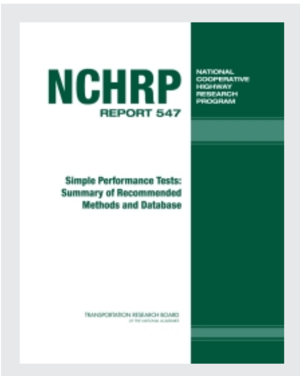

Simple Performance Tests: Summary of Recommended Methods and Database

DETAILS

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NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

NCHRP REPORT 547

Simple Performance Tests: Summary of Recommended Methods and Database

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SUBJECT AREAS
Pavement Design, Management, and Performance

Research Sponsored by the American Association of State Highway and Transportation Officials
in Cooperation with the Federal Highway Administration

TRANSPORTATION RESEARCH BOARD

WASHINGTON, D.C.
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NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

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FOREWORD

By Edward T. Harrigan
Staff Officer
Transportation Research Board

This report summarizes key information on three recommended simple performance tests for permanent deformation of hot mix asphalt (HMA). In the final phase of the work described here, and as described in two companion reports to be published later, the candidate tests for permanent deformation were validated with field performance data, and specifications for their use were developed. The report will be of particular interest to materials engineers in state highway agencies, as well as to materials suppliers and paving contractor personnel responsible for designing and producing HMA.

A key objective of NCHRP Project 9-19, "Superpave Support and Performance Models Management," was to develop simple performance tests for permanent deformation and fatigue cracking for incorporation in the Superpave volumetric mix design method. The 2002 *NCHRP Report 465: Simple Performance Test for Superpave Mix Design*, summarized analytical and experimental work conducted between 1995 and 2001 at the University of Maryland and Arizona State University to (1) survey the range of potential simple performance test methods and (2) select the most promising methods for a field validation program.

The resulting field validation and specification development program were conducted between 2001 and 2005. Both plant mixes and laboratory-blended, short-term oven-aged mixes were tested in the field validation program. Mixtures from MnRoad, NCAT Test Track, Indiana, Nevada I-80, WesTrack, FHWA-ALF, and Arizona I-10 sites constituted the complete test matrix. The results of the validation program supported the selection of the dynamic modulus (E^*), flow number (F_n), and flow time (F_t) tests as simple performance tests for permanent deformation of HMA mixes.

The project findings summarized in this report were extensively reviewed with the research team by the NCHRP Project 9-19 panel. In 2004, the project panel formally recommended the dynamic modulus test as the primary simple performance test for permanent deformation. The panel further recommended the flow number test as an optional, complementary procedure for evaluating the resistance of an HMA mix design to tertiary flow. Subsequently, the research agency prepared a specification, in the form of a Microsoft Excel spreadsheet, that determines a critical minimum E^* value for HMA, which is based on project-specific information on climate, traffic, pavement structure, and layer depth. The specification is based on a series of pavement design examples pre-solved using the pavement design guide software from NCHRP Project 1-37A. The agency also developed guidelines for using the flow number or flow time test to estimate the rutting potential of HMA mixes under specific project conditions. These detailed results, supported by the findings of the field validation program, will be presented in the two companion reports to this report. A fourth report will describe the use of the E^* test to estimate the fatigue cracking potential of HMA mixes.

This report summarizes the theory behind the three validated tests and briefly describes the test methods. A set of appendices, included (in DVD format) as *CRP-CD-46*, contains:

1. All test data, mixture data, master curves, and master curve parameters obtained from the E^* testing and analysis,

2. All test and mixture data obtained from the F_n and F_t tests, including ε_p (permanent strain at flow), ε_r (recoverable strain at flow), $\varepsilon_p/\varepsilon_r$ (from the F_n test), and compliance (from the F_t test), and
3. A collection of technical reports, theses and dissertations, and other relevant documents prepared during the course of NCHRP Project 9-19 and its predecessor FHWA project to support the development of the simple performance tests.

CONTENTS

CHAPTER 1

INTRODUCTION

A key objective of NCHRP Project 9-19, "Superpave Support and Performance Models Management," was to develop simple performance tests for permanent deformation and fatigue cracking for incorporation in the Superpave volumetric mix design method. *NCHRP Report 465: Simple Performance Test for Superpave Mix Design* summarized analytical and experimental work conducted originally at the University of Maryland from 1995 to 2000 and then at Arizona State University (ASU) to (1) survey the range of potential simple performance test methods and (2) select the most promising methods for a field validation program.

Based on the results of the testing program in Project 9-19, three tests were recommended for further field validation as promising simple performance tests for permanent deformation: (1) dynamic modulus, E^*, determined by the triaxial dynamic modulus test; (2) the flow number, $F_{n,}$ determined from the repeated load test; and (3) the flow time, $F_{t,}$ determined from the static creep test.

Between 2001 and 2004, ASU and its subcontractors carried out an extensive series of experiments to validate the dynamic modulus, flow time, and flow number tests with materials and data from accelerated pavement tests and full-scale field tests. In 2004, based on the results of these experiments, the dynamic modulus test was recommended as the primary simple performance test for rutting. The flow number test was recommended as a complementary procedure for evaluating the resistance of a hot mix asphalt (HMA) mix design to tertiary flow; the flow time test was shown to be a simple, practical surrogate for the flow number test.

In subsequent work, ASU prepared a specification for rutting, in the form of a Microsoft Excel spreadsheet, that determines a critical minimum E^* value for HMA (based on project-specific information on climate, traffic, pavement structure, and layer depth); work to develop a simple specification for fatigue cracking will be completed in 2005. Both specifications are based on a series of pavement design examples pre-solved with the mechanistic-empirical pavement design guide software developed in NCHRP Project 1-37A, "Development of the 2002 Guide for the Design of New and Rehabilitated Pavement Structures: Phase II."

This report summarizes the theory behind the three recommended simple performance tests, briefly describes the test methods, and presents appendixes on the included CD-ROM (*CRP-CD-46*) that contain (1) all the test data, mixture data, master curves, and master curve parameters obtained from the E^* testing and analysis; and (2) all the test and mixture data obtained from the F_n and F_t tests, including ε_p (permanent strain at flow), ε_r (recoverable strain at flow), $\varepsilon_p/\varepsilon_r$ (from the F_n test), and compliance (from the F_t test). Both plant mixes and laboratory-blended short-term oven-aged mixes were tested under the project. Mixtures from MnRoad, NCAT Test Track, Indiana, Nevada I-80, WesTrack, FHWA-ALF, and Arizona DOT (ADOT) I-10 sites constituted the complete test matrix.

ASU also conducted dynamic modulus, flow number, and flow time testing for these other research projects:

1. ADOT AC Mixture Stiffness Characterization Database (Project #3 of the ASU-ADOT Research Program: "Development of Performance Related Specifications for Asphalt Pavements in the State of Arizona") and associated tasks (US-60 plant mixes and Two Guns lab blend and plant-mixed conventional and rubber mixes);
2. Asphalt Rubber Demonstration Project (ADOT I-40 site);
3. Performance Evaluation of Arizona Asphalt Rubber Mixtures Using Advanced Dynamic Material Characterization Tests (ADOT I-17 site);
4. Alberta Asphalt Rubber Project (2002 AR Mix #1 and 2003 AR Mix #2);
5. NCHRP 9-23 Project (Environmental Effects in Pavement Mix and Structural Design Systems);
6. Development of an E^* Master Curve Database for Lime Modified Asphaltic Mixtures;
7. ADOT AC Mixture Permanent Deformation Database (Project #5 of the ASU-ADOT Research Program: "Development of Performance Related Specifications for Asphalt Pavements in the State of Arizona"); and
8. ADOT AC Mixture Simple Performance Tests (Project #7 of the ASU-ADOT Research Program: "Development of Performance Related Specifications for Asphalt Pavements in the State of Arizona").

