Demonstrating Innovative Concrete Pavement Concepts in Michigan

ROGER TILL, DAVE SMILEY, AND RANDY VANPORTFLIET

The Michigan Department of Transportation (MDOT) is using European design and construction practices for a portland cement concrete (PCC) pavement demonstration project on Interstate 75. The objective of the project is to determine if innovative concrete pavement features, similar to ones used in Europe, will provide a longer service life than the conventional PCC pavements typical in the United States.

The demonstration project is a part of a major Michigan project to reconstruct 2.3 mi (3.7 km) of the I-75 (Chrysler) freeway in downtown Detroit, between I-375 and the I-94 (Edsel Ford) freeway. The original I-75 six- to eight-lane pavement was opened to traffic in 1963. One of Michigan's busiest freeways, it carries about 111,000 vehicles a day, of which about 11 percent are trucks.

The experimental section is approximately 1 mi (1.6 km) long and is located on northbound I-75 between the Warren Avenue exit ramp northerly to Picquette Avenue. German and Austrian specifications were used as the basis of design for the section and were adjusted only slightly to fit U.S. practices. A conventional Michigan pavement design is used for the rest of the northbound roadway as a control section. Construction began on the European section in July 1993 and was completed in November 1993. Northbound I-75 traffic was detoured during construction. The entire project is scheduled for completion in November 1994 after the southbound direction of I-75 is reconstructed.

Roger Till is Supervising Engineer, Structural Research Department, Dave Smiley is Supervising Engineer, Pavement Technology Department, and Randy VanPortfliet is Construction Grading and Drainage Engineer, Michigan Department of Transportation.

1992 U.S. Tour of European Concrete Pavements

In 1992 transportation experts from across the nation examined, firsthand, concrete pavements used in Europe in an effort to produce a longer-lasting concrete pavement here in the United States. Stiffer pavements were thought to be a major contributor to a longer service life. This tour stimulated much interest in finding ways to implement key European features into American design and construction practices. With the goal of constructing a trial section, MDOT staff engineers participated in a follow-up technical tour in October 1992 to study concrete pavement construction practices in Germany and Austria. The Michigan engineers found rigid pavement designs in Germany and Austria to be typical of others in the European Community. For many years, Europeans have emphasized the strength and quality aspects of a pavement's design, materials, and construction; traditional American objectives have been to lower initial costs and shorten the time of construction while maintaining a highway system of high quality. German pavement cross sections have been standardized to account for the project's anticipated traffic loadings, soil support characteristics, and climatic conditions; these features are conveyed in a national pavement design manual. The efforts of the transportation agency are then concentrated on constructing high-quality concrete pavements through a cooperative working relationship with contractors and material suppliers. Performance warranties are frequently required of the contractor.

The heavier legal axle loads in Europe require a stronger, more durable roadway. The load limit in Germany for a single axle was 11.5 metric tons (25.3 kips) in 1992 and was to increase to 13 metric tons (28.6 kips) in 1993, as compared with Michigan's load limit of 18 kips (80 kN). However, Michigan allows a maximum gross truck weight of 164,000 lb (729 kN) when distributed over 11 axles. The use of super single tires, with 125-psi (860-kPa) inflation pressure, is also prevalent throughout Europe.

European Design Benefits and Implementation

The advantages of the European designs appear to include

- Longer and more reliable design service life,
- Ability to carry higher axle loads,
- Less reactive maintenance work required to maintain a satisfactory service life, and
- Higher surface friction values and less tire noise.

Higher initial costs for construction are associated with these features. Because of the limitations of state agencies to raise

Construction of experimental section, I-75 in Detroit.

revenues, European designs must be shown to be cost-effective over time if they are to become a competitive alternative to current U.S. standards.

