Technical Report Documentation Page

1. Report No. FHWA/TX-07/0-5445-1	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle Mechanistic-Empirical Data Collection Approach for Rigid Pavements		5. Report Date October 2006 6. Performing Organization Code
7. Author(s) Cesar Ivan Medina-Chavez and Moon Won		8. Performing Organization Report No. 0-5445-1
9. Performing Organization Name and Address Center for Transportation Research The University of Texas at Austin 3208 Red River, Suite 200 Austin, TX 78705-2650		10. Work Unit No. (TRAIS) 11. Contract or Grant No. 0-5445
12. Sponsoring Agency Name and Address Texas Department of Transportation Research and Technology Implementation Office P.O. Box 5080 Austin, TX 78763-5080		13. Type of Report and Period Covered Technical Report September 2005-October 2006 14. Sponsoring Agency Code

15. Supplementary Notes

Project performed in cooperation with the Texas Department of Transportation and the Federal Highway Administration.

16. Abstract

This report summarizes the tasks performed for TxDOT Research Project 0-5445 "Project Level Performance Database for Rigid Pavements in Texas." Other pavement databases have been evaluated and their successes and failures have been considered for the preparation of this database. It is intended that the information obtained for this study is fully useful for the validation and calibration of a mechanistic-empirical (M-E) model. A database structure has been proposed and data collection efforts have followed a methodology that will ensure the quality of the data. To address the M-E component, researchers reviewed the continuously reinforced concrete pavement (CRCP) design logic adopted in the mechanistic empirical pavement design guide (MEPDG) and performed sensitivity analysis. In the MEPDG, two design criteria were selected for CRCP performance—IRI and punchouts. Because only punchouts were included in IRI prediction, punchouts represent the only structural distress analyzed in MEPDG. Top-down cracking was adopted as the only mechanism for punchouts. Experience in Texas and Illinois indicate that there might be punchouts mechanisms other than top-down cracking. Sensitivity analysis was performed for key input variables to evaluate the reasonableness of the outputs from MEPDG. The results indicated that zero-stress temperature, and the percent and depth of the longitudinal steel, have substantial effects on punchouts.

17. Key Words Rigid Pavement Database (RPDB), Mechanistic-Empirical (M-E), Long-Term Pavement Performance (LTPP)		18. Distribution Statement No restrictions. This document is available to the public through the National Technical Information Service, Springfield, Virginia 22161; www.ntis.gov.	
19. Security Classif. (of report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No. of pages 56	22. Price

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

Mechanistic-Empirical Data Collection Approach for Rigid Pavements

Cesar Medina
Moon Won

CTR Technical Report:	0-5445-1
Report Date:	October 2006
Project:	0-5445
Project Title:	Project Level Performance Database for Rigid Pavements in Texas
Sponsoring Agency:	Texas Department of Transportation
Performing Agency:	Center for Transportation Research at The University of Texas at Austin

Project performed in cooperation with the Texas Department of Transportation and the Federal Highway Administration.

Center for Transportation Research
The University of Texas at Austin
3208 Red River
Austin, TX 78705

www.utexas.edu/research/ctr

Disclaimers

Author's Disclaimer: The contents of this report reflect the views of the authors, who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official view or policies of the Federal Highway Administration or the Texas Department of Transportation (TxDOT). This report does not constitute a standard, specification, or regulation.

Patent Disclaimer: There was no invention or discovery conceived or first actually reduced to practice in the course of or under this contract, including any art, method, process, machine manufacture, design or composition of matter, or any new useful improvement thereof, or any variety of plant, which is or may be patentable under the patent laws of the United States of America or any foreign country.

Notice: The United States Government and the State of Texas do not endorse products or manufacturers. If trade or manufacturers' names appear herein, it is solely because they are considered essential to the object of this report.

Engineering Disclaimer

NOT INTENDED FOR CONSTRUCTION, BIDDING, OR PERMIT PURPOSES.

Project Engineer: Moon Won
Professional Engineer License State and Number: Texas No. 76918
P. E. Designation: Research Supervisor

Acknowledgments

The authors express appreciation to the Project Director Hua Chen, who has participated very actively during the course of the project. The help and support of Randy Beck from Construction Division/M&P in Austin has been vital to the development of this project. Also, the support received from district pavement engineers and TxDOT staff in all districts visited has been invaluable. Thanks to all members of the Project Monitoring Committee.

Table of Contents

List of Figures

List of Tables

Chapter 1. Introduction

1.1 Background

This is the first report produced for TxDOT Research Project 0-5445, "Project Level Performance Database for Rigid Pavements in Texas." This three-year project focuses on collecting and tailoring information for a database that will be useful for the validation and calibration of a mechanistic-empirical (M-E) pavement design approach in Texas, either from the American Association of State Highway and Transportation Officials (AASHTO) or from an in-house program.

1.2 Scope

This report is divided into five chapters. Chapter 1 is an introduction to the work planned and performed in this project. Chapter 2 contains the results of the evaluation of other, existing pavement databases, e.g., the old Rigid Pavement Database (RPDB) developed at the Center for Transportation Research (CTR) of The University of Texas at Austin. Also, a discussion of the Long-Term Pavement Performance (LTPP) database funded by the Federal Highway Administration (FHWA) and its functionality is covered. Further, a general evaluation of the pavement database maintained by the Washington State Department of Transportation (WSDOT) and its contents are summarized. Chapter 3 describes the structure of the database in this project as proposed to TxDOT and accepted by the project management committee (PMC) members. In addition, this chapter contains the protocol that is followed for field data collection, which includes visual inspection of the pavement and deflection testing conducted with a falling weight deflectometer (FWD). Chapter 4 covers an in-depth assessment of AASHTO's current version of the M-E rigid design guide and its potential applicability for Texas' conditions. Chapter 5 contains a summary of the tasks that have been performed for the project and outlines some future efforts needed to enrich the quality of the database.

1.3 Methodology

To conduct the research tasks for this project, several technical meetings were held at CTR in a weekly basis. Likewise, PMC meetings were held approximately every quarter to inform TxDOT about the work being conducted and to discuss technical information about the data collected. This methodology has provided very good results and its implementation will continue throughout the development of the project.

Chapter 2. Review of Pavement Databases

2.1 Introduction

As part of the work to be conducted under this research project, the evaluation of other pavement databases was documented. The databases that were evaluated included the RPDB previously developed at CTR, the LTPP database, and the database developed by WSDOT. The main purpose of the database review was to determine the most critical inputs for the database developed for this study and also to define unnecessary and redundant information.

2.2 CTR's Rigid Pavement Database (RPDB)

The RPDB developed and maintained by the CTR of The University of Texas at Austin is probably the most comprehensive source of information related to concrete pavements in Texas. The first data collection effort was conducted in 1974, and at that time, only continuously reinforced concrete pavement (CRCP) sections were surveyed. Information was recorded for 246 sections throughout Texas. It was not until 1982 that jointed concrete pavement (JCP) sections were added to the RPDB and data were collected for 135 pavement sections.

The information collected over the years for the RPDB sections was not consistent, as input varied according to the requirements of the year in which the data were recorded. For instance, in 1974, less detailed information was gathered for several sections. At that time, the main objective of the database was to start collecting valuable data for as many sections as possible, so the database's population could be increased rapidly. In contrast, the information that was gathered during the latest collection efforts focused on obtaining more detailed data for a reduced number of sections.

The sections in the RPDB are all rigid pavement sections. While some sections remain in their original condition, or non-overlaid, others have been overlaid with asphalt. The asphalt treatments vary from thin to thick overlays and other special layers, such as open-graded friction courses and permeable friction courses.

2.2.1 Description of Data Collected

Visual condition surveys were performed for all pavement sections contained in the RPDB. These visual surveys allowed surveyors to walk on the pavement shoulder to record information efficiently. When existing sections in the RPDB were revisited, the collected data updated the previous information about the sections in terms of distresses and failures, if they existed; this information is defined as *performance data*. When new sections were added to the database, the information was deemed *inventory data*.

Inventory data included district name and number, county name, highway, reference markers (mileposts), global positioning system (GPS) coordinates, number of lanes per surveyed roadbed, surveyed lane, highway geometric characteristics (alignment and roadbed), coarse aggregate type, construction date, pavement thickness, and climatic information. To collect this information, district offices were first contacted to find out where new pavement projects were built or in construction stage. Next, the districts were visited and the sections were selected within those projects.

With regard to the type of surveyed pavements, JCP and CRCP sections were included. In both cases, overlaid and non-overlaid pavements were surveyed. Additionally, as was one of the primary objectives of the RPDB, recently constructed CRCP sections were added and while other older sections were removed, according to necessity. No new JCP sections were added to the database during the last collection efforts as JCPs are rarely constructed.

2.2.2 Structure of the RPDB

As previously mentioned, the RPDB contains two main components: the inventory data and the performance-related data. The difference between the two components is that inventory data usually does not vary through time; this information always remains the same. However, the performance-related data evolve through time, and contain the history of recorded conditions and distresses in the pavement observed during each field visit.

Inventory Data

The following variables are included in the inventory data: district name and number, the county name, the highway functional classification, the starting reference marker, the ending reference marker, the GPS coordinates (latitude and longitude), the number of lanes, the roadbed characteristics, the geometric characteristics, the coarse aggregate type in the concrete layer, the construction date, concrete slab thickness, overlaid and non-overlaid characteristics, and in the most recent updating process, detailed climatic information.

Performance-Related Data

In order to establish the historical performance of a pavement section, distress data must be added on a regular basis, i.e., annually or biannually, if a pattern is to be established. Some of the performance-related information contained in the RPDB is the number of asphalt concrete (ACP) and portland cement concrete (PCC) patches, the number of punchouts, D-cracking, corner breaks, number of cracked slabs, and the total number of cracks in the 0.2-mile section. Additionally, the cumulative crack spacing distribution is contained for the first 200 ft of each section.

Table 2.1 summarizes and briefly describes some of the variables contained in the RPDB and includes inventory and performance-related data. As indicated previously, the inventory data remain constant over time, whereas the performance-related data change each time a condition survey is performed.

