National Cooperative Highway Research Program

RESEARCH RESULTS DIGEST

December 2003—Number 284

Subject Areas: IIB Pavement Design, Management, and Performance and IIIB Materials and Construction

Responsible Senior Program Officer: Edward T. Harrigan

Refining the Calibration and Validation of Hot Mix Asphalt Performance Models: An Experimental Plan and Database

This digest summarizes key findings from NCHRP Project 9-30, "Experimental Plan for Calibration and Validation of Hot Mix Asphalt Performance Models for Mix and Structural Design," conducted by Fugro-BRE, Inc. The digest is an abridgement of portions of the project final report authored by the principal investigator, Harold L. Von Quintus, P.E., Fugro-BRE, Inc.; Charles Schwartz, Ph.D., P.E., University of Maryland–College Park; Richard H. McCuen, Ph.D., University of Maryland–College Park; and Dragos Andrei, Ph.D., Fugro-BRE, Inc.

INTRODUCTION

This digest summarizes findings from research conducted under NCHRP Project 9-30 with the objective of developing a detailed, statistically sound, and practical experimental plan to refine the calibration and validation of the performance models incorporated in the pavement design guide (hereinafter referred to as the 2002 Design Guide) produced in NCHRP Project 1-37A with laboratory-measured hot mix asphalt (HMA) material properties.

NCHRP Project 1-37A, entitled "Development of the 2002 Guide for the Design of New and Rehabilitated Pavement Structures: Phase II," identified state-of-the-practice performance models and supporting test methods for use in the 2002 Design Guide. Present plans call for adapting these same performance models to the requirements of the HMA mix design. Using these tools, the engineer will arrive at a final mix design by considering structural, traffic, and environmental factors, in addition to material properties, thus fulfilling the original goal of the 1993 Strategic Highway Research Program (SHRP) Superpave mix design and analysis method.

In Project 1-37A, an analytical approach was used for the calibration and validation of the HMA models; the calibration and validation were based on material properties either contained in the Long Term Pavement Performance (LTPP) database or derived from LTPP data by calculation. This digest presents an experimental plan for refining the calibration and validation of these models with measured material properties and briefly describes a supporting mechanistic-empirical (M-E) database developed in NCHRP Project 9-30.

CONFIRMATION OF MECHANISTIC-EMPIRICAL DISTRESS PREDICTION MODELS

Pavement distress prediction models, or transfer functions, are the key components of any M-E design and analysis procedure. Calibration and validation of these prediction models are mandatory steps in the development process to establish confidence in the design-analysis procedure and facilitate its acceptance and use. The term *calibration* refers to the mathematical process through which the total error or difference between observed and predicted values of distress is minimized. The term *validation* refers to the process to confirm that the calibrated model can produce robust and accurate predictions for cases other than those used for model calibration. A successful validation process requires that the bias and precision statistics of the model obtained for the validation data set be similar to those obtained during calibration.

Pavement design is a complex process that involves uncertainty, variability, and approxima-

CONTENTS

tions of all input parameters. Even though mechanistic concepts provide a more rational and realistic methodology to account for such variations and approximations, all calibrated models will have an error associated with them. This error explains the scatter in the data about the line of equality between the predicted and observed values of distress. The calibration process is used to determine the accuracy or the *standard error estimate* (S_e) of the predictions and the major components of the error term.

All performance models in the 2002 Design Guide were calibrated and validated on a global level to observed field performance at a representative set of pavement test sites around North America. LTPP test sections were used extensively in the calibration-validation process because of the consistency in the monitored data over time and the diversity of test sections spread throughout North America.

The highest-quality calibration of prediction models requires the testing and characterization of HMA, unbound pavement materials, and subgrade soils at selected field sites. No laboratory testing was completed as a part of NCHRP Project 1-37A; it was assumed that the material properties and other inputs needed for the calibration process were available from existing databases. However, this assumption was proven incorrect.

Many of the material property and site feature inputs for the 2002 Design Guide were unavailable from the LTPP database. Because of the limited number of pavement test sites with all levels of input data, minimal testing of selected properties, the use of calculated properties from regression equations, and the global scope of the calibration effort, the predictions from the calibrated models have a relatively high level of uncertainty and a limited inference space of application. Table 1 lists the standard error of each distress prediction model reported by the Project 1-37A research team in July 2003.

The standard error of the rutting model is relatively low, while the errors for the fracture models are relatively high. Tighter calibration of the fracture models based upon mea-

TABLE 1 Summary of the standard error for each distress prediction model included in the 2002 Design Guide software (as of July 2003)

Distress Prediction Model	**Design Level or Pavement Type**	**Standard Error of Model**	**Error Model, Standard Deviation[1]**
Rutting or Permanent Deformation, inches	HMA	0.14	$0.1282(RD_{Total})^{0.406}+0.001$
	Soil, Coarse-Grained		$0.1361(RD_{Subgrade})^{0.6501}+0.001$
	Soil, Fine-Grained		$0.1008(RD_{Subgrade})^{0.3139}+0.001$
Load-Related Fatigue Cracks—Area Cracking, ft^2/500 ft.			$32.7+\left(\frac{995.1}{1+e^{(2-2Log(D+0.001))}}\right)$
Load-Related Fatigue Cracks—Longitudinal Cracking, ft/500 ft.			$77+\left(\frac{114.8}{1+e^{(0.772-2.8527Log(D+0.0001))}}\right)$
Non-Load-Related Cracks—Transverse or Thermal Cracks	Level 1		$19+\left(\frac{24}{1+e^{(3-0.0025(TC))}}\right)$
	Level 2		$19+\left(\frac{24}{1+e^{(3-0.0025(TC))}}\right)$
	Level 3		$19+\left(\frac{24}{1+e^{(3-0.0025(TC))}}\right)$
Smoothness,[2] as measured by IRI, m/km	Conventional	0.386	
	Deep-Strength	0.292	
	Semi-Rigid	0.229	
	HMA over Flexible	0.179	
	HMA over Rigid	0.197	

Notes:

1. Where:
   D = Fatigue damage index.
   RD_{Total} = Total rut depth.
   TC = Length of Thermal Cracks.
2. Smoothness is calculated using regression models relating increases in various distress values to decreases in smoothness; M-E models are not used directly.

TABLE 2 Summary of the pavement types and rehabilitation strategies that were used in the calibration and validation of the 2002 Design Guide performance prediction models

Family of HMA Pavements & Rehabilitation Strategies			
New Construction	**HMA Overlay of HMA Pavement**	**HMA Overlay of Intact PCC**	**HMA Overlay of Fractured Slabs**
1. Conventional – thin HMA surface with untreated aggregate base	5. Unmilled surface or minimal surface preparation prior to overlay	7. JPCP	10. Rubblized PCC
2. Deep strength HMA pavement	6. Mill surface or extensive surface preparation & repairs prior to overlay	8. JRCP	11. Break and seat JRCP
3. Full-depth HMA pavement		9. CRCP	12. Crack and seat JPCP
4. Semi-rigid pavement			

Note: Twelve types of HMA pavements were considered in the NCHRP Project 1-37A calibration factorial, as listed above.

sured material properties, design and construction practices, and performance histories from a more localized region should yield better predictive accuracy. More importantly, there is a need to obtain consistent data that can be used for multiple outcomes, including the calibration-validation of HMA mixture and structural design procedures, performance-related specifications, and management of HMA pavements. Thus, the experimental plan and M-E database developed under NCHRP Project 9-30 to confirm and validate the distress prediction models for mixture and structural design were required to be applicable to other uses to reduce the amount of duplication and costs of future projects.

