National Cooperative Highway Research Program

RESEARCH RESULTS DIGEST

July 1998—Number 227

Subject Area: IIB Pavement Design, Management, and Performance   Responsible Senior Program Officer: Amir N. Hanna

Systems for Design of Highway Pavements

An NCHRP digest of the findings from the final report on NCHRP Project 1-32, "Systems for Design of Highway Pavements," conducted by ERES Consultants, Inc. Dr. Michael I. Darter served as Principal Investigator.

INTRODUCTION

An interactive CD-ROM is available for use by pavement engineers and others interested in the design of flexible and rigid pavements. This digest describes this CD-ROM-based catalog and other products of a project, including a CD-ROM-based catalog that will help pavement engineers in identifying pavement design alternatives, reviewing and checking proposed designs, and updating agency design practices, and will also serve as a training tool for entry-level pavement design engineers.

The objective of the design process is to identify pavement structures that will provide acceptable performance and economy over the intended design life. A rational pavement design must consider the effects of roadbed soil, climate, traffic loading, construction materials, and other design details and features on pavement performance and life-cycle costs.

In spite of similarities in environment, traffic, and roadbed soil within and among states, practices for design and construction vary widely. A catalog for pavement design that identifies recommended design structures and features for flexible and rigid pavements would help guide highway authorities in selecting suitable and reliable designs. Nearly all European highway agencies have developed and adopted such design catalogs. Supplementing such a catalog with a microcomputer-oriented, knowledge-based expert system would further enhance the catalog's use and facilitate its updating. NCHRP Project 1-32 was initiated to address this need.

The research was conducted under NCHRP Project 1-32, "Systems for Design of Highway Pavements," by ERES Consultants, Inc. The research, completed in 1997, provided (1) a catalog of current state pavement design features (2) a catalog of recommended (good practice) pavement design features, and (3) a prototype knowledge-based expert system.

The digest provides a summary of the work performed in this research. The material in this digest is extracted from the final report on the project.

FINDINGS

In this project, three practical and useful pavement design products were developed: the Catalog of Current State Pavement Design Features, the Catalog of Recommended Design Features, and a Prototype Knowledge-Based Expert System.

Catalog of Current State Pavement Design Features

This catalog provides a comprehensive summary of nearly all states' design practices for both rigid and flexible pavements. This information is organized into large synoptic tables of design features. The catalog also includes a state factorial design matrix of pavement design features that provides layer thickness for a wide range of traffic, subgrade, and climatic site conditions for major types of main highway pavement constructed by the state highway agencies.

TRANSPORTATION RESEARCH BOARD
NATIONAL RESEARCH COUNCIL

Catalog of Recommended Pavement Design Features

This catalog presents "good practice" recommendations for flexible and rigid pavement design features in an easy-to-use format for ranges of traffic loading, subgrade support, and climatic conditions. The recommendations for asphalt concrete and portland cement concrete pavements are presented in 36 and 26 "cells," respectively. These recommendations would help guide state highway agencies in selecting suitable and reliable designs. The catalog can also be used as a resource for training inexperienced personnel. Figures 1 and 2 show examples from the catalog illustrating structural design alternatives for flexible (asphalt concrete) and rigid (portland cement concrete) pavements, respectively.

Prototype Knowledge-Based Expert System

This expert system, dubbed "Designer," was developed to supplement the Catalog of Recommended Pavement Design Features; it compresses the printed catalog in an electronic format and adds further capabilities. "Designer" will help the pavement engineers to realize the full potential of the printed catalog. With "Designer," the pavement designer is more likely to obtain proper design inputs, to consider all feasible options for a given set of design inputs, and, thus, to make better pavement design decisions. "Designer" helps put pavement design expertise into the hands of less experienced personnel.

CONCLUSIONS

The benefits of pavement catalogs have been recognized by European highway agencies for many years. Such a catalog provides an effective means for identifying pavement design alternatives, reviewing and checking proposed designs, updating agency design practices, and training highway agency personnel. This project resulted in a Catalog of Recommended Pavement Design features for both flexible and rigid pavements, for the ranges of roadbed soil, climate, and traffic conditions encountered in the United States. However, to facilitate use of the catalog by a highway agency, the agency needs to adopt portions of the catalog that cover prevailing roadbed soil and climatic conditions and incorporate appropriate changes to reflect proven practices concerning cross section design, thickness design procedure, materials specifications, mix design, and other standards. In this manner, the agency would have a "customized design catalog" that can be easily used for project-level design process.

The project also produced "Designer," a prototype knowledge-based expert system to supplement the Catalog of Recommended Pavement Design Features. In addition, the project produced a Catalog of Current State Pavement Design Features that contains a comprehensive summary of states' design practices for both rigid and flexible pavements.