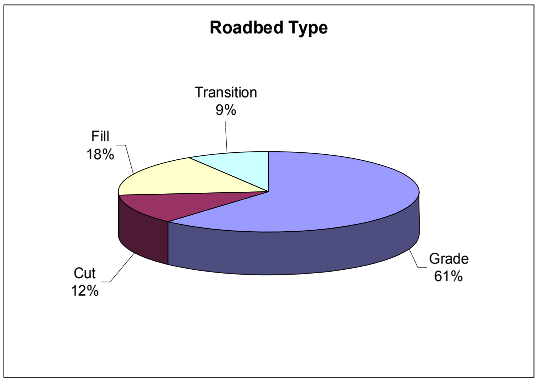
Table 2.1: Inventory and performance data included in the database

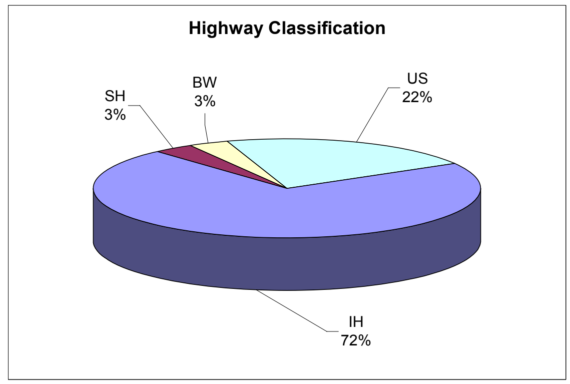
Field in Database	Description
Inventory Data	
DIS	District number
CFTR	Identification number of the section
COUNTY	County name
HWY	Highway functional classification and name
RM_1 *	Beginning reference marker and displacement of the section
RM_2 *	Ending reference marker and displacement of the section
GPSLON	Geographic coordinate (longitude W)
GPSLAT	Geographic coordinate (latitude N)
LANES *	Number of lanes in the surveyed direction
RBD	Roadbed type (cut, fill, at grade, or transition)
CURVE	Geometric Alignment (T=tangent, L=left curve, R=right curve)
OVER	Overlaid characteristics (Y=overlaid, N=nonoverlaid)
CAT	Coarse aggregate type (L=LS=limestone, SRG=siliceous river gravel, M=mixture)
CDATE	Construction date
D	Pavement thickness
AMAT	Average minimum annual temperature (°F)
AARF	Average annual rainfall (in.)
AMER	Average monthly evaporation rate ($lb/ft^2/hr$)
LTAC	Low temperature after construction (°F)
HTDC	High temperature during construction (°F)
Performance-Related Data	
AC	Asphalt concrete patches
PCC	Portland cement concrete patches
PUNCH	Number of punchouts
DCRACK	D-cracking
CORBREA	Corner breaks
SLABS	Number of cracked slabs
CRACK	Total number of cracks in the section
* According to TxDOT PMIS rater's manual	

2.2.3 CRCP Sections

The RPDB contains over 400 CRCP sections. Most of those sections have an 8-inch thickness as many of the pavement projects built fifteen or more years ago were constructed using that thickness. Thicker sections between 10 in. and 13 in. were added to the database from collections performed during the last two major collection efforts. According to the latest data collected, 43 percent of the CRCP are non-overlaid and 57 percent are overlaid [Medina et al., 2003]. Almost two-thirds of the sections are located at grade, meaning that they are positioned at the same vertical level as the surrounding terrain. One-third of the sections is located either at cut, fill, or transition profiles, as shown in Figure 2.1-a.

As for the location of the sections in the highway functional classification system, the interstate highway (IH) covers almost three-quarters of the CRCP population. The rest of the sections are located in either the United States (US), or beltway (BW), or state (SH). Figure 2.1-b shows how the sections are distributed. This classification is important because it allows identifying the influence of traffic volume and distribution on the performance of the pavement.





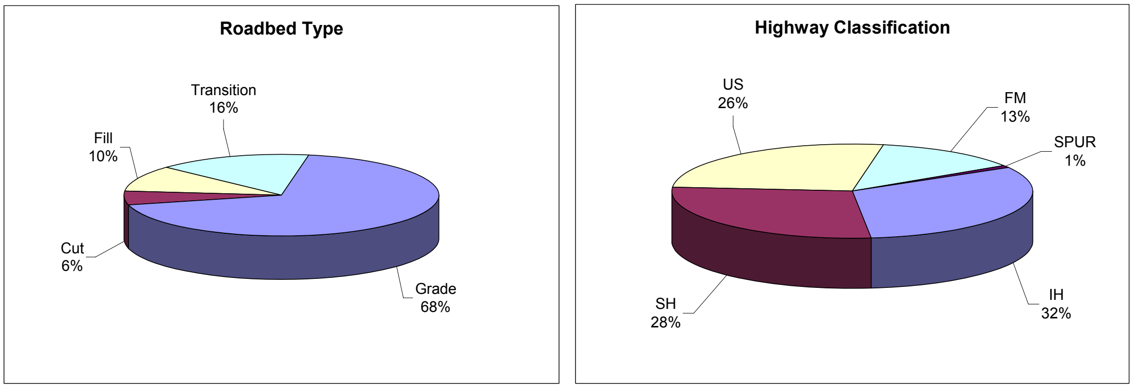
(b)

Figure 2.1: Distribution of CRCP sections: (a) Roadbed Type; (b) Functional Classification

2.2.4 JCP Sections

There are over 100 JCP sections in the RPDB distributed within eleven districts. Houston, Dallas, and Beaumont Districts encompass the bulk of the sections. Slab thicknesses vary from 6 in. to 13 in. and the majority is 10 in. thick. According to the latest data collected, 61 percent of the JCP are non-overlaid and 39 percent are overlaid [Medina et al., 2003]. Nearly three-quarters of the sections are located at grade, and the rest are located at cut, fill, or transition. Figure 2.2-a shows the precise distribution of the sections according to their profile or roadbed.

With regard to the functional classification of the highway where the sections are located, the distribution is well balanced between IH, US, and SH, and some sections are located in farm to market (FM) roads. Figure 2.2-b presents the exact figures.



(a) (b)

Figure 2.2: Distribution of JCP sections: (a) Roadbed Type; (b) Functional Classification

2.3 LTPP Database

The LTPP program was established as part of the Strategic Highway Research Program (SHRP) in 1987, and has been managed by the Federal Highway Administration (FHWA) since 1992. This LTPP program has worked toward the optimization of the investment in the highway system by providing information needed by highway engineers and managers to improve the design, build, maintain, and management of better-quality and more cost-effective roads; a philosophy also shared by CTR's RPDB.

The LTPP database contains lots of information about pavement sections spread across the United States. Figure 2.3 shows a print screen image of an LTPP report of the information provided by the database. The report includes five main components: identification, location, inventory/construction, climate, and pavement layers [LTPP, 2006]. Additionally, as displayed in Figure 2.4, performance trends provided by the LTPP are available for many sections. This information includes pavement deflection, traffic, roughness, and distress data such as longitudinal cracking, transverse cracking, fatigue cracking, rutting, faulting, spalling, and punchouts.

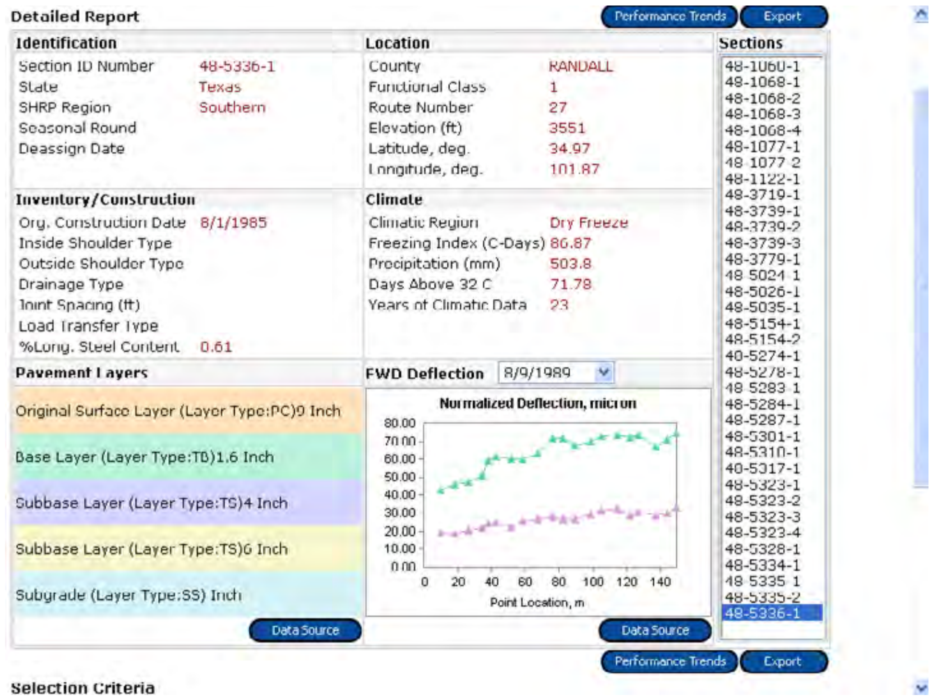


Figure 2.3: Detailed report provided by LTPP database search

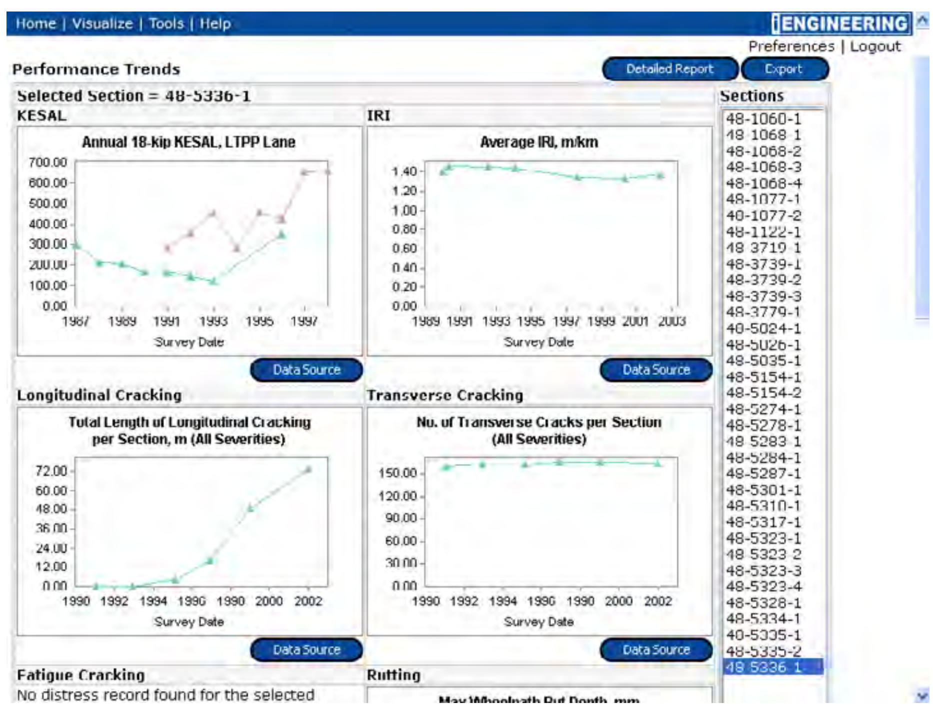


Figure 2.4: Pavement performance trends provided by LTPP database

The LTPP database organizes the information in general pavement studies (GPS-X), special pavement studies (SPS-X), and seasonal monitoring plan (SMP-X) sections. These three hierarchical levels contain different information that can be browsed as needed.

2.3.2 Summary of LTPP Data Codes

The data in the LTPP is described by many variables or codes. It has 310 different codes (CODETYPE), each code having various options; (CODE), which means that 5,897 CODETYPE are available. Table 2.2 is just a summary of the most relevant variables that are considered useful for the new RPDB to be developed under this research project. A complete list of CODETYPE is included in Appendix A.