DISTRESS-PERFORMANCE OBSERVATIONS INCLUDED IN THE PLAN

Distress prediction models are the backbone of the 2002 Design Guide procedure as well as any other design-analysis procedure based on M-E principles. However, the 2002 Design Guide is one of the first such procedures to include the capability to accumulate damage on a monthly basis (or bimonthly basis, depending on frost conditions) over the entire design period. This approach attempts to simulate how "real world" pavement damage occurs incrementally, load by load, over continuous time periods. By accumulating damage monthly, the design procedure is very versatile and comprehensive.

The 2002 Design Guide includes M-E models for distortion (rutting in each layer), load-related cracking (both surface-initiated and bottom-initiated cracks), non-load-related cracking, and smoothness. Reflection cracking is not included because no model was judged suitable for implementation in the 2002 Design Guide based on the scope of work and ground rules established by NCHRP.[1] The final output from the performance prediction system is predicted magnitudes of pavement distress over time.

Pavement Types and Rehabilitation Strategies

The pavement types and rehabilitation strategies that were considered in developing the 1-37A calibration and validation experimental factorials and in selecting pavement test sections are listed in Table 2. Table 3 summarizes the distresses and deterioration parameters considered for each pavement type and rehabilitation strategy.

Mixture Properties and Tests

Table 4 provides a generic tabulation of material properties that are considered important for calibrating and validating distress prediction models used for HMA mixture and structural design, performance-related specifications, and management of HMA pavement structures. The highlighted material properties are needed for the 2002 Design Guide. Table 5 tabulates the tests that are recommended for measuring the fundamental material properties included in Table 4.

---

[1] A fundamental "ground rule" for the 2002 Design Guide development was that it be based on existing models and technology. No development of new models or significant enhancement of existing models was allowed.

TABLE 3 Distresses and deterioration parameters considered in the 2002 Design Guide for each family of pavement and rehabilitation strategy

Pavement Type	Distress Type & Deterioration Parameters									
	Rutting[1]				Fatigue Cracking[2]		Other Cracking[3]		Rutting Variance	IRI – Ride Quality
	Total, Surface	HMA	Base	Subg.	Initiate, Bottom	Initiate, Surface	Thermal	Reflect.		
Thin HMA Surface, Thick Aggr. Base	Yes	Yes	Yes	Yes	Yes	No	Yes	NA	Yes	Yes
Deep Strength	Yes	Yes	Yes	Yes	Yes	No	Yes	NA	Yes	Yes
Full Depth	Yes	Yes	NA	Yes	Yes	No	Yes	NA	Yes	Yes
Semi-Rigid	Yes	Yes	NA	Yes	Yes	No	Yes	NA	Yes	Yes
HMA Overlay	Yes	Yes	NA	NA	Yes	No	Yes	No	Yes	Yes
Mill Prior to Overlay	Yes	Yes	NA	NA	Yes	No	Yes	No	Yes	Yes
HMA Overlay of Intact JPCP Slabs	Yes	Yes	NA	NA	NA	No	No	No	Yes	Yes
HMA Overlay of Intact JRCP Slabs	Yes	Yes	NA	NA	NA	No	No	No	Yes	Yes
HMA Overlay of CRCP	Yes	Yes	NA	NA	NA	No	Yes	No	Yes	Yes
HMA Overlay of Rubb. PCC	Yes	Yes	Yes	Yes	Yes	No	Yes	NA	Yes	Yes
HMA Overlay of Break & Seat – JRCP	Yes	Yes	NA	Yes	NA	No	Yes	No	Yes	Yes
HMA Overlay of Crack & Seat – JPCP	Yes	Yes	NA	Yes	NA	No	Yes	No	Yes	Yes

Notes:

[1] The individual layer rut depths were not confirmed through the calibration process because trenching studies were unavailable for the LTPP test sections.

[2] Damage indices were computed throughout the HMA layer. However, the greatest damage always occurred at the bottom of the HMA layer, as classical fatigue cracking initiated at the bottom of the layer. Without core studies, the reality of this finding and model accuracy for the LTPP test sections could not be confirmed.

[3] Reflection cracking was not included in the calibration work, because no M-E model was included in the 2002 Design Guide.

INITIAL CALIBRATION OF 2002 DESIGN GUIDE PREDICTION MODELS

The performance prediction models included in the 2002 Design Guide were calibrated using data from nearly 150 LTPP test sections, as well as from the ongoing Minnesota Road Research Project (MnROAD) and the AASHO Road Test conducted between 1958 and 1961. However, most of the HMA fundamental properties required in support of the performance prediction equations were not available in the LTPP and AASHO databases. These and other inputs were estimated from regression equations, and, in some cases, a "best-guessed" value was used. These mixture property estimates increased the uncertainty of the predictions and overall error between the predicted and observed performance values.

TABLE 4 Material properties considered important for predicting performance of HMA mixtures or estimating the life of HMA pavements and overlays using different M-E distress prediction models

Mix/Pavement Parameter and Test Type	Performance Indicator					
	Rut Depth	Fatigue Cracking	Thermal Cracking	Reflection Cracking	Smoothness	Other Distresses
HMA Mixture Fundamental/Mechanical Properties						
Dynamic Modulus Master Curve	√	√				
Compressive Resilient Modulus	√	√				
Shear Modulus Master Curve	√					
IDT Compliance Master Curve			√			
Flow Time in Compression	√					
Flow Number in Compression	√					
Slope/Intercept, Uniaxial Permanent Deformation	√					
Slope/Intercept, Shear Permanent Deformation	√					
IDT Resilient Moduls		√	√	√		√
IDT Strength		√	√	√		√
IDT Strain at Failure		√	√	√		√
Fatigue Strength		√		√		
HMA Thermal Coefficient			√			
HMA Phase Angle	√	√				
HMA Dissipated Energy/Work		√				

continues

A three-level hierarchical approach for defining the design inputs to the program was selected to simplify and facilitate the implementation process of the 2002 Design Guide. Level 1 inputs provide the highest level of accuracy and the lowest level of uncertainty or error in the design. A design based on Level 1 inputs requires laboratory or field tests or measurements to determine the requisite traffic, materials, and environmental inputs. Level 2 inputs provide an intermediate level of design accuracy; such a design is probably closest to the typical procedures used with the current and previous editions of the AASHTO *Guide for Design of Pavement Structures*. This level of input data could be used when resources or testing equipment needed for Level 1 data are not available. Input data might be user selected (possibly from an agency database), derived from a limited test program, or estimated through correlations. Level 3 inputs provide the lowest level of accuracy; input data might be user-selected values or typical regional averages.

