High Performance Concrete Pavements

Technical Summary of Results from Test and Evaluation Project 30

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Celebrating 50 Years 1956 50th 2006 Eisenhower Interstate System

CONCRETE PAVEMENT CPTP TECHNOLOGY PROGRAM

HIGH PERFORMANCE CONCRETE PAVEMENT

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Notice

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INTRODUCTION

Background

Under Test and Evaluation Project 30 (TE-30), High Performance Concrete Pavement (HPCP), the Federal Highway Administration (FHWA) is exploring the applicability of innovative portland cement concrete (PCC) pavement design and construction concepts in the United States. These innovative concepts, ranging from the use of trapezoidal cross sections to alternative dowel bar materials to fiber-reinforced concrete, all share the same TE-30 goal of providing long lasting, economical, PCC pavements that meet the specific performance requirements of their particular application.

The TE-30 program actually got its start in May 1992 when a team of State, industry, and Federal engineers participated in the U.S. Tour of European Concrete Highways (FHWA 1992). During that visit, the tour participants were exposed to a wealth of information on concrete pavement materials, structural designs, and construction that could benefit concrete pavements in the United States. Followup visits to Germany and Austria in October 1992 (Larson, Vanikar, and Forster 1993) provided additional information that was used to construct an experimental concrete pavement in the United States consisting of a German structural design (to provide long service life) and an Austrian exposed aggregate surface (to reduce tire/pavement noise). That pavement, a 1.6-km (1-mi) test section located in the northbound lanes of I-75 (Chrysler Freeway) in downtown Detroit, was constructed in 1993 (Weinfurter, Smiley, and Till 1994).

The success of the I-75 project in incorporating European design concepts that hold the promise of long lasting, low-maintenance concrete pavements spawned a great interest in pursuing similar projects. In 1994, both FHWA and industry agreed to pursue this effort, effectively launching the TE-30 program. Broad functional or performance criteria were established so that participating State highway agencies could select the area considered appropriate for improving the performance of concrete pavements in their States. Several innovation areas for the program were suggested:

- Increasing pavement service life.
- Decreasing construction time.
- Lowering life-cycle costs.
- Lowering maintenance costs.
- Constructing ultra-smooth riding concrete pavements.
- Incorporating recycled or waste products while maintaining quality.
- Utilizing innovative construction equipment or procedures.
- Utilizing innovative quality initiatives.

Specific target projects were later added, including joint sealing alternatives, alternative load transfer devices, durable concrete mix designs, alternative surface finishing techniques, and more cost-effective use of paving materials (such as widened lanes, trapezoidal cross sections, and two-lift construction).

In each of these applications, emphasis is given to an integrated design approach in which site influences (traffic loading, climate, and subgrade), concrete mix design, structural design, joint details, and construction are considered together to develop the appropriate pavement design. Consequently, the term “high performance” does not necessarily refer to high strength concrete, but rather to any of the materials and mix design, structural design, or construction components of the pavement that are expected to contribute to long-term performance.

Summary of Field Projects

The TE-30 program has funded approximately 25 field projects since 1996. These projects were intended to test and evaluate innovative concrete pavement technology in "on-the-road" applications. A preliminary report summarized the status of the projects initiated through December 2001 (FHWA 2002), and yielded two other reports, one on pavement texturing (Hoerner and Smith 2002) and one on alternative dowel bars (Smith 2002). Since that time, additional field projects have been constructed and several construction and early performance reports prepared. Additionally, projects under Task 7 of FHWA's Concrete Pavement Technology Program (CPTP), Field Trials of Concrete Pavement Product and Process Technology, share similar goals and objectives as those in the TE-30 program. The projects included in this report, consequently, are those from the original FHWA report (FHWA 2002) and an additional 15 projects identified by FHWA.

A list of the included projects is in Appendix A. For each project, the table includes information on the design features evaluated, the year built, whether the project was funded under the TE-30 program, and the type of concrete pavement: jointed plain concrete pavement (JPCP), jointed reinforced concrete pavement (JRCP), continuously reinforced concrete pavement (CRCP), precast post-tensioned concrete pavement (PPCP), or fiber-reinforced concrete pavement (FRCP).

Purpose and Overview of Updated Summary Report and Technical Summary

The report entitled *High Performance Concrete Pavements: Project Summary* (FHWA 2006) is the basis for this Technical Summary. It is the purpose of this Technical Summary to document the current status of concrete pavement projects constructed under the TE-30 program and under Task 7 of CPTP, as well as several other related concrete pavement projects. Current and anticipated results are also described, as are recommendations for relevant future research activities.

Significant findings are related to CPTP's six focus areas to aid others who are evaluating similar features or technologies. In some cases, more current project status information is provided that was not available when the updated summary report was prepared.

SUMMARY OF PROJECTS BY CPTP FOCUS AREA

A summary of the various projects as they pertain to the six focus areas identified in FHWA's concrete pavement technology program—advanced designs, optimized concrete materials, improved construction processes, rapid repair and rehabilitation, enhanced user satisfaction, and workforce training—is provided in the following sections. Preliminary findings and performance observations are noted where available, although most of these projects are new and have not been subjected to significant traffic or environmental loadings.

Advanced Designs

Long-Life Pavements

Michigan 1. The original high performance concrete pavement (HPCP) was the Michigan (MI) 1 project on I-75 (Chrysler Freeway) built in 1993 as a result of the FHWA-sponsored tour of European concrete pavement design and construction in 1992. MI 1-1 is the Michigan standard pavement: 279-mm (11-in.) JRCP, 12.5-m (41-ft) transverse joint spacing with a tied concrete shoulder, 32-mm (1.25-in.) epoxy-coated dowels, and 102-mm (4-in.) cement-treated, open-graded drainage layer with edgedrains over a 305-mm (12-in.) sand subbase.