Table 2.2: Summary of LTPP Codes (CODETYPE)

1. Dowel coat	
2. ESAL estimation scale	16. Portland cement type
3. Fault measure device	17. PCC Admixtures
4. Finish method	18. Photo-Video
5. Flexural strength	19. Profilograph type
6. General pavement rehabilitation cause	20. Region
7. Layer type	21. Spalling amount
8. Maintenance work	22. Subdrainage type
9. Method estimating ADT	23. Surface preparation overlay
10. Method estimating ESAL	24. Surface preparation rehabilitation
11. Monitoring category	25. Transverse joint
12. Monitoring change reason	26. Vehicle class
13. Patch material	27. Weather condition
14. Pavement type	
15. Paver type	

2.4 Washington State Pavement Database

WSDOT's route system is composed of about 17,900 lane-miles of pavements. Nearly 60 percent of this network (10,776 lane-miles) is Asphalt Concrete Pavement, 27 percent (4,843 lane-miles) is Bituminous Surface Treatment, and 13 percent (2,262 lane-miles) is comprised of Concrete Pavement. The rigid pavement's overall distress or pavement structural condition (PSC) is characterized by slab cracking, joint and crack spalling, pumping and blowing, faulting and settlement, patching, and raveling and scaling.

The database is accessible via the Internet and requires that the user register first. When logging in, the user can either browse or search routes, but there is no way to filter the search by keyword—e.g., asphalt, concrete, flexible, rigid, etc.—which makes the search inconvenient. Once a route, direction, and milepost are selected, the software displays a screen with a map for route location and a series of tabs that contain information about the pavement section. Figure 2.5 displays the information contained in the main screen of the database.

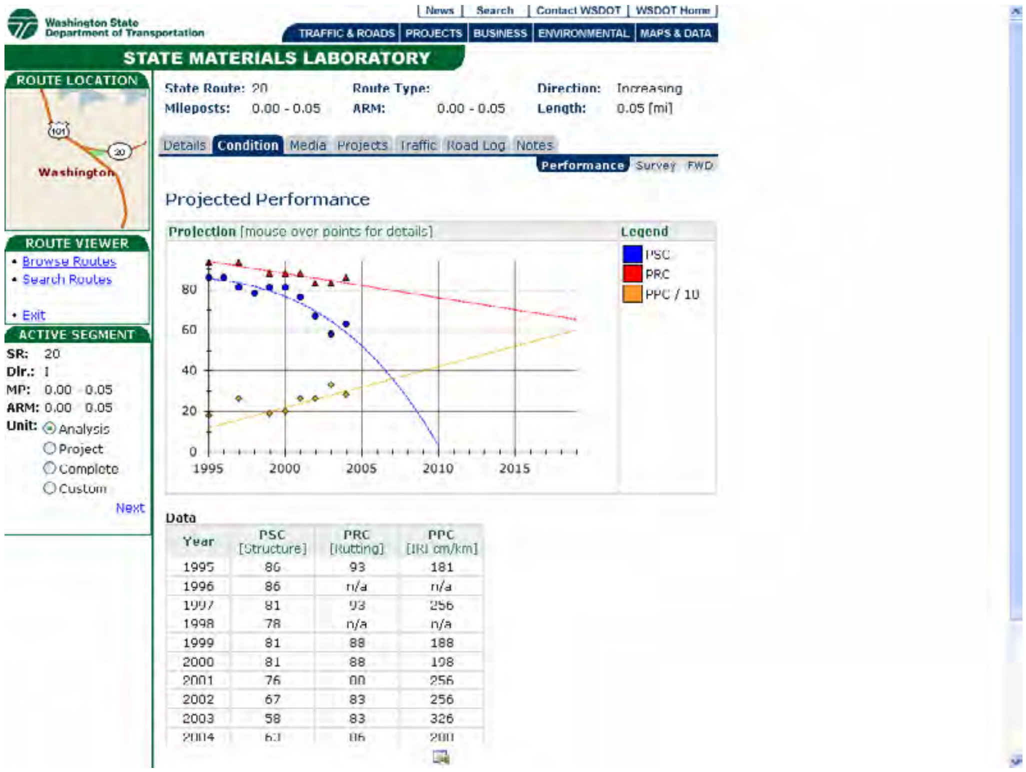


Figure 2.5: Main screen displayed in WSDOT database

Among the information contained in the tabs are the condition of the pavement (PSC), video footage, traffic, condition survey results, and falling weight deflectometer (FWD) data. It was noticed that for most of the sections, this information is incomplete.

Figure 2.6 shows the layout of the screen that presents the roadway structure for one section for which this information is available. The image shows the cross section of the pavement down to 2.0 ft and along the selected length of the project. The classification of the material is presented in tabular form and linked to the contract number and year in which it was constructed.

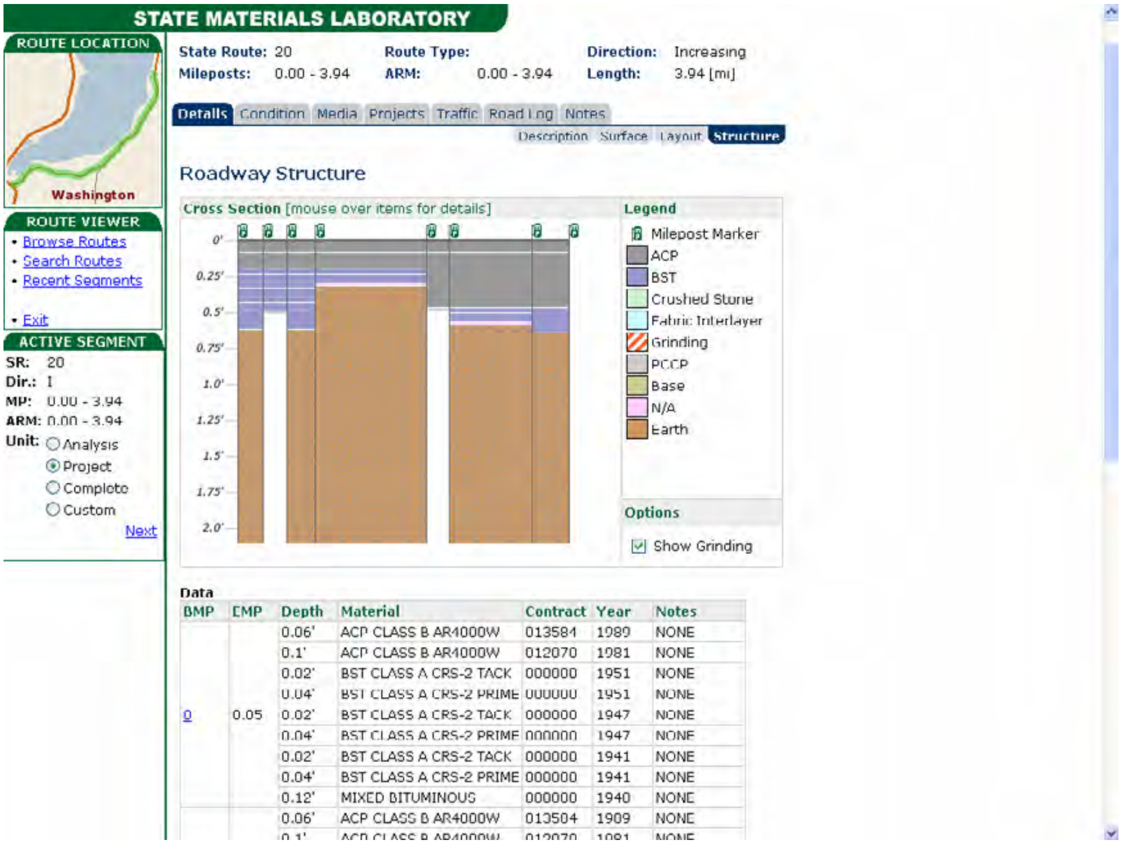


Figure 2.6: Roadway structure screen in WSDOT database

2.5 Summary

The information provided from the three databases reviewed in this section has been useful in defining the parameters or inputs that are required for a well-balanced database. On one side, the LTPP database contains invaluable information that sometimes is hard to interpret or even find through it search engine. It seems that the amount of information available has far exceeded the usefulness of the data itself and just complicates the searching procedure. As for the review of the old RPDB from CTR, it can be said that the information available is good overall, but lacks the deflection data fundamental for the calibration of the M-E model. Also, the RPDB has a large number of sections that were built in the 1960s and 1970s, which skews the distribution of the sections' thicknesses within the population of sections. Finally, WSDOT's database has a good web-based interface that illustrates the type of data that are evaluated; however, it lacks the quality of information that could be used for validation and calibration of an M-E design model.

Chapter 3. Structure of the Database

3.1 Introduction

As part of Tasks 1 and 3 of the proposed work plan, the former RPDB, the LTPP, and WSDOT's databases have been evaluated. The type of information collected and reported by each database has been reviewed. Based on the evaluation of those three databases, a new comprehensive data-gathering plan has been prepared for this research project and is presented herein.

3.2 Database Components

Figure 3.1 contains the new database's three main variables: input, pavement response, and pavement performance. The input variables are divided into five sections: general, pavement structure, traffic, materials, and environmental. Each section will contain different variables. The pavement response variables are divided in CRCP and JCP, and each contains different variables. Finally, the pavement performance variables are divided in CRCP and JCP, each containing different distress variables.

The information to be collected will depend on the hierarchical level of the section being studied. A Level 1 section will contain the most detailed data. To collect all this information, much work will be needed and cooperation from TxDOT will be required to obtain all the construction information. A Level 2 section will contain less data that a Level 1 section, but still will be useful enough to calibrate an M-E model with some degree of accuracy. Finally, a Level 3 section will contain only basic data that will probably be used to replace Level 1 data when it needs to be dropped from the database for any reason, e.g., new construction or rehabilitation. Table 3.1 shows the data that will be collected for the three different levels contained in the database.

Table 3.1: Proposed database parameters to be collected and section levels

		Level 1	Level 2	Level 3
INPUT VARIABLES				
General	District	√	√	√
	County	√	√	√
	CSJ	√	√	√
	Project Length	√	√	√
	Direction	√	√	√
	Construction Date	√	√	√
	PMIS Lane Designation	√	√	√
	GPS Coordinates	√	√	√
Pavement Structure	Cross Section Layout	√	√	√
	Layer Thickness and Type (including base)	√	√	√
	Surface Texture	√	√	√
	# of Steel Mat (CRCP)	√	√	√
	% & Bar Size of Longitudinal Steel (CRCP)	√	√	
	Depth of Longitudinal Steel (CRCP)	√		
	Drainage Characteristics	√	√	
	Base/Slab Friction Coefficient	√	√	
	Cut or Fill	√	√	
	Shoulder	√	√	
Traffic	Annual Average Daily Traffic	√	√	√
	Percent Trucks	√	√	
	Directional Distribution	√	√	
	Vehicle Class Distribution	√		
	Hourly Truck Distribution	√		
	Monthly Adjustments	√		
Materials	Concrete Mix Design	√		
	Concrete Strength	√		
	Concrete Modulus of Elasticity	√		
	Concrete CTE	√		
	Ultimate & Reversible Shrinkage (new construction)	√		
	Thermal Conductivity/Heat Capacity of Concrete	√		
	Cement Factor for CSB	√		
	AC Content for ASB	√		
	Soil Classifications	√	√	
	Soil PI & minus Sieve #200	√		
Environmental	Concrete Temperature at Placement	√	√	
	Min & Max Ambient Temperatures during Construction	√	√	
	Average Wind Speed during Construction	√		
	Solar Radiation during Construction	√		
	Cloud Coverage during Construction	√		
	Average Annual Rainfall	√	√	√
PAVEMENT RESPONSE VARIABLES				
CRCP	Transverse Crack Spacing	√	√	
	Longitudinal Cracking	√	√	
	Transverse Crack Width	√		
	Deflections (mid-slab, crack)	√		
	Load Transfer Efficiency	√		
JCP	Deflections (mid-slab, crack)	√		
	Load Transfer Efficiency	√		
PAVEMENT PERFORMANCE VARIABLES				
CRCP	Punchouts (Type I, II, III)	√	√	√
	Patch	√	√	√
	Spalling (minor, severe)	√	√	√
	Smoothness	√		
	Scaling (minor, severe)	√	√	
	Plastic Shrinakge Cracks	√	√	
	Shallow Delaminations	√	√	
JCP	Plastic Shrinkage Cracks	√	√	√
	Mid-slab Cracking	√	√	√
	Faulting	√	√	√
	Spalling (minor, severe)	√	√	√
	Smoothness	√		

3.3 Fieldwork Evaluation Protocol

Although fieldwork could be conducted in any order, depending of the crew's preferences, this section intends to describe the work that was performed by CTR's staff in the sections visited before press time. It has been observed that once the crew decides an approach for collecting data, the field tasks are conducted smoothly.