This hierarchical approach will allow state agencies with little experience in more advanced material characterization or agencies with little historical truck traffic data to use the program with a relatively low investment cost. However, the hierarchical approach complicates the calibration-validation process and increases the number of data elements that need to be considered in developing the database to refine the M-E design and analysis procedures. Ideally, the

TABLE 4 (continued)

Mix/Pavement Parameter and Test Type	**Performance Indicator**					
	Rut Depth	**Fatigue Cracking**	**Thermal Cracking**	**Reflection Cracking**	**Smoothness**	**Other Distresses**
HMA Volumetric/Component Properties						
Asphalt viscosity @ 70F	√	√				
Asphalt viscosity @ 135C	+	+				
Asphalt Viscosity-Temp. Relationship	√	√				
Asphalt Penetration Index		√				
Eff. Asphalt Content by Volume	√	√	√			√
Asphalt Content by Weight	√	√			√	
Air Voids of Mix	√	√			√	√
Voids in Mineral Aggregate (VMA)	√	√	√			
HMA Density			√			
Percent Passing No. 3/4 Sieve		√				
Percent Passing No. 3/8 Sieve		√				
Percent Passing No. 4 Sieve		√				
Percent Passing No. 200 Sieve	√	√				
Aggregate Angularity		√				√
Unbound Material Properties						
Resilient Modulus of Soil/Aggregate	√	√		√		
Triaxial Permanent Deformation Tests	√					
Percent Clay in Soil					√	
Percent Sand in Soil					√	
Percent Passing No. 200 Sieve			√		√	
Plasticity Index of Soil					√	
Moisture Content of Soil/Aggregate	√				√	

Note: The cells that are shaded or highlighted are the materials tests, response parameters, and material properties that are needed in support of the 2002 Design Guide.

TABLE 5 Material tests considered important for predicting performance of HMA mixtures or estimating the life of HMA pavements and overlays using different M-E distress prediction models

Mix/Pavement Parameter and Test Type	Performance Indicator					
	Rut Depth	Fatigue Cracking	Thermal Cracking	Reflection Cracking	Smoothness	Other Distresses
Fundamental (Mechanical) Tests in Support of the M-E Models						
HMA Compressive Dynamic Modulus	√	√		√		
Triaxial Resilient Modulus	√					
Shear Modulus-Constant Height	√					
IDT Indirect Tensile Creep/Strength		√	√	√		
IDT Resilient Modulus, HMA		√		√		√
IDT Strength-Failure Strain HMA		√	√	√		√
Constant-Height, Permanent Deformation Shear	√					
Triaxial Permanent Deformation, HMA	√					
Triaxial Creep, HMA	√					
Beam Fatigue Tests		√		√		
Resilient Modulus, Soils/Aggregates	√	√		√		
Triaxial Repeated Load Permanent Deformation Tests	√					

Note: The cells that are shaded or highlighted are the materials tests, response parameters, and material properties that are needed in support of the 2002 Design Guide.

error terms for each input level should be determined separately, rather than by combining all levels together, in order to allow the error term for each distress to be quantified by input level. However, only one set of error terms is in the current version of the 2002 Design Guide. These error terms were determined from the calibration process by using the best available data among input levels 1, 2, and 3.

JACKKNIFE TESTING TO REFINE MODEL CALIBRATION AND VALIDATION

Development of pavement performance models for M-E pavement design methods requires a rational procedure for performing calibration and validation. Given the effort and expense required to collect distress data, it is essential to have a means of accurately estimating the amount of data needed for calibration and validation.

Since distress data are expensive and time-consuming to collect, the use of a single database for both calibration and validation is preferable. *Jackknifing* is a model validation procedure that provides measures of goodness-of-fit that are independent of the corresponding calibration statistics that depend on the data used for fitting the model parameters. Thus, the model validation statistics are developed independently of the data used for calibration and are more likely to indicate the accuracy of future predictions than are statistics based on calibration of all data vectors. Multiple jackknifing is used to assess the stability of the prediction statistics and sensitivity of the validation goodness-of-fit statistics to sample size. Another advantage is that the method is easy to apply.

Split-sample validation differs from jackknifing in that the goodness-of-fit statistics for both calibration and prediction are based on $n/2$ values (for symmetric split sampling, the usual case) rather than n values. Traditional split-sample validation has the distinct disadvantage that, if *n* is small relative to the inference space being simulated, then *n*/2 is even smaller, which produces inaccurate calibrations, inaccurate coefficients, and less reliable prediction accuracy. To overcome in part this deficiency, the experimental plan developed in NCHRP Project 9-30 is based on the use of a method combining jackknifing and split-sample testing that is essentially an *n/2* jackknifing scheme termed *split-sample jackknifing*. Split-sample jackknifing provides somewhat better measures of prediction accuracy than the traditional split-sample validation. *NCHRP Research Results Digest 283: Jackknife Testing—An Experimental Approach to Refine Model Calibration and Validation* illustrates the use of split-sample jackknifing using simulations of rutting performance based on measured data from in-service MnROAD pavement sections.

EXPERIMENTAL PLAN AND MATRIX FOR REFINING CALIBRATION AND VALIDATION

Matrix Stratification Approach

Table 6 is a general table for categorizing each test section included in the calibration-validation refinement experimental plan for all four distresses of interest. Within this table, traffic and climate are treated as secondary parameters because traffic is probably interrelated with HMA thickness and climate is interrelated with asphalt binder grade. The table can be stratified or blocked by family of pavement for each distress. Each column in the table represents the effect of changing structure and mixture. This type of table was selected because the experiment will evaluate the effect of material characterization (laboratory tests) on reducing the overall error term or uncertainty caused by using best-guessed material properties or properties calculated from regression equations. The effect can be (and probably is) different for different distresses.

The number in each cell of Table 6 is that of the required paired or companion test sections, one with a relatively high magnitude of distress and one with a relatively low magnitude of distress. For experimental efficiency, the comparative test sections with relatively low magnitudes of distress will come from another distress matrix or factorial. For example, the test sections that exhibit relatively high amounts of fatigue cracking can be used in the rutting matrix or thermal cracking matrix for low magnitudes of those distresses. The testing plan to measure the HMA mixture properties needed for predicting all four major distress types will be implemented for each test section to keep the total number of test sections that are needed in the experimental matrix to a practical minimum.

TABLE 6 Categories for each test section included in the calibration-validation refinement experimental plan for all distresses

Pav't. Type	HMA Thick.	Mix Type	Family of Pavements								Total No. of Sections
			Thin Surf., Conv.	Thick Surf., Deep	Full-Depth	Semi-Rigid	HMA Overlay of:				
							HMA	Intact PCC	Break & Seat PCC	Rubb. PCC	
New	Thin	Conventional	1			4					5
		PMA	2			2					4
		Grading	1			1					2
		Drainage	2								2
	Thick	Conventional		1	1	4					6
		PMA		2	2	2					6
		Grading		1	1	1					3
		Drainage		2	2						4
Rehab.	Thin	Conventional					1	1	1		3
		PMA					1	1	1	1	4
		Grading					1	1	1	1	4
		Drainage									
	Thick	Conventional					1	1	1	2	5
		PMA					1	1	1	1	4
		Grading					2	1	1	1	5
		Drainage									
Total Sections			6	6	6	14	7	6	6	6	75

Notes:

1. HMA Thickness: Thin – less than or equal to 5 inches; Thick – greater than or equal to 8 inches.
2. Mix Type: Conventional – A conventional mix, unmodified; PMA – Polymer Modified Asphalt mix; Grading – A fine, coarse, or gap graded aggregate blend that is different than the conventional grading used; Drainage – Sections with subsurface drainage within structure.
3. Thin Surface Pavement Type – A conventional flexible pavement; thin surface with a relatively thick aggregate or granular base.
4. Thick Surface, Deep Strength – A thick HMA pavement with an asphalt-stabilized or -treated base mixture.
5. More semi-rigid pavements were included in the above table because so few were used in the initial calibration-validation experiment of NCHRP Project 1-37A.