MI 1-2 is the European pavement section: 254-mm (10-in.) JPCP with two-lift construction, 4.6-m (15-ft) transverse joint spacing with widened outside slab lane and tied concrete shoulders, 32-mm (1.25-in.) variably spaced plastic-coated dowels, and 152-mm (6-in.) lean concrete base over a 406-mm (16-in.) aggregate subbase. It should be noted that the Michigan Department of Transportation (DOT) used a higher quality aggregate in MI 1-1 (not the lower durability aggregate normally allowed by their specifications) so that the performance of the structural sections could be compared. A construction report and monitoring reports in 1995 and 2000 are available.

In 1996, the European section was slightly rougher than the Michigan section, but both exhibited international roughness index (IRI) values of 80 or lower. Deflection testing in the fall of 1993 and the spring of 1995 showed low average joint load transfer efficiencies (LTE) for both sections. It appears that a detailed investigation should be made to determine the cause of the low LTEs early in the service life of both pavement sections. (Low differential deflections, less than 0.13 mm [0.005 in.], might be the cause of low LTEs but may still result in satisfactory long-term performance.)

The surface friction was lower on the European section (exposed aggregate surface treatment) than on the Michigan standard section (transverse tining). Austrian experience has demonstrated that there is a learning curve associated with constructing a high friction exposed aggregate surface, with the friction numbers increasing as additional projects are constructed.

An informal inspection conducted in 2004 reported no significant difference in visual condition of the two pavement sections. Additional monitoring to determine the long-term performance and cost-effectiveness is needed (Buch, Lyles, and Becker 2000).

The cost of the European demonstration project was about 234 percent more than the Michigan standard section, which would not be typical for standard construction. The Michigan DOT estimates that the costs for the European section would have to be less than 17 percent more than the standard Michigan section to be cost competitive.

Minnesota 2. In 2000, the Minnesota Department of Transportation (Mn/DOT) reconstructed a 1.6-km (1-mi) section of I-35W in Minneapolis with a 60-year pavement design and modified objectives:

- Evaluate the cost/benefit of designing a pavement to last 60+ years with zero maintenance in a very high urban traffic environment.
- Evaluate the performance benefits of a high performance concrete with high durability featuring low permeability, high air content, well-graded aggregate, high-quality aggregate, low water/cement ratio (less than 0.40), and ground granulated blast furnace slag cement.
- Evaluate the durability of dowel bars clad in stainless steel compared to solid stainless steel and assess their ability to perform satisfactorily for 60+ years.
- Evaluate the long-term performance of epoxy-coated dowels (ramps) and plastic-coated dowels (shoulder bus lanes) compared to the stainless steel dowel bars used in the main lanes.
- Evaluate the performance of 38-mm (1.5-in.) and 44-mm (1.75-in.) diameter dowel bars.

The nominal pavement design for this project is 340-mm (13.4-in.) thick JPCP with 4.6-m (15-ft) transverse joints. The slab thickness was based on design traffic of 100 million equivalent single-axle lead (ESAL) applications over a 60-year design period. Tied concrete shoulders, 315-mm (12.4-in.) thick, were provided to carry traffic during construction or future rehabilitation activities. An existing thick sand subbase was left in place and was capped with a 305-mm (12-in.) select granular material topped with a 100-mm (4-in.) thick, Class 5 dense-graded granular base for a paving platform. No permeable base or edgedrains were included in the design.

One of the main variables on this project included the material type and size of dowel bars used. Due to corrosion concerns regarding epoxy-coated dowels, solid stainless steel clad or solid stainless steel dowels (Type 316L) were specified due to their corrosion resistance. The original experimental design had to be revised due to the unavailability of the adequate numbers and quality of stainless steel clad dowel bars. As constructed, the performance of stainless steel clad, solid stainless steel, plastic-coated, and epoxy-coated dowels can be compared for durability; however, the traffic loading on the plastic- and epoxy-coated dowels will be significantly lower due to their use in the shoulders and the ramps.

One of the other major features of this project is the unique concrete mix design. The cost of the higher quality structural concrete mix specified to increase durability was also estimated to be about 10 percent higher ($13.00/m^3$ or $10.00/yd^3$). The placement cost was estimated to be about 10 percent higher due primarily to the thicker pavement slowing production. It should be noted that these costs represent a much lower percentage of the total construction cost of the section being reconstructed. Often the incremental pavement cost is emphasized in life-cycle cost analyses, but it should be recognized that if the section is required to be shut down for reconstruction, the total value of the section (not the incremental pavement cost) is affected.

The cost-effectiveness of the 60-year design (including the higher quality concrete mix design and the solid/clad stainless steel dowel bars) will be determined based on the performance of the pavement. However, as a result of this initial project, Mn/DOT is constructing long-life pavements for other high-volume, urban roadways.

Wisconsin 4. In 2002, the Wisconsin Department of Transportation (WisDOT) constructed a pavement on the two eastbound lanes of I-90, near Tomah, with a 50-year design service life. Three sections were constructed: two were similar, with tied concrete shoulders, except one section had stainless steel dowels and a higher quality subbase, and the control section had asphalt shoulders and epoxy-coated dowels. Test section 1 had 343-mm (13.5-in.) thick JPCP, 4.6-m (15-ft) transverse joint spacing, 102-mm (4-in.) No. 2 open-graded base course with edgedrains and a 152-mm (6-in.) dense graded aggregate base. Test section 2 had a 343-mm (13.5-in.) JPCP, 4.6-m (15-ft) transverse joint spacing, type 316L stainless steel dowels with a non-corrodible basket system, 102 mm (4 in.) of No. 2 open graded base course with edgedrains, 254 mm (10 in.) of dense graded base (2 layer system) over 406 mm (16 in.) of breaker run material. Test section 3 was the control section.