For completeness all E^*, F_n, and F_t results obtained through the testing and analysis of these other projects are also included in the appendixes contained on *CRP-CD-46*.

CHAPTER 2

THEORY

2.1 DYNAMIC MODULUS (E^*)

For linear viscoelastic materials such as HMA, the stress-to-strain relationship under a continuous sinusoidal loading is defined by its complex dynamic modulus (E^*). This is a complex number that relates stress to strain for linear viscoelastic materials subjected to continuously applied sinusoidal loading in the frequency domain. The complex modulus is defined as the ratio of the amplitude of the sinusoidal stress (at any given time, t, and angular load frequency, ω), $\sigma = \sigma_0 \sin(\omega t)$, and the amplitude of the sinusoidal strain $\varepsilon = \varepsilon_0 \sin(\omega t - \phi)$, at the same time and frequency, that results in a steady-state response (Figure 1):

$$E^* = \frac{\sigma}{\varepsilon} = \frac{\sigma_0 e^{i\omega t}}{\varepsilon_0 e^{i(\omega t - \phi)}} = \frac{\sigma_0 \sin(\omega t)}{\varepsilon_0 \sin(\omega t - \phi)} \quad \text{(Eq. 1)}$$

where

σ_0 = peak (maximum) stress
ε_0 = peak (maximum) strain
ϕ = phase angle, degrees
ω = angular velocity
t = time, seconds

Mathematically, the dynamic modulus is defined as the absolute value of the complex modulus, or

$$|E^*| = \frac{\sigma_0}{\varepsilon_0} \quad \text{(Eq. 2)}$$

For a pure elastic material, $\phi = 0$, and it is observed that the complex modulus (E^*) is equal to the absolute value or dynamic modulus. For pure viscous materials, $\phi = 90°$. The dynamic modulus testing of HMA is normally conducted using a uniaxially applied sinusoidal stress pattern as shown in Figure 1.

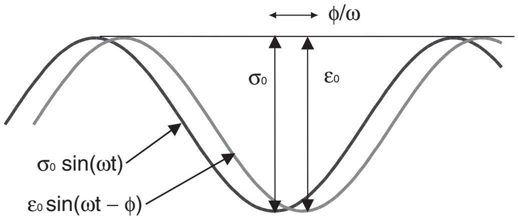


Figure 1. Dynamic (complex) modulus test.

2.1.1. Dynamic Modulus: Master Curve

In the *Mechanistic-Empirical Pavement Design Guide* developed in NCHRP Project 1-37A, the modulus of HMA at all levels of temperature and time rate of load is determined from a master curve constructed at a reference temperature (generally taken as 70°F). Master curves are constructed using the principle of time-temperature superposition. The data at various temperatures are shifted with respect to time until the curves merge into a single smooth function. The master curve of the modulus, as a function of time, formed in this manner describes the time dependency of the material. The amount of shifting at each temperature required to form the master curve describes the temperature dependency of the material. In general, the modulus master curve can be mathematically modeled by a sigmoidal function described as

$$\text{Log}|E^*| = \delta + \frac{\alpha}{1 + e^{\beta + \gamma(\log t_r)}} \quad \text{(Eq. 3)}$$

where

t_r = reduced time of loading at reference temperature
δ = minimum value of E^*
$\delta + \alpha$ = maximum value of E^*
β, γ = parameters describing the shape of the sigmoidal function

The shift factor can be shown in the following form:

$$a(T) = \frac{t}{t_r} \quad \text{(Eq. 4)}$$

where

$a(T)$ = shift factor as a function of temperature
t = time of loading at desired temperature
t_r = time of loading at reference temperature
T = temperature

Although classical viscoelastic fundamentals suggest a linear relationship between log $a(T)$ and T (in degrees Fahrenheit), experience has shown that for precision, a second-order polynomial relationship between the logarithm of the shift factor, that is log $a(T_i)$, and the temperature in degrees Fahrenheit (T_i) should be used. The relationship can thus be expressed as follows:

$$\text{Log } a(T_i) = aT_i^2 + bT_i + c \qquad \text{(Eq. 5)}$$

where

$a(T_i)$ = shift factor as a function of temperature T_i
T_i = temperature of interest, °F
a, b and c = coefficients of the second-order polynomial

If the value of the coefficient a approaches zero, the shift factor equation collapses to the classic linear form.

2.1.2. Dynamic Modulus: Levels of Analysis

The *Mechanistic-Empirical Pavement Design Guide* uses the laboratory-measured E^* data for the Level 1 design analysis; it uses E^* values predicted from the Witczak E^* predictive equation in Levels 2 and 3. The master curve for the Level 1 analysis is developed using numerical optimization to shift the laboratory mixture test data into a smooth master curve. Before shifting the test data, the relationship between binder viscosity and temperature must be established. This is done by first converting the binder stiffness data at each temperature to viscosity using Equation 6. The parameters of the ASTM A_i-VTS_i equation are then found by linear regression of Equation 7 after log-log transformation of the viscosity data and log transformation of the temperature data.

$$\eta = \frac{G^*}{10}\left(\frac{1}{\sin\delta}\right)^{4.8628} \qquad \text{(Eq. 6)}$$

$$\log\log\eta = A + VTS \log T_R \qquad \text{(Eq. 7)}$$

where

η = binder viscosity, cP
G^* = binder complex shear modulus, Pa
δ = binder phase angle, degree
A, VTS = regression parameters
T_R = temperature, °Rankine

The master curve for the Level 2 analysis is developed using the Witczak Dynamic Modulus Predictive Equation (Equation 8) from specific laboratory test data. The Level 3 analysis requires no laboratory test data for the AC binder, but requires those mixture properties included in the Witczak predictive equation.

$$\log|E^*| = -1.249937 + 0.02923\rho_{200} - 0.001767(\rho_{200})^2 - 0.002841\rho_4 - 0.058097V_a - 0.802208\frac{V_{beff}}{V_{beff}+V_a} + \frac{3.871977 - 0.0021\rho_4 + 0.003958\rho_{38} - 0.000017(\rho_{38})^2 + 0.00547\rho_{34}}{1+e^{[-0.603313-0.313351\log(f)-0.393532\log(\eta)]}} \qquad \text{(Eq. 8)}$$

where

$|E^*|$ = dynamic modulus, 10^5 psi
η = binder viscosity at the age and temperature of interest, 10^6 Poise
f = loading frequency, Hz
V_a = air void content, %
V_{beff} = effective binder content, % by volume
ρ_{34} = cumulative % retained on 19-mm sieve
ρ_{38} = cumulative % retained on 9.5-mm sieve
ρ_4 = cumulative % retained on 4.76-mm sieve
ρ_{200} = % passing 0.075-mm sieve

