.47	20.09	0.34
5082+00	A	1	26.23		
5082+00	A	2	27.78		
5082+00	A	3	25.58	26.53	1.13
5082+00	A	1	26.47		
5082+00	A	2	19.61		
5082+00	A	3	26.36	24.15	3.93
5082+00	B	1	29.99		
5082+00	B	2	20.16		
5082+00	B	3	21.19		
5082+00	B	4	27.57	24.73	4.8
5082+00	C	1	27.45		
5082+00	C	2	19.16		
5082+00	C	3	28.41	23.94	4.67
5082+00	C	1	33.29		
5082+00	C	2	23.45		
5082+00	C	3	30.7	29.15	5.1

Table 194. ***Modulus*** measured by ***Geogauge B24C*** in ***US-2 Section 2, ND Base, ksi***

Station	Point	Trial	Modulus	Average	Std Dev
2493+00	A	1	16.92		
2493+00	A	2	19.75		
2493+00	A	3	19.56	18.7433	1.58191
2491+00	C	1	18.35		
2491+00	C	2	17.72		
2491+00	C	3	19.41	18.4933	0.85407
2489+00	A	1	12.84		
2489+00	A	2	16.09		
2489+00	A	3	13.02	13.9833	1.82665
2485+00	D	1	19.39		
2485+00	D	2	18.74		
2485+00	D	3	20.89	19.6733	1.10265
2481+00	A	1	12.24		
2481+00	A	2	17.18		
2481+00	A	3	17.09	15.5033	2.82649
2479+00	D	1	17.31		
2479+00	D	2	15.81		
2479+00	D	3	18.39	17.17	1.29569
2477+00	C	1	18.39		
2477+00	C	2	17.92		
2477+00	C	3	17.98	18.0967	0.2558
2473+00	A	1	18.06		
2473+00	A	2	14.25		
2473+00	A	3	17.7	16.67	2.1035
2469+00	C	1	20.92		
2469+00	C	2	18.37		
2469+00	C	3	20.14	19.81	1.30664
2465+00	C	1	17.39		
2465+00	C	2	18.13		
2465+00	C	3	16.53	17.35	0.80075
2461+00	A	1	15.67		
2461+00	A	2	14.99		
2461+00	A	3	16.32	15.66	0.66506
2457+00	C	1	17.95		
2457+00	C	2	14.33		
2457+00	C	3	15.93	16.07	1.81406

Table 195. ***Penetration Index*** measured by ***DCP*** in ***US-2 Section 1, ND Base, mm/blow***

Station	Point	# of Blows	mm/blow	Average
5078+00	A	5	14.8	
5078+00	A	10	10.9	
5078+00	A	15	9	
5078+00	A	20	8.05	
5078+00	A	25	7.36	
5078+00	A	30	6.9	
5078+00	A	35	6.63	
5078+00	A	40	6.45	
5078+00	A	45	6.4	
5078+00	A	50	6.26	8.27
5082+00	A	5	14.2	
5082+00	A	10	10.4	
5082+00	A	15	8.67	
5082+00	A	20	7.65	
5082+00	A	25	7	
5082+00	A	30	6.47	
5082+00	A	35	6.09	
5082+00	A	40	5.93	
5082+00	A	45	5.8	
5082+00	A	50	5.8	
5082+00	A	55	5.84	7.62
5082+00	C	5	11	
5082+00	C	10	9.7	
5082+00	C	15	8.27	
5082+00	C	20	7.5	
5082+00	C	25	7.12	
5082+00	C	30	6.77	
5082+00	C	35	6.34	
5082+00	C	40	6.13	
5082+00	C	45	6.02	
5082+00	C	50	5.86	
5082+00	C	55	5.71	7.31
5082+00	C	5	8.4	
5082+00	C	10	7.7	
5082+00	C	15	7.27	
5082+00	C	20	6.85	
5082+00	C	25	6.6	
5082+00	C	30	6.43	
5082+00	C	35	6.31	
5082+00	C	40	6.1	

Table 195. ***Penetration Index*** measured by ***DCP*** in ***US-2 Section 1, ND Base, mm/blow***
Continued

Station	Point	# of Blows	mm/blow	Average

5082+00	C	45	5.93	
5082+00	C	50	5.84	
5082+00	C	55	5.76	6.65

Table 196. ***Penetration Index*** measured by ***DCP*** in ***US-2 Section 2, ND Base, mm/blow***

Station	# of Blows	mm/blow	Average
2465+00	5	15.6	
2465+00	10	11.4	
2465+00	15	9.8	
2465+00	20	8.7	
2465+00	25	7.72	
2465+00	30	6.97	
2465+00	35	6.37	
2465+00	40	6.03	
2465+00	45	5.71	
2465+00	50	5.54	8.38
2481+00	5	12.4	
2481+00	10	12	
2481+00	15	9	
2481+00	20	8.25	
2481+00	25	7.6	
2481+00	30	7.1	
2481+00	35	6.71	
2481+00	40	6.6	
2481+00	45	6.98	8.52
2485+00	5	9	
2485+00	10	8.4	
2485+00	15	8	
2485+00	20	7.35	
2485+00	25	6.76	
2485+00	30	6.2	
2485+00	35	5.69	
2485+00	40	5.4	
2485+00	45	5.11	
2485+00	50	4.9	
2485+00	55	4.67	
2485+00	60	4.55	
2485+00	65	4.43	6.19
2489+00	5	10.6	
2489+00	10	9.1	
2489+00	15	8.27	
2489+00	20	7.35	
2489+00	25	6.72	
2489+00	30	6.33	
2489+00	35	5.97	

Table 196. ***Penetration Index*** measured by ***DCP*** in ***US-2 Section 2, ND Base, mm/blow***
Continued

Station	# of Blows	mm/blow	Average

2489+00	40	5.85	
2489+00	45	5.73	
2489+00	50	5.74	7.17

Table 197. ***Modulus*** measured by ***DSPA*** in ***US-2 section 1, Base, ksi***

Station	Point	Trial	Average
5050+00	C	3	56
5052+00	A	3	34
5054+00	C	4	63
5056+00	A	3	30
5058+00	C	4	104
5062+00	A	3	61
5064+00	C	4	51
5066+00	A	3	49
5070+00	C	4	-
5072+00	A	4	59
5076+00	C	3	55
5078+00	A	3	39
5082+00	A	3	33
5082+00	A	3	64
5082+00	B	4	47
5082+00	C	3	47
5082+00	C	4	61

Table 198. ***Modulus*** measured by ***DSPA*** in ***US-2 section 2, Base, ksi***

Station	Point	Trial	Average
2457+00	B	3	95
2461+00	A	3	86
2465+00	C	3	82
2469+00	B	3	84
2473+00	A	3	103
2477+00	B	3	64
2479+00	C	3	90
2481+00	A	3	96
2485+00	C	3	69
2489+00	A	3	101
2491+00	B	3	39
2493+00	A	3	82

Table 199. Summary of ***Resilient Modulus Test Results*** in ***US-2, ND Base***

Sequence	σ_1 psi	σ_2 psi	σ_3 psi	θ psi	τ_{oct} psi	$\sigma_1 - \sigma_3$ psi	M_R psi	Pred. M_R psi
Repetition 1								
1	5.3	2.9	2.9	11.1	1.1	2.4	24855	18341
2	10.4	5.9	5.9	22.2	2.1	4.5	34276	33329
3	17.2	9.9	9.9	37.0	3.4	7.3	48794	50639
4	25.7	14.9	14.9	55.5	5.1	10.8	67769	69238
5	34.2	19.9	19.9	74.0	6.7	14.3	85945	85330
6	6.8	2.9	2.9	12.6	1.8	3.9	23848	19990
7	13.5	5.9	5.9	25.3	3.6	7.6	33882	35449
8	22.2	9.9	9.9	42.0	5.8	12.3	48316	52206
9	33.3	14.9	14.9	63.1	8.7	18.4	68820	69278
10	44.4	19.9	19.9	84.2	11.5	24.5	88965	83290
11	9.8	2.9	2.9	15.6	3.3	6.9	23457	22973
12	19.4	5.9	5.9	31.2	6.4	13.5	34971	38912
13	32.1	9.9	9.9	51.9	10.5	22.2	52585	54886
14	48.4	14.9	14.9	78.2	15.8	33.5	75899	69952
15	64.7	19.9	19.9	104.5	21.1	44.8	92907	81569
16	12.9	2.9	2.9	18.7	4.7	10.0	23972	25695
17	25.5	5.9	5.9	37.3	9.2	19.6	37769	41910
18	42.2	9.9	9.9	62.0	15.2	32.3	56902	57205
19	65.1	14.9	14.9	94.9	23.7	50.2	78012	71076
20	84.2	19.9	19.9	124.0	30.3	64.3	91419	81248
21	19.0	2.9	2.9	24.8	7.6	16.1	25899	30239
22	37.3	5.9	5.9	49.1	14.8	31.4	42162	46585
23	61.6	9.9	9.9	81.4	24.4	51.7	62373	60888
24	94.2	14.9	14.9	124.0	37.4	79.3	78307	73262
25	124.1	19.9	19.9	163.9	49.1	104.2	92307	82074
26	24.1	2.9	2.9	29.9	10.0	21.2	27021	33423
27	49.3	5.9	5.9	61.1	20.5	43.4	45078	50344
28	83.8	9.9	9.9	103.6	34.8	73.9	65329	64298
29	123.1	14.9	14.9	152.9	51.0	108.2	72600	75400
30	164.7	19.9	19.9	204.5	68.3	144.8	74341	83603
Repetition 2								
1	5.2	2.9	2.9	11.0	1.1	2.3	26148	19235
2	10.5	5.9	5.9	22.3	2.2	4.6	35301	33895
3	17.1	9.9	9.9	36.9	3.4	7.2	47243	50021
4	25.8	14.9	14.9	55.6	5.1	10.9	64651	67149
5	34.2	19.9	19.9	74.0	6.7	14.3	82513	81747

Sequence	σ_1 psi	σ_2 psi	σ_3 psi	θ psi	τ_{oct} psi	$\sigma_1 - \sigma_3$ psi	M_R psi	Pred. M_R psi
6	6.8	2.9	2.9	12.6	1.8	3.9	25397	20988
7	13.5	5.9	5.9	25.3	3.6	7.6	34276	35895
8	22.3	9.9	9.9	42.1	5.8	12.4	48132	51669
9	33.2	14.9	14.9	63.0	8.6	18.3	66332	67430
10	44.3	19.9	19.9	84.1	11.5	24.4	86332	80298
11	9.8	2.9	2.9	15.6	3.3	6.9	24536	23940
12	19.5	5.9	5.9	31.3	6.4	13.6	35363	39333
13	32.3	9.9	9.9	52.1	10.6	22.4	52627	54409
14	48.5	14.9	14.9	78.3	15.8	33.6	73451	68463
15	64.4	19.9	19.9	104.2	21.0	44.5	91229	79295
16	12.8	2.9	2.9	18.6	4.7	9.9	24713	26540
17	25.4	5.9	5.9	37.2	9.19239	19.5	37943	42173.6
18	42.5	9.9	9.9	62.3	15.3678	32.6	57628	56783.8
19	64.4	14.9	14.9	94.2	23.3345	49.5	76304	69780.7
20	83.9	19.9	19.9	123.7	30.1699	64	91990	79401.8
21	18.9	2.9	2.9	24.7	7.54247	16	26363	31020
22	37.7	5.9	5.9	49.5	14.9907	31.8	42605	46952.1
23	60.5	9.9	9.9	80.3	23.8531	50.6	63255	60287.7
24	94.2	14.9	14.9	124	37.3824	79.3	76479	72338.9
25	124.3	19.9	19.9	164.1	49.2146	104.4	90614	80802.1
26	24.1	2.9	2.9	29.9	9.99378	21.2	26941	34208.2
27	51.2	5.9	5.9	63	21.3546	45.3	44678	51052.4
28	85.6	9.9	9.9	105.4	35.6853	75.7	65056	64230.7
29	126.4	14.9	14.9	156.2	52.5616	111.5	70518	74953.8
30	165.5	19.9	19.9	205.3	68.6365	145.6	74895	82721.7
Repetition 3								
1	5.4	2.9	2.9	11.2	1.17851	2.5	17807	13634.7
2	10.4	5.9	5.9	22.2	2.12132	4.5	27697	26622.8
3	17.1	9.9	9.9	36.9	3.39411	7.2	41827	42797.7
4	25.7	14.9	14.9	55.5	5.09117	10.8	61283	61244.8
5	34.2	19.9	19.9	74	6.74108	14.3	79195	77866.9
6	6.7	2.9	2.9	12.5	1.79134	3.8	18014	14863.1
7	13.5	5.9	5.9	25.3	3.58267	7.6	27803	28680.1
8	22.2	9.9	9.9	42	5.79828	12.3	42672	44656.2
9	33.1	14.9	14.9	62.9	8.57956	18.2	63067	61877.2
10	44.2	19.9	19.9	84	11.4551	24.3	83283	76710.5

Sequence	σ_1 psi	σ_2 psi	σ_3 psi	θ psi	τ_{oct} psi	$\sigma_1 - \sigma_3$ psi	M_R psi	Pred. M_R psi
11	9.8	2.9	2.9	15.6	3.25269	6.9	18205	17577.7
12	19.6	5.9	5.9	31.4	6.45824	13.7	29261	32233.1
13	32.6	9.9	9.9	52.4	10.7009	22.7	47161	47977
14	49.1	14.9	14.9	78.9	16.122	34.2	69464	63661.5
15	64.4	19.9	19.9	104.2	20.9775	44.5	85849	76313.1
16	12.8	2.9	2.9	18.6	4.6669	9.9	19027	19957.3
17	25.5	5.9	5.9	37.3	9.23953	19.6	31693	35194.2
18	42.9	9.9	9.9	62.7	15.5563	33	49997	50814.4
19	64.1	14.9	14.9	93.9	23.1931	49.2	67017	65500.4
20	84	19.9	19.9	123.8	30.217	64.1	81106	77015.6
21	19	2.9	2.9	24.8	7.58961	16.1	20261	24265
22	37.4	5.9	5.9	49.2	14.8492	31.5	34096	40181.5
23	60.1	9.9	9.9	79.9	23.6645	50.2	50486	54869.5
24	94	14.9	14.9	123.8	37.2881	79.1	69269	69130.6
25	124.1	19.9	19.9	163.9	49.1204	104.2	87948	79551.5
26	24.3	2.9	2.9	30.1	10.0881	21.4	22802	27440.8
27	50	5.9	5.9	61.8	20.7889	44.1	40653	44491.2
28	83.3	9.9	9.9	103.1	34.6011	73.4	60903	59433.6
29	124.2	14.9	14.9	154	51.5245	109.3	71902	72549.5
30	164.7	19.9	19.9	204.5	68.2594	144.8	85467	82505.8

Calculated Mr coefficients for

	Rep 1	Rep 2	Rep 3
K_1	1,704.6	1,758.1	1,303.0
K_2	0.924	0.862	1.040
K_3	-0.709	-0.639	-0.739

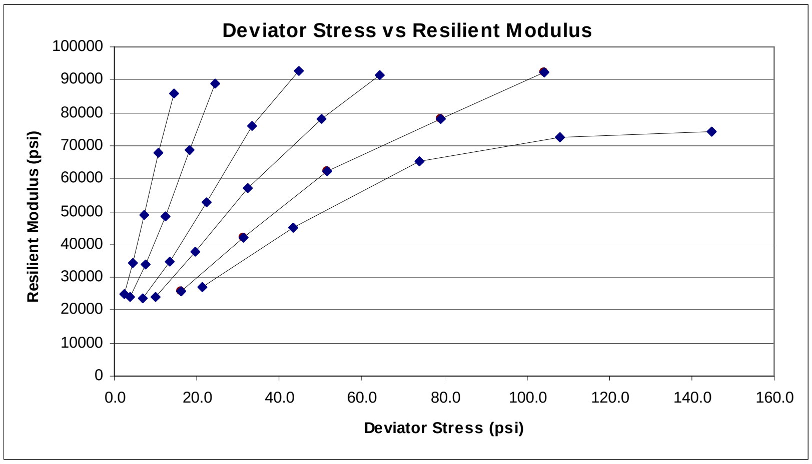


Figure 64. ***Resilient Modulus vs. Deviator Stress*** in ***US-2, ND Base - Rep 1***

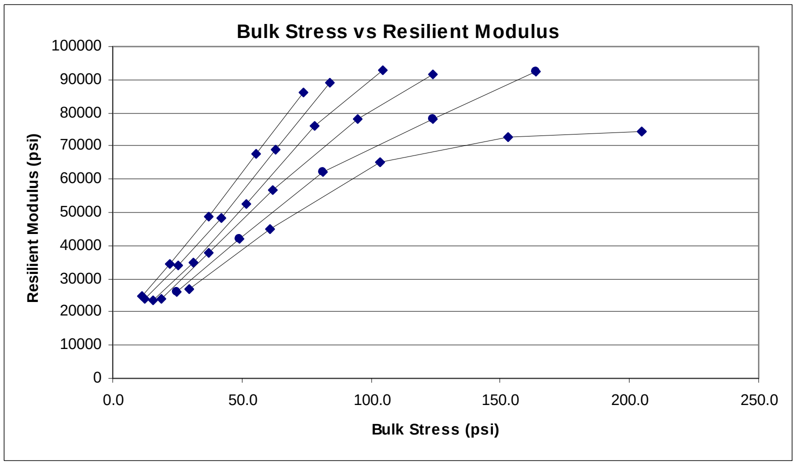


Figure 65. ***Bulk stress vs. Resilient Modulus*** in ***US-2, ND Base - Rep 1***

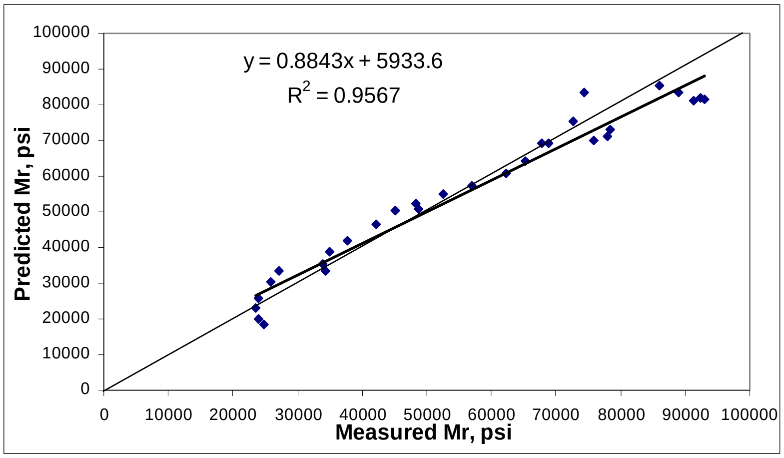


Figure 66. ***Predicted vs Measured Resilient Modulus*** in ***US-2, ND Base - Rep 1***

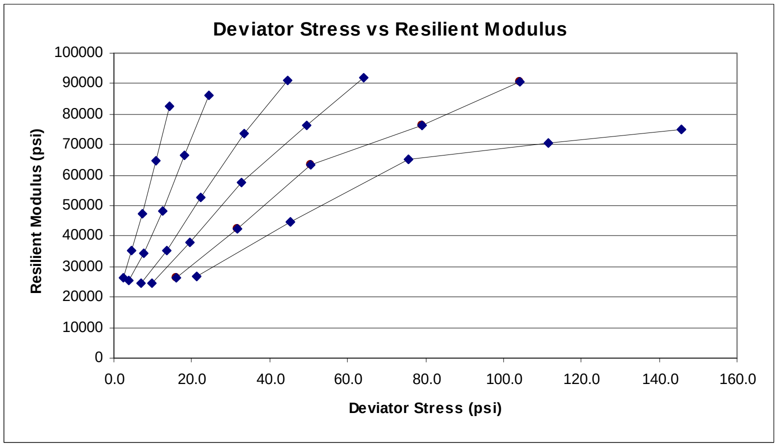


Figure 67. ***Resilient Modulus vs. Deviator Stress*** in ***US-2, ND Base - Rep 2***

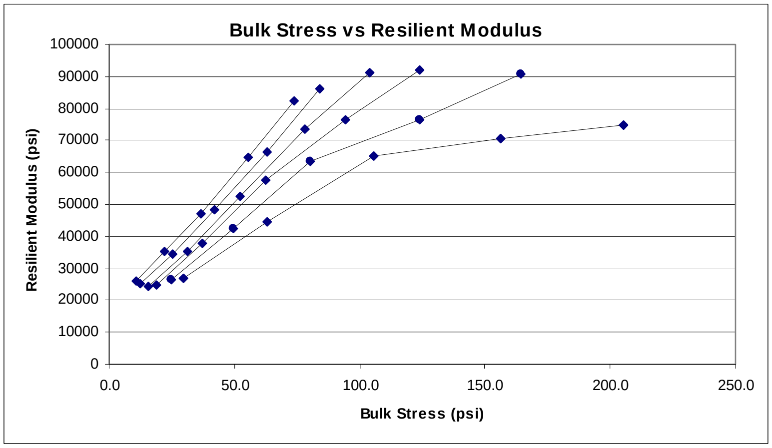


Figure 68. ***Bulk stress vs. Resilient Modulus*** in ***US-2, ND Base - Rep 2***

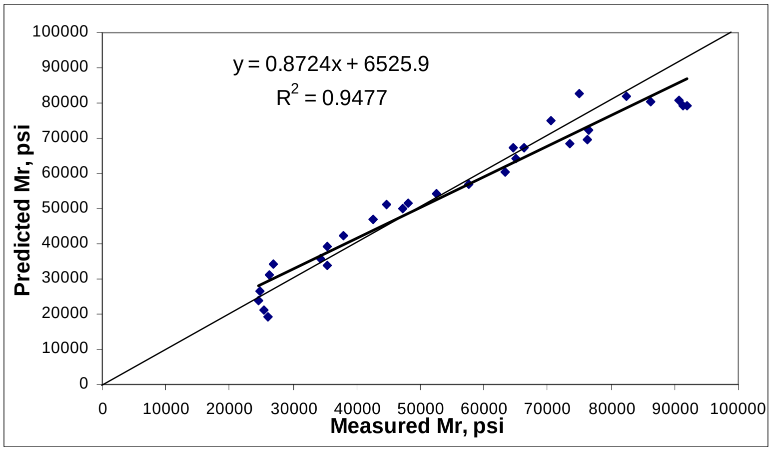


Figure 69. ***Predicted vs Measured Resilient Modulus*** in ***US-2, ND Base - Rep 2***

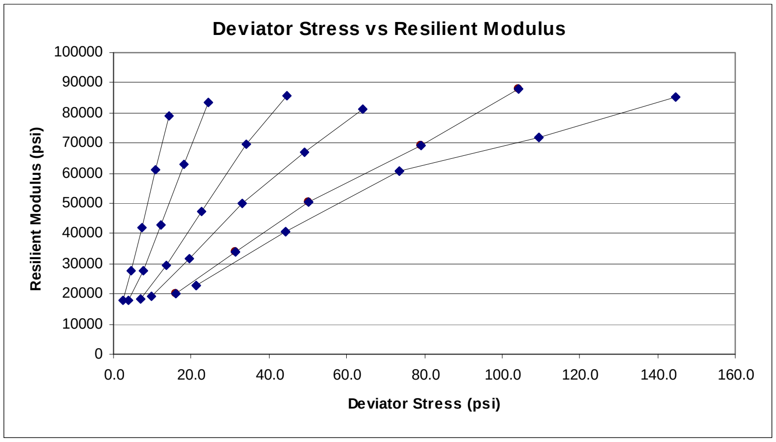


Figure 70. ***Resilient Modulus vs. Deviator Stress*** in ***US-2, ND Base*** - ***Rep 3***

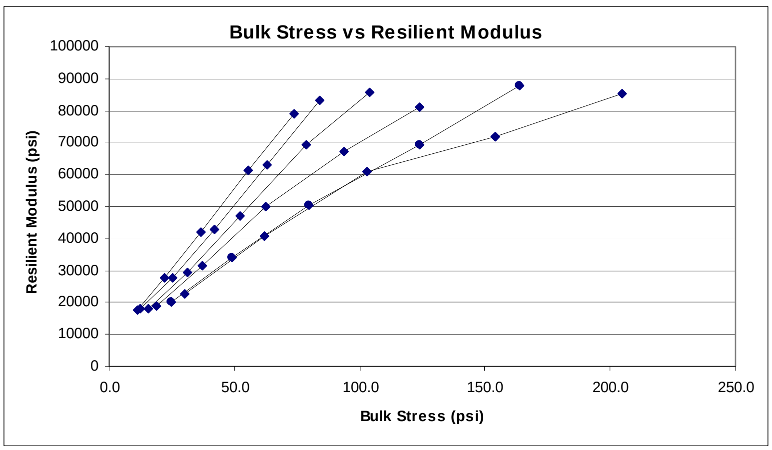


Figure 71. ***Bulk stress vs. Resilient Modulus*** in ***US-2, ND Base*** - ***Rep 3***

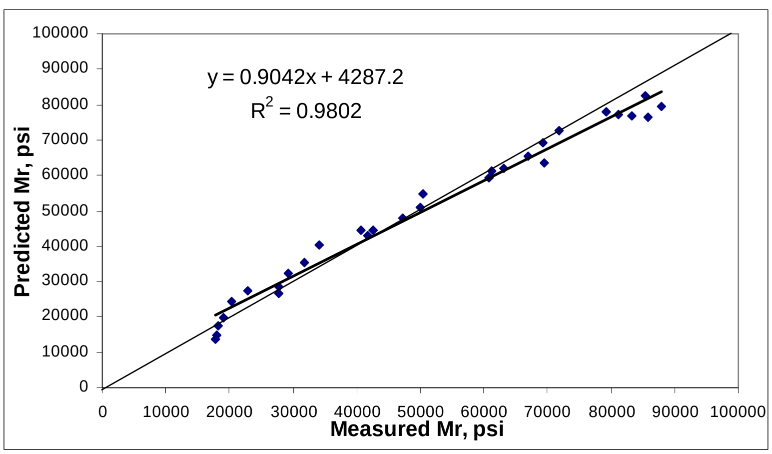
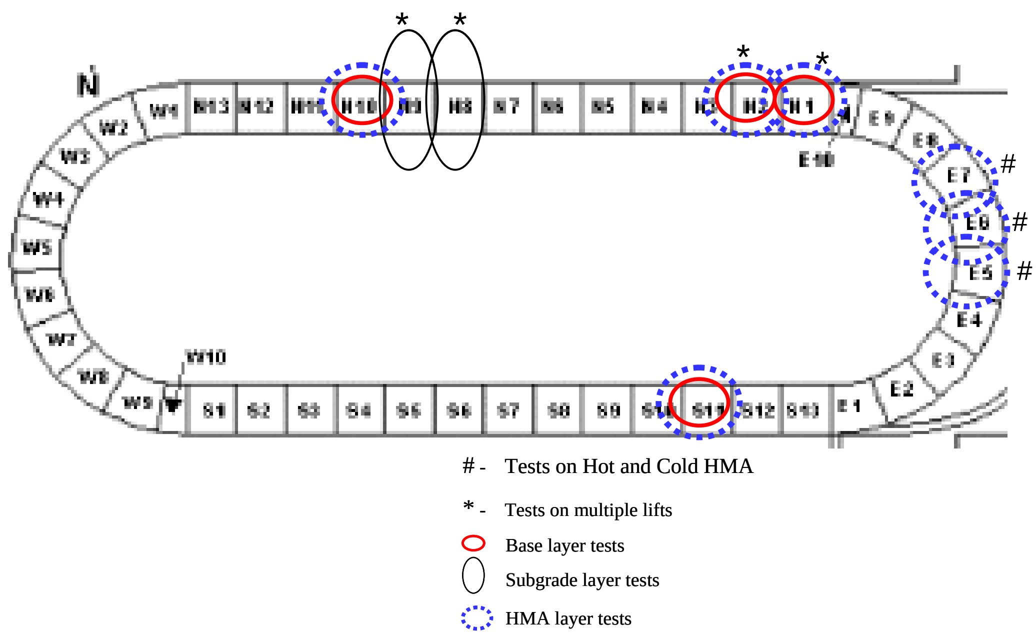
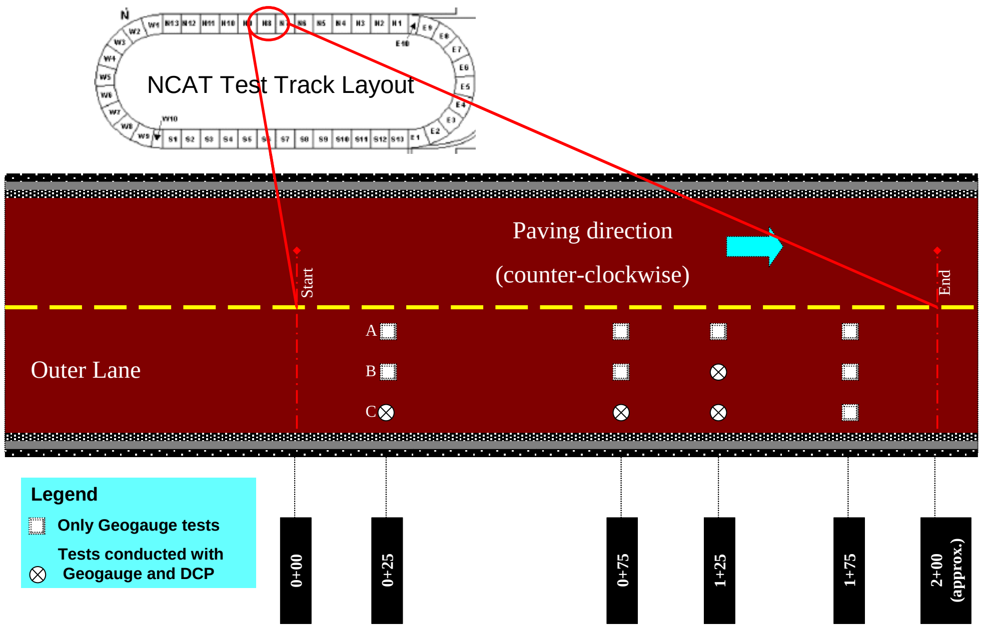


Figure 72. ***Predicted vs Measured Resilient Modulus*** in ***US-2, ND Base*** - ***Rep 3***

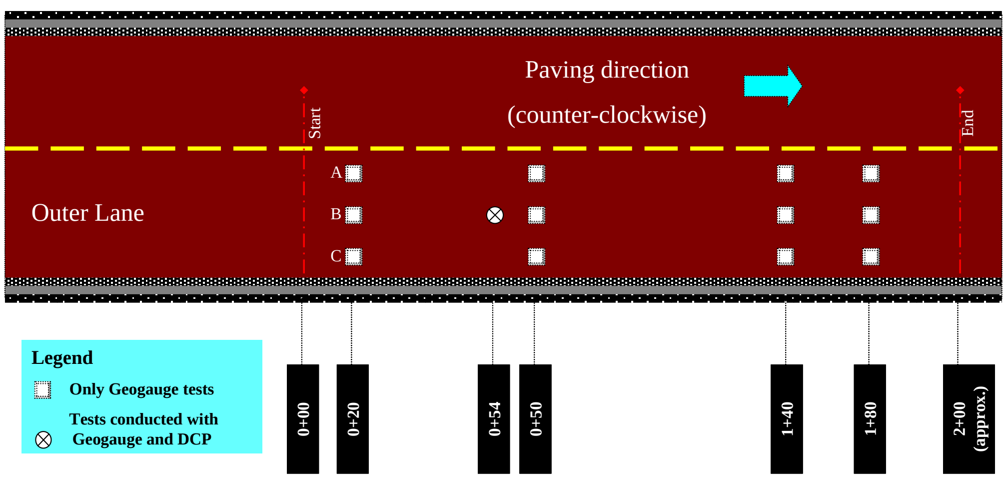
NCAT TEST SECTIONS, AL TESTING



NCAT TEST SECTIONS, N-8 SUBGRADE TESTING



Layout for first lift in September, 2006



Layout for last lift in October 2006

Table 200. ***Modulus*** measured by ***Geogauge B24C*** in ***N-8 1st lift, OK Subgrade, ksi***

Station	Point	Trial	Modulus	Average	Std Dev
0+25	A	1	24.27		
0+25	A	2	24.47		
0+25	A	3	27.2	25.31	1.64
0+25	B	1	26.88		
0+25	B	2	27.6		
0+25	B	3	25.41	26.63	1.12
0+25	C	1	23.23		
0+25	C	2	34.03		
0+25	C	3	29.33	28.86	5.42
0+75	A	1	24.86		
0+75	A	2	21.38		
0+75	A	3	26.04	24.09	2.42
0+75	B	1	23.87		
0+75	B	2	25.11		
0+75	B	3	23.81	24.26	0.73
0+75	C	1	14.75		
0+75	C	2	15.5		
0+75	C	3	18.07	16.11	1.74
1+25	A	1	24.57		
1+25	A	2	24.95		
1+25	A	3	25.09	24.87	0.27
1+25	B	1	33.42		
1+25	B	2	34.17		
1+25	B	3	25.48	31.02	4.82
1+25	C	1	17.05		
1+25	C	2	18.52		
1+25	C	3	19.24	18.27	1.12
1+75	A	1	34.6		
1+75	A	2	29.3		
1+75	A	3	26.61	30.17	4.07
1+75	B	1	28.12		
1+75	B	2	25.95		
1+75	B	3	24.22	26.1	1.95
1+75	C	1	24.07		
1+75	C	2	23.21		
1+75	C	3	24.53	23.94	0.67

Table 201. ***Modulus*** measured by ***Geogauge B24C*** in ***N-8 last lift, OK Subgrade, ksi***

Station	Point	Trial	Modulus	Average	Std Dev
0+10	A	1	26.18		
0+10	A	2	19.9		
0+10	A	3	20	22.03	3.6
0+10	B	1	23.01		
0+10	B	2	25.89		
0+10	B	3	27.31	25.4	2.19
0+10	C	1	18.6		
0+10	C	2	19.05		
0+10	C	3	19.85	19.17	0.63
0+50	A	1	25.17		
0+50	A	2	31.01		
0+50	A	3	34.98	30.39	4.93
0+50	B	1	32.08		
0+50	B	2	17.64		
0+50	B	3	25.56	25.09	7.23
0+50	C	1	37.89		
0+50	C	2	35.95		
0+50	C	3	36.95	36.93	0.97
1+40	A	1	21.8		
1+40	A	2	23.2		
1+40	A	3	25.31		
1+40	A	4	24.64	23.74	1.56
1+40	B	1	25.23		
1+40	B	2	25.58		
1+40	B	3	26.91		
1+40	B	4	25.26	25.75	0.79
1+40	C	1	7.72		
1+40	C	2	8.21		
1+40	C	3	6.21		
1+40	C	4	9.14	7.82	1.22
1+80	A	1	30.85		
1+80	A	2	25.22		
1+80	A	3	21.71		
1+80	A	4	26.41	26.05	3.77
1+80	B	1	21.49		
1+80	B	2	22.08		
1+80	B	3	19.95		
1+80	B	4	19.24	20.69	1.32
1+80	C	1	13.06		

Table 201. ***Modulus*** measured by ***Geogauge B24C*** in ***N-8 last lift, OK Subgrade, ksi***
Continued

Station	Point	Trial	Modulus	Average	Std Dev
1+80	C	2	22.33		
1+80	C	3	14.09		
1+80	C	4	12.2	15.42	4.67

Table 202. ***Modulus*** measured by ***Geogauge B25C*** in ***N-8 last lift, OK Subgrade, ksi***

Station	Point	Trial	Modulus	Average	Std Dev
0+10	A	1	22.74		
0+10	A	2	20.32		
0+10	A	3	21.52	21.53	1.21
0+10	B	1	18.27		
0+10	B	2	21.54		
0+10	B	3	23.1	20.97	2.46
0+10	C	1	14.99		
0+10	C	2	16.25		
0+10	C	3	14.75	15.33	0.81
0+50	A	1	29.23		
0+50	A	2	30.01		
0+50	A	3	31.21	30.15	1
0+50	B	1	25.55		
0+50	B	2	20.25		
0+50	B	3	19.95	21.92	3.15
0+50	C	1	34.1		
0+50	C	2	35.25		
0+50	C	3	32.74	34.03	1.26
1+40	A	1	21.74		
1+40	A	2	20.89		
1+40	A	3	23.62		
1+40	A	4	16.82	20.77	2.87
1+40	B	1	21.08		
1+40	B	2	20.88		
1+40	B	3	18.36		
1+40	B	4	21.23	20.39	1.36
1+40	C	1	9.92		
1+40	C	2	6.07		
1+40	C	3	7.7		
1+40	C	4	8.5	8.05	1.61
1+80	A	1	18.35		
1+80	A	2	19.35		
1+80	A	3	18.83		
1+80	A	4	17.39	18.48	0.83
1+80	B	1	16.84		
1+80	B	2	19.75		
1+80	B	3	16.49		
1+80	B	4	14.67	16.94	2.1
1+80	C	1	9.81		

Table 202. ***Modulus*** measured by ***Geogauge B25C*** in ***N-8 last lift, OK Subgrade, ksi***
Continued

Station	Point	Trial	Modulus	Average	Std Dev
1+80	C	2	17.51		
1+80	C	3	13.88		
1+80	C	4	8.69	12.47	4.03

Table 203. ***Penetration Index*** measured by ***DCP*** in ***N-8 1st lift, OK Subgrade, mm/blow***

Station	Point	# of Blows	mm/blow	Average
0+25	C	1	21	
0+25	C	2	19	
0+25	C	3	19.33	
0+25	C	4	20.5	
0+25	C	5	21	
0+25	C	6	21.5	
0+25	C	7	22.29	
0+25	C	8	22	
0+25	C	9	23.56	
0+25	C	10	25.4	21.56
0+75	C	1	15	
0+75	C	2	18	
0+75	C	3	25	
0+75	C	4	34.75	
0+75	C	5	37.6	
0+75	C	6	38	
0+75	C	7	40.57	29.85
1+25	C	1	54	
1+25	C	2	56	
1+25	C	3	57.33	
1+25	C	4	60.75	57.02
1+25	B	1	42	
1+25	B	2	39	
1+25	B	3	36.33	
1+25	B	4	37.25	
1+25	B	5	34.6	
1+25	B	6	32.83	
1+25	B	7	30.86	
1+25	B	8	23.38	35.16

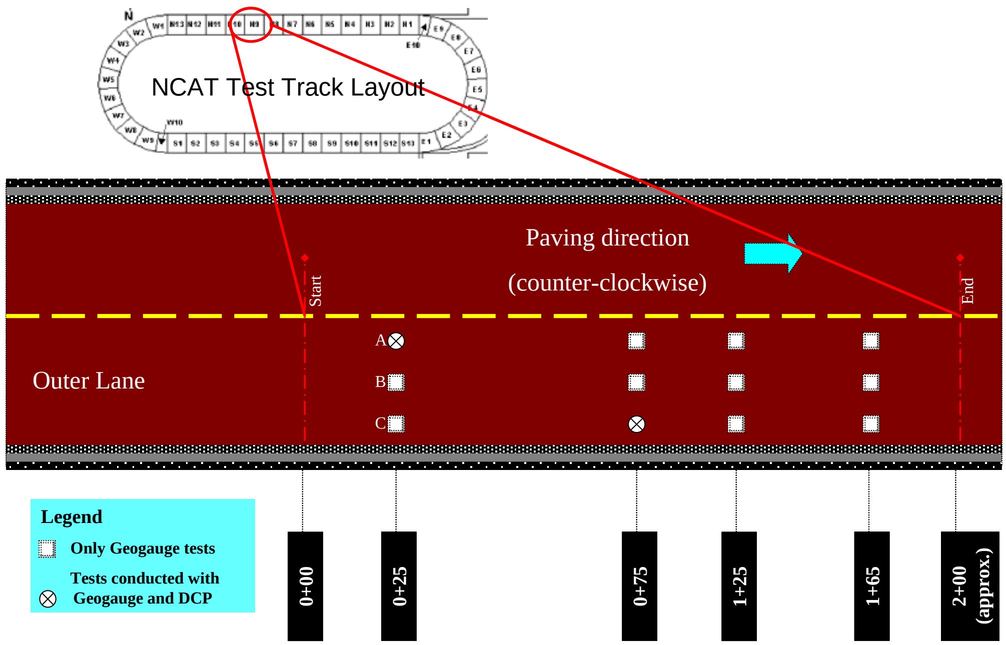
Table 204. ***Modulus*** measured by ***DSPA*** in ***N-8 1st lift, OK Subgrade, ksi***

Station	Point	Trial	Average
0+25	A	3	49
0+25	B	3	46
0+25	C	3	46
0+75	A	3	36
0+75	B	3	51
0+75	C	3	40
1+25	A	3	38
1+25	B	3	45
1+25	C	3	31
1+75	A	3	43
1+75	B	3	41
1+75	C	3	50

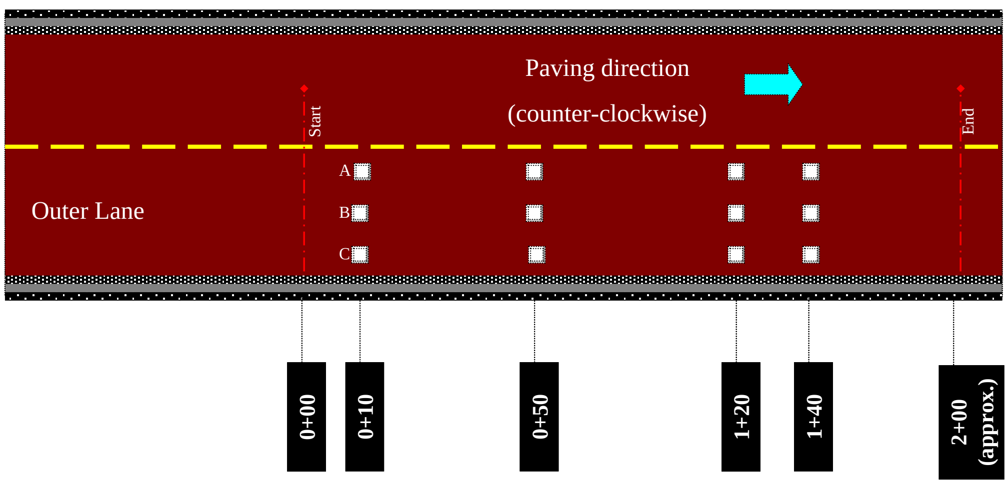
Table 205. ***Modulus*** measured by ***DSPA*** in ***N-8 last lift, OK Subgrade, ksi***

Station	Point	Trial	Average
0+10	A	3	71
0+10	B	3	60
0+10	C	3	60
0+50	A	3	56
0+50	B	3	56
0+50	C	3	68
1+40	A	4	44
1+40	B	4	53
1+40	C	4	51
1+80	A	4	57
1+80	B	4	74
1+80	C	4	59

NCAT TEST SECTIONS, N-9 SUBGRADE TESTING



Layout for first lift in September 2006



Layout for last lift in October 2006

Table 206. ***Modulus*** measured by ***Geogauge B24C*** in ***N-9 1st lift, OK Subgrade, ksi***

Station	Point	Trial	Modulus	Average	Std Dev
0+25	A	1	27.07		
0+25	A	2	28.35		
0+25	A	3	27.12	27.51	0.73
0+25	B	1	29.72		
0+25	B	2	28.54		
0+25	B	3	28.46	28.91	0.71
0+25	C	1	26.78		
0+25	C	2	18.86		
0+25	C	3	19.66	21.77	4.36
0+75	A	1	29.7		
0+75	A	2	28.89		
0+75	A	3	29.2	29.26	0.41
0+75	B	1	28.57		
0+75	B	2	30.72		
0+75	B	3	30.13	29.81	1.11
0+75	C	1	36.05		
0+75	C	2	33.08		
0+75	C	3	32.18	33.77	2.03
1+25	A	1	28.29		
1+25	A	2	28.09		
1+25	A	3	24.99	27.12	1.85
1+25	B	1	21.94		
1+25	B	2	25.86		
1+25	B	3	25.12	24.31	2.08
1+25	C	1	25.87		
1+25	C	2	26.57		
1+25	C	3	24.47	25.64	1.07
1+65	A	1	17.39		
1+65	A	2	20.04		
1+65	A	3	23.38	20.27	3
1+65	B	1	24.08		
1+65	B	2	25.86		
1+65	B	3	29.82	26.59	2.94
1+65	C	1	26.83		
1+65	C	2	24.94		
1+65	C	3	27.46	26.41	1.31

Table 207. ***Modulus*** measured by ***Geogauge B24C*** in ***N-9 last lift, OK Subgrade, ksi***

Station	Point	Trial	Modulus	Average	Std Dev
0+10	A	1	14.69		
0+10	A	2	16.1		
0+10	A	3	16.77		
0+10	A	4	14.67	15.56	1.05
0+10	B	1	23.08		
0+10	B	2	17.02		
0+10	B	3	25.11		
0+10	B	4	24.64	22.46	3.73
0+10	C	1	9.41		
0+10	C	2	9.88		
0+10	C	3	12.91		
0+10	C	4	9.53	10.43	1.66
0+50	A	1	25.9		
0+50	A	2	23.72		
0+50	A	3	19.42		
0+50	A	4	29.33	24.59	4.15
0+50	B	1	23.85		
0+50	B	2	29.47		
0+50	B	3	28.21		
0+50	B	4	26.27	26.95	2.45
0+50	C	1	16.12		
0+50	C	2	18.96		
0+50	C	3	19.1		
0+50	C	4	18.06	18.06	1.37
1+20	A	1	22.56		
1+20	A	2	24.98		
1+20	A	3	23.51		
1+20	A	4	21.59	23.16	1.44
1+20	B	1	20.8		
1+20	B	2	21.28		
1+20	B	3	20.2	20.76	0.54
1+20	C	1	20.89		
1+20	C	2	17.64		
1+20	C	3	21.45	19.99	2.06
1+40	A	1	23.15		
1+40	A	2	30.76		
1+40	A	3	22.27		

Table 207. ***Modulus*** measured by ***Geogauge B24C*** in ***N-9 last lift, OK Subgrade, ksi***
Continued

Station	Point	Trial	Modulus	Average	Std Dev
1+40	A	4	23.12	24.83	3.98
1+40	B	1	17.88		
1+40	B	2	16.46		
1+40	B	3	14.44	16.26	1.73
1+40	C	1	17.62		
1+40	C	2	15.67		
1+40	C	3	19.25	17.51	1.79

Table 208. ***Modulus*** measured by ***Geogauge B25C*** in ***N-9 last lift, OK Subgrade, ksi***

Station	Point	Trial	Modulus	Average	Std Dev
0+10	A	1	16.09		
0+10	A	2	15.86		
0+10	A	3	13.04		
0+10	A	4	15.37	15.09	1.4
0+10	B	1	18.32		
0+10	B	2	17.49		
0+10	B	3	19.49		
0+10	B	4	17.14	18.11	1.04
0+10	C	1	10.02		
0+10	C	2	9.87		
0+10	C	3	14.45		
0+10	C	4	11.65	11.5	2.13
0+50	A	1	16.38		
0+50	A	2	18.27		
0+50	A	3	15.36		
0+50	A	4	18.67	17.17	1.57
0+50	B	1	21.45		
0+50	B	2	20.52		
0+50	B	3	28.12		
0+50	B	4	18.22	22.08	4.25
0+50	C	1	16.68		
0+50	C	2	17.6		
0+50	C	3	18.07		
0+50	C	4	17.59	17.49	0.58
1+20	A	1	22.01		
1+20	A	2	17.08		
1+20	A	3	20.83		
1+20	A	4	20.4	20.08	2.11
1+20	B	1	22.59		
1+20	B	2	15.56		
1+20	B	3	18.03		
1+20	B	4	22.61	19.7	3.5
1+20	C	1	18.4		
1+20	C	2	22.02		
1+20	C	3	22.42		
1+20	C	4	19.13	20.49	2.02
1+40	A	1	20.89		
1+40	A	2	22.97		
1+40	A	3	20.98	21.61	1.18
1+40	B	1	13.8		

Table 208. ***Modulus*** measured by ***Geogauge B25C*** in ***N-9 last lift, OK Subgrade, ksi***
Continued

Station	Point	Trial	Modulus	Average	Std Dev
1+40	B	2	16.72		
1+40	B	3	13.97		
1+40	B	4	19.87	16.09	2.85
1+40	C	1	16.28		
1+40	C	2	21.39		
1+40	C	3	18.46		
1+40	C	4	19.13	18.82	2.1

Table 209. ***Penetration Index*** measured by ***DCP*** in ***N-9 1st lift, OK Subgrade, mm/blow***

Station	Point	# of Blows	mm/blow	Average
0+25	A	1	32.5	
0+25	A	2	29.25	
0+25	A	3	34.5	
0+25	A	4	43.38	
0+25	A	5	45.7	
0+25	A	6	43.08	38.07
0+75	A	1	34	
0+75	A	2	29	
0+75	A	3	25.33	
0+75	A	4	25.25	
0+75	A	5	26.6	
0+75	A	6	27.5	
0+75	A	7	28.29	
0+75	A	8	27.5	27.93
0+75	C	1	28	
0+75	C	2	31	
0+75	C	3	34	
0+75	C	4	32.75	
0+75	C	5	31	
0+75	C	6	28.5	
0+75	C	7	26.14	
0+75	C	8	24.75	
0+75	C	9	23.78	
0+75	C	10	23.4	
0+75	C	11	23.73	27.91

Table 210. ***Modulus*** measured by ***DSPA*** in ***N-9 1st lift, OK Subgrade, ksi***

Station	Point	Trial	Average
0+25	A	3	36
0+25	B	3	46
0+25	C	3	43
0+75	A	3	35
0+75	B	3	43
0+75	C	3	56
1+25	A	3	43
1+25	B	3	43
1+25	C	3	35
1+65	A	3	30
1+65	B	3	39
1+65	C	3	36

Table 211. ***Modulus*** measured by ***DSPA*** in ***N-9 last lift, OK Subgrade, ksi***

Station	Point	Trial	Average
0+10	A	4	74
0+10	B	4	61
0+10	C	4	60
0+50	A	4	103
0+50	B	4	88
0+50	C	4	55
1+20	A	4	78
1+20	B	4	62
1+20	C	4	69
1+40	A	4	97
1+40	B	4	60
1+40	C	4	64

Table 212. Summary of ***Resilient Modulus Test Results*** in ***N-8 and N-9, OK Subgrade***

Sequence	σ_1 psi	σ_2 psi	σ_3 psi	θ psi	τ_{oct} psi	$\sigma_1 - \sigma_3$ psi	M_R psi	Pred. M_R psi
Repetition 1								
1	13.8	7.9	7.9	29.6	2.8	5.9	8791	8615
2	11.4	5.9	5.9	23.2	2.6	5.5	8669	8268
3	8.9	3.9	3.9	16.7	2.4	5.0	7999	7800
4	6.6	1.9	1.9	10.4	2.2	4.7	7313	6909
5	16.8	7.9	7.9	32.6	4.2	8.9	6754	6889
6	14.4	5.9	5.9	26.2	4.0	8.5	6514	6646
7	12.0	3.9	3.9	19.8	3.8	8.1	6131	6292
8	9.6	1.9	1.9	13.4	3.6	7.7	5602	5756
9	19.8	7.9	7.9	35.6	5.6	11.9	5287	5596
10	17.4	5.9	5.9	29.2	5.4	11.5	5253	5421
11	15.0	3.9	3.9	22.8	5.2	11.1	4890	5173
12	12.6	1.9	1.9	16.4	5.0	10.7	4411	4812
13	23.9	7.9	7.9	39.7	7.5	16.0	4432	4304
14	21.5	5.9	5.9	33.3	7.4	15.6	4426	4188
15	19.0	3.9	3.9	26.8	7.1	15.1	4288	4052
16	16.6	1.9	1.9	20.4	6.9	14.7	3957	3826
Repetition 2								
1	13.8	7.9	7.9	29.6	2.8	5.9	8405	8203
2	11.2	5.9	5.9	23.0	2.5	5.3	8319	7925
3	9.0	3.9	3.9	16.8	2.4	5.1	7618	7240
4	6.7	1.9	1.9	10.5	2.3	4.8	6681	6325
5	16.8	7.9	7.9	32.6	4.2	8.9	6443	6604
6	14.4	5.9	5.9	26.2	4.0	8.5	6153	6326
7	11.9	3.9	3.9	19.7	3.8	8.0	5822	5974
8	9.5	1.9	1.9	13.3	3.6	7.6	5224	5393
9	19.8	7.9	7.9	35.6	5.6	11.9	5069	5398
10	17.4	5.9	5.9	29.2	5.4	11.5	4947	5196
11	14.9	3.9	3.9	22.7	5.2	11.0	4614	4948
12	12.5	1.9	1.9	16.3	5.0	10.6	4173	4553
13	23.9	7.9	7.9	39.7	7.5	16.0	4378	4185
14	21.8	5.9	5.9	33.6	7.5	15.9	4238	3979
15	18.9	3.9	3.9	26.7	7.1	15.0	4127	3911

Sequence	σ_1 psi	σ_2 psi	σ_3 psi	θ psi	τ_{oct} psi	$\sigma_1 - \sigma_3$ psi	M_R psi	Pred. M_R psi
16	16.6	1.9	1.9	20.4	6.9	14.7	3784	3641
Repetition 3								
1	13.8	7.9	7.9	29.6	2.8	5.9	8236	7991
2	11.4	5.9	5.9	23.2	2.6	5.5	8046	7621
3	9.0	3.9	3.9	16.8	2.4	5.1	7395	7082
4	6.5	1.9	1.9	10.3	2.2	4.6	6611	6283
5	16.8	7.9	7.9	32.6	4.2	8.9	6324	6474
6	14.4	5.9	5.9	26.2	4.0	8.5	6150	6211
7	12.0	3.9	3.9	19.8	3.8	8.1	5679	5839
8	9.6	1.9	1.9	13.4	3.6	7.7	5071	5293
9	19.8	7.9	7.9	35.6	5.6	11.9	4939	5323
10	17.4	5.9	5.9	29.2	5.4	11.5	4854	5130
11	15.0	3.9	3.9	22.8	5.2	11.1	4515	4865
12	12.6	1.9	1.9	16.4	5.0	10.7	4122	4490
13	24.0	7.9	7.9	39.8	7.6	16.1	4256	4134
14	21.4	5.9	5.9	33.2	7.3	15.5	4332	4050
15	19.0	3.9	3.9	26.8	7.1	15.1	4141	3873
16	16.7	1.9	1.9	20.5	7.0	14.8	3810	3615

Calculated Mr coefficients for

	Rep 1	Rep 2	Rep 3
K_1	828.2	765.3	739.0
K_2	0.314	0.344	0.333
K_3	-3.263	-3.213	-3.118

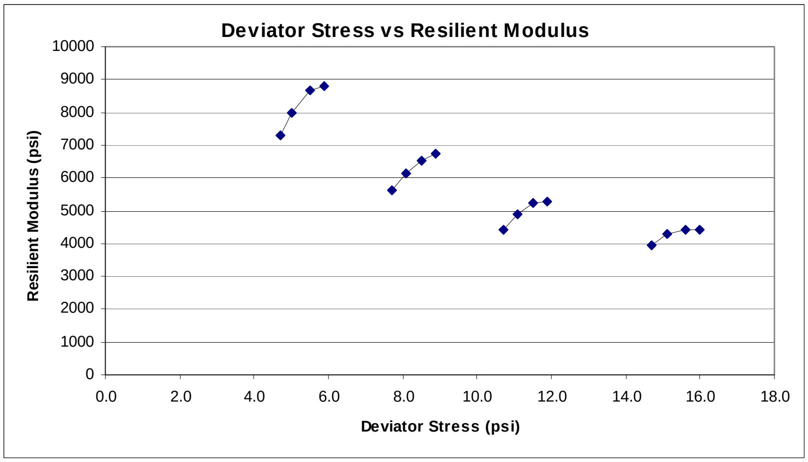


Figure 73.***Resilient Modulus vs. Deviator Stress*** in ***N-8 and N-9, OK Subgrade*** - ***Rep 1***

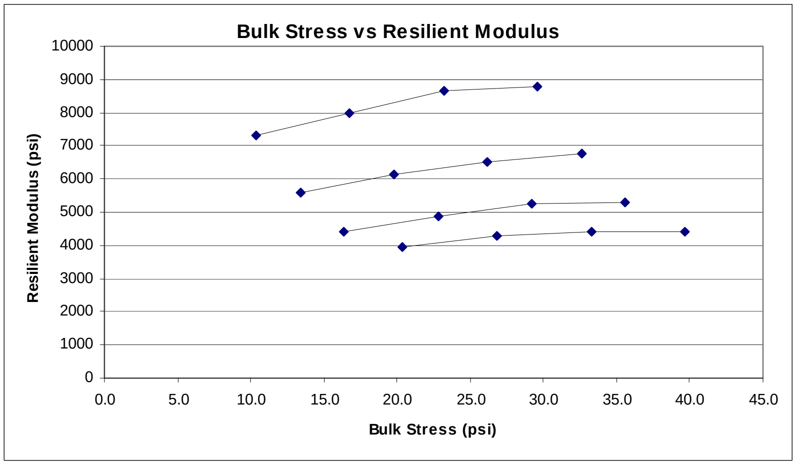


Figure 74. ***Bulk stress vs. Resilient Modulus*** in ***N-8 and N-9, OK Subgrade*** - ***Rep 1***

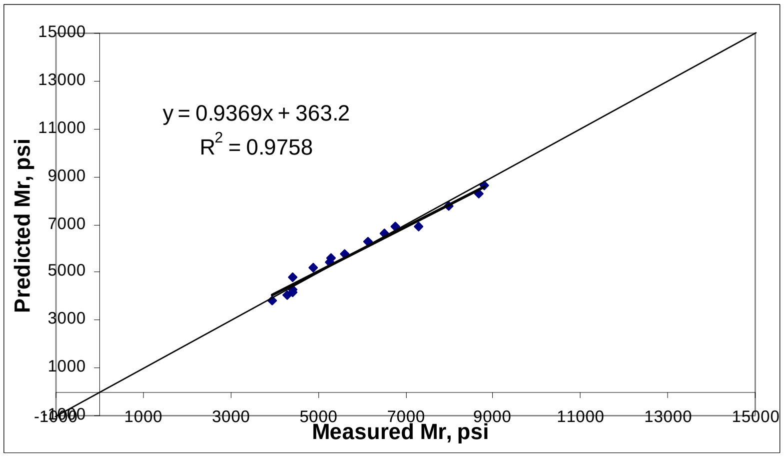


Figure 75.***Predicted vs Measured Resilient Modulus*** in ***N-8 and N-9, OK Subgrade*** - ***Rep 1***

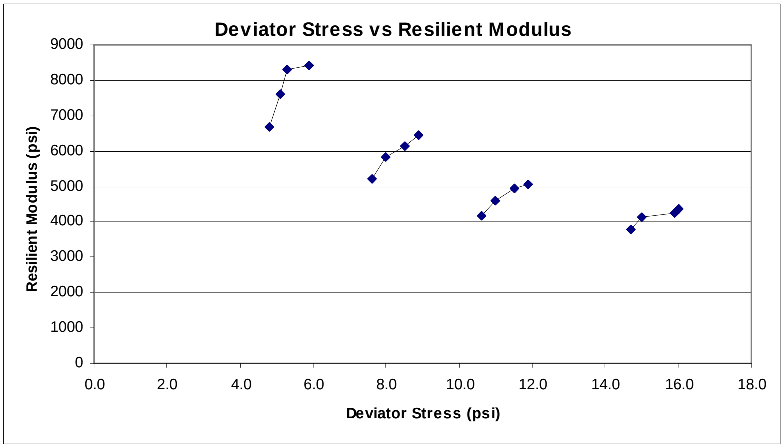


Figure 76.***Resilient Modulus vs. Deviator Stress*** in ***N-8 and N-9, OK Subgrade*** - ***Rep 2***

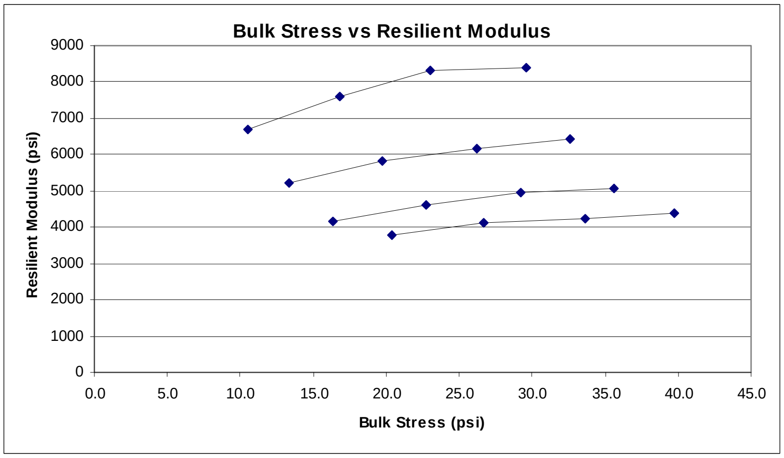


Figure 77. ***Bulk stress vs. Resilient Modulus*** in ***N-8 and N-9, OK Subgrade*** - ***Rep 2***

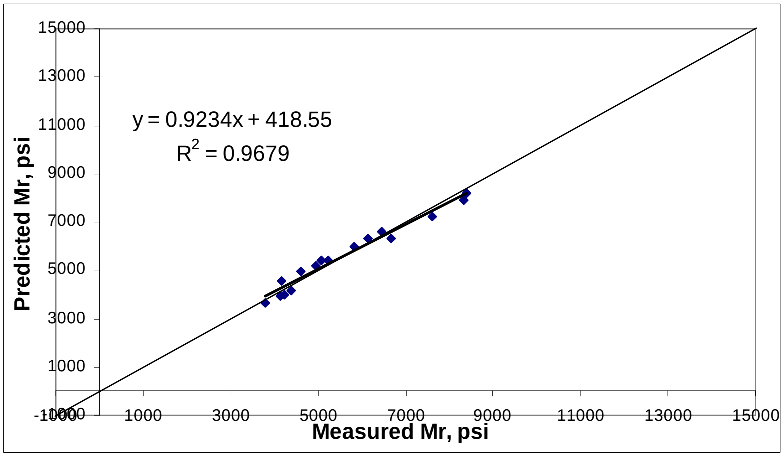


Figure 78. ***Predicted vs Measured Resilient Modulus*** in ***N-8 and N-9, OK Subgrade*** - ***Rep 2***

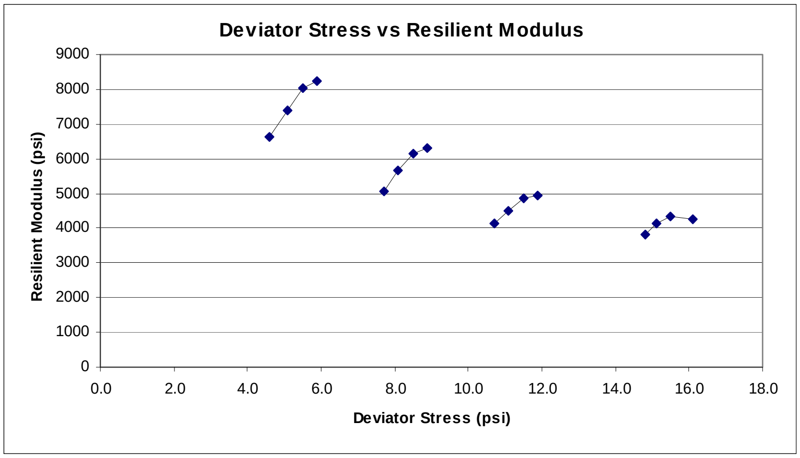


Figure 79.***Resilient Modulus vs. Deviator Stress*** in ***N-8 and N-9, OK Subgrade - Rep 3***

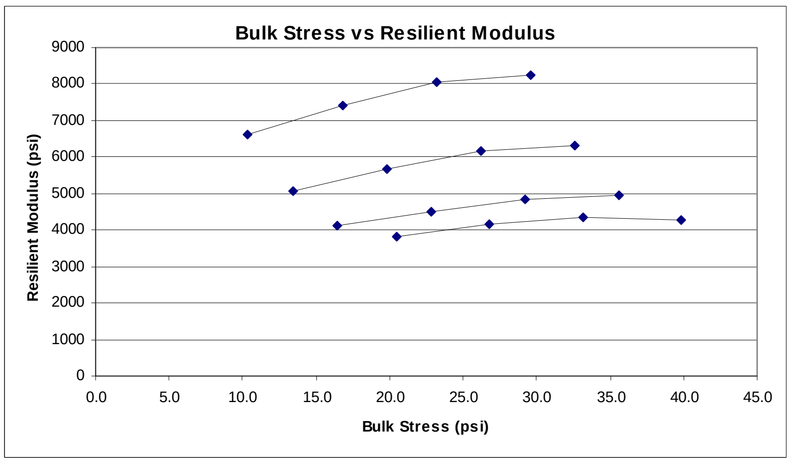


Figure 80. ***Bulk stress vs. Resilient Modulus*** in ***N-8 and N-9, OK Subgrade - Rep 3***

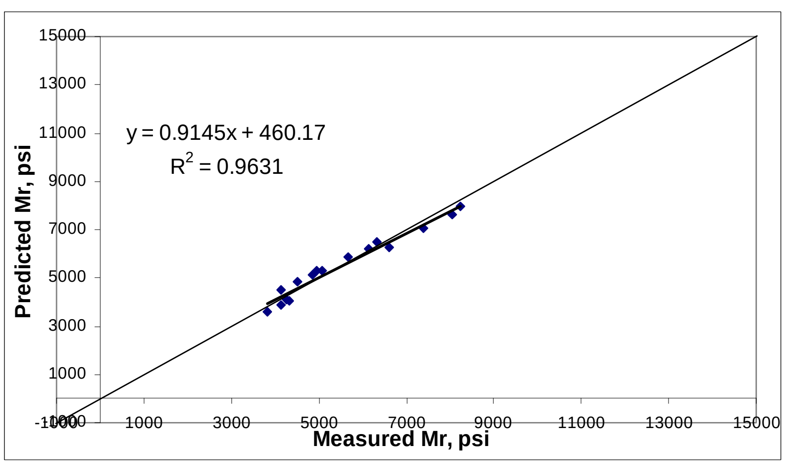


Figure 81. ***Predicted vs Measured Resilient Modulus*** in ***N-8 and N-9, OK Subgrade - Rep 3***

NCAT TEST SECTIONS, N-1 BASE TESTING

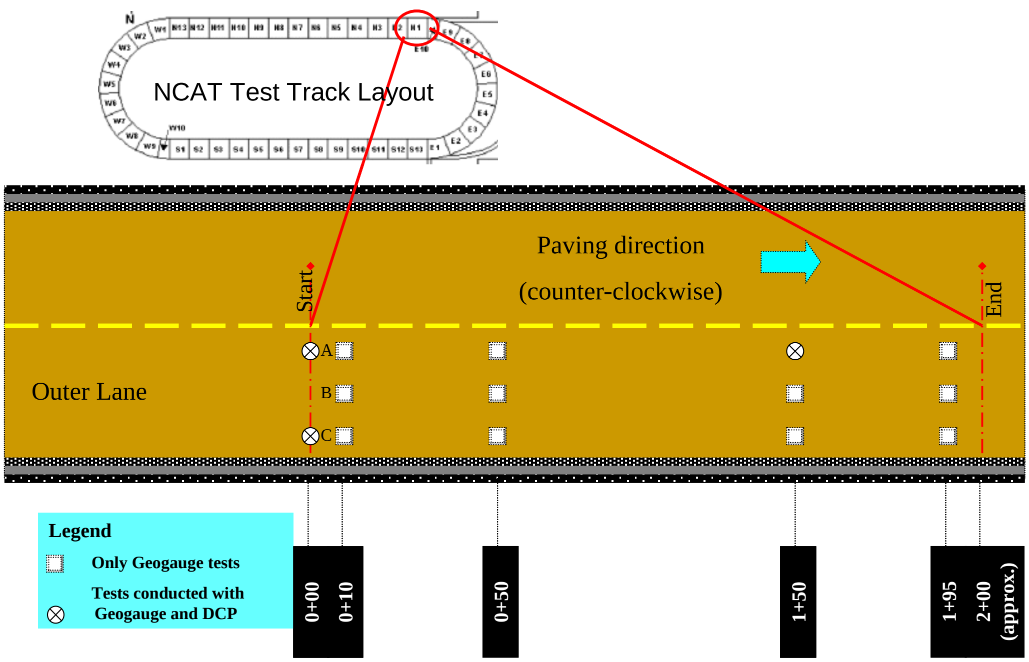


Table 213. ***Modulus*** measured by ***Geogauge B24C*** in ***N-1, FL Base, ksi***

