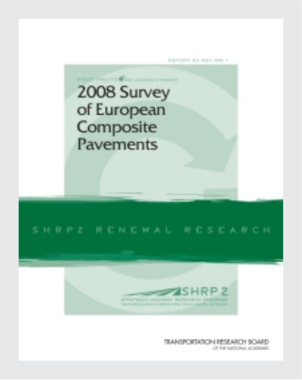


2008 Survey of European Composite Pavements

DETAILS

0 pages | 8.5 x 11 | PAPERBACK
ISBN 978-0-309-43005-0 | DOI 10.17226/22947

AUTHORS

The Second
STRATEGIC HIGHWAY RESEARCH PROGRAM

SHRP 2 REPORT S2-R21-RW-1

FIRST FRUITS Early outcomes of research

2008 Survey of European Composite Pavements

Derek Tompkins and Lev Khazanovich
University of Minnesota

Michael I. Darter
Applied Research Associates, Inc.

TRANSPORTATION RESEARCH BOARD
WASHINGTON, D.C.
2010
www.TRB.org

Subscriber Categories

Highways
Construction
Materials
Pavements

FIRST FRUITS *Early outcomes of research*

First Fruits are products that emerge from the early stages of SHRP 2 research projects. They may include case studies, annotated bibliographies, survey results, compilations of practices and technologies, and other information developed in support of the larger research objectives.

The Second Strategic Highway Research Program

America's highway system is critical to meeting the mobility and economic needs of local communities, regions, and the nation. Developments in research and technology—such as advanced materials, communications technology, new data collection technologies, and human factors science—offer a new opportunity to improve the safety and reliability of this important national resource. Breakthrough resolution of significant transportation problems, however, requires concentrated resources over a short time frame. Reflecting this need, the second Strategic Highway Research Program (SHRP 2) has an intense, large-scale focus, integrates multiple fields of research and technology, and is fundamentally different from the broad, mission-oriented, discipline-based research programs that have been the mainstay of the highway research industry for half a century.

The need for SHRP 2 was identified in *TRB Special Report 260: Strategic Highway Research: Saving Lives, Reducing Congestion, Improving Quality of Life,* published in 2001 and based on a study sponsored by Congress through the Transportation Equity Act for the 21st Century (TEA-21). SHRP 2, modeled after the first Strategic Highway Research Program, is a focused, time-constrained, management-driven program designed to complement existing highway research programs. SHRP 2 focuses on applied research in four focus areas: Safety, to prevent or reduce the severity of highway crashes by understanding driver behavior; Renewal, to address the aging infrastructure through rapid design and construction methods that cause minimal disruptions and produce lasting facilities; Reliability, to reduce congestion through incident reduction, management, response, and mitigation; and Capacity, to integrate mobility, economic, environmental, and community needs in the planning and designing of new transportation capacity.

SHRP 2 was authorized in August 2005 as part of the Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users (SAFETEA-LU). The program is managed by the Transportation Research Board (TRB) on behalf of the National Research Council (NRC). SHRP 2 is conducted under a memorandum of understanding among the American Association of State Highway and Transportation Officials (AASHTO), the Federal Highway Administration (FHWA), and the National Academy of Sciences, parent organization of TRB and NRC. The program provides for competitive, merit-based selection of research contractors; independent research project oversight; and dissemination of research results.

SHRP 2 Report S2-R21-RW-1

ISBN: 978-0-309-12887-2
Library of Congress Control Number: 2010925776

Copyright Information

Authors herein are responsible for the authenticity of their materials and for obtaining written permissions from publishers or persons who own the copyright to any previously published or copyrighted material used herein.

The second Strategic Highway Research Program grants permission to reproduce material in this publication for classroom and not-for-profit purposes. Permission is given with the understanding that none of the material will be used to imply TRB, AASHTO, or FHWA endorsement of a particular product, method, or practice. It is expected that those reproducing material in this document for educational and not-for-profit purposes will give appropriate acknowledgment of the source of any reprinted or reproduced material. For other uses of the material, request permission from SHRP 2.

Note: SHRP 2 report numbers convey the program, focus area, project number, and publication format. Report numbers ending in "w" are published as Web Documents only.

Notice

The project that is the subject of this report was a part of the second Strategic Highway Research Program, conducted by the Transportation Research Board with the approval of the Governing Board of the National Research Council.

The members of the technical committee selected to monitor this project and to review this report were chosen for their special competencies and with regard for appropriate balance. The report was reviewed by the technical committee and accepted for publication according to procedures established and overseen by the Transportation Research Board and approved by the Governing Board of the National Research Council.

The opinions and conclusions expressed or implied in this report are those of the researchers who performed the research and are not necessarily those of the Transportation Research Board, the National Research Council, or the program sponsors.

The Transportation Research Board of the National Academies, the National Research Council, and the sponsors of the second Strategic Highway Research Program do not endorse products or manufacturers. Trade or manufacturers' names appear herein solely because they are considered essential to the object of the report.

SHRP 2 Reports

Available by subscription and through the TRB online bookstore:
www.TRB.org/bookstore

Contact the TRB Business Office:
202-334-3213

More information about SHRP 2:
www.TRB.org/SHRP2

THE NATIONAL ACADEMIES

Advisers to the Nation on Science, Engineering, and Medicine

The **National Academy of Sciences** is a private, nonprofit, self-perpetuating society of distinguished scholars engaged in scientific and engineering research, dedicated to the furtherance of science and technology and to their use for the general welfare. On the authority of the charter granted to it by the Congress in 1863, the Academy has a mandate that requires it to advise the federal government on scientific and technical matters. Dr. Ralph J. Cicerone is president of the National Academy of Sciences.

The **National Academy of Engineering** was established in 1964, under the charter of the National Academy of Sciences, as a parallel organization of outstanding engineers. It is autonomous in its administration and in the selection of its members, sharing with the National Academy of Sciences the responsibility for advising the federal government. The National Academy of Engineering also sponsors engineering programs aimed at meeting national needs, encourages education and research, and recognizes the superior achievements of engineers. Dr. Charles M. Vest is president of the National Academy of Engineering.

The **Institute of Medicine** was established in 1970 by the National Academy of Sciences to secure the services of eminent members of appropriate professions in the examination of policy matters pertaining to the health of the public. The Institute acts under the responsibility given to the National Academy of Sciences by its congressional charter to be an adviser to the federal government and, on its own initiative, to identify issues of medical care, research, and education. Dr. Harvey V. Fineberg is president of the Institute of Medicine.

The **National Research Council** was organized by the National Academy of Sciences in 1916 to associate the broad community of science and technology with the Academy's purposes of furthering knowledge and advising the federal government. Functioning in accordance with general policies determined by the Academy, the Council has become the principal operating agency of both the National Academy of Sciences and the National Academy of Engineering in providing services to the government, the public, and the scientific and engineering communities. The Council is administered jointly by both the Academies and the Institute of Medicine. Dr. Ralph J. Cicerone and Dr. Charles M. Vest are chair and vice chair, respectively, of the National Research Council.

The **Transportation Research Board** is one of six major divisions of the National Research Council. The mission of the Transportation Research Board is to provide leadership in transportation innovation and progress through research and information exchange, conducted within a setting that is objective, interdisciplinary, and multimodal. The Board's varied activities annually engage about 7,000 engineers, scientists, and other transportation researchers and practitioners from the public and private sectors and academia, all of whom contribute their expertise in the public interest. The program is supported by state transportation departments, federal agencies including the component administrations of the U.S. Department of Transportation, and other organizations and individuals interested in the development of transportation. **www.TRB.org**

www.national-academies.org

SHRP 2 STAFF

ACKNOWLEDGMENTS

This work was sponsored by the Federal Highway Administration in cooperation with the American Association of State Highway and Transportation Officials. It was conducted in the second Strategic Highway Research Program (SHRP 2), which is administered by the Transportation Research Board of the National Academies. The project was managed by James W. Bryant, Jr., Senior Program Officer for SHRP 2 Renewal.

The R21 delegation was hosted in the Netherlands, Germany, and Austria by colleagues from the international pavement research community. Adrian van Leest of CROW Technology Platform in Ede, Netherlands, hosted the R21 delegation on May 6–10, 2008, to review several sections of PCC/PCC, the 10-year A12 motorway with porous AC/CRCP, and, along with George Jurriaans of ECCRA, a large porous AC/CRCP construction project on the motorway A73. Walter Fleischer and several staff of Heilit+Woerner GmbH in Munich, Germany, hosted the delegation on May 11–14, 2008, to review German research, German specifications, in-field PCC/PCC sections along the motorway A93, and construction techniques for PCC/PCC pavements on 21 km of the motorway A6. Hermann Sommer, formerly of VOZfi (Association of the Austrian Cement Industry Research Institute) in Vienna, Austria, and Stefan Krispel of VOZfi hosted the R21 delegates on May 15–16, 2008, to review PCC/PCC research and techniques and to visit PCC/PCC pavement sections along more than 100 km of the A1 motorway. Great appreciation is expressed to each of these individuals for hosting the R21 team in their countries. This required significant time and resources to plan the visits and to accompany the team, as well as to assist with the collection of data for the projects included in the R21 database. Without their assistance, this trip and all of the extremely valuable information gained from it would not have been possible.

FOREWORD

James W. Bryant, Jr., PhD, PE, *SHRP 2 Senior Program Officer*

This report documents a survey of in-service composite pavement sites in the Netherlands, Germany, and Austria that was conducted in May 2008 to assess the design, construction, and performance of composite pavement systems. These pavement systems were deliberately designed and constructed as composite pavements and had been in service under heavy vehicle loading for 10 to 20 years. The survey focused on the field performance of two types of composite pavements: asphalt over concrete and two-lift, wet-on-wet concrete. The report also discusses other issues that should be considered in the design and construction of new composite pavement systems. The information gathered for this report was used in the design and development of a plan to test composite pavements under SHRP 2 Renewal Project R21: Composite Pavement Systems.

The majority of composite pavements that exist in the United States came about as a result of normal pavement maintenance and rehabilitation. This is particularly the case with asphalt overlays on portland cement concrete (PCC) pavements. The use of a high-quality asphalt surface layer over newly placed PCC pavement is uncommon in most of the United States. Furthermore, there is limited experience in the United States in designing and constructing two-lift, wet-on-wet concrete composite pavements. Two-lift concrete composite pavements use a relatively thin, high-quality concrete surface atop a thicker, less-expensive concrete layer. The lower concrete layer may include high proportions of recycled and other materials that are not desirable for use in the surface layer. Although the two-lift, wet-on-wet technique is rare in the United States, it has been used in pavement construction in Austria and elsewhere.

Many transportation agencies have performance data and models for conventional pavement systems (flexible and rigid), but the behavior of new composite pavement systems is not well understood. Models for the performance of these hybrid systems are needed for design, performance prediction, and life-cycle cost analysis. Guidance on specifications, construction techniques, and quality-management procedures are also needed by the transportation community.

Under SHRP 2 Renewal Project R21, a research team led by Mike Darter of Applied Research Associates visited the Netherlands, Germany, and Austria to document the performance and construction techniques of in-service composite pavements. The review found that both types of composite pavements performed well under heavy traffic loading during the 10 to 20 years that they had been in service. Observations from this report were used to develop the field design, construction, testing, and evaluation plan for test pavement sections that will be constructed in 2010 at the MnROAD pavement test track in Minnesota.

This report is a SHRP 2 First Fruits publication. It was developed in an early stage of the R21 project to support the project's larger research objectives: determining the behavior of composite pavement systems and identifying critical material and performance parameters; developing and validating mechanistic–empirical performance models and design procedures consistent with the *Mechanistic-Empirical Pavement Design Guide;* and recommending model specifications, construction guidelines, and quality-management procedures.

CONTENTS

Executive Summary

Highway authorities are vitally interested in developing a consistent, systematic approach to highway renewal that makes it rapid and minimally disruptive and produces long-lasting facilities. Composite pavement systems have been identified as having potential to achieve these standards of highway renewal. Two systems of particular interest involve new portland cement concrete (PCC) pavement surfaced soon after placement and curing either with a new, relatively thin, high-quality asphalt concrete (AC) layer or with a relatively thin, high-quality PCC layer. Although these two systems show great promise for providing durable, rapidly renewable, and long-lasting pavements that require minimal maintenance, their structural performance and functional performance are not well understood or documented in the United States.

Some states and urban areas have constructed new AC over PCC with success. There have been virtually no two-layer PCC pavements constructed in the United States in many years. However, recent high-visibility federal concrete pavement initiatives have mentioned composite concrete pavements and have led to the development of the experimental two-layer PCC sections completed in Kansas on I-70 near Abilene in September 2008. These sections are the most recent U.S. research attempts to better understand two-layer PCC and its performance, economy, manner of construction, and ability to accommodate innovative designs and materials. Given the limited information provided by these new American studies into two-layer PCC and AC-over-PCC, members of the second Strategic Highway Research Program (SHRP 2) research team for Renewal Project R21 (Composite Pavement Systems) visited with pavement engineers and assessed field sections in the Netherlands, Germany, and Austria in May 2008. These three countries use composite pavements on a much larger scale than the United States.

AC/PCC composite pavement was studied in both the Netherlands and Germany. The Netherlands has built porous AC over recently placed continuously reinforced concrete pavement (CRCP) on numerous major projects during the past 10 years. These projects are all performing well with low noise levels and no reflection cracking from the CRCP, despite their relatively thin AC layer of approximately 2 to 3 inches. Germany has built stone matrix asphalt (SMA) surfaces on jointed plain concrete pavements (JPCP) and most recently over CRCP. One SMA/JPCP section was 15 years old, under heavy traffic, with sawed and sealed joints that had performed very well.

Two-layer PCC paving (wet-on-wet)—constructing two layers with different properties for structural, economic, environmental, or safety reasons—has been much more common in Europe than in the United States. Austria in particular has been active in regular two-layer PCC paving for concrete pavements; the standard concrete pavement in Austria is constructed according to the two-layer PCC specification. Two-layer PCC paving has been used in countries such as Switzerland, Belgium, the Netherlands, France, and Germany with regularity since the 1980s and even much earlier in some. Two-layer PCC is becoming more common as the techniques are refined further. European research related to two-layer PCC pavements includes construction techniques and the use of recycled materials, such as recycled concrete aggregates in the lower layer. One particular strategy in texturing that is often paired with two-layer PCC in Europe is exposed aggregate concrete (EAC) texturing, which is a brushed concrete surface that exposes the aggregates at the surface. This creates a unique texture that is an improvement over textures produced by conventional texturing methods in terms of durability, safety, and noise reduction.

This report describes projects visited in the Netherlands, Germany, and Austria. In reviewing these case studies and discussing the composite pavements with the host engineers and practitioners, the research team identified several benefits and potential challenges in implementing European techniques in the experimental sections to be constructed under the SHRP 2 Renewal Project R21.

The first major benefit of the two-layer method is that it can reduce costs in circumstances where high-quality aggregates are costly and in short supply and where using low-quality materials throughout a single layer is not an option. The benefit is achieved through utilizing low-cost, more plentiful materials—including reclaimed concrete asphalt and other secondary materials—in the lower PCC layer and reserving materials of higher cost, scarcity, and quality for the upper layer. The lower-cost materials, which have no effect on the structural integrity of the roadway, make composite pavement an attractive option when aggregates are difficult to obtain.

Furthermore, as sustainable practices such as recycling and reduced maintenance become more of a concern in the United States, American pavement engineers will need to look to technologies such as composite pavements to develop more efficient and economical recycling techniques. Austria in particular has a great deal of experience with recycling concrete pavements. In the late 1980s, Austria undertook the long process of recycling PCC pavements along the A1 motorway that were more than 30 years old into new two-layer PCC pavements (some of these are detailed in the case studies). This experience has led Austrian researchers to claim that the recycling concept is “an important innovation that is both economically and environmentally advantageous.”

Another important performance benefit of composite pavements is the ability to use better materials and more specialized techniques in the pavement-wearing course. These efforts—which can include the use of durable, high-quality aggregates, porous grading, or EAC texturing—can lead to reduced pavement noise, improved friction numbers and skid resistance, and smoother pavements. This particular benefit of composite pavements is one that the road user will immediately appreciate in a smoother, quieter, and safer ride. Rapid renewal of the shorter-lived porous AC-over-PCC composite is one of its advantages, whereas the EAC-over-PCC composite has the advantage of more than double or triple the service life.

The report also identifies potential challenges of composite pavements, particularly in the construction of PCC-over-PCC. Two-layer construction requires a consistent, quality effort. Construction techniques were one of two main areas emphasized in Germany and Austria (the other being the quality of the aggregate in the upper layer). The I-75 experiment near Detroit and a recent survey of two-layer PCC pavements have cited construction techniques as a major obstacle to the adoption of two-layer PCC pavements in the United States. To start, the use of multiple pavers in Europe for PCC-over-PCC is a technique that will be difficult to replicate in the United States. PCC-over-PCC used to be placed at once using a single slipform paver; however, countries such as Austria and Germany currently use multiple paving machines and are more comfortable with the “two-paver” system for two-layer PCC. The report discusses the use of multiple pavers and contrasts this with the single-paver option. Another challenge in PCC-over-PCC is the need for multiple batching plants, a drawback that has been previously cited by investigations into importing two-layer PCC into the United States. The report proposes means of overcoming this obstacle through proper planning and expanded batch plant capabilities. Another challenge will be the introduction of local techniques, such as exposed aggregate brushing, and local materials and mixes that are not commonly used in the United States. Overcoming these challenges will require careful planning, an awareness of materials used in the United States, and laboratory work in support of the full-scale experimental sections to account for these differences.

In short, Dutch, German, and Austrian researchers claim that composite pavements, such as two-layer PCC pavement, provide a structural performance similar to equivalently thick single-layer pavement at the same price, with the additional benefits of a road surface with higher-quality and longer-lasting friction and noise reduction resulting from the high-quality top layer. Furthermore, composite pavements allow for the optimization of costs and materials throughout the pavement cross-section:

1. High-quality materials can be used in lesser quantities in the upper layer, where they will be most beneficial to the system; and
2. Cheaper, lower-quality materials can be used in greater quantities in the lower layer, where they will contribute structurally without detracting from the quality and performance of the overall pavement.

Although there are several obstacles to the adoption of composite paving in the United States, it is clear from the Dutch, German, and Austrian experiences that overcoming these obstacles will result in quality, durable, and sustainable composite pavements. This European survey has provided ample information to help develop experimental sections for construction under SHRP 2 Renewal Project R21 at the MnROAD test site.

CHAPTER 1

Introduction

Congress created the second Strategic Highway Research Program (SHRP 2) to address the challenges of moving people and goods efficiently and safely on the nation's highways. One focus of SHRP 2 is the rapid renewal of highways, which led to the development of SHRP 2 Renewal Project R21: Composite Pavement Systems. The project objectives include developing construction specifications, guidelines, and procedures; design guidelines; and training materials for composite pavement systems. One early task in the research is to develop a database of full-scale applications of composite pavement systems, including data on performance to date, material properties, construction details, and design considerations. In later project phases, test sections may be constructed for validation purposes.

