# Long-Life Concrete Pavements in Europe and Canada

International Technology Scanning Program


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U.S. Department of Transportation
Federal Highway Administration

In Cooperation With

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National Cooperative Highway
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## NOTICE

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| 16. Abstract<br>Long-life concrete pavements require less frequent repair and rehabilitation and contribute to highway safety and congestion mitigation. The Federal Highway Administration, American Association of State Highway and Transportation Officials, and National Cooperative Highway Research Program sponsored a scanning study to identify design philosophies, materials requirements, construction procedures, and maintenance strategies used in Europe and Canada to build long-life concrete pavements.<br>The scan team observed that concrete pavements in the countries visited are designed for 30 or more years of low-maintenance service life. The countries are responding to pavement-tire noise issues in urban areas by using exposed aggregate surface. Some use catalog designs for pavements and geotextiles as a separator layer between the cement-treated base and concrete pavement.<br>Team recommendations for U.S. implementation include using two-lift construction to build pavements, developing pavement design catalogs, using better-quality materials in pavement subbases, paying greater attention to cement and concrete mixture properties, using a geotextile interlayer to prevent concrete slabs from bonding to the cement-treated base, and using exposed aggregate surfaces to reduce noise. | | | |
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Sponsors of the trip were the Federal Highway Administration (FHWA), the American Association of State Highway and Transportation Officials, and the National Cooperative Highway Research Program. American Trade Initiatives, Inc., under contract to FHWA, oversaw the execution of this international scan and coordinated the group's travel.

# Long-Life Concrete Pavements in Europe and Canada


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for

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# International Technology Scanning Program

The International Technology Scanning Program, sponsored by the Federal Highway Administration (FHWA), the American Association of State Highway and Transportation Officials (AASHTO), and the National Cooperative Highway Research Program (NCHRP), accesses and evaluates innovative foreign technologies and practices that could significantly benefit U.S. highway transportation systems. This approach allows advanced technology to be adapted and put into practice much more efficiently without spending scarce research funds to re-create advances already developed by other countries.

FHWA and AASHTO, with recommendations from NCHRP, jointly determine priority topics for teams of U.S. experts to study. Teams in the specific areas being investigated are formed and sent to countries where significant advances and innovations have been made in technology, management practices, organizational structure, program delivery, and financing. Scan teams usually include representatives from FHWA, State departments of transportation, local governments, transportation trade and research groups, the private sector, and academia.

After a scan is completed, team members evaluate findings and develop comprehensive reports, including recommendations for further research and pilot projects to verify the value of adapting innovations for U.S. use. Scan reports, as well as the results of pilot programs and research, are circulated throughout the country to State and local transportation officials and the private sector. Since 1990, about 70 international scans have been organized on topics such as pavements, bridge construction and maintenance, contracting, intermodal transport, organizational management, winter road maintenance, safety, intelligent transportation systems, planning, and policy.

The International Technology Scanning Program has resulted in significant improvements and savings in road program technologies and practices throughout the United States. In some cases, scan studies have facilitated joint research and technology-sharing projects with international counterparts, further conserving resources and advancing the state of the art. Scan studies have also exposed transportation professionals to remarkable advancements and inspired implementation of hundreds of innovations. The result: large savings of research dollars and time, as well as significant improvements in the Nation's transportation system.

Scan reports can be obtained through FHWA free of charge by e-mailing *international@fhwa.dot.gov*. Scan reports are also available electronically and can be accessed on the FHWA Office of International Programs Web Site at *www.international.fhwa.dot.gov*.

# International Technology Scan Reports

## International Technology Scanning Program: Bringing Global Innovations to U.S. Highways

### Safety

*Safety Applications of Intelligent Transportation Systems in Europe and Japan* (2006)

*Traffic Incident Response Practices in Europe* (2006)

*Underground Transportation Systems in Europe: Safety, Operations, and Emergency Response* (2006)

*Roadway Human Factors and Behavioral Safety in Europe* (2005)

*Traffic Safety Information Systems in Europe and Australia* (2004)

*Signalized Intersection Safety in Europe* (2003)

*Managing and Organizing Comprehensive Highway Safety in Europe* (2003)

*European Road Lighting Technologies* (2001)

*Commercial Vehicle Safety, Technology, and Practice in Europe* (2000)

*Methods and Procedures to Reduce Motorist Delays in European Work Zones* (2000)

*Innovative Traffic Control Technology and Practice in Europe* (1999)

*Road Safety Audits—Final Report and Case Studies* (1997)

*Speed Management and Enforcement Technology: Europe and Australia* (1996)

*Safety Management Practices in Japan, Australia, and New Zealand* (1995)

*Pedestrian and Bicycle Safety in England, Germany, and the Netherlands* (1994)

### Planning and Environment

*Active Travel Management: The Next Step in Congestion Management* (2007)

*Managing Travel Demand: Applying European Perspectives to U.S. Practice* (2006)

*Transportation Asset Management in Australia, Canada, England, and New Zealand* (2005)

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*Superior Materials, Advanced Test Methods, and Specifications in Europe* (2004)

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*Meeting 21st Century Challenges of System Performance Through Better Operations* (2003)

*Traveler Information Systems in Europe* (2003)

*Freight Transportation: The European Market* (2002)

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*Methods and Procedures to Reduce Motorist Delays in European Work Zones* (2000)

*Innovative Traffic Control Technology and Practice in Europe* (1999)

*European Winter Service Technology* (1998)

*Traffic Management and Traveler Information Systems* (1997)

*European Traffic Monitoring* (1997)

*Highway/Commercial Vehicle Interaction* (1996)

*Winter Maintenance Technology and Practices—Learning from Abroad* (1995)

*Advanced Transportation Technology* (1994)

*Snowbreak Forest Book—Highway Snowstorm Countermeasure Manual* (1990)

## Infrastructure—General

*Audit Stewardship and Oversight of Large and Innovatively Funded Projects in Europe* (2006)

*Construction Management Practices in Canada and Europe* (2005)

*European Practices in Transportation Workforce Development* (2003)

*Contract Administration: Technology and Practice in Europe* (2002)

*European Road Lighting Technologies* (2001)

*Geometric Design Practices for European Roads* (2001)

*Geotechnical Engineering Practices in Canada and Europe* (1999)

*Geotechnology—Soil Nailing* (1993)

## Infrastructure—Pavements

*Long-Life Concrete Pavements in Europe and Canada* (2007)

*Quiet Pavement Systems in Europe* (2005)

*Pavement Preservation Technology in France, South Africa, and Australia* (2003)

*Recycled Materials In European Highway Environments* (1999)

*South African Pavement and Other Highway Technologies and Practices* (1997)

*Highway/Commercial Vehicle Interaction* (1996)

*European Concrete Highways* (1992)

*European Asphalt Technology* (1990)

## Infrastructure—Bridges

*Prefabricated Bridge Elements and Systems in Japan and Europe* (2005)

*Bridge Preservation and Maintenance in Europe and South Africa* (2005)

*Performance of Concrete Segmental and Cable-Stayed Bridges in Europe* (2001)

*Steel Bridge Fabrication Technologies in Europe and Japan* (2001)

*European Practices for Bridge Scour and Stream Instability Countermeasures* (1999)

*Advanced Composites in Bridges in Europe and Japan* (1997)

*Asian Bridge Structures* (1997)

*Bridge Maintenance Coatings* (1997)

*Northumberland Strait Crossing Project* (1996)

*European Bridge Structures* (1995)

**All publications are available on the Internet at *www.international.fhwa.dot.gov.***

# Abbreviations

**AADT** average annual daily traffic

**AASHTO** American Association of State Highway and Transportation Officials

**ASFiNAG** Autobahnen und Schnellstraßen Finanzierungs Aktiengesellschaft

**ASR** alkali-silica reaction

**BASt** Bundesanstalt für Straßenwesen (German Federal Highway Research Institute)

**CBR** California bearing ratio

**CRIC** Centre National de Recherche Scientifique et Technique pour L'industrie Cimentière (Research Center of the Belgian Cement Industry)

**CRCP** continuously reinforced concrete pavement

**CROW** The Netherlands' national information and technology platform for infrastructure, traffic, transport, and public space

**CSH** or **C-S-H** calcium silicate hydrate

**DBFO** design-build-finance-operate

**DOT** department of transportation

**ELLPAG** European Long-Life Pavement Group

**ESAL** equivalent single-axle load

**ETR** electronic toll road

**EU** European Union

**FEBELCEM** Fédération de l'Industrie Cimentière Belge (Belgian Cement Industry Federation)

**FEHRL** Forum of European National Highway Research Laboratories

**FHWA** Federal Highway Administration

**FSV** Österreichische Forschungsgesellschaft Straße—Schiene—Verkehr (Austrian Association for Research on Road, Rail, and Transport)

**GNP** gross national product

**HMA** hot-mix asphalt

**IRI** International Roughness Index

**JPCP** jointed plain concrete pavement

**MET** Ministere de l'Equipemente et des Transports (Walloon Ministry of Equipment and Transport)

**MTO** Ontario Ministry of Transportation

**MTQ** Ministère des Transports du Quèbec (Québec Ministry of Transport)

**NCHRP** National Cooperative Highway Research Program

**PCA** Portland Cement Association

**PCC** portland cement concrete

**PMS** pavement management system

**PPP** public-private partnership

**RFP** request for proposal

**RVS** Richtlinien und Vorschriften für den Strassenbau (Austrian Guideline Code for the Planning, Construction, and Maintenance of Roads)

**STIP** scan technology implementation plan

**TRB** Transportation Research Board

**TRL** Transport Research Laboratory

**TRDI** Texas Research and Development Institute

**VDZ** Verein Deutscher Zementwerke (German Cement Works Association)

**VÖZ** Vereinigung der Österreichischen Zementindustrie (Austrian Cement Industry Association)

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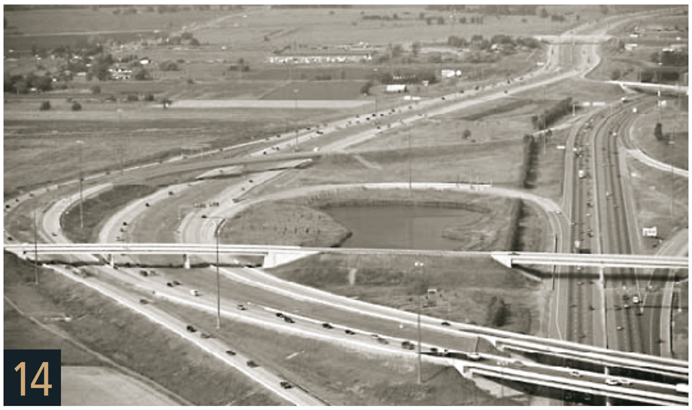
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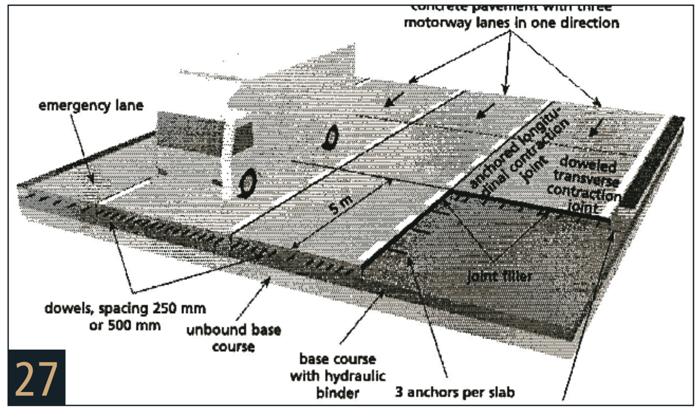
motorway lanes in one direction
emergency lane
anchored longitudinal contraction joint
doweled transverse contraction joint
5 m
joint filler
dowels, spacing 250 mm or 500 mm
unbound base course
base course with hydraulic binder
3 anchors per slab
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# Executive Summary

IN MAY 2006, A TEAM of concrete pavement and materials specialists from the United States visited Canada and five countries in Europe to identify design philosophies, materials requirements, construction practices, and maintenance strategies used to construct and manage portland cement concrete pavements with long life expectancies. They met with representatives of federal and provincial government roadway authorities, public-private partnerships for roadway construction and management, the cement and concrete pavement industries, and transportation research laboratories. The team members visited several long-lived concrete pavements and discussed with their hosts the design, construction, materials, and maintenance factors chiefly responsible for the longevity of these pavements.

The team also toured a major urban freeway operated as a public-private partnership (PPP) and talked with their hosts in each country about their policies on and experience with PPPs. This roadway construction and management approach has special relevance to long-life concrete pavements because the long time commitment typically involved favors the use of materials, design features, and construction techniques that result in long life and low maintenance.

The Technology Exchange Program of the Federal Highway Administration (FHWA) accesses and evaluates innovative foreign technologies and practices that could significantly benefit highway transportation systems in the United States. This approach allows advanced technology to be adapted and put into practice much more efficiently without spending scarce research funds to recreate advances already achieved in other countries. The main channel for accessing foreign innovations is the International Technology Scanning Program. The program is undertaken jointly with the American Association of State Highway and Transportation Officials (AASHTO) and its Special Committee on International Activity Coordination and the Transportation Research Board's National Cooperative Highway Research Program (NCHRP), with the cooperation of the private sector and academia.

## Team Members

The long-life concrete pavement scan team was made up of representatives of State departments of transportation (DOTs), FHWA, NCHRP, academia, and the consulting, cement, and concrete pavement industries. The team members were Tom Cackler (Concrete Pavement Technology Center at Iowa State University), Angel Correa (FHWA), Dan Dawood (cochair, Pennsylvania DOT), Peter Deem (Holcim (US) Inc.), Jim Duit (Duit Construction Co., Inc.), Georgene Geary (Georgia DOT), Andrew Giwsi (Kansas DOT), Amir Hanna (NCHRP), Steve Kosmatka (Portland Cement Association), Robert Rasmussen (The Transtec Group, Inc., representing the Concrete Reinforcing Steel Institute), Shiraz Tayabji (CTL Group, representing the International Society for Concrete Pavements), Suneel Vanikar (cochair, FHWA), and Gerald Voigt (American Concrete Pavement Association). They were joined for a portion of the trip by Robert Tally (cochair, FHWA). The trip reporter was Kathleen Hall (consultant).

The long-life concrete pavement (LLCP) scan effort began in November 2005 with the completion of a review that identified Australia, Austria, Belgium, Canada, France, Germany, the Netherlands, Sweden, and the United Kingdom as the countries most likely to provide useful insights into how to achieve long-lasting concrete pavements. At the scan team's initial planning meeting in Washington, DC, in December 2005, the team selected six countries to visit: Austria, Belgium, Canada, Germany, the Netherlands, and the United Kingdom. The scan trip to these countries took place May 11–27, 2006.

## Objectives

The following overview statement describes the motivation for an international scan of long-life concrete pavement technology:

Safety and mitigation of congestion are two of the most important strategic goals of the U.S. highway community. Long-life concrete pavements require less frequent repair, rehabilitation, and reconstruction, and therefore contribute to improving highway safety and mitigating congestion. Experience with long-life concrete pavements, including examples of concrete pavements that have remained in service for more than 40 years, has been noted in previous scans of European countries. Information about these long-lasting pavements and the design and construction practices that produced them will be valuable to those involved in the design, construction, and maintenance of concrete pavements in the United Sates.

In the United States, the typical design life for pavements in the past was 20 years, although a number of States use longer design lives. Major rehabilitation and reconstruction of pavements are difficult and expensive to accomplish, especially in urban areas. The next generation of portland cement concrete (PCC) pavements in the United States must be designed and constructed to achieve longer service life.

The purpose of this scan is to identify design philosophies, materials requirements, construction practices, and maintenance strategies (including winter maintenance strategies), used by selected European and other countries to construct and operate portland cement concrete pavements with life expectancies of 40 years or more, that differ from U.S. practices and would be applicable in the United States. The scope of the scan is to include the following:

- Materials evaluation and specification procedures for both virgin and recycled materials
- Methods used to design long-life concrete pavements
- Construction practices
- Maintenance practices

The ultimate benefit of the scan will be achieved by implementing technologies that will result in increased service life and reliability and decreased life-cycle costs of concrete pavements built in the United States in the future.

### *Issues of Interest*

The scan panel has also identified the following specific topics of interest pertaining to long-life concrete pavement technology in Canada and Europe:

- Materials (cement, coarse and fine aggregates, admixtures, and supplementary cementitious materials)
- Concrete mixture design
- Pavement thickness design (including geometrics, spacing, and location of joints)
- Specifications
- Construction procedures
- Maintenance procedures
- Rapid construction and rehabilitation techniques
- Performance of jointed plain, jointed reinforced, and continuously reinforced concrete pavements (JPCP, JRCP, and CRCP, respectively)
- Life-cycle costs

## Key Findings

The team's key findings and recommendations from the long-life concrete pavement scanning study are summarized below.

### *Pavement Selection Strategies*

**Long-life concrete pavements:** In every country visited, "concrete pavement" is considered synonymous with "long life." These countries expect concrete pavements to be strong and durable, provide service lives of 25, 30, or more years before rehabilitation or replacement, and require little if any maintenance intervention over the service life.

**The public and the environment:** The public is expressing concerns about environmental issues such as noise, congestion, and safety. Environmental issues, especially noise, are becoming major concerns to the driving public. In all the countries visited, there is a heavy emphasis on traffic safety, noise mitigation, congestion relief, and the use of recycled materials. In some countries, a multicriteria analysis process is used to address these factors in pavement type selection. In the United Kingdom, political forces have driven the decision that, to reduce noise, all highway pavements must have asphaltic surfaces.

**Public-private partnerships and innovative contracting:** To maintain and improve their roadway infrastructures, most European Union (EU) countries and Canadian provinces have adopted nontraditional financing methodologies such as public-private partnerships (PPP) and alternative bids. Politicians recognize the advantages of these financing mechanisms and of sharing risk with private entities. Most of the EU nations visited embraced PPP efforts to reduce the national debt and comply with EU financial requirements. As a result, contractors are accepting more responsibility for design, construction, and long-term maintenance of roadways. Under such systems, contractors are more likely to choose concrete pavement because its longer life and lower maintenance requirements reduce future risks. Another aspect of contracting practice observed was the awarding of contracts based on best value rather than low bid.

**Pavement management:** Use of pavement management systems is inconsistent among the EU countries visited and generally not a driving force in pavement type selection.

**Pavement type selection factors:** Although most countries visited state that they consider life-cycle costs, in practice, other factors such as functional class, truck traffic levels, initial cost, and environmental issues drive pavement type selection. In the province of Québec, a policy decision has been made that certain segments of the network will be concrete pavement, others will be asphalt, and others may be either. In Austria, it is policy that concrete pavement is used above a certain traffic level. The Netherlands has a similar policy.

### *Design*

**Catalog design:** Germany and Austria routinely use a design catalog to select pavement thickness and some other pavement features. The design features and thicknesses in the countries' catalogs reflect their long-term experience with their materials, climate, and traffic levels. Mechanistic modeling, laboratory testing, and field observations are used to validate the cross-sections in the design catalogs. In the Netherlands and the United Kingdom, mechanistic-empirical design software is used for project-level design work. However, these two countries construct only a few miles of concrete pavement per year. Maximum concrete slab thicknesses are a common feature of the German and Austrian design catalogs. The maximum slab thicknesses appear to be thinner than those designed in the United States for similar traffic levels and in many cases heavier trucks. Fatigue cracking does not appear to be a performance issue with these thinner concrete slabs.

**Design lives:** The design lives being used for concrete pavements in the countries visited are typically at least 30 years.

In the Netherlands, a design life of 40 years is typical, for both provincial roads and motorways. The agencies are satisfied with the design and construction practices they use to achieve service lives of up to 40 or 50 years.

**Traffic management and future expansion:** With an eye toward safety and the mitigation of congestion, widened lanes and full-depth concrete shoulders (emergency lanes that are wider than U.S. shoulders) are used in design. These emergency lanes are constructed with the same thickness and cross slope as the pavement lanes.

**Widened slabs:** Widened slabs are used routinely in the outer traffic lane to keep truck tires away from the pavement edge, thereby reducing slab stresses and deflections and extending pavement life. The traffic lane cross-section is carried out to the edge of the pavement, including the emergency lane. Some subsurface layers are daylighted beyond the edge of the concrete slab for drainage and constructability.

**Tie bars:** Most of the European countries visited place fewer tie bars across longitudinal joints to tie lanes together (about half the number used in the United States). No problems were reported with lane separation, longitudinal joint load transfer deficiency, or compromised pavement performance because of this.

**Doweled jointed concrete pavements (JCP):** In the European countries that build JCP (Germany, Austria, Belgium, and Netherlands), doweled joints with 1-inch (in) (25-millimeter (mm)) diameter bars are typically used and appear to be performing well, without joint faulting. This may be because of the large proportion and high quality of the aggregates used in the concrete mixes, which lead to good aggregate interlock and load transfer. The 1-in (25-mm) bars are used on sections that are typically 8 to 12 in (200 to 300 mm) thick and built on thick, usually stabilized, foundations.

**Continuously reinforced concrete pavement (CRCP):** This pavement type is recognized in the countries visited as a heavy-duty, long-life pavement. Some countries, such as Belgium and the United Kingdom, have a long history with CRCP. Belgium's CRCP design and construction technology was in fact adapted from U.S. practice years ago. The United Kingdom reported unique and undesirable crack patterns with skewed transverse steel. The techniques for longitudinal steel design (percent steel) varied from country to country, although crack width control appeared to be a common denominator. None of the countries visited used epoxy-coated steel, but the Québec Ministry of Transport (MTQ) in Québec, Canada, uses galvanized steel. In the Netherlands, as a rule of thumb, the thickness required for CRC is 90 percent of the thickness required for JCP. This can be confirmed with the VENCON 2.0 software; for example, for a motorway with a JCP thickness of 11 in (280 mm), the software calculates a CRCP thickness of 10 in (250 mm). In Belgium, CRCP is constructed about an inch (2 to 3 cm) thinner than JCP. Germany has just a few CRCP test sections, but on the 0.9-mile (1.5-kilometer) stretch of experimental CRCP test sections on the A-5 Autobahn near Darmstadt, the slab thickness is 9.5 in (24 cm), which is about an inch (2 to 3 cm) less than German design practice would dictate for JPCP for similar conditions. The thickness reduction was based on analyses conducted by the Technical University at Munich.

**Pavement bases:** Open-graded permeable base layers, using high-quality aggregates, are used in Canada but not in the European countries visited. Dense-graded hot-mix asphalt and cement-treated base layers were used in several countries. In Germany, where in the past cement-treated bases were constructed to bond with concrete slabs, an interlayer of either 0.2-in-thick (5-mm-thick) unwoven geotextile or dense-graded hot-mix asphalt is used now to separate a cement-treated base from the concrete layer. Unstabilized bases are used in Germany, based on the success of this base type in test sections built since 1986. Old concrete pavements in the former East Germany affected by alkali-silica reaction have also been successfully recycled for use in unstabilized bases.

## *Construction*

**Joint sealing:** Based on observations during site visits, sealed and unsealed joints appeared to have performed equally well on older projects. Belgium, however, reports that the long-term performance of unsealed joints is not the same as that of sealed joints, especially on heavily trafficked roads. Both hot-poured and compression seals are used in Austria and Germany. In Austria, strip drains (a few inches (5 to 10 cm) wide and at most 0.5 in (1.25 cm) thick) under about 3 feet (ft) (1 meter (m)) of the transverse joint in the emergency lane have recently been added as a design feature. Longitudinal contraction joints in some regions of Germany used to be left unsealed, but this practice was discontinued because it allowed water that entered unsealed longitudinal joints to flow beneath the sealant in transverse joints.

**Foundations:** Thick foundations are used for frost protection. These systems were drainable and stable, but not open graded. Recycled materials, including asphalt, concrete, and in one case, masonry from building demolition, were used in the foundations.

**Interlayers:** The use of a 0.2-in-thick (5-mm-thick) geotextile interlayer as a bond breaker between concrete pavement and cement-treated base is a recent requirement in Germany. German engineers indicated that the mortar is presumed to saturate the geotextile during construction, adding just enough stiffness to provide support while still acting as a bond breaker.

The required concrete thickness for the cement-treated base alternative was increased from 10.2 to 10.6 in (26 to 27 cm) when the design was changed from one with a bonded base to one with a base separated by from the slab by a geotextile. In the other countries visited, the typical interlayer between a concrete slab and a cement-treated base is a layer of hot-mix asphalt concrete.

**Jointless bridge joints:** A "jointless joint" bridge approach was described in the Netherlands, and although it was a trial section, the Dutch appear interested in what may be a low-maintenance solution to bridge approach joints. They made clear, however, that this technique is costly.

## *Materials*

**Cementitious materials:** Normal and blended cements, containing either slag or fly ash, are used. Limestone is allowed in all portland cements, at a dosage of up to 5 percent. Cements with varying sodium-equivalent contents (generally below 0.9 percent) or blended cements are used to mitigate alkali-silica reaction (ASR) if test results show ASR potential.

Most countries have minimum cement content requirements by mixture type. Supplementary cementitious materials are not considered in the water/cement ratio, nor as part of the cementitious materials content. In countries applying an exposed aggregate surface, mixtures and consolidation processes that produce low paste thickness at the surface are used.

**Aggregate requirements:** Great attention is given to aggregate selection, quality, and gradation, especially for the top layer, in countries using two-course construction. Good-quality aggregates are generally available (although there are cases of aggregate being imported). All of the countries use well-graded aggregates, with several separate aggregate sizes (three to four, depending on the layer).

The maximum aggregate size typically used in Europe is 0.8 in (20 mm). The top layer of concrete in two-lift construction usually has a 0.3- to 0.4-in (8- to 11-mm) maximum aggregate size. In the Netherlands, where primarily single-lift construction is done, 1.25 in (32 mm) is the maximum aggregate size. In some countries, the concrete mixtures are considered proprietary. The agency controls quality by specifying the end-product requirements.

**Recycling:** Recycled materials (including concrete and masonry from demolition) have been used in the base layers in various countries. Austria requires the use of recycled concrete and recycled asphalt pavement (RAP) in the lower layer of two-course concrete (and for base). Recycled asphalt is allowed up to a maximum of 30 percent of the coarse aggregate in these mixtures.

The polished stone value test is routinely applied by EU countries for aggregate durability assessment. In Austria, a Los Angeles abrasion test value of no more than 20 is required for the top layer in two-layer construction.

**Corrosion protection:** Québec now requires the use of galvanized rebar. Germany and Austria use tie bars coated in the middle third only and coated dowel bars.

**Compaction control:** Intelligent compaction control equipment (automated feedback on rollers, etc.) is used in Austria. The European countries visited are strict about control of compaction of all layers, and in some countries load testing of granular layers to check compaction is conducted with a small plate.

**Cement and concrete testing:** Construction process control is typically the responsibility of the contractor in the countries visited. Workability is evaluated using a compaction test, similar to the ASTM Vebe test. Ontario and Austria check the air content in hardened concrete, although in Austria this is done only if a problem is encountered or suspected. In the European countries visited, alkali-silica reaction (ASR) is controlled, if detected by preconstruction testing, using blended cements or cements with low alkali content. No country reported difficulty with controlling ASR.

**Pavement testing:** The countries visited do not perform quality control testing for noise, and no one method is used consistently from country to country to measure noise. Texture measurements are made, both for end-product and pavement management system-based data collection. The MIT-SCAN equipment developed in Germany for detecting dowel bar misalignment is specified in Canada (Ontario) for both quality control and quality assurance purposes, but not in the other countries visited. A 4-m straightedge is typically used to measure roughness in the EU countries visited. Belgium also uses the APL (Analyseur de Profil en Long, or length profile analyzer) to measure pavement profile. The smoothness of pavements on which the scan team traveled was excellent in all countries visited.

## *Maintenance*

**Maintenance techniques:** In general, most of the countries visited have had little or no need to do maintenance of concrete pavements. Joint resealing is conducted in a sporadic manner, if at all. One widely used maintenance technique is a thin asphalt overlay to correct rutting caused by studded tires or to mitigate tire-pavement noise. Only in Canada is diamond grinding used to improve smoothness on bare concrete pavements. In the United Kingdom, concrete pavement is overlaid with asphalt to reduce noise.

**Precast slabs for rapid repair:** Canada is evaluating the use of U.S.-developed precast concrete technology for rapid repair. In a field experiment the scan team visited, the team observed that panels were used for individual slab and multislab replacement. The Michigan and Fort Miller methods of placing precast slabs were examined in the Canadian experiment. Canada is also examining modification of the Michigan method. While both applications exhibited some premature distresses in the Canadian tests, primarily because of issues related to installation, the Ontario Ministry of Transportation believes that this will become a practical specialty method of construction and repair.

### *Research*

**Concrete pavement research:** In Europe, most research related to cement and concrete materials and concrete pavements is conducted by academic and trade institutions. For example, the German Cement Works Association (VDZ) in Germany is conducting research on the behavior of synthetic air entraining agents and alkali-silica reaction.