Once the crew arrives to the site, a construction joint is located. The test section is selected so that it extends 500 ft to both sides of the joint, so the total length of the section is 1000 ft. Next, global positioning system (GPS) coordinates are obtained at both ends and at the construction joint, which correspond to 0 ft, 500 ft, and 1000 ft (start, construction joint, and end) of the section. Paint marks are sprayed at these three locations indicating the identification number of the section, which is comprised of district number and highway name.

A regular crew is comprised of three people; two members do the visual condition survey and obtain the transverse crack spacing and other distresses. The form shown in Figure 3.1 is used for this purpose. If distresses are found in the pavement, they are recorded in this form.

District	Direction	Highway	Const Date	Survey Date	Surveyor	GPS Start
County	N S					0 ft
CFTR No.	E W					GPS C Joint
C-S-J	Project Length			Shoulder Type		500 ft
Reference Markers (Start to End)	No. Lanes			Surface Texture		GPS End
RM1 to RM2	PMIS Surveyed Lane			No. of Steel Mats		1000 ft

Vert Align: Cut Fill, Grade Trans; Hor Align: Curve L, Curve R, Tangent	% & Bar Size Long Steel	AADT
	Depth of Long Steel	Percent Trucks
	Concrete CAT	Dir Distribution
	Drainage Characteristics	
	Base/Slab Friction Coefficient	

Section Spans (ft)	Plastic Shrinkage Cracks Minor & Severe		Shallow Concrete Delamination Minor & Severe		Patches: size in square feet AC			Patches: size in square feet PCC			Smoothness			Punchout Type			Scaling Minor & Severe		Number of Spalling Joints/Cracks Minor & Severe		Total No. of Cracks
														I	II	III					
	M	S	M	S	0-50 ft^2	51-150 ft^2	>150 ft^2	0-50 ft^2	51-150 ft^2	>150 ft^2				M & S			M	S	M	S	
0 - 100																					
100 -200																					
200 - 300																					
300 - 400																					
400 - 500																					
500 - 600																					
600 - 700																					
700 - 800																					
800 - 900																					
900 -1000																					

Pavement Cross Section	D (in.)	Cumulative crack spacing. Circle joints and cracks for LTE
CRCP		
Bond Break		
SB/Base		
Subgrade		
Soil		

Figure 3.1: Condition survey form used for distress and crack spacing recording

While conducting the visual condition survey, the third member of the crew collects FWD data every 50 ft starting at the first end of the section, going with the flow of traffic. A total of twenty points are tested along the section. A file is saved containing this information of the 20 points and a separate file is prepared for load transfer efficiency (LTE) measurements.

At the same time, the condition survey is performed, and groups of cracks are selected for LTE evaluation. Three closely spaced (1 to 3 ft-long), three intermediately spaced (3 to 6 ft-long), and three widely spaced (over 6 ft-long) sets of cracks are labeled on the pavement using spray paint and are located using GPS coordinates. After FWD tests are finished every 50 ft for the entire section, LTE measurements are taken. Usually, Sensor 4 in the FWD is moved one foot behind the drop load of the FWD, so that deflection values from this sensor can be compared with values obtained from Sensor 2, which should be located one foot ahead of the drop load. To complement all this information related to the visual condition survey and FWD data, photos are taken at starting point, construction joint, end point, distresses, and all LTE sets of cracks at surveyor's discretion. The form shown in Figure 3.2 is used for LTE data collection.

Load Transfer Efficiency (LTE) Measurement Form

Section CFTR No. ______________________
Highway ______________________
Lane ______________________
Measurement Date ______________________
Crew ______________________

Location	GPS Coordinates		Crack Space		Time	Comments for Location
	Latitude	Longitude	Former	Latter		At Crack or Between Cracks

Figure 3.2: Field form used for LTE data collection

3.4 Summary

The structure of the database in this project has been discussed with TxDOT at different times and it has been approved. The data collection for test sections has been done following this structure and it has been found to be reliable. The same approach will be followed for future test sections.

Chapter 4. Mechanistic-Empirical Pavement Design Guide

4.1 Introduction

A number of variables affect pavement behavior and performance. Quantifying the relationships between those variables and pavement performance is quite important in advancing the state of the practice of pavement design and improving the efficiency of pavement management systems. Over the last few decades, tremendous efforts have been made to identify those variables and quantify the relationships. Some are theoretical analyses and some are field trials, and in most cases, a combination of both. A few examples on theoretical analysis include efforts made by Westergaard [Westergaard, 1926] and Bradbury [Bradbury, 1938]. A typical example of field trials includes the American Association of State Highway Officials (AASHO) Road Test. These efforts resulted in an accumulation of knowledge, information, and experience about how pavements behave, perform, and eventually, how they fail. This knowledge, information, and experience provided a solid foundation for a major effort to improve pavement design methodologies. Until the mid-1990s, the most current pavement design procedures for rigid pavements were AASHTO method and portland cement association (PCA) method. The AASHTO method was based on the findings from the AASHO Road Test, even though mechanistic element was added later on. One of the weaknesses of the AASHTO method is that the inference space for traffic applications was quite small compared with the range of design traffic currently designed for. The PCA method is more mechanistic than AASHTO's method; however, this method does not directly distinguish concrete pavement contraction design (CPCD) from CRCP. In 1997, in an effort to advance the pavement design technology, the National Cooperative Highway Research Program (NCHRP) 1-37A project was initiated. One of the major tasks given to the research team was to identify the most advanced and proven algorithms for pavement behavior and put them together to develop M-E pavement design procedures. The design procedures are still undergoing revisions at the time of this writing. Referred to as MEPDG (mechanistic-empirical pavement design guide), these design procedures represent the most advanced pavement design algorithm ever developed. This chapter discusses the continuously reinforced concrete pavement (CRCP) portion of the MEPDG and presents the findings of its evaluations.

4.2 Design Logic in MEPDG

Pavement design is used to determine a pavement structure that meets the performance requirements of the agency with a minimal life-cycle cost. The role of pavement design procedures is to provide pavement engineers with a tool that can be used to develop an optimum pavement design with a reasonable reliability. The accuracy and reliability of any pavement design procedure can be significantly improved if structural behavior or responses of a proposed pavement system are accurately estimated. The advancements made in mechanistic theories on how a pavement system behaves for given environmental condition (temperature and moisture variations) and external wheel loading, along with the availability of high speed computers, make it possible to accurately analyze pavement systems for structural responses. The MEPDG incorporated the most advanced theories along with a very efficient algorithm to estimate structural responses, which resulted in one of the most advanced pavement design procedures developed so far. The overall design logic incorporated in MEPDG for CRCP is shown in Figure 4.1.

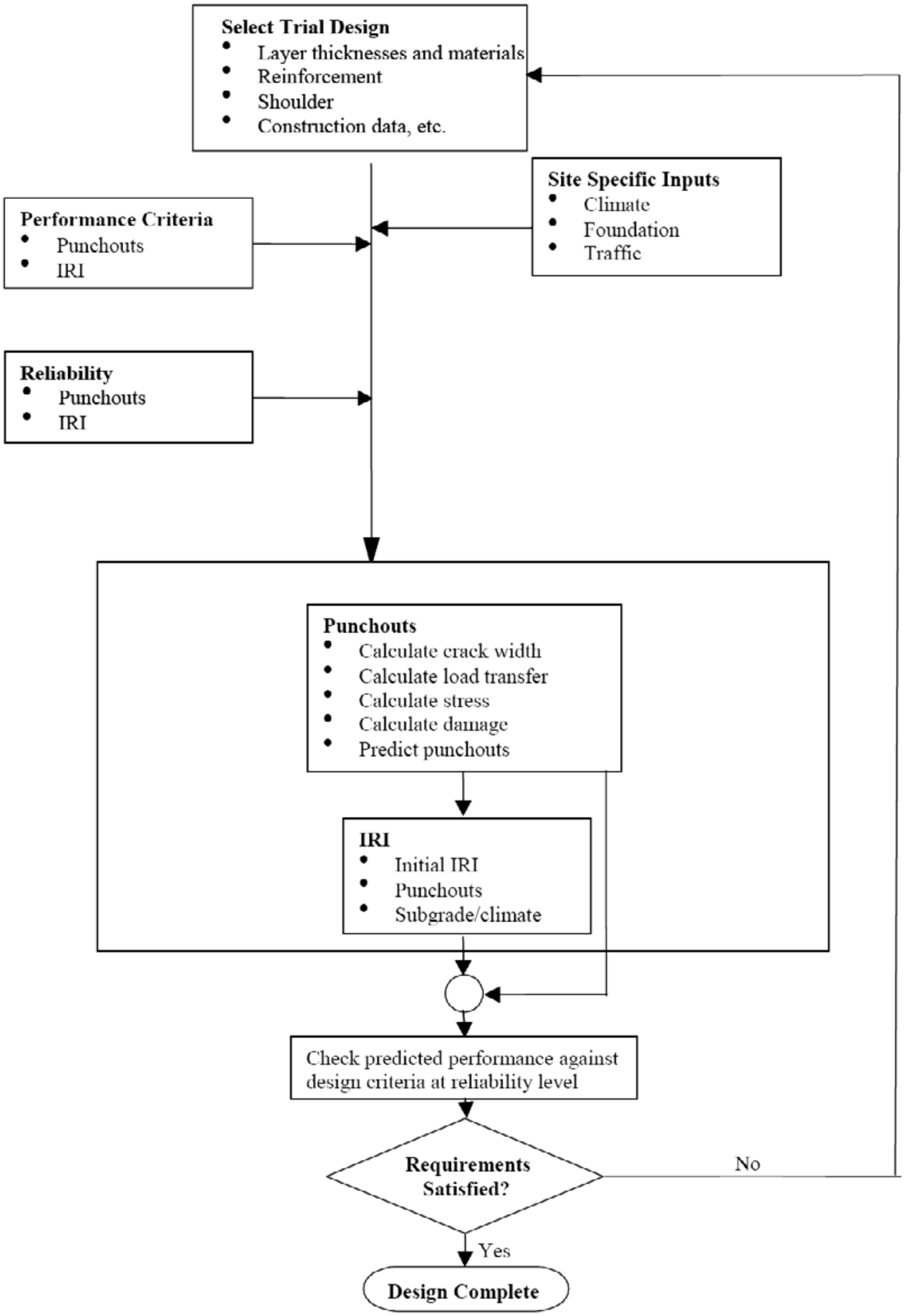


Figure 4.1: Overall design process for CRCP

Two criteria were adopted as performance measures of CRCP: international roughness index (IRI) and punchouts. Spalling, one of the primary distresses in CRCP in Texas, is not included. Spalling, at least in Texas, appears to be more materials- and/or construction-related, and may not be a design variable. In other words, spalling distress cannot be addressed by strengthening pavement systems, e.g., increasing slab thickness. In that sense, the methodology adopted by MEPDG to exclude spalling as a pavement distress is the right approach. Whether IRI should be a design variable remains a question, as simply strengthening pavement system might not result in maintaining better ride. However, punchouts is a structural distress, and including punchouts in MEPDG as a design criteria appears to be a right approach.