FINAL REPORT

The agency's final report on the project includes a summary report, the Catalog of Current State Pavement Design Features, the Catalog of Recommended Design Features, and a Prototype Knowledge-Based Expert System. The report has also been produced on a CD-ROM; copies of the report and the CD-ROM have been distributed to the NCHRP sponsors. Five copies of the CD-ROM have been sent to each member department's representative on AASHTO's Advisory Research Committee. The CD-ROM, titled "Design Tools," is available for purchase by writing to the TRB Publications Office, 2101 Constitution Avenue, N.W., Washington, D.C. 20418. The cost is $25.00 including postage. Checks or money orders should be made payable to the Transportation Research Board. The CD may be purchased using MasterCard, Visa, or American Express by calling 202/334-3214, or faxing 202/334-2519.

ACKNOWLEDGMENTS

The research summarized herein was performed under NCHRP Project 1-32 by ERES Consultants, Inc., Champaign, Illinois; Dr. Michael I. Darter served as principal investigator.

Flexible Cell 6

Traffic: 1-2 million flexible ESALs
Subgrade: Weak (Resilient Modulus, 4.5-9.0 ksi)

General Structural Design Inputs

Initial serviceability	4.5	Elastic modulus of surface HMAC	450 ksi
Terminal Serviceability	2.5	Resilient modulus of subgrade 5 ksi	
Overall standard deviation	0.49	Drainage coefficient, m	1.00
Reliability	85%		

Note: Subgrade is weak; some type of improvement should be considered (See Section 5).
Note: See Sections 4A.2 through 4A.5 for detailed guidelines on other asphalt concrete pavement design features.

Structural Layer Thickness - Conventional Unbound Granular Base

Dense Graded Asphalt Concrete Surface Thickness, in.	5.0-6.0	5.0-6.0
Crushed Stone Aggregate Base Thickness, in.	9.0	9.0
Granular/Aggregate Subbase Thickness, in.	9.5-10.5 Crushed Stone	10.0-11.0 Pit Run Gravel
Prepared Subgrade (See Section 5)		

- Controlled by Subgrade Vertical Compressive Strain Between Wheel Loads
- Controlled by Asphalt Concrete Tensile Strain Under Wheel Load

Dense Graded Asphalt Concrete Surface Thickness, in.	4.5-5.5	4.5-5.5
Crushed Stone Aggregate Base Thickness, in.	7.0	7.0
Granular/Aggregate Subbase Thickness, in.	8.0-9.0 Crushed Stone	9.0-10.0 Pit Run Gravel
Improved Subgrade Thickness, in.	6.0-12.0	6.0-12.0

- Controlled by Subgrade Vertical Compressive Strain Between Wheel Loads
- Controlled by Asphalt Concrete Tensile Strain Under Wheel Load

Structural Layer Thickness - Full-Depth Asphalt Concrete

A full-depth asphalt concrete pavement is not recommended for this site condition cell.

Structural Layer Thickness - Asphalt Treated Base

Dense Graded Asphalt Concrete Surface Thickness, in.	3.0-4.0	3.0-4.0
Asphalt Treated Base Thickness, in.	7.0 (Plant mixed)	8.0 (Roadway Mixed)
Granular/Aggregate (Pit Run Gravel) Subbase Thickness, in.	9.0	9.0
Prepared Subgrade (See Section 5)		

- Controlled by AASHTO-PSI Criteria

Dense Graded Asphalt Concrete Surface Thickness, in.	3.0-4.0	3.0-4.0
Asphalt Treated Base Thickness, in.	6.0 (Plant mixed)	7.0 (Roadway Mixed)
Granular/Aggregate (Pit Run Gravel) Subbase Thickness, in.	7.0	7.0
Improved Subgrade Thickness, in.	6.0 - 12.0	6.0 - 12.0

- Controlled by AASHTO-PSI Criteria

Dense Graded Asphalt Concrete Surface Thickness, in.	3.0-4.0	3.0-4.0
Asphalt Treated Base Thickness, in.	7.0 (Plant mixed)	8.0 (Roadway Mixed)
Crushed Stone Aggregate Subbase, in.	5.0	5.0
Granular/Aggregate (Pit Run Gravel) Subbase Thickness, in.	5.0	5.0
Prepared Subgrade (See Section 5)		

- Controlled by AASHTO-PSI Criteria

Dense Graded Asphalt Concrete Surface Thickness, in.	3.0-4.0	3.0-4.0
Asphalt Treated Base Thickness, in.	5.0 (Plant mixed)	6.0 (Roadway Mixed)
Crushed Stone Aggregate Subbase	5.0	5.0
Granular/Aggregate (Pit Run Gravel) Subbase Thickness, in.	5.0	5.0
Improved Subgrade Thickness, in.	6.0 - 12.0	6.0 - 12.0

- Controlled by AASHTO-PSI Criteria

Structural Layer Thickness - Cement Treated Base

Dense Graded Asphalt Concrete Surface Thickness, in.	3.5-4.5	3.5-4.5
Cement Treated Base Thickness, in.	7.0	7.0
Granular/Aggregate Subbase Thickness, in.	7.0 Crushed Stone	8.0 Pit Run Gravel
Prepared Subgrade (See Section 5)		

- Controlled by AASHTO-PSI Criteria

Dense Graded Asphalt Concrete Surface Thickness, in.	3.5-4.5
Cement Treated Base Thickness, in.	9.0
Improved Subgrade , in.	6.0 - 12.0

- Controlled by AASHTO-PSI Criteria

Figure 1. Example from the Design Catalog illustrating structural design alternatives for flexible pavements.