Details of European Design Features on I-75

The mile-long experimental design on northbound I-75 is a combination of features used in Germany and Austria. The layer thicknesses were selected by following the procedures noted in the German design manual for the climatic, soil, and traffic conditions found in the Detroit area. A typical cross section is shown in Figure 1. The cross section consists of three- and four-lane pavement with tied concrete shoulders. The key features include the following:

- *The non-frost-susceptible aggregate subbase is 16 in. (406 mm) thick.* The gradation and physical properties of the granular material match typical German specifications, which are similar to those for a dense-graded aggregate in Michigan except that very few fines are used. The material is placed in two layers of approximately equal thickness and compacted to not less than 100 percent of its maximum unit weight. An enclosed drain system is included to evacuate any free water in the subbase to the storm sewer system. No separation material is used between the aggregate subbase and the underlying stiff silty clay subgrade soil.
- *The nonreinforced lean concrete base with plane-of-weakness joints (no load transfer) is 6 in. (153 mm) thick.* All the joints match the location of the joints in the pavement above it. The lean base is extended beyond the outside shoulder edge to provide a level, solid base for the paver, which reportedly results in a smoother ride. No special equipment or mixtures are required for the base.
- *The nonreinforced concrete pavement is 10 in. (254 mm) thick and is constructed in two layers [2.5 over 7.5 in. (64 over 191 mm), while wet] with a 15-ft (4.57-m) spacing between contraction joints (not skewed).* No expansion joints are used. Both the right (truck) lane and far inside lane are widened 1.5 ft (460 mm) for additional edge support. Each travel lane is striped to be 12 ft (3.66 m) wide. The dowel bars are 20 in. (508 mm) long by 1.5 in. (38 mm) in diameter and are coated with polyethylene. The dowel spacing is varied, using a closer spacing in the wheelpaths to increase load transfer efficiency. The same dowel bars are

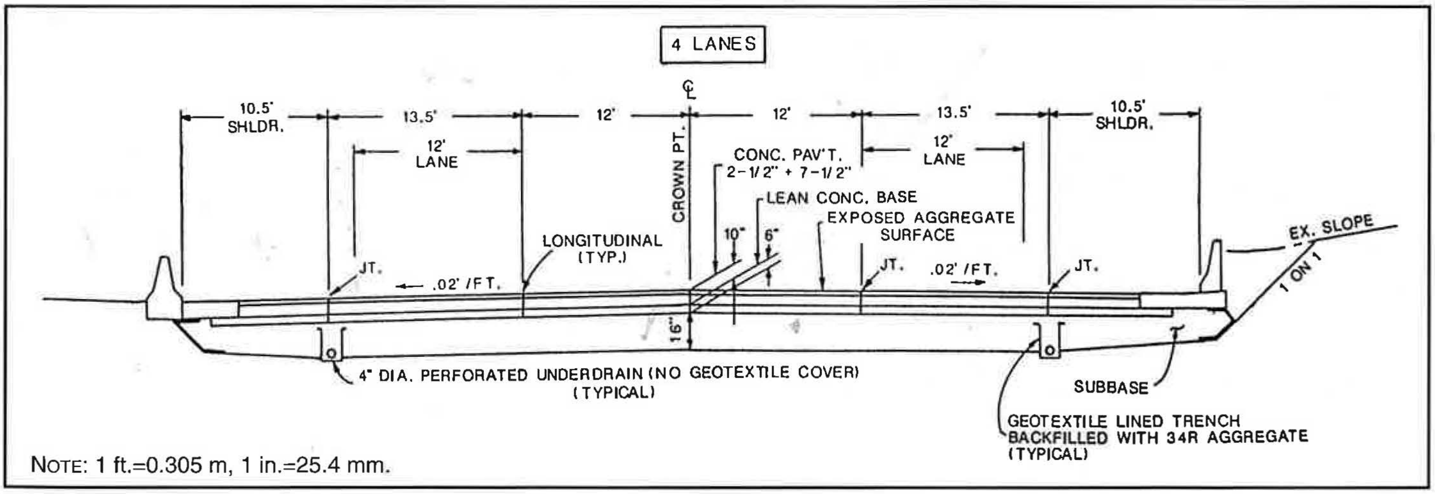

FIGURE 1 Typical cross section of experimental section.

Highway Research Technology: Learning from Abroad

In May 1992 the American Association of State Highway and Transportation Officials (AASHTO), American Concrete Pavement Association, Federal Highway Administration (FHWA), Portland Cement Association, Strategic Highway Research Program, and Transportation Research Board sponsored the 1992 U.S. Tour of European Concrete Highways, or U.S. TECH.

