STATUS OF HIGH-PERFORMANCE CONCRETE PAVEMENTS CONSTRUCTED UNDER FHWA'S TE-30 PROGRAM

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ABSTRACT

Since 1996, twenty-two concrete pavement projects incorporating innovative design and construction concepts have been constructed by participating State Highway Agencies (SHAs) under the Federal Highway Administration's (FHWA's) TE-30 program. However, to date there has been no formal attempt to ascertain the status of these projects, which increases the likelihood that any benefit or increased understanding of PCC pavement performance that might be obtained from these projects will be lost. To address this potential shortcoming, this paper introduces the different projects included in the TE-30 program, and summarizes the various design and construction innovations currently being investigated in those projects. It also highlights some preliminary findings from selected projects.

INTRODUCTION

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 (US TECH) (FHWA 1992). During that visit, the tour participants were exposed to a wealth of information on concrete pavement materials, structural design, and construction that could benefit concrete pavements in the U.S. Follow-up 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 U.S. 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 the 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 (SHAs) could select the area considered appropriate for improving concrete pavement performance in their States. Suggested innovation areas include:

- Increasing the service life.
- Decreasing construction time.
- Lowering life-cycle costs.
- Lowering maintenance costs.
- Constructing ultra-smooth ride quality 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 the pavement’s long-term performance.

OVERVIEW OF TE-30 PROJECTS

To date, twenty-two projects have been funded by the FHWA under the TE-30 program (Smith 2001). All but one of these include the construction of actual concrete pavement projects intended to provide insight into the effects of a broad range of innovative concrete pavement design features and construction concepts; the remaining project developed definitions of high-performance concrete pavements and produced a computer program to assist in the optimization of high-performance concrete pavement designs.

A complete listing of the current TE-30 projects is provided in table 1 (Smith 2001). The table includes information on the design features evaluated, the year built, the concrete pavement type (jointed plain concrete pavement [JPCP], jointed reinforced concrete pavement [JRCP], continuously reinforced concrete pavement [CRCP], or fiber reinforced concrete pavement [FRCP]), and whether the project is funded under TE-30. Three projects included in the table are not funded under the TE-30 program: Michigan 1, Illinois 1, and Illinois 4. The Michigan site is included because it is in essence the “first” TE-30 project; the additional Illinois projects are included because of their applicability and similarity to some of the other TE-30 studies.

Table 1. Listing of TE-30 and related projects (Smith 2001).

Project Designation/ Location	TE-30?	Pavement Type	Design Features/Variables Studied	Year Built
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 U.S. 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
Iowa 1a IA 5, Carlisle	Yes	JPCP	PCC Mixing Times on PCC Properties	1996
Iowa 1b U.S. 30, Carroll	Yes	JPCP	PCC Mixing Times on PCC Properties	1996
Iowa 2 U.S. 65 Bypass, Des Moines	Yes	JPCP	Alternative Dowel Bar Materials Alternative Dowel Bar Spacings	1997
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
Maryland 1 U.S. 50, Salisbury Bypass	Yes	JPCP FRCP	PCC Mix Design Fiber PCC	2001
Michigan 1 I-75 NB, Detroit	No	JPCP JRCP	Two-Lift Construction Exposed Aggregate Thick Foundation	1993
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
Mississippi 1 U.S. 72, Corinth	Yes	Resin-Modified	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 U.S. 50, Athens	Yes	JRCP	PCC Mix Design	1997-1998
Ohio 2 U.S. 50, Athens	Yes	JRCP	Alternative Dowel Bar Materials	1997
Ohio 3 U.S. 50, Athens	Yes	JRCP	Sealed/Unsealed Joints	1997-1998

Table 1. Listing of TE-30 and related projects (continued).