Station	Point	Trial	Modulus	Average	Std Dev
0+10	A	1	77.21		
0+10	A	2	82.1		
0+10	A	3	59.81	73.04	11.72
0+10	B	1	55.6		
0+10	B	2	53.82		
0+10	B	3	74.95	61.46	11.72
0+10	C	1	51.13		
0+10	C	2	52.13		
0+10	C	3	42.15	48.47	5.5
0+50	A	1	57.98		
0+50	A	2	49.74		
0+50	A	3	59.18	55.63	5.14
0+50	B	1	41.84		
0+50	B	2	46.26		
0+50	B	3	46.11	44.74	2.51
0+50	C	1	65.61		
0+50	C	2	62.55		
0+50	C	3	43.88	57.35	11.76
1+50	A	1	31.82		
1+50	A	2	30.47		
1+50	A	3	42.82	35.04	6.77
1+50	B	1	42.14		
1+50	B	2	47.3		
1+50	B	3	43.76	44.4	2.64
1+50	C	1	47.2		
1+50	C	2	46.59		
1+50	C	3	41.56	45.12	3.1
1+95	A	1	50.75		
1+95	A	2	53.82		
1+95	A	3	55.6	53.39	2.45
1+95	B	1	38.16		
1+95	B	2	47.19		
1+95	B	3	46.68	44.01	5.07
1+95	C	1	31.68		
1+95	C	2	37.47		
1+95	C	3	33.45	34.2	2.97

Table 214. ***Penetration Index*** measured by ***DCP*** in ***N-1, FL Base, mm/blow***

Station	Point	# of Blows	mm/blow	Average
0	A	5	4.6	
0	A	10	3.6	
0	A	15	4.2	
0	A	20	4.25	
0	A	25	4.12	
0	A	30	4.07	
0	A	35	4.06	
0	A	40	4	
0	A	45	4.02	
0	A	50	4.16	
0	A	55	4.27	4.12
0	C	5	2.6	
0	C	10	2.7	
0	C	15	2.6	
0	C	20	3.1	
0	C	25	2.64	
0	C	30	2.63	
0	C	35	2.66	
0	C	40	2.63	
0	C	45	2.56	
0	C	50	2.56	
0	C	55	2.47	
0	C	60	2.45	
0	C	65	2.43	
0	C	70	2.41	
0	C	75	2.43	
0	C	80	2.44	
0	C	85	2.48	2.58
1+50	A	5	5.4	
1+50	A	10	4.7	
1+50	A	15	4.73	
1+50	A	20	4.65	
1+50	A	25	4.48	
1+50	A	30	4.3	
1+50	A	35	4.09	
1+50	A	40	3.83	
1+50	A	45	3.67	
1+50	A	50	3.58	
1+50	A	55	3.55	
1+50	A	60	3.63	4.22

Table 215. ***Modulus*** measured by ***DSPA*** in ***N-1, FL Base, ksi***

Station	Point	Trial	Average
0+10	A	3	115
0+10	B	3	83
0+10	C	3	55
0+50	A	3	87
0+50	B	3	66
0+50	C	3	91
1+50	A	3	65
1+50	B	3	58
1+50	C	3	80
1+95	A	3	82
1+95	B	3	89
1+95	C	3	92

NCAT TEST SECTIONS, N-2 BASE TESTING

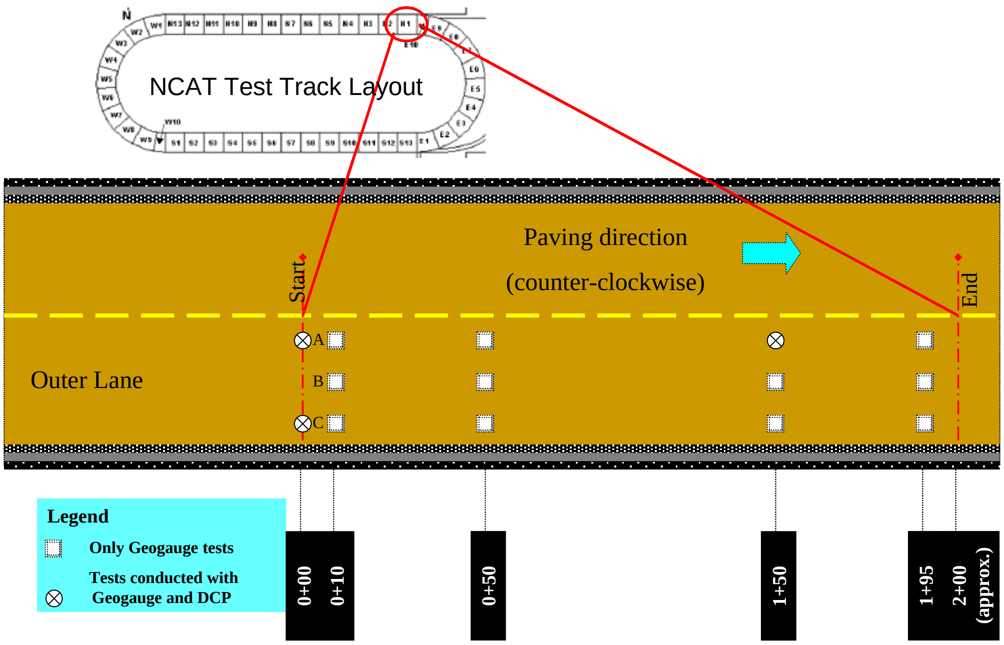


Table 216. ***Modulus*** measured by ***Geogauge B24C*** in ***N-2, FL Base, ksi***

Station	Point	Trial	Modulus	Average	Std Dev
0+10	A	1	54.3		
0+10	A	2	49.48		
0+10	A	3	47.11	50.3	3.66
0+10	B	1	40.1		
0+10	B	2	37.44		
0+10	B	3	47.87	41.8	5.42
0+10	C	1	29.97		
0+10	C	2	32.43		
0+10	C	3	35.51	32.64	2.78
0+50	A	1	75.38		
0+50	A	2	74.91		
0+50	A	3	66.04	72.11	5.26
0+50	B	1	60.63		
0+50	B	2	56.97		
0+50	B	3	59.48	59.03	1.87
0+50	C	1	49.18		
0+50	C	2	39.98		
0+50	C	3	48.08	45.75	5.02
1+50	A	1	69.27		
1+50	A	2	65.96		
1+50	A	3	74.03	69.75	4.06
1+50	B	1	58.81		
1+50	B	2	43.81		
1+50	B	3	63.65	55.42	10.34
1+50	C	1	53.25		
1+50	C	2	48.56		
1+50	C	3	31.04	44.28	11.71
1+95	A	1	43.75		
1+95	A	2	49.41		
1+95	A	3	50.27	47.81	3.54
1+95	B	1	46.65		
1+95	B	2	56.25		
1+95	B	3	43.44	48.78	6.67
1+95	C	1	41.35		
1+95	C	2	20.28		
1+95	C	3	28.15	29.93	10.65

Table 217. ***Penetration Index*** measured by ***DCP*** in ***N-2, FL Base, mm/blow***

Station	Point	# of Blows	mm/blow	Average
0+50	A	5	5	
0+50	A	10	4.8	
0+50	A	15	4.53	
0+50	A	20	4.55	
0+50	A	25	4.32	
0+50	A	30	4.03	
0+50	A	35	3.83	
0+50	A	40	3.6	
0+50	A	45	3.47	
0+50	A	50	3.4	
0+50	A	55	3.42	
0+50	A	60	3.38	4.03
0+50	C	5	3	
0+50	C	10	2.6	
0+50	C	15	2.53	
0+50	C	20	2.6	
0+50	C	25	2.56	
0+50	C	30	2.53	
0+50	C	35	2.51	
0+50	C	40	2.53	
0+50	C	45	2.42	
0+50	C	50	2.36	
0+50	C	55	2.27	
0+50	C	60	2.25	
0+50	C	65	2.23	
0+50	C	70	2.19	
0+50	C	75	2.19	
0+50	C	80	2.16	
0+50	C	85	2.16	
0+50	C	90	2.17	
0+50	C	95	2.19	2.39

Table 218. ***Modulus*** measured by ***DSPA*** in ***N-2, FL Base, ksi***

Station	Point	Trial	Average
0+10	A	3	118
0+10	B	3	120
0+10	C	3	131
0+50	A	3	120
0+50	B	3	78
0+50	C	3	68
1+50	A	3	87
1+50	B	3	70
1+50	C	3	87
1+95	A	3	78
1+95	B	3	81
1+95	C	3	120

Table 219. Summary of ***Resilient Modulus Test Results*** in ***N-1 and N-2, FL Base***

Sequence	σ_1 psi	σ_2 psi	σ_3 psi	θ psi	τ_{oct} psi	$\sigma_1 - \sigma_3$ psi	M_R psi	Pred. M_R psi
Repetition 1								
1	5.1	2.9	2.9	10.9	1.0	2.2	14117	11781
2	10.2	5.9	5.9	22.0	2.0	4.3	24774	25215
3	17.0	9.9	9.9	36.8	3.3	7.1	38149	42322
4	25.5	14.9	14.9	55.3	5.0	10.6	53731	61602
5	34.0	19.9	19.9	73.8	6.6	14.1	70681	78520
6	6.6	2.9	2.9	12.4	1.7	3.7	14465	12998
7	13.3	5.9	5.9	25.1	3.5	7.4	26139	26545
8	22.0	9.9	9.9	41.8	5.7	12.1	40851	42187
9	33.0	14.9	14.9	62.8	8.5	18.1	59084	58189
10	44.1	19.9	19.9	83.9	11.4	24.2	75488	70937
11	9.6	2.9	2.9	15.4	3.2	6.7	16267	15166
12	19.2	5.9	5.9	31.0	6.3	13.3	30430	28526
13	32.1	9.9	9.9	51.9	10.5	22.2	48214	41894
14	48.1	14.9	14.9	77.9	15.7	33.2	65089	53668
15	64.0	19.9	19.9	103.8	20.8	44.1	72813	62027
16	12.7	2.9	2.9	18.5	4.6	9.8	17303	17089
17	25.3	5.9	5.9	37.1	9.1	19.4	31619	30044
18	42.1	9.9	9.9	61.9	15.2	32.2	47140	41607
19	63.1	14.9	14.9	92.9	22.7	48.2	53838	50811
20	84.1	19.9	19.9	123.9	30.3	64.2	61837	56799
21	18.6	2.9	2.9	24.4	7.4	15.7	17221	20059
22	37.5	5.9	5.9	49.3	14.9	31.6	30063	32095
23	60.0	9.9	9.9	79.8	23.6	50.1	37025	41133
24	92.9	14.9	14.9	122.7	36.8	78.0	43691	47324
25	124.0	19.9	19.9	163.8	49.1	104.1	54530	50943
26	24.0	2.9	2.9	29.8	9.9	21.1	15620	22184
27	49.3	5.9	5.9	61.1	20.5	43.4	28228	33347
28	82.1	9.9	9.9	101.9	34.0	72.2	38198	40625
29	15.0	15.0	15.0	45.0	0.0	0.0		
Std	15.0	5.0	5.0	25.0	4.7	10.0		24327
Repetition 2								
1	5.1	2.9	2.9	10.9	1.0	2.2	16359	13316
2	10.2	5.9	5.9	22.0	2.0	4.3	30471	28576
3	17.0	9.9	9.9	36.8	3.3	7.1	43183	47867
4	25.5	14.9	14.9	55.3	5.0	10.6	60886	69320
5	34.1	19.9	19.9	73.9	6.7	14.2	77211	87708
6	6.6	2.9	2.9	12.4	1.7	3.7	16461	14637

Sequence	σ_1 psi	σ_2 psi	σ_3 psi	θ psi	τ_{oct} psi	$\sigma_1 - \sigma_3$ psi	M_R psi	Pred. M_R psi
7	13.2	5.9	5.9	25.0	3.4	7.3	30291	29787
8	22.0	9.9	9.9	41.8	5.7	12.1	45709	47064
9	33.1	14.9	14.9	62.9	8.6	18.2	64954	64182
10	44.0	19.9	19.9	83.8	11.4	24.1	80999	77577
11	9.7	2.9	2.9	15.5	3.2	6.8	18593	17025
12	19.2	5.9	5.9	31.0	6.3	13.3	33981	31573
13	32.1	9.9	9.9	51.9	10.5	22.2	52423	45653
14	48.0	14.9	14.9	77.8	15.6	33.1	69618	57488
15	64.0	19.9	19.9	103.8	20.8	44.1	76668	65372
16	12.7	2.9	2.9	18.5	4.6	9.8	18856	18966
17	25.2	5.9	5.9	37.0	9.1	19.3	33895	32785
18	42.1	9.9	9.9	61.9	15.2	32.2	50239	44478
19	63.0	14.9	14.9	92.8	22.7	48.1	56764	53127
20	84.0	19.9	19.9	123.8	30.2	64.1	63943	58269
21	18.6	2.9	2.9	24.4	7.4	15.7	17783	21975
22	37.5	5.9	5.9	49.3	14.9	31.6	31172	34235
23	59.9	9.9	9.9	79.7	23.6	50.0	38870	42771
24	93.0	14.9	14.9	122.8	36.8	78.1	46196	47678
25	123.9	19.9	19.9	163.7	49.0	104.0	55430	50188
26	24.0	2.9	2.9	29.8	9.9	21.1	15738	24040
27	49.4	5.9	5.9	61.2	20.5	43.5	28463	34915
28	82.1	9.9	9.9	101.9	34.0	72.2	38417	41112
29	15.0	15.0	15.0	45.0	0.0	0.0		
Std	15.0	5.0	5.0	25.0	4.7	10.0		27104
Repetition 3								
1	5.0	2.9	2.9	10.8	1.0	2.1	14183	12468
2	10.2	5.9	5.9	22.0	2.0	4.3	28333	27312
3	17.1	9.9	9.9	36.9	3.4	7.2	42211	46258
4	25.5	14.9	14.9	55.3	5.0	10.6	59946	67689
5	34.0	19.9	19.9	73.8	6.6	14.1	75380	86463
6	6.6	2.9	2.9	12.4	1.7	3.7	14903	13860
7	13.2	5.9	5.9	25.0	3.4	7.3	29432	28632
8	22.0	9.9	9.9	41.8	5.7	12.1	45015	45840
9	33.0	14.9	14.9	62.8	8.5	18.1	63610	63336
10	44.1	19.9	19.9	83.9	11.4	24.2	80077	77156
11	9.6	2.9	2.9	15.4	3.2	6.7	17380	16168
12	19.2	5.9	5.9	31.0	6.3	13.3	33791	30655
13	32.1	9.9	9.9	51.9	10.5	22.2	52146	45052
14	48.1	14.9	14.9	77.9	15.7	33.2	68840	57545
15	64.0	19.9	19.9	103.8	20.8	44.1	76202	66242
16	12.7	2.9	2.9	18.5	4.6	9.8	18383	18203

Sequence	σ_1 psi	σ_2 psi	σ_3 psi	θ psi	τ_{oct} psi	$\sigma_1 - \sigma_3$ psi	M_R psi	Pred. M_R psi
17	25.3	5.9	5.9	37.1	9.1	19.4	34166	32126
18	42.1	9.9	9.9	61.9	15.2	32.2	50209	44363
19	63.0	14.9	14.9	92.8	22.7	48.1	56447	53875
20	84.1	19.9	19.9	123.9	30.3	64.2	63811	59833
21	18.7	2.9	2.9	24.5	7.4	15.8	18080	21358
22	37.5	5.9	5.9	49.3	14.9	31.6	31635	34016
23	59.9	9.9	9.9	79.7	23.6	50.0	38621	43323
24	93.0	14.9	14.9	122.8	36.8	78.1	45431	49289
25	124.7	19.9	19.9	164.5	49.4	104.8	57790	52526
26	24.2	2.9	2.9	30.0	10.0	21.3	16665	23577
27	49.4	5.9	5.9	61.2	20.5	43.5	30306	35088
28	82.2	9.9	9.9	102.0	34.1	72.3	40343	42269
29	15.0	15.0	15.0	45.0	0.0	0.0		
Std	15.0	5.0	5.0	25.0	4.7	10.0		26137

Calculated Mr coefficients for

	Rep 1	Rep 2	Rep 3
K_1	1,248.3	1,429.6	1,349.9
K_2	1.193	1.208	1.223
K_3	-1.265	-1.392	-1.345

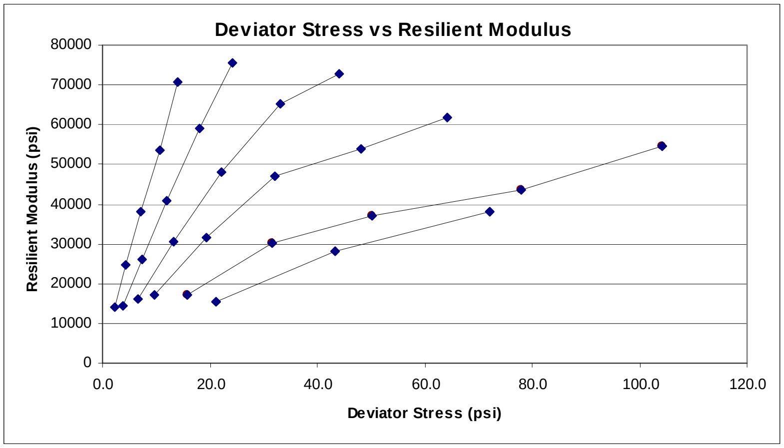


Figure 82. ***Resilient Modulus vs. Deviator Stress*** in ***N-1 and N-2, FL Base*** - ***Rep 1***

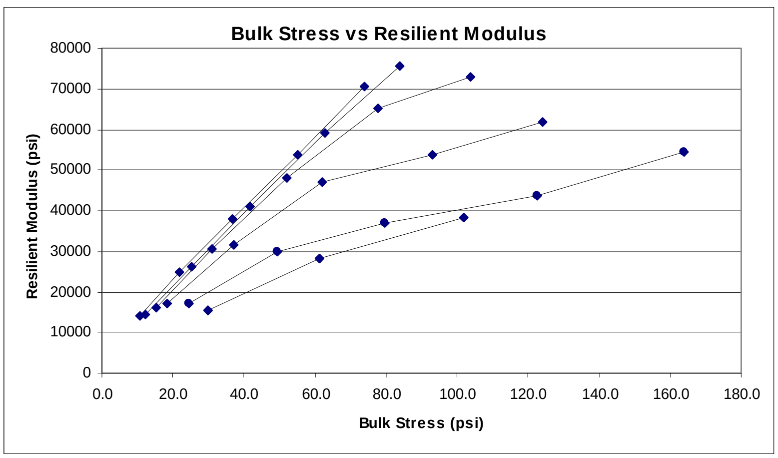


Figure 83. ***Bulk stress vs. Resilient Modulus*** in ***N-1 and N-2, FL Base*** - ***Rep 1***

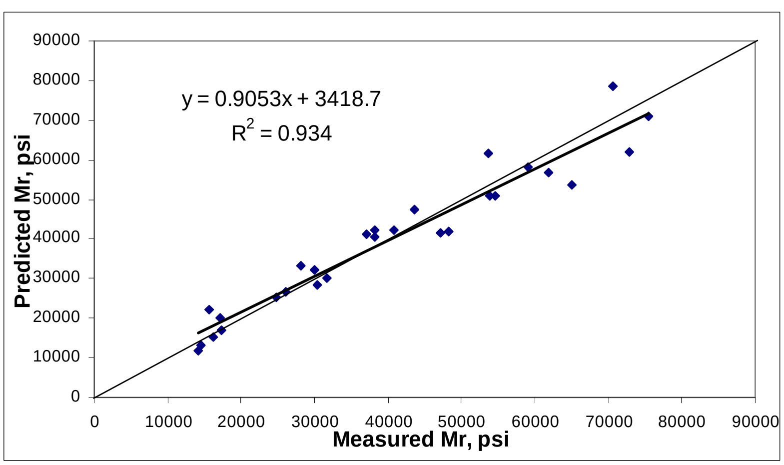


Figure 84. ***Predicted vs Measured Resilient Modulus*** in ***N-1 and N-2, FL Base*** - ***Rep 1***

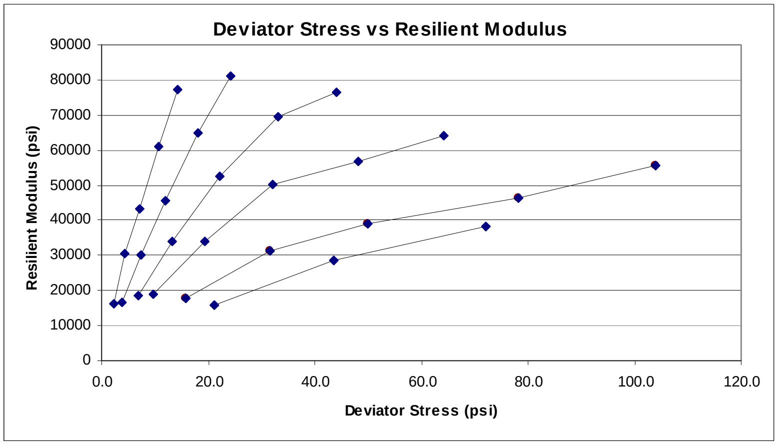


Figure 85. ***Resilient Modulus vs. Deviator Stress*** in ***N-1 and N-2, FL Base - Rep 2***

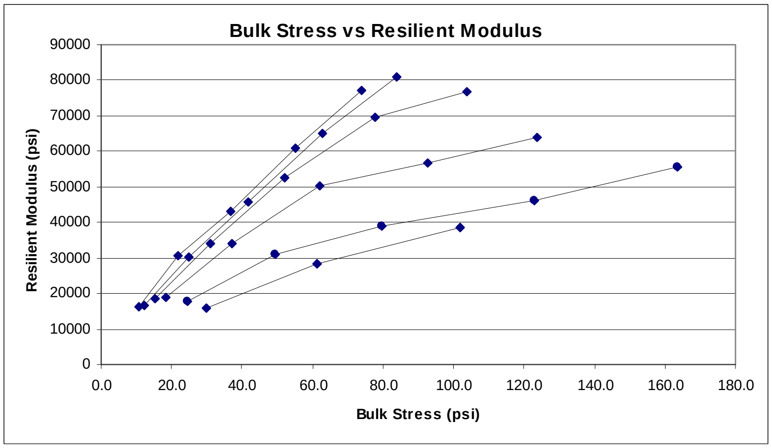


Figure 86. ***Bulk stress vs. Resilient Modulus*** in ***N-1 and N-2, FL Base - Rep 2***

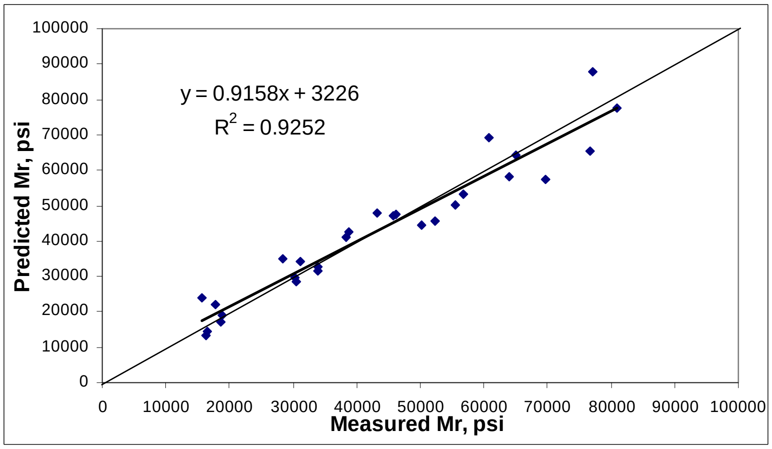


Figure 87. ***Predicted vs Measured Resilient Modulus*** in ***N-1 and N-2, FL Base - Rep 2***

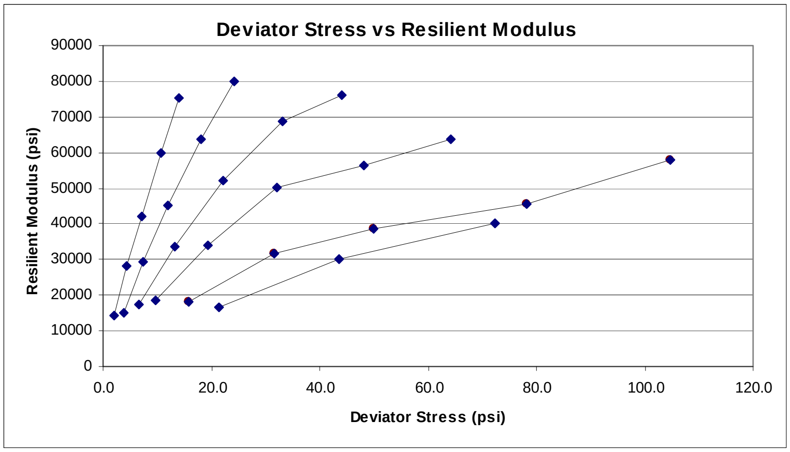


Figure 88. ***Resilient Modulus vs. Deviator Stress*** in ***N-1 and N-2, FL Base - Rep 3***

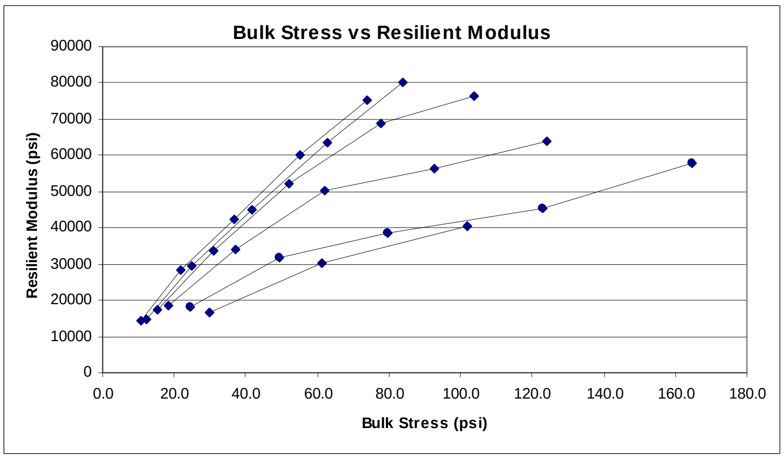


Figure 89. ***Bulk stress vs. Resilient Modulus*** in ***N-1 and N-2, FL Base - Rep 3***

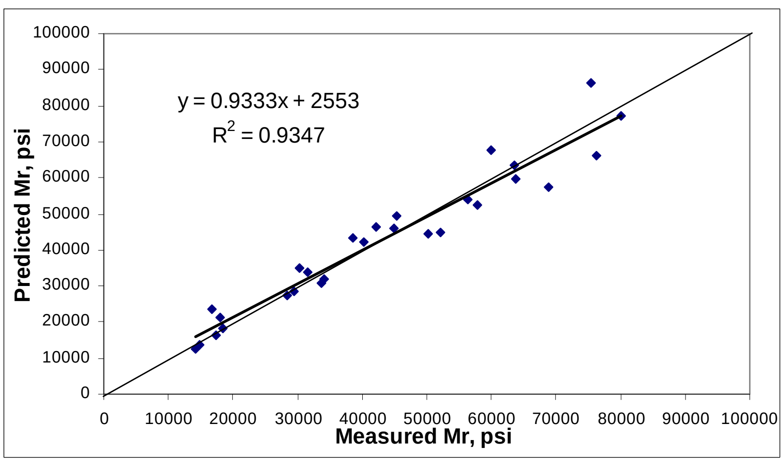


Figure 90. ***Predicted vs Measured Resilient Modulus*** in ***N-1 and N-2, FL Base - Rep 3***

NCAT TEST SECTIONS, N-10 BASE TESTING

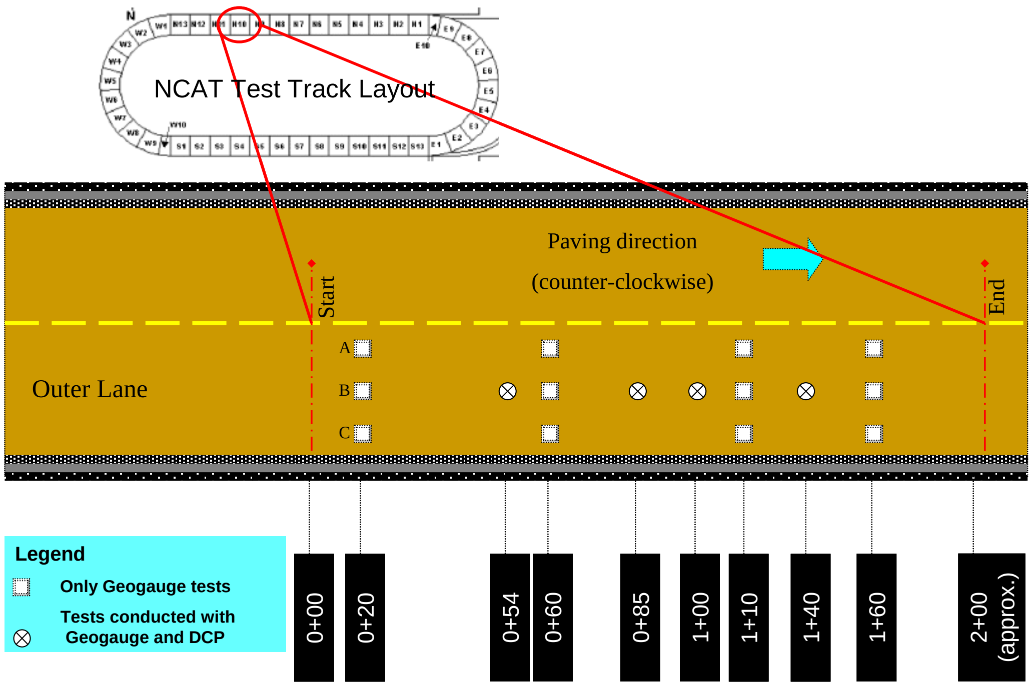


Table 220. ***Modulus*** measured by ***Geogauge B25C*** in ***N-2, MO Base, ksi***

Station	Point	Trial	Modulus	Average	Std Dev
0+20	A	1	30.67		
0+20	A	2	30.54		
0+20	A	3	31.81	31.01	0.7
0+20	B	1	39.64		
0+20	B	2	35.78		
0+20	B	3	29.34	34.92	5.2
0+20	C	1	25.43		
0+20	C	2	24.59		
0+20	C	3	22.65	24.22	1.43
0+54	B	1	25.47		
0+54	B	2	30.21		
0+54	B	3	27.57	27.75	2.38
0+60	A	1	26.79		
0+60	A	2	26.38		
0+60	A	3	26.34	26.5	0.25
0+60	B	1	28.41		
0+60	B	2	25.76		
0+60	B	3	26.92	27.03	1.33
0+60	C	1	21.67		
0+60	C	2	20.59		
0+60	C	3	20.66	20.97	0.6
0+85	B	1	20.39		
0+85	B	2	22.54		
0+85	B	3	19.7	20.88	1.48
1+00	B	1	23.91		
1+00	B	2	25.35		
1+00	B	3	21.31		
1+00	B	4	22.04	23.15	1.83
1+10	A	1	31.24		
1+10	A	2	25.39		
1+10	A	3	28.17	28.27	2.93
1+10	B	1	28.29		
1+10	B	2	25.34		
1+10	B	3	23.64	25.76	2.35
1+10	C	1	17.86		
1+10	C	2	17.43		
1+10	C	3	18.02	17.77	0.31
1+40	B	1	24.24		
1+40	B	2	24.6		
1+40	B	3	20.96	23.27	2.01

Table 220. ***Modulus*** measured by ***Geogauge B25C*** in ***N-2, MO Base, ksi***
Continued

Station	Point	Trial	Modulus	Average	Std Dev
1+60	A	1	31.52		
1+60	A	2	27.11		
1+60	A	3	26.61	28.41	2.7
1+60	B	1	25.49		
1+60	B	2	24.08		
1+60	B	3	26.9	25.49	1.41
1+60	C	1	13.81		
1+60	C	2	12.96		
1+60	C	3	13.48	13.42	0.43

Table 221. ***Modulus*** measured by ***Geogauge B24C*** in ***N-2, MO Base, ksi***

Station	Point	Trial	Modulus	Average	Std Dev
0+20	A	1	25.74		
0+20	A	2	25.83		
0+20	A	3	32	27.86	3.59
0+20	B	1	35.38		
0+20	B	2	39.58		
0+20	B	3	34.99	36.65	2.54
0+20	C	1	27.62		
0+20	C	2	20.77		
0+20	C	3	23.7	24.03	3.44
0+54	B	1	27.91		
0+54	B	2	27.6		
0+54	B	3	30.01	28.51	1.31
0+60	A	1	31.27		
0+60	A	2	28.14		
0+60	A	3	32.23	30.55	2.14
0+60	B	1	29.5		
0+60	B	2	24.55		
0+60	B	3	27.25	27.1	2.48
0+60	C	1	21.96		
0+60	C	2	22.9		
0+60	C	3	23.56	22.81	0.8
0+85	B	1	20.63		
0+85	B	2	21.7		
0+85	B	3	17.6	19.98	2.13
1+00	B	1	25.04		
1+00	B	2	28.21		
1+00	B	3	22.6	25.28	2.81
1+10	A	1	32.06		
1+10	A	2	27.78		
1+10	A	3	30.91	30.25	2.22
1+10	B	1	30.01		
1+10	B	2	27.48		
1+10	B	3	30.45	29.31	1.6
1+10	C	1	18.08		
1+10	C	2	19.29		
1+10	C	3	18.25	18.54	0.66
1+40	B	1	19.78		
1+40	B	2	25.39		
1+40	B	3	22.38	22.52	2.81

Table 221. ***Modulus*** measured by ***Geogauge B24C*** in ***N-2, MO Base, ksi***
Continued

Station	Point	Trial	Modulus	Average	Std

					Dev
1+60	A	1	24.26		
1+60	A	2	31.27		
1+60	A	3	26.74	27.42	3.55
1+60	B	1	23.86		
1+60	B	2	24.33		
1+60	B	3	26.14	24.78	1.2
1+60	C	1	14.4		
1+60	C	2	15.24		
1+60	C	3	15	14.88	0.43

Table 222. ***Modulus*** measured by ***DSPA*** in ***N-10, MO Base, ksi***

Station	Point	Trial	Average
0+20	A	4	97
0+20	B	4	80
0+20	C	4	105
0+54	B	4	123
0+60	A	4	81
0+60	B	4	104
0+60	C	4	113
0+85	B	4	130
1+00	B	4	81
1+10	A	4	96
1+10	B	4	111
1+10	C	4	91
1+40	B	4	98
1+60	A	4	56
1+60	B	4	129
1+60	C	4	58

Table 223. Summary of ***Resilient Modulus Test Results*** in ***N-10, MO Base***

Sequence	σ_1 psi	σ_2 psi	σ_3 psi	θ psi	τ_{oct} psi	$\sigma_1 - \sigma_3$ psi	M_R psi	Pred. M_R psi
Repetition 1								
1	5.1	2.9	2.9	10.9	1.0	2.2	13153	11189
2	10.3	5.9	5.9	22.1	2.1	4.4	20150	20596
3	17.0	9.9	9.9	36.8	3.3	7.1	28969	31392
4	25.6	14.9	14.9	55.4	5.0	10.7	41245	43078
5	34.0	19.9	19.9	73.8	6.6	14.1	53252	53221
6	6.6	2.9	2.9	12.4	1.7	3.7	12934	12229
7	13.2	5.9	5.9	25.0	3.4	7.3	20576	21867
8	22.1	9.9	9.9	41.9	5.8	12.2	30859	32461
9	33.0	14.9	14.9	62.8	8.5	18.1	43898	43221
10	44.0	19.9	19.9	83.8	11.4	24.1	56551	52133
11	9.6	2.9	2.9	15.4	3.2	6.7	14479	14115
12	19.3	5.9	5.9	31.1	6.3	13.4	24119	24171
13	32.0	9.9	9.9	51.8	10.4	22.1	36224	34259
14	47.9	14.9	14.9	77.7	15.6	33.0	48579	43832
15	63.9	19.9	19.9	103.7	20.7	44.0	56929	51315
16	12.7	2.9	2.9	18.5	4.6	9.8	15585	15840
17	25.2	5.9	5.9	37.0	9.1	19.3	25259	26045
18	42.0	9.9	9.9	61.8	15.1	32.1	35695	35808
19	63.1	14.9	14.9	92.9	22.7	48.2	44344	44633
20	84.1	19.9	19.9	123.9	30.3	64.2	54916	51307
21	18.7	2.9	2.9	24.5	7.4	15.8	16492	18689
22	37.2	5.9	5.9	49.0	14.8	31.3	26259	29140
23	60.1	9.9	9.9	79.9	23.7	50.2	35155	38155
24	93.1	14.9	14.9	122.9	36.9	78.2	44308	46312
25	20.0	20.0	20.0	60.0	0.0	0.0		
26	3.0	3.0	3.0	9.0	0.0	0.0		
27	6.0	6.0	6.0	18.0	0.0	0.0		
28	10.0	10.0	10.0	30.0	0.0	0.0		
29	15.0	15.0	15.0	45.0	0.0	0.0		
Std	15.0	5.0	5.0	25.0	4.7	10.0		20863
Repetition 2								
1	5.0	2.9	2.9	10.8	1.0	2.1	10626	9542
2	10.2	5.9	5.9	22.0	2.0	4.3	16473	16963
3	17.0	9.9	9.9	36.8	3.3	7.1	23309	25358
4	25.6	14.9	14.9	55.4	5.0	10.7	32850	34434
5	34.1	19.9	19.9	73.9	6.7	14.2	43791	42377
6	6.6	2.9	2.9	12.4	1.7	3.7	10584	10499
7	13.3	5.9	5.9	25.1	3.5	7.4	17311	18246

Sequence	σ_1 psi	σ_2 psi	σ_3 psi	θ psi	τ_{oct} psi	$\sigma_1 - \sigma_3$ psi	M_R psi	Pred. M_R psi
8	22.0	9.9	9.9	41.8	5.7	12.1	25246	26683
9	33.1	14.9	14.9	62.9	8.6	18.2	36436	35516
10	44.2	19.9	19.9	84.0	11.5	24.3	47449	43015
11	9.6	2.9	2.9	15.4	3.2	6.7	12217	12146
12	19.2	5.9	5.9	31.0	6.3	13.3	20811	20429
13	32.2	9.9	9.9	52.0	10.5	22.3	31155	29101
14	48.1	14.9	14.9	77.9	15.7	33.2	41457	37630
15	64.1	19.9	19.9	103.9	20.8	44.2	48193	44655
16	12.6	2.9	2.9	18.4	4.6	9.7	13214	13636
17	25.5	5.9	5.9	37.3	9.2	19.6	22115	22474
18	42.0	9.9	9.9	61.8	15.1	32.1	28888	31153
19	63.0	14.9	14.9	92.8	22.7	48.1	34227	39617
20	20.0	20.0	20.0	60.0	0.0	0.0		
21	3.0	3.0	3.0	9.0	0.0	0.0		
22	6.0	6.0	6.0	18.0	0.0	0.0		
23	10.0	10.0	10.0	30.0	0.0	0.0		
24	15.0	15.0	15.0	45.0	0.0	0.0		
25	20.0	20.0	20.0	60.0	0.0	0.0		
26	3.0	3.0	3.0	9.0	0.0	0.0		
27	6.0	6.0	6.0	18.0	0.0	0.0		
28	10.0	10.0	10.0	30.0	0.0	0.0		
29	15.0	15.0	15.0	45.0	0.0	0.0		
Std	15.0	5.0	5.0	25.0	4.7	10.0		17638
Repetition 5								
1	5.1	2.9	2.9	10.9	1.0	2.2	9203	8777
2	10.2	5.9	5.9	22.0	2.0	4.3	18063	17712
3	17.0	9.9	9.9	36.8	3.3	7.1	29244	29094
4	25.5	14.9	14.9	55.3	5.0	10.6	41308	42424
5	34.0	19.9	19.9	73.8	6.6	14.1	52314	54837
6	6.6	2.9	2.9	12.4	1.7	3.7	9440	9798
7	13.3	5.9	5.9	25.1	3.5	7.4	19564	19383
8	22.1	9.9	9.9	41.9	5.8	12.2	31292	31026
9	33.1	14.9	14.9	62.9	8.6	18.2	44650	44113
10	44.0	19.9	19.9	83.8	11.4	24.1	56112	55867
11	9.6	2.9	2.9	15.4	3.2	6.7	11333	11730
12	19.3	5.9	5.9	31.1	6.3	13.4	23512	22337
13	32.0	9.9	9.9	51.8	10.4	22.1	37072	34440
14	48.0	14.9	14.9	77.8	15.6	33.1	49619	47381
15	64.0	19.9	19.9	103.8	20.8	44.1	56721	58557
16	12.6	2.9	2.9	18.4	4.6	9.7	12833	13533

Sequence	σ_1 psi	σ_2 psi	σ_3 psi	θ psi	τ_{oct} psi	$\sigma_1 - \sigma_3$ psi	M_R psi	Pred. M_R psi
17	25.4	5.9	5.9	37.2	9.2	19.5	24910	25040
18	42.0	9.9	9.9	61.8	15.1	32.1	36009	37546
19	63.0	14.9	14.9	92.8	22.7	48.1	45066	50534
20	84.0	19.9	19.9	123.8	30.2	64.1	54517	61525
21	18.6	2.9	2.9	24.4	7.4	15.7	14476	16821
22	37.4	5.9	5.9	49.2	14.8	31.5	24541	29717
23	10.0	10.0	10.0	30.0	0.0	0.0		
24	15.0	15.0	15.0	45.0	0.0	0.0		
25	20.0	20.0	20.0	60.0	0.0	0.0		
26	3.0	3.0	3.0	9.0	0.0	0.0		
27	6.0	6.0	6.0	18.0	0.0	0.0		
28	10.0	10.0	10.0	30.0	0.0	0.0		
29	15.0	15.0	15.0	45.0	0.0	0.0		
Std	15.0	5.0	5.0	25.0	4.7	10.0		18592

Calculated Mr coefficients for

	Rep 1	Rep 2	Rep 5
K_1	1,052.6	869.9	850.0
K_2	0.926	0.851	1.050
K_5	-0.693	-0.468	-0.575

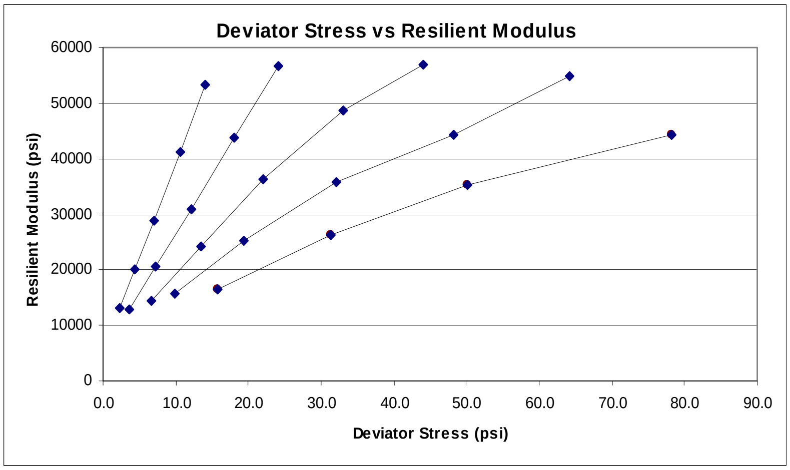


Figure 91. ***Resilient Modulus vs. Deviator Stress*** in ***N-10, MO Base - Rep 1***

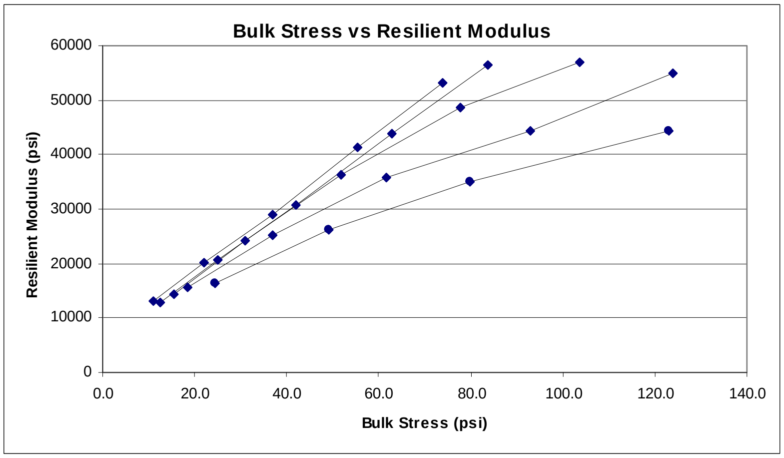


Figure 92. ***Bulk stress vs. Resilient Modulus*** in ***N-10, MO Base - Rep 1***

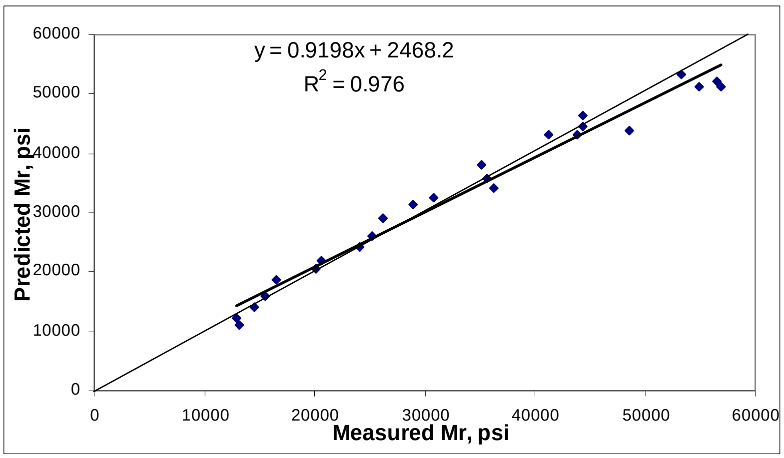


Figure 93. ***Predicted vs Measured Resilient Modulus*** in ***N-10, MO Base - Rep 1***

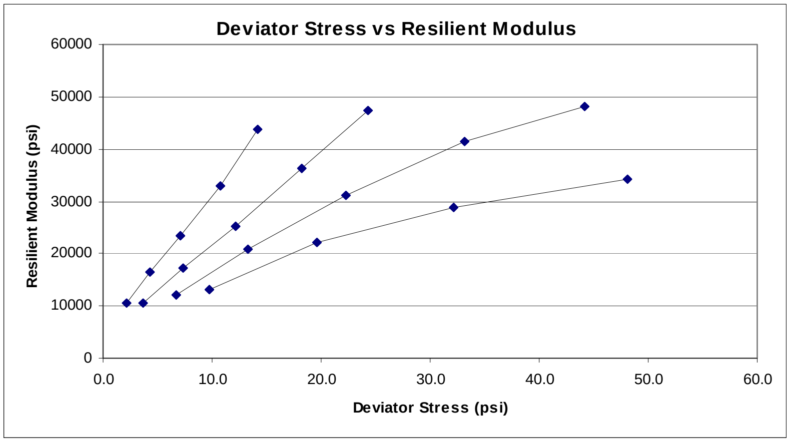


Figure 94. ***Resilient Modulus vs. Deviator Stress*** in ***N-10, MO Base*** - ***Rep 2***

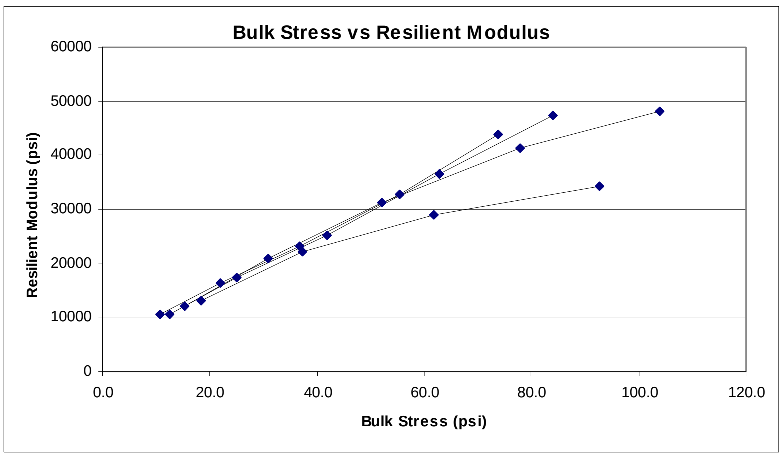


Figure 95. ***Bulk stress vs. Resilient Modulus*** in ***N-10, MO Base*** - ***Rep 2***

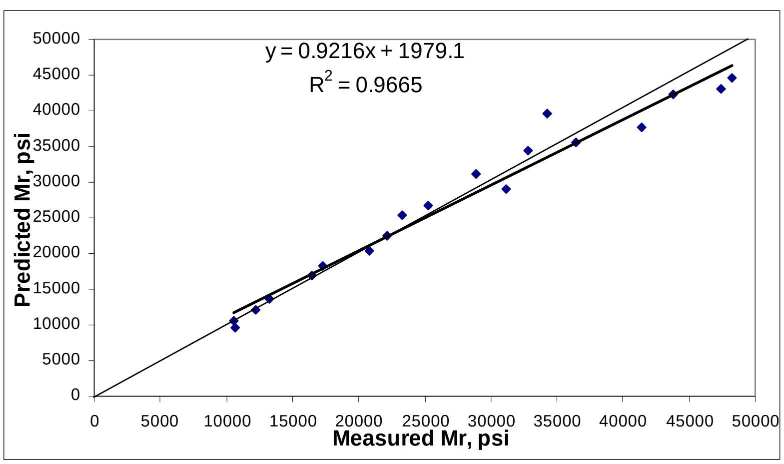


Figure 96. ***Predicted vs Measured Resilient Modulus*** in ***N-10, MO Base*** - ***Rep 2***

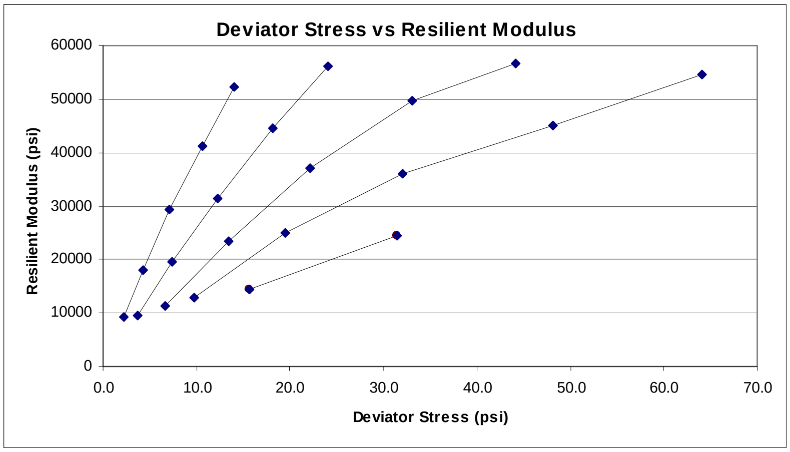


Figure 97. ***Resilient Modulus vs. Deviator Stress*** in ***N-10, MO Base*** - ***Rep 5***

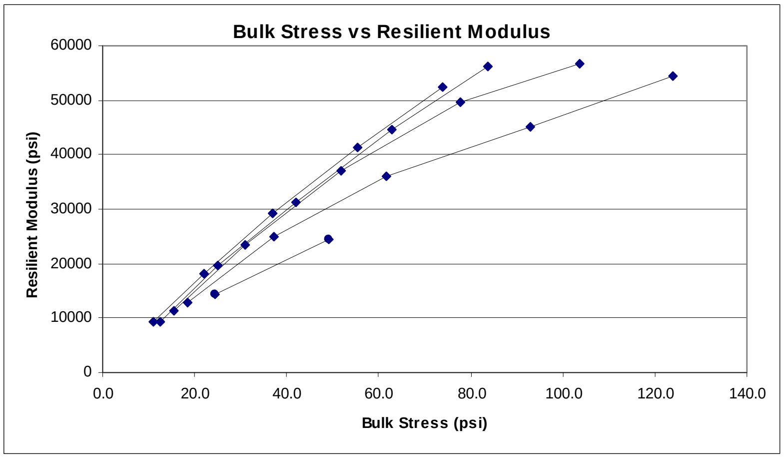


Figure 98. ***Bulk stress vs. Resilient Modulus*** in ***N-10, MO Base*** - ***Rep 5***

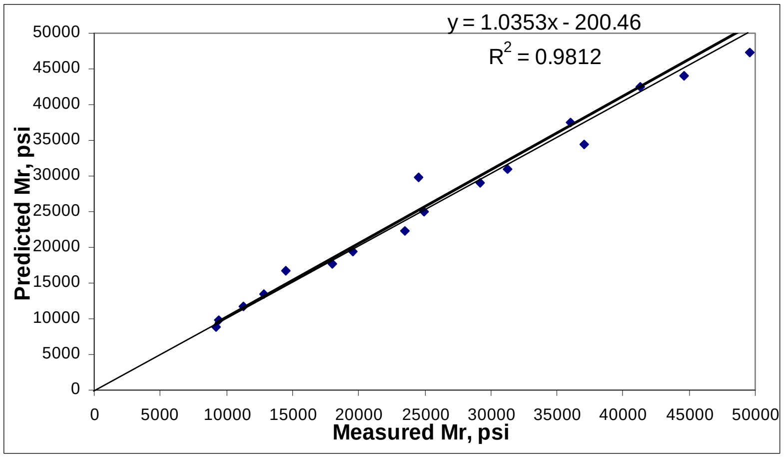


Figure 99. ***Predicted vs Measured Resilient Modulus*** in ***N-10, MO Base*** - ***Rep 5***

NCAT TEST SECTIONS, S-11 BASE TESTING

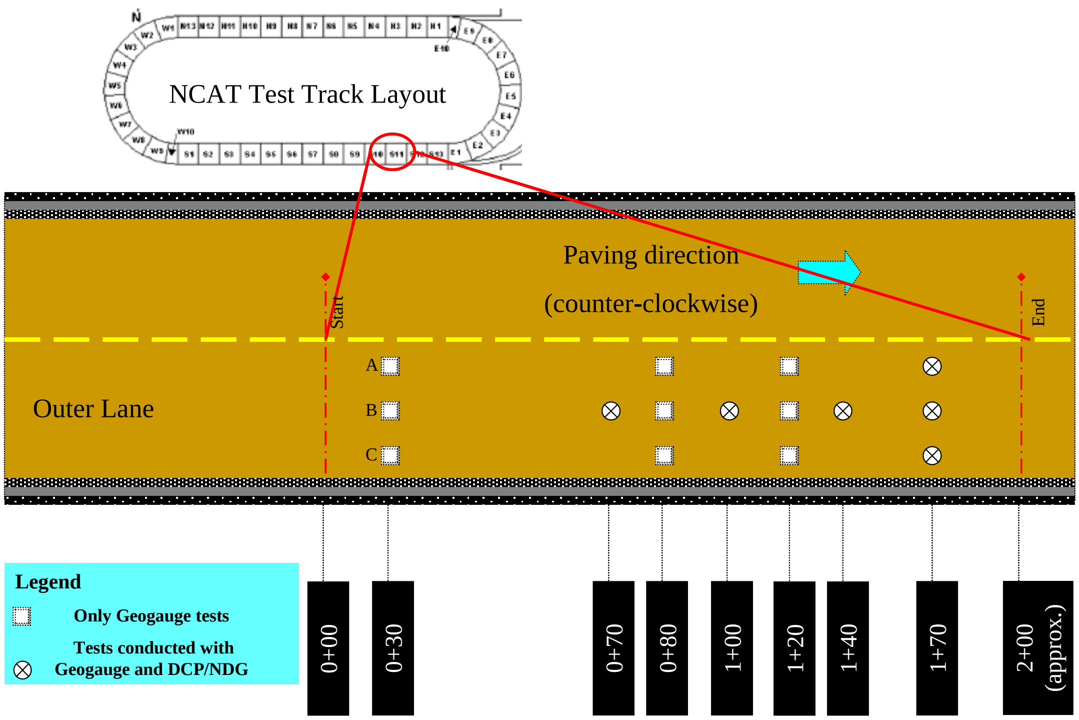


Table 224. ***Modulus*** measured by ***Geogauge B24C*** in ***S-11, AL Base, ksi***

Station	Point	Modulus	Average	Std Dev
0+30	A	15.23		
0+30	A	13.46		
0+30	A	15.35	14.68	1.06
0+30	B	14.89		
0+30	B	15.08		
0+30	B	12.45	14.14	1.47
0+30	C	11.31		
0+30	C	13.75		
0+30	C	11.43	12.16	1.38
0+70	B	20.66		
0+70	B	17.24		
0+70	B	19.69	19.2	1.76
0+80	A	14.07		
0+80	A	14.2		
0+80	A	15.79	14.69	0.96
0+80	B	21.54		
0+80	B	19.78		
0+80	B	17.36	19.56	2.1
0+80	C	13.13		
0+80	C	13.49		
0+80	C	13.22	13.28	0.19
1+00	B	16		
1+00	B	14.24		
1+00	B	16.3	15.51	1.11
1+20	A	11.09		
1+20	A	13.26		
1+20	A	14.87	13.07	1.9
1+20	B	16.64		
1+20	B	16.19		
1+20	B	17.2	16.68	0.51
1+20	C	14.06		
1+20	C	13.35		
1+20	C	13.13	13.51	0.49
1+40	B	13.17		
1+40	B	14.35		
1+40	B	14.25	13.92	0.65
1+70	A	12.5		
1+70	A	17.82		
1+70	A	15.66	15.33	2.68

Table 224. ***Modulus*** measured by ***Geogauge B24C*** in ***S-11, AL Base, ksi*** Continued

Station	Point	Modulus	Average	Std

				Dev
1+70	B	16.27		
1+70	B	13.3		
1+70	B	17.05	15.54	1.98
1+70	C	15.78		
1+70	C	15.19		
1+70	C	14.39	15.12	0.7

Table 225. ***Modulus*** measured by ***DSPA*** in ***S-11, AL Base, ksi***

Station	Point	Average
0+30	A	110
0+30	B	80
0+30	C	110
0+70	B	61
0+80	A	113
0+80	B	52
0+80	C	105
1+00	A	47
1+00	A	49
1+00	A	52
1+00	A	54
1+00	A	56
1+00	A	57
1+00	A	60
1+00	A	62
1+00	A	64
1+00	B	66
1+20	A	106
1+20	B	74
1+20	C	109
1+40	B	80
1+70	A	98
1+70	B	110
1+70	C	99

Table 226. Summary of ***Resilient Modulus Test Results*** in ***S-11, AL Base***

Sequence	σ_1 psi	σ_2 psi	σ_3 psi	θ psi	τ_{oct} psi	$\sigma_1 - \sigma_3$ psi	M_R psi	Pred. M_R psi
Repetition 1								
1	5.1	2.9	2.9	10.9	1.0	2.2	8702	7682
2	10.2	5.9	5.9	22.0	2.0	4.3	12426	12965
3	17.1	9.9	9.9	36.9	3.4	7.2	17528	18838
4	25.4	14.8	14.8	55.0	5.0	10.6	24280	24922
5	33.9	19.8	19.8	73.5	6.6	14.1	31204	30340
6	6.6	2.9	2.9	12.4	1.7	3.7	8624	8360
7	13.0	5.9	5.9	24.8	3.3	7.1	13017	13854
8	22.0	9.8	9.8	41.6	5.8	12.2	19200	19806
9	33.0	14.9	14.9	62.8	8.5	18.1	26423	26069
10	44.0	19.8	19.8	83.6	11.4	24.2	33617	31243
11	9.5	2.9	2.9	15.3	3.1	6.6	9494	9569
12	19.3	5.9	5.9	31.1	6.3	13.4	15521	15654
13	32.0	9.9	9.9	51.8	10.4	22.1	22812	21847
14	48.2	14.8	14.8	77.8	15.7	33.4	29806	27999
15	64.2	19.9	19.9	104.0	20.9	44.3	35031	33204
16	11.9	2.9	2.9	17.7	4.2	9.0	10364	10485
17	25.9	5.9	5.9	37.7	9.4	20.0	17675	17317
18	42.0	9.9	9.9	61.8	15.1	32.1	23912	23587
19	63.0	14.9	14.9	92.8	22.7	48.1	28664	29876
20	83.9	19.8	19.8	123.5	30.2	64.1	33937	34965
21	18.6	2.9	2.9	24.4	7.4	15.7	12081	12742
22	37.3	5.8	5.8	48.9	14.8	31.5	18260	19735
23	10.0	10.0	10.0	30.0	0.0	0.0		
24	15.0	15.0	15.0	45.0	0.0	0.0		
25	20.0	20.0	20.0	60.0	0.0	0.0		
26	3.0	3.0	3.0	9.0	0.0	0.0		
27	6.0	6.0	6.0	18.0	0.0	0.0		
28	10.0	10.0	10.0	30.0	0.0	0.0		
29	15.0	15.0	15.0	45.0	0.0	0.0		
Std	15.0	5.0	5.0	25.0	4.7	10.0		
Repetition 2								
1	5.1	2.9	2.9	10.9	1.0	2.2	9784	8737
2	10.2	5.9	5.9	22.0	2.0	4.3	14777	15527
3	17.0	9.9	9.9	36.8	3.3	7.1	21716	23310
4	25.5	14.8	14.8	55.1	5.0	10.7	30734	31604
5	34.0	19.8	19.8	73.6	6.7	14.2	39618	39020
6	6.6	2.9	2.9	12.4	1.7	3.7	9964	9559
7	13.3	5.9	5.9	25.1	3.5	7.4	15657	16711

Sequence	σ_1 psi	σ_2 psi	σ_3 psi	θ psi	τ_{oct} psi	$\sigma_1 - \sigma_3$ psi	M_R psi	Pred. M_R psi
8	22.0	9.9	9.9	41.8	5.7	12.1	23494	24533
9	32.9	14.8	14.8	62.5	8.5	18.1	33335	32597
10	43.9	19.8	19.8	83.5	11.4	24.1	42422	39594
11	9.7	2.9	2.9	15.5	3.2	6.8	11149	11122
12	19.3	5.9	5.9	31.1	6.3	13.4	18548	18758
13	32.0	9.8	9.8	51.6	10.5	22.2	27997	26611
14	47.9	14.8	14.8	77.5	15.6	33.1	37301	34561
15	63.9	19.8	19.8	103.5	20.8	44.1	43502	41114
16	12.6	2.9	2.9	18.4	4.6	9.7	12391	12446
17	25.3	5.8	5.8	36.9	9.2	19.5	20683	20443
18	41.9	9.8	9.8	61.5	15.1	32.1	29387	28540
19	62.9	14.8	14.8	92.5	22.7	48.1	36312	36417
20	84.0	19.8	19.8	123.6	30.3	64.2	42790	42791
21	18.6	2.9	2.9	24.4	7.4	15.7	14090	14864
22	37.2	5.9	5.9	49.0	14.8	31.3	22496	23616
23	59.9	9.8	9.8	79.5	23.6	50.1	28277	31593
24	14.8	14.8	14.8	44.4	0.0	0.0		
25	20.0	20.0	20.0	60.0	0.0	0.0		
26	3.0	3.0	3.0	9.0	0.0	0.0		
27	6.0	6.0	6.0	18.0	0.0	0.0		
28	10.0	10.0	10.0	30.0	0.0	0.0		
29	15.0	15.0	15.0	45.0	0.0	0.0		
Std	15.0	5.0	5.0	25.0	4.7	10.0		
Repetition 3								
1	5.1	2.9	2.9	10.9	1.0	2.2	10439	8742
2	10.2	5.9	5.9	22.0	2.0	4.3	14079	14270
3	17.1	9.9	9.9	36.9	3.4	7.2	19173	20207
4	25.4	14.8	14.8	55.0	5.0	10.6	25553	26182
5	34.0	19.8	19.8	73.6	6.7	14.2	32463	31379
6	6.6	2.9	2.9	12.4	1.7	3.7	9695	9444
7	13.3	5.9	5.9	25.1	3.5	7.4	14055	15213
8	22.0	9.9	9.9	41.8	5.7	12.1	20143	21129
9	33.1	14.9	14.9	62.9	8.6	18.2	27392	27071
10	43.9	19.8	19.8	83.5	11.4	24.1	34347	31879
11	9.6	2.9	2.9	15.4	3.2	6.7	10394	10718
12	19.3	5.9	5.9	31.1	6.3	13.4	16275	16825
13	32.2	9.9	9.9	52.0	10.5	22.3	23752	22836
14	47.9	14.8	14.8	77.5	15.6	33.1	30276	28472
15	63.9	19.8	19.8	103.5	20.8	44.1	34558	33092
16	12.6	2.9	2.9	18.4	4.6	9.7	11463	11852
17	25.4	5.9	5.9	37.2	9.2	19.5	18157	18250
18	42.0	9.9	9.9	61.8	15.1	32.1	24591	24274

Sequence	σ_1 psi	σ_2 psi	σ_3 psi	θ psi	τ_{oct} psi	$\sigma_1 - \sigma_3$ psi	M_R psi	Pred. M_R psi
19	62.9	14.9	14.9	92.7	22.6	48.0	29113	29937
20	83.9	19.8	19.8	123.5	30.2	64.1	33772	34370
21	18.6	2.9	2.9	24.4	7.4	15.7	12926	13817
22	37.5	5.9	5.9	49.3	14.9	31.6	19645	20639
23	9.8	9.8	9.8	29.4	0.0	0.0		
24	15.0	15.0	15.0	45.0	0.0	0.0		
25	20.0	20.0	20.0	60.0	0.0	0.0		
26	3.0	3.0	3.0	9.0	0.0	0.0		
27	6.0	6.0	6.0	18.0	0.0	0.0		
28	10.0	10.0	10.0	30.0	0.0	0.0		
29	15.0	15.0	15.0	45.0	0.0	0.0		
Std	15.0	5.0	5.0	25.0	4.7	10.0		

Calculated Mr coefficients for

	Rep 1	Rep 2	Rep 3
K_1	674.9	794.1	759.9
K_2	0.776	0.860	0.732
K_3	-0.350	-0.476	-0.388

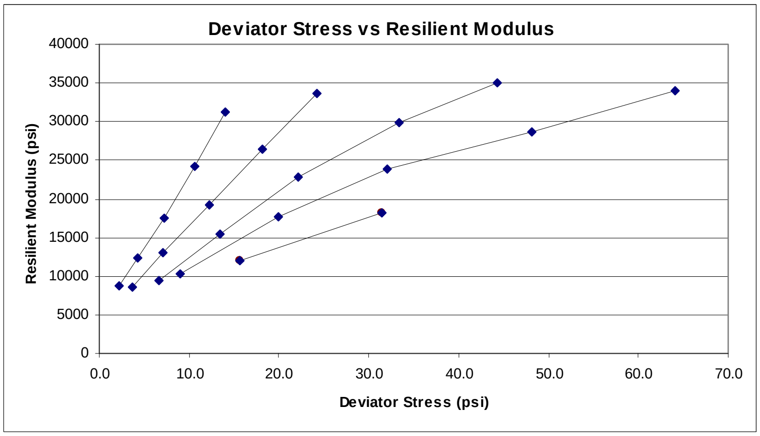


Figure 100. ***Resilient Modulus vs. Deviator Stress*** in ***S-11, AL Base - Rep 1***

