Performance-based Design Guide for New and Rehabilitated Concrete

Implementing the CP Road Map Design Track

BACKGROUND

Prior to the Mechanistic Empirical Pavement Design Guide (MEPDG), empirical and very limited mechanistic approaches to concrete pavement design were the standard practice. Empirical approaches are effective when all of the site and design feature conditions basically remain the same, which rarely occurs. The focus is on serviceability (or smoothness) only and not on understanding and managing specific distress or failure modes which create loss of smoothness and maintenance needs.

The primary source of much of today's pavement design is still the AASHTO road test of the 1950s. This one subgrade, one base, one climate, limited traffic design guide was constructed using better-than-normal construction practices. Data analysis techniques were also fairly basic and design reliability was not included. Moreover, the AASHTO road test did not incorporate many of the concepts and products used in concrete pavement practice today, including concrete overlays, non-doweled joints, longer joint spacing, tied concrete shoulders, CRCP, permeable bases, different cements, dowel bar retrofits, and other necessary repairs.

Under this track, the concrete pavement research community aims to continue the development of the next generation of mechanistic approaches to pavement design, but also to assure better integration with materials, construction, and environmental inputs. Because many materials properties are important to design success, it is critical that the research conducted under this track be closely coordinated with that done in Track 1 (Performance-Based Concrete Pavement Mix Design System).

The state-of-the-practice today is moving rapidly toward mechanistic-empirical approaches, particularly with the release of the M-E pavement design guide and the expressed interest of many States. These mechanistic-empirical approaches will allow the designer to account for new design features and characteristics, many materials properties, changing traffic characteristics, and differing construction procedures (such as curing and day/night construction). The designer can also now consider additional design features and focus more on pavement performance, including limiting key distress types.

In addition, the design reliability approach does not have the significant limitations of the current AASHTO empirical guide for heavy traffic.

This track builds off and continues the improvement of the excellent comprehensive work done under NCHRP 1-37A and recently approved by AASHTO as the Interim M-E Pavement Design Guide. This track requires a detailed understanding the AASHTO Interim M-E pavement design guide, committing researchers to improving the accuracy and comprehensiveness of performance modeling and prediction.

However, the CP Road Map also identifies the need for simplified design procedures for cities and counties, as well as a design catalog approach.

The pavement design practice of today is basically empirical with AASHTO, though the state-of-the-practice is moving toward mechanistic approaches.

Design Track Goal

Mechanistic-based concrete pavement designs will be reliable, economical, constructible, and maintainable throughout their design life and meet or exceed the multiple needs of the traveling public, taxpayers, and the owning highway agencies. The advanced technology developed under this track will increase concrete pavement reliability and durability (with fewer early failures and lane closures) and help develop cost-effective pavement design and rehabilitation.

In continuing this work, this track not only looks to the next generation of modeling improvements, but seriously considers the integration of design with materials, construction, presentation, and surface characteristics.

This track also explores the development of new high-speed computer analysis tools for optimizing pavement design that can address changes to multiple inputs and thus offer better data on potential life-cycle costs and reliability.

TRACK OBJECTIVES

1. Develop viable (e.g., reliable, economical, constructible, and maintainable) concrete pavement options for all classes of streets, low-volume roads, highways, and special applications.
2. Improve concrete pavement design by maximizing the use of fundamental mechanistic relationships.
3. Integrate pavement designs with materials, construction, traffic loading, and climate.
4. Develop a functional design manual (noise, spray, aesthetics, friction, texture, illumination).
5. Design preservation and rehabilitation treatments and strategies using mechanistic-based designs.
6. Develop and evaluate new and innovative designs for specific needs – high traffic; residential; and parkways.

STAKEHOLDERS INVOLVED AND CORE GROUPS

There are many groups organized to deal with concrete pavement design issues.

The State DOTs, through AASHTO's Joint Technical Committee on Pavements (JTCP) has historically led the country in identifying, funding (through NCHRP) and implementing design-related research.