It is hypothesized that the difference between the relative deviation (difference between distress observations and predictions) for these companion test sections within the same cell is caused by material properties that are measured in the laboratory. These relative deviations from using laboratory-measured mixture properties can also be compared with the relative deviations resulting from the use of best-guessed values determined in NCHRP Project 1-37A or other projects. In this manner, the total error from using the best-guessed values can be compared with the total error from using laboratory-measured values. The following summarizes the required number of test sections with a relatively high magnitude of each distress:

Rutting:	30 test sections.
Fatigue Cracking:	45 test sections.
Thermal Cracking:	28 test sections.
Reflection Cracking:	39 test sections.

Tables 7 through 10 provide the section categories for each of the four distresses. The categories for fatigue cracking (Table 8) and reflection cracking (Table 10) are subject to change based on the results and recommendations of NCHRP Projects 1-42, "Top-Down Fatigue Cracking of Hot-Mix Asphalt Layers," and 1-41, "Selection, Calibration, and Validation of a Reflective Cracking Model for Asphalt Concrete Overlays," respectively.

Experimental Test Sections and Related Requirements

Three types of experiment can be used for refinement of the model calibration and validation:

- Accelerated pavement testing (APT) experiments can be used for rapid verification of distress growth or deterioration models. Results from this type of test section can also be used to confirm the form of the distress transfer function. These test sections are basically independent of climatic factors and the long-term aging characteristics of the asphalt binder.
- Short-term test track experiments can be used to calibrate and validate the effects of wheel load on the distress predictions without the added complexity of long-term aging and extensive environmental variations. Results from this type of experiment slightly depend on the climatic factors and the long-term aging characteristics of the asphalt binder.
- Long-term, full-scale field experiments or test sections can be used to fully calibrate and validate the distress prediction models and define the effects of the environ-

TABLE 7 Categories for each test section included in the calibration-validation refinement experimental plan for rutting

Pav't. Type	HMA Thick.	Mix Type	Family of Pavements								Total No. of Sections
			Thin Surf., Conv.	Thick Surf., Deep	Full-Depth	Semi-Rigid	HMA Overlay of:				
							HMA	Intact PCC	Break & Seat PCC	Rubb. PCC	
New	Thin	Conventional	1			1					2
		PMA	2			1					3
		Grading	1								1
		Drainage									
	Thick	Conventional		1	1	1					3
		PMA		2	2	1					5
		Grading		1	1						2
		Drainage									
Rehab.	Thin	Conventional					1	1			2
		PMA					1	1		1	3
		Grading					1		1		2
		Drainage									
	Thick	Conventional					1	1			2
		PMA					1	1		1	3
		Grading					1		1		2
		Drainage									
Total Sections			4	4	4	4	6	4		4	30

Notes:

1. HMA Thickness: Thin – less than or equal to 5 inches; Thick – greater than or equal to 8 inches.
2. Mix Type: Conventional – A conventional mix, unmodified; PMA – Polymer Modified Asphalt mix; Grading – A fine, coarse, or gap graded aggregate blend that is different than the conventional grading used; Drainage – Sections with subsurface drainage within structure.
3. Thin Surface Pavement Type – A conventional flexible pavement; thin surface with a relatively thick aggregate or granular base.
4. Thick Surface, Deep Strength – A thick HMA pavement with an asphalt-stabilized or -treated base mixture.
5. More semi-rigid pavements were included in the above table because so few were used in the initial calibration-validation experiment of NCHRP Project 1-37A.

TABLE 8 Categories for each test section included in the calibration-validation refinement experimental plan for fatigue cracking

Pav't. Type	HMA Thick.	Mix Type	Family of Pavements								Total No. of Sections
			Thin Surf., Conv.	Thick Surf., Deep	Full-Depth	Semi-Rigid	HMA Overlay of:				
							HMA	Intact PCC	Break & Seat PCC	Rubb. PCC	
New	Thin	Conventional	1			4					5
		PMA	2			2					4
		Grading	1			1					2
		Drainage	2								2
	Thick	Conventional		1	1	4					6
		PMA		2	2	2					6
		Grading		1	1	1					3
		Drainage		2	2						4
Rehab.	Thin	Conventional					1			1	
		PMA					1			1	2
		Grading					1			1	2
		Drainage									
	Thick	Conventional					1			2	3
		PMA					1			1	2
		Grading					2			1	3
		Drainage									
Total Sections			6	6	6	14	7			6	45

Notes:

1. HMA Thickness: Thin – less than or equal to 5 inches; Thick – greater than or equal to 8 inches.
2. Mix Type: Conventional – A conventional mix, unmodified; PMA – Polymer Modified Asphalt mix; Grading – A fine, coarse, or gap graded aggregate blend that is different than the conventional grading used; Drainage – Sections with subsurface drainage within structure.
3. Thin Surface Pavement Type – A conventional flexible pavement; thin surface with a relatively thick aggregate or granular base.
4. Thick Surface, Deep Strength – A thick HMA pavement with an asphalt-stabilized or -treated base mixture.
5. More semi-rigid pavements were included in the above table because so few were used in the initial calibration-validation experiment of NCHRP Project 1-37A.

TABLE 9 Categories for each test section included in the calibration-validation refinement experimental plan for thermal cracking

Pav't. Type	HMA Thick.	Mix Type	Family of Pavements								Total No. of Sections
			Thin Surf., Conv.	Thick Surf., Deep	Full-Depth	Semi-Rigid	HMA Overlay of:				
							HMA	Intact PCC	Break & Seat PCC	Rubb. PCC	
New	Thin	Conventional	1			1					2
		PMA	2			2					4
		Grading	1			1					2
		Drainage									
	Thick	Conventional		1	1	1					3
		PMA		2	2	2					6
		Grading		1	1	1					3
		Drainage									
Rehab.	Thin	Conventional									
		PMA					1		1		2
		Grading					1		1		2
		Drainage									
	Thick	Conventional									
		PMA					1		1		2
		Grading					1		1		2
		Drainage									
Total Sections			4	4	4	8	4			4	28

Notes:

1. HMA Thickness: Thin – less than or equal to 5 inches; Thick – greater than or equal to 8 inches.
2. Mix Type: Conventional – A conventional mix, unmodified; PMA – Polymer Modified Asphalt mix; Grading – A fine, coarse, or gap graded aggregate blend that is different than the conventional grading used; Drainage – Sections with subsurface drainage within structure.
3. Thin Surface Pavement Type – A conventional flexible pavement; thin surface with a relatively thick aggregate or granular base.
4. Thick Surface, Deep Strength – A thick HMA pavement with an asphalt-stabilized or -treated base mixture.
5. More semi-rigid pavements were included in the above table because so few were used in the initial calibration-validation experiment of NCHRP Project 1-37A.