Project Designation/ Location	TE-30?	Pavement Type	Design Features/Variables Studied	Year Built
South Dakota 1 U.S. 83, Pierre	Yes	JPCP FRCP	Fiber PCC Joint Spacing Doweled/Nondoweled Joints	1996
Virginia 1 I-64, Newport News	Yes	JPCP	PCC Mix Design	1998-1999
Virginia 2 VA 288, Richmond	Yes	CRCP	PCC Mix Design CRCP Steel Contents	2000
Virginia 3 U.S. 29, Madison Heights	Yes	CRCP	PCC Mix Design CRCP Steel Contents	2000
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

DESIGN FEATURES/CONSTRUCTION VARIABLES BEING EVALUATED

As observed from table 1, a variety of design features and construction variables are being evaluated under the TE-30 program. These can be broadly grouped into the following categories: joint design studies, PCC mix design and materials studies, structural design studies, and construction methods and procedures. The following sections present the TE-30 projects that fall within each of these categories, describing the various types of design features or innovations that are being investigated.

Joint Design Studies

Several of the TE-30 projects are investigating joint design variables. Included in this category are studies on the use of alternative dowel bar materials, alternative spacings of dowel bars, and comparisons of the performance of pavements with sealed and unsealed joints.

Alternative Dowel Bar Materials

Eleven of the TE-30 projects, located in Illinois, Iowa, Kansas, Minnesota, Ohio, and Wisconsin, are evaluating the use of alternative dowel bar materials for providing load transfer across transverse joints. The purpose of these studies is to assess the feasibility of other dowel bar materials that are not susceptible to corrosion, which can be a problem with conventional epoxy-coated steel dowel bars. Among the types of dowel bar materials that are evaluated in the different projects are:

- Fiber composite dowel bars.
- Solid stainless steel dowel bars.
- Stainless steel clad dowel bars.

- Fiber composite tubes filled with hydraulic cement.
- Stainless steel tubes filled with hydraulic cement.
- Conventional epoxy-coated steel dowel bars.
- X-Flex™ load transfer devices (an experimental device that looks like a figure "8" placed on its side across the transverse joint).

Within the fiber composite dowel bar category, there are three resin types that can be used in the production of the material (polyester resin, vinyl ester resin, and epoxy resin), and each is represented in this study. In addition, dowel bars of different diameters and produced by different manufacturers are also represented. Table 2 summarizes the TE-30 projects evaluating alternative dowel bar materials (Smith 2001).

Alternative Dowel Bar Spacings

Three of the projects (IA 2, WI 2, and WI 3) are evaluating alternative spacings of dowel bars across transverse joints. These studies are being conducted to evaluate the number of dowel bars required across a transverse joint to provide effective load transfer. The Iowa project incorporates a dowel bar spacing of 203-mm (8-in) to compare to the standard dowel bar spacing of 305-mm (12-in) for the alternative dowel bar materials; this is because of concerns regarding the ability of the alternative dowel bar materials to provide effective load transfer.

The Wisconsin projects incorporate several different dowel bar layouts, each of which reduces the number of dowel bars in a joint. These layouts, which are illustrated in figure 1, cluster three and sometimes four dowel bars in the wheelpath, and also evaluate the need for dowel bars in the widened slab area of the outer traffic lane. WI 2 evaluates standard epoxy-coated dowels in each of these configurations, and also includes two sections with solid stainless steel dowels placed in layouts 3 and 4. WI 3 includes a section with standard epoxy-coated dowels placed in layout 1.

Sealed/Unsealed Joints

Four of the TE-30 projects (IL 2, IL 3, KS 1, and OH 3) compare the performance of pavement sections with sealed joints to pavement sections with unsealed joints. This is in response to the current debate in the pavement community regarding the long-term benefits of sealing joints in concrete pavements.

Table 3 summarizes the joint sealing features of the four TE-30 projects evaluating the effect of joint sealant on pavement performance. Hot-poured, silicone, and preformed compression seals are all represented in the study.

<u>PCC Mix Design and Materials Studies</u>

Many of the TE-30 projects are evaluating alternative PCC mix designs in pursuit of longer-lasting and more durable pavements. Included in this category are studies evaluating high-performance PCC mixtures, fiber-reinforced PCC mixtures, and the use of a modified PCC paving material.

Table 2. TE-30 projects evaluating alternative dowel bar materials (Smith 2001).