**Nanotechnology:** A cooperative venture for research in nanotechnology for cementitious materials (Nanoscience of Cementitious Materials, Nanocem) has been organized in Europe. The consortium consists of academia and industry members, with financial support from the cement industry and the European Community. This effort should lead to improvements in the durability and mechanical properties of concrete. The current focus of Nanocem's research activities is cement behavior; research into concrete mixture properties is some years away.

### *Industry Relations*

**Contractor training:** In most of the countries visited, no formal training of construction contractor personnel is routinely conducted through preconstruction meetings or other required education. Most construction training seems to occur on the job. However, most countries seemed to have well-educated and qualified field personnel. Some training is provided by the cement industry groups.

**Certification:** There are no certification standards for inspectors and contractors' employees in the European countries visited. Training is the contractor's responsibility and not a requirement. Concern was expressed that less-experienced paving construction workers come from eastern European countries, which may necessitate more training programs in the future.

**Communications:** In general, the European countries visited have good communications between contractors and highway agencies. Academic and industry input is highly valued. For example, committees of agency, industry, and academic experts are formed to develop design catalogs.

**Standards:** European standards are in the long, slow process of harmonization. Meanwhile, individual European countries continue to use their own standards. The Comité Européen de Normalisation (CEN) is mandated by the European Commission to develop standards for a variety of European Community products. The EC Construction Products Directive (CPD) requires that construction products be fit for their intended use. Works in which these products will be used must satisfy CPD requirements over an economically reasonable service life. Such products are placed on the market with a "CE" stamp. In the case of cement, even if the producer declares that a product conforms to the CEN standard, independent testing must be done to ensure this conformity. The CE "seal of approval" is useful, for example, if a paving contractor runs out of cement from one source in the middle of a paving job and must use cement from a different source (although tests have to be repeated with the new cement). CEN standards have not yet been developed, however, for many concrete paving materials (dowels, rebar, joint sealants, etc.). European (EN) or national standards continue to be used for these materials.

## Recommendations

The long-life concrete pavement scan team identified the following technologies as having the greatest potential for implementation in the United States:

**Two-lift construction:** Austria, Belgium, the Netherlands, and Germany use two-lift construction to build concrete pavements with good friction and noise characteristics, economize on the use of aggregates, and use reclaimed paving materials. In two-lift construction, a relatively exposed aggregate surface lift containing high-quality aggregates is placed atop a lift containing virgin aggregates of lesser quality or reclaimed aggregate from concrete or asphalt pavements, resulting in materials cost savings.

Two-lift construction is not new to the U.S. concrete paving industry. Two-lift paving was specified by many State DOTs in the past when wire-mesh-reinforced pavements were constructed and mesh depressors were not allowed. In recent decades, a number of States have experimented with two-lift construction to promote recycling and enhance surface characteristics.

**Catalog design:** Pavement design catalogs have been used successfully in Europe for many years. In the United States, the design of concrete pavement traditionally has been done on a project-by-project basis. This approach has served the U.S. pavement engineering community fairly well for many years. However, with the increasing difficulty of predicting traffic loads, volumes, and axle configurations, designing on a project-by-project basis may not always be required.

In addition, changes and new developments in materials have created a need for a design procedure with the flexibility to consider the effects of material properties on the responses of the pavement structure. This need is being addressed with the development of the *Mechanistic-Empirical Pavement Design Guide* (MEPDG).

The catalog design method is a simple procedure for selecting an initial pavement structure. Most of the European countries visited have routinely used design catalogs to select pavement thicknesses and some other pavement features. The countries using design catalogs recognize that simply extrapolating empirical trends is not reliable and often leads to overdesign of concrete pavements. The design features and thicknesses in the catalogs reflect long-term experience with the local climate, materials, and traffic levels. These experiences are validated through analysis by expert teams using mechanistic principles. The expert teams employ laboratory testing and field observations to validate the cross-sections in the design catalogs. The designs are defined and refined about every 5 years.

The use of a catalog for selection of pavement thicknesses and other pavement design features offers advantages of consistency and simplicity. Catalog design is not itself a design procedure, but rather a medium for identifying appropriate pavement design features for use in pavement analysis. The quickest form of developing a catalog design is simply to incorporate the standard designs that have shown good, consistent, long-term performance. A design features matrix is another part of the catalog concept that identifies alternatives for features (e.g., base types) and provides information on such items as the cost, performance, and feasibility of constructing the feature to allow an agency to make an informed decision on whether to include it in a design. Nevertheless, the information recommended in the catalog needs to be validated by laboratory and field investigations.

**Deep, high-quality foundations:** The unbound granular materials used for concrete pavement subbases in Europe are generally better quality materials (better graded, better draining although not open-graded, and with lower fines content) than the materials typically used as select fill and granular subbase in the United States. Aggregate standards were mentioned in all the countries visited. A closer look at the aggregate standards in place in the United States and a comparison to the European standard may provide some insights into improving foundations in this country.

Recycled concrete not reused in the pavement itself is commonly used in the base material of pavements in Europe. It appeared that it was also fractionated and part of the grading. Cement-treated bases were also in wide use in several countries, with an asphalt or geotextile interlayer as a separator. In addition, it was noted that intelligent compaction is used in Austria. Germany uses a plate load test for quality assurance of layer compaction equipment.

**Attention to mix design components:** One key to long-lasting concrete pavements in Europe appears to be the great attention to cement and concrete mixture properties. The mixtures produce strong, dense, and durable concrete, despite the apparent widespread presence of reactive aggregates in western Europe. The flexural strength noted in the top lift was about 1,000 pounds per square inch (7 megapascals), much higher than the typical flexural strength target in the United States. The careful consideration of cementitious materials used in the mix is one area that could yield benefits for the United States.

**Geotextile interlayer:** A key detail recently introduced in Germany for cement-treated bases is the use of a thick geotextile interlayer to prevent the concrete slab from bonding to the cement-treated base. This geotextile material is thicker than the materials commonly used for layer separation purposes in the United States. It is sufficiently porous that mortar from the fresh concrete permeates the geotextile, which provides a good mechanical bond of the geotextile to the concrete layer while achieving separation from the base layer. This geotextile may provide a suitable alternate to the asphalt interlayer used in many States.

**Low-noise exposed aggregate surfacing:** The public's concern about environmental issues is evident in densely populated, traffic-congested Europe. The solution to concrete pavement noise popular in some European countries is exposed aggregate surfacing, in which exceptionally high-quality, durable aggregates are used in the top course of the concrete slab, and a process of set retardation and abrasion is used to produce an exposed aggregate surface with good low-noise properties. Exposed aggregate is also touted as yielding other benefits, including good friction and durability. However, favorable noise levels may also be achieved by specific pavement texturing techniques.

# Chapter One
# Introduction

## Purpose of Scan

SAFETY AND MITIGATION OF CONGESTION are two of the most important strategic goals of the U.S. highway community. Long-life concrete pavements require less frequent repair, rehabilitation, and reconstruction, and therefore contribute to improving highway safety and mitigating congestion. Experience with long-life concrete pavements, including examples of concrete pavements that have remained in service for more than 40 years, has been noted in previous scans of European countries. Information about these long-lasting pavements and the design and construction practices that produced them will be valuable to pavement designers in the United States.

In the United States, the typical design life for pavements is about 20 years, although a number of States use longer design lives. Major rehabilitation and reconstruction of pavements are difficult and expensive to accomplish, especially in urban areas. Portland cement concrete (PCC) pavements built in the United States in the future must be designed and constructed for longer service life.

The purpose of this scan was to identify design philosophies, materials requirements, construction procedures, and maintenance strategies (including winter maintenance strategies), used by selected European and other countries to construct and operate portland cement concrete pavements with life expectancies of 40 years or more, that would be applicable in the United States.

The ultimate benefit of the scan will be achieved by implementing technologies that will result in increased service life and reliability and decreased life-cycle costs of concrete pavements built in the United States in the future.

## Background

While the U.S. highway community embraces the concept of long-life concrete pavements, it lacks a clear definition of what a long-life concrete pavement should be. The Federal Highway Administration's (FHWA) *Concrete Pavement Road Map,* formally known as the *Long-Term Plan for Concrete Pavement Research and Technology,*[1] identifies long-life concrete pavements as one of the 12 major tracks along which concrete pavement research over the next 7 to 10 years should be directed.

The road map team discovered that the concept of long-life pavements was difficult to define. Among the proposed definitions were the following:

- "A 'no-fix-required' pavement that would last 50 to 60 years with relatively heavy loads throughout its life"
- "Planned maintenance between 10 and 30 years, followed by heavy joint repair and possibly an overlay to take the total pavement life to 60 years"
- "A mandatory strong foundation with a thinner slab designed for 20 years of service, followed by the construction of a wraparound slab that would provide service for an additional 30 to 40 years"

Among the features mentioned as necessary to a long-life concrete pavement were the following:

- "Long-term foundation and drainage at initial construction with service life of 50 to 60 years or beyond"
- "Improvements to the functional requirements only (surface improvements)"
- "Predetermined staged construction for the slab"
- "Some major rehabilitation, but only if it can be done at very high speed and be limited to the slab only"

Yet another set of requirements for long-life concrete pavements, sharing some features with those already mentioned and identifying some not mentioned, is outlined in a paper presented at the 8th International Conference on Concrete Pavements.[2]

Given the prevailing lack of clarity and agreement on what a long-life concrete pavement should be, the concrete pavement road map identified the very first objective for this research track as "develop clear and detailed definitions of long-life concrete pavements, including information about warrants, required maintenance, a range of low- to high-traffic roadways, and other information."

The road map team specifically mentioned two topics it believed must be considered to effectively confront the issue of how to build longer-life concrete pavements: use of CRCP and costs. About the use of CRCP, the road map states the following:

> "Continuously reinforced concrete pavements (CRCP) should be considered in long-life solutions for heavy-duty pavements, but few States use the technology routinely. It would take considerable effort to reenergize CRCP, but it should be considered because it has a solid performance record in many locations."

About costs, the road map states the following:

> "The cost issue should be addressed in any final application of long-life principles. The challenge is not simply to add more 'bells and whistles,' but to add value and performance without increasing the cost significantly. Increasing life and holding the cost are inherent if long-life pavements are to have a role in pavement selection."

The challenge is not to build more conservative designs without improving existing design and construction practices, nor even to add value and performance without increasing the cost significantly. Indeed, the challenge is to increase the cost-effectiveness of concrete pavements by improving performance without increasing costs.

## Countries Building Long-Life Concrete Pavements

The variety of design, construction, and maintenance practices employed in the countries that have successful experience with long-life concrete pavements is expected to lend useful perspective on the ways long concrete pavement service lives can practically and cost-effectively be achieved.

While many countries build concrete pavements, not all have insights to offer the U.S. highway community on how to design and build long-life concrete pavements. It makes sense that the world's richer countries have the means to make investments in strategic infrastructure improvements such as long-life concrete pavements a high priority. Less economically developed countries must put strategic infrastructure improvement behind more pressing concerns, such as poverty, unemployment, violent crime, and civil unrest.

There are a variety of ways to quantify the wealth and economic development of countries.(3) Perhaps the most familiar measure is per capita (per person) gross national product (GNP). The countries with the highest per capita GNP are the United States, Canada, most of the countries in western Europe, Australia, New Zealand, Japan, and a few countries in the Middle East (although these latter ones, i.e., Israel and some of the petroleum-producing Arab states, rank among less developed economies by other measures).

A better measure of a country's relative wealth than per capita GNP is per capita purchasing power because it includes the relative prices of products. For example, Switzerland, Sweden, and Japan have higher per capita GNPs than the United States, but the United States has the world's highest per capita purchasing power because of relatively lower prices for food, housing, fuel, merchandise, and services. The countries with the highest per capita purchasing power are the United States, Canada, most western European countries, Australia, and Japan. By any of a variety of other specific and widely used economic measures, more or less the same group of countries is consistently identifiable as the world's richest and most highly developed.

In general, the most economically robust and densely populated countries have the greatest need for strategic infrastructure investments such as long-life concrete pavements. Important exceptions exist, however. For example, parts of southeastern Europe (e.g., Romania, Bulgaria, Turkey) and parts of the Indian subcontinent (India, Pakistan, and Bangladesh) are densely populated and have dense road networks, yet are economically far behind the most highly developed countries. India, for example, has an extensive road network, but the roads are overcrowded (traffic on the network has increased thirtyfold since independence in 1948), and 80 percent of villages lack all-weather roads. Other countries, most notably Canada and Australia, are sparsely populated overall, with most of the population concentrated in one or more small regions of the country. These are countries where strategic infrastructure investments such as long-life concrete pavements make sense only for those densely populated zones.

The United States is rather unusual in that it is almost completely blanketed by a dense roadway network, while at the same time it is relatively sparsely and unevenly populated.

Figures 1 and 2 illustrate where the U.S. population is concentrated. These figures provide insight into the regions of the United States for which long-life concrete pavements offer the greatest potential benefit in reducing passenger traffic congestion.

Another important place for long-life concrete pavements in the United States is on the most heavily truck-trafficked Interstate and U.S. routes, including but not limited to the east-west routes I-10, I-20, I-40, I-70, I-80, and I-90, the north-south routes I-5, I-15, I-25, I-35, I-55, I-65, and I-95, and the routes near the major ports (Miami, FL; New Orleans, LA; Houston, TX; Los Angeles, CA; Chicago, IL; and New York/New Jersey) where goods move in and out of the country.

Another factor to consider in assessing where long-life concrete pavements would be of greatest benefit in the United States is the effect that major airports have in spurring business and residential growth. Where there is a very busy airport—even in what once seemed the middle of nowhere—eventually there will be a buildup of commercial activity and housing construction. According to an article about this "aerotropolis" phenomenon in the ***The Economist,*** "when Washington Dulles National Airport opened in 1962 in rural Virginia, it was considered a white elephant, but it has spawned a high-tech corridor and now sits in the fastest-growing county in the United States. Denver's ten-year-old international airport, about 40 miles (64 kilometers) out of town, is expected to be the center of a community of 500,000 people by 2025—almost as many people as live in Denver itself."(4) ***The Economist*** article further points out that development near an airport is constrained by height restrictions on buildings, which forces growth outward rather than upward.

An additional factor to consider is the unusually rapid growth occurring in other specific regions of the country. Two examples often cited are Phoenix, AZ; and Las Vegas, NV; the fastest and fourth-fastest growing metropolitan areas in the United States. While California and Florida remain popular and populous, people are also moving to Arizona and Nevada in droves, attracted by lower housing prices. In 2005 alone, according to ***The Economist,*** 120,000 Californians were expected to move to Arizona, a group equivalent to about 2.5 percent of Arizona's existing population. In Las Vegas, driver's license records suggest that as many as 35 percent of newcomers are from California.(4)

In general, while the most densely populated areas of the United States remain the eastern seaboard and the Great Lakes region, shifts in the population are predominantly toward the southwest, west, and south. According to a recent report on urban sprawl, the top 20 fastest growing counties in the United States are in Arizona, California, Nevada, Texas, Florida, and Washington.[5]

How these and other metropolitan regions in the United States grow in coming years will be influenced by whether sprawl is controlled or uncontrolled, but in either case there is little doubt that these fast-growing regions will continue to experience rapidly increasing levels of traffic congestion. There is also no doubt that traffic congestion levels will be high even in more stably growing major metropolitan regions.

## Countries and Agencies Visited

Austria, Belgium, Canada, Germany, the Netherlands, and the United Kingdom were selected for inclusion in this international scan. They were chosen from among the countries that have the means to invest in strategic infrastructure improvements such as long-life concrete pavements, and that have population densities and passenger car and truck levels warranting consideration of long pavement service lives.

**Canada—**The scan team met in Toronto with representatives of the Ontario and Québec ministries of transport (MTO and MTQ), the Cement Association of Canada (CAC), and the consortium operating the 407 ETR, the world's first all-electronic, open-access toll highway.

**Germany—**The scan team visited the office of the German Cement Works Association (Verein Deutscher Zementwerke, VDZ) in Düsseldorf and met with personnel from the concrete technology department of the German cement industry's research institute. The team next visited the offices of the German Federal Research Institute (Bundesanstalt für Straßenwesen, BASt) in Bergisch-Gladbach, and then traveled to Munich, visiting concrete pavement sites along the way on the A-5 Autobahn. The team's final meetings in Germany were with faculty and researchers at the Technical University of Munich.

**Austria—**The scan team toured several concrete pavement sites between Vienna and Salzburg, accompanied by the head of the research institute of the Austrian Cement Industry Association (Vereinigung der Österreichischen Zementindustrie, VÖZ). The team also visited the offices of VÖZ for a meeting with representatives of the Austrian cement industry association and its research institute, as well as representatives of the Austrian Ministry of Transport, the University of Vienna, the Austrian Ministry of Finance, and Austrian concrete pavement consultants and builders. Some team members also visited a concrete paving job site in Austria to see its concrete plant and paving equipment.

While in Austria, the team attended a presentation on state-of-the-art research into nanotechnology in cement chemistry

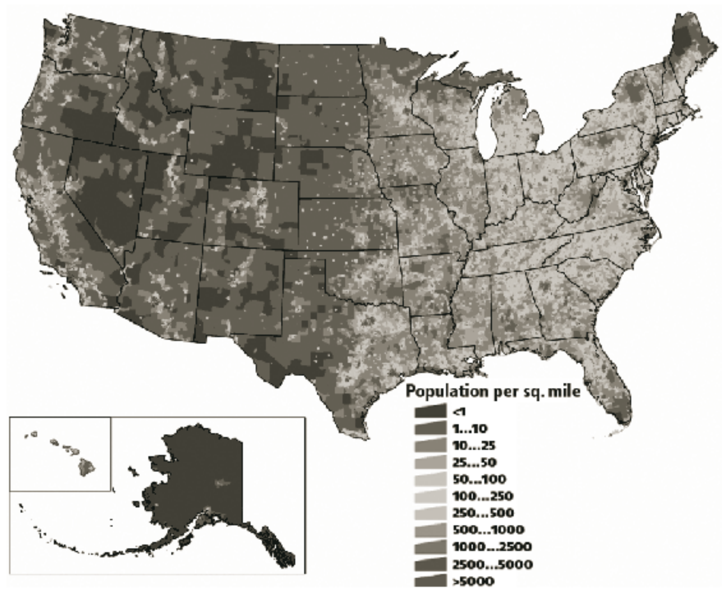


**Figure 1.** *United States population density map based on 2000 census data (1 square mi = 2.59 square km).*

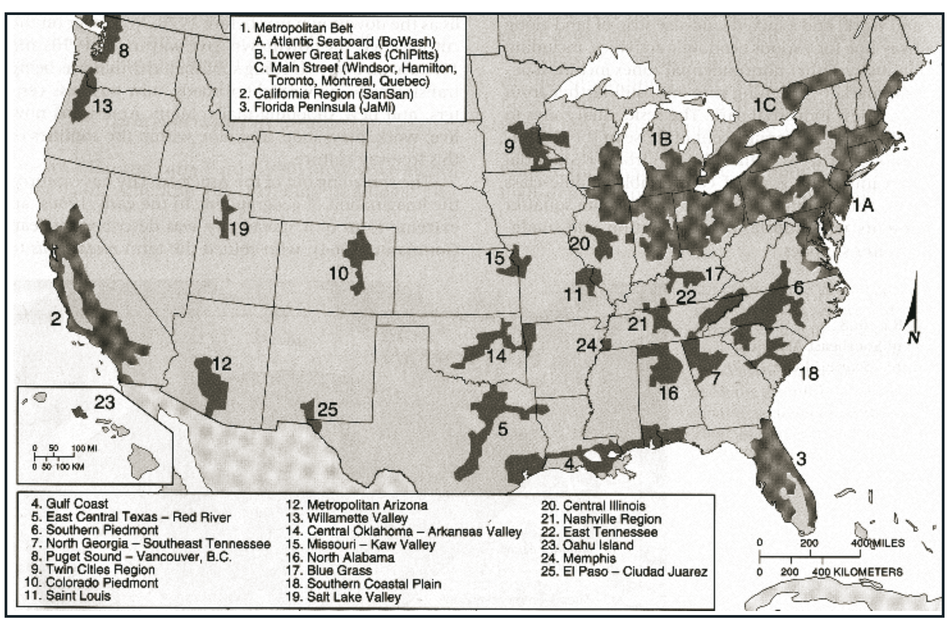


**Figure 2.** *Primary and secondary metropolitan areas of the United States.*

and microstructure being conducted by Europe's Nanocem Consortium. The director of the construction materials laboratory at the Federal Polytechnical School of Lausanne (École Polytechnique Fédérale de Lausanne, EPFL) in Switzerland gave the presentation.

**Belgium—**In Namur, the team met with personnel from the Walloon Ministry of Equipment and Transport (MET) and the Federation of the Belgian Cement Industry (FEBELCEM). The director-general of the Roads and Traffic Administration of the Flemish Community made a presentation to the scan team on concrete pavements in the Flemish region of Belgium. The team visited several long-lasting concrete pavements in Belgium with representatives of FEBELCEM.

**The Netherlands—**The team visited the office of the CROW (Foundation Center for Research and Contract Standardization in Civil and Traffic Engineering) Technology Center in Ede for presentations by CROW personnel and representatives of the Dutch cement industry, the provincial and state road authority in the Netherlands, and Dutch concrete paving contractors.

**The United Kingdom—**In England, the team met with representatives of the concrete pavement association, Britpave, and the Transport Research Laboratory (TRL).

## Comparison of Countries Visited with United States

Because the purpose of this scan is to study the performance of long-life concrete pavements in other countries for insights into how long-life concrete pavement performance and cost-effectiveness in the United States can be improved, it is relevant to make some comparisons between the United States and the countries visited.

**Geography, climate, and soils[5]—**The continental United States lies between the 25th and 49th parallels. The populous southeastern portions of the Canadian provinces of Ontario and Québec also lie below this latitude and share the climate of the Great Lakes region. In Québec, temperatures range from -22°F (-30°C) in the winter to 86°F (30°C) in the summer, and total precipitation is typically between 31.5 and 55 inches (in) (800 and 1,400 millimeters (mm)) per year. The depth of frost penetration is typically 4 to 10 feet (ft) (1.2 to 3.0 meters (m)).

The predominant soils in the Toronto area are high-nutrient soils (alfisols), which are also found in the United States in large areas of Ohio, Indiana, Michigan, Wisconsin, Minnesota, Pennsylvania, and New York.* Further north in the Ontario and Québec provinces, conifer forest soils (spodosols) predominate, as they do in large areas of Maine, New Hampshire, Vermont, upper New York, and northern Michigan and its Upper Peninsula. The vicinity of Ottawa and Montréal, along the Ottawa River, is an area of soils with little profile development (inceptisols); such soils are also found (although do not prevail) in southern New York, central and western Pennsylvania, West Virginia, eastern Ohio, and the Pacific Northwest.

The European countries visited are almost entirely located farther north than the northern border of the continental United States. Munich (in southern Germany) and Vienna (in central Austria) are at about the 48th parallel, further north than both Duluth, MN, and Seattle, WA. Central and northern Germany, Belgium, the Netherlands, and the United Kingdom all lie further north than the northern border of the United States.

Belgium, the Netherlands, and northern Germany all lie along the North Sea and have a temperate maritime climate, with cool, mild winters, fairly cool summers, and rain throughout the year. The Netherlands in particular is known (and indeed, named) for its low elevation: about half of the country's area is less than one meter above sea level, and large portions of it are actually below sea level, protected from flooding by an extensive network of dykes and dunes.

The climate in central (e.g., Frankfurt) and southern (e.g., Munich) Germany is cool and temperate, with mild, occasionally very cold winters and warm but rarely hot summers. The climate is similarly temperate, ranging to continental (with humid westerly winds) in upper Austria along the Danube River Valley, where both Salzburg and Vienna are located. The Alps, however, dominate the area and climate of southern Austria.

The climate of England, which makes up the central and southern portions of Great Britain, is temperate, with rainfall throughout the year and temperatures ranging typically from about 23°F (-5°C) in the winter to about 86°F (30°C) in the summer. It is driest in the east, near the Atlantic Ocean, and warmest in the southwest, near the European continent. The terrain is predominantly rolling hillside, with some low mountains in the north and low-lying marshland in the east. Snowfall is fairly uncommon except at higher elevations.

The same types of soils described as common in southeastern Canada and northeastern and north central United States—high-nutrient alfisols, conifer forest spodosols, and inceptisols without much profile development—are also common throughout much of northern Europe and the British Isles.

Overall, the geography, climate, and soils of the countries visited most resemble those of the upper Great Lakes and northeastern regions of the United States. Concrete pavements in other areas of the United States are subjected to colder winter temperatures and/or higher summer temperatures, as well as lower precipitation levels, than these regions.

** All soils information in this section is taken from reference 5.*

**Roadway networks**[**]—The United States has by far the most extensive road network of any country in the world: some 3.9 million miles (mi) (6.3 million kilometers (km)), nearly twice the mileage of second-place India, with 2.0 million mi (3.3 million km).[(6)] The mileage of roads in some of the other countries visited for this scan range from some 0.9 million mi (1.4 million km) in Canada to some 72,000 mi (116,000 km) in the Netherlands. However, the countries visited have denser roadway networks than the United States. Belgium, with 7.9 mi of road per square mi (4.9 km of road per square km) of land area, has the fourth-highest roadway density in the world, followed by the Netherlands at eighth with 4.7 mi/mi$^2$ (2.9 km/km$^2$), Austria at 10th with 3.9 mi/mi$^2$ (2.4 km/km$^2$), and the United Kingdom at 21st with 2.4 mi/mi$^2$ (1.5 km/km$^2$). The density of the roadway network in Germany is not among the top 40 in the world and, not surprisingly, neither is that of Canada or the United States.

Germany, however, has one of the most crowded roadway networks in the world, ranking fourth at 312.9 vehicles per mi (194.5 vehicles per km). Among the countries visited, the United Kingdom and the Netherlands are next, ranking 23rd and 24th at 100.2 and 93.2 vehicles per mi (62.3 and 57.9 vehicles per km), respectively. The traffic density of the United States and Belgium are similar, at 58.1 and 57.8 vehicles per mi (36.1 and 35.9 vehicles per km). Neither Austria nor Canada is in the top 50 countries in roadway traffic density.

Similar statistics emerge for annual roadway use, in vehicle-miles per year per mile of road network (or equivalently, vehicle-kilometers per year per km of road network). Germany ranks fourth in the world at 2.555 million vehicle-miles per mile, the United Kingdom ranks 10th at 1.243 million vehicle-miles per mile, Belgium ranks 11th at 1.062 million vehicle-miles per mile, and the Netherlands ranks 13th at 944,000 vehicle-miles per mile. The United States, meanwhile, ranks 17th at 700,000 vehicle-miles per mile. Neither Austria nor Canada is among the top 30 countries in terms of annual roadway use.

Roadway crowding and annual roadway use in the Toronto-Montréal corridor in southeastern Canada are comparable to those in the northeastern United States in general, while in both countries, traffic density is lower in other regions. While traffic density in Austria is lower than in European countries farther to the west, the reductions in trade barriers associated with the development of the European Union, along with the collapse of the Soviet Union, are contributing to increasing truck traffic between eastern and western Europe, and one of the principal routes for this traffic is through Austria.

*** All statistics in this section are taken from reference 6.*

# Chapter Two
# Pavement Selection Strategies

## Canada

About 75 percent of the population of Canada is concentrated within 100 mi (160 km) of the nation's southern border with the United States, with more than 60 percent living along the Great Lakes and St. Lawrence Seaway in the provinces of Ontario and Québec. Nearly 80 percent of Canadians live in urban areas. As in the United States and other highly developed nations, the economy is dominated by the service sector, which employs about 75 percent of all Canadians, about the same percentage as in the United States.[7] At the same time, the primary goods sector is an important part of the Canadian economy, especially the logging and oil industries. Possessing vast deposits of oil and natural gas as well as abundant hydroelectric power, Canada is one of the few developed countries that are net exporters of energy.

Canada has no federal equivalent of the U.S. Federal Highway Administration (FHWA) or American Association of State Highway and Transportation Officials (AASHTO). The provincial governments function largely independently. No federal funding goes to highways; the provinces are responsible for financing all highway work. Capital construction funds come from general revenue, not fuel taxes.

Ontario is the most populous of Canada's provinces, home to nearly 13 million people, about 38 percent of the total population of Canada. Most of Ontario's population and economic activity are concentrated in the southeastern portion along the Great Lakes and the St. Lawrence Seaway.

The key high-volume highways in Ontario are the 400-series highways in the southern part of the province. The most important of these is the 401, the busiest highway in North America, with average annual daily traffic (AADT) of more than 425,000 vehicles in 2004, and daily traffic sometimes exceeding 500,000 vehicles. In much of the Toronto area, the 401 has six lanes in each direction, but some segments have seven, eight, and even nine lanes in each direction. The next most heavily trafficked freeways in the 400 system are the 427, with an AADT of about 312,000 vehicles, and the Queen Elizabeth Way, with an AADT of about 175,000 vehicles.