One significant feature to be evaluated was the amount of construction curling and moisture warping developing and their effect on long-term performance. These sections do not have significant performance information available at this time to make any conclusions.

CRCP Designs

The long-life pavements evaluated under the HPCP program have been either JPCP (most common) or JRCP (MI 1 control section). Specific long-life CRCP pavement sections have not been constructed although they may be the premium long-life, low-maintenance pavement. Virginia (VA) 2 and 3 were constructed as HPCPs under the TE-30 program and evaluated for improved mix designs and higher steel contents for CRCP. Few monitoring data are currently available on these two projects. In the future (the project has not yet been constructed), the West Virginia 1 project will evaluate the use of fiber-reinforced polymer (FRP) reinforcement compared to the standard longitudinal steel reinforcement for CRCP. Illinois is now constructing CRCPs with a 40-year design life, and Texas is constructing very long life CRCPs in urbanized areas as a standard procedure. The cost-effectiveness of well-designed and constructed CRCP should also be considered. It is expected that some long-life CRCP will be constructed under the FHWA Highways for Life Pilot Program (FHWA 2005a).

Optimized Pavement Joint Details

A number of the HPCP and related projects (18 total) address the need for dowels (South Dakota [SD] 1 and Minnesota [MN] 2 particularly) and alternative dowel bar materials, sizes, and spacing (Illinois [IL] 1-4; Iowa [IA] 2, 4 and 5; Kansas (KS) 1, MI 1, MN 1-2; Ohio 2; West Virginia [WV] 1; WI 2-4; and MIT Scan-2 [dowel bar placement]). Dowels are needed for all JRCP projects and for JPCP projects that carry significant numbers of heavy trucks. The concern about corrosion of epoxy-coated dowels has increased the interest in alternative materials that possess reduced corrosion potential.

The most promising alternative materials being tested are solid stainless steel, stainless steel clad dowels, stainless steel tubes or pipes filled with grout, and solid glass-fiber-reinforced polymer (GFRP) bars or grout-filled GFRP tubes. While some of these designs are promising, the higher initial cost compared to the epoxy-coated dowels is encouraging researchers to look at other alternatives that are less costly (ISCP 2005). Furthermore, the lower load transfer efficiency of GFRP dowels compared to the epoxy-coated dowels used as a control raises concerns about their long-term performance and cost effectiveness. Iowa is also evaluating the use of elliptically shaped dowel bars compared to conventional round epoxy-coated steel and GFRP dowels.

Continued evaluation for an additional 10 to 20 years will be needed to resolve the cost-effectiveness and long-term performance of these alternative dowel bars. However, the preliminary findings are as follows:

- Dowel bars reduced curling and warping caused by curing temperature and moisture gradients.
- Steel bars induced greater environmental bending moments than fiberglass bars.
- Steel bars transferred greater dynamic bending moments and vertical shear stresses than fiberglass bars of the same size.
- Joint “lock-up” affects FWD results and evaluation of LTE.
- The use of elliptical shaped dowels had no effect on the handling or installation of standard, full-lane width, dowel baskets.

Another major issue is that there is no accepted model to help pavement designers optimize various dowel bar material properties, sizes, and spacing. Available models are primarily research tools to help compare various alternatives and are not an efficient design tool. In addition, the current evaluation procedures do not attempt to relate the lower LTEs on transverse joints measured the first few years (particularly with GFRP dowels but also on some of the epoxy-coated dowel sections) with the effect on long-term performance. This is a critical research need.

The MIT Scan-2 device is a promising piece of equipment to evaluate the actual placement of the dowel bars by inserters or baskets (tie wires must be cut and special calibration is needed). The data acquired will be used to re-evaluate existing dowel bar placement tolerances. The accuracy of tie bar placement can also be evaluated (FHWA 2004a).

Joint Sawing and Sealing

A few projects have been constructed to evaluate the effectiveness of sealing transverse joints in JPCPs (e.g., KS 1, IL 2 and 3, and Ohio 3). This is the result of Wisconsin research that suggested transverse joint sealing was not cost effective. The projects are not yet sufficiently old enough to make firm recommendations, but preliminary results from Ohio showed lower joint deflections and lower subgrade moisture under the unsealed joint test sections. The worst of the sealed sections in Ohio were those constructed with a narrow 3-mm (0.12-in.) joint width. On IL 2, the preformed elastomeric joint sealer used in the 16-mm (0.62-in.) wide hinge joint (no contraction or expansion) remained intact while the narrow 3-mm (0.12-in.) transverse joints sealed with an ASTM D3405 hot-poured sealant was performing poorly after 7 years. One narrow transverse joint test section was left unsealed. A major national research study is underway to evaluate this issue in more detail.

Joint Spacing and Fiber Reinforcement

Two projects looked at joint spacing for JPCP (SD 1 and MO 1). The SD 1 project on US 83 northeast of Pierre was constructed in 1996 to evaluate the use of non-metallic fiber reinforced concrete (NMFRC) pavements with different slab thicknesses, joint spacings, and load transfer systems. Sections with 165-mm (6.5-in.) and 203-mm (8-in.) slabs with 6-m (20-ft), 8-m (25-ft), 11-m (35-ft) and no joints were constructed. Results suggested that the doweling recommendations for conventional PCC pavements also apply to fiber-reinforced concrete pavements. In February 2004, a distress survey revealed no apparent distress of any kind except for the uncontrolled transverse cracks in the 203-mm (8-in.) NMFRC section with no dowels and no joints. A life-cycle cost analysis showed the conventional design (203-mm [8-in.] thick, 6-m [20-ft] slab length, with 25-mm [1-in.] epoxy-coated doweled JPCP) was 61 and 31 percent cheaper than the NMFRC design for analysis periods of 40 and 60 years.