The Witczak predictive equation (Equation 8) can be presented in the same form as Equation 3 for a mixture-specific master curve as follows:

$$\text{Log}|E^*| = \delta + \frac{\alpha}{1+e^{\beta+\gamma(\log t_r)}} \qquad \text{(Eq. 9)}$$

where

$|E^*|$ = dynamic modulus, 10^5 psi

$$\delta = -1.249937 + 0.02923\rho_{200} - 0.001767(\rho_{200})^2 - 0.002841\rho_4 - 0.058097V_a - 0.802208\left(\frac{V_{beff}}{V_{beff}+V_a}\right) \qquad \text{(Eq. 9a)}$$

$$\alpha = 3.871977 - 0.0021\rho_4 + 0.003958\rho_{38} - 0.000017(\rho_{38})^2 + 0.00547\rho_{34} \qquad \text{(Eq. 9b)}$$

$$\beta = -0.603313 - 0.393532\log(\eta_{Tr}) \qquad \text{(Eq. 9c)}$$

$$\gamma = 0.313351 \qquad \text{(Eq. 9d)}$$

t_r = reduced time of loading at reference temperature
V_a = air void content, %
V_{beff} = effective binder content, % by volume
ρ_{34} = cumulative % retained on 19-mm sieve
ρ_{38} = cumulative % retained on 9.5-mm sieve
ρ_4 = cumulative % retained on 4.76-mm sieve
ρ_{200} = % passing 0.075-mm sieve
η_{Tr} = binder RTFOT viscosity at the reference temperature, 10^6 Poise

2.2 FLOW NUMBER (F_n)

An approach to determine the permanent deformation characteristics of paving materials is to employ a repeated dynamic load test for several thousand repetitions and record the cumulative permanent deformation as a function of the number of cycles (repetitions) over the testing period. This approach was employed by Monismith and coworkers in the mid-1970s using uniaxial compression tests. Several research studies conducted by Witczak and coworkers used a temperature of 100ºF or 130ºF at 10, 20, or 30 psi deviator stress level. A haversine pulse load of 0.1 sec and 0.9 sec dwell (rest time) is applied for the test duration of approximately 3 hours. This approach results in approximately 10,000 cycles applied to the specimen.

Several parameters describing the accumulated permanent deformation response can be obtained from the F_n test. Figure 2 illustrates the typical relationship between the total cumulative permanent strain and number of load cycles. Like the creep test, the cumulative permanent strain curve is generally defined by three zones: primary, secondary, and tertiary. In the primary zone, permanent deformations accumulate rapidly. The incremental permanent deformations decrease reaching a constant value in the secondary zone. Finally, the incremental permanent deformations again increase and permanent deformations accumulate rapidly in the tertiary zone. The starting point, or cycle number, at which tertiary flow occurs is referred to as the *flow number*.

Typical permanent deformation parameters, which are obtained and analyzed from the repeated load permanent deformation test, include the intercept (a, μ) and slope (b, α) parameters. The permanent deformation properties (α, μ) have been used as input for predictive design procedures. All of the parameters derived from the linear (secondary) portion of the cumulative permanent strain–repetitions curve ignore the tertiary zone of material deformability. Thus, all four of the parameters noted (α, μ, b, a) are regression constants of a statistical model that is only based on the "linear" secondary phase of the permanent strain–repetition curve.

The log-log relationship between the permanent strain and the number of load cycles can be expressed by the classical power model: $\varepsilon_p = aN^b$, where a and b are regression constants depending on the material-test combination conditions. Figure 3 illustrates the relationship when plotted on a log-log scale.

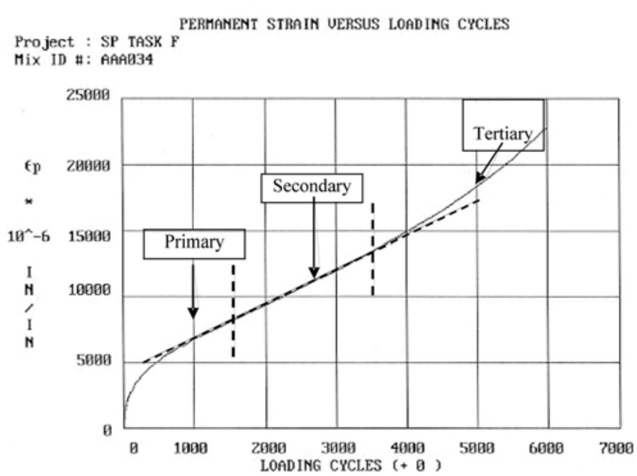


Figure 2. Typical relationship between total cumulative permanent strain and number of load cycles.

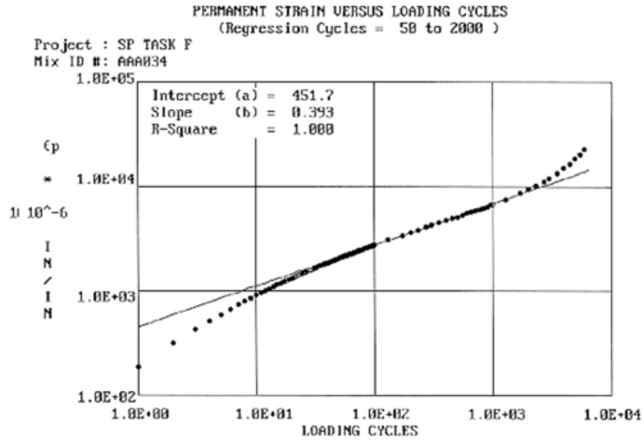


Figure 3. Regression constants "a" and "b" when plotted on a log-log scale.

The intercept a represents the permanent strain at $N = 1$, whereas the slope b represents the rate of change in permanent strain as a function of the change in loading cycles [log (N)]. An alternative form of the mathematical model used to characterize the permanent strain per load repetition (ε_{pn}) relationship can be expressed by

$$\frac{\partial \varepsilon_p}{\partial N} = \varepsilon_{pn} = \frac{\partial (aN^b)}{\partial N} \quad \text{or,} \quad \varepsilon_{pn} = abN^{(b-1)} \qquad \text{(Eq. 10)}$$

The resilient strain (ε_r) is generally assumed to be independent of the load repetition value (N). As a consequence, the ratio of permanent-to-elastic strain components of the material in question can be defined by

$$\frac{\varepsilon_{pn}}{\varepsilon_r} = \left(\frac{ab}{\varepsilon_r}\right) N^{b-1} \qquad \text{(Eq. 11)}$$

By letting $\mu = \dfrac{ab}{\varepsilon_r}$ and $\alpha = 1 - b$, one obtains

$$\frac{\varepsilon_{pn}}{\varepsilon_r} = \mu N^{-\alpha} \qquad \text{(Eq. 12)}$$

In the above equation, ε_{pn} is the permanent strain resulting from a single load application; that is, at the N^{th} application. μ is a permanent deformation parameter representing the constant of proportionality between permanent strain and elastic strain (i.e., permanent strain at $N = 1$). α is a permanent deformation parameter indicating the rate of decrease in incremental permanent deformation as the number of load applications increases.

Figure 4 illustrates the above relationship and the occurrence of the flow point when the rate of decrease in permanent strain is constant.

