CONCRETE PAVEMENT CPTP TECHNOLOGY PROGRAM

TechBrief

The Concrete Pavement Technology Program (CPTP) is an integrated, national effort to improve the long-term performance and cost-effectiveness of concrete pavements. Managed by the Federal Highway Administration through partnerships with State highway agencies, industry, and academia, CPTP's primary goals are to reduce congestion, improve safety, lower costs, improve performance, and foster innovation. The program was designed to produce user-friendly software, procedures, methods, guidelines, and other tools for use in materials selection, mixture proportioning, and the design, construction, and rehabilitation of concrete pavements.

www.fhwa.dot.gov/pavement/concrete

U.S. Department of Transportation
Federal Highway Administration

Long-Life Concrete Pavements: Best Practices and Directions From the States

INTRODUCTION

The International Conference on Long-Life Concrete Pavements was organized in October 2006 as a part of technology transfer activities for the Concrete Pavement Technology Program (CPTP), which operates within the Federal Highway Administration (FHWA) (Tayabji and Lim 2006). The conference objective was to provide a forum to address various aspects of concrete pavement design, construction, and materials technologies that result in long life for concrete pavements. Several State departments of transportation (DOTs) participated in the conference and presented information related to their current practices and future directions for achieving long-life concrete pavements. This TechBrief summarizes the long-life concrete pavement practices presented by the Illinois, Minnesota, Texas, and Washington State DOTs, practices that are representative of directions implemented by States that have strong concrete pavement construction programs.

BACKGROUND

In the past, concrete pavements were routinely designed and constructed to provide low-maintenance service lives of 20 to 25 years. In fact, the majority of pavements in the interstate and primary systems in the United States were designed on the basis of a 20- to 25-year initial service life. More recently, there has been a movement toward construction of pavements with a longer initial service life—40 or more years, particularly in high-volume, urban corridors where traffic disruptions and user delays can be especially acute because of frequent or extended lane closures. The use of long-life pavement strategies has proven to be a cost-effective tool for minimizing maintenance costs and reducing user delays for many highway agencies in the United States. As an example, the California Department of Transportation (Caltrans) requires use of a 40-year service life for designing pavements along a highway corridor where the 20-year projected average annual daily traffic equals or exceeds 150,000 vehicles or average annual daily truck traffic equals or exceeds 15,000 trucks (Caltrans 2006).

Long-life concrete pavements (LLCPs) have been quite attainable for a long time in the United States, as evidenced by the number of very old pavements that remain in service; however, recent advances in design, construction, and concrete materials technology give us the knowledge and technology needed to consistently achieve what we know to be attainable.

A useful definition of long-life concrete pavement in the United States is summarized as follows (Tayabji and Lim 2006):

- Original concrete service life is 40+ years.
- Pavement will not exhibit premature construction and materials-related distress.
- Pavement will have reduced potential for cracking, faulting, and spalling.
- Pavement will maintain desirable ride and surface texture characteristics with minimal intervention activities, if warranted, for ride and texture, joint resealing, and minor repairs.

The quest for long-life concrete pavements necessitates a much better understanding of design and construction factors that affect both short-term and long-term concrete pavement performance. Essentially, this requires that there be a better understanding of how concrete pavements deteriorate or fail. Concrete pavements deteriorate over a period of time as a result of distresses that develop due to a combination of traffic and environmental loading. Typical distresses that can develop include the following:

1. Cracking—Typically transverse cracking occurs, but longitudinal, random, and corner cracking may also develop due to poor design and construction practices. Cracking is typically referred to as a stress-based distress.

2. Joint faulting—Joint faulting may develop with or without outward signs of pumping. Faulting is typically referred to as a deflection-based response. Joint faulting is significantly affected by the type of load transfer provided at transverse joints.

3. Spalling—Spalling may develop along joints or cracks and may be caused by poor joint-sawing practices, incompressible materials in joints or cracks, winter snow removal operations, or poor-quality concrete.

4. Materials-related distress—The more significant materials-related distresses may include alkali-silica reactivity (ASR) and D-cracking in freezing environments.