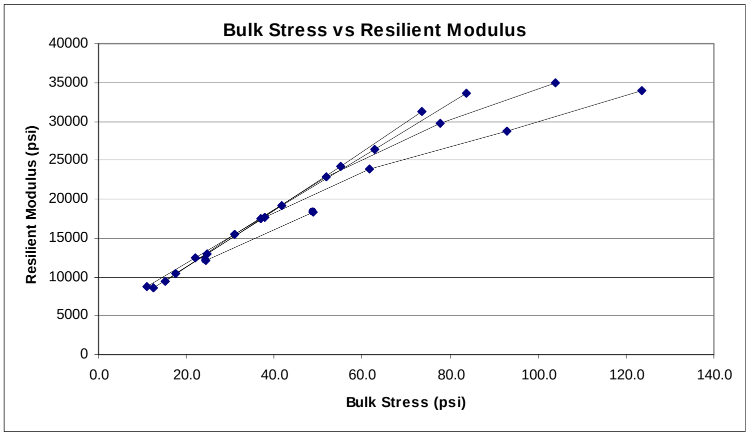


Figure 101. ***Bulk stress vs. Resilient Modulus*** in ***S-11, AL Base - Rep 1***

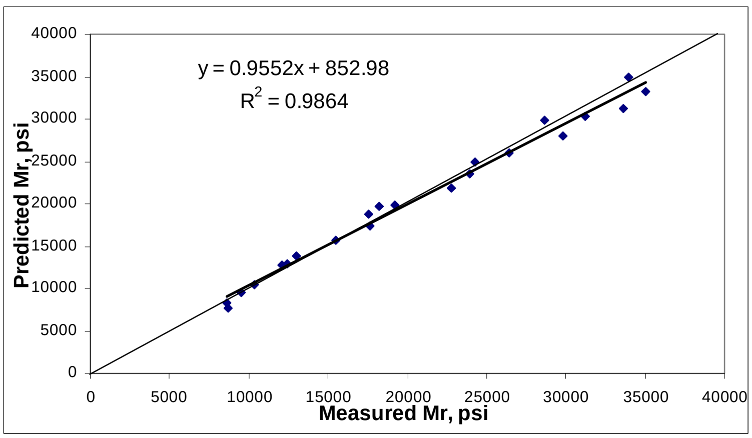


Figure 102. ***Predicted vs Measured Resilient Modulus*** in ***S-11, AL Base - Rep 1***

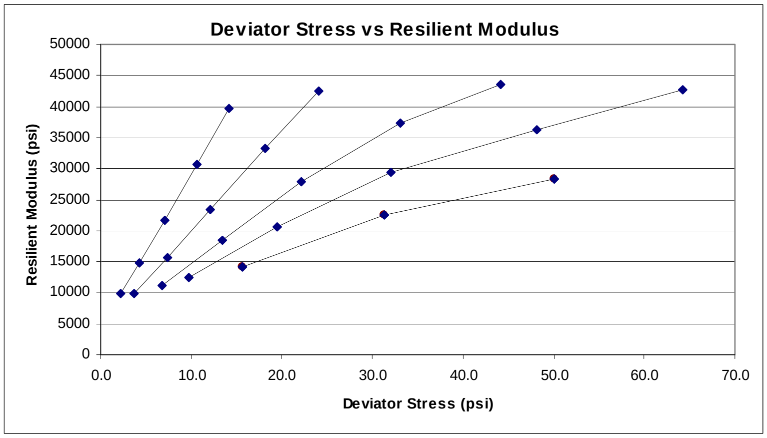


Figure 103. ***Resilient Modulus vs. Deviator Stress*** in ***S-11, AL Base - Rep 2***

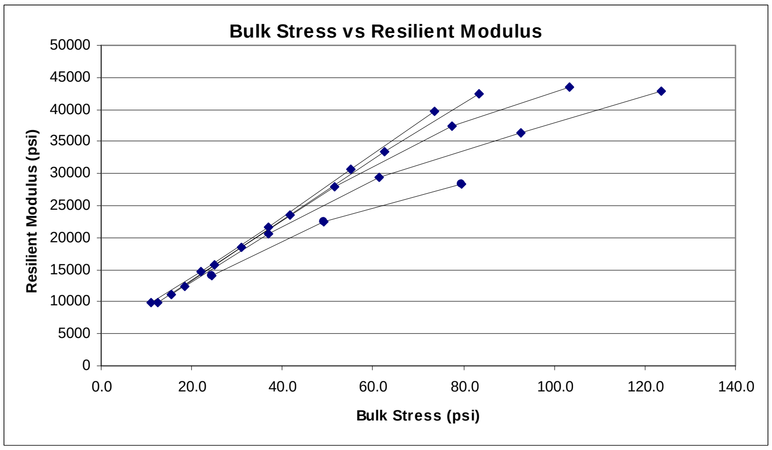


Figure 104. ***Bulk stress vs. Resilient Modulus*** in ***S-11, AL Base - Rep 2***

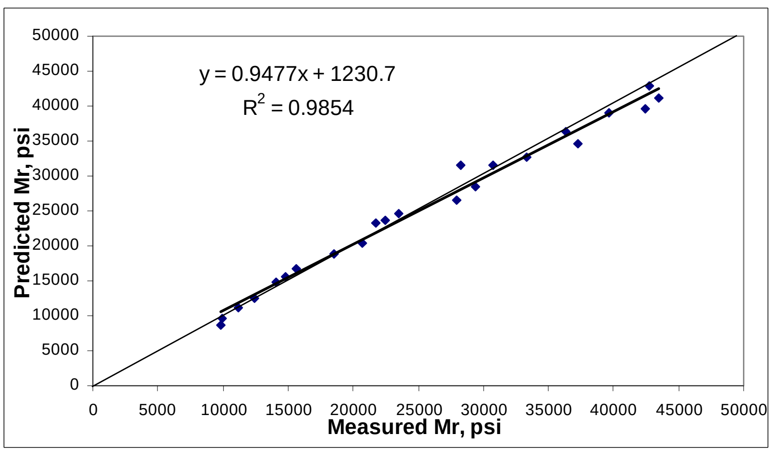


Figure 105. ***Predicted vs Measured Resilient Modulus*** in ***S-11, AL Base - Rep 2***

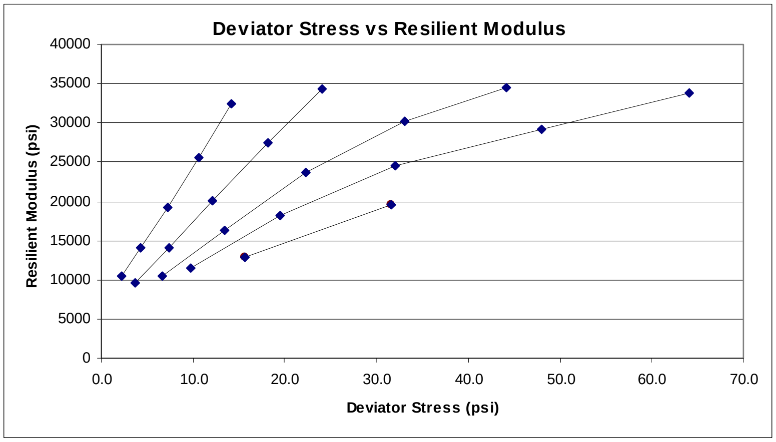


Figure 106. ***Resilient Modulus vs. Deviator Stress*** in ***S-11, AL Base*** - ***Rep 3***

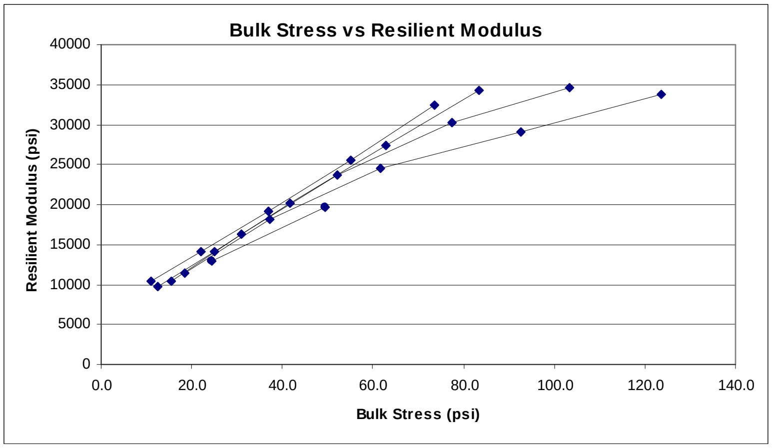


Figure 107. ***Bulk stress vs. Resilient Modulus*** in ***S-11, AL Base*** - ***Rep 3***

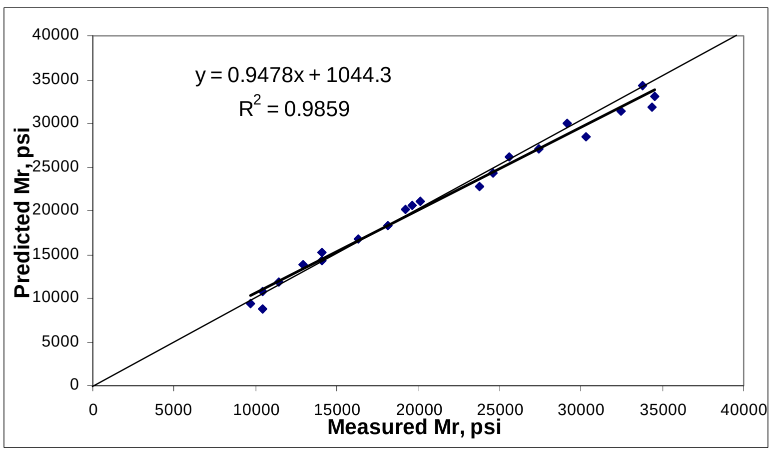


Figure 108. ***Predicted vs Measured Resilient Modulus*** in ***S-11, AL Base*** - ***Rep 3***

SR-53, OH - BASE TESTING

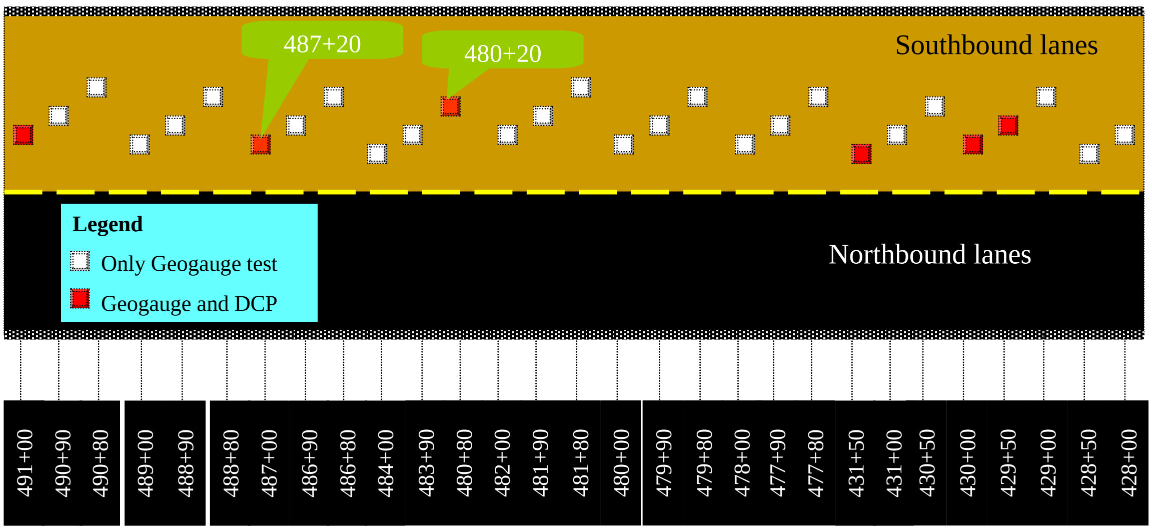


Table 227. ***Modulus*** measured by ***Geogauge B25C*** in ***SR-53, OH Base, ksi***

Station	Trial	Modulus	Average	Std Dev
428+00	1	22.7		
428+00	2	26.38		
428+00	3	22.2	23.76	2.28
428+50	1	21.62		
428+50	2	23.77		
428+50	3	21.55	22.31	1.26
429+00	1	22.31		
429+00	2	26.24		
429+00	3	23.46	24	2.02
429+50	1	22.47		
429+50	2	21.57		
429+50	3	24.89		
429+50	4	22.58	22.88	1.42
430+00	1	26.28		
430+00	2	16.35		
430+00	3	20.91		
430+00	4	19.78	20.83	4.12
430+50	1	17.72		
430+50	2	25.27		
430+50	3	23.59		
430+50	4	25.04	22.91	3.54
431+00	1	27.3		
431+00	2	23.02		
431+00	3	27.24		
431+00	4	25.05	25.65	2.04
431+50	1	28.19		
431+50	2	28.93		
431+50	3	23.43	26.85	2.98
477+80	1	24.01		
477+80	2	28.59		
477+80	3	22.14	24.91	3.32
477+90	1	29.42		
477+90	2	17.95		
477+90	3	25.4		
477+90	4	18.78	22.89	5.48
478+00	1	22.44		
478+00	2	18.68		
478+00	3	24.47	21.86	2.94
479+80	1	23.87		

Table 227. ***Modulus*** measured by ***Geogauge B25C*** in ***SR-53, OH Base, ksi***
Continued

Station	Trial	Modulus	Average	Std

				Dev
479+80	2	20.51		
479+80	3	23.75	22.71	1.91
479+90	1	26.91		
479+90	2	27		
479+90	3	23.77		
479+90	4	25.82	25.88	1.5
480+00	1	23.97		
480+00	2	23.89		
480+00	3	26.45	24.77	1.46
481+80	1	21.4		
481+80	2	22.2		
481+80	3	23.08	22.23	0.84
481+90	1	23.36		
481+90	2	20.01		
481+90	3	20.78	21.38	1.75
482+00	1	20.49		
482+00	2	16.62		
482+00	3	19.33	18.81	1.99
483+80	1	28.67		
483+80	2	23.33		
483+80	3	20.41		
483+80	4	26.97	24.85	3.7
483+90	1	20.26		
483+90	2	21.19		
483+90	3	23.17		
483+90	4	19.26	20.97	1.66
484+00	1	21.21		
484+00	2	25.64		
484+00	3	23.47	23.44	2.22
486+80	1	28.61		
486+80	2	26.73		
486+80	3	27.35	27.56	0.96
486+90	1	24.56		
486+90	2	28.99		
486+90	3	25.51	26.35	2.33
487+00	1	22.66		
487+00	2	22.3		
487+00	3	20.99	21.98	0.88
488+80	1	26.22		

Table 227. ***Modulus*** measured by ***Geogauge B25C*** in ***SR-53, OH Base, ksi***
Continued

Station	Trial	Modulus	Average	Std Dev
488+80	2	23.75		
488+80	3	24.78	24.92	1.24

488+90	1	26.75		
488+90	2	23.21		
488+90	3	27.66	25.87	2.35
489+00	1	21.11		
489+00	2	23.82		
489+00	3	22.96	22.63	1.38
490+80	1	21.7		
490+80	2	18.15		
490+80	3	23.12	20.99	2.56
490+90	1	16.1		
490+90	2	17.29		
490+90	3	14.26	15.88	1.53
491+00	1	16.26		
491+00	2	13.28		
491+00	3	17.91		
491+00	4	14.95	15.6	1.96

Table 228. ***Modulus*** measured by ***Geogauge B24C*** in ***SR-53, OH Base, ksi***

Station	Trial	Modulus	Average	Std Dev
428+00	1	28.9		
428+00	2	26.41		
428+00	3	26.24	27.18	1.49
428+50	1	24.65		
428+50	2	24.6		
428+50	3	23.26	24.17	0.79
429+00	1	26.9		
429+00	2	28.05		
429+00	3	26.36	27.1	0.86
429+50	1	23.03		
429+50	2	22.69		
429+50	3	19.09	21.6	2.18
430+00	1	24.61		
430+00	2	22.24		
430+00	3	20.78	22.54	1.93
430+50	1	23.37		
430+50	2	23.68		
430+50	3	21.6	22.88	1.12
431+00	1	25.12		
431+00	2	24.16		
431+00	3	23.48	24.25	0.82
431+50	1	28.66		
431+50	2	23.12		
431+50	3	24.26	25.35	2.93
477+80	1	26.67		
477+80	2	22.91		
477+80	3	26.66	25.41	2.17
477+90	1	24.5		
477+90	2	26.75		
477+90	3	27.29	26.18	1.48
478+00	1	25.04		
478+00	2	24.72		
478+00	3	23.35	24.37	0.9
479+90	1	23.1		
479+90	2	22.56		
479+90	3	24.49	23.38	1.03
480+00	1	29.91		
480+00	2	33.2		
480+00	3	24.22	29.11	4.54

Table 228. ***Modulus*** measured by ***Geogauge B24C*** in ***SR-53, OH Base, ksi***
Continued

Station	Trial	Modulus	Average	Std Dev
481+80	1	22.55		
481+80	2	20.78		
481+80	3	18.65	20.66	1.95
481+90	1	19.14		
481+90	2	22.5		
481+90	3	22.46	21.37	1.93
482+00	1	19.93		
482+00	2	17.5		
482+00	3	20.94	19.46	1.77
483+80	1	28.09		
483+80	2	25.34		
483+80	3	28.61	27.35	1.76
483+90	1	23.6		
483+90	2	20.44		
483+90	3	23.61	22.55	1.83
484+00	1	23.21		
484+00	2	19.12		
484+00	3	21.37	21.23	2.05
486+80	1	25.82		
486+80	2	24.19		
486+80	3	22.96	24.32	1.43
486+90	1	29.83		
486+90	2	29.38		
486+90	3	28.39	29.2	0.74
487+00	1	20.58		
487+00	2	21.36		
487+00	3	23.59	21.84	1.56
488+80	1	26.77		
488+80	2	23.04		
488+80	3	25.46	25.09	1.89
488+90	1	23.09		
488+90	2	28.32		
488+90	3	26.91	26.11	2.71
489+00	1	20.56		
489+00	2	25.57		
489+00	3	21.24	22.46	2.72
490+80	1	21.43		
490+80	2	20.15		
490+80	3	20.71	20.76	0.64

Table 228. ***Modulus*** measured by ***Geogauge B24C*** in ***SR-53, OH Base, ksi***
Continued

Station	Trial	Modulus	Average	Std Dev
490+90	1	15.25		
490+90	2	15.97		
490+90	3	14.43	15.22	0.77
491+00	1	15.92		
491+00	2	16.98		
491+00	3	16.15	16.35	0.56

Table 229. ***Penetration Index*** measured by ***DCP*** in ***SR-53, OH Base, mm/blow***

Station	# of Blows	mm/blow	Average
429+50	2	13.5	
429+50	4	12.25	
429+50	6	10.17	
429+50	8	10.13	
429+50	10	9.4	
429+50	12	9.25	
429+50	14	8.79	
429+50	16	8.25	
429+50	18	7.94	9.96
430+00	2	4	
430+00	4	5.75	
430+00	6	5	
430+00	8	5	
430+00	10	5	
430+00	12	4.75	
430+00	14	4.43	
430+00	16	4.31	
430+00	18	4.17	
430+00	20	4.15	
430+00	22	4.18	
430+00	24	4.08	
430+00	26	4.08	
430+00	28	4	
430+00	30	4.1	
430+00	32	4.22	
430+00	34	4.53	4.46
431+50	2	9	
431+50	4	8	
431+50	6	7.17	
431+50	8	6.5	
431+50	10	6	
431+50	12	5.42	
431+50	14	5.14	
431+50	16	4.81	
431+50	18	4.56	
431+50	20	4.4	
431+50	22	4.23	
431+50	24	4.08	
431+50	26	4.04	

Table 229. ***Penetration Index*** measured by ***DCP*** in ***SR-53, OH Base, mm/blow***
Continued

Station	# of Blows	mm/blow	Average
431+50	28	3.93	
431+50	30	3.9	
431+50	32	3.88	
431+50	34	3.91	
431+50	36	3.92	
431+50	38	3.95	5.1
480+20	2	5.5	
480+20	4	6	
480+20	6	6	
480+20	8	6	
480+20	10	5.7	
480+20	12	5.67	
480+20	14	5.71	
480+20	16	6.13	
480+20	18	6.11	
480+20	20	5.95	
480+20	22	5.73	
480+20	24	5.58	5.84
487+20	2	10.5	
487+20	4	7.5	
487+20	6	6.17	
487+20	8	5.63	
487+20	10	5.1	
487+20	12	4.83	
487+20	14	4.64	
487+20	16	4.56	
487+20	18	4.56	
487+20	20	4.4	
487+20	22	4.27	
487+20	24	4.13	
487+20	26	4.08	
487+20	28	3.96	
487+20	30	3.97	
487+20	32	3.91	
487+20	34	3.82	
487+20	36	3.78	
487+20	38	3.71	
487+20	40	3.7	4.86

Table 229. ***Penetration Index*** measured by ***DCP*** in ***SR-53, OH Base, mm/blow***
Continued

Station	# of Blows	mm/blow	Average
491+00	5	6.4	
491+00	10	5.9	
491+00	15	6.47	
491+00	20	6.9	
491+00	25	7.08	6.55

Table 230. ***Modulus*** measured by ***DSPA*** in ***SR-53, OH Base, ksi***

Station	Trial	Average
428+00	3	65
428+50	3	58
429+00	3	76
429+50	4	23
430+00	4	44
430+50	4	38
431+00	4	58
431+50	3	69
477+80	3	75
477+90	4	77
478+00	3	54
479+80	3	43
479+90	3	72
480+00	3	80
481+80	3	55
481+90	3	53
482+00	3	40
483+80	4	61
483+90	4	52
484+00	3	53
486+80	3	78
486+90	3	84
487+00	3	61
488+80	3	72
488+90	3	93
489+00	3	51
490+80	3	55
490+90	3	56
491+00	3	79

Table 231. Summary of ***Resilient Modulus Test Results*** in ***SR-53, OH Base***

Sequence	σ_1 psi	σ_2 psi	σ_3 psi	θ psi	τ_{oct} psi	$\sigma_1 - \sigma_3$ psi	M_R psi	Pred. M_R psi
Repetition 1								
1	5.2	2.9	2.9	11.0	1.1	2.3	17877	14948
2	10.2	5.9	5.9	22.0	2.0	4.3	27070	27886
3	17.0	9.9	9.9	36.8	3.3	7.1	40655	43097
4	25.6	14.9	14.9	55.4	5.0	10.7	57713	59442
5	34.1	19.9	19.9	73.9	6.7	14.2	74996	73502
6	6.6	2.9	2.9	12.4	1.7	3.7	17743	16224
7	13.2	5.9	5.9	25.0	3.4	7.3	27538	29496
8	22.0	9.9	9.9	41.8	5.7	12.1	41984	44011
9	33.3	14.9	14.9	63.1	8.7	18.4	60112	58569
10	45.1	19.9	19.9	84.9	11.9	25.2	74969	70145
11	9.6	2.9	2.9	15.4	3.2	6.7	19228	18684
12	19.2	5.9	5.9	31.0	6.3	13.3	31265	32195
13	32.1	9.9	9.9	51.9	10.5	22.2	47246	45562
14	48.3	14.9	14.9	78.1	15.7	33.4	63049	57755
15	64.1	19.9	19.9	103.9	20.8	44.2	71966	66940
16	12.6	2.9	2.9	18.4	4.6	9.7	20259	20833
17	25.3	5.9	5.9	37.1	9.1	19.4	32776	34419
18	41.9	9.9	9.9	61.7	15.1	32.0	46939	46805
19	62.9	14.9	14.9	92.7	22.6	48.0	60425	57520
20	83.9	19.9	19.9	123.7	30.2	64.0	71344	65242
21	18.9	2.9	2.9	24.7	7.5	16.0	21783	24589
22	37.3	5.9	5.9	49.1	14.8	31.4	32627	37807
23	59.8	9.9	9.9	79.6	23.5	49.9	42308	48648
24	15.0	15.0	15.0	45.0	0.0	0.0		
25	20.0	20.0	20.0	60.0	0.0	0.0		
26	3.0	3.0	3.0	9.0	0.0	0.0		
27	6.0	6.0	6.0	18.0	0.0	0.0		
28	10.0	10.0	10.0	30.0	0.0	0.0		
29	15.0	15.0	15.0	45.0	0.0	0.0		
Repetition 2								
1	5.1	2.9	2.9	10.9	1.0	2.2	17660	15230
2	10.2	5.9	5.9	22.0	2.0	4.3	25151	26464
3	17.0	9.9	9.9	36.8	3.3	7.1	35966	39153
4	25.4	14.8	14.8	55.0	5.0	10.6	49578	52544
5	33.9	19.8	19.8	73.5	6.6	14.1	64311	64501
6	6.4	2.9	2.9	12.2	1.6	3.5	17545	16445
7	13.3	5.9	5.9	25.1	3.5	7.4	26733	28483

Sequence	σ_1 psi	σ_2 psi	σ_3 psi	θ psi	τ_{oct} psi	$\sigma_1 - \sigma_3$ psi	M_R psi	Pred. M_R psi
8	21.9	9.8	9.8	41.5	5.7	12.1	38428	41063
9	32.9	14.8	14.8	62.5	8.5	18.1	54113	54482
10	44.0	19.8	19.8	83.6	11.4	24.2	69071	65925
11	9.7	2.9	2.9	15.5	3.2	6.8	19534	19281
12	19.2	5.9	5.9	31.0	6.3	13.3	31039	31931
13	32.0	9.9	9.9	51.8	10.4	22.1	46801	45183
14	47.9	14.8	14.8	77.5	15.6	33.1	63769	58200
15	64.0	19.8	19.8	103.6	20.8	44.2	76229	69146
16	12.6	2.9	2.9	18.4	4.6	9.7	21916	21532
17	25.3	5.9	5.9	37.1	9.1	19.4	35664	35084
18	42.0	9.9	9.9	61.8	15.1	32.1	53167	48624
19	63.1	14.8	14.8	92.7	22.8	48.3	67374	61719
20	84.4	19.8	19.8	124.0	30.5	64.6	78646	72535
21	18.7	2.9	2.9	24.5	7.4	15.8	25157	25715
22	37.5	5.9	5.9	49.3	14.9	31.6	41823	40506
23	59.9	9.9	9.9	79.7	23.6	50.0	55902	54022
24	93.8	14.8	14.8	123.4	37.2	79.0	65553	68139
25	125.0	19.8	19.8	164.6	49.6	105.2	71447	79006
26	23.9	2.9	2.9	29.7	9.9	21.0	23895	28836
27	50.5	5.9	5.9	62.3	21.0	44.6	39315	45396
28	83.8	9.8	9.8	103.4	34.9	74.0		
29	15.0	15.0	15.0	45.0	0.0	0.0		
Std								
Repetition 3								
1	5.1	2.9	2.9	10.9	1.0	2.2	17646	14740
2	10.2	5.9	5.9	22.0	2.0	4.3	27340	28195
3	17.1	9.9	9.9	36.9	3.4	7.2	40995	44222
4	25.6	14.9	14.9	55.4	5.0	10.7	58229	61680
5	34.0	19.9	19.9	73.8	6.6	14.1	75080	76961
6	6.6	2.9	2.9	12.4	1.7	3.7	17872	16164
7	13.3	5.9	5.9	25.1	3.5	7.4	28375	30014
8	22.1	9.9	9.9	41.9	5.8	12.2	43295	45391
9	33.0	14.9	14.9	62.8	8.5	18.1	61523	61154
10	44.0	19.9	19.9	83.8	11.4	24.1	79688	74162
11	9.7	2.9	2.9	15.5	3.2	6.8	19868	18822
12	19.3	5.9	5.9	31.1	6.3	13.4	32879	32999
13	32.0	9.9	9.9	51.8	10.4	22.1	49538	47367
14	48.0	14.9	14.9	77.8	15.6	33.1	67006	60874
15	64.0	19.9	19.9	103.8	20.8	44.1	82410	71251
16	12.7	2.9	2.9	18.5	4.6	9.8	21585	21089
17	25.2	5.9	5.9	37.0	9.1	19.3	35420	35426
18	42.0	9.9	9.9	61.8	15.1	32.1	50563	49039

Sequence	σ_1 psi	σ_2 psi	σ_3 psi	θ psi	τ_{oct} psi	$\sigma_1 - \sigma_3$ psi	M_R psi	Pred. M_R psi
19	63.0	14.9	14.9	92.8	22.7	48.1	65429	61092
20	84.0	19.9	19.9	123.8	30.2	64.1	80570	70000
21	18.6	2.9	2.9	24.4	7.4	15.7	23301	24876
22	37.3	5.9	5.9	49.1	14.8	31.4	35308	39366
23	61.0	9.9	9.9	80.8	24.1	51.1	45649	51636
24	94.1	14.9	14.9	123.9	37.3	79.2	59485	62103
25	124.2	19.9	19.9	164.0	49.2	104.3	75213	69399
26	24.0	2.9	2.9	29.8	9.9	21.1	23261	27757
27	49.2	5.9	5.9	61.0	20.4	43.3	36285	42359
28	85.5	9.9	9.9	105.3	35.6	75.6	50112	54280
29	124.4	14.9	14.9	154.2	51.6	109.5	63660	63291
std								

Calculated Mr coefficients for

	Rep 1	Rep 2	Rep 3
K_1	1,429.4	1,363.5	1,427.7
K_2	0.970	0.823	0.995
K_3	-0.835	-0.418	-0.819

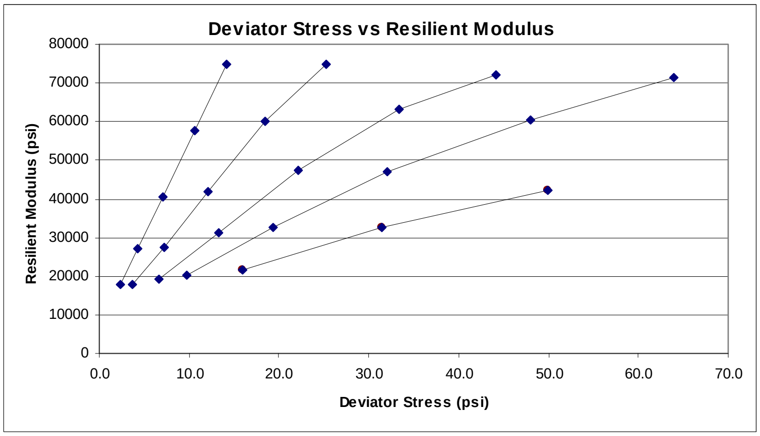


Figure 109. ***Resilient Modulus vs. Deviator Stress*** in ***SR-53, OH Base - Rep 1***

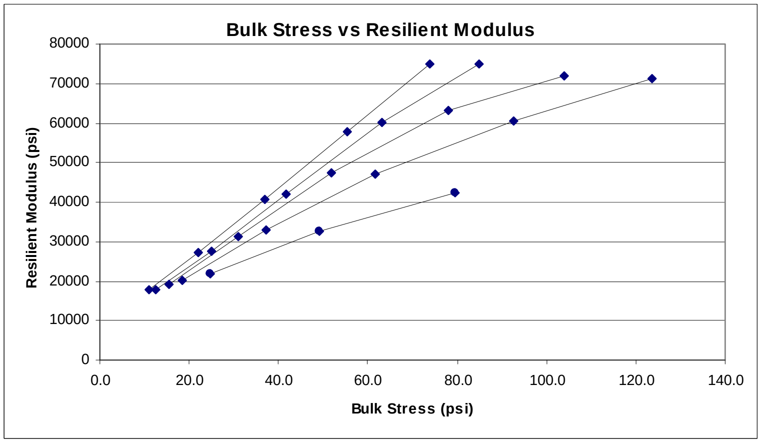


Figure 110. ***Bulk stress vs. Resilient Modulus*** in ***SR-53, OH Base - Rep 1***

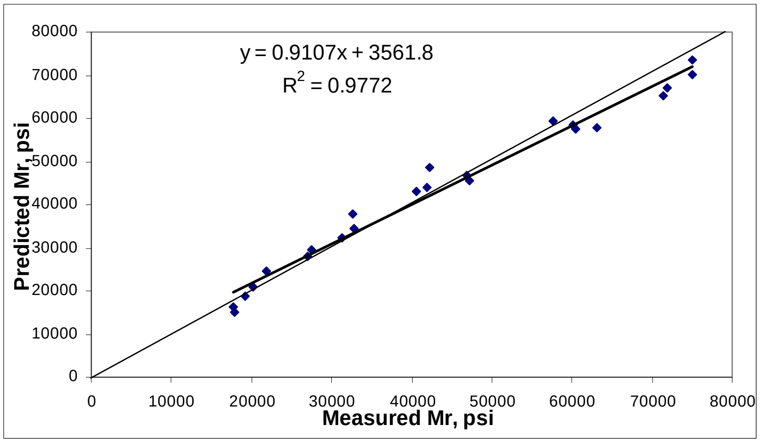


Figure 111. ***Predicted vs Measured Resilient Modulus*** in ***SR-53, OH Base - Rep 1***

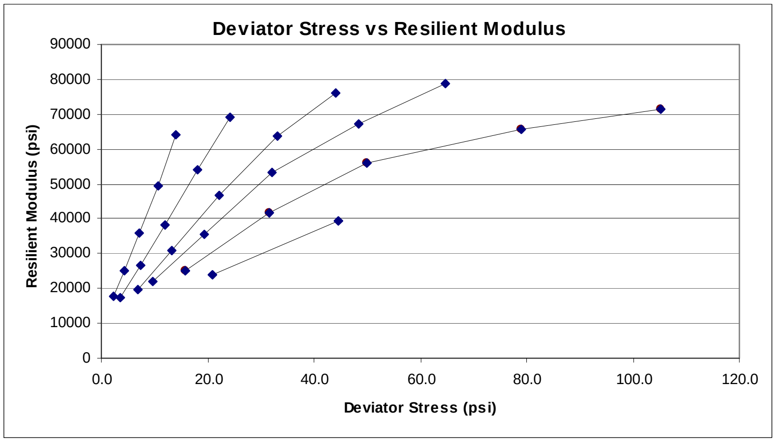


Figure 112. ***Resilient Modulus vs. Deviator Stress*** in ***SR-53, OH Base - Rep 2***

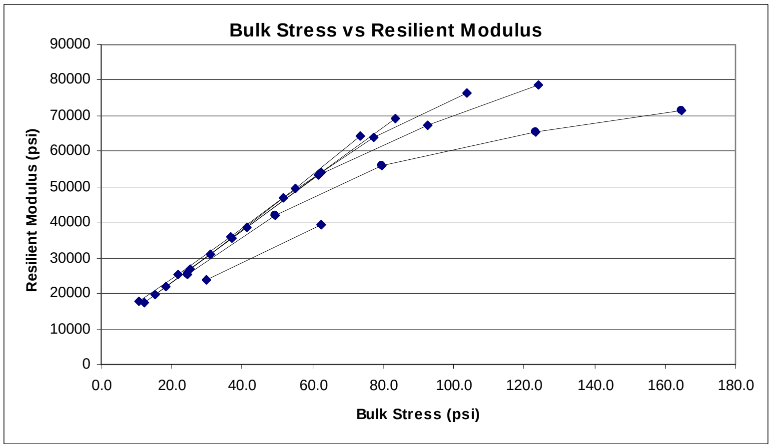


Figure 113. ***Bulk stress vs. Resilient Modulus*** in ***SR-53, OH Base - Rep 2***

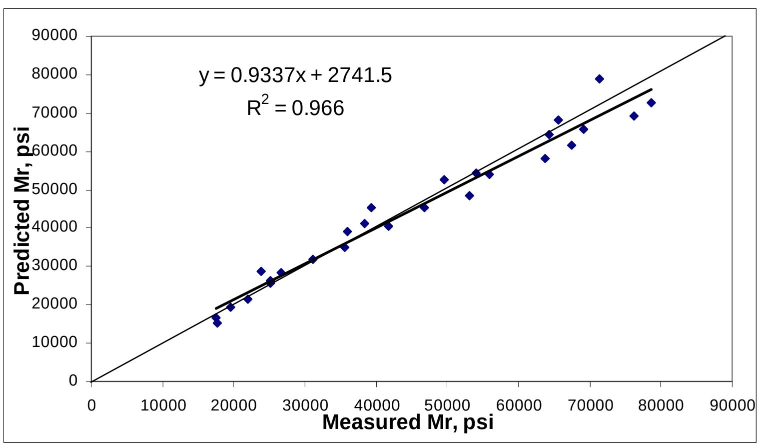


Figure 114. ***Predicted vs Measured Resilient Modulus*** in ***SR-53, OH Base - Rep 2***

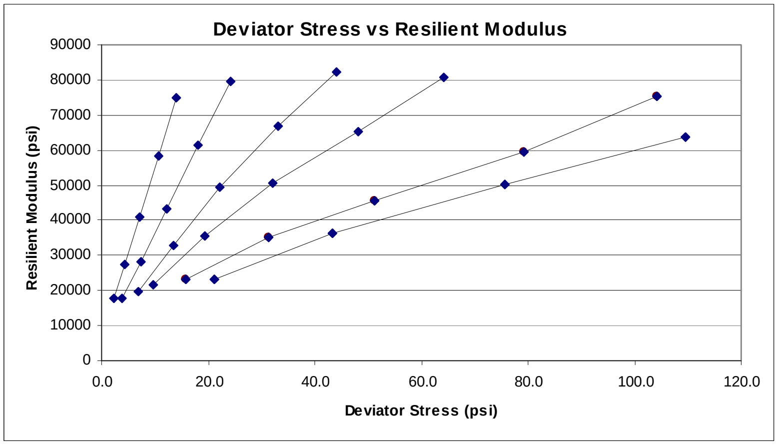


Figure 115. ***Resilient Modulus vs. Deviator Stress*** in ***SR-53, OH Base - Rep 3***

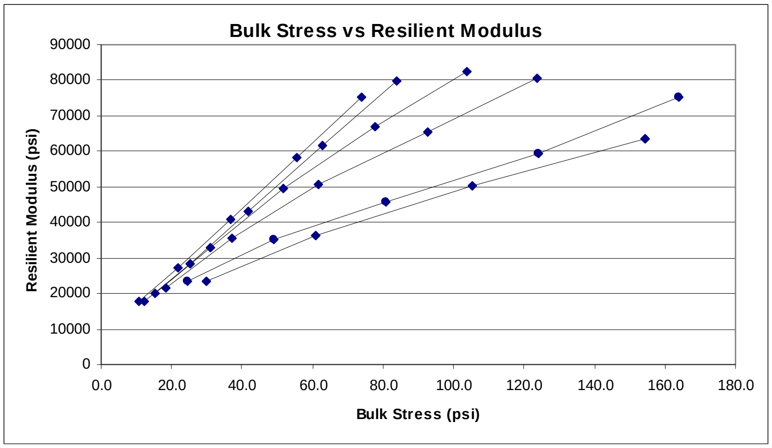


Figure 116. ***Bulk stress vs. Resilient Modulus*** in ***SR-53, OH Base - Rep 3***

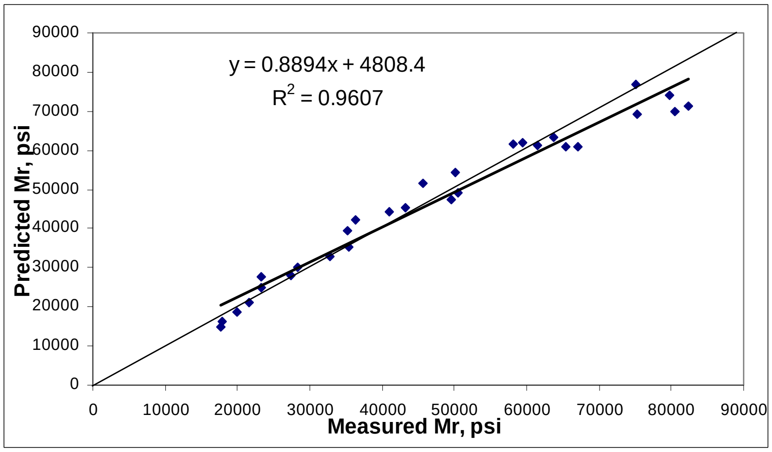
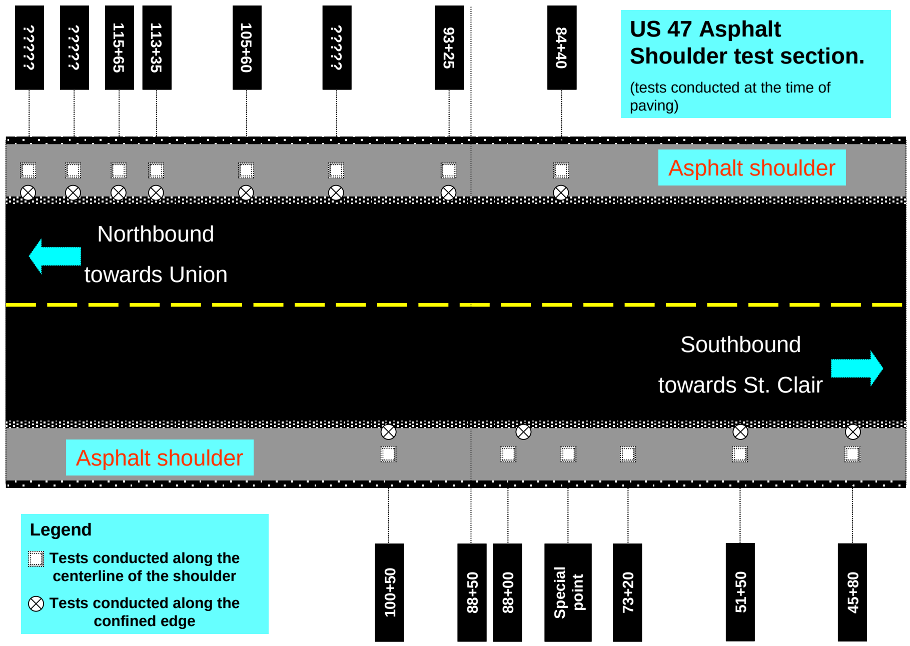


Figure 117. ***Predicted vs Measured Resilient Modulus*** in ***SR-53, OH Base - Rep 3***

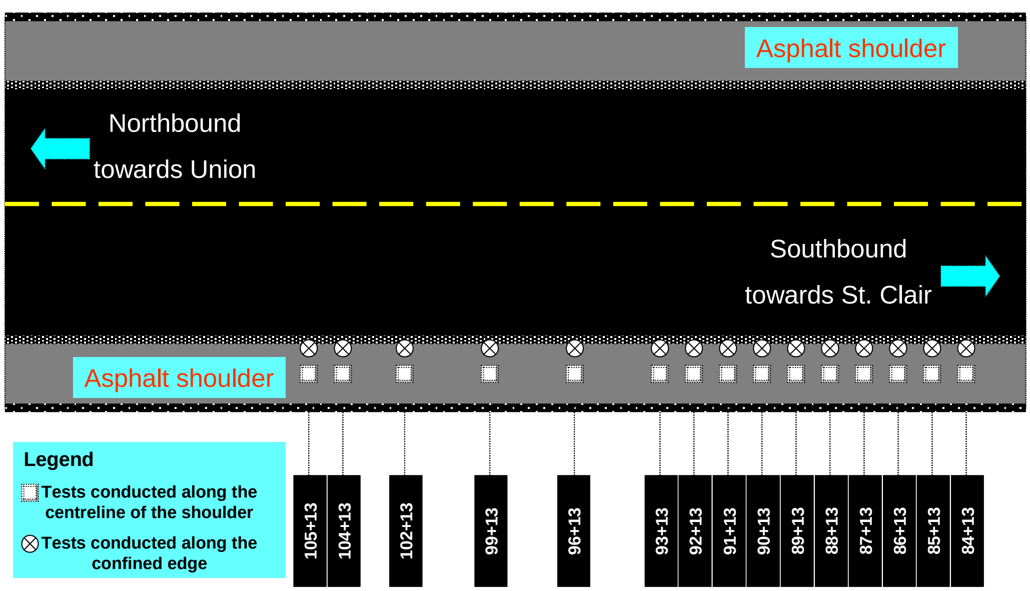
PART B TESTING

HMA MATERIAL TEST DATA

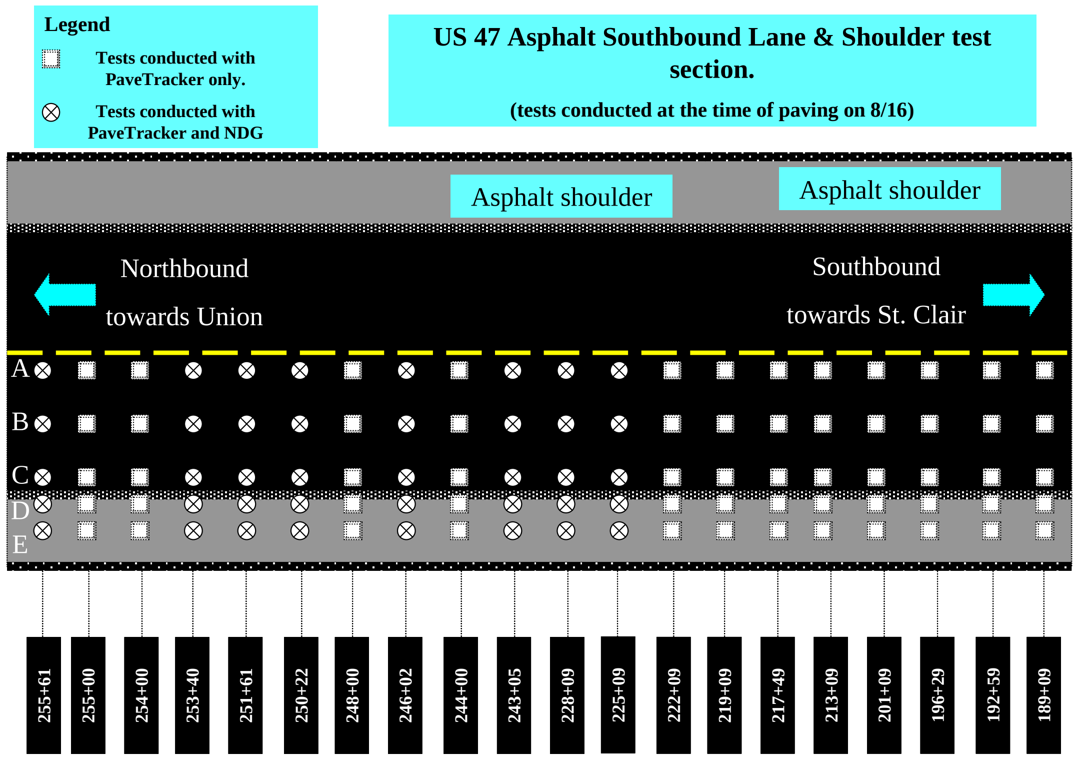
US-47, MISSOURI HMA SECTIONS



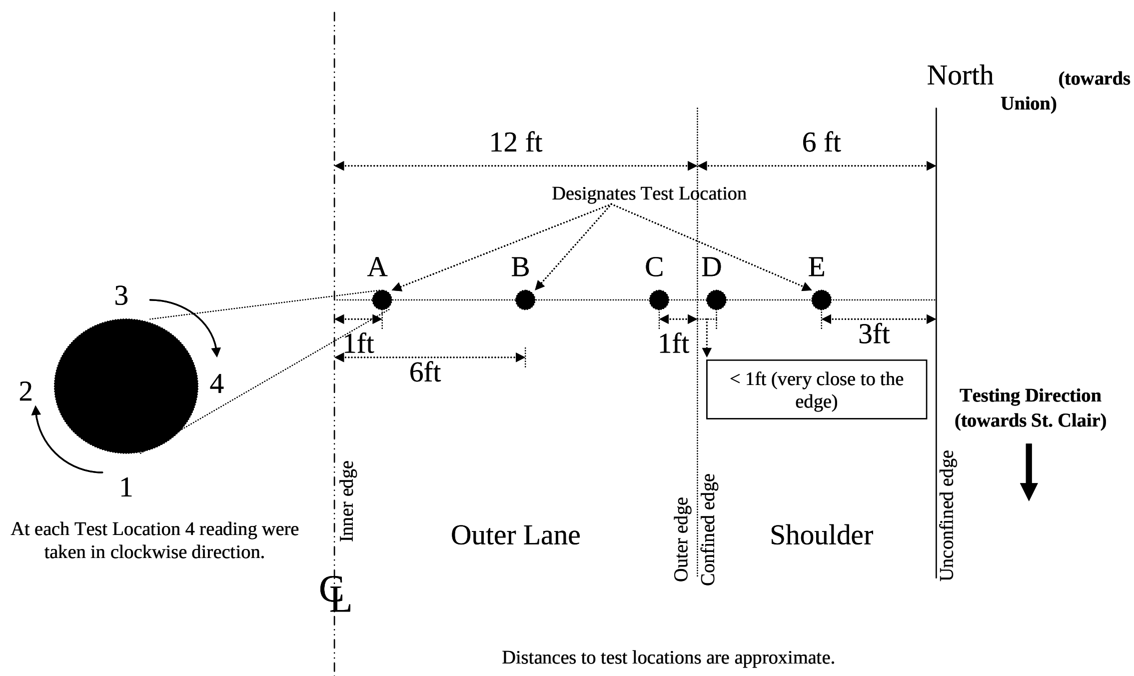
Layout of Test Points on the Shoulder



Layout of Points for Tests Conducted Three Days After Paving on the Shoulder Paved in the Southbound Direction

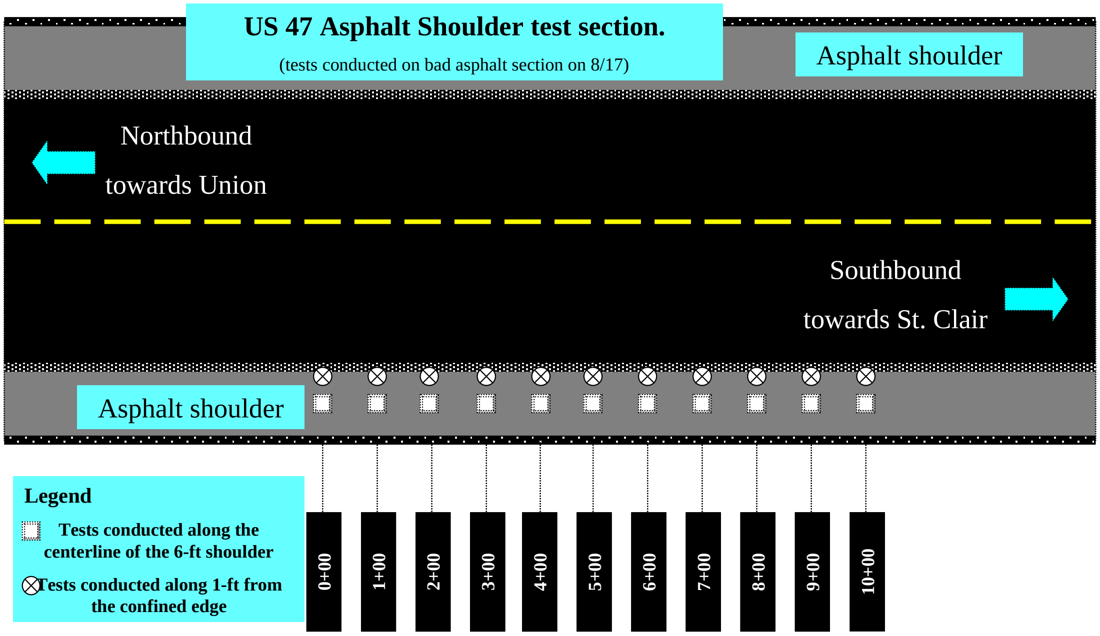


a) Test points in US-47 mainline testing

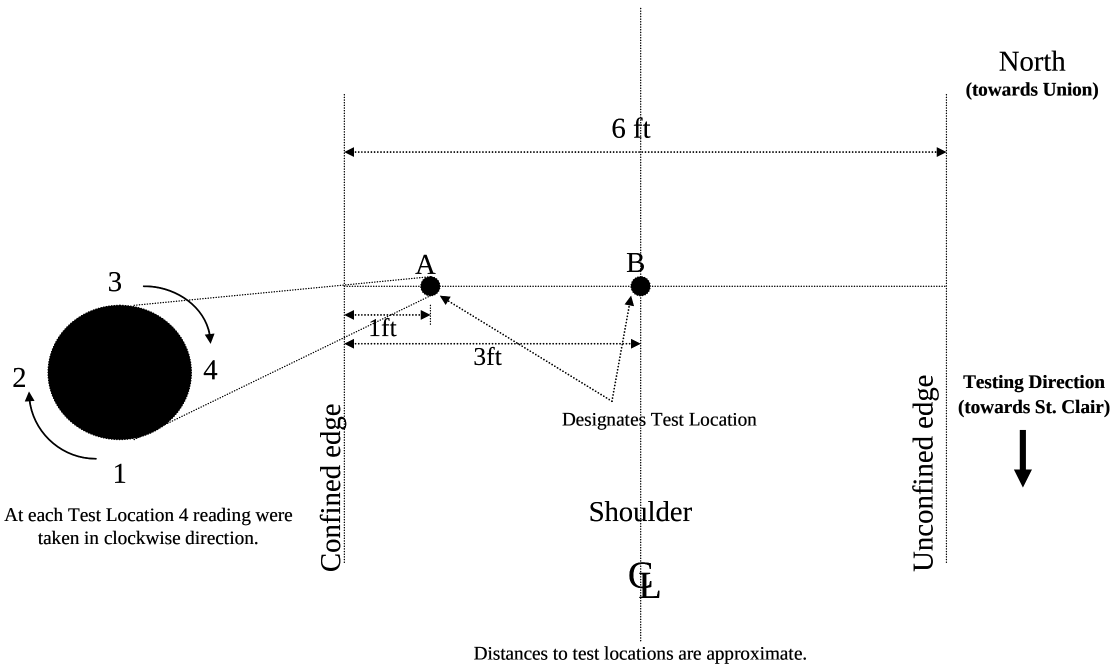


b) Test points layout at each test station

Layout of Points for Tests Conducted During Mainline and Shoulder Paving in the Southbound Direction



a) Test points layout along section



b) Test points layout at each test station

Layout of Points for Supplemental Testing of the HMA Mixture that Was Rejected

Table 232. ***Density*** meas. by ***Pavetracker 10232*** – Non-nuclear Gage on ***US-47, MO, pcf***

Test Date	Lane	Station	Point	Trial #	Density	Temperature	Average	Std Dev
08/16/2006	Shoulder	189+09	D	1	131.8	117.0		
08/16/2006	Shoulder	189+09	D	2	138.2	110.0		
08/16/2006	Shoulder	189+09	D	3	132.4	117.0		
08/16/2006	Shoulder	189+09	D	4	133.1	119.0	133.88	2.9319
08/16/2006	Shoulder	189+09	E	1	128	121.0		
08/16/2006	Shoulder	189+09	E	2	128.5	121.0		
08/16/2006	Shoulder	189+09	E	3	128.5	120.0		
08/16/2006	Shoulder	189+09	E	4	126.3	121.0	127.83	1.0436
08/16/2006	Shoulder	192+59	D	1	142.6	103.0		
08/16/2006	Shoulder	192+59	D	2	135.7	125.0		
08/16/2006	Shoulder	192+59	D	3	135.6	114.0		
08/16/2006	Shoulder	192+59	D	4	135.8	119.0	137.43	3.451
08/16/2006	Shoulder	192+59	E	1	127.8	121.0		
08/16/2006	Shoulder	192+59	E	2	132.2	120.0		
08/16/2006	Shoulder	192+59	E	3	131	120.0		
08/16/2006	Shoulder	192+59	E	4	129.1	120.0	130.03	1.9568
08/16/2006	Shoulder	196+29	D	1	128.9	112.0		
08/16/2006	Shoulder	196+29	D	2	130.1	109.0		
08/16/2006	Shoulder	196+29	D	3	129.2	111.0		
08/16/2006	Shoulder	196+29	D	4	129	114.0	129.3	0.5477
08/16/2006	Shoulder	196+29	E	1	124.4	109.0		
08/16/2006	Shoulder	196+29	E	2	124.1	97.0		
08/16/2006	Shoulder	196+29	E	3	124.8	107.0		
08/16/2006	Shoulder	196+29	E	4	124.7	107.0	124.5	0.3162
08/16/2006	Shoulder	201+09	D	1	133.5	130.0		
08/16/2006	Shoulder	201+09	D	2	134.1	132.0		
08/16/2006	Shoulder	201+09	D	3	133.2	130.0		
08/16/2006	Shoulder	201+09	D	4	137	125.0	134.45	1.7407
08/16/2006	Shoulder	201+09	E	1	129.6	109.0		
08/16/2006	Shoulder	201+09	E	2	136	102.0		
08/16/2006	Shoulder	201+09	E	3	134.7	110.0		
08/16/2006	Shoulder	201+09	E	4	128.7	107.0	132.25	3.6373
08/16/2006	Shoulder	213+09	D	1	139.6	105.0		
08/16/2006	Shoulder	213+09	D	2	142.6	107.0		
08/16/2006	Shoulder	213+09	D	3	137.2	105.0		
08/16/2006	Shoulder	213+09	D	4	127.8	102.0	136.8	6.3937
08/16/2006	Shoulder	213+09	E	1	131.1	101.0		
08/16/2006	Shoulder	213+09	E	2	129.2	101.0		

Table 232. ***Density*** meas. by ***Pavetracker 10232*** – Non-nuclear Gage on ***US-47, MO, pcf***
Continued

Test Date	Lane	Station	Point	Trial #	Density	Temperature	Average	Std Dev
08/16/2006	Shoulder	213+09	E	3	130.6	101.0		
08/16/2006	Shoulder	213+09	E	4	130.3	100.0	130.3	0.8042
08/16/2006	Shoulder	217+49	D	1	134.8	106.0		
08/16/2006	Shoulder	217+49	D	2	137.5	106.0		
08/16/2006	Shoulder	217+49	D	3	135.6	107.0		
08/16/2006	Shoulder	217+49	D	4	134.3	108.0	135.55	1.4059
08/16/2006	Shoulder	217+49	E	1	133	109.0		
08/16/2006	Shoulder	217+49	E	2	132.2	109.0		
08/16/2006	Shoulder	217+49	E	3	132.5	109.0		
08/16/2006	Shoulder	217+49	E	4	131.5	110.0	132.3	0.6272
08/16/2006	Shoulder	219+09	D	1	135.1	105.0		
08/16/2006	Shoulder	219+09	D	2	135.1	106.0		
08/16/2006	Shoulder	219+09	D	3	134	105.0		
08/16/2006	Shoulder	219+09	D	4	135	105.0	134.8	0.5354
08/16/2006	Shoulder	219+09	E	1	131.4	101.0		
08/16/2006	Shoulder	219+09	E	2	132	101.0		
08/16/2006	Shoulder	219+09	E	3	131.6	101.0		
08/16/2006	Shoulder	219+09	E	4	129.5	99.0	131.13	1.1117
08/16/2006	Shoulder	222+09	D	1	137.6	103.0		
08/16/2006	Shoulder	222+09	D	2	137.5	103.0		
08/16/2006	Shoulder	222+09	D	3	137	104.0		
08/16/2006	Shoulder	222+09	D	4	137.8	96.0	137.48	0.3403
08/16/2006	Shoulder	222+09	E	1	128.6	104.0		
08/16/2006	Shoulder	222+09	E	2	131.5	104.0		
08/16/2006	Shoulder	222+09	E	3	129.7	104.0		
08/16/2006	Shoulder	222+09	E	4	129.7	104.0	129.88	1.201
08/16/2006	Shoulder	225+09	D	1	136.7	107.0		
08/16/2006	Shoulder	225+09	D	2	136.4	107.0		
08/16/2006	Shoulder	225+09	D	3	136.2	108.0		
08/16/2006	Shoulder	225+09	D	4	136	108.0	136.33	0.2986
08/16/2006	Shoulder	225+09	E	1	129.5	107.0		
08/16/2006	Shoulder	225+09	E	2	132.1	107.0		
08/16/2006	Shoulder	225+09	E	3	133	109.0		
08/16/2006	Shoulder	225+09	E	4	131.6	109.0	131.55	1.4844
08/16/2006	Shoulder	228+09	D	1	135.7	115.0		
08/16/2006	Shoulder	228+09	D	2	136.7	115.0		
08/16/2006	Shoulder	228+09	D	3	137.1	116.0		

Table 232. ***Density*** meas. by ***Pavetracker 10232*** – Non-nuclear Gage on ***US-47, MO, pcf***
Continued

Test Date	Lane	Station	Point	Trial #	Density	Temperature	Average	Std Dev
08/16/2006	Shoulder	228+09	D	4	134.2	114.0	135.93	1.292
08/16/2006	Shoulder	228+09	E	1	131	114.0		
08/16/2006	Shoulder	228+09	E	2	131.8	114.0		
08/16/2006	Shoulder	228+09	E	3	130.4	114.0		
08/16/2006	Shoulder	228+09	E	4	130.6	114.0	130.95	0.6191
08/16/2006	Shoulder	243+05	D	1	132.4	99.0		
08/16/2006	Shoulder	243+05	D	2	130.5	99.0		
08/16/2006	Shoulder	243+05	D	3	131.9	98.0		
08/16/2006	Shoulder	243+05	D	4	129.6	99.0	131.1	1.2832
08/16/2006	Shoulder	243+05	E	1	127.4	98.0		
08/16/2006	Shoulder	243+05	E	2	130.2	99.0		
08/16/2006	Shoulder	243+05	E	3	127.1	98.0		
08/16/2006	Shoulder	243+05	E	4	124	99.0	127.18	2.5356
08/16/2006	Shoulder	244+00	D	1	132.9	98.0		
08/16/2006	Shoulder	244+00	D	2	135.7	96.0		
08/16/2006	Shoulder	244+00	D	3	132.7	97.0		
08/16/2006	Shoulder	244+00	D	4	130.5	102.0	132.95	2.1315
08/16/2006	Shoulder	244+00	E	1	123.9	104.0		
08/16/2006	Shoulder	244+00	E	2	126.8	104.0		
08/16/2006	Shoulder	244+00	E	3	122.6	104.0		
08/16/2006	Shoulder	244+00	E	4	124.5	105.0	124.45	1.7559
08/16/2006	Shoulder	246+02	D	1	135	99.0		
08/16/2006	Shoulder	246+02	D	2	136	98.0		
08/16/2006	Shoulder	246+02	D	3	136.8	99.0		
08/16/2006	Shoulder	246+02	D	4	135.9	99.0	135.93	0.7365
08/16/2006	Shoulder	246+02	E	1	128.4	101.0		
08/16/2006	Shoulder	246+02	E	2	131	101.0		
08/16/2006	Shoulder	246+02	E	3	126.6	101.0		
08/16/2006	Shoulder	246+02	E	4	127.2	101.0	128.3	1.9494
08/16/2006	Shoulder	248+00	D	1	136.2	103.0		
08/16/2006	Shoulder	248+00	D	2	136.3	102.0		
08/16/2006	Shoulder	248+00	D	3	135.9	102.0		
08/16/2006	Shoulder	248+00	D	4	136.4	103.0	136.2	0.216
08/16/2006	Shoulder	248+00	E	1	128.1	105.0		
08/16/2006	Shoulder	248+00	E	2	128.7	103.0		
08/16/2006	Shoulder	248+00	E	3	128.6	103.0		
08/16/2006	Shoulder	248+00	E	4	128.8	104.0	128.55	0.3109

Table 232. ***Density*** meas. by ***Pavetracker 10232*** – Non-nuclear Gage on ***US-47, MO, pcf***
Continued

Test Date	Lane	Station	Point	Trial #	Density	Temperature	Average	Std Dev
08/16/2006	Shoulder	250+22	D	1	135.4	104.0		
08/16/2006	Shoulder	250+22	D	2	135.9	103.0		
08/16/2006	Shoulder	250+22	D	3	135.3	103.0		
08/16/2006	Shoulder	250+22	D	4	132.3	104.0	134.73	1.6378
08/16/2006	Shoulder	250+22	E	1	129.8	103.0		
08/16/2006	Shoulder	250+22	E	2	127.1	102.0		
08/16/2006	Shoulder	250+22	E	3	127.8	102.0		
08/16/2006	Shoulder	250+22	E	4	124.9	103.0	127.4	2.0216
08/16/2006	Shoulder	251+61	D	1	135.5	107.0		
08/16/2006	Shoulder	251+61	D	2	136.6	109.0		
08/16/2006	Shoulder	251+61	D	3	134.6	106.0		
08/16/2006	Shoulder	251+61	D	4	133.7	107.0	135.1	1.241
08/16/2006	Shoulder	251+61	E	1	127.8	105.0		
08/16/2006	Shoulder	251+61	E	2	129	105.0		
08/16/2006	Shoulder	251+61	E	3	128.8	103.0		
08/16/2006	Shoulder	251+61	E	4	126.3	103.0	127.98	1.2339
08/16/2006	Shoulder	253+40	D	1	133.2	107.0		
08/16/2006	Shoulder	253+40	D	2	139.4	105.0		
08/16/2006	Shoulder	253+40	D	3	132.6	105.0		
08/16/2006	Shoulder	253+40	D	4	131.7	105.0	134.23	3.5046
08/16/2006	Shoulder	253+40	E	1	127.1	103.0		
08/16/2006	Shoulder	253+40	E	2	126.4	103.0		
08/16/2006	Shoulder	253+40	E	3	126.1	101.0		
08/16/2006	Shoulder	253+40	E	4	123.1	101.0	125.68	1.7671
08/16/2006	Shoulder	254+00	D	1	136.8	110.0		
08/16/2006	Shoulder	254+00	D	2	135.8	110.0		
08/16/2006	Shoulder	254+00	D	3	138.5	110.0		
08/16/2006	Shoulder	254+00	D	4	137.1	111.0	137.05	1.115
08/16/2006	Shoulder	254+00	E	1	131.7	108.0		
08/16/2006	Shoulder	254+00	E	2	131.7	109.0		
08/16/2006	Shoulder	254+00	E	3	128.3	107.0		
08/16/2006	Shoulder	254+00	E	4	129.4	107.0	130.28	1.7056
08/16/2006	Shoulder	255+00	D	1	133.8	110.0		
08/16/2006	Shoulder	255+00	D	2	135.5	110.0		
08/16/2006	Shoulder	255+00	D	3	131.8	110.0		
08/16/2006	Shoulder	255+00	D	4	131.7	110.0	133.2	1.8129
08/16/2006	Shoulder	255+00	E	1	124.7	109.0		

Table 232. ***Density*** meas. by ***Pavetracker 10232*** – Non-nuclear Gage on ***US-47, MO, pcf***
Continued

Test Date	Lane	Station	Point	Trial #	Density	Temperature	Average	Std Dev
08/16/2006	Shoulder	255+00	E	2	127.4	108.0		
08/16/2006	Shoulder	255+00	E	3	125.2	107.0		
08/16/2006	Shoulder	255+00	E	4	125.2	107.0	125.63	1.2066
08/16/2006	Shoulder	255+61	D	1	133.2	118.0		
08/16/2006	Shoulder	255+61	D	2	131.2	112.0		
08/16/2006	Shoulder	255+61	D	3	134	119.0		
08/16/2006	Shoulder	255+61	D	4	132.3	126.0	132.68	1.2038
08/16/2006	Shoulder	255+61	E	1	115	125.0		
08/16/2006	Shoulder	255+61	E	2	122.8	125.0		
08/16/2006	Shoulder	255+61	E	3	113.5	124.0		
08/16/2006	Shoulder	255+61	E	4	125.1	123.0	119.1	5.7114
08/16/2006	ML	189+09	A	1	134.5	127.0		
08/16/2006	ML	189+09	A	2	132.6	123.0		
08/16/2006	ML	189+09	A	3	135.3	124.0		
08/16/2006	ML	189+09	A	4	134	123.0	134.1	1.1343
08/16/2006	ML	189+09	B	1	138.4	106.0		
08/16/2006	ML	189+09	B	2	137.8	107.0		
08/16/2006	ML	189+09	B	3	138	107.0		
08/16/2006	ML	189+09	B	4	139.9	101.0	138.53	0.95
08/16/2006	ML	189+09	C	1	140.2	103.0		
08/16/2006	ML	189+09	C	2	138.6	107.0		
08/16/2006	ML	189+09	C	3	140.7	104.0		
08/16/2006	ML	189+09	C	4	139.8	103.0	138.53	0.95
08/16/2006	ML	192+59	A	1	134.8			
08/16/2006	ML	192+59	A	2	137.4	125.0		
08/16/2006	ML	192+59	A	3	135.5	125.0		
08/16/2006	ML	192+59	A	4	137.5	124.0	136.3	1.3589
08/16/2006	ML	192+59	B	1	137.4	118.0		
08/16/2006	ML	192+59	B	2	136.9	118.0		
08/16/2006	ML	192+59	B	3	136.7	115.0		
08/16/2006	ML	192+59	B	4	137.4	105.0	137.1	0.3559
08/16/2006	ML	192+59	C	1	136.8	120.0		
08/16/2006	ML	192+59	C	2	135.5	117.0		
08/16/2006	ML	192+59	C	3	137	120.0		
08/16/2006	ML	192+59	C	4	138.2	124.0	136.88	1.1057
08/16/2006	ML	196+29	A	1	128.2	117.0		
08/16/2006	ML	196+29	A	2	127.7	118.0		