Two strategies that show great promise for providing strong, durable, safe, smooth, and quiet pavements needing minimal maintenance are

1. Surfacing of new portland cement concrete (PCC) layers with high-quality asphalt concrete (AC) layers; and
2. Placement of a two-layer wet-on-wet PCC pavement with a relatively thin, high-quality PCC surface atop a thicker, less expensive PCC layer.

However, neither the structural performance nor the functional performance of these two types of composite pavements is well understood or documented. In addition, specifications and construction techniques for these composite pavements, especially PCC-over-PCC, have not been studied closely in the United States, thus hindering their adoption.

Members of the R21 research team previously had observed both of these composite pavement systems and had discussed them with engineers in several countries, because these pavements have been constructed successfully in Europe for many years. On the basis of this knowledge, the research team proposed a brief survey of these two composite pavements in three European countries; this was accomplished in May 2008. The performance and construction techniques were assessed, and several sections were surveyed to include in the R21 database. The delegation consisted of R21 project investigator Dr. Michael I. Darter of Applied Research Associates, Inc. (ARA); project co-investigator Prof. Lev Khazanovich of the University of Minnesota; and Mr. Derek Tompkins, graduate student at the University of Minnesota.

The R21 delegation was hosted in the Netherlands, Germany, and Austria by colleagues from the international pavement research community:

- Mr. Adrian van Leest of CROW Technology Platform in Ede, Netherlands, first hosted the R21 delegation on May 6–10, 2008, to review several sections of PCC/PCC and, along with Mr. George Jurriaans of ECCRA, a large AC/continuously reinforced concrete pavement (CRCP) construction project on the A73 motorway.
- R21 project consultant Dr. Walter Fleischer of Heilit+ Woerner GmbH in Munich, Germany, hosted the delegation on May 11–14, 2008, to review German research, German specifications, in-field PCC/PCC sections along the A93 motorway, and construction techniques for PCC/PCC pavements on 21 km of the A6 motorway.
- Dr. Hermann Sommer, formerly of VOZfi (Association of the Austrian Cement Industry Research Institute) in Vienna, Austria, and Stefan Krispel of VOZfi hosted the R21 delegates on May 15–16, 2008, to review PCC/PCC research and techniques and to visit PCC/PCC pavement sections along more than 100 km of the A1 motorway.

Great appreciation is expressed to all of these individuals for hosting the R21 team in their countries. It required significant time and resources to plan and accompany the team, as well as to assist with the collection of data for the projects included in the R21 database. Without their assistance, this trip and the valuable information gained from it would not have been possible.

This report documents information gained from a brief survey of composite pavement systems in three European countries. Chapter 2 describes each of the projects examined during the field survey. Chapter 3 documents the two-layer exposed aggregate concrete (EAC) composite pavements, and Chapter 4 documents the two-layer thin asphalt surfacing over concrete composite pavements. Chapter 5 sets out critical observations drawn from the survey on both types of pavements for construction of test sections under SHRP 2 Renewal Project R21.

CHAPTER 2

Summary of Projects Visited

This chapter provides brief descriptions about the projects visited. Chapters 3 and 4 provide more detail about the materials, construction, pavement design, and performance of the portland cement concrete (PCC)/PCC and asphalt concrete (AC)/PCC sections, respectively.

N279, Near Veghel, Netherlands

Numerous exposed aggregate concrete composite sections were built on 17 km of the N279 located in southern Netherlands in 2000, as shown in Figure 2.1. The Netherlands has a long history of building exposed aggregate concrete (EAC) surfaces. These are subjected to an average of 25,000 vehicles per day, 30% of which are commercial trucks. The sections originally were asphalt but were replaced with two-layer EAC over jointed plain concrete pavement (JPCP) to ensure that the pavement would have improved noise levels and require less maintenance over its lifespan, thereby reducing traffic congestion resulting from maintenance. Measurements in the Netherlands have shown that the EAC noise level is about 2 dB(A) less than dense-graded, hot mix asphalt.

A6, Near Amberg, Germany

The A6 motorway in Germany, at the time of the R21 team's visit, was in the process of construction that would connect the two halves of A6, thereby allowing the roadway to run uninterrupted across Germany. The A6 construction project involved 21 km of two traffic lanes in each direction, as shown in Figure 2.2. The project was entirely EAC/PCC with exposed aggregate surfacing (or *waschbeton,* as it is known in German). Work began on the project in March 2004, and it was completed in September 2008. According to 2005 estimates by the German Federal Highway Research Institute (BASt), the A6 motorway receives as many as 70,000 to 90,000 vehicles per day (*1*). Although the eastern stretch of A6 currently receives lower traffic volumes (20,000 to 30,000 vehicles per day), the project contractor designed the pavement with the higher traffic volumes of other stretches of A6 in mind.

A93, Between Brannenburg and Kiefersfelden, Germany

The A93 motorway in Germany, which connects Munich to Innsbruck, is shown in Figure 2.3. Several full-scale test sections in various texturing methods for PCC pavements exist along this roadway. A93 is a main connector to Italy and, as such, receives a great deal of commercial truck traffic. A 2005 estimate by BASt states that the A93 motorway in this region receives 50,000 to 70,000 vehicles per day (*1*). The sections examined along A93 were spaced at intervals between Brannenburg and Kiefersfelden. These sections originally were constructed in 1995 and 1996 as two-layer pavements with a variety of longitudinal burlap drag, tining, and EAC. One section was diamond ground after a few years. Another section received a stone matrix asphalt (SMA) surfacing just after placement of the concrete. Some of the pavement was recycled into new two-layer EAC pavements.

A99, Near Ottobrunn, Germany

The construction of an off-ramp onto the A99 motorway near Ottobrunn, shown in Figure 2.4, includes the whitetopping of existing asphalt pavement. A 2005 estimate by BASt states that the A99 motorway near Ottobrunn receives more than 90,000 vehicles per day (*1*). Though whitetopping is not relevant to R21, the project was notable for three reasons: it is the first whitetopping project in Germany, it features fiber-reinforced panels, and the panel texture is

Courtesy of A. van Leest of CROW, Netherlands.

Figure 2.1. Location of N279 test sections reviewed by the R21 delegation.

EAC. Later sections will detail the rare combination of fiber reinforcement and EAC.

A1, Near Eugendorf, Austria

The A1 motorway (known as the *Westautobahn* in Austria) is an important roadway that connects Salzburg and Vienna, as shown in Figure 2.5. A1 is 292 km long and is notable because it was the first motorway to be constructed in Austria, the final sections having been completed in the 1970s. The full length of A1 was originally constructed of PCC pavements of varying designs.

Over the years, sections of A1 have been rehabilitated in several ways. One of these rehabilitated sections is a two-layer EAC pavement reconstructed in 1993 near Eugendorf. This section, shown in Figure 2.6, receives average daily traffic of 56,000 vehicles (12% trucks).

A1, Near Regau, Austria

The two-layer concrete pavement section along A1 near Regau, shown in Figure 2.7, was originally constructed between 1963 and 1966 without an EAC texture. These sections, more than 40 years old, are currently slated for

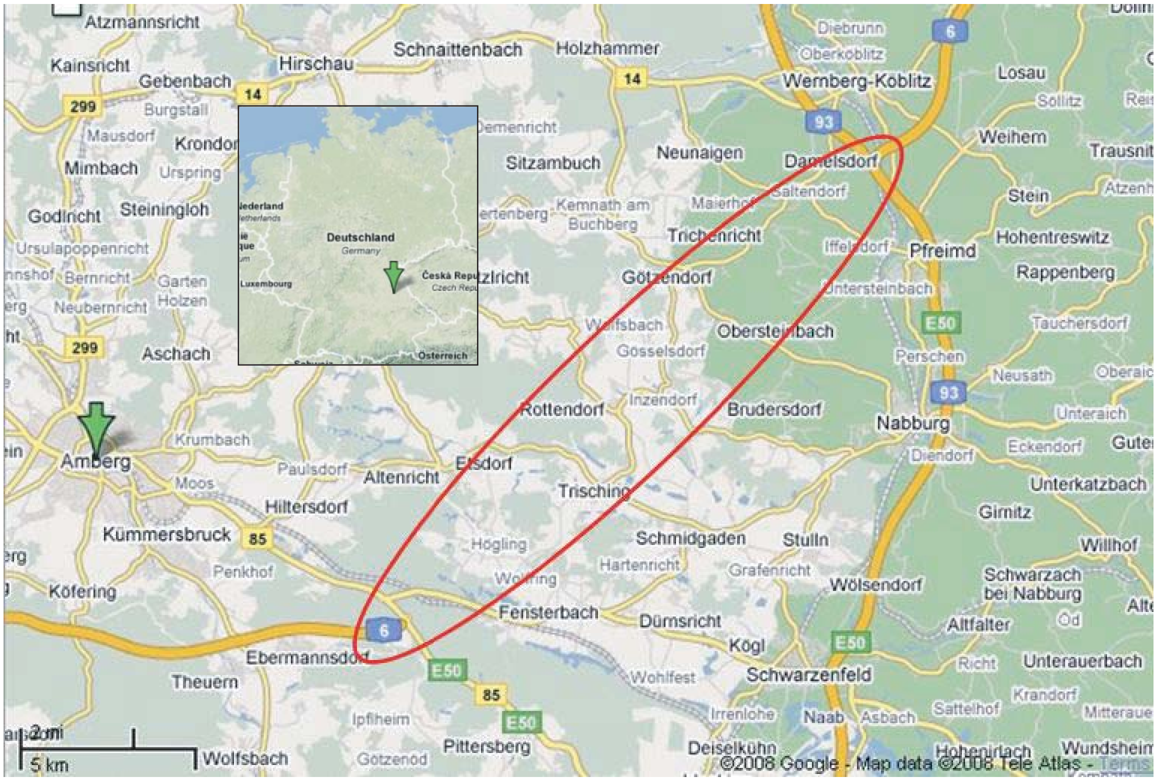


Figure 2.2. Location of A6 construction project near Amberg, Germany.

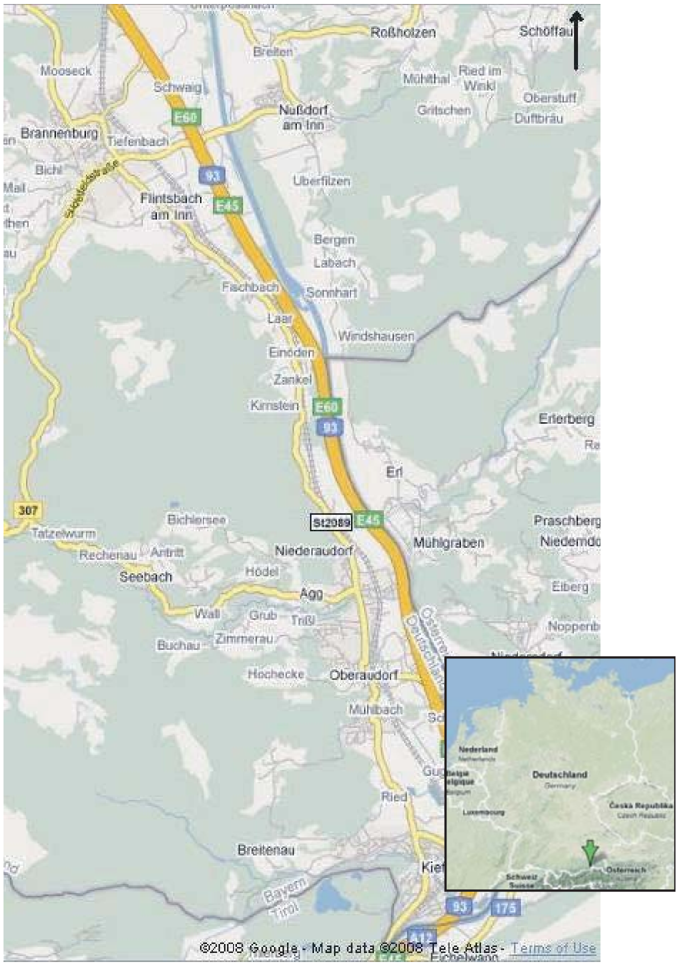


Figure 2.3. The A93 motorway near Brannenburg and Kiefersfelden, Germany.

reconstruction and additional lanes. This section receives average daily traffic of 56,000 vehicles (12% trucks).

A1, Near Vorchdorf, Austria

The two-layer concrete pavement section shown in Figure 2.8—along A1, near a toll station at Vorchdorf—was reconstructed in 1999. The section has an EAC texture and receives average daily traffic of 56,000 vehicles (12% trucks).

A1, Near Traun, Austria

The two-layer concrete pavement section along A1 near the intersection of A1 and A25 near Traun, shown in Figure 2.9, was reconstructed in 1994. The section has an EAC texture. The section of A1 immediately before the merger with A25 receives average daily traffic of about 55,000 vehicles per day (truck traffic not indicated). The section of A1 immediately after the merger with A25 receives about 100,000 vehicles per day.

A12, Near Utrecht, Netherlands

This section is located west of Utrecht on the A12, between kilometers 64.36 and 67.66 (this is just before exit 19), as shown in Figure 2.10. The section consists of three lanes in the southbound direction and inner and outer shoulders.

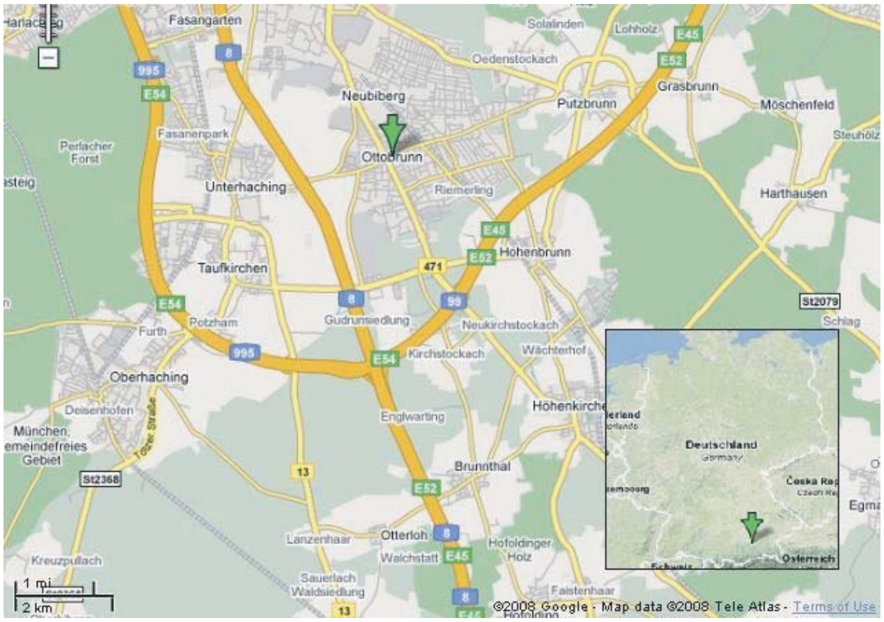


Figure 2.4. The A99 motorway near Ottobrunn, Germany.

© 2008 Google. Map data © 2008 Tele Atlas.

*Figure 2.5. The 292-km A1 motorway (*Westautobahn*) in Austria.*

© 2008 Google. Map data © 2008 Tele Atlas.

Figure 2.6. The A1 motorway near Eugendorf, Austria.

Figure 2.7. The A1 motorway near Regau, Austria.

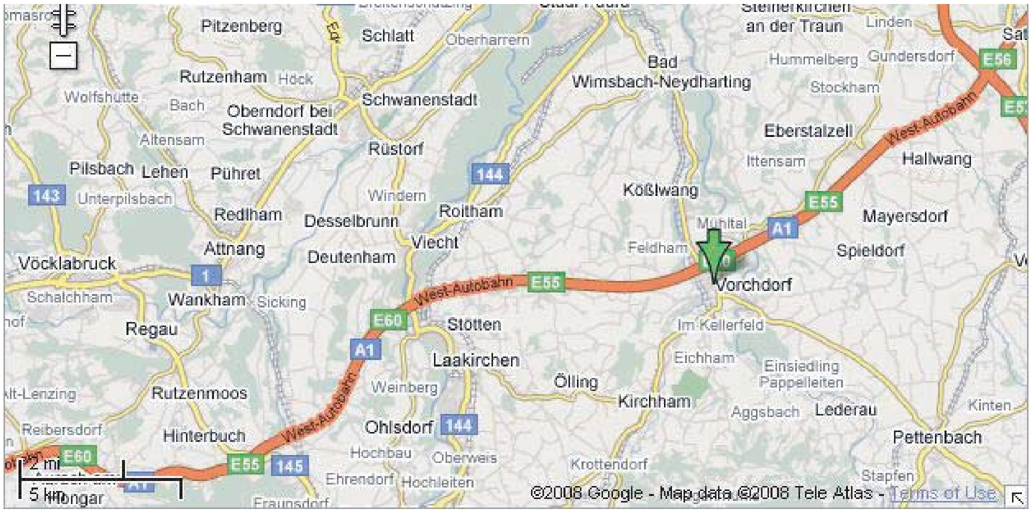
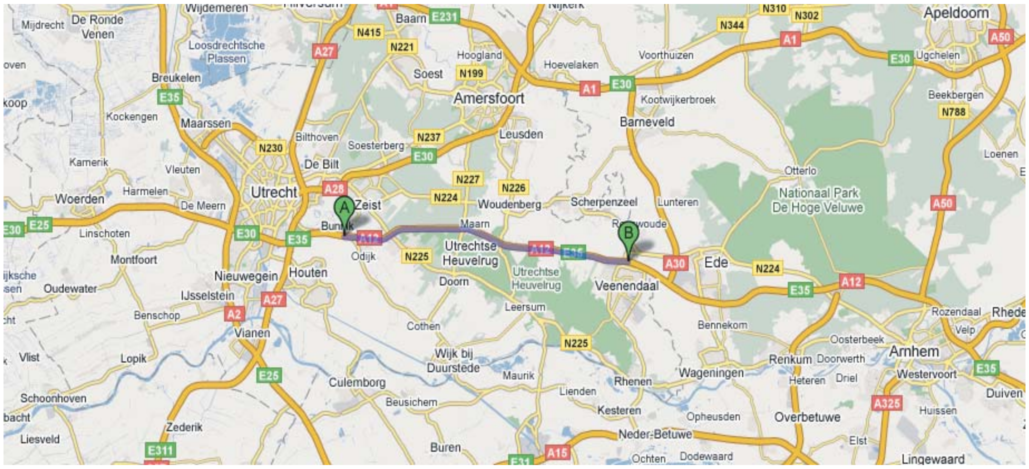


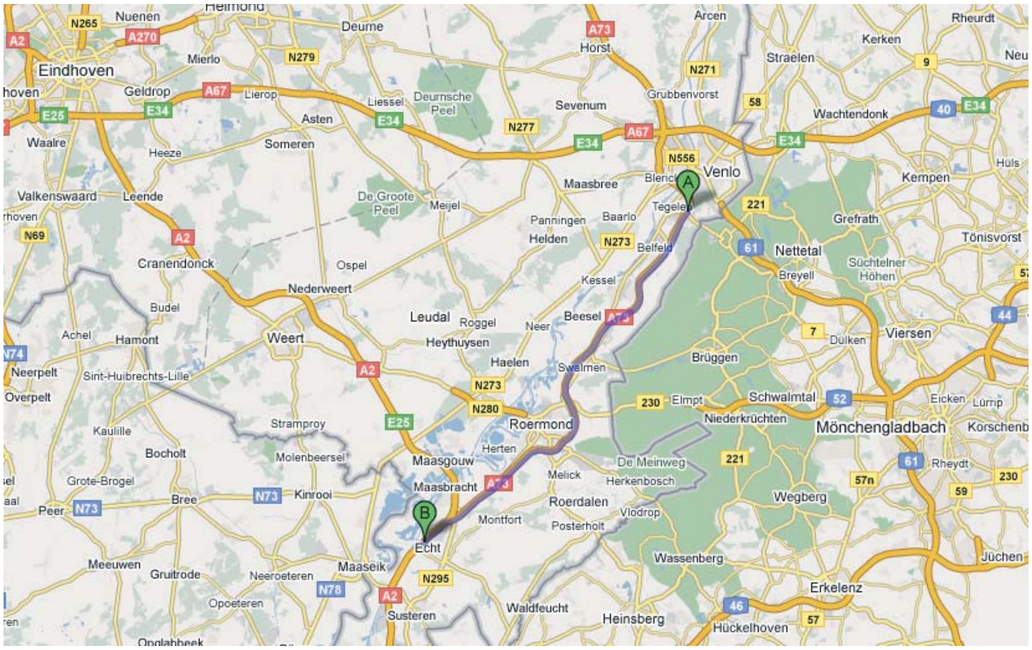
Figure 2.8. The A1 motorway near Vorchdorf, Austria.