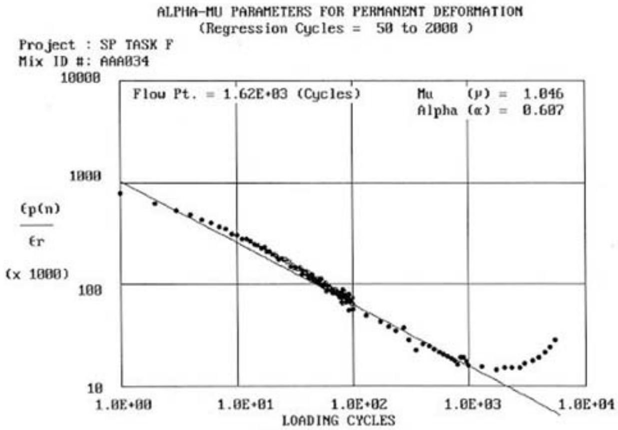


Figure 4. Permanent deformation parameters α *and* μ *and the flow number.*

2.3 FLOW TIME (F_t)

Figure 5 shows a typical relationship between the calculated total compliance and time measured in a static creep test. This figure shows that the total compliance can be divided into three major zones: (1) primary, (2) secondary, and (3) tertiary. In the primary zone, the strain rate decreases; in the secondary zone, the creep rate is constant; and in the tertiary zone, the creep rate increases.

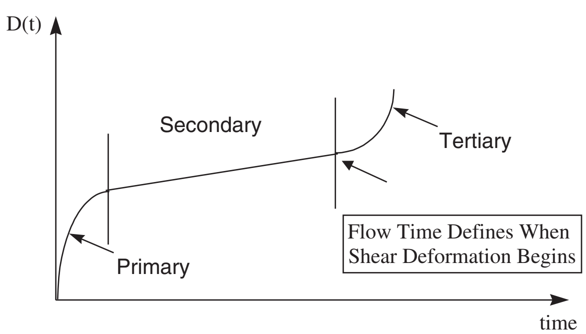


Figure 5. Typical test results between the calculated total compliance and time.

The flow time, F_t, is therefore defined as the time when shear deformation, under constant volume, starts. The flow time is also viewed as the minimum point in the relationship of rate of change of compliance versus loading time. Figures 6 and 7 show typical static creep test plots. Figure 6 shows the total axial strain versus loading time on a log-log scale. The estimation of compliance parameters *a* and *m* are obtained from the regression analysis of the linear portion of the curve. Figure 7 shows a plot of the rate of change in compliance versus loading time in log-log scale along with the calculated value of the flow time.

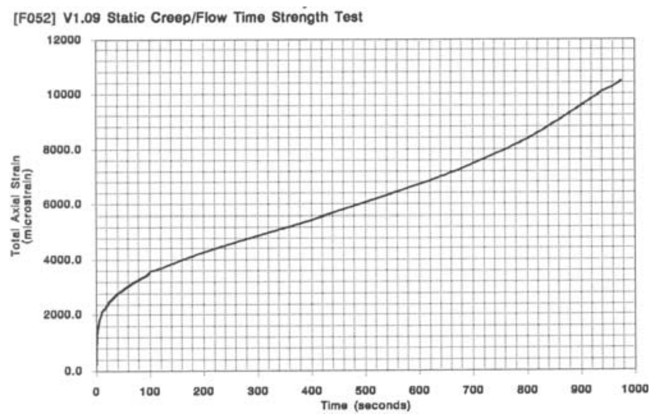


Figure 6. Total axial strain vs. time from an actual static creep / flow time test.

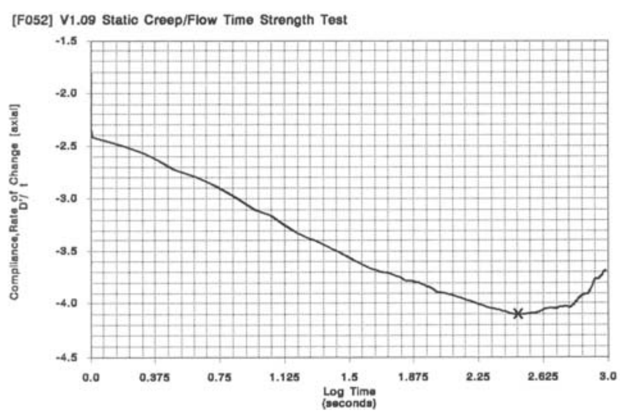


Figure 7. Typical plot of the rate of change in compliance vs. loading time.

CHAPTER 3

SUMMARY OF TEST METHODS

3.1 DYNAMIC MODULUS

The NCHRP 1-37A Test Method DM-1 (available as AASHTO TP-62, Determining Dynamic Modulus of Hot-Mix Asphalt Concrete Mixtures) was followed for *E** testing. For each mix, generally two or three replicates were prepared for testing. For each specimen, *E** tests were generally conducted at 14, 40, 70, 100, and 130°F and 25, 10, 5, 1, 0.5, and 0.1 Hz loading frequencies. A 60-second rest period was used between each frequency to allow some specimen recovery before applying the new loading at the next lower frequency. Table 1 presents the *E** test conditions.

The *E** tests were done using a controlled stress mode, which produced strains smaller than 200 micro-strain. This ensured, to the best possible degree, that the response of the material was linear across the temperature range used in the study. The dynamic stress levels were 10 to 100 psi for colder temperatures (14°F to 70°F) and 2 to 10 psi for higher temperatures (100°F to 130°F). All *E** tests were conducted in a temperature-controlled chamber capable of holding temperatures from 3.2 to 140°F (−16 to 60°C).

The axial deformations of the specimens were measured through two spring-loaded linear variable differential transducers (LVDTs) placed vertically on diametrically opposite sides of the specimen. Parallel brass studs were used to secure the LVDTs in place. Two pairs of studs were glued on the two opposite cylindrical surfaces of a specimen with each stud in a horizontal pair being 100 mm (4 inches) apart and located approximately the same distance from the top and bottom of the specimen. Top and bottom surface friction is a very practical problem for compressive type testing. To eliminate the possibility of having shear stresses on the specimen ends during testing, pairs of rubber membranes, with vacuum grease within the pairs, were placed on the top and bottom of each specimen during testing. Figure 8 is a schematic presentation of the instrumentation of the test samples used in the dynamic modulus testing.

All *E** test specimens were prepared and the *E** tests were carried out according to the NCHRP Project 1-37A Test Method DM-1. Before compaction, the laboratory-blended HMA mixtures were short-term aged in the oven for 4 hours at 275°F, according to the AASHTO Test Method AASHTO PP2, "Standard Practice for Short and Long Term Aging of Hot Mix Asphalt." Any laboratory-blended or plant-obtained mixture was compacted in a Servopac gyratory compactor to a 6-inch diameter by 6.7 inches high. All test specimens were sawed and cored to obtain the final 4-inch-diameter by 6-inch-high *E** test specimen. Before the *E** testing, AASHTO T166-93 was followed to measure the bulk specific gravity and water absorption of the specimens. All final 4-inch-diameter by 6-inch-high *E** test specimens were prepared to have the target in-place air voids ± 0.5 percent.

3.2 FLOW NUMBER AND FLOW TIME

F_n and F_t test methods are presented in *NCHRP Report 465*. Test methods adapted for the simple performance tester developed in NCHRP Project 9-29, "Simple Performance Tester for Superpave Mix Design," are presented in Appendix D of *NCHRP Report 513*: *Simple Performance Tester for Superpave Mix Design: First-Article Development and Evaluation*, which is available online at http://gulliver.trb.org/publications/nchrp/nchrp_rpt_513.pdf.

