Technical Report Documentation Page

1. Report No. FHWA/TX-10/0-5513-2	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle Development of the Texas Flexible Pavements Database		5. Report Date October 2008; Revised February 2010
		6. Performing Organization Code
7. Author(s) Ambarish Banerjee, Jose Pablo Aguiar-Moya, Andre de F. Smit and Jorge A. Prozzi		8. Performing Organization Report No. 0-5513-2
9. Performing Organization Name and Address Center for Transportation Research The University of Texas at Austin 1616 Guadalupe, Suite 4.202 Austin, Texas 78701-1255		10. Work Unit No. (TRAIS)
		11. Contract or Grant No. 0-5513
12. Sponsoring Agency Name and Address Texas Department of Transportation Research and Technology Implementation Office P.O. Box 5080 Austin, TX 78763-5080		13. Type of Report and Period Covered Technical Report September 1, 2005-August 31, 2008
		14. Sponsoring Agency Code

15. Supplementary Notes
Project performed in cooperation with the Texas Department of Transportation and the Federal Highway Administration.
Project Title: Development of a Flexible Pavements Database

16. Abstract

The goal of this research project was the development of the Texas Flexible Pavement Database (TFPD) to serve as a reference database comprising design, construction, structural and performance data for selected roadway sections in Texas. The database was designed as a project-level application with the purpose of developing, validating and calibrating mechanistic-empirical pavement design models. To achieve this objective it was necessary to evaluate pavement sections with performance data spanning a number of years and for this reason the database was initially populated with Texas sections from the Long Term Pavement Performance (LTPP) studies. In addition, a number of newly constructed sections within Texas were included in the database. The performances of these new sections were monitored over a two-year period and performance data collected on these sections on two occasions have been included in the database. The TFPD comprises 70 sections (35 from LTPP and 35 new) spanning the climate, traffic, and structure types found in Texas. It is recommended that these sections continue to be monitored on an annual basis to track the performance of these pavements throughout their design life. It should be noted that the entire database consist of close to 200 sections, though few of them are missing information related to material properties and testing.

A second objective of this project was to provide guidelines for local calibration of the Mechanistic Empirical Pavement Design Guide (MEPDG). The performance models used in the MEPDG are calibrated using sections spread throughout the U.S. Hence, it is necessary to calibrate these models for specific states and regional conditions because of the differences in terms of materials, environmental conditions, and construction practices. The regional calibration factors were obtained by minimizing the sum of squared errors between the observed and the predicted distresses. In this case, a simultaneous joint optimization routine was used because it is theoretically sound. Finally, an average of the regional calibration coefficients for AC and subgrade rutting was computed to obtain the set of state-default calibration coefficients for Texas. The report outlines the procedure followed and reports the initial local and statewide calibration factors determined based on the LTPP sections currently in the TFPD.

17. Key Words	18. Distribution Statement
Pavement Management Information System, Mechanistic-Empirical Pavement Design, Long Term Pavement Performance, Pavement Design	No restrictions. This document is available to the public through the National Technical Information Service, Springfield, Virginia 22161; www.ntis.gov.

19. Security Classif. (of report)	20. Security Classif. (of this page)	21. No. of pages	22. Price
Unclassified	Unclassified	190	

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Ambarish Banerjee
Jose Pablo Aguiar-Moya
Andre de F. Smit
Jorge A. Prozzi

CTR Technical Report: 0-5513-2
Report Date: October 2008; Revised February 2010
Research Project: 0-5513
Research Project Title: Development of a Flexible Pavements Database
Sponsoring Agency: Texas Department of Transportation
Performing Agency: Center for Transportation Research at The University of Texas at Austin

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

Center for Transportation Research
The University of Texas at Austin
1616 Guadalupe, Suite 4.202
Austin, Texas 78701-1255

www.utexas.edu/research/ctr

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Research Supervisor: Jorge Prozzi

Acknowledgments

The authors thank Mike Murphy, PC, Construction Division and Ahmed Eltahan, PD, Construction Division, for their assistance during the development of this project. Special thanks to Karen van Hooser for supporting the development of the data dictionary and to Brett Haggerty and Joe Leidy for helping the research team with running the GPR. Likewise, gratitude is expressed to all the personnel from TxDOT that provided expertise and guidance in the development of the database for this project. Larry Wise from the LTPP Office of the Federal Highway Administration is greatly acknowledged for his continuous support and help. This project would not have been possible without the generous support, feedback, guidance, and assistance from all of these individuals. The authors also extend special appreciation to the many individuals in the districts who provided traffic control in so many locations across the state. The research team would also like to thank Harold L. von Quintus, for the time and effort he has put into this project to make it a success.