The Federal Highway Administration also has been key to identifying long term research needs in concrete pavement design, especially the development of models, best practices, and training and implementation efforts.

The concrete pavement industry through the American Concrete Pavement Association, have been actively involved in many design-related efforts. They include the concrete overlays, simplified software development, professor training seminars, tie-bar design, and applications for cities and counties, for example. They also are the voice of the industry, giving input to AASHTO, FHWA, and the individual states.

Several national and regional consortia/groups have formed to evaluate and/or advance the MEPDG implementation. A search of TRB's Research In Progress website suggests that nearly two dozen states have active project related to the MEPDG in particular and the Design Track in general.

Examples include the FHWA Lead States (includes 19 states), State Pavement Technology Consortium (SPTC) comprising of Minnesota, Texas, California, and Washington, Northeast States, Rocky Mountain States, and North Central States.

The National Center for Concrete Pavement Technology is currently developing a national effort to better implement concrete overlays. Included in this effort is the recognition of the need for a more integrated and simplified way to design overlays supplementing the procedure included in the ME pavement design guide. The National Center is also coordinating regional programs across the country to set up MEPDG discussions.

State DOTs have come together regionally through groups such as the Midwest Concrete Consortium (now the National Concrete Consortium). The North Central States MEPDG User Group is another example.

The Concrete Reinforcing Steel Institute, in partnership with the FHWA, has organized an Expert Task Group that is looking at issues related to continuously reinforced concrete pavements, with a focus on the M-E Guide.

There are many other groups, formal and ad-hoc that are looking into specific elements of concrete pavement design.

ONGOING WORK RELATED TO THE DESIGN GUIDE TRACK

Fueled by the interest generated by the AASHTO Interim Mechanistic Empirical Pavement Design Guide (MEPDG), a tremendous amount of work is currently ongoing related to rigid pavement design which meets several of the Track Objectives noted above; especially, objectives 1, 2, and 3, and 5. Objective 4 of the Design Track is partially addressed by the recently completed NCHRP 1-43 project (Pavement Friction Guide) and the ongoing work sponsored by ISU-FHWA-ACPA consortium (Concrete Pavement Surface Characteristics Field Experiments).

Specifically, federal, state, and industry sponsored work is ongoing in 17 of the 21 subtracks of the Design Guide Track. These include:

- DG 1.1 - Development of Benchmark Problems for Concrete Pavement Structural Models Verification
- DG 1.2 - Improvement of 2D and/or 3D Structural Models for JPCP & CRCP Used for Reconstruction and Overlays
- DG 1.4 - Improvements to Dynamic Modeling of Concrete Pavement Systems for Use in Design and Analysis
- DG 1.5 - Structural Models for Special New Types of Concrete Pavements and Overlays
- DG 2.1 - Enhancement and Validation of Enhanced Integrated Climatic Models for Temperature, Moisture, and Moduli
- DG 2.2 - Development and Enhancement of Concrete Materials Models and Improved Pavement Design
- DG 2.3 - Enhancement and Validation of Traffic Loading Models Unique to Concrete Pavements
- DG 2.4 - Improved JPCP Deterioration Models
- DG 2.5 - Improved CRCP Cracking and Punchout Prediction Models
- DG 2.6 - Improved Consideration of Foundation and Subdrainage Models
- DG 3.1 - Concrete Pavement Design Aspects Related to Multiple/Additional Lanes
- DG 3.3 - Improvements to Concrete Overlay Design Procedures
- DG 3.4 - Improvements to Concrete Pavement Restoration (CPR)/Preservation Procedures
- DG 3.5 - Development of New and Innovative Concrete Pavement Type Designs
- DG 4.1 - Incremental Improvements to Mechanistic-Empirical Pavement Design Guide Procedures
- DG 4.2 - New Mechanistic-Empirical Pavement Design Guide Procedures for Paradigm Shift Capabilities
- DG 5.1 - Implementation of the Mechanistic-Empirical Pavement Design Guide

Not surprisingly, spurred by the recent positive ballot received by the MEPDG from the AASHTO subcommittees on Materials and Design to make it an AASHTO Interim Pavement Design Guide, there has been a wealth of activity related to the MEPDG. This work is related to Subtrack DG 5.1 on MEPDG implementation. Some of the projects go across multiple tracks, e.g., Mix Design. In addition, several industry and FHWA sponsored training activities related to the MEPDG are ongoing.