The design logic adopted in MEPDG for the design of CRCP, as shown in Figure 4.1, can be summarized as follows:

a. Select a trial design (thickness of each layer along with material properties, reinforcement, roadway geometry).

b. Collect all pertinent information required, such as climate, traffic, & foundation.

c. Analyze the pavement system for punchouts and IRI.

d. If the predicted punchouts and IRI at the end of the design period do not meet the pre-selected criteria, new design is selected and the above steps 2) and 30 are repeated.

e. If the predicted punchouts and IRI at the end of the design period meet the pre-selected criteria, the design is accepted as a feasible design, and life-cycle cost analysis is conducted.

f. The above procedures 1) through 5) are repeated for a number of trial designs and the one with the lowest life-cycle cost is considered for the best pavement design.

Accordingly, the key to the MEPDG CRCP design procedures is the accurate prediction of IRI and punchouts, which is discussed below.

4.3 IRI Determination in MEPDG

Smoothness is the only characteristic the general public perceives as a condition of the pavement, and should be an important variable pavement designers need to consider. Smoothness is the result of a combination of the initial as-constructed profile of the pavement and any changes in the longitudinal profile over time and traffic (1).

In MEPDG, the following equation, which was derived from the data in the LTPP (long-term pavement performance), is used to predict IRI.

$$IRI = IRIi + C1 \bullet PO + C2 \bullet SF$$

where,
IRI_i = initial IRI, in/mi
PO = number of punchout/mi at all severity levels (low, medium and high)
SF = site factor
 $= AGE \bullet (1+0.556FI) \bullet (1+P_{200}) * 10^{-6}$
AGE = pavement age, years
FI = freezing index, °F days
P_{200} = percent subgrade material passing No 200 sieve
C1 = 3.15
C2 = 28.35

The above equation indicates IRI depends on the initial as-constructed IRI, punchouts, and site factor. In Texas, freezing index is quite low, and minus 200 materials in subgrade cannot be practically changed. According to this equation, preventing or minimizing the occurrence of punchouts, along with building smooth surface in the first place during the initial construction, is the best way to keep the pavement smooth, which underlines the importance of proper design to minimize the occurrence of punchouts.

4.4 Punchouts Prediction in MEPDG

Punchouts is one of the most serious distresses in CRCP and considered a distress due to structural deficiencies for a given level of traffic. In MEPDG, punchouts is assumed to take place due to cumulative damage in concrete from repeated environmental and wheel loading applications. Since punchouts is considered as a structural distress, mechanistic analysis is used to predict the frequency of punchouts for a given level of traffic. In MEPDG, punchouts is the only distress included in the equation for the prediction of IRI, and IRI and punchouts are the only criteria for the structural design of CRCP. Therefore, the entire structural design for CRCP amounts to estimating punchouts, and the design logic used in MEPDG to predict punchouts is further described.

Figure 4.2 illustrates the logic adopted in MEPDG to predict punchouts. For a given trial design, transverse crack spacing is estimated or provided by a user. For each time increment, loss of edge support and crack width along with associated crack stiffness & LTE are determined. For given traffic level (weight, axle configuration, and wander), this information is used to estimate concrete tensile stress in the transverse direction at the top of the slab. Damage is computed based on the stress level and wheel load applications. This damage is accumulated over time and the probability of punchouts is computed.

More detailed descriptions of each step are provided.

After average crack spacing is determined, erosion is estimated. Erosion plays an important role in the deterioration of PCC pavement, including CRCP. Erosion and resulting pumping was the most critical cause of distresses in the AASHO Road Test. Even though erosion plays such an important role in the deterioration of PCC pavement, no model, procedures, or even field data were available to be included in the MEPDG (1). Therefore, an empirical equation based on expert opinion was developed and incorporated in the MEPDG as follows:

$$e = -7.4 + 0.342P_{200} + 1.557BEROD + 0.234PRECIP$$

where

e	=	maximum width of eroded base/subbase measured inward from the slab edge, in (if $e < 0$, set $e = 0$).
P_{200}	=	percent subgrade soil (layer beneath treated base course) passing the No. 200 sieve.
BEROD	=	base material erosion class (1, 2, 3, or 4).
PRECIP	=	mean annual precipitation, in.

This equation indicates that the maximum width of erosion depends on minus 200 materials in subgrade, base material erosion class, and precipitation. It does not include the effects of different shoulder type, nor truck traffic. In Texas, most of the tied shoulders are constructed monolithically with outside main-lane, and the joint provided between the shoulder and outside main-lane is, thus, warping joint, which is maintained quite tight by transverse steel. Sealing material is also provided at the warping joint. Therefore, chances of water getting into the joint to the subbase are quite slim, substantially reducing the potential for erosion. On the other hand, when asphalt shoulder is used, it is quite difficult to keep the water from getting into the joint. In addition, deflections at the edge of the outside main-lane due to the use of various shoulder types are quite different, resulting in different erosion potential. In addition, truck traffic will have a substantial effect on erosion of the base, since large deflections will cause more pumping and subsequent erosion.

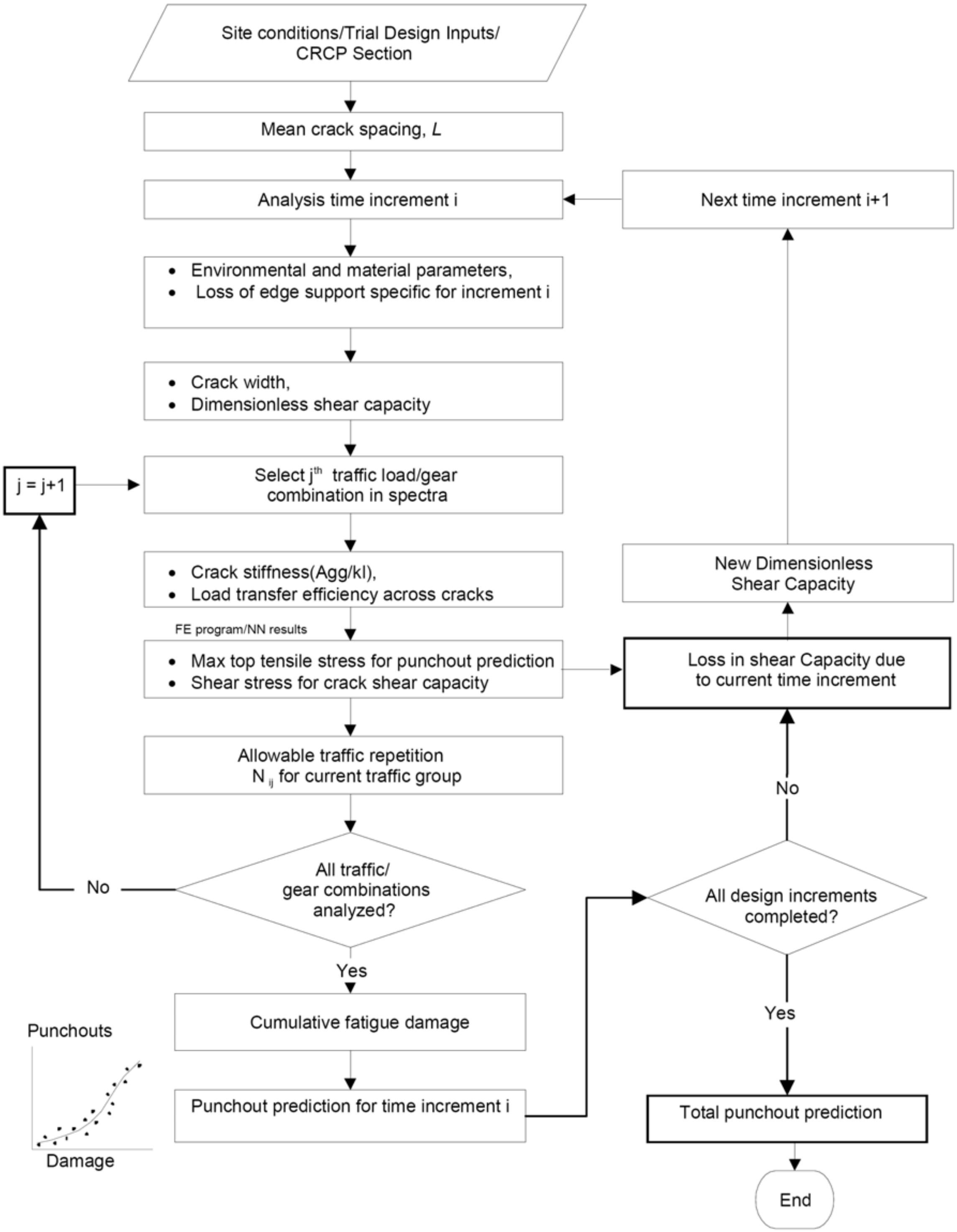


Figure 4.2: Punchouts prediction algorithm in MEPDG

The next step in predicting punchouts requires an accurate estimate of crack width. In MEPDG, crack width that is used to compute LTE and slab stiffness is the value at the depth of the longitudinal steel. The following equation is used to estimate crack width:

$$cw = Max\left(L \cdot \left(\varepsilon_{shr} + \alpha_{PCC} \Delta T_{\zeta} - \frac{c_2 f_{\sigma}}{E_{PCC}} \right) \cdot 1000 \cdot CC, 0.001 \right)$$

where,

cw	=	average crack width at the depth of the steel, mils.
L	=	crack spacing based on design crack distribution, in.
ε_{shr}	=	unrestrained concrete drying shrinkage at the depth of the steel, $x10^{-6}$.
α_{PCC}	=	PCC coefficient of thermal expansion, /°F.
ΔT_{ζ}	=	drop in PCC temperature from the concrete "zero-stress" temperature at the depth of the steel for each season, °F.
c_2	=	second bond stress coefficient.
f_{σ}	=	maximum longitudinal tensile stress in PCC at the steel level, psi.
E_{PCC}	=	PCC elastic modulus, psi.
CC	=	local calibration constant (CC = 1 for the national calibration).