Figure 2.9. The A1 motorway near Traun, Austria.



© 2008 Google. Map data © 2008 Tele Atlas.

Figure 2.10. The A12 motorway between Arnhem and Utrecht, Netherlands.



© 2008 Google. Map data © 2008 Tele Atlas.

Figure 2.11. The A73 motorway in the Province of Limburg, near Venlo in southern Netherlands, built in 2007–2008.

This project is a typical heavily trafficked freeway with controlled access that carries a large volume of auto and truck traffic between Arnhem and Utrecht. The porous AC/continuously reinforced concrete pavement (CRCP) was constructed in 1998.

A73, Province of Limburg, Southern Netherlands

The A73 is a 42-km, four-lane, divided freeway with inner and outer shoulders. The project is located on the A73 freeway in south Netherlands in the Province of Limburg to connect the city of Venlo, via Roermond, to the existing A2 highway near the community of Echt-Susteren, as shown in Figure 2.11. This roadway is a heavily trafficked freeway with controlled access that carries a large volume of auto and truck traffic.

The section includes two layers of porous asphalt surface over CRCP and represents the latest thinking for low noise and other excellent surface characteristics. This type of project has been built in the Netherlands during the past 10 years and has provided excellent performance. The project was nearing completion at the time of visit in May 2008 and was open to traffic.

Reference

1. *Heavy Traffic on Federal Highways and Federal Roads: Results of Road Survey 2005* (*Verkehrsstärken auf Bundesautobahnen und Bundesstrassen: Ergebnisse der Strassenverkehrszahlung 2005*). Bundesanstalt für Straßenwesen (BASt), Bergisch Gladbach, Germany, 2007/2008.

CHAPTER 3

Two-Layer Concrete Composite Pavement System

Two-Layer Exposed Aggregate Concrete

All two-layer concrete pavements observed during the trip included a top surface of exposed aggregate concrete (EAC). This surfacing has been used on concrete pavements since first employed by Belgian engineers in the 1970s (*1*). Gradually, this surface has become more popular among European countries. The Netherlands has used EAC since the early 1990s as a low-noise, high-friction, long-term surfacing on its jointed plain concrete pavements (JPCP). Germany built experimental sections in the 1990s and has been specifying exposed aggregate texture in its concrete pavements since 2006. Austria has used and extensively developed EAC since 1990 (*2*). Various countries, including those mentioned, have investigated the properties of EAC on full-scale test sections constructed from the late 1980s onward (*3–5*).

EAC typically is employed to provide texture and surfacing to reduce noise and increase friction. EAC has become the concrete surface standard of choice in several European countries. Figure 3.1 shows an example of the surface texture in EAC.

In countries that have adopted or are in the process of adopting EAC on a large scale, the EAC texture has replaced other, older textures that are very familiar to American pavement engineers. One of the textures replaced by EAC is the longitudinal burlap (or jute) drag. Burlap texturing was the standard in Germany for more than 15 years, and during that time German pavement engineers observed the durability of this texture. The generally held opinion of burlap drag in both Germany and Austria is that it provides excellent noise reduction and friction in the first 5 years after construction (*2, 6, 7*); however, after this initial period, if the traffic volume is sufficiently high (Austrian engineers estimate this to be approximately 25,000 vehicles per day), the texture is eroded by traffic and the pavement loses some of its desired noise and friction qualities. Figure 3.2 shows an example of polishing in a 12-year-old longitudinal burlap drag encountered by the R21 delegation on the A93 motorway near Kiefersfelden, Germany.

Because the longitudinal burlap (jute) drag is not durable under long-term traffic, German pavement engineers no longer employ it in PCC pavements and are in the process of making EAC as the top layer for a two-layer JPCP the new standard for concrete pavements.

The main justification for using EAC is that it makes for more durable, safer, and quieter pavements. While the noise-reduction capability of EAC has been only of recent interest to American pavement engineers (*8*), it has been the subject of several studies in Europe. Austrian studies found that EAC reduced pavement noise by 5 dB(A) over conventional concrete surfacing (*9*). Other studies have noted that the EAC texture does not lose its noise-reduction qualities as quickly as other popular surfaces do, including porous asphalt, dense-graded asphalt, and stone matrix asphalt (SMA) (*10, 11*).

In addition to its noise-reduction properties, the texture of EAC is an effective method for increasing the friction of a concrete surface. Studies have shown the durability and friction of EAC surfaces to be superior to longitudinal finishes, giving average values of 0.50 at 80 km/h and 0.60 at 60 km/h versus the required 0.30 and 0.38 using the Stuttgart device with blocked, PIARC (Permanent International Association of Road Congresses—World Road Association)-type wheel (*2, 9*). The friction numbers for EAC pavements have been shown to suffer very little reduction after 5 and 7 years (*10*). In addition, the R21 delegation's Austrian hosts noted on many occasions that the application of studded tires on EAC surfaces "renews" and can sometimes improve the surface in terms of friction (though the studded tires do not help the surface in its noise-reduction capabilities).

The noise-reduction and friction properties of the EAC texture result in part from the aggregates that are in the mix used for the layer that receives the EAC texturing. Recent research and years of engineering experience relayed to the

Figure 3.1. An example of exposed aggregate texture (with maximum aggregate size of 8 mm) of a two-layer PCC pavement taken along the A1 motorway near Eugendorf, Austria.

R21 delegation suggest that the most effective use of EAC is with a mix design that features a relatively small maximum aggregate size (at most 8 mm) with high-quality, durable, cubical aggregates that resist polishing (*2, 4, 7*). A later section of this report discusses the importance of aggregates in more detail.

Although the EAC surface can be accomplished on a single-layer PCC pavement, most typically it is found in two-lift PCC/PCC pavements, wherein the lower lift contains a larger, lower-cost aggregate and the upper lift contains a smaller aggregate EAC that is very resistant to polishing. The EAC surface is obtained as shown in Figure 3.3: the finished pavement is first sprayed with a curing/retarding material, then the surface mortar is removed using a rotating wire brush to obtain the proper texture (usually two passes are required), and the finished, textured pavement is sprayed with a curing compound.

Figure 3.2. Loss of texture, especially noticeable in wheelpaths, in longitudinal burlap drag textured sections along A93 motorway (km 1.490–1.910) near Kiefersfelden, Germany.

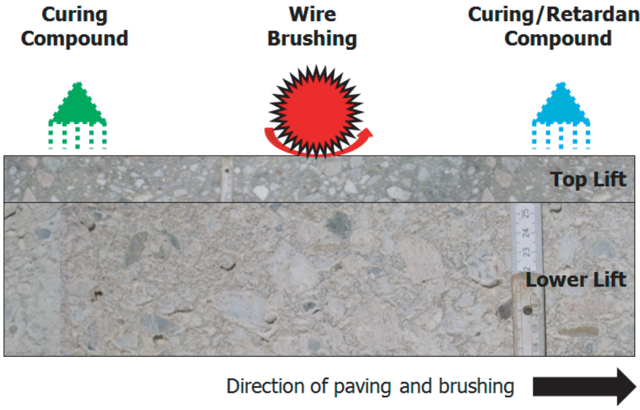


Figure 3.3. EAC texturing on a two-layer EAC PCC/PCC pavement.

The result is a high-quality ride surface that, as mentioned, has better long-term noise and friction characteristics than conventional texturing (longitudinal burlap drag or transverse/longitudinal tining). The use of exposed aggregate texturing on European pavements was of particular interest to the R21 delegation, given this novel and widespread use of PCC/PCC.

EAC Materials and Mix Design

Accepted practices in all three countries use very similar materials in a two-layer EAC pavement. The following subsections discuss materials and mix designs as described to the delegation by its hosts in Europe and by the literature provided to the delegation.

Netherlands EAC

The construction in 2000 of the full-scale EAC test sections along N279 was accomplished mainly to provide the Netherlands with insight into noise reduction regarding the aggregate selection for the EAC top layer of the two-layer concrete composite. Dutch engineers desired, in addition to a size that optimized noise reduction, a durable aggregate that would prevent the pavement from losing its noise-reduction qualities over the course of being heavily trafficked.

In constructing PCC pavements (either single-layer or two-layer composite) with EAC, the various pavements featured mixes that had aggregates of maximum aggregate size as small as 7 mm and as large as 22 mm. These aggregates were crushed gray quartzite, a high-quality, durable, hard stone (Figure 3.4), or a locally available crushed gravel.

Furthermore, the aggregates were part of a gap-graded mix (one that uses only the finest and coarsest aggregates) or continuous mix (one that has a full spectrum of sizes from fine to coarse). The full-scale test sections were examined for noise and skid resistance. Pavement engineers in the Netherlands have concluded that a gap-graded 5/8-mm mix using gray quartzite performed best, both reducing noise and increasing skid resistance.

Figure 3.4. Top: A sample of gray quartzite, a high-quality aggregate used in EAC pavements, such as the N279 test sections in the Netherlands (*12*). Bottom: A hand specimen of diabase, an aggregate frequently encountered in EAC pavements along A1 in Austria (*13*).

Germany EAC

Engineers in Germany were quick to point out that the gradation of the aggregate (e.g., maximum aggregate size, gap-graded) is important in achieving proper texture. The exposed aggregate layer typically is gap-graded with an 8-mm maximum aggregate size. The delegation inquired about any requirements on the shape of the aggregate and was informed that a certain shape is desired for the sake of workability and strength. The shape is measured using an index popular in Europe. The German hosts also were keenly aware of another measure of aggregate quality—PSV, or polished stone value. No demands on the type of aggregate used in EAC were mentioned (outside of prevalent alkali–silica reaction concerns).

Although the delegation was interested in the use of lower-quality aggregates and less cement content in the lower layer of a two-layer PCC pavement, the German hosts were unable to discuss this topic at length, because conservative German design and theory have prevented contractors from attempting these kinds of "risky" lower layers. Both the top layer and lower layer of a two-layer PCC pavement in Germany use Type I cement, with slightly different cement contents and admixtures in each layer. The top layer uses superplasticizers for workability, whereas the lower layer uses none, to keep the mix relatively stiff for placement using two paving machines (for more information, see the A6 construction case study).

It also should be noted that fly ash is not used in Germany and Austria. Although air entrainment and plasticizers are added to the top layer of EAC mixes, conventional wisdom in Germany is that fly ash is not necessarily helpful.

Austria EAC

In surveying pavement sections along the A1 motorway in Austria, the delegation noted that the EAC pavements that featured a particular dark aggregate appeared to be in excellent condition, given their age and the volume of traffic they had received. This aggregate was said to be diabase (also known as dolerite), which is an igneous rock that is similar in composition to basalt. A hand specimen of this aggregate is shown in Figure 3.4.

The pavement experts in Austria were as adamant as their counterparts in Germany about the need for high-quality construction and high-quality aggregates to make a successful, durable two-layer EAC pavement. Typical mixes for the top layer use a gap-graded aggregate (30% of 0/1 mm, 70% of 4/8 mm). The aggregate for the 4/8-mm size is fairly cubical and is expected to be very durable.

Austrian attitudes toward fly ash were similar to those in Germany. The Austrian hosts cited three main reasons for the lack of fly ash in Austria and Germany: 1) cement industry interests, 2) suspicion that fly ash may harm durability and make pavement more susceptible to freeze–thaw damage, and 3) fly ash quality is producer dependent. The Austrians prefer slag to fly ash, and they use as much as 32% slag in their PCC mixes. The PCC mix for the top layer is designed to have a higher strength content for the top lift, which ensures that smaller aggregates will stay in the cement paste–aggregate matrix, thereby creating a durable surface. The top layer has a water/cement ratio of 0.38 for the top lift and 0.41 to 0.42 for the bottom layer.

Construction of EAC and Two-Layer Concrete Pavement

Construction practices for two-lift PCC-over-PCC and EAC have varied during the past decade. At one time, the two-layer PCC pavement was placed at once using one slipform paver; however, this method has been replaced by a train of multiple, independent paving machines. In addition, there have been numerous innovations in the brushing techniques and the curing compounds and retardants used before and after the brushing process. The R21 delegation was able to spend a great deal of time on-site to observe the construction of two-layer EAC pavement, and a case study is appended to this section illustrating a construction project along the A6 motorway near Amberg, Germany.

Netherlands

On the basis of full-scale EAC test sections constructed along N279, Dutch engineers recommend texture depth of no more than 1.8 mm. The use of super-smoother in the paving process is recommended to help in noise reduction, although it is noted that super-smoother can further embed the aggregate near the surface and contribute to a loss of texture depth after brushing. Finally, because the layered construction had no influence on performance in terms of noise or friction, researchers in the Netherlands recommend that the cost of construction and selection of materials be left to the contractor, provided certain performance measures are achieved (*3*).

The delegation's hosts in the Netherlands stressed the importance of having a technician carrying out quality-control checks for texture depth (using the sand patch test) at all times. They also emphasized the need for a knowledgeable contractor who understands when to initiate brushing. In addition, the Dutch find highly variable work for certain contractors and thus emphasize the need to know the contractor and the consistency of that contractor's work, as consistency of texture is very important for successful EAC. Finally, given their experience with testing several surface treatment compounds, the Dutch emphasize the careful selection of the retarding agent and curing compound used in the EAC process.

Austria

The delegation's Austrian hosts stressed the need for two separate paving machines in two-layer PCC construction to ensure consistent thickness of the layers. They also pointed to the dangers of vibrators and to the minimization of vibration to prevent the high-quality aggregates needed in the top layer from being dispersed into the lower layer. Overall, the Austrian researchers stated that two-layer PCC pavement provides similar structural performance as an equivalently thick single layer at the same price, with the additional benefits of improved skid resistance and noise reduction due to the high-quality top layer.

Austria has a great deal of experience with the recycling of concrete pavements. In the late 1980s, Austria undertook the long process of recycling PCC pavements that were more than 30 years old along the A1 motorway into new two-layer PCC pavements. This experience has led Austrian researchers to claim that the recycling concept is "an important innovation that is both economically and environmentally advantageous" (*14*). The R21 delegation was able to visit some of these recycled PCC pavements (featuring EAC texture) along A1 in Austria, and more details are provided in the case studies section of this report.

As a result of their decades of experience with EAC, Austrian pavement engineers have gained considerable insight on the texturing process and the tests needed to evaluate texture (*10, 15*). The texture depth measurement that results from a sand patch test has been closely scrutinized in Austria. Assuming a maximum aggregate size of 8 mm, Austrian engineers recommend a narrow range of 0.8 to 1.0 mm. A texture depth below 0.8 mm will not provide adequately reduced noise; on the other hand, if texture depth is above 1.0 mm (with a maximum aggregate size of 8 mm), the aggregate will become dislodged from the mortar either during the initial EAC brushing or later, when the pavement experiences traffic.

Austria uses an additional metric for EAC texturing beyond the sand patch test. This additional test is the profile point test, which is a 5 cm × 5 cm test patch of texture. Within this patch, the pavement is required to have a certain number of visible aggregates, or "profile points." Austrian researchers recommend a profile point count for a 25 cm^2 test patch of approximately 60 for an 8-mm maximum aggregate size, and approximately 45 for an 11-mm maximum aggregate size (*10*). The aim of the profile point test is to ensure an optimal number of exposed aggregates so that the passing tire is mostly in contact with the aggregate tips, thereby allowing sufficient space between the tire and the mortar for drainage.

A profile point count that is too high describes a surface that will not allow sufficient drainage between aggregates, and a low profile point count would allow the tire to contact too much of the mortar, resulting in a very noisy surface.

Germany

Much of the discussion about two-layer PCC construction with the delegation's German hosts concerned the equipment used to construct two-layer pavements. In preparation for a survey of the construction site along the A6 motorway, Dr. Walter Fleischer of Heilit+Woerner GmbH in Munich detailed the equipment that his firm developed for two-layer construction.

An important point for EAC texture discussed with the German pavement engineers is that, although there are several qualified contractors in Germany for the construction of PCC pavements (including two-layer PCC composites), there are only two contractors at this time capable of EAC texture (Ruboco and Heilit+Woerner). More details on the EAC texturing process are provided in the A6 construction case study.

The delegation also discussed curing techniques for PCC pavements and learned that plastic sheeting has been abandoned entirely by German and Austrian engineers because of the expense and unreliability in protecting the pavement during early age (first 72 hours). In the experience of both countries, the plastic sheeting increases the heat of hydration, makes joint saw cutting difficult, and creates pockets of inconsistent moisture levels at the surface. Furthermore, the plastic cannot be reused and may embed itself locally in cured PCC. In short, plastic sheeting is viewed as expensive and difficult to maintain (air bubbles between the sheet and the PCC create problems), and its only advantage is its resistance to effects from rain, should foul weather occur. Instead of plastic sheeting, curing compounds are applied immediately after placement, and water curing is used if possible and required. If exposed aggregate is constructed, a combination curing/retarding compound is sprayed, and after the surface is brushed to achieve the texture, a curing compound is again applied as a precautionary measure.

