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Texas Flexible Pavements and Overlays: Interim Report for Phases II and III—Data Collection and Model Calibration

Technical Report 0-6658-2

Cooperative Research Program

TEXAS A&M TRANSPORTATION INSTITUTE
COLLEGE STATION, TEXAS

in cooperation with the
Federal Highway Administration and the
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Sang Ick Lee, Lubinda F. Walubita, Abu N. M. Faruk, Tom Scullion, Soheil Nazarian, and Imad Abdallah

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16. Abstract
This five-year project was initiated to collect materials and pavement performance data on a minimum of 100 highway test sections around the state of Texas, incorporating both flexible pavements and overlays. Besides being used to calibrate and validate mechanistic-empirical (M-E) design models, the data collected will also serve as an ongoing reference data source and/or diagnostic tool for Texas Department of Transportation engineers and other transportation professionals.

Toward this goal, this second interim report provides documentation of the work performed from Year 1 through Year 5 of this project, focusing on Phases II and III activities, including the following: (a) collection, processing, and analysis of laboratory and field data; (b) data population and update in the data storage system (DSS) and raw data storage system for the project 0-6658 (RDSSP), respectively; (c) development of M-E calibration plans and guideline; and (d) preliminary calibration of the M-E models and software to Texas conditions using the collected data in the DSS.

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HMA, Flexible Pavements, Overlays, MS Access, Data Storage System, DSS, Raw Data Storage System, RDSS, Calibration, M-E Model, M-E Software, FPS, TxACOL, TxME, M-E PDG

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TEXAS FLEXIBLE PAVEMENTS AND OVERLAYS: INTERIM REPORT FOR PHASES II AND III—DATA COLLECTION AND MODEL CALIBRATION

by

Sang Ick Lee
Assistant Transportation Researcher
Texas A&M Transportation Institute

Lubinda F. Walubita
Research Scientist
Texas A&M Transportation Institute

Abu N. M. Faruk
Research Associate
Texas A&M Transportation Institute

Tom Scullion
Senior Research Engineer
Texas A&M Transportation Institute

Soheil Nazarian, Ph.D., P.E.
Center Director
Center for Transportation Infrastructure Systems

Imad Abdallah, E.I.T.
Associate Director
Center for Transportation Infrastructure Systems

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TEXAS A&M TRANSPORTATION INSTITUTE
College Station, Texas 77843-3135

CENTER FOR TRANSPORTATION INFRASTRUCTURE SYSTEMS
University of Texas at El Paso
El Paso, Texas 79968-0582

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The contents of this report reflect the views of the authors, who are responsible for the facts and the accuracy of the data presented here. The contents do not necessarily reflect the official view or policies of the Federal Highway Administration (FHWA) or the Texas Department of Transportation (TxDOT). This report does not constitute a standard, specification, or regulation, nor is it intended for construction, bidding, or permit purposes.

The United States Government and the State of Texas do not endorse products or manufacturers. Trade or manufacturers' names appear herein solely because they are considered essential to the object of this report. The researcher in charge was Lubinda F. Walubita.

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LIST OF ABBREVIATIONS AND SYMBOLS

AASHTO	American Association of State Highway and Transportation Officials
AC	Asphalt concrete
ACP	Asphalt concrete pavement
AADTT	Annual average daily truck traffic
ADT	Average daily traffic
ADTT	Average daily truck traffic
BBR	Bending beam rheometer
CSJ	Control, section, and job
CTB	Cement-treated base
CV	Coefficient of variation
DC	Dry-cold
DCP	Dynamic cone penetrometer
DM	Dynamic modulus
DSR	Dynamic shear rheometer
DSS	Data storage system
DW	Dry-warm
EICM	Enhanced integrated climatic model
ESAL	Equivalent single axle load
FDR	Full depth reclamation
FE	Fracture energy
FFRC	Free-free resonance column
FHWA	Federal Highway Administration
FN	Flow number
FPD	Field performance data
FPS	Flexible Pavement System
FWD	Falling weight deflectometer
GPR	Ground penetrating radar
GWT	Ground water table
HMA	Hot-mix asphalt
HWTT	Hamburg wheel tracking test
Hwy	Highway
IDT	Indirect tensile test
IRI	International roughness index
LTB	Lime-treated base
LTE	Load transfer efficiency
M	Moderate
MD	Moisture density
MDD	Maximum dry density
M-E	Mechanistic empirical
M-E PDG	Mechanistic-Empirical Pavement Design Guide
MoR	Modulus of rupture
MS	Microsoft©
MSCR	Multi-stress creep and recovery
NCHRP	National Cooperative Highway Research Program
OT	Overlay Tester

PAV	Pressure aging vessel
PCC	Portland concrete cement
PG	Performance grade
PP	Perpetual pavement
PSI	Pavement serviceability index
PVMNT	Pavement
QC/QA	Quality control/Quality assurance
RDSSP	Raw Data Storage System for Project 0-6658
RLPD	Repeated load permanent deformation
RTFO	Rolling thin-film oven
SPG	Surface performance grade
SPST	Simple punching shear test
STDEV	Standard deviation
TTI	Texas A&M Transportation Institute
TxACOL	Texas Asphalt Concrete Overlay Design and Analysis System
TxDOT	Texas Department of Transportation
TxME	Texas Mechanistic-Empirical Flexible Pavement Design System
UCS	Unconfined compressive strength
UTEP	University of Texas at El Paso
WC	Wet-cold
WIM	Weigh-in-motion
WP	Wheel path
WW	Wet-warm

CHAPTER 1
INTRODUCTION

Proper calibration and validation of mechanistic-empirical (M-E) design and rehabilitation performance models to conditions in Texas is essential for cost-effective flexible pavement designs. To achieve proper calibration and validation and to produce tangible benefits, quality and reliable pavement performance data should be collected on a sustained basis. The veracity of the calibration of TxDOT's pavement design models will determine how optimally billions of dollars of future roadway investment capital will be spent. The research team initiated this study to develop a comprehensive Microsoft© (MS) Access® data storage system (DSS) containing material properties and performance data for a minimum of 100 flexible pavement and HMA overlaid test sections in Texas. Besides being used to calibrate and validate M-E design models, the data collected will also serve as an ongoing reference data source and/or diagnostic tool for TxDOT engineers and other transportation professionals.

PROJECT OBJECTIVES

The primary goal of this project was to collect and then develop a data storage system of material and pavement performance data on a minimum of 100 flexible pavement and HMA overlaid highway test sections around Texas. Phase II focused on the following objectives:

- Conduct laboratory and field testing.
- Conduct periodic performance monitoring of the test sections.
- Process and analyze the collected data including accuracy verification.
- Review and evaluate the processed data to ensure they are readily accessible and useful.

For easy management and access, all laboratory and field data were collected in two data repository systems, namely the MS Access DSS for the processed data and the Raw Data Storage System for Project 0-6658 (RDSSP) for unprocessed raw data. A CD of the data storage systems is included as an integral part of this report. Principally, the data collected and the associated DSS and RDSSP were intended to serve two purposes:

- Calibrate and validate the M-E design models.
- Serve as an ongoing reference data source and/or diagnostic tool for TxDOT engineers and other transportation professionals.

The objectives of Phase III were to:

- Develop a calibration and validation process for the M-E models and associated software including the Flexible Pavement System (FPS), Texas Asphalt Concrete Overlay Design and Analysis System (TxACOL), Texas Mechanistic-Empirical Flexible Pavement Design System (TxME), and Mechanistic-Empirical Pavement Design Guide (M-E PDG).

- Provide a description of how the collected data would be utilized in the calibration and validation process.
- Conduct preliminary calibration and validation of the M-E models.

For each of the above M-E models/software, the scope of work included: relating the material's model to response (i.e., stress, strain), relating response to field distresses, and relating distresses to some overall performance indicators or indices such as pavement serviceability index (PSI), international roughness index (IRI), etc.

RESEARCH TASK AND WORK PLAN

Figure 1 summarizes the four-phase work plan and the associated research tasks; it also includes the specific tasks and the periods of execution. Researchers designed the four phases to specifically address the following key aspects of the project:

1. Phase I–Literature review, planning, and pilot data demonstration. This aspect was covered in Year 1 of the project.
2. Phase II–Data collection. This task constituted the bulk workload of the whole project and ran for the duration of the project. The task incorporated extensive field and laboratory testing to generate data for input into the MS Access data storage system.
3. Phase III–Model calibration. Run in Year 3 through Year 5 of the study, this phase focused on calibrating and validating the M-E structural design systems.
4. Phase IV–Project management, data demonstration, and report writing. Under this task, progress meetings were held annually to monitor progress and provide updates on the project. In the final year of the project, a workshop was held to demonstrate the data collected.

Phase	Tasks	Period
PHASE I: LITERATURE REVIEW, PLANNING, & PILOT DATA DEMO	1) Literature search & project kick-off meeting 2) Review of M-E models & data requirements 3) Review of existing databases 4) Development of data collection, analyses, & reporting plans 5) Selection of field test sections 6) Project meeting on Tasks 4 & 5 7) Pilot & prototype data demo Submit report @ End of Phase I	Year 1
PHASE II: DATA COLLECTION	8) Data collection including extensive laboratory and field testing • West Texas – UTEP • Remaining regions – TTI 9) Data processing & analysis 10) Data population & updates 11) Evaluation of the data storage & reporting formats	Year 1 to 5
PHASE III: MODEL CALIBRATION	12) M-E model calibration plans 13) M-E model calibration & validation 14) Project meeting on Tasks 12 & 13 Submit report @ End of Phase II & III	Year 3 to 5
PHASE IV: DATA DEMO & REPORTS	15) Data demonstration workshop (June 2015) 16) Report writing	Year 5
	17) Project management (Annual progress meeting)	Yearly (August)

Figure 1. Work Plan and Research Tasks.

REPORT CONTENT AND ORGANIZATION

Based on the work plan shown in Figure 1, the primary objective of this second report is to document the work completed in Years 1 to 5 of this project, focusing on Phase II and III activities. Itemized as Task 8 through 14 in Figure 1, the main scope of work covered under Phase II and III was:

- Phase II:
  - Evaluate material properties and collect field performance data.
  - Process and analyze data generated from laboratory and field testing.
  - Populate and update data in the DSS and RDSSP including processed and unprocessed data, respectively.
- Phase III:
  - Develop calibration plan and process.
  - Conduct preliminary calibration and validation of M-E models and software using the data collected.

This report consists of seven chapters including this one (Chapter 1), which provides the background, research objectives, methodology, and scope of work. Chapter 2 discusses the criteria and procedures for selecting test sections and provides an update of the test section data by pavement type and service life. Chapters 3 through 6 are the main backbone of this report and cover the following key items:

- Chapter 3—Data collection and analysis.
- Chapter 4—Data population and update.
- Chapter 5—Calibration plan and data analysis for M-E models.
- Chapter 6—Preliminary calibration of M-E models.
- Chapter 7—Major findings and recommendations.

Some appendices containing important data are also included at the end of the report. A CD of the MS Access Data Storage System is also included as integral part of this interim report.

SUMMARY

This introductory chapter presented the project background and research objectives, followed by the research methodology, scope of work, and report overview. Specifically, this report provides a documentation of the work accomplished in Years 2 to 5 of the project. In particular, the report focuses on Phase II and III activities, which include the data collection and analysis and the M-E model calibration, respectively.

CHAPTER 2
TEST SECTIONS TO DATE

The primary objective of this project was to collect and then develop a data storage system of material and pavement performance data on a minimum of 100 flexible pavement and HMA overlaid highway test sections around Texas. In total, the DSS includes 112 highway test sections with the distribution between the University of Texas at El Paso (UTEP) and the Texas A&M Transportation Institute (TTI) as follows:

- UTEP = 33 test sections.
- TTI = 79 test sections.

This distribution of the test sections was based on geographic proximity and resource capacity in terms of facilities, equipment, and personnel. Since UTEP is located in West Texas, researchers deemed it practical for UTEP to handle the test sections in the dry-cold (DC) and dry-warm (DW) climatic regions, while TTI handled the central and eastern parts of Texas covering the moderate (M), wet-cold (WC), wet-warm (WW), and some parts of the DC and DW climatic regions, as shown in Figure 2.

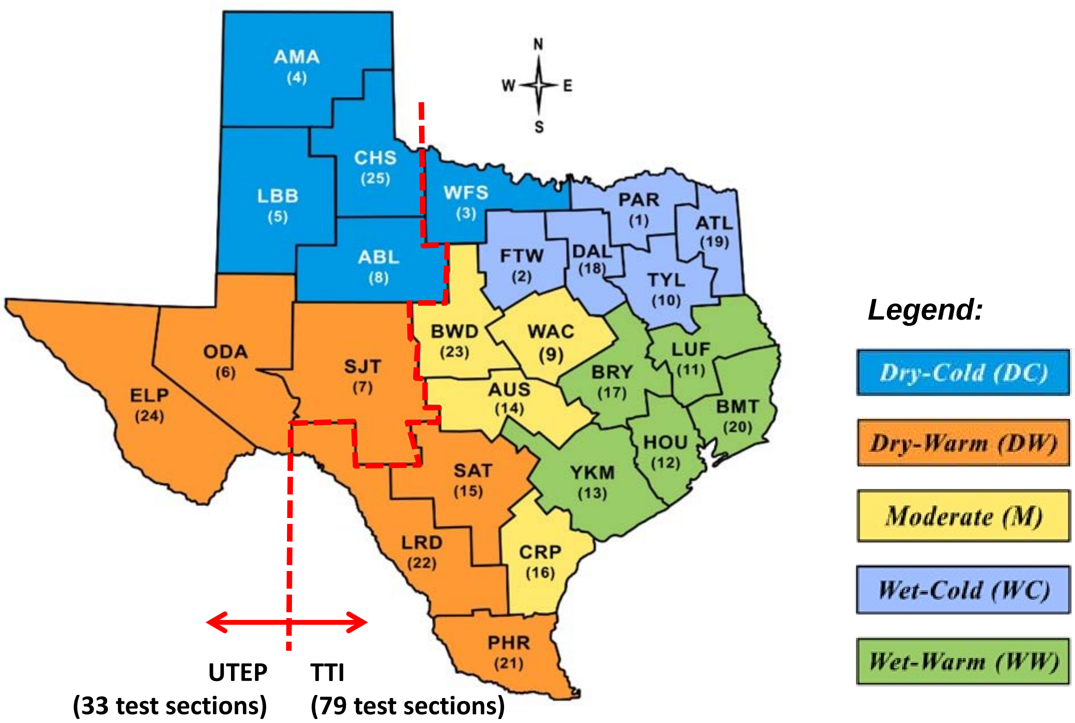


Figure 2. Climatic Distribution of Test Sections between UTEP and TTI.

CRITERIA FOR SELECTING TEST SECTIONS

In order to collect meaningful data required to effectively calibrate and validate the M-E models and software, researchers needed to select the test sections based on influencing variables such as pavement type, traffic levels, environmental types, etc. For instance, the test sections could not be only overlays or new construction; instead, the coverage needed to be as broad as possible to cover all the variables listed in Table 1. It was also critical for researchers to consider monitoring distress over time.

Table 1. Variables for Selecting Test Sections.

No.	Variable	Description	Comment
1	Pavement type	• Perpetual • Hot-mix asphalt (HMA) overlay • Full depth reclamation (FDR) • New construction	
2	Surface/sublayer type	• HMA on HMA • HMA on flex base • HMA on treated base (cement-treated base [CTB], lime-treated base [LTB], and asphalt) • HMA on Portland cement concrete (PCC) • Surface treatments (seal coat, etc.)	Warm-mix asphalt, reclaimed asphalt pavement (RAP), reclaimed asphalt shingles (RAS), and perpetual pavements (PPs) were also considered.
3	Surface thickness	• Thin (≤ 3 inches) • Thick (> 3 inches)	
4	Traffic levels	• Low volume • High volume	Included interstate, state, and farm roads.
5	Environmental types	• Dry-warm • Dry-cold • Wet-warm • Wet-cold • Moderate	

The length of test sections was 500 ft of homogenous pavement structure, preferably in the outside lane. In cases where the pavement structure varied, such as in the number of layers, layer thickness, or material composition within a highway segment, then more than one 500-ft test section could be used. Table 2 lists the test sections with more than 500 ft due to different pavement structures in a single project.

Table 2. List of More Than 500 ft Test Sections.

Highway	District/County	Length	Direction/Lane	Note
US 59	Atlanta/Panola	720 ft	Westbound/ Outside	Different interlayer for HMA overlay – Sec01 No-interlayer – Sec13 Petromat – Sec14 TruPavet
US 59	Atlanta/Panola	720 ft	Westbound/ Inside	Different interlayer for HMA overlay – Sec73 No-interlayer – Sec74 Petromat – Sec75 TruPavet
US 59	Atlanta/Panola	1,000 ft	Westbound/ Outside	Different binder contents of HMA overlay – Sec61 5.2% – Sec62 5.5% – Sec72 5.2%

MARKING AND IDENTIFICATION OF TEST SECTIONS

Once a test section was selected, the start and end points were marked using the following identifiers:

- Painting (white or orange paint) on the shoulders: start/end points and every 100 ft of test section.
- Global position system (GPS) coordinates: start/end points and every 100 ft of test section.
- Offset from established Texas Reference Markers (TRM): nearest start/end points of test section.
- Offsets from nearby physical landmarks such as intersections: start/end points of test section.
- Road signs: at 50 ft from start/end points of test section.

Road signs were installed at the appropriate locations following the guidelines outlined in the Texas *Manual on Uniform Traffic Control Devices* (TxDOT 2006) as follows:

- The signs should be installed at 50 ft from the start and end points of the test section, respectively; however, field conditions may also dictate the exact location of the road signs.
- The signs should be vertically mounted at right angles to the direction of, and facing, the traffic that they are intended to serve.
- The lateral offset should not be less than 6 ft from the edge of the shoulder or 12 ft from the edge of the traveled way.

Figure 3 illustrates the road sign installation at a test section.

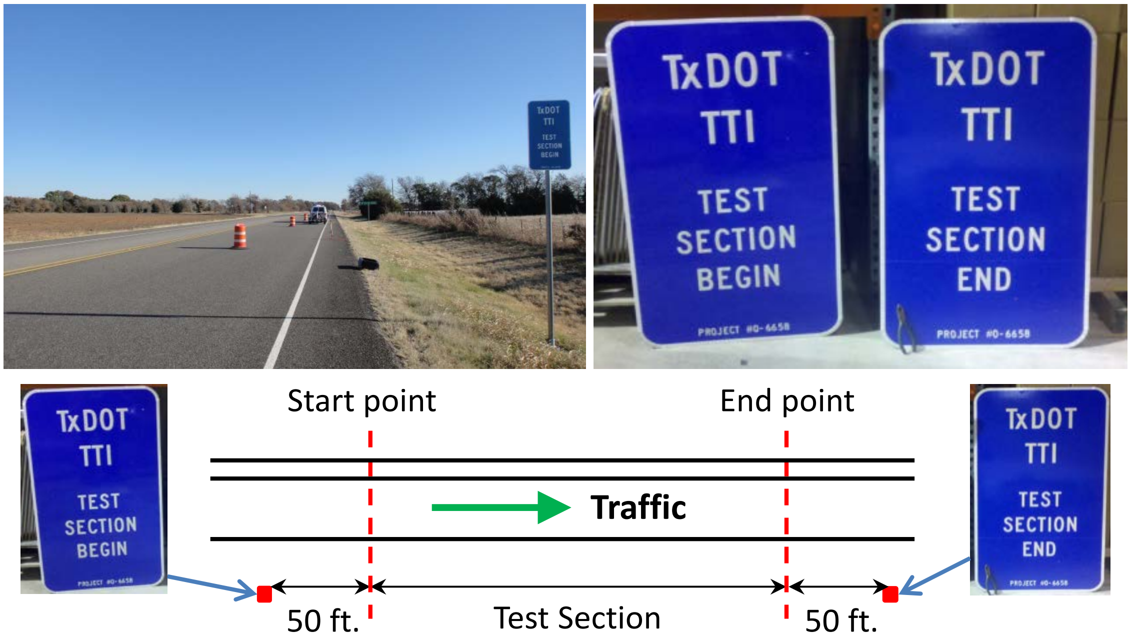


Figure 3. Installation of Road Signs at Test Section.

FIELD TEST SECTIONS TO DATE

The study called for the selection of a minimum of 100 highway test sections around Texas, and the research team identified and selected 112 test sections, consisting of 79 test sections monitored by TTI and 33 test sections monitored by UTEP. The test sections were selected based on distribution of the following categories:

- Pavement types.
- Districts.
- Climatic zones.
- Service life.

Pavement Type

As Table 3 shows, the test sections identified in this study were comprised of PP, HMA overlays, FDR, and new construction. Each type of pavement was subdivided according to material types used for the base layer, namely flex or treated material. Figure 4 illustrates the location of test sections by pavement type as well as stationary TxDOT weigh-in-motion (WIM) stations across Texas.

Table 3. Test Sections by Pavement Type.

No.	Pavement Type	Base Layer Type	Agency		Total
			TTI	UTEP	
1	Perpetual		11		11
2	Overlay	CTB	5		5
3		Flex base	14	15	29
4		LTB	11		11
5		PCC	5		5
6		Asphalt base	3		3
7	FDR	Flex base	4	2	6
8		CTB	8		8
9	New Construction	Flex base	12		12
10		CTB	1	12	13
11		Lime/fly ash treated base		1	1
12		Emulsion		1	1
13	Seal Coat	Flex base	5	2	7
		Total	79	33	112

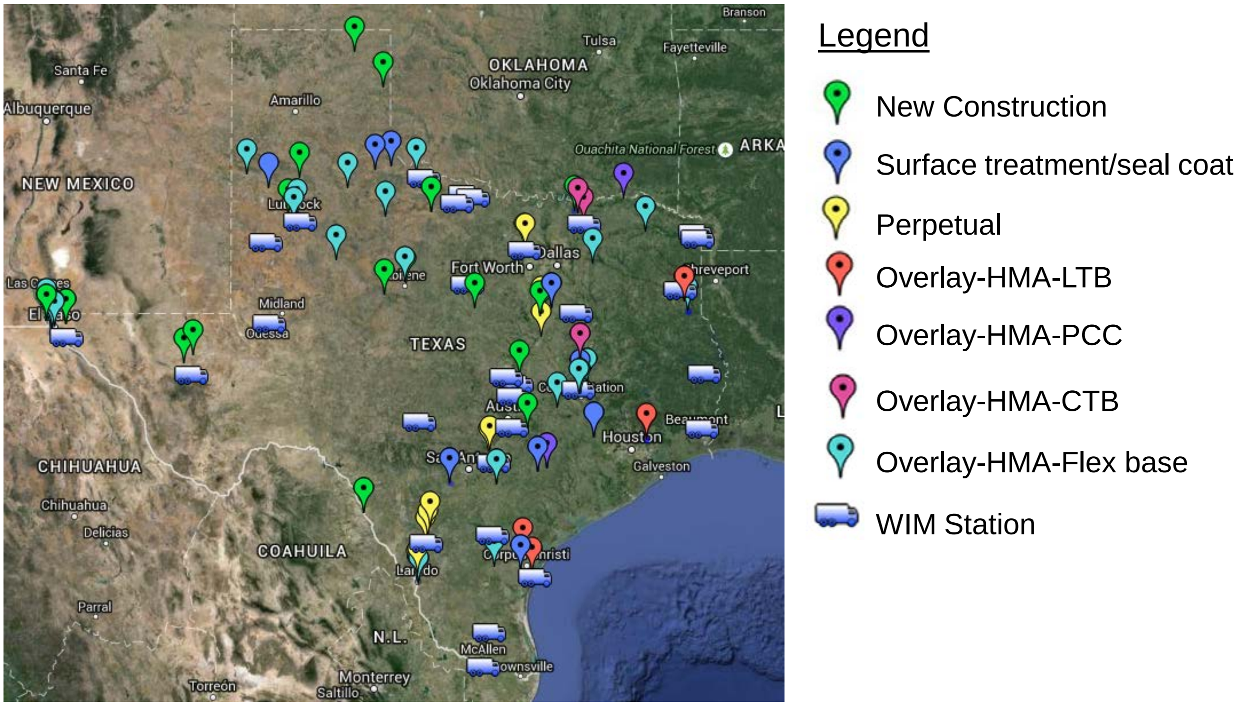


Figure 4. Location of Test Sections and WIM Stations.

District and Climatic Zone

The Texas climatic zone scheme consists of five regions including DC, DW, M, WC, and WW, as shown in Figure 2. Each climatic region has different annual temperatures, precipitation, and freeze/thaw cycles that affect the development of pavement distresses such as thermal cracking or rutting. Therefore, collecting information in each climatic region is imperative to calibration of M-E distress models susceptible to climatic effects. Consequently, the research team identified and selected all test sections with the goal of collecting pavement performance data from all climatic regions. Also, in order to assist TxDOT districts and engineers with making better decisions for rehab strategy selections and design-related issues, researchers selected the test sections from 21 out of 25 districts. Table 4 presents the number of test sections by TxDOT climatic zone and district.