As demonstrated in the above equation, it is assumed that crack width is approximately proportional to transverse crack spacing. It also increases with drying shrinkage and temperature drop from zero-stress temperature. In MEPDG, average crack spacing is estimated using the equation below or anticipated crack spacing can be provided by a user.

It is noted that wheel load stress is not included in the prediction of crack spacing. Even though warping/curling stress could be quite large compared with wheel load stresses, it's not clear whether wheel load stress could be ignored in predicting transverse cracking, especially in relatively thin slabs. The crack spacing estimated from the equation below or provided by the user is used to estimate crack width over time. Because air and concrete temperatures vary cyclically, daily and seasonally, and drying shrinkage is assumed to increase over time, estimated crack width increases over time, with seasonal variations within a year.

$$\bar{L} = \frac{\left\{ f_t - C\sigma_0 \left(1 - \frac{2\zeta}{H}\right) \right\}}{\frac{f}{2} + \frac{U_m P_b}{c_1 d_b}}$$

where,

$\bar{L}$	=	mean crack spacing, in.
f_t	=	concrete tensile strength, psi.
f	=	AASHTO subbase friction coefficient from the table below based on subbase type.
U_m	=	peak bond stress, psi
P_b	=	percent steel, fraction equal to area of steel reinforcement (A_s) per area of concrete (A_c), percent. $P_b = A_s/A_c$.
d_b	=	reinforcing steel bar diameter, in
c_1	=	first bond stress coefficient
σ_{env}	=	tensile stress in the PCC due to environmental curling, psi.
H	=	slab thickness, in.
ζ	=	depth to steel layer, in.
C	=	Bradbury's curling/warping stress coefficient (*36*).
σ_0	=	Westergaard's nominal stress factor.

LTE is estimated from predicted crack widths along with other variables in accordance with the following equation.

$$LTE_{TOT} = 100 * \left(1 - \left(1 - \frac{1}{1 + \log^{-1}\left[(0.214 - 0.183\frac{a}{\ell} - \log(J_c) - R)/1.18 \right]} \right) \left(1 - \frac{LTE_{Base}}{100} \right) \right)$$

where,

LTE_{TOT}	=	total crack LTE due to aggregate interlock, steel reinforcement, and base support, percent.
l	=	radius of relative stiffness computed for time increment i, in
a	=	radius for a loaded area, in
R	=	residual dowel-action factor to account for residual load transfer provided by the steel reinforcement
	=	$2.5Pb - 1.25$
Pb	=	percent of longitudinal reinforcement
LTE_{Base}	=	the base layer contribution to the LTE across transverse crack, %. Typical values are given in table 3.4.8.

With all the information derived from the equations given above, at each time increment, concrete stress in the transverse direction on top of the concrete slab is computed and resulting damage is estimated. The damage is accumulated to estimate the potential for longitudinal cracks and punchouts are predicted.

4.5 Discussion on the Punchouts Prediction Model in MEPDG

The punchouts prediction model described above presents an advanced, state-of-the-art algorithm. However, as discussed earlier, top-down cracking is the only punchouts mechanism included in MEPDG, which raises a serious question. In Texas, most of the CRCPs are constructed with tied concrete shoulder, and it's a normal practice to place concrete for outside main-lane and shoulder together. Therefore, a warping joint is provided between them and good load transfer is maintained at the longitudinal warping joint. In CRCP with tied concrete shoulder, critical stress might be at the bottom of the slab, resulting in bottom-up cracking. Also, field experimentation conducted at the University of Illinois indicates that LTEs were maintained at a quite high level at transverse cracks before punchouts took place. In other words, deterioration of transverse cracks and resulting low LTE was not a precursor for punchouts. Their findings raise a possibility for another punchouts mechanism.

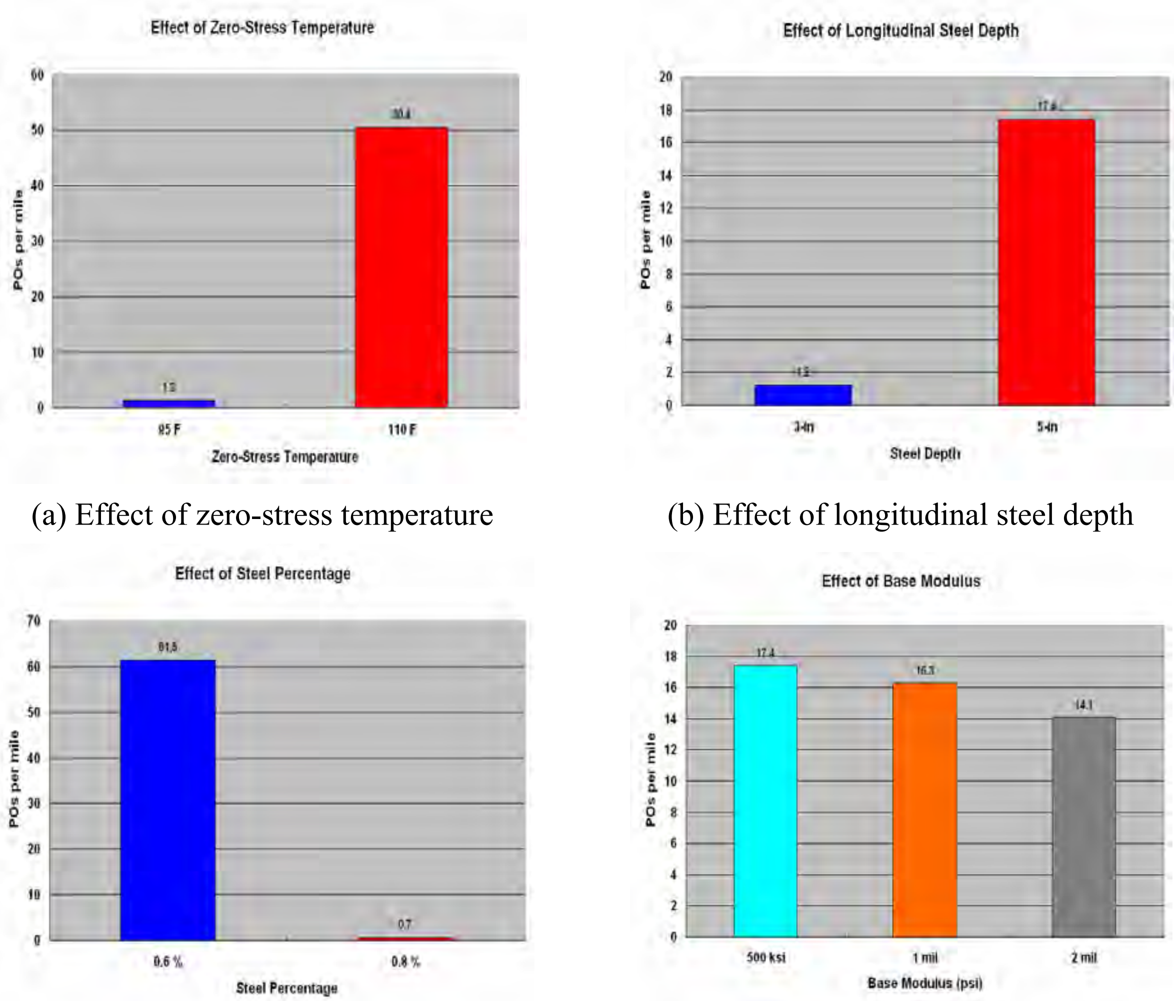
In addition, most of what appears to be punchouts in Texas are actually distresses caused by horizontal cracking at the depth of longitudinal steel. A research study is currently under way, and the findings will shed lights on yet another distress mechanism.

These issues need to be addressed for the future enhancements of punchouts prediction model.

4.6 Sensitivity Analysis

Extensive sensitivity analysis on CRCP of MEPDG was conducted by researchers at TTI under TxDOT research program (2). However, the version of the program used was 0.7, while more recent version 0.91 was available lately, which incorporated the comments made by NCHRP 1-40(A) panel. In this study, a small sensitivity analysis was conducted to evaluate the reasonableness of the results from MEPDG. In order to completely evaluate the model, a full sensitivity analysis needs to be conducted; however, due to the limitations on time, only a small sensitivity analysis was performed. The variables evaluated include zero-stress temperature, steel percentage, the depth of longitudinal steel, and base modulus. Typical input values used for the sensitivity analysis is shown in Appendix B.

Figure 4.3 (a) illustrates the effect of zero-stress temperature on punchouts. It is shown that zero-stress temperature has a significant effect on punchouts. In MEPDG, the effect of environmental loading on punchouts is quite substantial because drying shrinkage occurring in the upper portion of the slab exacerbates top-down cracking. If bottom-up cracking mechanism is adopted for punchouts, drying shrinkage effect will actually counteract with positive temperature gradient, and environmental effect is expected to decrease substantially. In this case, reducing zero-stress temperature from 110 °F to 95 °F decreased punchouts from 50 per mile to just one. Whether zero-stress temperature has such a significant effect needs to be further examined with field data. In this database project, efforts are underway in this respect by evaluating structural responses in sections before and after transverse construction joint. Since the zero-stress temperatures before and after construction joints are quite different, the efforts in the database project are expected to provide information on whether zero-stress temperature has such a profound effect on punchouts. Figure 4.3 (b) shows the effect of the depth of longitudinal steel on punchouts. The slab analyzed is 10-in thick. It shows a substantial effect the depth of steel has on punchouts. The reason for this significant effect is that, if the steel is placed near the surface, the algorithm in MEPDG assumes that crack widths will be kept much tighter, resulting in better LTEs and reduced punchouts. Two test sections were constructed in Texas, one in Dallas and the other in El Paso Districts, where sections with two different steel depths were constructed. So far, no distresses took place and the continued observations of the performance of these sections will provide valuable information on this. Figure 4.3 (c) indicates the effects of longitudinal steel percentage on punchouts, which shows quite substantial effects. Whether steel amount will have the effect of this magnitude needs to be verified in the field. In 1989 and 1990, test sections were built in Houston with varying steel percentages. They are about 17 years old at the time of this writing and performance has been monitored periodically. So far, no punchouts have taken place. Continued monitoring those sections will provide valuable information on the effects of longitudinal steel percentage on punchouts. Figure 4.3 (d) illustrates the effect of subbase stiffness on punchouts as predicted by MEPDG. It shows that as the stiffness increases, the frequency of punchouts decreases, which agrees with the field observation made in Texas.



(a) Effect of zero-stress temperature

(b) Effect of longitudinal steel depth

(c) Effect of steel percentage

(d) Effect of base modulus

Figure 4.3: Effects of various parameters on punchouts per mile

Chapter 5. Summary and Future Efforts

5.1 Introduction

This research study was planned for three years. During the first year, most of the efforts concentrated on the evaluation of other pavement databases and on the preparation of the structure of the database; fieldwork was not the priority during the first year. The second year has included considerable work on field data collection and a preliminary evaluation of the information contained in the database. The third year will focus on gathering more field data and preparing various analyses that will enhance the importance of this project and the data that are collected.

5.2 Summary of Work Completed

At press time, a comprehensive evaluation of other pavement databases has been completed and documented. Valuable information has been obtained from those databases and the do's and don'ts have been learned. Special attention has been given to collect information that is not redundant and is subject for reasonable post-processing and analysis.