Construction Case Study: A6, Near Amberg, Germany

As noted in Chapter 2, at the time of the R21 delegation's visit, the A6 motorway in Germany was in the process of construction that would connect the two halves of A6, thereby allowing the roadway to run uninterrupted across Germany. The A6 construction project involved 21 km of two traffic lanes in each direction. The project was entirely EAC/PCC with exposed aggregate surfacing (or *waschbeton,* as it is known in German). Work began on the project in March 2004, and it was completed in September 2008.

The project's design specified a two-layer PCC pavement, with the layers constructed as "wet-on-wet," or immediately after one another. Particulars of the design included the following:

- PCC top: 5-cm PCC with crushed granite gap-graded (2/8 mm) with maximum aggregate size of 8 mm, 430 kg/m^2, air content 5%, water/cement ratio 0.45.
- PCC bottom: 25-cm PCC with river gravel, 350 kg/m^2, air content 4%, water/cement ratio 0.4.
- Base: 30-cm unbound aggregate (type and gradation unknown).
- Subbase: 25-cm unbound local aggregate extracted from excavation for roadway and crushed on site; layer acts as a frost blanket.
- Subgrade: Type unknown (delegation guess is class A-2), treated with cement to achieve modulus of 45 MPa.
- Slab dimensions: Shoulder width 2.5 m; inner slab width 4.75 m; outer slab width 4.25 m.
- Joints: 5 m between transverse joints; transverse and longitudinal joints use bituminous hot seal; dowels are 25 mm in diameter, 50 cm in length; tiebars are 20 mm in diameter, 80 cm in length.

On the day the R21 delegation visited the A6 construction site (May 13, 2008), the temperature was 26°C (78.8°F), and conditions were sunny and slightly windy. In part because of the weather, the site manager expected that more than 800 m of new two-layer PCC pavement would be placed and textured in the exposed aggregate style that day, well over the daily average of 700 m per day.

En route to the paving site, the delegation was impressed with the organization of the construction site. In addition to the meticulous subgrade, base, and drainage preparations under way (Figures 3.5 and 3.6), the contractor was able to take advantage of aggregates found on site during the process of excavating to clear for the roadway. These aggregates were crushed on site and used in the frost blanket subbase of the pavements.

The two-layer PCC slab is placed with a train of three machines with an estimated total value of approximately 3 million euros. Each of the paving machines can be transported to and from the site in an International Organization for Standardization (ISO) marine container. In addition, the pavers are modular and can accept several attachments, including a super-smoother, automated dowel inserter, or spray arm. The entire paving operation, including dump-truck operators, crane-arm loader, spray tank, and other miscellaneous equipment, appeared to be working smoothly under the efforts of approximately 25 crew workers.

The delegation noticed that a tanker truck directly in front of the first paver was liberally spraying the base layer in front

Figure 3.5. Left: Site cleared for two lanes in each direction. Right: Stabilizing the subgrade with cementitious compound.

Figure 3.6. Left: Frequent spraying of base layer in front of the first paver minimizes moisture loss in the lower layer of PCC to base. Right: Prepared, stabilized subgrade awaits frost blanket aggregate layer.

of the slab with water (Figure 3.6). This practice saturates the base layer and minimizes the amount of moisture in the PCC lost to the base layer. The mix for the lower layer is dumped immediately in front of the first paving machine. The first paver in the paving train forms the lower layer of the two-layer PCC pavement (Figure 3.7). The delegation took particular notice that string lines were established on both sides of the slab to guide the paving machines.

It is apparent from the bottom photo in Figure 3.7 that the PCC mix being placed is stiff. This photo and Figure 3.8 show the use of an automated dowel inserter, which is attached to the back of the first paver. Two crew workers were required to insert the tiebars at regular intervals using a specialized tiebar inserter. The inset in Figure 3.8 is a comparison of the tiebar and dowel used in the pavement. The dowels were 25 mm in diameter and 50 cm in length, while the tiebars were 20 mm in diameter and 80 cm in length.

Figure 3.7. Front (top) and rear (bottom) views of the first paving machine, responsible for the lower of two PCC layers.

Figure 3.8. Close-up of the rear of the first paving machine, which has an automated dowel inserter attachment. Inset: A tiebar and a dowel.

The next paving machine in line formed the top layer of the two-layer slab. This second paver was equipped with a super-smoother attachment. Front and rear views of the second paver are provided in Figure 3.9.

The mix for the top layer of concrete was placed between the first and second pavers using a crane-arm loader. Dump trucks with the mix for the top layer positioned themselves parallel to and very near the slab so that the crane-arm operator could lift the mix from the bed of the truck easily and place it directly in front of the second paver. This process is shown in Figure 3.10.

The third and final machine, while technically capable of being a paving machine, was a finishing platform (Figure 3.11). The platform allows for last-minute finishing touches to be applied to the slab before it is sprayed with a curing compound and retarding agent. The finishing platform has a spray arm attached to accommodate spraying.

The slabs were sprayed with a compound specifically designed to accommodate EAC texturing (Figure 3.12). This compound is a combination of curing compound and retarding agent, and the particular compound used on-site was manufactured by the Austrian company TAL. The retarding agent in the compound slows the hydration process in the mortar near the surface and prevents it from adequately bonding with the aggregates. This allows for the mortar to be brushed easily from the surface during the EAC texturing process.

In addition to quality construction, the slab and mixes are regularly tested to ensure quality concrete. Hourly air content tests are conducted on both mixes, and strength cubes on both

Figure 3.9. **Front (top) and rear (bottom) views of the second paving machine, responsible for the upper of two PCC layers. Note the use of a super-smoother at the rear of the machine.**

mixes are conducted at least once per day. Cores are taken once per 1,000 m^2 of paving. The cross-section in Figure 3.13 illustrates the result of a properly constructed two-layer PCC pavement: the high-quality, smaller aggregates in the top layer are segregated from the low-quality, larger aggregates in the lower layer.

In discussing successful EAC texturing, the delegation's hosts continually stressed two factors: quality construction and quality aggregates. The final observation of the R21 delegation during its tour of the A6 construction site, then, was to observe the quality construction of an EAC texture. Although paving for the day began at 0800, brushing on this particular day did not begin until 1630. This falls in line with German experience, wherein brushing is said to begin anywhere between 7 and 20 hours after paving. Figure 3.14 shows the brushing equipment.

From the discussions of the EAC texturing process with experts in Austria and Germany, the delegation was given the impression that the EAC process is very much operator dependent. The experience at A6 confirmed this. To determine when to begin brushing, the brush operator would hand broom sections at 10-m intervals every hour (Figure 3.15). This process allowed the operator to observe if the aggregate was moving in the mortar, if the aggregate resisted the broom and stayed embedded in the mortar, if the mortar was drying, how quickly the mortar was drying, and so forth.

Once the hand-broom test indicated that the surface was ready for texturing, the operator would brush approximately 20 to 30 linear meters of a slab at a time using a small grader mounted with a large, machine-driven, steel-bristled, cylindrical brush rotating clockwise (Figures 3.15 and 3.16).

After completely brushing 20 linear meters of slab, the operator would conduct more hand brushing tests in the regions that had been brushed once and in the 20 m beyond that region. Eventually, the operator would make a second pass over the original 20 m to achieve the desired texture (Figure 3.17). The process appeared to remove approximately 5 mm of mortar (Figure 3.18).

Shortly after the second pass, a tractor equipped with a sprayer passes over the slab and applies a curing compound (the R21 delegation did not observe this step).

Testing for the appropriate texture involves a sand patch test conducted four times per day on the first day of paving and once per day thereafter. These standards are less strict than elsewhere; in Austria and the Netherlands, frequent sand patch testing is conducted behind the operator to check for consistency of texture. In this particular case, the site manager chose to forgo this quality control check on this site, given the expertise of the brush operator.

The EAC brushing is done to obtain a texture depth of 0.6 to 0.8 mm, though currently Germany has no regulations about texture depth. New specifications in development will require a texture depth of 0.6 to 1.1 mm.

The R21 delegation did not observe joint saw cutting, but the site manager indicated that it follows brushing by approximately 2 to 5 hours, though these estimates are highly dependent on ambient conditions. Having observed the construction of the pavement from subgrade to texture, the delegation was able to view a few examples of a finished pavement awaiting lane markings, shown in Figure 3.19.

Overall, the delegation learned much from the construction techniques on display. In addition to the observations already noted, the delegation noticed a lack of anecdotes about paving in subprime weather (rainy, for instance) when discussing previous projects with the contractor. In this sense, the delegation had the impression that our hosts were "fair-weather pavers," in that they insisted on optimal conditions for paving.

(a) (b)

(c) (d)

Figure 3.10. Use of loader to place top layer mix between lower- and top-layer paving machines.

Figure 3.11. Left: Front view of the final machine in the paving train, the finishing machine. Right: A close-up of last-second touch-ups as the finishing machine continues along.

Figure 3.12. Left: Rear view of the finishing machine with spray arm attachment. Right: View of placed two-layer PCC slab with combination curing compound and retardant sprayed on surface.

Although it may be an incorrect assumption, it would explain in part the outstanding condition of many PCC pavements that were more than 20 years old encountered on the way to the A6 construction site.

In addition to touring the paving, the delegation also visited the batching plant for the pavement construction (Figures 3.20 and 3.21). The batching plant on this day was located 3 km from the paving site. As with the paving machines, the batching plant was modular and portable and could be assembled from the contents of 13 ISO marine containers.

Figure 3.13. Cross-section of completed two-layer PCC pavement. Smaller aggregates are in the top layer, and larger aggregates are in the lower layer.

The plant is designed for the construction of two-layer PCC pavements, and as a result, it batches both layer mixes simultaneously in an organized fashion. It is as simple as one side of the plant being responsible for the upper-layer mix and its constituents, while the other side handles the lower-layer mix.

The batching plant is able to supply trucks continuously with mix for the pavers. The minimum mix time for the upper layer was 60 seconds, and the minimum mix time for the lower layer was 45 seconds. The delegation noted a steady stream of trucks passing through the batching plant with no discernible delays or problems. Part of this efficiency resulted from preparation, as illustrated in Figure 3.22.

Pavement Design and Condition Case Studies

The following sections discuss the various two-layer PCC pavements reviewed by the R21 delegation in the Netherlands, Germany, and Austria. These pavements contain a variety of interesting features, including EAC texturing.

N279, Near Veghel, Netherlands

The N279 sections were constructed in 2000 and currently are subjected to an average of 25,000 vehicles per day, 30% of which are commercial truck traffic. The sections originally were asphalt but were replaced with two-layer PCC to investigate various exposed aggregate surfaces. Photos of some of these sections are shown in Figure 3.23.

Figure 3.14. Left: A small grader with wire brush attachment for EAC texturing. Right: A close-up of wire bristles on brush.

Two-layer construction was done with EAC as the top layer. The following was the design of this project:

- 9 cm for top layer. This is crushed aggregate. A minimum thickness of 9 cm is required for production and construction purposes (Figure 3.24).
- 18 cm as lower-layer PCC (this can be varied for design). This aggregate does not need to be crushed. Separation of the wet-on-wet layers over time has never been observed. Photos of the 4/22-mm section in May 2008 are shown in Figures 3.25 and 3.26. The transverse joint is narrow and not sealed.

The experimental features of this test site included the following (see Figure 3.24 for photos of four specific EAC surfaces):

- Two aggregate types
  - ○ Quartzite crushed
  - ○ Dutch crushed gravel
- Two gap-graded mixtures with 0/2 mm sand
  - ○ 4/8 mm (fine gradation)
  - ○ 11/16 mm (coarse gradation)

Texture depth (sand patch method) varied from 1.1 to 1.8 mm for the 11/16-mm aggregate; the other textures were 1.8 mm. A new product was used that combined a retarding agent and a curing compound. This eliminated the need for plastic sheeting used before this. After 12 to 24 hours, the surface was subjected to steel wire brushing, which removed the surface mortar and exposed the surface aggregates to a desired texture depth, as stated previously. After brushing, the surface

Figure 3.15. Left: Brush operator conducts hand brushing tests at regular intervals to determine when to initiate brushing. Right: First of two passes with brush to develop EAC texture.

Figure 3.16. EAC texture after first pass of brush is shown in left half of photo. Unbrushed surface with compound still visible is shown in right half of photo.

was then sprayed with a curing compound to complete the curing of the surface. They also used and recommended the super-smoother, which removed small surface unevenness, improving smoothness and reducing pavement/tire noise level.

The full-scale sections of EAC on the N279 (Figures 3.27 and 3.28) resulted in valuable information regarding their construction and performance:

- A maximum texture depth of 1.8 mm is recommended for these mixtures.
- The smaller gradations of exposed aggregate types are preferred for reduced noise levels.
- The fine quartzite aggregate with 5/8-mm gradation produced the lowest noise for both cars and trucks.
- The quartzite aggregate had better friction than the Dutch crushed gravel.
- The friction level of EAC is comparable to that of brushed concrete (tined).
- Use of a super-smoother behind the slipform paver leads to a lesser texture depth and has a positive effect on the noise level.
- The noise level of one- and two-layer pavements with similar aggregates is comparable.

A93, Between Brannenburg and Kiefersfelden, Germany

The R21 delegation visited numerous pavement sections along A93 between Brannenburg and Kiefersfelden, Germany. The A93 motorway connects Munich to Innsbruck and is heavily trafficked, because it is considered a main connector to Italy. No specific average daily traffic figures were available, but the

Figure 3.17. Top: Brush operator conducts more hand brushing tests at regular intervals to determine when to initiate second pass with brush. Bottom: Final of two passes with brush to complete EAC texture.

Figure 3.18. Close-up of finished EAC texture on sections constructed on A6.

Figure 3.19. Left: Finished two-layer EAC pavement. Right: Bituminous seal used for both longitudinal and transverse joints.

delegation noted that traffic volume seemed particularly high during the surveys, and truck traffic seemed especially frequent.

The A93 sections (except where indicated) are two-layer PCC/PCC originally constructed in 1995 or 1996. Their original design was (to the best of the knowledge of the delegation's host for that day):

- PCC top: 7-cm PCC with crushed quality aggregate and higher cement content than that of the bottom.
- PCC bottom: 19-cm PCC with recycled PCC aggregate.
- Base: Unknown, most likely 10- to 15-cm asphalt, 15- to 25-cm concrete-treated base (CTB), or 25+-cm crushed aggregate.
- Subbase: Unknown; depending on base type, would be anywhere from 30 to 50 cm of aggregate to provide required frost protection.
- Slab dimensions: Unknown, though driving and passing slabs were of unequal widths, and the total width of both slabs was said to be 11 m.
- Joints: 5 m between transverse joints; transverse and longitudinal doweled joints use bituminous hot seal.

In addition, all sections originally were textured with a longitudinal burlap drag, with the exception of a few sections that acted as test sites for the use of longitudinal tining or EAC.

The delegation visited the A93 sections to investigate the various methods of texture rehabilitation used on these two-layer pavements. Many of the pavements had texture problems soon after construction. The delegation's host has several hypotheses for these difficulties. Some sections (designated E through K in the following subsections) had

Figure 3.20. The concrete batching plant located near the A6 construction site is specifically designed for placement of two-layer PCC pavement.

Figure 3.21. ***Top: Aggregate bins are double sided to accommodate aggregates for top-layer and lower-layer batches. Bottom left and right: Sand (0/2 mm) and crushed granite (4/8 mm) used as aggregates in the gap-graded, top-layer mix.***

degraded texture resulting from rain after placement. The main hypothesis was mortar difficulties: miscellaneous sand problems (sand is too calcite), high water/cement ratio, etc. The delegation's observations agreed with the possibility of problems in the mortar.

Following is a brief review of the pavement sections visited and any interesting details related to these sections. Note that these discussions assume unofficial section labels, for ease of discussion.

Section A, Longitudinal Burlap Drag (Original Design), km 1.490–1.910

Section A was the first of many sections surveyed along A93 to illustrate polishing or wear in mortar. The shoulder was textured, along with the remainder of the pavement, which revealed a nontrafficked version of the texturing (holds for all sections). In this particular case, the polishing of the longitudinal burlap drag was severe (Figure 3.29).

Figure 3.22. Plates on the dash of all trucks (left) allowed the batch plant manager to deliver appropriate layer mixes quickly and efficiently.

As discussed earlier in this report, Germany has more than 20 years of experience with longitudinal burlap drag, and during 15 of those years burlap texturing was the standard for German pavements. Approximately 4 years ago, after years of observation, German pavement engineers concluded that burlap dramatically loses its noise reduction and skid resistance after approximately 5 years, resulting mostly from accelerated wearing of the burlap texture. The pavement shown in Figure 3.30 has received far more than 5 years of traffic, and it illustrates this wearing of the burlap texture into a highly polished surface that is both noisy and dangerous.

Section B, Longitudinal Wide Tining ("American"), km 1.910–2.070, and Section C, Longitudinal Narrow Tining ("Spanish"), km 2.070–3.335

Sections B and C were the only sections along A93 originally constructed without the burlap drag texturing. These sections were textured with longitudinal tining in either a so-called American style or Spanish style. The only difference between the two styles seemed to be that the American style was slightly wider and the Spanish style was shallower (Figure 3.31). The tines were attached to the paver and, as a result, the stopping and starting of the paving train allowed the tines to settle into

Figure 3.23. Full-scale EAC test sections along N279 near Veghel, Netherlands.