Ontario is a cement-rich province, and as a result, Canada is able to satisfy all of its domestic cement demand and export its surplus. In 2004, Canada exported about 7 million tons (6.4 million metric tons) of cement, of which about 6.3 million tons (5.7 million metric tons) went to the United States.[8] The United States, in contrast, despite being the world's third-largest producer of cement, can meet only about 75 percent of its domestic cement demand and must import the other 25 percent.

In the 1980s, the Ontario Ministry of Transportation (MTO) began using life-cycle cost analysis in its pavement type selection process. Pavement design alternatives are compared based on present worth over a 50-year analysis period. Concrete pavements are assumed to have an initial service life of 28 years to the first rehabilitation; asphalt pavements are assumed to have an initial service life of 19 years.

MTO uses a social discount rate, set by the Ministry of Finance, in life-cycle cost analysis. A social discount rate, also called a social or societal rate of time preference, "reflects the government's judgment about the relative value which the community as a whole assigns, or which the government feels it ought to assign, to present versus future consumption."[9] The societal time preference rate "need bear no relation to the rates of return in the private sector, interest rates, or any other measurable market phenomena."[10]

In MTO's life-cycle cost procedure, the salvage value of a pavement is defined as the prorated remaining life at the end of the analysis period. User costs are not currently incorporated in the life-cycle cost procedure; MTO is studying what user cost model would be most appropriate.

MTO implemented alternate bid contracts on major freeway projects in 2001. Alternate bid contracts allow both the asphalt and concrete industries to bid on the same contract. Since then, concrete has been selected for all six of the alternate bid contracts awarded. MTO sets bid adjustment factors in advance based on life-cycle cost analysis results. Alternate bid contracting procedures result in higher upfront engineering costs for MTO because two separate sets of bid documents must be prepared. However, allowing the two industries to compete on the work has resulted in US$23 million (Can$26 million) in savings in initial construction costs. (Note: all currency conversions to U.S. dollars in this report are based on late April 2007 exchange rates.)

Ontario's most prominent experience with public-private partnerships to date is the 407 (shown in figure 3 on next page), originally planned as a bypass for the 401 and leased to a private consortium in 1999 for about US$2.8 billion (Can$3.1 billion). This purchase price covered the existing 43-mi (69-km) central section (built as concrete pavement) and the right to build extensions on the east and west ends (these extensions were built as asphalt pavement) to increase the full length of the highway to 67 mi (108 km). Work is already underway to widen 30 mi

(50 km) in the central section from six to eight lanes, and another 30 mi (50 km) of widening is planned. By the end of 2020, nearly the entire 67-mi (108-km) length will have 10 lanes, with one short section having eight lanes.

The 99-year lease agreement allows for the private operation of the 407 ETR (electronic toll road), but requires adherence to the provincial government's highway safety and design standards and auditing on a regular basis. MTO conducts about 10 audits of the 407 ETR and its subcontractors and subconsultants per year. In addition, an independent auditor, hired by and reporting to both parties, conducts frequent auditing.

The 407 ETR is the world's first all-electronic, open-access tollway. Electronic sensors mounted on overhead gantries at on- and off-ramps detect transponders mounted on vehicle windshields and log toll transactions (see figure 4). Trips on the 407 by vehicles not equipped with transponders are logged using a state-of-the-art license plate recognition system (by law, transponders are mandatory for vehicles with gross weights of 5 metric tons or more). Users receive monthly statements by mail

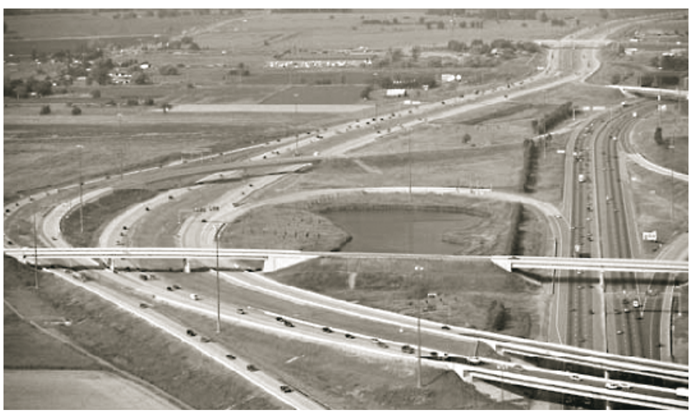

**Figure 3.** *Highway 401 at 407 ETR.*

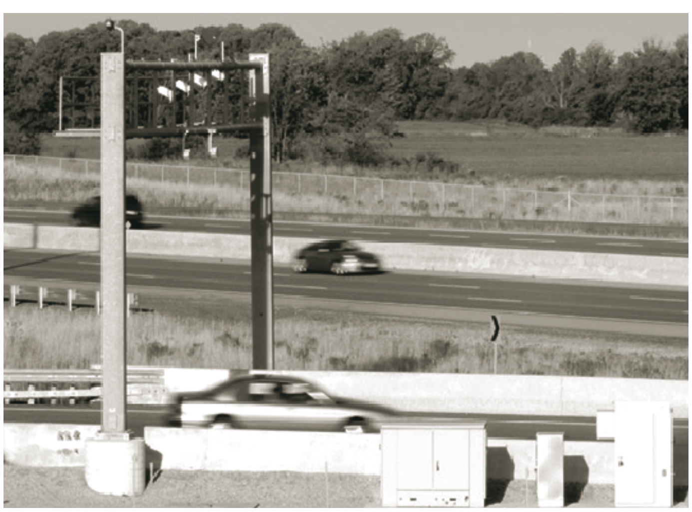

**Figure 4.** *Vehicle passes under electronic sensors on gantry at on-ramp to 407 ETR.*

and can check their account balance and sign up for automatic credit card billing on the 407 ETR Web site.

Traffic on the 407 ETR averages about 300,000 trips per day. Tolls on the 407 ETR are about five times higher than on the New York State Thruway. A trip from one end of the 407 ETR to the other costs about US$18 (Can$20). The leaseholder sets tolls for trucks much higher than for cars, with the intent of shifting truck traffic to the public highway system.

Ontario anticipates that major new roadway construction will be done by public-private partnerships (PPP). The ministry is exploring PPP contracts or area-term contracts, in which a private contractor will be responsible for design, rehabilitation, and maintenance of all provincial roads within a certain geographic area. PPP contracts are viewed as a growing trend throughout Canada, consistent with a trend of government downsizing out of operations and into a management role.

In the province of Québec, concrete pavements make up 767 two-lane mi (1,239 two-lane km) of the 18,000-mi (29,000-km) road network, only about 4 percent, but carry about 75 percent of Québec's traffic. Most of this concrete pavement is in and around the city of Montréal. Québec builds both jointed plain concrete pavements and continuously reinforced concrete pavements. The appeal of the CRCP option is the "get in, get out, stay out!" aspect that is important because of the limited funds available for pavement maintenance. Life-cycle cost calculations conducted by the Québec Ministry of Transport (MTQ) indicate that for one case, CRCP is about 5 percent lower in cost than JPCP in terms of net present value over a 50-year analysis period. The actual life-cycle cost differential for a specific route depends on the traffic level.

MTQ has used life-cycle cost analysis since the mid 1990s. Projects over about US$900,000 (Can$1 million) are subjected to life-cycle cost analysis to help in the selection of the best construction or rehabilitation alternative. A 50-year analysis period is used, and discount rates between 4 and 6 percent are considered. Both residual value and work zone user costs are considered in the life-cycle cost analysis. MTQ uses two computer programs to conduct life-cycle cost analysis: one (RealCost) developed by the U.S. FHWA and one (Visual LCCA) developed by the Transportation Research and Development Institute (TRDI).

In 2001, Québec adopted a departmental policy on pavement type selection that dictates which routes in the Montréal and Québec city areas—a total of 484 mi (779 km)—will be concrete pavement. The choice of JPCP or CRCP for pavements in the "white zone" is a regional decision, which can be based on life-cycle cost analysis but does not necessarily need to be. Another 226 mi (364 km) of nearby routes are classified by the policy as being in the "gray zone," and for these routes, life-cycle cost analysis and other factors (environmental concerns, technical criteria, and economic consequences) are to be used in pavement type selection. The policy dictates that all other routes in the province will be asphalt pavement. Figure 5 illustrates the assignment of routes to the concrete and gray zone groups. This assignment of concrete pavement to specific routes largely corresponded to the location of existing concrete pavements in the province, and was well received by government authorities and industry.

MTQ uses pavement management software called Visual/PMS, developed by TRDI, to store pavement construction, inventory, and condition data; project future pavement conditions; and assist in developing long-term maintenance plans.

Québec embraced the concept of public-private partnerships as part of its 2004–2007 Modernization Plan. MTQ considers three types of PPP contracts as options for large projects: (1) design and construction, (2) delegation of exploitation and maintenance, and (3) conception-design-maintenance-exploitation and funding. Planned PPP projects are the completion of Highways 25 and 30 around Montréal, and construction and maintenance of several rest areas.

The Highway 30 project, which will have a cost of about US$900,000 (Can$1 billion), involves a 22-mi (35-km) stretch of highway and 4 mi (7 km) of other roads to complete a link between Châteaugauy and Highway 20 in Ontario. Plans are for this work to be done under a conception-design-maintenance-exploitation and funding arrangement, but whether this will be a concrete pavement has not been determined.

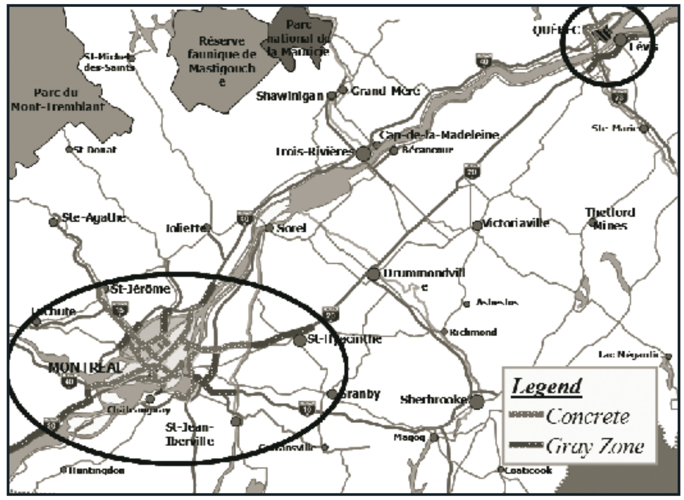


**Figure 5.** *Concrete and "gray zone" routes for which a multiple criteria analysis is used in pavement type selection, according to Québec Ministry of Transport policy.*

## Germany

Germany considers concrete pavements to be long-life pavements, and jointed plain concrete pavements make up some 25 percent of the German high-volume motorway network. Germany has no long-term experience with continuously reinforced concrete pavement on motorways. The scan team visited a 0.9-mi (1.5-km) stretch of CRCP test sections built in 2005 on the A-5 Autobahn near Darmstadt.

When a new motorway or reconstruction is planned, the government issues a request for proposals, specifying the construction class (e.g., motorway). Bidders use the catalog to select the type of construction (asphalt or concrete pavement and base type). Alternative offers with different construction types are permitted.

The bidders' offers include only the initial construction cost, not life-cycle costs, and while the concrete pavement alternatives tend to have a slightly higher initial cost than the corresponding asphalt pavement alternatives, concrete pavements are given a credit of US$0.22 per square foot (€1.80 per square meter) because their maintenance costs are presumed to be lower. The selection of this value was arbitrary and the German cement industry believes it is too low, although it has not yet proposed another specific value.

On government-funded projects (as opposed to public-private partnerships), contractors must provide a 4-year warranty for concrete and asphalt paving. Regulations are being developed to stipulate the functional requirements of the pavement at the end of the 4-year warranty period. In addition to the mix design, the contractor is responsible for construction testing of concrete strength, air content, thickness, smoothness, and skid resistance.

For PPP projects, the construction company is responsible for constructing the road and maintaining it for up to 30 years. Some PPP projects have maintenance periods of 20 or fewer years. The contractual provision related to maintenance becomes void at an earlier age if the actual accumulated traffic loadings reach the traffic loadings forecasted for the contract-specified maintenance period. The construction company derives its revenue from tolls. Life-cycle costs play a role in the construction method selected because alternatives with lower life-cycle costs yield higher profits for the construction company. Public-private partnerships are less common than conventional construction contracting arrangements.

Three types of alternative contracting models have been employed in Germany for public-private partnership contracts for road construction projects of 6 to 9 mi (10 to 15 km). Under the "functional building contract" (or "C") model, a 30-year contract is let to build and maintain the road, with financing from the Federal budget. Four pilot projects, two in asphalt and two in concrete, totaling about 25 mi (40 km), have been built under this model. Under the "F" model, a maximum of 20 percent of the startup financing comes from the Federal budget; the remainder of the construction and maintenance costs is paid by tolls. Several concrete and asphalt pavement projects have been built using this model. The "A" model is similar to the "F" model except that 50 percent of the startup financing, rather than 20 percent, comes from the Federal budget. About 148 mi (238 km) of roadways have been built under five contracts using "A" model financing.

A pavement management system maintained by the Federal Highway Research Institute (Bundesanstalt für Straßenwesen, BASt) is used to store construction information, monitoring data (friction and high-speed profile measurements), traffic data, and accident data. Noise data are not collected.

Most monitoring data are collected by contractors, with government oversight in each German state. Monitoring data are collected on a 4-year cycle; during the first 2 years the expressways are measured and during the second 2 years the other federal trunk roads are measured. The pavement management system is used primarily to generate short-term maintenance plans.

## Austria

MOTORWAYS MAKE UP ABOUT ONE fourth of Austria's Federal road network (8,700 mi (14,000 km)).[11] About two thirds of high-volume motorways (about 2,485 one-directional mi (4,000 one-directional km)) are concrete pavements.

Austria built its first concrete pavement in 1925 and its first motorway just before World War II. Austria's high-volume roadways constructed after World War II were built in concrete, following the model of the German Autobahns. At the time, bituminous pavement designs for heavy traffic had not been developed, and there was no competition for concrete for high-traffic applications. In the 1970s, the Ministry of Transport adopted a pavement plan dictating which pavement type would be used for which roadways, as a function of truck traffic volume, soils and geologic conditions, and local government preferences.

The ministry's pavement type selection plan was abandoned in the 1980s, and the life-cycle costs began to be considered in pavement type selection. Asphalt pavement technology developed rapidly in Austria in the 1980s. Concrete pavements were also viewed during this era to be too expensive, noisy, and difficult to repair. Budget constraints in the 1980s required financing of motorway construction by loans, and cost-cutting measures such as reductions in layer thicknesses and lane and shoulder widths were instituted.

Something of a renaissance in concrete pavement technology in Austria began in the early 1990s, when a program of reconstruction, widening, and geometric improvements of some of the older roads in the network began in 1990. Figure 6, for example, shows a section of the A1 motorway between Vienna and Salzburg, originally constructed in concrete between 1959 and 1961 and reconstructed in concrete in 2003. Among the technological improvements that contributed to increased use of concrete pavements in Austria beginning in the 1990s were the development of techniques for exposed aggregate surfacing, recycling of old concrete pavements, and rapid repair methods. Increasing traffic volumes and a decrease in the price difference between asphalt and concrete pavement also contributed to resurgence in concrete pavement construction. With the collapse of the Soviet Union and the opening of previously closed borders to the east, truck volumes on Austrian roads have increased and are expected to continue increasing greatly.

**Figure 6.** *The A1 motorway in Austria, reconstructed in 2003 after more than 50 years of service.*

Not all of Austria's concrete pavements built in the 1950s and 1960s have been reconstructed. One such road is the Mölltalroad, in the Carinthia region in southern Austria, which opened to traffic in 1956. About half of its original length (some 30 mi (50 km)) is still in use and in good condition. The remaining half was redesigned to improve the alignment and intersections. The road is located in a mountainous area. Along its length, its average annual daily traffic ranges from 3,325 vehicles (5.7 percent trucks) to 6,136 vehicles (4.5 percent trucks). The Mölltalroad's concrete surface is only 8 inches (in) (20 centimeters (cm)) thick, and was constructed on grade without any base layer. Despite the inadequacy of its design by modern Austrian standards, it still has good smoothness and friction and little distress after 50 years in service.[12]

In the late 1990s, the Austrian Association for Research on Road, Rail, and Transport (FSV) developed the guide document RVS 2.21, *Economic Evaluation of Different Pavement Alternatives,* which became mandatory for use in pavement type selection for all Federal roads in 2001. Today, pavement type selection is done using life-cycle cost analysis as outlined in RVS 2.21. In general, concrete is preferred for heavy-duty roads (over 8,000 heavy vehicles per day) and for roadway sections with slow-moving, heavy traffic. Figure 7 illustrates conceptually the

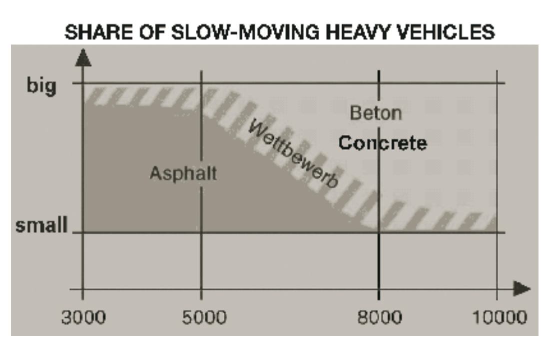


**Figure 7.** *Influence of traffic volume and proportion of slow-moving heavy vehicles on pavement type selection in Austria.*

roles that average annual daily heavy truck traffic and proportion of slow-moving heavy vehicles in the traffic stream tend to play in the choice between asphalt and concrete.

In Austria, concrete pavements are viewed as the economical pavement choice for heavily loaded roads in the following cases:

- Their life cycle is at least 40 to 50 years.
- No major maintenance is required for the first 15 to 20 years.
- Only one or two maintenance interventions (e.g., joint sealing, sporadic slab replacement, thin overlay) are required in the second 20 years or more of the life cycle.

Proper design (thickness, joint spacing, dowels, etc.) and uniformly high construction quality along the length of the project are believed to be crucial to attaining the life-cycle benefits of concrete pavements.

Austria has a sophisticated pavement management system used to store pavement data, forecast pavement conditions, and conduct life-cycle cost analysis of pavement maintenance strategies. Austria uses pavement management software called VIAPMS (a commercial pavement management program developed by a Canadian company) to manage its road network. A key component of this network is the motorway network, shown in figure 8. The structure of the Austrian pavement management system is shown in figure 9.

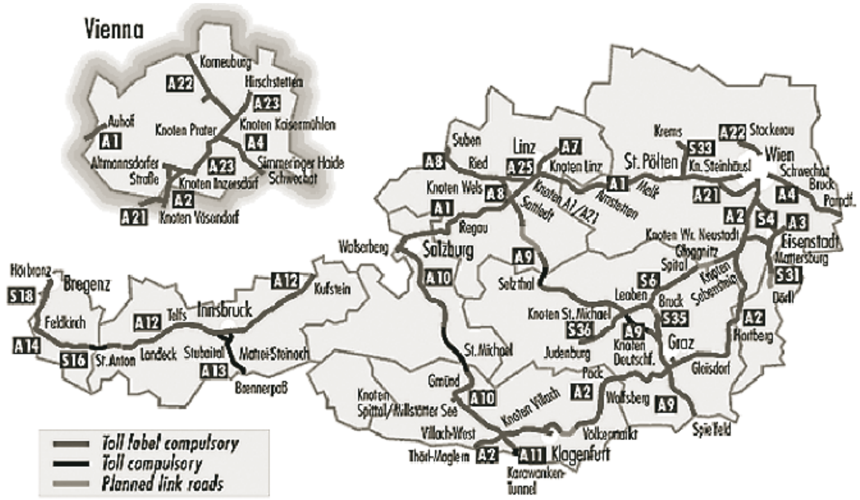


**Figure 8.** *Austrian motorway network.*

Network-wide pavement condition monitoring includes collection of data on rutting, friction, roughness, cracking in concrete pavements, and surface defects. To keep the number of pavement sections in the database manageable, a dynamic segmentation algorithm is used to combine similar sections based on condition as well as inventory data.

Friction, rutting, and longitudinal profile data are used to compute a Comfort and Safety Index (CSI) for each pavement section, while surface defects, slab cracking, and (for concrete pavements) age are used to compute a Structure Index (SI). These indexes are used to compute a Total Condition Index (TCI) for each pavement section, which is the parameter used in network-level optimization algorithms.

Linear and logarithmic regression models are used to project future pavement conditions. Simplified models and a limited number of regression variables (age, equivalent single-axle loads (ESALs), a design index, and a frost index) are used for various pavement types. A recent research project in conjunction with the Technical University of Vienna focuses on improving the existing pavement condition prediction models and developing new ones.

The cost-benefit analysis routine of Austria's VIPMS system uses incremental benefit-cost analysis to select from among multiple treatment options for each of the many pavement sections in the network. Benefit is quantified as the area between the forecasted condition curves of the treatment option and the do-nothing alternative, weighted for traffic. Figure 10 (see next page) illustrates this benefit definition.

Work is underway to develop a user cost model for the

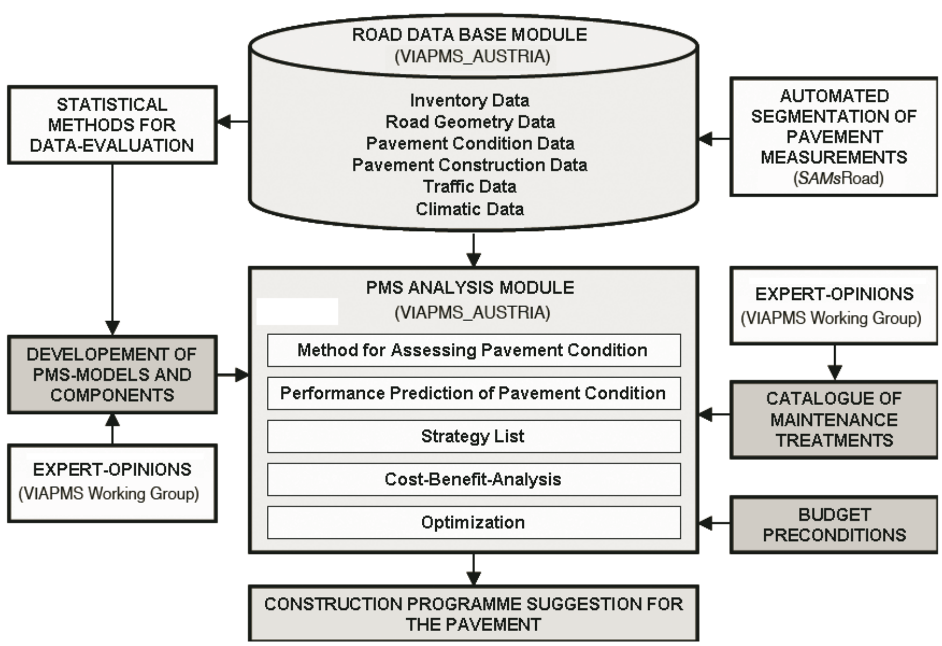


**Figure 9.** *Structure of Austrian pavement management system.*

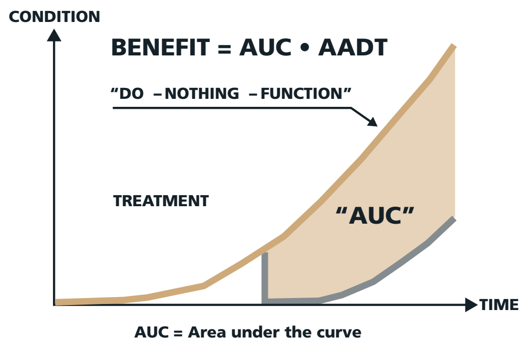


**Figure 10.** *Calculation of benefit for each pavement treatment strategy considered in the incremental benefit-cost algorithm in Austria's pavement management system.*

Austrian pavement management system that takes into account travel time, fuel consumption, and accidents. The model is expected to be ready to implement in 2007.

Among the outputs of the VIAPMS software are color-coded maps illustrating road condition by pavement section, as shown in figure 11. The portion of roadway highlighted in figure 11 is on the A1 motorway between Vienna and St. Pölten.

Pavement surface friction is a significant safety consideration in Austria, especially in mountainous areas with heavy snowfall, steep gradients, and numerous tunnels. Friction testing is mandated in Austria for construction acceptance and at the end of the warranty period. Periodic friction testing of in-service pavements is also conducted for network-level pavement management purposes. Three cycles of friction testing of the entire motorway network have been conducted (1991–1994, 1994, and 2004–2005), as well as two cycles of friction testing of the trunk roads network (1991–1996 and 2001–2002).

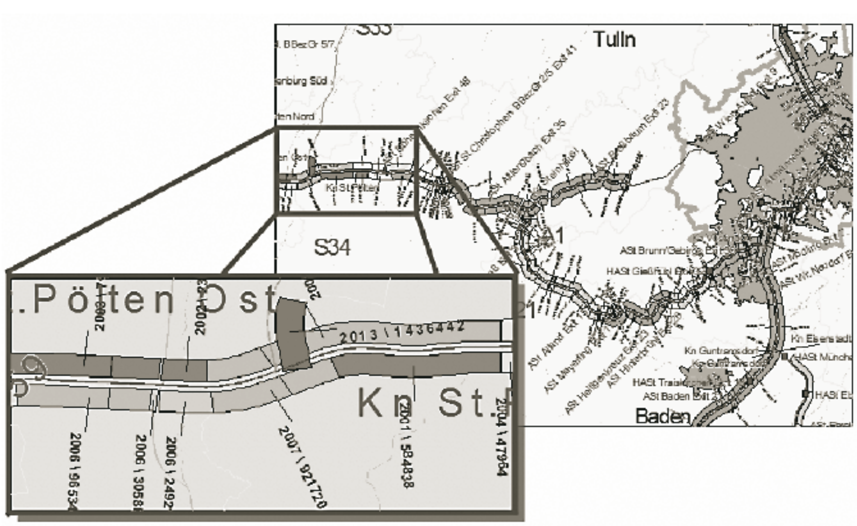


**Figure 11.** *Pavement section condition mapping by Austrian pavement management software.*

Friction testing in Austria is done with a vehicle called a RoadSTAR (Road Surface Tester of Arsenal Research), developed by Austrian arsenal research experts in cooperation with the Stuttgart Research Institute of Automotive Engineering and Vehicle Engines. RoadSTAR's measuring equipment is mounted on a two-axle truck with a 1,585-gallon (6,000-liter) water tank. RoadSTAR is capable of measuring surface friction at driving speeds of 25 to 75 miles per hour (mi/h) (40 to 120 kilometers per hour (km/h)), and at a speed of 50 mi/h (80 km/h) can measure friction on pavements with gradients of up to 8 percent. Recently, examination of friction acceptance testing data has revealed that new pavements in tunnels tend to have noticeably lower friction levels than other new pavements on the road network, and a national research study has been launched to investigate the reasons for this difference.(13)

Today, management of the Austrian motorway network is the responsibility of a rather unusual form of public-private partnership: a private company owned by the Austrian Federal government. The Austrian motorway company ASFiNAG (Autobahnen und Schnellstrassen Finanzierungs Aktiengesellschaft) plans, finances, maintains, and operates the entire Austrian motorway and expressway network. ASFiNAG was formed as a financing company in 1982 as a step toward achieving a balanced national budget, a requirement for entry into the European Union. In 1997, its scope of responsibilities was increased through the Austrian government's passage of the ASFiNAG Authorization Act. ASFiNAG is authorized to charge tolls and receive any income generated from property or other installations on the Federal road network. It is not authorized to set the tolls; that authority remains with the Austrian government. ASFiNAG is a public limited company and its shares are held entirely by the Republic of Austria.

At the beginning of 2004, a fully electronic distance-related toll system for vehicles with a total weight over 3.5 tons (3.1 metric tons) was introduced on the primary road network. From this design-build-finance-operate public-private partnership (DBFO PPP) with EUROPASS, a subsidiary of the Italian firm AUTOSTRADE, ASFiNAG expects revenues of about US$816 million (€600 million) per year and another US$816 million (€600 million) per year from tolls charged on lighter vehicles.

ASFiNAG has planned four packages of motorway improvement contracts to be let as public-private partnerships. These packages make up a program for building 70 mi (113 km) of roads in eastern Austria around Vienna to reduce traffic congestion in the Vienna area, improve traffic movement between Vienna and areas to the north, and provide an efficient north-south connection with the Czech Republic.(14)

## Belgium

LINGUISTICALLY AND CULTURALLY, Belgium is composed of two regions: the Dutch-speaking Flanders region to the north, where Brussels, the capital of Belgium, is located and the predominantly French-speaking Walloon region to the south. Legally, Belgium is composed of three regions: the two aforementioned and the capital region of Brussels, where both French and Dutch are spoken. Three separate road administration authorities oversee matters relating to road construction and maintenance in these three regions. Belgium does not have dedicated funds for highways; general revenue funds are used.