Table 232. ***Density*** meas. by ***Pavetracker 10232*** – Non-nuclear Gage on ***US-47, MO, pcf***
Continued

Test Date	Lane	Station	Point	Trial #	Density	Temperature	Average	Std Dev
08/16/2006	ML	196+29	A	3	127.9	117.0		
08/16/2006	ML	196+29	A	4	130.6	118.0	128.6	1.3491
08/16/2006	ML	196+29	B	1	128.6	107.0		
08/16/2006	ML	196+29	B	2	128.3	11.0		
08/16/2006	ML	196+29	B	3	128.3	109.0		
08/16/2006	ML	196+29	B	4	130.2	112.0	128.85	0.911
08/16/2006	ML	196+29	C	1	131	120.0		
08/16/2006	ML	196+29	C	2	130	119.0		
08/16/2006	ML	196+29	C	3	130.1	119.0		
08/16/2006	ML	196+29	C	4	129.1	117.0	128.85	0.911
08/16/2006	ML	201+09	A	1	135.4	117.0		
08/16/2006	ML	201+09	A	2	132.1	116.0		
08/16/2006	ML	201+09	A	3	135.7	116.0		
08/16/2006	ML	201+09	A	4	136.4	117.0	134.9	1.9131
08/16/2006	ML	201+09	B	1	136.8	106.0		
08/16/2006	ML	201+09	B	2	136.6	107.0		
08/16/2006	ML	201+09	B	3	136.5	107.0		
08/16/2006	ML	201+09	B	4	137.5	107.0	136.85	0.4509
08/16/2006	ML	201+09	C	1	136.1	124.0		
08/16/2006	ML	201+09	C	2	135.1	119.0		
08/16/2006	ML	201+09	C	3	136.5	120.0		
08/16/2006	ML	201+09	C	4	132	127.0	134.93	2.037
08/16/2006	ML	213+09	A	1	137.2	120.0		
08/16/2006	ML	213+09	A	2	133.7	120.0		
08/16/2006	ML	213+09	A	3	134.6	119.0		
08/16/2006	ML	213+09	A	4	134.4	119.0	134.98	1.5327
08/16/2006	ML	213+09	B	1	137.3	115.0		
08/16/2006	ML	213+09	B	2	137.7	114.0		
08/16/2006	ML	213+09	B	3	136.9	116.0		
08/16/2006	ML	213+09	B	4	138.6	115.0	137.63	0.7274
08/16/2006	ML	213+09	C	1	137.6	112.0		
08/16/2006	ML	213+09	C	2	136.2	117.0		
08/16/2006	ML	213+09	C	3	137.4	113.0		
08/16/2006	ML	213+09	C	4	141.2	110.0	137.63	0.7274
08/16/2006	ML	217+49	A	1	137.6	106.0		
08/16/2006	ML	217+49	A	2	136.3	105.0		
08/16/2006	ML	217+49	A	3	138.8	105.0		

Table 232. ***Density*** meas. by ***Pavetracker 10232*** – Non-nuclear Gage on ***US-47, MO, pcf***
Continued

Test Date	Lane	Station	Point	Trial #	Density	Temperature	Average	Std Dev
08/16/2006	ML	217+49	A	4	136.3	105.0	137.25	1.2014
08/16/2006	ML	217+49	B	1	138.1	99.0		
08/16/2006	ML	217+49	B	2	137	98.0		
08/16/2006	ML	217+49	B	3	136	98.0		
08/16/2006	ML	217+49	B	4	137.7	98.0	137.2	0.9201
08/16/2006	ML	217+49	C	1	140.2	102.0		
08/16/2006	ML	217+49	C	2	139.8	102.0		
08/16/2006	ML	217+49	C	3	139.7	103.0		
08/16/2006	ML	217+49	C	4	137.6	103.0	139.33	1.1701
08/16/2006	ML	219+09	A	1	134.6	110.0		
08/16/2006	ML	219+09	A	2	132.7	110.0		
08/16/2006	ML	219+09	A	3	134.4	109.0		
08/16/2006	ML	219+09	A	4	135.2	109.0	134.23	1.072
08/16/2006	ML	219+09	B	1	134.5	102.0		
08/16/2006	ML	219+09	B	2	135.8	101.0		
08/16/2006	ML	219+09	B	3	136.1	102.0		
08/16/2006	ML	219+09	B	4	138.4	103.0	136.2	1.6228
08/16/2006	ML	219+09	C	1	134.7	105.0		
08/16/2006	ML	219+09	C	2	139.8	106.0		
08/16/2006	ML	219+09	C	3	135.4	103.0		
08/16/2006	ML	219+09	C	4	132.5	107.0	136.2	1.6228
08/16/2006	ML	222+09	A	1	134	109.0		
08/16/2006	ML	222+09	A	2	132.3	109.0		
08/16/2006	ML	222+09	A	3	133.3	11.0		
08/16/2006	ML	222+09	A	4	138.1	110.0	134.43	2.5474
08/16/2006	ML	222+09	B	1	138	106.0		
08/16/2006	ML	222+09	B	2	139.7	107.0		
08/16/2006	ML	222+09	B	3	136.6	106.0		
08/16/2006	ML	222+09	B	4	137	105.0	137.83	1.3817
08/16/2006	ML	222+09	C	1	140.4	105.0		
08/16/2006	ML	222+09	C	2	138.7	106.0		
08/16/2006	ML	222+09	C	3	143.1	105.0		
08/16/2006	ML	222+09	C	4	139.3	105.0	140.38	1.9483
08/16/2006	ML	225+09	A	1	138	115.0		
08/16/2006	ML	225+09	A	2	136.5	114.0		
08/16/2006	ML	225+09	A	3	137.1	116.0		
08/16/2006	ML	225+09	A	4	133.1	116.0	136.18	2.1407

Table 232. ***Density*** meas. by ***Pavetracker 10232*** – Non-nuclear Gage on ***US-47, MO, pcf***
Continued

Test Date	Lane	Station	Point	Trial #	Density	Temperature	Average	Std Dev
08/16/2006	ML	225+09	B	1	136.6	112.0		
08/16/2006	ML	225+09	B	2	134.1	113.0		
08/16/2006	ML	225+09	B	3	134.1	112.0		
08/16/2006	ML	225+09	B	4	134.1	113.0	134.73	1.25
08/16/2006	ML	225+09	C	1	138.1	105.0		
08/16/2006	ML	225+09	C	2	131.1	100.0		
08/16/2006	ML	225+09	C	3	133.8	106.0		
08/16/2006	ML	225+09	C	4	135.1	107.0	134.73	1.25
08/16/2006	ML	228+09	A	1	138.7	116.0		
08/16/2006	ML	228+09	A	2	136.3	115.0		
08/16/2006	ML	228+09	A	3	136.4	115.0		
08/16/2006	ML	228+09	A	4	137.5	116.0	137.23	1.1236
08/16/2006	ML	228+09	B	1	137.5	113.0		
08/16/2006	ML	228+09	B	2	139.1	112.0		
08/16/2006	ML	228+09	B	3	136.1	113.0		
08/16/2006	ML	228+09	B	4	140.5	114.0	138.3	1.9114
08/16/2006	ML	228+09	C	1	135.6	112.0		
08/16/2006	ML	228+09	C	2	139.4	106.0		
08/16/2006	ML	228+09	C	3	137.7	111.0		
08/16/2006	ML	228+09	C	4	136.2	112.0	137.23	1.6978
08/16/2006	ML	243+05	A	1	139.2	101.0		
08/16/2006	ML	243+05	A	2	137.2	101.0		
08/16/2006	ML	243+05	A	3	136.6	101.0		
08/16/2006	ML	243+05	A	4	137.9	101.0	137.73	1.1177
08/16/2006	ML	243+05	B	1	140.4	97.0		
08/16/2006	ML	243+05	B	2	138.4	98.0		
08/16/2006	ML	243+05	B	3	142	98.0		
08/16/2006	ML	243+05	B	4	140.5	98.0	140.33	1.4773
08/16/2006	ML	243+05	C	1	138.1	97.0		
08/16/2006	ML	243+05	C	2	135.2	96.0		
08/16/2006	ML	243+05	C	3	137	97.0		
08/16/2006	ML	243+05	C	4	141.2	99.0	140.33	1.4773
08/16/2006	ML	244+00	A	1	138.8	102.0		
08/16/2006	ML	244+00	A	2	131	99.0		
08/16/2006	ML	244+00	A	3	136.1	101.0		
08/16/2006	ML	244+00	A	4	141.3	102.0	136.8	4.4113
08/16/2006	ML	244+00	B	1	136.2	101.0		

Table 232. ***Density*** meas. by ***Pavetracker 10232*** – Non-nuclear Gage on ***US-47, MO, pcf***
Continued

Test Date	Lane	Station	Point	Trial #	Density	Temperature	Average	Std Dev
08/16/2006	ML	244+00	B	2	139.5	100.0		
08/16/2006	ML	244+00	B	3	140	101.0		
08/16/2006	ML	244+00	B	4	138.2	101.0	138.48	1.6958
08/16/2006	ML	244+00	C	1	133.9	101.0		
08/16/2006	ML	244+00	C	2	139.8	102.0		
08/16/2006	ML	244+00	C	3	135.8	101.0		
08/16/2006	ML	244+00	C	4	136.5	98.0	136.5	2.459
08/16/2006	ML	246+02	A	1	141.3	101.0		
08/16/2006	ML	246+02	A	2	138.1	101.0		
08/16/2006	ML	246+02	A	3	139.1	102.0		
08/16/2006	ML	246+02	A	4	139.4	101.0	139.48	1.3376
08/16/2006	ML	246+02	B	1	138.2	98.0		
08/16/2006	ML	246+02	B	2	136.8	97.0		
08/16/2006	ML	246+02	B	3	140.5	98.0		
08/16/2006	ML	246+02	B	4	138.9	98.0	138.6	1.5384
08/16/2006	ML	246+02	C	1	140.2	98.0		
08/16/2006	ML	246+02	C	2	141.3	96.0		
08/16/2006	ML	246+02	C	3	138.6	98.0		
08/16/2006	ML	246+02	C	4	137.6	99.0	138.6	1.5384
08/16/2006	ML	248+00	A	1	132.3	103.0		
08/16/2006	ML	248+00	A	2	132.7	101.0		
08/16/2006	ML	248+00	A	3	134.6	103.0		
08/16/2006	ML	248+00	A	4	135.9	103.0	133.88	1.682
08/16/2006	ML	248+00	B	1	135.8	101.0		
08/16/2006	ML	248+00	B	2	135.7	102.0		
08/16/2006	ML	248+00	B	3	133.6	101.0		
08/16/2006	ML	248+00	B	4	136	99.0	135.28	1.1236
08/16/2006	ML	248+00	C	1	138.9	99.0		
08/16/2006	ML	248+00	C	2	137.7	99.0		
08/16/2006	ML	248+00	C	3	139.9	99.0		
08/16/2006	ML	248+00	C	4	139	101.0	138.88	0.9032
08/16/2006	ML	250+22	A	1	137.2	106.0		
08/16/2006	ML	250+22	A	2	137.3	106.0		
08/16/2006	ML	250+22	A	3	136.2	106.0		
08/16/2006	ML	250+22	A	4	140.7	106.0	137.85	1.9638
08/16/2006	ML	250+22	B	1	140.2	102.0		
08/16/2006	ML	250+22	B	2	138	102.0		

Table 232. ***Density*** meas. by ***Pavetracker 10232*** – Non-nuclear Gage on ***US-47, MO, pcf***
Continued

Test Date	Lane	Station	Point	Trial #	Density	Temperature	Average	Std Dev
08/16/2006	ML	250+22	B	3	139	102.0		
08/16/2006	ML	250+22	B	4	138.2	103.0	138.85	0.9983
08/16/2006	ML	250+22	C	1	137.4	102.0		
08/16/2006	ML	250+22	C	2	138	102.0		
08/16/2006	ML	250+22	C	3	138.6	103.0		
08/16/2006	ML	250+22	C	4	136.2	103.0	137.55	1.0247
08/16/2006	ML	251+61	A	1	135.2	111.0		
08/16/2006	ML	251+61	A	2	133.8	110.0		
08/16/2006	ML	251+61	A	3	136.7	110.0		
08/16/2006	ML	251+61	A	4	138.2	112.0	135.98	1.898
08/16/2006	ML	251+61	B	1	139.5	107.0		
08/16/2006	ML	251+61	B	2	139	107.0		
08/16/2006	ML	251+61	B	3	137.1	107.0		
08/16/2006	ML	251+61	B	4	141	107.0	139.15	1.6093
08/16/2006	ML	251+61	C	1	136	107.0		
08/16/2006	ML	251+61	C	2	138.5	106.0		
08/16/2006	ML	251+61	C	3	137.1	106.0		
08/16/2006	ML	251+61	C	4	136	109.0	136.9	1.186
08/16/2006	ML	253+40	A	1	134.5	109.0		
08/16/2006	ML	253+40	A	2	136.3	109.0		
08/16/2006	ML	253+40	A	3	136.3	109.0		
08/16/2006	ML	253+40	A	4	137.7	108.0	136.2	1.3115
08/16/2006	ML	253+40	B	1	133.7	101.0		
08/16/2006	ML	253+40	B	2	136.5	102.0		
08/16/2006	ML	253+40	B	3	133.9	99.0		
08/16/2006	ML	253+40	B	4	137.2	101.0	135.33	1.7858
08/16/2006	ML	253+40	C	1	135	101.0		
08/16/2006	ML	253+40	C	2	136.4	101.0		
08/16/2006	ML	253+40	C	3	135.9	98.0		
08/16/2006	ML	253+40	C	4	137.3	102.0	136.15	0.9609
08/16/2006	ML	254+00	A	1	138.6	119.0		
08/16/2006	ML	254+00	A	2	135.7	117.0		
08/16/2006	ML	254+00	A	3	135.5	119.0		
08/16/2006	ML	254+00	A	4	136.3	119.0	136.53	1.4245
08/16/2006	ML	254+00	B	1	136.4	109.0		
08/16/2006	ML	254+00	B	2	137	110.0		
08/16/2006	ML	254+00	B	3	136.7	109.0		

Table 232. ***Density*** meas. by ***Pavetracker 10232*** – Non-nuclear Gage on ***US-47, MO, pcf***
Continued

Test Date	Lane	Station	Point	Trial #	Density	Temperature	Average	Std Dev
08/16/2006	ML	254+00	B	4	138.1	110.0	137.05	0.7416
08/16/2006	ML	254+00	C	1	138.8	106.0		
08/16/2006	ML	254+00	C	2	132.2	105.0		
08/16/2006	ML	254+00	C	3	138.9	105.0		
08/16/2006	ML	254+00	C	4	139.9	109.0	137.45	3.5351
08/16/2006	ML	255+00	A	1	137.7	119.0		
08/16/2006	ML	255+00	A	2	135.8	118.0		
08/16/2006	ML	255+00	A	3	133.1	118.0		
08/16/2006	ML	255+00	A	4	135.9	118.0	135.63	1.8963
08/16/2006	ML	255+00	B	1	138.6	110.0		
08/16/2006	ML	255+00	B	2	141.5	112.0		
08/16/2006	ML	255+00	B	3	139	110.0		
08/16/2006	ML	255+00	B	4	135.6	109.0	135.63	1.8963
08/16/2006	ML	255+00	C	1	136.8	109.0		
08/16/2006	ML	255+00	C	2	136	107.0		
08/16/2006	ML	255+00	C	3	137.1	110.0		
08/16/2006	ML	255+00	C	4	138.3	111.0	137.05	0.9539
08/16/2006	ML	255+61	A	1	133.6	143.0		
08/16/2006	ML	255+61	A	2	132.5	142.0		
08/16/2006	ML	255+61	A	3	133.5	142.0		
08/16/2006	ML	255+61	A	4	135.2	141.0	133.7	1.1165
08/16/2006	ML	255+61	B	1	130.1	125.0		
08/16/2006	ML	255+61	B	2	129	131.0		
08/16/2006	ML	255+61	B	3	124.3	120.0		
08/16/2006	ML	255+61	B	4	123	114.0	126.6	3.4766
08/16/2006	ML	255+61	C	1	132.7	117.0		
08/16/2006	ML	255+61	C	2	130.6	114.0		
08/16/2006	ML	255+61	C	3	134.3	111.0		
08/16/2006	ML	255+61	C	4	128.6	112.0	131.55	2.4826
08/17/2006	Shoulder	0	A	1	126.3	92.0		
08/17/2006	Shoulder	0	A	2	124.1	93.0		
08/17/2006	Shoulder	0	A	3	131	94.0		
08/17/2006	Shoulder	0	A	4	127.8	92.0	127.3	2.8971
08/17/2006	Shoulder	400	B	1	124.3	98.0		
08/17/2006	Shoulder	400	B	2	128.4	98.0		
08/17/2006	Shoulder	400	B	3	126.3	95.0		
08/17/2006	Shoulder	400	B	4	127.5	96.0	126.63	1.7727

Table 232. ***Density*** meas. by ***Pavetracker 10232*** – Non-nuclear Gage on ***US-47, MO, pcf***
Continued

Test Date	Lane	Station	Point	Trial #	Density	Temperature	Average	Std Dev
08/17/2006	Shoulder	900	B	1	132.3	105.0		
08/17/2006	Shoulder	900	B	2	131.6	103.0		
08/17/2006	Shoulder	900	B	3	132	103.0		
08/17/2006	Shoulder	900	B	4	132.3	105.0	132.05	0.3317

Table 233. ***Density*** meas. by ***Pavetracker 10233*** – Non-nuclear Gage on ***US-47, MO, pcf***

Test Date	Station	Point	Trial #	Density	Temperature	Average	Std Dev
08/16/2006	189+09	D	1	131.3	111.0		
08/16/2006	189+09	D	2	133	106.0		
08/16/2006	189+09	D	3	134.3	111.0		
08/16/2006	189+09	D	4	132.5	114.0	132.78	1.242
08/16/2006	189+09	E	1	129.2	116.0		
08/16/2006	189+09	E	2	129.5	115.0		
08/16/2006	189+09	E	3	127.5	117.0		
08/16/2006	189+09	E	4	127	116.0	128.3	1.2356
08/16/2006	196+29	D	1	128.2	107.0		
08/16/2006	196+29	D	2	127.1	105.0		
08/16/2006	196+29	D	3	124.3	106.0		
08/16/2006	196+29	D	4	127.3	108.0	126.73	1.686
08/16/2006	196+29	E	1	124.2	103.0		
08/16/2006	196+29	E	2	123	95.0		
08/16/2006	196+29	E	3	124	104.0		
08/16/2006	196+29	E	4	123.9	102.0	123.78	0.5315
08/16/2006	213+09	D	1	140.7	102.0		
08/16/2006	213+09	D	2	143.2	103.0		
08/16/2006	213+09	D	3	137.7	102.0		
08/16/2006	213+09	D	4	131.1	99.0	138.18	5.2252
08/16/2006	213+09	E	1	130.7	96.0		
08/16/2006	213+09	E	2	127.1	99.0		
08/16/2006	213+09	E	3	129.3	97.0		
08/16/2006	213+09	E	4	129.9	98.0	129.25	1.5438
08/16/2006	225+09	D	1	137.8	104.0		
08/16/2006	225+09	D	2	136.4	103.0		
08/16/2006	225+09	D	3	136.6	105.0		
08/16/2006	225+09	D	4	134.1	105.0	136.23	1.5457
08/16/2006	225+09	E	1	128.1	105.0		
08/16/2006	225+09	E	2	130.6	103.0		
08/16/2006	225+09	E	3	135.2	104.0		
08/16/2006	225+09	E	4	132.8	106.0	131.68	3.0347
08/16/2006	228+09	D	1	135.1	109.0		
08/16/2006	228+09	D	2	137.7	110.0		
08/16/2006	228+09	D	3	138.2	110.0		
08/16/2006	228+09	E	1	130.6	110.0		
08/16/2006	228+09	E	2	132.1	109.0		

Table 233. ***Density*** meas. by ***Pavetracker 10233*** – Non-nuclear Gage on ***US-47, MO, pcf***
Continued

Test Date	Station	Point	Trial #	Density	Temperature	Average	Std Dev
08/16/2006	228+09	E	3	131.8	109.0		
08/16/2006	228+09	E	4	131.6	110.0	131.53	0.65
08/16/2006	248+00	D	1	138.4	101.0		
08/16/2006	248+00	D	2	135.6	100.0		
08/16/2006	248+00	D	3	137.8	100.0		
08/16/2006	248+00	D	4	136.3	100.0	137.03	1.2971
08/16/2006	248+00	E	1	128.1	102.0		
08/16/2006	248+00	E	2	128.6	101.0		
08/16/2006	248+00	E	3	129.7	101.0		
08/16/2006	248+00	E	4	128.8	101.0	128.8	0.6683
08/16/2006	250+22	D	1	136	100.0		
08/16/2006	250+22	D	2	138.9	101.0		
08/16/2006	250+22	D	3	136.8	99.0		
08/16/2006	250+22	D	4	133.2	101.0	136.23	2.3585
08/16/2006	250+22	E	1	127.2	99.0		
08/16/2006	250+22	E	2	127	99.0		
08/16/2006	250+22	E	3	126.8	99.0		
08/16/2006	250+22	E	4	124.4	99.0	126.35	1.3102
08/16/2006	251+61	D	1	134.6	104.0		
08/16/2006	251+61	D	2	133.3	105.0		
08/16/2006	251+61	D	3	132.4	103.0		
08/16/2006	251+61	D	4	132.8	103.0	133.28	0.957
08/16/2006	251+61	E	1	127.4	101.0		
08/16/2006	251+61	E	2	130.6	102.0		
08/16/2006	251+61	E	3	128.7	101.0		
08/16/2006	251+61	E	4	127.1	100.0	128.45	1.5927
08/16/2006	253+40	D	1	134.6	103.0		
08/16/2006	253+40	D	2	138.6	102.0		
08/16/2006	253+40	D	3	134	102.0		
08/16/2006	253+40	D	4	128.5	102.0	133.93	4.1532
08/16/2006	253+40	E	1	126.7	99.0		
08/16/2006	253+40	E	2	130.9	100.0		
08/16/2006	253+40	E	3	128.2	99.0		
08/16/2006	253+40	E	4	124.7	99.0	127.63	2.612
08/16/2006	254+00	D	1	134.5	106.0		

Table 233. ***Density*** meas. by ***Pavetracker 10233*** – Non-nuclear Gage on ***US-47, MO, pcf***
Continued

Test Date	Station	Point	Trial #	Density	Temperature	Average	Std Dev
08/16/2006	254+00	D	2	140.1	107.0		
08/16/2006	254+00	D	3	138.8	107.0		
08/16/2006	254+00	D	4	134.1	107.0	136.88	3.0248
08/16/2006	254+00	E	1	131.6	105.0		
08/16/2006	254+00	E	2	132	106.0		
08/16/2006	254+00	E	3	126.7	104.0		
08/16/2006	254+00	E	4	125	102.0	128.83	3.5084
08/16/2006	255+00	D	1	133	106.0		
08/16/2006	255+00	D	2	135.5	106.0		
08/16/2006	255+00	D	3	132.4	106.0		
08/16/2006	255+00	D	4	132.8	106.0	133.43	1.4056
08/16/2006	255+00	E	1	124.3	105.0		
08/16/2006	255+00	E	2	127.7	105.0		
08/16/2006	255+00	E	3	124.9	104.0		
08/16/2006	255+00	E	4	124.4	103.0	125.33	1.6049
08/16/2006	255+61	D	1	128.2	110.0		
08/16/2006	255+61	D	2	131.3	107.0		
08/16/2006	255+61	D	3	131.5	113.0		
08/16/2006	255+61	D	4	131.7	110.0	130.68	1.6581
08/16/2006	255+61	E	1	115.7	118.0		
08/16/2006	255+61	E	2	121.8	119.0		
08/16/2006	255+61	E	3	119.7	117.0		
08/16/2006	255+61	E	4	123.3	116.0	120.13	3.2989
08/16/2006	189+09	A	1	134.7	118.0		
08/16/2006	189+09	A	2	133.5	117.0		
08/16/2006	189+09	A	3	136.9	118.0		
08/16/2006	189+09	A	4	137.1	117.0	135.55	1.7464
08/16/2006	189+09	B	1	137.4	103.0		
08/16/2006	189+09	B	2	139.8	105.0		
08/16/2006	189+09	B	3	136.8	103.0		
08/16/2006	189+09	B	4	137.6	97.0	137.9	1.3115
08/16/2006	189+09	C	1	139.9	99.0		
08/16/2006	189+09	C	2	137.7	101.0		
08/16/2006	189+09	C	3	137.7	99.0		
08/16/2006	189+09	C	4	138.8	100.0	137.9	1.3115
08/16/2006	196+29	A	1	130.2	112.0		

Table 233. ***Density*** meas. by ***Pavetracker 10233*** – Non-nuclear Gage on ***US-47, MO, pcf***
Continued

Test Date	Station	Point	Trial #	Density	Temperature	Average	Std Dev
08/16/2006	196+29	A	2	128.5	111.0		
08/16/2006	196+29	A	3	127.3	110.0		
08/16/2006	196+29	A	4	131.6	112.0	129.4	1.8886
08/16/2006	196+29	B	1	127	103.0		
08/16/2006	196+29	B	2	128	103.0		
08/16/2006	196+29	B	3	127.2	103.0		
08/16/2006	196+29	B	4	129.5	107.0	127.93	1.1354
08/16/2006	196+29	C	1	129.8	114.0		
08/16/2006	196+29	C	2	127.9	113.0		
08/16/2006	196+29	C	3	133	114.0		
08/16/2006	196+29	C	4	130.6	111.0	127.93	1.1354
08/16/2006	213+09	A	1	133.5	113.0		
08/16/2006	213+09	A	2	132.1	113.0		
08/16/2006	213+09	A	3	134.7	113.0		
08/16/2006	213+09	A	4	136.1	113.0	134.1	1.7049
08/16/2006	213+09	B	1	137.7	109.0		
08/16/2006	213+09	B	2	136.5	110.0		
08/16/2006	213+09	B	3	137.3	110.0		
08/16/2006	213+09	B	4	141.5	110.0	138.25	2.2234
08/16/2006	213+09	C	1	134.2	106.0		
08/16/2006	213+09	C	2	134.8	107.0		
08/16/2006	213+09	C	3	135.7	106.0		
08/16/2006	213+09	C	4	142.9	103.0	138.25	2.2234
08/16/2006	225+09	A	1	137.9	112.0		
08/16/2006	225+09	A	2	136	110.0		
08/16/2006	225+09	A	3	137.6	110.0		
08/16/2006	225+09	A	4	135.2	111.0	136.68	1.2894
08/16/2006	225+09	B	1	137.1	109.0		
08/16/2006	225+09	B	2	133.6	108.0		
08/16/2006	225+09	B	3	134.9	107.0		
08/16/2006	225+09	B	4	137.8	109.0	135.85	1.9434
08/16/2006	225+09	C	1	136.9	103.0		
08/16/2006	225+09	C	2	133.5	98.0		
08/16/2006	225+09	C	3	134.3	103.0		
08/16/2006	225+09	C	4	133.1	103.0	135.85	1.9434

Table 233. ***Density*** meas. by ***Pavetracker 10233*** – Non-nuclear Gage on ***US-47, MO, pcf***
Continued

Test Date	Station	Point	Trial #	Density	Temperature	Average	Std Dev
08/16/2006	228+09	A	1	137.1	112.0		
08/16/2006	228+09	A	2	136.1	111.0		
08/16/2006	228+09	A	3	137.9	111.0		
08/16/2006	228+09	A	4	137	110.0	137.03	0.7365
08/16/2006	228+09	B	1	137.6	109.0		
08/16/2006	228+09	B	2	138.3	106.0		
08/16/2006	228+09	B	3	136.9	108.0		
08/16/2006	228+09	B	4	140.6	110.0	138.35	1.6052
08/16/2006	228+09	C	1	136.2	108.0		
08/16/2006	228+09	C	2	135.8	104.0		
08/16/2006	228+09	C	3	135.8	108.0		
08/16/2006	228+09	C	4	137.5	107.0	136.33	0.8057
08/16/2006	248+00	A	1	133.8	100.0		
08/16/2006	248+00	A	2	134	99.0		
08/16/2006	248+00	A	3	135.3	101.0		
08/16/2006	248+00	A	4	137.7	101.0	135.2	1.7944
08/16/2006	248+00	B	1	136	98.0		
08/16/2006	248+00	B	2	131.4	99.0		
08/16/2006	248+00	B	3	133.6	98.0		
08/16/2006	248+00	B	4	133	98.0	133.5	1.9079
08/16/2006	248+00	C	1	138.4	96.0		
08/16/2006	248+00	C	2	139.2	96.0		
08/16/2006	248+00	C	3	141.8	97.0		
08/16/2006	248+00	C	4	139.9	97.0	139.83	1.4523
08/16/2006	250+22	A	1	133.3	103.0		
08/16/2006	250+22	A	2	135.4	103.0		
08/16/2006	250+22	A	3	136.2	103.0		
08/16/2006	250+22	A	4	136.1	103.0	135.25	1.3478
08/16/2006	250+22	B	1	140.3	99.0		
08/16/2006	250+22	B	2	136.7	99.0		
08/16/2006	250+22	B	3	137.4	99.0		
08/16/2006	250+22	B	4	138.4	99.0	138.2	1.5642
08/16/2006	250+22	C	1	136.3	99.0		
08/16/2006	250+22	C	2	139.4	99.0		
08/16/2006	250+22	C	3	138.8	99.0		
08/16/2006	250+22	C	4	136.5	101.0	137.75	1.5801

Table 233. ***Density*** meas. by ***Pavetracker 10233*** – Non-nuclear Gage on ***US-47, MO, pcf***
Continued

Test Date	Station	Point	Trial #	Density	Temperature	Average	Std Dev
08/16/2006	251+61	A	1	134.5	108.0		
08/16/2006	251+61	A	2	136.1	106.0		
08/16/2006	251+61	A	3	137.2	107.0		
08/16/2006	251+61	A	4	136.4	107.0	136.05	1.1328
08/16/2006	251+61	B	1	140.1	104.0		
08/16/2006	251+61	B	2	139.2	103.0		
08/16/2006	251+61	B	3	139.4	103.0		
08/16/2006	251+61	B	4	139.4	104.0	139.53	0.3948
08/16/2006	251+61	C	1	136.5	104.0		
08/16/2006	251+61	C	2	139.2	103.0		
08/16/2006	251+61	C	3	137.4	104.0		
08/16/2006	251+61	C	4	135	105.0	137.03	1.7557
08/16/2006	253+40	A	1	136	106.0		
08/16/2006	253+40	A	2	136.6	106.0		
08/16/2006	253+40	A	3	137.9	106.0		
08/16/2006	253+40	A	4	135.9	105.0	136.6	0.9201
08/16/2006	253+40	B	1	134.1	98.0		
08/16/2006	253+40	B	2	136.1	99.0		
08/16/2006	253+40	B	3	133.6	98.0		
08/16/2006	253+40	B	4	136.5	99.0	135.08	1.4385
08/16/2006	253+40	C	1	137.3	98.0		
08/16/2006	253+40	C	2	137.8	98.0		
08/16/2006	253+40	C	3	137.8	98.0		
08/16/2006	253+40	C	4	139.1	99.0	138	0.7703
08/16/2006	254+00	A	1	136.5	115.0		
08/16/2006	254+00	A	2	132.3	113.0		
08/16/2006	254+00	A	3	138.7	112.0		
08/16/2006	254+00	A	4	136	113.0	135.88	2.6563
08/16/2006	254+00	B	1	135.1	105.0		
08/16/2006	254+00	B	2	134.4	105.0		
08/16/2006	254+00	B	3	137.8	104.0		
08/16/2006	254+00	B	4	137	105.0	136.08	1.5903
08/16/2006	254+00	C	1	141.5	102.0		
08/16/2006	254+00	C	2	131.6	102.0		
08/16/2006	254+00	C	3	138.3	102.0		

Table 233. ***Density*** meas. by ***Pavetracker 10233*** – Non-nuclear Gage on ***US-47, MO, pcf***
Continued

Test Date	Station	Point	Trial #	Density	Temperature	Average	Std Dev
08/16/2006	254+00	C	4	137.1	105.0	137.13	4.125
08/16/2006	255+00	A	1	136.4	114.0		
08/16/2006	255+00	A	2	134.6	113.0		
08/16/2006	255+00	A	3	137.1	112.0		
08/16/2006	255+00	A	4	134	113.0	135.53	1.4637
08/16/2006	255+00	B	1	140.1	106.0		
08/16/2006	255+00	B	2	140.7	107.0		
08/16/2006	255+00	B	3	139.4	106.0		
08/16/2006	255+00	B	4	136.1	106.0	135.53	1.4637
08/16/2006	255+00	C	1	138	105.0		
08/16/2006	255+00	C	2	136.4	103.0		
08/16/2006	255+00	C	3	139.3	105.0		
08/16/2006	255+00	C	4	140.3	107.0	138.5	1.6872
08/16/2006	255+61	A	1	132.2	131.0		
08/16/2006	255+61	A	2	131.1	128.0		
08/16/2006	255+61	A	3	130.7	128.0		
08/16/2006	255+61	A	4	133.3	128.0	131.83	1.1701
08/16/2006	255+61	B	1	131.7	118.0		
08/16/2006	255+61	B	2	128.3	112.0		
08/16/2006	255+61	B	3	122.2	115.0		
08/16/2006	255+61	B	4	129.8	108.0	128	4.1093
08/16/2006	255+61	C	1	132.7	112.0		
08/16/2006	255+61	C	2	135.9	108.0		
08/16/2006	255+61	C	3	126.5	106.0		
08/16/2006	255+61	C	4	121	107.0	129.03	6.6219
08/17/2006	0	A	1	126.1	90.0		
08/17/2006	0	A	2	126.6	91.0		
08/17/2006	0	A	3	128.8	88.0		
08/17/2006	0	A	4	124.7	90.0	126.55	1.702
08/17/2006	0	B	1	126.5	91.0		
08/17/2006	0	B	2	127.2	90.0		
08/17/2006	0	B	3	123.9	90.0		
08/17/2006	0	B	4	120.1	90.0	124.43	3.2139
08/17/2006	100	A	1	123	93.0		
08/17/2006	100	A	2	125	92.0		
08/17/2006	100	A	3	130.6	90.0		

Table 233. ***Density*** meas. by ***Pavetracker 10233*** – Non-nuclear Gage on ***US-47, MO, pcf***
Continued

Test Date	Station	Point	Trial #	Density	Temperature	Average	Std Dev
08/17/2006	100	A	4	130	92.0	127.15	3.7359
08/17/2006	100	B	1	126.8	94.0		
08/17/2006	100	B	2	130	94.0		
08/17/2006	100	B	3	125.4	92.0		
08/17/2006	100	B	4	126.7	92.0	127.23	1.9568
08/17/2006	1000	A	1	133.2	105.0		
08/17/2006	1000	A	2	132	105.0		
08/17/2006	1000	A	3	130.5	102.0		
08/17/2006	1000	A	4	131.9	103.0	131.9	1.1045
08/17/2006	1000	B	1	125.7	105.0		
08/17/2006	1000	B	2	123.6	104.0		
08/17/2006	1000	B	3	125.8	103.0		
08/17/2006	1000	B	4	121.1	104.0	124.05	2.2128
08/17/2006	200	A	1	127.5	95.0		
08/17/2006	200	A	2	127.7	96.0		
08/17/2006	200	A	3	129.2	95.0		
08/17/2006	200	A	4	131.2	95.0	128.9	1.7108
08/17/2006	200	B	1	126.2	95.0		
08/17/2006	200	B	2	126.3	94.0		
08/17/2006	200	B	3	125.4	94.0	125.97	0.4933
08/17/2006	300	A	1	131	95.0		
08/17/2006	300	A	2	130.8	95.0		
08/17/2006	300	A	3	133.6	95.0		
08/17/2006	300	A	4	124	94.0	129.85	4.1033
08/17/2006	300	B	1	130	95.0		
08/17/2006	300	B	2	129.8	95.0		
08/17/2006	300	B	3	125.1	95.0		
08/17/2006	300	B	4	125.8	95.0	127.68	2.5863
08/17/2006	400	A	1	127.7	95.0		
08/17/2006	400	A	2	125.5	95.0		
08/17/2006	400	A	3	128.6	94.0		
08/17/2006	400	A	4	122.9	94.0	126.18	2.5421
08/17/2006	400	B	1	125.4	95.0		
08/17/2006	400	B	2	123.9	95.0		
08/17/2006	400	B	3	125.1	94.0		

Table 233. ***Density*** meas. by ***Pavetracker 10233*** – Non-nuclear Gage on ***US-47, MO, pcf***
Continued

Test Date	Station	Point	Trial #	Density	Temperature	Average	Std Dev
08/17/2006	400	B	4	127.8	94.0	125.55	1.634
08/17/2006	500	A	1	126.7	97.0		
08/17/2006	500	A	2	129.6	95.0		
08/17/2006	500	A	3	128.6	94.0		
08/17/2006	500	A	4	128.7	96.0	128.4	1.2193
08/17/2006	500	B	1	124	96.0		
08/17/2006	500	B	2	125.4	96.0		
08/17/2006	500	B	3	128.6	95.0		
08/17/2006	500	B	4	127.1	96.0	126.28	2.0023
08/17/2006	600	A	1	125.9	98.0		
08/17/2006	600	A	2	125.1	97.0		
08/17/2006	600	A	3	128	98.0		
08/17/2006	600	A	4	131.5	96.0	127.63	2.8582
08/17/2006	600	B	1	125.5	99.0		
08/17/2006	600	B	2	122.5	97.0		
08/17/2006	600	B	3	124.6	99.0		
08/17/2006	600	B	4	126.3	97.0	124.73	1.6378
08/17/2006	700	A	1	125.7	98.0		
08/17/2006	700	A	2	133.6	98.0		
08/17/2006	700	A	3	128.1	95.0		
08/17/2006	700	A	4	129.9	96.0	129.33	3.329
08/17/2006	700	B	1	128.3	98.0		
08/17/2006	700	B	2	121.5	97.0		
08/17/2006	700	B	3	126.9	97.0		
08/17/2006	700	B	4	127	96.0	125.93	3.0181
08/17/2006	800	A	1	124.3	102.0		
08/17/2006	800	A	2	126	103.0		
08/17/2006	800	A	3	126.2	102.0		
08/17/2006	800	A	4	125	100.0	125.38	0.8884
08/17/2006	800	B	1	124.3	103.0		
08/17/2006	800	B	2	123.9	102.0		
08/17/2006	800	B	3	127.2	101.0		
08/17/2006	800	B	4	124.4	100.0	124.95	1.5155
08/17/2006	900	A	1	134.6	103.0		
08/17/2006	900	A	2	134.9	102.0		
08/17/2006	900	A	3	133.6	101.0		

Table 233. ***Density*** meas. by ***Pavetracker 10233*** – Non-nuclear Gage on ***US-47, MO, pcf***
Continued

Test Date	Station	Point	Trial #	Density	Temperature	Average	Std Dev
08/17/2006	900	A	4	124.6	101.0	131.93	4.9149
08/17/2006	900	B	1	130.4	102.0		
08/17/2006	900	B	2	129	102.0		
08/17/2006	900	B	3	129.8	102.0		
08/17/2006	900	B	4	131.4	102.0	130.15	1.0116

Table 234. ***Modulus*** measured by ***PSPA*** on ***US-47, MO, ksi***

Test Date	Station	Point	Modulus	Average
08/17/2006	0	A	646	
08/17/2006	0	A	643	
08/17/2006	0	A	643	644
08/17/2006	0	B	667	
08/17/2006	0	B	653	
08/17/2006	0	B	568	629
08/17/2006	100	A	670	
08/17/2006	100	A	596	
08/17/2006	100	A	520	595
08/17/2006	100	B	598	
08/17/2006	100	B	535	
08/17/2006	100	B	489	541
08/17/2006	200	A	618	
08/17/2006	200	A	521	
08/17/2006	200	A	493	544
08/17/2006	200	B	598	
08/17/2006	200	B	589	
08/17/2006	200	B	482	556
08/17/2006	300	A	664	
08/17/2006	300	A	650	
08/17/2006	300	A	646	653
08/17/2006	300	B	603	
08/17/2006	300	B	566	
08/17/2006	300	B	539	570
08/17/2006	400	A	695	
08/17/2006	400	A	663	
08/17/2006	400	A	623	660
08/17/2006	400	B	579	
08/17/2006	400	B	561	
08/17/2006	400	B	536	559
08/17/2006	500	A	760	
08/17/2006	500	A	705	
08/17/2006	500	A	573	679
08/17/2006	500	B	610	
08/17/2006	500	B	540	
08/17/2006	500	B	525	558
08/17/2006	600	A	714	

Table 234. ***Modulus*** measured by ***PSPA*** on ***US-47, MO, ksi***
Continued

Test Date	Station	Point	Modulus	Average
08/17/2006	600	A	655	
08/17/2006	600	A	618	662
08/17/2006	600	B	599	
08/17/2006	600	B	522	
08/17/2006	600	B	520	547
08/17/2006	700	A	652	
08/17/2006	700	A	547	
08/17/2006	700	A	536	578
08/17/2006	700	B	545	
08/17/2006	700	B	544	
08/17/2006	700	B	503	531
08/17/2006	800	A	687	
08/17/2006	800	A	574	
08/17/2006	800	A	529	597
08/17/2006	800	B	616	
08/17/2006	800	B	614	
08/17/2006	800	B	575	602
08/17/2006	900	A	656	
08/17/2006	900	A	627	
08/17/2006	900	A	595	626
08/17/2006	900	B	610	
08/17/2006	900	B	595	
08/17/2006	900	B	587	597
08/17/2006	1000	A	789	
08/17/2006	1000	A	701	
08/17/2006	1000	A	636	709
08/17/2006	1000	B	618	
08/17/2006	1000	B	602	
08/17/2006	1000	B	580	600
08/16/2006	189+09	A	231	
08/16/2006	189+09	A	231	
08/16/2006	189+09	A	206	223
08/16/2006	189+09	B	348	
08/16/2006	189+09	B	344	
08/16/2006	189+09	B	329	340

Table 234. ***Modulus*** measured by ***PSPA*** on ***US-47, MO, ksi***
Continued

Test Date	Station	Point	Modulus	Average
08/16/2006	189+09	C	356	
08/16/2006	189+09	C	319	
08/16/2006	189+09	C	308	328
08/16/2006	189+09	D	255	
08/16/2006	189+09	D	239	
08/16/2006	189+09	D	225	240
08/16/2006	189+09	E	255	
08/16/2006	189+09	E	231	
08/16/2006	189+09	E	208	231
08/16/2006	192+59	A	275	
08/16/2006	192+59	A	243	
08/16/2006	192+59	A	243	254
08/16/2006	192+59	B	325	
08/16/2006	192+59	B	319	
08/16/2006	192+59	B	304	316
08/16/2006	192+59	C	263	
08/16/2006	192+59	C	255	
08/16/2006	192+59	C	255	258
08/16/2006	192+59	D	299	
08/16/2006	192+59	D	278	
08/16/2006	192+59	D	211	263
08/16/2006	192+59	E	309	
08/16/2006	192+59	E	307	
08/16/2006	192+59	E	203	273
08/16/2006	196+29	A	358	
08/16/2006	196+29	A	267	
08/16/2006	196+29	A	210	278
08/16/2006	196+29	B	296	
08/16/2006	196+29	B	279	
08/16/2006	196+29	B	241	272
08/16/2006	196+29	C	259	
08/16/2006	196+29	C	241	
08/16/2006	196+29	C	206	235
08/16/2006	196+29	D	234	
08/16/2006	196+29	D	193	
08/16/2006	196+29	D	191	206

Table 234. ***Modulus*** measured by ***PSPA*** on ***US-47, MO, ksi***
Continued

Test Date	Station	Point	Modulus	Average
08/16/2006	196+29	E	246	
08/16/2006	196+29	E	183	
08/16/2006	196+29	E	177	202
08/16/2006	201+09	A	286	
08/16/2006	201+09	A	261	
08/16/2006	201+09	A	257	268
08/16/2006	201+09	B	276	
08/16/2006	201+09	B	257	
08/16/2006	201+09	B	219	251
08/16/2006	201+09	C	294	
08/16/2006	201+09	C	249	
08/16/2006	201+09	C	199	247
08/16/2006	201+09	D	335	
08/16/2006	201+09	D	294	
08/16/2006	201+09	D	234	287
08/16/2006	201+09	E	263	
08/16/2006	201+09	E	249	
08/16/2006	201+09	E	228	247
08/16/2006	213+09	A	286	
08/16/2006	213+09	A	267	
08/16/2006	213+09	A	247	267
08/16/2006	213+09	B	343	
08/16/2006	213+09	B	311	
08/16/2006	213+09	B	303	319
08/16/2006	213+09	C	329	
08/16/2006	213+09	C	317	
08/16/2006	213+09	C	312	319
08/16/2006	213+09	D	306	
08/16/2006	213+09	D	298	
08/16/2006	213+09	D	280	295
08/16/2006	213+09	E	287	
08/16/2006	213+09	E	283	
08/16/2006	213+09	E	262	278
08/16/2006	217+49	A	315	
08/16/2006	217+49	A	304	
08/16/2006	217+49	A	221	280

Table 234. ***Modulus*** measured by ***PSPA*** on ***US-47, MO, ksi***
Continued

Test Date	Station	Point	Modulus	Average
08/16/2006	217+49	B	321	
08/16/2006	217+49	B	314	
08/16/2006	217+49	B	311	315
08/16/2006	217+49	C	357	
08/16/2006	217+49	C	354	
08/16/2006	217+49	C	306	339
08/16/2006	217+49	D	327	
08/16/2006	217+49	D	320	
08/16/2006	217+49	D	305	317
08/16/2006	217+49	E	293	
08/16/2006	217+49	E	282	
08/16/2006	217+49	E	255	277
08/16/2006	219+09	A	317	
08/16/2006	219+09	A	309	
08/16/2006	219+09	A	243	290
08/16/2006	219+09	B	317	
08/16/2006	219+09	B	317	
08/16/2006	219+09	B	303	312
08/16/2006	219+09	C	338	
08/16/2006	219+09	C	322	
08/16/2006	219+09	C	295	318
08/16/2006	219+09	D	336	
08/16/2006	219+09	D	321	
08/16/2006	219+09	D	310	323
08/16/2006	219+09	E	344	
08/16/2006	219+09	E	322	
08/16/2006	219+09	E	274	313
08/16/2006	222+09	A	296	
08/16/2006	222+09	A	292	
08/16/2006	222+09	A	269	286
08/16/2006	222+09	B	356	
08/16/2006	222+09	B	338	
08/16/2006	222+09	B	323	339
08/16/2006	222+09	C	341	
08/16/2006	222+09	C	341	
08/16/2006	222+09	C	326	336

Table 234. ***Modulus*** measured by ***PSPA*** on ***US-47, MO, ksi***
Continued

Test Date	Station	Point	Modulus	Average
08/16/2006	222+09	D	322	
08/16/2006	222+09	D	322	
08/16/2006	222+09	D	314	319
08/16/2006	222+09	E	354	
08/16/2006	222+09	E	295	
08/16/2006	222+09	E	255	301
08/16/2006	225+09	A	333	
08/16/2006	225+09	A	333	
08/16/2006	225+09	A	305	324
08/16/2006	225+09	B	312	
08/16/2006	225+09	B	300	
08/16/2006	225+09	B	300	304
08/16/2006	225+09	C	329	
08/16/2006	225+09	C	303	
08/16/2006	225+09	C	303	312
08/16/2006	225+09	D	367	
08/16/2006	225+09	D	329	
08/16/2006	225+09	D	329	341
08/16/2006	225+09	E	343	
08/16/2006	225+09	E	324	
08/16/2006	225+09	E	293	320
08/16/2006	228+09	A	306	
08/16/2006	228+09	A	298	
08/16/2006	228+09	A	294	300
08/16/2006	228+09	B	352	
08/16/2006	228+09	B	324	
08/16/2006	228+09	B	293	323
08/16/2006	228+09	C	373	
08/16/2006	228+09	C	335	
08/16/2006	228+09	C	320	343
08/16/2006	228+09	D	325	
08/16/2006	228+09	D	325	
08/16/2006	228+09	D	315	321
08/16/2006	228+09	E	335	
08/16/2006	228+09	E	311	
08/16/2006	228+09	E	303	316

Table 234. ***Modulus*** measured by ***PSPA*** on ***US-47, MO, ksi***
Continued

Test Date	Station	Point	Modulus	Average
08/16/2006	243+05	A	320	
08/16/2006	243+05	A	319	
08/16/2006	243+05	A	308	316
08/16/2006	243+05	B	322	
08/16/2006	243+05	B	315	
08/16/2006	243+05	B	311	316
08/16/2006	243+05	C	406	
08/16/2006	243+05	C	395	
08/16/2006	243+05	C	388	396
08/16/2006	243+05	D	340	
08/16/2006	243+05	D	337	
08/16/2006	243+05	D	316	331
08/16/2006	243+05	E	301	
08/16/2006	243+05	E	284	
08/16/2006	243+05	E	277	287
08/16/2006	244+00	A	306	
08/16/2006	244+00	A	303	
08/16/2006	244+00	A	284	298
08/16/2006	244+00	B	381	
08/16/2006	244+00	B	374	
08/16/2006	244+00	B	313	356
08/16/2006	244+00	C	399	
08/16/2006	244+00	C	385	
08/16/2006	244+00	C	338	374
08/16/2006	244+00	D	364	
08/16/2006	244+00	D	322	
08/16/2006	244+00	D	315	333
08/16/2006	244+00	E	284	
08/16/2006	244+00	E	273	
08/16/2006	244+00	E	248	269
08/16/2006	246+02	A	372	
08/16/2006	246+02	A	328	
08/16/2006	246+02	A	281	327
08/16/2006	246+02	B	402	
08/16/2006	246+02	B	356	
08/16/2006	246+02	B	328	362

Table 234. ***Modulus*** measured by ***PSPA*** on ***US-47, MO, ksi***
Continued

Test Date	Station	Point	Modulus	Average
08/16/2006	246+02	C	378	
08/16/2006	246+02	C	378	
08/16/2006	246+02	C	371	375
08/16/2006	246+02	D	397	
08/16/2006	246+02	D	390	
08/16/2006	246+02	D	348	378
08/16/2006	246+02	E	334	
08/16/2006	246+02	E	320	
08/16/2006	246+02	E	288	314
08/16/2006	248+00	A	349	
08/16/2006	248+00	A	308	
08/16/2006	248+00	A	279	312
08/16/2006	248+00	B	338	
08/16/2006	248+00	B	313	
08/16/2006	248+00	B	275	309
08/16/2006	248+00	C	404	
08/16/2006	248+00	C	400	
08/16/2006	248+00	C	354	386
08/16/2006	248+00	D	353	
08/16/2006	248+00	D	345	
08/16/2006	248+00	D	331	343
08/16/2006	248+00	E	288	
08/16/2006	248+00	E	277	
08/16/2006	248+00	E	270	278
08/16/2006	250+22	A	319	
08/16/2006	250+22	A	308	
08/16/2006	250+22	A	308	311
08/16/2006	250+22	B	317	
08/16/2006	250+22	B	314	
08/16/2006	250+22	B	208	280
08/16/2006	250+22	C	342	
08/16/2006	250+22	C	334	
08/16/2006	250+22	C	239	305
08/16/2006	250+22	D	364	
08/16/2006	250+22	D	323	
08/16/2006	250+22	D	316	334

Table 234. ***Modulus*** measured by ***PSPA*** on ***US-47, MO, ksi***
Continued

Test Date	Station	Point	Modulus	Average
08/16/2006	250+22	E	292	
08/16/2006	250+22	E	273	
08/16/2006	250+22	E	263	276
08/16/2006	251+61	A	315	
08/16/2006	251+61	A	280	
08/16/2006	251+61	A	280	292
08/16/2006	251+61	B	348	
08/16/2006	251+61	B	329	
08/16/2006	251+61	B	306	328
08/16/2006	251+61	C	359	
08/16/2006	251+61	C	291	
08/16/2006	251+61	C	284	311
08/16/2006	251+61	Core Location	308	
08/16/2006	251+61	Core Location	305	
08/16/2006	251+61	Core Location	289	301
08/16/2006	251+61	D	325	
08/16/2006	251+61	D	310	
08/16/2006	251+61	D	306	314
08/16/2006	251+61	E	272	
08/16/2006	251+61	E	257	
08/16/2006	251+61	E	250	260
08/16/2006	253+40	A	312	
08/16/2006	253+40	A	296	
08/16/2006	253+40	A	292	300
08/16/2006	253+40	B	319	
08/16/2006	253+40	B	311	
08/16/2006	253+40	B	308	313
08/16/2006	253+40	C	354	
08/16/2006	253+40	C	328	
08/16/2006	253+40	C	321	334
08/16/2006	253+40	D	356	
08/16/2006	253+40	D	338	
08/16/2006	253+40	D	296	330
08/16/2006	253+40	E	289	

Table 234. ***Modulus*** measured by ***PSPA*** on ***US-47, MO, ksi***
Continued

Test Date	Station	Point	Modulus	Average
08/16/2006	253+40	E	270	
08/16/2006	253+40	E	255	271
08/16/2006	254+00	A	304	
08/16/2006	254+00	A	304	
08/16/2006	254+00	A	284	297
08/16/2006	254+00	B	336	
08/16/2006	254+00	B	302	
08/16/2006	254+00	B	223	287
08/16/2006	254+00	C	328	
08/16/2006	254+00	C	324	
08/16/2006	254+00	C	305	319
08/16/2006	254+00	D	340	
08/16/2006	254+00	D	301	
08/16/2006	254+00	D	282	308
08/16/2006	254+00	E	311	
08/16/2006	254+00	E	292	
08/16/2006	254+00	E	288	297
08/16/2006	255+00	A	325	
08/16/2006	255+00	A	317	
08/16/2006	255+00	A	317	320
08/16/2006	255+00	B	363	
08/16/2006	255+00	B	321	
08/16/2006	255+00	B	276	320
08/16/2006	255+00	C	304	
08/16/2006	255+00	C	296	
08/16/2006	255+00	C	285	295
08/16/2006	255+00	D	305	
08/16/2006	255+00	D	286	
08/16/2006	255+00	D	278	289
08/16/2006	255+00	E	295	
08/16/2006	255+00	E	265	
08/16/2006	255+00	E	261	273
08/16/2006	255+61	A	163	
08/16/2006	255+61	A	135	
08/16/2006	255+61	A	132	143
08/16/2006	255+61	B	193	

Table 234. ***Modulus*** measured by ***PSPA*** on ***US-47, MO, ksi***
Continued

Test Date	Station	Point	Modulus	Average
08/16/2006	255+61	B	158	
08/16/2006	255+61	B	152	168
08/16/2006	255+61	C	162	
08/16/2006	255+61	C	124	
08/16/2006	255+61	C	112	133
08/16/2006	255+61	D	166	
08/16/2006	255+61	D	166	
08/16/2006	255+61	D	154	162
08/16/2006	255+61	E	184	
08/16/2006	255+61	E	156	
08/16/2006	255+61	E	156	165

Table 235. ***Density*** measured by ***NDG*** on ***US-47, MO, pcf***

Test Date	Station	Point	Trial #	Density
08/16/2006	225+09	A	1	142.1
08/16/2006	225+09	A	1	142.1
08/16/2006	225+09	A	1	142.1
08/16/2006	225+09	A	1	142.1
08/16/2006	225+09	A	1	142.1
08/16/2006	225+09	A	1	142.1
08/16/2006	225+09	B	1	143.1
08/16/2006	225+09	B	1	143.1
08/16/2006	225+09	B	1	143.1
08/16/2006	225+09	B	1	143.1
08/16/2006	225+09	B	1	143.1
08/16/2006	225+09	C	1	144.2
08/16/2006	225+09	C	1	144.2
08/16/2006	225+09	C	1	144.2
08/16/2006	225+09	C	1	144.2
08/16/2006	225+09	C	1	144.2
08/16/2006	225+09	C	1	144.2
08/16/2006	225+09	D	1	140.7
08/16/2006	225+09	D	1	140.7
08/16/2006	225+09	D	1	140.7
08/16/2006	225+09	D	1	140.7
08/16/2006	225+09	D	1	140.7
08/16/2006	225+09	E	1	134.7
08/16/2006	225+09	E	1	134.7
08/16/2006	225+09	E	1	134.7
08/16/2006	225+09	E	1	134.7
08/16/2006	225+09	E	1	134.7
08/16/2006	225+09	E	1	134.7
08/16/2006	228+09	A	1	142.5
08/16/2006	228+09	A	1	142.5
08/16/2006	228+09	A	1	142.5
08/16/2006	228+09	A	1	142.5
08/16/2006	228+09	A	1	142.5
08/16/2006	228+09	B	1	145.3
08/16/2006	228+09	B	1	145.3
08/16/2006	228+09	B	1	145.3
08/16/2006	228+09	B	1	145.3

Table 236. ***Density*** measured by ***NDG*** on ***US-47, MO, pcf***
Continued

Test Date	Station	Point	Trial #	Density
08/16/2006	228+09	B	1	145.3
08/16/2006	228+09	B	1	145.3
08/16/2006	228+09	B	1	145.3
08/16/2006	228+09	C	1	144.4
08/16/2006	228+09	C	1	144.4
08/16/2006	228+09	C	1	144.4
08/16/2006	228+09	C	1	144.4
08/16/2006	228+09	C	1	144.4
08/16/2006	228+09	C	1	144.4
08/16/2006	228+09	D	1	139.2
08/16/2006	228+09	D	1	139.2
08/16/2006	228+09	D	1	139.2
08/16/2006	228+09	D	1	139.2
08/16/2006	228+09	D	1	139.2
08/16/2006	228+09	E	1	135.2
08/16/2006	228+09	E	1	135.2
08/16/2006	228+09	E	1	135.2
08/16/2006	243+05	A	1	144.9
08/16/2006	243+05	A	1	144.9
08/16/2006	243+05	B	1	143.8
08/16/2006	243+05	B	1	143.8
08/16/2006	243+05	B	1	143.8
08/16/2006	243+05	C	1	141.5
08/16/2006	243+05	C	1	141.5
08/16/2006	243+05	C	1	141.5
08/16/2006	243+05	C	1	141.5
08/16/2006	243+05	D	1	139.6
08/16/2006	243+05	D	1	139.6
08/16/2006	243+05	D	1	139.6
08/16/2006	243+05	E	1	131.1
08/16/2006	243+05	E	1	131.1
08/16/2006	243+05	E	1	131.1
08/16/2006	246+02	A	1	141.9
08/16/2006	246+02	A	1	141.9
08/16/2006	246+02	A	1	141.9

Table 236. ***Density*** measured by ***NDG*** on ***US-47, MO, pcf***
Continued

Test Date	Station	Point	Trial #	Density
08/16/2006	246+02	B	1	141.8
08/16/2006	246+02	B	1	141.8
08/16/2006	246+02	B	1	141.8
08/16/2006	246+02	C	1	145.4
08/16/2006	246+02	C	1	145.4
08/16/2006	246+02	C	1	145.4
08/16/2006	246+02	C	1	145.4
08/16/2006	246+02	D	1	142.2
08/16/2006	246+02	D	1	142.2
08/16/2006	246+02	D	1	142.2
08/16/2006	246+02	E	1	136.6
08/16/2006	246+02	E	1	136.6
08/16/2006	250+22	A	1	142.6
08/16/2006	250+22	A	1	142.6
08/16/2006	250+22	B	1	143.2
08/16/2006	250+22	B	1	143.2
08/16/2006	250+22	B	1	143.2
08/16/2006	250+22	C	1	143.1
08/16/2006	250+22	C	1	143.1
08/16/2006	250+22	C	1	143.1
08/16/2006	250+22	C	1	143.1
08/16/2006	250+22	D	1	145.1
08/16/2006	250+22	D	1	145.1
08/16/2006	250+22	D	1	145.1
08/16/2006	250+22	D	1	145.1
08/16/2006	250+22	D	1	145.1
08/16/2006	250+22	E	1	133.3
08/16/2006	250+22	E	1	133.3
08/16/2006	250+22	E	1	133.3
08/16/2006	251+61	A	1	142.5
08/16/2006	251+61	A	1	142.5
08/16/2006	251+61	A	1	142.5
08/16/2006	251+61	A	1	142.5
08/16/2006	251+61	A	1	142.5
08/16/2006	251+61	A	1	142.5
08/16/2006	251+61	B	1	145.3

Table 236. ***Density*** measured by ***NDG*** on ***US-47, MO, pcf***
Continued

Test Date	Station	Point	Trial #	Density
08/16/2006	251+61	B	1	145.3
08/16/2006	251+61	B	1	145.3
08/16/2006	251+61	C	1	143.1
08/16/2006	251+61	C	1	143.1
08/16/2006	251+61	C	1	143.1
08/16/2006	251+61	C	1	143.1
08/16/2006	251+61	C	1	143.1
08/16/2006	251+61	C	1	143.1
08/16/2006	251+61	D	1	139.7
08/16/2006	251+61	D	1	139.7
08/16/2006	251+61	D	1	139.7
08/16/2006	251+61	D	1	139.7
08/16/2006	251+61	D	1	139.7
08/16/2006	251+61	D	1	139.7
08/16/2006	251+61	E	1	135.1
08/16/2006	251+61	E	1	135.1
08/16/2006	251+61	E	1	135.1
08/16/2006	251+61	E	1	135.1
08/16/2006	251+61	E	1	135.1
08/16/2006	253+40	A	1	143.7
08/16/2006	253+40	A	1	143.7
08/16/2006	253+40	A	1	143.7
08/16/2006	253+40	A	1	143.7
08/16/2006	253+40	B	1	140.2
08/16/2006	253+40	B	1	140.2
08/16/2006	253+40	B	1	140.2
08/16/2006	253+40	B	1	140.2
08/16/2006	253+40	C	1	142.2
08/16/2006	253+40	C	1	142.2
08/16/2006	253+40	C	1	142.2
08/16/2006	253+40	C	1	142.2
08/16/2006	253+40	D	1	139.4
08/16/2006	253+40	D	1	139.4
08/16/2006	253+40	D	1	139.4
08/16/2006	253+40	D	1	139.4
08/16/2006	253+40	E	1	134.6

Table 236. ***Density*** measured by ***NDG*** on ***US-47, MO, pcf***
Continued

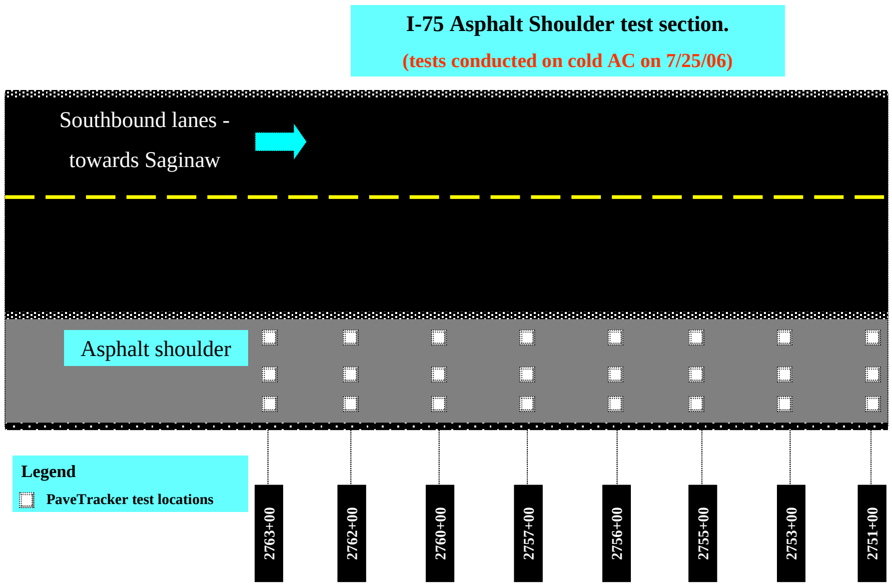
Test Date	Station	Point	Trial #	Density
08/16/2006	253+40	E	1	134.6
08/16/2006	253+40	E	1	134.6
08/16/2006	253+40	E	1	134.6
08/16/2006	255+61	A	1	141.1
08/16/2006	255+61	A	1	141.1
08/16/2006	255+61	A	1	141.1
08/16/2006	255+61	A	1	141.1
08/16/2006	255+61	A	1	141.1
08/16/2006	255+61	B	1	145.7
08/16/2006	255+61	B	1	145.7
08/16/2006	255+61	B	1	145.7
08/16/2006	255+61	B	1	145.7
08/16/2006	255+61	B	1	145.7
08/16/2006	255+61	B	1	145.7
08/16/2006	255+61	B	1	145.7
08/16/2006	255+61	B	1	145.7
08/16/2006	255+61	C	1	144.1
08/16/2006	255+61	C	1	144.1
08/16/2006	255+61	C	1	144.1
08/16/2006	255+61	C	1	144.1
08/16/2006	255+61	C	1	144.1
08/16/2006	255+61	C	1	144.1
08/16/2006	255+61	C	1	144.1
08/16/2006	255+61	D	1	140.9
08/16/2006	255+61	D	1	140.9
08/16/2006	255+61	D	1	140.9
08/16/2006	255+61	D	1	140.9
08/16/2006	255+61	D	1	140.9
08/16/2006	255+61	D	1	140.9
08/16/2006	255+61	D	1	140.9
08/16/2006	255+61	E	1	133.7
08/16/2006	255+61	E	1	133.7
08/16/2006	255+61	E	1	133.7
08/16/2006	255+61	E	1	133.7
08/16/2006	255+61	E	1	133.7
08/16/2006	255+61	E	1	133.7

Table 236. ***Density*** measured by ***NDG*** on ***US-47, MO, pcf***

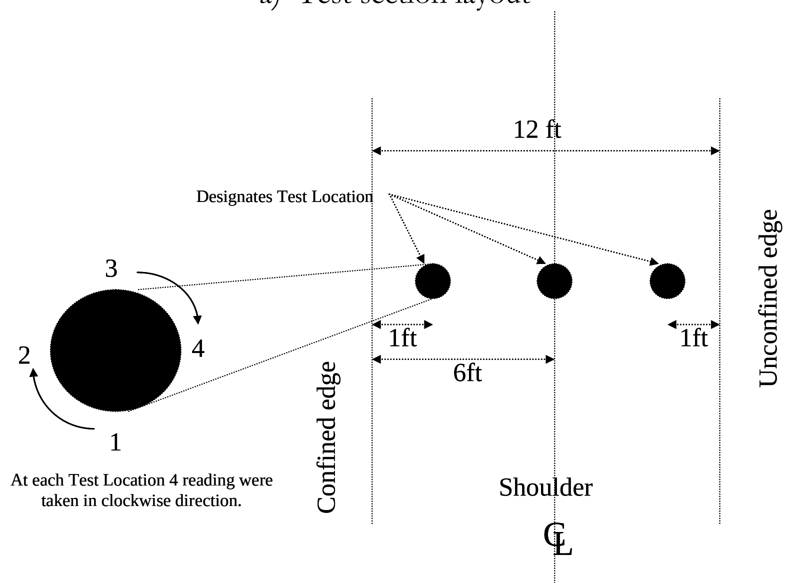
Continued

Test Date	Station	Point	Trial #	Density
08/16/2006	255+61	E	1	133.7

I-75, MICHIGAN HMA SECTIONS

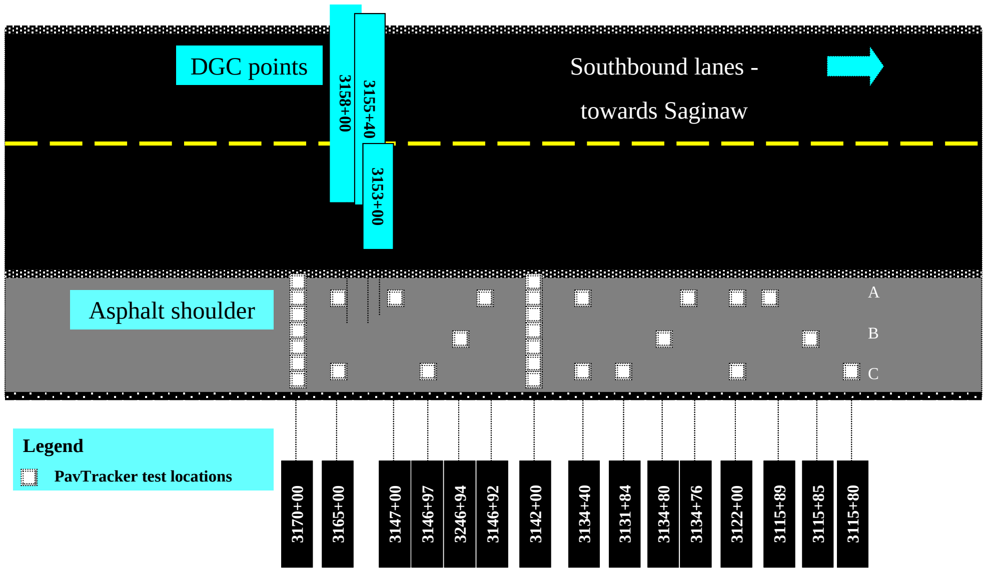


a) Test section layout

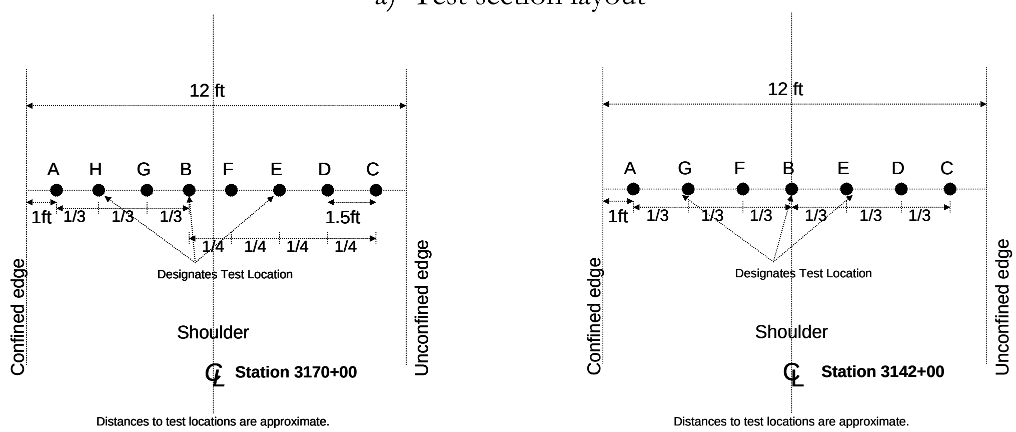


b) Transverse position of test points at each station

General Layout of Test Points Along Shoulder for Section 1; Paved on July 19 to 21 and Tested on July 25, 2006



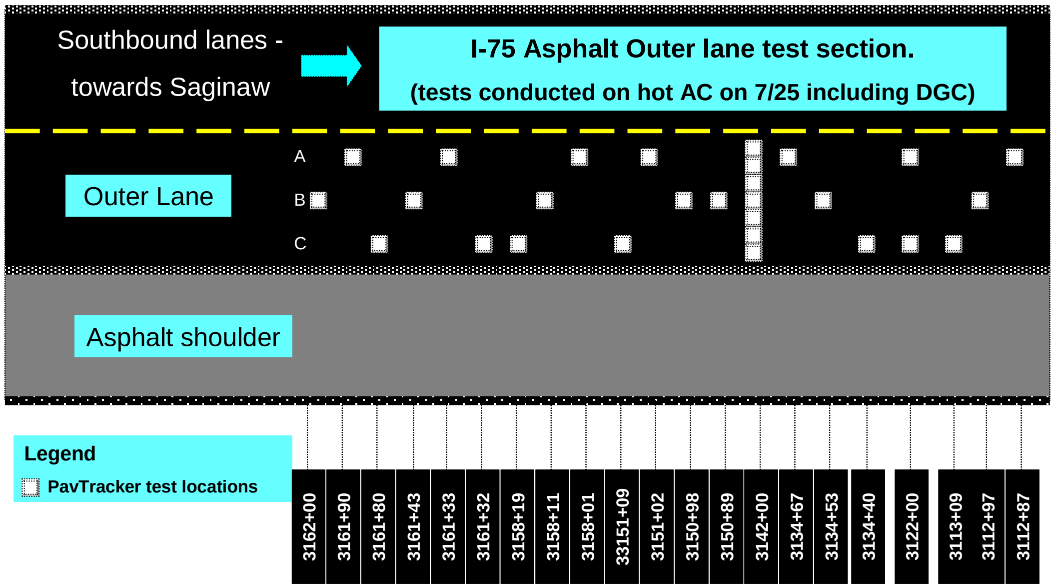
a) Test section layout



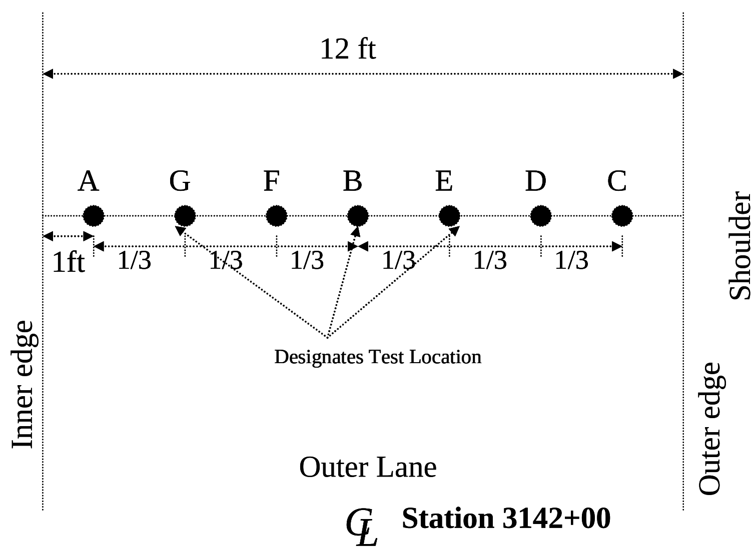
b) Layout for stations 3170+00 and 3142+00

Note: All other points on test section were more or less centered and evenly distributed across width of the section

General Layout of Test Points Along Shoulder for Section 2; Testing Performed Immediately After Paving on July 25, 2006



a) Test section layout

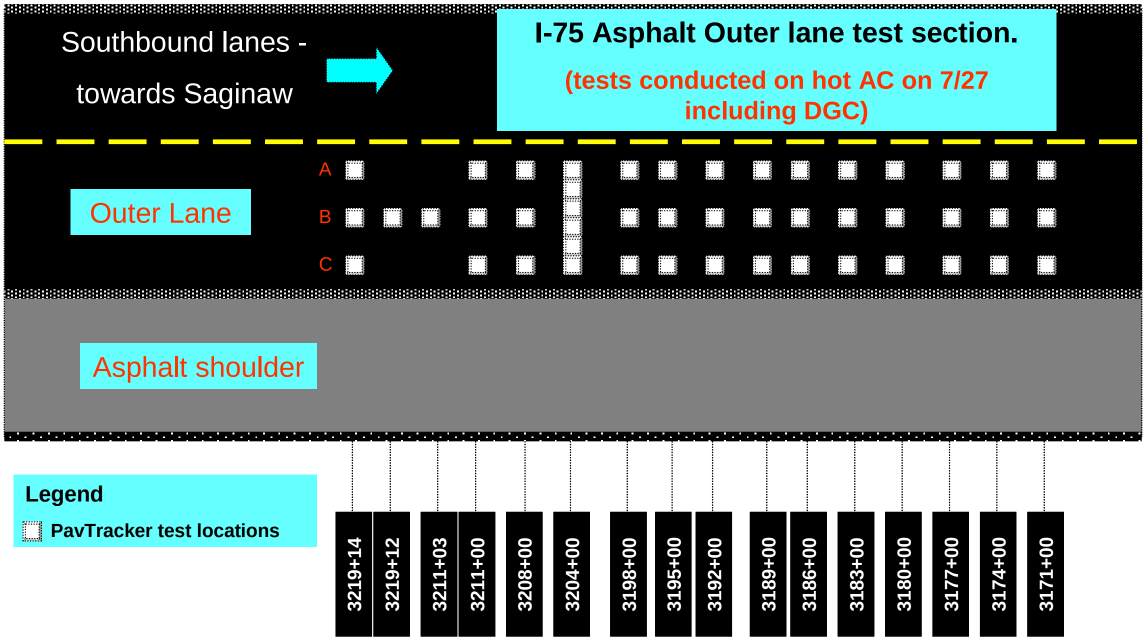


Distances to test locations are approximate.