5. Roughness—The lack of pavement smoothness, or roughness, is affected by the development of various distresses in the concrete pavement, as listed in items 1 through 4 above. The effect of each distress type is additive and results in pavement roughness over a period of time. Some pavement roughness is also built in during construction. Initial pavement smoothness is needed in order that the pavement does not become prematurely rough. Construction specifications typically utilize incentives and disincentives to control new pavement smoothness.

6. Texture loss—Although not conventionally considered a distress, texture loss is a significant distress for pavements in high-volume, high-speed applications.

It is realized that it would be impossible or impractical to design and construct concrete pavements that exhibit very little or no distress. Distress development over the pavement's service life is expected. However, the rate of distress development is managed by incorporating sound designs, durable paving materials, and quality construction practices. Generally recognized threshold values in the United States for distresses at the end of the pavement's service life are listed in Table 1 for jointed plain concrete pavements (JPCPs) and continuously reinforced concrete pavements (CRCPs).

Typical pavement performance trends are illustrated in Figure 1. When the pavement serviceability has reached the threshold level, the pavement no longer efficiently or safely serves the driving public. This corresponds to the point in time at which one or

Table 1. Threshold Values for Concrete Pavement Distresses

Distress	Threshold Value
Cracked slabs, % of total slabs (JPCP)	10 to 15
Faulting, mm (in.) (JPCP)	6 to 7 (0.25)
Smoothness (IRI), m/km (in./mi) (JPCP and CRCP)	2.5 to 3.0 (150 to 180)
Spalling (length, severity) (JPCP and CRCP)	Minimal
Materials-related distress (JPCP and CRCP)	None
Punchouts, no. per km (mi) (CRCP)	10 to 12 (16 to 20)

JPCP = jointed plain concrete pavement, CRCP = continuously reinforced concrete pavement, IRI = International Roughness Index

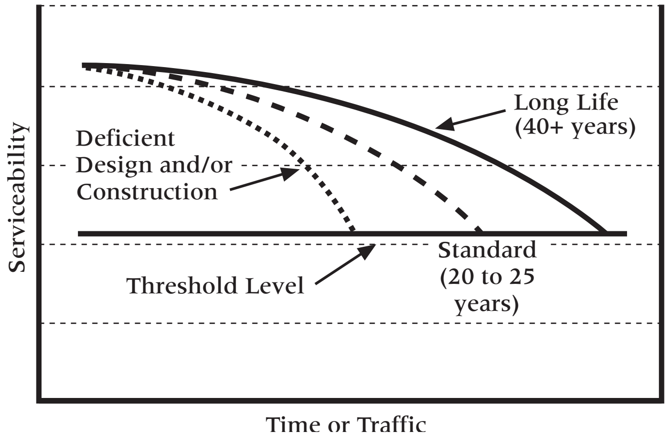

Figure 1. Pavement performance trends.

more of the distress threshold values listed in Table 1 is reached. In the past, the threshold levels were expected to be reached at about 20 to 25 years. The threshold would be reached earlier if the pavement incorporated design or construction deficiencies. For long-life pavements, the threshold is expected to be reached at 40+ years.

The above requirements can be met only through sound pavement design, use of durable materials, ensured quality during construction, and timely maintenance. Design and construction of a successful concrete pavement require attention to many details, and most require little additional effort to be performed correctly.

PRACTICES AND DIRECTIONS OF STATE DEPARTMENTS OF TRANSPORTATION

Illinois

During the late 1990s, the Illinois DOT (IDOT) began investigating concepts in the design and construction of extended-life concrete pavements. IDOT carried out the following activities (Winkelman 2006):

1. Cooperative research with the University of Illinois—Accelerated testing was performed to determine the optimal structural design features for CRCP.
2. Identification of long-life design and construction features—Structural design features, concrete materials requirements, and construction processes were refined.
3. Construction projects—To demonstrate the feasibility of the construction of long-life pavement, several projects were constructed across the State.

Subsequently, IDOT's concrete pavement construction specifications were changed to incorporate rigorous concrete materials requirements to prevent freeze–thaw and ASR-related damage and to tighten construction tolerances. Details of the changes are summarized in Table 2.

The changes in the specifications were successfully incorporated in five demonstration projects, and the performance of the pavements has been excellent to date. IDOT is pursuing additional extended-life concrete pavement projects and will be incorporating more of the extended-life features into the current standard design procedure.