Service Life

Because typical flexible pavement design parameters are established based on a 20-year analysis period, the test sections needed to be monitored so that the design and material properties could be correlated to the actual field performance of the pavement. However, a majority of the test sections (over 70 percent) over the course of this study (5 year duration) were relatively early in their service life with very limited field performance data and little to no distresses. Only perpetual pavement sections, which were constructed between 2003 and 2008, were older than five years and had no critical failure. Table 5 and Figure 5 present the distribution of test sections by service life.

Table 4. Test Sections by Climatic Zone and District.

Climatic Zone	District		No. of Test Sections
	No.	Name	
Dry-Cold	3	Wichita Falls	2
	4	Amarillo	1
	5	Lubbock	7
	8	Abilene	4
	25	Childress	6
Dry-Warm	6	Odessa	2
	7	San Angelo	–
	15	San Antonio	6
	24	El Paso	13
	21	Pharr	–
	22	Laredo	13
Moderate	9	Waco	6
	14	Austin	2
	16	Corpus Christi	8
	23	Brownwood	–
Wet-Cold	1	Paris	4
	2	Fort Worth	3
	10	Tyler	2
	18	Dallas	2
	19	Atlanta	11
Wet-Warm	11	Lufkin	–
	12	Houston	4
	13	Yoakum	4
	17	Bryan	11
	20	Beaumont	1
	Total		112

Table 5. Distribution of Test Sections by Service Life.

Age (year)	TTI		UTEP		Total	
	No.	%	No.	%	Number	%
Under construction	6	7.6	–		6	5.4
1	26	32.9	–		26	23.2
2	5	6.3	10	30.3	15	13.4
3	14	17.7	14	42.4	28	25.0
4	8	10.1	9	27.3	17	15.2
5	10	12.7	–		10	8.9
> 5	10	12.7	–		10	8.9
Total	79	100	33	100	112	100

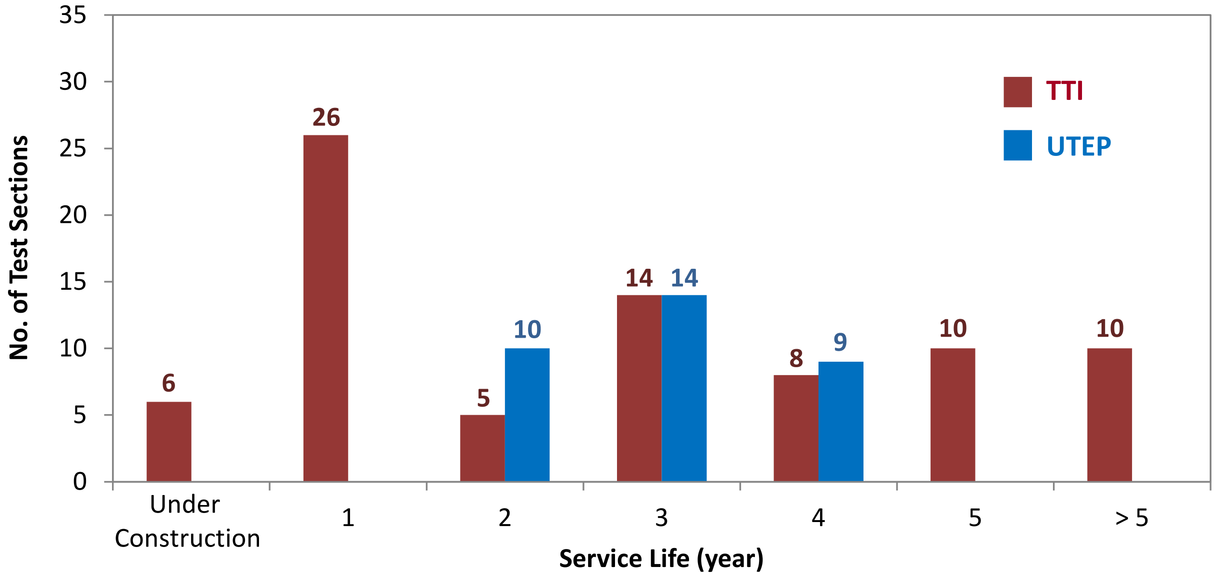


Figure 5. Distribution of Test Sections by Service Life.

In order to facilitate the effective and accurate calibration of the performance models in the current and future analysis software tools developed for or by TxDOT (e.g., TxME and TxACOL), a more complete history of field performance data was required. Even though performance data until failure were desirable, at a minimum, five years of field performance data was required to project performance trends for well-performing or early failing pavements.

SUMMARY

This chapter discussed the test section selection criteria and the selected test sections to date. A total of 112 test sections were selected in accordance with pavement type, climatic zone, district, and service life. However, due to the limited project duration, the test sections were relatively early in their service life and thus had very limited field performance data and little to no distresses. Even though performance data until failure were desirable, at a minimum, five years of field performance data was required to project performance trends for well-performing or early failing pavements. . Therefore, continued field performance monitoring and data collection is essential to evaluate and fine tune the performance predictive capability of the M-E models.

CHAPTER 3
DATA COLLECTION AND ANALYSIS

Data collection and analysis for this study involved laboratory and field testing to generate material properties and performance data for the database and calibration of the M-E models and associated structural design software. This chapter discusses the collection and analysis of data included in the DSS, as listed in Table 6.

Table 6. Types of Data Collected in the Database.

Item		Type of Data
Material properties	Asphalt binder	Specific gravity, viscosity, dynamic shear rheometer (DSR), multi-stress creep and recovery (MSCR), bending beam rheometer (BBR), elastic recovery, performance grade (PG).
	HMA	Repeated load permanent deformation (RLPD), Hamburg wheel tracking test (HWTT), dynamic modulus (DM), Overlay Tester (OT), indirect tensile test (IDT), thermal coefficient.
	Base/subgrade soil	Gradation, Atterberg limit, Specific gravity, moisture-density (MD) curve, Texas triaxial, shear strength, resilient modulus, permanent deformation, unconfined compressive strength (UCS), modulus of rupture (MoR).
Field performance		Surface rutting and cracking survey, profiling, falling weight deflectometer (FWD), dynamic cone penetrometer (DCP), ground penetrating radar (GPR).
Climate		Avg. temperature, precipitation, ground water table (GWT).
Traffic		Volume and classification, load spectra by axle types, truck distribution and growth factor.
Supplementary test		• HMA: flow number (FN), OT monotonic, and simple punching shear test (SPST). • Base: UCS, MoR, free-free resonance column (FFRC), IDT (adding cement into flex base in lab).

LABORATORY DATA

The material properties of each pavement layer are a critical input to predict the pavement performance using M-E models. Therefore, measuring material properties in the laboratory using materials collected from a test section was the best scenario to generate pavement material properties for input into the DSS as well as the M-E models and associated design software. This chapter discusses the laboratory test plans and data collected in this study, including:

- Asphalt-binder tests.
- HMA tests.
- Base and subgrade soil tests.

Note that the laboratory tests were conducted for the highway test sections where the research team could sample and obtain the pavement materials. Some test sections such as the perpetual pavements that were built before initiating this research project were not available to sample the materials.

Asphalt-Binder Tests

All asphalt-binder tests for this study were conducted on extracted binders from the plant mix obtained from haul trucks at the production plant or directly from the HMA mix delivered to the site. These sources represented in-situ field conditions. If the sample came from a mix hauled to the site, it was collected from a minimum of three, but not more than five, different trucks. All mix samples were from deliveries to the travel lane of the test section. The Tex-210-F and 236-F methods were used for extracting the binders (TxDOT 2015). The asphalt-binder tests used to generate the required rheological and engineering properties as well as PG of the extracted binders for this study were:

- SG.
- Viscosity.
- DSR.
- MSCR.
- BBR.
- Elastic recovery (ductility).
- PG grading of asphalt binders.

The Appendix provides a summary of the test procedures and the related test parameters and output data. Detailed descriptions of these tests along with the data analysis methods can be found in Reports 0-6658-P1 and 0-6658-P3 (Walubita et al. 2011, 2012). At a minimum, and for better statistical representation in order to generate the average, standard deviation (STDEV), and coefficient of variation (CV), each HMA test was performed using three replicate samples.

For sections with surface treatments, the neat binder was obtained either from the plant or directly from asphalt distributors during construction to facilitate laboratory testing. The tests for the seal coat binders were similar to the asphalt-binder tests for HMA except for differences in the asphalt-binder grading system and the fact that residual recovery testing was required in the case of emulsions. All test data from the seal coat binders are stored in the asphalt-binders group in the DSS.

Table 7 lists the number of asphalt-binder test data collected in the study for all the test sections that were sampled during the construction stage or cored just after construction. Some test sections such as the perpetual pavements that were built before initiating this research project were not available to sample the asphalt-binders or HMA plant-mix materials to extract the asphalt-binders for testing.

Table 7. Asphalt-Binder Data Collected in the Database.

No.	Test Type	Number of Data		Total
		TTI	UTEP	
1	SG	143	43	186
2	Viscosity	123	85	208
3	DSR	176	84	260
4	MSCR	180	120	300
5	BBR	91	83	174
6	Elastic Recovery	135	81	216
7	PG Grading	67	62	129

Hot-Mix Asphalt Tests

The HMA testing for this project was conducted mainly on plant-mixed materials. Raw materials and highway cores that represented in-situ field conditions were considered only if plant-mix could not be obtained or were otherwise unavailable. The plant-mix was either hauled directly to the construction site or taken from the production plant. As with asphalt-binder testing, if the sample came from a mix hauled to the site, it was collected from a minimum of three, but not more than five, different trucks. All mix samples were collected from the travel lane of the test section. Where extraction tests such as determining the asphalt-binder content and aggregate gradation were required, test methods Tex-210-F and 236-F were used (TxDOT 2015). The HMA mix tests used to generate the required HMA material properties for this study were:

- Asphalt-binder extractions and gradations.
- HWTT.
- OT.
- OT for measuring fracture properties.
- DM.
- RLPD.
- IDT.
- HMA thermal coefficient.

The Appendix provides a summary of the test procedures and the related test parameters and output data. Detailed descriptions of these tests along with the data analysis methods can be found in Reports 0-6658-P1 and 0-6658-P3 (Walubita et al. 2011, 2012). At a minimum, and for better statistical representation in order to generate the average, STDEV, and CV, each HMA test was performed using three replicate samples. For the overlay tests, five samples were run, including regular OT, OT fracture, and monotonic OT, to decrease the CV. Table 8 lists the number of HMA test data collected in the study.

Table 8. HMA Data Collected in the Database.

No.	Test Type	Number of Data		Total
		TTI	UTEP	
1	Volumetrics	93	34	127
2	AC Extractions	165	94	259
3	Gradation Extractions	244	39	283
4	RLPD	340	131	471
5	HWTT (Tex-242-F)	179	69	248
6	DM	1,200	340	1,540
7	OT (Tex-248-F)	399	165	564
8	IDT	179	77	256
9	OT Fracture Properties	273	165	438
10	Thermal Coefficient	172	100	272

Base and Subgrade Soil Tests

In general, the base and subgrade soil tests related to the following materials:

- Flex base (untreated).
- Treated base (using cement, lime, asphalt, or fly ash).
- Subgrade soil (raw).
- Subgrade soil (using cement, lime, or fly ash).

All the base and subgrade soil tests were conducted using materials sampled from test sections where these materials were available, such as new construction and FDR sections. The required materials were sampled either from the construction site or from the quarry or pit's stockpiled materials, as shown in Figure 6. The materials were collected at a minimum of three locations within the test section construction site and at three distinct locations within the stockpile, respectively, as outlined in Reports 0-6658-P1 and 0-6658-P3 (Walubita et al. 2011, 2012). For treated base and soil materials, the raw materials were sampled before the stabilizing agent was added. All materials were sampled from the travel lane of the test section.

Figure 6. Sources to Collect Base Material: (a) Construction Site and (b) Quarry.

The base and subgrade soil tests used to generate the required material properties for this study were:

- Sieve analysis.
- Atterberg limits.
- SG.
- MD curve.
- Texas triaxial.
- Resilient modulus.
- Permanent deformation (i.e., RLPD).
- Shear strength.
- UCS.
- MoR.

The Appendix provides a summary of the test procedures and the related test parameters and output data for the base and subgrade soils. Detailed descriptions of these tests along with the data analysis methods can be found in Reports 0-6658-P1 and 0-6658-P3 (Walubita et al. 2011, 2012). Table 9 and Table 10 list the number of the base and subgrade soil test data collected in the study, respectively.

Table 9. Base Material Data Collected in the Database.

No.	Test Type	Number of Data				Total	
		TTI		UTEP			
		Flex	Treated	Flex	Treated	Flex	Treated
1	Sieve Analysis	57	27	3	48	60	75
2	Atterberg Limits	36	22	2	24	38	46
3	SG	34	–	2	–	36	–
4	MD Curve	17	9	2	32	19	41
5	Texas Triaxial	12	–	2	–	14	–
6	Shear Strength	28	–	2	–	30	–
7	Resilient Modulus	18	–	2	–	20	–
8	Permanent Deformation (i.e., RLPD)	16	–	2	–	18	–
9	UCS	–	31	–	38	–	69
10	MoR	–	19	–	4	–	23
11	Soil Classification	17	9	1	16	18	25
12	FFRC	16	29	3	27	19	56

Table 10. Subgrade Soil Material Data Collected in the Database.

No.	Test Type	Number of Data				Total	
		TTI		UTEP			
		Flex	Treated	Flex	Treated	Flex	Treated
1	Sieve Analysis	45	27	32	3	77	30
2	Atterberg Limits	33	20	24	2	57	22
3	SG	32	–	24	–	56	–
4	Sulfate Content	–	6	–	1	–	7
5	MD Curve	15	9	24	2	39	11
6	Texas Triaxial	13	–	24	–	37	–
7	Shear Strength	26	–	24	–	50	–
8	Resilient Modulus	32	2	24	1	56	3
9	Permanent Deformation (i.e., RLPD)	30	8	24	1	54	9
10	UCS	–	25	–	2	–	27
11	Soil Classification	15	8	12	1	27	9
12	FFRC	28	23	12	3	40	26

FIELD PERFORMANCE DATA

The field performance data were collected at the test sections based on the criteria described in Chapter 2. The primary objective of the field test program was to evaluate the supporting material property characteristics and pavement performance in-situ. In addition, certain field performance data such as rutting and cracking histories were the source of the empirical calibration component of the M-E models in comparing predicted and actual pavement performance. In general, researchers conducted the field tests listed in Table 11 sequentially as follows:

1. Prior to and during test section selection to aid in selecting homogeneous pavement sections and to document the existing pavement structural capacity and distresses.
2. During and just after construction to document the construction process and the pavement condition just after construction.
3. Periodically, twice per year (just after summer and just after winter), for performance evaluation of the test sections.

Table 11. List of Field Performance Testing and Data Characteristics.

No.	Test	Test Procedure	Frequency	Output Data
1	Cracking	Visual walking surveys • Alligator cracking • Block cracking • Transverse cracking • Longitudinal cracking	• Pre-construction • Just after construction • Twice per year (just after winter and summer)	• Crack length/width • # of cracks • % of cracking • Severity
2	Surface Rutting	Straightedge at 100-ft interval in both wheel paths		Rut depth (in.)
3	Other Distress	Visual walking surveys • Raveling • Bleeding • Patching • Spalling		• Severity • % coverage
4	Surface Profiles	High-speed profiler in both wheel paths		• IRI (inch/mile) • PSI
5	FWD	9 kips drop every 25 ft in outside wheel path		• Surface deflections • Back-calculated modulus • Load transfer efficient
6	GPR	Outside wheel path		• Layer thickness • Forensic defects
7	DCP	Min 6 test points as follows: • ≥ 2 points in the outside wheel path • ≥ 2 points in the inside wheel path • ≥ 2 points in between the wheel paths	• Just after construction	• Layer thickness • Modulus

The Appendix provides other detailed test procedures and the related test parameters and output data for the field performance testing. Detailed descriptions of these tests along with the data analysis methods can be found in Reports 0-6658-P1 and 0-6658-P3 (Walubita et al. 2011, 2012). Table 12 lists the number of field performance test data collected in the study.

Table 12. Field Performance Data Collected in the Database.

No.	Test Type	Number of Data		Total
		TTI	UTEP	
1	Test Segment GPS Location (500/720/1,000 ft)	67/6/6	33/–/ –	100/6/6
2	Visual Surface Survey	148	129	277
3	Surface Rutting and Temperature	148	131	279
4	Surface Profile—PSI and IRI	153	25	178
5	9 kips Normalized FWD Deflections	106	57	163
6	FWD Back-Calculated Modulus	428	210	638
7	FWD Load Transfer Efficiency	64	–	64
8	DCP Test Data	26	11	37
9	Alligator/Block/Transverse/Longitudinal Cracking	148/148/148/148	129/129/129/129	277/277/277/277
10	Other Distresses	148	129	277
11	GPR Data	70	31	101

CLIMATIC AND ENVIRONMENTAL DATA

Since pavement materials are susceptible to property changes influenced by climatic and environmental factors such as temperature, moisture, and humidity that directly impact pavement response, the climatic data are a core input for pavement design and analysis using the M-E pavement design approach as well as for calibrating the M-E models. Thus, the climatic and environmental data were collected and analyzed using available web sources, including the National Environmental Satellite, Data, and Information Service from the National Oceanic and Atmospheric Administration, as follows:

- Air temperatures (minimum, maximum, and average on daily, monthly, and yearly basis).
- Precipitation (daily, monthly, and yearly).
- Average wind speed.
- Average sunshine (percent).
- Number of wet days.
- GWT (depth and nearest well coordinates from test sections).
- GPS coordinates of test sections.

Also, the climatic data files were generated using the M-E PDG and TxACOL programs and saved in the DSS so that the generated fields could be used for the corresponding program. The following steps were taken to generate the climatic file for the M-E PDG and TxACOL:

1. Select "Interpolate climatic data for given location" in M-E PDG and TxACOL programs.
2. Enter the GPS coordinate (latitude, longitude, and elevation) of test section.
3. Select weather stations geographically close to the test section in differing directions.
4. Generate a climatic file and save as Road ID.icm.

The other M-E software such as TxME does not have the function to generate and save the climate data files for later use, so that the climate data should be generated whenever running the software for the project-specific pavement design. Figure 7 presents the screens of M-E PDG and TxACOL used to climatic data generation. Table 13 lists the number of the climatic-environmental data collected in the study.

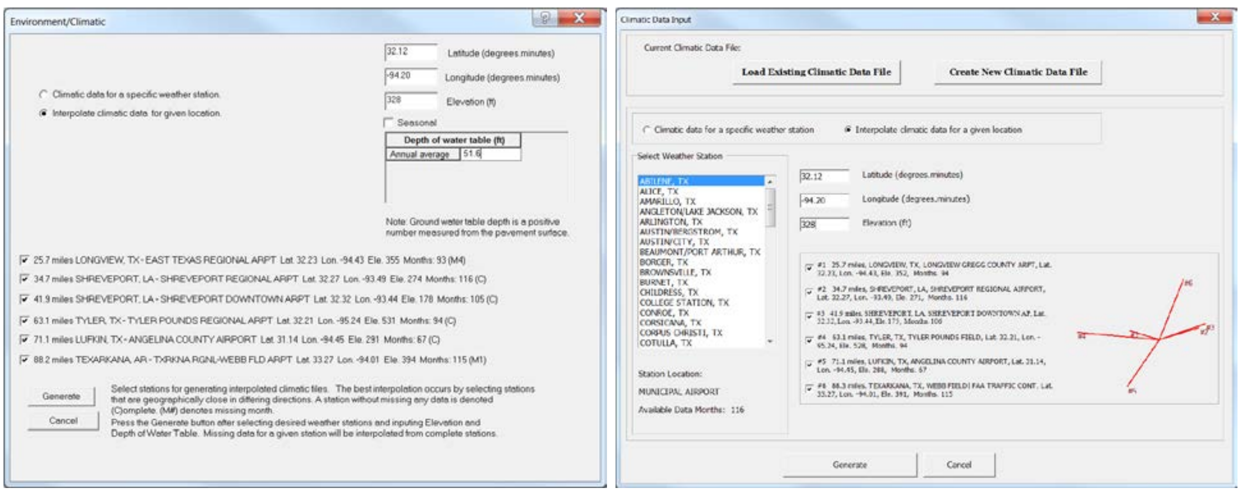


Figure 7. Climatic Data Generation Screen: (a) M-E PDG and (b) TxACOL.

Table 13. Climatic-Environmental Data Collected in the Database.

No.	Test Type	Number of Data		Total
		TTI	UTEP	
1	Climatic-Environmental Data • Air temperature • Precipitation • Wind speed • # of wet days • GWT, etc.	1,551	396	1,947

TRAFFIC DATA

Traffic is one of the most important factors in highway pavement design. The consideration of traffic should include the configuration and number of load repetitions as well as the loading magnitude. Therefore, parameters that characterize traffic flow can be classified in terms of the following (Walubita et al. 2015b):

- Traffic composition and classification.
- Traffic volume quantities.
- Traffic weight parameters.
- Traffic growth rate.

The accurate and efficient collection of traffic data, including vehicle count, classification, and weight (load spectra) data, is critical in establishing project-specific traffic for pavement design. Growth rates are typically assumed from past volume growth trends and evaluation of changes in land use. For this study, the research team made an elaborative effort to collect and analyze site-specific traffic data for a wide variety of Texas flexible pavements and HMA overlays across different levels of traffic loading and climatic zones, including the following:

- Volume and classification:
    - Average daily traffic (ADT) and average daily truck traffic (ADTT).
    - Truck percentage.
    - Growth factor.
    - Vehicle speed.
    - Vehicle classification distribution.
    - Monthly and hourly adjustment factors.
- Vehicle loads
    - Estimated 18 kips equivalent single axle load (ESAL).
    - Load spectra by axle type:
        - Steering.
        - Non-steering single-axle.
        - Combined singles: steering + non-steering.
        - Tandem.
        - Tridem.
        - Quad.
- Truck distribution and growth (axles per truck).

In this study, the traffic data were collected from two major sources, namely field data using pneumatic traffic tubes (Figure 8) as the primary source and traffic data from permanent WIM stations where available. At present, TxDOT has about 32 permanent WIM stations installed on selected busy or heavily trafficked highways. Analysis procedures and templates were developed to facilitate easy traffic data analysis for both pneumatic tube and WIM data. Table 14 presents the number of the traffic data sets collected for the test sections in the study.

Figure 8. Traffic Tubes and Counter/Classifier.

Table 14. Traffic Data Collected in the Database.

No.	Test Type	Number of Data		Total
		TTI	UTEP	
1	Volume and Classification	200	52	252
2	Monthly Adjustment Factors	228	–	228
3	Hourly Adjustment Factors	73	44	117
4	Load Spectra (Steering/Non-steering Single)	1,755/1,755	975/975	2,730/2,730
5	Load Spectra (Tandem/Tridem/Quad)	1,755/1,395/1,395	975/775/775	2,730/2,170/2,170
6	Truck Distribution and Growth (Axles per Truck)	210	–	210

SUPPLEMENTARY TEST DATA

One objective of this study was to assist TxDOT engineers and transportation professionals in making better decisions for pavement design and maintenance strategies with an ongoing reference data source. To further assist in the design decision process, the researchers collected supplementary lab test data from other engineering analysis and research endeavors in which they were involved. Although the supplementary data were not required as an M-E input parameter, nor were they mandated under this study, the material properties collected can serve as a useful reference to improve pavement design and rehab strategies for Texas. That is, the data can be correlated with quantifiable field performance data in the DSS to develop prediction or evaluation models related to material properties and field performance (e.g., correlation between the SPST data and surface rutting data). Accordingly, the research team collected the following supplementary data:

- HMA: FN, OT monotonic, SPST.
- Treated base: sulfate content.
- CTB (laboratory mixed): UCS, MoR, FFRC, IDT.

Due to limited test sections using CTB, a cement variation lab study was conducted by adding cement (2, 3, and 4 percent) into the flex base material in the lab after conducting all the standard tests. The test data were used to evaluate the properties of CTB by varying the cement content. Figure 9 presents the MoR and IDT tests using the CTB mixed in the lab. Table 15 lists the number of supplementary test data collected in the study.

Table 15. Supplementary Test Data Collected in the Database.

No.	Material	Test	Number of Data		Total
			TTI	UTEP	
1	HMA	FN	129	–	129
2		OT Monotonic	193	–	193
3		SPST	147	–	147
4	Treated base	Sulfate Content	–	32	32
5	Flex base + cement	UCS	28	–	28
6		MoR	24	–	24
7		FFRC	10	–	10
8		IDT	12	–	12

Figure 9. Lab-Mixed CTB Test: (a) IDT and (b) MoR.