In this research at ASU, repeated load and static creep tests, confined and unconfined, were conducted using at least two replicate test specimens for each mixture. All tests were carried out on cylindrical specimens, 100 mm (4 inches) in diameter and 150 mm (6 inches) in height. For the repeated load tests, a haversine pulse load of 0.1 second and a 0.9 second dwell (rest time) was applied for a target of 300,000 cycles. This number was lower if the test specimen failed under tertiary flow before reaching this target level. For the static creep tests, a static constant load was applied until tertiary flow occurred.

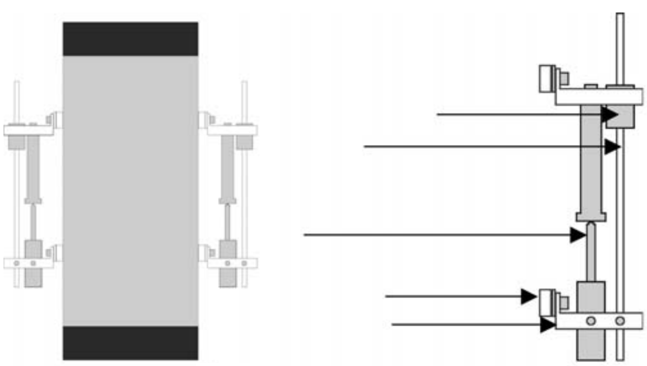
An IPC Universal Testing Machine (UTM 25 kN) electro-pneumatic system was used to load the unconfined specimens. For confined testing, an IPC UTM 100 kN machine was used. The machines were equipped to apply necessary confining pressure. The load was measured through the load cell; the deformations were measured through six spring-loaded LVDTs. Two axial LVDTs were mounted vertically on diametrically opposed specimen sides. Parallel studs, mounted on the test specimen, placed 100 mm (4 inches) apart, and located at the center of the specimen were used to secure the LVDTs in place. The studs were glued using a commercial 5-minute epoxy. An alignment rod with a frictionless bushing was used to keep the studs aligned at extreme failure

TABLE 1 Test conditions of the dynamic modulus (*E) test**

Test Temp. (°F)	Freq. (Hz)	Cycles	Rest Period (Sec)	Cycles to Compute E*
14, 40, 70, 100, 130 (Unless otherwise specified)	25	200	-	196 to 200
	10	100	60	196 to 200
	5	50	60	96 to 100
	1	20	60	16 to 20
	0.5	15	60	11 to 15
	0.1	15	60	11 to 15

conditions. Figure 9 is a photograph of an actual specimen set up for an unconfined test. For radial deformations, four externally mounted LVDTs aligned on diametrical and perpendicular lines were located at the center of the specimen and along opposite specimen sides. The radial LVDTs set-up is also shown in Figure 9. Thin and fully lubricated membranes at the test specimen ends were used to warrant frictionless surface conditions. All tests were conducted within an environmentally controlled chamber throughout the testing sequence (i.e., temperature was held constant within the chamber to ±1°F throughout the entire test).

Figures 10 and 11 show a typical confined test set-up.



a. Sample Assembly b. Lateral View

Figure 8. Specimen instrumentation of E testing.*

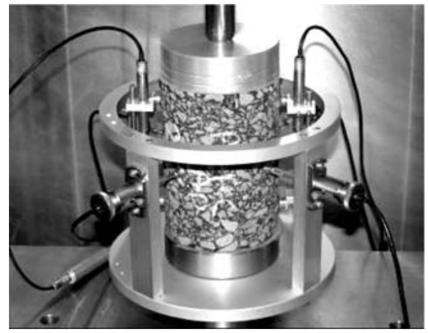


Figure 9. Vertical and radial LVDTs set-up for an unconfined test.

Figure 10. Confined test set-up.

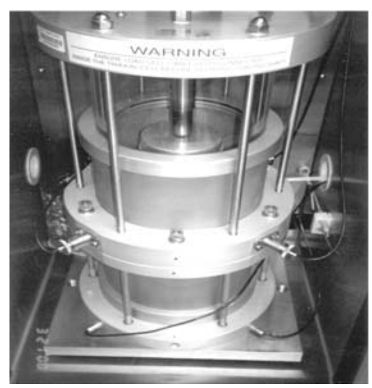


Figure 11. Test set-up within triaxial cell with mounted radial LVDTs.

CHAPTER 4

ORGANIZATION OF CRP-CD-46

This report is accompanied by *CRP-CD-46* (in DVD format), which contains two main folders: (1) Testing Databases and (2) Ancillary Reports.

The Testing Databases folder contains subfolders of Excel files (named Appendixes A through M) that present the following databases of dynamic modulus (E^*), flow number (F_n), and flow time (F_t) test results:

1. Appendix A: Summary of all major E^* testing conducted at Arizona State University during 1999-2004.
2. Appendix B: E^* Database of Task C of NCHRP Project 9-19.
3. Appendix C: E^* Database of ADOT AC Mixture Stiffness Characterization Database Project (Project #3 of the ASU-ADOT Research Program titled: "Development of Performance Related Specifications for Asphalt Pavements in the State of Arizona") and associated tasks (US-60 plant mixes and Two Guns lab blend and plant-mixed conventional and rubber mixes).
4. Appendix D: E^* Database of the "Asphalt Rubber Demonstration Project" (ADOT I-40 Section).
5. Appendix E: E^* Database (AR Tasks 2 and 3) of the ASU-ADOT project titled: "Performance Evaluation of Arizona Asphalt Rubber Mixtures Using Advanced Dynamic Material Characterization Tests" (Arizona Asphalt Rubber Mixtures of ADOT I-17 Section).
6. Appendix F: E^* Database of 2002 and 2003 phases of the "Alberta Asphalt Rubber Project" (Alberta AR mix #1 and #2).
7. Appendix G: E^* Database of NCHRP Project 9-23, "Environmental Effects in Pavement Mix and Structural Design Systems."
8. Appendix H: E^* Database of Lime Modified Asphaltic Mixtures of the NLA-Arizona State University research project titled: "Development of an E^* Master Curve Database for Lime Modified Asphaltic Mixtures."
9. Appendix I: Summary of major F_n and F_t testing conducted on conventional AC mixtures at Arizona State University during 1999-2005.
10. Appendix J: F_n Database of Task C of NCHRP Project 9-19.
11. Appendix K: F_n Database of Projects #5 and #7 of the ASU-ADOT research program titled "Development of Performance Related Specifications for Asphalt Pavements in the State of Arizona."
12. Appendix L: F_t Database of Task C of NCHRP Project 9-19.
13. Appendix M: F_t Database of Projects #5 and #7 of the ASU-ADOT research program.

The Ancillary Reports folder contains the portable document format (PDF) files listed in Table 2. These are technical reports, theses and dissertations, and other relevant documents prepared during the course of NCHRP Project 9-19 and its predecessor FHWA project to support the development of the simple performance tests.