Belgium is densely populated—10 million people in an area of 11,600 square miles (30,000 square kilometers), less than the size of Maryland. About 10 percent of the population resides in Brussels, another 60 percent lives in Flanders, and the remaining 30 percent lives in Wallonia. The economy of Belgium is highly service oriented, and the Flanders region has one of the highest per capita GNPs in the European Union. The Walloon economy lags about one quarter behind in terms of personal income.

A large portion of the Belgian motorway network has been constructed in continuously reinforced concrete pavement. Belgium and France are the only two European countries to have employed CRCP on a large scale; Belgium in particular has embraced it enthusiastically. Even more interesting for the purposes of this scan is the fact that Belgium's CRCP design and construction technology was adapted from the United States. With the Belgian motorway network largely complete, much of the current investment in roads is allocated to renovation of the oldest concrete pavements in the network. Some old asphalt roads are also being replaced with concrete, sometimes by complete reconstruction and sometimes by a concrete inlay of the outer traffic lane.

Environmental awareness is a significant public and political influence in Belgium. Tire-pavement noise and recycling of construction materials are factors in pavement design, materials, and construction choices made in Belgium. As one recent Belgian research paper[15] puts it:

> "While most people are now convinced that concrete can be a preferred solution in economical terms, when taking into account the whole-life cost including maintenance and if possible costs to the user, it has certainly become just as important to show that concrete roads are environmentally friendly and sustainable."

The Belgian concrete industry produces about 30 million tons (27.2 million metric tons) of concrete and concrete products every year. Concrete has a good reputation in Belgium for being recyclable at the end of its life. In addition, in the Flanders region, about 85 percent of all rock-like building rubble is recycled. Two-lift construction, wherein lower quality materials are used in the thicker lower lift and higher quality, more wear-resistant, more durable aggregates are used in the thinner upper lift, has been used for a few special projects in Belgium. Good-quality aggregates are readily available in Belgium, so recycling of crushed concrete in the bottom layer has not been done in Belgium. A first trial of this type of construction, however, is planned. The exposed aggregate surface finishing technique popular in Austria is also used in Belgium. Both Belgium and Austria have found that one of the low-noise surface alternatives, a porous concrete surface, tends not to remain very porous or quiet for very long.

The Walloon and Flanders regions are responsible for nearly equal amounts of the Belgian motorway network (both between 530 and 560 mi (850 and 900 km)), and the Brussels region is responsible for a smaller amount (7 mi (11 km)). Overall, Belgium has the highest roadway density (length of roads per unit land area) of any country in Europe, followed closely by the Netherlands.

The Belgian road network consists of about 83,000 mi (134,000 km) of motorways and regional, provincial, local, and rural roads. Motorways make up about 1,100 mi (1,700 km), just over 1 percent, of this total. Concrete pavements make up 40 percent of these motorways. Concrete pavements are used more on lower-volume roads in Belgium than in most of the other countries visited on this scan, even rural roads, 60 percent of which are concrete. Overall, concrete pavements make up 17 percent of all roads in Belgium.

Belgium has many examples of concrete pavements that have provided several decades of service. Belgium's first concrete pavement, Lorraine Avenue, shown in figure 12, was constructed in 1925 and remained in service until 2003, when it received a concrete overlay.[16]

In the Flanders region, management of the roadway network (shown in figure 13 on next page) is the responsibility of the Infrastructure Agency (IAA) in the Flemish Ministry for Mobility and Public Works. With a staff of about 1,600, the agency manages a network of some 3,900 mi (6,300 km) of roads and 4,200 mi (6,700 km) of bicycle paths. Highways

**Figure 12.** *Belgium's first concrete pavement, built in 1925, remained in service for 78 years.*

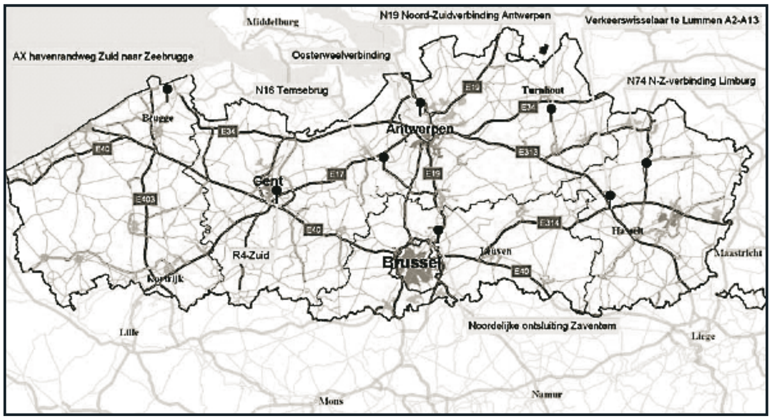


**Figure 13.** *Major roads in the Flemish region of Belgium.*

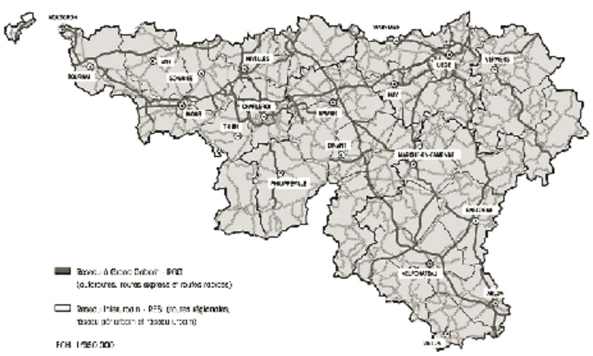

**Figure 14.** *Major roads in the Walloon region of Belgium.*

make up 531 mi (855 km) of the Flemish road network. The annual budget of IAA is about US$426 million (€313 million), of which US$303 million (€223 million) is earmarked for investments in the road network and US$121 million (€89 million) for road maintenance.

In the Walloon region, management of the roadway network (figure 14) is the responsibility of the Directorate-General of Highways and Roads in the Walloon Ministry of Equipment and Transport. With a staff of about 1,600, the Directorate-General manages a network of some 540 mi (870 km) of motorways and some 4,200 mi (6800 km) of other roads. The annual budget of the Directorate-General of Highways and Roads is about US$265 million (€195 million). About US$83 million (€61 million) of this goes to motorway and road investments, about US$91 million (€67 million) goes to routine maintenance (which includes winter maintenance), and about US$66 million (€49 million) goes to special maintenance projects.

Life-cycle cost analysis is not used for pavement type selection at the project level in Belgium, except for large projects. A recent report by the Walloon Ministry of Equipment and Transport (MET) demonstrates why CRCP is the predominant pavement type used on motorways. In an economic comparison of asphalt pavement and CRC pavement for motorways, asphalt pavement was found to have lower initial construction costs, but CRC was judged more cost-effective over any analysis period greater than about 14 years.(17)

Primarily for non-motorway roads, the MET is developing a multicriteria analysis method for pavement type selection. The quantitative factors considered include cost, rutting resistance, skid resistance, cracking rate, and noise. The qualitative factors considered include surface and subsurface drainability, disruption to traffic, inconvenience for the public, ease of access to utilities for future repairs, compatibility with other pavement types nearby on the route, suitability of the surfacing for local conditions, ease of maintenance, ease of construction, susceptibility to frost damage, and ease of winter maintenance.(18)

No roadway projects have been constructed in Belgium by a public-private partnership, though PPPs are being used for other types of public projects (e.g., school construction). However, six large roadway improvement projects now in the planning stages will be done as public-private partnerships. For these projects, the contractor will contribute to the initial construction cost and will be responsible for maintaining the roadway for 30 years. Functional requirements (friction and ride) will be defined for these projects and will not necessarily be the same functional requirements used for publicly managed roads. Lane rental fees will be charged every time during the 30-year period that the contractor closes a portion of the road for repairs.

## The Netherlands

THE NETHERLANDS, WITH A POPULATION of 16 million, is the most densely populated country in Europe. Despite its relatively small size and the fact that 18 percent of the country's area is water, food processing is an important industry in the Netherlands. It is the world's third-largest exporter of agricultural products, after the United States and France. The energy sector is another important part of the Dutch economy. The world's second-largest oil company, Royal Dutch Shell, is based in the Netherlands, and one of the world's largest natural gas fields is located in the northeast part of the country. Nonetheless, gasoline consumption is heavily taxed; gasoline prices are higher in the Netherlands than in any other country in Europe and two to three times higher than in the United States. Funding for highway projects comes from fuel taxes and vehicle registration fees. Of the 24 percent of the annual public works budget of nearly US$11 billion (€8,000 million) that goes to highways, about 60 percent goes to construction and about 40 percent to operations and maintenance.

The roadway network of the Netherlands consists of some 70,000 mi (113,000 km) of roads. Some 1,400 mi (2,300 km) are motorways, only 2 percent of the total by length, but these motorways carry 38 percent of all traffic by volume. Five percent of the motorway mileage in the Netherlands is concrete pavement. About half is CRCP and the other half is JPCP. The country also has 87 mi (140 km) of JPCP on the regional roadway network. Overall, concrete pavements make up about 4 percent of the roads in the Netherlands. In addition to roadways for motorized traffic, the Netherlands also has 12,000 mi (20,000 km) of bicycle paths, 10 percent of which are concrete.

The Noise Abatement Act of 1985 stirred discussion in the Netherlands about traffic noise associated with different types of pavement surfaces. Concrete pavements with the traditional brushed finish were found to produce about 3 dBA (decibels adjusted) more noise than that of the reference pavement surface (dense asphalt concrete) defined in the *Prescribed Standards for the Calculation and Measurement of Traffic Noise.* In the late 1980s, the Motorways Department decided to address this issue by using porous asphalt concrete surfacing on concrete pavements.

In general, concrete pavement is favored over asphalt pavement for Dutch roads with average annual daily traffic levels of about 50,000 vehicles per direction or more. Concrete is also preferred for roundabout construction. In the late 1980s and early 1990s, the prevailing practice to reduce surface noise with concrete pavements was to apply a porous asphalt surface course. In the mid 1990s, however, the Netherlands began to experiment with exposed aggregate finishes for concrete pavement, in either one-lift or two-lift construction.

In recent years, interest in concrete pavements has revived because of their lower life-cycle costs and maintenance needs—heavy traffic congestion being an obstacle to lane closures for pavements, especially around the four big cities of Amsterdam, Rotterdam, The Hague, and Utrecht. While concrete pavements have higher initial construction costs and are not considered in the Netherlands as environmentally friendly as asphalt pavements, the drawback of asphalt pavements is seen to be their higher maintenance costs, with intervention required more frequently to remove ruts and extend service life. This renewed interest in longer-life concrete pavements coincides with a trend toward government downsizing in the Netherlands, with public-private partnerships expected to play an increasingly important role in roadway investment and maintenance.

In the past 5 years, design-build contracts for road construction with a 7-year warranty period have become increasingly common in the Netherlands. Contractors' bids for design-build contracts will be rated according to the following weighting scheme:

- Price—60 percent
- Past performance—15 percent
- Technical quality—10 percent
- Durability—10 percent
- Aesthetics—5 percent

In contracts awarded after 2007, the government will make the decision on pavement type, but the contractor will be allowed to select the design details, using the government's pavement design software.

A CROW working group of representatives of government, industry, consultants, and contractors has been formed to develop a decision support model to select pavement type and design details as a function of economic, environmental, and other factors.[19] Up to six design options can be compared in a single analysis. For each option, the user must enter or select data on the composition of the pavement, subbase, and sand bed for the road type in question. The program includes default pavement cross-sections for different pavement types and road classes.

The three major factors used in the Dutch decision support model are costs, environmental impact, and other factors. Costs include those for construction, reconstruction, maintenance, and demolition. All costs are calculated based on net present value. Environmental impact is assessed using a model that considers both quantitative (e.g., emissions) and qualitative (e.g., nuisance) components. The "other factors" category gives the user the latitude to consider a range of other items of potential interest.

In 1995, the Dutch government decided that the economic assessment of national projects must take into account a 4 percent discount rate. For this reason, the multicriteria decision support program uses a default discount rate of 4 percent. According to the developers of the Dutch decision support model, other European countries use different government-set discount rates (e.g., Germany uses 3 percent, the United Kingdom 6 percent, Denmark 7 percent, and France 8 percent), while the European Union considers 5 percent an appropriate discount rate.

The decision support model uses a criteria weighting system, perhaps the most debated aspect of the model, because the subjective assignment of weights influences the outcome of the analysis. The counterargument is that not applying weights to the decision criteria would in fact be a form of weighting too, but one that would not allow the flexibility to consider priorities that might be different in the future than they are today.

For the three major decision criteria used in the program (costs, environmental impact, and other factors), a weighting triangle, shown in figure 15 (see next page), can be used to compare different sets of weights and indicate the degree to which the weighting set influences the final result. The sides of the triangle represent the weighting factors for the "cost," "environmental impact," and "other factors" criteria on scales of 0 to 100 percent. The pavement alternatives evaluated in the analysis are numbered (up to a maximum of six; only two alternatives are compared in the example shown in figure 15). Each cell in the triangle represents a possible combination of the

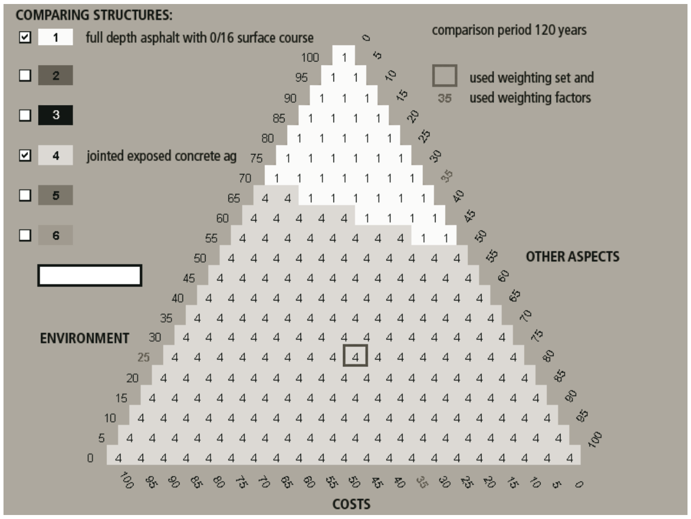


**Figure 15.** *Triangle illustrating sensitivity of multicriteria analysis results to weighting factors.*

three factors' weights, and the number in each cell is the design alternative favored for that combination. The box around the cell represents the actual combination of factor weights used in the present analysis. The box's proximity to any boundary where the preferred option changes is a graphical illustration of the sensitivity of the result to the combination of weighting factors selected.

While concrete pavements traditionally have not been as popular in the Netherlands as in some other European countries, they have long been popular in parts of the country, especially in the southern province of Noord-Brabant. Here, concrete pavements have been constructed steadily since the 1950s, and about 35 percent of the roadway network now consists of concrete pavements. In a recent survey of the pavement construction and maintenance practices in Noord-Brabant and other Dutch provinces, a key finding was that "the analysis data confirm the generally held, but not yet substantiated, notion that a concrete pavement is practically maintenance-free during its lifespan."[20]

The same study arrived at a summary, shown in table 1, of typical design lives and actual expected lifespans for four types of concrete pavements on Dutch roads of different functional classes. These actual lifespans are based on more than 50 years of experience in the Netherlands. Type 1 roads are on the primary roadway network and on motorways managed by the Motorways Department and the provinces. Type 2 roads are heavily used roads and county roads managed by the provinces. Type 3 roads are moderately used roads, access roads, and bus lanes managed by the provinces, municipalities, and water boards. Type 4 roads are lightly used roads and farm tracks managed by municipalities and water boards.

**Table 1.** *Expected lifespans for different classes of Dutch concrete roads.*

| Road Type | Design Life, years | Expected Lifespan, years | Comment |
|---|---|---|---|
| 1 | 30 | 45 to 50 | Provincial concrete roads |
| 1 | 30 | 30 to 40 | Concrete motorways |
| 1 | 30 | 25 to 30 | Motorways subject to overloading (not representative) |
| 2 | 30 | 40 to 50 | Provincial concrete roads |
| 3 | 30 | 40 to 50 | Water board roads |
| 4 | 20 to 30 | 40 to 50 | Municipal concrete roads |
| 4 | 20 to 30 | 25 to 30 | Water board farm tracks (not representative) |

## United Kingdom

The United Kingdom is a political union made up of four countries: England, Scotland, Wales, and Northern Ireland. The United Kingdom also has several overseas territories, including Gibraltar and the Falkland Islands. The United Kingdom is a constitutional monarchy with close relationships with—but not direct administrative control over—15 other Commonwealth countries that share the same monarch, Queen Elizabeth II, as head of state.

With more than 58 million people, the United Kingdom is the third most populous state in the European Union, after Germany and France. About 83 percent of the population of the United Kingdom lives in England; a quarter lives in southeast England, with some 7.5 million in London.

The United Kingdom is a highly developed country with the fifth-largest economy in the world and the second largest in Europe after Germany. Manufacturing and agriculture are far smaller segments of the British economy than they used to be, but a perennially important industry that places a significant demand on the road network is tourism. The United Kingdom is the sixth most popular tourist destination in the world. The energy sector is another important part of the economy. The United Kingdom has large coal, natural gas, and oil reserves. Nonetheless, gasoline taxes are among the highest in Europe, partly to control congestion on the motorways. Recently, London's municipal government took the controversial step of imposing a stiff tax on all vehicles entering the city during the workweek in an effort to reduce traffic congestion in the city center.

There are some 177,000 mi (285,000 km) of roads in the United Kingdom's roadway network, about 900 lane-mi (1,500 lane-km) of which are concrete pavements. The English portion of this roadway network is shown in figure 16; the road networks of Wales, Scotland, and Northern Ireland are not shown in this figure.

Until the early 1980s, JPCP and JRCP were the most common concrete pavement types built. From the mid 1980s to the mid 1990s, the typical concrete pavement construction was CRCP with a brushed surface. In the late 1990s, as a matter of public policy, thin hot-mix asphalt surfacing (see figure 17) came to be required on concrete pavements. This occurred because of public pressure on lawmakers to compel the Highways Agency to find a way to reduce noise from road surfaces. This Highways Agency prohibition on bare concrete road surfaces applies only in England, not elsewhere in the United Kingdom.

In the case of a public-private partnership project, the contractor may request a "departure from standards" and select any pavement type. The Highways Agency generally approves such requests because the contractor bears the risk. The typical requirement for PPP projects is that the roadway must be returned after 30 years with 10 years of remaining life. The Highways Agency does not have a protocol for how the remaining life in the 30th year is to be established. An asphalt overlay, for example, placed during that last year would very likely be considered to meet the requirement for furnishing 10 years of remaining life.

One of the first roadway improvement projects in the United Kingdom conducted as a public-private partnership was the widening of the A1(M) motorway between Alconbury and Peterborough. This DBFO contract, awarded in 1996, required the consortium of partners to finance the widening, operation, and maintenance of a 13-mi (21-km) section of the A1 motorway between London and Newcastle until 2026. The estimated construction cost was US$255 million (€128 million). In exchange, the consortium receives payments from the Highways Agency in the form of a "shadow toll" (roadway users do not pay tolls) computed as a function of the road's usage. The Highways Agency retains ownership of the road and has hired an independent consultant to act as the agency's representative in monitoring the construction, operation, and maintenance of the roadway.

The Highways Agency maintains a pavement management system for the United Kingdom's roadway network. Traffic data stored in the pavement management system is now limited to information on heavy commercial vehicles because the original focus of the pavement management system was pavement deterioration. Now, as operational issues gain importance, work is underway to improve the information on passenger car volumes in the pavement management system's database.

The Highways Agency operates the TRAC equipment for measuring longitudinal profile, the SCRIM device for measuring skid resistance, and a deflectograph for testing nondestructive deflection. Visual surveys of pavement condition are also conducted.

A computer program called SWEEP (software for the whole-life economic evaluation of pavements) is used for project-level maintenance treatment selection. A network-level analysis program has been under development for 7 years and for the last 4 years has been used to help generate the annual program of pavement investment and maintenance activities. This stand-alone, network-level analysis program was developed by the private-sector Transport Research Laboratory. It does not interact with the other modules in the Highway Agency's pavement management system software.

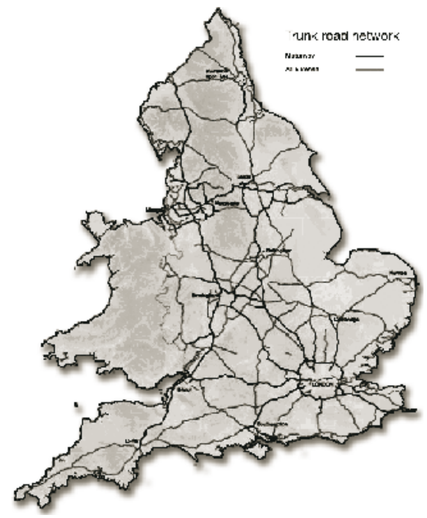

**Figure 16.** *Network of motorways and all-purpose roads in England.*

**Figure 17.** *Thin asphalt surfacing mandated on concrete roads in England.*

# Chapter Three
# Concrete Pavement Design

## Canada

Ontario has built concrete pavements since the 1930s, with the 1960s and early 1970s a period of major expansion of the freeway network. Many of Ontario's major freeways were originally constructed in concrete. This era of expansion was followed by one of reduced highway construction activity and a loss of experience and expertise because of the retirement of many older engineers. A highway technology program launched in the 1980s formed the basis for the pavement design and construction practices used in Ontario today.

The standard concrete pavement in Ontario is a dowelled, jointed plain concrete pavement with a 14-ft (4.25-m) widened outside lane. Perpendicular transverse joints are randomly spaced at an average 14 ft (4.25 m). Concrete pavement thicknesses range from 8 to 11 in (200 to 280 mm). The thickness design is based on both the 1993 AASHTO *Guide for the Design of Pavement Structures* and the Canadian Portland Cement Association's mechanistic-empirical rigid design method. Since 1992, a 4-in-thick (100-mm-thick), asphalt-treated, open-graded drainage layer (0.75-in (19 mm) top size crushed stone, 1.8 percent asphalt cement) has been used for pavements on the highest-volume routes. Untreated open-graded layers, 6 in (150 mm) thick, are allowed on lower-volume routes. The design standards allow open-graded cement-treated base as an option, and a project to be built in 2007 on Highway 410 will be the first with this type of base. Full-length perforated plastic pipe subdrains are placed in a filter-wrapped trench in the shoulder area, backfilled with open-graded aggregate.

After trying various concrete pavement designs over the past 50 years, the province of Québec now builds both jointed plain and continuously reinforced concrete pavements. In the 1950s and '60s, Québec built 9-in (230-mm) jointed reinforced concrete pavements, but had problems with joint deterioration. In the 1970s, Québec switched to an undowelled jointed plain concrete pavement design, also with 9-in (230-mm) slabs, but these pavements experienced problems with joint faulting and frost heave. In the 1980s, Québec built 8-in (200-mm) jointed plain concrete pavements, which experienced construction, structural, and frost heave problems. By the early 1990s, nearly all of Québec's concrete highway pavements were in need of reconstruction.

In 1994, two standard concrete pavement designs were adopted by the Québec Ministry of Transportation (MTQ). The first is JPCP, with the slab thickness designed for truck traffic over a 30-year design period according to the 1993 AASHTO *Guide for the Design of Pavement Structures*[21] method (using 50 percent reliability), and a total pavement thickness adequate for protection against frost heave. Truck factors (ESALs/truck) have been developed to characterize expected truck traffic for pavement design purposes. Typical JPCP slab thicknesses built according to the current standard are between 10 and 13 in (250 and 325 mm). Jointed concrete pavements are dowelled, with sealed joints, and rest on 6 in (150 mm) of granular base and a variable thickness of granular subbase for frost protection. Since making these changes to the standard JPCP design in 1994, fewer than 1 percent of the JPCP slabs constructed have exhibited cracking. The main distress type in these pavements is joint and corner spalling, usually addressed by partial-depth repair.

The second standard concrete pavement design used in Québec is CRCP. The first experiment in CRCP, a 1.2-mi (2-km) section, was built on Highway 13 in 2000. This pavement was a 10.6-in (270-mm) slab on granular subbase with 0.70 percent black steel. The right shoulder was paved as JPCP, and the left shoulder was paved as CRCP. Six other CRCP projects have been built in Québec since 2003. The 5.6-mi (9.1-km) section on Highway 40 is typical of these. It has an 11-in (285-mm) slab on an open-graded cement-stabilized layer, 0.76 percent galvanized steel, and JPCP shoulders. A 30-year design period is also used for CRCP. Uncertainty about the potential for steel corrosion in CRCP is a concern because Québec applies 44 to 66 tons (40 to 60 metric tons) of deicing salt per two-lane km to its roadways every winter (about two to three times as much salt as Illinois uses, for example).

## Germany

Germany began building concrete roads in the late 1880s and in 1934 started using concrete pavement extensively in the construction of its motorway (expressway) system. Between 1935 and 1939, some 2,200 mi (3,500 km) of motorways were built in Germany with a pavement cross-section of about 9 in (220 mm) of wire-mesh reinforced concrete on 4 in (100 mm) of sand base course, and expansion joints every 33 to 66 ft (10 to 20 m).

Until the early 1960s, Germany built primarily jointed reinforced concrete pavements on unbound base courses, using expansion joints and transverse contraction joints spaced 25 to 33 ft (7.5 to 10 m) apart. The standard jointed plain concrete pavement design for motorways in Germany was changed in 1972 to one without expansion joints and with transverse contraction joints spaced 16 ft (5 m) apart on cement-treated or asphalt-treated base. The first slipform paving on German motorways was done in 1982.[22]

Today, about 25 percent of Germany's 7,500 mi (12,050 km) of motorways are concrete pavements. Motorways make up about 2 percent of Germany's total road network (389,500 mi (626,800 km)), but their investment value is estimated at about 26 percent of the total value of Germany's roadway network, about US$342 billion (€250 billion) in 2003.

The average traffic load on German expressways is about 8,000 trucks per day, although some routes carry three to four times that. The axle load limit is 11.5 tons (10.4 metric tons) for German trucks and 13 tons (11.7 metric tons) for trucks from neighboring countries. These heavy traffic volumes and loads are a major reason for using concrete for many of the expressway resurfacing and new construction projects in the former German Democratic Republic.

Germany uses a catalog for selecting concrete pavement slab thickness and other details as a function of traffic level and other factors. This catalog[23] is updated about every 10 years (most recently in 2001). The standard designs are based on the forecasted traffic loads over a period of 30 years. The number of standard axle loads through the 30th year is termed the load value, B, and this value determines the construction class, which in turn determines the pavement layer thicknesses required. Of the seven construction classes defined in the German catalog, the highest class, labeled SV, corresponds to 32 million or more standard axle loads over 30 years. Motorways are assumed to fall into the SV construction class.

The total pavement thickness to be constructed, according to the requirements of the German catalog, is the sum of the thicknesses of the concrete surface, base course (cement-treated, asphalt-treated, or untreated), and frost protection layer. The thickness of the frost protection layer depends on the climate of the region and the frost sensitivity of the subsoil. The typical total pavement thickness is 22 to 35 in (55 to 90 cm). Figure 18 illustrates the motorway (construction class SV) cross-section designs indicated in the German design catalog for three base types (cement-treated, asphalt-treated, and untreated) for a location requiring a total pavement depth of 35 in (90 cm) for frost protection. Figure 19 shows a portion of Germany's design catalog page for concrete pavement design alternatives.

Germany's pavement design catalog now requires the use of a geotextile to separate a concrete slab from a cement-treated base. In the past, Germany's standard design for cement-treated base depended on these two layers being bonded and the cement-treated base being notched at locations matching the joints in the concrete slab to facilitate controlled cracking in the base. The required concrete slab thickness for the new cement-treated base alternative is 10.6 in (27 cm); it was 10.2 in (26 cm) for the old design with a bonded base. The design compressive strength of the cement-treated base is 2,100 pounds per square inch (psi) (15 megapascals (MPa)) under a concrete slab and 1,000 psi (7 MPa) under asphalt layers.