Project/ Location	Type of Load Transfer Devices	Dowel Diameter
Illinois 1 I-55 SB, Williamsville	Epoxy-coated dowels	38 mm (1.5 in)
	Fiberglass and polyester dowels	38 mm (1.5 in)
Illinois 2 Route 59, Naperville	Epoxy-coated dowels	38 mm (1.5 in)
	Fiberglass and polyester dowels	38 mm (1.5 in) 44 mm (1.75 in)
	Fiberglass and epoxy resin dowels	38 mm (1.5 in)
Illinois 3 U.S. 67 WB, Jacksonville	Epoxy-coated dowels	38 mm (1.5 in)
	Fiberglass and polyester dowels	38 mm (1.5 in)
	Fiberglass and vinyl ester dowels	38 mm (1.5 in)
	Fiberglass and polyester resin tube filled with cement	N/A
	Stainless steel clad dowels	38 mm (1.5 in)
Illinois 4 SR 2 NB, Dixon	Fiberglass and polyester resin tube filled with cement	N/A
	Stainless steel tube filled with cement	38 mm (1.5 in) 44 mm (1.75 in)
	Stainless steel clad dowels	38 mm (1.5 in) 44 mm (1.75 in)
Iowa 2 U.S. Route 65, Des Moines	Epoxy-coated dowels	38 mm (1.5 in)
	Solid stainless steel dowel	38 mm (1.5 in)
	Fiberglass and polyester dowels	38 mm (1.5 in)
	Fiber composite dowel	48 mm (1.88 in)
Kansas 1 K-96, Haven	Epoxy-coated dowels	32 mm (1.25 in)
	Fiberglass and polyester resin tube filled with cement	51 mm (2 in)
	X-Flex™ Device	—
Minnesota 1 I-35W, Richfield	Epoxy-coated dowels	38 mm (1.5 in)
	Stainless steel clad dowels	38 mm (1.5 in) 44 mm (1.75 in)
	Solid stainless steel dowels	38 mm (1.5 in) 44 mm (1.75 in)
Minnesota 2 Mn/Road Low Volume Road Facility, Albertville	Epoxy-coated dowels	25 mm (1 in) 32 mm (1.25 in)
	Fiber-reinforced polymer	32 mm (1.25 in) 38 mm (1.5 in)
Ohio 2 U.S. Route 50, Athens	Epoxy-coated dowels	38 mm (1.5 in)
	Fiber and polyester dowels	38 mm (1.5 in)
	Stainless steel tube filled with cement	38 mm (1.5 in) outer diameter
Wisconsin 2 WI 29, Owen	Epoxy-coated dowel	38 mm (1.5 in)
	Solid stainless steel dowel	38 mm (1.5 in)
	Fiber composite dowels	38 mm (1.5 in)
	Stainless steel tube filled with cement	38 mm (1.5 in)
Wisconsin 3 WI 29, Hatley	Epoxy-coated dowel	38 mm (1.5 in)
	Solid stainless steel dowel	38 mm (1.5 in)
	Fiber composite dowels	38 mm (1.5 in)