SUMMARY

This chapter presented an overview of the data collection and analysis completed in this study, namely:

- Laboratory data for asphalt-binder, HMA mix, and base and subgrade soil materials.
- Test section field performance data.
- Climatic-environmental data.
- Traffic data.
- Supplementary test data.

The data collection and analysis for this study involved laboratory and field testing to generate material properties and performance data for the database as well as calibration of the M-E models and associated structural design software. In addition, supplementary lab test data were collected from other engineering analyses and research endeavors, that can be of use in the design decision-making process.

CHAPTER 4
DATA POPULATION AND UPDATES

In general, the database system containing material properties and performance data should be multifunctional. While focusing on the data requirements for the Texas M-E models and related software, significant efforts were also made to collect, related pavement section data that could serve as a progressive reference data source and/or general diagnostic tool for TxDOT engineers and other transportation professionals.

A database is considered useful only if it is populated with sufficient data, both in terms of quantity and accuracy. Accordingly, the research team collected information related to pavement design and construction as well as a variety of both laboratory and field data, as described in Chapter 3. In order to fulfill these database requirements, the data storage system was developed with two repositories, one for the processed data and one for the unprocessed raw data, as follows:

- MS Access DSS for the processed data.
- RDSSP for the unprocessed raw data.

A CD of the data storage systems is included as an integral part of this report.

DATA STORAGE SYSTEM

For the processed data, MS Access was selected as the database platform due to its commercial availability, familiarity, user friendliness, and easy access to TxDOT engineers. Figure 10 shows the DSS main menu screenshot.

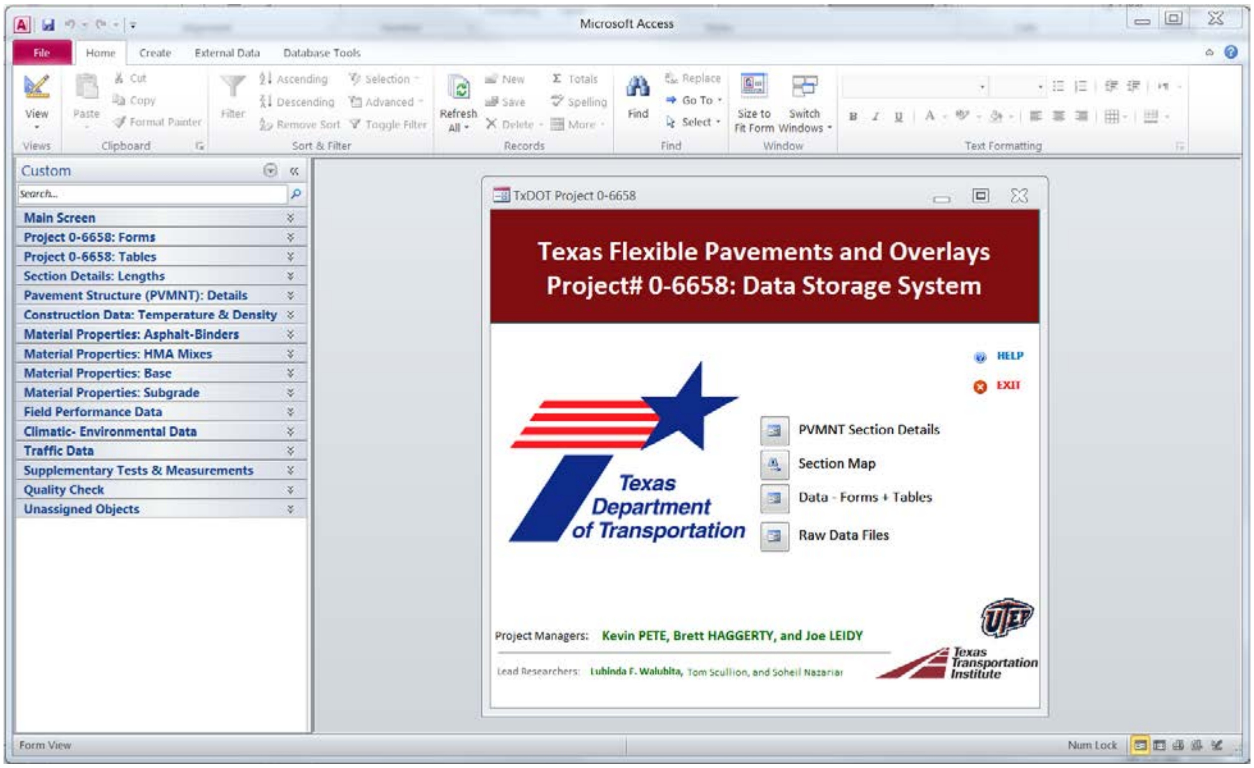


Figure 10. The DSS—Main Menu Screenshot.

Data Structure

Since a database is considered useful only if it is populated with sufficient data, both in terms of quantity and accuracy, the DSS consists of a variety of both laboratory and field data, including but not limited to the following:

- Design data and drawings including pavement cross sections.
- Construction data, quality control/quality assurance (QC/QA) charts, and coring.
- Material properties of each pavement layer (through both lab and field testing).
- Field testing and pavement performance data.
- Traffic data including volume, classification, vehicle speeds, and load spectra.
- Climatic data including temperature and precipitation in Texas's five climatic zones.
- Supplementary material properties of HMA and CTB mixed in the lab.

The DSS consists mainly of three data storage objects—map, form, and table—as Figure 11 illustrates. Each object provides information on all test sections identified in this study.

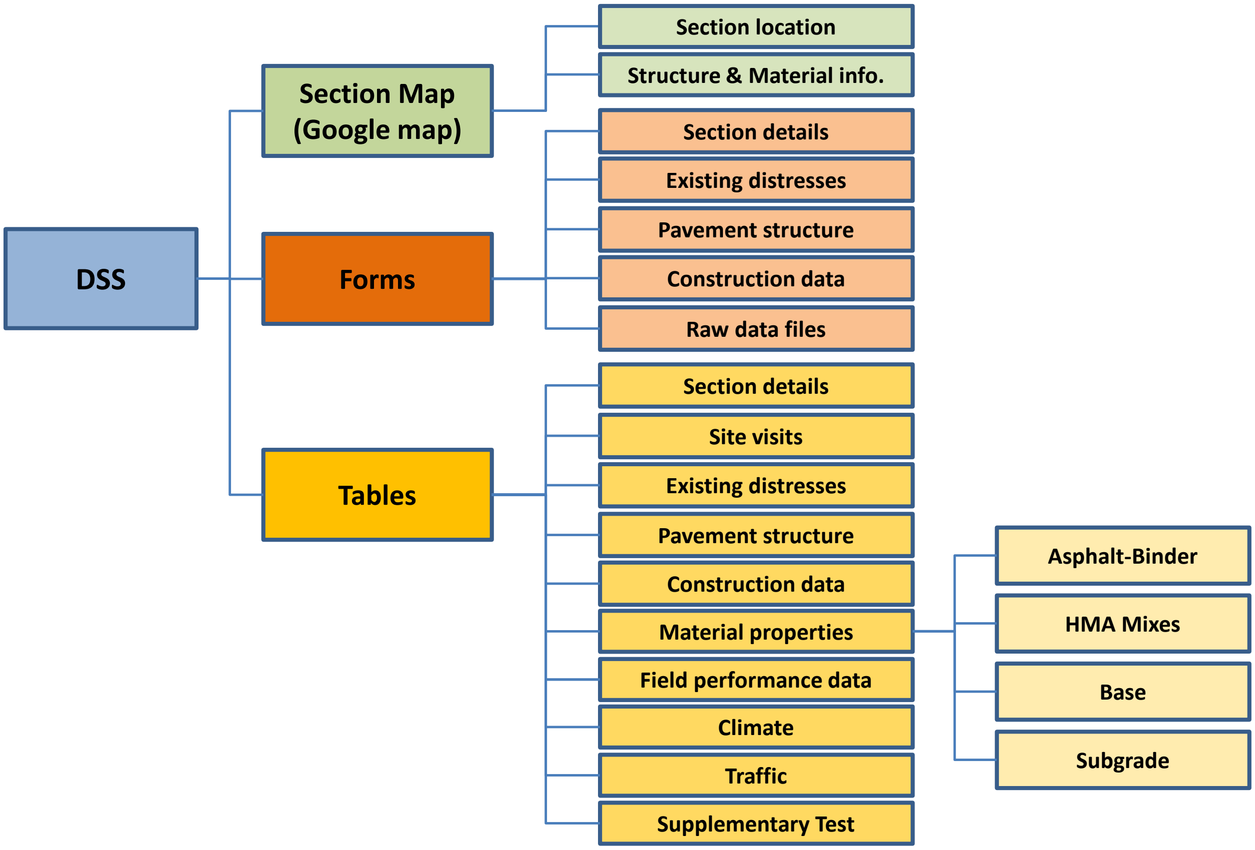


Figure 11. Structure of DSS.

Section Map

Left clicking on the Section Map in the DSS main switchboard opens the Google® map in a web browser, which shows the location and type of highway test sections and WIM stations around Texas, as illustrated in Figure 12. Clicking on any test section on the map displays the latest section picture and corresponding pavement structure information. From the section map, users can easily identify the general information on test section, including location, number of layers, material type, layer thickness, and construction year. As an example, Figure 13 shows the Google picture of Test Section No. 1, US 59 in the Atlanta District.

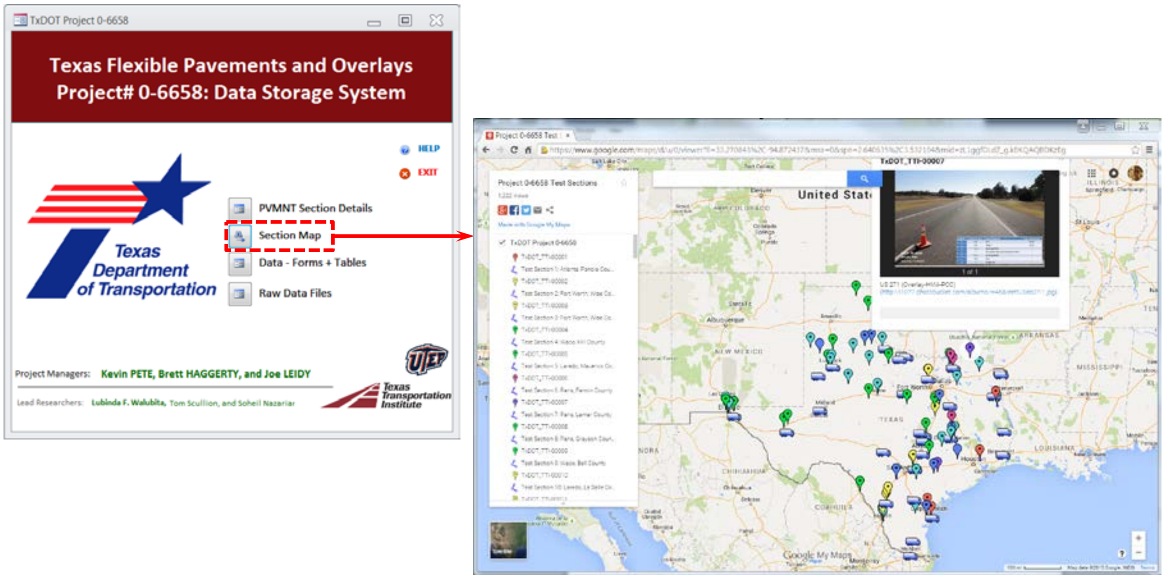
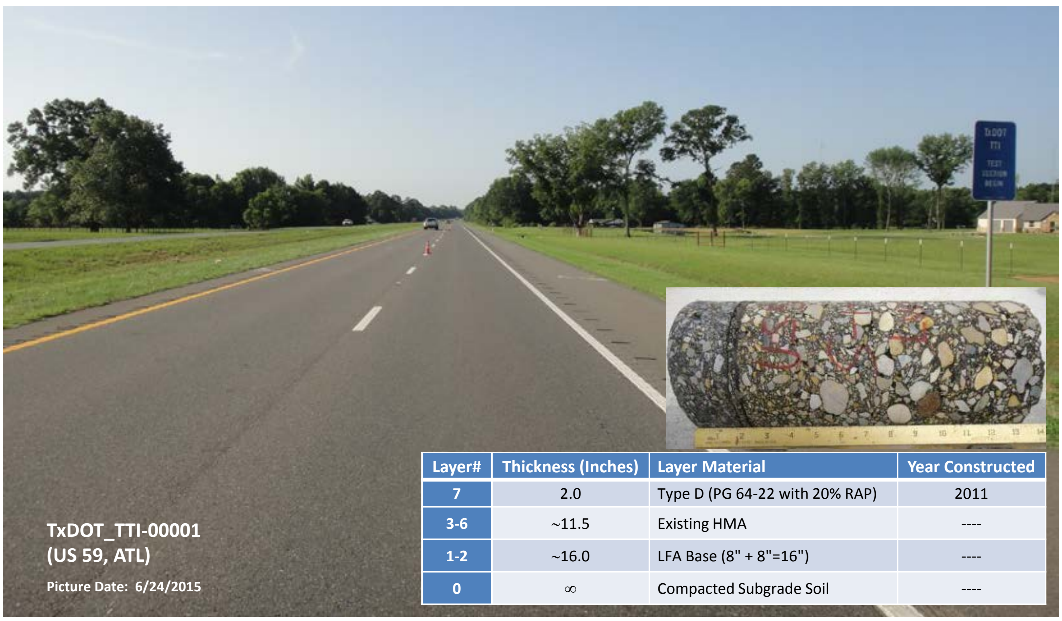


Figure 12. Section Map.



Layer#	Thickness (Inches)	Layer Material	Year Constructed
7	2.0	Type D (PG 64-22 with 20% RAP)	2011
3-6	~11.5	Existing HMA	----
1-2	~16.0	LFA Base (8" + 8"=16")	----
0	∞	Compacted Subgrade Soil	----

Figure 13. Google Picture (Sec01 US 59 Atlanta District).

DSS Data Entry: Form and Table

The data contents collected in this study are stored in the two formats of form and table. The form format allows the user to view one data entry at a time. It provides easy access to view the contents of the data entries rather than fields or columns. It also stores files such as design drawings, field surveying sheets, and pictures. The forms in MS Access can all be found grouped in one chapter, and the bottom left arrows on the form window provide the user access to all section entries in the form, as shown in Figure 14. On the other hand, tables are used to store and organize the data by fields in columns so all data entries can be viewed at once, as illustrated in Figure 15. Also, MS Access offers various ways to access, display, and present information entered in the table format, including graphs and bar charts, as described in the following subsections. Some data are more efficiently presented in the form style, while other data contents are best reviewed in the table format. Table 16 presents the list of data stored in the table and/or form formats.

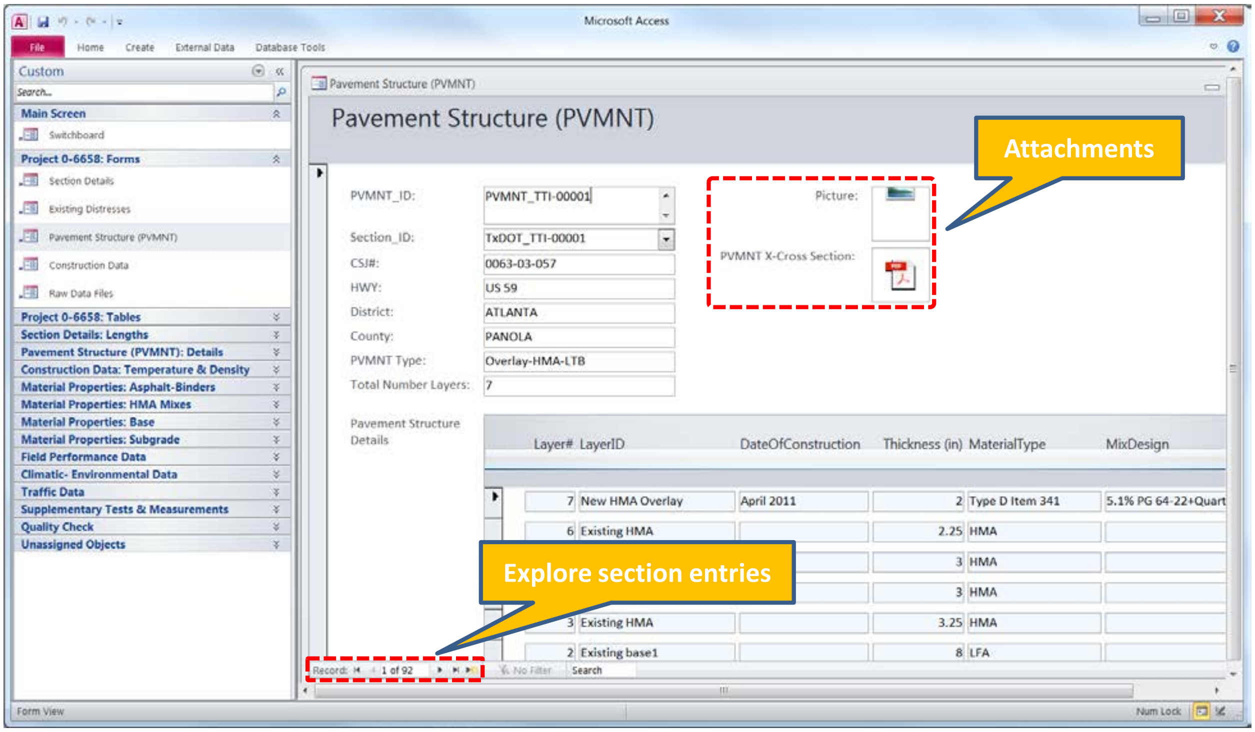


Figure 14. Database Objects: Form.

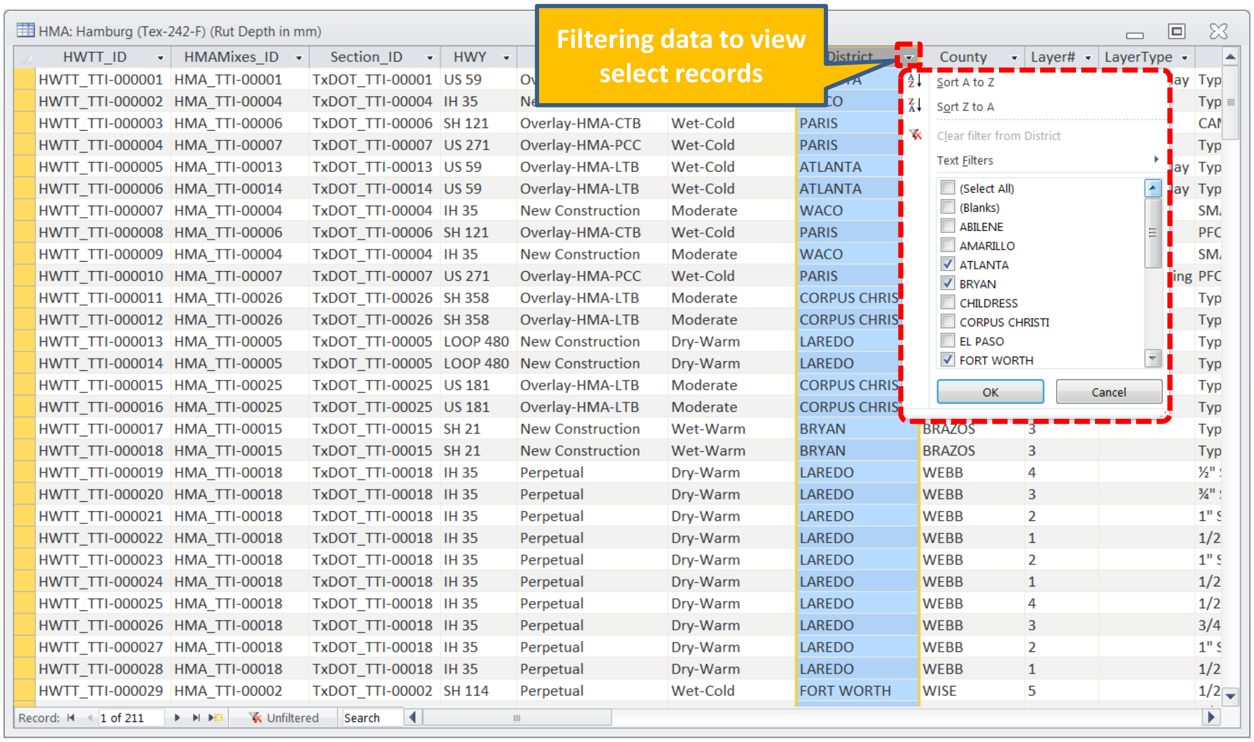


Figure 15. Database Objects: Table.

Table 16. List of Data Content Stored in Form and Table Formats.

No.	Data Content	Form	Table
1	Section details	Yes	Yes
2	Site visits	No	Yes
3	Existing distresses (overlays only)	Yes	Yes
4	Pavement structure	Yes	Yes
5	Construction data	Yes	Yes
6	Material properties	No	Yes
7	Field performance	No	Yes
8	Climatic data	No	Yes
9	Traffic	No	Yes
10	Supplementary tests	No	Yes

DSS Data Access and Navigation

The MS Access database used as the platform for the DSS provides structured storage for the data so that users can readily access and retrieve the data for general use. The DSS provides options for exporting data directly to an MS-supported format (e.g., MS Word®, MS Excel®, PDF) but not directly to third-party software. However, one can export the data to an MS-supported format and then manipulate it as required. Additionally, the MS Access data storage system allows direct emailing through MS Outlook®. All these aspects will be discussed in the subsequent subsections; moreover, a detailed description of DSS data access and navigation can be found in Product 0-6658-P2 *User's Manual for the MS Access Data Storage System* (Walubita et al. 2015a).

Help Function

As Figure 16 illustrates, the Help function, shown in the upper right side of the main menu, provides the information related to this project and the DSS. Clicking on this button displays the user's manual, technical reports, test procedures and specifications, data collection forms, M-E pavement (PVMNT) software, and credits directory, as seen in Figure 16. By double clicking each field, the user can open a zipped attachment screen that provides access to all data entries in the Help function. Figure 17 shows the contents included in Help.

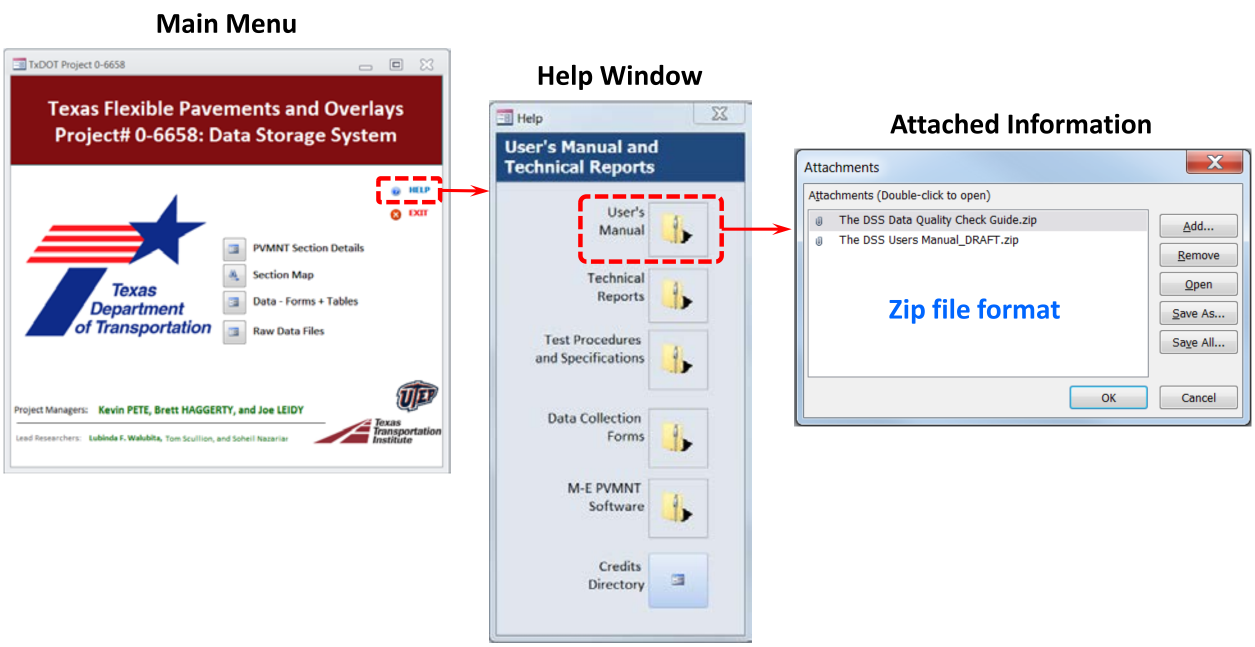


Figure 16. Opening User's Manual Files in Help.