In 1998, the Missouri DOT constructed a project to compare the performance of fiber-reinforced unbonded concrete overlays to conventional unbonded concrete overlays. The eight 762-m (2500-ft) long sections included three sections with steel fibers in the concrete mix, three sections with polyolefin fibers in the mix, and two sections that use a conventional concrete mix. The two control sections with conventional concrete mix are a 229-mm (9-in.) unbonded JPCP with 4.6-m (15-ft) transverse joints and a 279-mm (11-in.) unbonded JPCP with 4.6-m (15-ft) transverse joints. Paraffin-treated, epoxy-coated steel dowels were included in all test sections. The 279-mm (11-in.) test sections all contained 38-mm (1.5-in.) diameter bars whereas the rest of the test sections contained 32-mm (1.25-in.) diameter bars. The two fibers selected based on laboratory evaluations were 50-mm (2-in.) 3M polyolefin fibers and 60-mm (2.4-in.) Dramix steel fibers. Each of the fiber-reinforced sections is differentiated by slab thickness, with thicknesses of 229 mm (9 in.), 152 mm (6 in.), and 127 mm (5 in.) included in the study. Furthermore, within each fiber-reinforced test section, four subsections with variable joint spacings (4.6 m [15 ft], 9.1 m [30 ft], 18.3 m [60 ft], and 61 m [200 ft]) are also included. The final surface texture was established by diamond grinding the overlay after 21 days. The initial cost of the steel fiber concrete and the polyolefin concrete was

$56.22 and $71.77 more per m^2 [$47 and $60 more per yd^3], respectively, than the conventional concrete.

Due to the cracking and spalling of the 127-mm (5-in.) steel and polyolefin sections, they were replaced with full-depth PCC pavement in 2000. Four general conclusions were drawn (Buch, Lyles, and Becker 2000):

- The steel fiber-reinforced test sections exhibited more transverse cracking than the polyolefin fiber-reinforced test sections.
- The longer panels exhibited more cracking than the short panels.
- The thinner sections exhibited more cracking than the thicker sections.
- Cracks that developed in the steel-reinforced test sections were tighter than those in the polyolefin fiber-reinforced test section (3 mm [0.12 in.] versus 6 mm [0.25 in.]).

In 2003, repairs were performed on some of the transverse cracks near the joints in the fiber-reinforced unbonded overlay. Monitoring of the performance will be continued.

Thin and Ultrathin Whitetopping Design

Evaluation of thin (thicker than 102 mm [4 in.] but less than 203 mm [8 in.]) and ultrathin (102 mm [4-in.] or less thickness) whitetopping was conducted at Colorado (CO) 1 and MN 3. The CO 1 project was constructed in 2001 on S.H. 121 south of Denver to evaluate the design procedure developed earlier for CDOT. The design procedure developed is being further evaluated by others (FHWA 2005b). The MN 3 project evaluated three typical ultrathin test sections on US 169 near Elk River carrying about 400,000 ESALs per year and six test sections on I-94 at the Mn/ROAD test facility near Albertville carrying over 1 million ESALs per year that were constructed in 1997. These sections were heavily instrumented.

The 1.8-m x 1.8-m (6-ft x 6-ft) slabs performed significantly better because the longitudinal joint does not lie in the inside wheelpath. Sealing joints should be considered to limit the water coming into contact with the hot mix asphalt (HMA) layer. Very tight longitudinal cracks developed on the thin 152-mm (6-in.) overlay with 1.8-m x 1.8--m (6-ft x 6-ft) joint pattern on I-94. In 2004, three additional test sections were reconstructed on I-94. The new test sections will consist of a 127-mm (5-in.) and a 102-mm (4-in.) overlays with 1.52-m x 1.8-m (5-ft x 6-ft) panels. Half of the sections will have sealed joints and the joints in the other half will remain unsealed. The test section will be instrumented and monitored in the future. Both the CO and MN test sections will be used to develop improved design guidelines for thin and ultrathin whitetopping (UTW) projects. The problem of UTW overlays moving transversely (shoving under traffic due to the crown) causing opening of the longitudinal joints also needs further evaluation.

Low-Volume Road Designs

MN 2, located on the Mn/ROAD Low-Volume Road Loop Facility, was opened in 1994 to study the performance of asphalt-, concrete-, or aggregate-surfaced roadways. So far, all the PCC sections initially constructed are performing very well. In 2000, three new PCC sections were constructed under the TE-30 program to look at ground granulated blast furnace slag (GGBFS) versus conventional concrete, 127-mm (5-in.) versus 191-mm (7.5-in.), slab thicknesses, 3-m (10-ft) versus 4.6-m (15-ft) joint spacing, and aggregate interlock versus epoxy or FRP dowels of diameters of 25 mm (1 in.), 32 mm (1.25 in.), or 38 mm (1.50 in.) with either hot-pour or silicone joint sealant. After about 2 years of service, the LTE of the FRP dowels dropped to approximately 70 to 75 percent with a differential joint deflection about twice that of the epoxy-coated steel dowels (0.0559 to 0.0711 mm [0.0022 to 0.0028 in.] for the FRP versus 0.025 to 0.0406 mm [0.001 to 0.0016 in.] for the epoxy-coated steel dowels; both these values are below the 0.0127 mm [0.005 in.] maximum suggested value). The sections are instrumented and will be used to evaluate mechanistic-empirical designs for low-volume roads (usually in design catalog format).