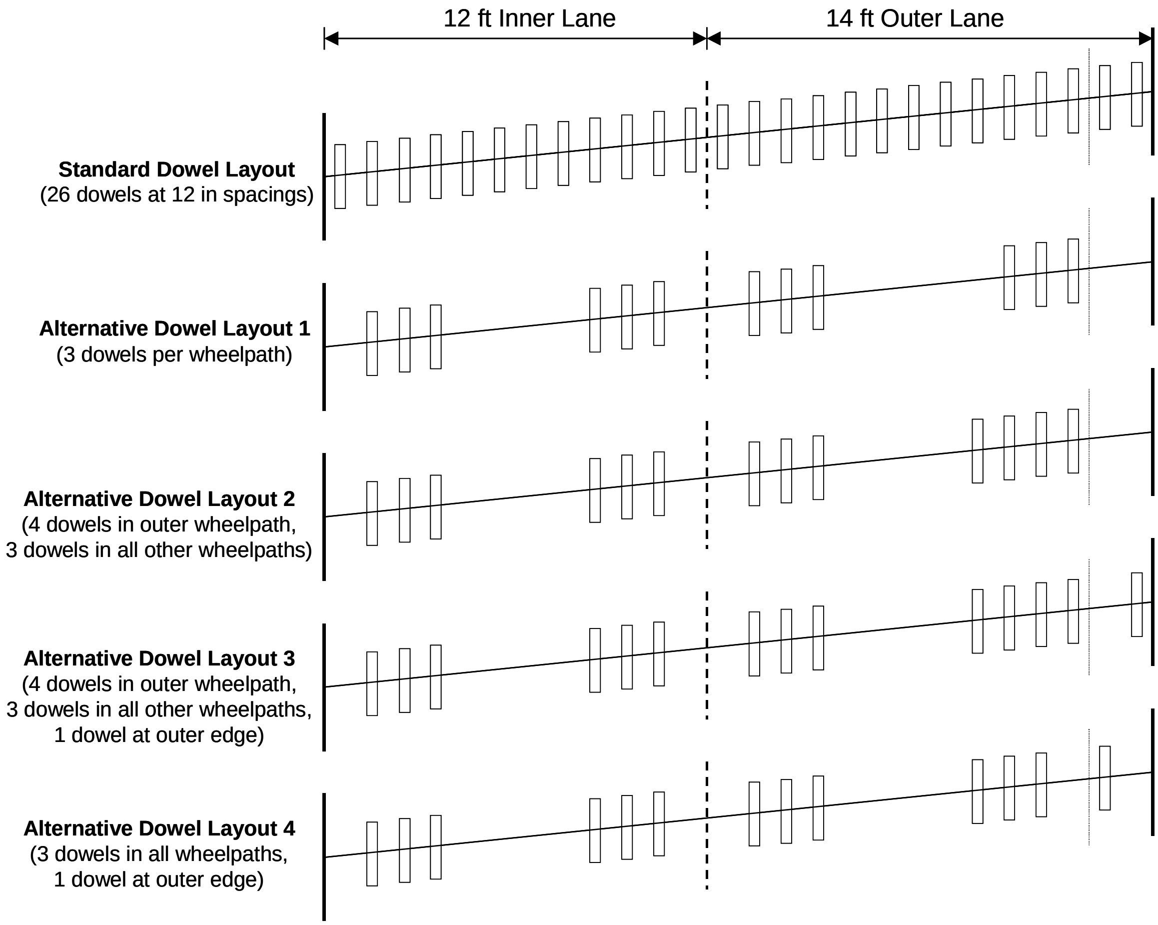

Figure 1. Layout of alternative dowel layouts used in WI 2 (Smith 2001).

Table 3. Summary of TE-30 joint sealing projects (Smith 2001).

Project/ Location	**Number of Comparable Sections**	**Sealant Type(s)/ Joint Width(s)**	**Unsealed Joint Width(s)**
Illinois 2 Route 59, Naperville	7 sealed 1 unsealed	Hot-poured sealant/3 mm (0.12 in)	3 mm (0.12 in)
Illinois 3 U.S. 67 WB, Jacksonville	6 sealed 1 unsealed	Hot-poured sealant/16 mm (0.62 in)	6 mm (0.25 in)
Kansas 1 Highway K-96, Haven	2 sealed 1 unsealed	Hot-poured sealant/13 mm (0.5 in) Compression seal/13 mm (0.5 in)	6 mm (0.25 in)
Ohio 3 U.S. Route 50, Athens	26 sealed 4 unsealed	Compression seal/10 mm (0.38 in) Silicone sealant/10 mm (0.38 in) Silicone sealant/6 mm (0.25 in) Silicone sealant/3 mm (0.12 in) Hot-poured sealant/10 mm (0.38 in)	3 mm (0.12 in) 6 mm (0.25)

High-Performance PCC Mixtures

High-performance PCC mixtures for pavements are generally thought of as being less permeable mixtures that are highly durable and that exhibit low shrinkage; they often also exhibit slightly higher flexural strengths. These properties can be achieved in a number of ways, including the following:

- Use of durable aggregates to prevent freeze-thaw and alkali-aggregate reactivity problems.
- Use of “well-graded” aggregate to reduce water demand and shrinkage.
- Use of larger coarse aggregate, which reduces paste and water requirements.
- Use of reduced water-to-cement ratio (w/c).
- Addition of supplementary cementitious or pozzolanic materials (such as fly ash or ground granulated blast furnace slag [GGBFS]) to decrease the overall permeability of the mix.

All of these mix design characteristics are represented in the TE-30 program. Table 4 summarizes the TE-30 projects that evaluate different types of high-performance PCC mixtures.