One of the purposes of the study tour was to evaluate the applicability of European design practices for concrete pavements on U.S. highways. Participants concluded that innovative European practices for high-performance pavement should be examined under traffic, climate, and soil conditions in the United States so that the suitability of these techniques for U.S. conditions and their potential advantages could be assessed. The reconstruction of the Chrysler Freeway in downtown Detroit described in the feature article will help experts judge whether these design concepts are appropriate in the United States.

Tour participants also stressed the need for developing a conceptual design catalog, similar to that used by European agencies, as a guide for U.S. highway agencies and contractors. In recognition of this need, AASHTO authorized National Cooperative Highway Research Program (NCHRP) Project 1-32, Systems for Design of Highway Pavements.

The objective of this project is to evaluate the practicability of producing a comprehensive catalog of recommended design for flexible and rigid pavements as well as a corresponding prototype expert system; if it is judged to be feasible, such a catalog and system will then be developed. ERES Consultants, Inc., of Champaign, Illinois, has been awarded a contract to undertake this research.

In the interest of information exchange, a report summarizing observations, findings, and recommendations from the tour, entitled *Report on the 1992 U.S. Tour of European Concrete Highways*, has been published by FHWA's Office of Technology Applications.

Because highway authorities around the world share many concerns in the planning, design, construction, operation, and maintenance of highway systems, and because of the great potential for information sharing and technology transfer, AASHTO also authorized NCHRP Project 20-36, Highway Research and Technology—International Information Sharing. Its purpose is to develop and promote a program for a sustained international information exchange, with participation by state highway agencies.

Under the auspices of Project 20-36, an international scanning tour on winter maintenance was cosponsored with FHWA in March 1994. The purpose of the tour was to exchange information on ice and snow control operations with counterparts in Japan and Europe and to identify practices used elsewhere for potential use in the United States. Among the participants' recommendations is the establishment of a national center for assessing the applicability of foreign winter maintenance practices for U.S. conditions and judging their possible benefits.

Amir Hanna
Senior Program Officer, TRB

also placed for load transfer in the shoulder transverse joints. In Europe dowels are usually placed with a dowel bar inserter incorporated into the paver, but because of economic considerations support baskets were used in the Michigan project. Lane ties in the longitudinal joints are 7/8 in. (22 mm) in diameter by 32 in. (813 mm) long and are epoxy-coated. There are four equally spaced ties per 15-ft slab.

- *The pavement has an exposed aggregate surface.* The procedure follows the patented process developed by Robuco, Ltd., in Belgium using the equipment shown in the photograph on page 17. The process includes spraying the finished surface with a retarder (citric acid admixture), covering the surface with a minimum 2-mil (0.05-mm) plastic sheet, removing the sheet after 20 hr, wire brushing to expose the aggregate, and applying a permanent curing compound.
- *The longitudinal and transverse joints are sealed with an elastomeric seal.* A soapy solution lubricant is used to aid installation. The material and sizes are the same as those used in Germany. A plastic band is placed at the bottom of the initial transverse saw cut (one-third depth) to prevent incompressible slurry material from the subsequent saw cut from filling the crack cavity below the initial saw cut. The subsequent saw cut is sized to fit the elastomeric seal.

Material Requirements

German and Austrian designs require high-durability aggregates consisting of either natural gravel or crushed stone. The I-75 project specified a similar aggregate. The coarse aggregate for the bottom layer of the 10-in. pavement and the 6-in. lean concrete base is required to meet Michigan's 6AA gradation (1-in. top size). The sources for the aggregate are required to have a maximum freeze-thaw dilation of 0.008 percent per 100 cycles, after Michigan Test Method 115 (similar to ASTM C666 Procedure B).

The coarse aggregate for the top layer is required to be 100 percent crushed basalt rock meeting the same durability

Equipment used to finish surface of experimental section.

requirements as for the bottom layer. The coarse aggregate gradation for the top layer is the same as that used in Austria. The maximum particle size is 0.31 in. (8 mm) with a maximum 5 percent passing the No. 5 (4-mm) sieve and a maximum 2 percent passing the No. 200 sieve. The maximum Los Angles abrasion loss is 20 percent. The minimum aggregate wear index allowed by MDOT is 300 (similar to a polished stone value of at least 50).