TABLE 2 Technical reports, theses and dissertations, and other documents from NCHRP Project 9-19

Major Area	PDF File No.	Report Date	NCHRP 9-19 Report Title
1 - Initial FHWA SP Support and Performance Models Management	01-A	Sep-95	FHWA No DTFH 61-94-R-00045, Project Deliverable, Task A Report; Information Acquisition and Management
	01-B	Dec-95	FHWA No DTFH 61-94-R-00045, Project Deliverable, Task B Report; Final ETG Coordination Plan
	01-C	Dec-95	FHWA No DTFH 61-94-R-00045, Project Deliverable, Task D Report; Final Models Evaluation Plan
	01-D	May-98	FHWA No DTFH 61-94-R-00045, Project Deliverable, Interim Task C Report; Preliminary Recommendations for the Simple Performance Test
	01-E	May-98	FHWA No DTFH 61-94-R-00045, Project Deliverable, Calibration and Evaluation Plan for the Superpave Models
	01-F	Jul-96	FHWA No DTFH 61-94-R-00045, Superpave Software Review I Update, Presentation Handouts, ETG Meeting
	01-G	Jul-96	FHWA No DTFH 61-94-R-00045, Field Verification and Lab Test Plans, Presentation Handouts, ETG Meeting
	01-H	Jul-96	FHWA No DTFH 61-94-R-00045, Models Evaluation Status, Presentation Handouts, ETG Meeting
	01-I	Aug-98	FHWA No DTFH 61-94-R-00045, Quarterly Progress Report (April 1,1998 to June 30, 1998)
	01-J	Jun-97	FHWA No DTFH 61-94-R-00045, Superpave Models Newsletter, Number 2, Spring 1997
	01-K	Dec-98	FHWA No DTFH 61-94-R-00045, Superpave Models Newsletter, Number 3, Winter 1998
2 - Evaluation of SHRP Performance Models System	02-A	Sep-96	Task D, FHWA DTFH 61-95-C-00100, Subtask D.1.c; Volume I- Key Findings and Recommendations
	02-B	Sep-96	Task D, FHWA DTFH 61-95-C-00100, Subtask D.1.c; Volume II (1 of 2) - Appendix: Work Elements #s 1 to 4 Reports
	02-C	Sep-96	Task D, FHWA DTFH 61-95-C-00100, Subtask D.1.c; Volume II (2 of 2) - Appendix: Work Elements #s 5 to 7 Reports
	02-D	Sep-96	Task D, FHWA DTFH 61-95-C-00100, Subtask D.1.c; Volume III (1 of 2) - Appendix: Work Elements #s 8 to 10 Reports
	02-E	Sep-96	Task D, FHWA DTFH 61-95-C-00100, Subtask D.1.c; Volume III (2 of 2) - Appendix: Work Elements #11 (Appendices) Reports
	02-F	Sep-96	Task D, FHWA DTFH 61-95-C-00100, Subtask D.1.c; Volume IV (1 of 2) - Appendix: Work Elements #s 12 to 14 Reports
	02-G	Sep-96	Task D, FHWA DTFH 61-95-C-00100, Subtask D.1.c; Volume IV (2 of 2) - Appendix: Work Elements #s 15 and 16 Reports
	02-H	Aug-97	Task D, FHWA DTFH 61-95-C-00100, Subtask D.1.c; Review and Evaluation of Superpave Distress Prediction Software (Summary of Errors and Discrepancies)
	02-I	Sep-97	Superpave Support and Performance Models Management: Evaluation of the SHRP Performance Models System

(*continued on next page*)

TABLE 2 (Continued)

Major Area	PDF File No	Report Date	NCHRP 9-19 Report Title
3 - International Coordination Meetings	03-A	Aug-98	Superpave Models International Meeting: Coordination / Cooperation to Enhance/Improve Asphalt Materials Characterization in Support of Predictive Distress Models
	03-B	Jun-98	Austroads Pavement Research Group, Document No APRG 98/12 (GE): Report on Superpave International Cooperation and Coordination Feasibility
4 - AC Binder Characterization / Analysis	04-A	May-98	FHWA DTFH 61-94-R-00045, Project Deliverable: Development of Relationships Between Binder Viscosity and Stiffness
	04-B	May-98	Binder Characterization, Team Report BC-1, Development of Relationship Between Binder Viscosity and Stiffness
	04-C	Feb-99	Binder Characterization, Team Report BC-2, Relationship For Standard PG 64-22 Binder Used by the University of Maryland Models Team
	04-D	Oct-99	Binder Characterization, Team Report BC-3, Rheological Characterization of the MnRoad Binders
	04-E	Jun-00	Binder Characterization, Team Report BC-4, Rheological Characterization of the FHWA-ALF Binders
	04-F	Jun-00	Binder Characterization, Team Report BC-5, Rheological Characterization of the WesTrack Binders
	04-G	Feb-04	An Evaluation of the Probable Aging Effects of Plant Mixtures Used in the NCHRP 9-19 Report
5 - AC Mixture Design of Standard Mixes Used in Special Geometry and Aggregate Size Studies	05-A	Apr-99	FHWA DTEH 61-94-R-00045, Volumetric Design of Standard Mixtures Used by University of Maryland Models Team
6 - Sample / Specimen Preparation	06-A	Sep-99	Effects of Aggregate Size and Specimen Geometry on HMA Mixture Properties, Internal Team Report
	06-B	Dec-99	Task F Team Report SLS-3, Vol. I: TechReport, Specimen Geometry and Aggregate Size Lab Test Study
	06-C	Dec-99	Task F Team Report SLS-3, Vol.II: Appendices, Specimen Geometry and Aggregate Size Lab Test Study
	06-D	Dec-99	Task F Team Report SLS-3, Vol.II: Appendix C, Specimen Geometry and Aggregate Size Lab Test Study
	06-E	Dec-00	Subtask C4c(1) Reports; Air Void Distribution in Gyrated Compaction Specimens
	06-F	Sep-02	Subtask C4-C6 Report; Standard Procedures for Achieving Target Air Void Content of Gyratory HMA Specimens (Provisional Protocol)

TABLE 2 (Continued)