Minnesota

The Minnesota DOT (MnDOT) has adopted LLCPs as the standard design for high-volume, urban highways since 2000. The current design features and construction specifications associated with the LLCP are provided in Table 3 (Burnham et al. 2006).

Although LLCP has been successfully implemented in a number of projects within Minnesota, MnDOT continues to investigate concerns related to the expected service life of LLCP. MnDOT's concerns include concrete durability and construction-related issues. Current materials specifications used in the design of LLCP rely on accelerated laboratory testing. However, the laboratory performance may significantly differ from actual long-term performance in the field. There is concern whether the permeability and air content systems in the LLCP will be able to provide the necessary level of durability for the entire design period under the State's extreme climate conditions.

MnDOT has also experienced some construction problems from the use of new materials. Most LLCP projects include supplementary cementitious material (SCM) to meet the concrete mixture requirements. Many contractors who were not familiar with the LLCP concrete mixtures containing SCM have complained of difficulties in handling these mixtures. In this regard, training of the engineers

Table 2. Changes in Illinois Specifications to Achieve Long-life Concrete Pavements

Item	Long-Life Pavement Specification Change
Thickness design	- JPCP: IDOT-developed mechanistic–empirical design procedure. - CRCP: IDOT-modified AASHTO process. - Design life: 30 to 40 years.
Typical structure	- Up to 350-mm (14-in.) CRCP slab. - 100 to 150 mm (4 to 6 in.) stabilized base (hot-mix asphalt stabilized base for CRCP). - 300 mm (12 in.) well-graded aggregate subbase (top 75 mm [3 in.] maximum size of 40 mm [1.5 in.]; bottom 230 mm [9 in.] maximum size of 200 mm [8 in.] aggregate). - Compacted subgrade.
Tie bars	- Use of tie bars at centerline and at lane-to-shoulder longitudinal joints. - Use of 25 mm (1 in.) (# 8) steel bars, 750 mm (30 in.) long, spaced at 600 mm (24 in.).
CRCP reinforcement	- Reinforcement ratio: increased from 0.7% to 0.8%. - Reinforcing steel depth: increased from 90 to 115 mm (3.5 to 4.5 in.) for 350-mm-thick (14-in.) slabs. - All reinforcements in CRCP, including the support chairs, must be epoxy-coated.
Aggregate requirements	- Freeze–thaw expansion (using IDOT-modified ASTM C 666): • 0.040% for 30-year design and 0.025% for 40-year design (in the past, 0.060%). - Alkali–silica reactivity (ASR) susceptibility (by ASTM C 1260) (applies only for 40-year designs): • If the expansion is greater than 0.1%, limit the equivalent alkalis of the cement source to not greater than 0.6%. When fly ash is used, the available alkali as Na_2O shall be a maximum of 1.5% for the fly ash source. • If any blended cement is used, the mortar expansion at 14 days and 8 weeks shall be a maximum of 0.02% and 0.06%, respectively. • ASR requirements are subject to change. Contact IDOT Bureau of Materials and Physical Research for the latest specifications.
Construction requirements	- Concrete mixture temperature: 10 to 32 °C (50 to 90 °F). If the temperature exceeds 32 °C (90 °F), concrete production will cease until appropriate corrective action is taken. - Slipform paving machine is required to be equipped with internal vibration and vibration monitoring device. - Curing: Type II (white-pigmented) curing compound must be applied to the pavement surface and edge faces within 10 minutes of concrete finishing and tining. - At least 7 days of curing are required before opening the pavement to any construction or regular traffic.
Construction quality	- Surface texture: provisions for tining (for safety and low tire–pavement noise): • Use of variable spacing between 17 and 54 mm (0.70 and 2.15 in.). • Use of 10-degree skewed tining (for the sections with speed limit of 90 km/h [55 mi/h] or higher). • Use of perpendicular tining (for the sections with lower speed limits). - Surface profile: Profile Index (PI) using California Profilograph (0-in. blanking band). • Grinding is required if the average PI value is above 760 mm/km (48 in./mi) for major highways. - Pavement warranty: covers pavement distress up to 5 years on demonstration projects only. IDOT currently does not use warranties.