Specific projects are shown in Appendix 1.

TRACK LEADERSHIP MISSION

The CP Road Map supports organizational mechanisms that will lead to

1) Improved coordination, cooperation, and collaboration of research and implementation;
2) Identification and promotion of research that is currently unfunded but needed;
3) Integration of the design track with Track 1 Mix Design and Track 3 NDT for Construction; and
4) Implementation and training efforts.

The CP Road Map is being administered by the National Center for Concrete Pavement Technology through funding from both the FHWA and the State DOTs. For the Design Track to proceed in an orderly fashion and to assure that the above four mechanisms are addressed.

It is proposed that a group of leaders knowledgeable with design issues, understand the work going on, and are committed to the long term goals of the Design Track.

Design Track Leadership Scope

It is recommended that representatives from the AASHTO JTCP, the industry, and FHWA begin to formally discuss ways to promote the overall goals of the Track and undertake the following activities

1) Identify and support a slate of design research
2) Develop a framework for cooperation and sharing of work underway in design research and implementation
3) Organize implementation and training efforts
4) Work with other tracks to assure proper integration.

TRACK LEADERSHIP MEMBERS

State DOTs

Andy Gisi, KS
John Donahue, MO
Mohamed Elfino. VA
Danny Dawood, PA
Jeff Uhlmeyer, WA

Industry

Randy Riley, IL ACPA
Matt Zeller, MN ACPA
Todd LaTorella, MO-KS ACPA

Jim Powell, ACPA-NW
Mike Ayers, ACPA National

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Tom Harman
Angel Corera
Gary Crawford

Academia
Julie Vandenbossche
Jeff Roesler

TRACK KICK-OFF INITIATION

On June 30, 2008, a conference was held with all the track leaders to discuss the potential missions. It is intended for the next year that conference calls and webinars be the vehicle for communication. The minutes of that meeting are included as Appendix 1.

SUGGESTED SHORT -RANGE RESEARCH AND IMPLEMENTATION PROJECTS

Concrete Overlays

Guidance for concrete overlay design has been published by ACI, AASHTO, FHWA, PIARC, NCHRP, ACPA, PCA, the U.S. Army Corps of Engineers, Federal Aviation Administration, and various state departments of transportation. These procedures use a variety of underlying assumptions and design strategies. No single document exists now to design the various concrete overlay solutions – bonded, unbonded, whitetopping, CRCP, overlays, etc.

It is suggested that a comprehensive review of the design procedures lead to two efforts:

1) Building off the current Concrete Overlay Project (ISU and FHWA), pull together a comprehensive design manual that is heavy on case studies developed under that initiative and shows how to use the various design tools in specific situations.
2) Develop a more comprehensive strategy on pulling together one design practice, by integrating existing procedures and continuing research on some of the key weaknesses. (See Appendix 2.)
3) Continued training and outreach on overlay design and construction efforts.

This effort should be presented as part of the Concrete Overlay Initiative to see if support can be gathered for this initiative.

Cost Range: $600,000 - $700,000

Concrete Tie Bars

On the recent Scan of Long Life Pavements, the Scan Team noted that the Europeans use less tie bars than is customary here in the U.S. As part of the implementation of that Scan, the ACPA has research underway to look at how tie bars are actually designed and see if there is a way to reduce the number and spacing.

The Minnesota DOT and the National Concrete Pavement technology Center, with cooperation of FHWA, are working to develop a project at MnROAD to install various diameters and lengths of tie bars at different spacing. The slabs will be instrumented to compare the field results to the theoretical results from the MEPDG.