Optimized Concrete Materials

Mix Designs

A number of HPCP and related projects have looked at various aspects of concrete mix design. Overall concrete mix design optimization was evaluated under NH 1, whereas several construction projects evaluated various aspects of concrete mix design. For example, the use of two-lift construction to provide a more durable wearing surface was used on MI 1-2 (with an exposed aggregate surface) and KS 1 (two-lift construction with igneous rock or low w/c mix on top 75-mm [3-in.]). Projects IN 1, MD 1, MN 1 and 2, and WI 4 are looking at the effect of curl and warp and reduced shrinkage on long-term performance. MN 1 and 2, Ohio 1, and VA 1 looked at adding GGBFS to improve mix properties. VA 2 and 3 looked at mixes to develop low shrinkage and high flexural strength (along with varying the steel content) to improve CRCP performance.

Alternative Concrete Materials

A number of projects looked at the effect of adding fibers to improve PCC performance including KS 1, MD 1, Missouri [MO] 1, and SD 1. Generally, the use of fibers did not appear to be cost effective but can be used to improve concrete materials properties for special applications. The use of fibers did not appear to affect load transfer performance significantly.

The Mississippi 1 project compared the performance of a thin layer (50-mm [2-in.]) of open graded HMA whose internal voids (approximately 30 percent) were filled with a latex rubber-modified portland cement grout (i.e., a resin-modified pavement, RMP) to that of a UTW overlay and a polymer-modified HMA overlay. Four test sections were constructed at two different intersections on US 72 in Corinth. Preliminary conclusions and recommendations included:

- The UTW smoothness was less than satisfactory, and smoothness specifications should be used in the future.
- The gradation of the open-graded HMA must be carefully controlled to get the target 30 percent air voids, and adequate curing time (about 72 hours) should be required to get design compressive strengths of the RMP.
- The initial skid resistance of the RMP was less than satisfactory until traffic wears the top film of grout off the sections.

The performance of the sections will be monitored for a minimum of 5 years.

Discussion on Concrete Materials

The evaluation period is too short to make long-term performance and cost-effective determinations for the wide variety of concrete mixes placed. The individual States will be able to evaluate the results of the revised concrete mix design properties with those of their control sections (which generally represent their standard practice) and the subsequent effect on long-term performance. A significant amount of additional research is currently underway to optimize concrete mix designs for the wide variety of individual site conditions. These HPCP and related projects should help to evaluate the reasonableness of the mix optimization guidelines subsequently developed. The new Mechanistic-Empirical Design Guide (ERES 2004) being evaluated includes the shrinkage and thermal coefficient properties of the concrete in addition to the flexural strength previously used. Also, there is a general trend to use larger maximum sizes and well-graded aggregates to minimize shrinkage, improve workability, and improve fracture properties. The effect of these improved concrete material properties is particularly important when designing longer life pavements.

Improved Construction Processes

Mixing Times

Mixing times were evaluated on the IA 1a and 1b projects comparing a standard drum mixer and a modified drum mixer employing rotation of the blades within the drum. Results of shorter mixing cycles were not satisfactory and it was recommended that the minimum 60-second mixing time be retained.

Evaluations of HIPERPAV and TEMP

HIPERPAV was evaluated on OH 1 and PA 1. Initial evaluation results were promising and an updated version (HIPERPAV II) is now available at the FHWA Web site www.tfhrc.gov/pavement/pccp/hipemain.htm.

The TEMP (Total Environmental Management for Paving) program uses the maturity concept to aid in controlling the construction process and was tested initially on IA 7 (and more recently on I-64 near Williamsburg, VA, but no data are currently available). The opening time can be predicted based on the past (known) and future (predicted) concrete temperatures. It is expected that this program will also be used to evaluate the optimal time to saw joints in the pavement (FHWA 2004b).

Improved Curing

Improved curing (in terms of using a high solids curing compound, increased application rates, or wet curing procedures) was used on KS 1, MN 1, and VA 2 and 3. No findings on the effect of curing on performance are currently available from any of these projects.

Performance-Related Specifications

Performance-related specifications (PRS) developed under other FHWA research are being demonstrated on Tennessee 1 (FHWA 2005d).

Dowel Bar Placement

The MIT Scan-2 device is being used to evaluate the accuracy of dowel bar placement by inserters or dowel bar baskets (provided the tie wires are cut and a special calibration is conducted). Information obtained will help revise current specifications on dowel placement tolerances. This equipment is now available for State highway agencies to loan through the CPTP (FHWA 2004a).

Base/Subbase/Subgrade Stabilization

A number of projects have looked at the issue of providing improved support for concrete pavements. Projects MI 1, IA 3 and 6, WI 4, and OH 4 specifically looked at this issue.

The details of the MI 1 project (European JPCP section and the Michigan JRCP control section) were provided earlier. Generally, European designers provide greater base/subbase/subgrade support than routinely used in the U.S. Their concept is to renew only the pavement surface, not to reconstruct the underlying layers.

The IA 3 subgrade and pavement are of a conventional design and thickness, with the only difference being the use of 15 percent fly ash (two different types) in the top 12 inches of two different types of soil. The effect of subgrade type on curling and warping was also to be evaluated. No performance data are currently available.

A series of projects were constructed under IA 6 beginning in 2002 to develop and implement practical guidelines for soil stabilization for a wide range of fly ashes. Field and laboratory testing are being conducted. Planned monitoring activities had not yet been determined.

OH 4, a project located on US 35 in Jamestown, OH, was undertaken to compare the available nondestructive testing (NDT) devices for measuring the support of the subgrade and aggregate base layers of the pavement section. NDT was performed using a nuclear density gauge, the Humboldt Stiffness Gauge, the German plate loading test, the falling weight deflectometer (FWD), and dynamic cone penetrometer (DCP). Testing was conducted at 15-m (50-ft) intervals except for the German plate loading test, which was conducted at 30-m (100-ft) intervals.