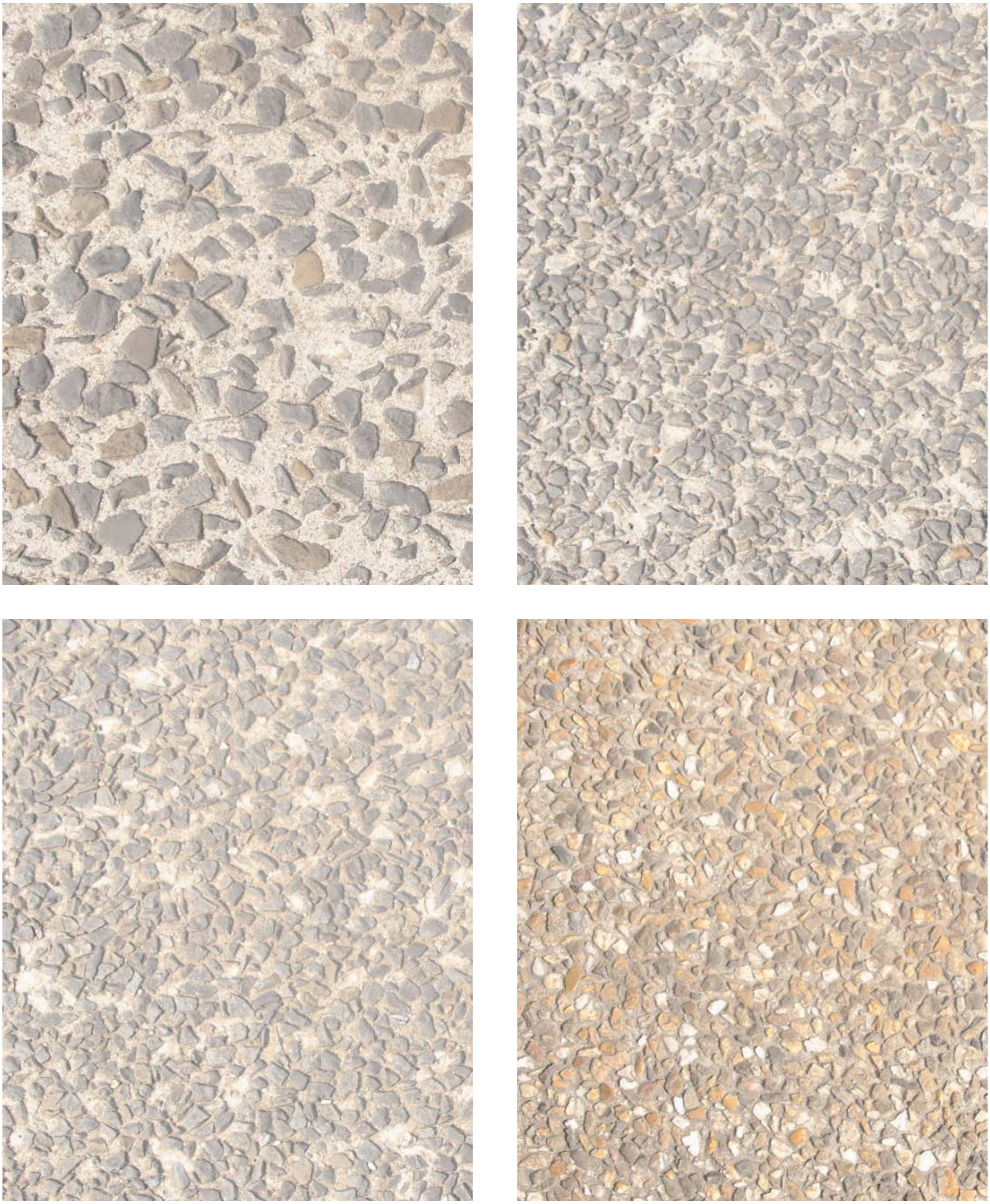


Figure 3.24. Different textures used in N279 test sections (top left, quartzite 11/16 mm; top right, quartzite 5/8 mm; bottom left, quartzite 5/8 mm; bottom right, Dutch gravel 4/8 mm).

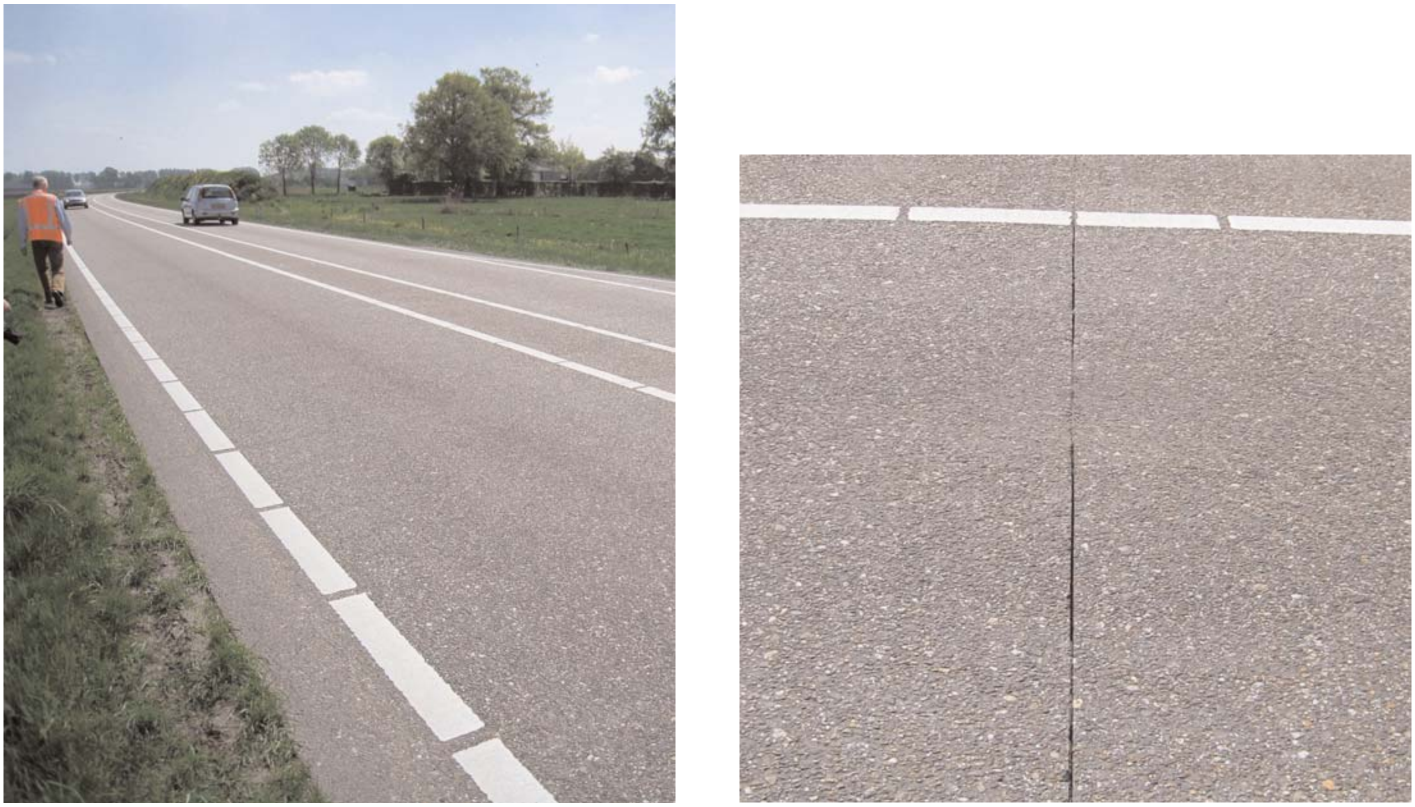


Figure 3.25. The 4/22-mm sections along N279 in the Netherlands.

Figure 3.26. The texturing on the 4/22-mm sections along N279 in the Netherlands.

Figure 3.27. A 5/8-mm section along N279 in the Netherlands.

Figure 3.28. Texturing on a 5/8-mm section along N279 in the Netherlands.

the pavement and create inconsistent, "wavy" depth. The texture depth from the tines generally was shallower than the longitudinal tining applied in the United States.

Section G, Rehabilitated with Grooved Texturing, km 5.600–5.700, and Section K, Rehabilitated with Fine Diamond Grind, km 5.900–5.950

The construction on Sections G and K was marred by frequent rain. As a result, the original burlap texture wore quickly and had to be rehabilitated in 1999. Section G was rehabilitated with a grooved texture that has been applied in the United States. The grooved texture typically is used to eliminate hydroplaning and normally is applied on airfield pavements.

Figure 3.29. Original burlap drag on A93, Section A (km 1.490–1.910).

Figure 3.30. Significant polishing of burlap drag after 13 years of traffic on A93, Section A (km 1.490–1.910).

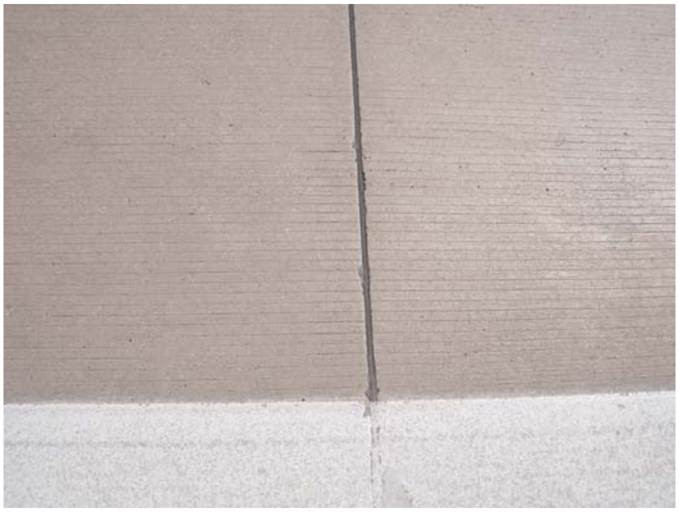


Figure 3.31. Top: Longitudinal tining known as "American comb" (km 1.910–2.070). Bottom: "Spanish comb" (km 2.070–3.335).

Figure 3.32. Left: Grooved texture on section along A93 (km 5.600–5.700). Right: Diamond-ground texture on another section of A93 (km 5.900–5.950).

Although diamond grinding is not typically done in Europe because of the expense of the process, Germany has good experience with diamond grinds when they are used. While the grooved Section G looked to have its texture in good condition, the finely ground Section K had worn almost completely in the wheelpath (Figure 3.32).

Section M, Exposed Aggregate Concrete Pavement, km 7.440–8.600

Section M originally was constructed in 1995 and 1996 using an EAC texture. The aggregate gradation for the pavement was a continuous 0/8 mm. The delegation's hosts for the A93 survey did not know the aggregate in the top layer but claimed that it looked similar to the quartzite used in other EAC projects on which they had worked. The delegation observed slight polishing (relative to the shoulder, which was also textured), but overall the pavement looked to be in outstanding condition, given both its age and the amount of traffic it receives (Figure 3.33). The skid resistance measures for the pavement were said to be as good as they were shortly after construction.

Section N, SMA Overlay, km 8.600–11.000

To rehabilitate the surface of Section N, a 3-cm layer of SMA was overlaid atop the original total 26-cm two-layer PCC pavement in 1995 and 1996. The SMA was a gap-graded mix with a maximum aggregate size of 8 mm. The SMA was paved in two 5.5-m passes over the PCC because of width restrictions on the

Figure 3.33. Exposed aggregate section and texture (km 7.440–8.600).

paver. The SMA-over-PCC was sawed and sealed over the PCC transverse joints and on longitudinal joints between the paving passes (and not over the longitudinal joints between the PCC slabs). The saw and seal work looked outstanding and of very high quality. The longitudinal joints between PCC slabs had propagated up through the SMA, between both the inner/outer slabs and the inner/shoulder slabs. The only significant maintenance conducted was placing a few patches at transverse joints where the SMA must have debonded from the PCC surface and cracked. These rectangular repairs can be seen in Figure 3.34.

Section P, SMA Overlay, km 12.500–22.780

Section P originally had the same design as Section N (3-cm SMA over 26-cm two-layer PCC). However, because of reflective cracking in the SMA and a poor bond between the SMA and PCC layers, the old pavement was completely reclaimed in 2004 and used for the new Section P.

Figure 3.34. Top: SMA over PCC in Section N (km 8.600–11.000). Bottom: Sections similar to Section N were reclaimed for EAC/PCC in new Section P (km 12.500–22.780).

The design of the reconstructed Section P is as follows:

- PCC top: 5-cm PCC with crushed quality, gap-graded aggregate and higher cement content than that of the bottom.
- PCC bottom: 21-cm PCC with recycled PCC aggregate from top and lower lifts of previous pavement.
- Base: Crushed aggregate base of unknown thickness containing recycled SMA from previous pavement.
- Subbase: Unknown composition and thickness.
- Slab dimensions: Unknown, though driving and passing slabs were of unequal widths, and the total width of both slabs was said to be 11 m.
- Joints: 5 m between transverse joints; transverse and longitudinal joints use bituminous hot seal.

The two-layer PCC pavement was finished with EAC texturing, as depicted in Figure 3.35.

An interesting point about Section P's reuse of the previous pavement is that the previous pavement itself used recycled PCC aggregate in the lower of its two PCC layers. The recycling of concrete pavements has been common in Europe since the 1980s for several reasons, including the scarcity and expense of aggregates and the difficulties and cost of dumping old pavement material. In the late 1980s, Austria undertook the long process of recycling PCC pavements more than 30 years old (some with SMA overlays, as in Section P) into new two-layer PCC pavements. This experience has led Austrian researchers to claim that the recycling concept is "an important innovation that is both economically and environmentally advantageous" (*14*).

A99, Near Ottobrunn, Germany

The R21 delegation made a brief stop at a whitetopping project, the first of its kind in Germany, at an off-ramp for the A99 motorway near Ottobrunn. Although whitetopping is not relevant to R21, the project was notable for the R21 team because the panels used in the A99 project combined an EAC texture with a PCC mix design that included polypropylene fiber reinforcement (Figures 3.36 and 3.37).

The panels in the A99 project were 14 cm thick and had dimensions of 2.6 m by 2.6 m. The PCC mix had a maximum aggregate size of 11 mm with gap-grading of 0/2 mm, 5/8 mm, and 8/11 mm.

A1, Near Eugendorf, Austria

The section at Eugendorf is a reconstructed two-layer PCC pavement with exposed aggregate texturing (Figures 3.38

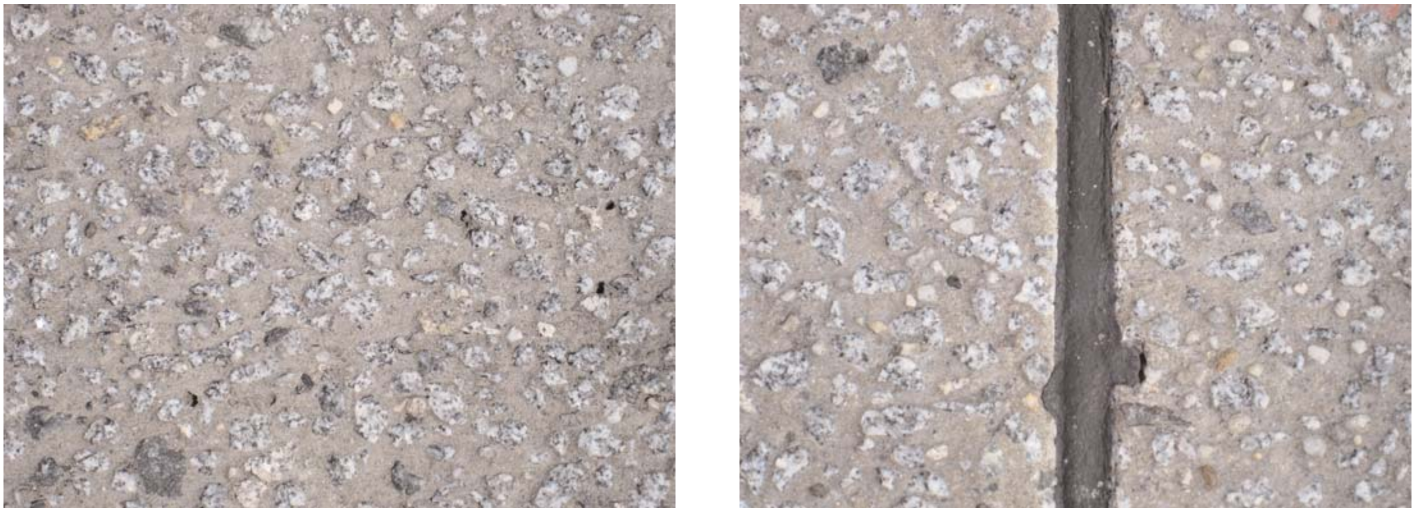


Figure 3.35. Texture close-ups in EAC sections and close-up of bituminous seal used on both transverse and longitudinal joints on A93 Section P (km 12.500–22.780).

and 3.39). The original PCC pavement was recycled into the lower lift of the reconstructed pavement in 1993 and 1994.

Particulars of the pavement design include the following:

- PCC top: 4-cm PCC with diabase aggregate of maximum aggregate size 8 mm (gap-graded 0/8 mm).
- PCC bottom: 21-cm PCC with recycled PCC aggregates of maximum aggregate size 32 mm.
- Base: 5-cm asphalt.
- Subbase: 25-cm cement-stabilized aggregate.
- Slab dimensions: 3.75 m-wide driving-lane slab, 3.75 m-wide passing-lane slab, 3 m-wide shoulder; 5.5 m-long slabs.
- Joints: 5.5 m between transverse joints; transverse and longitudinal joints use preformed rubber seal with no bituminous hot seal.

In general, the Eugendorf section appeared to be in very good condition, given that the section has been exposed to heavy traffic (average daily traffic of 56,000, with 12% trucks) and 6 full months per year of metal snow plows and salting for 14 years. In addition, the pavement had to endure studded tires for 10 years. These conditions resulted in slight wear in the wheelpath, as shown in Figure 3.40. In the figure, the worn wheelpaths are lighter than the surrounding darker, lesser-trafficked portions of the driving lane.

The noise level of the pavement was observed to be louder than expected (all observations are by ear and are not based on conclusive measurements) but still quieter than German sections because of the lack of a bituminous hot seal at the transverse joint that typically created a regular, faulting-like noise in the German sections. One likely explanation for the increase in noise is the presence of studded tires, which do not

Figure 3.36. Left: Finished whitetopped ramp along A99. Right: A handful of polypropylene fibers included in PCC for the A99 project.

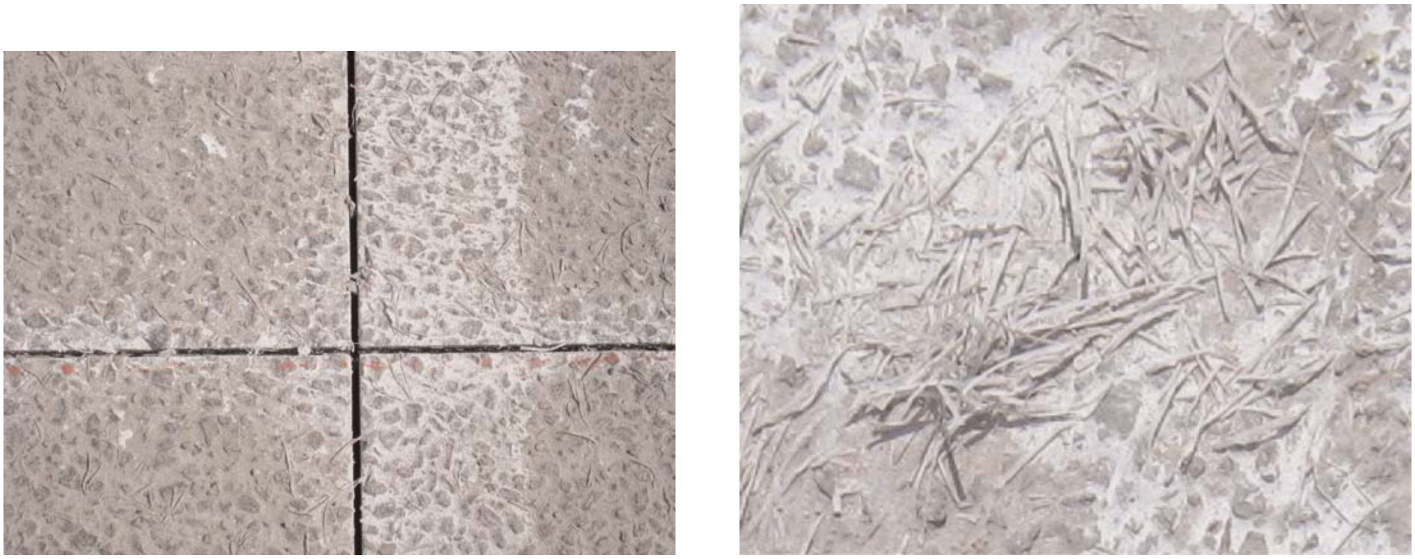


Figure 3.37. Left: Close-up of the interesting combination of EAC and fiber reinforcement, which creates a "fuzzy" appearance. Right: One of the challenges of using fibers in PCC is the so-called clumping, made more visible in the A99 panels because of EAC.

polish the pavement in the wheelpath so much as they roughen the texture and remove mortar. The Austrian hosts noted that studded tires in fact help the upkeep of the skid-resistance numbers, though they are a major contributor to a loss in noise reduction.