The Germans and Austrians specify higher concrete strengths than are used in Michigan. The I-75 project will contrast those differences. Typically the two-layer pavement is used in both countries. The strength and mixture requirements for the bottom layer (German origin) and for the top layer (Austrian origin) of the 10-in. European pavement are shown in Table 1. The strength and mixture requirements for the 6-in. lean concrete base are given in Table 2.

The top-layer concrete must be placed within 30 min of screeding the bottom layer and within 45 min of unloading the bottom concrete on to the lean concrete base. The project contractor is given the option of constructing the shoulder in two layers, just like the 10-in. pavement, or in one layer using the concrete mixture for the bottom layer.

Construction Aspects

The European design caused only minor changes in the contractor's usual construction methods. The aggregate subbase and the lean concrete base proved to be an excellent haul road. No special construction methods were required for either operation.

Coupling the two-layer, wet-on-wet concrete pavement with the two different concrete mixes was the greatest change from normal practices. The contractor used a paving train consisting of four pieces of equipment when paving the inside two lanes [25.5 ft (7.77 m) wide]. The concrete was placed on the lean concrete base with a spreader used to distribute the concrete initially. A paver then consolidated and struck off the 7.5-in. bottom concrete layer. A second spreader was used to distribute the 2.5-in. top-layer concrete for the second paver, which provided the final consolidation and screeding of the pavement. When the contractor paved one lane at a time, two pavers without the spreaders were used. Two spreaders were needed in the 25.5-ft-wide pavement to distribute the low slump concrete to the edges. The contractor had no problem distributing the concrete with a paver in the one lane-wide pass.

The contractor had to monitor closely the delivery of the concrete mixes. Two concrete batch plants were needed to produce the bottom- and top-layer concrete. The coordination of the delivery and batch times for the different mixtures required special attention. The contractor managed this issue successfully. There were no cold joints, nor was concrete placed in the wrong layer as a result of using two different concrete mix designs for the pavement.

The transverse and longitudinal joint system was new to the contractor. There were no problems with the alignment of the joints in the lean concrete base and the concrete pavement. The saw cuts and

TABLE 1 Strength and Mixture Requirements for 10-in. European Pavement

	REQUIREMENT	
	Bottom	Top
Minimum 28-day compressive strength [psi (MPa)]	4,500 (31.0)	5,000 (34.5)
Maximum water/content (w/c) ratio	0.42	0.40
Minimum cement content [lb/yd³ (kg/m³)]	588 (349)	752 (446)
Maximum slump [in. (mm)]	3 (76)	3 (76)

TABLE 2 Strength and Mixture Requirements for 6-in. Lean Concrete Base

	REQUIREMENT
Minimum 28-day compressive strength [psi (MPa)]	2,000 (13.8)
Maximum w/c ratio	0.70
Minimum cement content [lb/yd³ (kg/m³)]	400 (237)
Maximum slump [in. (mm)]	3 (76)

material installation were also done with minor changes from standard practices.

Michigan Standard Pavement

To contrast the difference in design standards, a control section of conventional Michigan pavement is included in the same project. The concrete pavement thickness is 11 ft (3.35 m) with steel mesh reinforcement. Mesh reinforcement is uncoated with transverse bars 0.225 in. (5.7 mm) in diameter spaced at 12 in. (305 mm) and longitudinal bars 0.331 in. (8.4 mm) in diameter spaced at 6 in. (152 mm) Transverse joint spacing is 41 ft on northbound I-75 and 27 ft (8.23 m) on southbound I-75 in an effort to compare performance. Load transfer across transverse joints is accomplished using epoxy-coated dowel bars that are 1 in. (31 mm) in diameter. The concrete shoulder is tied and reinforced, with transverse joint spacing matching the mainline pavement. A stabilized, open-graded drainage course (OGDC) 4 in. (102 mm) thick is the base layer under the pavement. The aggregate for the OGDC is made from crushing the old I-75 concrete pavement (Michigan 5G gradation) and coating it with approximately 6 percent cement by weight. The OGDC is separated from the 12-in. (305-mm) sand subbase with a geotextile. Underdrains are placed longitudinally as used in the European I-75 design. The riding surface is burlap dragged longitudinally then tined transversely.