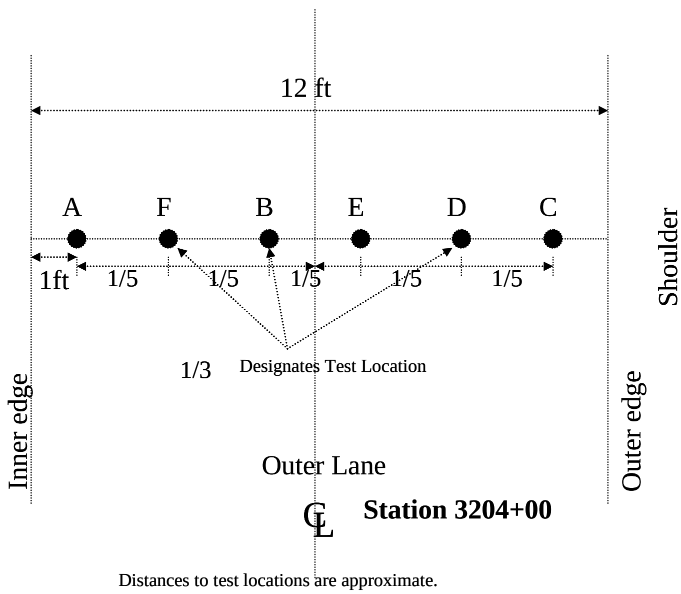
b) Layout for stations 3142+00

Note: All other points on test section were more or less centered and evenly distributed across width of the section

General Layout of Test Points Along Section 3, Outer Lane; Testing Performed Immediately After Paving on July 25, 2006



a) Test section layout



b) Layout for stations 3204+00

Note: All other points on test section were more or less centered and evenly distributed across width of the section

General Layout of Test Points Along Section 4, Outer Lane; Testing Performed Immediately After Paving on July 27, 2006

Table 237. ***Density*** meas. by ***Pavetracker 10232*** – Non-nuclear Gage on ***I-75, MI, pcf***

Test Date	Station	Point	Trial #	Density	Average	Std Dev
07/25/2006	2751+00	A	1	151.9		
07/25/2006	2751+00	A	2	150.7		
07/25/2006	2751+00	A	3	148.7		
07/25/2006	2751+00	A	4	150.6	150.48	1.3226
07/25/2006	2751+00	B	1	146.4		
07/25/2006	2751+00	B	2	155.6		
07/25/2006	2751+00	B	3	157.5		
07/25/2006	2751+00	B	4	156.9	154.1	5.1942
07/25/2006	2751+00	C	1	144.3		
07/25/2006	2751+00	C	2	153.4		
07/25/2006	2751+00	C	3	147.1		
07/25/2006	2751+00	C	4	142.9	146.93	4.6564
07/25/2006	2753+00	A	1	147.7		
07/25/2006	2753+00	A	2	142.4		
07/25/2006	2753+00	A	3	145.2		
07/25/2006	2753+00	A	4	138.4	143.43	3.9886
07/25/2006	2753+00	B	1	142.4		
07/25/2006	2753+00	B	2	144.7		
07/25/2006	2753+00	B	3	149.7		
07/25/2006	2753+00	B	4	145.6	145.6	3.0474
07/25/2006	2753+00	C	1	143.9		
07/25/2006	2753+00	C	2	141.7		
07/25/2006	2753+00	C	3	145.7		
07/25/2006	2753+00	C	4	146.8	144.53	2.2307
07/25/2006	2755+00	A	1	150		
07/25/2006	2755+00	A	2	147.9		
07/25/2006	2755+00	A	3	143.4		
07/25/2006	2755+00	A	4	155.2	149.13	4.8972
07/25/2006	2755+00	B	1	146.6		
07/25/2006	2755+00	B	2	156.2		
07/25/2006	2755+00	B	3	148.3		
07/25/2006	2755+00	B	4	144.9	149	4.9967
07/25/2006	2755+00	C	1	147		
07/25/2006	2755+00	C	2	150.8		
07/25/2006	2755+00	C	3	156.9		
07/25/2006	2755+00	C	4	153.3	152	4.1689

Table 237. ***Density*** meas. by ***Pavetracker 10232*** – Non-nuclear Gage on ***I-75, MI, pcf***
Continued

Test Date	Station	Point	Trial #	Density	Average	Std Dev
07/25/2006	2756+00	A	1	144.9		
07/25/2006	2756+00	A	2	135.2		
07/25/2006	2756+00	A	3	148.9		
07/25/2006	2756+00	A	4	140.4	142.35	5.8972
07/25/2006	2756+00	B	1	145.9		
07/25/2006	2756+00	B	2	148.6		
07/25/2006	2756+00	B	3	150.3		
07/25/2006	2756+00	B	4	148.8	148.4	1.8312
07/25/2006	2756+00	C	1	147.8		
07/25/2006	2756+00	C	2	145.1		
07/25/2006	2756+00	C	3	144.2		
07/25/2006	2756+00	C	4	145.6	145.68	1.5305
07/25/2006	2757+00	A	1	144.8		
07/25/2006	2757+00	A	2	143.4		
07/25/2006	2757+00	A	3	138.5		
07/25/2006	2757+00	A	4	142.2	142.23	2.7011
07/25/2006	2757+00	B	1	152.9		
07/25/2006	2757+00	B	2	144.9		
07/25/2006	2757+00	B	3	140.3		
07/25/2006	2757+00	B	4	138.7	144.2	6.3676
07/25/2006	2757+00	C	1	143.4		
07/25/2006	2757+00	C	2	142.2		
07/25/2006	2757+00	C	3	139		
07/25/2006	2757+00	C	4	142.7	141.83	1.9466
07/25/2006	2760+00	A	1	139.4		
07/25/2006	2760+00	A	2	130.5		
07/25/2006	2760+00	A	3	141.2		
07/25/2006	2760+00	A	4	142.4	138.38	5.3928
07/25/2006	2760+00	B	1	148.6		
07/25/2006	2760+00	B	2	137.6		
07/25/2006	2760+00	B	3	145.8		
07/25/2006	2760+00	B	4	147.9	144.98	5.0586
07/25/2006	2760+00	C	1	142.2		
07/25/2006	2760+00	C	2	146.7		
07/25/2006	2760+00	C	3	141.8		

Table 237. ***Density*** meas. by ***Pavetracker 10232*** – Non-nuclear Gage on ***I-75, MI, pcf***
Continued

Test Date	Station	Point	Trial #	Density	Average	Std Dev
07/25/2006	2760+00	C	4	143.4	143.53	2.2232
07/25/2006	2762+00	A	1	150.1		
07/25/2006	2762+00	A	2	143.5		
07/25/2006	2762+00	A	3	150.1		
07/25/2006	2762+00	A	4	145.8	147.38	3.2837
07/25/2006	2762+00	B	1	148.6		
07/25/2006	2762+00	B	2	132.5		
07/25/2006	2762+00	B	3	149.6		
07/25/2006	2762+00	B	4	146.4	144.28	7.963
07/25/2006	2762+00	C	1	141.5		
07/25/2006	2762+00	C	2	148.8		
07/25/2006	2762+00	C	3	145.3		
07/25/2006	2762+00	C	4	145.9	145.38	3.0015
07/25/2006	2763+00	A	1	145.9		
07/25/2006	2763+00	A	2	147		
07/25/2006	2763+00	A	3	132.6		
07/25/2006	2763+00	A	4	135.8	140.33	7.2062
07/25/2006	2763+00	B	1	140.7		
07/25/2006	2763+00	B	2	137		
07/25/2006	2763+00	B	3	144.8		
07/25/2006	2763+00	B	4	148.9	142.85	5.1397
07/25/2006	2763+00	C	1	138		
07/25/2006	2763+00	C	2	144		
07/25/2006	2763+00	C	3	130.9		
07/25/2006	2763+00	C	4	141.1	138.5	5.6279
07/25/2006	3115+80	C	1	137		
07/25/2006	3115+80	C	2	144.3		
07/25/2006	3115+80	C	3	141.3		
07/25/2006	3115+80	C	4	140	140.65	3.0271
07/25/2006	3115+85	B	1	144.6		
07/25/2006	3115+85	B	2	143.7		
07/25/2006	3115+85	B	3	143.9		
07/25/2006	3115+85	B	4	147.4	144.9	1.7108
07/25/2006	3115+89	A	1	142		
07/25/2006	3115+89	A	2	137.9		
07/25/2006	3115+89	A	3	142.8		

Table 237. ***Density*** meas. by ***Pavetracker 10232*** – Non-nuclear Gage on ***I-75, MI, pcf***
Continued

Test Date	Station	Point	Trial #	Density	Average	Std Dev
07/25/2006	3115+89	A	4	141.8	141.13	2.193
07/25/2006	3122+00	A	1	141.6		
07/25/2006	3122+00	A	2	138.2		
07/25/2006	3122+00	A	3	140		
07/25/2006	3122+00	A	4	138.6	139.6	1.5406
07/25/2006	3122+00	C	1	143.5		
07/25/2006	3122+00	C	2	142.2		
07/25/2006	3122+00	C	3	142.2		
07/25/2006	3122+00	C	4	144.3	143.05	1.0344
07/25/2006	3131+76	A	1	145.8		
07/25/2006	3131+76	A	2	148.9		
07/25/2006	3131+76	A	3	146.3		
07/25/2006	3131+76	A	4	147.5	147.13	1.3817
07/25/2006	3131+80	B	1	150.4		
07/25/2006	3131+80	B	2	152.8		
07/25/2006	3131+80	B	3	150.8		
07/25/2006	3131+80	B	4	147.5	150.38	2.1854
07/25/2006	3131+84	C	1	145		
07/25/2006	3131+84	C	2	145.6		
07/25/2006	3131+84	C	3	141.1		
07/25/2006	3131+84	C	4	144.8	144.13	2.0451
07/25/2006	3134+40	A	1	148.2		
07/25/2006	3134+40	A	2	144		
07/25/2006	3134+40	A	3	144.6		
07/25/2006	3134+40	A	4	149.8	146.65	2.8018
07/25/2006	3134+40	C	1	155		
07/25/2006	3134+40	C	2	154.9		
07/25/2006	3134+40	C	3	152.8		
07/25/2006	3134+40	C	4	153.4	154.03	1.0966
07/25/2006	3142+00	A	1	149.7		
07/25/2006	3142+00	A	2	148.6		
07/25/2006	3142+00	A	3	148.8		
07/25/2006	3142+00	A	4	143.9	147.75	2.6109
07/25/2006	3142+00	D	1	148		
07/25/2006	3142+00	D	2	150.1		
07/25/2006	3142+00	D	3	143.1		

Table 237. ***Density*** meas. by ***Pavetracker 10232*** – Non-nuclear Gage on ***I-75, MI, pcf***
Continued

Test Date	Station	Point	Trial #	Density	Average	Std Dev
07/25/2006	3142+00	D	4	146.6	146.95	2.9422
07/25/2006	3142+00	E	1	149.1		
07/25/2006	3142+00	E	2	150.5		
07/25/2006	3142+00	E	3	148		
07/25/2006	3142+00	E	4	147.9	148.88	1.2121
07/25/2006	3142+00	F	1	150.6		
07/25/2006	3142+00	F	2	151.6		
07/25/2006	3142+00	F	3	150.9		
07/25/2006	3142+00	F	4	151.9	151.25	0.6028
07/25/2006	3142+00	G	1	145.2		
07/25/2006	3142+00	G	2	148.4		
07/25/2006	3142+00	G	3	148.9		
07/25/2006	3142+00	G	4	146.7	147.3	1.6872
07/25/2006	3142+00	B	1	149.5		
07/25/2006	3142+00	B	2	146.8		
07/25/2006	3142+00	B	3	147.6		
07/25/2006	3142+00	B	4	149	148.23	1.2447
07/25/2006	3142+00	C	1	147.6		
07/25/2006	3142+00	C	2	145.6		
07/25/2006	3142+00	C	3	145.3		
07/25/2006	3142+00	C	4	143.7	145.55	1.601
07/25/2006	3165+00	A	1	150.9		
07/25/2006	3165+00	A	2	153.1		
07/25/2006	3165+00	A	3	151.7		
07/25/2006	3165+00	A	4	154.5	152.55	1.5864
07/25/2006	3165+00	C	1	149.2		
07/25/2006	3165+00	C	2	152		
07/25/2006	3165+00	C	3	150.9		
07/25/2006	3165+00	C	4	152.7	151.2	1.5253
07/25/2006	3170+00	B	1	154.7		
07/25/2006	3170+00	B	2	152		
07/25/2006	3170+00	B	3	152.5		
07/25/2006	3170+00	B	4	148.5	151.93	2.5669
07/25/2006	3170+00	A	1	148.7		
07/25/2006	3170+00	A	2	142.5		
07/25/2006	3170+00	A	3	147.1		

Table 237. ***Density*** meas. by ***Pavetracker 10232*** – Non-nuclear Gage on ***I-75, MI, pcf***
Continued

Test Date	Station	Point	Trial #	Density	Average	Std Dev
07/25/2006	3170+00	A	4	150.6	147.23	3.4596
07/25/2006	3170+00	D	1	149.2		
07/25/2006	3170+00	D	2	152		
07/25/2006	3170+00	D	3	148.4		
07/25/2006	3170+00	D	4	149	152.7	1.4166
07/25/2006	3170+00	E	1	150.6		
07/25/2006	3170+00	E	2	153.3		
07/25/2006	3170+00	E	3	153.2		
07/25/2006	3170+00	E	4	153.7	152.7	1.4166
07/25/2006	3170+00	F	1	149.4		
07/25/2006	3170+00	F	2	150.4		
07/25/2006	3170+00	F	3	155.4		
07/25/2006	3170+00	F	4	150.7	151.48	2.675
07/25/2006	3170+00	G	1	150.4		
07/25/2006	3170+00	G	2	149.3		
07/25/2006	3170+00	G	3	151		
07/25/2006	3170+00	G	4	149.9	150.15	0.7234
07/25/2006	3170+00	H	1	150.7		
07/25/2006	3170+00	H	2	149.8		
07/25/2006	3170+00	H	3	150.5		
07/25/2006	3170+00	H	4	146.6	149.4	1.9061
07/25/2006	3170+00	C	1	148		
07/25/2006	3170+00	C	2	149.3		
07/25/2006	3170+00	C	3	147.6		
07/25/2006	3170+00	C	4	142.2	146.78	3.1352
07/25/2006	3112+87	A	1	159.2		
07/25/2006	3112+87	A	2	156.8		
07/25/2006	3112+87	A	3	158.9		
07/25/2006	3112+87	A	4	156.5	157.85	1.3964
07/25/2006	3112+97	B	1	150.8		
07/25/2006	3112+97	B	2	148.8		
07/25/2006	3112+97	B	3	159.5		
07/25/2006	3112+97	B	4	153.2	153.08	4.6457
07/25/2006	3113+09	C	1	156.3		
07/25/2006	3113+09	C	2	157.6		
07/25/2006	3113+09	C	3	156.5		

Table 237. ***Density*** meas. by ***Pavetracker 10232*** – Non-nuclear Gage on ***I-75, MI, pcf***
Continued

Test Date	Station	Point	Trial #	Density	Average	Std Dev
07/25/2006	3113+09	C	4	156	156.6	0.6976
07/25/2006	3122+00	A	1	146.7		
07/25/2006	3122+00	A	2	141.9		
07/25/2006	3122+00	A	3	149.8		
07/25/2006	3122+00	A	4	148.8	146.8	3.5128
07/25/2006	3122+00	C	1	147.2		
07/25/2006	3122+00	C	2	149.7		
07/25/2006	3122+00	C	3	153.2		
07/25/2006	3122+00	C	4	147.1	149.3	2.8647
07/25/2006	3134+40	C	1	148.7		
07/25/2006	3134+40	C	2	150.1		
07/25/2006	3134+40	C	3	151.1		
07/25/2006	3134+40	C	4	147.9	149.45	1.4271
07/25/2006	3134+53	B	1	148.1		
07/25/2006	3134+53	B	2	148.9		
07/25/2006	3134+53	B	3	150.3		
07/25/2006	3134+53	B	4	150.1	149.35	1.0376
07/25/2006	3134+67	A	1	149.2		
07/25/2006	3134+67	A	2	151		
07/25/2006	3134+67	A	3	150		
07/25/2006	3134+67	A	4	147.3	149.38	1.5671
07/25/2006	3142+00	B	1	153.7		
07/25/2006	3142+00	B	2	155.3		
07/25/2006	3142+00	B	3	155.4		
07/25/2006	3142+00	B	4	155.7	155.03	0.8995
07/25/2006	3142+00	D	1	149.9		
07/25/2006	3142+00	D	2	148.4		
07/25/2006	3142+00	D	3	151.6		
07/25/2006	3142+00	D	4	155.9	151.45	3.2419
07/25/2006	3142+00	E	1	153.4		
07/25/2006	3142+00	E	2	154.2		
07/25/2006	3142+00	E	3	153.7		
07/25/2006	3142+00	E	4	154.9	154.05	0.6557
07/25/2006	3142+00	F	1	152		
07/25/2006	3142+00	F	2	154.1		
07/25/2006	3142+00	F	3	156.6		

Table 237. ***Density*** meas. by ***Pavetracker 10232*** – Non-nuclear Gage on ***I-75, MI, pcf***
Continued

Test Date	Station	Point	Trial #	Density	Average	Std Dev
07/25/2006	3142+00	F	4	155.1	154.45	1.9296
07/25/2006	3142+00	G	1	156.6		
07/25/2006	3142+00	G	2	155.4		
07/25/2006	3142+00	G	3	153		
07/25/2006	3142+00	G	4	155.7	155.18	1.537
07/25/2006	3142+00	A	1	150.5		
07/25/2006	3142+00	A	2	137.3		
07/25/2006	3142+00	A	3	145.3		
07/25/2006	3142+00	A	4	152.8	146.48	6.8743
07/25/2006	3142+00	C	1	149.4		
07/25/2006	3142+00	C	2	152.6		
07/25/2006	3142+00	C	3	154.6		
07/25/2006	3142+00	C	4	151.8	152.1	2.151
07/25/2006	3150+89	B	1	151.6		
07/25/2006	3150+89	B	2	155.1		
07/25/2006	3150+89	B	3	153.9		
07/25/2006	3150+89	B	4	154.3	153.73	1.5019
07/25/2006	3150+98	B	1	158.1		
07/25/2006	3150+98	B	2	156.7		
07/25/2006	3150+98	B	3	155.9		
07/25/2006	3150+98	B	4	154.3	156.25	1.5864
07/25/2006	3151+02	A	1	149.9		
07/25/2006	3151+02	A	2	148		
07/25/2006	3151+02	A	3	148.9		
07/25/2006	3151+02	A	4	153.2	150	2.2701
07/25/2006	3151+09	C	1	151.2		
07/25/2006	3151+09	C	2	153		
07/25/2006	3151+09	C	3	152.3		
07/25/2006	3151+09	C	4	153	152.38	0.85
07/25/2006	3158+01	A	1	152.2		
07/25/2006	3158+01	A	2	150.2		
07/25/2006	3158+01	A	3	152.8		
07/25/2006	3158+01	A	4	154.1	152.33	1.6235
07/25/2006	3158+11	B	1	157.8		
07/25/2006	3158+11	B	2	155.6		
07/25/2006	3158+11	B	3	154.9		

Table 237. ***Density*** meas. by ***Pavetracker 10232*** – Non-nuclear Gage on ***I-75, MI, pcf***
Continued

Test Date	Station	Point	Trial #	Density	Average	Std Dev
07/25/2006	3158+11	B	4	152.2	155.13	2.3085
07/25/2006	3158+19	C	1	147.8		
07/25/2006	3158+19	C	2	153.8		
07/25/2006	3158+19	C	3	150.6		
07/25/2006	3158+19	C	4	151.9	151.03	2.5198
07/25/2006	3161+32	C	1	150.8		
07/25/2006	3161+32	C	2	151.6		
07/25/2006	3161+32	C	3	150.4		
07/25/2006	3161+32	C	4	152.2	151.25	0.8062
07/25/2006	3161+33	A	1	153.7		
07/25/2006	3161+33	A	2	151.8		
07/25/2006	3161+33	A	3	153.8		
07/25/2006	3161+33	A	4	148.3	151.9	2.5703
07/25/2006	3161+43	B	1	148.8		
07/25/2006	3161+43	B	2	146.8		
07/25/2006	3161+43	B	3	149.3		
07/25/2006	3161+43	B	4	146	147.73	1.5777
07/25/2006	3161+80	C	1	156.1		
07/25/2006	3161+80	C	2	154.7		
07/25/2006	3161+80	C	3	155.8		
07/25/2006	3161+80	C	4	150.1	154.18	2.7825
07/25/2006	3161+90	A	1	156		
07/25/2006	3161+90	A	2	159.2		
07/25/2006	3161+90	A	3	155.6		
07/25/2006	3161+90	A	4	158.4	157.3	1.7701
07/25/2006	3162+00	B	1	154.3		
07/25/2006	3162+00	B	2	151.3		
07/25/2006	3162+00	B	3	155.7		
07/25/2006	3162+00	B	4	153.4	153.68	1.8446
07/26/2006	2760+00	A	1	140		
07/26/2006	2760+00	A	2	134.4		
07/26/2006	2760+00	A	3	149.3		
07/26/2006	2760+00	A	4	148.9	143.15	7.2427
07/26/2006	2760+00	B	1	150.7		
07/26/2006	2760+00	B	2	143.5		
07/26/2006	2760+00	B	3	141.7		

Table 237. ***Density*** meas. by ***Pavetracker 10232*** – Non-nuclear Gage on ***I-75, MI, pcf***
Continued

Test Date	Station	Point	Trial #	Density	Average	Std Dev
07/26/2006	2760+00	B	4	149.2	146.28	4.35
07/26/2006	2760+00	C	1	148.3		
07/26/2006	2760+00	C	2	141.4		
07/26/2006	2760+00	C	3	145.6		
07/26/2006	2760+00	C	4	149.1	146.1	3.4728
07/26/2006	2762+00	A	1	153.1		
07/26/2006	2762+00	A	2	140.8		
07/26/2006	2762+00	A	3	151.1		
07/26/2006	2762+00	A	4	151.4	149.1	5.603
07/26/2006	2762+00	B	1	153.1		
07/26/2006	2762+00	B	2	143.4		
07/26/2006	2762+00	B	3	150.8		
07/26/2006	2762+00	B	4	149.3	149.15	4.1396
07/26/2006	2762+00	C	1	146.4		
07/26/2006	2762+00	C	2	150.1		
07/26/2006	2762+00	C	3	144.1		
07/26/2006	2762+00	C	4	145.5	146.53	2.5643
07/26/2006	2763+00	A	1	147.2		
07/26/2006	2763+00	A	2	153.1		
07/26/2006	2763+00	A	3	150.3		
07/26/2006	2763+00	A	4	146.2	149.2	3.1316
07/26/2006	2763+00	B	1	143		
07/26/2006	2763+00	B	2	142.7		
07/26/2006	2763+00	B	3	149.2		
07/26/2006	2763+00	B	4	152.5	146.85	4.8128
07/26/2006	2763+00	C	1	143		
07/26/2006	2763+00	C	2	143.8		
07/26/2006	2763+00	C	3	137.3		
07/26/2006	2763+00	C	4	140.7	141.2	2.9132
07/27/2006	3171+00	B	1	158.8		
07/27/2006	3171+00	B	2	159		
07/27/2006	3171+00	B	3	157		
07/27/2006	3171+00	B	4	156	157.7	1.4468
07/27/2006	3171+00	A	1	159.4		
07/27/2006	3171+00	A	2	156		
07/27/2006	3171+00	A	3	160.2		

Table 237. ***Density*** meas. by ***Pavetracker 10232*** – Non-nuclear Gage on ***I-75, MI, pcf***
Continued

Test Date	Station	Point	Trial #	Density	Average	Std Dev
07/27/2006	3171+00	A	4	160.4	159	2.0461
07/27/2006	3171+00	C	1	158		
07/27/2006	3171+00	C	2	155.9		
07/27/2006	3171+00	C	3	156.2		
07/27/2006	3171+00	C	4	158.3	157.1	1.2247
07/27/2006	3174+00	B	1	157.6		
07/27/2006	3174+00	B	2	158.6		
07/27/2006	3174+00	B	3	162.8		
07/27/2006	3174+00	B	4	157.5	159.13	2.4998
07/27/2006	3174+00	A	1	160.5		
07/27/2006	3174+00	A	2	157.1		
07/27/2006	3174+00	A	3	162.5		
07/27/2006	3174+00	A	4	162.1	160.55	2.457
07/27/2006	3174+00	C	1	157.1		
07/27/2006	3174+00	C	2	159.8		
07/27/2006	3174+00	C	3	158.8		
07/27/2006	3174+00	C	4	158	158.43	1.15
07/27/2006	3177+00	B	1	158.7		
07/27/2006	3177+00	B	2	158.2		
07/27/2006	3177+00	B	3	154.5		
07/27/2006	3177+00	B	4	156.6	157	1.8921
07/27/2006	3177+00	A	1	157.4		
07/27/2006	3177+00	A	2	156.3		
07/27/2006	3177+00	A	3	156.4		
07/27/2006	3177+00	A	4	158.4	157.13	0.9845
07/27/2006	3177+00	C	1	155.7		
07/27/2006	3177+00	C	2	159.8		
07/27/2006	3177+00	C	3	160.2		
07/27/2006	3177+00	C	4	155.8	157.88	2.4595
07/27/2006	3180+00	B	1	159.4		
07/27/2006	3180+00	B	2	157		
07/27/2006	3180+00	B	3	161.1		
07/27/2006	3180+00	B	4	158.3	158.95	1.7369
07/27/2006	3180+00	A	1	156.6		
07/27/2006	3180+00	A	2	157.2		
07/27/2006	3180+00	A	3	156.4		

Table 237. ***Density*** meas. by ***Pavetracker 10232*** – Non-nuclear Gage on ***I-75, MI, pcf***
Continued

Test Date	Station	Point	Trial #	Density	Average	Std Dev
07/27/2006	3180+00	A	4	160.4	157.65	1.8646
07/27/2006	3180+00	C	1	159.6		
07/27/2006	3180+00	C	2	159.8		
07/27/2006	3180+00	C	3	159.2		
07/27/2006	3180+00	C	4	154.6	158.3	2.4792
07/27/2006	3183+00	B	1	158.6		
07/27/2006	3183+00	B	2	157		
07/27/2006	3183+00	B	3	157.8		
07/27/2006	3183+00	B	4	156.9	157.58	0.7932
07/27/2006	3183+00	A	1	159.7		
07/27/2006	3183+00	A	2	153.2		
07/27/2006	3183+00	A	3	158.5		
07/27/2006	3183+00	A	4	157.4	157.2	2.8272
07/27/2006	3183+00	C	1	156.8		
07/27/2006	3183+00	C	2	156.4		
07/27/2006	3183+00	C	3	154.6		
07/27/2006	3183+00	C	4	158.3	156.53	1.5218
07/27/2006	3186+00	B	1	157.4		
07/27/2006	3186+00	B	2	156.5		
07/27/2006	3186+00	B	3	157.4		
07/27/2006	3186+00	B	4	161.8	158.28	2.388
07/27/2006	3186+00	A	1	155.6		
07/27/2006	3186+00	A	2	156.9		
07/27/2006	3186+00	A	3	158.6		
07/27/2006	3186+00	A	4	157	157.03	1.2285
07/27/2006	3186+00	C	1	157.4		
07/27/2006	3186+00	C	2	155.7		
07/27/2006	3186+00	C	3	156.5		
07/27/2006	3186+00	C	4	155	156.15	1.0344
07/27/2006	3189+00	B	1	160		
07/27/2006	3189+00	B	2	158.1		
07/27/2006	3189+00	B	3	156.8		
07/27/2006	3189+00	B	4	161.2	159.03	1.9568
07/27/2006	3189+00	A	1	160.5		
07/27/2006	3189+00	A	2	157.4		
07/27/2006	3189+00	A	3	157		

Table 237. ***Density*** meas. by ***Pavetracker 10232*** – Non-nuclear Gage on ***I-75, MI, pcf***
Continued

Test Date	Station	Point	Trial #	Density	Average	Std Dev
07/27/2006	3189+00	A	4	160.9	158.95	2.0339
07/27/2006	3189+00	C	1	160.8		
07/27/2006	3189+00	C	2	160.3		
07/27/2006	3189+00	C	3	159.1		
07/27/2006	3189+00	C	4	159.3	159.88	0.8098
07/27/2006	3192+00	B	1	159.2		
07/27/2006	3192+00	B	2	159.3		
07/27/2006	3192+00	B	3	159.2		
07/27/2006	3192+00	B	4	158.3	159	0.469
07/27/2006	3192+00	A	1	164.3		
07/27/2006	3192+00	A	2	159		
07/27/2006	3192+00	A	3	162.6		
07/27/2006	3192+00	A	4	156.5	160.6	3.5147
07/27/2006	3192+00	C	1	159.5		
07/27/2006	3192+00	C	2	156.7		
07/27/2006	3192+00	C	3	158		
07/27/2006	3192+00	C	4	158.8	158.25	1.2014
07/27/2006	3195+00	B	1	158.7		
07/27/2006	3195+00	B	2	160.5		
07/27/2006	3195+00	B	3	156.1		
07/27/2006	3195+00	B	4	157.8	158.28	1.8337
07/27/2006	3195+00	A	1	159.2		
07/27/2006	3195+00	A	2	156.2		
07/27/2006	3195+00	A	3	156.3		
07/27/2006	3195+00	A	4	159.7	157.85	1.8592
07/27/2006	3195+00	C	1	154.1		
07/27/2006	3195+00	C	2	154.9		
07/27/2006	3195+00	C	3	156.3		
07/27/2006	3195+00	C	4	158	155.83	1.7115
07/27/2006	3198+00	B	1	158.9		
07/27/2006	3198+00	B	2	154.7		
07/27/2006	3198+00	B	3	158.1		
07/27/2006	3198+00	B	4	160.8	158.13	2.5487
07/27/2006	3198+00	A	1	157.4		
07/27/2006	3198+00	A	2	158.5		
07/27/2006	3198+00	A	3	156.3		

Table 237. ***Density*** meas. by ***Pavetracker 10232*** – Non-nuclear Gage on ***I-75, MI, pcf***
Continued

Test Date	Station	Point	Trial #	Density	Average	Std Dev
07/27/2006	3198+00	A	4	162.1	158.58	2.5158
07/27/2006	3198+00	C	1	157.7		
07/27/2006	3198+00	C	2	159.2		
07/27/2006	3198+00	C	3	152.3		
07/27/2006	3198+00	C	4	157.7	156.73	3.0336
07/27/2006	3204+00	B	1	156.7		
07/27/2006	3204+00	B	2	160.2		
07/27/2006	3204+00	B	3	157.6		
07/27/2006	3204+00	B	4	153.8	157.08	2.6399
07/27/2006	3204+00	D	1	158.6		
07/27/2006	3204+00	D	2	155.4		
07/27/2006	3204+00	D	3	155.3		
07/27/2006	3204+00	D	4	157.8	156.78	1.678
07/27/2006	3204+00	E	1	160.2		
07/27/2006	3204+00	E	2	159.7		
07/27/2006	3204+00	E	3	163.8		
07/27/2006	3204+00	E	4	158.8	160.63	2.1945
07/27/2006	3204+00	F	1	159		
07/27/2006	3204+00	F	2	160.1		
07/27/2006	3204+00	F	3	160.2		
07/27/2006	3204+00	F	4	161.9	160.3	1.1972
07/27/2006	3204+00	A	1	155.1		
07/27/2006	3204+00	A	2	154.6		
07/27/2006	3204+00	A	3	160.2		
07/27/2006	3204+00	A	4	159.1	157.25	2.8148
07/27/2006	3204+00	C	1	156.8		
07/27/2006	3204+00	C	2	154.7		
07/27/2006	3204+00	C	3	155.1		
07/27/2006	3204+00	C	4	157.8	156.1	1.4537
07/27/2006	3208+00	B	1	151.6		
07/27/2006	3208+00	B	2	157.1		
07/27/2006	3208+00	B	3	157.6		
07/27/2006	3208+00	B	4	158.8	156.28	3.1973
07/27/2006	3208+00	A	1	156.9		
07/27/2006	3208+00	A	2	157.5		
07/27/2006	3208+00	A	3	156.3		

Table 237. ***Density*** meas. by ***Pavetracker 10232*** – Non-nuclear Gage on ***I-75, MI, pcf***
Continued

Test Date	Station	Point	Trial #	Density	Average	Std Dev
07/27/2006	3208+00	A	4	158.2	157.23	0.8139
07/27/2006	3208+00	C	1	161.7		
07/27/2006	3208+00	C	2	159		
07/27/2006	3208+00	C	3	162.4		
07/27/2006	3208+00	C	4	159.9	160.75	1.5716
07/27/2006	3211+00	B	1	159.3		
07/27/2006	3211+00	B	2	163.5		
07/27/2006	3211+00	B	3	159.1		
07/27/2006	3211+00	B	4	160.2	160.53	2.0402
07/27/2006	3211+00	A	1	161		
07/27/2006	3211+00	A	2	155.1		
07/27/2006	3211+00	A	3	158.6		
07/27/2006	3211+00	A	4	161.3	159	2.8671
07/27/2006	3211+00	C	1	154.8		
07/27/2006	3211+00	C	2	156.3		
07/27/2006	3211+00	C	3	154.9		
07/27/2006	3211+00	C	4	157.7	155.93	1.3672
07/27/2006	3211+03	B	1	161.5		
07/27/2006	3211+03	B	2	161.6		
07/27/2006	3211+03	B	3	158.5		
07/27/2006	3211+03	B	4	164.1	161.43	2.2911
07/27/2006	3219+12	B	1	159.4		
07/27/2006	3219+12	B	2	161.6		
07/27/2006	3219+12	B	3	163.8		
07/27/2006	3219+12	B	4	152.9	159.43	4.7063
07/27/2006	3219+14	B	1	162.5		
07/27/2006	3219+14	B	2	162.6		
07/27/2006	3219+14	B	3	161.6		
07/27/2006	3219+14	B	4	154.2	160.23	4.0418
07/27/2006	3219+14	A	1	151		
07/27/2006	3219+14	A	2	148.5		
07/27/2006	3219+14	A	3	155.3		
07/27/2006	3219+14	A	4	153.4	152.05	2.949
07/27/2006	3219+14	C	1	154.6		
07/27/2006	3219+14	C	2	162.1		
07/27/2006	3219+14	C	3	151.5		

Table 237. ***Density*** meas. by ***Pavetracker 10232*** – Non-nuclear Gage on ***I-75, MI, pcf***
Continued

Test Date	Station	Point	Trial #	Density	Average	Std Dev
07/27/2006	3219+14	C	4	157.6	156.45	4.5155

Table 238. ***Density*** meas. by ***Pavetracker 10233***– Non-nuclear Gage on ***I-75, MI, pcf***

Test Date	Station	Point	Trial #	Density	Average	Std Dev
07/25/2006	2751+00	A	1	152.7		
07/25/2006	2751+00	A	2	150.1		
07/25/2006	2751+00	A	3	145.7		
07/25/2006	2751+00	A	4	148	149.13	2.9848
07/25/2006	2751+00	B	1	149		
07/25/2006	2751+00	B	2	158.6		
07/25/2006	2751+00	B	3	157		
07/25/2006	2751+00	B	4	158	155.65	4.4822
07/25/2006	2751+00	C	1	148.9		
07/25/2006	2751+00	C	2	152.6		
07/25/2006	2751+00	C	3	149.4		
07/25/2006	2751+00	C	4	141.1	148	4.8833
07/25/2006	2753+00	A	1	150.4		
07/25/2006	2753+00	A	2	144.5		
07/25/2006	2753+00	A	3	147.1		
07/25/2006	2753+00	A	4	143.7	146.43	3.0215
07/25/2006	2753+00	B	1	143.3		
07/25/2006	2753+00	B	2	142.1		
07/25/2006	2753+00	B	3	148.7		
07/25/2006	2753+00	B	4	147.2	145.33	3.1309
07/25/2006	2753+00	C	1	146.3		
07/25/2006	2753+00	C	2	142.3		
07/25/2006	2753+00	C	3	144.8		
07/25/2006	2753+00	C	4	146	144.85	1.8193
07/25/2006	2755+00	A	1	143.3		
07/25/2006	2755+00	A	2	149.8		
07/25/2006	2755+00	A	3	150.4		
07/25/2006	2755+00	A	4	152	148.88	3.8309
07/25/2006	2755+00	B	1	142.6		
07/25/2006	2755+00	B	2	153.9		
07/25/2006	2755+00	B	3	146		
07/25/2006	2755+00	B	4	150.9	148.35	5.0296
07/25/2006	2755+00	C	1	146.6		
07/25/2006	2755+00	C	2	149.9		
07/25/2006	2755+00	C	3	158.7		
07/25/2006	2755+00	C	4	153.5	152.18	5.1829
07/25/2006	2756+00	A	1	145.6		

Table 238. ***Density*** meas. by ***Pavetracker 10233***– Non-nuclear Gage on ***I-75, MI, pcf***
Continued

Test Date	Station	Point	Trial #	Density	Average	Std Dev
07/25/2006	2756+00	A	2	134.7		
07/25/2006	2756+00	A	3	131.8		
07/25/2006	2756+00	A	4	150.9	140.75	9.0046
07/25/2006	2756+00	B	1	136.2		
07/25/2006	2756+00	B	2	149.3		
07/25/2006	2756+00	B	3	146.5		
07/25/2006	2756+00	B	4	149.4	145.35	6.2463
07/25/2006	2756+00	C	1	146.4		
07/25/2006	2756+00	C	2	144.8		
07/25/2006	2756+00	C	3	141.6		
07/25/2006	2756+00	C	4	146.4	144.8	2.2627
07/25/2006	2757+00	A	1	147.1		
07/25/2006	2757+00	A	2	143.9		
07/25/2006	2757+00	A	3	145.2		
07/25/2006	2757+00	A	4	143.8	145	1.5384
07/25/2006	2757+00	B	1	147		
07/25/2006	2757+00	B	2	142.6		
07/25/2006	2757+00	B	3	144.1		
07/25/2006	2757+00	B	4	151	146.18	3.699
07/25/2006	2757+00	C	1	142.3		
07/25/2006	2757+00	C	2	142.5		
07/25/2006	2757+00	C	3	143.5		
07/25/2006	2757+00	C	4	131.7	140	5.5582
07/25/2006	2760+00	A	1	143.7		
07/25/2006	2760+00	A	2	131.2		
07/25/2006	2760+00	A	3	146.6		
07/25/2006	2760+00	A	4	147.4	142.23	7.5199
07/25/2006	2760+00	B	1	138.7		
07/25/2006	2760+00	B	2	132.8		
07/25/2006	2760+00	B	3	143.8		
07/25/2006	2760+00	B	4	149.6	141.23	7.1677
07/25/2006	2760+00	C	1	146.7		
07/25/2006	2760+00	C	2	142		
07/25/2006	2760+00	C	3	138.6		
07/25/2006	2760+00	C	4	141.8	142.28	3.336

Table 238. ***Density*** meas. by ***Pavetracker 10233***– Non-nuclear Gage on ***I-75, MI, pcf***
Continued

Test Date	Station	Point	Trial #	Density	Average	Std Dev
07/25/2006	2762+00	A	1	151.2		
07/25/2006	2762+00	A	2	137.6		
07/25/2006	2762+00	A	3	151.2		
07/25/2006	2762+00	A	4	149.6	147.4	6.5767
07/25/2006	2762+00	B	1	148.3		
07/25/2006	2762+00	B	2	133.9		
07/25/2006	2762+00	B	3	146.4		
07/25/2006	2762+00	B	4	146.4	143.75	6.6275
07/25/2006	2762+00	C	1	140.7		
07/25/2006	2762+00	C	2	149.9		
07/25/2006	2762+00	C	3	141.1		
07/25/2006	2762+00	C	4	143.8	143.88	4.2461
07/25/2006	2763+00	A	1	140.5		
07/25/2006	2763+00	A	2	147.6		
07/25/2006	2763+00	A	3	131.7		
07/25/2006	2763+00	A	4	134.3	138.53	7.0873
07/25/2006	2763+00	B	1	145.9		
07/25/2006	2763+00	B	2	143.6		
07/25/2006	2763+00	B	3	144.3		
07/25/2006	2763+00	B	4	134.7	142.13	5.0427
07/25/2006	2763+00	C	1	138.3		
07/25/2006	2763+00	C	2	145.8		
07/25/2006	2763+00	C	3	139.3		
07/25/2006	2763+00	C	4	141.3	141.18	3.326
07/25/2006	3115+80	C	1	152.6		
07/25/2006	3115+80	C	2	152.4		
07/25/2006	3115+80	C	3	151.4		
07/25/2006	3115+80	C	4	151.1	151.88	0.7365
07/25/2006	3115+85	B	1	156		
07/25/2006	3115+85	B	2	155.7		
07/25/2006	3115+85	B	3	155.8		
07/25/2006	3115+85	B	4	154.5	155.5	0.6782
07/25/2006	3115+89	A	1	153.1		
07/25/2006	3115+89	A	2	149.2		
07/25/2006	3115+89	A	3	154.6		
07/25/2006	3115+89	A	4	151.9	152.2	2.2847

Table 238. ***Density*** meas. by ***Pavetracker 10233***– Non-nuclear Gage on ***I-75, MI, pcf***
Continued

Test Date	Station	Point	Trial #	Density	Average	Std Dev
07/25/2006	3122+00	A	1	149.2		
07/25/2006	3122+00	A	2	150		
07/25/2006	3122+00	A	3	148.2		
07/25/2006	3122+00	A	4	145.3	148.18	2.0532
07/25/2006	3122+00	C	1	153.2		
07/25/2006	3122+00	C	2	154.6		
07/25/2006	3122+00	C	3	152.3		
07/25/2006	3122+00	C	4	151.2	152.83	1.4385
07/25/2006	3131+76	A	1	149.3		
07/25/2006	3131+76	A	2	152.1		
07/25/2006	3131+76	A	3	148.6		
07/25/2006	3131+76	A	4	152	150.5	1.8129
07/25/2006	3131+80	B	1	155.8		
07/25/2006	3131+80	B	2	154.1		
07/25/2006	3131+80	B	3	156.5		
07/25/2006	3131+80	B	4	155.2	155.4	1.0165
07/25/2006	3131+84	C	1	152.6		
07/25/2006	3131+84	C	2	156.3		
07/25/2006	3131+84	C	3	151.4		
07/25/2006	3131+84	C	4	154.6	153.73	2.1654
07/25/2006	3134+40	A	1	149.1		
07/25/2006	3134+40	A	2	145.2		
07/25/2006	3134+40	A	3	148.2		
07/25/2006	3134+40	A	4	154.1	149.15	3.6973
07/25/2006	3134+40	C	1	157.2		
07/25/2006	3134+40	C	2	157.7		
07/25/2006	3134+40	C	3	157.1		
07/25/2006	3134+40	C	4	156.1	157.03	0.6702
07/25/2006	3142+00	A	1	151.8		
07/25/2006	3142+00	A	2	153.6		
07/25/2006	3142+00	A	3	150.8		
07/25/2006	3142+00	A	4	144.2	150.1	4.1004
07/25/2006	3142+00	D	1	149.9		
07/25/2006	3142+00	D	2	153.3		
07/25/2006	3142+00	D	3	146.6		
07/25/2006	3142+00	D	4	151.8	150.4	2.8902

Table 238. ***Density*** meas. by ***Pavetracker 10233***– Non-nuclear Gage on ***I-75, MI, pcf***
Continued

Test Date	Station	Point	Trial #	Density	Average	Std Dev
07/25/2006	3142+00	E	1	153.9		
07/25/2006	3142+00	E	2	155.1		
07/25/2006	3142+00	E	3	155.2		
07/25/2006	3142+00	E	4	149.3	153.38	2.7801
07/25/2006	3142+00	F	1	152.2		
07/25/2006	3142+00	F	2	154.6		
07/25/2006	3142+00	F	3	155.4		
07/25/2006	3142+00	F	4	155.8	154.5	1.6125
07/25/2006	3142+00	G	1	151.8		
07/25/2006	3142+00	G	2	150.2		
07/25/2006	3142+00	G	3	149.3		
07/25/2006	3142+00	G	4	151.4	150.68	1.1413
07/25/2006	3142+00	B	1	154.7		
07/25/2006	3142+00	B	2	154.6		
07/25/2006	3142+00	B	3	151.9		
07/25/2006	3142+00	B	4	154.5	153.93	1.3525
07/25/2006	3142+00	C	1	150.4		
07/25/2006	3142+00	C	2	154		
07/25/2006	3142+00	C	3	149.6		
07/25/2006	3142+00	C	4	147.4	150.35	2.7441
07/25/2006	3165+00	A	1	150.8		
07/25/2006	3165+00	A	2	152.4		
07/25/2006	3165+00	A	3	151.4		
07/25/2006	3165+00	A	4	154.4	152.25	1.578
07/25/2006	3165+00	C	1	152.1		
07/25/2006	3165+00	C	2	153.7		
07/25/2006	3165+00	C	3	152.3		
07/25/2006	3165+00	C	4	152.9	152.75	0.7188
07/25/2006	3170+00	B	1	151.5		
07/25/2006	3170+00	B	2	150.8		
07/25/2006	3170+00	B	3	153.8		
07/25/2006	3170+00	B	4	149	151.28	1.9856
07/25/2006	3170+00	A	1	148		
07/25/2006	3170+00	A	2	143.3		
07/25/2006	3170+00	A	3	147.5		
07/25/2006	3170+00	A	4	152.4	147.8	3.7211

Table 238. ***Density*** meas. by ***Pavetracker 10233***– Non-nuclear Gage on ***I-75, MI, pcf***
Continued

Test Date	Station	Point	Trial #	Density	Average	Std Dev
07/25/2006	3170+00	D	1	149		
07/25/2006	3170+00	D	2	150.3		
07/25/2006	3170+00	D	3	152.7		
07/25/2006	3170+00	D	4	147.9	149.98	2.0646
07/25/2006	3170+00	E	1	155		
07/25/2006	3170+00	E	2	151.4		
07/25/2006	3170+00	E	3	154.4		
07/25/2006	3170+00	E	4	150.2	152.75	2.3173
07/25/2006	3170+00	F	1	154.3		
07/25/2006	3170+00	F	2	149.8		
07/25/2006	3170+00	F	3	151.2		
07/25/2006	3170+00	F	4	151.7	151.75	1.8806
07/25/2006	3170+00	G	1	150.1		
07/25/2006	3170+00	G	2	150.6		
07/25/2006	3170+00	G	3	150		
07/25/2006	3170+00	G	4	152.6	150.83	1.2121
07/25/2006	3170+00	H	1	149.3		
07/25/2006	3170+00	H	2	149		
07/25/2006	3170+00	H	3	149.6		
07/25/2006	3170+00	H	4	150.3	149.55	0.5568
07/25/2006	3170+00	C	1	146.5		
07/25/2006	3170+00	C	2	150.2		
07/25/2006	3170+00	C	3	146.2		
07/25/2006	3170+00	C	4	140.5	145.85	4.0037
07/25/2006	3112+87	A	1	153.8		
07/25/2006	3112+87	A	2	157.5		
07/25/2006	3112+87	A	3	156.8		
07/25/2006	3112+87	A	4	156.8	156.23	1.65
07/25/2006	3112+97	B	1	156		
07/25/2006	3112+97	B	2	156.8		
07/25/2006	3112+97	B	3	156.3		
07/25/2006	3112+97	B	4	158	156.78	0.8808
07/25/2006	3113+09	C	1	157.3		
07/25/2006	3113+09	C	2	157.5		
07/25/2006	3113+09	C	3	157.9		
07/25/2006	3113+09	C	4	153.8	156.63	1.8998

Table 238. ***Density*** meas. by ***Pavetracker 10233***– Non-nuclear Gage on ***I-75, MI, pcf***
Continued

Test Date	Station	Point	Trial #	Density	Average	Std Dev
07/25/2006	3122+00	A	1	143.8		
07/25/2006	3122+00	A	2	146.1		
07/25/2006	3122+00	A	3	149.7		
07/25/2006	3122+00	A	4	148.8	147.1	2.6796
07/25/2006	3122+00	C	1	153.5		
07/25/2006	3122+00	C	2	154.1		
07/25/2006	3122+00	C	3	156.4		
07/25/2006	3122+00	C	4	150.6	153.65	2.3868
07/25/2006	3134+40	C	1	156.2		
07/25/2006	3134+40	C	2	157.3		
07/25/2006	3134+40	C	3	158		
07/25/2006	3134+40	C	4	155.8	156.83	1.0079
07/25/2006	3134+53	B	1	156.8		
07/25/2006	3134+53	B	2	154.2		
07/25/2006	3134+53	B	3	156.1		
07/25/2006	3134+53	B	4	154.5	155.4	1.2517
07/25/2006	3134+67	A	1	154.7		
07/25/2006	3134+67	A	2	154.4		
07/25/2006	3134+67	A	3	155		
07/25/2006	3134+67	A	4	155	154.78	0.2872
07/25/2006	3142+00	B	1	157.8		
07/25/2006	3142+00	B	2	157.9		
07/25/2006	3142+00	B	3	155		
07/25/2006	3142+00	B	4	158.5	157.3	1.5642
07/25/2006	3142+00	D	1	155.7		
07/25/2006	3142+00	D	2	154.7		
07/25/2006	3142+00	D	3	153.7		
07/25/2006	3142+00	D	4	156.5	155.15	1.2152
07/25/2006	3142+00	E	1	156.2		
07/25/2006	3142+00	E	2	156.2		
07/25/2006	3142+00	E	3	156.2		
07/25/2006	3142+00	E	4	154.4	155.75	0.9
07/25/2006	3142+00	F	1	155.6		
07/25/2006	3142+00	F	2	161.2		
07/25/2006	3142+00	F	3	157.5		
07/25/2006	3142+00	F	4	161	158.83	2.7403

Table 238. ***Density*** meas. by ***Pavetracker 10233***– Non-nuclear Gage on ***I-75, MI, pcf***
Continued

Test Date	Station	Point	Trial #	Density	Average	Std Dev
07/25/2006	3142+00	G	1	157.2		
07/25/2006	3142+00	G	2	162.5		
07/25/2006	3142+00	G	3	153		
07/25/2006	3142+00	G	4	157.6	157.58	3.8871
07/25/2006	3142+00	A	1	148.1		
07/25/2006	3142+00	A	2	141.5		
07/25/2006	3142+00	A	3	151.1		
07/25/2006	3142+00	A	4	157.3	149.5	6.5666
07/25/2006	3142+00	C	1	155.9		
07/25/2006	3142+00	C	2	156.3		
07/25/2006	3142+00	C	3	157.8		
07/25/2006	3142+00	C	4	153	155.75	2.0075
07/25/2006	3150+89	B	1	158.7		
07/25/2006	3150+89	B	2	156.9		
07/25/2006	3150+89	B	3	158.4		
07/25/2006	3150+89	B	4	158.4	158.1	0.8124
07/25/2006	3150+98	B	1	154.6		
07/25/2006	3150+98	B	2	155.7		
07/25/2006	3150+98	B	3	154.4		
07/25/2006	3150+98	B	4	159.4	156.03	2.3215
07/25/2006	3151+02	A	1	154.7		
07/25/2006	3151+02	A	2	152.4		
07/25/2006	3151+02	A	3	157.9		
07/25/2006	3151+02	A	4	158	155.75	2.7086
07/25/2006	3151+09	C	1	157.8		
07/25/2006	3151+09	C	2	157.4		
07/25/2006	3151+09	C	3	153.2		
07/25/2006	3151+09	C	4	152	155.1	2.9326
07/25/2006	3158+01	A	1	152.4		
07/25/2006	3158+01	A	2	153.9		
07/25/2006	3158+01	A	3	153.2		
07/25/2006	3158+01	A	4	157.9	154.35	2.4447
07/25/2006	3158+11	B	1	159.4		
07/25/2006	3158+11	B	2	157.8		
07/25/2006	3158+11	B	3	160.1		
07/25/2006	3158+11	B	4	153.2	157.63	3.1031

Table 238. ***Density*** meas. by ***Pavetracker 10233***– Non-nuclear Gage on ***I-75, MI, pcf***
Continued

Test Date	Station	Point	Trial #	Density	Average	Std Dev
07/25/2006	3158+19	C	1	152.1		
07/25/2006	3158+19	C	2	154.8		
07/25/2006	3158+19	C	3	152.6		
07/25/2006	3158+19	C	4	149.9	152.35	2.0108
07/25/2006	3161+32	C	1	155.3		
07/25/2006	3161+32	C	2	156		
07/25/2006	3161+32	C	3	156.4		
07/25/2006	3161+32	C	4	151.2	154.73	2.3936
07/25/2006	3161+33	A	1	157.3		
07/25/2006	3161+33	A	2	157.6		
07/25/2006	3161+33	A	3	149.1		
07/25/2006	3161+33	A	4	150.8	153.7	4.3871
07/25/2006	3161+43	B	1	156.7		
07/25/2006	3161+43	B	2	154.3		
07/25/2006	3161+43	B	3	155.1		
07/25/2006	3161+43	B	4	150.6	154.18	2.5838
07/25/2006	3161+80	C	1	158.4		
07/25/2006	3161+80	C	2	157.1		
07/25/2006	3161+80	C	3	158.3		
07/25/2006	3161+80	C	4	153.8	156.9	2.1494
07/25/2006	3161+90	A	1	161.1		
07/25/2006	3161+90	A	2	157.4		
07/25/2006	3161+90	A	3	156.2		
07/25/2006	3161+90	A	4	160	158.68	2.2648
07/26/2006	2760+00	A	1	140.1		
07/26/2006	2760+00	A	2	139.8		
07/26/2006	2760+00	A	3	137.9		
07/26/2006	2760+00	A	4	147.2	141.25	4.0845
07/26/2006	2760+00	B	1	149.6		
07/26/2006	2760+00	B	2	144.3		
07/26/2006	2760+00	B	3	147.1		
07/26/2006	2760+00	B	4	146.5	146.88	2.1793
07/26/2006	2760+00	C	1	146.1		
07/26/2006	2760+00	C	2	142.4		
07/26/2006	2760+00	C	3	137.2		
07/26/2006	2760+00	C	4	145.5	142.8	4.0702

Table 238. ***Density*** meas. by ***Pavetracker 10233***– Non-nuclear Gage on ***I-75, MI, pcf***
Continued

Test Date	Station	Point	Trial #	Density	Average	Std Dev
07/26/2006	2762+00	A	1	152.2		
07/26/2006	2762+00	A	2	137.1		
07/26/2006	2762+00	A	3	150.3		
07/26/2006	2762+00	A	4	148.8	147.1	6.8103
07/26/2006	2762+00	B	1	150.4		
07/26/2006	2762+00	B	2	140.8		
07/26/2006	2762+00	B	3	151.9		
07/26/2006	2762+00	B	4	148.2	147.83	4.9237
07/26/2006	2762+00	C	1	144.6		
07/26/2006	2762+00	C	2	148.2		
07/26/2006	2762+00	C	3	135.8		
07/26/2006	2762+00	C	4	143.6	143.05	5.2214
07/26/2006	2763+00	A	1	147.7		
07/26/2006	2763+00	A	2	152.6		
07/26/2006	2763+00	A	3	153.6		
07/26/2006	2763+00	A	4	129	145.73	11.444
07/26/2006	2763+00	B	1	143.1		
07/26/2006	2763+00	B	2	145.7		
07/26/2006	2763+00	B	3	147.3		
07/26/2006	2763+00	B	4	153.1	147.3	4.2364
07/26/2006	2763+00	C	1	138.7		
07/26/2006	2763+00	C	2	142.3		
07/26/2006	2763+00	C	3	132.5		
07/26/2006	2763+00	C	4	145.5	139.75	5.5746
07/27/2006	3146+92	A	1	147.8		
07/27/2006	3146+92	A	2	152		
07/27/2006	3146+92	A	3	152.1		
07/27/2006	3146+92	A	4	150.4	150.58	2.0073
07/27/2006	3146+94	B	1	149.5		
07/27/2006	3146+94	B	2	147.2		
07/27/2006	3146+94	B	3	145.9		
07/27/2006	3146+94	B	4	145.4	147	1.8312
07/27/2006	3147+00	A	1	150.6		
07/27/2006	3147+00	A	2	146.9		
07/27/2006	3147+00	A	3	149.6		
07/27/2006	3147+00	A	4	146.5	148.4	2.0116

Table 238. ***Density*** meas. by ***Pavetracker 10233***– Non-nuclear Gage on ***I-75, MI, pcf***
Continued

Test Date	Station	Point	Trial #	Density	Average	Std Dev
07/27/2006	3153+00	A	1	155.6		
07/27/2006	3153+00	A	2	151.2		
07/27/2006	3153+00	A	4	150.1	152.85	2.6185
07/27/2006	3153+00	A	3	154.5		
07/27/2006	3155+40	A	1	146.8		
07/27/2006	3155+40	A	2	152.7		
07/27/2006	3155+40	A	4	156	149.23	6.4572
07/27/2006	3155+40	A	3	141.4		
07/27/2006	3158+00	A	1	148		
07/27/2006	3158+00	A	2	152.2		
07/27/2006	3158+00	A	4	147	148.43	2.5928
07/27/2006	3158+00	A	3	146.5		
07/27/2006	3165+00	A	1	147.9		
07/27/2006	3165+00	A	2	150.3		
07/27/2006	3165+00	A	3	151.4		
07/27/2006	3165+00	A	4	152.1	150.43	1.8392
07/27/2006	3165+00	C	1	145		
07/27/2006	3165+00	C	2	140.7		
07/27/2006	3165+00	C	3	145.7		
07/27/2006	3165+00	C	4	144.8	144.05	2.2664
07/27/2006	3170+00	B	1	146		
07/27/2006	3170+00	B	2	152.2		
07/27/2006	3170+00	B	3	155.5		
07/27/2006	3170+00	B	4	152.9	151.65	4.0253
07/27/2006	3170+00	A	1	149.7		
07/27/2006	3170+00	A	2	151.2		
07/27/2006	3170+00	A	3	148.8		
07/27/2006	3170+00	A	4	152.7	150.6	1.7146
07/27/2006	3170+00	D	1	149		
07/27/2006	3170+00	D	2	150.3		
07/27/2006	3170+00	D	3	152.7		
07/27/2006	3170+00	D	4	147.9	149.98	2.0646
07/27/2006	3170+00	E	1	155		
07/27/2006	3170+00	E	2	151.4		
07/27/2006	3170+00	E	3	154.4		
07/27/2006	3170+00	E	4	150.2	152.75	2.3173

Table 238. ***Density*** meas. by ***Pavetracker 10233***– Non-nuclear Gage on ***I-75, MI, pcf***
Continued