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Chapter 1. Introduction

1.1 Background

For more than 30 years, in a quasi-continuous effort that began in 1972, the Texas Transportation Institute (TTI) has maintained a Texas Flexible Pavement Database. Originally, the database comprised 350 pavement sections that were selected following a stratified random sampling approach. The number of sections selected in each Texas Department of Transportation (TxDOT) district was proportional to the total number of miles in each district for each type of facility [e.g., Interstate (IH), U.S. (US) and State Highways (SH), Farm-to-Market (FM) and Ranch-to-Market (RM) roads, etc.]. This process would have resulted in the sampling of a large number of FM roads. However, because of the strategic and economic importance of the interstate system, the Interstate Highways were sampled at a higher rate. The data collected and contained in this database were the basis for developing the performance equations and pavement condition prediction capabilities that were incorporated into various optimization routines, which eventually became part of the Flexible Pavement System (FPS) software for flexible pavement design (Scullion, T., and Michalak, C., 1997).

In addition to structural and basic condition information, deflection measurements were performed and complete condition surveys were carried out to determine the serviceability index of the various sections contained in the database. Weather data were also taken from the records of weather stations in the counties where the sections were located. In the process, a backup system of weather stations was also installed. With the advent of mechanistically based pavement design approaches, the popularization of the Falling Weight Deflectometer (FWD) and back calculation techniques, and the increased need for designing overlays, data needs became more demanding and maintaining such a large database for design purposes became unrealistic and unfeasible. Thus, in 1988, TxDOT Project 0-187-6, "Preserving the Texas Pavement Database," was initiated to:

- Preserve, update and improve the Texas Flexible Pavement Database,
- Store all condition and deflection data that are collected by TxDOT personnel on the pavement sections in the database, and
- Revise, using the new data, the pavement distress and performance equations for each type of pavement represented in the database.

Once Project 0-187-6 concluded, a period of time followed during which data were not collected and the database was not maintained. This was addressed in 2001, when another project modification was put in place to re-establish the Texas Flexible Pavement Database and to facilitate its full implementation. The objective of this modification was to fill in the experimental cells that were lacking, primarily covering pavement structures in different environmental regions. The full experimental design included the following variables: type of pavement structure, environmental conditions, traffic loads, layer thickness, and material types. The experimental design necessary to take into account possible levels for all these variables was not economically feasible, so the project focused on a partial experiment that was more realistic.

The implementation plan established that the database was *"to be used to validate and verify design data being generated by District Pavement Engineers."* In addition, the database was to be applied for calibrating the performance curves used in FPS-19W and other design algorithms used by TxDOT. The database was also to be used to validate modulus values used in FPS-19W and to monitor the changes in material stiffness during the life of the pavement.

The experimental design considered in this project consisted of almost 500 sections that included:

1) Six pavement types,
2) Two subgrade types (weak and strong),
3) Five traffic levels, and
4) Five environmental regions (dry-cold, dry-warm, wet-cold, wet-warm, and mixed).

Although logical, this goal turned out to be challenging due to the significant effort that it implied. Thus, in 2003, another project modification contemplated the incorporation of the data corresponding to the Long Term Pavement Performance (LTPP) studies contained in the DataPave database (http://www.ltpp-products.com/). Sections from the LTPP General Pavement Studies (GPS) and Specific Pavement Studies (SPS) were incorporated into the scope of the project. These data were to be used to perform a sensitivity analysis to the design variables using the 2002 Mechanistic-Empirical Pavement Design Guide (MEPDG) Version 1.0.