Table 4. Summary of TE-30 projects with high-performance PCC mixtures (Smith 2001).

Project/ Location	**High-Performance PCC Mix Design Feature(s)**
Kansas 1 Highway K-96, Haven	Well-graded aggregate Low w/c
Maryland 1 U.S. 50, Salisbury Bypass	Larger coarse aggregate size
Minnesota 1 I-35W, Richfield	High-quality aggregate Well-graded aggregate Ground granulated blast furnace slag
Minnesota 2 Mn/Road Low Volume Road Facility	Ground granulated blast furnace slag
Ohio 1 U.S. 50, Athens	Ground granulated blast furnace slag
Virginia 1 I-64, Newport News	Larger coarse aggregate size Class F flyash Ground granulated blast furnace slag
Virginia 2 and Virginia 3 Route 288, Richmond and U.S. 29 Madison Heights	Larger coarse aggregate size

Fiber Reinforced PCC

The use of three fibers for PCC reinforcement are being evaluated in the TE-30 program: polypropylene, polyolefin, and steel. Polypropylene fibers are expected to reduce plastic shrinkage cracking in concrete (as do both polyolefin and steel fibers), but provide little enhancement to the mechanical properties of the concrete. Polyolefin fibers are purported to increase the toughness, ductility, and post-cracking behavior of concrete, benefits also provided by steel fibers. Steel fibers also have the added benefit of increasing the flexural strength of the concrete. The TE-30 projects incorporating fibers are listed below:

- Kansas 1—polyolefin fibers (at a dosage of 15 kg/m^3 [25 lb/yd^3]).
- Maryland 1—polypropylene fibers (project to be constructed in 2001).
- Missouri 1—polyolefin fibers (at a dosage of 15 kg/m^3 [25 lb/yd^3]) and steel fibers (at a dosage of 45 kg/m^3 [75 lb/yd^3]).
- South Dakota 1—polyolefin fibers (at a dosage of 15 kg/m^3 [25 lb/yd^3]).

All of these projects have an adjacent control section for comparing the performance of the fiber-reinforced section.

Modified PCC Paving Material

One experimental project funded under the TE-30 program is investigating the performance of a resin-modified pavement (RMP). RMPs are a new composite paving material consisting of a thin layer (50 mm [2 in]) of open-graded asphalt concrete (AC) pavement whose internal voids (approximately 30 percent) are filled with a latex rubber-modified portland cement grout (Smith 2001). RMPs are expected to provide a tough and durable pavement surface that resists rutting, surface abrasion, and deterioration due to fuel spillage (Smith 2001).

This project is slated for construction by the Mississippi Department of Transportation in March 2001. It will be constructed on U.S. 72 in Corinth at several intersections with a history of rutting and heavy traffic. An ultra-thin whitetopping (UTW) pavement and a polymer-modified hot-mix asphalt (HMA) pavement will also be constructed for comparison purposes (Smith 2001).

<u>Structural Design Studies</u>

A few of the TE-30 projects are evaluating specific aspects of the PCC pavement's structural design. These include one project investigating the use of a variable thickness cross section and two projects investigating varying longitudinal steel contents in a continuously reinforced concrete pavement (CRCP) design.

Variable Thickness Cross Section

The WI 3 project includes the evaluation of variable thickness cross sections as well as alternative dowel bars. Variable thickness cross sections use thinner slab thicknesses in the inner (less traveled) lane, while maintaining the required structural thickness for the outer (truck) lane. The goal is the more efficient use of materials, resulting in more cost-effective designs. Figure 2 illustrates the variable thickness cross section pavement design currently being evaluated on the WI 3 project.

CRCP Steel Contents

Two TE-30 projects in Virginia are evaluating PCC mixtures exhibiting low shrinkage as well as the effect of longitudinal steel contents on the development of cracking in CRCP designs. These projects, located on Route 288 near Richmond and on U.S. 29 near Madison Heights, were constructed in the late fall of 2000.