JPCP = jointed plain concrete pavement, IDOT = Illinois Department of Transportation, CRCP = continuously reinforced concrete pavement, AASHTO = American Association of State Highway and Transportation Officials

Table 3. Minnesota's Standards for High-Performance Concrete Pavements

Item	Present Standard
Design life	- Design long-life concrete pavements (LLCPs) for 60 years.
Cross section	- Slab thickness: 290 to 340 mm (11.5 to 13.5 in.), depending on truck traffic. - Base: 75 to 200 mm (3 to 8 in.) dense-graded granular base (MnDOT CL-5 material) or 125 mm (5 in.) open-graded aggregate base on top of 100 mm (4 in.) CL-5. - Subbase: 300 to 1200 mm (12 to 48 in.) select granular (frost-resistant) subbase.
Joint design	- Joint spacing: 4.6 m (15 ft). - All transverse joints are doweled.
Dowel bar	- Diameter: 38 to 45 mm (38 mm typical) (1.50 to 1.75 in. [1.50 in. typical]). - Length: 380 to 450 mm (380 mm typical) (15 to 18 in. [15 in. typical]). - Spacing: 300 mm (12 in.). - Bar material: must be corrosion-resistant (stainless steel solid, clad, pipe, or tube; plastic-coated steel; zinc-clad steel).
Surface texture	- AstroTurf or broom drag. - Requires 1 mm (0.04 in.) average depth in sand patch test (ASTM E 965). Note: Transverse tining is not used due to noise concerns.
Alkali-silica reactivity (ASR)	- Fine aggregates requires test for ASR potential by ASTM C 1260. - Expansion to be 0.15% or less. Reject if the expansion is greater than 0.3%. - Mitigation is required by using GGBFS or class C fly ash when the expansion is between 0.15 and 0.30%: • 0.15 to 0.25%: GGBFS 35% or fly ash 20%. • 0.25 to 0.30%: GGBFS 35% or fly ash 30%.
Aggregate gradation	- Combined gradation based on 8-to-18 specification: percentage retained in all specified sieves should be between 8 and 18%, except finer than no. 30, and the coarsest sieve.
Concrete permeability	- Use of supplementary cementitious materials (GGBFS or class C fly ash) is required to lower the permeability of concrete. - Specification requires rapid chloride ion permeability test value of 2500 coulomb or less at 28 days, by ASTM C 1202.
Air content	- LLCP concrete mixtures: 7.0 ± 1.5%. • Increased air content for possible loss of entrained air due to over-vibration or in-filling with secondary compounds at later ages.
w/cm	- 0.40 or less.
Curing	- A poly-alpha-methylstyrene membrane cure is used under normal weather conditions. - No construction or general public traffic is allowed for 7 days or until the flexural strength of concrete reaches 2.4 MPa (350 lb/in^2).
Construction quality	- Requires monitoring the vibrators during paving. Paver track speed and vibrator operating frequencies must be reported daily. - Initial Profile Index values, using 5-mm (0.2-in.) blanking band, greater than 126 mm/km (8 in./mi) require corrective action, generally diamond grinding.

MnDOT = Minnesota Department of Transportation, ASTM = American Society for Testing and Materials, GGBFS = ground granulated blast furnace slag, w/cm = water to cementitious material ratio and contractors will be critical for continuous success of LLCP in the future.

Texas

The Texas DOT (TxDOT) uses CRCP as the primary LLCP. Over the years, TxDOT has observed that the primary distresses in CRCP are punchouts, wide cracks, spalling, and construction joint failures. Based on the results of many investigations, TxDOT identified the primary causes of these distresses and modified its design and construction practices to provide longer lasting pavements, as shown in Table 4 (Won et al. 2006). The current practices followed by TxDOT to achieve LLCP are summarized in Table 5 (Won et al. 2006).

Table 4. Texas Modifications to Design and Construction Practices for Longer Lasting Pavements

Distress	Cause	Modified Practice
Punchouts	- Insufficient slab thickness - Base erosion and pumping - Absence of a tied concrete shoulder	- Increases pavement thickness - Requires stabilized base - Recommends tied PCC shoulder
Wide cracks	- Insufficient longitudinal steel - Inadequate steel splicing	- Increases amount of longitudinal steel - Implements design details for staggering splices
Spalling	- Occurs only when coarse aggregates with high CTEs are used.	- Several districts limit the CTE of concrete
Construction joint failure	- Inadequate steel designs	- Currently in process of revising steel design details