Test Date	Station	Point	Trial #	Density	Average	Std Dev
07/27/2006	3170+00	F	1	154.3		
07/27/2006	3170+00	F	2	149.8		
07/27/2006	3170+00	F	3	151.2		
07/27/2006	3170+00	F	4	151.7	151.75	1.8806
07/27/2006	3170+00	C	1	146.5		
07/27/2006	3170+00	C	2	150.2		
07/27/2006	3170+00	C	3	146.2		
07/27/2006	3170+00	C	4	140.5	145.85	4.0037
07/27/2006	3171+00	B	1	155.2		
07/27/2006	3171+00	B	2	157.5		
07/27/2006	3171+00	B	3	156.3		
07/27/2006	3171+00	B	4	153.7	155.68	1.6174
07/27/2006	3171+00	A	1	158.6		
07/27/2006	3171+00	A	2	154.5		
07/27/2006	3171+00	A	3	156.9		
07/27/2006	3171+00	A	4	161.9	157.98	3.1106
07/27/2006	3171+00	C	1	156		
07/27/2006	3171+00	C	2	155.5		
07/27/2006	3171+00	C	3	155.5		
07/27/2006	3171+00	C	4	158.4	156.35	1.3868
07/27/2006	3174+00	B	1	160.3		
07/27/2006	3174+00	B	2	157.5		
07/27/2006	3174+00	B	3	160.6		
07/27/2006	3174+00	B	4	161.1	159.88	1.6174
07/27/2006	3174+00	A	1	162.9		
07/27/2006	3174+00	A	2	158.4		
07/27/2006	3174+00	A	3	156.9		
07/27/2006	3174+00	A	4	159.9	159.53	2.5617
07/27/2006	3174+00	C	1	155.3		
07/27/2006	3174+00	C	2	160		
07/27/2006	3174+00	C	3	156		
07/27/2006	3174+00	C	4	155.9	156.8	2.1556
07/27/2006	3177+00	B	1	157		
07/27/2006	3177+00	B	2	161.7		
07/27/2006	3177+00	B	3	157.2		
07/27/2006	3177+00	B	4	157.8	158.43	2.2096

Table 238. ***Density*** meas. by ***Pavetracker 10233***– Non-nuclear Gage on ***I-75, MI, pcf***
Continued

Test Date	Station	Point	Trial #	Density	Average	Std Dev
07/27/2006	3177+00	A	1	159.1		
07/27/2006	3177+00	A	2	156.1		
07/27/2006	3177+00	A	3	157.2		
07/27/2006	3177+00	A	4	160.8	158.3	2.0769
07/27/2006	3177+00	C	1	157.2		
07/27/2006	3177+00	C	2	157.5		
07/27/2006	3177+00	C	3	157.8		
07/27/2006	3177+00	C	4	152.4	156.23	2.5617
07/27/2006	3180+00	B	1	158.5		
07/27/2006	3180+00	B	2	158.2		
07/27/2006	3180+00	B	3	159.2		
07/27/2006	3180+00	B	4	155.7	157.9	1.5253
07/27/2006	3180+00	A	1	158.2		
07/27/2006	3180+00	A	2	159.1		
07/27/2006	3180+00	A	3	160.2		
07/27/2006	3180+00	A	4	160.8	159.58	1.1558
07/27/2006	3180+00	C	1	155.9		
07/27/2006	3180+00	C	2	115.7		
07/27/2006	3180+00	C	3	155.4		
07/27/2006	3180+00	C	4	152.9	144.98	19.561
07/27/2006	3183+00	B	1	156.4		
07/27/2006	3183+00	B	2	154.9		
07/27/2006	3183+00	B	3	156.7		
07/27/2006	3183+00	B	4	154.7	155.68	1.021
07/27/2006	3183+00	A	1	159.6		
07/27/2006	3183+00	A	2	156.7		
07/27/2006	3183+00	A	3	158.5		
07/27/2006	3183+00	A	4	150.5	156.33	4.0631
07/27/2006	3183+00	C	1	155.3		
07/27/2006	3183+00	C	2	155.7		
07/27/2006	3183+00	C	3	157.3		
07/27/2006	3183+00	C	4	152	155.08	2.2247
07/27/2006	3186+00	B	1	155.4		
07/27/2006	3186+00	B	2	154.8		
07/27/2006	3186+00	B	3	153.4		
07/27/2006	3186+00	B	4	158.8	155.6	2.292

Table 238. ***Density*** meas. by ***Pavetracker 10233***– Non-nuclear Gage on ***I-75, MI, pcf***
Continued

Test Date	Station	Point	Trial #	Density	Average	Std Dev
07/27/2006	3186+00	A	1	157.6		
07/27/2006	3186+00	A	2	156.9		
07/27/2006	3186+00	A	3	156.6		
07/27/2006	3186+00	A	4	158.8	157.48	0.9777
07/27/2006	3186+00	C	1	159.5		
07/27/2006	3186+00	C	2	154.8		
07/27/2006	3186+00	C	3	1553		
07/27/2006	3186+00	C	4	156.3	505.9	698.07
07/27/2006	3189+00	B	1	159.7		
07/27/2006	3189+00	B	2	157.5		
07/27/2006	3189+00	B	3	156.3		
07/27/2006	3189+00	B	4	156.5	157.5	1.5578
07/27/2006	3189+00	A	1	157.9		
07/27/2006	3189+00	A	2	156.6		
07/27/2006	3189+00	A	3	158.6		
07/27/2006	3189+00	A	4	159.4	158.13	1.1871
07/27/2006	3189+00	C	1	158		
07/27/2006	3189+00	C	2	156.1		
07/27/2006	3189+00	C	3	155.9		
07/27/2006	3189+00	C	4	157.4	156.85	1.0149
07/27/2006	3192+00	B	1	156.7		
07/27/2006	3192+00	B	2	155.5		
07/27/2006	3192+00	B	3	154.3		
07/27/2006	3192+00	B	4	155.7	155.55	0.9849
07/27/2006	3192+00	A	1	161		
07/27/2006	3192+00	A	2	161.7		
07/27/2006	3192+00	A	3	158.6		
07/27/2006	3192+00	A	4	158.3	159.9	1.7029
07/27/2006	3192+00	C	1	156		
07/27/2006	3192+00	C	2	158.8		
07/27/2006	3192+00	C	3	156.5		
07/27/2006	3192+00	C	4	158.2	157.38	1.3376
07/27/2006	3195+00	B	1	159		
07/27/2006	3195+00	B	2	157.6		
07/27/2006	3195+00	B	3	156.7		
07/27/2006	3195+00	B	4	157.6	157.73	0.95

Table 238. ***Density*** meas. by ***Pavetracker 10233***– Non-nuclear Gage on ***I-75, MI, pcf***
Continued

Test Date	Station	Point	Trial #	Density	Average	Std Dev
07/27/2006	3195+00	A	1	158.6		
07/27/2006	3195+00	A	2	153.8		
07/27/2006	3195+00	A	3	155.4		
07/27/2006	3195+00	A	4	157.4	156.3	2.126
07/27/2006	3195+00	C	1	153.7		
07/27/2006	3195+00	C	2	154.4		
07/27/2006	3195+00	C	3	154		
07/27/2006	3195+00	C	4	157.9	155	1.9545
07/27/2006	3198+00	B	1	160.3		
07/27/2006	3198+00	B	2	156.3		
07/27/2006	3198+00	B	3	155.4		
07/27/2006	3198+00	B	4	155	156.75	2.4283
07/27/2006	3198+00	A	1	155.5		
07/27/2006	3198+00	A	2	157.5		
07/27/2006	3198+00	A	3	155.7		
07/27/2006	3198+00	A	4	149.5	154.55	3.4847
07/27/2006	3198+00	C	1	156		
07/27/2006	3198+00	C	2	153		
07/27/2006	3198+00	C	3	149.1		
07/27/2006	3198+00	C	4	154.1	153.05	2.9103
07/27/2006	3204+00	B	1	156.2		
07/27/2006	3204+00	B	2	158.8		
07/27/2006	3204+00	B	3	158.2		
07/27/2006	3204+00	B	4	154.5	156.93	1.9619
07/27/2006	3204+00	D	1	152.6		
07/27/2006	3204+00	D	2	153.3		
07/27/2006	3204+00	D	3	157.1		
07/27/2006	3204+00	D	4	160	155.75	3.4549
07/27/2006	3204+00	E	1	160.7		
07/27/2006	3204+00	E	2	161.1		
07/27/2006	3204+00	E	3	159.1		
07/27/2006	3204+00	E	4	160.8	160.43	0.8995
07/27/2006	3204+00	F	1	160.8		
07/27/2006	3204+00	F	2	155.6		
07/27/2006	3204+00	F	3	156.5		
07/27/2006	3204+00	F	4	158.4	157.83	2.3013

Table 238. ***Density*** meas. by ***Pavetracker 10233***– Non-nuclear Gage on ***I-75, MI, pcf***
Continued

Test Date	Station	Point	Trial #	Density	Average	Std Dev
07/27/2006	3204+00	A	1	157.8		
07/27/2006	3204+00	A	2	156		
07/27/2006	3204+00	A	3	159.5		
07/27/2006	3204+00	A	4	158.6	157.98	1.4886
07/27/2006	3204+00	C	1	156.6		
07/27/2006	3204+00	C	2	154.6		
07/27/2006	3204+00	C	3	157.5		
07/27/2006	3204+00	C	4	157.3	156.5	1.3241
07/27/2006	3208+00	B	1	151.8		
07/27/2006	3208+00	B	2	157.3		
07/27/2006	3208+00	B	3	157.2		
07/27/2006	3208+00	B	4	156	155.58	2.5851
07/27/2006	3208+00	A	1	155.1		
07/27/2006	3208+00	A	2	154.3		
07/27/2006	3208+00	A	3	156.4		
07/27/2006	3208+00	A	4	156.4	155.55	1.0344
07/27/2006	3208+00	C	1	158.6		
07/27/2006	3208+00	C	2	155.6		
07/27/2006	3208+00	C	3	160.4		
07/27/2006	3208+00	C	4	155.1	157.43	2.5145
07/27/2006	3211+00	B	1	159.7		
07/27/2006	3211+00	B	2	159.3		
07/27/2006	3211+00	B	3	161.9		
07/27/2006	3211+00	B	4	159.2	160.03	1.2685
07/27/2006	3211+00	A	1	159.2		
07/27/2006	3211+00	A	2	153.9		
07/27/2006	3211+00	A	3	158		
07/27/2006	3211+00	A	4	159.4	157.63	2.5591
07/27/2006	3211+00	C	1	153.4		
07/27/2006	3211+00	C	2	155.8		
07/27/2006	3211+00	C	3	150.6		
07/27/2006	3211+00	C	4	158.1	154.48	3.218
07/27/2006	3211+03	B	1	162.2		
07/27/2006	3211+03	B	2	157.1		
07/27/2006	3211+03	B	3	159.4		
07/27/2006	3211+03	B	4	158.6	159.33	2.1407

Table 238. ***Density*** meas. by ***Pavetracker 10233***– Non-nuclear Gage on ***I-75, MI, pcf***
Continued

Test Date	Station	Point	Trial #	Density	Average	Std Dev
07/27/2006	3219+12	B	1	161.4		
07/27/2006	3219+12	B	2	160.8		
07/27/2006	3219+12	B	3	158.3		
07/27/2006	3219+12	B	4	150.7	157.8	4.92
07/27/2006	3219+14	B	1	162.9		
07/27/2006	3219+14	B	2	158		
07/27/2006	3219+14	B	3	162.4		
07/27/2006	3219+14	B	4	153.7	159.25	4.3054
07/27/2006	3219+14	A	1	153.4		
07/27/2006	3219+14	A	2	148		
07/27/2006	3219+14	A	3	151.4		
07/27/2006	3219+14	A	4	153.3	151.53	2.5237
07/27/2006	3219+14	C	1	154		
07/27/2006	3219+14	C	2	155.7		
07/27/2006	3219+14	C	3	147.3		
07/27/2006	3219+14	C	4	156.6	153.4	4.2071

Table 239. ***Modulus*** measured by ***PSPA*** on ***I-75, MI, ksi***

Test Date	Station	Point	Trial #	Modulus	Average
07/26/2006	2751+00	A	0°	882	
07/26/2006	2751+00	A	90°	631	
07/26/2006	2751+00	A	180°	710	741
07/26/2006	2751+00	B	0°	785	
07/26/2006	2751+00	B	90°	856	
07/26/2006	2751+00	B	180°	773	804
07/26/2006	2751+00	C	0°	656	
07/26/2006	2751+00	C	90°	747	
07/26/2006	2751+00	C	180°	715	706
07/26/2006	2753+00	A	0°	739	
07/26/2006	2753+00	A	90°	626	
07/26/2006	2753+00	A	180°	798	721
07/26/2006	2753+00	B	0°	682	
07/26/2006	2753+00	B	90°	706	
07/26/2006	2753+00	B	180°	755	714
07/26/2006	2753+00	C	0°	562	
07/26/2006	2753+00	C	90°	630	
07/26/2006	2753+00	C	180°	734	642
07/26/2006	2755+00	A	0°	778	
07/26/2006	2755+00	A	90°	739	
07/26/2006	2755+00	A	180°	833	783
07/26/2006	2755+00	B	0°	687	
07/26/2006	2755+00	B	90°	801	
07/26/2006	2755+00	B	180°	690	726
07/26/2006	2755+00	C	0°	746	
07/26/2006	2755+00	C	90°	693	
07/26/2006	2755+00	C	180°	737	725
07/26/2006	2756+00	A	0°	602	
07/26/2006	2756+00	A	90°	754	
07/26/2006	2756+00	A	180°	754	703
07/26/2006	2756+00	B	0°	864	
07/26/2006	2756+00	B	90°	780	
07/26/2006	2756+00	B	180°	751	798
07/26/2006	2756+00	C	0°	670	
07/26/2006	2756+00	C	90°	569	
07/26/2006	2756+00	C	180°	573	604
07/26/2006	2757+00	A	0°	644	

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Table 240. ***Modulus*** measured by ***PSPA*** on ***I-75, MI, ksi***
Continued

Test Date	Station	Point	Trial #	Modulus	Average
07/26/2006	2757+00	A	90°	604	
07/26/2006	2757+00	A	180°	604	617
07/26/2006	2757+00	B	0°	693	
07/26/2006	2757+00	B	90°	559	
07/26/2006	2757+00	B	180°	591	615
07/26/2006	2757+00	C	0°	658	
07/26/2006	2757+00	C	90°	706	
07/26/2006	2757+00	C	180°	681	682
07/26/2006	2760+00	A	0°	792	
07/26/2006	2760+00	A	90°	661	
07/26/2006	2760+00	A	180°	732	728
07/26/2006	2760+00	B	0°	697	
07/26/2006	2760+00	B	90°	668	
07/26/2006	2760+00	B	180°	722	695
07/26/2006	2760+00	C	0°	629	
07/26/2006	2760+00	C	90°	545	
07/26/2006	2760+00	C	180°	620	598
07/26/2006	2762+00	A	0°	663	
07/26/2006	2762+00	A	90°	738	
07/26/2006	2762+00	A	180°	637	680
07/26/2006	2762+00	B	0°	682	
07/26/2006	2762+00	B	90°	761	
07/26/2006	2762+00	B	180°	587	676
07/26/2006	2762+00	C	0°	716	
07/26/2006	2762+00	C	90°	738	
07/26/2006	2762+00	C	180°	645	700
07/26/2006	2763+00	A	0°	545	
07/26/2006	2763+00	A	90°	718	
07/26/2006	2763+00	A	180°	575	613
07/26/2006	2763+00	B	0°	736	
07/26/2006	2763+00	B	90°	776	
07/26/2006	2763+00	B	180°	712	742
07/26/2006	2763+00	C	0°	661	
07/26/2006	2763+00	C	90°	669	
07/26/2006	2763+00	C	180°	692	674

Table 240. ***Modulus*** measured by ***PSPA*** on ***I-75, MI, ksi***
Continued

Test Date	Station	Point	Trial #	Modulus	Average
07/27/2006	3112+87	A	0°	512	
07/27/2006	3112+87	A	90°	655	
07/27/2006	3112+87	A	180°	429	532
07/27/2006	3112+97	B	0°	644	
07/27/2006	3112+97	B	90°	607	
07/27/2006	3112+97	B	180°	668	639
07/27/2006	3113+09	C	0°	673	
07/27/2006	3113+09	C	90°	575	
07/27/2006	3113+09	C	180°	525	591
07/27/2006	3115+80	C	0°	485	
07/27/2006	3115+80	C	90°	481	
07/27/2006	3115+80	C	180°	635	534
07/27/2006	3115+85	B	0°	536	
07/27/2006	3115+85	B	90°	657	
07/27/2006	3115+85	B	180°	577	590
07/27/2006	3115+89	A	0°	415	
07/27/2006	3115+89	A	90°	569	
07/27/2006	3115+89	A	180°	455	480
07/27/2006	3122+00	C	0°	581	
07/27/2006	3122+00	C	90°	715	
07/27/2006	3122+00	C	180°	782	693
07/27/2006	3122+00	A	0°	644	
07/27/2006	3122+00	A	90°	536	
07/27/2006	3122+00	A	180°	493	557
07/27/2006	3122+00	C	0°	536	
07/27/2006	3122+00	C	90°	726	
07/27/2006	3122+00	C	180°	676	646
07/27/2006	3131+76	A	0°	590	
07/27/2006	3131+76	A	90°	750	
07/27/2006	3131+76	A	180°	711	684
07/27/2006	3131+80	B	0°	751	
07/27/2006	3131+80	B	90°	540	
07/27/2006	3131+80	B	180°	713	668
07/27/2006	3134+40	C	0°	526	
07/27/2006	3134+40	C	90°	598	
07/27/2006	3134+40	C	180°	630	585

Table 240. ***Modulus*** measured by ***PSPA*** on ***I-75, MI, ksi***
Continued

Test Date	Station	Point	Trial #	Modulus	Average
07/27/2006	3134+40	A	0°	642	
07/27/2006	3134+40	A	90°	588	
07/27/2006	3134+40	A	180°	584	605
07/27/2006	3134+53	B	0°	664	
07/27/2006	3134+53	B	90°	725	
07/27/2006	3134+53	B	180°	678	689
07/27/2006	3134+67	A	0°	653	
07/27/2006	3134+67	A	90°	661	
07/27/2006	3134+67	A	180°	732	682
07/27/2006	3142+00	A	0°	521	
07/27/2006	3142+00	A	90°	708	
07/27/2006	3142+00	A	180°	628	619
07/27/2006	3142+00	B	0°	732	
07/27/2006	3142+00	B	90°	811	
07/27/2006	3142+00	B	180°	612	718
07/27/2006	3142+00	C	0°	527	
07/27/2006	3142+00	C	90°	570	
07/27/2006	3142+00	C	180°	615	571
07/27/2006	3142+00	A	0°	739	
07/27/2006	3142+00	A	90°	711	
07/27/2006	3142+00	A	180°	693	714
07/27/2006	3142+00	B	0°	732	
07/27/2006	3142+00	B	90°	686	
07/27/2006	3142+00	B	180°	803	740
07/27/2006	3146+94	B	0°	638	
07/27/2006	3146+94	B	90°	596	
07/27/2006	3146+94	B	180°	653	629
07/27/2006	3146+97	C	0°	689	
07/27/2006	3146+97	C	90°	706	
07/27/2006	3146+97	C	180°	806	734
07/27/2006	3147+00	A	0°	529	
07/27/2006	3147+00	A	90°	710	
07/27/2006	3147+00	A	180°	650	630
07/27/2006	3147+00	A	0°	605	
07/27/2006	3147+00	A	90°	608	
07/27/2006	3147+00	A	180°	642	618

Table 240. ***Modulus*** measured by ***PSPA*** on ***I-75, MI, ksi***
Continued

Test Date	Station	Point	Trial #	Modulus	Average
07/27/2006	3150+89	B	0°	617	
07/27/2006	3150+89	B	90°	687	
07/27/2006	3150+89	B	180°	685	663
07/27/2006	3150+98	B	0°	581	
07/27/2006	3150+98	B	90°	700	
07/27/2006	3150+98	B	180°	700	660
07/27/2006	3151+02	A	0°	601	
07/27/2006	3151+02	A	90°	684	
07/27/2006	3151+02	A	180°	709	665
07/27/2006	3151+09	C	0°	791	
07/27/2006	3151+09	C	90°	655	
07/27/2006	3151+09	C	180°	594	680
07/27/2006	3153+00	A	0°	754	
07/27/2006	3153+00	A	90°	795	
07/27/2006	3153+00	A	180°	644	731
07/27/2006	3153+00	A	0°	658	
07/27/2006	3153+00	A	90°	738	
07/27/2006	3153+00	A	180°	687	694
07/27/2006	3157+00	A	0°	679	
07/27/2006	3157+00	A	90°	615	
07/27/2006	3157+00	A	180°	596	630
07/27/2006	3158+00	A	0°	634	
07/27/2006	3158+00	A	90°	533	
07/27/2006	3158+00	A	180°	641	603
07/27/2006	3158+01	A	0°	713	
07/27/2006	3158+01	A	90°	757	
07/27/2006	3158+01	A	180°	738	736
07/27/2006	3158+11	B	0°	767	
07/27/2006	3158+11	B	90°	822	
07/27/2006	3158+11	B	180°	862	817
07/27/2006	3158+19	C	0°	609	
07/27/2006	3158+19	C	90°	724	
07/27/2006	3158+19	C	180°	694	676
07/27/2006	3161+32	C	0°	571	
07/27/2006	3161+32	C	90°	696	
07/27/2006	3161+32	C	180°	650	639

Table 240. ***Modulus*** measured by ***PSPA*** on ***I-75, MI, ksi***
Continued

Test Date	Station	Point	Trial #	Modulus	Average
07/27/2006	3161+33	A	0°	555	
07/27/2006	3161+33	A	90°	546	
07/27/2006	3161+33	A	180°	578	560
07/27/2006	3161+43	B	0°	543	
07/27/2006	3161+43	B	90°	666	
07/27/2006	3161+43	B	180°	612	607
07/27/2006	3161+80	C	0°	571	
07/27/2006	3161+80	C	90°	691	
07/27/2006	3161+80	C	180°	587	616
07/27/2006	3161+90	A	0°	637	
07/27/2006	3161+90	A	90°	641	
07/27/2006	3161+90	A	180°	745	674
07/27/2006	3162+00	B	0°	735	
07/27/2006	3162+00	B	90°	707	
07/27/2006	3162+00	B	180°	596	680
07/27/2006	3165+00	A	0°	817	
07/27/2006	3165+00	A	90°	729	
07/27/2006	3165+00	A	180°	682	743
07/27/2006	3165+00	C	0°	663	
07/27/2006	3165+00	C	90°	710	
07/27/2006	3165+00	C	180°	773	715
07/27/2006	3170+00	A	0°	696	
07/27/2006	3170+00	A	90°	792	
07/27/2006	3170+00	A	180°	713	734
07/27/2006	3170+00	B	0°	789	
07/27/2006	3170+00	B	90°	688	
07/27/2006	3170+00	B	180°	716	731
07/27/2006	3171+00	A	1	152	152
07/27/2006	3171+00	B	1	258	258
07/27/2006	3171+00	C	1	181	181
07/27/2006	3174+00	A	1	258	258
07/27/2006	3174+00	B	1	255	255
07/27/2006	3174+00	C	1	173	173
07/27/2006	3177+00	A	1	328	328
07/27/2006	3177+00	B	1	251	251
07/27/2006	3177+00	C	1	162	162

Table 240. ***Modulus*** measured by ***PSPA*** on ***I-75, MI, ksi***
Continued

Test Date	Station	Point	Trial #	Modulus	Average
07/27/2006	3180+00	A	1	255	255
07/27/2006	3180+00	B	1	274	274
07/27/2006	3180+00	C	1	335	335
07/27/2006	3183+00	A	1	272	272
07/27/2006	3183+00	B	1	362	362
07/27/2006	3183+00	C	1	278	278
07/27/2006	3186+00	A	1	242	242
07/27/2006	3186+00	B	1	273	273
07/27/2006	3186+00	C	1	335	335
07/27/2006	3189+00	A	1	143	143
07/27/2006	3189+00	B	1	247	247
07/27/2006	3189+00	C	1	194	194
07/27/2006	3192+00	A	1	155	155
07/27/2006	3192+00	B	1	208	208
07/27/2006	3192+00	C	1	135	135
07/27/2006	3195+00	A	1	213	213
07/27/2006	3195+00	B	1	258	258
07/27/2006	3195+00	C	1	183	183
07/27/2006	3198+00	A	1	244	244
07/27/2006	3198+00	B	1	353	353
07/27/2006	3198+00	C	1	157	157
07/27/2006	3201+00	A	1	191	191
07/27/2006	3201+00	B	1	302	302
07/27/2006	3201+00	C	1	312	312
07/27/2006	3204+00	A	1	275	275
07/27/2006	3204+00	B	1	238	238
07/27/2006	3204+00	C	1	196	196
07/27/2006	3206+00	A	1	280	280
07/27/2006	3206+00	B	1	297	297
07/27/2006	3206+00	C	1	263	263
07/27/2006	3208+00	A	1	272	272
07/27/2006	3208+00	B	1	313	313
07/27/2006	3208+00	C	1	306	306
07/27/2006	3211+00	A	1	369	369
07/27/2006	3211+00	B	1	174	174
07/27/2006	3211+00	C	1	138	138

Table 240. ***Modulus*** measured by ***PSPA*** on ***I-75, MI, ksi***
Continued

Test Date	Station	Point	Trial #	Modulus	Average
07/27/2006	3214+00	A	1	361	361
07/27/2006	3214+00	B	1	391	391
07/27/2006	3214+00	C	1	320	320

Table 241. ***Density*** measured by ***NDG*** on ***I-75, MI, pcf***

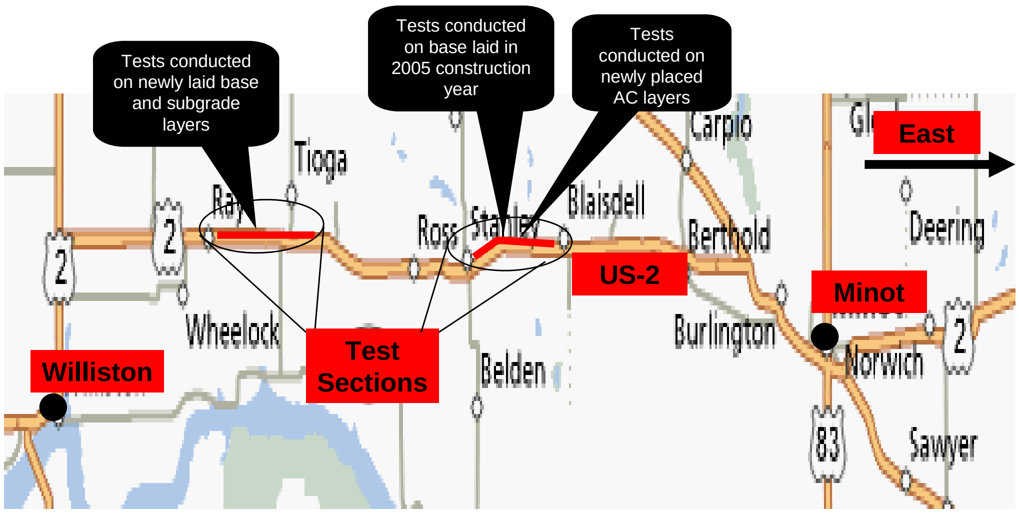
Test Date	Station	Point	Trial #	Density
07/25/2006	3112+87	A	1	149.4
07/25/2006	3112+87	A	1	149.4
07/25/2006	3112+97	B	1	152.2
07/25/2006	3112+97	B	1	152.2
07/25/2006	3113+09	C	1	151.9
07/25/2006	3113+09	C	1	151.9
07/25/2006	3115+80	C	1	149.3
07/25/2006	3115+80	C	1	149.3
07/25/2006	3115+85	B	1	151.4
07/25/2006	3115+85	B	1	151.4
07/25/2006	3115+89	A	1	148.7
07/25/2006	3115+89	A	1	148.7
07/25/2006	3131+76	A	1	147.6
07/25/2006	3131+76	A	1	147.6
07/25/2006	3131+80	B	1	151.5
07/25/2006	3131+80	B	1	151.5
07/25/2006	3131+84	C	1	151.5
07/25/2006	3131+84	C	1	151.5
07/25/2006	3134+40	C	1	151.1
07/25/2006	3134+40	C	1	151.1
07/25/2006	3134+53	B	1	150.6
07/25/2006	3134+53	B	1	150.6
07/25/2006	3134+67	A	1	149.4
07/25/2006	3134+67	A	1	149.4
07/25/2006	3146+92	A	1	146.2
07/25/2006	3146+94	B	1	149.9
07/25/2006	3146+97	C	1	146.9
07/25/2006	3147+00	A	1	145
07/25/2006	3150+89	B	1	150.6
07/25/2006	3150+89	B	1	150.6
07/25/2006	3150+98	B	1	148.8
07/25/2006	3150+98	B	1	148.8
07/25/2006	3151+02	A	1	150.4
07/25/2006	3151+02	A	1	150.4
07/25/2006	3151+09	C	1	151.2
07/25/2006	3151+09	C	1	151.2
07/25/2006	3158+01	A	1	145.5

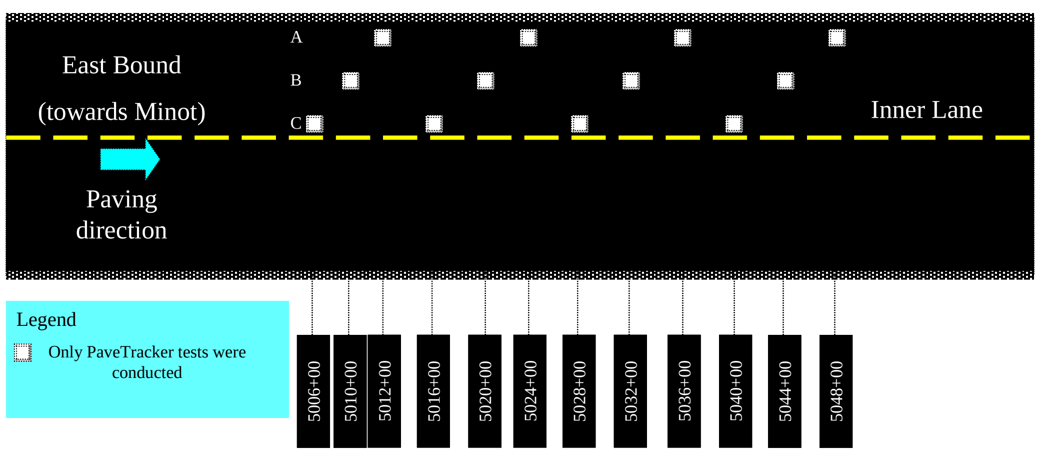
Table 242. ***Density*** measured by ***NDG*** on ***I-75, MI, pcf***
Continued

Test Date	Station	Point	Trial #	Density
07/25/2006	3158+11	B	1	147.1
07/25/2006	3158+11	B	1	147.1
07/25/2006	3158+19	C	1	145.5
07/25/2006	3158+19	C	1	145.5
07/25/2006	3161+32	C	1	149.9
07/25/2006	3161+32	C	1	149.9
07/25/2006	3161+33	A	1	151.4
07/25/2006	3161+33	A	1	151.4
07/25/2006	3161+43	B	1	154
07/25/2006	3161+43	B	1	154
07/25/2006	3161+80	C	1	151.7
07/25/2006	3161+80	C	1	151.7
07/25/2006	3161+90	A	1	153.2
07/25/2006	3161+90	A	1	153.2
07/25/2006	3162+00	B	1	151.7
07/25/2006	3162+00	B	1	151.7
07/27/2006	3146+92	A	1	146.2
07/27/2006	3146+94	B	1	149.9
07/27/2006	3146+97	C	1	146.9
07/27/2006	3147+00	A	1	145
07/27/2006	3211+03	B	1	154.5
07/27/2006	3211+03	B	1	154.5
07/27/2006	3219+12	B	1	156.6
07/27/2006	3219+12	B	1	156.6
07/27/2006	3219+14	B	1	157.9
07/27/2006	3219+14	B	1	157.9

US-2, NORTH DAKOTA, HMA SECTIONS

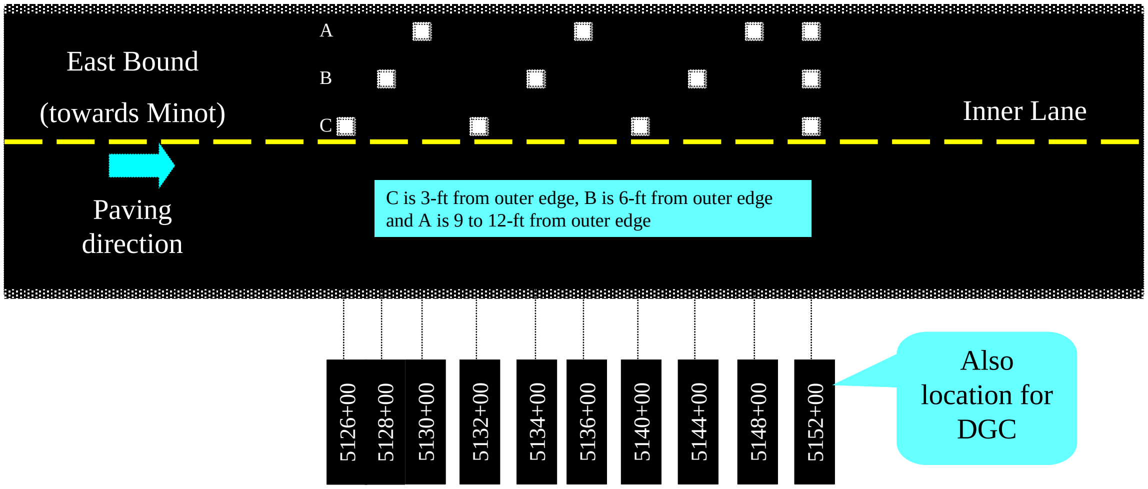
.



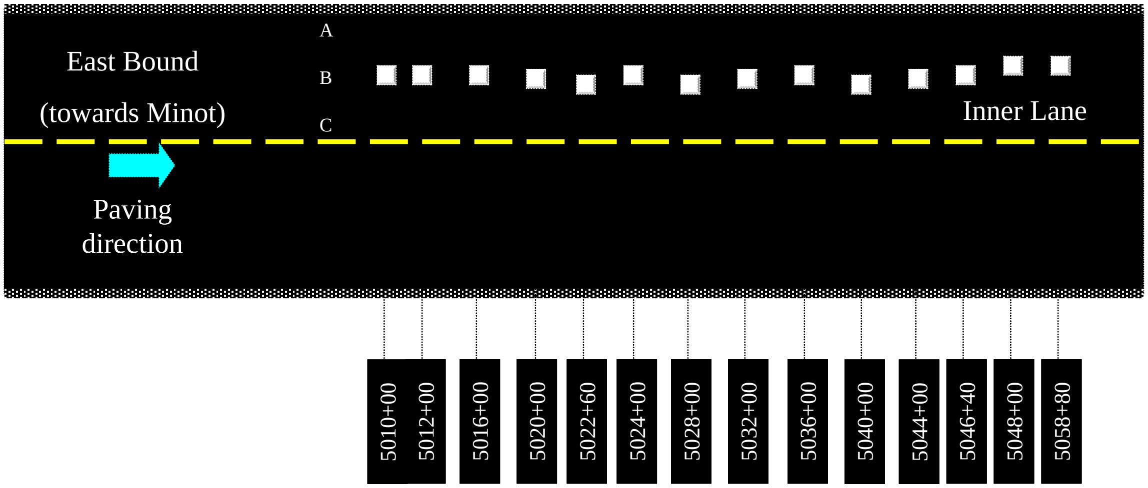


Note: Tests conducted during paving on August 23, 2006 and also on cold pavement on August 24, 2006 after a rain event.

General Layout of Test Points Along Section 1



General Layout of Test Points Along Section 2



General Layout of Test Points along Section 3

Table 243. ***Density*** meas. by ***Pavetracker 10232*** – Non-nuclear Gage on ***US-2, ND, pcf***

Test Date	Cold/Hot	Station	Point	Trial #	Density	Average	Std Dev
08/23/2006	Cold	5006+00	C	1	138.8		
08/23/2006	Cold	5006+00	C	2	137.9		
08/23/2006	Cold	5006+00	C	3	137.8		
08/23/2006	Cold	5006+00	C	4	139.2	138.43	0.685
08/23/2006	Hot	5006+00	C	1	134.4		
08/23/2006	Hot	5006+00	C	2	133.6		
08/23/2006	Hot	5006+00	C	3	131.8		
08/23/2006	Hot	5006+00	C	4	130.5	132.58	1.7595
08/23/2006	Cold	5010+00	B	1	138.3		
08/23/2006	Cold	5010+00	B	2	138.7		
08/23/2006	Cold	5010+00	B	3	142.4		
08/23/2006	Cold	5010+00	B	4	143.3	140.68	2.5435
08/23/2006	Hot	5010+00	B	1	135.3		
08/23/2006	Hot	5010+00	B	2	136		
08/23/2006	Hot	5010+00	B	3	134		
08/23/2006	Hot	5010+00	B	4	135.1	135.1	0.8287
08/23/2006	Cold	5012+00	A	1	140.8		
08/23/2006	Cold	5012+00	A	2	139.6		
08/23/2006	Cold	5012+00	A	3	138.5		
08/23/2006	Cold	5012+00	A	4	140.4	139.83	1.0145
08/23/2006	Hot	5012+00	A	1	130		
08/23/2006	Hot	5012+00	A	2	130.3		
08/23/2006	Hot	5012+00	A	3	132.6		
08/23/2006	Hot	5012+00	A	4	131.6	131.13	1.2038
08/23/2006	Cold	5016+00	C	1	141.8		
08/23/2006	Cold	5016+00	C	2	143.1		
08/23/2006	Cold	5016+00	C	3	139.2		
08/23/2006	Cold	5016+00	C	4	136.9	140.25	2.7598
08/23/2006	Hot	5016+00	C	1	134.2		
08/23/2006	Hot	5016+00	C	2	135.5		
08/23/2006	Hot	5016+00	C	3	131.6		
08/23/2006	Hot	5016+00	C	4	132.9	133.55	1.6783
08/23/2006	Cold	5020+00	B	1	139.1		
08/23/2006	Cold	5020+00	B	2	140.2		
08/23/2006	Cold	5020+00	B	3	139.3		
08/23/2006	Cold	5020+00	B	4	138.7	139.33	0.6344

Table 244. ***Density*** meas. by ***Pavetracker 10232*** – Non-nuclear Gage on ***US-2, ND, pcf***
Continued

Test Date	Cold/Hot	Station	Point	Trial #	Density	Average	Std Dev
08/23/2006	Hot	5020+00	B	1	135.5		
08/23/2006	Hot	5020+00	B	2	134.5		
08/23/2006	Hot	5020+00	B	3	137.2		
08/23/2006	Hot	5020+00	B	4	134.7	135.48	1.2285
08/23/2006	Cold	5024+00	A	1	139		
08/23/2006	Cold	5024+00	A	2	139		
08/23/2006	Cold	5024+00	A	3	15.7		
08/23/2006	Cold	5024+00	A	4	141.6	108.83	62.095
08/23/2006	Hot	5024+00	A	1	131.6		
08/23/2006	Hot	5024+00	A	2	132.3		
08/23/2006	Hot	5024+00	A	3	133.9		
08/23/2006	Hot	5024+00	A	4	132.8	132.65	0.9678
08/23/2006	Cold	5028+00	C	1	150.4		
08/23/2006	Cold	5028+00	C	2	141.7		
08/23/2006	Cold	5028+00	C	3	140.7		
08/23/2006	Cold	5028+00	C	4	143.6	144.1	4.3688
08/23/2006	Hot	5028+00	C	1	131.9		
08/23/2006	Hot	5028+00	C	2	131.8		
08/23/2006	Hot	5028+00	C	3	129.8		
08/23/2006	Hot	5028+00	C	4	132.7	131.55	1.2342
08/23/2006	Cold	5032+00	B	1	142.1		
08/23/2006	Cold	5032+00	B	2	145.4		
08/23/2006	Cold	5032+00	B	3	142.6		
08/23/2006	Cold	5032+00	B	4	142.5	143.15	1.5155
08/23/2006	Hot	5032+00	B	1	133.4		
08/23/2006	Hot	5032+00	B	2	132		
08/23/2006	Hot	5032+00	B	3	134		
08/23/2006	Hot	5032+00	B	4	130.9	132.58	1.3961
08/23/2006	Cold	5036+00	A	1	138.6		
08/23/2006	Cold	5036+00	A	2	139.5		
08/23/2006	Cold	5036+00	A	3	141.7		
08/23/2006	Cold	5036+00	A	4	134.6	138.6	2.9676
08/23/2006	Hot	5036+00	A	1	129.6		
08/23/2006	Hot	5036+00	A	2	131.4		
08/23/2006	Hot	5036+00	A	3	133.1		
08/23/2006	Hot	5036+00	A	4	134.5	132.15	2.1205

Table 244. ***Density*** meas. by ***Pavetracker 10232*** – Non-nuclear Gage on ***US-2, ND, pcf***
Continued

Test Date	Cold/Hot	Station	Point	Trial #	Density	Average	Std Dev
08/23/2006	Cold	5040+00	C	1	133.3		
08/23/2006	Cold	5040+00	C	2	142.6		
08/23/2006	Cold	5040+00	C	3	141.1		
08/23/2006	Cold	5040+00	C	4	143.2	140.05	4.5858
08/23/2006	Hot	5040+00	C	1	133		
08/23/2006	Hot	5040+00	C	2	133		
08/23/2006	Hot	5040+00	C	3	130.5		
08/23/2006	Hot	5040+00	C	4	130.7	131.8	1.388
08/23/2006	Cold	5044+00	B	1	141.4		
08/23/2006	Cold	5044+00	B	2	143.9		
08/23/2006	Cold	5044+00	B	3	140.2		
08/23/2006	Cold	5044+00	B	4	136.4	140.48	3.1234
08/23/2006	Hot	5044+00	B	1	135.7		
08/23/2006	Hot	5044+00	B	2	130.2		
08/23/2006	Hot	5044+00	B	3	136.1		
08/23/2006	Hot	5044+00	B	4	134.1	134.03	2.6924
08/23/2006	Hot	5048+00	A	1	128.2		
08/23/2006	Hot	5048+00	A	2	128		
08/23/2006	Hot	5048+00	A	3	130.3		
08/23/2006	Hot	5048+00	A	4	130.5	129.25	1.3329
08/23/2006	Hot	5048+00	A	1	131		
08/23/2006	Hot	5048+00	A	2	133.6		
08/23/2006	Hot	5048+00	A	3	133.8		
08/23/2006	Hot	5048+00	A	4	134.3	133.18	1.4796

Table 245. ***Density*** meas. by ***Pavetracker 10233*** – Non-nuclear Gage on ***US-2, ND, pcf***

Test Date	Cold/Hot	Station	Trial #	Density	Average	Std Dev
08/23/2006	Cold	5006+00	1	140.5		
08/23/2006	Cold	5006+00	2	139.1		
08/23/2006	Cold	5006+00	3	137.4		
08/23/2006	Cold	5006+00	4	139.5	139.13	1.292
08/23/2006	Hot	5006+00	1	133.5		
08/23/2006	Hot	5006+00	2	132.2		
08/23/2006	Hot	5006+00	3	130.4		
08/23/2006	Hot	5006+00	4	129.3	131.35	1.8664
08/23/2006	Cold	5010+00	1	139.6		
08/23/2006	Cold	5010+00	2	140.7		
08/23/2006	Cold	5010+00	3	143.3		
08/23/2006	Cold	5010+00	4	144	141.9	2.0897
08/23/2006	Hot	5010+00	1	133.4		
08/23/2006	Hot	5010+00	2	135		
08/23/2006	Hot	5010+00	3	133.8		
08/23/2006	Hot	5010+00	4	133.6	133.95	0.7188
08/23/2006	Cold	5012+00	1	140.3		
08/23/2006	Cold	5012+00	2	138.8		
08/23/2006	Cold	5012+00	3	141.1		
08/23/2006	Cold	5012+00	4	142.2	140.6	1.4306
08/23/2006	Hot	5012+00	1	131.6		
08/23/2006	Hot	5012+00	2	130.1		
08/23/2006	Hot	5012+00	3	131.3		
08/23/2006	Hot	5012+00	4	131.2	131.05	0.6557
08/23/2006	Cold	5016+00	1	143.5		
08/23/2006	Cold	5016+00	2	143.9		
08/23/2006	Cold	5016+00	3	140.4		
08/23/2006	Cold	5016+00	4	139.6	141.85	2.1672
08/23/2006	Hot	5016+00	1	132.7		
08/23/2006	Hot	5016+00	2	134.9		
08/23/2006	Hot	5016+00	3	131.6		
08/23/2006	Hot	5016+00	4	132.3	132.88	1.4245
08/23/2006	Cold	5020+00	1	139.7		
08/23/2006	Cold	5020+00	2	141.3		
08/23/2006	Cold	5020+00	3	142.4		
08/23/2006	Cold	5020+00	4	140.5	140.98	1.1529
08/23/2006	Hot	5020+00	1	133.1		

Table 246. ***Density*** meas. by ***Pavetracker 10233*** – Non-nuclear Gage on ***US-2, ND, pcf***
Continued

Test Date	Cold/Hot	Station	Trial #	Density	Average	Std Dev
08/23/2006	Hot	5020+00	2	133.1		
08/23/2006	Hot	5020+00	3	135		
08/23/2006	Hot	5020+00	4	134	133.8	0.9055
08/23/2006	Hot	5024+00	1	129.6		
08/23/2006	Hot	5024+00	2	132.3		
08/23/2006	Hot	5024+00	3	134.8		
08/23/2006	Hot	5024+00	4	131	131.93	2.2111
08/23/2006	Hot	5028+00	1	128.7		
08/23/2006	Hot	5028+00	2	129.8		
08/23/2006	Hot	5028+00	3	128.8		
08/23/2006	Hot	5028+00	4	133.5	130.2	2.2554
08/23/2006	Hot	5032+00	1	129.5		
08/23/2006	Hot	5032+00	2	130.7		
08/23/2006	Hot	5032+00	3	130.9		
08/23/2006	Hot	5032+00	4	130.5	130.4	0.6218
08/23/2006	Hot	5036+00	1	128.4		
08/23/2006	Hot	5036+00	2	130.5		
08/23/2006	Hot	5036+00	3	132.4		
08/23/2006	Hot	5036+00	4	133.1	131.1	2.1087
08/23/2006	Hot	5040+00	1	132.1		
08/23/2006	Hot	5040+00	2	131.4		
08/23/2006	Hot	5040+00	3	130.7		
08/23/2006	Hot	5040+00	4	129.2	130.85	1.2396
08/23/2006	Hot	5044+00	1	133.7		
08/23/2006	Hot	5044+00	2	129.5		
08/23/2006	Hot	5044+00	3	133.9		
08/23/2006	Hot	5044+00	4	131.5	132.15	2.0744
08/23/2006	Hot	5048+00	1	128.1		
08/23/2006	Hot	5048+00	2	128.2		
08/23/2006	Hot	5048+00	3	130.3		
08/23/2006	Hot	5048+00	4	127.3	128.48	1.2816
08/25/2006	Hot	16	1	131.6		
08/25/2006	Hot	16	2	130.4		
08/25/2006	Hot	16	3	132.2		
08/25/2006	Hot	16	4	132.4	131.65	0.9

Table 246. ***Density*** meas. by ***Pavetracker 10233*** – Non-nuclear Gage on ***US-2, ND, pcf***
Continued

Test Date	Cold/Hot	Station	Trial #	Density	Average	Std Dev
08/25/2006	Hot	17	1	129.3		
08/25/2006	Hot	17	2	129.5		
08/25/2006	Hot	17	3	130.8		
08/25/2006	Hot	17	4	130.7	130.08	0.7848
08/25/2006	Hot	18	1	130.1		
08/25/2006	Hot	18	2	124.8		
08/25/2006	Hot	18	3	128.8		
08/25/2006	Hot	18	4	127.5	127.8	2.2642
08/25/2006	Hot	19	1	132.5		
08/25/2006	Hot	19	2	131.9		
08/25/2006	Hot	19	3	130.2		
08/25/2006	Hot	19	4	128.9	130.88	1.6378
08/25/2006	Hot	20	1	130.9		
08/25/2006	Hot	20	2	133.3		
08/25/2006	Hot	20	3	132		
08/25/2006	Hot	20	4	130.8	131.75	1.1676
08/25/2006	Hot	21	1	130.1		
08/25/2006	Hot	21	2	130.7		
08/25/2006	Hot	21	3	132		
08/25/2006	Hot	21	4	130.6	130.85	0.8103
08/25/2006	Hot	22	1	130.4		
08/25/2006	Hot	22	2	130.6		
08/25/2006	Hot	22	3	126.9		
08/25/2006	Hot	22	4	130.9	129.7	1.8779
08/25/2006	Hot	23	1	128.1		
08/25/2006	Hot	23	2	126.1		
08/25/2006	Hot	23	3	131.3		
08/25/2006	Hot	23	4	126.6	128.03	2.3429
08/25/2006	Hot	24	1	127.6		
08/25/2006	Hot	24	2	126.3		
08/25/2006	Hot	24	3	129.3		
08/25/2006	Hot	24	4	126.9	127.53	1.2971
08/25/2006	Hot	25	1	130.4		
08/25/2006	Hot	25	2	129.9		
08/25/2006	Hot	25	3	127.7		
08/25/2006	Hot	25	4	125.3	128.33	2.3329

Table 246. ***Density*** meas. by ***Pavetracker 10233*** – Non-nuclear Gage on ***US-2, ND, pcf***
Continued

Test Date	Cold/Hot	Station	Trial #	Density	Average	Std Dev
08/25/2006	Hot	26	1	130.9		
08/25/2006	Hot	26	2	127		
08/25/2006	Hot	26	3	129.1		
08/25/2006	Hot	26	4	127.2	128.55	1.8303
08/25/2006	Hot	27	1	130.9		
08/25/2006	Hot	27	2	127.5		
08/25/2006	Hot	27	3	132.2		
08/25/2006	Hot	27	4	126.7	129.33	2.6437
08/25/2006	Hot	28	1	128.1		
08/25/2006	Hot	28	2	127.3		
08/25/2006	Hot	28	3	127.5		
08/25/2006	Hot	28	4	127.2	127.53	0.4031
08/25/2006	Hot	5010	1	135.3		
08/25/2006	Hot	5010	2	135.9		
08/25/2006	Hot	5010	3	135.3		
08/25/2006	Hot	5010	4	135.1	135.4	0.3464
08/25/2006	Hot	5012	1	130.6		
08/25/2006	Hot	5012	2	132.5		
08/25/2006	Hot	5012	3	128.8		
08/25/2006	Hot	5012	4	131.4	130.83	1.5586
08/25/2006	Hot	5016	1	136.9		
08/25/2006	Hot	5016	2	134.1		
08/25/2006	Hot	5016	3	134.1		
08/25/2006	Hot	5016	4	135.2	135.08	1.3226
08/25/2006	Hot	5020	1	138.2		
08/25/2006	Hot	5020	2	135.5		
08/25/2006	Hot	5020	3	136.7		
08/25/2006	Hot	5020	4	134.2	136.15	1.7059
08/25/2006	Hot	5024	1	132.3		
08/25/2006	Hot	5024	2	131.4		
08/25/2006	Hot	5024	3	133.6		
08/25/2006	Hot	5024	4	132	132.33	0.9287
08/25/2006	Hot	5028	1	129.7		
08/25/2006	Hot	5028	2	130.7		
08/25/2006	Hot	5028	3	131.2		
08/25/2006	Hot	5028	4	129.6	130.3	0.7789

Table 246. ***Density*** meas. by ***Pavetracker 10233*** – Non-nuclear Gage on ***US-2, ND, pcf***
Continued

Test Date	Cold/Hot	Station	Trial #	Density	Average	Std Dev
08/25/2006	Hot	5032	1	130.5		
08/25/2006	Hot	5032	2	130.7		
08/25/2006	Hot	5032	3	132.5		
08/25/2006	Hot	5032	4	129.6	130.83	1.2148
08/25/2006	Hot	5036	1	131.7		
08/25/2006	Hot	5036	2	132.3		
08/25/2006	Hot	5036	3	133.6		
08/25/2006	Hot	5036	4	132.2	132.45	0.8103
08/25/2006	Hot	5040	1	132.1		
08/25/2006	Hot	5040	2	132.2		
08/25/2006	Hot	5040	3	130.2		
08/25/2006	Hot	5040	4	130.3	131.2	1.0985
08/25/2006	Hot	5126	1	129.3		
08/25/2006	Hot	5126	2	131.3		
08/25/2006	Hot	5126	3	130		
08/25/2006	Hot	5126	4	129.5	130.03	0.8995
08/25/2006	Hot	5128	1	128.8		
08/25/2006	Hot	5128	2	131.8		
08/25/2006	Hot	5128	3	128.8		
08/25/2006	Hot	5128	4	128.6	129.5	1.5362
08/25/2006	Hot	5130	1	128.5		
08/25/2006	Hot	5130	2	129.5		
08/25/2006	Hot	5130	3	130.5		
08/25/2006	Hot	5130	4	129.1	129.4	0.8406
08/25/2006	Hot	5132	1	130.1		
08/25/2006	Hot	5132	2	133.2		
08/25/2006	Hot	5132	3	129.1		
08/25/2006	Hot	5132	4	132.7	131.28	1.9873
08/25/2006	Hot	5134	1	129.9		
08/25/2006	Hot	5134	2	128.7		
08/25/2006	Hot	5134	3	132.9		
08/25/2006	Hot	5134	4	132.7	131.05	2.0809
08/25/2006	Hot	5136	1	128.7		
08/25/2006	Hot	5136	2	130		
08/25/2006	Hot	5136	3	135.2		
08/25/2006	Hot	5136	4	133.3	131.8	2.9811

Table 246. ***Density*** meas. by ***Pavetracker 10233*** – Non-nuclear Gage on ***US-2, ND, pcf***
Continued

Test Date	Cold/Hot	Station	Trial #	Density	Average	Std Dev
08/25/2006	Hot	5140	1	130		
08/25/2006	Hot	5140	2	129.3		
08/25/2006	Hot	5140	3	130.4		
08/25/2006	Hot	5140	4	131.4	130.28	0.877
08/25/2006	Hot	5144	1	134.6		
08/25/2006	Hot	5144	2	133.8		
08/25/2006	Hot	5144	3	135.4		
08/25/2006	Hot	5144	4	135	134.7	0.6831
08/25/2006	Hot	5148	1	128.9		
08/25/2006	Hot	5148	2	128.4		
08/25/2006	Hot	5148	3	126.5		
08/25/2006	Hot	5148	4	127.3	127.78	1.0813
08/25/2006	Hot	5152	1	127.3		
08/25/2006	Hot	5152	2	125.6		
08/25/2006	Hot	5152	3	128.1		
08/25/2006	Hot	5152	4	129.3	127.58	1.5521
08/25/2006	Hot	5152	1	128.8		
08/25/2006	Hot	5152	2	128.5		
08/25/2006	Hot	5152	3	129.7		
08/25/2006	Hot	5152	4	130.9	129.48	1.0782
08/25/2006	Hot	5152	1	128.4		
08/25/2006	Hot	5152	2	128		
08/25/2006	Hot	5152	3	132.1		
08/25/2006	Hot	5152	4	129	129.38	1.8626
08/25/2006	Hot	5022+60	1	134.8		
08/25/2006	Hot	5022+60	2	134.9		
08/25/2006	Hot	5022+60	3	132.3		
08/25/2006	Hot	5022+60	4	135.7	134.43	1.4728
08/26/2006	Hot	29	1	133.8		
08/26/2006	Hot	29	2	134.1		
08/26/2006	Hot	29	3	131.5		
08/26/2006	Hot	29	4	130.8	132.55	1.6462
08/26/2006	Hot	30	1	134.6		
08/26/2006	Hot	30	2	133.7		
08/26/2006	Hot	30	3	134.3		
08/26/2006	Hot	30	4	134.1	134.18	0.3775

Table 246. ***Density*** meas. by ***Pavetracker 10233*** – Non-nuclear Gage on ***US-2, ND, pcf*** Continued

Test Date	Cold/Hot	Station	Trial #	Density	Average	Std Dev
08/26/2006	Hot	31	1	133.6		
08/26/2006	Hot	31	2	133.6		
08/26/2006	Hot	31	3	133		
08/26/2006	Hot	31	4	132.2	133.1	0.6633
08/26/2006	Hot	32	1	131.1		
08/26/2006	Hot	32	2	131		
08/26/2006	Hot	32	3	129.9		
08/26/2006	Hot	32	4	129.6	130.4	0.7616
08/26/2006	Hot	33	2	133.5		
08/26/2006	Hot	33	3	132.4		
08/26/2006	Hot	33	4	134.4	133.13	1.0243
08/26/2006	Hot	33	1	132.2		
08/26/2006	Hot	34	2	135.2		
08/26/2006	Hot	34	3	134.1		
08/26/2006	Hot	34	4	133.8	134.23	0.6652
08/26/2006	Hot	34	1	133.8		
08/26/2006	Hot	35	2	133.3		
08/26/2006	Hot	35	3	134.5		
08/26/2006	Hot	35	4	135.9	134.5	1.0708
08/26/2006	Hot	35	1	134.3		
08/26/2006	Hot	36	2	133.2		
08/26/2006	Hot	36	3	132.8		
08/26/2006	Hot	36	4	132.6	133.28	0.8539
08/26/2006	Hot	36	1	134.5		
08/26/2006	Hot	37	2	131.9		
08/26/2006	Hot	37	3	129.5		
08/26/2006	Hot	37	4	130.4	130.23	1.242
08/26/2006	Hot	37	1	129.1		
08/26/2006	Hot	38	2	126.7		
08/26/2006	Hot	38	3	127.1		
08/26/2006	Hot	38	4	128.1	126.9	0.9933
08/26/2006	Hot	38	1	125.7		
08/26/2006	Hot	39	2	130.5		
08/26/2006	Hot	39	3	132.1		
08/26/2006	Hot	39	4	131.8	131.33	0.75
08/26/2006	Hot	39	1	130.9		

Table 246. ***Density*** meas. by ***Pavetracker 10233*** – Non-nuclear Gage on ***US-2, ND, pcf***
Continued

Test Date	Cold/Hot	Station	Trial #	Density	Average	Std Dev
08/26/2006	Hot	40	2	128.2		
08/26/2006	Hot	40	3	129.8		
08/26/2006	Hot	40	4	131	130.23	1.6008
08/26/2006	Hot	40	1	131.9		
08/26/2006	Hot	41	1	130.5		
08/26/2006	Hot	41	2	130.8		
08/26/2006	Hot	41	3	131.5		
08/26/2006	Hot	41	4	131.4	131.05	0.4796
08/26/2006	Hot	42	1	131.7		
08/26/2006	Hot	42	2	132		
08/26/2006	Hot	42	3	131		
08/26/2006	Hot	42	4	131.3	131.5	0.4397
08/26/2006	Hot	43	1	131.3		
08/26/2006	Hot	43	2	131.2		
08/26/2006	Hot	43	3	130.8		
08/26/2006	Hot	43	4	132.5	131.45	0.7326
08/26/2006	Hot	44	1	128.1		
08/26/2006	Hot	44	2	127.6		
08/26/2006	Hot	44	3	129		
08/26/2006	Hot	44	4	128.9	128.4	0.6683
08/26/2006	Hot	45	2	127.1		
08/26/2006	Hot	45	3	128.9		
08/26/2006	Hot	45	4	126.6	127.3	1.0924
08/26/2006	Hot	45	1	126.6		
08/26/2006	Hot	46	2	132.7		
08/26/2006	Hot	46	3	133.6		
08/26/2006	Hot	46	4	132.7	133.2	0.5831
08/26/2006	Hot	46	1	133.8		
08/29/2006	Hot	47	1	129.6		
08/29/2006	Hot	47	2	131.7		
08/29/2006	Hot	47	3	129.3		
08/29/2006	Hot	47	4	128.4	129.75	1.3964
08/29/2006	Hot	48	1	131.9		
08/29/2006	Hot	48	2	133.8		
08/29/2006	Hot	48	3	131.1		
08/29/2006	Hot	48	4	133.1	132.48	1.2066

Table 246. ***Density*** meas. by ***Pavetracker 10233*** – Non-nuclear Gage on ***US-2, ND, pcf***
Continued

Test Date	Cold/Hot	Station	Trial #	Density	Average	Std Dev
08/29/2006	Hot	49	1	127.3		
08/29/2006	Hot	49	2	126.8		
08/29/2006	Hot	49	3	132		
08/29/2006	Hot	49	4	133.8	129.98	3.4625
08/29/2006	Hot	50	1	131.3		
08/29/2006	Hot	50	2	129.6		
08/29/2006	Hot	50	3	131.3		
08/29/2006	Hot	50	4	132.4	131.15	1.1561
08/29/2006	Hot	51	2	132.1		
08/29/2006	Hot	51	3	133.5		
08/29/2006	Hot	51	4	132.5	133.03	0.877
08/29/2006	Hot	51	1	134		
08/29/2006	Hot	52	2	129.6		
08/29/2006	Hot	52	3	128.9		
08/29/2006	Hot	52	4	129.1	129.18	0.2986
08/29/2006	Hot	52	1	129.1		
08/29/2006	Hot	53	2	130.8		
08/29/2006	Hot	53	3	130		
08/29/2006	Hot	53	4	131.2	130.65	0.5
08/29/2006	Hot	53	1	130.6		
08/29/2006	Hot	54	2	136.3		
08/29/2006	Hot	54	3	134.1		
08/29/2006	Hot	54	4	133	134.38	1.3841
08/29/2006	Hot	54	1	134.1		
08/29/2006	Hot	55	2	134.7		
08/29/2006	Hot	55	3	132.2		
08/29/2006	Hot	55	4	133.1	133.65	1.2124
08/29/2006	Hot	55	1	134.6		
08/29/2006	Hot	56	2	133.8		
08/29/2006	Hot	56	3	130		
08/29/2006	Hot	56	4	129	131.35	2.2293
08/29/2006	Hot	56	1	132.6		
08/29/2006	Hot	57	2	127.5		
08/29/2006	Hot	57	3	131.1		
08/29/2006	Hot	57	4	133.8	130.43	2.6875
08/29/2006	Hot	57	1	129.3		

Table 246. ***Density*** meas. by ***Pavetracker 10233*** – Non-nuclear Gage on ***US-2, ND, pcf***
Continued

Test Date	Cold/Hot	Station	Trial #	Density	Average	Std Dev
08/29/2006	Hot	58	2	130.8		
08/29/2006	Hot	58	3	131.9		
08/29/2006	Hot	58	4	131.6	131.55	0.5196
08/29/2006	Hot	58	1	131.9		
08/29/2006	Hot	59	1	130.7		
08/29/2006	Hot	59	2	130.2		
08/29/2006	Hot	59	3	130.9		
08/29/2006	Hot	59	4	130.1	130.48	0.3862
08/29/2006	Hot	60	1	134.8		
08/29/2006	Hot	60	2	133.5		
08/29/2006	Hot	60	3	132.7		
08/29/2006	Hot	60	4	133.1	133.53	0.9106
08/30/2006	Hot	61	1	128.9		
08/30/2006	Hot	61	2	128.4		
08/30/2006	Hot	61	3	128.6		
08/30/2006	Hot	61	4	127.5	128.35	0.6028
08/30/2006	Hot	62	1	134.9		
08/30/2006	Hot	62	2	131.8		
08/30/2006	Hot	62	3	133.9		
08/30/2006	Hot	62	4	132.6	133.3	1.3736
08/30/2006	Hot	63	1	133.4		
08/30/2006	Hot	63	2	134.8		
08/30/2006	Hot	63	3	134.1		
08/30/2006	Hot	63	4	134.6	134.23	0.6238
08/30/2006	Hot	64	1	132.1		
08/30/2006	Hot	64	2	135		
08/30/2006	Hot	64	3	134.3		
08/30/2006	Hot	64	4	133.7	133.78	1.2366
08/30/2006	Hot	65	2	128		
08/30/2006	Hot	65	3	128.7		
08/30/2006	Hot	65	4	129.4	128	1.5122
08/30/2006	Hot	65	1	125.9		
08/30/2006	Hot	66	2	129		
08/30/2006	Hot	66	3	132		
08/30/2006	Hot	66	4	131.5	130.78	1.3175
08/30/2006	Hot	66	1	130.6		

Table 246. ***Density*** meas. by ***Pavetracker 10233*** – Non-nuclear Gage on ***US-2, ND, pcf*** Continued

Test Date	Cold/Hot	Station	Trial #	Density	Average	Std Dev
08/30/2006	Hot	67	2	133.6		
08/30/2006	Hot	67	3	132.6		
08/30/2006	Hot	67	4	133.4	133.33	0.4992
08/30/2006	Hot	67	1	133.7		
08/30/2006	Hot	68	2	131.7		
08/30/2006	Hot	68	3	133.8		
08/30/2006	Hot	68	4	135	133.03	1.6621
08/30/2006	Hot	68	1	131.6		
08/30/2006	Hot	69	2	133		
08/30/2006	Hot	69	3	133.2		
08/30/2006	Hot	69	4	131.6	132.75	0.7724
08/30/2006	Hot	69	1	133.2		
08/30/2006	Hot	70	2	130.8		
08/30/2006	Hot	70	3	129.4		
08/30/2006	Hot	70	4	128.6	129.3	1.0893
08/30/2006	Hot	70	1	128.4		
08/30/2006	Hot	71	2	132.7		
08/30/2006	Hot	71	3	133.9		
08/30/2006	Hot	71	4	133.6	133.2	0.6481
08/30/2006	Hot	71	1	132.6		
08/30/2006	Hot	72	2	132.9		
08/30/2006	Hot	72	3	131.8		
08/30/2006	Hot	72	4	132.6	133.18	1.5543
08/30/2006	Hot	72	1	135.4		
08/30/2006	Hot	73	1	133.2		
08/30/2006	Hot	73	2	134.4		
08/30/2006	Hot	73	3	134		
08/30/2006	Hot	73	4	132.3	133.48	0.9287
08/30/2006	Hot	74	1	134.8		
08/30/2006	Hot	74	2	133.5		
08/30/2006	Hot	74	3	133.5		
08/30/2006	Hot	74	4	133.7	133.88	0.6238
08/30/2006	Hot	75	1	133.2		
08/30/2006	Hot	75	2	134.4		
08/30/2006	Hot	75	3	133.6		
08/30/2006	Hot	75	4	133	133.55	0.6191

Table 246. ***Density*** meas. by ***Pavetracker 10233*** – Non-nuclear Gage on ***US-2, ND, pcf***
Continued

Test Date	Cold/Hot	Station	Trial #	Density	Average	Std Dev
08/31/2006	Hot	76	1	132.3		
08/31/2006	Hot	76	2	131.3		
08/31/2006	Hot	76	3	128.1		
08/31/2006	Hot	76	4	126.3	129.5	2.7857
08/31/2006	Hot	77	1	128.9		
08/31/2006	Hot	77	2	132		
08/31/2006	Hot	77	3	124.3		
08/31/2006	Hot	77	4	130.3	128.88	3.3029
08/31/2006	Hot	78	1	134.7		
08/31/2006	Hot	78	2	134.6		
08/31/2006	Hot	78	3	135		
08/31/2006	Hot	78	4	136.6	135.23	0.9323
08/31/2006	Hot	79	1	134.3		
08/31/2006	Hot	79	2	135.4		
08/31/2006	Hot	79	3	131.8		
08/31/2006	Hot	79	4	131.9	133.35	1.7898
08/31/2006	Hot	80	1	133.6		
08/31/2006	Hot	80	2	136.4		
08/31/2006	Hot	80	3	135.9		
08/31/2006	Hot	80	4	135.9	135.45	1.2557
08/31/2006	Hot	81	1	134.1		
08/31/2006	Hot	81	2	134.1		
08/31/2006	Hot	81	3	133.2		
08/31/2006	Hot	81	4	132.5	133.48	0.7762
08/31/2006	Hot	82	1	131.7		
08/31/2006	Hot	82	2	131.1		
08/31/2006	Hot	82	3	134.7		
08/31/2006	Hot	82	4	136.5	133.5	2.5456
08/31/2006	Hot	83	1	128.8		
08/31/2006	Hot	83	2	129.8		
08/31/2006	Hot	83	3	126.8		
08/31/2006	Hot	83	4	125.5	127.73	1.938
08/31/2006	Hot	84	1	128		
08/31/2006	Hot	84	2	132.3		
08/31/2006	Hot	84	3	128.1		
08/31/2006	Hot	84	4	130.9	129.83	2.1282