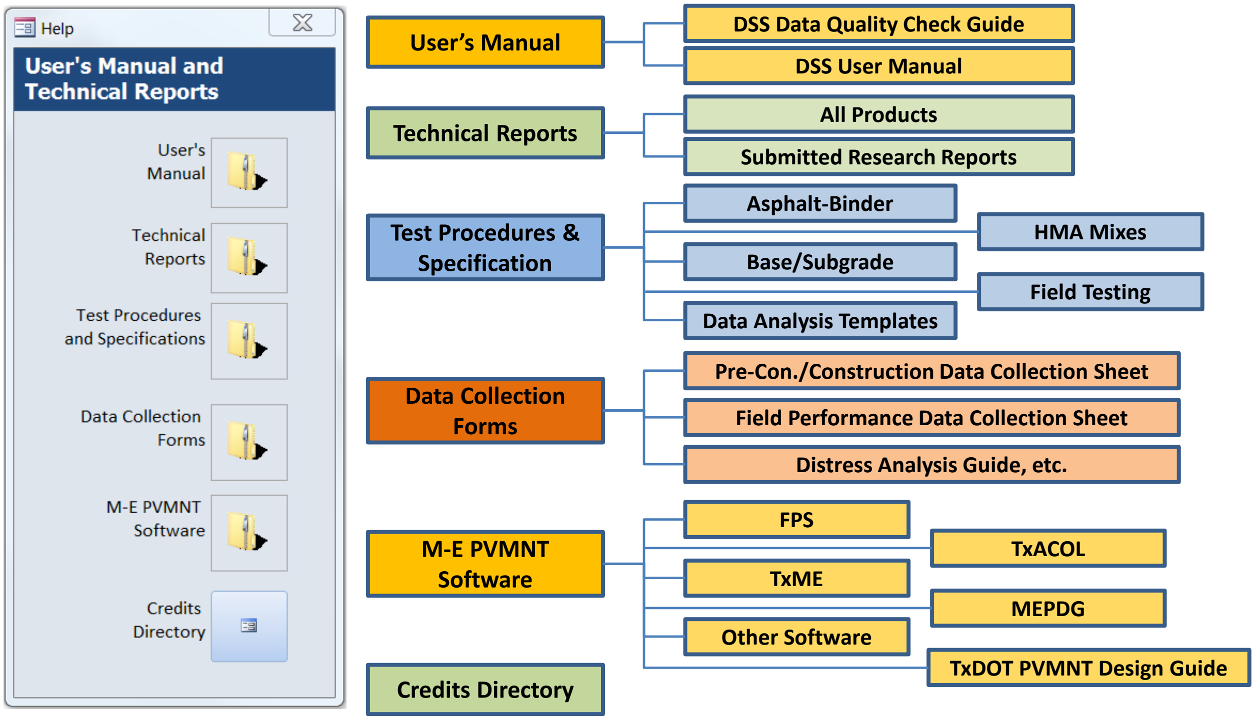


Figure 17. Data Contents in Help.

Exporting a Table to Excel or PDF File

All tables in the MS Access DSS can be exported as a specific file type such as an Excel spreadsheet or PDF file directly from MS Access. This can be done by clicking on the Export group in the External Data tab, and then clicking on Excel or PDF or XPS, as shown in Figure 18.

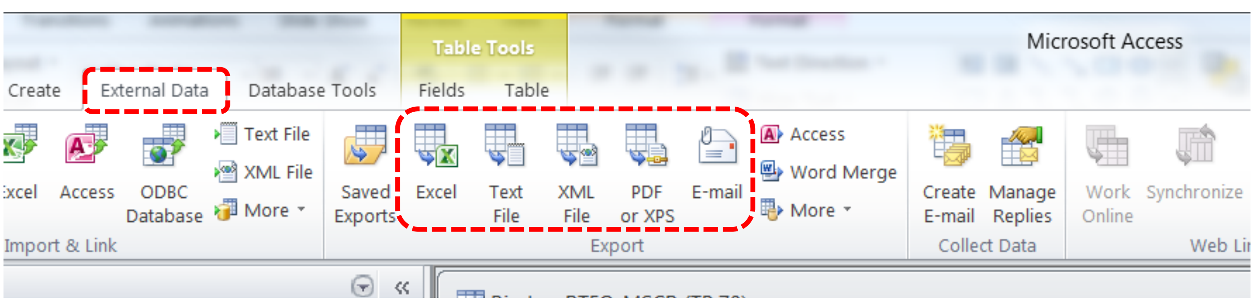


Figure 18. Exporting Tables to Excel or PDF.

When clicking on Excel on the Export group, the user will see a menu asking for a destination file name and format, as shown in Figure 19(a). By specifying a folder location for the table and clicking OK, the user can find the Excel file in the destination folder, as presented in Figure 19(b). A PDF file can be exported from a specific table in the DSS through a similar process to Excel exporting.

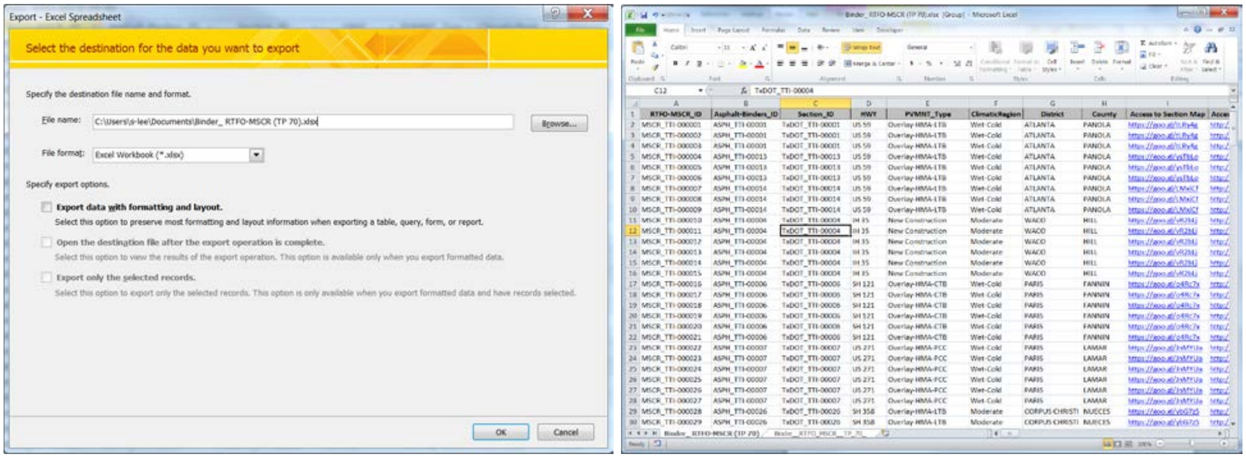


Figure 19. Excel Exporting: (a) Option Menu and (b) Exported Excel Spreadsheet.

Emailing a Table to Excel or PDF File

Users can send a DSS data table as a specific file type through email using MS Outlook by clicking the email option in the Export group, as shown in Figure 19(a). Once a file format to be sent has been selected, such as Excel workbook or PDF format, MS Outlook will open a new message window with the file as an attachment, as shown in Figure 20(b). The email option to export tables requires MS Outlook.

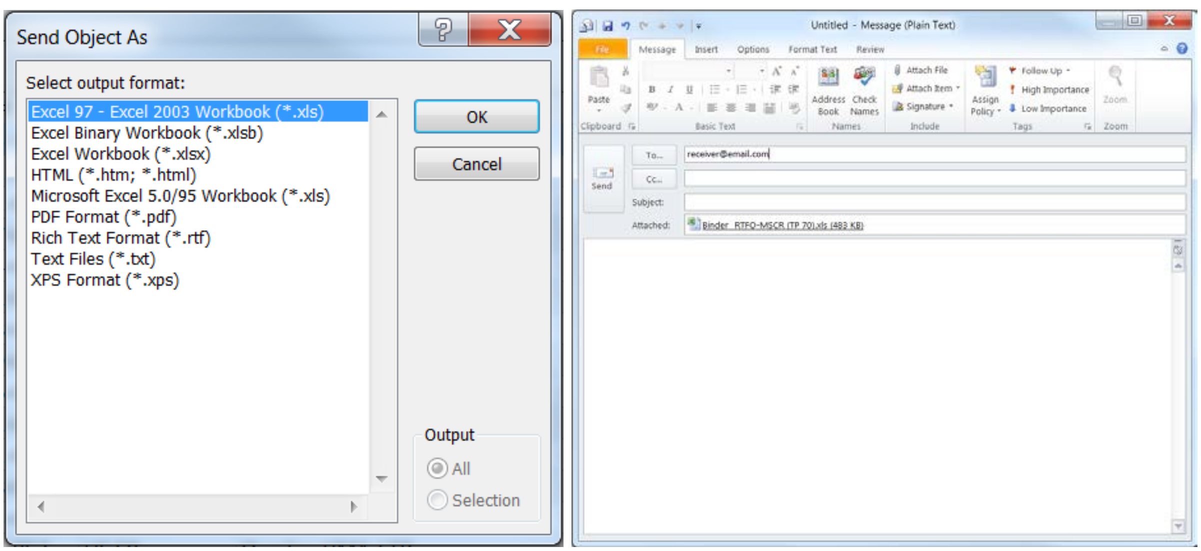


Figure 20. Emailing a Table: (a) Option Menu and (b) Message Window Including Table.

Generating Pivot Tables and Charts

The DSS allows users to conveniently access, analyze, and display the stored data. The four view options at the bottom right corner of MS Access (in MS Office 2010), namely the datasheet view, the pivot table view, the pivot chart view, and the design view, as shown in Figure 21, are useful for these purposes.

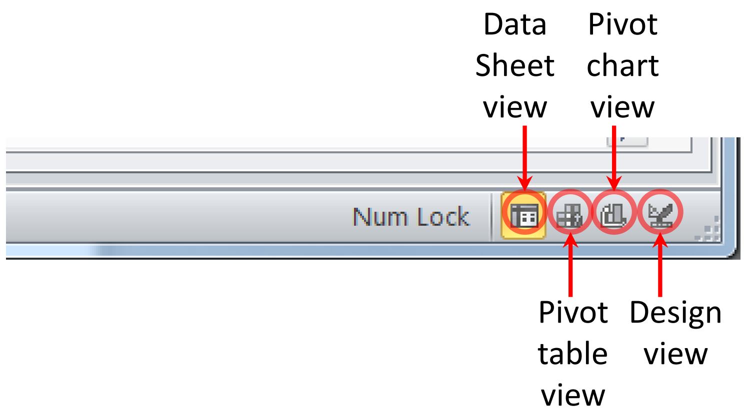


Figure 21. View Options in MS Access for Displaying Data.

Mathematical operations such as average, maximum, minimum, and standard deviation can be performed in the pivot table view. In the pivot table view, the user can select the data set to be analyzed from a pivot table field list and drag it to the desired position in the pivot table, as shown in Figure 22. The desired analyses can be performed by right clicking on the data table and selecting AutoCalc, followed by the appropriate analysis option (e.g., average, maximum, minimum, and standard deviation). The desired analysis result/results for all the data in the column will be presented at the end of the data column, as exemplified in Figure 23.

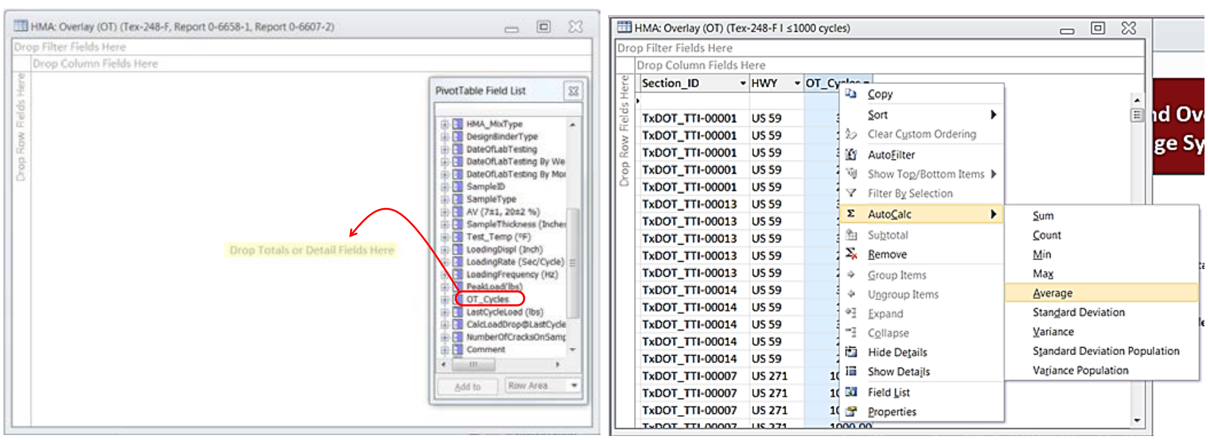
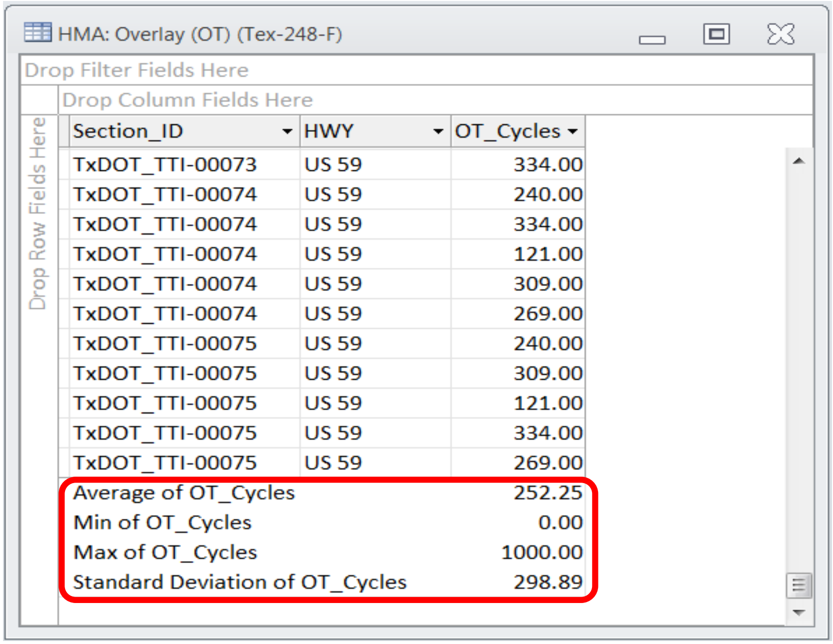


Figure 22. Mathematical Calculation in Pivot Table View.



HMA: Overlay (OT) (Tex-248-F)

Drop Filter Fields Here

Drop Column Fields Here

Drop Row Fields Here

Section_ID	HWY	OT_Cycles
TxDOT_TTI-00073	US 59	334.00
TxDOT_TTI-00074	US 59	240.00
TxDOT_TTI-00074	US 59	334.00
TxDOT_TTI-00074	US 59	121.00
TxDOT_TTI-00074	US 59	309.00
TxDOT_TTI-00074	US 59	269.00
TxDOT_TTI-00075	US 59	240.00
TxDOT_TTI-00075	US 59	309.00
TxDOT_TTI-00075	US 59	121.00
TxDOT_TTI-00075	US 59	334.00
TxDOT_TTI-00075	US 59	269.00
Average of OT_Cycles		252.25
Min of OT_Cycles		0.00
Max of OT_Cycles		1000.00
Standard Deviation of OT_Cycles		298.89

Figure 23. Calculation Results in Pivot Table.

Pivot charts can be generated in the pivot chart view. The data to be presented in the chart are dragged and dropped to their appropriate axes from a chart field list in a similar process to the pivot table. Multiple data sets can be presented in this procedure by simply adding the desired data to the appropriate axes, as shown in Figure 24.

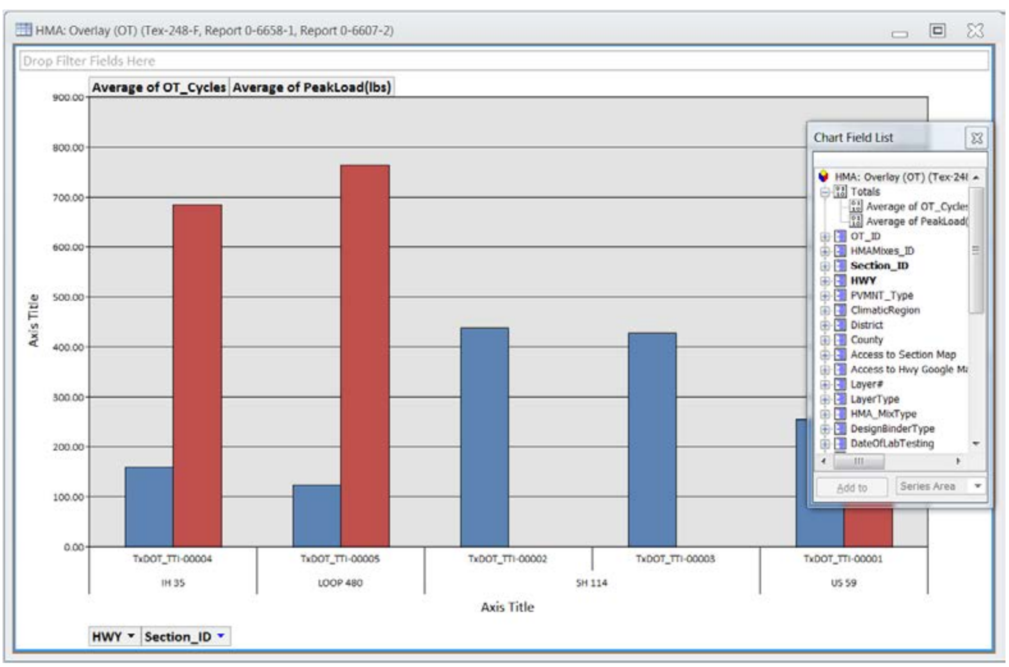


Figure 24. Pivot Chart View in MS Access.

A detailed description on how to navigate through the data, including accessing, displaying, and generating charts, as well as exporting the data, can be found in Product 0-6658-P2, *User's Manual for the MS Access Data Storage System* (Walubita et al. 2015a).

RAW DATA STORAGE SYSTEM

As a backup and to provide opportunities for data verification and future analyses as users deem necessary, the raw data files for all the data measured and collected in this study are concurrently kept in the RDSSP, as shown in Figure 25.

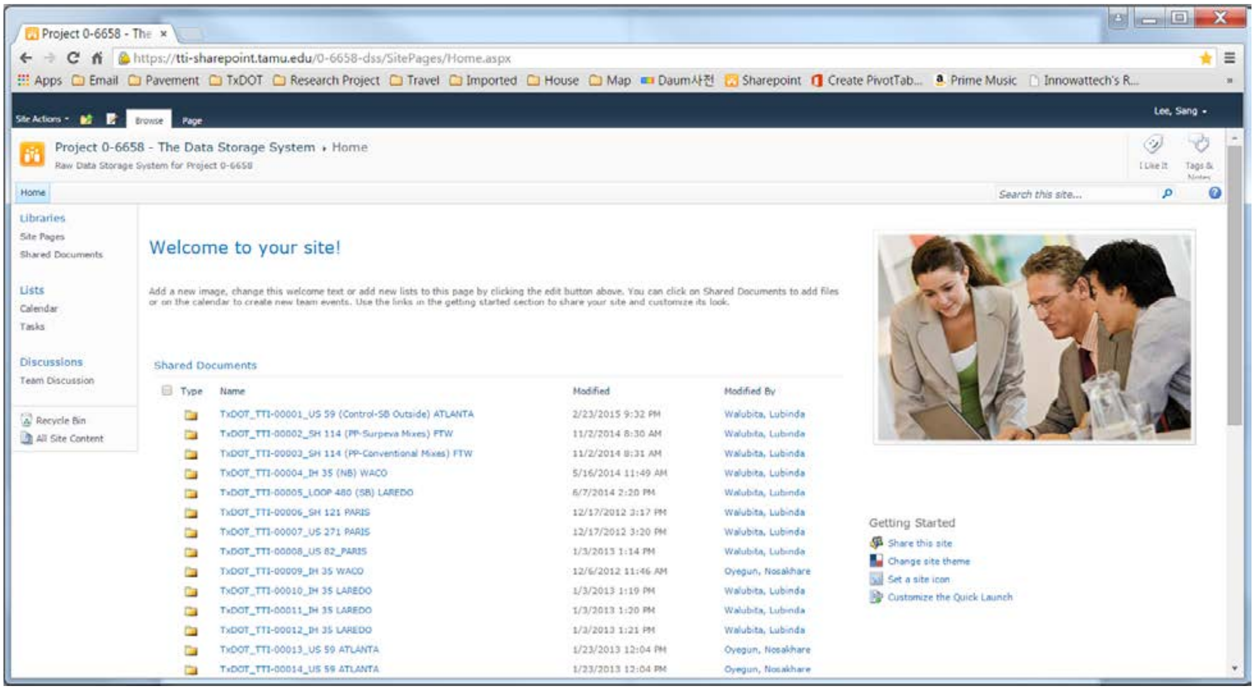


Figure 25. The RDSSP Website.

Data Structure and Entry

The RDSSP contains all unprocessed raw data collected from the field and laboratory, categorized by test section. Figure 26 illustrates the structure and data contents of the RDSSP.

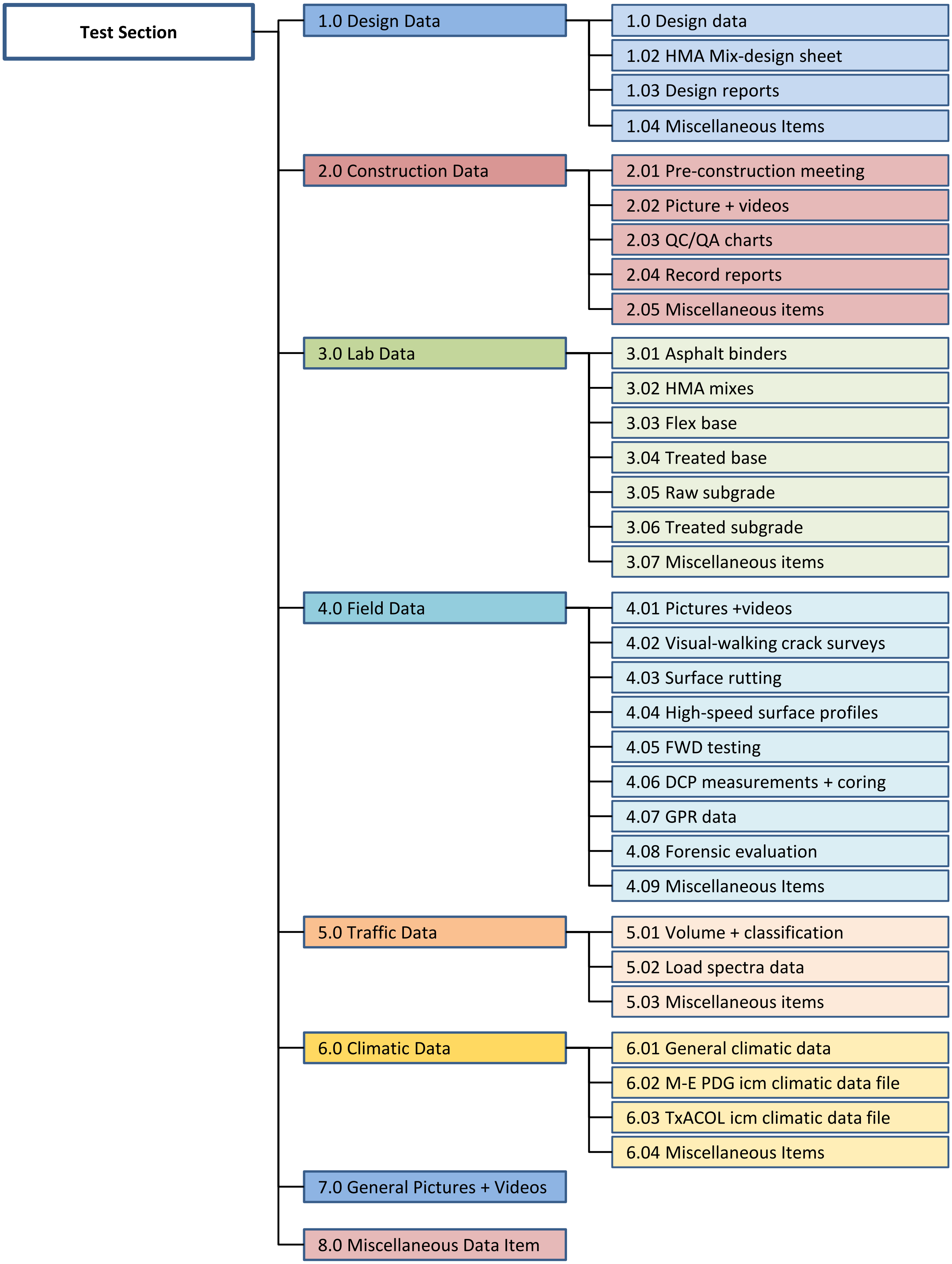


Figure 26. Data Structure of RDSSP.