The geotextile used with the cement-treated base design

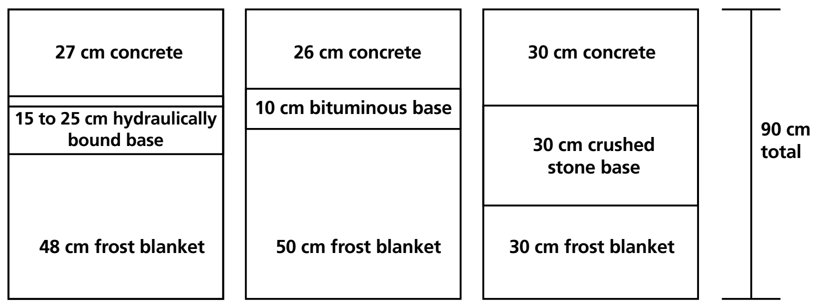


**Figure 18.** *Concrete pavement design alternatives in German catalog for motorway traffic (construction class SV, >32 million axle loads over 30 years) and 35 in (90 cm) total depth (1 in = 2.54 cm).*

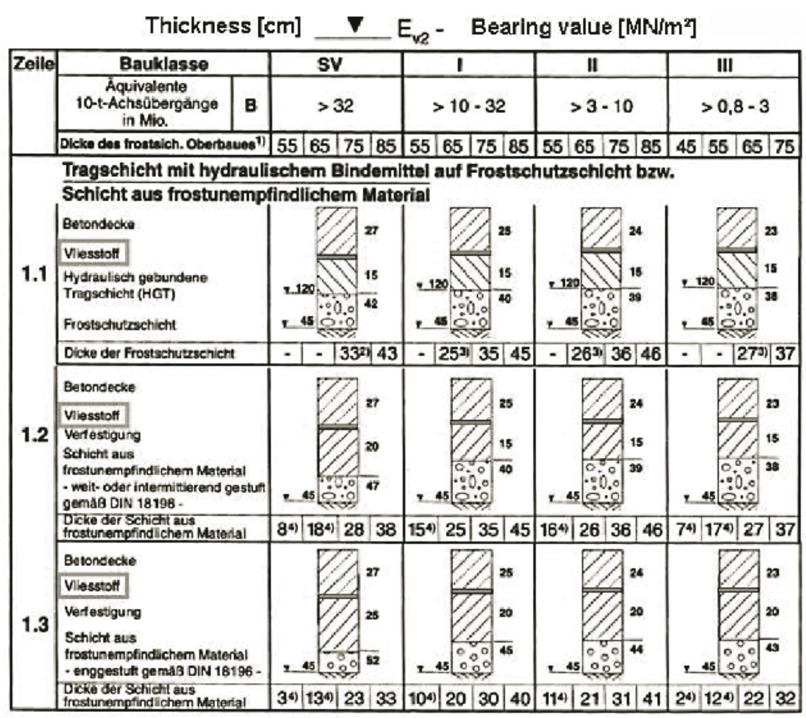


**Figure 19.** *Portion of Germany's design catalog page for concrete pavement design alternatives.*

alternative is a nonwoven polyethylene or polypropylene, 0.2 in (5 mm) thick. This fabric is attached to the cement-treated base before the concrete slab is placed, and care is taken to prevent construction traffic from damaging the geotextile once it has been laid. Figure 20 shows a core through a concrete pavement with cement-treated base and geotextile interlayer.

The unbound base used with the third design alternative is crushed aggregate with a minimum thickness of 12 in (300 mm), and a gradation sufficiently open to prevent water that enters the pavement structure from accumulating near joints and cracks and pumping out under traffic loads.(24)

For all three JPCP design alternatives, the joint spacing is 16 ft (5 m). Dowel bars at the transverse joints are spaced every 10 in (250 mm) in the wheel paths and every 20 in (500 mm) outside of the wheel paths. The dowels are plastic-coated steel, with a diameter of 1 in (25 mm) and length of 20 in (500 mm). Deformed, plastic-coated tie bars, 0.8 in (20 mm) in diameter and 31.5 in (800 mm long), are used at the longitudinal joints. Five tie bars per slab are used in longitudinal construction joints, and three tie bars per slab are used in longitudinal contraction joints. Concrete slabs for the driving lanes are paved wider than the painted traffic lane to reduce stresses and deflections at the slab edges. The joint layout details are illustrated in figure 21.

**Figure 20.** *Concrete, cement-treated base, and geotextile interlayer used in Germany.*

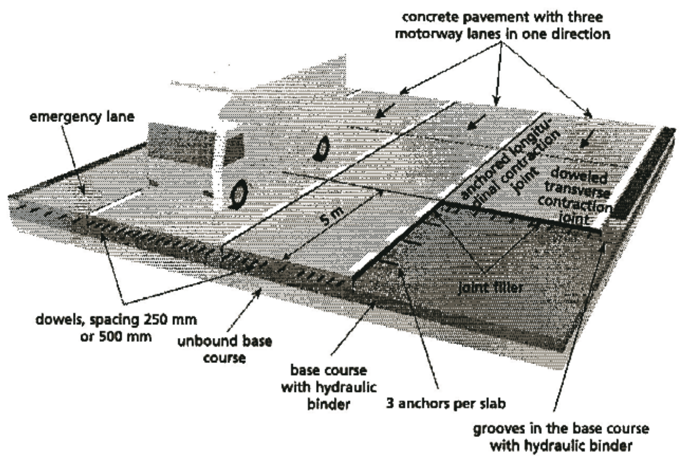


**Figure 21.** *Joint layout details for standard German concrete pavement design.*

## Austria

AUSTRIA'S CONCRETE PAVEMENT DESIGN and construction standard, RVS 8S.06.32, was developed and is kept up to date by the Concrete Pavements Working Group of the Austrian Association for Research on Road, Rail, and Transport (Österreichische Forschungsgesellschaft Strasse–Schiene–Verkehr, FSV).(25) This standard dictates the thicknesses of concrete surfacing and underlying layers to be used for each of six different traffic load classes, as illustrated in figure 22. The highest traffic loading class, the "S" class (18 to 40 million design axle loads), is used for motorways. The standard concrete pavement design constructed in Austria for motorways and other roadways in the S traffic loading class is a jointed plain concrete pavement, 10 in (25 cm) thick, on 2 in (5 cm) of bituminous interlayer and either 18 in (45 cm) of unbound base or 8 in (20 cm) of cement-stabilized base. The joints are spaced at 18 to 20 ft (5.5 to 6 m).(26)

All concrete pavement surfaces in Austria are built in two lifts,

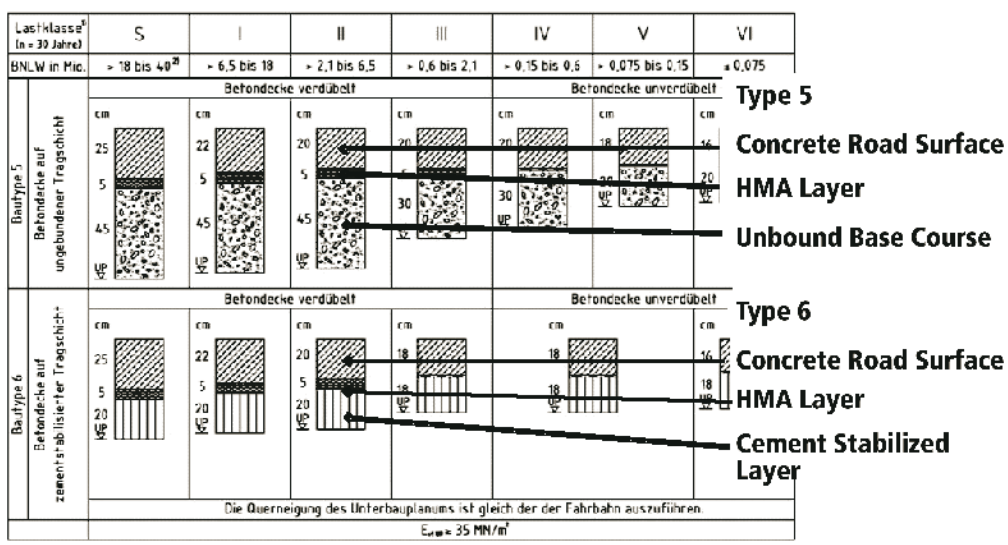


**Figure 22.** *Portion of Austria's design catalog page showing concrete pavement layer thicknesses for different traffic loading levels. Motorways are in the S class.*

with virgin or recycled concrete aggregate used in the lower 8 in (21 cm) and more wear-resistant aggregate used in the upper 1.5 in (4 cm). The surface is given an exposed aggregate texture. Details of the two-lift construction process and exposed aggregate surface texturing process are described in Chapter 4.

Dowels in the transverse joints are 1 in (26 mm) in diameter and 20 in (500 mm) long. Dowels are spaced more closely in the traffic lane wheelpaths and farther apart between the wheelpaths. Tie bars in the longitudinal joints are 0.55 in (14 mm) in diameter and 27.5 in (700 mm) long, and spaced 6.5 ft (2 m) apart (three tie bars per slab). Sealant reservoirs are sawed 0.3 in (8 mm) wide in both transverse and longitudinal joints; preformed seals are used in transverse joints and liquid sealant is used in longitudinal joints. Figure 23 shows details of the standard Austrian concrete pavement design.

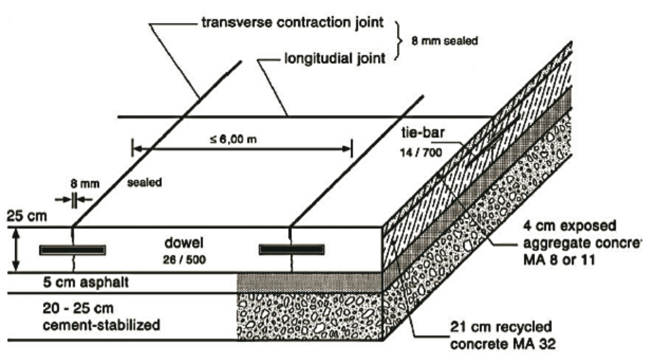


**Figure 23.** *Standard Austrian jointed plain concrete pavement design (1 in = 2.54 cm).*

## Belgium

BELGIUM HAS A LONG HISTORY of concrete road construction. The Avenue de Lorraine in Brussels, constructed in 1925, remained in service until 2003, when it received a concrete overlay. This pavement, on an old forestry road connecting southern Brussels to the highway, was just 6 in (15 cm) thick.

Examination of Belgian design details from the 1930s reveal a recognition of the influence of edge loadings on concrete pavement cracking, as shown in figure 24. The design alternatives at the time were a minimum thickness of 5 in (12 cm) for slabs constructed on a gravel base and a minimum thickness of 6 in (15 cm) for slabs on grade, with the slab 2 in (5 cm) thicker at the edges for either case.

The Avenue de Lorraine is not unique; Brussels has many examples of concrete roads that have served traffic for 50 years or more. Figure 25 shows a photo of a concrete pavement built in 1950 on the road between Leopoldsburg and Hechtel that is still in service today.

Problems over the years with slab cracking because of excessive length, as well as joint spalling and faulting, led to incremental changes in the standard Belgian concrete pavement design. Today, jointed plain concrete pavements in Belgium are constructed with a joint spacing between 13 and 16 ft (4 and 5 m), dowels in the transverse joints, and a rigid base layer.

Belgium built its first continuously reinforced concrete pavement in 1960. The steel content in this pavement was between 0.3 and 0.5 percent. The second CRC pavement in Belgium was built in 1964, and the first CRC overlay was built in 1968.

In the late 1960s, a team of Belgian engineers of the Road Authorities and the Belgium Cement Research Centre made a field trip to the United States, where by that time more than 2,400 mi (3,800 km) of CRCP had been constructed. American CRCP design and construction technologies were adapted to Belgium and used to construct a large portion of the Belgian motorway network in the 1970s.

Between 1970 and 1977, CRC pavements were built 8 in (20 cm) thick, with 0.85 percent steel placed at a depth of 30 percent of the slab thickness. A 2.4-in (6-cm) bituminous separation layer was used between the concrete slab and the lean concrete base, which was built over a drainable granular layer.

In 1977, the steel content in the standard Belgian CRCP design was reduced to 0.67 percent, and this was the design used until 1991. The depth of steel placement was changed from 2.4 in (6 cm) to 3.5 in (9 cm). The concrete slab and lean concrete base thicknesses remained 8 in (20 cm), but the bituminous separation layer was eliminated. The layer thickness reductions, steel reduction, and elimination of the bituminous separation layer were all done to reduce costs.

A typical problem of the CRC pavements built with these design details was erosion of the lean concrete base, pumping of water and fines from the longitudinal joint (see figure 26), and the formation of punchouts. A large research study in 1992 identified several deficiencies in the then-current design practices for CRCP.

As a result, the 2.4-in (6-cm) bituminous separation layer was reintroduced to the standard CRCP design, the standard CRCP slab thickness was increased to 9 in (23 cm), and the steel content was increased to 0.72 percent. In 1995, the steel content was changed to 0.76 percent. This change in the reinforcement design was made not for engineering reasons but because of the disappearance of 0.7-in (18-mm) bars from the market. The 0.76 percent steel content, as well as the 9-in (23-cm) slab thickness, 2.4-in (6-cm) separation layer, and 8-in (20-cm) lean concrete base, remain Belgium's standard CRCP design today for the construction class corresponding to the heaviest traffic loads and a design life of 30 years.

The standard JPCP design for the same construction class and 30-year design life is 10 in (25 cm) of concrete on a 2.4-in (6-cm) bituminous separation layer and 8 in (20 cm) of lean concrete. For both JPCP and CRCP, these standard designs produce pavements that easily meet the 30-year design life and survive 40 years or more without requiring major intervention.

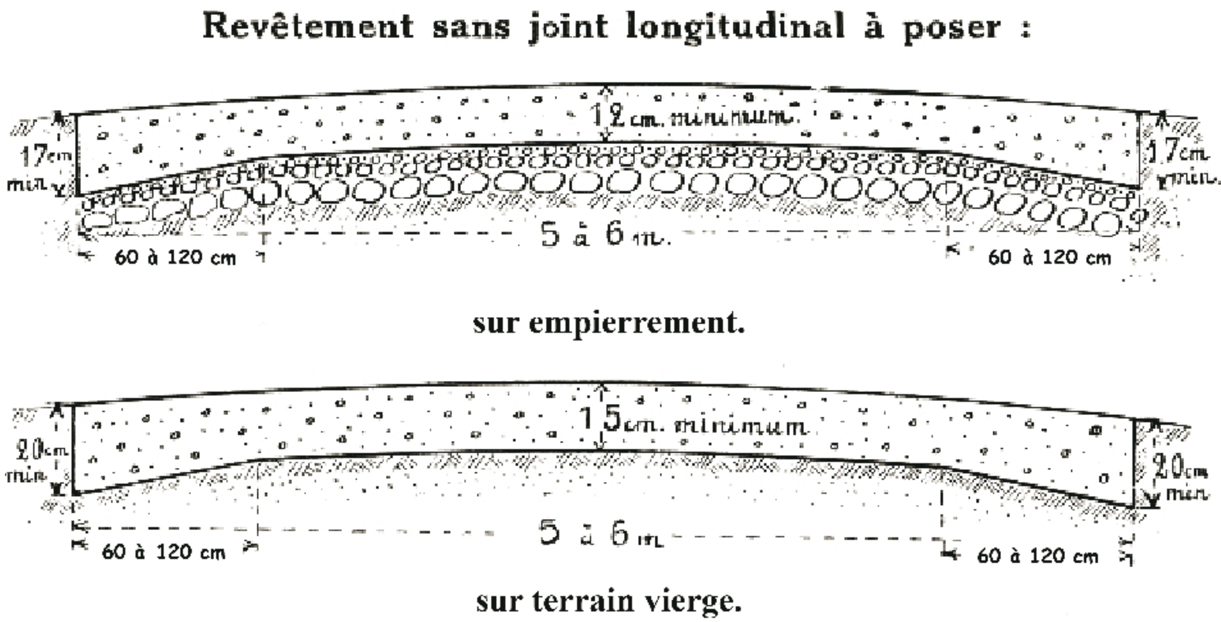


**Figure 24.** *Thickened-edge concrete pavement design used in Belgium in the 1930s.*

**Figure 25.** *Concrete pavement in Belgium still in service after 55 years.*

**Figure 26.** *Pumping of fines from lean concrete base under Belgian CRCP built between 1977 and 1991.*

## The Netherlands

IN THE 1950S, CONCRETE PAVEMENTS built on the Netherlands' motorway system were undowelled JPCP. Dowelling of transverse joints in JPCP became the practice in the Netherlands in the 1960s. While about half of the existing concrete pavements on Dutch motorways are JPCP, in recent years, almost all new concrete pavements on the motorways have been built as CRCP.

Before 2005, concrete pavement construction in the Netherlands used materials and methods specifications. A change to end-result specifications occurred in 2005 and, as discussed earlier, the current trend in concrete pavement construction contracting is the use of design-build contracts with a 7-year post-construction warranty period.

The Netherlands uses a mechanistic-design software package called VENCON for concrete pavement design.[27,28] The Netherlands also has a pavement design catalog. Typical cross sections and other details for pavements for different roadway functional classes and traffic levels are available in the *Dutch Cement Concrete Pavement Manual—Basic Structures.*[29]

Based on field measurements, a preset distribution of axle types is used in the pavement design software. The total number of axles applied is assumed to be 39 percent dual-wheel front axles, 38 percent dual-wheel rear axles, and 23 percent wide-based single-wheel axles. There are plans to introduce super wide-base single-wheel axles in the near future. Default axle load spectra (distribution of axle loads by weight) are also assumed in the program, depending on the road class.

Jointed concrete pavements are designed according to a slab-on-dense-liquid model (springs with stiffness represented by a k value). Stresses in the concrete slab are calculated using Westergaard's 1948 equations, modified by van Cauwelaert's multilayer slab model to include consideration of a treated base. Thermal stresses in the concrete slab are recalculated using Eisenmann's equations. A table of typical degrees of deflection load transfer for different types of joints and bases is used to calculate an effective reduction in applied load. A fatigue damage accumulation model is used to determine the life of a candidate slab thickness.

A tensile stress model developed at Delft University is used to determine the required steel content for CRCP. Design lives of 30 to 40 years are typically used for CRC pavements. A typical design would be 10 in (25 cm) of CRC with a 2-in (5-cm) porous asphalt surface, 2.4 in (6 cm) of bituminous material below the CRC slab to separate it from the base, and 10 in (25 cm) of base composed of a mix of crushed concrete, crushed masonry, and a hydraulic binder. These treated layers would be constructed on a roadbed of at least 16 in (40 cm) of sand. (Frost penetration depth is not so much the issue in the Netherlands as the minimum height of the roadway above the water table. The bottom of the subbase must be at least 31.5 in (80 cm) above the highest recorded level of the water table.)[30] The longitudinal steel content in a 10-in (25-cm) CRC slab would be 0.70 percent. Figure 27 shows longitudinal joint details.

## United Kingdom

AN EMPIRICAL DESIGN APPROACH was used for CRC pavements built in the United Kingdom before 1975. According to this approach, a minimum thickness was used up to a certain level of traffic, and above this level, the required thickness was a function of the traffic level. The required thickness was based on an assumed concrete strength of 5,800 psi (40 MPa), and no credit was given for higher concrete strength. New design curves for CRCP have recently been developed, based on the design flexural strength of the concrete rather than a fixed strength value.[31] The longitudinal steel content used is 0.6 percent.

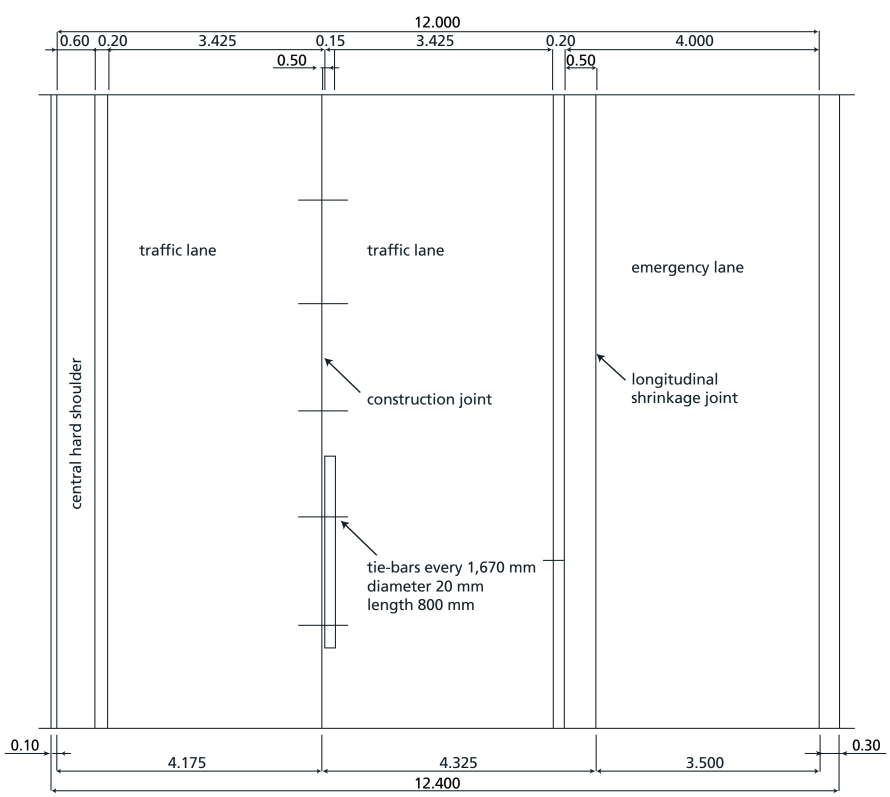


**Figure 27.** *Longitudinal joint layout details for concrete pavement in the Netherlands.*

# Chapter Four
# Concrete Pavement Construction

## Canada

Around 1995, Ontario switched from using predominantly method specifications to end-result specifications. This was envisioned as a transition to long-term (e.g., 20-year) warranties, but this vision did not have the support of the financial industry. MTO is experimenting with performance-based warranty contracts in which the ministry asks contractors to warrant a specific condition level (e.g., greater than or equal to 79 on MTO's 0–100 Pavement Condition Index scale) 7 years after construction. So far, this type of construction warranty has been obtained only for lower-volume asphalt pavements, not concrete freeways.

MTO's acceptance for concrete freeways is based on the mean and standard deviation of the lot measurements for core compressive strength, slab thickness, and surface roughness. The contractor may receive a combined bonus of up to 5 percent of the item or a penalty of up to 20 percent. Notwithstanding the overall percent within limits, the contractor is required to repair a sublot if any individual compressive strength or thickness is less than 60 percent of the specified value or if any individual sublot for surface roughness is greater than a specified value. Scallops greater than 0.4 in (10 mm) for concrete pavements and 0.6 in (15 mm) for concrete bases must be repaired by diamond grinding. The contractor uses a computerized California profilograph, which is approved by the owner on an annual basis.

Ontario is moving away from the use of epoxy-coated dowels in favor of stainless steel and black steel. Joints in concrete pavements are sealed with rubberized hot-poured sealant in 0.4-in-wide (10-mm-wide) reservoirs. Tining is done transversely, at a 0.75-in (19-mm) uniform spacing. A longitudinal tining trial was constructed on Highway 401 in 2006.

Ontario has allowed the use of dowel bar inserters since the 1990s, and still allows both baskets and inserters, though the latter are more often used. In 2006, MTO implemented the use of MIT-SCAN equipment during construction to assess dowel bar alignment on a few trial contracts. Random scanning is done daily during construction, usually within 24 hours after paving. Concrete paving contractors in Ontario also have MIT-SCAN equipment and do their own testing for quality control. MTO's acceptance for concrete pavement on these trial contracts also includes the alignment and position of dowel bars. Data from the MIT-SCAN during production is used to assess bonus or penalty.

Québec paves full-width concrete shoulders with concrete pavements and uses preformed sealants in transverse joints in JPCP. Joint reservoirs are not sawn for longitudinal joints. The standard JPCP joint spacing used is 16 ft (5 m). Tie bars and dowels are placed before paving. Québec uses random transverse tining to texture concrete pavement surfaces, but has experimented with exposed aggregate and shotpeened surfaces as possible low-noise solutions.

MTQ has used smoothness specifications for all concrete pavement projects since the early 1990s.[32] The Profile Ride Index (PRI) was replaced by the International Roughness Index (IRI) in 1998 so that the same smoothness specification would apply to both asphalt and concrete pavements. Some contractors still use a profilograph for control purposes. Based on a 2000 study comparing different kinds of roughness measuring equipment, the rolling profiler was selected as best suited for construction control. MTQ's smoothness specifications include penalties for inadequate smoothness.

MTQ enters into contracts with warranty, or "performance guarantee," requirements with paving contractors. The contractor must guarantee the performance of the roadway for a period of time (5 to 10 years for several contracts let between 1995 and 2005). Annual performance monitoring, including measurement of profile, skid resistance, rutting, and distress, is conducted on 328-ft (100-m) control lots in the traffic lane.

## Germany

Slipform pavers are used to place concrete pavements in Germany, normally in two courses. Old concrete pavements are reclaimed and crushed into aggregate for use in the lower course of two-course concrete pavement slabs and in crushed aggregate base courses. Concrete recycled from old pavements with concrete durability problems (alkali-aggregate reaction or damage caused by freezing or deicing agents) cannot be used in new concrete slabs.

Concrete resurfacing work on existing expressways typically must be carried out within short timeframes, and thus severe penalties are imposed on contractors if deadlines are not met. Either batch mixers, with capacities of 130 to 390 cubic yards (yd$^3$) (100 to 300 cubic meters (m$^3$)) per hour, or continuous mixers, with capacities of up to 390 yd$^3$ (300 m$^3$) per hour, are used to produce the volume of concrete (up to 3,900 yd$^3$ (3,000 m$^3$) per day) typically needed for such projects.

For single-course concrete paving, dowels and tie bars are placed in baskets. For two-course paving, dowels and tie bars are vibrated into the slab after the first course has been placed, and then the second concrete course is placed. The two concrete layers must be placed wet on wet to achieve full bond between them. Two-course construction may be done using two slipform pavers or with a large single paver.

To achieve concrete pavement surfaces with good skid resistance, smoothness, and low noise, the concrete surface is finished and smoothed, and then textured using a longitudinal heavy burlap drag.

Since May 2006, the standard surfacing method for concrete roads on motorways in Germany has been the exposed aggregate technique, which has been used for many years in Austria and Belgium.[33] The top lift in two-lift construction is 1.6 in (4 cm) thick, and the maximum aggregate size in the top lift is 0.3 in (8 mm). The mix for the top lift has a cement content of at least 26 pounds per cubic foot (420 kilograms per cubic meter), a water-cement ratio of about 0.40, and a gap-graded aggregate composed of 30 percent sand and 70 percent crushed stone. Two surface preparation techniques have been used in Germany for two-lift construction: application of a set retarder combined with a liquid curing compound, and application of a set retarder followed by covering with a plastic sheet. With both techniques, the goal is to be able to brush the surface of the concrete while it is still green to remove the mortar at the surface and expose the coarse aggregates.

Transverse and longitudinal joints are cut 0.12 in (3 mm) wide as soon as possible to prevent uncontrolled slab cracking. Transverse joints are cut to 25 to 30 percent of the slab thickness, and longitudinal joints are cut to 40 to 45 percent of the slab thickness. Joint sealant reservoirs are cut 0.24 to 0.6 in (6 to 15 mm) wide and 0.6 to 1.4 in (15 to 35 mm) deep. Transverse joints are sealed with preformed elastomeric joint seals, and longitudinal joints are sealed with bituminous sealant compounds.

Cores taken every 10,800 square feet (1,000 square meters) from the finished pavement are tested for strength and thickness, and the smoothness and skid resistance of the finished pavement are also measured. A 13-ft (4-m) straightedge is used for initial smoothness acceptance testing.

## Austria

CONCRETE PAVEMENT SLABS in Austria are paved in two lifts, wet on wet, above the base layer and bituminous interlayer. The lower concrete course is 8.3 in (21 cm) thick, made with virgin or recycled concrete aggregates (1.25-in (32-mm) maximum aggregate size) that do not need to be highly wear resistant. The upper concrete course is 1.5 in (4 cm) thick and contains smaller (0.3- to 0.43-in (8- to 11-mm) maximum aggregate size) aggregates with high wear resistance. Figure 28 shows the upper course being placed on top of the lower course. Figure 29 shows the dowel and tie bar inserters on the back of the front paver.

The exposed aggregate surface texture is created by a set retarder on the concrete after texturing, followed within 20 minutes by curing compound or plastic sheeting. The mortar is later brushed off the surface with a brushing machine, exposing the aggregate. Figure 30 shows an exposed aggregate surface constructed using a 0.3-in (8-mm) maximum aggregate size.

Transverse joints are cut before the longitudinal joints, between 8 and 24 hours after concrete placement, depending on the weather conditions. For concrete motorways with concrete slab thicknesses of 10 in (25 cm), transverse joints are sawed 3 in (75 mm) deep and longitudinal joints are sawed 4 in (100 mm) deep.

To facilitate drainage of water that infiltrates the joints, flat drainage tapes are placed below the concrete slab at locations corresponding to the transverse joint locations and running from the middle of the outer traffic lane to the outside edge of the emergency lane, as shown in figure 31. Figure 32 shows these drainage tapes placed before paving.