Table 246. ***Density*** meas. by ***Pavetracker 10233*** – Non-nuclear Gage on ***US-2, ND, pcf***
Continued

Test Date	Cold/Hot	Station	Trial #	Density	Average	Std Dev
08/31/2006	Hot	85	1	132.5		
08/31/2006	Hot	85	2	130.5		
08/31/2006	Hot	85	3	135.1		
08/31/2006	Hot	85	4	135.4	133.38	2.3171
08/31/2006	Hot	86	1	134.6		
08/31/2006	Hot	86	2	135.1		
08/31/2006	Hot	86	3	135.1		
08/31/2006	Hot	86	4	134.3	134.78	0.3948
08/31/2006	Hot	87	1	135.5		
08/31/2006	Hot	87	2	132.9		
08/31/2006	Hot	87	3	133.8		
08/31/2006	Hot	87	4	132.7	133.73	1.2764
08/31/2006	Hot	88	1	135.9		
08/31/2006	Hot	88	2	137.8		
08/31/2006	Hot	88	3	137		
08/31/2006	Hot	88	4	135.1	136.45	1.1902
08/31/2006	Hot	89	1	134		
08/31/2006	Hot	89	2	130		
08/31/2006	Hot	89	3	134.4		
08/31/2006	Hot	89	4	131.8	132.55	2.0486
08/31/2006	Hot	90	1	132.3		
08/31/2006	Hot	90	2	131.3		
08/31/2006	Hot	90	3	126.9		
08/31/2006	Hot	90	4	129	129.88	2.4171
08/31/2006	Hot	91	1	132.3		
08/31/2006	Hot	91	2	131		
08/31/2006	Hot	91	3	130.7		
08/31/2006	Hot	91	4	131.6	131.4	0.7071
08/31/2006	Hot	92	1	131		
08/31/2006	Hot	92	2	130		
08/31/2006	Hot	92	3	128.4		
08/31/2006	Hot	92	4	132.3	130.43	1.646
08/31/2006	Hot	93	1	133		
08/31/2006	Hot	93	2	131.7		
08/31/2006	Hot	93	3	128.5		
08/31/2006	Hot	93	4	132.4	131.4	2.005

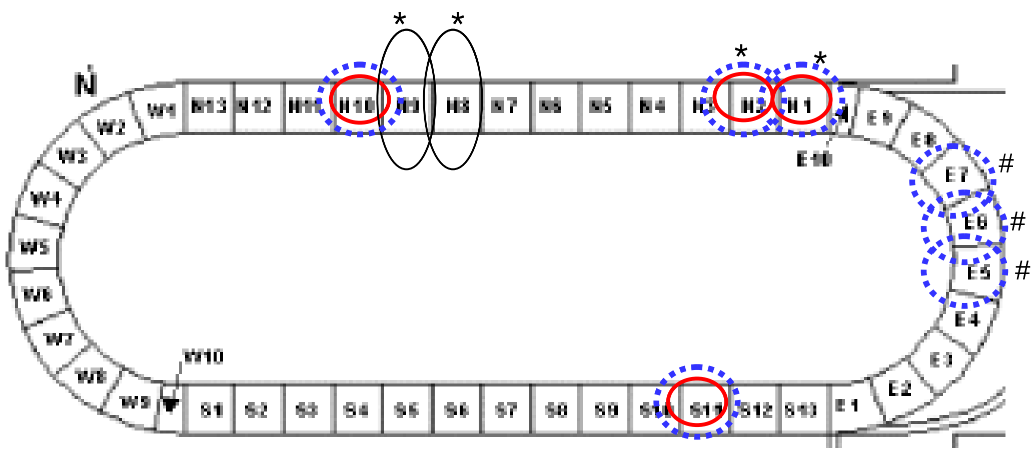
Table 247. ***Modulus*** measured by ***PSPA*** on ***US-2, ND, ksi***

Test Date	Station	Point	Trial #	Modulus	Average
08/23/2006	5006+00	C	1	105	105
08/23/2006	5010+00	B	1	120	120
08/23/2006	5012+00	A	1	107	107
08/23/2006	5016+00	C	1	125	125
08/23/2006	5020+00	B	1	127	127
08/23/2006	5024+00	A	1	102	102
08/23/2006	5028+00	C	1	82	82
08/23/2006	5032+00	B	1	115	115
08/23/2006	5036+00	A	1	104	104
08/23/2006	5040+00	C	1	155	155
08/23/2006	5044+00	B	1	101	101
08/23/2006	5048+00	A	1	112	112
08/24/2006	5006+00	C	1	419	419
08/24/2006	5010+00	B	1	406	406
08/24/2006	5012+00	A	1	356	356
08/24/2006	5016+00	C	1	412	412
08/24/2006	5020+00	B	1	459	459
08/24/2006	5024+00	A	1	453	453
08/24/2006	5028+00	C	1	413	413
08/24/2006	5032+00	B	1	428	428
08/24/2006	5036+00	A	1	418	418
08/24/2006	5040+00	C	1	421	421
08/24/2006	5044+00	B	1	480	480
08/25/2006	5006+00	C	1	267	267
08/25/2006	5010+00	B	1	256	256
08/25/2006	5012+00	A	1	277	277
08/25/2006	5016+00	C	1	270	270
08/25/2006	5020+00	B	1	317	317
08/25/2006	5024+00	A	1	272	272
08/25/2006	5028+00	C	1	283	283
08/25/2006	5032+00	B	1	296	296
08/25/2006	5036+00	A	1	289	289
08/25/2006	5040+00	C	1	282	282
08/25/2006	5044+00	B	1	293	293
08/25/2006	5048+00	A	1	248	248
08/25/2006	5152	B	1	129	129
08/25/2006	5126	B	1	160	160

Table 248. ***Modulus*** measured by ***PSPA*** on ***US-2, ND, ksi***
Continued

Test Date	Station	Point	Trial #	Modulus	Average
08/25/2006	5128	C	1	142	142
08/25/2006	5130	A	1	137	137
08/25/2006	5132	C	1	175	175
08/25/2006	5134	B	1	153	153
08/25/2006	5136	A	1	148	148
08/25/2006	5140	C	1	148	148
08/25/2006	5144	B	1	170	170
08/25/2006	5148	A	1	132	132
08/25/2006	5152	A	1	167	167
08/25/2006	5152	B	1	130	130
08/25/2006	5152	C	1	180	180

NCAT, AL, HMA SECTIONS



- Tests on Hot and Cold HMA

* - Tests on multiple lifts

Base layer tests

Subgrade layer tests

HMA layer tests

E-5 ALABAMA TEST SECTION AT NCAT

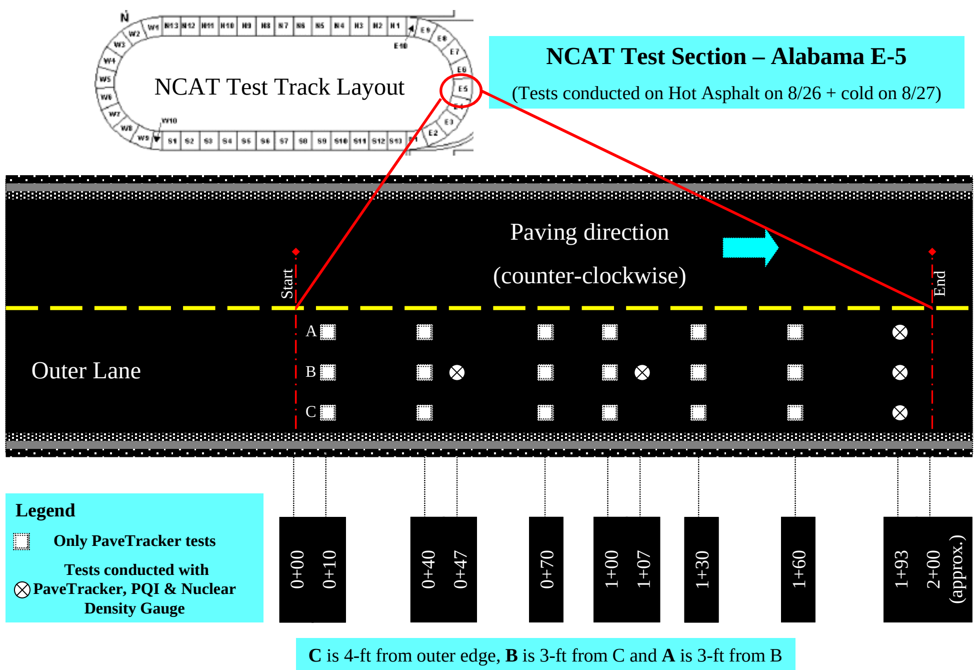


Table 249. ***Density*** meas. by ***Pavetracker 10232*** – Non-nuclear Gage on ***E-5, AL, pcf***

Test Date	Station	Point	Trial #	Density	Average	Std Dev
09/26/2006	0+10	A	1	124.8		
09/26/2006	0+10	A	2	122.7		
09/26/2006	0+10	A	3	125.2		
09/26/2006	0+10	A	4	124	124.18	1.1026
09/26/2006	0+10	B	1	123.9		
09/26/2006	0+10	B	2	121.8		
09/26/2006	0+10	B	3	122.7		
09/26/2006	0+10	B	4	123.5	122.98	0.9287
09/26/2006	0+10	C	1	122.7		
09/26/2006	0+10	C	2	122.8		
09/26/2006	0+10	C	3	122.2		
09/26/2006	0+10	C	4	121.2	122.23	0.732
09/26/2006	0+40	A	1	124		
09/26/2006	0+40	A	2	124.2		
09/26/2006	0+40	A	3	123.4		
09/26/2006	0+40	A	4	124	123.9	0.3464
09/26/2006	0+40	B	1	124.6		
09/26/2006	0+40	B	2	123.5		
09/26/2006	0+40	B	3	124.3		
09/26/2006	0+40	B	4	122.8	123.8	0.8124
09/26/2006	0+40	C	1	124.6		
09/26/2006	0+40	C	2	124.3		
09/26/2006	0+40	C	3	126.1		
09/26/2006	0+40	C	4	123.1	124.53	1.2339
09/26/2006	0+47	B	1	122.9		
09/26/2006	0+47	B	2	122.6		
09/26/2006	0+47	B	3	124.1		
09/26/2006	0+47	B	4	124.3	123.48	0.85
09/26/2006	0+70	A	1	125.1		
09/26/2006	0+70	A	2	123.9		
09/26/2006	0+70	A	3	123.6		
09/26/2006	0+70	A	4	123.8	124.1	0.6782
09/26/2006	0+70	B	1	122.9		
09/26/2006	0+70	B	2	123.3		
09/26/2006	0+70	B	3	123.6		
09/26/2006	0+70	B	4	122	122.95	0.6952
09/26/2006	0+70	C	1	126.8		

Table 250. ***Density*** meas. by ***Pavetracker 10232*** – Non-nuclear Gage on ***E-5, AL, pcf***
Continued

Test Date	Station	Point	Trial #	Density	Average	Std Dev
09/26/2006	0+70	C	2	123.7		
09/26/2006	0+70	C	3	124.9		
09/26/2006	0+70	C	4	125.7	125.28	1.3074
09/26/2006	1+00	A	1	126.8		
09/26/2006	1+00	A	2	126.7		
09/26/2006	1+00	A	3	125.5		
09/26/2006	1+00	A	4	125.6	126.15	0.6952
09/26/2006	1+00	B	1	124.8		
09/26/2006	1+00	B	2	125.6		
09/26/2006	1+00	B	3	124.5		
09/26/2006	1+00	B	4	125.3	125.05	0.4933
09/26/2006	1+00	C	1	126		
09/26/2006	1+00	C	2	123.8		
09/26/2006	1+00	C	3	123.3		
09/26/2006	1+00	C	4	126.2	124.83	1.4886
09/26/2006	1+07	B	1	124.4		
09/26/2006	1+07	B	2	124.3		
09/26/2006	1+07	B	3	123.1		
09/26/2006	1+07	B	4	124.5	124.08	0.6551
09/26/2006	1+30	A	1	125		
09/26/2006	1+30	A	2	126.1		
09/26/2006	1+30	A	3	124.2		
09/26/2006	1+30	A	4	123.5	124.7	1.1165
09/26/2006	1+30	B	1	122.3		
09/26/2006	1+30	B	2	124.4		
09/26/2006	1+30	B	3	123.9		
09/26/2006	1+30	B	4	123.5	123.53	0.8958
09/26/2006	1+30	C	1	127.2		
09/26/2006	1+30	C	2	125.5		
09/26/2006	1+30	C	3	127.1		
09/26/2006	1+30	C	4	126.3	126.53	0.7932
09/26/2006	1+60	A	1	125.8		
09/26/2006	1+60	A	2	126		
09/26/2006	1+60	A	3	127.4		
09/26/2006	1+60	A	4	127	126.55	0.7724

Table 250. ***Density*** meas. by ***Pavetracker 10232*** – Non-nuclear Gage on ***E-5, AL, pcf***
Continued

Test Date	Station	Point	Trial #	Density	Average	Std Dev
09/26/2006	1+60	B	1	124.1		
09/26/2006	1+60	B	2	124.9		
09/26/2006	1+60	B	3	125.7		
09/26/2006	1+60	B	4	125.5	125.05	0.7188
09/26/2006	1+60	C	1	122.4		
09/26/2006	1+60	C	2	125.2		
09/26/2006	1+60	C	3	123.8		
09/26/2006	1+60	C	4	127.5	124.73	2.1747
09/26/2006	1+93	A	1	121		
09/26/2006	1+93	A	2	123.6		
09/26/2006	1+93	A	3	121.4		
09/26/2006	1+93	A	4	124.9	122.73	1.8464
09/26/2006	1+93	B	1	124		
09/26/2006	1+93	B	2	124.3		
09/26/2006	1+93	B	3	124.4		
09/26/2006	1+93	B	4	125.1	124.45	0.4655
09/26/2006	1+93	C	1	124.6		
09/26/2006	1+93	C	2	125.4		
09/26/2006	1+93	C	3	125.8		
09/26/2006	1+93	C	4	125.4	125.3	0.5033
09/27/2006	0+10	A	1	124.4		
09/27/2006	0+10	A	2	121.5		
09/27/2006	0+10	A	3	124.3		
09/27/2006	0+10	A	4	124.9	123.78	1.5392
09/27/2006	0+10	B	1	123		
09/27/2006	0+10	B	2	120.8		
09/27/2006	0+10	B	3	123.6		
09/27/2006	0+10	B	4	123.3	122.68	1.2738
09/27/2006	0+10	C	1	122.8		
09/27/2006	0+10	C	2	122.4		
09/27/2006	0+10	C	3	124.1		
09/27/2006	0+10	C	4	122.5	122.95	0.7853
09/27/2006	0+40	A	1	124.1		
09/27/2006	0+40	A	2	122.7		
09/27/2006	0+40	A	3	125.4		
09/27/2006	0+40	A	4	124.4	124.15	1.115

Table 250. ***Density*** meas. by ***Pavetracker 10232*** – Non-nuclear Gage on ***E-5, AL, pcf***
Continued

Test Date	Station	Point	Trial #	Density	Average	Std Dev
09/27/2006	0+40	B	1	124.8		
09/27/2006	0+40	B	2	124.4		
09/27/2006	0+40	B	3	123.6		
09/27/2006	0+40	B	4	122.8	123.9	0.8869
09/27/2006	0+40	C	1	124.7		
09/27/2006	0+40	C	2	124.4		
09/27/2006	0+40	C	3	125.6		
09/27/2006	0+40	C	4	125.7	125.1	0.6481
09/27/2006	0+47	B	1	123.1		
09/27/2006	0+47	B	2	124.5		
09/27/2006	0+47	B	3	124.7		
09/27/2006	0+47	B	4	125.3	124.4	0.9309
09/27/2006	0+70	A	1	123.1		
09/27/2006	0+70	A	2	124		
09/27/2006	0+70	A	3	123.7		
09/27/2006	0+70	A	4	123	123.45	0.4796
09/27/2006	0+70	B	1	122		
09/27/2006	0+70	B	2	124.1		
09/27/2006	0+70	B	3	123.7		
09/27/2006	0+70	B	4	125.8	123.9	1.5599
09/27/2006	0+70	C	1	126.2		
09/27/2006	0+70	C	2	125.4		
09/27/2006	0+70	C	3	126.7		
09/27/2006	0+70	C	4	127.8	126.53	1.0046
09/27/2006	1+00	A	1	126.9		
09/27/2006	1+00	A	2	125.9		
09/27/2006	1+00	A	3	126.1		
09/27/2006	1+00	A	4	125.7	126.15	0.526
09/27/2006	1+00	B	1	124.4		
09/27/2006	1+00	B	2	126.5		
09/27/2006	1+00	B	3	124		
09/27/2006	1+00	B	4	124.3	124.8	1.146
09/27/2006	1+00	C	1	122.2		
09/27/2006	1+00	C	2	124.3		
09/27/2006	1+00	C	3	125.5		
09/27/2006	1+00	C	4	125.6	124.4	1.5811

Table 250. ***Density*** meas. by ***Pavetracker 10232*** – Non-nuclear Gage on ***E-5, AL, pcf***
Continued

Test Date	Station	Point	Trial #	Density	Average	Std Dev
09/27/2006	1+07	B	1	123.8		
09/27/2006	1+07	B	2	124.2		
09/27/2006	1+07	B	3	123.4		
09/27/2006	1+07	B	4	124.2	123.9	0.383
09/27/2006	1+30	A	1	125.3		
09/27/2006	1+30	A	2	126.1		
09/27/2006	1+30	A	3	124.6		
09/27/2006	1+30	A	4	125.3	125.33	0.6131
09/27/2006	1+30	B	1	123.6		
09/27/2006	1+30	B	2	123.8		
09/27/2006	1+30	B	3	123.4		
09/27/2006	1+30	B	4	125.6	124.1	1.0132
09/27/2006	1+30	C	1	126.3		
09/27/2006	1+30	C	2	127		
09/27/2006	1+30	C	3	126.1		
09/27/2006	1+30	C	4	127.2	126.65	0.5323
09/27/2006	1+60	A	1	124.5		
09/27/2006	1+60	A	2	124.7		
09/27/2006	1+60	A	3	124.7		
09/27/2006	1+60	A	4	126	124.98	0.6898
09/27/2006	1+60	B	1	123.4		
09/27/2006	1+60	B	2	125		
09/27/2006	1+60	B	3	125.7		
09/27/2006	1+60	B	4	124.9	124.75	0.9678
09/27/2006	1+60	C	1	126.1		
09/27/2006	1+60	C	2	125.8		
09/27/2006	1+60	C	3	126.4		
09/27/2006	1+60	C	4	127.8	126.53	0.8846
09/27/2006	1+93	A	1	124.4		
09/27/2006	1+93	A	2	121.2		
09/27/2006	1+93	A	3	125.2		
09/27/2006	1+93	A	4	123.2	123.5	1.7397
09/27/2006	1+93	B	1	125.6		
09/27/2006	1+93	B	2	122.5		
09/27/2006	1+93	B	3	123.6		
09/27/2006	1+93	B	4	124.2	123.98	1.292

Table 250. ***Density*** meas. by ***Pavetracker 10232*** – Non-nuclear Gage on ***E-5, AL, pcf***
Continued

Test Date	Station	Point	Trial #	Density	Average	Std Dev
09/27/2006	1+93	C	1	125.2		
09/27/2006	1+93	C	2	124.2		
09/27/2006	1+93	C	3	121.7		
09/27/2006	1+93	C	4	122.8	123.48	1.5392

Table 251. ***Modulus*** measured by ***PSPA*** on ***E-5, AL, ksi***

Test Date	Station	Point	Trial #	Modulus	Average
09/26/2006	0+10	A	1	173	173
09/26/2006	0+10	B	1	260	260
09/26/2006	0+10	C	1	184	184
09/26/2006	0+40	A	1	262	262
09/26/2006	0+40	B	1	253	253
09/26/2006	0+40	C	1	225	225
09/26/2006	0+47	B	1	296	296
09/26/2006	0+70	A	1	350	350
09/26/2006	0+70	B	1	233	233
09/26/2006	0+70	C	1	188	188
09/26/2006	0+78	B	1	203	203
09/26/2006	1+00	A	1	294	294
09/26/2006	1+00	B	1	259	259
09/26/2006	1+00	C	1	202	202
09/26/2006	1+07	B	1	256	256
09/26/2006	1+30	A	1	328	328
09/26/2006	1+30	B	1	239	239
09/26/2006	1+30	C	1	232	232
09/26/2006	1+60	A	1	249	249
09/26/2006	1+60	B	1	219	219
09/26/2006	1+60	C	1	204	204
09/26/2006	1+93	A	1	304	304
09/26/2006	1+93	B	1	292	292
09/26/2006	1+93	C	1	296	296
09/27/2006	0+10	A	1	466	466
09/27/2006	0+10	B	1	508	508
09/27/2006	0+10	C	1	537	537
09/27/2006	0+40	A	1	499	499
09/27/2006	0+40	B	1	534	534
09/27/2006	0+40	C	1	470	470
09/27/2006	0+47	B	1	567	567
09/27/2006	0+70	A	1	557	557
09/27/2006	0+70	B	1	522	522
09/27/2006	0+70	C	1	567	567
09/27/2006	0+78	B	1	487	487
09/27/2006	1+00	A	1	533	533
09/27/2006	1+00	B	1	488	488

Table 252. ***Modulus*** measured by ***PSPA*** on ***E-5, AL, ksi***
Continued

Test Date	Station	Point	Trial #	Modulus	Average
09/27/2006	1+00	C	1	502	502
09/27/2006	1+07	B	1	506	506
09/27/2006	1+30	A	1	480	480
09/27/2006	1+30	B	1	470	470
09/27/2006	1+30	C	1	509	509
09/27/2006	1+60	A	1	522	522
09/27/2006	1+60	B	1	477	477
09/27/2006	1+60	C	1	459	459
09/27/2006	1+93	A	1	493	493
09/27/2006	1+93	B	1	547	547
09/27/2006	1+93	C	1	557	557

E-6 ALABAMA TEST SECTION AT NCAT

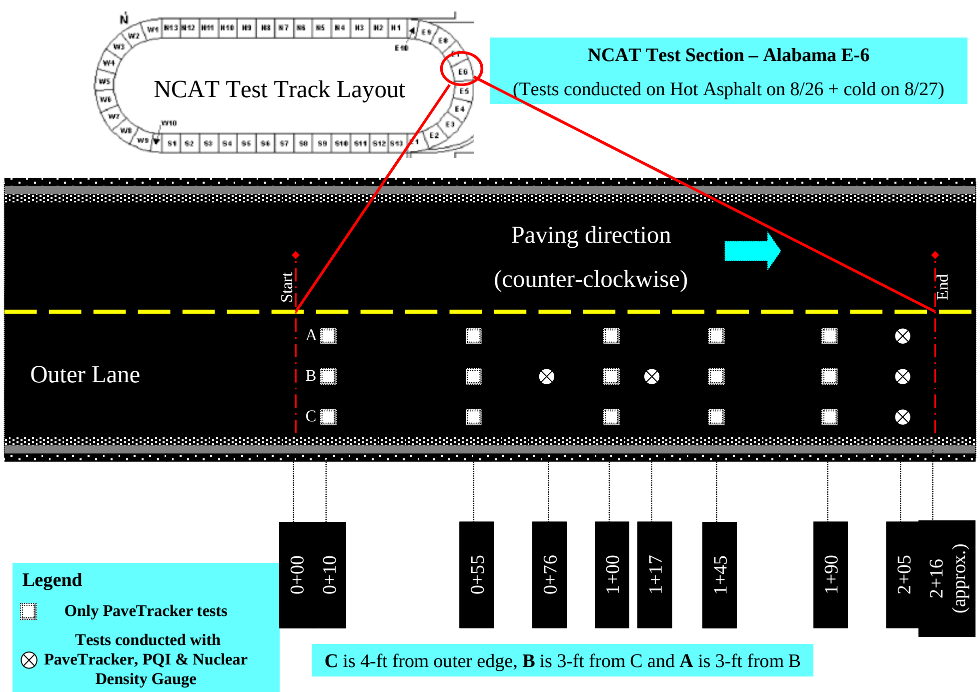


Table 253. ***Density*** meas. by ***Pavetracker 10232*** – Non-nuclear Gage on ***E-6, AL, pcf***

Test Date	Station	Point	Trial #	Density	Average	Std Dev
09/26/2006	0+10	A	1	124.6		
09/26/2006	0+10	A	2	124.4		
09/26/2006	0+10	A	3	124.4		
09/26/2006	0+10	A	4	125.4	124.7	0.4761
09/26/2006	0+10	B	1	123.1		
09/26/2006	0+10	B	2	124.9		
09/26/2006	0+10	B	3	123.6		
09/26/2006	0+10	B	4	124.8	124.1	0.8907
09/26/2006	0+10	C	1	126.5		
09/26/2006	0+10	C	2	124		
09/26/2006	0+10	C	3	125.1		
09/26/2006	0+10	C	4	126.6	125.55	1.2396
09/26/2006	0+55	A	1	125.1		
09/26/2006	0+55	A	2	125.2		
09/26/2006	0+55	A	3	124.9		
09/26/2006	0+55	A	4	126.4	125.4	0.6782
09/26/2006	0+55	B	1	124.9		
09/26/2006	0+55	B	2	124.5		
09/26/2006	0+55	B	3	125.4		
09/26/2006	0+55	B	4	124.4	124.8	0.4546
09/26/2006	0+55	C	1	125.9		
09/26/2006	0+55	C	2	127.6		
09/26/2006	0+55	C	3	127.2		
09/26/2006	0+55	C	4	126.3	126.75	0.7853
09/26/2006	0+76	B	1	126.7		
09/26/2006	0+76	B	2	125		
09/26/2006	0+76	B	3	126		
09/26/2006	0+76	B	4	127.9	126.4	1.2193
09/26/2006	1+00	A	1	123.8		
09/26/2006	1+00	A	2	123.2		
09/26/2006	1+00	A	3	124.8		
09/26/2006	1+00	A	4	126.2	124.5	1.3115
09/26/2006	1+00	B	1	123.8		
09/26/2006	1+00	B	2	124.4		
09/26/2006	1+00	B	3	124.5		
09/26/2006	1+00	B	4	124.4	124.28	0.3202
09/26/2006	1+00	C	1	126.6		

Table 254. ***Density*** meas. by ***Pavetracker 10232*** – Non-nuclear Gage on ***E-6, AL, pcf***
Continued

Test Date	Station	Point	Trial #	Density	Average	Std Dev
09/26/2006	1+00	C	2	126.9		
09/26/2006	1+00	C	3	129.4		
09/26/2006	1+00	C	4	127.8	127.68	1.258
09/26/2006	1+17	B	1	124		
09/26/2006	1+17	B	2	124.4		
09/26/2006	1+17	B	3	124.5		
09/26/2006	1+17	B	4	125.1	124.5	0.4546
09/26/2006	1+45	A	1	122.7		
09/26/2006	1+45	A	2	123.3		
09/26/2006	1+45	A	3	123		
09/26/2006	1+45	A	4	124.6	123.4	0.8367
09/26/2006	1+45	B	1	123.5		
09/26/2006	1+45	B	2	123.3		
09/26/2006	1+45	B	3	125		
09/26/2006	1+45	B	4	124.2	124	0.7703
09/26/2006	1+45	C	1	126		
09/26/2006	1+45	C	2	126.9		
09/26/2006	1+45	C	3	127		
09/26/2006	1+45	C	4	128.1	127	0.8602
09/26/2006	1+90	A	1	125.8		
09/26/2006	1+90	A	2	126.9		
09/26/2006	1+90	A	3	127.4		
09/26/2006	1+90	A	4	124.8	126.23	1.1615
09/26/2006	1+90	B	1	121.3		
09/26/2006	1+90	B	2	124.3		
09/26/2006	1+90	B	3	123.2		
09/26/2006	1+90	B	4	122.6	122.85	1.2503
09/26/2006	1+90	C	1	125.7		
09/26/2006	1+90	C	2	123.2		
09/26/2006	1+90	C	3	124		
09/26/2006	1+90	C	4	123.6	124.13	1.0996
09/26/2006	2+05	A	1	126.2		
09/26/2006	2+05	A	2	126.2		
09/26/2006	2+05	A	3	126.2		
09/26/2006	2+05	A	4	126	126.15	0.1

Table 254. ***Density*** meas. by ***Pavetracker 10232*** – Non-nuclear Gage on ***E-6, AL, pcf***
Continued

Test Date	Station	Point	Trial #	Density	Average	Std Dev
09/26/2006	2+05	B	1	121.3		
09/26/2006	2+05	B	2	124		
09/26/2006	2+05	B	3	121.5		
09/26/2006	2+05	B	4	120.5	121.83	1.513
09/26/2006	2+05	C	1	125.7		
09/26/2006	2+05	C	2	125		
09/26/2006	2+05	C	3	125.4		
09/26/2006	2+05	C	4	125.8	125.48	0.3594
09/27/2006	0+10	A	1	125.1		
09/27/2006	0+10	A	2	125.7		
09/27/2006	0+10	A	3	125.4		
09/27/2006	0+10	A	4	125.7	125.48	0.2872
09/27/2006	0+10	B	1	123.4		
09/27/2006	0+10	B	2	124.2		
09/27/2006	0+10	B	3	122.1		
09/27/2006	0+10	B	4	123.5	123.3	0.8756
09/27/2006	0+10	C	1	125.5		
09/27/2006	0+10	C	2	127		
09/27/2006	0+10	C	3	126.8		
09/27/2006	0+10	C	4	127.2	126.63	0.7676
09/27/2006	0+55	A	1	126		
09/27/2006	0+55	A	2	124.2		
09/27/2006	0+55	A	3	126.2		
09/27/2006	0+55	A	4	125.7	125.53	0.9069
09/27/2006	0+55	B	1	124.9		
09/27/2006	0+55	B	2	124.6		
09/27/2006	0+55	B	3	124.9		
09/27/2006	0+55	B	4	124.8	124.8	0.1414
09/27/2006	0+55	C	1	126.9		
09/27/2006	0+55	C	2	127		
09/27/2006	0+55	C	3	128		
09/27/2006	0+55	C	4	125.8	126.93	0.8995
09/27/2006	0+76	B	1	125.4		
09/27/2006	0+76	B	2	123.3		
09/27/2006	0+76	B	3	124.6		
09/27/2006	0+76	B	4	127.5	125.2	1.7607

Table 254. ***Density*** meas. by ***Pavetracker 10232*** – Non-nuclear Gage on ***E-6, AL, pcf***
Continued

Test Date	Station	Point	Trial #	Density	Average	Std Dev
09/27/2006	1+00	A	1	124.9		
09/27/2006	1+00	A	2	121.8		
09/27/2006	1+00	A	3	124		
09/27/2006	1+00	A	4	125.1	123.95	1.5111
09/27/2006	1+00	B	1	124.2		
09/27/2006	1+00	B	2	123.5		
09/27/2006	1+00	B	3	124.3		
09/27/2006	1+00	B	4	122.6	123.65	0.7853
09/27/2006	1+00	C	1	128.6		
09/27/2006	1+00	C	2	126.4		
09/27/2006	1+00	C	3	127.5		
09/27/2006	1+00	C	4	127.6	127.53	0.8995
09/27/2006	1+17	B	1	125.3		
09/27/2006	1+17	B	2	123.7		
09/27/2006	1+17	B	3	126.3		
09/27/2006	1+17	B	4	125.1	125.1	1.0708
09/27/2006	1+45	A	1	126.6		
09/27/2006	1+45	A	2	124.3		
09/27/2006	1+45	A	3	126.2		
09/27/2006	1+45	A	4	126.7	125.95	1.121
09/27/2006	1+45	B	1	125.2		
09/27/2006	1+45	B	2	124.4		
09/27/2006	1+45	B	3	126.1		
09/27/2006	1+45	B	4	125.1	125.2	0.6976
09/27/2006	1+45	C	1	127.4		
09/27/2006	1+45	C	2	127		
09/27/2006	1+45	C	3	126.8		
09/27/2006	1+45	C	4	126.6	126.95	0.3416
09/27/2006	1+90	A	1	127.2		
09/27/2006	1+90	A	2	126.9		
09/27/2006	1+90	A	3	126.5		
09/27/2006	1+90	A	4	125.8	126.6	0.6055
09/27/2006	1+90	B	1	122.2		
09/27/2006	1+90	B	2	122.7		
09/27/2006	1+90	B	3	122.4		
09/27/2006	1+90	B	4	122.4	122.43	0.2062

Table 254. ***Density*** meas. by ***Pavetracker 10232*** – Non-nuclear Gage on ***E-6, AL, pcf***
Continued

Test Date	Station	Point	Trial #	Density	Average	Std Dev
09/27/2006	1+90	C	1	125.6		
09/27/2006	1+90	C	2	123.5		
09/27/2006	1+90	C	3	124.1		
09/27/2006	1+90	C	4	124.1	124.33	0.8958
09/27/2006	2+05	A	1	126.1		
09/27/2006	2+05	A	2	123.7		
09/27/2006	2+05	A	3	125.8		
09/27/2006	2+05	A	4	124.1	124.93	1.201
09/27/2006	2+05	B	1	122.4		
09/27/2006	2+05	B	2	122.8		
09/27/2006	2+05	B	3	122.2		
09/27/2006	2+05	B	4	119.9	121.83	1.3074
09/27/2006	2+05	C	1	124.2		
09/27/2006	2+05	C	2	125		
09/27/2006	2+05	C	3	123.6		
09/27/2006	2+05	C	4	121.4	123.55	1.5438

Table 255. ***Modulus*** measured by ***PSPA*** on ***E-6, AL, ksi***

Test Date	Station	Point	Trial #	Modulus	Average
09/26/2006	0+10	A	1	308	308
09/26/2006	0+10	B	1	326	326
09/26/2006	0+10	C	1	246	246
09/26/2006	0+55	A	1	272	272
09/26/2006	0+55	B	1	374	374
09/26/2006	0+55	C	1	326	326
09/26/2006	0+76	B	1	277	277
09/26/2006	1+00	A	1	329	329
09/26/2006	1+00	B	1	319	319
09/26/2006	1+00	C	1	350	350
09/26/2006	1+17	B	1	298	298
09/26/2006	1+45	A	1	375	375
09/26/2006	1+45	B	1	402	402
09/26/2006	1+45	C	1	304	304
09/26/2006	1+90	A	1	373	373
09/26/2006	1+90	B	1	285	285
09/26/2006	1+90	C	1	212	212
09/26/2006	2+05	A	1	285	285
09/26/2006	2+05	B	1	294	294
09/26/2006	2+05	C	1	255	255
09/27/2006	0+10	A	1	516	516
09/27/2006	0+10	B	1	523	523
09/27/2006	0+10	C	1	556	556
09/27/2006	0+55	A	1	472	472
09/27/2006	0+55	B	1	490	490
09/27/2006	0+55	C	1	509	509
09/27/2006	0+76	B	1	553	553
09/27/2006	1+00	A	1	450	450
09/27/2006	1+00	B	1	412	412
09/27/2006	1+00	C	1	561	561
09/27/2006	1+17	B	1	500	500
09/27/2006	1+45	A	1	412	412
09/27/2006	1+45	B	1	400	400
09/27/2006	1+45	C	1	430	430
09/27/2006	1+90	A	1	459	459
09/27/2006	1+90	B	1	383	383
09/27/2006	1+90	C	1	461	461

Table 256. ***Modulus*** measured by ***PSPA*** on ***E-6, AL, ksi***
Continued

Test Date	Station	Point	Trial #	Modulus	Average
09/27/2006	2+05	A	1	519	519
09/27/2006	2+05	B	1	434	434
09/27/2006	2+05	C	1	427	427

E-7 ALABAMA TEST SECTION AT NCAT

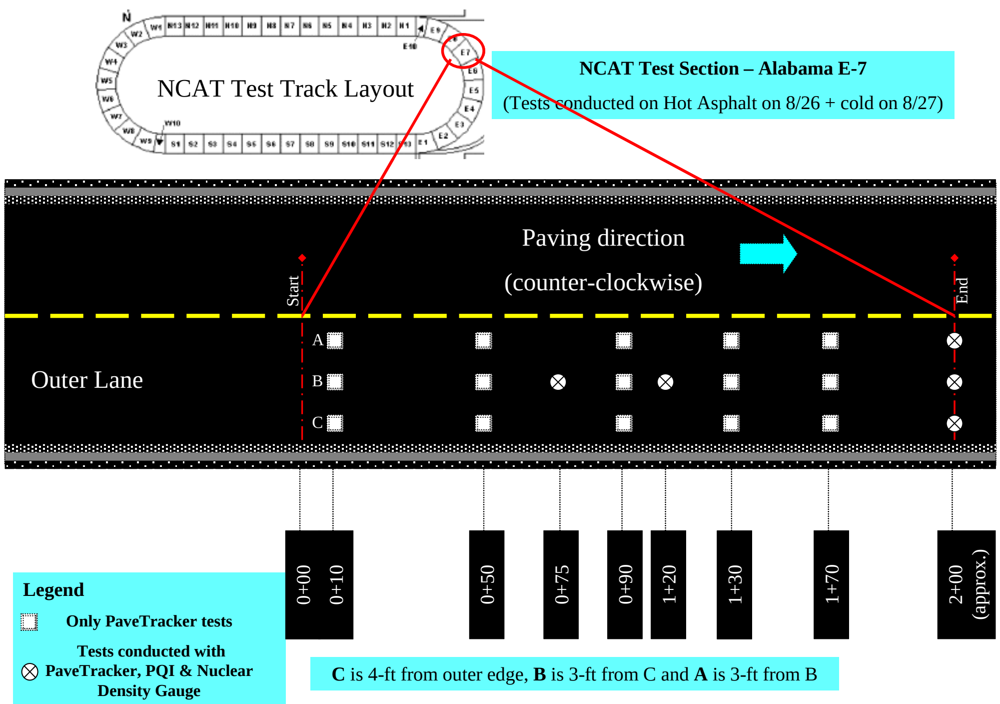


Table 257. ***Density*** meas. by ***Pavetracker 10232*** – Non-nuclear Gage on ***E-7, AL, pcf***

Test Date	Station	Point	Trial #	Density	Average	Std Dev
09/26/2006	0+10	A	1	125.8		
09/26/2006	0+10	A	2	126.4		
09/26/2006	0+10	A	3	125.9		
09/26/2006	0+10	A	4	125.6	125.93	0.3403
09/26/2006	0+10	B	1	122		
09/26/2006	0+10	B	2	121.4		
09/26/2006	0+10	B	3	122.6		
09/26/2006	0+10	B	4	121	121.75	0.7
09/26/2006	0+10	C	1	125.2		
09/26/2006	0+10	C	2	125		
09/26/2006	0+10	C	3	124.3		
09/26/2006	0+10	C	4	124.8	124.83	0.3862
09/26/2006	0+50	A	1	126.7		
09/26/2006	0+50	A	2	125.2		
09/26/2006	0+50	A	3	126.5		
09/26/2006	0+50	A	4	124.3	125.68	1.1325
09/26/2006	0+50	B	1	123.9		
09/26/2006	0+50	B	2	123.8		
09/26/2006	0+50	B	3	123.3		
09/26/2006	0+50	B	4	124.1	123.78	0.3403
09/26/2006	0+50	C	1	125.8		
09/26/2006	0+50	C	2	125.9		
09/26/2006	0+50	C	3	126.1		
09/26/2006	0+50	C	4	125	125.7	0.483
09/26/2006	0+75	B	1	124.1		
09/26/2006	0+75	B	2	123.8		
09/26/2006	0+75	B	3	125.1		
09/26/2006	0+75	B	4	123	124	0.8679
09/26/2006	0+90	A	1	125.9		
09/26/2006	0+90	A	2	125.1		
09/26/2006	0+90	A	3	126.2		
09/26/2006	0+90	A	4	125.1	125.58	0.562
09/26/2006	0+90	B	1	123.5		
09/26/2006	0+90	B	2	123.6		
09/26/2006	0+90	B	3	122.9		
09/26/2006	0+90	B	4	123.1	123.28	0.3304
09/26/2006	0+90	C	1	125.5		
09/26/2006	0+90	C	2	124.2		

Table 258. ***Density*** meas. by ***Pavetracker 10232*** – Non-nuclear Gage on ***E-7, AL, pcf***
Continued

Test Date	Station	Point	Trial #	Density	Average	Std Dev
09/26/2006	0+90	C	3	124.9		
09/26/2006	0+90	C	4	125.4	125	0.5944
09/26/2006	1+20	B	1	124.4		
09/26/2006	1+20	B	2	125.9		
09/26/2006	1+20	B	3	125.8		
09/26/2006	1+20	B	4	124.9	125.25	0.7234
09/26/2006	1+30	A	1	126.8		
09/26/2006	1+30	A	2	125.5		
09/26/2006	1+30	A	3	125.8		
09/26/2006	1+30	A	4	125.3	125.85	0.6658
09/26/2006	1+30	B	1	124.6		
09/26/2006	1+30	B	2	125.9		
09/26/2006	1+30	B	3	123.8		
09/26/2006	1+30	B	4	125.3	124.9	0.9055
09/26/2006	1+30	C	1	127.3		
09/26/2006	1+30	C	2	126.4		
09/26/2006	1+30	C	3	127.6		
09/26/2006	1+30	C	4	127	127.08	0.5123
09/26/2006	1+70	A	1	126		
09/26/2006	1+70	A	2	126.7		
09/26/2006	1+70	A	3	125.1		
09/26/2006	1+70	A	4	125.6	125.85	0.6758
09/26/2006	1+70	B	1	123.3		
09/26/2006	1+70	B	2	122.7		
09/26/2006	1+70	B	3	124.6		
09/26/2006	1+70	B	4	124.2	123.7	0.8602
09/26/2006	1+70	C	1	128.1		
09/26/2006	1+70	C	2	125.1		
09/26/2006	1+70	C	3	128.2		
09/26/2006	1+70	C	4	124.9	126.58	1.8209
09/26/2006	2+00	A	1	126.2		
09/26/2006	2+00	A	2	123.9		
09/26/2006	2+00	A	3	126.4		
09/26/2006	2+00	A	4	124.3	125.2	1.2832
09/26/2006	2+00	B	1	125.4		
09/26/2006	2+00	B	2	123.9		
09/26/2006	2+00	B	3	123.1		

Table 258. ***Density*** meas. by ***Pavetracker 10232*** – Non-nuclear Gage on ***E-7, AL, pcf***
Continued

Test Date	Station	Point	Trial #	Density	Average	Std Dev
09/26/2006	2+00	B	4	123	123.85	1.1091
09/26/2006	2+00	C	1	124.8		
09/26/2006	2+00	C	2	125.7		
09/26/2006	2+00	C	3	123.3		
09/26/2006	2+00	C	4	126.4	125.05	1.3379
09/27/2006	0+10	A	1	124.6		
09/27/2006	0+10	A	2	125.4		
09/27/2006	0+10	A	3	124.8		
09/27/2006	0+10	A	4	122.7	124.38	1.1673
09/27/2006	0+10	B	1	123.6		
09/27/2006	0+10	B	2	118.8		
09/27/2006	0+10	B	3	120.5		
09/27/2006	0+10	B	4	120	120.73	2.0451
09/27/2006	0+10	C	1	124.8		
09/27/2006	0+10	C	2	124.1		
09/27/2006	0+10	C	3	124		
09/27/2006	0+10	C	4	124	124.23	0.3862
09/27/2006	0+50	A	1	125.7		
09/27/2006	0+50	A	2	124.6		
09/27/2006	0+50	A	3	127.1		
09/27/2006	0+50	A	4	123.9	125.33	1.3961
09/27/2006	0+50	B	1	122.6		
09/27/2006	0+50	B	2	123.8		
09/27/2006	0+50	B	3	124.3		
09/27/2006	0+50	B	4	122.8	123.38	0.8098
09/27/2006	0+50	C	1	125.7		
09/27/2006	0+50	C	2	124.5		
09/27/2006	0+50	C	3	124.7		
09/27/2006	0+50	C	4	125.3	125.05	0.5508
09/27/2006	0+75	B	1	120.9		
09/27/2006	0+75	B	2	126.7		
09/27/2006	0+75	B	3	121.4		
09/27/2006	0+75	B	4	123.1	123.03	2.6247
09/27/2006	0+90	A	1	125.1		
09/27/2006	0+90	A	2	124.5		
09/27/2006	0+90	A	3	124.6		
09/27/2006	0+90	A	4	124.5	124.68	0.2872

Table 258. ***Density*** meas. by ***Pavetracker 10232*** – Non-nuclear Gage on ***E-7, AL, pcf***
Continued

Test Date	Station	Point	Trial #	Density	Average	Std Dev
09/27/2006	0+90	B	1	122.9		
09/27/2006	0+90	B	2	123.1		
09/27/2006	0+90	B	3	122		
09/27/2006	0+90	B	4	122.6	122.65	0.4796
09/27/2006	0+90	C	1	125.7		
09/27/2006	0+90	C	2	124.4		
09/27/2006	0+90	C	3	124.5		
09/27/2006	0+90	C	4	123.9	124.63	0.7632
09/27/2006	1+20	B	1	124.6		
09/27/2006	1+20	B	2	122		
09/27/2006	1+20	B	3	120.9		
09/27/2006	1+20	B	4	123.8	122.83	1.682
09/27/2006	1+30	A	1	127		
09/27/2006	1+30	A	2	126.1		
09/27/2006	1+30	A	3	125.3		
09/27/2006	1+30	A	4	123	125.35	1.7137
09/27/2006	1+30	B	1	124		
09/27/2006	1+30	B	2	124.8		
09/27/2006	1+30	B	3	124		
09/27/2006	1+30	B	4	124	124.2	0.4
09/27/2006	1+30	C	1	126.7		
09/27/2006	1+30	C	2	126		
09/27/2006	1+30	C	3	126.4		
09/27/2006	1+30	C	4	125	126.03	0.7411
09/27/2006	1+70	A	1	125.6		
09/27/2006	1+70	A	2	126.1		
09/27/2006	1+70	A	3	125.3		
09/27/2006	1+70	A	4	125.8	125.7	0.3367
09/27/2006	1+70	B	1	123.8		
09/27/2006	1+70	B	2	123.6		
09/27/2006	1+70	B	3	123.3		
09/27/2006	1+70	B	4	123.6	123.58	0.2062
09/27/2006	1+70	C	1	127.1		
09/27/2006	1+70	C	2	123.5		
09/27/2006	1+70	C	3	126.7		
09/27/2006	1+70	C	4	123.5	125.2	1.9698
09/27/2006	2+00	A	1	124.5		

Table 258. ***Density*** meas. by ***Pavetracker 10232*** – Non-nuclear Gage on ***E-7, AL, pcf***
Continued

Test Date	Station	Point	Trial #	Density	Average	Std Dev
09/27/2006	2+00	A	2	124.4		
09/27/2006	2+00	A	3	123.5		
09/27/2006	2+00	A	4	124.5	124.23	0.4856
09/27/2006	2+00	B	1	122.8		
09/27/2006	2+00	B	2	124		
09/27/2006	2+00	B	3	123.3		
09/27/2006	2+00	B	4	123.9	123.5	0.5598
09/27/2006	2+00	C	1	125.1		
09/27/2006	2+00	C	2	124.4		
09/27/2006	2+00	C	3	124.2		
09/27/2006	2+00	C	4	123.2	124.23	0.7848

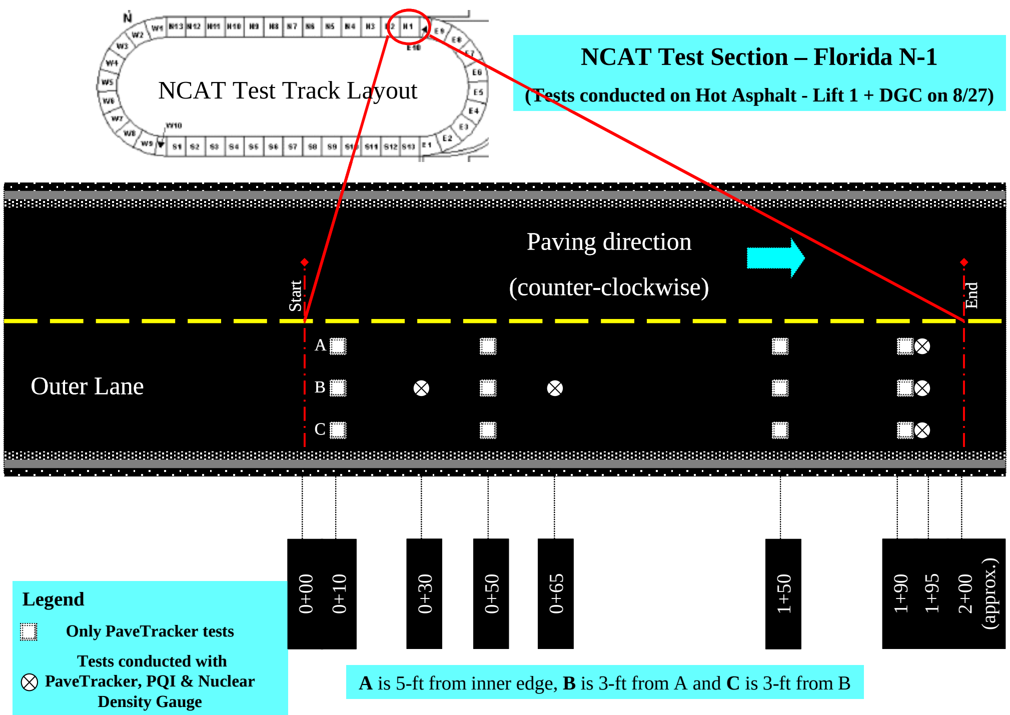
Table 259. ***Modulus*** measured by ***PSPA*** on ***E-7, AL, ksi***

Test Date	Station	Point	Trial #	Modulus	Average
09/26/2006	0+10	A	1	223	223
09/26/2006	0+10	B	1	293	293
09/26/2006	0+10	C	1	228	228
09/26/2006	0+50	A	1	249	249
09/26/2006	0+50	B	1	352	352
09/26/2006	0+50	C	1	334	334
09/26/2006	0+75	B	1	284	284
09/26/2006	0+90	A	1	246	246
09/26/2006	0+90	B	1	292	292
09/26/2006	0+90	C	1	315	315
09/26/2006	1+20	B	1	289	289
09/26/2006	1+30	A	1	240	240
09/26/2006	1+30	B	1	351	351
09/26/2006	1+30	C	1	267	267
09/26/2006	1+70	A	1	214	214
09/26/2006	1+70	B	1	174	174
09/26/2006	1+70	C	1	185	185
09/26/2006	2+00	A	1	242	242
09/26/2006	2+00	B	1	209	209
09/26/2006	2+00	C	1	232	232
09/27/2006	0+10	A	1	521	521
09/27/2006	0+10	B	1	427	427
09/27/2006	0+10	C	1	459	459
09/27/2006	0+50	A	1	512	512
09/27/2006	0+50	B	1	384	384
09/27/2006	0+50	C	1	455	455
09/27/2006	0+75	B	1	434	434
09/27/2006	0+90	A	1	483	483
09/27/2006	0+90	B	1	407	407
09/27/2006	0+90	C	1	420	420
09/27/2006	1+20	B	1	458	458
09/27/2006	1+30	A	1	409	409
09/27/2006	1+30	B	1	410	410
09/27/2006	1+30	C	1	452	452
09/27/2006	1+70	A	1	457	457
09/27/2006	1+70	B	1	426	426
09/27/2006	1+70	C	1	474	474

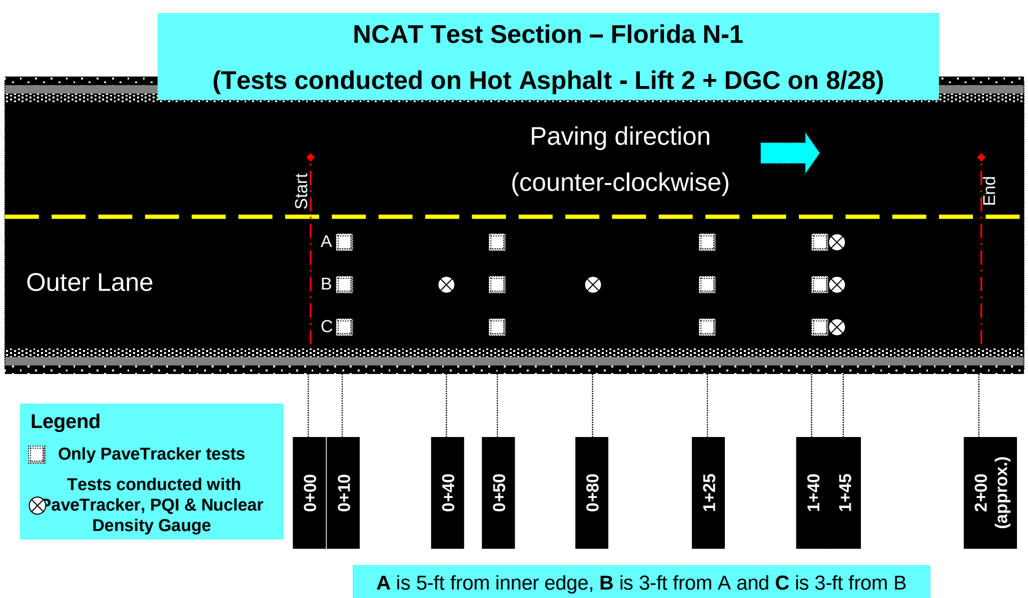
Table 260. ***Modulus*** measured by ***PSPA*** on ***E-7, AL, ksi***
Continued

Test Date	Station	Point	Trial #	Modulus	Average
09/27/2006	2+00	A	1	506	506
09/27/2006	2+00	B	1	412	412
09/27/2006	2+00	C	1	380	380

N-1 FLORIDA TEST SECTION AT NCAT



a) Lift 1 tested on August 28, 2006



b) Lift 2 tested on August 29, 2006

Table 261. ***Density*** meas. by ***Pavetracker 10232*** – Non-nuclear Gage on ***N-1, FL, pcf***

Test Date	Station	Point	Trial #	Density	Average	Std Dev
09/27/2006	0+10	A	1	129.6		
09/27/2006	0+10	A	2	129		
09/27/2006	0+10	A	3	126.8		
09/27/2006	0+10	A	4	129.7	128.78	1.3525
09/27/2006	0+10	B	1	130.6		
09/27/2006	0+10	B	2	130.2		
09/27/2006	0+10	B	3	132.2		
09/27/2006	0+10	B	4	131	131	0.8641
09/27/2006	0+10	C	1	131.9		
09/27/2006	0+10	C	2	131.5		
09/27/2006	0+10	C	3	133.1		
09/27/2006	0+10	C	4	132.6	132.28	0.7136
09/27/2006	0+30	B	1	130.2		
09/27/2006	0+30	B	2	132.7		
09/27/2006	0+30	B	3	130.1		
09/27/2006	0+30	B	4	135.1	132.03	2.3768
09/27/2006	0+50	A	1	127.4		
09/27/2006	0+50	A	2	126.3		
09/27/2006	0+50	A	3	130.2		
09/27/2006	0+50	A	4	129.9	128.45	1.9053
09/27/2006	0+50	B	1	131.9		
09/27/2006	0+50	B	2	129		
09/27/2006	0+50	B	3	130.2		
09/27/2006	0+50	B	4	132.2	130.83	1.5019
09/27/2006	0+50	C	1	130.6		
09/27/2006	0+50	C	2	136.7		
09/27/2006	0+50	C	3	134.4		
09/27/2006	0+50	C	4	133.7	133.85	2.5173
09/27/2006	0+65	B	1	132.7		
09/27/2006	0+65	B	2	130.6		
09/27/2006	0+65	B	3	129.5		
09/27/2006	0+65	B	4	128	130.2	1.9782
09/27/2006	1+50	A	1	132.7		
09/27/2006	1+50	A	2	130		
09/27/2006	1+50	A	3	129.5		
09/27/2006	1+50	A	4	130.8	130.75	1.4059
09/27/2006	1+50	B	1	132.1		

Table 262. ***Density*** meas. by ***Pavetracker 10232*** – Non-nuclear Gage on ***N-1, FL, pcf***
Continued

Test Date	Station	Point	Trial #	Density	Average	Std Dev
09/27/2006	1+50	B	2	133.9		
09/27/2006	1+50	B	3	133.8		
09/27/2006	1+50	B	4	132.6	133.1	0.8907
09/27/2006	1+50	C	1	132.8		
09/27/2006	1+50	C	2	135.7		
09/27/2006	1+50	C	3	135.7		
09/27/2006	1+50	C	4	132.8	134.25	1.6743
09/27/2006	1+90	A	1	130.5		
09/27/2006	1+90	A	2	129.5		
09/27/2006	1+90	A	3	132.1		
09/27/2006	1+90	A	4	131.8	130.98	1.2038
09/27/2006	1+90	B	1	129.3		
09/27/2006	1+90	B	2	129.2		
09/27/2006	1+90	B	3	128		
09/27/2006	1+90	B	4	127.9	128.6	0.7528
09/27/2006	1+90	C	1	130.2		
09/27/2006	1+90	C	2	130.6		
09/27/2006	1+90	C	3	130.3		
09/27/2006	1+90	C	4	127.4	129.63	1.493
09/27/2006	1+95	A	1	131.6		
09/27/2006	1+95	A	2	132.6		
09/27/2006	1+95	A	3	133.2		
09/27/2006	1+95	A	4	130.3	131.93	1.2685
09/27/2006	1+95	B	1	128.8		
09/27/2006	1+95	B	2	131.9		
09/27/2006	1+95	B	3	129.4		
09/27/2006	1+95	B	4	127.4	129.38	1.8804
09/27/2006	1+95	C	1	130.3		
09/27/2006	1+95	C	2	127.2		
09/27/2006	1+95	C	3	130.7		
09/27/2006	1+95	C	4	130.7	129.73	1.6939
09/28/2006	0+10	A	1	127.6		
09/28/2006	0+10	A	2	129.1		
09/28/2006	0+10	A	3	128.7		
09/28/2006	0+10	A	4	128.3	128.43	0.6397

Table 262. ***Density*** meas. by ***Pavetracker 10232*** – Non-nuclear Gage on ***N-1, FL, pcf***
Continued

Test Date	Station	Point	Trial #	Density	Average	Std Dev
09/28/2006	0+10	B	1	126.4		
09/28/2006	0+10	B	2	127.3		
09/28/2006	0+10	B	3	125.4		
09/28/2006	0+10	B	4	126.7	126.45	0.7937
09/28/2006	0+10	C	1	126.8		
09/28/2006	0+10	C	2	126.4		
09/28/2006	0+10	C	3	125.3		
09/28/2006	0+10	C	4	125.1	125.9	0.8287
09/28/2006	0+40	B	1	127		
09/28/2006	0+40	B	2	127.2		
09/28/2006	0+40	B	3	126.7		
09/28/2006	0+40	B	4	127.1	127	0.216
09/28/2006	0+50	A	1	125.9		
09/28/2006	0+50	A	2	124.6		
09/28/2006	0+50	A	3	128		
09/28/2006	0+50	A	4	125.3	125.95	1.4663
09/28/2006	0+50	B	1	125.9		
09/28/2006	0+50	B	2	126.6		
09/28/2006	0+50	B	3	125.2		
09/28/2006	0+50	B	4	125.2	125.73	0.6702
09/28/2006	0+50	C	1	124.4		
09/28/2006	0+50	C	2	127.1		
09/28/2006	0+50	C	3	125.2		
09/28/2006	0+50	C	4	125.3	125.5	1.1402
09/28/2006	0+80	B	1	128.8		
09/28/2006	0+80	B	2	126.2		
09/28/2006	0+80	B	3	127.6		
09/28/2006	0+80	B	4	128.8	127.85	1.2369
09/28/2006	1+25	A	1	128.8		
09/28/2006	1+25	A	2	128.1		
09/28/2006	1+25	A	3	128.8		
09/28/2006	1+25	A	4	127.5	128.3	0.6272
09/28/2006	1+25	B	1	128.5		
09/28/2006	1+25	B	2	128.3		
09/28/2006	1+25	B	3	128.1		
09/28/2006	1+25	B	4	128.3	128.3	0.1633

Table 262. ***Density*** meas. by ***Pavetracker 10232*** – Non-nuclear Gage on ***N-1, FL, pcf***
Continued

Test Date	Station	Point	Trial #	Density	Average	Std Dev
09/28/2006	1+25	C	1	125.2		
09/28/2006	1+25	C	2	126.9		
09/28/2006	1+25	C	3	127		
09/28/2006	1+25	C	4	125.9	126.25	0.8583
09/28/2006	1+40	A	1	128		
09/28/2006	1+40	A	2	127		
09/28/2006	1+40	A	3	127.7		
09/28/2006	1+40	A	4	126.2	127.23	0.8016
09/28/2006	1+40	B	1	126.1		
09/28/2006	1+40	B	2	127.5		
09/28/2006	1+40	B	3	126.2		
09/28/2006	1+40	B	4	126.9	126.68	0.6551
09/28/2006	1+40	C	1	125.6		
09/28/2006	1+40	C	2	124.9		
09/28/2006	1+40	C	3	125.7		
09/28/2006	1+40	C	4	125.4	125.4	0.3559
09/28/2006	1+45	A	1	128.3		
09/28/2006	1+45	A	2	128		
09/28/2006	1+45	A	3	126.4		
09/28/2006	1+45	A	4	127.6	127.58	0.8342
09/28/2006	1+45	B	1	126.5		
09/28/2006	1+45	B	2	126.7		
09/28/2006	1+45	B	3	126.5		
09/28/2006	1+45	B	4	127	126.68	0.2363
09/28/2006	1+45	C	1	130.2		
09/28/2006	1+45	C	2	130.5		
09/28/2006	1+45	C	3	130.9		
09/28/2006	1+45	C	4	127.7	129.83	1.4454

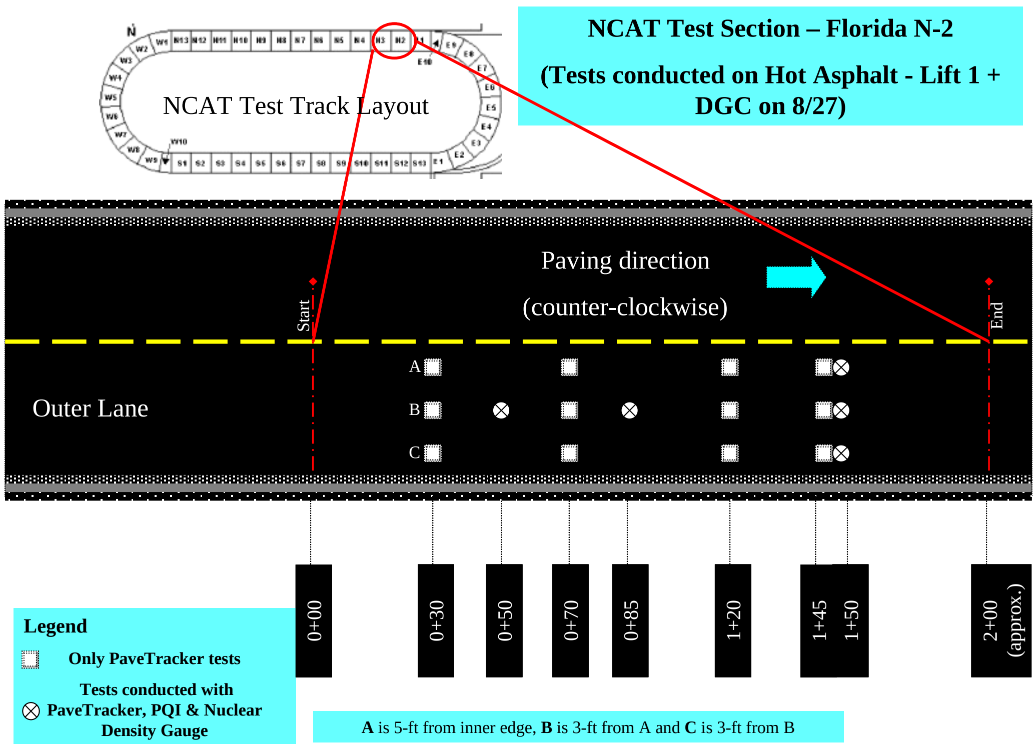
Table 263. ***Modulus*** measured by ***PSPA*** on ***N-1, FL, ksi***

Test Date	Station	Point	Trial #	Modulus	Average
09/27/2006	0+10	A	1	127	127
09/27/2006	0+10	B	1	130	130
09/27/2006	0+10	C	1	113	113
09/27/2006	0+30	B	1	127	127
09/27/2006	0+50	A	1	107	107
09/27/2006	0+50	B	1	113	113
09/27/2006	0+50	C	1	115	115
09/27/2006	0+65	B	1	141	141
09/27/2006	1+50	A	1	122	122
09/27/2006	1+50	B	1	120	120
09/27/2006	1+50	C	1	117	117
09/27/2006	1+90	A	1	121	121
09/27/2006	1+90	B	1	111	111
09/27/2006	1+90	C	1	123	123
09/27/2006	1+95	A	1	144	144
09/27/2006	1+95	B	1	137	137
09/27/2006	1+95	C	1	115	115
09/28/2006	0+10	B	1	402	402
09/28/2006	0+10	C	1	416	416
09/28/2006	0+40	B	1	426	426
09/28/2006	0+50	A	1	461	461
09/28/2006	0+50	B	1	433	433
09/28/2006	0+50	C	1	422	422
09/28/2006	0+80	B	1	542	542
09/28/2006	1+25	A	1	426	426
09/28/2006	1+25	B	1	454	454
09/28/2006	1+25	C	1	390	390
09/28/2006	1+40	A	1	432	432
09/28/2006	1+40	B	1	453	453
09/28/2006	1+40	C	1	447	447
09/28/2006	1+45	A	1	497	497
09/28/2006	1+45	B	1	490	490
09/28/2006	1+45	C	1	539	539
09/28/2006	0+10	A	1	370	370
09/28/2006	0+10	B	1	252	252
09/28/2006	0+10	C	1	286	286
09/28/2006	0+40	B	1	252	252

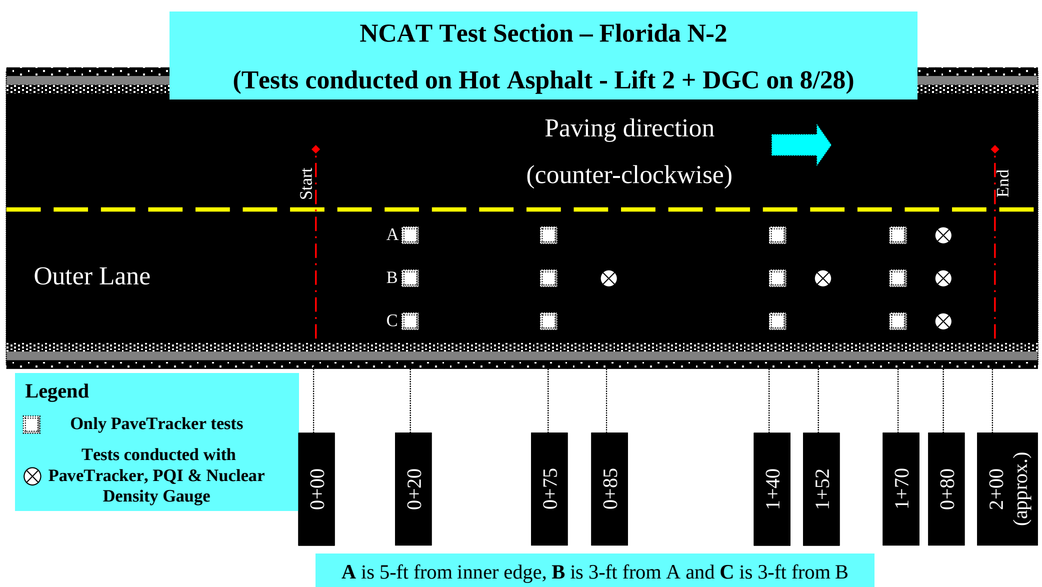
Table 264. ***Modulus*** measured by ***PSPA*** on ***N-1, FL, ksi***
Continued