The concrete mixture specifications for the Michigan control section include a 3,000-psi (20.7-MPa) minimum (28-day) compressive strength, a 650-psi (4.5 MPa) minimum (28-day) flexural strength, a maximum 3-in. (76-mm) slump, a minimum 550 lb/yd^3 (326 kg/m^3) cement content, and a maximum 0.50 w/c ratio. The same durability requirements for the European coarse aggregate used in the bottom layer are specified for the Michigan control section on northbound I-75. The coarse aggregate used in the southbound portion of I-75 needs to meet normal MDOT standards, which are lower than the European standard.

Initial Project Evaluation

The contractor had the equipment and capability to construct the European design. Construction of the European pavement caused no problems that were not readily resolved, and experience working with the design will allow increased production rates.

Initial friction tests were performed approximately 2 days after the project was opened to traffic. These tests were conducted according to ASTM E274, which requires a ribbed tire and wet pavement for testing. Tests on the Michigan pavement design resulted in friction numbers (FNs) ranging from 38 to 57, averaging 46, with a standard deviation of 4.6; tests on the European pavement design resulted in FNs ranging from 31 to 47, averaging 38, with a standard deviation of 4.5. The curing compound applied to the pavement during construction was evident during the testing, which may have reduced the FNs. Historically, initial tests conducted on concrete pavement in Michigan have resulted in FNs ranging from 44 to 66 and averaging 52.

Initial falling weight deflectometer (FWD) measurements were taken on the European and Michigan concrete pavement sections before they were opened to traffic. A 9,000-lb (40-kN) impact load was used, which simulates the wheel load of Michigan's 18,000-lb (80-kN) legal axle load.

Tests on the European section involved measuring deflections at the middle of the 15-ft slabs in each lane. In contrast, midslab deflections of Michigan's standard concrete pavement with transverse joints spaced at 41 ft (12.5 m) were measured. Results of these tests are given in Table 3.

Deflections measured by the FWD were used to evaluate the load transfer efficiency across the joints. The transverse and longitudinal joints on the European concrete pavement had average load transfer efficiencies of 95 and 87 percent, respectively.

The initial noise study will be done in 1994 during the reconstruction of the southbound roadway. During the reconstruction, only the northbound roadway will carry traffic, which will allow a direct comparison of traffic noise between an exposed aggregate surface and a transverse-tined surface. The background noise from the southbound roadway traffic will not be present during the initial noise study.

The long-term performance of the project will be evaluated to predict the pavement life expectancy of the European and Michigan pavement sections. The performance criteria to be evaluated are ride quality, surface distress characteristics, surface friction levels, and reduction in tire noise. Seasonal deflection measurements will be taken with MDOT's FWD to determine any differences in structural capacity. Additional tests will be conducted annually to monitor the performance of the two designs. From these data it will be determined what pavement section is most cost-effective for its respective predicted pavement service life.

TABLE 3 Midslab Maximum Deflection, in. (mm)

	INSIDE LANE		MIDDLE LANE		OUTSIDE LANE	
	European	Michigan	European	Michigan	European	Michigan
Average	0.00127 (0.03)	0.00228 (0.06)	0.00137 (0.03)	0.00214 (0.05)	0.00130 (0.03)	0.00207 (0.05)
Standard deviation	0.00010 (0.03)	0.0001 (0.03)	0.00008 (0.02)	0.00007 (0.02)	0.0008 (0.02)	0.00008 (0.02)
Maximum	0.00142 (0.04)	0.00256 (0.07)	0.00150 (0.04)	0.00255 (0.06)	0.00144 (0.04)	0.00251 (0.06)
Minimum	0.00115 (0.03)	0.00198 (0.05)	0.00125 (0.03)	0.00191 (0.05)	0.00115 (0.03)	0.00184 (0.05)