The section showed very few distresses, and those that were apparent did not appear to be indicators of chronic problems in the pavement. The delegation's host for this particular section oversaw the reconstruction of the section in 1993 and 1994 and relayed stories about early difficulties in the reuse of old PCC pavement in the lower PCC layer of the new two-layer PCC pavement. These stories only emphasized that Austria has two full decades of experience in the full-depth reclamation of old PCC into new two-layer PCC pavements, and as such Austria has many lessons to offer the United States as it works toward sustainable composite pavements. Furthermore, A1 near Eugendorf is an example that EAC texturing under extreme conditions can hold up for at least 14 years without any need for major rehabilitation.

A1, Near Regau, Austria

The section along A1 near Regau was included to provide an idea of the design and composition of the old two-layer PCC pavement that preceded the reconstructed sections along A1 being visited by the delegation. This section is shown in Figure 3.41 with the driving lane resurfaced with a thin asphalt layer. The passing lane shows the original PCC surface.

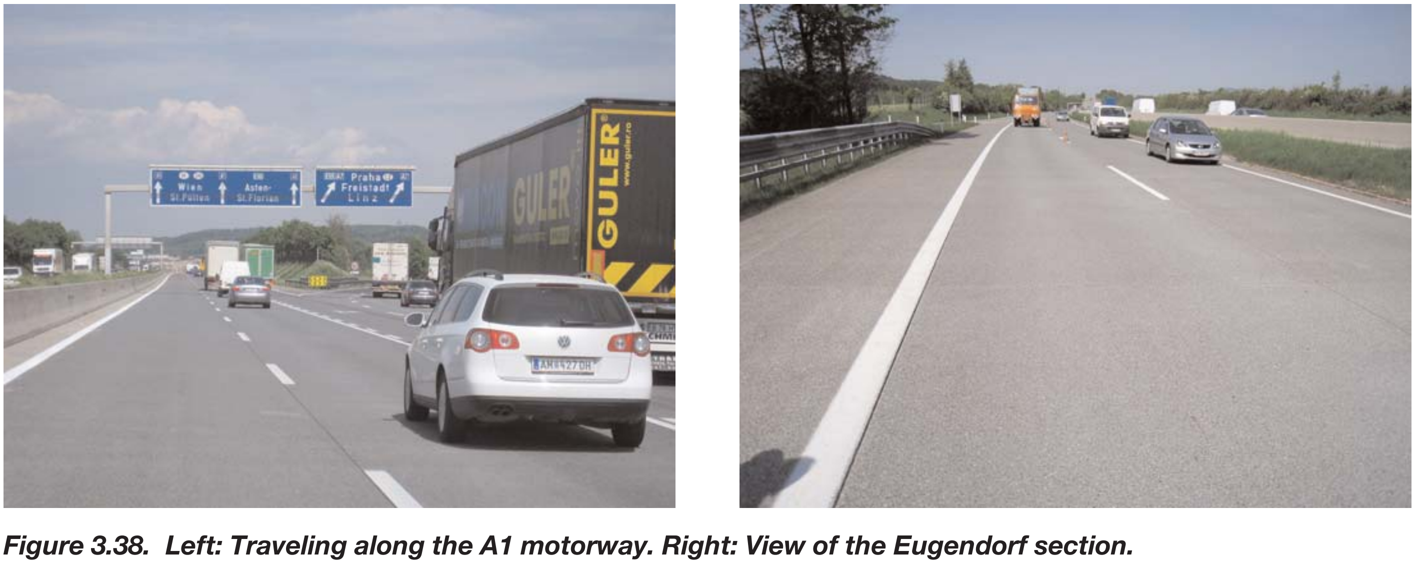


Figure 3.38. Left: Traveling along the A1 motorway. Right: View of the Eugendorf section.

Figure 3.39. The exposed aggregate texturing on the Eugendorf section.

This section near Regau was interesting in that it had transverse joint spacing of 12.5 m, resulting in numerous mid-slab transverse cracking in the section slabs. The Regau two-layer section was constructed between 1963 and 1966. Its upper PCC layer is 6 cm thick with a maximum aggregate size of 22 mm, and the lower PCC layer is 16 cm thick with a maximum aggregate size of 32 mm.

A1, Near Vorchdorf, Austria

The section at Vorchdorf is a reconstructed two-layer PCC pavement with exposed aggregate texturing (Figure 3.42). The original PCC pavement was recycled into the lower lift of the reconstructed pavement in 1999.

Figure 3.40. The section at Eugendorf exhibited slight wear in the wheelpaths of the driving lane, resulting mainly from 14 years of regular salting and plowing and 10 years of studded tires.

Figure 3.41. The old two-layer PCC Regau section, built in the 1960s, has a thin asphalt surface placed on the driving lane. The passing lane has the original concrete surface, which is more than 42 years old.

The pavement design is similar to that of the Eugendorf section:

- PCC top: 5-cm PCC with crushed gravel aggregate of maximum aggregate size 11 mm (gap-graded 0/11 mm).
- PCC bottom: 21-cm PCC with recycled PCC aggregates of maximum aggregate size 32 mm.
- Base: 5-cm asphalt.
- Subbase: 20-cm cement-stabilized aggregate.
- Slab dimensions: 3.75-m-wide driving lane slab, 3.75-m-wide passing lane slab, 3-m-wide shoulder; 5.5-m-long slabs.
- Joints: 5.5 m between transverse joints; transverse and longitudinal joints use preformed rubber seal with no bituminous hot seal.

Figure 3.42. Traffic on the Vorchdorf section of the A1 motorway.

The delegation observed that the condition of the pavement was worse than that of the Eugendorf sections, which were constructed 4 years before the Vorchdorf sections. Although there were no chronic distresses and the overall condition was relatively sound, the pavement exhibited noticeable polishing of aggregates in the wheelpath of the driving lane (Figure 3.43). As a result, the Vorchdorf sections were noisy.

Given the similarities in traffic and design, the difference in performance was observed to be one of materials. An inspection of the aggregates clearly indicated that the two pavements do not have the same aggregate in their upper layers: where the Eugendorf sections have the highly durable diabase, the Vorchdorf sections use a less-durable, locally available river gravel (Figure 3.44).

The severity of polishing in the Vorchdorf sections made obvious the need for high-quality aggregates in the top layer, if EAC is to be applied. Along with notes on construction techniques, this was one of the more valuable lessons to be exported to the United States. In addition to lessons on polishing and aggregates, the Vorchdorf sections had an untextured shoulder, so the delegation was able to develop a feel for the relatively small amount of mortar that is removed in the EAC brushing process. The unbrushed shoulder also was encountered later on the Traun sections.

A1, Near Traun, Austria

The final sections reviewed along A1 were near the intersection of A1 and A25 (Figure 3.45). These sections were reconstructed in 1994. The sections located after the merger of the two motorways receive slightly more than 100,000 vehicles per day.

The design of the sections is similar to Eugendorf and Vorchdorf:

Figure 3.44. Exposed aggregate texture on the Vorchdorf section reveals top-layer use of crushed gravel with a maximum aggregate size of 11 mm.

- PCC top: 5-cm PCC with diabase aggregate of maximum aggregate size 11 mm (gap-graded 0/11 mm).
- PCC bottom: 20-cm PCC with recycled PCC aggregates of maximum aggregate size 32 mm.
- Base: 5-cm asphalt.
- Subbase: 25-cm cement-stabilized aggregate.
- Slab dimensions: 3.75-m-wide driving lane slab, 3.75-m-wide passing lane slab, 3-m-wide shoulder; 5.5-m-long slabs.
- Joints: 5.5 m between transverse joints; transverse and longitudinal joints use preformed rubber seal with no bituminous hot seal.

Figure 3.43. The Vorchdorf sections showed noticeable polishing in the wheelpaths despite being only 9 years old.

Figure 3.45. View of the Traun section along A1. Note the lack of texture on the shoulder.

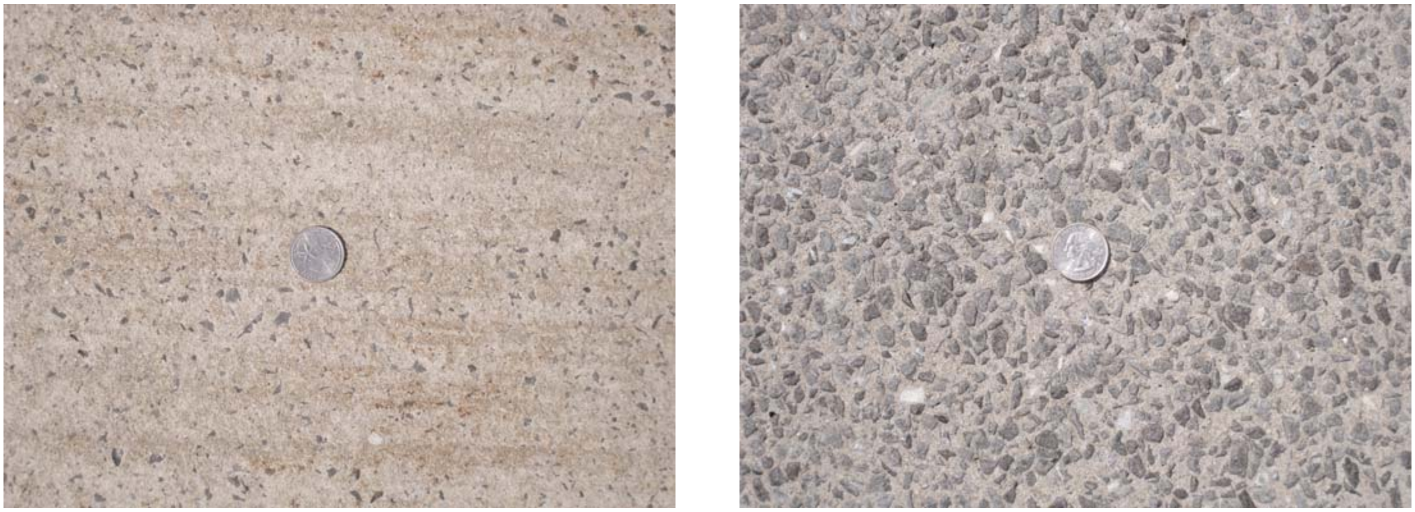


Figure 3.46. Left: Unbrushed shoulder from a section along A1 near Traun, Austria. Right: EAC textured pavement from another section of A1.

The condition of the Traun sections was very good. The pavement sections examined by the delegation showed no distresses. Little polishing was observed in the wheelpath, an impressive observation given the age of the pavement and the conditions it experiences. The noise level was loud, but noise was difficult for the delegation to judge given the high volume of traffic experienced while reviewing the sections. It should be noted that the top layer used diabase, and the high-quality aggregate seemed to be performing well after 14 years of high-volume traffic. The Traun sections were again evidence that, provided that quality construction techniques are present, aggregate quality in the top lift is the second most important factor in an effective two-layer EAC pavement.

The Traun sections had an unbrushed and untextured shoulder, so the delegation was able to develop a feel for the relatively small amount of mortar that is removed in the EAC brushing process. Figure 3.46 illustrates the significant texture generated simply by removing mortar from the surface within anywhere between 7 and 20 hours of paving.

Success Factors for Two-Layer EAC Composite PCC Pavements

The R21 delegation left its tour of Europe impressed with the number and quality of two-layer PCC pavements visited. Furthermore, the delegation saw in EAC a potentially beneficial surfacing for American pavements. EAC texture currently is the surfacing used for bare concrete pavements in the three countries visited. It is the standard in Austria; it is becoming the standard in Germany (and is replacing Germany's decades of experience with longitudinal burlap drag); and it is used on provincial highways in the Netherlands.

The benefits of two-layer PCC with EAC texture are reduced noise, durable friction numbers, and improved smoothness. The two-layer method manages to reduce costs in circumstances where high-quality aggregates are costly and in short supply. The concrete paver for the upper layer must be modified to meet special requirements, including the orientation of the vibrators and the use of a super-smoother. The thickness of the upper layer ranged from 5 to 9 cm in the pavements visited by the delegation. Austria specifies a 5-cm minimum with experienced paving operations; Germany also uses 5 cm. The Netherlands uses a minimum 9-cm thickness for the upper layer. The thickness of the lower layer can vary to accommodate the structural design requirements. The two-layer EAC projects visited were durable (over 18 years old in Austria), not requiring any additional maintenance. In short, the two-layer composite PCC pavement is a sustainable technology because of its durability, use of recycled concrete in the lower layer, lower maintenance costs, and limited use of high-quality aggregate in the thin upper layer.

The delegation also established that laboratory tests and experiments must be performed using project aggregates to establish an optimum mixture for two-layer construction and EAC texturing. Particulars that deserve attention include the water/cement ratio and strength and durability (especially regarding the use of fly ash, which is common in the United States but not in Europe). There is also a need to cast slab specimens for determining appropriate textures and brush timing. In the lower-layer mix, the mixture should be stiff enough so that dowels and tiebars can be inserted behind the paver. Furthermore, the mix must be designed economically, using lower-cost materials to offset the cost of two-layer construction, but the lower layer must be of adequate strength as an important structural component of the pavement.

The top-layer mixture should be more fluid than that of the lower layer because it requires minimal vibration. Furthermore, to be a safe, quiet roadway, it must contain high-quality, highly durable aggregate with an appropriate cubical shape. To achieve the EAC texture, a combination of curing compound and retarding agent rather than plastic sheeting is used, and it is applied immediately after the upper layer is placed. After brushing, the surface must again be treated with a curing compound, and frequent testing of the EAC texture is necessary to ensure an appropriate texture depth. The timing and quality of surface brushing are critical to successfully reducing noise and increasing friction. According to the recommendations of the delegation's hosts, the maximum aggregate size in the upper layer should be 8 mm or less to minimize noise levels. Austria, on the basis of long-term measurements, has made its maximum aggregate size 8 mm and does not build 11 mm any longer because of distance from large projects. As indicated, the texture depth in Austria is specified to fall between 0.8 mm and 1.0 mm.

All hosts of the delegation identified and reiterated two critical success factors for two-layer EAC composite PCC pavements. First, more than a typical single-layer pavement, the two-layer construction requires a consistent, quality effort. In addition to the use of two separate pavers, several small modifications were noted by the delegation (including the use of two string lines to guide the pavers) in observing the construction of a two-layer PCC pavement in Germany. In addition, the success of the brushing technique depends greatly on the experience of the construction crew, particularly the operator of the brush. For this technique to succeed in the United States, the delegation believes that the R21 project will need to "import" a knowledgeable EAC brushing expert when test sections are built.

The second and final critical success factor is that the upper layer must involve a careful mix design and, most important, a high-quality aggregate of the appropriate shape and durability. The delegation noted that in all EAC pavements surveyed the quality of the aggregate was a major contributor to the overall condition and life span of the surfacing. This observation was confirmed by the engineers and researchers in Europe.

References

1. *Report on 2006 Tour of Long-life Concrete Pavements in Europe and Canada.* FHWA-PL-07-027. Federal Highway Administration, 2007.
2. Sommer, H. Developments for the Exposed Aggregate Technique in Austria [Entwicklungen für das Waschbetonverfahren in Österreich]. *Proc., 7th International Symposium on Concrete Roads,* Vienna, Austria, Oct. 3–5, 1994.
3. Teuns, K. C. J. G., M. J. A. Stet, and W. van Keulen. Full-Scale Pavement Tests of Exposed Aggregate Concrete: Acoustical Aspects and Friction Characteristics. *Proc., 9th International Symposium on Concrete Roads,* Istanbul, Turkey, April 27–30, 2003.
4. van Keulen, W., and A. van Leest. The Acoustical Properties of Optimized Exposed Aggregate Concrete in the Netherlands. *Proc., 9th International Symposium on Concrete Roads,* Istanbul, Turkey, April 27–30, 2003.
5. van Leest, A., and W. van Keulen. The Structural Properties of Optimized Exposed Aggregate Concrete in the Netherlands. *Proc., 9th International Symposium on Concrete Roads,* Istanbul, Turkey, April 27–30, 2003.
6. Fleischer, W. Concrete for Heavily Loaded Modern Traffic Areas (part 1). *Beton,* Nov. 2003, pp. 536–538.
7. Fleischer, W. Concrete for Heavily Loaded Modern Traffic Areas (part 2). *Beton,* Dec. 2003, pp. 592–597.
8. Fults, K. *Quiet Pavement Systems in Europe.* FHWA-PL-05-011. Federal Highway Administration, 2005.
9. Stinglhammer, H., and H. Krenn. Noise Reducing Exposed Aggregate Surfaces—Experience and Recommendations [Lärmmindernde Waschbetonoberflächen—Erfahrungen und Empfehlungen]. *Proc., 7th International Symposium on Concrete Roads,* Vienna, Austria, Oct. 3–5, 1994.
10. Haider, M., J. Steigenberger, and H. Piber. Long-Term Performance of Low-Noise Concrete Pavements. *Proc., 10th International Symposium on Concrete Roads,* Brussels, Belgium, Sept. 18–22, 2006.
11. Haider, M. Lärmemission von Fahrbahnoberflächen—Betonstraßen. *Austrian Conference on Concrete Roads,* Vienna, Austria, 2007.
12. Wikipedia. Quartzite. http://en.wikipedia.org/w/index.php?title=Quartzite&oldid=215845290. Accessed May 31, 2008.
13. National Park Service. Golden Gate National Recreational Area: Diabase FAQ. www.nps.gov/goga/forteachers/diabase-faq.htm. Accessed May 27, 2008.
14. Krenn, H., and H. Stinglhammer. New from Old: Recycling Concrete Pavements [Aus alt mach neu: Betondeckenerstellung in recyclingbauweise]. *Proc., 7th International Symposium on Concrete Roads,* Vienna, Austria, Oct. 3–5, 1994.
15. Steigenberger, J. Concrete Roads in Austria: The Newest Trends and Developments. *Proc., International Concrete Roads Conference,* Bratislava, Slovakia, 2003.