Test Date	Station	Point	Trial #	Modulus	Average
09/28/2006	0+50	A	1	250	250
09/28/2006	0+50	B	1	256	256
09/28/2006	0+50	C	1	240	240
09/28/2006	0+80	B	1	245	245
09/28/2006	1+25	A	1	277	277
09/28/2006	1+25	B	1	300	300
09/28/2006	1+25	C	1	345	345
09/28/2006	1+40	A	1	310	310
09/28/2006	1+40	B	1	264	264
09/28/2006	1+40	C	1	289	289
09/28/2006	1+45	A	1	215	215
09/28/2006	1+45	B	1	247	247
09/28/2006	1+45	C	1	226	226
09/28/2006	0+10	A	1	208	208

N-2 FLORIDA TEST SECTION AT NCAT



a) Lift 1 tested on August 28, 2006



b) Lift 2 tested on August 29, 2006

Table 265. ***Density*** meas. by ***Pavetracker 10232*** – Non-nuclear Gage on ***N-2, FL, pcf***

Test Date	Station	Point	Trial #	Density	Average	Std Dev
09/27/2006	0+30	A	1	130.7		
09/27/2006	0+30	A	2	130.6		
09/27/2006	0+30	A	3	130.9		
09/27/2006	0+30	A	4	133.6	131.45	1.4387
09/27/2006	0+30	B	1	128.9		
09/27/2006	0+30	B	2	127.1		
09/27/2006	0+30	B	3	126.5		
09/27/2006	0+30	B	4	130.1	128.15	1.6523
09/27/2006	0+30	C	1	132		
09/27/2006	0+30	C	2	134.4		
09/27/2006	0+30	C	3	130.5		
09/27/2006	0+30	C	4	131.1	132	1.7146
09/27/2006	0+50	B	1	128.3		
09/27/2006	0+50	B	2	129.5		
09/27/2006	0+50	B	3	131.5		
09/27/2006	0+50	B	4	130	129.83	1.3251
09/27/2006	0+70	A	1	133.1		
09/27/2006	0+70	A	2	131.2		
09/27/2006	0+70	A	3	134.1		
09/27/2006	0+70	A	4	129.4	131.95	2.0825
09/27/2006	0+70	B	1	129.8		
09/27/2006	0+70	B	2	132.3		
09/27/2006	0+70	B	3	129.4		
09/27/2006	0+70	B	4	131.3	130.7	1.3441
09/27/2006	0+70	C	1	133.6		
09/27/2006	0+70	C	2	133		
09/27/2006	0+70	C	3	133.4		
09/27/2006	0+70	C	4	130.2	132.55	1.5864
09/27/2006	0+85	B	1	130.9		
09/27/2006	0+85	B	2	131.8		
09/27/2006	0+85	B	3	129.3		
09/27/2006	0+85	B	4	131.2	130.8	1.0677
09/27/2006	1+20	A	1	132.7		
09/27/2006	1+20	A	2	131		
09/27/2006	1+20	A	3	132.5		
09/27/2006	1+20	A	4	132.1	132.08	0.7588
09/27/2006	1+20	B	1	132.1		

Table 266. ***Density*** meas. by ***Pavetracker 10232*** – Non-nuclear Gage on ***N-2, FL, pcf***
Continued

Test Date	Station	Point	Trial #	Density	Average	Std Dev
09/27/2006	1+20	B	2	131.5		
09/27/2006	1+20	B	3	131.9		
09/27/2006	1+20	B	4	130	131.38	0.95
09/27/2006	1+20	C	1	132.3		
09/27/2006	1+20	C	2	131.9		
09/27/2006	1+20	C	3	133.1		
09/27/2006	1+20	C	4	132.4	132.43	0.4992
09/27/2006	1+45	A	1	130.1		
09/27/2006	1+45	A	2	132.1		
09/27/2006	1+45	A	3	130.3		
09/27/2006	1+45	A	4	134.5	131.75	2.0421
09/27/2006	1+45	B	1	131.5		
09/27/2006	1+45	B	2	130.4		
09/27/2006	1+45	B	3	130.6		
09/27/2006	1+45	B	4	132.8	131.33	1.0935
09/27/2006	1+45	C	1	130.3		
09/27/2006	1+45	C	2	131.2		
09/27/2006	1+45	C	3	131.3		
09/27/2006	1+45	C	4	129.5	130.58	0.8461
09/27/2006	1+50	A	1	131.2		
09/27/2006	1+50	A	2	136.7		
09/27/2006	1+50	A	3	133		
09/27/2006	1+50	A	4	132.8	133.43	2.3272
09/27/2006	1+50	B	1	133.3		
09/27/2006	1+50	B	2	133.9		
09/27/2006	1+50	B	3	131.5		
09/27/2006	1+50	B	4	131.8	132.63	1.1587
09/27/2006	1+50	C	1	136.2		
09/27/2006	1+50	C	2	132.4		
09/27/2006	1+50	C	3	130.9		
09/27/2006	1+50	C	4	132.9	133.1	2.2346
09/28/2006	0+20	A	1	128.9		
09/28/2006	0+20	A	2	126.5		
09/28/2006	0+20	A	3	127.2		
09/28/2006	0+20	A	4	127.3	127.48	1.0145

Table 266. ***Density*** meas. by ***Pavetracker 10232*** – Non-nuclear Gage on ***N-2, FL, pcf***
Continued

Test Date	Station	Point	Trial #	Density	Average	Std Dev
09/28/2006	0+20	B	1	128.1		
09/28/2006	0+20	B	2	126.9		
09/28/2006	0+20	B	3	128.2		
09/28/2006	0+20	B	4	128.9	128.03	0.8302
09/28/2006	0+20	C	1	127.8		
09/28/2006	0+20	C	2	129.3		
09/28/2006	0+20	C	3	128.2		
09/28/2006	0+20	C	4	128.2	128.38	0.6449
09/28/2006	0+75	A	1	130.5		
09/28/2006	0+75	A	2	130.3		
09/28/2006	0+75	A	3	128.9		
09/28/2006	0+75	A	4	129.8	129.88	0.7136
09/28/2006	0+75	B	1	128.4		
09/28/2006	0+75	B	2	128.2		
09/28/2006	0+75	B	3	127.8		
09/28/2006	0+75	B	4	128.2	128.15	0.2517
09/28/2006	0+75	C	1	128.6		
09/28/2006	0+75	C	2	128.7		
09/28/2006	0+75	C	3	128.6		
09/28/2006	0+75	C	4	126.8	128.18	0.9179
09/28/2006	0+85	B	1	128.5		
09/28/2006	0+85	B	2	126.1		
09/28/2006	0+85	B	3	127.4		
09/28/2006	0+85	B	4	126.9	127.23	1.0046
09/28/2006	1+40	A	1	128.1		
09/28/2006	1+40	A	2	127.7		
09/28/2006	1+40	A	3	127.5		
09/28/2006	1+40	A	4	127.6	127.73	0.263
09/28/2006	1+40	B	1	126.7		
09/28/2006	1+40	B	2	126.1		
09/28/2006	1+40	B	3	126.9		
09/28/2006	1+40	B	4	125	126.18	0.8539
09/28/2006	1+40	C	1	127.6		
09/28/2006	1+40	C	2	128.2		
09/28/2006	1+40	C	3	127.6		
09/28/2006	1+40	C	4	128.2	127.9	0.3464

Table 266. ***Density*** meas. by ***Pavetracker 10232*** – Non-nuclear Gage on ***N-2, FL, pcf***
Continued

Test Date	Station	Point	Trial #	Density	Average	Std Dev
09/28/2006	1+52	B	1	128		
09/28/2006	1+52	B	2	129.3		
09/28/2006	1+52	B	3	127.3		
09/28/2006	1+52	B	4	127.5	128.03	0.8995
09/28/2006	1+70	A	1	128.8		
09/28/2006	1+70	A	2	127.2		
09/28/2006	1+70	A	3	128.1		
09/28/2006	1+70	A	4	128.6	128.18	0.7136
09/28/2006	1+70	B	1	127.5		
09/28/2006	1+70	B	2	127.4		
09/28/2006	1+70	B	3	126.2		
09/28/2006	1+70	B	4	128.2	127.33	0.8302
09/28/2006	1+70	C	1	128		
09/28/2006	1+70	C	2	126		
09/28/2006	1+70	C	3	127.4		
09/28/2006	1+70	C	4	127.8	127.3	0.9018
09/28/2006	1+80	A	1	130.1		
09/28/2006	1+80	A	2	128.8		
09/28/2006	1+80	A	3	130.7		
09/28/2006	1+80	A	4	130.7	130.08	0.8958
09/28/2006	1+80	B	1	128.5		
09/28/2006	1+80	B	2	128.3		
09/28/2006	1+80	B	3	127.6		
09/28/2006	1+80	B	4	126.2	127.65	1.0408
09/28/2006	1+80	C	1	127.1		
09/28/2006	1+80	C	2	128.4		
09/28/2006	1+80	C	3	128.2		
09/28/2006	1+80	C	4	126.3	127.5	0.9832

Table 267. ***Modulus*** measured by ***PSPA*** on ***N-2, FL, ksi***

Test Date	Station	Point	Trial #	Modulus	Average
09/27/2006	0+30	A	1	112	112
09/27/2006	0+30	B	1	88	88
09/27/2006	0+30	C	1	100	100
09/27/2006	0+50	B	1	104	104
09/27/2006	0+70	A	1	114	114
09/27/2006	0+70	B	1	118	118
09/27/2006	0+70	C	1	117	117
09/27/2006	0+85	B	1	107	107
09/27/2006	1+20	A	1	99	99
09/27/2006	1+20	B	1	102	102
09/27/2006	1+20	C	1	107	107
09/27/2006	1+45	A	1	119	119
09/27/2006	1+45	B	1	117	117
09/27/2006	1+45	C	1	111	111
09/27/2006	1+50	A	1	184	184
09/27/2006	1+50	B	1	228	228
09/27/2006	1+50	C	1	198	198
09/28/2006	0+20	B	1	497	497
09/28/2006	0+20	C	1	441	441
09/28/2006	0+75	A	1	460	460
09/28/2006	0+75	B	1	498	498
09/28/2006	0+75	C	1	402	402
09/28/2006	0+85	B	1	511	511
09/28/2006	1+40	A	1	469	469
09/28/2006	1+40	B	1	438	438
09/28/2006	1+40	C	1	477	477
09/28/2006	1+52	B	1	532	532
09/28/2006	1+70	A	1	399	399
09/28/2006	1+70	B	1	441	441
09/28/2006	1+70	C	1	390	390
09/28/2006	1+80	A	1	592	592
09/28/2006	1+80	B	1	523	523
09/28/2006	1+80	C	1	541	541
09/28/2006	0+20	A	1	477	477
09/28/2006	0+20	B	1	246	246
09/28/2006	0+20	C	1	276	276
09/28/2006	0+75	A	1	307	307

Table 268. ***Modulus*** measured by ***PSPA*** on ***N-2, FL, ksi***
Continued

Test Date	Station	Point	Trial #	Modulus	Average
09/28/2006	0+75	B	1	297	297
09/28/2006	0+75	C	1	354	354
09/28/2006	0+85	B	1	270	270
09/28/2006	1+40	A	1	359	359
09/28/2006	1+40	B	1	321	321
09/28/2006	1+40	C	1	268	268
09/28/2006	1+52	B	1	290	290
09/28/2006	1+70	A	1	292	292
09/28/2006	1+70	B	1	335	335
09/28/2006	1+70	C	1	239	239
09/28/2006	1+80	A	1	279	279
09/28/2006	1+80	B	1	253	253
09/28/2006	1+80	C	1	273	273
09/28/2006	0+20	A	1	229	229

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N-10 MISSOURI TEST SECTION AT NCAT

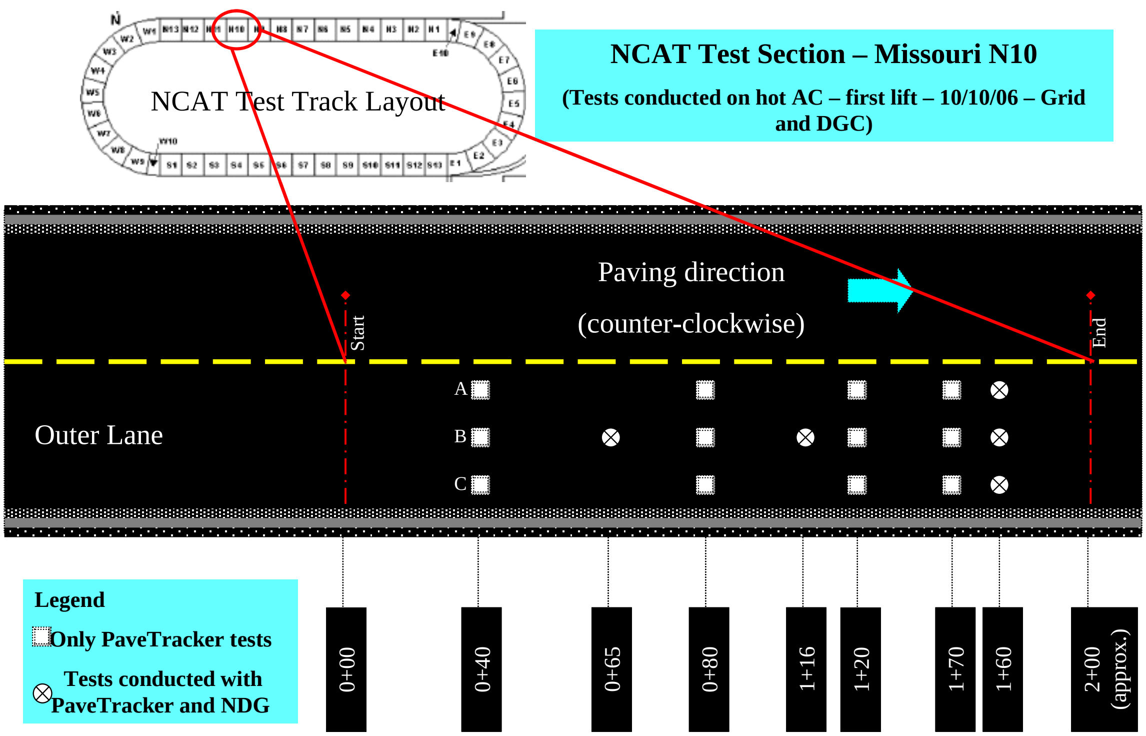


Table 269. ***Density*** meas. by ***Pavetracker 10232*** – Non-nuclear Gage on ***N-10, MO, pcf***

Test Date	Station	Point	Trial #	Density	Average	Std Dev
10/10/2006	0+40	A	1	140.2		
10/10/2006	0+40	A	2	141.7		
10/10/2006	0+40	A	3	142.2		
10/10/2006	0+40	A	4	140.4	141.13	0.9777
10/10/2006	0+40	B	1	147.4		
10/10/2006	0+40	B	2	141.2		
10/10/2006	0+40	B	3	147.4		
10/10/2006	0+40	B	4	143.6	144.9	3.0485
10/10/2006	0+40	C	1	137.4		
10/10/2006	0+40	C	2	141.1		
10/10/2006	0+40	C	3	137		
10/10/2006	0+40	C	4	137.3	138.2	1.9408
10/10/2006	0+65	B	1	140.9		
10/10/2006	0+65	B	2	140.8		
10/10/2006	0+65	B	3	140.7		
10/10/2006	0+65	B	4	140.8	140.8	0.0816
10/10/2006	0+80	A	1	138.2		
10/10/2006	0+80	A	2	141.9		
10/10/2006	0+80	A	3	139.9		
10/10/2006	0+80	A	4	141.1	140.28	1.6091
10/10/2006	0+80	B	1	135.1		
10/10/2006	0+80	B	2	139.5		
10/10/2006	0+80	B	3	134.8		
10/10/2006	0+80	B	4	138.8	137.05	2.4447
10/10/2006	0+80	C	1	138.8		
10/10/2006	0+80	C	2	137.9		
10/10/2006	0+80	C	3	139		
10/10/2006	0+80	C	4	138.4	138.53	0.4856
10/10/2006	1+16	B	1	138.2		
10/10/2006	1+16	B	2	138.4		
10/10/2006	1+16	B	3	138.7		
10/10/2006	1+16	B	4	137.1	138.1	0.6976
10/10/2006	1+20	A	1	136.2		
10/10/2006	1+20	A	2	140.9		
10/10/2006	1+20	A	3	138		
10/10/2006	1+20	A	4	139.5	138.65	2.0174
10/10/2006	1+20	B	1	138.9		

Table 270. ***Density*** meas. by ***Pavetracker 10232*** – Non-nuclear Gage on ***N-10, MO, pcf***
Continued

Test Date	Station	Point	Trial #	Density	Average	Std Dev
10/10/2006	1+20	B	2	136.4		
10/10/2006	1+20	B	3	139.6		
10/10/2006	1+20	B	4	143	139.48	2.722
10/10/2006	1+20	C	1	137.7		
10/10/2006	1+20	C	2	143		
10/10/2006	1+20	C	3	140.6		
10/10/2006	1+20	C	4	136.1	139.35	3.0643
10/10/2006	1+70	A	1	138		
10/10/2006	1+70	A	2	137.2		
10/10/2006	1+70	A	3	138		
10/10/2006	1+70	A	4	138.7	137.98	0.6131
10/10/2006	1+70	B	1	136.9		
10/10/2006	1+70	B	2	136.5		
10/10/2006	1+70	B	3	136.7		
10/10/2006	1+70	B	4	137.7	136.95	0.526
10/10/2006	1+70	C	1	137.7		
10/10/2006	1+70	C	2	137.8		
10/10/2006	1+70	C	3	137		
10/10/2006	1+70	C	4	136	137.13	0.8302
10/10/2006	1+88	A	1	136.7		
10/10/2006	1+88	A	2	141.5		
10/10/2006	1+88	A	3	138.8		
10/10/2006	1+88	A	4	147	141	4.4565
10/10/2006	1+88	B	1	138.2		
10/10/2006	1+88	B	2	140.6		
10/10/2006	1+88	B	3	139.1		
10/10/2006	1+88	B	4	136.2	138.53	1.8392
10/10/2006	1+88	C	1	142.2		
10/10/2006	1+88	C	2	138.3		
10/10/2006	1+88	C	3	138.9		
10/10/2006	1+88	C	4	139.7	139.78	1.7154

Table 271. ***Modulus*** measured by ***PSPA*** on ***N-10, MO, ksi***

Test Date	Station	Point	Trial #	Modulus	Average
10/10/2006	0+40	A	1	360	360
10/10/2006	0+40	B	1	306	306
10/10/2006	0+40	C	1	320	320
10/10/2006	0+65	B	1	311	311
10/10/2006	0+80	A	1	275	275
10/10/2006	0+80	B	1	352	352
10/10/2006	0+80	C	1	365	365
10/10/2006	1+16	B	1	356	356
10/10/2006	1+20	A	1	304	304
10/10/2006	1+20	B	1	324	324
10/10/2006	1+20	C	1	362	362
10/10/2006	1+70	A	1	338	338
10/10/2006	1+70	B	1	333	333
10/10/2006	1+70	C	1	369	369
10/10/2006	1+88	A	1	340	340
10/10/2006	1+88	B	1	401	401
10/10/2006	1+88	C	1	344	344
10/11/2006	0+40	A	1	374	374
10/11/2006	0+40	B	1	423	423
10/11/2006	0+40	C	1	397	397
10/11/2006	0+65	B	1	402	402
10/11/2006	0+80	A	1	320	320
10/11/2006	0+80	B	1	410	410
10/11/2006	0+80	C	1	390	390
10/11/2006	1+16	B	1	422	422
10/11/2006	1+20	A	1	378	378
10/11/2006	1+20	B	1	357	357
10/11/2006	1+20	C	1	456	456
10/11/2006	1+70	A	1	355	355
10/11/2006	1+70	B	1	477	477
10/11/2006	1+70	C	1	466	466
10/11/2006	1+88	A	1	370	370
10/11/2006	1+88	B	1	487	487
10/11/2006	1+88	C	1	465	465
10/16/2006	0+40	B	1	635	635
10/16/2006	0+40	C	1	634	634
10/16/2006	0+80	A	1	664	664

Table 272. ***Modulus*** measured by ***PSPA*** on ***N-10, MO, ksi***
Continued

Test Date	Station	Point	Trial #	Modulus	Average
10/16/2006	0+80	B	1	642	642
10/16/2006	0+80	C	1	651	651
10/16/2006	1+10	A	1	618	618
10/16/2006	1+10	B	1	653	653
10/16/2006	1+10	C	1	683	683
10/16/2006	1+80	A	1	723	723
10/16/2006	1+80	B	1	736	736
10/16/2006	1+80	C	1	690	690
10/16/2006	1+90	A	1	669	669
10/16/2006	1+90	B	1	661	661
10/16/2006	1+90	C	1	629	629
10/16/2006	0+40	A	1	681	681

S-11 SOUTH CAROLINA TEST SECTION AT NCAT

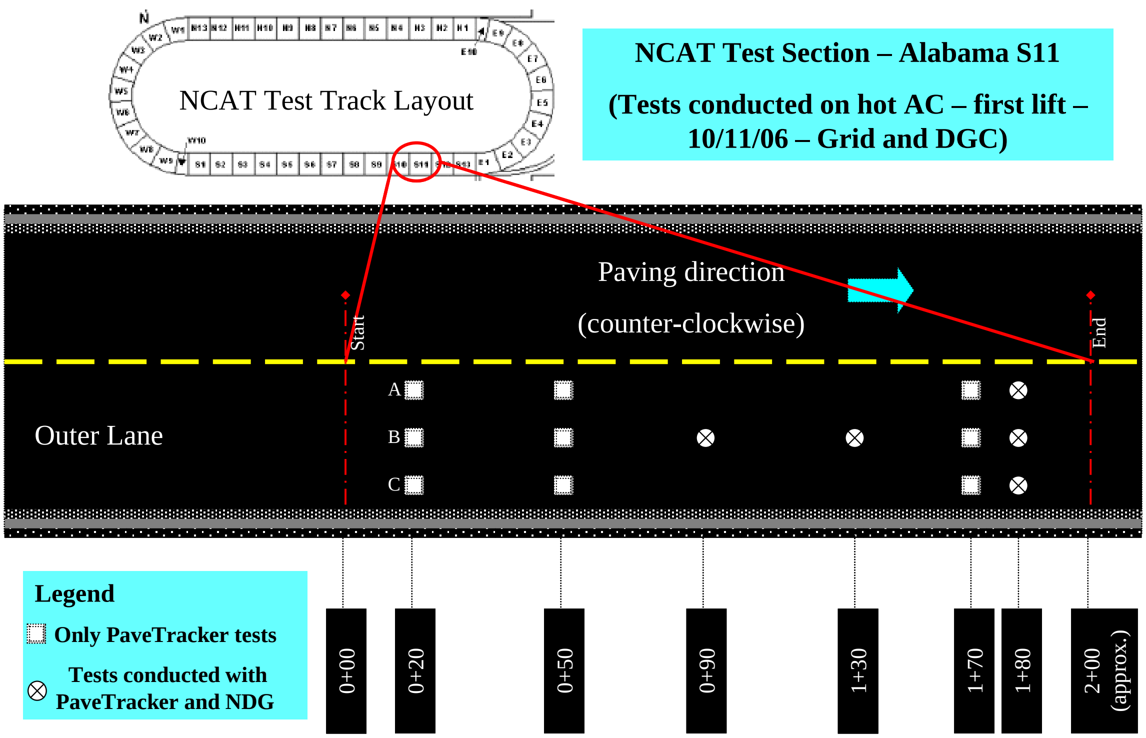


Table 273. ***Density*** meas. by ***Pavetracker 10232*** – Non-nuclear Gage on ***S-11, SC, pcf***

Test Date	Station	Point	Trial #	Density	Average	Std Dev
10/11/2006	0+20	A	1	133.8		
10/11/2006	0+20	A	2	133.8		
10/11/2006	0+20	A	3	135.4		
10/11/2006	0+20	A	4	133	134	1.0066
10/11/2006	0+20	B	1	136.3		
10/11/2006	0+20	B	2	134.6		
10/11/2006	0+20	B	3	133.5		
10/11/2006	0+20	B	4	133.4	134.45	1.3478
10/11/2006	0+20	C	1	133.3		
10/11/2006	0+20	C	2	135.1		
10/11/2006	0+20	C	3	131.8		
10/11/2006	0+20	C	4	132.4	133.15	1.4387
10/11/2006	0+50	A	1	136.9		
10/11/2006	0+50	A	2	133		
10/11/2006	0+50	A	3	135.8		
10/11/2006	0+50	A	4	135.6	135.33	1.652
10/11/2006	0+50	B	1	134.3		
10/11/2006	0+50	B	2	134.5		
10/11/2006	0+50	B	3	135.4		
10/11/2006	0+50	B	4	135	134.8	0.4967
10/11/2006	0+50	C	1	135.2		
10/11/2006	0+50	C	2	134.4		
10/11/2006	0+50	C	3	136.1		
10/11/2006	0+50	C	4	132.1	134.45	1.7137
10/11/2006	0+90	B	1	134.7		
10/11/2006	0+90	B	2	134.4		
10/11/2006	0+90	B	3	136.9		
10/11/2006	0+90	B	4	133.3	134.83	1.5086
10/11/2006	1+30	B	1	132.2		
10/11/2006	1+30	B	2	131.2		
10/11/2006	1+30	B	3	130.9		
10/11/2006	1+30	B	4	133.4	131.93	1.1295
10/11/2006	1+70	A	1	133.9		
10/11/2006	1+70	A	2	132.7		
10/11/2006	1+70	A	3	132.6		
10/11/2006	1+70	A	4	132.3	132.88	0.7042
10/11/2006	1+70	B	1	135.2		

Table 274. ***Density*** meas. by ***Pavetracker 10232*** – Non-nuclear Gage on ***S-11, SC, pcf***
Continued

Test Date	Station	Point	Trial #	Density	Average	Std Dev
10/11/2006	1+70	B	2	133.3		
10/11/2006	1+70	B	3	135.2		
10/11/2006	1+70	B	4	137.1	135.2	1.5513
10/11/2006	1+70	C	1	135.5		
10/11/2006	1+70	C	2	134.6		
10/11/2006	1+70	C	3	134.7		
10/11/2006	1+70	C	4	135.1	134.98	0.4113
10/11/2006	1+80	A	1	133.1		
10/11/2006	1+80	A	2	135.3		
10/11/2006	1+80	A	3	133.9		
10/11/2006	1+80	A	4	131.1	133.35	1.754
10/11/2006	1+80	B	1	133		
10/11/2006	1+80	B	2	133.4		
10/11/2006	1+80	B	3	133.5		
10/11/2006	1+80	B	4	137.2	134.28	1.9619
10/11/2006	1+80	C	1	132.8		
10/11/2006	1+80	C	2	133.5		
10/11/2006	1+80	C	3	134		
10/11/2006	1+80	C	4	134.9	133.8	0.8832

Table 275. ***Modulus*** measured by ***PSPA*** on ***S-11, SC, ksi***

Test Date	Station	Point	Trial #	Modulus	Average
10/11/2006	0+20	A	1	175	175
10/11/2006	0+20	B	1	186	186
10/11/2006	0+20	C	1	119	119
10/11/2006	0+50	A	1	113	113
10/11/2006	0+50	B	1	156	156
10/11/2006	0+50	C	1	108	108
10/11/2006	0+90	B	1	116	116
10/11/2006	1+30	B	1	136	136
10/11/2006	1+70	A	1	104	104
10/11/2006	1+70	B	1	98	98
10/11/2006	1+70	C	1	97	97
10/11/2006	1+80	A	1	150	150
10/11/2006	1+80	B	1	100	100
10/11/2006	1+80	C	1	120	120
10/16/2006	0+20	A	1	537	537
10/16/2006	0+20	B	1	510	510
10/16/2006	0+20	C	1	487	487
10/16/2006	0+50	A	1	462	462
10/16/2006	0+50	B	1	495	495
10/16/2006	0+50	C	1	501	501
10/16/2006	0+90	B	1	537	537
10/16/2006	1+30	A	1	506	506
10/16/2006	1+30	B	1	502	502
10/16/2006	1+30	C	1	526	526
10/16/2006	1+70	A	1	489	489
10/16/2006	1+70	B	1	417	417
10/16/2006	1+70	C	1	458	458
10/16/2006	1+80	A	1	513	513
10/16/2006	1+80	B	1	459	459
10/16/2006	1+80	C	1	524	524

SR-53, OHIO, HMA TEST SECTION

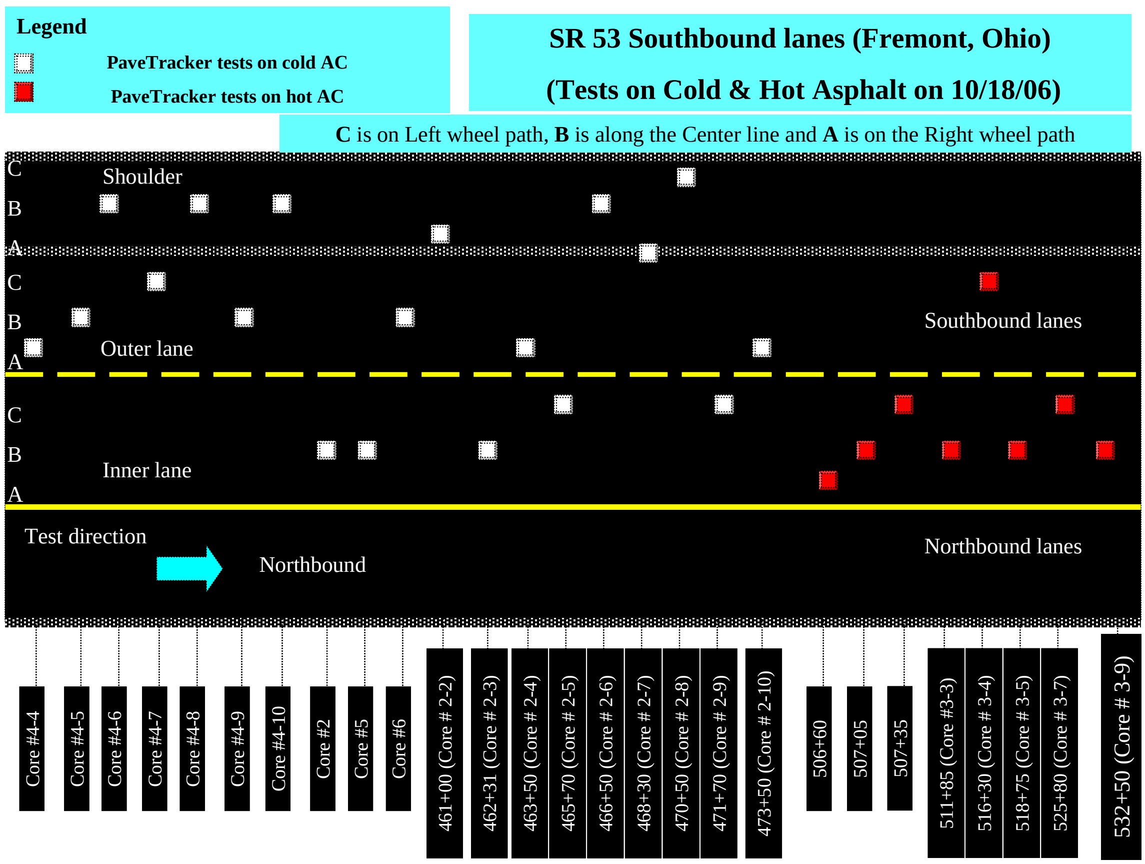


Table 276. ***Density*** meas. by ***Pavetracker 10232*** – Non-nuclear Gage on ***US-53, OH, pcf***

Test Date	Station	Point	Trial #	Density	Average	Std Dev
10/18/2006	506+60	A	1	158.4		
10/18/2006	506+60	A	2	157.6		
10/18/2006	506+60	A	3	154.1		
10/18/2006	506+60	A	4	160.2	157.58	2.5591
10/18/2006	507+05	B	1	162		
10/18/2006	507+05	B	2	163.5		
10/18/2006	507+05	B	3	157.5		
10/18/2006	507+05	B	4	161.5	161.13	2.5617
10/18/2006	507+35	C	1	143.6		
10/18/2006	507+35	C	2	158.2		
10/18/2006	507+35	C	3	156.3		
10/18/2006	507+35	C	4	158.7	154.2	7.1419
10/18/2006	511+85	B	1	153.7		
10/18/2006	511+85	B	2	162		
10/18/2006	511+85	B	3	160.1		
10/18/2006	511+85	B	4	157.8	158.4	3.573
10/18/2006	518+75	B	1	160		
10/18/2006	518+75	B	2	159.4		
10/18/2006	518+75	B	3	157		
10/18/2006	518+75	B	4	148.7		
10/18/2006	518+75	B	5	163.6	157.74	5.5784
10/18/2006	525+80	C	1	159.1		
10/18/2006	525+80	C	2	152.6		
10/18/2006	525+80	C	3	159.9		
10/18/2006	525+80	C	4	162.2	158.45	4.1154
10/18/2006	532+50	B	1	161		
10/18/2006	532+50	B	2	165.1		
10/18/2006	532+50	B	3	160		
10/18/2006	532+50	B	4	156.9		
10/18/2006	532+50	B	5	148.2	158.24	6.3319
10/18/2006	516+30	C	1	166.6		
10/18/2006	516+30	C	2	164		
10/18/2006	516+30	C	3	172		
10/18/2006	516+30	C	4	167	167.4	3.3427
10/18/2006	461+00	A	1	144.5		
10/18/2006	461+00	A	2	148.8		
10/18/2006	461+00	A	3	143.9		

Table 277. ***Density*** meas. by ***Pavetracker 10232*** – Non-nuclear Gage on ***US-53, OH, pcf***
Continued

Test Date	Station	Point	Trial #	Density	Average	Std Dev
10/18/2006	461+00	A	4	142.3	144.88	2.7765
10/18/2006	466+50	B	1	144.8		
10/18/2006	466+50	B	2	143.9		
10/18/2006	466+50	B	3	145.8		
10/18/2006	466+50	B	4	146.6	145.28	1.1758
10/18/2006	470+50	C	1	144.7		
10/18/2006	470+50	C	2	147.8		
10/18/2006	470+50	C	3	148.3		
10/18/2006	470+50	C	4	145.8	146.65	1.6902
10/18/2006	core # 4-10	B	1	140.4		
10/18/2006	core # 4-10	B	2	142.4		
10/18/2006	core # 4-10	B	3	142.5		
10/18/2006	core # 4-10	B	4	139.1	141.1	1.6472
10/18/2006	core # 4-6	B	1	142.3		
10/18/2006	core # 4-6	B	2	147		
10/18/2006	core # 4-6	B	3	143.9		
10/18/2006	core # 4-6	B	4	141.5	143.68	2.4309
10/18/2006	core # 4-8	B	1	143.4		
10/18/2006	core # 4-8	B	2	142.8		
10/18/2006	core # 4-8	B	3	140.5		
10/18/2006	core # 4-8	B	4	141.8	142.13	1.2685
10/18/2006	462+31	B	1	143.3		
10/18/2006	462+31	B	2	150.8		
10/18/2006	462+31	B	3	145.4		
10/18/2006	462+31	B	4	148.4	146.98	3.2989
10/18/2006	465+70	C	1	148.2		
10/18/2006	465+70	C	2	145.4		
10/18/2006	465+70	C	3	148		
10/18/2006	465+70	C	4	150.2	147.95	1.9689
10/18/2006	468+30	C	1	144.1		
10/18/2006	468+30	C	2	141		
10/18/2006	468+30	C	3	149.5		
10/18/2006	468+30	C	4	146.9	145.38	3.6564
10/18/2006	471+70	C	1	148.2		
10/18/2006	471+70	C	2	148.8		

Table 277. ***Density*** meas. by ***Pavetracker 10232*** – Non-nuclear Gage on ***US-53, OH, pcf***
Continued

Test Date	Station	Point	Trial #	Density	Average	Std Dev
10/18/2006	471+70	C	3	149.1		
10/18/2006	471+70	C	4	147.4	148.38	0.75
10/18/2006	core # 2	B	1	140.3		
10/18/2006	core # 2	B	2	147.7		
10/18/2006	core # 2	B	3	140.3		
10/18/2006	core # 2	B	4	140.2	142.13	3.717
10/18/2006	core # 4-5	B	1	148.2		
10/18/2006	core # 4-5	B	2	149		
10/18/2006	core # 4-5	B	3	145.7		
10/18/2006	core # 4-5	B	4	145	146.98	1.9259
10/18/2006	core # 5	B	1	146.4		
10/18/2006	core # 5	B	2	142.6		
10/18/2006	core # 5	B	3	144.4		
10/18/2006	core # 5	B	4	148.3	145.43	2.4663
10/18/2006	463+50	A	1	149.7		
10/18/2006	463+50	A	2	143.5		
10/18/2006	463+50	A	3	144.2		
10/18/2006	463+50	A	4	150.8	147.05	3.7332
10/18/2006	473+50	A	1	152.7		
10/18/2006	473+50	A	2	146.2		
10/18/2006	473+50	A	3	141.2		
10/18/2006	473+50	A	4	142.2	145.58	5.2182
10/18/2006	core # 4-4	A	1	147.6		
10/18/2006	core # 4-4	A	2	145.8		
10/18/2006	core # 4-4	A	3	148.6		
10/18/2006	core # 4-4	A	4	147.3	147.33	1.1587
10/18/2006	core # 4-7	C	1	141		
10/18/2006	core # 4-7	C	2	144.8		
10/18/2006	core # 4-7	C	3	146.7		
10/18/2006	core # 4-7	C	4	145.2	144.43	2.4254
10/18/2006	core # 4-9	B	1	149.3		
10/18/2006	core # 4-9	B	2	146.1		
10/18/2006	core # 4-9	B	3	144.8		
10/18/2006	core # 4-9	B	4	143.7	145.98	2.424
10/18/2006	core # 6	B	1	142.1		
10/18/2006	core # 6	B	2	145.1		

Table 277. ***Density*** meas. by ***Pavetracker 10232*** – Non-nuclear Gage on ***US-53, OH, pcf***
Continued

Test Date	Station	Point	Trial #	Density	Average	Std Dev
10/18/2006	core # 6	B	3	143.8		
10/18/2006	core # 6	B	4	145.6	144.15	1.5631

Table 278. ***Density*** meas. by ***Pavetracker 10233*** – Non-nuclear Gage on ***US-53, OH, pcf***

Test Date	Station	Point	Trial #	Density	Average	Std Dev
10/18/2006	506+60	A	1	160.9		
10/18/2006	506+60	A	2	158.2		
10/18/2006	506+60	A	3	154.6		
10/18/2006	506+60	A	4	156.5	157.55	2.6739
10/18/2006	507+05	B	1	158.9		
10/18/2006	507+05	B	2	161.2		
10/18/2006	507+05	B	3	162.9		
10/18/2006	507+05	B	4	159.9	160.73	1.7289
10/18/2006	507+35	C	1	146.3		
10/18/2006	507+35	C	2	151		
10/18/2006	507+35	C	3	152.7		
10/18/2006	507+35	C	4	149.2	149.8	2.7362
10/18/2006	511+85	B	1	157.2		
10/18/2006	511+85	B	2	160.5		
10/18/2006	511+85	B	3	158.3		
10/18/2006	511+85	B	4	162.1	159.53	2.1975
10/18/2006	518+75	B	1	156.3		
10/18/2006	518+75	B	2	161.5		
10/18/2006	518+75	B	3	160.9		
10/18/2006	518+75	B	4	151.7		
10/18/2006	518+75	B	5	162.5	158.58	4.5224
10/18/2006	525+80	C	1	158.9		
10/18/2006	525+80	C	2	154		
10/18/2006	525+80	C	3	158.5		
10/18/2006	525+80	C	4	157	157.1	2.2226
10/18/2006	532+50	B	1	156.5		
10/18/2006	532+50	B	2	161.3		
10/18/2006	532+50	B	3	156.2		
10/18/2006	532+50	B	4	155.8		
10/18/2006	532+50	B	5	147.3	155.42	5.0603
10/18/2006	516+30	C	1	156.8		
10/18/2006	516+30	C	2	160.2		
10/18/2006	516+30	C	3	163		
10/18/2006	516+30	C	4	164.2	161.05	3.2919
10/18/2006	461+00	A	1	140.8		
10/18/2006	461+00	A	2	151.9		
10/18/2006	461+00	A	3	143.9		

Table 279. ***Density*** meas. by ***Pavetracker 10233*** – Non-nuclear Gage on ***US-53, OH, pcf***
Continued

Test Date	Station	Point	Trial #	Density	Average	Std Dev
10/18/2006	461+00	A	4	144.9	145.38	4.6871
10/18/2006	466+50	B	1	146.5		
10/18/2006	466+50	B	2	143.1		
10/18/2006	466+50	B	3	145.9		
10/18/2006	466+50	B	4	144.5	145	1.5188
10/18/2006	470+50	C	1	141.1		
10/18/2006	470+50	C	2	146.6		
10/18/2006	470+50	C	3	147.9		
10/18/2006	470+50	C	4	147.7	145.83	3.2014
10/18/2006	core # 4-10	B	1	140.7		
10/18/2006	core # 4-10	B	2	141.2		
10/18/2006	core # 4-10	B	3	144.2		
10/18/2006	core # 4-10	B	4	137.9	141	2.5807
10/18/2006	core # 4-6	B	1	141.8		
10/18/2006	core # 4-6	B	2	143		
10/18/2006	core # 4-6	B	3	147.5		
10/18/2006	core # 4-6	B	4	141.7	143.5	2.7313
10/18/2006	core # 4-8	B	1	146.3		
10/18/2006	core # 4-8	B	2	140.5		
10/18/2006	core # 4-8	B	3	140.1		
10/18/2006	core # 4-8	B	4	140.2	141.78	3.0215
10/18/2006	462+31	B	1	143.4		
10/18/2006	462+31	B	2	147.3		
10/18/2006	462+31	B	3	144.3		
10/18/2006	462+31	B	4	147.1	145.53	1.9704
10/18/2006	465+70	C	1	147.6		
10/18/2006	465+70	C	2	154		
10/18/2006	465+70	C	3	150.6		
10/18/2006	465+70	C	4	147	149.8	3.2125
10/18/2006	468+30	C	1	143.2		
10/18/2006	468+30	C	2	145.6		
10/18/2006	468+30	C	3	147.5		
10/18/2006	468+30	C	4	147.9	146.05	2.1486
10/18/2006	471+70	C	1	150.4		
10/18/2006	471+70	C	2	146.4		

Table 279. ***Density*** meas. by ***Pavetracker 10233*** – Non-nuclear Gage on ***US-53, OH, pcf***
Continued

Test Date	Station	Point	Trial #	Density	Average	Std Dev
10/18/2006	471+70	C	3	146.2		
10/18/2006	471+70	C	4	150.5	148.38	2.3977
10/18/2006	core # 2	B	1	141.9		
10/18/2006	core # 2	B	2	147.1		
10/18/2006	core # 2	B	3	145		
10/18/2006	core # 2	B	4	142.5	144.13	2.395
10/18/2006	core # 4-5	B	1	145.9		
10/18/2006	core # 4-5	B	2	143.5		
10/18/2006	core # 4-5	B	3	149		
10/18/2006	core # 4-5	B	4	150.8	147.3	3.2424
10/18/2006	core # 5	B	1	149.4		
10/18/2006	core # 5	B	2	143.8		
10/18/2006	core # 5	B	3	143.1		
10/18/2006	core # 5	B	4	146.6	145.73	2.8791
10/18/2006	463+50	A	1	147.5		
10/18/2006	463+50	A	2	144.5		
10/18/2006	463+50	A	3	145.8		
10/18/2006	463+50	A	4	147.7	146.38	1.513
10/18/2006	473+50	A	1	149.2		
10/18/2006	473+50	A	2	145.6		
10/18/2006	473+50	A	3	141.3		
10/18/2006	473+50	A	4	140.2	144.08	4.1355
10/18/2006	core # 4-4	A	1	148		
10/18/2006	core # 4-4	A	2	153		
10/18/2006	core # 4-4	A	3	150.6		
10/18/2006	core # 4-4	A	4	150.9	150.63	2.05
10/18/2006	core # 4-7	C	1	148.4		
10/18/2006	core # 4-7	C	2	147.9		
10/18/2006	core # 4-7	C	3	149.2		
10/18/2006	core # 4-7	C	4	145.9	147.85	1.4059
10/18/2006	core # 4-9	B	1	148.8		
10/18/2006	core # 4-9	B	2	145.1		
10/18/2006	core # 4-9	B	3	146.9		
10/18/2006	core # 4-9	B	4	147.1	146.98	1.513
10/18/2006	core # 6	B	1	46.8		
10/18/2006	core # 6	B	2	145		

Table 279. ***Density*** meas. by ***Pavetracker 10233*** – Non-nuclear Gage on ***US-53, OH, pcf***
Continued

Test Date	Station	Point	Trial #	Density	Average	Std Dev
10/18/2006	core # 6	B	3	148.8		
10/18/2006	core # 6	B	4	153	123.4	51.171

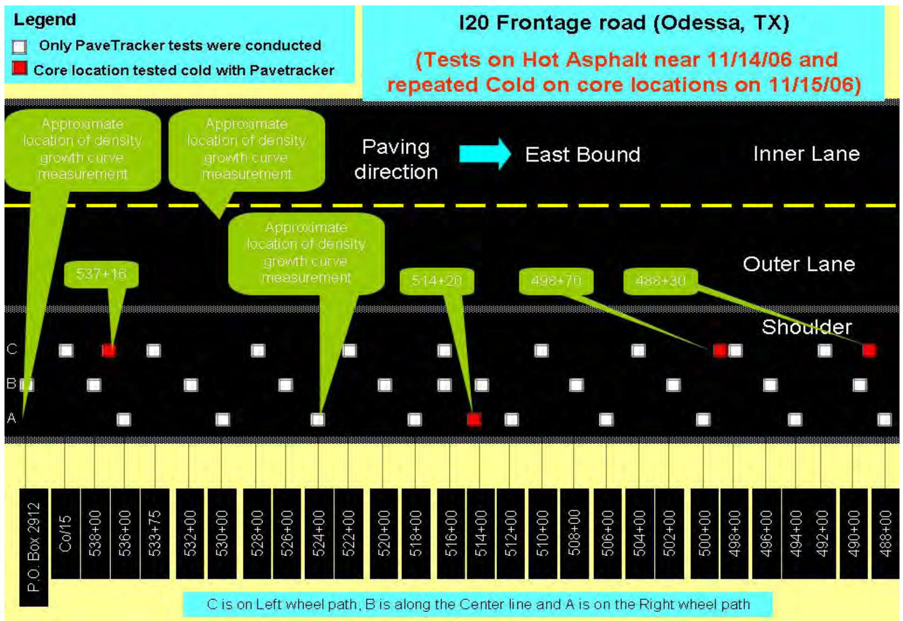
Table 280. ***Modulus*** measured by ***PSPA*** on ***US-53, OH, ksi***

Test Date	Station	Point	Trial #	Modulus	Average
10/18/2006	461+00	A	1	704	704
10/18/2006	466+50	B	1	779	779
10/18/2006	470+50	C	1	637	637
10/18/2006	core # 4-10	B	1	560	560
10/18/2006	core # 4-6	B	1	708	708
10/18/2006	core # 4-8	B	1	657	657
10/18/2006	462+31	B	1	718	718
10/18/2006	465+70	C	1	725	725
10/18/2006	468+30	C	1	690	690
10/18/2006	471+70	C	1	705	705
10/18/2006	core # 2	B	1	594	594
10/18/2006	core # 4-5	B	1	668	668
10/18/2006	core # 5	B	1	728	728
10/18/2006	463+50	A	1	737	737
10/18/2006	473+50	A	1	624	624
10/18/2006	core # 4-4	A	1	738	738
10/18/2006	core # 4-7	C	1	738	738
10/18/2006	core # 4-9	B	1	717	717
10/18/2006	core # 6	B	1	765	765
10/20/2006	506+60	A	1	609	609
10/20/2006	507+05	B	1	708	708
10/20/2006	507+35	C	1	716	716
10/20/2006	511+85	B	1	641	641
10/20/2006	518+75	B	1	632	632
10/20/2006	525+80	C	1	678	678
10/20/2006	532+50	B	1	674	674
10/20/2006	532+50	B	5	692	692
10/20/2006	516+30	C	1	720	720

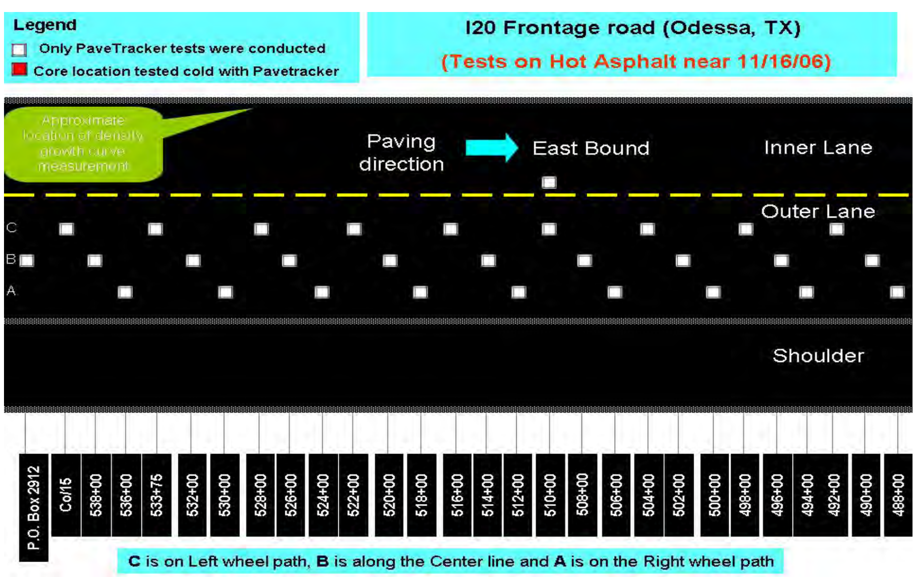
Table 281. ***Density*** measured by ***NDG*** on ***US-53, OH, pcf***

Test Date	Station	Point	Trial #	Density
10/18/2006	506+60	A	1	147.5
10/18/2006	506+60	A	1	147.5
10/18/2006	507+05	B	1	152.6
10/18/2006	507+35	C	1	154.8
10/18/2006	507+35	C	1	154.8

I-20 FRONTAGE ROAD, ODESSA, TX
HMA TEST SECTIONS



Section 1



Section 2

Table 282. ***Density*** meas. by ***Pavetracker 10233*** – Non-nuclear Gage on ***I-20FR, TX, pcf***

Test Date	Station	Point	Trial #	Density	Average	Std Dev
11/14/2006	488+00	C	1	123.8		
11/14/2006	488+00	C	2	120		
11/14/2006	488+00	C	3	122.8		
11/14/2006	488+00	C	4	126.2	123.2	2.5665
11/14/2006	490+00	B	1	127.2		
11/14/2006	490+00	B	2	124.2		
11/14/2006	490+00	B	3	124.6		
11/14/2006	490+00	B	4	124.3	125.08	1.4268
11/14/2006	492+00	A	1	127		
11/14/2006	492+00	A	2	126.6		
11/14/2006	492+00	A	3	121.7		
11/14/2006	492+00	A	4	122	124.33	2.8652
11/14/2006	494+00	C	1	125		
11/14/2006	494+00	C	2	123.7		
11/14/2006	494+00	C	3	126.7		
11/14/2006	494+00	C	4	124.9	125.08	1.2339
11/14/2006	496+00	B	1	121		
11/14/2006	496+00	B	2	118.2		
11/14/2006	496+00	B	3	121.9		
11/14/2006	496+00	B	4	121.6	120.68	1.6919
11/14/2006	498+00	A	1	123.1		
11/14/2006	498+00	A	2	122.5		
11/14/2006	498+00	A	3	122.9		
11/14/2006	498+00	A	4	122	122.63	0.4856
11/14/2006	500+00	C	1	121.7		
11/14/2006	500+00	C	2	122.8		
11/14/2006	500+00	C	3	123.4		
11/14/2006	500+00	C	4	121.3	122.3	0.9695
11/14/2006	502+00	B	1	120.3		
11/14/2006	502+00	B	2	122		
11/14/2006	502+00	B	3	122.9		
11/14/2006	502+00	B	4	122.3	121.88	1.1147
11/14/2006	504+00	A	1	120.8		
11/14/2006	504+00	A	2	122.3		
11/14/2006	504+00	A	3	122.4		
11/14/2006	504+00	A	4	122.2	121.93	0.7544
11/14/2006	506+00	C	1	122.3		

Table 283. ***Density*** meas. by ***Pavetracker 10233*** – Non-nuclear Gage on ***I-20FR, TX, pcf***
Continued

Test Date	Station	Point	Trial #	Density	Average	Std Dev
11/14/2006	506+00	C	2	125		
11/14/2006	506+00	C	3	124		
11/14/2006	506+00	C	4	121.6	123.23	1.5543
11/14/2006	508+00	B	1	123		
11/14/2006	508+00	B	2	123		
11/14/2006	508+00	B	3	124		
11/14/2006	508+00	B	4	126.3	124.08	1.5564
11/14/2006	510+00	A	1	126.4		
11/14/2006	510+00	A	2	122.7		
11/14/2006	510+00	A	3	124.8		
11/14/2006	510+00	A	4	121.9	123.95	2.0404
11/14/2006	512+00	C	1	122.1		
11/14/2006	512+00	C	2	121.7		
11/14/2006	512+00	C	3	122.6		
11/14/2006	512+00	C	4	123	122.35	0.5686
11/14/2006	514+00	B	1	123.6		
11/14/2006	514+00	B	2	121.6		
11/14/2006	514+00	B	3	121.4		
11/14/2006	514+00	B	4	124.3	122.73	1.4454
11/14/2006	516+00	A	1	117.3		
11/14/2006	516+00	A	2	119.9		
11/14/2006	516+00	A	3	117.5		
11/14/2006	516+00	A	4	116.7	117.85	1.4083
11/14/2006	516+00	B	1	122		
11/14/2006	516+00	B	2	123.2		
11/14/2006	516+00	B	3	121		
11/14/2006	516+00	B	4	121	121.8	1.0456
11/14/2006	518+00	C	1	121.2		
11/14/2006	518+00	C	2	121.4		
11/14/2006	518+00	C	3	121.8		
11/14/2006	518+00	C	4	121.4	121.45	0.2517
11/14/2006	520+00	B	1	125.7		
11/14/2006	520+00	B	2	124		
11/14/2006	520+00	B	3	124		
11/14/2006	520+00	B	4	125	124.68	0.8302

Table 283. ***Density*** meas. by ***Pavetracker 10233*** – Non-nuclear Gage on ***I-20FR, TX, pcf***
Continued

Test Date	Station	Point	Trial #	Density	Average	Std Dev
11/14/2006	522+00	A	1	122.7		
11/14/2006	522+00	A	2	122.3		
11/14/2006	522+00	A	3	121.2		
11/14/2006	522+00	A	4	121.7	121.98	0.6602
11/14/2006	524+00	C	1	121.1		
11/14/2006	524+00	C	2	120.2		
11/14/2006	524+00	C	3	121.9		
11/14/2006	524+00	C	4	120.6	120.95	0.7326
11/14/2006	526+00	B	1	124.4		
11/14/2006	526+00	B	2	125.3		
11/14/2006	526+00	B	3	124.1		
11/14/2006	526+00	B	4	125.5	124.83	0.6801
11/14/2006	528+00	A	1	124.7		
11/14/2006	528+00	A	2	125		
11/14/2006	528+00	A	3	124.4		
11/14/2006	528+00	A	4	122.7	124.2	1.0296
11/14/2006	530+00	C	1	122.1		
11/14/2006	530+00	C	2	121.4		
11/14/2006	530+00	C	3	122.6		
11/14/2006	530+00	C	4	123.6	122.43	0.9251
11/14/2006	532+00	B	1	124.4		
11/14/2006	532+00	B	2	125.4		
11/14/2006	532+00	B	3	127.6		
11/14/2006	532+00	B	4	126.6	126	1.3952
11/14/2006	533+75	A	1	123.5		
11/14/2006	533+75	A	2	123.7		
11/14/2006	533+75	A	3	124.8		
11/14/2006	533+75	A	4	122.3	123.58	1.0243
11/14/2006	536+00	C	1	120.2		
11/14/2006	536+00	C	2	118.9		
11/14/2006	536+00	C	3	121.9		
11/14/2006	536+00	C	4	123.6	121.15	2.0437
11/14/2006	538+00	B	1	120.8		
11/14/2006	538+00	B	2	121.2		
11/14/2006	538+00	B	3	122.3		
11/14/2006	538+00	B	4	121.4	121.43	0.6344

Table 283. ***Density*** meas. by ***Pavetracker 10233*** – Non-nuclear Gage on ***I-20FR, TX, pcf***
Continued

Test Date	Station	Point	Trial #	Density	Average	Std Dev
11/14/2006	CO/15	A	1	122.4		
11/14/2006	CO/15	A	2	121.6		
11/14/2006	CO/15	A	3	122.8		
11/14/2006	CO/15	A	4	121	121.95	0.8062
11/14/2006	P.O. Box - 2912	B	1	125.8		
11/14/2006	P.O. Box - 2912	B	2	123.8		
11/14/2006	P.O. Box - 2912	B	3	126.5		
11/14/2006	P.O. Box - 2912	B	4	124.5	125.15	1.2234
11/16/2006	488+00	C	1	119.8		
11/16/2006	488+00	C	2	119.3		
11/16/2006	488+00	C	3	123		
11/16/2006	488+00	C	4	124	121.53	2.3258
11/16/2006	490+00	B	1	116.9		
11/16/2006	490+00	B	2	117.5		
11/16/2006	490+00	B	3	121.2		
11/16/2006	490+00	B	4	120.8	119.1	2.2136
11/16/2006	492+00	A	1	118.9		
11/16/2006	492+00	A	2	119.5		
11/16/2006	492+00	A	3	117.8		
11/16/2006	492+00	A	4	116	118.05	1.5373
11/16/2006	494+00	C	1	119.3		
11/16/2006	494+00	C	2	116		
11/16/2006	494+00	C	3	119.6		
11/16/2006	494+00	C	4	119.4	118.58	1.7212
11/16/2006	496+00	B	1	117		
11/16/2006	496+00	B	2	116		
11/16/2006	496+00	B	3	116.6		
11/16/2006	496+00	B	4	116.9	116.63	0.45
11/16/2006	498+00	A	1	117.8		
11/16/2006	498+00	A	2	121.5		
11/16/2006	498+00	A	3	120.3		
11/16/2006	498+00	A	4	119.8	119.85	1.5416
11/16/2006	500+00	C	1	117.7		

Table 283. ***Density*** meas. by ***Pavetracker 10233*** – Non-nuclear Gage on ***I-20FR, TX, pcf***
Continued

Test Date	Station	Point	Trial #	Density	Average	Std Dev
11/16/2006	500+00	C	2	120.2		
11/16/2006	500+00	C	3	119.4		
11/16/2006	500+00	C	4	118.8	119.03	1.0532
11/16/2006	502+00	B	1	118.6		
11/16/2006	502+00	B	2	118.9		
11/16/2006	502+00	B	3	121.6		
11/16/2006	502+00	B	4	118.8	119.48	1.4221
11/16/2006	504+00	A	1	115.7		
11/16/2006	504+00	A	2	115.8		
11/16/2006	504+00	A	3	117.5		
11/16/2006	504+00	A	4	117.1	116.53	0.9106
11/16/2006	504+00	B	1	118.4		
11/16/2006	504+00	B	2	122.5		
11/16/2006	504+00	B	3	118.4		
11/16/2006	504+00	B	4	119.5	119.7	1.9374
11/16/2006	506+00	C	1	117.3		
11/16/2006	506+00	C	2	116.5		
11/16/2006	506+00	C	3	118.3		
11/16/2006	506+00	C	4	117.5	117.4	0.7394
11/16/2006	508+00	B	1	121.2		
11/16/2006	508+00	B	2	121.9		
11/16/2006	508+00	B	3	120.6		
11/16/2006	508+00	B	4	122.7	121.6	0.9055
11/16/2006	510+00	A	1	122.4		
11/16/2006	510+00	A	2	121.5		
11/16/2006	510+00	A	3	122.4		
11/16/2006	510+00	A	4	121.5	121.95	0.5196
11/16/2006	510+00	A	1	116.7		
11/16/2006	510+00	A	2	121.2		
11/16/2006	510+00	A	3	115.6		
11/16/2006	510+00	A	4	120.3	118.45	2.7185
11/16/2006	512+00	C	1	119.9		
11/16/2006	512+00	C	2	119.4		
11/16/2006	512+00	C	3	121.4		
11/16/2006	512+00	C	4	122.9	120.9	1.5811
11/16/2006	514+00	B	1	121.7		

Table 283. ***Density*** meas. by ***Pavetracker 10233*** – Non-nuclear Gage on ***I-20FR, TX, pcf***
Continued

Test Date	Station	Point	Trial #	Density	Average	Std Dev
11/16/2006	514+00	B	2	119.7		
11/16/2006	514+00	B	3	124		
11/16/2006	514+00	B	4	122.1	121.88	1.7633
11/16/2006	516+00	A	1	120.6		
11/16/2006	516+00	A	2	121.4		
11/16/2006	516+00	A	3	119.4		
11/16/2006	516+00	A	4	119.3	120.18	1.0079
11/16/2006	518+00	C	1	120.9		
11/16/2006	518+00	C	2	118.8		
11/16/2006	518+00	C	3	122.3		
11/16/2006	518+00	C	4	121.8	120.95	1.546
11/16/2006	520+00	B	1	123.6		
11/16/2006	520+00	B	2	121		
11/16/2006	520+00	B	3	122.8		
11/16/2006	520+00	B	4	121.2	122.15	1.2583
11/16/2006	522+00	A	1	120.1		
11/16/2006	522+00	A	2	118.4		
11/16/2006	522+00	A	3	119.2		
11/16/2006	522+00	A	4	119.7	119.35	0.7326
11/16/2006	524+00	C	1	124.4		
11/16/2006	524+00	C	2	122.6		
11/16/2006	524+00	C	3	124.5		
11/16/2006	524+00	C	4	123	123.63	0.9674
11/16/2006	526+00	B	1	119.5		
11/16/2006	526+00	B	2	120		
11/16/2006	526+00	B	3	120.2		
11/16/2006	526+00	B	4	121.9	120.4	1.0424
11/16/2006	528+00	A	1	124.3		
11/16/2006	528+00	A	2	121.7		
11/16/2006	528+00	A	3	123.4		
11/16/2006	528+00	A	4	125	123.6	1.4259
11/16/2006	530+00	C	1	122.2		
11/16/2006	530+00	C	2	120.7		
11/16/2006	530+00	C	3	121.7		
11/16/2006	530+00	C	4	125.1	122.43	1.8892
11/16/2006	532+00	B	1	124.2		

Table 283. ***Density*** meas. by ***Pavetracker 10233*** – Non-nuclear Gage on ***I-20FR, TX, pcf***
Continued

Test Date	Station	Point	Trial #	Density	Average	Std Dev
11/16/2006	532+00	B	2	122.5		
11/16/2006	532+00	B	3	123.1		
11/16/2006	532+00	B	4	121	122.7	1.3342
11/16/2006	533+75	A	1	121.5		
11/16/2006	533+75	A	2	118.7		
11/16/2006	533+75	A	3	120.8		
11/16/2006	533+75	A	4	121.2	120.55	1.2662
11/16/2006	536+00	C	1	119.7		
11/16/2006	536+00	C	2	118.5		
11/16/2006	536+00	C	3	119		
11/16/2006	536+00	C	4	118.9	119.03	0.4992
11/16/2006	538+00	B	1	121.4		
11/16/2006	538+00	B	2	116.7		
11/16/2006	538+00	B	3	120		
11/16/2006	538+00	B	4	121.2	119.83	2.1731
11/16/2006	CO/15	A	1	122.1		
11/16/2006	CO/15	A	2	122.8		
11/16/2006	CO/15	A	3	121.6		
11/16/2006	CO/15	A	4	120.6	121.78	0.9251
11/16/2006	CO/15	A	1	114		
11/16/2006	CO/15	A	2	123.3		
11/16/2006	CO/15	A	3	114.2		
11/16/2006	CO/15	A	4	117.2	117.18	4.3377
11/16/2006	P.O. Box - 2912	B	1	117.4		
11/16/2006	P.O. Box - 2912	B	2	119.1		
11/16/2006	P.O. Box - 2912	B	3	117.3		
11/16/2006	P.O. Box - 2912	B	4	117.5	117.83	0.8539

Table 284. ***Modulus*** measured by ***PSPA*** on ***I-20FR, TX, ksi***

Test Date	Station	Point	Trial #	Density	Average
11/14/2006	488+00	A	1	206	206
11/14/2006	490+00	B	1	246	246
11/14/2006	492+00	C	1	238	238
11/14/2006	494+00	A	1	292	292
11/14/2006	496+00	B	1	256	256
11/14/2006	498+00	C	1	269	269
11/14/2006	500+00	A	1	242	242
11/14/2006	502+00	B	1	261	261
11/14/2006	504+00	C	1	228	228
11/14/2006	506+00	A	1	252	252
11/14/2006	508+00	B	1	234	234
11/14/2006	510+00	C	1	266	266
11/14/2006	512+00	A	1	277	277
11/14/2006	514+00	B	1	238	238
11/14/2006	516+00	B	1	285	285
11/14/2006	516+00	C	1	245	245
11/14/2006	518+00	A	1	274	274
11/14/2006	520+00	B	1	268	268
11/14/2006	522+00	C	1	260	260
11/14/2006	524+00	A	1	281	281
11/14/2006	526+00	B	1	301	301
11/14/2006	528+00	C	1	247	247
11/14/2006	530+00	A	1	320	320
11/14/2006	532+00	B	1	314	314
11/14/2006	533+75	C	1	291	291
11/14/2006	536+00	A	1	262	262
11/14/2006	538+00	B	1	217	217
11/14/2006	CO/15	C	1	276	276
11/14/2006	P.O. Box – 2912	B	1	233	233
11/15/2006	488+30	C	1	494	494
11/15/2006	498+70	C	1	506	506
11/15/2006	514+20	A	1	492	492
11/15/2006	537+16	C	1	451	451
11/16/2006	488+00	A	1	447	447
11/16/2006	490+00	B	1	413	413
11/16/2006	492+00	C	1	405	405

Table 285. ***Modulus*** measured by ***PSPA*** on ***I-20FR, TX, ksi***
Continued

Test Date	Station	Point	Trial #	Density	Average
11/16/2006	494+00	A	1	410	410
11/16/2006	496+00	B	1	381	381
11/16/2006	498+00	C	1	407	407
11/16/2006	500+00	A	1	433	433
11/16/2006	502+00	B	1	385	385
11/16/2006	504+00	C	1	430	430
11/16/2006	506+00	A	1	429	429
11/16/2006	508+00	B	1	416	416
11/16/2006	510+00	C	1	460	460
11/16/2006	510+00	C	1	523	523
11/16/2006	512+00	A	1	498	498
11/16/2006	514+00	B	1	419	419
11/16/2006	516+00	C	1	423	423
11/16/2006	518+00	A	1	482	482
11/16/2006	520+00	B	1	443	443
11/16/2006	522+00	C	1	471	471
11/16/2006	524+00	A	1	454	454
11/16/2006	526+00	B	1	447	447
11/16/2006	528+00	C	1	452	452
11/16/2006	530+00	A	1	453	453
11/16/2006	532+00	B	1	427	427
11/16/2006	533+75	C	1	285	285
11/16/2006	536+00	A	1	232	232
11/16/2006	538+00	B	1	239	239
11/16/2006	CO/15	C	1	265	265
11/16/2006	CO/15	C	1	329	329
11/16/2006	P.O. Box - 2912	B	1	212	212