TABLE 10 Categories for each test section included in the calibration-validation refinement experimental plan for reflection cracking

Pav't. Type	HMA Thick.	Mix Type	Family of Pavements								Total No. of Sections
							HMA Overlay of:				
			Thin Surf., Conv.	Thick Surf., Deep	Full-Depth	Semi-Rigid	HMA	Intact PCC	Break & Seat PCC	Rubb. PCC	
New	Thin	Conventional		▨	▨	4	▨	▨	▨	▨	4
		PMA		▨	▨	2	▨	▨	▨	▨	2
		Grading		▨	▨	1	▨	▨	▨	▨	1
		Drainage		▨	▨		▨	▨	▨	▨	
	Thick	Conventional	▨			4	▨	▨	▨	▨	4
		PMA	▨			2	▨	▨	▨	▨	2
		Grading	▨			1	▨	▨	▨	▨	1
		Drainage	▨				▨	▨	▨	▨	
Rehab.	Thin	Conventional	▨	▨	▨	▨	1	1	1		3
		PMA	▨	▨	▨	▨	1	1	1	1	4
		Grading	▨	▨	▨	▨	1	1	1	1	4
		Drainage	▨	▨	▨	▨	▨	▨	▨	▨	
	Thick	Conventional	▨	▨	▨	▨	1	1	1	2	5
		PMA	▨	▨	▨	▨	1	1	1	1	4
		Grading	▨	▨	▨	▨	2	1	1	1	5
		Drainage	▨	▨	▨	▨	▨	▨	▨	▨	
Total Sections						14	7	6	6	6	39

Notes:

1. HMA Thickness: Thin – less than or equal to 5 inches; Thick – greater than or equal to 8 inches.
2. Mix Type: Conventional – A conventional mix, unmodified; PMA – Polymer Modified Asphalt mix; Grading – A fine, coarse, or gap graded aggregate blend that is different than the conventional grading used; Drainage – Sections with subsurface drainage within structure.
3. Thin Surface Pavement Type – A conventional flexible pavement; thin surface with a relatively thick aggregate or granular base.
4. Thick Surface, Deep Strength – A thick HMA pavement with an asphalt-stabilized or -treated base mixture.
5. More semi-rigid pavements were included in the above table because so few were used in the initial calibration-validation experiment of NCHRP Project 1-37A.

TABLE 11 Experiments and projects suggested for use in the calibration-validation refinement plan.

Climate Independent or Climate Controlled				**Climate dependent, plus long-term aging of asphalt**	
Little to no aging (test completed in less than 1 or 2 years)		Some Aging (test completed in 3 years or less)			
FHWA-ALF	Round 1	WesTrack	PRS Study	MnRoad	Round 1
FWHA-ALF	Round 2	NCAT	Round 1	MnRoad	Round 2
LSU-ALF	CTB Testing	NCAT	Round 2	LTPP	SPS-1
Caltrans	HVS 1			LTPP	SPS-5
Caltrans	HVS 2			LTPP	SPS-6
				LTPP	SPS-9
				Nevada	I-80
				Mississippi	I-55

ment, aging, and wheel load on these predictions. The majority of the test sections included in the original calibration study in NCHRP Project 1-37A came from this category. Similarly, many of the test sections included in the present experimental plan will come from this type of experiment.

All three types of experiment are needed to evaluate selected aspects of the distress prediction system, as noted above. The field projects that are suggested for use in the experimental plan are listed in Table 11. These experiments and projects can be used to confirm the aging and climatic effects on pavement performance by evaluating and comparing the calibration factors between each experiment.

TABLE 12 Checklist for collecting the minimum data that are needed to determine the inputs to execute various M-E design-analysis models for refining the calibration-validation process

Data Category	Data Element Definition	1-37A Input Parameter	Comment
Structure	Layer type & thickness	Yes	
	Depth to apparent rigid layer	Yes	
	Depth to water table	Yes	
	Trenches		Confirms rutting in individual layers & mechanisms causing distress
	Cores through cracks		Confirms direction of crack propagation
Climate	Geographical location	Yes	Latitude
			Longitude
	Automated weather station data	Yes	No. of days
Traffic	Weigh-in-motion data	Yes	No. of days; specific to full-scale experiments (suggested minimum of 180 days over 3 years)
	Automated vehicle classification data	Yes	No. of days; specific to full-scale experiments (suggested minimum of 180 days over 3 years)
HMA Mixtures	Dynamic modulus in compression – triaxial	Yes	Generate master curve
	Poisson's ratio	Yes	Value normally assumed
	Indirect tensile creep compliance	Yes	Test temperatures of -4, 14, & 32˚F
	Indirect tensile strength	Yes	Test temperature of 14˚F
	Air voids at construction	Yes	
	Total unit weight	Yes	
	Voids in mineral aggregate	Yes	
	Effective asphalt content by volume	Yes	
	Mix coefficient of thermal contraction	Yes	Value normally assumed
	Surface shortwave absorptivity	Yes	Value normally assumed
	Asphalt thermal conductivity	Yes	Value normally assumed
	Asphalt heat capacity	Yes	Value normally assumed
	Beam fatigue tests		
	Triaxial permanent deformation tests		
	Dynamic shear at constant height tests		
	Shear permanent deformation at constant height		
	Indirect tensile modulus (dynamic or resilient)		Test temperatures of 40, 60, & 80˚F
	Indirect tensile strength		Test temperatures of 40, 60, & 80˚F
	Moisture sensitivity		

continues

The following sections briefly discuss the requirements for the test sections used for refining the calibration and validation of the 2002 Design Guide distress prediction models with Level 1 design inputs. Table 12 is a checklist of the data needed to execute a variety of M-E design-analysis models.

Consistency of Distress Measurements

A consistent definition and measurement of the surface distresses must be used throughout the calibration and validation process. The distresses should be measured in accordance with the LTPP distress identification guide (Miller and Bellinger, 2003). All data used to establish the inputs

TABLE 12 (continued)

Data Category	Data Element Definition	1-37A Input Parameter	Comment
Cement-Treated Materials	Elastic Modulus	Yes	
	Unconfined Compressive Strength	Yes	
	Third Point Modulus of Rupture	Yes	
	Poisson's Ratio	Yes	Value normally assumed
Unbound Materials & Soils	Resilient Modulus	Yes	
	Poisson's Ratio	Yes	Value normally assumed
	Soil-Water Characteristics Curve	Yes	Value normally assumed
	Coefficient of Lateral Pressure	Yes	Value normally assumed
	Saturated Hydraulic Conductivity	Yes	Value normally assumed
	Maximum Dry Unit Weight	Yes	
	Optimum Gravimetric Water Content	Yes	
	Specific Gravity of Solids	Yes	
	Plasticity Index	Yes	
	Percent Passing #200 Sieve	Yes	
	Percent Passing #4 Sieve	Yes	
	Diameter at 60 Percent Passing	Yes	

for the models (including material test results, climatic data, and traffic data) and performance monitoring should be collected or measured in accordance with standard procedures (Federal Highway Administration, 1993).

Time-Series Distress Data

Projects or test sections should have at least four or more distress surveys or observations. Distress measurements should be made in 2-year intervals, with the exception of rutting, until the distress starts to approach critical levels that will trigger some type of rehabilitation. At that point, the frequency of observations should increase to once per year. For rutting or transverse profile readings, readings must be made each year for the first 3 years after construction. The reason for taking these early measurements is to distinguish the initial or primary densification rate from the long-term or secondary (also referred to as the steady-state region) permanent deformation rate. All distress measurements should be made in accordance with the LTPP distress identification guide (Miller and Bellinger, 2003) for consistency between projects.

Level 1 Input Parameters

All of the data elements listed in Table 12 must be either available from project records or determined or measured to fully implement the NCHRP Project 9-30 calibration-validation refinement experimental plan.

Traffic Data

Since truck traffic or the number of wheel loads needs to be well defined, Level 1 traffic inputs are required.