Overall results indicated that each device has a useful function in evaluating subgrade and base uniformity conditions. The laboratory resilient modulus test is limited to materials sampled at specific designated locations. Additionally, the results are very much a function of test conditions. The level of confining pressure used during the testing was found to have an effect on the computed modulus values.

The nuclear density gauge is limited to a layer thickness of 300 mm (12 in.), and is greatly affected by any non-uniformity within the layers tested. However, it provides a quick means of controlling the uniformity of material density during construction, and the density measurements recorded can be correlated with material stiffness (higher density generally correlates with higher stiffness).

The DCP is a quick and simple automated field test method for evaluating the in situ stiffness of layers in a highway pavement structure. It measures the strength and stiffness of the subgrade and non-stabilized base layers. The DCP's ability to penetrate into underlying layers and accurately locate zones of weakness represent its greatest advantage over other tests considered. The automated device includes software for storing the collected data.

The Humboldt Gauge measures stiffness of the upper 152 mm (6 in.) of material by electrical impedance. In this respect it is quite different from the other NDT measurement devices evaluated. Other devices measure the composite response of the upper layer measured, and any supporting layers beneath. The Humboldt gauge was considered effective for monitoring the integrity of individual material layers as they are being placed.

The remaining devices identified significant pavement support variation along the length of the test. Since the Humboldt Gauge only measures 152-mm (6-in.) depth, the variation represented is much smaller than these other test showing composite results. Both stiffness and calculated moduli values were evaluated for each device. Sample results are provided in Table 1.

Table 1. Stiffness and Modulus Sample Results

NDT TEST	STIFFNESS, lb/in	MODULUS, ksi
Subgrade (15 stations)		
Humboldt Gauge	88,758	18.75
FWD, Large Load[1]	249,703	22.61
FWD, Small Load[2]	210,785	19.09
German Plate	1st Cycle	
	131,889	11.96
	2nd Cycle	
	153,795	13.93
Composite Base (16 stations)		
Humboldt Gauge	129,730	27.41
FWD, Large Load[1]	252,747	36.22
FWD, Small Load[2]	257,114	40.97
German Plate	1st Cycle	
	67,793	16.87
	2nd Cycle	
	206,533	44.50

FWD = falling weight deflectometer
1. 2,948 to 4,082 kg (6,500 to 9,000 lb)
2. 1,588 to 2,041 kg (3,500 to 4,500 lb)

The large load FWD represented 2,948 to 4,082-kg (6,500 to 9,000-lb) loads, while the small load represented 1,588 to 2,041-kg (3,500 to 4,500-lb) loads.

The FWD and the German plate load test are considered effective for measuring the total composite stiffness of the in situ pavement structures. Comparisons of the devices, and the Humboldt Gauge, are difficult because each generates different types of loads that are imparted to different depths in the pavement structure, and also use different equations to convert surface deflections to layer modulus values. The dynamic loading applied by the FWD typically results in higher material stiffness than static loads used in the German Plate Test. The Humboldt Gauge produces small excitations, which limits its depth of effectiveness.

The FWD has a definite advantage for field measurement over the load plate, because the testing goes much faster. The German load plate is more labor intensive, and requires more test time at a single location. The DCP is considered useful for identifying and locating the causes of low pavement stiffness results that were identified from FWD testing.

Rapid Repair and Rehabilitation

Precast Slabs

California 1. The California precast demonstration project was constructed in 2004 under CPTP Task 58. The project consisted of 76.2 m (250 ft) of two-lane, precast, prestressed pavement placed over a lean concrete base and post-tensioned longitudinally in 37.8-m (124-ft) sections. Thickness varied from 254 to 330 mm (10 to 13 in.) due to a cross slope variation. The 31 panels were placed in approximately 8 hours over two nights of construction, with post-tensioning completed in just a few additional hours. Demonstration projects of the "Texas method" are also scheduled in Missouri, Iowa, and Indiana (FHWA 2005c).

Colorado 2. The CO 2 project called for precast pavement repairs using Uretek's Stitch-in-Time™ System. The project was constructed in 2004 on I-25, and included nearly 450 panels. Preliminary results indicated a large amount of early cracking. Construction and monitoring reports are being prepared.

Michigan 2. The factory cast panels, 3.7 m by 1.8 m by 254 mm (12 ft by 6 ft by 10 in.), were installed to repair deteriorated joints. Repairs were opened to traffic within 6 to 8 hours of lane closure. The initial performance of the full-depth precast panels is reported to be acceptable. Long-term performance is being monitored by the Michigan DOT (FHWA 2005c).

UTW Repair

A joint venture between FHWA and the American Concrete Pavement Association (ACPA) was initiated in 1998 to research UTW. The research consisted of constructing eight 15-m (50-ft) test lanes of UTW placed on an existing HMA. Loading of the test sections occurred between May 1998 and November 1999.

The objective of the original UTW study was to validate the design equations and performance prediction models used in the ACPA UTW design procedure. The specific research objectives were as follows:

- Evaluate UTW performance under controlled wheel-loads and temperature.
- Study the effects of a range of design features (thickness, joint spacing and fiber reinforcement) on the performance of UTW.
- Measure pavement response and develop mechanistic models based on these responses.

As a followup to the original testing, a procedure was developed for repairing failed UTW panels (Wu, Tayabji, and Sherwood 2002). Following are the steps used in performing the repairs:

1. Identify panels to be repaired.
2. Mark boundaries for saw cuts, which should be at least 102-mm (4 in.) inward from each joint.
3. Perform saw cuts.
4. Use jackhammer to break up slabs and to dislodge the bonded portions of the concrete overlay from the HMA.
5. Remove debris and clean surface in the repair area.
6. Place new concrete.
7. Saw joints.