Since 1996, Austria has been constructing roundabouts using concrete pavement, especially in the eastern part of the country. About 40 percent of these concrete roundabouts have been designed for the highest traffic loading class in the Austrian pavement catalog (class S, the same traffic loading level used for designing motorways). The key differences between motorway

**Figure 28.** *Two-lift paving in Austria.*

**Figure 29.** *Dowel and tie bar inserters on back of front paver for two-lift paving in Austria.*

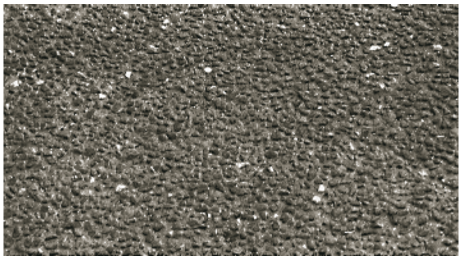

**Figure 30.** *Exposed aggregate surface on Austrian concrete pavement.*

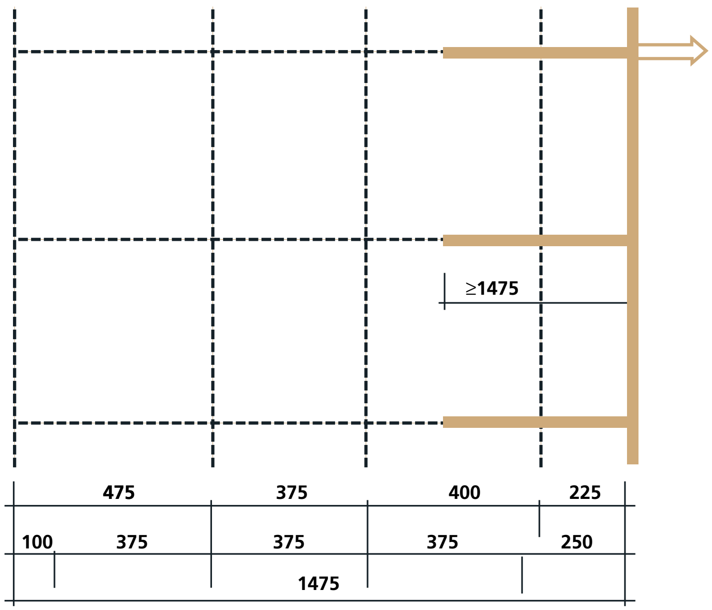


**Figure 31.** *Placement of flat tape drains under concrete pavement joints in Austria.*

**Figure 32.** *Flat drain tapes placed before paving.*

construction and roundabout construction are in the details of the joints. Because heavy loads frequently cross the lanes in a roundabout, dowels are used in the longitudinal joints instead of tie bars. Slabs with free edges must have a 1:1 ratio of length to width, and the free edges are thickened by 1.2 in (3 cm). Concrete for roundabouts is placed primarily by hand, but recently some roundabout paving has been done using small slipform pavers. Careful attention to joint design and layout, both in plan preparation and at the job site, are considered crucial to good long-term performance of concrete roundabouts.[34,35]

## Belgium

CRCP IS THE CONCRETE PAVEMENT of choice in Belgium for motorways, but JPCP is also built. Dowels are 1 in (25 mm) in diameter, 24 in (60 cm) long, and spaced every 12 in (30 cm) across transverse joints. Dowels are coated with epoxy or bitumen. Tie bars are deformed steel, uncoated, 0.6 in (16 mm) in diameter, 31.5 in (80 cm) long, and spaced every 30 in (75 cm) along longitudinal joints. Black (iron-oxide-coated) steel is used for CRCP. Transverse steel in CRCP is skewed 60 degrees. For JPCP, the contractor can choose what type of joint sealants to use. Typically, hot-poured sealants are used in transverse joints and preformed elastomeric seals are used in longitudinal joints.

The government typically does all testing during construction, but for some large projects, quality assurance/quality control (QA/QC) approaches are being used. Recent contracts have included pay factors for thickness, compressive strength, smoothness, and friction. The warranty practice in Belgium is to require a 3-year guarantee from the contractor.

Slipform pavers were first used in Belgium around 1970. Figure 33 (see next page) shows the paving of the E34 road between Vosselaar and Turnhout, one of the first slipform paving projects in Belgium. This pavement is still in service 35 years later, carrying more than 40,000 vehicles per day with 12 percent trucks.

One of the most prominent concrete pavement projects undertaken in Belgium to date is the reconstruction of the Antwerp Ring Road, one of the most heavily trafficked freeways in Europe.[36] The Ring Road is about 9 mi (14 km) long, with four to seven lanes in each direction. Six radial freeways tie into it, and on its busiest sections it carries nearly 200,000 vehicles per day, with 25 percent heavy trucks.

The new pavement is a 9-in (23-cm) CRC slab over 2 in (5 cm) of bituminous interlayer, 10 in (25 cm) of cement-treated granulated asphalt rubble, and 6 in (15 cm) of granulated lean concrete rubble. The CRC slab has an exposed aggregate surface. CRCP was selected based on multicriteria analysis that included consideration of life-cycle costs, noise, recycling opportunities, comfort, safety, and other factors.

The reconstruction of the Antwerp Ring Road was notable for its cost, about US$136 million (€100 million), and tight construction schedule. The outer ring was reconstructed in a 5-month period beginning in November 2004, and the inner ring was reconstructed in a 5-month period beginning in April 2005. An A+B contract was used, and the contractor worked around the clock to meet the construction schedule.

Belgium has constructed more than 50 intersection roundabouts (see figure 34) with CRCP since 1995. They are built with a slipform paver or with sideforms and a vibrating beam.

Belgium's first experiences with exposed aggregate surfaces were in the 1970s. Major improvements to the technique, especially in mix design, were made in 1996 after a field study of low-noise surfaces (see figure 35). Six different surfaces were built on a layer of CRCP. The top layers were asphalt, porous asphalt, porous concrete, and fine exposed aggregate concrete. Noise measurements were done on the sections immediately after construction and 3 years later. Initially the porous surfaces had the lowest noise levels, but after 3 years the exposed-aggregate concrete surface appeared to have a lower noise level.

In another field test, conducted in 2003, four test sections were constructed within a larger two-lift CRC paving job to compare four combinations of lower lift thickness, upper lift thickness, and upper lift maximum aggregate size. The influence of maximum aggregate size on measured noise levels is illustrated in figure 36.

Exposed aggregate surfaces are now used on all high-speed roads in Belgium. On motorways, after the set retarder is applied to the surface, plastic sheeting is used for the first 24 hours and then removed for brushing of the surface. For JPCP, the transverse joints are sawcut through the plastic. For non-motorway construction, the liquid curing compound, rather than plastic, is applied after the set retarder.

In Belgium, contractors have been pleased with the results obtained with laser guidance of the slipform paver on some round-the-clock paving jobs and others done at night to avoid daytime traffic congestion. Employees sometimes trip over the stringline during nighttime paving, and this problem is eliminated using a laser system.

**Figure 33.** *Slipform paving in Belgium began around 1970.*

**Figure 34.** *CRCP roundabout construction in Belgium.*

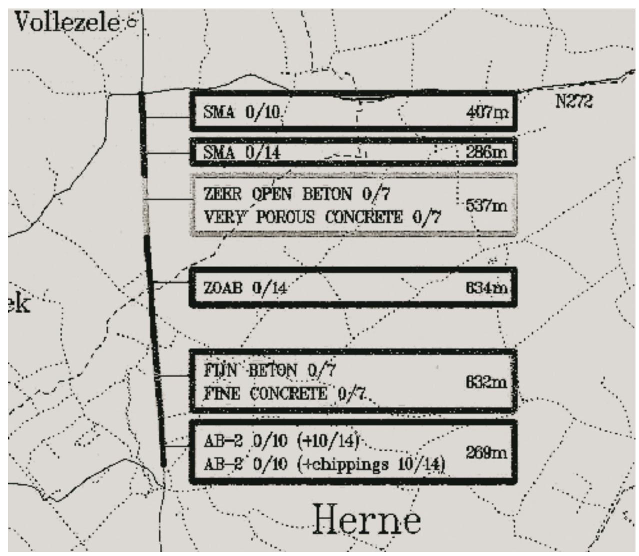


**Figure 35.** *Field test of low-noise surfacings in Belgium in 1996.*

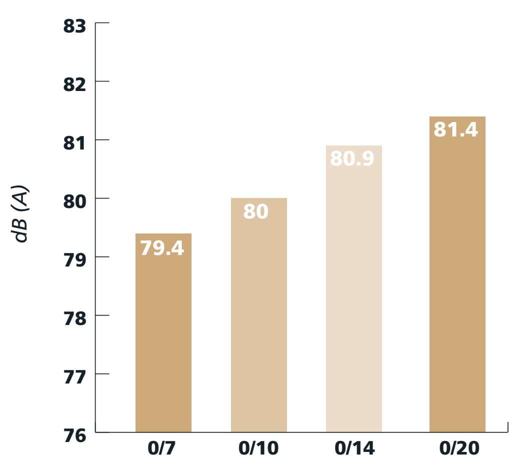


**Figure 36.** *Effect on noise level of maximum aggregate size in exposed aggregate surface layer.*

## The Netherlands

THE NETHERLANDS' PRACTICES in CRCP construction are based largely on the Belgian model and by experience gained with successive projects. Sections of CRCP were constructed on the A76 motorway in 1991, the A73 motorway in 1993, the A12 motorway in 1998, and the A5 and A50 motorways in 2004 and 2005. Construction of a 12-mi (20-km) segment on the A73/74 motorway began in 2006.

Minor maintenance work is commonly done at night in the Netherlands because of daytime traffic congestion. New construction and major maintenance work are done in the daytime, with full closure of the motorway and alternate routes provided for traffic. The outer shoulder is paved full width to serve as an emergency lane (see figure 37).

Tie bars across longitudinal joints in JPCP are 0.8 in (20 mm) in diameter, 31.5 in (800 mm) long, and spaced every 5.5 ft (1.67 m). The steel used for CRCP is uncoated. Standard procedure in the Netherlands is to place the steel at the mid-depth of the concrete slab, although in theory and according to the VENCON 2.0 design program, the steel can be placed at a depth of 35 to 50 percent of the slab thickness. The required 0.7 percent steel for a 10-in (25-cm) slab is obtained using 0.6-in-diameter (16-mm-diameter) bars spaced at 4.7 in (120 mm). Transverse steel (0.5-in-diameter (12-mm-diameter) bars, spaced at 27.5 in (700 mm)) is skewed 60 degrees. Tie bars are used in CRCP only in longitudinal construction joints, not in longitudinal contraction joints. When used, tie bars have the same 0.5-in (12-mm) diameter as the transverse steel, are 31.5 in (800 mm) long, and are spaced every 3 ft (1 m). The tie bars are placed in the fresh concrete if it is paved in two lifts, or drilled in and grouted later. The tie bars for both JPCP and CRCP are covered by a synthetic coating in the middle third to inhibit corrosion. Sealing of joints is not standard procedure in the Netherlands.

The typical end treatment for a CRC slab is four anchor beams 5 ft (1.5 m) deep (from the top of the pavement), spaced 23 ft (7 m) apart. At the transition to a bridge structure, the end of the CRC slab is typically separated by the head joint of the structure by a 49-ft (15-m) transitional section of asphalt pavement. A novel "jointless joint" (see figure 38) has been used in conjunction with CRCP at bridge approaches on the A50 motorway in the Netherlands. It is recognized, however, that this is an expensive solution to the CRCP/bridge junction problem.

The Dutch standards do not provide definitive requirements for opening to traffic. In general, no traffic or pedestrians are allowed on a concrete slab for the first 24 hours, pedestrians and cyclists may be granted access after 24 hours, cars and other light two-axle vehicles (maximum weight 3,300 pounds (1,500 kg)) are permitted after 48 hours, and opening to other traffic is allowed after 7 days or attainment of 70 percent of the design 28-day compressive strength, whichever comes first.

In the past 10 years or so, some regions of the Netherlands have used exposed aggregate surfaces on concrete pavements as an alternative to a porous asphalt concrete surface course. Noise levels with the exposed aggregate surfaces appear to be comparable to those for asphalt pavements. Full-scale field tests (see figure 39 on next page) have been conducted to examine the effects of different aggregate types and gradations, texture depths, set retarding methods, and paving methods (one-lift versus two-lift construction, and use of a super smoother to correct localized surface unevenness).[37,38,39]

The different set retarding methods, construction methods, and mix designs used were not found to produce significant differences in smoothness. The initial friction level achieved was found to be related to the type of curing compound used. The different aggregate types examined yielded similar initial friction results. A 0.3-in (8-mm) top size quartzite was found to provide the most durable friction properties. Small gradations were found to produce more desirable noise characteristics for both cars and trucks. Although the use of a super smoother reduces texture depth, its contribution to the evenness of the surface was found to be beneficial in terms of noise.

**Figure 37.** *Jointed concrete motorway pavement in the Netherlands with full-width outer shoulder as emergency lane.*

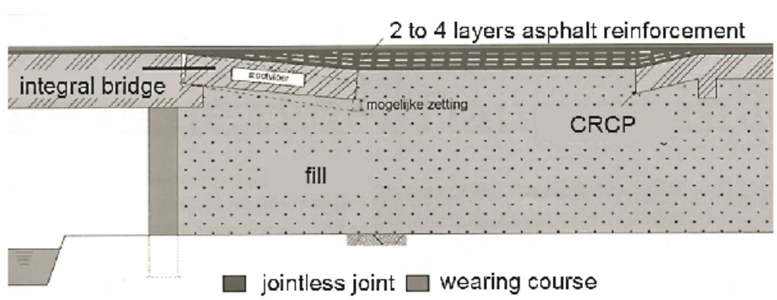


**Figure 38.** *"Jointless joint" bridge approach used in CRCP construction of A50 motorway in the Netherlands.*

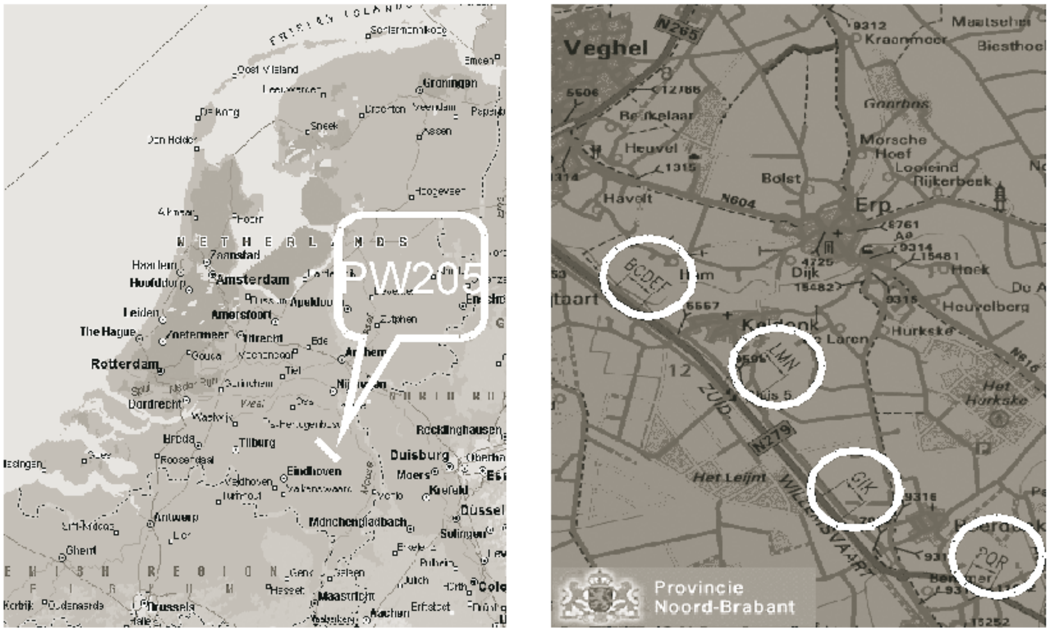


**Figure 39.** *Location of exposed aggregate test sections in the Netherlands.*

Concrete roundabouts are becoming more popular in the Netherlands. Technical guidance has been developed for the construction of both JPC and CRC roundabouts. The thickness designs are standardized for simplicity. The construction guidelines emphasize the details of joint and reinforcement layouts.(40)

## United Kingdom

A RECENT REVIEW OF the U.K.'s CRC design procedure found, among other things, that the cement-treated base used under CRCP is significantly higher in strength than the cement-treated base used in other countries. This high strength is considered a contributor to the formation of wide cracks in the base and increased crack spacings in the CRCP, bringing with them an increased risk for localized slab failures. The new design guidelines for CRCP would allow a wider range of lower-strength, cement-bound bases than previously specified.(41)

# Chapter Five
# Cement and Concrete

## Canada

ONTARIO REQUIRES THAT the contractor be responsible for the concrete mix design. A minimum concrete compressive strength of 4,350 psi (30 MPa) is required. The coarse aggregate has a combined gradation of nominal maximum size 1.5-in (37.5-mm) and 0.75-in (19-mm) aggregates. The air content is specified as 6.0 percent, plus or minus 1.5 percent. Portland cement is required, but a portion of it may be replaced by supplementary cementitious material. The supplementary cementitious material can be a ground granulated blast furnace slag (up to 25 percent) or fly ash (up to 10 percent) or a combination of the two materials (a mixture of slag and fly ash up to 25 percent except that the amount of fly ash shall not exceed 10 percent by mass of the total cementitious materials).

Québec allows the use of ternary mixes (portland cement, blast furnace slag, and fly ash) in mix designs for CRCP, but not for JPCP. Blended cements are also allowed. For both CRCP and JPCP, a compressive strength of 5,100 psi (35 MPa) is required.

## Germany

GERMANY ADOPTED THE EUROPEAN concrete standard EN 206-1 in 2000. This standard, together with German standard DIN 1045-2, now constitutes the new German concrete standard. In some areas, the European standard provides only framework definitions, making supplementation by national standards possible and indeed necessary because EN 206 does not yet have the legal status of a harmonized standard in the European Union.[42] One feature of the new standard is an increased emphasis on durability through the use of exposure classes. Roads and bridge decks are in the most extreme exposure class, XF4, characterized by a high degree of water saturation and exposure to freezing and deicing agents. The German concrete standard sets the maximum water-cement ratio (0.50), minimum strength class (C30/37*), minimum cement content (20 lb/ft$^3$ (320 kg/m$^3$)), and minimum air content (4.0 percent) for concrete used in road construction. Beyond the requirements of this standard, the German guideline ZTV Beton-StB 2001, *Additional Guidelines for the Construction of Concrete Pavements,* sets an upper limit of 0.45 on the water-cement ratio and a minimum cement content of 22 lb/ft$^3$ (350 kg/m$^3$) for paving concrete, as well as a minimum cement content of 26 lb/ft$^3$ (420 kg/m$^3$) for concrete used in an exposed aggregate layer.

** Minimum cylinder compressive strength of 4,350 psi (30 MPa) at 60 days and minimum cube compressive strength of 5,400 psi (37 MPa) at 28 days.*

The European cement standard EN 197 was adopted at about the same time as the European concrete standard. It defines 27 types of cement. The types of cement to be used for different concrete construction applications are identified in the German standard DIN 1045-2. Among the European standards for cement, aggregate, admixtures, mixing water, etc., so far only the cement standard EN 197 has been adopted as a harmonized standard.

Aggregates must meet the requirements of the European standard EN 12620. Higher standards apply to aggregates for road construction than for aggregates used in buildings and other structures. These include a limit on loss of mass in freeze-thaw resistance testing, limits on the content of lightweight organic contaminants, shape and flakiness index requirements, polished stone value requirements (50 for conventional road surfacing, 53 for exposed aggregate surfacing), and guidelines for mitigating alkali-silica reaction.

Portland cement grade CEM I 32.5 R (equivalent to ASTM Type I), which also has to satisfy additional requirements, is used for concrete paving in Germany.[22,43] With the client's agreement, portland slag cement CEM II/A-2 or CEM II/B-S, portland burnt shale cement CEM II/A-T or B-T, portland limestone cement CEM II/A-LL, or blast furnace cement CEM III/A (at least 42.5 strength class) may also be used.

The cement may not be too finely ground (maximum fineness 3,500 square centimeters per gram (cm$^2$/g)), and must not set for at least 2 hours after placement. In the 1980s, cracking resembling that caused by alkali-aggregate reaction was observed in several pavements between 5 and 10 years old, all built with cements having alkali contents ($Na_2O$ equivalent) between 1.0 and 1.4 percent. Since then, only cements with alkali contents less than 1.0 percent have been used for road construction, and these pavements have not exhibited the kind of cracking observed in pavements built earlier. The current German standard limits the alkali content of the CEM I cement to 0.80 percent $Na_2O$ equivalent by mass.

Germany has 25 cement-producing groups and plants and 10 concrete pavement contractors. Contractors have responsibility for mix design in Germany and in general the mixes are not proprietary. (Cement products, however, are proprietary.) Fly ash or fillers may be added to the concrete, but fly ash and silica fume may not be used together. Supplementary cementitious materials are not taken into account in the calculation of the cementitious content or the water-cement ratio.

In two-course construction, recycled materials or inexpensive gravels may be used in the lower course, and different strength requirements exist for the upper and lower courses. At least 35 percent of all aggregates must be crushed. High freezing resistance and high resistance to polishing are also required. Germany imports some aggregate from Norway to meet its concrete pavement construction needs.

Concrete in the C30/37 strength class required for road construction must have compressive strength of 4,350 psi (30 MPa) in 6-in-diameter (150-mm-diameter) cores at 60 days, and a compressive strength of 5,400 psi (37 MPa) in 6-in (150-mm) cubes at 28 days. Bending tensile strength is tested only in qualification tests before paving begins. It must be at least 650 psi (4.5 MPa) at 28 days in four-point testing in accordance with EN 12 390-5 (which is nearly identical to a required bending strength of 800 psi (5.5 MPa) tested in accordance with the former DIN 1048 under three-point loading and different test conditions).

## Austria

AUSTRIA'S SPECIFICATION for cement and concrete for concrete paving (RVS 8S.06) requires the European standard type CEM II cement, with an initial set time of no less than 2 hours at 68°F (20°C), Blaine fineness no greater than 3,500 cm$^2$/g, and 28-day cube strength no less than 1,000 psi (7 MPa).

Austria's concrete paving specification (RVS 8S.06.32) requires the concrete mix used in the lower course of two-lift construction to have a 28-day flexural strength of at least 800 psi (5.5 MPa) and a 28-day compressive strength of at least 5,000 psi (35 MPa). The material used in the upper course is required to have a 28-day flexural strength of at least 1,000 psi (7 MPa) and a 28-day compressive strength of at least 5,800 psi (40 MPa).

Concrete mix design is the contractor's responsibility, and the laboratory that the contractor hires can use any method its wants to develop the mix. The contractor's mixture is not considered a proprietary product.

Aggregates used in an exposed aggregate concrete surface layer must have, among other properties, a polished stone value of at least 50. The aggregate used in the lower concrete course may be recycled from old concrete pavement as well as from old asphalt pavement, although the recycled asphalt pavement content is restricted to no more than 10 percent of the total aggregate amount. When an old concrete pavement is recycled, 100 percent of the old pavement is reclaimed, crushed, graded, and reused on site in the new concrete pavement and the cement-treated base, if any.

Portland cement with 20 to 25 percent slag is used in Austria. The minimum cement content for concrete in the lower course is 20 lb/ft$^3$ (320 kg/m$^3$) for fixed-form paving and 22 lb/ft$^3$ (350 kg/m$^3$) for slipform paving. The minimum cement content for concrete in the upper course is 23 lb/ft$^3$ (370 kg/m$^3$) for fixed-form paving, 25 lb/ft$^3$ (400 kg/m$^3$) for slipform paving, and 28 lb/ft$^3$ (450 kg/m$^3$) for an exposed aggregate layer. An air content of 3.5 to 5.5 percent is required for fixed-form paving and 4.0 to 6.0 percent for slipform paving.

## Belgium

THREE TYPES OF CONCRETE MIXES are used for concrete pavements in Belgium. The cements used are either portland cement (CEM I) or a blast furnace slag cement (CEM III/A) of strength class 42.5, with a limited alkali content to prevent alkali-aggregate reaction. High cement contents, low water-cement ratios, and the use of air entraining agents lead to a very durable, high-strength concrete.

Belgium has not had a problem with alkali-aggregate reaction with its local aggregates, so cements with alkali contents up to 0.9 percent are allowed. Air entraining agents were not used in concrete pavements in Belgium until about 10 years ago.

Figure 40 shows gradation curves for aggregates used in concrete pavement mixes in Belgium for maximum aggregate sizes of 20 mm and 32 mm.

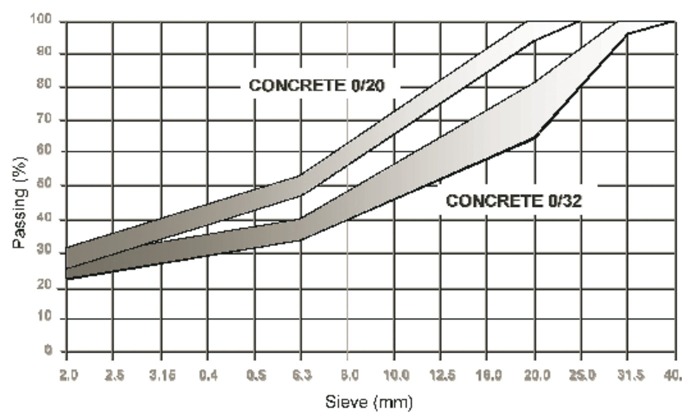


**Figure 40.** *Aggregate gradations for concrete paving mixes in Belgium.*

## The Netherlands

ALTHOUGH NOT STIPULATED AS A requirement, the use of portland fly ash cement (CEM II/B-V 32.5 R, containing 30 to 35 percent fly ash) or portland cement is preferred for concrete pavement construction in the Netherlands. Blended cements containing up to 60 percent slag are also used.

Concrete in the 35/45 strength class is used for concrete paving in the Netherlands. An air-entrained concrete mix with a minimum cement content of 20 lb/ft$^3$ (320 kg/m$^3$) and a water- cement ratio no greater than 0.55 is used. The Netherlands has had no problems with alkali-silica reaction with its local aggregates.

# Chapter Six
# Maintenance Practices

## Canada

In Ontario, maintenance and rehabilitation schedules for concrete pavements are included in the life-cycle costing procedure. For doweled JPC pavement, the initial joint resealing operation occurs in year 12, with resealing operations in years 18 and 28. Diamond grinding to improve friction is scheduled for years 18 and 28. Major rehabilitation of JPC in the form of concrete pavement restoration (CPR) occurs in year 28. CPR includes full- and partial-depth repairs, including some slab replacements, diamond grinding, and joint resealing.

Ontario has conducted field tests of different types of precast slab installations for rapid repair. Two methods for individual slab replacement and one for multiple slab replacement have been tested. These techniques are applicable in situations where the only possible time for a lane closure for slab repair is between 11 a.m. and 5 p.m. MTO believes that slab repairs can be accomplished using precast slabs at production rates comparable to fast-track cast-in-place slab repair, with less dependence on weather conditions.

Québec developed manuals for rigid pavement distress identification(44) and rigid pavement maintenance and rehabilitation.(45) However, no budget for pavement maintenance is provided.

## Germany

Germany uses high-early-strength concrete to repair individual slabs in existing concrete pavements, opening the road to traffic during the evening of the same day the repairs are cast. A cement content of 22 to 25 lb/ft$^3$ (360 to 400 kg/m$^3$) is required to achieve a compressive strength of 1,740 psi (12 MPa) at 6 hours. Superplasticizers are used to achieve sufficient workability in these mixes.

## Austria

On motorways in the Vienna area, pavement repairs are started on Friday evening or early Saturday afternoon, and pavement must be reopened to traffic by Sunday afternoon. To open repairs in 3 days, a concrete mix with a water-cement ratio of 0.42 is used; for one-day opening, a mix with a water-cement ratio of no more than 0.40 is used; and for opening in 12 hours or less, a mix with a water-cement ratio of no more than 0.36 is used.

Austria has recently been studying the use of whitetopping (thin bonded concrete overlay of asphalt) to correct rutting in asphalt pavements. Testing conducted by the Research Institute of the Austrian Cement Industry Association indicates that a wedge-splitting test is a better way to measure the bond between the asphalt and concrete than the more commonly used tensile test. Other tests showed that the asphalt-concrete bond achieved by thoroughly cleaning the milled asphalt surface was not improved by the application of bonding agents.(46)

## Belgium

Concrete overlays and inlays are important techniques for rehabilitating old asphalt and concrete pavements in Belgium. An overlay raises the pavement grade and the old pavement structure becomes the base for the new pavement structure. With an inlay, the existing asphalt (often just in the outer traffic lane) is milled out to a depth equal to the new concrete pavement thickness required. Belgium was the only country visited to mention a concrete inlay as an often-used rehabilitation technique.

Belgium constructed its first concrete inlay in 1933. Concrete inlays in Belgium may be either JPCP or CRCP. In either case, a bituminous layer is required below the concrete slab. Figure 41 shows a CRC inlay being placed.

The first concrete overlay in Belgium was constructed in 1960 over a concrete pavement originally constructed in 1934.

**Figure 41.** *CRC inlay construction in Belgium.*

The jointed concrete overlay was constructed of 7-in-thick (18-cm-thick) reinforced concrete slabs. Figure 42 shows the overlay still in service nearly 45 years later.

Belgium's first concrete pavement, the Avenue de Lorraine in Brussels, was overlaid with concrete in 2003 after 78 years in service. The overlay, shown in figure 43, is 7.8 in (20 cm) thick and 1.8 miles (2.95 km) long and was constructed in 11 days.