Unbound Material and Soil Properties

Unbound material tests or properties are required for each distress prediction model. The material properties of the unbound pavement layers must be measured with the same test protocols to ensure that the results are compatible between different projects and test sections. All structural layers of test sections selected for the experiment must be tested and characterized in accordance with the standard guidelines selected and used to develop the distress prediction models. The properties of the unbound layer should simulate the condition at construction. The results from repeated load-resilient modulus tests should be available or measured in accordance with the applicable LTPP protocol or an equivalent procedure—AASHTO T307.

Number of Layers

Test sections should be selected with the fewest structural layers and materials (e.g., one or two asphalt concrete layers, one unbound base layer, and one subbase layer) to reduce the amount of testing required for material characterization.

Rehabilitation and New Construction

Test sections with and without overlays are needed for the model calibration and validation. Test sections that have detailed time-series performance data prior to and after rehabilitation are preferred because these test sections can serve in dual roles as both new construction and rehabilitated pavements.

Nonconventional Mixtures

Test sections that include nonconventional mixtures or layers should be included in the experimental plan to ensure that the model forms and calibration factors are representative of these mixtures. Nonconventional mixtures include stone matrix asphalt (SMA), polymer-modified asphalt (PMA), and open-graded drainage layers. Most of the test sections used to calibrate the NCHRP Project 1-37A performance models were built with conventional HMA mixtures.

HMA Bulk Mixture

At lease 800 lb of bulk mixture is required for each HMA layer. If this amount of bulk mixture is not stored or available, then at least 1,000 lb of aggregate and 100 lb of the asphalt binder is required. Bulk mixture is preferred because it is most representative of the mix in place in the pavement.

HMA Volumetric Properties

The initial air voids and other HMA volumetric properties must be available from construction or project records. All test specimens will be compacted with an approved gyratory compactor in accordance with AASHTO T312 to the air voids measured immediately after construction.

Field Forensic and Evaluation Studies

The field evaluation activities in the experimental plan consist of sampling and testing the pavement structure and taking truck traffic and climate measurements.

Trenches

Trenches are needed to (1) measure the amount of rutting within each paving layer and the subgrade and (2) take a sufficient number of samples from the underlying layers and subgrade for laboratory testing. The rutting measurements are used to improve on the calibration of the permanent deformation within each layer of the pavement structure. The trenches can also be used to determine the direction of crack propagation.

Cores

Cores should be taken to determine the direction of crack propagation. This information is used to determine the cause and mechanism of the crack—for example, whether the crack was caused by segregation of the HMA mixture or a weak bond between two adjacent HMA layers and whether it started at the surface or bottom of the HMA layer. Cores should also be taken to measure the air voids and other in-place properties of the HMA.

Traffic

For test sections located on the highway network, weigh-in-motion (WIM) and automated vehicle classifiers (AVCs) should be used to measure the actual truck traffic in terms of both axle weight and number of applications. The historical truck traffic data should be based on actual measurements over the analysis period. Tire pressures should also be measured on trucks selected at random at enforcement sites or ports of entry. If traffic data are missing or unavailable, the field site should be excluded from the experiment.

Nondestructive Deflection Tests

Falling weight deflectometer (FWD) deflection basin tests should be taken periodically, but at a minimum of two time periods, immediately after construction (i.e., within the same season that the wearing surface was placed, to establish the baseline values) and prior to sampling and testing the pavement structure. The optimum time periods include after construction and within each season of a typical year, both prior to and after the occurrence of any cracks.

Distress Surveys

Distress surveys measure the magnitude and severity of distress. Distress surveys should be performed in accordance with the LTPP distress identification manual (Miller and Bellinger, 2003), with the exception that rut depths should be measured every year for the first 3 years after construction. The distress surveys should be completed once the distress has occurred. Four distress surveys are needed, at a minimum, but if fewer surveys are available, the field site should be dropped, unless the time-series data show a consistent trend in the distress magnitude and severity level.

Climate

Automated weather stations (AWSs) can be used to collect the climate data that are needed to predict pavement performance with the 2002 Design Guide software. The 2002 Design Guide software contains historical data for many weather stations. The test section location should be checked against the AWS sites included in the software to ensure that a site or a combination of sites (to develop a virtual weather station) have a sufficient amount of weather data for the subject calibration site. If the data are insufficient, the field site should be dropped.

Materials Sampling

In addition to the HMA bulk mixture requirements presented above, at least 300 lb of material from each unbound aggregate layer and the foundation soil is required to perform the testing needed for measuring the base-year properties input to the 2002 Design Guide.

Materials Testing Plan

The materials testing plan focuses on the 2002 Design Guide and the test protocols that support determination of the Level 1 material property inputs. However, the M-E database discussed in a later section also provides for the inclusion of test protocols and material properties required by the other M-E model forms listed in Table 12.

The Level 1 inputs to the 2002 Design Guide require the following HMA mixture testing:

- Triaxial dynamic modulus.
- Indirect tensile creep-compliance.
- Indirect tensile strength.
- Beam fatigue strength.
- Triaxial repeated load permanent deformation.

Beam fatigue tests and triaxial repeated permanent deformation tests are included in the test program to adjust the predictions to better account for the effects of mixture or gradation type than in the original NCHRP Project 1-37A calibration. The results of the WesTrack project (Epps et al., 2002) showed that the fatigue strength of HMA mixtures could not be solely explained by the dynamic modulus of the mix; aggregate gradation also had a significant effect. Thus, the experimental plan must account for these type of factors to reduce the total error and decrease the level of uncertainty in the predictions.

Beam fatigue tests are also included in the test plan for measuring the fatigue and fracture strength of nonconventional mixtures. It is expected that up to half of the mixtures included in the experimental plan will consist of PMA or some other nonconventional mixture for which the exponents and coefficients of the fatigue relationships have yet to be well defined.

An M-E prediction model for reflection cracks is not included in the 2002 Design Guide software, and the mechanism of surface-initiated fatigue cracks has yet to be confirmed. Thus, the preliminary test program was developed under the assumption that the fracture properties of an HMA mixture can be adequately measured using the indirect tensile and beam fatigue tests for predicting both reflection cracks and surface-initiated fatigue cracks.

Other mechanistic tests are included in Table 12 to ensure that agencies can accurately characterize HMA mixtures for forensic investigations, when bulk mixture is unavailable, and for acceptance testing using in-place properties.

Table 13 summarizes the minimum tests for determining the HMA mixture properties. These tests should be performed in accordance with the procedures recommended by

TABLE 13 Preliminary test program and minimum sample size requirements for determining the Level 1 inputs for the 2002 Design Guide

Test Protocol	Test Condition	**No. of Test Specimens**	**Sample Size; Amount of Material, lb**
Triaxial Dynamic Modulus Test – Master Curve	Test Temperatures: 25, 40, and 50°C. Test Frequency: 0.1, 0.3, 1.0, 3.0, & 10 Hz.	6	120
Triaxial Repeated Load Permanent Deformation Test	Test Temperatures: 40 and 50°C Haversine Loading: 0.1 load duration; 0.9 rest period	6	120
Indirect Tensile Creep-Compliance Test – Master Curve	Test Temperature: -20, -10, 0, 5 & 20°C.	10	125
Indirect Tensile Strength Test	Test Temperature: –20, -10, 5, and 20°C.	8	100
Beam Fatigue Test	Test Temperature: 20°C Strain Levels: 250, 550, & 850 micro-strains	9	100

Notes:

1. 800 lb of each HMA mixture should be sampled for sampling option number 1 (bulk mixture); or 1,000 lb of aggregate for sampling option number 2 (mixture components).
2. This testing plan will need to be updated after NCHRP Projects 1-41 (reflection cracking model selection) and 1-42 (surface-initiated fatigue cracks) begin to take direction and the prediction models for reflection cracks and surface-initiated fatigue cracks have been selected or defined.