PCC = portland concrete cement; CTE = co-efficient of thermal expansion

Table 5. Texas Long-Life Concrete Pavement Standards

Items	Present Standards
Thickness	- Use of AASHTO 1986 pavement design guide. - Use of a reliability value of 95%.
Stabilized bases	- Two types are used: • 150 mm (6 in.) cement-stabilized base with 25-mm (1-in.) asphalt bond breaker layer on top. • 100 mm (4 in.) asphalt-stabilized base.
Longitudinal steel design	- Use of higher steel content: generally results in more cracks but at shorter spacing and are tight. - Requires staggering splices: to avoid weak spots (less than 1/3 of the splices within a 0.6-m (2-ft) length of each lane of the pavement).
CTE	- Limits the CTE of concrete to 10.7 microstrain per °C (6.0 microstrain per °F).
Construction joint	- Past practice for placing additional rebars of same size in a line caused weak spots at the end of the rebars. Revised design details so that the ends of rebars will stagger.

AASHTO = American Association of State Highway and Transportation Officials, CTE = co-efficient of thermal expansion

Washington

About 38 percent of concrete pavements in Washington State were over 35 years old as of 2006. These pavements have lasted longer than their original 20-year design life with little or no maintenance or rehabilitation. Three primary distress types have been observed on the concrete pavements in the State: joint faulting due to lack of dowel bars and to poor conditions in underlying layers; longitudinal cracking that is believed to have occurred during the early years; surface wear due to studded tires.

Based on experience over the last 40 years and studies related to pavement performance, Washington State DOT (WSDOT) has modified its materials, design, and construction practices to achieve LLCP, as summarized in Table 6 (Muench et al. 2006).

Table 6. Washington State's Modifications for Long-Life Concrete Pavements

Item	Long-Life Pavement
Design life	- Increased to 50 years.
Thickness design	- Typical: 305 mm (12 in.) PCC over 60 to 100 mm (2.4 to 4.0 in.) dense-graded HMA base over 60 to 100 mm (2.4 to 4.0 in.) crushed stone subbase (top 25 mm [1 in.] of PCC is considered as sacrificial for future grinding to restore profile and texture). - Design basis: 1993 AASHTO Guide for the Design of Pavements.
Base material	- For high-volume truck routes, requires 100 mm (4 in.) dense-graded HMA base on aggregate subbase to limit base deflection, pumping, and joint faulting. - Asphalt-treated base: minimized use due to its potential for stripping. - Cement-treated base: not allowed due to increased potential for slab cracking and higher risk of pumping.
Joint design	- 4.6-m (15 ft) spacing. - Requires dowel bars. - Saw cut width: 5 to 8 mm (0.2 to 0.3 in.) single cut. - Joint seal: hot-poured sealant. - Tie bars: No. 5 bars, 750 mm (30 in.) long, 900-mm (36-in.) spacing.
Dowel bar	- Dowel bar types (depending on the risk of corrosion): • Stainless steel: stainless steel clad, stainless steel sleeves with an epoxy coated insert, MMFX2 steel bars. • Zinc-clad steel bars. • Epoxy-coated: traditional black steel bar with epoxy coating (ASTM A 943). - Bar dimension: 38-mm (1.5-in.) diameter, 450-mm (18-in.) length, 300-mm (12-in.) spacing. - 8 dowels for non-truck and HOV lanes (4 dowels in each wheelpath) and 12 dowels for truck lanes.
Outside shoulder	- 4.3-m-wide slab (14 ft) with tied PCC or HMA shoulder. - 3.7 m-wide-slab (12 ft) with tied and doweled PCC shoulder.
Mix design	- Use of combined aggregate gradation with maximum size of 20 mm (0.8 in.). - Contractor developed concrete mixtures. - Use of Class F fly ash: max 35% by weight of total cementitious materials. - Use of GGBFS and blended cements.
Concrete quality	- Traffic opening compressive strength: 17 MPa (2500 lb/in^2) by cylinder test or maturity method.
Surface texture	- Transverse tining: 3.2 to 4.8 mm (0.13 to 0.19 in.) tine depth and width, 12.5 to 32.0 mm (0.50 to 1.25 in.) variable spacing.
Studded tire mitigation	- Research to minimize studded tire wear and mitigate its effect is ongoing. The features under investigation include combined aggregate gradation, higher flexural strength, use of higher cement and slag contents, and use of paste-hardening additives.

