TECHBRIEF

LTPP Data Analysis, Validation of Guidelines for k-Value Selection and Concrete Pavement Performance Prediction

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FHWA Contact: Cheryl Richter, HNR-30 (703) 285-2183

Background

Concrete pavement performance depends greatly on the support that it receives from the base course and underlying soil layers as well as other support-related factors such as slab curling and warping and slab-base friction. The National Cooperative Highway Research Program (NCHRP) Project 1-30, “Support Under Concrete Pavements” (see Reference 1) developed improved procedures for estimating support design inputs and designing concrete pavements. The new recommended design model gives greatly enhanced capabilities to pavement designers. Concepts for use in future mechanistic design methodology were also developed.

Objectives

This LTPP data analysis was conducted to further test and verify the improved pavement support guidelines and the improved American Association of State Highway and Transportation Officials (AASHTO) performance model proposed in NCHRP Project 1-30 using the design, materials, climate, traffic, and performance data available in the LTPP database. This validation was performed to establish their practicality and appropriateness for use in concrete pavement design nationwide.

Key Products of This Research

- Proposed supplement to the AASHTO Design Guide.
- Incorporate improvements in k-value selection, critical stress computation, the performance/design model, and checks for joint faulting and corner cracking in non-doweled pavements.
- Improved support characterization concepts for mechanistic design.

Impacts of This Study

The findings and procedures developed and verified under this study will result in the following improvements in the design of jointed plain concrete pavement (JPCP) when implemented into the day-to-day operations of State highway agencies:

- Improved design of slab dimensions, including: (1) thickness, (2) length

The Long-Term Pavement Performance (LTPP) program is a 20-year study of inservice pavements across North America. Its goal is to extend the life of highway pavements through various designs of new and rehabilitated pavement structures, using different materials and under different loads, environments, subgrade soil, and maintenance practices. LTPP was established under the Strategic Highway Research Program, and is now managed by the Federal Highway Administration.

U.S. Department of Transportation
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Research and Development
Turner-Fairbank Highway
Research Center
6300 Georgetown Pike
McLean, VA 22101-2296

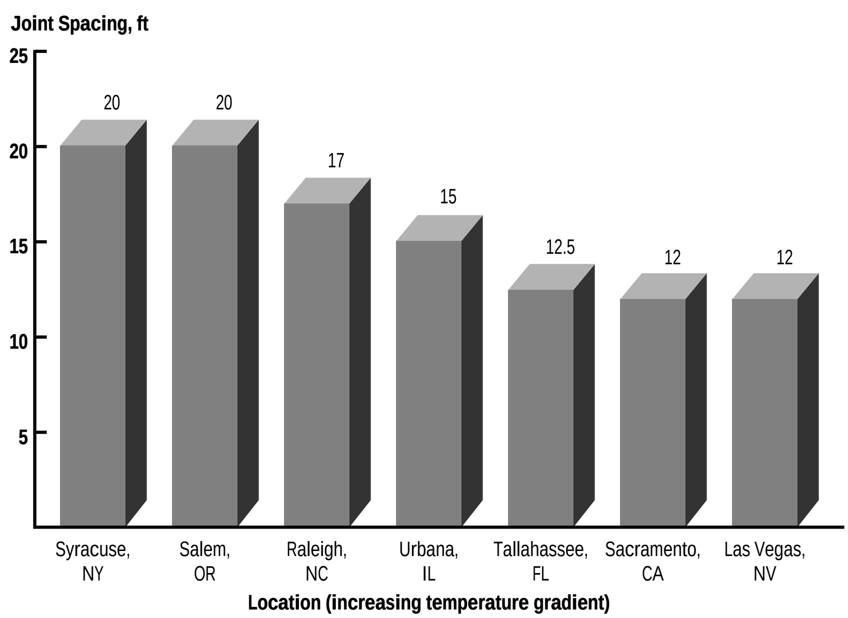
(joint spacing), and (3) width. These procedures make it possible to select slab dimensions for specific project site conditions by directly considering subgrade stiffness, loss of support of base/subgrade, base course as a structural layer, friction between the slab and base, longitudinal edge support (shoulder design and widened lane designs), and particularly thermal gradients for the project site. (See figure 1.) Slab thickness requirements show some reduction from that obtained using the current AASHTO procedure.

- Direct check on joint faulting and procedures to prevent faulting for both doweled and nondoweled joints for specific project design and site conditions.
- Better estimation of subgrade elastic k-value through improved correlations with soil properties and tests, improved backcalculation procedures and slab size adjustments, and consideration of bedrock and embankments of better material.
- Improved design of non-doweled JPCP through a check for slab corner, diagonal and transverse cracking with nighttime thermal gradient, and transverse joint faulting.

These findings and improved procedures will collectively decrease the frequency of premature failures that result from deficient design for specific site conditions (i.e., early cracking from too long transverse joint spacing for specific site conditions, and early faulting from inadequate joint load transfer provisions). These procedures will also result in more cost-effective design through better representation of subgrade support, the structural impact of the base course, and design features such as widened slabs.

FIGURE 1

Maximum allowable joint spacing to control transverse cracking for a given (example) slab thickness, base type, subgrade, and traffic loading for different climatic areas in the United States.*



*Varying design conditions would require different maximum joint spacings than those shown.