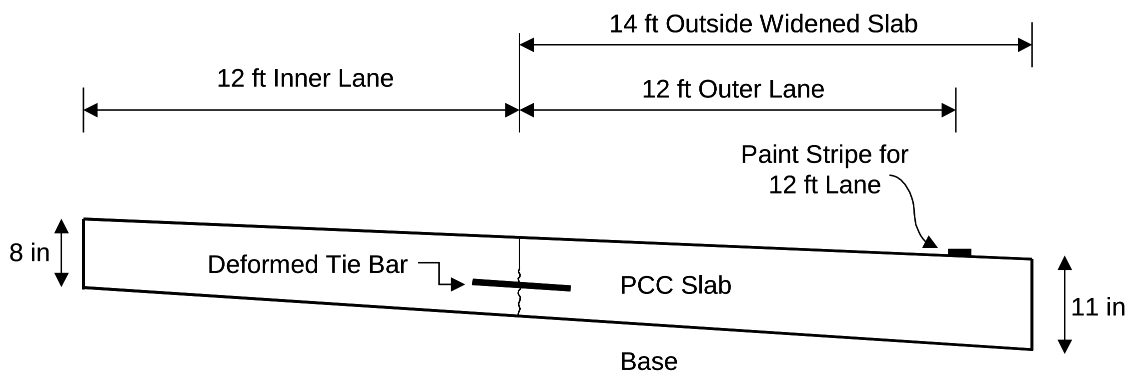

Figure 2. Variable thickness cross section used on WI 3 (Smith 2001).

Construction Methods and Procedures

Several TE-30 projects are evaluating different aspects of PCC pavement construction, including the use of different construction equipment, processes, or materials. Included in this category are a study on the effect of PCC mixing times, several investigations on the use of two-layer PCC construction, a study on the use lightweight joint sawing equipment and a high-solids curing compound, and several studies on alternative surface texturing techniques.

PCC Mixing Times

Two projects in Iowa (IA 1a and IA 1b) evaluated the effect of mixing time on the resultant air content, air distribution, consolidation, and workability of PCC used in the construction of PCC pavements. This study was conducted in response to concerns regarding claims of consistent and sufficient mixing in as short as 30 seconds.

Two-Layer Construction

Two-layer construction involves the placement of concrete in two lifts, with the first (bottom-most) lift generally consisting of a lower quality concrete and the second (top-most) lift consisting of a higher quality concrete. Two-layer construction processes were used on two TE-30 projects: KS 1 and MI 1. The KS 1 project includes three sections with two-lift construction:

- Top lift of 76-mm (3-in) thick, well-graded PCC over 178-mm (7-in) thick PCC incorporating 15 percent recycled asphalt pavement.
- Top lift of 76-mm (3-in) thick, well-graded PCC incorporating a hard igneous rock over 178-mm (7-in) thick PCC incorporating a soft, high-absorption durable limestone.
- Top lift of 76-mm (3-in) thick, well-graded PCC with a reduced w/c of 0.42 over a 178-mm (7-in) thick PCC incorporating a soft, high-absorptive limestone.

The MI 1 project contains a 64-mm (2.5-in) thick top layer incorporating a crushed basalt rock to reduce polishing of the surface. The bottom 190-mm (7.5-in) layer incorporates a limestone aggregate.

Joint Sawing and Curing

The KS 1 project also evaluated the use of different joint sawing equipment and curing compounds. Three sections were constructed using lightweight saws for the establishment of the transverse joints: one section used a Soff-Cut™ saw (to depths of 38 and 64 mm [1.5 and 2.5 in]), one section used a Target saw (to depths of 25, 44, and 64 mm [1, 1.75, and 2.5 in]), and one section used a Magnum saw (to depths of 25, 44, and 64 mm [1, 1.75, and 2.5 in]). A separate section was constructed in which a special high solids curing compound, conforming to ASTM C 1315, was applied to this pavement section at a rate of 0.036 L/m^2 (0.03 gal/yd^2).

Texturing

Three projects investigated the use of different surface texturing methods. On the KS 1 project, two sections incorporate different surface texturing methods, one with longitudinal tining and one with randomly spaced transverse tining.

The MI 1 project incorporated an exposed aggregate surface. In this process, a set retarder is sprayed on the surface and then the concrete is covered with plastic sheeting for a period of about 20 hours. Afterwards, the sheeting is removed and the surface brushed with a brushing machine.