The proposed structure of the database has been revised and approved by TxDOT and data collection efforts have been done regarding that structure. So far, all the sections in the database belong to Level 1, which means that comprehensive data has been collected for them all. Once more information is collected on other sections the PMC and researchers will decide if only Level 1 data are collected or if the proposed Levels 2 and 3 are also required. This assumption based upon the fact that time is always a constraint and if the crew is in the field, it might be of worth just collecting comprehensive information, rather than basic information only.

An evaluation of the MEPDG has been conducted and preliminary statements have been made concerning the type of information that is required for validation and calibration of the M-E guide. Once more information is available, the data will be retrofitted to the M-E model to validate it and steps will be taken then either to use this model or to develop an in-house model for Texas.

According to the proposed schedule of activities, most of the tasks that were proposed in this study have been completed on time. There are a couple of areas that are subject to improvement and in which researchers are focusing more, those areas include the preparation of the web based database and the collection of FWD in additional sections across Texas.

References

[Medina et al, 2003] Medina-Chavez, Cesar Ivan, B. Frank McCullough, and Terry Dossey. "Assessment of Data Collection and Supplementary Tasks Conducted for the Texas Rigid Pavement Database." Research Report 1778-4. Center for Transportation Research, The University of Texas at Austin, June 2003.

[LTPP, 2006] Long-Term Pavement Performance (LTPP) Database. Internet website http://www.datapave.com/

[Westergaard, 1926] "Stresses in Concrete Pavements Computed by Theoretical Analysis," Public Roads, Vol. 7, pp. 25-35.

[Bradbury, 1938] "Reinforced Concrete Pavements," Wire Reinforcement Institute, Washington, D.C.

Appendix A: List of LTPP CODETYPE

CODETYPE	CODETYPE
AASHTO_SOIL_CLASS	METH_EST_TRK_TOT
AC_MATERIAL_TYPE	METH_EST_VOL_LTPP
ACCEPT_FLAG	METH_VEHICLE_CLASS
AGG_COND_MOIST	METHOD_GMG_MNT
AGGR_DUR	METHOD_GMG_RHB
AGGR_SOURCE	METHOD_TRAFFIC_RESTRICTION
AGGR_TYPE	MILL_LAYER_MATL
ANTISTRIP	MINERAL_FILLER
APPL_METHOD	MIX_DESIGN_TYPE
AREA_DETERMINATION	MIX_PROCEDURE
ASPHALT	MLTD_METHOD
AVC_METH_COUNT_LENGTH	MNT_3_4
AVC_METH_VOL_MEASURE	MNT_4_7
AXLE_GROUP	MNT_5_4
BACKFILL_MATERIAL	MNT_6_7
BASE_MAT	MNT_SOURCE
BEFORE_AFTER	MODIFIER
BOND	MOIST_SUSCEPT_TEST
BOND_AGENT	MONITORING_CATEGORY
BOND_AGENT_BACKFILL	MONITORING_CHANGE_REASON
BOND_BREAK	MONITORING_OF_LIFT
BOND_PREVENT	MR_MATL_TYPE
BOUNDARY_METHOD	NO_YES
BOUNDARY_METHOD_PART	NON_DEC_DEFL
BREAK_METHOD	NUMBER_SEALED
BREAKER_TYPE	OFFSET_FLAG
BREAKUP_EQUIPMENT	OUTLIER_FLAG
BREAKUP_METHOD	PARAMETER_NO
BUBBLES_PRESENT	PATCH_BOUNDARY_METHOD
BUFFER_SHAPE	PATCH_MATERIAL
CLASS	PATCH_MATL_AC
CLASS_COUNT_TYPE	PATCH_MATL_PCC
CLASS_EQUIPMENT_TYPE	PATCH_REASON_FD
CLEAN_METHOD_PATCH	PATCH_REASON_PD
CLEAN_METHOD_SEAL	PATCHING
COARSE_AGG_COMP	PAVE_TYPE_MNT
COATING_ABILITY	PAVE_TYPE_TRF
COMMENT	PAVEMENT
COMP_TEST_TYPE	PAVEMENT_BREAKER
COMPACTION	PAVEMENT_PROCESSING
COMPACTION_EQUIP_TYPE	PAVER_TYPE
COMPACTION_TYPE	PC_TYPE
CONC_BREAK_METHOD	PCCA
CONC_REMOVAL	PCCO_COARSE_AGG

CODETYPE	CODETYPE
CONCRETE_CURE	PHOTO_VIDEO
CONCRETE_TEXTURE_METHOD	PLACE_METHOD
CONDITION	PLANT_TYPE
CONSOLIDATE_METHOD_FULL	PRESSURE_RELIEF_REASON
CONSOLIDATE_METHOD_PART	PRIMARY_REASON_RHB
COUNT_DURATION_UNIT	PROFILOGRAPH_TYPE
COUNT_TYPE	QA_LEVEL
COUNTY	RCO_CODE
CRACK_CLEAN	REASON_CALIB
CRACK_JOINT	RECESSED_SLOT_METHOD
CRACK_SEVERITY	RECORD_TYPE
CRACKS	RECYCLE
CURE_METHOD	REFACED
CUT_FILL_TYPE	REFINER
CUT_METHOD_FULL	REGION
CUT_METHOD_PART	REINFORCE_PLACE_METHOD
CUT_REMOVE_METHOD	REINFORCING_TYPE
CUTOFF_CRITERIA	REMOVAL_CLEAN_METHOD
DATA_AVAIL_CODE	REMOVAL_CLEAN_REASON
DATA_AVAILABILITY	REMOVAL_METHOD
DATA_TYPE	REPLACE_MATL
DEFLECTION_LOCATION	RESERVOIR_MOISTURE
DEFLECTION_MEASURE_DEVICE	ROAD_MOISTURE
DEICE_TYPE	ROLLER_CODE
DELAM_DETECTION_METHOD	ROLLER_CODE_HEATER_SCARIF
DESCRIPTION	ROLLER_TYPE
DEVICE_CODE_PROFILE	ROUTE_SIGNING
DEVICE_CODE_RUT	RUT_PREP
DEVICE_SOURCE	S_CLASS
DIR_TRAV_LTPP	SAMPLE_LOC_PCC
DIRECTION_OF_TRAVEL	SAMPLE_LOC_UNCOMP
DISTRESS_SEVERITY	SAMPLE_TYPE
DISTRESS_TYPE	SEAL_CURE_TIME
DLR_POINT_TYPE	SEAL_REASON
DLR_TRIGGER	SEAL_REMOVAL_METHOD
DOWEL_COAT	SEAL_ROLLER
DOWEL_COATING	SEAL_TYPE
DRAINAGE_LOCATION	SEALANT_BONDED_TO_BOTH
DRAINAGE_PIPE	SEALANT_TYPE
DRAINAGE_TYPE	SECTION_STAT_INCLUDE_FLAG
DROP_HEIGHT	SELECTION_TYPE
ELASTIC_MODULUS_METHOD	SENSORS_LTPP_PIEZO_CABLE
EQUATION_TYPE	SEPARATE_METHOD
ESAL_EST_WGHTSCALE	SH_JOINT_FORMED
ESAL_EST_WGHTSRC	SH_JOINT_FORMED_SPS
EXPERIMENT	SH_SURFACE_TYPE
FAULT_STATUS	SHOULDER_RESTORE

CODETYPE	CODETYPE
FILLER_TYPE	SHOULDER_SURFACE_TYPE
FILTER_MODE	SIDE_LOCATION
FILTER_TYPE	SIDEWALL_CLEAN
FINE_AGG_COMP	SIDEWALL_CLEAN_SPS
FINISH_METHOD_A	SIDEWALL_CLEAN_SPS6
FINISH_METHOD_B	SIDEWALL_CLEAN_SPS7
FINISH_SEAL	SITE_LOCATION
FLEXURAL_STRENGTH_TYPE	SMP_FREEZE_STATE_BASIS
FRACTURE	SOIL_CRITERIA
FREQUENCY	SOURCE_DRY_DENSITY_TDR
FREQUENCY_DEICE	SOURCE_SOIL_TYPE
FRICTION_METHOD	SPALLING_AMOUNT
FROST_SUSCEPTIBILITY_CODE	SPREAD_MIX_METHOD
FUNC_CLASS	STABIL_AGENT_INV
GEN_PAVEMENT_RHB_CAUSE	STABIL_AGENT_SPS
GEOL_CLASS	START_STOP_METHOD
GMG_EXTENT	STAT_FLAG
GRINDING_REASON	STATE_PROVINCE
GROUT_TYPE	STEEL_PLACE_METHOD
HMA_MIX_DESIGN_METHOD	SUB_DRAINAGE_TYPE
HOLE_INSTALL_UNDERSEAL	SUBDRAIN_EXTENT
INSTALL_FREQUENCY	SUBDRAIN_PURPOSE
INTERPRETATION_METHOD	SUBSEAL_MIX_TYPE
JOINT_LOC	SUBSEAL_MIXTURE
JOINT_METHOD	SUPPLY_UNIT
JOINT_OPEN_PROCESS	SURFACE_COND
JOINT_SEAL_BACKER	SURFACE_MAT
JOINT_SEALANT	SURFACE_MOISTURE
JOINT_TIE_SYSTEM_TYPE	SURFACE_MOISTURE_SPS34
JOINT_TYPE	SURFACE_PREP
L05B_COMMENT_CODES	SURFACE_PREP_CRACK_SEAT
LAB_AGE_TEST_PROC	SURFACE_PREP_OVERLAY
LAB_CODE	SURFACE_PREP_RHB
LANE_SPEC	SURFACE_TEXTURE
LAYER_TYPE	SURFACE_TREAT_TYPE
LAYER_TYPE_INV	SWELL_PRESSURE_TEST
LAYER_TYPE_RES_MOD	TACK_COAT_MATL
LAYER_TYPE_UNCOMP	TEST_NO
LENGTH_SECTION_COVERED	TEST_PURPOSE
LEVEL_UP_MATL	TEST_TYPE
LIQUID_SOLID	TEXTURING
LOAD_TRANS_RESTORATION	THICKNESS_CODE
LOC_SIZE_METHOD	TRACE_TYPE
LOCATION	TRANS_CONT_JLTS_INV
LOCATION_AT	TRANS_CONT_JLTS_RHB
LOCATION_DESC	TRANS_CONT_JLTS_SPS
LOCATION_OF_LANE	TRANS_JOINT

CODETYPE	CODETYPE
LONG_JOINT_FORMED	TRANS_METHOD
MACRO_TEXTURE	TRANS_SEAL_TYPE
MAINT_MAT	TRANSFER_DEVICE
MAINT_WORK	TRANSFER_SYS
MAT_TYPE	TREAT_TYPE
MATERIAL	TYPE_EQUIPMENT_CALIB
MATERIAL_TYPE	TYPE_LOC_FILTER
MATL_EST	VEHICLE_CLASS
MAX_DRY_DENSITY_TEST	VEHICLE_TYPE
MAX_LAB_DRY_DENSITY_TEST	VISUAL_ACPC
MAX_LAB_DRY_DENSITY_TEST_METHOD	VOLUMETRIC_MOISTURE_MODEL
MEASURE	WEATHER_CONDITION
MEASURE_TYPE	WIM_CALIB_TECHNIQUE
MEGADAC_EVENTS	WIM_CALIB_TRUCK_SUSPNSN
MEGADAC_FILTER	Y_N
METH_EST_AADT_TOT	YES_NEVER
METH_EST_ESAL_VEH	YES_NO

Appendix B: Sample Input Screen in MEPDG

Project: Sensitivity Analysis.dgp

General Information

Design Life	30 years
Pavement construction:	September, 2006
Traffic open:	October, 2006
Type of design	CRCP

Description:
Sensitivity Analysis

Analysis Parameters

Performance Criteria

	Limit	Reliability
Initial IRI (in/mi)	63	
Terminal IRI (in/mi)	172	90
CRCP Punchouts (per mi)	10	90
Maximum CRCP Crack Width (in)	0.02	
Minimum Crack Load Transfer Efficiency (LTE%)	75	
Minimum Crack Spacing (ft)	3	
Maximum Crack Spacing (ft)	6	

Location:	Houston
Project ID:	
Section ID:	
Date:	2/17/2007
Station/milepost format:	
Station/milepost begin:	
Station/milepost end:	
Traffic direction:	East bound

Default Input Level

Default input level	Level 3, Default and historical agency values.