The current research team's belief is that the resources required to maintain and manage a project-level database containing information of several hundred sections are very significant and may not be sustainable. The database generated as a result of the LTPP studies, DataPave (FHWA, 2004), is the largest and most comprehensive pavement performance database generated to date. The database contains a large number of fields, which makes data collection and maintenance a task that is economically and practically challenging. The database is rich in data that can easily be collected and processed, such as FWD deflection data and back calculated moduli. However, it often lacks accurate essential information such as well-characterized highway traffic loads (counts, classification, axle load spectra) (Prozzi and Hong, 2006; Prozzi, Hong and Leidy, 2006). One other area that lacks significant amounts of data is the Material Information section.

As discussed earlier, to some extent, the same applies to local efforts with similar objectives. Work on the development of a Texas Flexible Pavement Database has been ongoing for more than 30 years. But it has been observed in the past that the research objectives were too wide-ranging and almost exhaustive and became unachievable and unrealistic within reasonable budget and time constraints. Lessons were learnt from these experiences, and for the current project every effort was made to keep the objectives reasonable rather than aiming for a lofty, unobtainable goal.

1.2 Pavement Design

In recent years the Transportation Research Board (TRB), through their National Cooperative Highway Research Program (NCHRP), invested more than 6 years and $6.5 million putting together the recommended "Mechanistic-Empirical Guide for the Design of New and Rehabilitated Pavement Structures," or simply the MEPDG (NCHRP, 2006). More than 20 years of pavement research and experience were compiled into a comprehensive document, and corresponding software was developed for designing new and rehabilitated flexible and rigid pavement structures. The software and relevant information is available at http://www.trb.org/mepdg/. The performance models contained in the software have been calibrated for national standards and, therefore, their applicability to specific regional conditions is questionable (Prozzi and Hong, 2005).

In particular, two recent TxDOT-sponsored research projects, 0-4510, *"Evaluate Equipment, Methods, and Pavement Design Implications for Texas Conditions of the AASHTO 2002 Axle Load Spectra Traffic Methodology,"* and 0-4714, *"Development of a Strategic Plan for the Implementation of the AASHTO 2002 Design Guide for TxDOT Operations"* indicated that, in numerous instances, the MEPDG produced unreasonable results for typical Texas structures and environmental conditions (Prozzi, Hong and Leidy, 2006). Similar conclusions have been observed in other states. There are a number of potential reasons for these discrepancies, including:

1) Lack of calibration to local environmental conditions in Texas;
2) Inaccurate pavement response models (e.g., multi-layer linear elasticity);
3) Inadequate/incorrect transfer functions or pavement performance models to capture Texas pavement design technology; and
4) Problems inherent to the functionality of the software itself.

The lack of accuracy in the performance predictions can partially be attributed to the lack of an accurate local pavement database to calibrate the models. Interestingly, the following observation is relevant: the original intent of NCHRP 1-37A was to use data from LTPP for development, validation, and calibration of the performance models. This task proved to be extremely laborious due to the reduced number of LTPP sections containing complete information. It should be noted that some of the Texas LTPP sections provided some of the best data available for national calibration of the MEPDG.

Other data sources were also utilized, including the results of the American Association of State Highway Officials (AASHO) Road Test, which took place in the late 1950s and early 1960s (probably the most accurate pavement performance database available to date). The AASHO Road Test database, however, has other limitations related to the changes in technology over the past 50 years. These changes affect material technology, construction techniques, and traffic characteristics. Furthermore, the subgrade conditions and environmental effects from the AASHO Road Test are drastically different from those found in Texas.

Given the above-mentioned shortcomings, it should be emphasized that, in its current format, the MEPDG and associated software can be considered the most powerful and comprehensive pavement performance analysis tool ever put together. Nonetheless, the specific data that are required by the MEPDG are not necessarily the most practical or the best type of data for design or for TxDOT's needs. A typical example is the use of dynamic modulus (E*) to estimate pavement response and fatigue and rutting performance. National and local experimental work has already indicated that dynamic modulus is a relatively complex test that does not correlate to actual fatigue performance. This research includes projects at Texas A&M University and The University of Texas at Austin and El Paso. Hence, before embarking on populating a database, some essential planning was necessary to determine the type, quality, and level of reliability of the data to be incorporated into the database. For instance, the MEPDG characterizes axle loads by means of more than 10,000 parameters, while only one parameter is used for tire inflation pressure, and only one parameter is used to characterize traffic speed

(Prozzi and Luo, 2005; Prozzi and Hong, 2007b). A compromise had to be made as to the data that needed to be collected before collecting everything the MEPDG recommends.