On the WI 1 project, ten sections were constructed with unique surface texturing characteristics, including conventional uniform transverse tining, longitudinal tining, random transverse tining, and random skewed transverse tining. These sections were tested for noise and surface friction, and analyzed along with forty-seven additional sections incorporating a variety of pavement surface textures.

PRELIMINARY FINDINGS

Most of the projects included in the TE-30 program are not very old and, consequently, have not yet generated any significant findings. Nevertheless, some notable findings have already resulted from three of the projects, as described in the following sections.

Iowa 1a and 1b (PCC Mixing Study)

In this project, the Iowa Department of Transportation conducted an evaluation of the effect of concrete mixing time on several critical plastic and hardened concrete properties. This investigation was conducted using several different mix designs for pavements constructed at two different sites: Iowa Highway 5 near Carlisle and U.S. Route 30 near Carroll (Cable and McDaniel 1998). Extensive statistical analyses were conducted on the data collected from each test site. Comparisons of key concrete properties (slump, unit weight, air content, and compressive strength) were made between testing location (side, center, or on grade) and between the various mixing times (30, 45, 60, and 90 seconds). Based on these analyses, the following general conclusions were drawn (Cable and McDaniel 1998):

- Dump-truck-type hauling units do not significantly alter the quality of the material delivered to the paver and should continue to be allowed in addition to agitator-type hauling vehicles.

- Mixing times of 60 seconds or greater do have a positive influence on the physical characteristics of the concrete product and should be retained as the minimum mixing time for all mixer types.

- Mixing times did not significantly affect the hardened air content or distribution for the Iowa DOT mix designs, but the data showed conflicting results for the contractor-designed mix.

- Mixing times of less than 60 seconds should be allowed only when steps have been taken to change the mixing process to ensure coating of all aggregates prior to mixer discharge into the hauling unit.

- Visual examination of the mix at the Carlisle site (which used 30- and 45-second mixing times) indicated visible sand seams (uncoated sand particles) in the discharged material. The resulting concrete was also noted to be very difficult to place and finish.

Ohio 2 (Instrumented Dowel Bar Study)

The OH 2 project, constructed on U.S. 50 near Athens, evaluated dowel response under a variety of loading and environmental conditions and also compared the measured responses of different types of dowel bars (Sargand 2000). Three types of dowel bars were used in the dowel bar project: 38-mm (1.5 in) epoxy-coated steel dowel bars, 38 mm (1.5 in) fiberglass dowel bars, and 38 mm (1.5 in) outer diameter stainless steel tubes filled with concrete. An analysis of the strains in both the fiberglass and steel dowel bars under environmental and dynamic loading was conducted, with the following important findings (Sargand 2000):

- Environmental forces (caused by thermal curling and/or moisture warping) produced greater bending moments in both the steel and fiberglass dowels than dynamic loading forces. The dynamic bending stresses induced by a 56.9 kN (12,800 lb) load were considerably less than the environmental bending stresses induced by a 3 ^{o}C (5.4 ^{o}F) temperature gradient.

- Steel bars induced greater environmental bending moments than fiberglass bars.

- Significant stresses were induced by steel dowel bars early in the life of this pavement as it cured late in the fall under minimal temperature and thermal gradients. PCC pavements paved under more severe conditions may develop even larger environmental stresses.

- Both types of dowels induced a permanent bending moment in the PCC slabs during curing, the magnitude of which is a function of bar stiffness.

- Curling and warping during the first few days after concrete placement can result in large bearing stresses being applied to the concrete around the dowels. This stress may exceed the allowable stress of the concrete at that early age and result in some permanent loss of contact around the bars.

- Steel bars transferred greater dynamic bending moments and vertical shear stresses across transverse joints than fiberglass bars of the same size.

It is noted that these results are based on the analysis of the instrumented steel and fiberglass dowel bars only, as the instrumentation on the stainless steel tubes did not survive the paving operations.