Traffic

Initial two-way aadtt:	20000
Number of lanes in design direction:	2
Percent of trucks in design direction (%):	50
Percent of trucks in design lane (%):	95
Operational speed (mph):	60

Traffic -- Volume Adjustment Factors

Monthly Adjustment Factors (Level 3, Default MAF)

Month	Vehicle Class									
	Class 4	Class 5	Class 6	Class 7	Class 8	Class 9	Class 10	Class 11	Class 12	Class 13
January	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
February	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
March	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
April	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
May	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
June	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
July	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
August	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
September	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
October	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
November	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
December	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

Vehicle Class Distribution

(Level 3, Default Distribution)

AADTT distribution by vehicle class

Class 4	1.8%
Class 5	24.6%
Class 6	7.6%
Class 7	0.5%
Class 8	5.0%
Class 9	31.3%
Class 10	9.8%
Class 11	0.8%
Class 12	3.3%
Class 13	15.3%

Hourly truck traffic distribution

by period beginning:

Midnight	2.3%	Noon	5.9%
1:00 am	2.3%	1:00 pm	5.9%
2:00 am	2.3%	2:00 pm	5.9%
3:00 am	2.3%	3:00 pm	5.9%
4:00 am	2.3%	4:00 pm	4.6%
5:00 am	2.3%	5:00 pm	4.6%
6:00 am	5.0%	6:00 pm	4.6%
7:00 am	5.0%	7:00 pm	4.6%
8:00 am	5.0%	8:00 pm	3.1%
9:00 am	5.0%	9:00 pm	3.1%
10:00 am	5.9%	10:00 pm	3.1%
11:00 am	5.9%	11:00 pm	3.1%

Traffic Growth Factor

Vehicle Class	Growth Rate	Growth Function
Class 4	4.0%	Compound
Class 5	4.0%	Compound
Class 6	4.0%	Compound
Class 7	4.0%	Compound
Class 8	4.0%	Compound
Class 9	4.0%	Compound
Class 10	4.0%	Compound
Class 11	4.0%	Compound
Class 12	4.0%	Compound
Class 13	4.0%	Compound

Traffic -- Axle Load Distribution Factors

Level 3: Default

Traffic -- General Traffic Inputs

Mean wheel location (inches from the lane marking):	18
Traffic wander standard deviation (in):	10
Design lane width (ft):	12

Number of Axles per Truck

Vehicle Class	Single Axle	Tandem Axle	Tridem Axle	Quad Axle
Class 4	1.62	0.39	0.00	0.00
Class 5	2.00	0.00	0.00	0.00
Class 6	1.02	0.99	0.00	0.00
Class 7	1.00	0.26	0.83	0.00
Class 8	2.38	0.67	0.00	0.00
Class 9	1.13	1.93	0.00	0.00
Class 10	1.19	1.09	0.89	0.00
Class 11	4.29	0.26	0.06	0.00
Class 12	3.52	1.14	0.06	0.00
Class 13	2.15	2.13	0.35	0.00

Axle Configuration

Average axle width (edge-to-edge) outside dimensions,ft):	8.5
Dual tire spacing (in):	12

Axle Configuration

Tire Pressure (psi) :	120

Average Axle Spacing

Tandem axle(psi):	51.6
Tridem axle(psi):	49.2
Quad axle(psi):	49.2

Wheelbase Truck Tractor

	Short	Medium	Long
Average Axle Spacing (ft)	12	15	18
Percent of trucks	33%	33%	34%

Climate

icm file:	
	C:\2002 Analysis\Houston-Hobby.icm
Latitude (degrees.minutes)	29.39
Longitude (degrees.minutes)	-95.17
Elevation (ft)	48
Depth of water table (ft)	10

Structure--Design Features

Permanent curl/warp effective temperature difference (°F):	-10
Shoulder type:	Asphalt

Steel Reinforcement

Percent steel (%):	0.8
Bar diameter (in):	0.625
Steel depth (in):	3

Base Properties

Base type:	Asphalt treated
Erodibility index:	Erosion Resistant (3)
Base/slab friction coefficient:	7.5

Crack Spacing

Cracking Model	Generate using model.

Structure--ICM Properties

Surface shortwave absorptivity:	0.85

Structure--Layers

Layer 1 -- CRCP

General Properties

PCC material	CRCP
Layer thickness (in):	10
Unit weight (pcf):	150
Poisson's ratio	0.2

Thermal Properties

Coefficient of thermal expansion (per F° x 10- 6):	6
Thermal conductivity (BTU/hr-ft-F°) :	1.25
Heat capacity (BTU/lb-F°):	0.28

Mix Properties

Cement type:	Type I
Cementitious material content (lb/yd^3):	600
Water/cement ratio:	0.42
Aggregate type:	Limestone
PCC zero-stress temperature (F°)	110
Ultimate shrinkage at 40% R.H (microstrain)	Derived
Reversible shrinkage (% of ultimate shrinkage):	50
Time to develop 50% of ultimate shrinkage (days):	35
Curing method:	Curing compound

Strength Properties

Input level:	Level 3
28-day PCC modulus of rupture (psi):	620
28-day PCC compressive strength (psi):	n/a

Layer 2 -- Asphalt concrete

Material type:	Asphalt concrete
Layer thickness (in):	1

General Properties

General

Reference temperature (F°):	70

Volumetric Properties as Built

Effective binder content (%):	11
Air voids (%):	8.5
Total unit weight (pcf):	148

Poisson's ratio: 0.35 (user entered)

Thermal Properties

Thermal conductivity asphalt (BTU/hr-ft-F°):	0.67
Heat capacity asphalt (BTU/lb-F°):	0.23

Asphalt Mix

Cumulative % Retained 3/4 inch sieve:	15
Cumulative % Retained 3/8 inch sieve:	38
Cumulative % Retained #4 sieve:	89
% Passing #200 sieve:	4

Asphalt Binder

Option:	Conventional penetration grade
Viscosity Grade	Pen 85-100
A	10.8232 (correlated)
VTS:	-3.621 (correlated)

Layer 3 -- Cement Stabilized

General Properties

Material type:	Cement Stabilized
Layer thickness (in):	6
Unit weight (pcf):	150
Poisson's ratio:	0.2

Strength Properties

Elastic/resilient modulus (psi):	1000000

Thermal Properties

Thermal conductivity (BTU/hr-ft-F°) :	1.25
Heat capacity (BTU/lb-F°):	0.28

Layer 4 -- A-6

Unbound Material:	A-6
Thickness(in):	6

Strength Properties

Input Level:	Level 3
Analysis Type:	ICM inputs (ICM Calculated Modulus)
Poisson's ratio:	0.35
Coefficient of lateral pressure,Ko:	0.5
Modulus (input) (psi):	14000

ICM Inputs

Gradation and Plasticity Index

Plasticity Index, PI:	16
Liquid Limit (LL)	33
Compacted Layer	No
Passing #200 sieve (%):	63.2
Passing #40	82.4
Passing #4 sieve (%):	93.5
D10(mm)	0.000285
D20(mm)	0.0008125
D30(mm)	0.002316
D60(mm)	0.05364
D90(mm)	1.922

Sieve	Percent Passing
0.001mm	
0.002mm	
0.020mm	
#200	63.2
#100	
#80	73.5
#60	
#50	
#40	82.4
#30	
#20	
#16	
#10	90.2
#8	
#4	93.5
3/8"	96.4
1/2"	97.4
3/4"	98.4
1"	99
1 1/2"	99.5
2"	99.8
2 1/2"	
3"	
3 1/2"	100
4"	100

Calculated/Derived Parameters

Maximum dry unit weight (pcf):	107.9 (derived)
Specific gravity of solids, Gs:	2.70 (derived)
Saturated hydraulic conductivity (ft/hr):	1.95e-005 (derived)
Optimum gravimetric water content (%):	17.1 (derived)
Calculated degree of saturation (%):	82.1 (calculated)

Soil water characteristic curve parameters: Default values

Parameters	Value
a	108.41
b	0.68007
c	0.21612
Hr.	500

Layer 5 -- A-6

Unbound Material:	A-6
Thickness(in):	Semi-infinite

Strength Properties

Input Level:	Level 3
Analysis Type:	ICM inputs (ICM Calculated Modulus)
Poisson's ratio:	0.35
Coefficient of lateral pressure,Ko:	0.5
Modulus (input) (psi):	14000

ICM Inputs

Gradation and Plasticity Index

Plasticity Index, PI:	16
Liquid Limit (LL)	33
Compacted Layer	No
Passing #200 sieve (%):	63.2
Passing #40	82.4
Passing #4 sieve (%):	93.5
D10(mm)	0.000285
D20(mm)	0.0008125
D30(mm)	0.002316
D60(mm)	0.05364
D90(mm)	1.922

Sieve	Percent Passing
0.001mm	
0.002mm	
0.020mm	
#200	63.2
#100	
#80	73.5
#60	
#50	
#40	82.4
#30	
#20	
#16	
#10	90.2
#8	
#4	93.5
3/8"	96.4
1/2"	97.4
3/4"	98.4
1"	99
1 1/2"	99.5
2"	99.8
2 1/2"	
3"	
3 1/2"	100
4"	100

Calculated/Derived Parameters

Maximum dry unit weight (pcf):	107.9 (derived)
Specific gravity of solids, Gs:	2.70 (derived)
Saturated hydraulic conductivity (ft/hr):	1.95e-005 (derived)
Optimum gravimetric water content (%):	17.1 (derived)
Calculated degree of saturation (%):	82.1 (calculated)

Soil water characteristic curve parameters: Default values

Parameters	Value
a	108.41
b	0.68007
c	0.21612
Hr.	500

Distress Model Calibration Settings - Rigid (new)

Punchouts

Fatigue

C1	2
C2	1.22

Punchout

C3	195.7895
C4	19.89474
C5	-0.52632

Crack Width

C6	1

Reliability (PO)

Std. Dev.	-0.00609*POWER(PO,2) + 0.58242*PO + 3.36783

IRI(crcp)

C1	1
C2	3.15
C3	28.35
C4	10.03
Standard deviation in initial IRI (in/mile):	5.4