Data Access and Navigation

For easy accessibility, the RDSSP is linked to the DSS via the Raw Data Files function on the DSS main screen. Clicking on the button displays the Raw Data Prompt dialogue box, which shows the destinations of the raw data collected, as illustrated in Figure 27. When specifying a destination—TTI or UTEP—the linked website opens in a web browser containing the data. Upon selecting a test section and then a data folder to access, users can access and download the data files and email the link. Figure 28 illustrates how to email a link and download a copy of a file in the RDSSP.

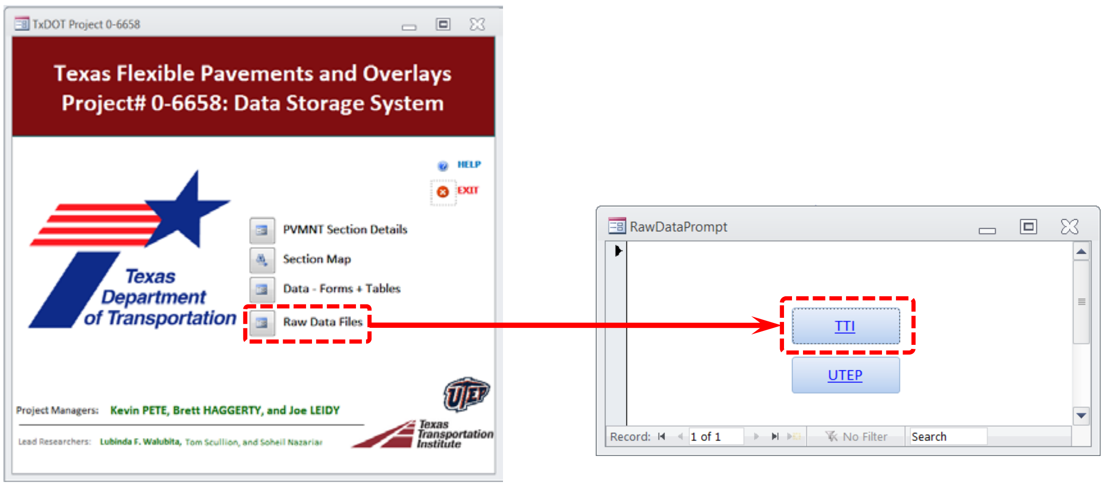


Figure 27. Opening the RDSSP Website.

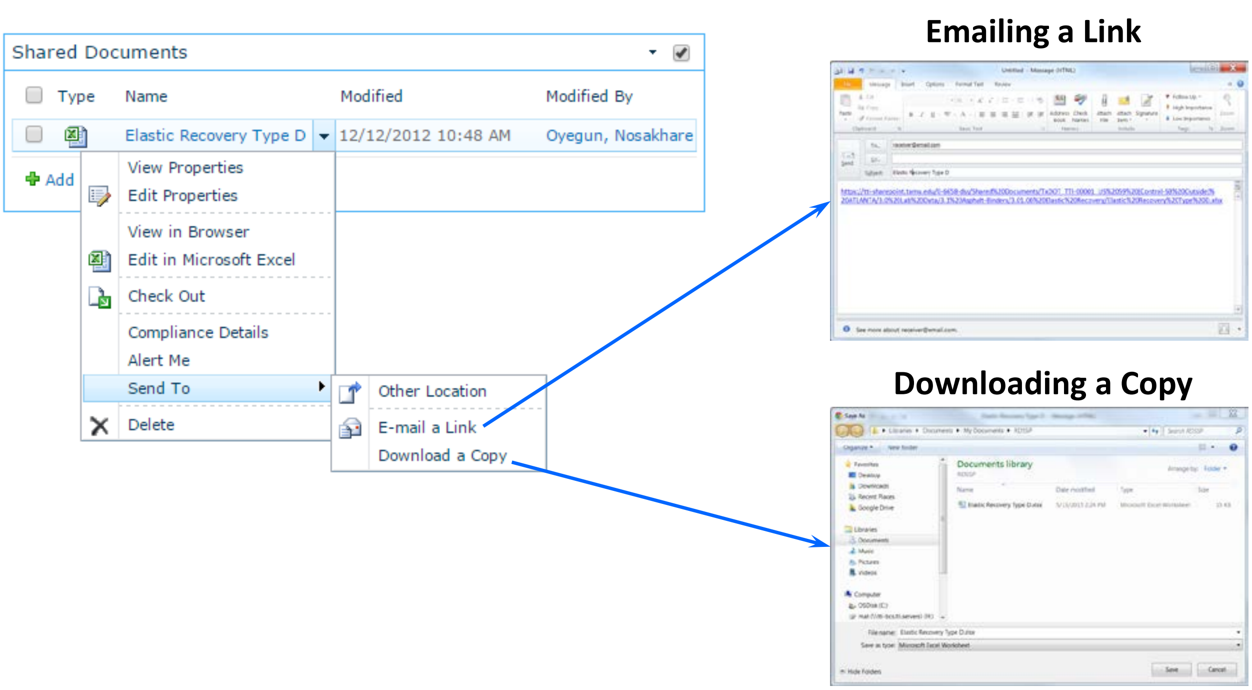


Figure 28. Emailing or Downloading Data from the RDSSP.

SUMMARY

This chapter provided a description of the Project 0-6658 data repository system, namely the DSS for the processed data and the RDSSP for the unprocessed raw data, with a focus on the data content, structure, and accessibility. As discussed in the chapter, each database is well organized to provide the data required for running Texas M-E models and related software, as well as to serve as an ongoing reference source and general diagnostic tool for TxDOT engineers. While the DSS provides options for exporting data directly to preferred formats (e.g., Excel spreadsheet, PDF, or text) and emailing the data through MS Outlook, the RDSSP supports downloading data files or emailing a link containing a data file.

CHAPTER 5
CALIBRATION PLAN AND DATA ANALYSIS FOR M-E MODELS

This chapter discusses the framework for calibrating the M-E models and the related software. Calibration essentially involves determining the calibration factors that relate the predicted pavement performance to actual measured field performance data, such as pavement distresses. Ideally, these calibration factors serve as the interface relating the M-E models to actual field conditions. The calibration of these models to Texas local conditions will result in pavement and overlay designs that maintain superior performance expectations and are more economical in the long term.

CALIBRATION PROCESS

Calibration is a process used to adjust the M-E models for local settings using actual pavement design input and response data by comparing predicted to measured pavement performance. This effort will ensure validity and accuracy of M-E models and enhance the ability of local agencies to confidently predict pavement performance. In addition, it improves the ability to assess maintenance and rehabilitation needs over pavement life (Federal Highway Administration [FHWA] 2010). Figure 29 illustrates the calibration approach used in this study. The approach allows for a sensitivity analysis and determination of the systematic differences within the experimental factorial as well as the possibility to evaluate the residual differences between the predictions and measured values. As shown in Figure 29, the calibration process consists of the following steps:

1. Assemble the M-E input data and actual measured field performance (distress) data. In this study, these data were extracted from the DSS and RDSSP as:
    a. Pavement structure and material properties.
    b. Traffic data.
    c. Climatic data.
    d. Measured field performance data (e.g., surface rutting, cracking, IRI).
2. Run the related M-E software to predict pavement performance using the data from the DSS and RDSSP.
3. Compare and analyze the M-E model prediction relative to the actual measured performance. The comparative analysis incorporates scatter plots and statistical analysis.
4. Adjust the calibration factors of M-E models if the predictions are statistically significantly different from the measured field data and re-run Step 2 and 3 iteratively.

M-E model calibration is complete if the predicted and measured performance values are statistically similar.

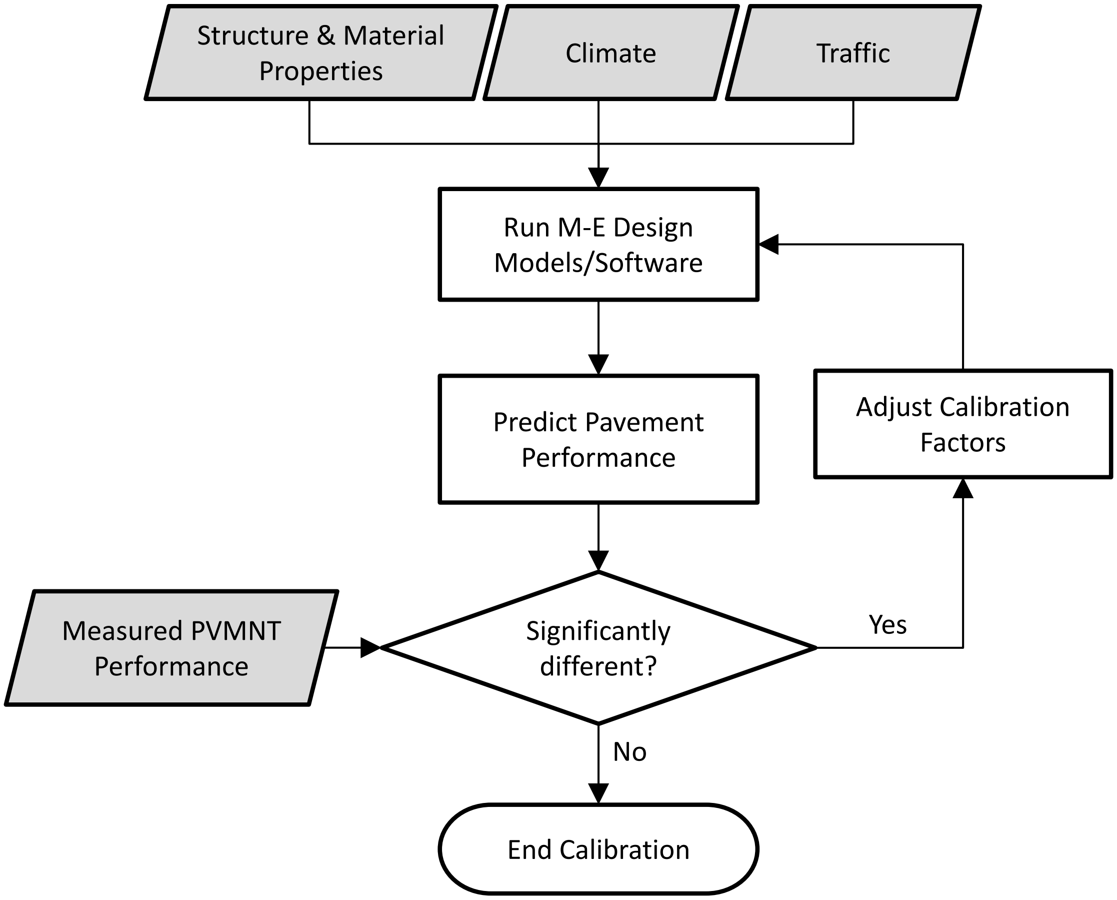


Figure 29. Calibration Process.

RELATED M-E SOFTWARE

This subsection presents an overview of the M-E software, including the basic input data, output data, and key M-E models to be calibrated, namely:

- FPS.
- TxACOL.
- TxME.
- M-E PDG.

FPS

FPS is rudimentary M-E based software that TxDOT routinely uses for:

- Pavement structural (thickness) design.
- Overlay design.
- Stress-strain response analysis.
- Pavement life prediction.

Overview

The design approach of FPS is based on a linear-elastic analysis system, and the key material input is the back-calculated elastic modulus values of the pavement layers. The FPS design system is comprised of the trial pavement structure development, thickness design, and design checks including performance prediction. The FPS system has an embedded performance function relating the computed surface curvature index (deflection-based index) of the pavement to the loss in ride quality. The design check is principally based on either the simplistic mechanistic design concepts or the Texas triaxial criteria. TxDOT traditionally uses FPS for conventional flexible HMA pavement design. Figure 30 shows the main screen of the current version, FPS 21, and Table 17 lists the full FPS input parameters along with the DSS location details.

Figure 30. FPS Main Screen.

Required Input Data and Location in DSS

The input design data of FPS consists of six major categories, namely basic design criteria, program controls, traffic data, construction and maintenance data, detour design for overlays, and structure and material properties. In the basic design criteria category, most of the information to be provided is discretionary user-based inputs related to cost-budget considerations and desired performance constraints related to reliability and serviceability. The guidelines for selecting this information are outlined in the Help file provided with the software. The program control category includes three parameters that are designed to act as analysis constraints or design controls. These can be adjusted to limit the number of available solutions to a given set of data sets. The most important category in the input design data page is the traffic data. The required traffic data in FPS are available in the DSS data group of Traffic Data under the Volume and Classification table. Table 17 lists the full FPS input parameters along with the DSS location details.

Table 17. List of Input Parameters for FPS and Location in DSS.

Item	Description	Data Source/Location in DSS
General Information	Problem #	User input
	Highway, district, county	Tables/Section details
	Control, section, and job (CSJ) #	Tables/Section details
	Date	Automatically generated (editable)
Basic Design Criteria	Length of analysis period (yr)	User input
	Min. time to first overlay (yr)	User input
	Min. time between overlays (yr)	User input
	Design confidence level	User input based on Help file guidelines
	Initial and final serviceability index	Field performance data (FPD): surface profiles—PSI and IRI
	Serviceability index after overlay	FPD: surface profiles—PSI and IRI
	District temperature constant	Automatically generated
	Interest rate (%)	User input
Program Controls	Max. funds/sq yd, initial construction	User input
	Max. thickness, initial construction	User input
	Max. thickness, all overlays	User input
Traffic Data	ADT begin (veh/day)	Traffic data/Volume and classification (and Excel macro)
	ADT end 20 yr (veh/day)	
	18 kip ESALs 20 yr—one direction (millions)	
	Avg. approach speed to overlay zone	User input based on Help file guidelines
	Avg. speed overlay and non-overlay direction	User input based on Help file guidelines
	Percent ADT/HR construction	User input based on Help file guidelines
	Percent trucks in ADT	Traffic data/Volume and classification
Construction and Maintenance Data	Min. overlay thickness (in.)	User input
	Overlay const. time, hr/day	User input
	Asphalt concrete pavement (ACP) comp. density, tons/CY	User input
	ACP production rate, tons/hr	User input
	Width of each lane, ft	Tables/Section details
	First year cost, routine maintenance	User input
	Annual incremental increase in maintenance cost	User input
Detour Design for Overlays	Detour model during overlays	User input
	Total number of lanes	Tables/Section details
	Num. open lanes, overlay direction	User input
	Num. open lanes, non-overlay direction	User input
	Distance traffic slowed, overlay direction	User input
	Distance traffic slowed, non-overlay direction	User input
	Detour distance, overlay zone	User input
Structure and Material Properties	Layer and material name	PVMNT structure details
	Cost per CY	User input
	Modulus E (ksi)	Field performance data/FWD back-calculated modulus
	Min and max depth	PVMNT structure details
	Salvage percentage and Poisson’s ratio	User input or default value

Output Data from Software

The FPS design program checks for all the viable solutions/designs within the design criteria and program controls, based on the material properties defined and the structural boundaries outlined to meet the applied loading parameters. In some cases, the number of viable solutions to a design problem can be more than one (i.e., FPS has the potential to yield multiple design options). The FPS pavement design result shown in Figure 31 presents some viable solutions based on the given input parameters.

Figure 31. FPS Design Output: Pavement Design Result.

The key design output parameters to be noted are layer depths, number of performance periods, and performance time. The design also indicates the necessity of overlays to be constructed on the highway through the end of the user defined analysis period. It also forecasts the total lifetime cost of the highway section. The check design parameter shows a detailed graphical presentation of the layer thicknesses and provides options for mechanistic and triaxial design checks as well as stress analysis. The mechanistic check option, as illustrated in Figure 32, helps the designer fine-tune the layer thicknesses based on the projected long-term cracking and rutting performances of the highway and contains the M-E models to be calibrated, as shown in Figure 33.

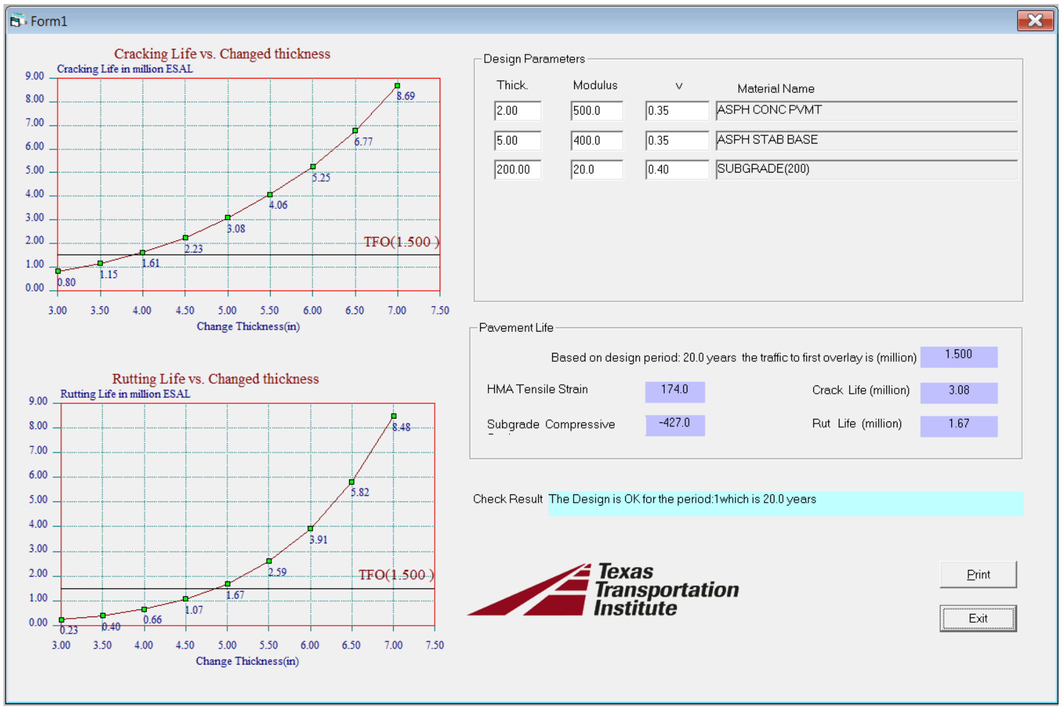


Figure 32. FPS Design Output: Mechanistic Check.

Related M-E Models

The FPS mechanistic design check involves two key M-E models—cracking and rutting—as seen in Figure 33. These models are the primary focus of the FPS calibration and validation to ensure that the model predictions match the field performance. Model calibration will be achieved through iterative and sensitivity variations of the calibration factors (f_i) until the FPS predictions and actual field performance measurements/observations match each other within the given error tolerance, namely:

- Cracking (fatigue) model:

$$N_f = f_1(\varepsilon_t)^{-f_2}(E_1)^{-f_3} \tag{5.1}$$

where N_f = number of 18 kip load repetitions that result in 20% fatigue cracking of the wheel paths.
ε_t = tensile strain at bottom of asphalt layer.
E_1 = elastic modulus of asphalt layer.
f_1, f_2, and f_3 = cracking calibration factors.

- Rutting model:

$$N_d = f_4(\varepsilon_v)^{-f_5} \tag{5.2}$$

where N_d = number of 18 kip load repetitions that result in 0.5 in. full depth rutting.
ε_v = compressive strain on top of subgrade.
f_4 and f_5 = rutting calibration factors.

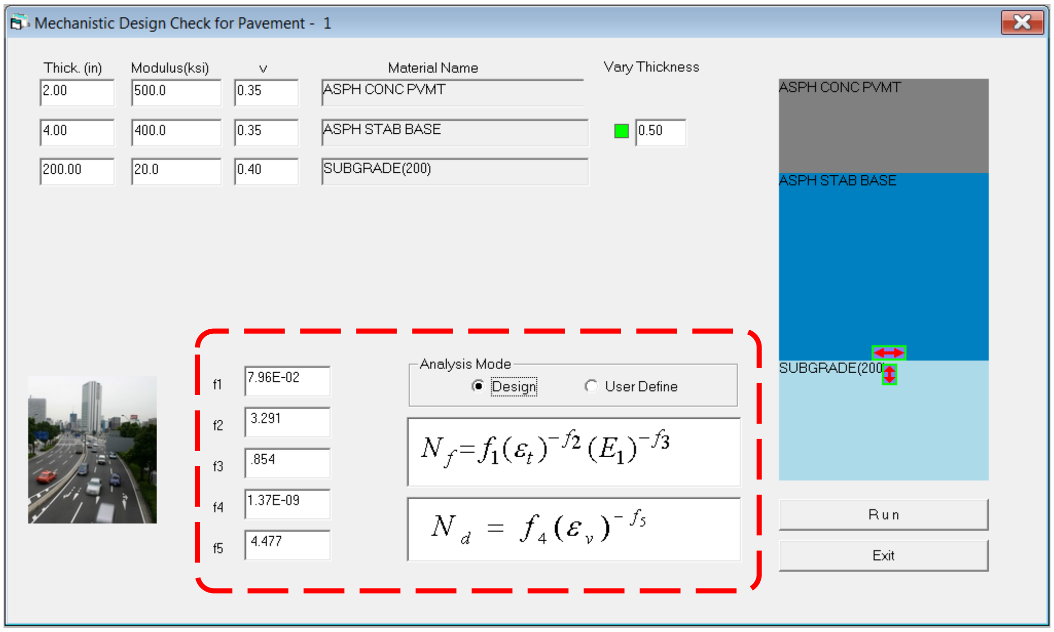


Figure 33. FPS Cracking and Rutting Models.

TxACOL

TxACOL is an M-E based software that is primarily developed for HMA overlay thickness design and analysis, with the two calibrated distress types integrated as follows:

- Reflective cracking.
- Permanent deformation (rutting).

Overview

The TxACOL software allows users to choose different overlay structures (single- or double-layer overlay) and different types of mixes and binders. The required input properties for overlay mixes are dynamic modulus, fracture properties (A and n), and rutting properties (α and μ); default values are provided in the TxACOL software for a number of HMA mixture and PG binder types. The required input parameters describing existing pavement conditions are layer thickness, layer modulus, joints/crack spacing, load transfer efficiency (LTE) at joints, and severity level of existing cracks. These parameters are obtained by visual field surveys and non-destructive testing such as GPR and FWD. TxACOL employs the enhanced integrated climatic model (EICM), which is also used in the M-E PDG to predict pavement layer temperature based on weather station data in Texas. To input climatic data, users can either load an existing EICM file from a design project or create a new file by selecting the closest weather stations. The standard traffic inputs in the TxACOL software are the cumulative ESALs in the 20-year design period and ADT at the beginning and end of the 20-year service, which are also used in the FPS software. Figure 34 shows the main screen of TxACOL.

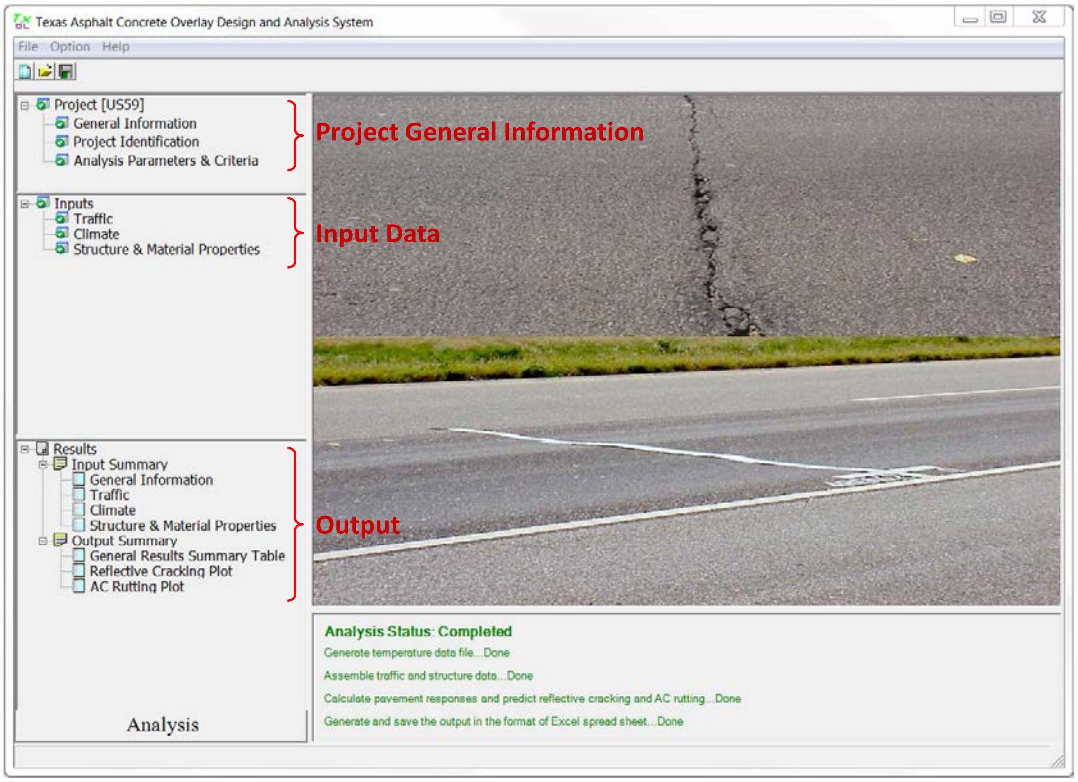


Figure 34. TxACOL Main Screen.