Wisconsin 1 (Surface Texturing Study)

As described previously, the WI 1 project involved the construction of ten concrete pavement sections with specific surface texturing characteristics, and these sections were supplemented with forty-seven additional pavement sections from Wisconsin, Colorado, Iowa, Michigan, Minnesota, and North Dakota. A comprehensive analysis of the noise, texture, and surface friction data collected from the fifty-seven test sections was conducted, and yielded the following conclusions (Kuemmel et al. 2000):

- The depth of the tining varies considerably between pavement test sections, as well as within a test section. In many cases, specified tining depths were not achieved.
- Uniformly tined pavements exhibit discrete frequencies that produce an annoying “whine” to travelers.
- Transversely tined pavements with the widest and deepest textures were among the noisiest.
- HMA and longitudinally tined PCC pavements exhibit the lowest exterior noise levels while still providing adequate texture. Longitudinal spacings of 19 mm (0.75 in) reduce the impact on motorcycles and compact vehicles.
- The longitudinally tined PCC pavements, the randomly skewed (1:6) tined pavements, and an HMA pavement exhibit the lowest interior noise levels while still providing adequate texture.
- Randomly skewed (1:6) tined pavements can be constructed relatively easily, exhibit low interior noise levels and no discrete frequencies, and have the best subjective ranking. They have higher levels of exterior noise than longitudinally tined PCC and HMA pavements, but lower than random transverse PCC pavements. The also exhibit good friction and texture.
- The effectiveness of perpendicular random transverse tining is very sensitive to the spacing pattern. When spacings tend to be more uniform, discrete frequencies may develop, resulting in higher noise levels.
- The diamond-ground PCC pavement, although not as quiet as other PCC pavements, did not exhibit any predominant frequency or spike.

Based on the results of the data analysis, the following primary recommendations were developed (Kuemmel et al. 2000):

- If overall noise considerations are paramount, longitudinal tining that provides satisfactory friction may be considered.

- If subjective perceptions and texture considerations are paramount, a randomly skewed (1:6) textured pavement, offset from any skewing of the transverse joints, may be used.

- If texture considerations are paramount, and a skewed pattern is impractical, randomly spaced transverse tining may be employed. However, this should employ a highly variable spacing.

SUMMARY

The FHWA's TE-30 program, *High Performance Concrete Pavement*, was launched in 1994 to investigate innovative design features, construction practices, or paving materials that can lead to long-lasting or more cost-effective concrete pavements. 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 its long-term performance. Among some of the design features being investigated are alternative dowel bar materials, alternative dowel bar layouts, various "high performance" PCC mix designs, fiber reinforced concrete, sealed and nonsealed joints, and surface texturing techniques.

To date, a total of twenty-two concrete pavements have been funded under the TE-30 program. The oldest of these was built in 1996, with the majority of the projects constructed between 1996 and 1998. A few projects were constructed in 2000, and several are scheduled for construction in late fall 2000 or early spring 2001. Additionally, one other TE-30 project developed a computer program that "optimizes" concrete pavement designs.

Some preliminary findings are presented from three of the projects, but continued monitoring of the TE-30 projects is strongly recommended. This is because the performance of many of the design innovations will not be apparent until after 10 or more years of service (for example, the durability of some of the concrete mixtures or the long-term load transfer efficiency of alternative dowel bar materials). By continuing to monitor these and other innovative pavements, it will be possible to further enhance our understanding of high performance concrete pavements, and obtain better performing, longer-lasting concrete pavements.

DISCLAIMER

ACKNOWLEDGMENTS

Many individuals contributed to the development of this paper by willingly providing research reports, work plans, internal memos, and other documentation on their TE-30 projects. The following individuals are gratefully acknowledged for providing that assistance:

Mark Gawedzinski, Illinois DOT
David Lippert, Illinois DOT
Jim Cable, Iowa State University
Mark Dunn, Iowa DOT
John Wojakowski, Kansas DOT
Dimitrios Goulias, Univ. of Maryland
David Smiley, Michigan DOT
David Rettner, Minnesota DOT
Tom Burnham, Minnesota DOT
Randy Battey, Mississippi DOT
Tim Chojnacki, Missouri DOT
Charles Goodspeed, University of New Hampshire
Shad Sargand, Ohio University
Anastasios Ioannides, University of Cincinnati
Roger Green, Ohio DOT
V. Ramakrishnan, South Dakota School of Mines and Technology
Daniel Strand, South Dakota DOT
Celik Ozyildirim, Virginia Transportation Research Council
David Kuemmel, Marquette University
Jim Crovetti, Marquette University
Debbie Bischoff, Wisconsin DOT

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