PCC = portland cement concrete, HMA = hot-mix asphalt, AASHTO = American Association of State Highway and Transportation Officials, ASTM = American Society for Testing and Materials, HOV = high occupancy vehicle, GGBFS = ground granulated blast furnace slag

The extended-life design and construction practices have been successfully implemented in a number of concrete pavement projects in Washington State. WSDOT continues to study concrete- and dowel-bar–related issues to ensure that these materials will provide the required long-term durability. The durability of the concrete surface in the presence of studded tires, tire–pavement noise, and need for accelerated construction in the Seattle area are expected to drive future developments in LLCPs.

SUMMARY

Presentations at the International Conference on LLCP indicated that many U.S. highway agencies have begun to implement strategies to achieve LLCPs that will provide a low-maintenance service life of 40 or more years. As reported in this TechBrief, the effort by most of these agencies involves refining design and construction practices and requiring improved construction quality control. The current directions indicate that no "out of the box" technologies are necessary to achieve LLCPs. As stated in the introduction to this TechBrief, long-life concrete pavements have been attainable for quite a long time in the United States, as evidenced by the number of very old pavements that remain in service. However, recent advances in design, construction, and concrete materials technology give us the knowledge and technology needed to consistently achieve what we already know to be attainable.

REFERENCES

Burnham, T., B. Izevbekhai, and P. R. Rangaraju. 2006. "The Evolution of High-Performance Concrete Pavement Design in Minnesota," *Proceedings, International Conference on Long-Life Concrete Pavements*, pp. 135–151, held in Chicago, IL, October 25–27, 2006. Federal Highway Administration, Washington, DC.

Caltrans. 2006. *Highway Design Manual*, Chapter 610—Pavement Engineering Considerations. September 1, 2006. California Department of Transportation, Sacramento.

Muench, S., L. Pierce, J. Uhlmeyer, and K. Anderson. 2006. "The Evolution of Long-Life Concrete Pavements in Washington State," *Proceedings: International Conference on Long-Life Concrete Pavements*, pp. 19–35, held in Chicago, IL, October 25–27, 2006. Federal Highway Administration, Washington, DC.

Tayabji, S., and S. Lim (eds.). 2006. *Proceedings, International Conference on Long-Life Concrete Pavements*, held in Chicago, IL, October 25–27, 2006, Federal Highway Administration, Washington, DC.

Winkelman, T. J. 2006. "Design and Construction of Extended Life Concrete Pavements in Illinois," *Proceedings, International Conference on Long-Life Concrete Pavements*, pp. 3–18, held in Chicago, IL, October 25–27, 2006. Federal Highway Administration, Washington, DC.

Won, M., D. Kim, Y. Cho, and C. Medina-Chavez. 2006. "Long-Term Performance of Continuously Reinforced Concrete Pavement in Texas," *Proceedings of the International Conference on Long-Life Concrete Pavements*, pp. 171–180, held in Chicago, IL, October 25–27, 2006. Federal Highway Administration, Washington, DC.

Contact—For information about the Federal Highway Administration's (FHWA's) activities related to long-life concrete pavement, contact the following:

Federal Highway Administration
Office of Pavement Technology
Sam Tyson—sam.tyson@dot.gov

CPTP Implementation Team
Shiraz Tayabji, CTLGroup—stayabji@ctlgroup.com

Research—This Techbrief was developed by Shiraz Tayabji, Ph.D., P.E., and Seungwook Lim, Ph.D., P.E., CTLGroup, as part of FHWA's CPTP Task 65 product implementation activity. This publication is based on papers presented at the International Conference on Long-Life Concrete Pavements held in Chicago, Illinois, October 2006, organized as part of FHWA's CPTP Task 65 product implementation activity.

Distribution—This TechBrief is being distributed according to a standard distribution. Direct distribution is being made to the Resource Centers and Divisions.

Availability—This document is based on papers presented at the International Conference on Long-Life Concrete Pavements. For information on the availability of the conference proceedings, please refer to the contact information above.

Key Words—Concrete, concrete pavement, pavement construction, pavement design, pavement performance.

JULY 2007 **FHWA-HIF-07-030**