Required Input Data and Location in DSS

To support entering all required input parameters easily, the TxACOL software interface provides an easy navigation system. Users can enter general information, project identification, and analysis parameters and criteria, followed by design-governing input data in three main categories—traffic, climate, and structure and material properties—as shown in Figure 34. Table 18 presents the list of general, traffic, and climatic input parameters required for the TxACOL software and the location of each parameter in the DSS. Table 19 lists the input parameters related to the structure and material properties of the pavement layers.

Table 18. List of Input Parameters for TxACOL and Location in DSS: General, Traffic, and Climatic Information.

Item	Description	Data Source/Location in the DSS
General Information	Type of AC overlay design	Tables/Section details PVMNT structure details
	Analysis/design life (yr)	User input
	Pavement overlay construction month and year Traffic open month and year	Tables/Construction data PVMNT structure details
Project Identification	District, county, CSJ	Tables/Section details
	Functional class	Traffic data: Volume and classification
	Date	User input
	Reference mark format (lat/long) Reference mark (start-end)	Tables/Section details
Analysis Parameters and Performance Criteria	Reflective cracking rate (%)	User input
	AC rutting (in.)	User input
Traffic	ADT begin (veh/day) ADT end 20 yr (veh/day) 18-kip ESALs 20 yr—one direction (millions) Operation speed (mph)	Traffic data: Volume and classification
Climate	EICM weather station data	Raw data files or user input
	Latitude, longitude, and elevation	Tables/Section details Climatic-environmental data/Climatic data

Table 19. List of Input Parameters for TxACOL and Location in DSS: Structure and Material Properties.

Layer	Material	Description	Data Source/Location in the DSS
Overlay	**HMA**	Layer thickness (inches)	PVMNT structure details
		Material type	PVMNT structure details
		Thermal coefficient of expansion	HMA: thermal coefficient
		Poisson's ratio	User input (default value)
		Superpave PG binder grading	PVMNT structure details
		Dynamic modulus by temp. and freq.	HMA: DM
		Fracture property data: temperature, A and n	HMA: OT fracture properties
		Rutting property data: temperature, α and μ	HMA: RLPD
Existing Surface	**HMA**	Layer thickness (inches)	PVMNT structure details
		Material type	PVMNT structure details
		Thermal coefficient of expansion	User input (default value)
		Poisson's ratio	User input (default value)
		Main cracking pattern	
		1) Alligator/longitudinal/block cracking	
		a) Severity level (low/medium/high)	Form/Existing distress
		b) FWD temperature and modulus	FPD: FWD back-calculated modulus
		2) Transverse cracking	
		a) Crack spacing, severity level, LTE	Form/Existing distress
		b) FWD temperature and modulus	FPD: FWD back-calculated modulus
	Jointed Plain Cement Pavement/ Continuously Reinforced Concrete Pavement	Layer thickness (inches)	PVMNT structure details
		Material type	PVMNT structure details
		Thermal coefficient of expansion	User input (default value)
		Poisson's ratio	User input (default value)
		Joint/crack spacing (ft)	FPD: transverse cracking
		PCC modulus (ksi)	FPD: FWD back-calculated modulus
		LTE (%) and LTE standard deviation	FPD: FWD load transfer efficiency
Existing Sublayer	**Granular Base, Stabilized Base/ Subbase, and Subgrade**	Layer thickness (inches)	PVMNT structure details
		Material type	PVMNT structure details
		Poisson's ratio	User input (default value)
		Modulus (ksi)	FPD: FWD back-calculated modulus
		Thermal coefficient of expansion	User input (default value)

Output Data from Software

The software automatically creates the input and output summaries, in of the analyzed overlay design project in MS Excel format. The input summary provides the general information, traffic, climate, structure, and material properties. Also, a summary of the predictions for reflective cracking and rutting distresses is provided both in tabular and graphical (as a function of time in months) formats. Figure 35 shows the reflective cracking and rutting development plots.

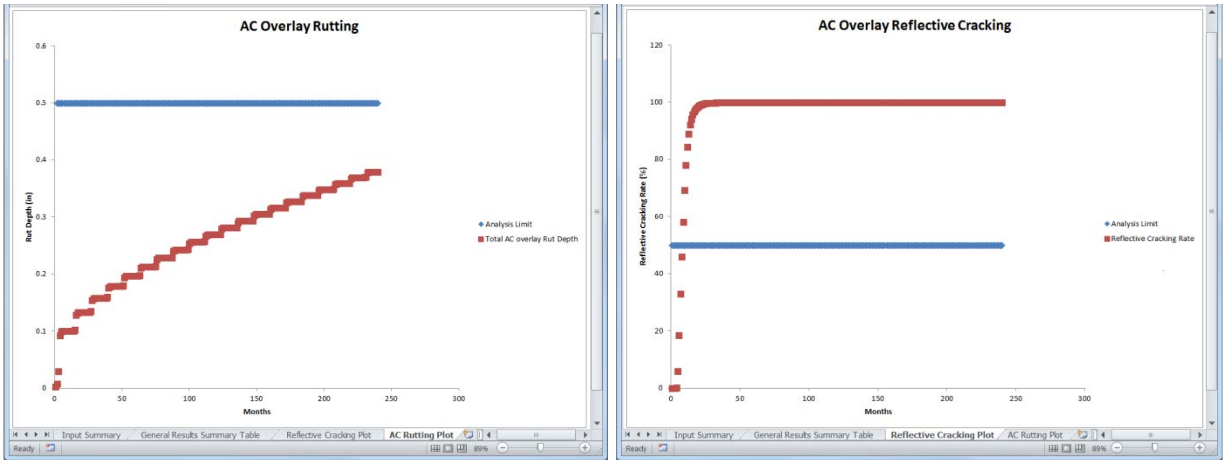


Figure 35. TxACOL Design Output: Rutting and Reflective Cracking.

Related M-E Models

TxACOL involves two key M-E models: rutting and reflective cracking. TxACOL considers rutting only from the HMA overlay layer since the rut from existing pavement layers occurred before the new overlay. Model calibration will be achieved through iterative and sensitivity variations of the calibration factors of each model until the TxACOL predictions and actual field performance measurements match each other within the given error tolerance. The following distress models are utilized in the software:

- AC rutting model:

$$\frac{\Delta\varepsilon_p(N)}{\varepsilon_r} = k_1 \mu N^{-k_2 \alpha} \tag{5.3}$$

where $\Delta\varepsilon_p(N)$ = permanent strain at the N^{th} load repetition.
ε_r = resilient strain.
N = number of load repetitions.
μ, α = rutting properties.
k_1 and k_2 = calibration factors.

- Reflection crack propagation model:

$$\Delta C = k_1 \Delta N_i A K_{bend}^n + k_2 \Delta N_i A K_{shear}^n + k_3 A K_{thermal}^n \tag{5.4}$$

where ΔC = crack length increment.
K_{bend} = stress intensity factor caused by bending load.
K_{shear} = stress intensity factor caused by shearing load.
$K_{thermal}$ = stress intensity factor caused by daily temperature variation.

A, n = cracking properties, determined by Overlay Tester.
k_1, k_2, and k_3 = calibration factors.

- Reflection cracking rate model:

$$RCR = \frac{100}{e^{ConstA(\rho/m)^{\beta}}} \tag{5.5}$$

where RCR = reflective cracking rate (%).
$ConstA$ = 0.693147.
ρ = curve width, determined based on the crack length calculation.
m = month number.
β = calibration factor (curve slope).

TxME

The TxME flexible pavement design system was developed by TxDOT to enable designers to make more economical, reliable designs based on M-E modeling and performance-based material characterization. It is used for performance prediction of the following distresses:

- AC thermal and fatigue cracking.
- AC and subsurface rutting.
- Stabilized base fatigue cracking.

Overview

In TxME, three types of flexible pavement structures can be designed, including:

- Surface-treated pavement.
- Conventional or thin HMA.
- Perpetual pavement.

The FPS establishes a link to TxME to conduct performance checks on the FPS recommended design options. Figure 36 shows the main screen of TxME.

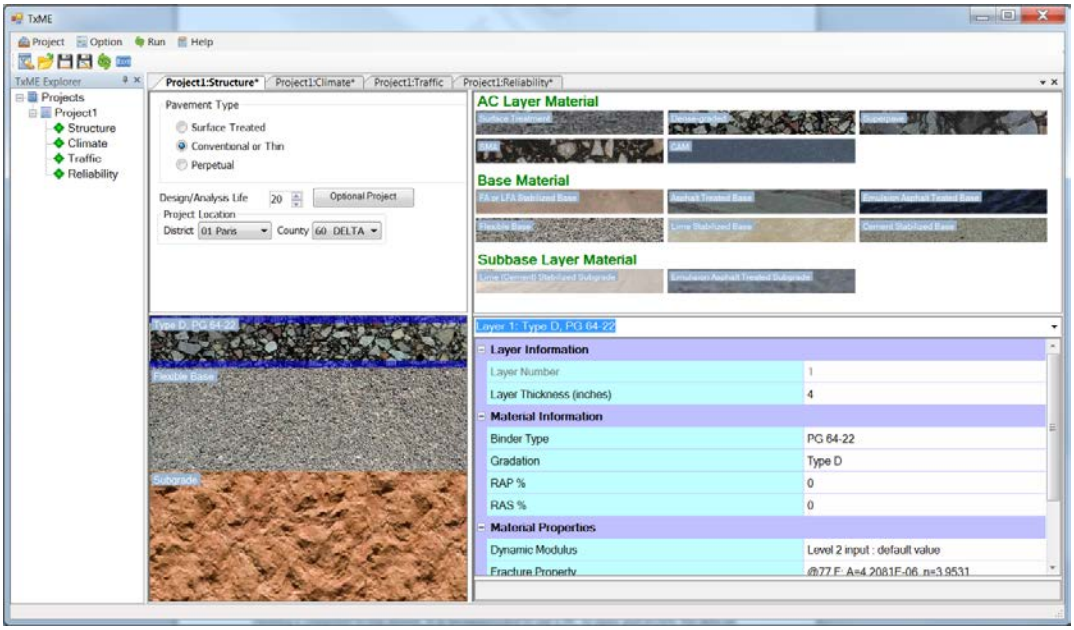


Figure 36. TxME Main Screen.

Required Input Data and Location in DSS

For any type of pavement design and analysis, there are four categories of input:

- Pavement structure and associated material properties.
- Traffic, including ESALs and load spectrum.
- Climate, EICM incorporated.
- Reliability-related input, including performance criteria and variability.

Table 20 and Table 21 list the full TxME input parameters along with the DSS location details.

Table 20. List of Input Parameters for TxME and Location in DSS: Structure and Climate.

Item	Description		Data Source/Location in DSS
Structure	Pavement Type		Tables/Section Details
	Design/Analysis Life		User Input
	Project Location (District/County)		Tables/Section Details
	Optional Project		
		Construction and Traffic Open Time	PVMNT Structure Details
		Reference Mark Begin/End	Tables/Section Details
		CSJ	Tables/Section Details
		Functional Class	Traffic Data: Volume and Classification
		Date	User Input
	AC Layer Material Information		
		Material Type	PVMNT Structure Details
		Layer Thickness	PVMNT Structure Details
		Binder Type	PVMNT Structure Details
		Gradation	PVMNT Structure Details
		RAP %	PVMNT Structure Details
		RAS %	PVMNT Structure Details
		Dynamic Modulus (ksi)	HMA: DM
		Fracture Property (*A* and *n*)	HMA: OT Fracture Properties
		Rutting Properties	HMA: RLPD
		Poisson Ratio	User Input (Default Value)
		Thermal Coefficient of Expansion	HMA: Thermal Coefficient
	Base and Subbase Material Information		
		Material Type	PVMNT Structure Details
		Layer Thickness	PVMNT Structure Details
		Modulus	FLEXBASE and TREATEDBASE: resilient modulus or FFRC
		Rutting Properties (α and μ)	FLEXBASE and TREATEDBASE: permanent deformation
		Modulus of Rupture	TREATEDBASE: MoR
		Fatigue Crack Parameter (B1 and B2)	Default Value
		Poisson Ratio	Default Value
	Subgrade Material Information		
		Modulus	RAWSUBGRADE and TREATEDBASE: resilient modulus or FFRC
		Rutting Properties (α and μ)	RAWSUBGRADE and TREATEDSUBGRADE: permanent deformation
		Poisson Ratio	Default Value
Climate	EICM Weather Station Data		Raw Data Files or User Input
	Latitude, Longitude, Elevation		Tables/Section Details Climatic-Environmental Data/Climatic Data

Table 21. List of Input Parameters for TxME and Location in DSS: Traffic and Reliability.

Item		Description	Data Source/Location in DSS
Traffic	**Level 2**	Tire Pressure	Default Value
		ADT Beginning ADT End 20 yr 18-kip ESALs 20 yr (one direction, millions) Operation Speed	Traffic Data: Volume and Classification
	Level 1	General Traffic Information	
		Traffic Two-Way Annual Average Daily Truck Traffic (AADTT) No. of Lanes in Design Direction % of Trucks in Design Direction % of Trucks in Design Lane Operation Speed	Traffic Data: Volume and Classification
		Axle Configuration	
		Axle Tire (Single and Dual Tire Pressure) Axle Spacing (Tandem, Tridem, and Quad)	User Defined or Default Value
		Monthly Adjustment	Traffic Data: Monthly Adjustment Factors
		Axle Load Distribution	Traffic Data: Load Spectra
		Vehicle Class Distribution and Growth	Traffic Data: Volume and Classification
		Axle per Truck	Traffic Data: Vehicle Classification System
Reliability		Performance Criteria	User Input
		Variability of Input Parameters	User Input

Output Data from Software

Similar to TxACOL, the TxME software generates summaries in the MS Excel format including the input summary and general performance results of the analyzed design project. The input summary provides the general information, traffic climate, structure, and material properties. Also, the general results of the predictions for thermal cracking, AC fatigue cracking, and rutting distresses are provided both in tabular and graphical (as a function of time in months) formats. Figure 37 shows the AC fatigue cracking and rutting development plots.

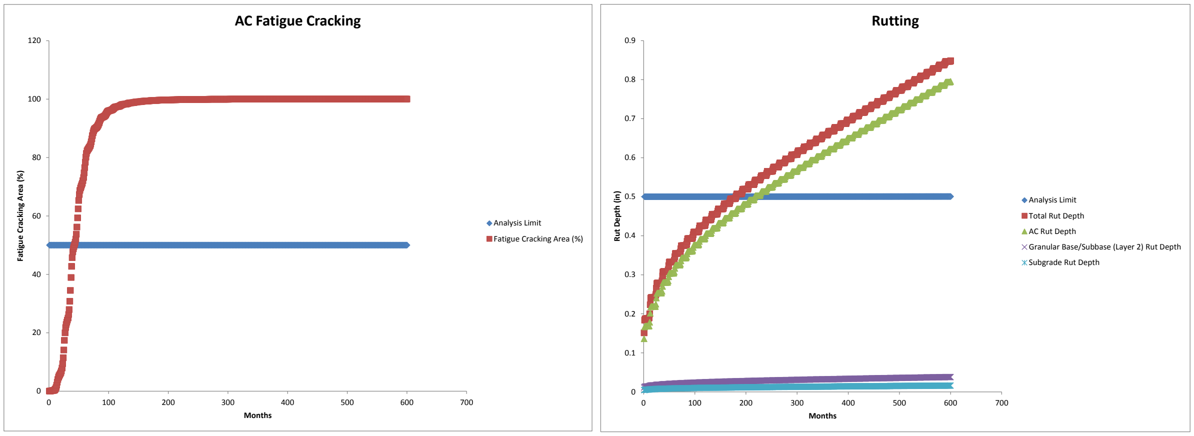


Figure 37. TxME Design Output: Fatigue Cracking and Rutting.

Related M-E Models

TxME involves three key M-E models: rutting, fatigue, and thermal cracking. TxME considers rutting from all pavement layers including AC, base, and subgrade for new and reconstructed pavements, while TxACOL considers rutting only from the HMA overlay layer. Model calibration can be achieved through iterative and sensitivity variations of the calibration factors of each model until the predictions and actual field performance measurements match each other within the given error tolerance. The following distress models are utilized in the software:

- AC rutting model:

$$RD = \sum_{i=1}^{n} kf(T,E,h) \int \left(U_i^+ - U_i^-\right) \mu_i N^{-\alpha_i} \tag{5.6}$$

where RD = rutting depth from AC layers.
U_i^+ and U_i^- = deflection at the top and bottom of AC layer i, respectively.
n = total number of AC layers.
μ_i, α_i = rutting properties of AC layer i.
$f(T,E,h)$ = adjustment factor according to AC layer temperature T, modulus E, and thickness h.
k = calibration factor.

- Base rutting model:

$$RD_{granular} = \sum_{i=1}^{M} k_{granular} \int \left(U_i^+ - U_i^-\right) \mu_i N^{-\alpha_i} \tag{5.7}$$

where RD_{granular} = rutting depth from granular base layers.
U_i^+ = deflection at the top of finite layer i.
U_i^- = deflection at the bottom of finite layer i.
M = total number of granular base layers.
μ_i, α_i = rutting properties of layer i.
k_{granular} = calibration factor.

- Subgrade rutting model:

$$RD_{subgrade} = k_{subgrade} U \mu N^{-\alpha} \tag{5.8}$$

where $RD_{subgrade}$ = rutting depth from subgrade layer.
U = deflection at the top of subgrade.
μ, α = rutting properties of subgrade.
$k_{subgrade}$ = calibration factor.

- AC fatigue:

$$N_f = k_i N_i + k_p N_p$$
$$fatigued\_area(\%) = \frac{100}{1 + e^{C \log D}} \tag{5.9}$$

where N_f = fatigue life.
N_i, N_p = crack initiation and propagation life.
k_i, k_p, C = field calibration factors.
D = accumulated fatigue damage.

- AC thermal cracking:

$$\Delta C = kA(\Delta K)^n$$
$$CA = \frac{100 * B}{e^{0.693147 * (\rho / m)^{\beta}}} \tag{5.10}$$

where ΔC = daily crack length increment.
A, n = cracking properties, determined by Overlay Tester.
ΔK = stress intensity factor caused by thermal load.
ρ = time point (months) when ΔC equals AC layer thickness.
CA = low temperature cracking amount (ft/mi).
k, β, B = calibration factor.

- Stabilized base fatigue:

$$N_{f-CTB} = 10^{\frac{k_1 B_1 - \left(\frac{\sigma_t}{M_r}\right)}{k_2 B_2}}$$
$$D = \sum \frac{N}{N_{f-CTB}}$$
$$fatigued\_area(\%) = \frac{100}{1 + e^{C \log D}} \tag{5.11}$$

where $N_{f\text{-}CTB}$ = number of repetitions to fatigue cracking of stabilized layer.

σ_t = maximum traffic induced tensile stress at the bottom of stabilized layer (psi).

M_r = 28-day modulus of rupture (psi).

k_1, k_2, C = calibration factors.

B_1, B_2 = stabilized layer fatigue cracking properties.

D = accumulated fatigue damage.

M-E PDG

M-E PDG is an M-E based analytical software for pavement structural design analysis and performance prediction, over a given service period. The MEPDG is the predecessor of the current AASHTO Pavement M-E licensed product. It is a shareware product of the NCHRP 1-37A and 1-40D research with a final publication made in 2009. Overview

The M-E PDG design procedure is primarily based on pavement performance predictions of increased levels of distress over time. Instead of generating pavement layer thickness designs like FPS, trial pavement layer thicknesses/material combinations are iteratively input into the software and the thicknesses/material combinations that meet the prescribed performance criteria are selected as the final designs. The performance predictions include permanent deformation, rutting, cracking (bottom-up and top-down), thermal fracture, and surface roughness (IRI). Figure 38 shows the main screen of M-E PDG.

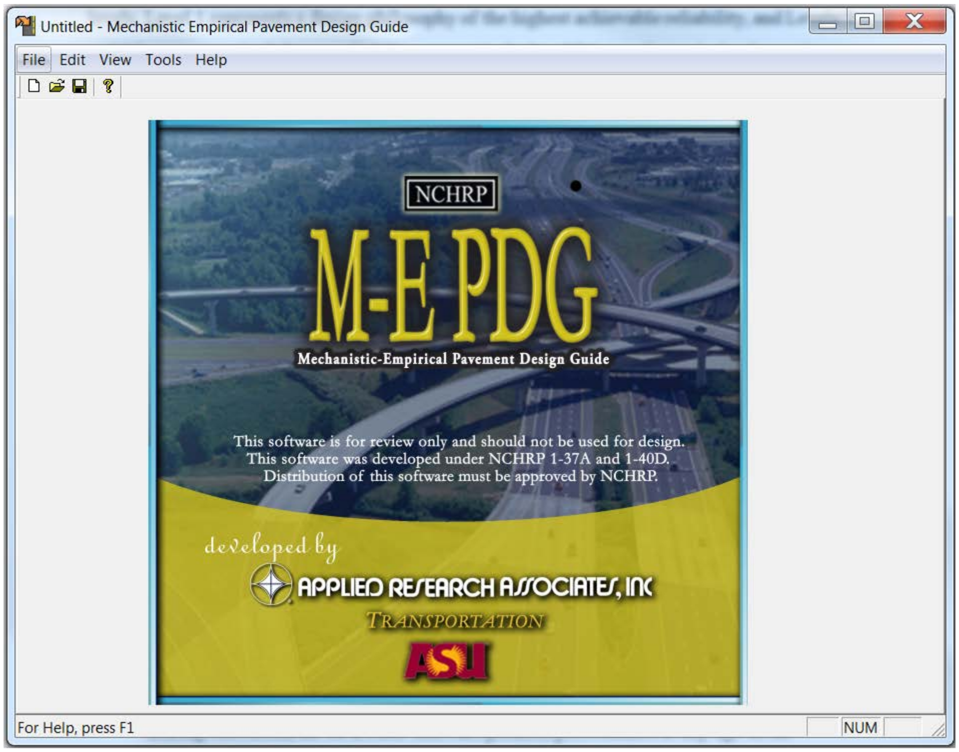


Figure 38. M-E PDG Main Screen.

Required Input Data and Location in DSS

In terms of the input data, M-E PDG uses a hierarchical system for both material characterization and analysis. This system has three material property input levels. Level 1 represents a design philosophy of the highest achievable reliability, and Levels 2 and 3 have successively lower reliability, respectively. In addition to the typical volumetrics, Level 1 input requires laboratory-measured binder and asphalt mixture properties such as the shear and dynamic modulus, respectively, whereas Level 3 input requires only the PG binder grade and aggregate gradation characteristics. Level 2 uses measured binder shear modulus properties and aggregate gradation characteristics. The basic M-E PDG input data include the general project information, traffic, climate (environment), pavement structure and material properties, distress failure limits, pavement design life, and design reliability level. Table 22 lists the full M-E PDG input data along with the DSS location details.

Table 22. List of Input Parameters for M-E PDG and Location in DSS.

Item	Description	Location in DSS
General Information	Project name	
	Design life (yr)	User Input
	Base/Subgrade construction month/year Pavement construction month/year Traffic open month/year	PVMNT Structure Details
	Section/Date/Job/Type of design	Tables/Section Details
Site/Project Identification	Location/Project ID/Section ID/Date Station/Milepost format/Begin/End Traffic direction	Tables/Section Details
Analysis Parameters	Project name	Tables/Section Details
	Initial IRI (inches/mi)	FPD: Surface Profile—PSI and IRI
	Terminal IRI (inches/mi) AC surface-down cracking, long. crack (ft/mi) AC bottom-up cracking, alligator crack (%) AC thermal fracture (ft/mi) Chemically stabilized layer fatigue fracture (%) Permanent deformation—total pavement (in.) Permanent deformation—AC only (in.)	User Defined or Default Values
Traffic	Design life (yr)	User Input
	Opening date	PVMNT Structure Details
	Initial two-way AADTT Number of lanes in design direction Percent of trucks in design direction (%) Percent of trucks in design lane (%) Operational speed (mph)	Traffic Data: Volume and Classification
Traffic Volume Adjustment Factors	Monthly adjustment Vehicle class distribution Hourly distribution Traffic growth factors	Traffic Data: Monthly Adjustment Factors
Axle Load Distribution Factors	Single/Tandem/Tridem/Quad axle	Traffic Data: Load Spectra
General Traffic Inputs	Mean wheel location Traffic wander standard deviation (inches)	User Defined or Default Value
	Design lane width (ft) (Note: not slab width)	PVMNT Structure Details or Default Value
Number Axles/Truck	Single, tandem, tridem, and quad (Class 4 to 13)	Traffic Data Tables
Axle Configuration	Average axle width outside dimensions Dual tire spacing/Tire pressure Tandem/Tridem/Quad Axle spacing	User Defined or Default Value
Wheelbase	Average axle spacing (ft)	User Defined or Default Value
	Percent of trucks (%)	Traffic Data: Volume and Classification
Climate	Latitude/Longitude/Elevation Depth of water table (ft)	Climatic-Environmental Data: Climatic Data

Table 22. List of Input Parameters for M-E PDG and Location in DSS. (Continued).