A comprehensive review of the use of UTW/TW is available in *Best Practices for Ultrathin and Thin Whitetoppings* (FHWA 2005b).

Intersection Reconstruction

The Washington State DOT reconstructed an asphalt concrete intersection with JPCP over a weekend in a 70-hour period (WA 1). The intersection was located at SR 395 and West Kennewick Avenue in Kennewick. The goal to successfully accomplish accelerated reconstruction was met by investigating three activities:

- Methods to accelerate the rate of concrete strength gain.
- Methods to minimize construction time.
- Traffic control strategies to minimize user delay.

Type III cement used gained the necessary strength in 8 hours. The intersection was opened to traffic 16 hours ahead of schedule. Public complaints were reduced 70 percent compared to a project conducted 2 years earlier.

Enhanced User Satisfaction

Smoothness

Kansas 1, Kansas 2, and Missouri 1. For the KS 1 sections, the 1998 Initial Profile Index (zero blanking band) varied from 129 to a high of 319 mm/km. More recent IRI data are not available. The KS 2 project (with five special sections) was constructed in Hutchinson in 2001. The initial smoothness was to be monitored and controlled by new smoothness measuring equipment while the post-construction smoothness was to be evaluated for different construction conditions (weather), mixture properties (w/c ratio) and joint spacing (3.7, 4.6, and 5.2 m [12, 15, and 17 ft]). No monitoring data for the KS 2 project were available. The MO 1 project (see details under the Alternative Materials section) was constructed to compare the performance of fiber-reinforced bonded overlays to that of conventional unbonded overlays. The initial finishing was with an unweighted burlap drag with the final surface texture established by diamond grinding the overlay 21 days after construction for smoothness and rideability. The contractor received a smoothness bonus for the original construction. Followup monitoring data are not available. Due to the very limited amount of monitoring data available, no conclusions can be made at this time for these projects.

Texturing (Friction and Noise)

Kansas 1, Michigan 1, and Wisconsin 1. The KS 1 project includes standard transverse tining with one longitudinal and one random transverse tining section. No friction or noise data are currently available on any of the test sections. The MI 1-2 (European pavement section-exposed aggregate) had lower friction numbers (38 in November 1993 and 42 in April 1994) compared to 46 and 53 for the Michigan standard pavement section. Measurements of the interior and exterior noise level results in June 1994 indicated that the exposed aggregate surface did not produce the expected reduction in noise levels that was anticipated. One possible reason is that the exposed aggregate surface had too much macrotexture from the excessive spacing of the coarse aggregate.

The most extensive pavement texturing research was conducted on the WI 1 project, which included results from five other States as well. The same noise meter and FHWA Road Surface Analyzer (ROSAN) were used during all measurements so the noise levels and actual surface texture measurements were comparable among sections and among States. Friction data were collected by the various States. A total of 57 sections were analyzed. Based on the results of the data analysis, the following primary recommendations were developed:

- If overall noise considerations are paramount, longitudinal tining that provides satisfactory friction may be considered. A uniform tine spacing of 19 mm (0.75 in.) will provide adequate friction and, according to other studies, will minimize effects on small tired vehicles. However, the safety aspects of longitudinal tining have not been documented.
- If subjective perceptions and texture considerations are paramount, a randomly skewed (1:6) textured pavement, offset the opposite of any skewing of the transverse joints, may be used. This pattern achieves the texture and

friction of a conventional transversely tined pavement while also obtaining most of the noise reductions associated with longitudinal tining.

- If texture considerations are paramount, and a skewed pattern is impractical, randomly spaced transverse tining may be employed. However, this should be carefully designed and built using a highly variable spacing. A 3-m (10-ft) long rake with spacings between 10 and 76 mm (0.4 and 3.0 in.), designed using spectral analysis, is recommended, and has been successfully tested by three States.
- Diamond grinding, if sufficiently deep to remove most of the uniform transverse texture, can be considered a treatment for PCC pavements with excessive whine.

FHWA has now issued Technical Advisory T5040.36, dated June 17, 2005, on *Surface Texture for Asphalt and Concrete Pavements*, which provides current guidance on surface texturing (FHWA 2005e).

Workforce Training

No specific projects in this category. Implementation of promising concepts are being conducted under Task 65 of the Concrete Pavement Technology Program.

CLOSURE

The updated HPCP Project Summary (TE-30 and related projects) provides a large amount of information on the performance of a wide variety of subjects developed by the various States and FHWA (FHWA 2006). The goal was to explore the applicability of innovative portland cement concrete pavement design and construction concepts in the United States. This Technical Summary provides the preliminary results from these projects along with references to some more recent status or research findings. For references to the large number of related individual project research reports, the main report should be consulted.