It is suggested that their research be examined and evaluated, with technology transfer and implementation efforts promoted, as a continuation of this work.

Cost Range: $350,000 –$400,000

SUGGESTED LONGER RANGE RESEARCH PROJECTS

Two projects that might be offered from the track that are worthy of consideration are noted below. These projects have been selected since they (1) are considered as high priority items for the stakeholder design community and (2) they have good synergy with other Track work. They also promote the performance goals of the track.

The overall funding needed to accomplish these projects is also noted. This work could be further prioritized and segmented so that it can be accomplished incrementally in stages under multiple funding mechanisms. The incremental deliverables could be designed to be modular in nature to facilitate further enhancement and integration under future research products.

Develop an Integrated Concrete Materials Modeling and Design/analysis Tool

Background: Concrete materials properties have a great effect on the short- and long-term performance of concrete pavements. While tools currently exist for early age performance prediction (e.g., HIPERPAV) and long-term performance prediction (MEPDG), they have not been fully integrated from a materials modeling standpoint. Several materials inputs are common to both these tools making the integration a relatively easy process, however, more work needs to be done to integrate and optimize the materials, climate, traffic, and other inputs. Such an integrated tool would have tremendous obvious benefits to all the stakeholders involved with designing, constructing, and building concrete roadways.

Tasks: Key aspects of this improvement of PCC materials and construction to be addressed are as follows.

1. Several concrete material properties vary over time which must be considered in design. These properties include strength, modulus, shrinkage, creep, and others. Provide further data on these properties on how they vary over time as a function of mix design and exposure conditions.
2. Determine the effect of construction factors on concrete materials properties in the slab. This would include the following as a minimum:
   - slab curing
   - slab zero-stress temperature
   - built-in curling (thermal gradient through slab as it solidifies)
   - differential slab shrinkage
3. Development of new tests for characterizing concrete strength and modulus that reflects field behavior better than those used today.
4. Achieve early-age and long-range performance predictions.

Cost Range: $1,000,000

*Implementation***:** Implemented into the MEPDG

<u>Development of Improved JPCP Deterioration Models</u>

*Background***:** JPCP is by far the most popular type of concrete built in the world. This is due to its relative cost effectiveness and its reliability. The design of JPCP has greatly improved through increased knowledge over the past several decades.

Tasks: There remain some important aspects of improvement as listed below.

1. Improve on the top down & bottom up transverse cracking models for new & rehab developed under NCHRP 1-37A.
2. Longitudinal cracking (fatigue related). There has been longitudinal cracking in JPCP that could not be explained by traditional fatigue cracking calculations. A major study is needed to determine under what circumstances longitudinal cracking could occur that is fatigue based. The effect of widened slabs will be investigated.
3. Improved joint and crack faulting & spalling models for new and overlays. The existing models will be considered and improved upon to model faulting for all kinds of design and rehabilitation situations needed for design. An improved joint opening/closing model may be needed.

The end product of all this research would be greatly improved and more comprehensive distress and smoothness prediction models for JPCP. The key benefit will be a reduced prediction uncertainty which results in a more cost-effective design for a given level of reliability for JPCP.

Cost Range: $1,000,000 – 1,500,000

*Implementation***:** Implemented into design procedure.

Design of new and Innovative Concrete Pavement Type Design

JPCP is the world's most widely constructed concrete pavement. Historically, rectangular sections have been used extensively for this type of pavement.

Tasks:

1. Conduct a literature study to explore many new and innovative shapes for concrete pavement designs. This study will involve both performing a literature search and contacting as many agencies as possible around the world to investigate the latest innovative designs.
2. Identify key design innovations that could optimize the structural and material design of these pavements, examining trapezoidal cross sections for example.
3. Complete an analytical analysis of these various sections, identifying possible strengths and weaknesses of the new shapes
4. From the most promising, develop an experimental project that builds and monitors several of these sections.

Cost Range: $$400,000 - $600,000
*Implementation***:** Implemented into design and construction procedures.