Figure 44 shows construction of a concrete overlay on the E40/A10 road from Brussels to Ostende. Two mobile concrete plants were used to produce the 2,600 $yd^3$ (2,000 $m^3$) of concrete a day required for this project. The average paving rate was 3,900 ft (1,200 m) per day, 24 ft (7.25 m) wide. Figure 45 shows a closer view of the paver. Because of the tight schedule for this project, concrete was placed without interruption, 24 hours a day, 7 days a week. As a result, the CRC overlay has no construction joints. A slipform paver was also used to construct the safety barriers on this job, as shown in figure 46.

Fast-track concrete paving mixes are used for rapid repair and reopening to traffic in Belgium. Typically, the base layer is also replaced. These fast-track mixes contain either 28 lb/$ft^3$ (450 kg/$m^3$) of type CEM I, strength class 42.5 cement with

**Figure 42.** *Belgium's first concrete overlay after 45 years in service.*

**Figure 43.** *Concrete overlay constructed in 2003 on Avenue de Lorraine in Brussels.*

**Figure 44.** *CRC overlay construction on E40/A10 in Belgium.*

**Figure 45.** *CRC overlay paving on E40/A10 in Belgium.*

**Figure 46.** *Slipform paving of the safety barriers on the E40/A10 CRC overlay project.*

a water-cement ratio of 0.33, or 28 lb/ft$^3$ (450 kg/m$^3$) of type CEM I, strength class 52.5 cement with a water-cement ratio of 0.38. The mixes used are designed to achieve a compressive strength of 5,800 psi (40 MPa) after 30 to 36 hours, the maximum allowable lane closure time according to Belgian standard specifications. The concrete mixture contained no fly ash or silica fume. Belgium experimented with using precast slabs for rapid repair, but abandoned the technique because of problems with joint faulting.

## The Netherlands

THE FREQUENCY OF PAVEMENT maintenance in the Netherlands depends on the type of surface. Single-layer porous asphalt surfaces are assumed to need replacement in the right lane after 10 years and across all lanes after 14 years. Double-layer porous asphalt surfaces are assumed to need replacement of the top layer in the right lane after 6 years and replacement of both layers across all lanes after 10 years. Bare CRC pavements are assumed to need no maintenance in the first 15 years of service.

Sealing joints in JPCP was tried in the Netherlands in the 1980s, but no beneficial effect of sealing on pavement performance or life was observed. Joints in JPCP now are typically left unsealed.[20]

# Chapter Seven
# Research, Training, and Cooperation

## Canada

The Ontario Ministry of Transportation works closely with the Ontario Road Builders Association (ORBA), Cement Association of Canada (CAC), and Ready Mix Concrete Association of Ontario (RMCAO), and participates in various Transportation Association of Canada (TAC), FHWA, TRB, ASTM, and AASHTO committees. Research partnerships also exist between the ministry and various universities, including Carleton, Queens, McMaster, the University of Toronto, and the University of Waterloo. These partnerships provide input in developing specifications and carrying out trials for using the MIT-SCAN, precast concrete pavement repairs, noise studies, etc.

The Québec Ministry of Transport interacts on a regular basis with members of the Road Builders Association, the Canadian Cement Association, and Bitume Québec (the asphalt industry's organization in Québec). Industry representatives participate with MTQ personnel on technical committees that discuss contracts, standards, and specifications. For example, MTQ's 2001 policy on pavement type selection was based on 2 years of discussion between government authorities and representatives of the asphalt and concrete industries. MTQ sponsors some research activities by the concrete and asphalt industries in Québec.

MTQ is conducting research on the use of glass fiber-reinforced polymer bars in CRCP, based on a similar study done in Illinois. At the end of a 2006 CRCP project, a set of test sections was constructed with 12 combinations of steel content, slab thickness, and single-versus-double layering of the steel. MTQ is also researching the potential use of glass fiber-reinforced polymer dowel bars in jointed plain concrete pavements.

Other areas of research for MTQ include skid resistance and noise mitigation with different concrete pavement surface preparations (exposed aggregate, longitudinal tining, shotpeening, and microgrinding), and development of a device called the ADR (audiomètre routier dynamique) for measuring tire-pavement noise. Thirty field sites are being monitored with the ADR device to assess the progression of tire-pavement noise over time.

## Germany

The German Cement Works Association (Verein Deutscher Zementwerke, VDZ), located in Düsseldorf, is the technical and scientific association of the German cement industry. The organizational structure of VDZ is similar to that of the Portland Cement Association (PCA) in the United States. Nearly all of Germany's cement producers are members of VDZ, which has 29 international members as well.

VDZ's Research Institute conducts research in environment and plant technology, cement chemistry, concrete technology, environmental measuring, and quality assurance. VDZ's laboratories are equipped with state-of-the-art equipment for cement and concrete testing. VDZ maintains a library and an electronic database of literature in cement and concrete research. This electronic database is accessible on the Internet as well as at the Research Institute. About 38 percent of VDZ's budget goes to research (some of which is done at universities), and another 37 percent goes to consulting services, including kiln emissions testing, cement sampling, frost testing, and measurement of air content in hardened concrete.

The German government's research arm within the Federal Ministry of Transport is the Federal Highway Research Institute (Bundesanstalt für Straßenwesen, BASt), located in Bergisch-Gladbach. BASt's research activities encompass highway construction, highway capacity, safety, accidents, and winter maintenance. BASt also provides technical guidance to the state highway authorities, which administer the federal interstate highways and autobahns on behalf of the German government. BASt has a staff of 400 and an annual budget of about US$40 million (€32 million).

The Technical University of Munich (TUM) plays a leading role in developing German pavement design standards and researching many aspects of concrete pavement behavior and performance.

The scan team was impressed with both the quality of concrete pavement research in Germany and the cooperation among the industry, government, and academia. The three entities also work together to set standards (such as the design catalog). VDZ, BASt, and TUM conveyed an image of cooperation and a shared desire to provide the driving public with good, safe, long-lasting pavements.

VDZ does a considerable amount of training for kiln and plant operations. Paving contractors, however, do not have access to as much training. The Federal government in Germany does not work closely with contractors in training and implementation.

## Austria

THE AUSTRIAN CEMENT INDUSTRY Association (VÖZ) represents Austria's 13 cement producers. VÖZ's technical branch is its Research Institute (Forschungsinstitut), which has a staff of 18. It is an accredited inspection body and testing laboratory for cement and concrete. The Research Institute does work in testing, inspection, consulting, product development, and technology transfer. Past and current studies on concrete pavement topics include the following:

- Recycling of concrete for new concrete pavements and the influence of asphalt particles
- Noise-reducing concrete surfaces for roads
- Retarders and curing compounds for the exposed aggregate technique
- Early trafficking of concrete pavements
- High-performance concrete: heat of hydration, shrinkage, and modulus of elasticity
- Recycling of building concrete
- Thin bonded concrete overlays for existing asphalt pavements
- Alkali-aggregate reaction
- Minimization of reflection cracking from cement-bound bases
- Adaptation of concrete pavement strength requirements to European standards
- New cements for concrete pavements with alkali-aggregate reaction

The Austrian Association for Research on Road, Rail, and Transport (Österreichische Forschungsgesellschaft Strasse–Schiene–Verkehr, FSV) serves as a forum for the nine Austrian regional governments, the Ministry of Transport, ASFiNAG, consultants, academics, and construction industry representatives to set uniform technical standards for constructing roads and railways. A managing committee and advisory boards provide oversight of FSV's activities. A full-time secretary-general manages the FSV headquarters in Vienna. Some 70 working groups and committees develop technical guidelines, instruction sheets, and working papers on a broad range of road and rail topics. The flowchart in figure 47 illustrates how ideas for new standards or revision of existing standards proceed through FSV's standards development process.

FSV publishes a series of guidelines for planning, construction, and maintenance. One publication in this series is the concrete pavement standard RVS 8S.06.32, developed and kept up to date by FSV's Concrete Pavements Working Group.

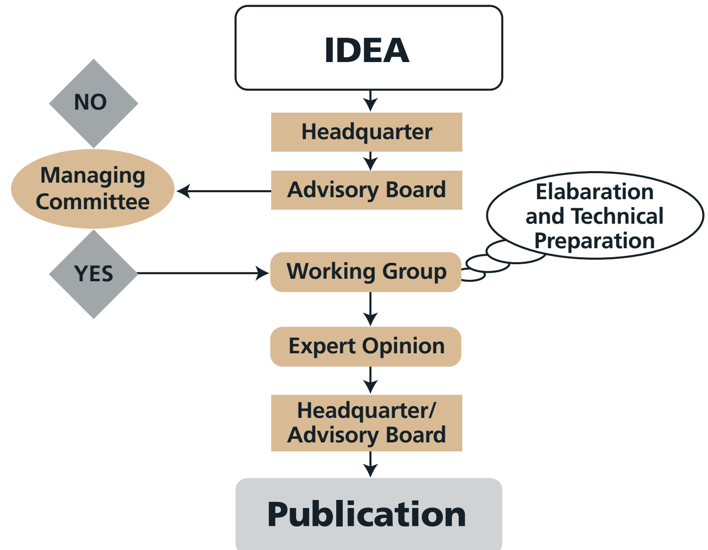


**Figure 47.** *Process for developing road standards in Austria.*

## Belgium

THE BELGIAN GOVERNMENT created the National Center for Scientific and Technical Research for the Cement Industry (Centre National de Recherche Scientifique et Technique pour L'industrie Cimentière, CRIC) in 1960 to oversee research on cement and concrete materials. Representatives of the Belgian cement industry, academia, business, the unions, and the government ministries overseeing research all participate in CRIC's managing boards. The following are some of the CRIC research topics related to concrete pavements:

- Environmental compatibility of concrete
- Durability of concrete exposed to chemical environments
- Prevention of alkali-silica reaction
- Interaction of air-entraining admixtures with type CEM III cement
- Effects of air-entraining admixtures on concrete strength and durability
- Optimal use of concrete admixtures
- Effects of fillers and admixtures on early-age concrete strength

Some of CRIC's research is sponsored by the Belgian Cement Industry Federation (Fédération de l'Industrie Cimentière Belge, FEBELCEM), which is composed of Belgium's three cement producers. FEBELCEM also conducts its own cement and concrete research through its department for promotion, research, and development.

Belgium has about a dozen large concrete pavement contractors, all but one or two of whom also do asphalt paving. Contractors train their own personnel; the government and industry do not provide any construction training.

## The Netherlands

IN 1972, THE DUTCH MINISTRY of Transport and the Dutch Road Builders Association established the RAW Foundation to develop standard specifications for road building. As the group's activities grew beyond specifications development to research, it became necessary to restructure the organization in 1987 as the Foundation Center for Research and Contract Standardization in Civil and Traffic Engineering, better known as CROW.

CROW is the Netherlands' national information and technology platform for infrastructure, traffic, transport, and public space. It is a not-for-profit organization with a mission to develop, disseminate, and manage practically applicable knowledge on policy development, planning, design, construction, management, and maintenance. The national, regional, and local governments, water boards, private consultants, construction companies, materials suppliers, transport organizations, public transit companies, and research and education institutes are all CROW partners. CROW is financed by member subsidies, research sponsorship, and profits from the sale of RAW system standard specifications.

CROW's activities are clustered in seven areas: infrastructure, contract standardization, alternative contract forms, building process management, public space, mobility/transport, and traffic engineering. In each area, steering committees oversee working groups that develop guidelines and recommendations on specific topics and disseminate information to the concrete paving community in the Netherlands. In addition to its technical publications, CROW publishes the monthly ***Wegen (Roads)*** magazine, organizes the annual Roads Conference, and conducts workshops and training courses for thousands of participants every year. CROW also maintains a library of technical publications, journals, reports, and conference papers, and this library is open to the public. Some of CROW's publications are available on the CROW Web site.

The Netherlands' seven cement companies plan to form a cement association in 2007 and dedicate a budget of US$3 million (€2.2 million) to promoting concrete and government affairs. The cost to each cement association member will be based on its market share in cement tonnage. The cement association will be small, with only seven full-time employees, and will outsource much of its promotion work. The cement association itself will probably not operate a laboratory, since the member cement companies have their own laboratories.

The Netherlands has about a half dozen concrete pavement contractors, most of whom do asphalt paving as well. The contractors share their concrete paving equipment but have their own asphalt plants. Practical construction training is done on the job, but several training courses on concrete paving technology are provided for contractor and government personnel by consultants and education institutes.

## United Kingdom

THE LEADING TRANSPORTATION research organization in the United Kingdom is the Transport Research Laboratory (TRL). Established in 1936 as a government laboratory, TRL was made independent and self-supporting in 1990. It has four major divisions, the largest of which is the infrastructure and environment division, which employs about 140 people. Other divisions do a great deal of research on a wide variety of topics related to vehicle safety, public transportation, resource management, and sustainable development. TRL also has one of the oldest and largest pavement testing facilities in Europe.

TRL participates in the Forum of European National Highway Research Laboratories (FEHRL), along with highway research laboratories in 11 other European countries. FEHRL has initiated a collaboration called the European Long-Life Pavement Group (ELLPAG). The aim of ELLPAG is to provide a forum for initiating and stimulating new ideas in the field of long-life pavement design, assessment, and maintenance in an economic and sustainable manner. ELLPAG also aims to encourage the exchange of information on long-life pavements, coordinate research efforts in this area, and promote the wider use of long-life pavements. The first specific objective of ELLPAG was to review the state of the art of design and maintenance of fully flexible long-life pavements in Europe.[47] Work is underway to develop a similar review of the state of the art of design and maintenance of concrete pavements. ELLPAG's long-term objective is to produce user-friendly best practices guidelines on long-life pavement design and maintenance for all common types of pavement construction in Europe.

The concrete paving industry in the United Kingdom is represented by Britpave, the British In-situ Concrete Paving Association, formed in 1991. Its members include contractors, consulting engineers, materials suppliers, and academics. Britpave's task groups focus on roads, airfields, rail, soil stabilization, sustainable construction, and specialist applications.

Concrete pavements have a poor image in the United Kingdom with the public and engineers. As a consequence, few researchers and consultants work in the area of concrete pavements, and contractors involved in concrete paving projects are hard-pressed to find and retain skilled personnel. An independent pavement consultant that briefed the scan team on the status of concrete pavement research in the United Kingdom identified the following areas of research needed to improve the image, economic viability, and technical excellence of concrete pavements in that country:

- Publication and dissemination of up-to-date, definitive guidance on concrete pavement maintenance needs and treatment options
- Development of training programs on concrete pavement maintenance
- Development of the concept of indeterminate-life pavements

for concrete roads, with the aim of capping concrete pavement thickness at the appropriate traffic level

- Development and integration of whole-life costing models for concrete pavements into the Highways Agency's procedures and models
- Development of concrete pavement condition assessment technology for use in network-level and project-level monitoring
- Monitoring of selected CRCP projects to build up a knowledge base on CRCP performance and maintenance needs
- Development of new design approaches, incorporating mechanistic models as appropriate, for concrete pavements and asphalt-overlaid concrete pavements
- Pursuit of the objective of maintaining concrete pavements as concrete

## European Union

THE SCAN TEAM WAS BRIEFED on Nanocem, a European Union-wide initiative in nanotechnology research in cementitious materials. The briefing was given by Professor Karen Scrivener of the Ecole Polytechnique Fédérale (Federal Institute of Technology) in Lausanne, Switzerland. Nanocem is a consortium of more than 30 academic and cement industry partners (see figure 48), with a mission to manage an integrated research and education organization to generate basic knowledge of phenomena on the nanoscopic and microscopic scales that influence the macroscopic performance of cementitious materials.

Nanotechnology is research and development at the atomic, molecular, or macromolecular level of 1 to 100 nanometers (a nanometer is one billionth of a meter, about 100,000 times less than the thickness of a human hair). Nanotechnology is being pursued in many countries in a wide variety of fields.

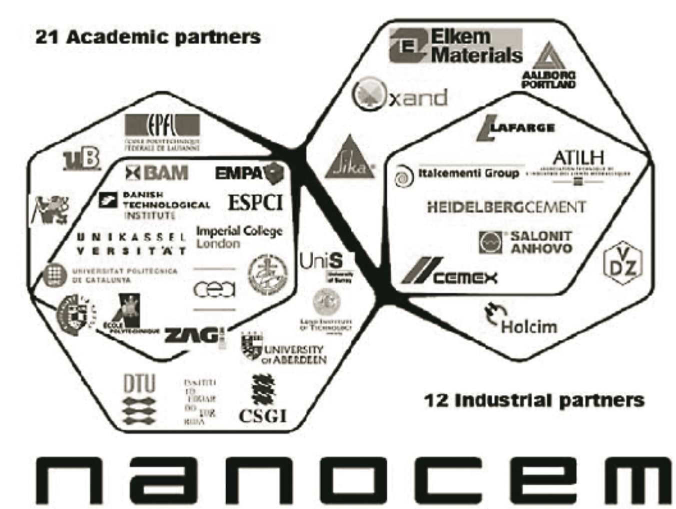


**Figure 48.** *Academic and industrial partners in the Nanocem consortium.*

To date, nanotechnology applications have been predominantly in the field of medicine.

The Nanocem consortium has four core research projects in cementitious materials underway:

- Assemblages of calcium silicate hydrate (C-S-H) and other hydrates: determination of thermodynamic data to predict phase assemblages occurring in (portland) cementitious systems
- Magnetic resonance analysis of nanoscale water interactions in cement paste and relationship to microtransport: use of proton resonance as a nondestructive method to probe the state of water in pores over a range of length scales
- Organo-aluminate interactions: synthesis and characterization of compounds formed between superplasticizers and aluminate phases during early hydration
- Hydration of blended cements: development of a methodology for measuring the reactivity of clinker phases and supplementary cementitious materials independently in blended cements

Nanotechnology research in cementitious materials is expected to produce better understanding and more quantitative measures of such things as cement mortar durability, alkali-silica reaction, the effects of temperature on cement hydration and compressive strength, the phases present in anhydrous cement, the structure of C-S-H, and the microstructure of cement.

In the United States, the potential benefits of nanotechnology research and development are being explored through the National Nanotechnology Initiative *(www.nano.gov)*. The U.S. Department of Transportation is one of 21 Federal agencies participating in this initiative.

# Chapter Eight
# Key Findings and Recommendations

## Key Findings

The team's key findings and recommendations from the long-life concrete pavement scanning study are summarized below.

### Pavement Selection Strategies

**Long-life concrete pavements:** In every country visited, "concrete pavement" is considered synonymous with "long life." These countries expect concrete pavements to be strong and durable, provide service lives of 25, 30, or more years before rehabilitation or replacement, and require little if any maintenance intervention over the service life.

**The public and the environment:** The public is expressing concerns about environmental issues such as noise, congestion, and safety. Environmental issues, especially noise, are becoming major concerns to the public. In all the countries visited, there is a heavy emphasis on traffic safety, mitigation of noise, congestion relief, and the use of recycled materials. In some of the countries, a multicriteria analysis process is used to address these factors in pavement type selection. In the United Kingdom, political forces have driven the decision that, to reduce noise, all highway pavements must have asphaltic surfaces.

**Public-private partnerships and innovative contracting:** To maintain and improve their roadway infrastructures, most EU countries and Canadian provinces have adopted nontraditional financing methodologies such as public-private partnerships and alternative bids. Politicians recognize the advantages of these financing mechanisms and of sharing risk with private entities. Most of the EU nations visited embraced PPP efforts to reduce the national debt and comply with EU financial requirements. As a result, contractors are accepting more responsibility for design, construction, and long-term maintenance of roadways. Under such systems, contractors are more likely to choose concrete pavement because its longer life and lower maintenance requirements reduce future risks. Another aspect of contracting practice observed was the awarding of contracts based on best value rather than low bid.

**Pavement management:** Use of pavement management systems is inconsistent among the EU countries visited and generally is not a driving force in pavement type selection.

**Pavement type selection factors:** Although most countries visited state that they consider life-cycle costs, in practice, other factors such as functional class, truck traffic levels, initial cost, and environmental issues drive pavement type selection. In the province of Québec, a policy decision has been made that certain segments of the network will be concrete pavement, others will be asphalt, and others may be either. In Austria, it is policy that concrete pavement is used above a certain traffic level. A similar policy is exists in the Netherlands.

### Design

**Catalog design:** Germany and Austria routinely use a design catalog to select pavement thickness and some other pavement features. The design features and thicknesses in the countries' catalogs reflect their long-term experience with their materials, climate, and traffic levels. Mechanistic modeling, laboratory testing, and field observations are used to validate the cross-sections in the design catalogs. In the Netherlands and the United Kingdom, mechanistic-empirical design software is used for project-level design work. However, these two countries construct only a few miles of concrete pavement per year. Maximum concrete slab thicknesses are a common feature of the German and Austrian design catalogs. The maximum slab thicknesses appear to be thinner than those designed in the United States for similar traffic levels and in many cases heavier trucks. Fatigue cracking does not appear to be a performance issue with these thinner concrete slabs.

**Design lives:** The design lives used for concrete pavements in the countries visited are typically at least 30 years. In the Netherlands, a design life of 40 years is typical for provincial roads and motorways. The agencies are satisfied with the design and construction practices they use in achieving service lives of up to 40 or 50 years.

**Traffic management and future expansion:** With an eye toward safety and congestion mitigation, widened lanes and full-depth concrete shoulders (emergency lanes wider than U.S. shoulders) are used in design. These emergency lanes are constructed with the same thickness and cross slope as the pavement lanes.

**Widened slabs:** Widened slabs are used routinely in the outer traffic lane to keep truck tires away from the pavement edge, thereby reducing slab stresses and deflections and extending pavement life. The traffic lane cross-section is carried out to the edge of the pavement, including the emergency lane. Some subsurface layers are daylighted beyond the edge of the concrete slab for drainage and constructability.

**Tie bars:** Most of the European countries visited place fewer tie bars across longitudinal joints to tie lanes together (about half the number used in the United States). No problems were reported with lane separation, longitudinal joint load transfer deficiency, or compromised pavement performance because of this.

**Doweled jointed concrete pavements (JCP):** In the European countries that build JCP (Germany, Austria, Belgium, and the Netherlands), doweled joints with 1-in-diameter (25-mm-diameter) bars are typically used and appear to perform well, without joint faulting. This may be because of the large proportion and high quality of the aggregates used in the concrete mixes, which lead to good aggregate interlock and load transfer. The 1-in (25-mm) bars are used on sections that are typically 8 to 12 in (200 to 300 mm) thick and built on thick, usually stabilized, foundations.

**Continuously reinforced concrete pavement (CRCP):** This pavement type is recognized in the countries visited as a heavy-duty, long-life pavement. Some countries, such as Belgium and the United Kingdom, have a long history with CRCP. Belgium's CRCP design and construction technology was in fact adapted from U.S. practice years ago. The United Kingdom reported unique and undesirable crack patterns with skewed transverse steel. The techniques for longitudinal steel design (percent steel) varied from country to country, although crack width control appeared to be a common denominator. None of the countries visited used epoxy-coated steel, but the MTQ in Québec, Canada, uses galvanized steel. In the Netherlands, as a rule of thumb, the thickness required for CRC is 90 percent of the thickness required for JCP. This can be confirmed with the VENCON 2.0 software; for example, for a motorway with a JCP thickness of 11 in (280 mm), the software calculates a CRCP thickness of 10 in (250 mm). In Belgium, CRCP is constructed about an inch (2 to 3 cm) thinner than JCP. Germany has just a few CRCP test sections, but on the 0.9-mi (1.5-km) stretch of experimental CRCP test sections on the A-5 Autobahn near Darmstadt, the slab thickness is 9.5 in (24 cm), which is about an inch (2 to 3 cm) less than German design practice would dictate for JPCP for similar conditions. The thickness reduction was based on analyses conducted by the Technical University at Munich.

**Pavement bases:** Open-graded permeable base layers, using high-quality aggregates, are used in Canada but not in the European countries visited. Dense-graded hot-mix asphalt and cement-treated base layers were used in several countries. In Germany, where in the past cement-treated bases were constructed to bond with concrete slabs, an interlayer of 0.2-in-thick (5-mm-thick) unwoven geotextile or dense-graded hot-mix asphalt is used now to separate a cement-treated base from the concrete layer. Unstabilized bases are used in Germany, based on the success of this base type in test sections built since 1986. Old concrete pavements in the former East Germany affected by alkali-silica reaction have also been successfully recycled for use in unstabilized bases.

## Construction

**Joint sealing:** Based on observations during site visits, sealed and unsealed joints appeared to have performed equally well on older projects. Belgium, however, reports that the long-term performance of unsealed joints is not the same as that of sealed joints, especially on heavily trafficked roads. Both hot-poured and compression seals are used in Austria and Germany. In Austria, strip drains (a few inches (5 to 10 cm) wide and at most 0.5 in (1.25 cm) thick) under about 3 ft (1 m) of the transverse joint in the emergency lane have recently been added as a design feature. Longitudinal contraction joints in some regions of Germany used to be left unsealed, but this practice was discontinued because it allowed water that entered unsealed longitudinal joints to flow beneath the sealant in transverse joints.

**Foundations:** Thick foundations are used for frost protection. These systems were drainable and stable, but not open graded. Recycled materials, including asphalt, concrete, and in one case, masonry from building demolition, were used in the foundations.

**Interlayers:** The use of a 0.2-in-thick (5-mm-thick) geotextile interlayer as a bond breaker between concrete pavement and cement-treated base is a recent requirement in Germany. German engineers indicated that the mortar is presumed to saturate the geotextile during construction, adding just enough stiffness to provide support while still acting as a bond breaker. The required concrete thickness for the cement-treated base alternative was increased from 10.2 to 10.6 in (26 to 27 cm) when the design was changed from one with a bonded base to one with a base separated from the slab by a geotextile. In the other countries visited, the typical interlayer between a concrete slab and a cement-treated base is a layer of hot-mix asphalt concrete.

**Jointless bridge joints:** A "jointless joint" bridge approach was described in the Netherlands, and although it was a trial section, the Dutch appear interested in what may be a low-maintenance solution to bridge approach joints. They made clear, however, that this technique is costly.

## Materials

**Cementitious materials:** Normal and blended cements, containing either slag or fly ash, are used. Limestone is allowed in all portland cements, at a dosage of up to 5 percent. Cements with varying sodium-equivalent contents (generally below 0.9 percent) or blended cements are used to mitigate alkali-silica reaction (ASR) if test results show ASR potential.

Most countries have minimum cement content requirements by mixture type. Supplementary cementitious materials are not considered in the water/cement ratio, nor as part of the cementitious materials content. In countries applying an exposed aggregate surface, mixtures and consolidation processes that produce low paste thickness at the surface are used.

**Aggregate requirements:** Great attention is given to aggregate selection, quality, and gradation, especially for the top layer, in countries using two-course construction. Good-quality aggregates are generally available (although aggregate is imported in some cases). All of the countries use well-graded aggregates, with several separate aggregate sizes (three to four, depending on the layer).

The maximum aggregate size typically used in Europe is 0.8 in (20 mm). The top layer of concrete in two-lift construction usually has a 0.3- to 0.4-in (8- to 11-mm) maximum aggregate size. In the Netherlands, where primarily single-lift construction is done, 1.25 in (32 mm) is the maximum aggregate size. In some countries, the concrete mixtures are considered proprietary. The agency controls quality by specifying the end-product requirements.

**Recycling:** Recycled materials (including concrete and masonry from demolition) have been used in the base layers in various countries. Austria requires the use of recycled concrete and recycled asphalt pavement (RAP) in the lower layer of two-course concrete (and for base). Recycled asphalt is allowed up to a maximum of 30 percent of the coarse aggregate in these mixtures.

The polished stone value test is routinely applied by EU countries for aggregate durability assessment. In Austria, a Los Angeles abrasion test value of no more than 20 is required for the top layer in two-layer construction.

**Corrosion protection:** Québec now requires the use of galvanized rebar. Germany and Austria use tie bars coated only in the middle third and coated dowel bars.

**Compaction control:** Intelligent compaction control equipment (automated feedback on rollers, etc.) is used in Austria. The European countries visited are strict about control of compaction of all layers, and in some countries, load testing of granular layers to check compaction is conducted with a small plate.

**Cement and concrete testing:** Construction process control is typically the responsibility of the contractor in the countries visited. Workability is evaluated using a compaction test, similar to the ASTM Vebe test. Ontario and Austria check the air content in hardened concrete, although in Austria this is done only if a problem is encountered or suspected. In the European countries visited, alkali-silica reaction (ASR) is controlled, if detected by preconstruction testing, using blended cements or cements with low alkali content. No country reported difficulty with controlling ASR.

**Pavement testing:** The countries visited do not perform quality control testing for noise, and no one method is used consistently from country to country to measure noise. Texture measurements are made both for end-product and pavement management system-based data collection. The MIT-SCAN equipment developed in Germany for detecting dowel bar misalignment is specified in Canada (Ontario) for both quality control and quality assurance purposes, but not in the other countries visited. A 4-m straightedge is typically used to measure roughness in the EU countries visited. Belgium also uses the APL (Analyseur de Profil en Long, or length profile analyzer) to measure pavement profile. The smoothness of pavements on which the scan team traveled was excellent in all countries visited.