Improved Support Characterization for Mechanistic Design

Mechanistic design requires characterization of the subgrade and base layers so that the critical tensile stresses in the slab due to loading and climate can be accurately computed for design purposes. Key practical findings of this research include the following:

- Use of an “elastic” k-value results in proper modeling for stress computation for vehicles moving at creep speed.
- Speed of loading has a major effect on the backcalculated k-value of the AASHO Road Test soil. This may be true for other soils as well and should be considered in the design.
- The frictional resistance between the base and the slab is an important factor in the computation of stress in the slab.
- The effect of subgrade and base stiffness on slab stress is very different when a temperature differential exists through the slab. Construction curl (negative) and moisture differentials (also negative) are also important as they tend to counteract positive temperature differentials.
- Analyses showed that two different loading positions could produce critical tensile stresses for a given pavement: midslab loading and joint or corner loading.
- The presence of properly sized dowels at the joint will eliminate corner cracking and transverse cracking near the joint as well as minimize joint faulting.

TABLE 1

Comparison between existing and proposed design methods.

Feature	Existing AASHTO Procedure	Proposed Revision
Subgrade Stiffness Characterization	Gross k-value required that includes permanent deformation and results in too high slab stresses under moving load. Lowest springtime value incorporated into equation, NOT seasonally adjusted k-value. Subgrade stiffness not considered in slab thermal curling stresses.	Elastic k-value of subgrade soil. Seasonal adjustment if desired. Subgrade stiffness directly considered in slab design for load AND thermal curling stresses. Ability to estimate elastic k-value for a variety of soils, bedrock layer, and embankment layer.
Estimating Elastic k-value	Erroneous correlation with resilient modulus and erroneous use of top of base k-value for design.	Three methods for subgrade elastic k-value: (1) correlation with soil properties and tests, (2) backcalculation with slab size correction, (3) plate load-bearing test.
Base Course	Considered only through a composite (top-of-base) k-value. Base stiffness and friction are not considered in load or curl stresses.	Direct consideration of base as structural layer (thickness, stiffness, and friction). Base considered in load and thermal curl stresses.
Joint Spacing	Built-in 15-ft [4.6-m] JPCP. Built-in 40-ft [12.2-m] JRCP. Not considered otherwise	Direct consideration of load and thermal curl stresses on joint spacing. Brings climate directly into design process.
Climatic Effects	AASHO site climate built into design model. Only adjustment is through seasonal composite k-value. Other climates not considered.	Seasonal variation of subgrade elastic k-value possible. Effective thermal gradients can be determined for any other site.
Loss of Support	Substantial loss of support built into existing model. Additional reduction of k-value for loss of support is overdesign.	Substantial loss of support built into model from AASHO site; no further adjustment is needed.
Joint Faulting	Not considered in current procedure. Mistakenly thought to be considered through J factor, which results in increased slab thickness, not reduced faulting.	Faulting checked after slab thickness design is completed. If joint design is inadequate, joint load transfer or base type changes are allowed, but not slab thickness increase.
Joint Load Transfer	Doweled joints built into existing model. J factor attempts to adjust corner stress for more or less load transfer. No way to consider curling or warping of corners, especially for undoweled joints.	Effect of joint load transfer on corner load, curl, and moisture gradient stresses for undoweled joints are checked directly.
Widened Slab, Tied Shoulders	Inadequate stress adjustment through J factor.	Direct adjustment of critical stress through consideration of wider slab or longitudinal load transfer.
Overall Impact on Design	Serious problems with gross k-value, correlation between resilient modulus and k-value, J factor, no consideration of load transfer and thermal gradients, and poor subdrainage with thickness.	Reduction of slab thickness, maximum joint spacing, need and proper diameter of dowel bars, base type consideration, significant effect of widened slab, subdrainage impact on faulting, etc.

- Thermal gradients, moisture gradients, and built-in construction curling are important considerations in overall slab support and should be used along with traffic loadings in the selection of appropriate joint spacings for JPCP.

Improved Concrete Pavement Performance Model

There exist several major deficiencies in the current AASHTO design procedure for concrete pavements related to the full consideration of base and subgrade support. These deficiencies were addressed and an improved methodology was developed. Proposed revisions to the AASHTO design procedure for concrete pavements were developed to correct the deficiencies identified. A summary of the differences between the existing and revised design methodology is given in Table 1. This table shows that the revised and validated procedure provides many improved and increased design capabilities for jointed concrete pavements.

Validation of New Rigid Pavement Design Model

The predictive capability of the proposed new rigid pavement design model (developed under NCHRP Project 1-30) was evaluated using the LTPP data from General Pavement Section 3 (GPS-3) (JPCP), GPS-4 (jointed reinforced concrete pavement), and GPS-5 (continuously reinforced concrete pavement). The predicted number of equivalent single-axle loads (ESALs) was calculated for each section in the LTPP database using the new NCHRP 1-30 model and compared to the accumulated "actual" ESALs for that section. Plots of predicted versus actual ESALs were prepared for a variety of design comparisons (climatic zone, base type, thick versus thin slabs). In addition, statistical tests were conducted to determine if there were significant differences between predicted and actual ESALs. Results showed that there is no overall bias of the new NCHRP 1-30 model for overpredicting or underpredicting ESALs.

There was, however, considerable scatter of LTPP test section data about the predicted versus actual plot. An approximate analysis of the components of this variation was conducted. The results show significant variation associated with the estimation of historical ESALs, with model inputs for each section, normal random variation between replicate sections, and, of course, model error. Estimates of the prediction model error indicate that the model is reasonable and can be used in design with confidence provided that an appropriate design reliability procedure, such as in the AASHTO Design Guide, is included. The new design/performance model provides a much better accounting of the many concrete pavement design details that ultimately affect performance.

Reference

1. Darter, M.I., K.T. Hall, and C.M. Kuo, "Support Under Portland Cement Concrete Pavements," NCHRP Report 372, Transportation Research Board, Washington, DC, 1995.

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Key Words: AASHTO Guide, PCC pavement design, concrete pavement

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