CHAPTER 4

Asphalt Surfaced Composite Pavement System

Several European countries have built thin, high-quality asphalt surfacing on newly placed concrete pavements for many years (*1*). Two main types of asphalt surfaces were identified during the surveys, although other types (particularly microsurfacing) also have been placed successfully:

- **Porous asphalt.** The surfacing in the Netherlands included both one- and two-layer porous asphalt. The one-layer porous was 5 cm, and the two porous layers were 2.5 and 4.5 cm thick. The porous asphalt surface was constructed over continuously reinforced concrete pavement (CRCP) and has produced excellent results for up to 10 years of performance. This design is the standard in the Netherlands. Other countries known to build this type of design include the United Kingdom, France, Belgium, and Italy.
- **SMA.** The stone matrix asphalt (SMA) surfacing in Germany ranged from 2 to 4 cm thick and included a high-quality aggregate and polymer modified binders. These composite pavements were sawed and sealed at transverse and longitudinal joints when placed over jointed plain concrete pavement (JPCP). Beginning in the early 1990s, SMA has been placed on JPCP, and more recently (2007–2008) it has been placed over CRCP to reduce reflection cracking. This SMA surfacing is now the standard in Germany.

Italy has constructed many miles of CRCP with a porous asphalt concrete (AC) surfacing. This design has existed on the ring road around Rome since the early 1990s and carries heavy traffic. About every 7 to 10 years, the porous AC needs to be milled off and replaced because of clogging from fines or other problems. The total structural design life is 40 years. A cost comparison conducted in the 1990s of the composite AC/CRCP versus the conventional semi-rigid pavement with an AC surface over lean concrete or concrete-treated base (CTB) shows the following, where R equals the ratio of cost of composite versus the conventional (*1*):

- Construction cost: R = 1.3
- Maintenance: R = 0.3
- User costs: R = 0.55
- Total life cycle costs: R = 0.87

This chapter includes the R21 research project's May 2008 survey results for thin, high-quality asphalt surfaces over concrete that were observed in the Netherlands and Germany.

Netherlands Composite AC/CRCP Projects

Noise has been a big issue in the Netherlands for at least two decades. This is especially true in urban areas where highways are near houses. The Netherlands has built several major projects in the past 10 years using porous asphalt surfacing over CRCP and has considerable confidence in this design. The following projects are among those visited on this and other occasions:

- A12, west of Utrecht, 1998
- A76, Southern Netherlands, 8 km, 1991
- A5, Schiphol Amsterdam Airport, 5 km, 2000
- A50, Eindhoven, 35 km, 2004–2005
- A73, Province of Limburg, between Venlo and Echt-Susteren, 42 km, 2007

The challenge is how to provide low noise and good friction, as well as reduced splash and spray. The Netherlands believes that porous asphalt over CRCP provides a good solution.

Exposed aggregate (small stone, 4/8 mm) is approximately equal in noise quality to a dense AC mixture. The two look similar, and one may be confused regarding which is which. However, porous AC provides < 3 dB(A) than cross-tined PCC. Porous AC usually fails from raveling over CRCP. No reflection cracking has occurred for this design. The Netherlands expects 8 to 10 years of life from the porous AC surface but expects overall porous AC/CRCP to be a "perpetual" pavement, where only the surface needs to be replaced over time as needed.

Porous AC mixtures and layering used in the Netherlands include the following:

- Single semi-porous AC layer: 2.5 to 3 cm, 14% air voids (called semi-porous) in porous AC surface course. No modified asphalts used in Limburg Province, but they are used on national highways.
- Double porous AC layers: Surface semi-porous AC layer plus elastic stress absorbing interlayer (SAMI).
- Triple AC layers: Semi-porous AC surface, elastic layer, more porous AC layer (25% air voids) directly on PCC to provide drainage. Dense AC is 7% air voids.

It is expected that porous AC/PCC will require more maintenance. They expect to mill off the top semi-porous layer and replace when needed—about every 8 to 15 years, mainly because of raveling.

A12 AC/CRCP Composite Project

This project was surveyed in May 2008. The survey consisted of walking along portions of the project that could be accessed safely and observing the pavement from the outer shoulder, noting all types of distress and taking photographs.

The project is located west of Utrecht on the A12, in the southbound direction between km 64.36 and 67.66 (this is just before exit 19) (*2–4*). The highway consists of three lanes in the southbound direction and inner and outer shoulders. This project is a typical heavily trafficked freeway with controlled access that carries a large volume of auto (100,000 vehicles per day in 1998) and truck traffic between Arnhem and Utrecht. This freeway is one of the main routes into Germany (Figure 4.1).

The design of this porous AC over CRCP is given as follows (*2–4*):

- Porous AC surfacing.
- 250-mm CRCP.
- Mean as-constructed strength of concrete: 57 MPa at 90 days.
- 60-mm AC dense-graded base layer.
- 256-mm AGRAC subbase layer.
- 261-mm sand sublayer.
- Subgrade.

The various moduli of these layers are provided in Table 4.1.

The following observations were made regarding the visual condition of the pavement:

- Overall condition was very good.
- Smoothness: Ride rating was "very good," or about 4.0 on a scale of 0 to 5.
- Raveling of the porous asphalt friction surface layer (Figure 4.2). This layer had been in service for 10 years. The raveling was not excessive but likely will necessitate that the surface layer be replaced within about 2 to 3 years.
- The measured noise level was not known, and a current measurement would be useful. It appeared to have relatively low noise during the drive to the site. The raveling of the porous asphalt surface was somewhat discernible. A photo taken on the shoulder showed considerable fines infiltrating the porous AC surface (Figure 4.3).
- No clear transverse reflection cracking was observed from the underlying CRCP. There were slight indications in several locations, but even after 10 years no distinct transverse cracking existed (Figure 4.4). There was no longitudinal cracking either, except possibly in one location that may have been out of the project limits.

Figure 4.1. A12 between Utrecht and Ede, Netherlands, May 2008.

A73 Porous AC/CRCP Composite Pavement Project

The A73 is a 42-km, four-lane divided freeway with inner and outer shoulders. This project is a heavily trafficked freeway with controlled access that carries a large volume of traffic (truck traffic consisted of 7,000 trucks per day in one direction in the first year). The project is located in the south Netherlands Province of Limburg to connect the city of Venlo, via Roermond, to the existing A2 highway near the community of Echt-Susteren. The recently completed A73 is shown in Figures 4.5 and 4.6.

This project, completed in 2007, was surveyed in May 2008. Discussions were held concerning the design, materials, and construction. The R21 delegation then performed a visual

Parameter	Design Objective	Actual Realized
Thickness sand subgrade	250 mm	261 mm
E-modulus sand subgrade	100 MPa	>200 MPa
k-value subgrade	0.045 N/mm^3	~0.070 N/mm^3
Thickness lean concrete base	150 mm	Not realized
E-modulus base	9.000 MPa	-
Thickness AGRAC base	250 mm	256 mm
E-modulus AGRAC base	Not designed	4.000 MPa
Composed k-value	0.118 N/mm^3	~0.160 N/mm^3
Thickness asphalt interlayer	60 mm	Approximately 60 mm
E-modulus asphalt interlayer	Unknown	7,500 MPa
Thickness concrete	252 mm nonreinforced	250 mm min./261 mm average
Strength class concrete	C45	C57 average

Table 4.1. Summary of A12 Design and As-Constructed Pavement Properties

survey consisting of driving and walking along portions of the project that could be accessed safely, observing the pavement from the outer shoulder and on off-ramps, and noting any distress and taking photographs.

This two-layer porous asphalt surfacing over CRCP composite pavement consists of the following structure:

- 2.5-cm porous asphalt 4/8 mm (modified with polymer).
- 4.5-cm porous asphalt 6/11 mm (modified with polymer).
- 25-cm CRCP with 0.7% reinforcement (at exits, lanes are bare 32-cm CRCP).
- Concrete quality of the pavement: C35/45.
- 6-cm dense asphalt base course with E-mod of 400 N/mm^2.
- Granular subbase with an E-mod of 400 N/mm^2.
- Sand layer of 500 mm with an E-mod of 100 N/mm^2.
- Subgrade has a k-value of 0.036 N/mm^3 (E-mod 75 N/mm^2), sand and gravel with good grading curve.

No transverse steel was used. Longitudinal steel was lapped. Transverse supports for the steel were placed at 20-degree

Figure 4.2. Raveling of porous AC surfacing in the outer lane wheelpaths of the A12 motorway.

Figure 4.3. Close-up of the porous asphalt surface of the A12 motorway. Note fines infiltrating the porous asphalt surface on the edge of the traffic lane.

Figure 4.4. A12 motorway between Utrecht and Ede after 10 years in service.

angles from perpendicular to eliminate any possibility of transverse cracking over the transverse steel supports (Figure 4.7). Transverse supports served as tiebars.

Plastic inserts were used for longitudinal joints. They were placed at 10 cm deep, or 40% of the 25-cm slab thickness. This provided for an effective depth to form the longitudinal joint.

The paving was 12 m wide and consisted of two lanes and two shoulders, as illustrated (for another similar project) in Figure 4.8.

The CRCP surface was textured longitudinally with burlap drag. No curing compound was applied. Thin, whole plastic sheets were used to cure the PCC for 7 days (which reduces the brushed texture). A tack coat of 0.2 kg/m^2 emulsion was applied twice because of the texturing.

The CRCP was cracked at about 2- to 3-m spacing. The transverse cracking in the CRCP ramps is shown in Figure 4.9.

Figure 4.5. Completed A73 composite AC/CRCP motorway in the Netherlands, May 2008.

Figure 4.6. Double-layer porous AC surface of the A73 motorway, recently opened to traffic.

Figure 4.7. A73 CRCP reinforcing steel. The transverse supports are placed at a 20-degree angle from transverse perpendicular.

Figure 4.8. Paving of CRCP motorway in the Netherlands.

Some additional details of the design of this AC/CRCP pavement are as follows:

- Design life: 40 years.
- Annual number of traffic days/year: 270.
- Average daily traffic (averaged over 7 days per week), heavy traffic in one direction: 7,000 initially.
- Annual growth in traffic: 2.5%.
- Tire types that will be used on the road:
  - Type of tire: 30% single, 30% double, 40% wide tire.
  - The wander of the traffic across the traffic lanes and over the longitudinal joints:
    - Merge lane: 2% of traffic, 94% lateral wander.
    - Heavy traffic lane: 93% of truck traffic, 92% lateral wander.
    - Fast lane: 5% of truck traffic, 92% lateral wander.
    - 1% of traffic on the shoulder edge and 5% over the longitudinal joints.

Figure 4.9. Transverse cracking on the unsurfaced A73 CRCP.

The truck axle load distribution (single, tandem, and tridems) are given in Table 4.2.

It is planned to remove and replace the top 2.5 cm of porous AC as needed over time (perhaps every 7 to 8 years). Filling of the voids with fines also may be needed, which would increase the pavement/tire noise level. The quality of construction was believed to be very good.

Terminal anchors. Four are used at bridges with 7-m spacing center to center. They are 1.5 m deep from top of CRCP.

The visual condition of the pavement was found to be as follows:

- Smoothness: Ride rating was “very good,” or about 4.8 on a scale of 0 to 5.
- The porous asphalt friction surface layer was just opened to traffic and was in excellent condition.

Load Class	Single, Tandem, Tridem Axle Load (kN)	Average of Axle Load (kN)	Percentage of Heavy Loaded Highway
1	20–40	30	20.26
2	40–60	50	30.72
3	60–80	70	25.98
4	80–100	90	12.46
5	100–120	110	6.45
6	120–140	130	2.67
7	140–160	150	1.00
8	160–180	170	0.31
9	180–200	190	0.12
10	200–220	210	0.03
Maximum axle load [kN]			210
Number of axles per truck			4.0

Table 4.2. Axle Load Distribution of All Types of Axles

Figure 4.10. A ramp end on the A73 showing the unsurfaced CRCP.

- The noise level of the surface appeared to be very low. We observed the noise level of vehicles driving off the exit ramp from the porous AC onto the bare, transversely tined CRCP at end of the ramp (Figure 4.10). There was a significant noise increase on the bare CRCP.
- No transverse reflection cracking or any other kind of cracking was observed from the underlying CRCP.
- The bare CRCP was observed on off-ramps. It was spaced at about 2 to 3 m, but longer at the free ends of the ramps. The cracks were tight and typical of cracks of newly constructed CRCP.
- Overall condition was excellent, and the delegation's hosts stated that the construction quality was excellent on this project.

SMA/JPCP AND SMA/CRCP, Germany

A11 Motorway SMA/JPCP, Near Berlin

Germany has built SMA surfaces over a few JPCP since 1992–1993, when a section was built on the A11 near Berlin. This particular section was not visited on this trip, but it included the following design and construction details, which are similar to the project on the A93 built in 1995–1996 (*5*) (Figures 4.11 and 4.12):

- 4-cm SMA surfacing with crushed gravel and a polymer modified bitumen for a binder. The bitumen content was 6.4% and air voids were 5.96%.
- Adhesion layer (tack coat) consisting of a polymer modified bitumen emulsion was placed and fine gravel was placed on top to prevent damage from truck tires.

With permission of ISCP.

Figure 4.11. German adhesion tensile strength test between SMA and the JPCP slab surface (5).

- Transverse joints were cut into the SMA/JPCP and sealed with bitumen soon after placement of the SMA.
- 26-cm JPCP doweled transverse joints at 5 m.
- 15-cm cement treated or lean concrete base course.
- 25 cm of a granular frost protection layer.

An adhesion tensile strength test was conducted in the field, as shown in Figure 4.11, that showed a range of 0.59 to 0.87 N/mm^2, which met the German standard of

With permission of ISCP.

Figure 4.12. Sawed and sealed joints on the A11 near Berlin in 1993 (5).

0.50 N/mm². A small area of pavement that was not covered with the fine granular material to prevent damage was noted to have been disturbed by truck tires, and the tensile strength at this location was much lower than that achieved with the fine granular material. After 15 years of heavy truck traffic, the SMA/JPCP section on the A11 was still performing well.

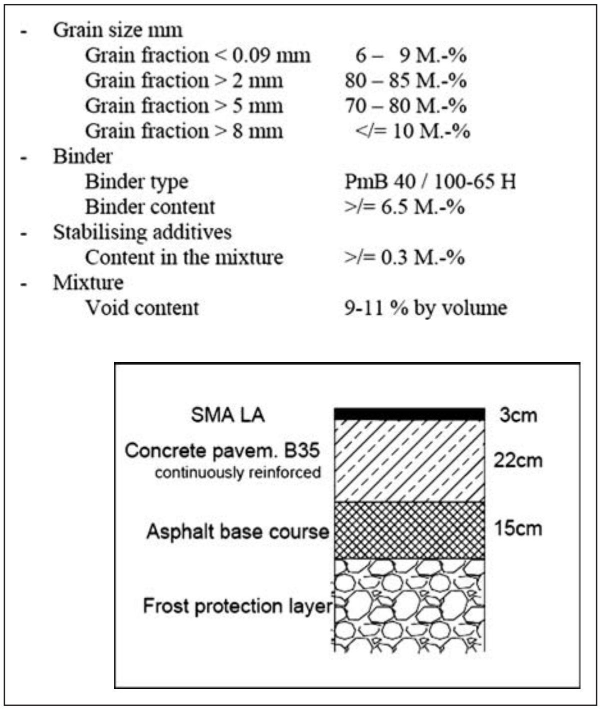
B56 Highway SMA/CRCP

Recently, additional testing has been conducted using a special low-noise SMA over CRCP. Figure 4.13 shows the grain size, binder, and air void content, which is 9% to 11% by volume for the B56 highway. Note that the field void content was specified as 10% to 15%.

A93 Motorway SMA/JPCP, South of Munich

One of the oldest German projects was built in 1995–1996 south of Munich on the A93. This project was surveyed by the R21 research team in May 2008, and photos of the pavement are shown in Figures 4.14 through 4.18. The design consisted of the following:

- 3-cm SMA surface. The SMA was paved in two 5.5-m passes over PCC because of the width of the paver. It is not known if an adhesive layer (tack coat) was applied to the PCC surface prior to placement of the SMA, as was done on the A11 described.
- Saw and seal on transverse joints (over PCC transverse joints) and on longitudinal joints (between paving passes) looked very good after 13 years, with the exception of those that were patched.
- 26-cm JPCP with 5 m doweled joint spacing over a 15-cm lean concrete base.



- Grain size mm	
Grain fraction < 0.09 mm	6 – 9 M.-%
Grain fraction > 2 mm	80 – 85 M.-%
Grain fraction > 5 mm	70 – 80 M.-%
Grain fraction > 8 mm	</= 10 M.-%
- Binder	
Binder type	PmB 40 / 100-65 H
Binder content	>/= 6.5 M.-%
- Stabilising additives	
Content in the mixture	>/= 0.3 M.-%
- Mixture	
Void content	9-11 % by volume

With permission of ISCP.

Figure 4.13. Details of the low-noise SMA used in 2007 in Germany (5).

References

1. Darter, M. I. *Report on the 1992 U.S. Tour of European Concrete Highways.* FHWA-SA-93-012. Federal Highway Administration, 1993.
2. Van der Ven, D., K. P. Drenth, R. J. Dekkers, and L. Houben. Monitoring Program CRCP Highway Pavement: Interim Performance Evaluation. *Proc., 7th International Conference on Concrete Pavements,* International Society for Concrete Pavements, Orlando, Fla., 2001.
3. Dekkers, R. J., and D. van der Ven. 10 Years Monitoring the A12. Technical Report. KOAC-NPC, Netherlands, 2006 (in Dutch).
4. Dekkers, R. J., and W. F. Stas. Monitoring the A12. Asfalt nr. 3. Netherlands, Sept. 2000 (in Dutch).
5. Holler, F. Continuously Reinforced Concrete Pavement with SMA Coating—The Composite Structure for the Challenges of the Future. *Proc., 9th International Conference on Concrete Pavements,* International Society for Concrete Pavements, San Francisco, Calif., 2008.

Figure 4.14. A93 motorway in Germany showing SMA over JPCP with sawed and sealed joints after 13 years of heavy truck traffic.

Figure 4.15. A93 SMA over JPCP with sawed and sealed transverse and longitudinal joints. Note patch placed in wheelpath of transverse joints.

Figure 4.16. A93 SMA/JPCP motorway near Munich, with sawed and sealed longitudinal and transverse joints.

Figure 4.17. A93 motorway showing transverse sawed and sealed joint in SMA over JPCP after 13 years of heavy traffic. In center of photo, note longitudinal joint that is also sawed and sealed.

Figure 4.18. Close-up of A93 SMA surface and transverse sawed and sealed joint over JPCP after 13 years of heavy traffic. Some transverse joints required patching for unknown reasons.