Rigid
Cell 8

Traffic: 3-6 million rigid ESALs
Subgrade: Weak/Fair (k-value of 100-200 psi/in)

General Structural Design Inputs

Initial serviceability	4.5	Elastic modulus of PCC	4,000,000 psi
Terminal serviceability	2.5	PCC mean flexural strength	650 psi
Overall standard deviation	0.39	Load transfer coef, J-value	Varies w/ edge support type
Reliability	90%	Drainage coef, Cd	1.05

Structural Layer Thickness - NonDoweled JPCP

	Aggregate base			Treated base		
Edge support type	Type I	Type II	Type III	Type I	Type II	Type III
PCC slab thickness, in	9-10.5	9.5-10.5	9.5-11	8.5-10	9-10.5	9.5-10.5
Base thickness, in	4-6	4-6	4-6	4-6	4-6	4-6
Prepared subgrade (See Section 5)						

Transverse Joint Design

Maximum Joint spacing, ft.

JPCP:

Climate	Edge support Type I	Type II	Type III
WF, DF	16-18	16-18	17-19
WNF	14-16	14-16	16-17
DNF	13-15	13-15	14-16

Joint reservoir and other joint design features

For recommended transverse joint reservoir width and other transverse joint design details, see Section 4B.8, "Joint Sealant Reservoir and Joint Sealants" and Section 4B.4, "Transverse Joints for JPCP and JRCP".

Other Design Features

Tie bar design for longitudinal joints: No. 5 (0.625 in diameter) deformed reinforcing bars spaced at 30 in

Subdrainage design: Dry Climate: Level1 - Seal joints and cracks.
Wet Climate: Level 3 - Edge drains and non-erodible materials (treated base required) (see Section 4B).

Note See Sections 4B.2 through 4B.12 for additional detailed guidelines on all the rigid pavement design features.

Rigid
Cell 8

Traffic: 3-6 million rigid ESALs
Subgrade: Weak/Fair (k-value of 100-200 psi/in)

General Structural Design Inputs

Initial serviceability	4.5	Elastic modulus of PCC	4,000,000 psi
Terminal serviceability	2.5	PCC mean flexural strength	650 psi
Overall standard deviation	0.39	Load transfer coef, J-value	Varies w/ edge support type
Reliability	90%	Drainage coef, Cd	1.05

Structural Layer Thickness - Doweled JPCP/JRCP

	Aggregate base			Treated base		
Edge support type	Type I	Type II	Type III	Type I	Type II	Type III
PCC slab thickness, in	7.5-8.5	8-9	8.5-9.5	7-8.5	7.5-9	8-9
Base thickness	4-6	4-6	4-6	4-6	4-6	4-6
Prepared subgrade, in (See Section 5)						

Transverse Joint Design

Maximum Joint spacing, ft.

JRCP: 45 ft

JPCP:

Climate	Edge support Type I	Type II	Type III
WF, DF	14-16	14-16	15-17
WNF	12-15	13-15	14-16
DNF	12-13	12-13	12-14

Joint reservoir and other joint design features

For recommended transverse joint reservoir width and other transverse joint design details, see Section 4B.8, "Joint Sealant Reservoir and Joint Sealants" and Section 4B.4, "Transverse Joints for JPCP and JRCP".

Other Design Features

Tie bar design for longitudinal joints: No. 5 (0.625 in diameter) deformed reinforcing bars spaced at 30 in

Subdrainage design: Dry climate: Level 1 - Joint and crack reseal.
Wet climate: Level 2 - Non-erodible materials (see Section 4C).

Minimum % reinforcement content for JRCP: 0.16%-0.18%

Dowel bar design: 1.25 in diameter corrosion-resistant dowel bars spaced at 12 in

Note See Sections 4B.2 through 4B.12 for additional detailed guidelines on all the rigid pavement design features.

Figure 2. Example from the Design Catalog illustrating structural design alternatives for rigid pavements.

TRANSPORTATION RESEARCH BOARD
National Research Council
2101 Constitution Avenue, NW
Washington, DC 20418

000021-02 *
Tom Baker
Materials Engineer
Idaho Transportation Dept
P O Box 7129
Boise ID 83707-1129