Item	Description	Location in the DSS
Structure	Surface shortwave absorptivity	User Defined or Default Value
	Layer/Type/Material/Thickness/Interface	PVMNT Structure Details
	For overlay design:	
	Level 1: existing rutting and milled thickness	Form: Existing Distresses Form: Construction Data
	Level 2: existing rutting, crack (%) in existing AC, and milled thickness	Form: Existing Distresses Form: Construction Data
	Level 3: milled thickness, total rutting, and pavement rating	Form: Existing Distresses Form: Construction Data
	Fatigue analysis endurance limit (national calibration based on no endurance limit)	User Defined or Default Value
HMA (use Level 3 if most data are unavailable)	Dynamic modulus—Level 1	HMA: DM
	DSR—Level 1 to 3	Binder: DSR
	Gradation—Level 2 and 3	HMA: Gradation Extractions
	Effective binder content	HMA: Volumetrics
	Air void	HMA: Volumetrics
	Total unit weight	HMA: Volumetrics
	Poisson's ratio	User Defined or Default Value
	Thermal conductivity	User Defined or Default Value
	Shear capacity asphalt	User Defined or Default Value
	Tensile strength and creep compliance	User Defined or Default Value
Base and Subgrade (use Level 3 if most data are unavailable)	Resilient modulus	BASE and SUBGRADE: Resilient Modulus or FFRC
	Soil classification	BASE and SUBGRADE: Soil Classification
	Gradation	BASE and SUBGRADE: Sieve Analysis
	Atterberg limits	BASE and SUBGRADE: Atterberg Limits
	Maximum dry unit weight	BASE and SUBGRADE: Maximum Dry Density (MDD) Curve
	Specific gravity (calculated or tested)	BASE and SUBGRADE: Specific Gravity
	Optimum gravimetric moisture content	BASE and SUBGRADE: MDD Curve
	Saturated hydraulic conductivity (calculated)	Default Values or User Defined
	Degree of saturation at optimum (calculated)	Default Values or User Defined
	Coefficient of later pressure	Default Values or User Defined
	Soil suction coefficients (tested or calculated)	Default Values or User Defined

Output Data from Software

During execution, the M-E PDG software predicts performance at any age of the pavement for a given pavement structure and traffic level for a particular environmental location (AASHTO, 2008). The M-E PDG predicted performance is then matched against predefined performance criteria at a given reliability level and design life. The basic M-E PDG output data (typically plotted as a function of time) include pavement rutting, cracking, roughness (IRI), etc. Figure 39 shows the rutting and IRI prediction plots.

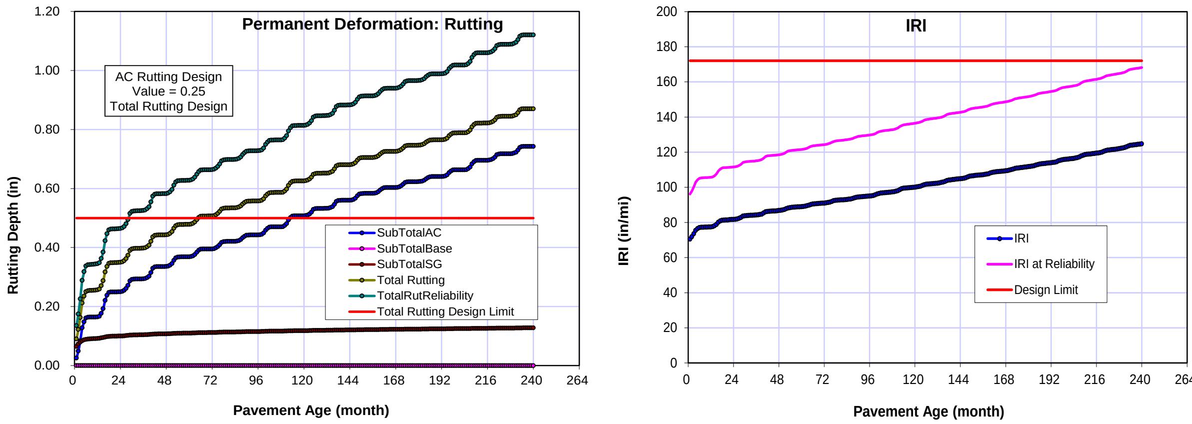


Figure 39. M-E PDG Design Output: Rutting and IRI.

Related M-E Models

M-E PDG involves three types of pavement distresses: rutting, fatigue, and thermal fracture. Model calibration can be achieved through iterative and sensitivity variations of the calibration factors of each model until the predictions and actual field performance measurements match each other within the given error tolerance. The following distress models are utilized in the software:

- AC rutting model:

$$\frac{\varepsilon_p}{\varepsilon_r} = k_z \beta_{r1} 10^{k_1} T^{k_2 \beta_{r2}} N^{k_3 \beta_{r3}} \tag{5.12}$$

where ε_p, ε_r = plastic and resilient strain (in./in.).
β_{r1}, β_{r2}, β_{r3} = calibration coefficients for asphalt mixtures
T = layer temperature.
N = number of load repetitions.
k_1, k_2, k_3 = non-linear regression coefficient.

- Subgrade rutting model:

$$\delta_a(N) = \beta_{s_1} k_1 \ \varepsilon_v \ h \left(\frac{\varepsilon_o}{\varepsilon_r}\right) \left| e^{-\left(\frac{\rho}{N}\right)^{\beta}} \right| \tag{5.13}$$

where δ_a = rutting depth at subgrade layer.
k_1 = calibration factor.

- AC fatigue:

$$N_f = 0.00432 C \beta_{f1} k_1 \left(\frac{1}{\varepsilon_t}\right)^{k_2 \beta_{f2}} \left(\frac{1}{E}\right)^{k_3 \beta_{f3}} \tag{5.14}$$

where k_1, k_2, k_3, β_{f1}, β_{f2}, β_{f3} = calibration factors.
ε_t = tensile strain at the critical location.
E = stiffness of the material

- Thermal fracture:

$$C_f = 400 * N\left(\frac{\log C / h_{ac}}{\sigma}\right)$$
$$\Delta C = (k * \beta t)^{n+1} * A * \Delta K^n \qquad (5.15)$$

where $N(\ )$ = standard normal distribution evaluated at ( ).
k = regression coefficient determined through field calibration
β_t = calibration factor.
A, n = fracture parameters for asphalt mixture
ΔC = change in the crack depth due to a cooling cycles.
ΔK = change in the stress intensity factor due to a cooling cycles.

- Stabilized base fatigue:

$$N_{f-CTB} = 10^{\frac{k_1 B_1 - \left(\frac{\sigma_t}{M_r}\right)}{k_2 B_2}} \qquad (5.16)$$

where k_1, k_2 = regression coefficients
σ_t = tensile stress
M_r = modulus of rupture.
B_1, B_2 = calibration factors.

- Stabilized base cracking:

$$FC_{ctb} = C_1 + \frac{C_2}{1 + e^{C_3 - C_4(Damage)}} \qquad (5.17)$$

where C_1, C_2, C_3, C_4 = calibration factors.

SUMMARY

This chapter presented the M-E model calibration process and an overview of M-E software, along with the following key aspects:

- The required input data and their location in DSS for running the M-E software, including FPS, TxACOL, TxME, and M-E PDG.
- The target M-E models to be calibrated for each M-E software:
    - FPS: fatigue cracking and full-depth rutting models.

- TxACOL: AC rutting, reflection crack propagation, and reflection cracking rate models.
- TxME: rutting (AC, base, and subgrade) and cracking (AC fatigue, AC thermal, and stabilized base fatigue) models.
- M-E PDG: rutting (AC, base, and subgrade), cracking (AC fatigue, AC thermal, and stabilized base fatigue), and IRI models.

Overall, this chapter demonstrated that the Project 0-6658 DSS has the proper format and structure to successfully run and calibrate the M-E models and associated software.

CHAPTER 6
CALIBRATION OF M-E MODELS

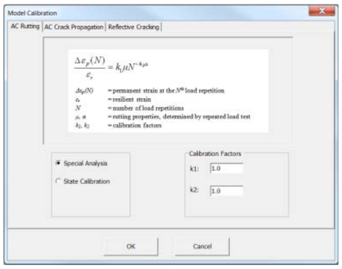
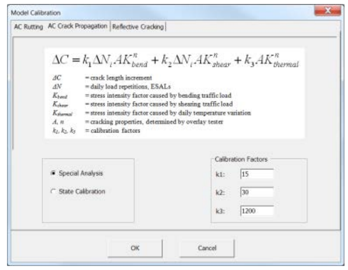
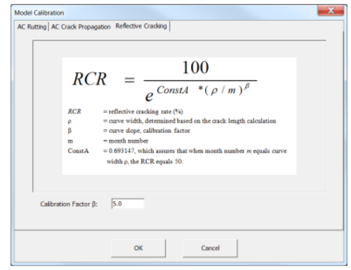
This chapter describes the research team's efforts involving preliminary calibration of M-E models and associated software using the material properties, climatic, traffic, and field performance data collected in the Project 0-6658 DSS.

PERFORMANCE MODELS AND CALIBRATION FACTORS

The calibration process aims to reduce the errors between the field-measured and model-predicted distresses in order to enhance the ability of local agencies to predict pavement performance. However, there are limitations regarding the availability of data in the DSS required for effective M-E model calibrations. A majority of the test sections (over 70 percent) sourced in Project 0-6658 were relatively early in their service life and thus had very limited field performance data and little to no distresses. In particular, the new construction test sections were relatively fresh and did not show any meaningful distress progress that could be used for M-E model calibration. Therefore, in this study, a preliminary calibration is limited to the performance models in TxACOL developed for HMA overlay thickness design and analysis due to insufficient field performance data for other distresses and programs. Continued monitoring of the remaining test sections is necessary to develop the distress progression relationship performance models. Similarly, continued monitoring of the overlaid test section is necessary to refine the preliminary calibrations offered here.

As described in Chapter 5, TxACOL consists of two pavement performance models, namely rutting and reflective cracking, which are regression equations that relate a material property to observed distresses. Also, each model includes the calibration factors with the default values calibrated primarily using eight test sections of the 2006 National Center for Asphalt Technology test track program (Hu et al. 2011). The software enables users such as local agencies to adjust the calibration factors and to calibrate the M-E models for local settings using their performance data in order to enhance their ability to predict pavement performance. Table 23 presents the TxACOL screen shots, performance models, default calibration factors, and corresponding field data location in DSS.

Table 23. TxACOL Model Calibration.

Type	AC Rutting	AC Reflective Cracking	
		AC Crack Propagation	Reflective Cracking Rate
TxACOL Screen			
Calibration factors and default values	k1 = 1.0 k2 = 1.0	k1 = 15 k2 = 30 k2 = 1,200	β = 5.0 (Curve slope)
Field data location in DSS	FPD: Temperature and Surface Rutting	FPD: Transverse Cracking FPD: Longitudinal Cracking	

TEST SECTIONS AND INPUT FOR CALIBRATION

The TxACOL performance parameters include rutting and reflective cracking, as described in Chapter 5. For the preliminary calibration in this study, three test sections (on US 59 in the Atlanta District) were used because those test sections had been in service for four years following overlay placement and show rutting distress for M-E model calibration:

- TxDOT_TTI-00001 (US 59, Atlanta District).
- TxDOT_TTI-00013 (US 59, Atlanta District).
- TxDOT_TTI-00014 (US 59, Atlanta District).

These sections are located in the Atlanta District, Panola County, in a WC climatic region and have the same structural layers and material types except for the inclusion of an interlayer (between overlay and existing HMA layers). The pavement structure consists of a 2-inch HMA overlay layer placed on April 2011, an 11.5-inch existing HMA surface, and a 16-inch lime-fly ash treated base. As noted in the previous chapter, certain required input parameters were obtained from the DSS, while default values were used for data unavailable in the DSS, such as the Poisson's ratio. The running process of TxACOL is discussed in Product 0-6658-P4, *Texas Flexible Pavements and Overlays: Calibration Plans for M-E Models and Related Software* (Walubita et al. 2013). All input parameters used to analyze and predict the performance in the TxACOL software are presented in Table 24 in accordance with each category.

Table 24. TxACOL Input Data of Test Sections for Calibration (US 59, Atlanta District).

Category	Value	Category	Value
General Information		Material Properties: AC Overlay 1	
Type of AC overlay design	AC/AC	Thermal coefficient of expansion	13.0
Analysis/Design life (yr)	20	Poisson's ratio	0.35*
PVMNT overlay const. month	April 2011	PG binder grading	64-22
Traffic open month	April 2011	Dynamic modulus	See DSS**
Analysis Parameter and Criteria		Fracture properties: temp./A/n	77F/4.56E-8/5.234
Reflective cracking rate (%)	50	Rutting properties: temp./α /μ	104/0.62/0.48 102/0.66/0.47
AC rutting	0.5		
Traffic		Material Properties: Existing AC	
ADT—beginning (veh/day)	3,711	Thermal coefficient of expansion	13.5*
ADT—end 20 yr (veh/day)	5,099	Poisson's ratio	0.35*
18-kip ESALs 20 yr (one direct.)	18.4M	Cracking type/spacing (ft)	Allig. Crack
Operation speed (mph)	70	Severity level	Medium
Climate (create new climatic file)		FWD back-calculated modulus	77°F/639ksi
Latitude (degree.minutes)	32.12	Material Properties: Existing Base	
Longitude (degrees.minutes)	−94.20	Poisson's ratio	0.2*
Elevation (ft)	328	Thermal coefficient of expansion	5.5*
Structural Input: Thickness/Material Type		Modulus (ksi)	176
AC overlay 1	2 in./Type D	Material Properties: Subgrade	
Existing AC	11.5 in./AC	Poisson's ratio	0.4*
Existing base 1	16 in./Stab. Base	Modulus (ksi)	26.0
Subgrade layer	−/Subgrade		

* Default values in TxACOL software.
** Material properties: HMA mixes in DSS.

CALIBRATION PROCESS

Figure 40 presents the reflective cracking and rutting plots generated from TxACOL based on the input parameters listed in Table 24 and the uncalibrated performance models. The results show that the rutting prediction suggests satisfactory performance without significant rutting failure over the 20 years analysis period, while the reflective cracking failure is very critical since its development reaches 50 percent at just 20 months. However, the surface condition of the US 59 section surveyed visually in June 2015 indicates that the sections had no reflection cracking on the surface even though they had been in service for 48 months since the overlay placement, as shown in Figure 41. This difference between predicted and actual field performances may indicate the need for calibrating the performance models in TxACOL. In this study, the calibration was performed only for the rutting model due to the absence of reflection cracking on those test sections.

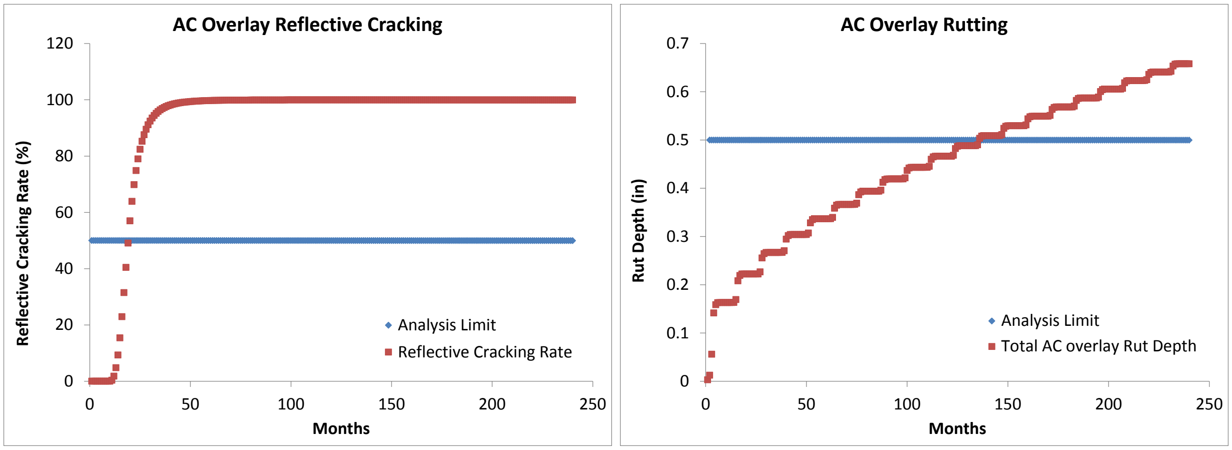


Figure 40. Overlay Performance Plots of US 59 Test Sections: (a) Reflective Cracking and (b) Rutting.

Figure 41. US 59 after 48 Months of Service.

Uncalibrated Rutting Performance from TxACOL

Figure 42 illustrates the comparison of the field rutting performance with the predicted performance with default calibration factors (k1 = 1.0 and k2 = 1.0) and the differences between both rutting performances using the line of equity, respectively.

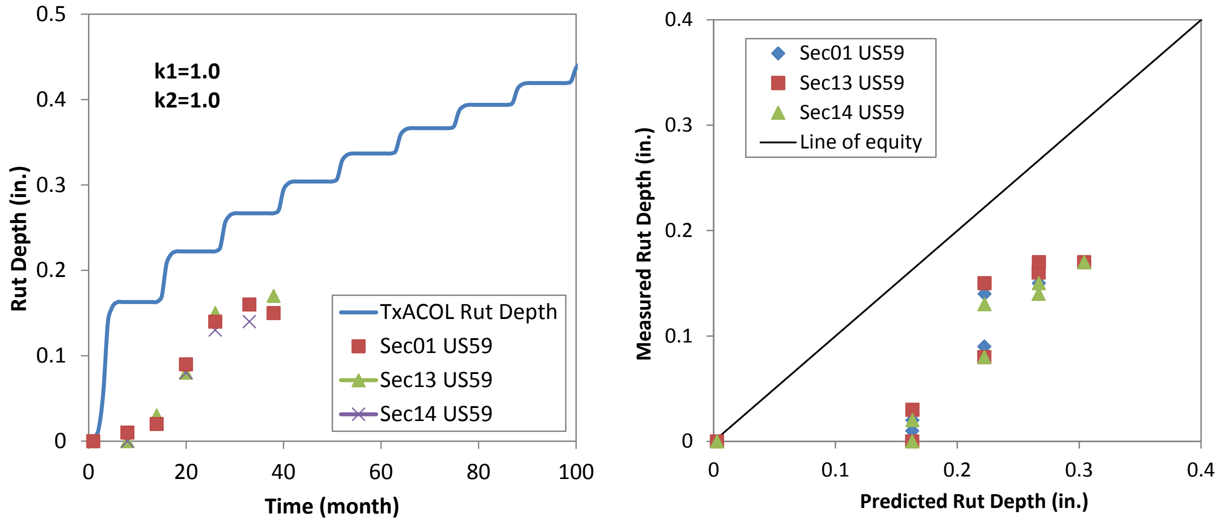


Figure 42. TxACOL-Predicted vs. Field-Measured Rutting (Uncalibrated).

As shown in Figure 42, the predicted rutting performance using nationally calibrated models is higher than the measured rutting performance. The square of residuals (deviations of predicted from measured rutting depths) for the test sections using default calibration factors is shown in Figure 43. The residual errors on all sections show a decrease with time except for the rutting performance at 26 months. This finding indicates that rutting prediction can be improved through adjustment of the calibration factors in TxACOL.

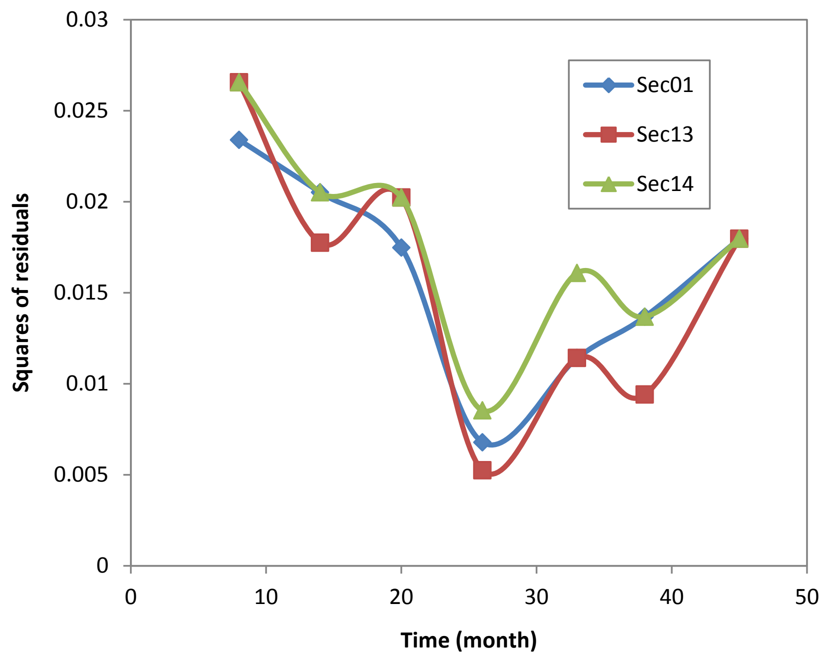


Figure 43. Square of Residuals for Rutting Predictions (Uncalibrated).

Local Calibration of Rutting Performance Model in TxACOL

In order to calibrate the rutting models in TxACOL, the trial and error method was adopted, meaning the software was run continuously until it found the best fit between predicted performance and field measurement with different rutting calibration factors. For this process, MS Excel was employed to minimize the sum of square errors between the predicted and measured rutting data. Through the calibration process, the calibration factors for HMA rutting were obtained based on the different calibration factors listed in Table 25. The sum of square error was minimized by adjusting k1 and k2 to 0.48 and 1.0, respectively. As seen in the table, the calibration was performed by adjusting only k1 since the k2 required sensitive adjustment to control the square errors.

Table 25. TxACOL Calibration Factors and Sum of Square Errors.

Calibration Factors		Sum of Square Error			
k1	**k2**	**Sec01**	**Sec02**	**Sec03**	**Avg.**
1.0	1.0	0.1113	0.1086	0.1236	0.1145
1.0	1.20	0.0253	0.0300	0.0222	0.0259
1.0	1.201	0.0256	0.0303	0.0224	0.0261
0.52	1.00	0.0118	0.0142	0.0131	0.0130
0.50	1.00	0.0115	0.0141	0.0124	0.0127
0.48	**1.00**	**0.0115**	**0.0144**	**0.0120**	**0.0126**
0.47	1.00	0.0116	0.0146	0.0119	0.0127

The comparison of the field rutting performance with the calibrated rutting prediction model is shown in Figure 44 for the three test sections. The calibrated model does provide a much better fit with the measured rutting performance, although the predicted rutting performance at an early age appears to still be an overprediction compared to the measured data. Also, Figure 45 presents the square of residuals from the calibrated rutting model to measured rutting for each test section. The lower residual errors from the calibrated model, compared to the uncalibrated model (Figure 43), show improved rutting prediction of TxACOL.

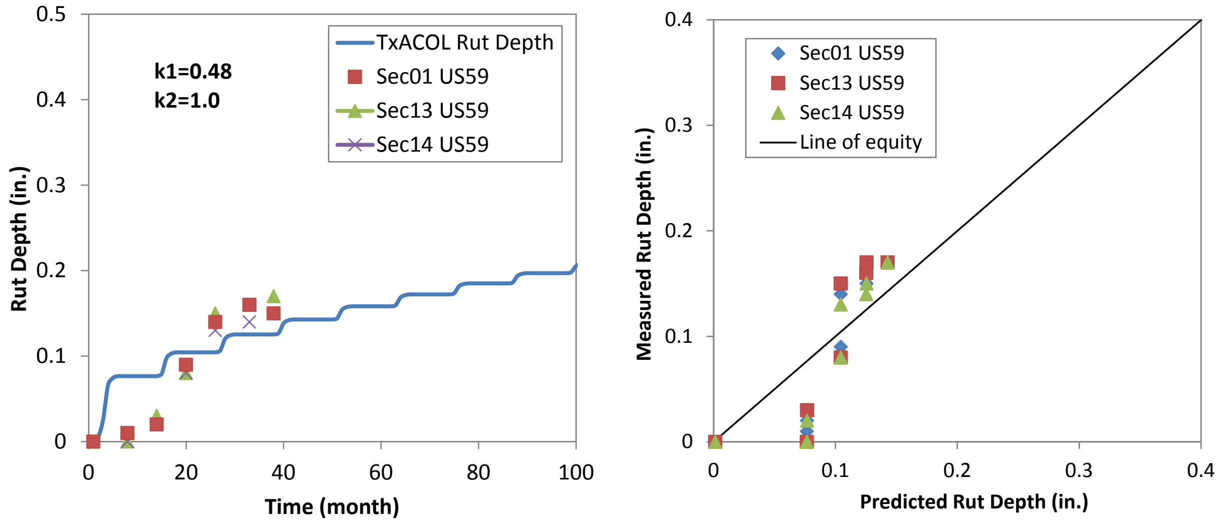


Figure 44. TxACOL-Predicted vs. Field-Measured Rutting (Calibrated).