TABLE 14 Estimated number of projects or HMA mixtures that should be included in the laboratory test plan by distress type, at a minimum

Pavement Type or Family of Pavements	Distress Category			
	Rutting	Fatigue Cracking	Thermal Cracking	Reflection Cracking
Conventional Pavements; Thin HMA Surfaces	2	2	2	NA
Deep Strength Pavements; Thick HMA Surfaces & Bases	2	2	2	NA
Full Depth HMA Pavements	2	2	6	NA
Semi-Rigid Pavements	4	14	NA	14
HMA Overlays of Flexible Pavements	2	2	2	7
HMA Overlays of Intact PCC Slabs	0	NA	NA	6
HMA Overlays of Cracked & Seated PCC Pavements	2	NA	NA	6
HMA Overlays of Rubblized PCC Slabs	4	6	6	6
Total Number of Sections	**18**	**28**	**18**	**39**

NCHRP Projects 1-37A and 9-19 or the test protocols developed during SHRP that are now available in AASHTO format. As discussed above, other HMA mixture tests can be performed and the results included in the M-E database for calibrating other M-E distress prediction models, but these tests were not included in the table because it focuses on tests needed in support of the 2002 Design Guide.

Materials from all bound and unbound pavement layers also need to be tested and evaluated for the pavement sections included in the parts of the experiments dealing with load-related distresses. Repeated load-resilient modulus tests should be completed in accordance with LTPP Test Protocol TP46 or AASHTO T 307. This eliminates the need to rely on more variable, back-calculated material properties, properties calculated through the use of regression equations, or the use of the best-guessed values for the surface and underlying pavement layers and subgrade. Repeated load-resilient modulus tests were used to test the unbound layers in accordance with TP46 for many of the projects listed in Table 11.

Table 14 lists the estimated number of projects or HMA mixtures to be included in the laboratory test plan for mixture characterization by distress type, taking into consideration the HMA mixture testing already completed on other projects. The following projects are those for which no M-E laboratory tests have been performed; some of these projects are still under construction or in the planning stage.

- SPS-1: Alabama, Montana, Nebraska
- SPS-5: Colorado, Mississippi, Texas
- SPS-6: Alabama, California
- SPS-9: Montana
- LA-ALF: Louisiana; cement-treated base (CTB) experiment
- FHWA-ALF: Round 2 (under construction)
- Mississippi: I-55, PMA Experiment
- MnRoad: Round 2 (planned)
- NCAT: Round 2 (under construction)

The LA-ALF experiment is the only project of those listed above that includes a semi-rigid pavement structure, a pavement type that is underrepresented among the test sections available for the experimental plan.

The testing program for reflection cracking may change as the findings of NCHRP Project 1-41 become available; the number of sections shown in Table 10 could increase or decrease.

PRELIMINARY SCHEDULE AND BUDGET

The HMA materials testing and field studies described above will take about 2 years to complete. This time frame will permit the inclusion of relevant results from the second round of testing underway at the NCAT test track and the FHWA-ALF.

Table 15 summarizes the expected cost per test section to carry out the materials testing plan. This cost assumes that sufficient HMA mixture is available in bulk; costs might be as much as $4,000 higher if HMA specimens must be prepared by compaction and aging from component materials. In addition to the laboratory tests in the table, field studies are needed to determine the permanent deformation

TABLE 15 Costs per HMA mixture for measuring the Level 1 materials property inputs required for the 2002 Design Guide

Item or Activity		**Item Unit**	**Unit Cost, $**
Shipping of materials from storage point to laboratory; asphalt binder and bulk HMA mixture.		800 to 1,000 lb	1,000
Binder testing and characterization to determine performance grade of original asphalt binder.		AASHTO MP1 tests	1,000
Binder extraction from field sample, testing, and characterization to determine performance grade of aged asphalt binder.		AASHTO MP1 tests	1,500
Test specimen preparation and triaxial dynamic modulus tests to develop master curve for rutting and fatigue cracking characterization.		6 specimens	1,200
Test specimen preparation and triaxial permanent deformation tests for rutting characterization.		6 specimens	1,800
Test specimen preparation for low-temperature cracking characterization.	Indirect tensile creep and compliance tests to develop master curve.	6 specimens	1,200
	Indirect tensile strength tests.	4 specimens	400
Test specimen preparation for fracture characterization.	Indirect tensile creep and compliance tests.	4 specimens	800
	Indirect tensile strength tests.	4 specimens	800
Test specimen preparation and beam fatigue tests for fracture characterization.		9 specimens	6,300
Total Unit Costs for Materials Characterization			16,000
Total Unit Costs for Field Investigations—Forensic Studies		Project Site	7,500

in each layer, confirm the direction of crack propagation, measure the propagation depth of thermal cracks, or all three. The cost of this field work, as shown in the table, including traffic control and repairs to trenched or cored pavement areas, is estimated at $7,500 per project site, assuming three test sections at each project site.

MECHANISTIC-EMPIRICAL DATABASE FOR MODEL CALIBRATION AND VALIDATION

Microsoft Access Database

Model calibration and validation require the assembly and analysis of large quantities of data for each of many field sites. A well-designed and easy-to-use relational database can greatly ease the management and access of this information. Consequently, the design of an appropriate database structure was an important product within the overall development of the NCHRP Project 9-30 experimental plan.

The M-E Distress Prediction Models (*M-E_DPM*) database was developed in Microsoft Access to provide an appropriate database structure for storing all pavement and materials data required for the continued refinement of the HMA M-E distress prediction models in the 2002 Design Guide. However, the database was designed with the flexibility to encompass the calibration and validation of other distress prediction models such as those developed in the WesTrack project (Epps et al., 2002).

The starting point for the database design was the LTPP DataPave 3.0 database. The LTPP database is well designed to store climate, traffic, and measured performance data, and it was desirable to retain as much of the familiar LTPP database structure as possible.

Characteristics and Features of the Database

M-E_DPM should be perceived as a living source of data to be used in the future, similar to the LTPP database. *M-E_DPM* was developed with the following characteristics and features to satisfy the NCHRP Project 9-30 objective and goals:

- Flexibility.
- Links to LTPP DataPave.
- Maximization of potential use.