## Maintenance

**Maintenance techniques:** In general, most of the countries visited have had little or no need to do maintenance of concrete pavements. Joint resealing is conducted in a sporadic manner, if at all. One widely used maintenance technique is a thin asphalt overlay to correct rutting caused by studded tires or mitigate tire-pavement noise. Only in Canada is diamond grinding used to improve smoothness on bare concrete pavements. In the United Kingdom, concrete pavement is overlaid with asphalt to reduce noise.

**Precast slabs for rapid repair:** Canada is evaluating the use of U.S.-developed precast concrete technology for rapid repair. In a field experiment the scan team visited, the team observed that panels were used for individual slab and multislab replacement. The Michigan and Fort Miller methods of placing precast slabs were examined in the Canadian experiment. Canada is also examining modification of the Michigan method. While both applications exhibited some premature distresses in the Canadian tests, primarily because of issues related to installation, the Ontario Ministry of Transportation believes this will become a practical specialty method of construction and repair.

## Research

**Concrete pavement research:** In Europe, academic and trade institutions conduct most research related to cement and concrete materials and concrete pavements. For example, the VDZ in Germany is conducting research on the behavior of synthetic air entraining agents and alkali-silica reaction.

**Nanotechnology:** A cooperative venture for research in nanotechnology for cementitious materials (Nanoscience of Cementitious Materials, Nanocem) has been organized in Europe. The consortium consists of academia and industry members, with financial support from the cement industry and the European Community. This effort should lead to improvements in the durability and mechanical properties of concrete. The focus of Nanocem's research activities is cement behavior; research into concrete mixture properties is some years away.

### *Industry Relations*

**Contractor training:** In most countries visited, no formal training of construction contractor personnel is routinely conducted through preconstruction meetings or other required education. Most construction training appears to occur on the job. However, most countries visited appeared to have well-educated and qualified field personnel. Some training is provided by the cement industry groups.

**Certification:** There are no certification standards for inspectors and contractors' employees in the European countries visited. Training is the contractor's responsibility and not a requirement. Concern was expressed that less-experienced paving construction workers come from eastern European countries, which may necessitate more training programs in the future.

**Communications:** In general, the European countries visited have good communications between contractors and the highway agencies. Academic and industry input is highly valued. For example, committees of agency, industry, and academic experts are formed to develop design catalogs.

**Standards:** European standards are in the long, slow process of harmonization. Meanwhile, individual European countries continue to use their own standards. The Comité Européen de Normalisation (CEN) is mandated by the European Commission to develop standards for a variety of European Community products. The EC's Construction Products Directive (CPD) requires that construction products be fit for their intended use. Works in which these products will be used must satisfy CPD requirements over an economically reasonable service life. Such products are placed on the market with a "CE" stamp. In the case of cement, even if the producer declares that a product conforms to the CEN standard, independent testing must be done to ensure this conformity. The CE "seal of approval" is useful, for example, if a paving contractor runs out of cement from one source in the middle of a paving job and must use cement from a different source (although tests have to be repeated with the new cement). CEN standards have not yet been developed, however, for many concrete paving materials (dowels, rebar, joint sealants, etc.). European (EN) or national standards continue to be used for these materials.

## Recommendations

The long-life concrete pavement scan team identified the following technologies as having the greatest potential for implementation in the United States.

**Two-lift construction:** Austria, Belgium, the Netherlands, and Germany use two-lift construction to build concrete pavements with good friction and noise characteristics, economize on the use of aggregates, and use reclaimed paving materials. In two-lift construction, a relatively exposed aggregate surface lift containing high-quality aggregates is placed atop a lift containing virgin aggregates of lesser quality or reclaimed aggregate from concrete or asphalt pavements, resulting in materials cost savings.

Two-lift construction is not new to the U.S. concrete paving industry. Two-lift paving was specified by many State DOTs in the past when wire mesh-reinforced pavements were constructed and mesh depressors were not allowed. In recent decades, a couple of States have experimented with two-lift construction to promote recycling and enhance surface characteristics.

**Catalog design:** Pavement design catalogs have been successfully used in Europe for many years. In the United States, the design of concrete pavement has traditionally been done on a project-by-project basis. This approach has served the U.S. pavement engineering community fairly well for many years. However, with the increasing difficulty of predicting traffic loads, volumes, and axle configurations, designing on a project-by-project basis may not always be required.

In addition, changes and new developments in materials have created a need for a design procedure with the flexibility to consider the effects of material properties on the responses of the pavement structure. This need is being addressed with the development of the *Mechanistic-Empirical Pavement Design Guide* (MEPDG).

The catalog design method is a simple procedure for selecting an initial pavement structure. Most European countries visited have routinely used design catalogs to select pavement thicknesses and some other pavement features. The countries using design catalogs recognize that simply extrapolating empirical trends is not reliable and often leads to overdesign of concrete pavements. The design features and thicknesses in the catalogs reflect long-term experience with the local climate, materials, and traffic levels. These experiences are validated through analysis by expert teams using mechanistic principles. The expert teams employ laboratory testing and field observations to validate the cross-sections in the design catalogs. The designs are defined and refined about every 5 years.

The use of a catalog for selecting pavement thicknesses and other pavement design features offers advantages of consistency and simplicity. Catalog design is not itself a design procedure, but rather a medium for identifying appropriate pavement design features for use in pavement analysis. The quickest form of developing a catalog design is simply to incorporate the standard designs that have shown good, consistent, long-term performance. A design features matrix is another part of the catalog concept that identifies alternatives for features (e.g., base types) and provides information on such items as the cost, performance, and feasibility of constructing the feature to allow an agency to make an informed decision on whether to include it in a design. Nevertheless, the information recommended in the catalog needs to be validated by laboratory and field investigations.

**Deep, high-quality foundations:** The unbound granular materials used for concrete pavement subbases in Europe are generally better-quality materials (better graded, better draining although not open-graded, and with lower fines content) than the materials typically used as select fill and granular subbase in the United States. Aggregate standards were mentioned in all the countries visited. A closer look at the aggregate standards in place in the United States and a comparison to the European standard may provide some insights into improving foundations in this country.

Recycled concrete not reused in the pavement itself is commonly used in the base material of pavements in Europe. It appeared that it was also fractionated and part of the grading. Cement-treated bases were also in wide use in several countries, with an asphalt or geotextile interlayer as a separator. In addition, it was noted that intelligent compaction is used in Austria. Germany uses a plate load test for quality assurance of layer compaction equipment.

**Attention to mix design components:** One key to long-lasting concrete pavements in Europe appears to be the great attention to cement and concrete mixture properties. The mixtures produce strong, dense, and durable concrete, despite the apparent widespread presence of reactive aggregates in western Europe. The flexural strength noted in the top lift was about 1,000 psi (7 MPa), much higher than the typical flexural strength target in the United States. The careful consideration of cementitious materials used in the mix is one area that could yield benefits for the United States.

**Geotextile interlayer:** A key detail recently introduced in Germany for cement-treated bases is the use of a thick geotextile interlayer to prevent the concrete slab from bonding to the cement-treated base. This geotextile material is thicker than the materials commonly used for layer separation purposes in the United States. It is sufficiently porous that mortar from the fresh concrete permeates the geotextile, which provides a good mechanical bond of the geotextile to the concrete layer while achieving separation from the base layer. This geotextile may provide a suitable alternate to the asphalt interlayer used in many States.

**Low-noise exposed aggregate surfacing:** The public's concern about environmental issues is evident in densely populated, traffic-congested Europe. A concrete pavement noise solution popular in some European countries is exposed aggregate surfacing, in which exceptionally high-quality, durable aggregates are used in the top course of the concrete slab, and a process of set retardation and abrasion is used to produce an exposed aggregate surface with good low-noise properties. Exposed aggregate is also touted as yielding other benefits, including good friction and durability. However, favorable noise levels may also be achieved by specific pavement texturing techniques.

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# Appendix A
# Amplifying Questions

**The following general questions were submitted to the host countries before the scan team's visit.**

## 1. Experience

- Please provide a brief history of pavement and pavement types in your country.
- Describe the role that concrete pavement has played in this timeframe.
- What types of concrete pavements have been used, and how have they performed?

## 2. Current Usage

- Please describe the current situation with concrete pavement in your country, with respect to pavement type selection, performance expectations, and short-term and long-term applications.
- What role does life-cycle cost analysis play in decisions about pavement type and pavement design?
- What are the factors considered in life-cycle cost analysis?

## 3. Terminology

- Do you use a term such as "long-life pavements" or something similar?
- How do you distinguish between a "long-life" concrete pavement and concrete pavement designed for a "normal" life?

## 4. Pavement Management

- Do you use long-life pavements as part of your network-level pavement management?
- Do you use pavements with longer service lives in some situations and pavements with shorter service lives in other situations to optimize the overall condition and performance of your pavement network?
- How is information about pavement performance, specifically concrete pavement performance, used in your pavement management system?

## 5. Government-Industry Relations

- Please describe the relationship between government and the paving industry in your country with respect to pavement research and development, technical services, and training.
- How does the industry work with the government?
- What role do industry associations play?

## 6. Public-Private Partnerships

- How do public-private partnerships and concessionaires operate in your country, in terms of investment, pavement type selection, etc.?
- What do you see as the probable future trends in public-private interaction in the pavement field in your country?

## 7. Methods Used to Maximize Concrete Pavement Life

- Materials evaluation (coarse and fine aggregate properties, cements, additives, fly ash, etc.)
- Concrete mix design
- Pavement thickness design
- Pavement geometric design (slab dimensions, joint design, etc.)
- Specifications
- Construction procedures
- Maintenance practices (including winter maintenance)
- Rapid construction and rehabilitation techniques

**The following detailed questions were used by the scan team members in discussions with their hosts in the countries visited.**

## 1. Experience

1.1. What types of concrete pavements do you build?
1.2. What are the typical failure modes for your concrete pavements?

## 2. Current Usage

2.1. How are initial costs and life-cycle costs balanced in the decisionmaking process of pavement selection and design?

## 3. Terminology

3.1. What design life (in years or accumulated traffic) is used for concrete pavements?

## 4. Pavement Management

4.1. Are materials and construction data stored and subsequently linked to long-term performance?
4.2. How are functional characteristics (smoothness, friction, noise) controlled during the life cycle of a "long-life" pavement?

## 5. Government-Industry Relations

(No detailed questions)

## 6. Public-Private Partnerships

(No detailed questions)

## 7. Methods Used To Maximize Concrete Pavement Life

7.1. How much emphasis is placed on concrete materials versus structural design when designing a "long-life" pavement?
7.2. What types of aggregates do you use in concrete slabs?
7.3. What quality requirements do you have for aggregates used in concrete slabs?
7.4. What types of aggregates do you use in bases and subbases?
7.5. What quality requirements do you have for aggregates used in bases and subbases?
7.6. Is aggregate availability a concern? If so, how do you address that?
7.7. In the United States, the practice for aggregates is shifting to use of combined aggregate grading (e.g., the Shilstone approach) instead of gap-graded aggregates for slipform paving. What is your agency's current practice? Is this practice a change from previous practice?
7.8. What types of cements do you use?
7.9. What kinds of supplementary cementitious materials and/or chemical admixtures do you use? What limits, if any, do you place on the use of supplementary cementitious materials for paving concrete?
7.10. For what types of materials will you accept the manufacturer's certification in lieu of testing upon receipt? Is there a trend toward or away from acceptance of manufacturer's certification in lieu of testing?
7.11. How willing is the agency to accept substitutions for conventional materials using new and innovative alternatives? How are the costs and risks shared when substitutions are used?
7.12. What has been the result of European Committee for Standardization (CEN) and European Organization for Technical Approvals (EOTA) normalization on concrete pavement material evaluations in your country? Does your country use specifications or procedures not standardized under CEN or EOTA?
7.13. What procedures are used to design your concrete mixtures? What materials properties, performance indicators, or other factors (e.g., cost, air content, strength, workability, cracking resistance) are used to optimize and/or select your concrete mixtures? Which of these factors is most important?
7.14. Is compatibility of concrete materials a concern for your agency? Do you test for compatibility of various concrete materials?
7.15. Are alkali-silica reactivity (ASR) and/or D-cracking concerns for your agency? If so, how do you address these problems?
7.16. Are recycled materials used in concrete pavements? If so, what requirements do you have for recycled materials used as aggregate?
7.17. Is the concrete mixture used by the contractor considered a proprietary product?
7.18. Do you test for concrete drying shrinkage and/or coefficient of thermal expansion? If so, how?
7.19. Do you perform testing for concrete permeability?
7.20. What type(s) of joint sealing materials do you use?
7.21. What are the typical thicknesses and thickness ranges for the base, concrete slab, and asphalt concrete surface (if any) for the type or types of concrete pavements you build?
7.22. Do you use a structural design procedure to design pavements or do you use a design catalog approach?
7.23. What performance measures (smoothness, International Roughness Index (IRI), noise, specific distresses) do you use in concrete pavement design? What condition levels are used to define "failure?"
7.24. What are your practices with respect to the following:
- Joint spacing
- Dowels at transverse joints (size, spacing, materials, corrosion prevention, etc.)
- JRCP steel reinforcement (size, spacing, layers, corrosion prevention, etc.)
- CRCP steel reinforcement (size, spacing, layers, corrosion prevention, etc.)
- Texturing
- Curing
- Joint sawing (one versus two cuts, conventional versus early entry saws)
- Joint sealing

7.25. Do you use any of the following, and if so, do you have any design or performance issues associated with them?
- Concrete shoulders
- Widened slabs
- Subsurface drainage systems

7.26. What types of stabilized or unstabilized bases and subbases do you use? Do you have any design or performance issues with any particular base types?
7.27. What types of reinforcement (e.g., round steel, flat "ribbon" steel, glass fiber reinforced polymer (GFRP), etc.) have been used in concrete pavements in your country? What, if any, differences in performances have there been in pavements with different types of reinforcement?
7.28. How are pavement terminals designed for your rein-

forced pavements? Is terminal anchorage (e.g., anchor lugs, slabs) used? Is pavement reinforcement ever tied into reinforcement of adjacent bridges or structures?

7.29. What concrete strength do you specify?

7.30. What surface texture requirements do you specify?

7.31. How do you specify concrete workability? What testing is conducted to determine concrete workability?

7.32. Do you use end result, quality assurance/quality control, or performance-based specifications for paving concrete?

7.33. Who performs construction testing—the agency or the contractor?

7.34. Is the contractor required to submit a quality management plan?

7.35. Do you use warranties for concrete pavements and, if so, for what duration?

7.36. What materials properties are evaluated by the public agency if the project is constructed under a warranty contract versus another contract type? What pavement performance indicators are monitored in each instance?

7.37. What requirements do you have for the foundation (including embankment)?

7.38. What are your workability requirements for slipformed concrete? Do you conduct any testing to determine concrete workability?

7.39. How do you test freshly placed concrete? Do you test for the following?

- Consolidation
- Air content
- Segregation

7.40. How much hand finishing is allowed behind the paver for slipformed concrete?

7.41. For dowel bars, do you use baskets or inserter machines? If inserters are used, what has been your experience with them? Do you test for dowel alignment? If so, what method is used?

7.42. Are multiple-lift pavers used?

7.43. Are nondestructive test methods (e.g., maturity, pulse velocity, MIT-SCAN) used to check in-place concrete properties? If so, do these supplement or replace traditional test methods?

7.44. What acceptance criteria do you think are most important?

7.45. What are the certification requirements for the contractor's crew and for testing and inspection personnel?

7.46. Do you reseal joints? If so, is it done on a regular predetermined cycle or as needed based on sealant condition?

7.47. What types of maintenance and repair cycles (surface grinding, etc.) do you consider acceptable?

7.48. Do you consider expedited construction a tradeoff with longer life, or can both be achieved for a single project?

7.49. What rapid construction methods are used for long-life concrete pavements?

7.50. What rapid rehabilitation methods are used for long-life concrete pavements?

7.51. Do you use high early strength concrete mixtures for rapid construction and/or rehabilitation? If so, what are the criteria for opening to traffic?

7.52. Do you use precast paving, and if so, in what situations?

7.53. How are repairs performed on CRCP?

7.54. What deicing materials do you use on concrete pavements?

# Appendix B
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## Biographic Sketches

**Dan Dawood** *(AASHTO cochair)* is chief of the Pavement Design and Analysis Section for the Pennsylvania Department of Transportation in Harrisburg, PA. Dawood is responsible for all policy, specifications, and standards that relate to pavement design and construction statewide. He is also responsible for establishing and managing research projects that enhance pavement design and construction technology. Before becoming chief pavement engineer, Dawood worked in regional district offices as a highway designer and traffic safety engineer. He also spent time as a private sector engineer after beginning his career as a geotechnical engineer. Dawood received a bachelor's degree in civil engineering from Pennsylvania State University and is a licensed professional engineer in Pennsylvania. He serves on various task forces and committees nationally. He chairs the American Association of State Highway and Transportation Officials (AASHTO) Joint Technical Committee on Pavements.

**Suneel Vanikar** *(FHWA cochair)* is the Concrete Team leader for the Federal Highway Administration (FHWA) in the Office of Pavement Technology in Washington, DC. Vanikar directs activities related to concrete pavement and concrete materials, including policy, guidance, research, and technology transfer. He is involved in fast-track construction, nondestructive testing of concrete, and high-performance concrete programs. He has written numerous publications on high-performance concrete and is a frequent speaker at national and international meetings. Vanikar earned a master's degree in civil engineering from Colorado State University and is a licensed professional engineer in New Hampshire. He serves on technical committees of the Transportation Research Board (TRB) and the American Concrete Institute (ACI). He is a recipient of the FHWA Administrator's Award and the Public Official of the Year Award from the American Concrete Pavement Association (ACPA).

**Robert F. Tally, Jr.** *(FHWA cochair)* is the division administrator for the FHWA Indiana Division. Tally directs a multidisciplinary staff that administers the Federal-Aid Highway Program throughout Indiana to improve its transportation system. Before his promotion to division administrator, he served as the assistant division administrator in the Texas Division, Program Delivery Team leader in the California Division, and bridge engineer in the Arizona Division, and in other engineering positions in the South Carolina, Michigan, and Louisiana Divisions. During his FHWA career, Tally has worked on a number of noteworthy projects, including the $3.5 billion Central Texas Turnpike project in Austin, TX; the $3.2 billion San Francisco/Oakland Bay Bridge replacement project in San Francisco, CA; the Hoover Dam Bypass Bridge Project in Boulder City, NV; the Navajo Bridge project in Arizona; and the Cooper River Bridge and Wando River Bridge projects in Charleston, SC. Tally received bachelor's and master's degrees in civil engineering from the University of Louisville and is a licensed civil engineer in South Carolina. Tally's expertise and focus are on implementing applied research and technological advances to improve delivery of transportation systems in the United States.

**Tom Cackler** is the director of the National Concrete Pavement Technology Center at Iowa State University. The CP Tech Center manages more than $8 million in concrete pavement technology research, including four Transportation Pooled Fund Program studies. Cackler was part of the research team that produced the *CP Road Map* publication and directed the acquisition of the CP Tech Center's 2,500-square-foot mobile laboratory. Before joining the CP Tech Center, Cackler worked for more than 25 years for the Iowa Department of Transportation, most recently serving as the director of the Highway Division. Cackler earned a bachelor's degree in civil engineering from Iowa State University and is a licensed professional engineer in Iowa. He serves on the TRB Construction Management Committee (A2F05) and has served on the AASHTO Standing Committee on Highways, AASHTO Subcommittee on Construction, and joint industry quality improvement committees with the Associated General Contractors of Iowa, Asphalt Paving Association of Iowa, and Iowa Concrete Paving Association.

**Angel L. Correa** is a pavement and materials engineer for the FHWA Resource Center in Atlanta, GA. Correa provides technical assistance and training to State departments of transportation in all aspects of portland cement concrete pavement design, construction, materials, and rehabilitation. Correa has been with FHWA for more than 15 years, spending the past 10 years in concrete pavement rehabilitation and preservation. He has held technical positions in the FHWA Resource Center in Atlanta and the Office of Pavement Technology in Washington, DC. Correa received a bachelor's degree in civil engineering from the University of Puerto Rico and a master's degree in civil engineering from the University of Illinois at Urbana-Champaign. He is a licensed professional engineer in Maryland and serves on various State and TRB technical committees on concrete pavements.

**Peter Deem** is vice president of national and regional promotion for Holcim (US) Inc. Deem works with the major national associations in the cement industry and represents Holcim (US) on many of their boards and committees. Deem's position as chairman of the American Concrete Pavement Association (ACPA) involves him in all aspects of the concrete paving industry. Before becoming vice president of national and regional promotion, Deem was vice president for sales for the Holcim West Division. He received a bachelor's degree in liberal arts from the University of Minnesota. He is on the board of directors and executive committee of ACPA, the board of directors of the American Concrete Pipe Association, and several committees of the Portland Cement Association and the National Ready Mix Concrete Association. He is also involved with the boards of directors of a number of regional promotion groups for the cement industry.

**Jim Duit** is the president of Duit Construction Company, Inc., a concrete paving contractor in Edmond, OK. Duit is now constructing concrete paving projects in Oklahoma, Texas, Arkansas, and Kansas. He started his company in 1969 and has been building concrete pavements ever since. He is a graduate of Iowa State University. He is the past national chair of the American Concrete Paving Association and past president of the Oklahoma Associated General Contractors and Oklahoma/Arkansas American Concrete Paving Association. Duit is also active on many association committees.

**Georgene M. Geary** is the State materials and research engineer for the Georgia Department of Transportation. Geary oversees the testing, pavement, geotechnical, and administration functions of the Office of Materials and Research, involving more than 380 employees. Her office is responsible for the quality of all materials used in Georgia DOT construction projects and the management of a $6 million-a-year research program. The Georgia DOT is involved in a "Fast Forward" program that includes widening, reconstruction, and rehabilitation of the Interstates, many of which were originally constructed as concrete pavements. Geary earned a bachelor's degree in civil engineering from the University of Illinois at Urbana-Champaign and a master's degree in civil engineering from the Georgia Institute of Technology. She is a licensed professional engineer in Georgia. She serves on several TRB technical committees, is on several committees for ASTM and AASHTO, and is on the American Society of Civil Engineers' (ASCE) Transportation and Development Institute Research Committee.

**Andrew Gisi** is the geotechnical engineer with the Kansas Department of Transportation in Topeka, KS. Gisi directs the activities of the Geotechnical Unit with responsibilities in soil, pavement, geology, and pavement management. He serves as technical expert in design, construction, maintenance, and performance of highway pavements. He has served in his present capacity for 4 years. He has 30 years of experience in pavement evaluation and design and 7 years of experience in the accelerated pavement testing arena. Gisi is a graduate of South Dakota State University and holds a master's degree in civil engineering from Kansas State University. He is a licensed professional engineer in Kansas and serves on several technical committees of the ASCE, ASTM, AASHTO, and National Cooperative Highway Research Program (NCHRP).

**Dr. Kathleen T. Hall** *(report facilitator)* is a consultant specializing in design, evaluation, structural analysis, and rehabilitation of concrete and asphalt-overlaid concrete pavements. She has served as the principal investigator for several NCHRP and FHWA research studies on subjects including the cost-effectiveness of sealing joints in concrete pavements; the effectiveness of subsurface drainage systems in asphalt and concrete pavements in the Long-Term Pavement Performance program (LTPP) SPS-1 and SPS-2 experiments; the performance of concrete and asphalt pavement maintenance and rehabilitation techniques in the LTPP SPS-3, SPS-4, SPS-5, and SPS-6 experiments; and the development of guidelines for pavement rehabilitation. She is a codeveloper of the National Highway

Institute (NHI) training course "Concrete Pavement Design Details and Construction Practices," principal investigator for presentation of the NHI course "Pavement Subsurface Drainage Design," and coprincipal investigator for the development of the NHI course "Analysis of New and Rehabilitated Pavement Performance with Mechanistic-Empirical Design Guide Software." Hall received her bachelor's, master's, and Ph.D. degrees in civil engineering from the University of Illinois at Urbana-Champaign and is a licensed professional engineer in Illinois and Indiana. She is a past chair of the TRB Committee on Rigid Pavement Design, as well as a member of TRB's committees on pavement rehabilitation, and sealants and fillers for joints and cracks. She is vice president of the International Society of Concrete Pavements and a member of ACPA.

**Dr. Amir N. Hanna** is a senior program officer with the National Cooperative Highway Research Program (NCHRP), a division of the National Academy of Sciences' Transportation Research Board. Hanna joined NCHRP in 1992. He manages research projects in the areas of pavement design, materials, construction, and maintenance. He was responsible for the $7 million project that developed the ***Mechanistic-Empirical Pavement Design Guide*** and several projects dealing with concrete pavements and concrete materials used in pavements and bridges. Previously, he worked for 5 years as a project manager for the Strategic Highway Research Program, during which he was part of the Long-Term Pavement Performance (LTPP) studies group and was responsible for the development of the Specific Pavement Studies. He worked for 15 years as a principal engineer for the Construction Technology Laboratories of the Portland Cement Association. He also worked for the Transportation Development Centre of the Canadian Ministry of Transport and the Technical University of Munich, Germany. Hanna holds a Ph.D. degree from the Technical University of Munich and is a registered professional engineer in the Province of Ontario, Canada. He is a fellow and life member of ASCE, a fellow of ACI, and a member of ASCE and ACI technical committees. He was a member of several TRB technical committees for more than 20 years and chaired the TRB committee on strength and deformation characteristics of pavements from 1979 to 1985. Hanna was a member of the 1992 U.S. Tour of European Concrete Highways.

**Steven Kosmatka** is staff vice president of Research and Technical Services for the Portland Cement Association (PCA), in Skokie, IL. Kosmatka oversees PCA's Research, Construction Technology Center, Product Standards and Technology, and Cement Manufacturing programs. This includes research and standards development aimed at improving durability of concrete pavements. Kosmatka has 25 years of experience addressing durability issues, such as alkali-aggregate reactivity, deicer scaling, frost resistance, and sulfate attack. He received his civil engineering degree from the University of North Dakota. He is a licensed professional engineer and serves on technical committees of ACI, TRB, and the American Society for Testing and Materials.

**Dr. Robert Rasmussen** is vice president and chief engineer of The Transtec Group, Inc., a pavement, materials, and construction engineering firm headquartered in Austin, TX. On this scanning tour, he represented the Concrete Reinforcing Steel Institute, with which he has worked on numerous projects. Rasmussen's accomplishments include the development of design and construction guidelines for concrete overlays, the FHWA HIPERPAV software to predict the early age behavior of concrete pavements, and a concrete materials and mix performance analysis system (COMPASS), as well as the measurement and modeling of concrete pavement unevenness, texture, friction, and tire-pavement noise. He received a bachelor's degree in civil engineering from the University of Arizona, and master's and Ph.D. degrees from the University of Texas at Austin. Rasmussen is a registered professional engineer in Texas, has written dozens of peer-reviewed papers, and is the recipient of an international award from the World Road Association (PIARC). He belongs to numerous editorial boards, expert task groups, and industry groups, including TRB, ASCE, ACPA, Association of Asphalt Pavement Technologists, RILEM (International Union of Laboratories and Experts in Construction Materials, Systems, and Structures), and Institute of Noise Control Engineering.

**Dr. Shiraz D. Tayabji** is the regional manager for the CTL Group of Columbia, MD. A past president and founding member of the International Society for Concrete Pavements, he is involved in developing, improving, and implementing technologies for highway and airfield concrete pavements. He has been involved in design, construction, testing, and rehabilitation of concrete pavements for many years, and provides consulting services on problems related to airfield and highway concrete pavements. He serves as the project manager for two major multiyear contracts funded by FHWA to improve pavement performance and implement technology transfer activities for concrete pavements. He was recently awarded a project funded by the Federal Aviation Administration (FAA) and overseen by the Innovative Pavement Research Foundation (IPRF) to revise the P-501 specification for construction of FAA-funded airfield concrete pavements. Tayabji received a bachelor's degree in civil engineering from the University of East Africa in Nairobi, Kenya, and master's and Ph.D. degrees in civil engineering from the University of Illinois at Urbana-Champaign. He is a registered engineer in Illinois, Pennsylvania, Maryland, Delaware, Virginia, and New Jersey.

**GERALD VOIGT** is the president and chief executive officer of the American Concrete Pavement Association, headquartered in Skokie, IL. Voigt leads the association in its full array of services, including technical, market development, research, and government affairs. Under his leadership, the association has formed a National Concrete Pavement Technology Center that will provide research and technology transfer support to the industry. He is the author of many industry technical documents covering a broad range of concrete pavement topics, including design, construction, rehabilitation, and materials. He was appointed ACPA president in 2005, having been with the association since 1988. Voigt earned bachelor's and master's degrees in civil engineering from the University of Illinois at Urbana-Champaign and is a registered professional engineer in Illinois. He serves on several boards and technical committees, including the National Concrete Pavement Technology Center, Transportation Engineering Road Research Alliance, and TRB.


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