Major Area	PDF File No	Report Date	NCHRP 9-19 Report Title
7 - SPT Candidate Test Sensitivity / Full Specimen Size Results	07-A	Jun-01	Superpave Support and Performance Models Management: Subtasks C4-C6 (C4e) Report: Dynamic Modulus Testing of Ministry Transport Quebec (MTQ) AC Mixtures
	07-B	Oct-01	Superpave Support and Performance Models Management: Subtasks C4-C6 (C4d) Report: Sensitivity of SPT Test-Rapid vs. Geotechnical Triaxial Cell
	07-C	Oct-01	Superpave Support and Performance Models Management: Subtasks C4-C6 (C4e) Report: Comparison of E* Tests in Repeated Beam Flexure and Uniaxial Comp. Modes
	07-D	Dec-01	Superpave Support and Performance Models Management; Subtasks C4-C6 (C4b) Report: Sensitivity of Simple Performance Test - Dynamic Modulus E*
	07-E	Dec-01	Superpave Support and Performance Models Management; Subtasks C4-C6 (C4c) Report: Utilization of Full Gyratory Samples - Dynamic Modulus E*
	07-F	Dec-01	Superpave Support and Performance Models Management; Subtasks C4-C6 (C4b) Report: Sensitivity of Simple Performance Test - Static Creep Flow Time-Ft
	07-G	Dec-01	Superpave Support and Performance Models Management; Subtasks C4-C6 (C4b) Report: Sensitivity of Simple Performance Test - Repeated Load Flow Number - Fn
	07-H	Dec-01	Superpave Support and Performance Models Management; Subtasks C4-C6 (C4c) Report: Utilization of Full Gyratory Samples - Flow Time Ft and Flow Number Fn
	07-I	Apr-02	Superpave Support and Performance Models Management; Subtask C4 Report: Summary of Ancillary Studies of Candidate Simple Performance Tests
8 - Initial Task C SPT Candidate Tests (MnRoad, WesTrack, FHWA-ALF)	08-A	Oct-99	Task C: SPT Team Report SPT-MN-2A (Indirect Tensile Strength Tests- Data for the MnRoad Mixtures)
	08-B	Nov-99	Task C: SPT Team Report SPT-MN-2B (Indirect Creep Tests- Data for the MnRoad Mixtures)
	08-C	Oct-99	Task C: SPT Team Report SPT-MN-2C (Indirect Fatigue Tests- Data for the MnRoad Mixtures)
	08-D	Dec-99	Task C: SPT Team Report SPT-MN-2D (Triaxial Strength Tests- Data for the MnRoad Mixtures)
	08-E	Nov-99	Task C: SPT Team Report SPT-MN-2E (G* Field Shear Test FST-Data for the MnRoad Mixtures)
	08-F	Oct-99	Task C: SPT Team Report SPT-MN-2F (G* Simple Shear Tests- Data for the MnRoad Mixtures)
	08-G	Oct-99	Task C: SPT Team Report SPT-MN-2G (Repeated Shear Perm Def Tests Data for the MnRoad Mixtures)
	08-H	Oct-99	Task C: SPT Team Report SPT-MN-2H (Repeated Normal Perm Def Tests- Data for the MnRoad Mixtures)
	08-I	Oct-99	Task C: SPT Team Report SPT-MN-2 I (Triaxial Static Creep Tests-Flow/Compliance- Data for the MnRoad Mixtures)
	08-J	Oct-99	Task C: SPT Team Report SPT-MN-2(J-K) (E* Dynamic Modulus and Ed Dynamic Pulse Wave Velocity Tests- Data for the MnRoad Mixtures)
	08-K	Oct-99	Task C: SPT Team Report SPT-MN-2L (E* and Sm Prediction Equation Methodology Results- Data for the MnRoad Mixtures)

(*continued on next page*)

TABLE 2 (Continued)

Major Area	PDF File No	Report Date	NCHRP 9-19 Report Title
8 - Initial Task C SPT Candidate Tests (MnRoad, WesTrack, FHWA-ALF)	08-L	Feb-00	Task C: SPT Team Report SPT-ALF-1 (In-Situ Mix Composition and Performance- Data for the FHWA ALF Mixtures)
	08-M	May-00	Task C: SPT Team Report SPT-ALF-2A (Indirect Tensile Strength Tests- Data for the FHWA ALF Mixtures)
	08-N	May-00	Task C: SPT Team Report SPT-ALF-2B (Indirect Creep Tests- Data for the FHWA ALF Mixtures)
	08-O	May-00	Task C: SPT Team Report SPT-ALF-2C (Indirect Fatigue Tests- Data for the FHWA ALF Mixtures)
	08-P	May-00	Task C: SPT Team Report SPT-ALF-2D (Triaxial Strength Tests- Data for the FHWA ALF Mixtures)
	08-Q	May-00	Task C: SPT Team Report SPT-ALF-2F (G* Simple Shear Tests- Data for the FHWA ALF Mixtures)
	08-R	May-00	Task C: SPT Team Report SPT-ALF-2G (Repeated Shear Perm Def Tests- Data for the FHWA ALF Mixtures)
	08-S	May-00	Task C: SPT Team Report SPT-ALF-2H (Repeated Normal Perm Def Tests- Data for the FHWA ALF Mixtures)
	08-T	May-00	Task C: SPT Team Report SPT-ALF-2 I (Triaxial Static Creep Tests-Flow/Compliance- Data for the FHWA ALF Mixtures)
	08-U	May-00	Task C: SPT Team Report SPT-ALF-2(J-K) (E* Dynamic Modulus and Ed Dynamic Pulse Wave Velocity Tests- Data for the FHWA ALF Mixtures)
	08-V	May-00	Task C: SPT Team Report SPT-ALF-2L (E* and Sm Prediction Equation Methodology Results - Data for the FHWA ALF Mixtures)
	08-W	Feb-00	Task C: SPT Team Report SPT-WST-1 (In-Situ Mix Composition and Performance- Data for the WesTrack Mixtures)
	08-X	Jul-00	Task C: SPT Team Report SPT-WST-2A (Indirect Tensile Strength Tests- Data for the WesTrack Mixtures)
	08-Y	Jul-00	Task C: SPT Team Report SPT-WST-2B (Indirect Creep Tests- Data for the WesTrack Mixtures)
	08-Z	Jul-00	Task C: SPT Team Report SPT-WST-2C (Indirect Fatigue Tests- Data for the WesTrack Mixtures)
	08-ZA	Jul-00	Task C: SPT Team Report SPT-WST-2D (Triaxial Strength Tests- Data for the WesTrack Mixtures)
	08-ZB	Jul-00	Task C: SPT Team Report SPT-WST-2F (G* Simple Shear Tests- Data for the WesTrack Mixtures)
	08-ZC	Jul-00	Task C: SPT Team Report SPT-WST-2G (Repeated Shear Perm Def Tests- Data for the WesTrack Mixtures)
	08-ZD	Jul-00	Task C: SPT Team Report SPT-WST-2H (Repeated Normal Perm Def Tests- Data for the WesTrack Mixtures)
	08-ZE	Jul-00	Task C: SPT Team Report SPT-WST-2 I (Triaxial Static Creep Tests-Flow/Compliance- Data for the WesTrack Mixtures)
	08-ZF	Jul-00	Task C: SPT Team Report SPT-WST-2(J-K) (E* Dynamic Modulus and Ed Dynamic Pulse Wave Velocity Tests- Data for the WesTrack Mixtures)
	08-ZG	Jul-00	Task C: SPT Team Report SPT-WST-2L (E* and Sm Prediction Equation Methodology Results - Data for the WesTrack Mixtures)

TABLE 2 (Continued)

Major Area	PDF File No	Report Date	NCHRP 9-19 Report Title
9 - Task F & G Advanced Materials Characterization	09-A	Feb-01	Advanced Material Characterization Studies: Subtask F-3 Exploratory Tests: Anisotropy Study
	09-B	Jul-01	Advanced Material Characterization Studies: Subtask F-6, Evaluation Tests: Flexural Fatigue Tests
	09-C	Dec-01	Advanced Material Characterization Studies: Subtask F-6, Evaluation Tests: Repeated Load (ep/er) Deformation Tests
	09-D	Apr-02	Advanced Material Characterization Studies: Subtask F-6, Evaluation Tests: Random Repeated Load (ep/er) Deformation Tests
	09-E	Apr-02	Advanced Material Characterization Studies: Subtask F-6, Evaluation Tests: Thermal Stress Restrained Specimen Tensile Strength (TSRST)
	09-F	Sep-02	Advanced Material Characterization Studies: Subtask F-6, Evaluation Tests: Thermal Coefficient Tests
	09-G	Dec-03	Advanced Material Characterization Studies: Subtask F-6, Evaluation Tests: Thermal Properties of Asphalt Mixtures
	09-H	Dec-02	Task G Evaluation Tests: Repeated Load Permanent Deformation Tests
10 - Materials / Mix Properties; Construction; Traffic; Performance Results (Field Test Sites Used in Calibration Studies)	10-A	Apr-03	Subtasks C4-C6; Materials and Mix Properties, Construction Information and Performance Data Report, Part 1, MnRoad Test Sections
	10-B	Apr-03	Subtasks C4-C6; Materials and Mix Properties, Construction Information and Performance Data Report, Part 2, NCAT Test Sections
	10-C	Apr-03	Subtasks C4-C6; Materials and Mix Properties, Construction Information and Performance Data Report, Part 3, Indiana Test Sections
	10-D	Apr-03	Subtasks C4-C6; Materials and Mix Properties, Construction Information and Performance Data Report, Part 4, Nevada 1-80 Test Sections
	10-E	Apr-03	Subtasks C4-C6; Materials and Mix Properties, Construction Information and Performance Data Report, Part 5, WesTrack Test Sections
	10-F	Apr-03	Subtasks C4-C6; Materials and Mix Properties, Construction Information and Performance Data Report, Part 6, FHWA-ALF Test Sections
	10-G	Apr-03	Subtasks C4-C6; Materials and Mix Properties, Construction Information and Performance Data Report, Part 7, ADOT 1-10 Test Sections