CHAPTER 5

Critical Observations Drawn from Field Survey in Europe

Potential Sections for R21 Composite Pavement Database

The survey included the examination of several composite pavement sections that are candidates for inclusion in the SHRP 2 Renewal Project R21 database (Table 5.1). This database was set up in Phase 1 of the R21 contract to include design, materials, climate, traffic, construction, and performance data from selected asphalt concrete (AC)/portland cement concrete (PCC) and PCC/PCC composite pavements. The database includes all inputs from the *Mechanistic-Empirical Pavement Design Guide* (*MEPDG*) (*1*), as well as other available performance data.

The surveyed pavements include nine EAC/JPCP sections that exhibited very good performance. Currently, the R21 database includes only one such section (the section in Detroit built in 1993). The exposed aggregate concrete (EAC) surfaces represent the most promising type of thin, high-quality surface for composite concrete pavements.

The surveyed European pavement sections also include three porous AC surfaces and one stone matrix asphalt (SMA) surface section that exhibited very good performance.

Summary of European Field Survey

The composite pavement types observed in the Netherlands, Germany, and Austria in the summer of 2008 performed well and were believed by the highway agencies involved to be economical.

Composite Concrete Sections

The following points were taken from the survey of two-layer PCC in Germany, Austria, and the Netherlands.

1. Two-layer EAC surface over jointed plain concrete pavement (JPCP) is being used extensively today in all three countries visited, as well as in others, such as Belgium. This experience extends for more than 20 years and covers a range of climates, including harsh winter conditions at high elevations and milder sea-level climates. Their performance has been exceptional, carrying large volumes of heavily loaded European and international trucks with very little deterioration.
2. The economic advantage of this two-layer pavement lies in the lower-cost, thicker lower concrete layer. All contractors and government officials who were asked about this issue believed that the two-layer concrete pavement would be economical wherever high-quality aggregate was expensive and especially where recycled concrete could be used as the lower layer.
3. The exceptional characteristics of the EAC surfacing lies in its noise-abatement abilities (similar to dense AC material), its ability to maintain a long-term friction coefficient and to not polish, and the durability of the surface, enabling it to resist studded tires and other types of wear.
4. The sustainability advantage of this type of pavement is nowhere more evident than on the 300-km A1 motorway across Austria. A1 was gradually reconstructed by recycling the existing AC/PCC pavement into the lower layer of a new PCC/PCC pavement. The lower PCC mix was designed to accommodate recycled asphalt pavement (RAP) that had bonded to coarse recycled concrete aggregates. The amount of RAP in the lower PCC mix can be as much as 15% of the total coarse aggregate. The remaining RAP is used as base material. The long life achieved with this pavement is also likely to show substantial savings in natural materials, lane closures for maintenance, and accidents arising from lane closures.
5. The typical design and materials used in these pavements are as follows:
   a. Top layer of 5 to 9 cm of exposed aggregate concrete that includes a high-quality, gap-graded, polish-resistant aggregate with a top size of 8 mm. It was recommended

Country	Highway	Pavement Type	Year Constructed	Layer Thicknesses	Comments
Netherlands	**A12**	AC/CRCP	1998	5 cm porous AC 25 cm CRCP 6 cm AC	First AC/CRCP project
	A50	AC/CRCP	2002	7 cm porous AC 25 cm CRCP 6 cm AC	Two-layer porous AC
	A73	AC/CRCP	2007	7 cm porous AC 25 cm CRCP 6 cm AC	Two-layer porous AC
	N279	EAC/JPCP	2000	9 cm EAC 18 cm JPCP	Main construction
	N279	EAC/JPCP	2000	9 cm EAC 18 cm JPCP	Section P quartzite
Germany	**A6**	EAC/JPCP	2008	5 cm EAC 25 cm JPCP	Major new construction
	A93	EAC/JPCP	1995	7 cm EAC 19 cm JPCP	13 years of very heavy trucks
	A93	Long. burlap	1995	7 cm EAC 19 cm JPCP	
	A93	2 Long. tining	1995	7 cm EAC 19 cm JPCP	
	A93	Long. grooved	1995	7 cm EAC 19 cm JPCP	
	A93	Diamond grind	1999	7 cm EAC 19 cm JPCP	
	A93	SMA/JPCP	1995	3 cm EAC 7+19 cm JPCP	Sawing and sealing of SMA and joints
	A93	EAC/JPCP	2004	7 cm EAC 19 cm JPCP	19 cm recycled PCC
Austria	**A1**	EAC/JPCP	1993	4 cm EAC 21 cm JPCP	21 cm recycled PCC
	A1	EAC/JPCP	1999	5 cm EAC 21 cm JPCP	21 cm recycled PCC
	A1	EAC/JPCP	1994	5 cm EAC 20 cm JPCP	20 cm recycled PCC
	A1	EAC/JRCP	1963	6 cm EAC 16 cm JRCP	Still in service, badly cracked

Table 5.1. European Composite Pavement Sections Included in the R21 Database

to use 5/8-mm gradation to obtain best surface texture (gap-grading is not a must; gradation overall is situation dependent; 11 cm is too large a maximum size).

b. The EAC texture should be measured and specified in two different ways:

(1) Texture depth measured by the standard ASTM sand patch procedure. The texture is somewhat varied between countries, but research shows that shallower texture depth reduces noise. The Austrian recommendation is to target 0.8 mm. The German contractor also recommended 0.8 mm.

(2) The appropriate number of aggregates in a specific 5-cm by 5-cm square area is 55 in Austria. This test provides a check of the spacing of the aggregates. It may be that not achieving this was the main reason for the high noise level on the Detroit EAC.

(3) Both of these tests are necessary to control the texture and noise level of the EAC surface.

c. The cement content of this mix is relatively high. Thickness of the top layer should be 5 cm; if it is too thick, segregation may occur.

d. 19 to 25 cm of lower-cost concrete (often recycled concrete), placed with dowels and tiebars. Dowel position in the lower lift is helped by adequate thickness of the lower lift, 15 cm minimum for this purpose. The dowel is placed at mid-depth of composite thickness. The upper lift thickness should be at least three times the largest aggregate size. The lower lift has lower cement content. The lower-quality aggregate in the lower lift can be recycled material. Be careful to not sacrifice too much strength. In addition, be careful about using recycled materials from nonpavement sources.

e. The base layer is composed of unbound aggregate or hot mix asphalt.

f. The transverse joints are approximately 5 m, with dowel bars and tiebars across longitudinal joints.

g. The construction uses two pavers, one to place the lower layer and the other following immediately behind with the top layer. Mixing can be done with two plants, but it is done in Europe with one plant and specially designed mixers.

Before construction, laboratory trials are needed to determine what local materials may be used to achieve appropriate mix. Also required will be the development of a test strip at MnROAD to give both contractor and researcher an opportunity to develop skills necessary to achieve a successful surface texture.

Laboratory tests must be done using project aggregates to establish optimum mixture and aggregate gradation for construction, ability to texture the surface of slabs, the timing of texturing in slabs, and so forth. The process should begin with laboratory tests to construct test slabs that are sprayed and brushed to ensure that gradation gives the desired texture. Freeze-thaw testing is also recommended. The sand patch test should be used to investigate depth of texturing. Sand in the mix is a concern. In addition, reduce vibrating energy and use T-shaped vibrators. There is also a need to include a superplasticizer in the concrete mixtures.

6. The two layers bond securely; there has been no instance where this wet-on-wet bond has broken. Field observation of cross sections showed a well-bonded upper and lower layer with little to no desegregation between layers.

Composite Asphalt Sections

The following points were taken from the survey of AC/PCC composite pavements in the Netherlands and a discussion of experience with AC/PCC composite pavements with experts in the Netherlands, Germany, and Austria.

1. Two-layer composites featuring asphalt surfaces over JPCP and continuously reinforced concrete pavement (CRCP) are being used in the Netherlands and Germany, as well as in other countries, such as Belgium and the United Kingdom.
2. Porous asphalt surfaces (similar to an open-graded friction course in the United States) are placed over CRCP in the Netherlands, the United Kingdom, Italy, and other countries. Problems mentioned with porous asphalt over CRCP include raveling (which is the major problem requiring future rehabilitation) and filling with fines after a few years, which would negate the low-noise benefit. No reflection cracking has occurred over CRCP for up to 10 years.
3. SMA is used over JPCP and CRCP in Germany and other countries. This experience extends over 10 to 15 years. Reflection cracking is a problem when JPCP is used, and the joints reflect through unless significant efforts are made. Sawing and sealing above transverse and longitudinal joints have been effective in Germany. SMA over CRCP also has been effective in not reflecting through.
4. SMA is used in harsh winter conditions in Germany; porous asphalt is used in milder climates such as the Netherlands, the United Kingdom, and Italy. The recommendation received in these countries (particularly Austria, where serious icing problems occurred) is that porous asphalt not be used in deep-freeze areas, because of the difficulty of controlling icing and the amount of deicing materials needed. Thus, it is not recommended for the MnROAD test site.
5. The performance of both types of surfaces has been exceptional, carrying large volumes of heavily loaded European and international trucks with very little deterioration over a 10- to 13-year period.
6. The economic advantage of this two-layer pavement lies in the lower cost of the lower concrete layer. All contractors and government officials who were asked about this believed that the two-layer asphalt-surfaced concrete pavement would be economical wherever high-quality aggregate was expensive and especially where recycled concrete could be used as the lower layer.
7. The exceptional characteristics of the porous asphalt surfacing include its ability to abate noise (the lowest noise of all known surfaces), to maintain the friction coefficient and to not polish, to prevent splash or spray, and to be renewed quickly whenever needed in the future. Porous asphalt currently is the surfacing used on CRCP in the Netherlands, the main reasons being its low-noise, no-splash-and-spray, and high-friction qualities. Six or more large projects have been built on freeways with this composite design, and good performance has been achieved over 10 years. All these projects are in milder climates in the Netherlands.

8. The sustainability advantage of this type of pavement lies in its long-life perpetual-pavement design concept, where the base slab is designed to not fatigue significantly (no punchouts) and the surface can be renewed rapidly. In the Netherlands, only the upper 2.5-cm layer is removed and replaced. The lower 4-cm layer is not removed.
9. The following are the design and materials for the porous AC friction course over CRCP:
    - *a.* Both a single and a double porous asphalt surface have been constructed. The double-layer porous asphalt, which provides a very low-noise surfacing, is designed as follows:
        - (1) 2.5-cm porous asphalt 4/8 mm (modified with polymer).
        - (2) 4.5-cm porous asphalt 6/11 mm (modified with polymer).
    - *b.* Timing of placement of the porous AC: The porous asphalt is the last work item on the project. Therefore, after the CRCP is placed there normally is a period of several weeks or months before the AC surfacing is placed. This is done to avoid damaging the final surface by construction traffic. The surface of the CRCP is textured using a longitudinal burlap drag to provide mechanical interlock with the asphalt surfacing.
    - *c.* A tack coat of 0.2 kg/m^2 emulsion is applied twice because of the texturing.
    - *d.* 19 to 25 cm of lower-cost concrete (often recycled concrete), placed with sufficient longitudinal reinforcement (e.g., 0.7%) and tiebars. The reinforcement position in the layer is important and should be above mid-depth of the CRCP slab. The lower lift has lower cement content. The lower-quality aggregate in the lower lift can be recycled material, as long as the strength and thickness are sufficient to produce very low fatigue damage.
    - *e.* A base layer specifically of hot mix asphalt provides sufficient random crack spacing of 1 to 2 m maximum.
    - *f.* Construction is similar to conventional pavements, where the lower layer is placed, textured, and cured and allowed to gain sufficient strength before the AC layer is placed. This is one of the last items of work to avoid damaging the surface.
    - *g.* Before construction, laboratory trials are needed to determine what local materials may be used to achieve appropriate mix for the porous asphalt and the lower concrete layer. The asphalt surface typically bonds securely when the lower concrete layer is textured and a tack coat is used. There has been no instance where this wet-on-wet bond has broken. A double dose of tack coat is used in the Netherlands because of the texturing.

Recommendations for Construction of Experimental Composite Pavement Systems Under SHRP 2 Renewal Project R21

Major factors that should be considered in an experiment at MnROAD include the following:

1. Type of AC material used in the surface course. SMA is recommended for the MnROAD site. It has been used successfully in Germany under a similar climate. Mn/DOT has built several SMAs with success, and these specifications should prove adequate. Sawing and sealing of the transverse and longitudinal joints are recommended.
2. Other asphaltic surfaces, such as Superpave® and rubberized surfacing, can be placed. The saw-and-seal technique is recommended for handling reflection cracking for any of these mixtures.
3. The thickness of the lower layer can be varied to provide adequate structure for the I-94 loadings and prevent fatigue damage and cracking. *MEPDG* provides for a significant thickness reduction with the AC surface, which dampens out temperature and moisture gradients through the slab. It is recommended that the upper layer be held constant at 7 cm.
4. The material used in the lower layer should be recycled concrete (using the large aggregate component only).
5. The material used in the upper layer must be a very high-quality aggregate, such as granite or quartzite, with low potential for polishing. The particles must be reasonably cubical. The maximum texture of 8 mm should not be varied.
6. Wire brushing to achieve the proper texture depth requires care and skill and should be practiced on another section of pavement. Laboratory slabs should be cast to practice the wire brushing to achieve proper texture depth. The 5-cm by 5-cm square test to count the number of aggregate peaks also should be included, with a target value of 55.

Reference

1. *Mechanistic-Empirical Pavement Design Guide: A Manual of Practice,* interim ed. American Association of State Highway and Transportation Officials, Washington, D.C., 2008.

TRB OVERSIGHT COMMITTEE FOR THE STRATEGIC HIGHWAY RESEARCH PROGRAM 2*

CHAIR: **Kirk T. Steudle,** *Director, Michigan Department of Transportation*

MEMBERS

H. Norman Abramson, *Executive Vice President (Retired), Southwest Research Institute*
Anne P. Canby, *President, Surface Transportation Policy Partnership*
Alan C. Clark, *MPO Director, Houston-Galveston Area Council*
Frank L. Danchetz, *Vice President, ARCADIS G&M, Inc.*
Dan Flowers, *Director, Arkansas State Highway and Transportation Department*
Stanley Gee, *Acting Commissioner, New York State Department of Transportation*
Michael P. Lewis, *Director, Rhode Island Department of Transportation*
Susan Martinovich, *Director, Nevada Department of Transportation*
John R. Njord, *Executive Director, Utah Department of Transportation*
Charles F. Potts, *Chief Executive Officer, Heritage Construction and Materials*
Pete K. Rahn, *Director, Missouri Department of Transportation*
Gerald Ross, *Chief Engineer, Georgia Department of Transportation*
George E. Schoener, *Executive Director, I-95 Corridor Coalition*
Kumares C. Sinha, *Olson Distinguished Professor of Civil Engineering, Purdue University*

EX OFFICIO

Victor M. Mendez, *Administrator, Federal Highway Administration*
Ron Medford, *Acting Administrator, National Highway Transportation Safety Administration*
John C. Horsley, *Executive Director, American Association of State Highway and Transportation Officials*

LIAISONS

Tony Kane, *Director, Engineering and Technical Services, American Association of State Highway and Transportation Officials*
Jeffrey F. Paniati, *Executive Director, Federal Highway Administration*
John Pearson, *Program Director, Council of Deputy Ministers Responsible for Transportation and Highway Safety, Canada*
Margie Sheriff, *Director, SHRP 2 Implementation Team, Office of Corporate Research, Technology, and Innovation Management, Federal Highway Administration*
Michael F. Trentacoste, *Associate Administrator, Research, Development, and Technology, Federal Highway Administration*

RENEWAL TECHNICAL COORDINATING COMMITTEE*

CHAIR: **Randell H. Iwasaki,** *Executive Director, Contra Costa Transportation Authority*

MEMBERS

Rachel Arulraj, *Director of Virtual Design & Construction, Parsons Brinckerhoff*
Michael E. Ayers, *Director of Pavement Technology Services, American Concrete Pavement Association*
Thomas E. Baker, *State Materials Engineer, Washington State Department of Transportation*
John E. Breen, *Al-Rashid Chair in Civil Engineering, The University of Texas at Austin*
Daniel D'Angelo, *Director and Deputy Chief Engineer, Office of Design, New York State Department of Transportation*
Rocco A. DePrimo, *Manager of Quality Assurance, Utility Manager, Keith and Schnars, P.A.*
Steven D. DeWitt, *Chief Engineer, North Carolina Turnpike Authority*
Tom Donovan, *Senior Right of Way Agent (retired), California Department of Transportation*
Alan D. Fisher, *Manager, Construction Structures Group, Cianbro Corporation*
Michael Hemmingsen, *Davison Transportation Service Center Manager, Michigan Department of Transportation*
Bruce Johnson, *State Bridge Engineer, Oregon Department of Transportation, Bridge Engineering Section*
Leonnie Kavanagh, *PhD Candidate, Seasonal Lecturer, Civil Engineering Department, University of Manitoba*
Thomas W. Pelnik III, *Director, Innovative Project Delivery Division, Virginia Department of Transportation*
Mary Lou Ralls, *Principal, Ralls Newman, LLC*
John J. Robinson, Jr., *Assistant Chief Counsel, Pennsylvania Department of Transportation, Governor's Office of General Counsel*
Michael Ryan, *Vice President, Michael Baker Jr., Inc.*
Cliff J. Schexnayder, *Eminent Scholar Emeritus, Arizona State University*
Ted M. Scott, II, *Director, Special Projects, American Trucking Associations, Inc.*
Gary D. Taylor, *Professional Engineer*
Thomas R. Warne, *President, Tom Warne and Associates, LLC*
Gary C. Whited, *Program Manager, Construction and Materials Support Center, University of Wisconsin–Madison*

AASHTO LIAISON

James T. McDonnell, *Associate Program Director for Engineering, American Association of State Highway and Transportation Officials*

FHWA LIAISONS

Cheryl Allen Richter, *Infrastructure Research Program Manager, Office of Infrastructure Research and Development, Federal Highway Administration*
Steve Gaj, *Leader, System Management and Monitoring Team, Office of Asset Management, Federal Highway Administration*

CANADA LIAISON

Lance Vigfusson, *Assistant Deputy Minister of Engineering & Operations, Manitoba Infrastructure and Transportation*

---

*Membership as of May 2010.

Related SHRP 2 Research

- Geotechnical Solutions for Soil Improvement, Rapid Embankment Construction, and Stabilization of the Pavement Working Platform (R02)
- Modular Pavement Technology (R05)
- Real-Time Smoothness Measurements on Portland Cement Concrete Pavements During Construction (R06E)
- Composite Pavement Systems (R21)
- Using Existing Pavement in Place and Achieving Long Life (R23)
- Preservation Approaches for High Traffic Volume Roadways (R26)

WWW.TRB.ORG/SHRP2

THE NATIONAL ACADEMIES™
Advisers to the Nation on Science, Engineering, and Medicine

The nation turns to the National Academies—National Academy of Sciences, National Academy of Engineering, Institute of Medicine, and National Research Council—for independent, objective advice on issues that affect people's lives worldwide.
www.national-academies.org

ISBN 978-0-309-12887-2
90000
9 780309 128872