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APPENDIX: Listing of TE-30 and Related Projects

PROJECT	TE-30?	PAVEMENT TYPE	DESIGN FEATURES EVALUATED	YEAR BUILT
California 1 I-10, El Monte	No	PPCP	Precast, post-tension concrete pavement	2004
Colorado 1 S.H. 121, Wadsworth	No	UTW	Ultrathin whitetopping	2001
Colorado 2 I-25, Loveland	No	JPCP	Precast concrete slabs for full depth repairs	2004
Illinois 1 I-55 SB, Williamsville	No	JRCP	Alternative dowel bar materials	1996
Illinois 2 IL 59, Naperville	Yes	JRCP JPCP	Alternative dowel bar materials Sealed/unsealed joints Traffic counters	1997
Illinois 3 US 67 WB, Jacksonville	Yes	JPCP	Alternative dowel bar materials Sealed/unsealed joints	1999
Illinois 4 SR 2 NB, Dixon	No	JPCP	Alternative dowel bar materials	2000
Indiana 1 I-65 at SR-60, Clark County	Yes	JPCP	Factors to reduce curling/warping	2004
Iowa 1a IA 5, Carlisle	Yes	JPCP	PCC mixing times on PCC properties	1996
Iowa 1b US 30, Carroll	Yes	JPCP	PCC mixing times on PCC properties	1996
Iowa 2 US 65 Bypass, Des Moines	Yes	JPCP	Alternative dowel bar materials Alternative dowel bar spacings	1997
Iowa 3 US 151, Linn/Jones	Yes	JPCP	Fly-ash stabilization of PCC	2001
Iowa 4 IA 330, Jasper, Story, and Marshall Counties	No	JPCP	Elliptical steel dowel bars	2002
Iowa 5 Iowa 330, Melbourne	No	JPCP	Elliptical fiber reinforced polymer dowel bars	2002
Iowa 6 Various Locations	No	Various	Fly-ash stabilization of subgrade for PCC pavements	N/A
Iowa 7	No	Various	Total Environmental Management for Paving (TEMP)	N/A
Kansas 1 K-96, Haven	Yes	JPCP FRCP	Alternative dowel bar materials Alternative PCC mix designs (including fiber PCC) Joint sawing alternatives Joint sealing alternatives Surface texturing Two-lift construction	1997
Kansas 2 Hutchinson	Yes	JPCP	Smoothness monitoring of plastic concrete	2001
Maryland 1 US 50, Salisbury Bypass	Yes	JPCP FRCP	PCC mix design Fiber PCC	2001

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PROJECT	TE-30?	PAVEMENT TYPE	DESIGN FEATURES EVALUATED	YEAR BUILT
Michigan 1 I-75 NB, Detroit	No	JRCP JPCP	Two-lift construction Exposed aggregate Thick foundation Alternative dowel bar materials and spacing	1993
Michigan 2 M25, Port Austin I- 675 Zilwaukee	No	JRCP	Precast concrete slabs for full depth repairs	2003
Minnesota 1 I-35W, Richfield	Yes	JPCP	Alternative dowel bars PCC mix design	2000
Minnesota 2 Mn/Road Low Volume Road Facility, Albertville	Yes	JPCP	Alternative dowel bar materials Doweled/nondoweled joints PCC mix design	2000
Minnesota 3 Mn/ROAD, Mainline Road Facility and US 169, Albertville	No	UTW	Application of ultrathin whitetopping	1997
Mississippi 1 US 72, Corinth	Yes	Resin-Modified Pavement	Alternative PCC paving material (resin-modified pavement)	2001
Missouri 1 I-29 SB, Rock Port	Yes	JPCP FRCP	Fiber PCC Slab thickness Joint spacing	1998
New Hampshire 1	Yes	N/A	HPCP definitions “Design Optimization” computer program	N/A
Ohio 1 US 50, Athens	Yes	JRCP	PCC mix design (GGBFS) Evaluation of HIPERPAV	1997-1998
Ohio 2 US 50, Athens	Yes	JRCP	Alternative dowel bar materials	1997
Ohio 3 US 50, Athens	Yes	JRCP	Sealed/unsealed joints	1997-1998
Ohio 4 US 35, Jamestown	Yes	JPCP	Evaluation of soil stiffness using nondestructive testing devices	2001
Pennsylvania 1 SR 22, Murrysville	Yes	JPCP	Evaluation of HIPERPAV	2004
South Dakota 1 US 83, Pierre	Yes	JPCP FRCP	PCC mix design Joint spacing Doweled/nondoweled joints	1996
Tennessee 1 I-65, Nashville	No	JPCP	Implementation of PRS	2004
Virginia 1 I-64, Newport News	Yes	JPCP	PCC mix design	1998-1999
Virginia 2 VA 288, Richmond	Yes	CRCP	PCC mix design Steel contents	2004
Virginia 3 US 29, Madison Heights	Yes	CRCP	PCC mix design Steel contents	2004
Washington 1 SR 395, Kennewick	No	JPCP	PCC mix design for rapid construction	2000

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PROJECT	TE-30?	PAVEMENT TYPE	DESIGN FEATURES EVALUATED	YEAR BUILT
West Virginia 1 Corridor H, Route 219, Elkins	No	JPCP	Alternative dowel bar materials, size, spacing	2002
University Ave.-Routes 857 and 119, Morgan-town		JPCP	Alternative dowel bar materials and FRP moisture diffusion	2002
Rte. 9 between Martinsburg and Charlestown		CRCP	FRP versus steel longitudinal reinforcing bars	2006?
Wisconsin 1 WI 29, Abbotsford	Yes	JPCP	Surface texturing	1997
Wisconsin 2 WI 29, Owen	Yes	JPCP	Alternative dowel bar materials Alternative dowel bar spacings	1997
Wisconsin 3 WI 29, Hatley	Yes	JPCP	Alternative dowel bar materials Alternative dowel bar spacings Trapezoidal cross section	1997
Wisconsin 4 I-90, Tomah	Yes	JPCP	Alternative dowel bar materials PCC mix design	2002
FHWA 1	No	UTW	UTW repair techniques	1998-1999
Various States 1	No	JPCP	Evaluation of magnetic tomography for dowel bar location (MIT Scan-2)	2003 +

KEY: JPCP = jointed plain concrete pavement; CRCP = continuously reinforced concrete pavement; PPCP = precast post-tension concrete pavement; JRCP = jointed reinforced concrete pavement; FRCP = fiber-reinforced concrete pavement; UTW = ultrathin whitetopping

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