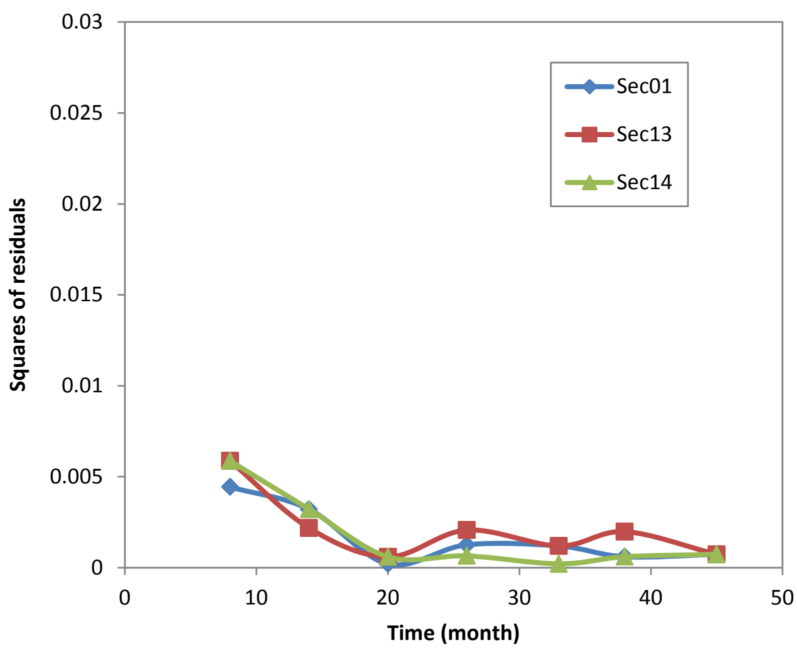


Figure 45. Square of Residuals for Rutting Predictions (Calibrated).

CALIBRATION CHALLENGES

Since the typical flexible pavement design parameters are established based on a 20-year analysis life prediction, the test sections need to be monitored just as long so that the design properties can be correlated to the actual field performance of the pavement over a typical expected life. However, a majority of the test sections (over 70 percent) sourced in Project 0-6658 were relatively early in their service life and thus had very limited field performance data and little to no distresses at the time of this study. In particular, the new construction test sections were relatively fresh and did not show any meaningful distress progress that could be used for

M-E model calibration. Therefore, continued field performance monitoring and data collection should be conducted for successful calibration and validation of M-E models and associated Texas M-E design software.

SUMMARY

This chapter described the preliminary calibration performed on three test sections as follows:

- Preliminary calibration was performed for the rutting model in TxACOL using three test sections on US 59 in the Atlanta District.
- While the test sections had been in service for 48 months since overlay placement, the surface conditions indicated that the sections showed rutting distress but not reflection cracking. Therefore, only the rutting model was calibrated due to the absence of reflection cracking on those sections.
- The calibrated factors for the rutting model were 0.48 for k1 and 1.0 for k2, which improved the rutting prediction of the test sections by decreasing the sum of square errors on the three sections as follows:
    - Sec01 US 59: from 0.1113 to 0.0115.
    - Sec13 US 59: from 0.1086 to 0.0144.
    - Sec14 US 59: from 0.1236 to 0.0120.

Overall, this chapter has demonstrated the preliminary calibration process and proved that the DSS can satisfactorily be used to run the M-E software and calibrate the associated M-E models. However, since a majority of the test sections were relatively early in their service life and had very limited field performance data with little to no distresses, field performance monitoring and data collection must be continued for successful calibration of M-E models.

CHAPTER 7
SUMMARY AND RECOMMENDATIONS

As discussed in the preceding chapters, the primary objective of this report is to document and demonstrate the work completed in Phase II and III of Project 0-6658, including the collection of material properties and pavement performance data and the calibration of M-E models using data collected in the DSS. As discussed in Chapters 2 through 6, the activities summarized below have been completed.

DATA COLLECTION AND POPULATION

Data collection and analysis involved laboratory and field testing to generate material properties and performance data for the database and calibration of the M-E models and associated structural design software. The work completed in this activity can be summarized as:

- A total of 112 test sections, well distributed in accordance with pavement type, climatic zone, districts, and service life, were collected.
- Data collection and analysis involved laboratory and field testing to generate material properties and performance data from the test sections, including:
    - Laboratory data (characterization of asphalt binders, HMA mixes, and base and subgrade soils).
    - Field performance data (twice per year, just after summer and just after winter).
    - Climatic and environmental data.
    - Traffic data (volume and classification, load spectra by axle type, monthly and hourly adjustment factors, etc.).
    - Supplementary data.
- Supplementary lab test data were collected from the research team's other engineering analysis and research projects. Although these data were not required as an M-E input parameter, nor were they mandated under this study, the material properties collected can serve as a useful data source to improve pavement design and rehab strategies for Texas. The supplementary data include the following:
    - HMA: FN, OT monotonic, SPST.
    - Treated base: sulfate content.
    - CTB (laboratory mixed): UCS, MoR, FFRC, and IDT.
- In order to store information related to pavement design and construction as well as a variety of both laboratory and field data, a data storage system consisting of two repositories was developed:
    - MS Access DSS for the processed data.
    - RDSSP for the unprocessed raw data.
- Each data storage system provides the data required for running Texas M-E models and related software, as well as the pavement section data for an ongoing reference source and general diagnostic tool for TxDOT engineers and other transportation professionals.

Also, the systems provide options for exporting data directly to preferred formats (e.g., Excel spreadsheet or PDF) and emailing the data for easy accessibility.

CALIBRATION OF M-E MODELS AND ASSOCIATED SOFTWARE

The preliminary calibration of M-E models and associated software was conducted using the material properties, climatic, traffic, and field performance data collected in the Project 0-6658 DSS.

- It was established that the Project 0-6658 DSS has the proper format and structure to successfully run and calibrate the M-E design software and associated performance models, including:
    - FPS: fatigue cracking and full-depth rutting models.
    - TxACOL: rutting and reflection cracking models.
    - TxME: rutting and cracking models.
    - M-E PDG: rutting, cracking, and IRI models.
- Due to insufficient field performance data for all distresses and programs, a preliminary calibration was performed only for the overlay rutting model in TxACOL using three test sections on US 59 in the Atlanta District.
- From the calibration, the calibration factors shown in Table 26 were obtained.

Table 26. Test Section Calibration Factors.

Calibration Factor	Default Value	Adjusted Value
k1	1.0	0.48
k2	1.0	1.0

CHALLENGES AND RECOMMENDATIONS

Based on the work completed and forgoing discussions, the following challenges are recognized and corresponding recommendations were made:

- Around 70 percent of the 112 test sections selected under Project 0-6658 were constructed within the last three years, and during the time of this study, they had satisfactory field performances with little to no distresses due to their relatively short service lives. As a result, no representative distresses such as fatigue or reflection cracking were available for use in the calibration of the M-E models and associated software. Thus, continued field performance monitoring and data collection are essential in facilitating the effective and accurate calibration of M-E models with representative field data.
- Completion of field performance data collection through terminal failure (i.e., more than three years) will serve as an effective data source to help TxDOT districts and engineers make better decisions for rehab strategy selections and design-related issues.

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APPENDIX
LIST OF LAB TESTS

Table A-1. Asphalt-Binder Test (Extracted Binders Only).

#	Test	Spec	Test Parameters	Output Data	Sample Replicates			Comment
					TTI	UTEP	*TxDOT Recommendation*	
1	AC extraction	Tex-210-F[a]	As per spec	N/A – just binder	≥ 65 lb		≥ 65 lb	Extract enough to run all the necessary tests (i.e., about 100 lb)
2	Specific gravity	T 228	As per spec	Specific gravity	3		*1*[a]	Report 0-6658-1
3	Viscosity	T 316	135 °C	Viscosity	3		*1*[a]	Report 0-6658-1
4	DSR[b]	T 315	As per spec	True grade, G*, and G*/Sin(δ)	3		*1*[a]	Report 0-6658-1
5	DSR – RTFO	T 240	As per spec	True grade, G*, and G*/Sin(δ)	3		*0*[c]	Report 0-6658-1
6	DSR _ PAV	R 28	As per spec	G*, G*/Sin(δ), and true grade	3		*0*[c]	Report 0-6658-1
7	MSCR	TP 70	As per spec; min 3 test temperatures per binder	R100, R3200, R_{diff}, $J_{nr}100$, $J_{nr}3200$, and $J_{nr-diff}$	9		*9 (3 × 3 temps)*	Report 0-6658-1
8	BBR[b]	T 313, R 28	As per spec; min 2 temps	Stiffness, m-value	6 (3 × 2 temps)		*2*[a] (1 × 2 temps)	Report 0-6658-1
9	Elastic recovery (ductility)	(D 6084-A)	As per TxDOT spec @ 50°F	Elastic recovery	3		*3*	Report 0-6658-1
10	Binder PG grading	M 320, Item 300, MP 19	As per spec	PG grade	–	–	–	Report 0-6658-1
Total number of replicates					33		*17*	

Note: Approximate material requirement ≥ 65 lb of plant mix (better to target 100 lb).
[a] Results for first test sections were repeatable with CV less than 5 percent, so no need for three or more replicates.
[b] Run the intermediate temperature DSR and BBR on the extracted binders as is (with no PAV) for mixes with RAP or RAS.
[c] Tests will be done on extracted binders only and treated as rolling thin-film oven (RTFO) residue, so no need for RTFO or pressure aging vessel (PAV).

Table A-2. HMA Mix Tests (Plant Mix and Cores Only).

#	Test	Spec	Test Parameters	Output Data	Sample Replicates			Comment
					TTI	UTEP	*TxDOT Recommend.*	
1	AC extraction	Tex-210-F[a]	As per spec	AC % (by weight)	3		***3***	
		Tex-236-F	As per spec	AC %	3		***0**[b]*	
2	Aggregate gradation	Tex-200-F	As per spec	Particle size distribution	3		***3***	Use aggregates from Tex-210-F
3	HWTT	Tex-242-F	As per spec, but run all samples to 20,000 load passes	Test temp., rut depth and number of wheel passes (i.e., 0, 5,000, 10,000, 15,000, and 20,000)	3 (3 sets of 2)		***1**[c]* *(1 set of 2)*	During testing, it is recommended to set the maximum rut depth to about 25 mm (instead of 12.5 mm)
4	OT	Tex-248-F	0.025 in., 93% load drop, 77°F	Test temperature, max load, and cycles to failure	5		***5***	
5	OT fracture properties		0.017 in. @ 77°F for 100 cycles	Test temp., *E(OT)*, *A*, and *n*	5		***5***	Test parameters recommended from Study 0-6622
6	DM	AASHTO TP 62-03	As per spec; 5 temps; 6 frequencies	Dynamic modulus (|E|), temperature, and frequency	3		***3***	Report 0-6658-1
7	RLPD	Reports 0-6658-P3 and 0-6658-1	(a)104°F, 20 psi, and 10,000 cycles, and (b) 122°F, 10 psi, and 10,000 cycles	Test temperatures, α, μ , and microstrains	6 (3 × 2 temps)		***6*** (3 × 2 temps)	Report 0-6658-1
8	IDT	Tex-226-F	As per spec	Test temp., IDT strength, and displacement @ peak load	3	–	***3***	Report 0-6658-1
9	Thermal coefficient	Reports 0-6658-P3 and 0-6658-1	14–104°F	Thermal coefficient (α)	3		***3***	Report 0-6658-1
10	FN	Reports 0-6658-P3 and 0-6658-1	50°C, 30 psi	Test temp., FN, Time to FN, accumulated microstrain @ FN (εP), and εP/FN	3		**–**	Report 0-6658-1
11	OT monotonic	Report 0-6607-2	0.125 in./min @ 77°F	Peak load, HMA tensile strength, strain, Fracture energy (FE), FE index	5	–	**–**	Report 0-6607-2
Total number of replicates					45		***32***	

Note: Approximate material requirement ≥ 405 lb of plant mix (better to target 450 lb).
[a] Test to be performed only if data cannot be obtained from QC/QA records.
[b] No need to do Tex-236-F if Tex-210-F is being conducted, though time consuming and costly, TxDOT prefers Tex-210 because it is more accurate.
[c] Results for first test sections were very repeatable with coefficient of variation less than 5%, so no need for 3 replicate sets.

Table A-3. Base Tests (Flex).

#	Test	Spec	Test Parameters	Output Data	Sample Replicates			Comments
					TTI	UTEP	*TxDOT Recom.*	
1	Sieve analysis[a,b]	Tex-110-E	As per spec	Gradation	3	Stock	*Stock (Tex-110-E for +#40 and Tex-111-E for −#40)*	Report 0-6658-1
2	Atterberg limits[a]	Tex-104-E, Tex-105-E, Tex-106-E	As per spec	PI, LL, and PL	3	2[d]	*1+*	Report 0-6658-1
3	Specific gravity	ASTM C-127, 128	As per spec	Specific gravity value	3	2[d]	*2[c]*	Report 0-6658-1
4	Wet Ball Mill[a,d]	Tex-116-E	As per spec	Wet Ball Mill value	3	2[d]	*0*	Report 0-6658-1
5	MD Curve[a]	Tex-113-E	6″ × 8″	MDD, OMC	3	2[d]	*1+*	Report 0-6658-1
6	Texas Triaxial	Tex-117-E	6″ × 8″	Classification, C, and ϕ	3	2[d]	*1[e]*	Report 0-6658-1
7	Resilient modulus	NCHRP 1-28A	6″ × 12″ OMC	k-parameters	3	2[d]	*2[c]*	Report 0-6658-1
8	Permanent deformation	NCHRP 1-28A	6″ × 12″ OMC	α and μ	3	2[d]	*2[c]*	Report 0-6658-1
9	Shear strength	Tex-143	6″ × 8″	C and ϕ	3	2[d]	*2[c]*	Report 0-6658-1
10	Soil suction	ASTM D5298		Suction coefficient	3	–	*0*	Report 0-6658-1
Total material to sample from the field					33		*11*	

Note: Approximate material requirement ≥ 700 lb (better to target 800 lb or more).

[a] Perform sieve analysis and compare gradation to TxDOT. If gradation matches, then use TxDOT QC data; otherwise, run test.

[b] Include sieves #100 and #200, which will be washed.

[c] A third test is performed if the duplicate results vary by a wide margin.

[d] If available, use from TxDOT QC. Researchers to run one test, if the results match the districts, they can use district results; if not, the researchers will run two samples.

[e] One sample at each confining pressure.

Table A-4. Base Tests (Treated—CTB).

#	Test	Spec	Test Parameters	Output Data	Sample Replicates			Comments
					TTI	UTEP	*TxDOT Recommendation*	
1	Sieve analysis[a,b]	Tex-110-E	As per spec	Gradation	3	Stock	*Stock*	Report 0-6658-1
2	Atterberg limit[d]	Tex-104-E, Tex-105-E, Tex-106-E	As per spec	PI, LL, and PL	3	2[f]	*1+*	Report 0-6658-1
3	Sulfate content[c]	Tex-145-E	As per spec	Sulfate content	3	2[f]	*0*	Report 0-6658-1
4	Wet Ball Mill[c]	Tex-116-E	As per spec	Wet Ball Mill value	3	2[f]	*0*	Report 0-6658-1
5	MD Curve[d]	Tex-113-E	As per spec	MDD and OMC	3	2[f]	*1+*	Report 0-6658-1
6	Unconfined compressive strength[d]	Tex-120-E, Tex-121-E	As per spec	UCS	3	2[f]	*1*[h]	Report 0-6658-1
7	Resilient modulus[d, g]	NCHRP 1-28A	6″ × 12″ OMC	k-parameters	3	2[f]	*2*[e]	Zero confinement, Report 0-6658-1
8[i]	Modulus of rupture[d, f]	-	Beam 6″ × 6″ × 12″ OMC	Modulus of rupture	3	2[f]	*2*[e]	ASTM D1632, ASTM C78, Report 0-6658-1
Total material to sample from the field					24		*7*	

Note: Approximate material requirement ≥ 550 lb (better to target 600 lb or more).
[a] Perform sieve analysis and compare gradation to TxDOT. If gradation matches then use TxDOT QC data; otherwise; run test.
[b] Include sieves #100 and #200.
[c] Test is performed before treatment.
[d] Test is performed after treatment.
[e] A third test is performed if the duplicate results vary by a wide margin.
[f] Test only for cement treated (>2%).
[g] Run FFRC instead of resilient modulus test at zero confinement.
[h] Includes running three samples at the cement content.
[i] When the cement stabilization content is 2 percent or less, reclassify the material as “untreated base” and test according to that protocol. For all other materials that have more than 2 percent stabilization content, leave them as a treated material, and if the modulus of rupture specimens cannot be fabricated, make a note in the DSS in the comments field.

Table A-5. Base Tests (Treated—Asphalt/Low Stabilizers).

#	Test	Spec	Test Parameters	Output Data	Sample Replicates			Comments
					TTI	UTEP	*TxDOT Recommendation*	
1	Sieve analysis[a,b]	Tex-110-E	As per spec	Gradation	3	Stock	*Stock*	Report 0-6658-1
2	Atterberg limit[c]	Tex-104-E, Tex-105-E, Tex-106-E	As per spec	PI, LL, and PL	3	2[f]	*1+*	Report 0-6658-1
3	Sulfate content[c]	Tex-145-E	As per spec	Sulfate content	3	2[f]	*0*	Report 0-6658-1
4	Wet Ball Mill[c]	Tex-116-E	As per spec	Wet Ball Mill value	3	2[f]	*0*	Report 0-6658-1
5	MD curve[d]	Tex-113-E	As per spec	Optimum moisture content and maximum dry density	3	2[f]	*1+*	Report 0-6658-1
6	Unconfined compressive strength[d]	Tex-120-E, Tex-121-E	As per spec	UCS	3	2[f]	*1*[f]	Report 0-6658-1
7	Resilient modulus[d,g]	NCHRP 1-28A	6″ × 12″ OMC	k-parameters	3	2[f]	*2*[e]	Zero confinement, Report 0-6658-1
8	Permanent deformation[d,f]	NCHRP 1-28A	6″ × 12″ OMC	α and μ	3	2[f]	*2*[e]	Zero confinement, Report 0-6658-1
Total material to sample from the field					24		*9*	

Note: Approximate material requirement ≥ 550 lb (better to target 600 lb or more).
[a] Perform sieve analysis and compare gradation to TxDOT. If gradation matches, then use TxDOT QC data; otherwise, run test.
[b] Include sieves #100 and #200.
[c] Test is performed before treatment.
[d] Test is performed after treatment.
[e] A third test is performed if the duplicate results vary by a wide margin.
[f] Test only for asphalt treated and low stabilizer content (< 2 percent).
[g] Run FFRC instead of resilient modulus test at zero confinement.

Table A-6. Subgrade Soil Tests (Raw).

#	Test	Spec	Test Parameters	Output Data	Sample Replicates			Comment
					TTI	UTEP	*TxDOT Recommendation*	
1	Sieve Analysis[a,b]	Tex-110-E	As per spec	Gradation	3	Stock	*Stock (Tex-110-E, Part I for +#40 and Part II for –#40 [hydrometer])*	Report 0-6658-1
2	Atterberg limits	Tex-104-E, Tex-105-E, Tex-106-E	As per spec	PI, LL, and PL	3	2[d]	*1+*	Report 0-6658-1
3	Specific gravity	Tex-108-E	As per spec	SG value	3	2[d]	*2[c]*	Report 0-6658-1
4	Sulfate content	Tex-145-E	As per spec	Sulfate content	3	2[d]	*0*	Report 0-6658-1
5	Organic content	Tex-408-A	As per spec	Organic content	3	2[d]	*0*	Report 0-6658-1
6	MD curve	Tex-114-E	As per spec	MDD and OMC	3	2[d]	*1+*	Report 0-6658-1
7	Texas triaxial	Tex-117-E	As per spec	Classification, C, and ϕ	3	2[d]	*1*	Report 0-6658-1
8	Resilient modulus	NCHRP 1-28A	4″ × 8″ OMC	k-parameters	3	2[d]	*2[c]*	Report 0-6658-1
9	Permanent deformation	NCHRP 1-28A	4″ × 8″ OMC	α and μ	3	2[d]	*2[c]*	Report 0-6658-1
10	Shear strength	Tex-143	As per spec	C and ϕ	3	2[d]	*2[c]*	Report 0-6658-1
11	Soil suction	ASTM D5298		Suction coefficient	3	–	*0*	Report 0-6658-1
Total material to sample from the field					33		*11*	

Note: Approximate material requirement ≥ 350 lb (better to target 400 lb or more).
[a] Perform sieve analysis and compare gradation to TxDOT. If gradation matches, then use TxDOT QC data; otherwise, run test.
[b] Include sieves #100 and #200.
[c] A third test is performed if the duplicate results vary by a wide margin.
[d] Plus one sample for every change in material.

Table A-7. Subgrade Soil Tests (Treated).

#	Test	Spec	Test Parameters	Output Data	Sample Replicates			Comment
					TTI	UTEP	*TxDOT Recommendation*	
1	Sieve analysis[a,b]	Tex-110-E	As per spec	Gradation	3	Stock	*Stock (Tex-110-E, Part I for +#40 and Part II for −#40 [hydrometer])*	Report 0-6658-1
2	Atterberg limits[c,d]	Tex-104-E, Tex-105-E, Tex-106-E	As per spec	PI, LL, and PL	3	2[f]	*1+*[g]	Report 0-6658-1
3	Sulfate content[d]	Tex-145-E	As per spec	Sulfate content	3	2[f]	*2*[e]	Report 0-6658-1
4	Organic content[d]	Tex-408-A	As per spec	Organic content	3	2[f]	*0*	Report 0-6658-1
5	MD curve[d]	Tex-114-E	As per spec	MDD and OMC	3	2[f]	*0*	Report 0-6658-1
6	Unconfined compressive strength[d]	Tex-120-E, Tex-121-E	As per spec	UCS	3	2[f]	*1+*	Report 0-6658-1
7	Resilient modulus[d,f]	NCHRP 1-28A	4″ × 8″ OMC	k-parameters	3	2[f]	*2*[d]	Report 0-6658-1
8	Permanent deformation[d]	NCHRP 1-28A	4″ × 8″ OMC	α and μ	3	2[f]	*2*[d]	Report 0-6658-1
Total material to sample from the field					24		*8*	

Note: Approximate material requirement ≥ 150 lb (better to target 200 lb or more).
[a] Perform sieve analysis and compare gradation to TxDOT. If gradation matches then use TxDOT QC data, otherwise run test.
[b] Include sieves #100 and #200.
[c] Test is performed before treatment.
[d] Test is performed after treatment.
[e] A third test is performed if the duplicate results vary by a wide margin.
[f] Run FFRC instead of resilient modulus test at zero confinement.
[g] Plus one sample for every change in material.

Table A-8. Lab Tests (Neat Asphalt Binders: Obtained Directly from the Plant or Truck [Onsite during Construction]).

#	Test	Spec	Parameters	Sample Replicates			Comments/Reference
				TTI	UTEP	*TxDOT Recommendation*	
1	Residual recovery (emulsions only)	Texas Oven (6 hr @ 60°C)	Residual recovery	3 (60 g)		*3*	Silicon sheets may be obtained from Bed, Bath and Beyond Report 0-6658-1
2	Viscosity	T 316	Viscosity	1 (40 g)		*1*	Report 0-6658-1
3	Specific gravity	T 228	SG	1 (40 g)		*1*	Report 0-6658-1
4	RTFO and PAV	T 240, R 28		1 (60 g)		*1*	Report 0-6658-1
5	DSR	T 315	G* and G*/Sin(δ)	1 (60 g)		*1*	Report 0-6658-1
6	MSCR	TP 70	Jnr, Jnr ratio % recoverable strain	9 *(3 × 3 temps)* (60 g)		9 *(3 × 3 temps)*	Report 0-6658-1
7	BBR	T 313	S and m-values	2 *(1 × 2 temps)* (60 g)		2 *(1 × 2 temps)*	Report 0-6658-1
8	Elastic recovery	D 6084	% recovery	3 (100 g)		3	Report 0-6658-1
9	Surface performance grade (SPG)	Report 0-1710-2	SPG binder grade	–		–	1) Report 0-1710-2 2) Report 0-6658-1
Total number of replicates				21		*21*	

Note: Approximate material requirement = one 5-gal (≅ 38 lb) bucket of neat binder obtained either from the plant or directly from the truck onsite during construction.