(*continued on next page*)

TABLE 2 (Continued)

Major Area	PDF File No	Report Date	NCHRP 9-19 Report Title
11 - Miscellaneous Technical Issues Reports	11-A	Jun-98	FHWA DTFH 61-94-R-00045, Task F.3 Project Deliverable: A Review of Advanced Instrumentation and Testing Techniques and Their Potential Application to the Constitutive Modeling of Asphalt Concrete Materials
	11-B	May-99	Technical Team Report: Assessing the Ultrasonic Pulse Velocity Technique for Measuring the Elastic Modulus of Asphalt Concrete
	11-C	Aug-99	Project Report: Laboratory Sample Temperature Equilibrium Program
	11-D	Dec-99	Task C - Proposed Method of Predicting Fracture Parameters for ALF and WesTrack Testing Using Notched Specimens with the Indirect Fatigue Tests
	11-E	Dec-00	Project Deliverable B, Modification and Re-Calibration of the Superpave Thermal Cracking Model
	11-F	Feb-04	A Recommended Methodology for Developing Dynamic Modulus E* Master Curves From Non Linear Optimization
	11-G	Mar-04	Assessment of the Allowable (Threshold) Rut Depths by Layers in Asphalt Pavement Systems
12 - Task F & G Planning and Final Technical Reports	12-A	Sep-99	Subtask F-2: Advanced AC Mixtures Materials Characterization Models Framework and Laboratory Test Plan
	12-B	May-01	NCSU Report; Task F & G: Time - Temperature Superposition Principle for Asphalt Concrete in Damaged States
	12-C	Oct-02	NCSU Report; Task F & G: Advanced Characterization of Asphalt, Concrete Using a Fracture Mechanics Approach: Final Report
	12-D	Jun-04	NCSU Report; Task F & G: Development of Viscoelastic-ViscoPlastic Continuum Damage Model for Asphalt-Aggregate Mixtures: Final Report
	12-E	Jun-04	NCSU Report; Task F & G: Development of Viscoelastic-ViscoPlastic Continuum Damage Model for Asphalt-Aggregate Mixtures: Appendices
	12-F	Feb-06	UMD Report; Task F & G: A Viscoelastic-ViscoPlastic Continuum Damage Constitutive Model for Asphalt-Concrete: Final Report

TABLE 2 (Continued)

Major Area	PDF File No	Report Date	NCHRP 9-19 Report Title
13 - Final Project Reports on SPT Evaluation	13-A	Jan-00	Work Plan for the Field Validation of the Simple Performance Test; Subtasks C.4 and C.5
	13-B	Feb-03	Inter Team Technical Report, Revised Future Plan for Simple Performance Testing
	13-C	Jul-02	Simple Performance Test for Superpave Mix Design, NCHRP Report 465
	13-D	Sep-05	Superpave Support and Performance Models Management: Use of the Dynamic Modulus (E*) Test as a Simple Performance Test for Asphalt Pavement Systems (AC Permanent Deformation Distress): Vol I of IV
	13-E	Sep-05	Superpave Support and Performance Models Management: Use of the Flow Number (Fn) and Flow Time (Ft) Test as a Simple Performance Test for Asphalt Pavement Systems (AC Permanent Deformation Distress): Vol II of IV
	13-F	Apr-05	Superpave Support and Performance Models Management: Database; Dynamic Modulus (E*) Test and Master Curves (AC Mixture Simple Performance Test): Vol III of IV
	13-G	Apr-05	Superpave Support and Performance Models Management: Database; Flow Number (Fn) and Flow Time (Ft) (AC Mixture Simple Performance Test): Vol IV of IV
	13-H	Dec-05	Development of a New Revised Version of The Witczak E* Predictive Models For Hot Mix Asphalt Mixtures
14 - Project Related Thesis / PhD Dissertations	14-A	May-01	Simple Performance Test for Permanent Deformation of Asphalt Mixtures (Kaloush-PhD Dissertation: Arizona State University)
	14-B	May-01	Investigation of the Use of Dynamic Modulus as an Indicator of Hot-Mix Asphalt Performance (T. Pellinen-PhD Dissertation: Arizona State University)
	14-C	May-02	Time-Temperature Superposition for Asphalt Concrete at Large Compressive Strains (N. Gibson-MSCE Thesis: University of Maryland)
	14-D	May-06	A Comprehensive Model for the Compressive Behavior of Asphalt Concrete (N. Gibson- MSCE PhD Dissertation: University of Maryland)
	14-E	May-04	Calibration and Validation of Asphalt Pavement Distress Models for 2002 Design Guide (M.El-Basyouny-PhD Dissertation: Arizona State University)
	14-F	May-02	Characterization of Asphalt Concrete in Tension Using a ViscoElastoPlastic Model (Ghassan Riad Chehab - PhD Dissertation: North Carolina State University)
	14-G	May-03	A Comprehensive Study of Crack Growth in Asphalt Concrete Using Fracture Mechanics (Young Guk Seo - PhD Dissertation: North Carolina State University)

Abbreviations used without definitions in TRB publications:

AASHO	American Association of State Highway Officials
AASHTO	American Association of State Highway and Transportation Officials
APTA	American Public Transportation Association
ASCE	American Society of Civil Engineers
ASME	American Society of Mechanical Engineers
ASTM	American Society for Testing and Materials
ATA	American Trucking Associations
CTAA	Community Transportation Association of America
CTBSSP	Commercial Truck and Bus Safety Synthesis Program
DHS	Department of Homeland Security
FAA	Federal Aviation Administration
FHWA	Federal Highway Administration
FMCSA	Federal Motor Carrier Safety Administration
FRA	Federal Railroad Administration
FTA	Federal Transit Administration
IEEE	Institute of Electrical and Electronics Engineers
ITE	Institute of Transportation Engineers
NCHRP	National Cooperative Highway Research Program
NCTRP	National Cooperative Transit Research and Development Program
NHTSA	National Highway Traffic Safety Administration
NTSB	National Transportation Safety Board
SAE	Society of Automotive Engineers
TCRP	Transit Cooperative Research Program
TRB	Transportation Research Board
TSA	Transportation Security Administration
U.S.DOT	United States Department of Transportation