Flexibility

Flexibility is designed into *M-E_DPM* to permit the addition of other parameters that may need to be added based on future studies. The basic structure of the database consists of three parts or tables:

- Part I—Descriptive Database. This part consists of text files that define or document details of the data included in the second part of the database. Ample provision was provided for including explanatory notes for each data record. In most instances, the data fields for these

TABLE 16 Summary of data table descriptions and data identifications in the M-E database, *M-E_DPM*

1 CAL_Sections	General section information
2 CAL_Layers	Layer structure information
3 CAL_Property_Dictionary	Listing of all material property types that can be stored in the database
4 CAL_Property_Values	Values for material properties
5 CAL_Lookup_Aggregates	Lookup table for aggregate types—e.g., limestone, basalt
6 CAL_Lookup_Binder_Grades	Lookup table for binder grading systems—e.g., Superpave vs. conventional viscosity
7 CAL_Lookup_Cement_Types	Lookup table for cement types—e.g., Type I
8 CAL_Lookup_Cement_Curing_Methods	Lookup table for cement curing method types—e.g., wet curing
9 CAL_Lookup_Infiltration	Lookup table for pavement infiltration categories
10 CAL_Lookup_Materials	Lookup table for material types—e.g., asphalt, PCC
11 CAL_Lookup_Pavement_Types	Lookup table for types of pavement construction—e.g., flexible, composite
12 CAL_Lookup_Property_Qualifiers	Lookup table for property qualifiers—e.g., temperature, frequency, water content
13 CAL_Lookup_Property_Types	Lookup table for property types—e.g., mechanical vs. thermohydraulic
14 CAL_Lookup_Property_Value_Method	Lookup table for methods of determining material property values—e.g., measured vs. estimated
15 CAL_Lookup_Units	Lookup table for material property unit of measure—e.g., mm, kpa

explanatory notes are of the “Memo” type, which in Microsoft Access permits entry of up to 64,000 characters of information.

- Part II—Inputs/Data for M-E Model Execution. This part consists of the actual data that are needed to execute the distress prediction models. This part is further subdivided into pavement structure, material properties, traffic, and climatic data.
- Part III—Performance Data. These data include the date on which the distress surveys were made and the values for the magnitude and severity of the distress.

Following the LTPP schema, a prefix is used throughout *M-E_DPM* to designate the general topic area (module, in LTPP terms) for the various data tables. All new data tables in *M-E_DPM* begin with a CAL prefix. Tables in the database that are lookup tables (e.g., contain the universe of values for other fields in the database) have a CAL_Lookup prefix, as listed and defined in Table 16.

Links to LTPP DataPave

The design of *M-E_DPM* was based on new, improved tables for general project information, pavement structure (layer) data, and material property data. However, *M-E_DPM* retained and provides a link to the climate, traffic, and performance tables from the LTPP DataPave 3.0 database. The design of the new material property data tables in *M-E_DPM* is highly flexible. Instead of predefining the material properties to be stored for each layer, multiple material property records are linked to each layer, with the material property name part of the content of the data record. This flexibility allows other material properties to be entered that are not required inputs to the 2002 Design Guide.

The listing of possible material property names and their characteristics is specified in a separate “property dictionary” table or the descriptive database portion. Although the initial implementation of *M-E_DPM* focuses on the material properties required for the 2002 Design Guide models, the material property tables are designed in such a way that other properties can be added in the future.

Maximization of Potential Use

M-E_DPM was developed to maximize its potential use for calibrating and validating M-E distress prediction models for use in design and analysis. Besides the national-scale calibration and validation of distress prediction models, other potential uses of *M-E_DPM* include the following:

- Documenting regional calibration studies.
- Tying mixture design to structural design to performance-related specifications.
- Confirming or rejecting various hypotheses for distress mechanisms (for example, surface-initiated fatigue cracks).

TABLE 17 Projects and test sections that were used to initially populate the M-E database

Project or Experiment Identification		Applicable Distresses	Test Section Information	
MnRoad		Fatigue & Thermal Fracture, Rutting, IRI	Conventional & Deep Strength HMA Pavement	1, 3, 4, 14, 15, 16, 17, 18, 19, 20, 21, 22
WesTrack		Fatigue Fracture, Rutting & IRI	Conventional HMA Pavement	1, 3 to 24
NCAT	Round 1	Rutting & IRI	Deep Strength Pavement	E06, N02, N03, N05, N07, N11, N12, N13, S02, S12, S13
Nevada	I-80; Modifier	Fatigue & Thermal Fracture, Rutting, IRI	Conventional Pavement	SPAC-20P, SPPG64-22, NVAC-20P, NVPG64-22
Mississippi	I-55; Modifier	Fatigue Fracture, Rutting, IRI	Conventional Pavement	9 Sections with different modifiers
FHWA-ALF	Round 1	Fatigue Fracture, Rutting	Conventional Pavement	Lanes: 5_S2, 7_S2, 8_S1, 9_S2, 10_S1, 10_S2, 11_S1, 11_S2, 12_S1
LA-ALF	CTB Experiment	Fatigue Fracture, Rutting	Semi-Rigid Pavement	Lanes: 2 to 10
LTPP	SPS-9 Experiment	Fatigue & Thermal Fracture, Rutting, IRI	HMA Overlay	Arizona; 902, 903
		Fatigue Fracture, Rutting, IRI	HMA Overlay	Indiana; 901, 902, 904
		Fatigue Fracture, Rutting, IRI	HMA Overlay	Indiana; A901, A902, A903, A959, A960, A961
LTPP	SPS-9 Experiment	Fatigue & Thermal Fracture, Rutting, IRI	Conventional Pavement	Montana; 901, 902, 903
		Fatigue Fracture, Rutting, IRI	Conventional Pavement	Arizona; B901, B902, B903, B960, B961, B962, B964
		Fatigue & Thermal Fracture, Rutting, IRI	Conventional Pavement	Ontario; 901, 902, 903
LTPP	SPS-6 Experiment	Rutting, IRI	HMA Overlay of PCC	Alabama, California
LTPP	SPS-1 Experiment	Fatigue Fracture, Rutting, IRI	Conventional & Deep Strength Pavement	Alabama; 01 to 12; Montana; 13 to 24; Nebraska; 13 to 24
LTPP	SPS-5 Experiment	Fatigue Fracture, Rutting, IRI	HMA Overlay of HMA Pavement	Colorado; 02 to 09; Minnesota; 02 to 09; Mississippi; 02 to 09; Texas; A502 to A509

Notes:

- Data from the two Caltrans HVS experimental studies were not used to initially populate the M-E database.
- Other LTPP projects that can provide valuable data but have limited materials available for testing include the SPS–9 projects in Michigan, Quebec, Texas, and Wisconsin; the SPS-1 projects in Florida, New Mexico, Nevada, and Texas; and the SPS-5 projects in Arizona, California, and Maine.

Population of Database

The starting point for population of the database was the project databases developed in the *Superpave Simple Performance Test* field validation effort in NCHRP Project 9-19 and, most especially, the calibration and validation database developed for the 2002 Design Guide. These databases drew extensively from other sources, including LTPP, MnRoad, WesTrack, and FHWA ALF. Table 17 lists the projects and test sections that were used to initially populate the M-E database. Population of the database with information from new sites identified in the NCHRP Project 9-30 experimental plan will be carried in future projects that implement the plan. In addition, data from regional calibration studies may be included in *M-E_DPM*.

REFERENCES

Epps, J. A., et al., *NCHRP Report 455: Recommended Performance-Related Specification for Hot-Mix Asphalt Construction: Results of the WesTrack Project*, Transportation Research Board of the National Academies, Washington, DC, 2002.

Federal Highway Administration, LTPP Division, *Data Collection Guide for Long-Term Pavement Performance Studies*, Operational Guide No. SHRP-LTPP-OG-001, Revised October 1993.

Miller, J. S., and Bellinger, W. Y., *Distress Identification Manual for the Long-Term Pavement Performance Program*, Report FHWA-RD-03-031, Federal Highway Administration, McLean, Virginia, June 2003.