1.2.1 Design Reliability and Risk Analysis

With the incorporation of design reliability in the 1986 version of the AASHTO Guide for the Design of Pavement Structures, an important advancement was achieved. However, when designing pavement, it should be kept in mind that what is being designed is probably the most complex civil engineering structure due to the high variability of road building materials and the typical dimensions of the pavement structures: *"miles long, feet wide but only inches deep."* These highly variable materials are exposed to the action of the environment and traffic, both elements that are very difficult to predict with a high degree of confidence (Prozzi, Gossain, and Manuel, 2005). Hence, we should rethink what levels of reliability are reasonable and economically achievable with current technologies: What is the purpose of aiming at 95 percent design reliability if environmental conditions cannot be predicted but merely estimated based on historical data? Are levels of 95 percent, 90 percent, or even 80 percent reliability actually achievable with a reasonable pavement structure?

TxDOT should establish appropriate and realistic standards to guide the level of effort. The selection of an appropriate level of reliability of a particular facility depends on the project level of usage and the economic and socio-political consequences associated with early failures. Suggested levels of reliability range from 99.9 percent for interstate highways to 50 percent for some local roads. The higher recommended levels are only achievable if all data are collected (at least) at the selected level of reliability. Bearing in mind (1) the inability to accurately estimate traffic loads far into the future and to predict the environmental conditions and (2) the high variability typical of any road construction process, it is questionable whether those high levels are reasonable and can actually be achieved within current economic constraints.

Another strategic decision to be made relates to the length of historical data that need to be collected to develop realistic performance trends. As traffic volumes increase, highways are growing more and more congested, maintenance and rehabilitation budgets are shrinking in real terms, and there is a national drive toward long-lasting or perpetual types of pavement structures. These structures are designed to last more than 25 years and up to 50 years or more. By the time performance information is available, design and construction technology would have changed, as would vehicle technology. To this effect, and in order to deliver some historical data for calibration purposes, the incorporation of some sections of the LTPP database was recommended.

The final discussion point is related to the appropriate design level consistent with the research objectives (Prozzi and Hong, 2007). The MEPDG proposes the following design levels:

1) Level 1, the highest level of accuracy and reliability, implies specific data collection and material testing,
2) Level 2, the intermediate level or regional level, proposes limited data collection efforts and the use of surrogate laboratory tests, and
3) Level 3, lowest accuracy and reliability, makes use of default data or state defaults.

Current thinking at the national level is that Level 1 will probably never be implemented by the states, except for individual high-dollar projects that warrant the extensive and costly data collection and testing effort. Besides, Level 1 calibration lacks general applicability because of the fact that the calibration parameters consistent with Level 1 design is only suited for a very specific project or pavement section. However, the agencies are more often interested in calibration parameters that are suited to a particular geographic region. For example, in Texas there are five different climatic regions and therefore the aim of the calibration exercise should be to come up with a set of calibration factors for each of the geographic regions rather than obtaining a set of calibration factors for a very specific site. Therefore, the data was used to develop Level 1 calibration factors. These Level 1 factors were then used in an optimization procedure to develop Level 2 calibration factors. In turn, these Level 2 factors were combined to establish state-defaults, or Level 3, calibration factors.

1.2.2 Design Inputs for the 2002 Mechanistic Empirical Pavement Design Guide

To develop and calibrate any pavement design and rehabilitation method, a number of reliable databases are required. This concept applies to both empirical design methods, such as the AASHTO Guide for the Design of Pavement Structures (AASHTO, 1993), as well as mechanistic-empirical design methods, such as the NCHRP 1-37A Mechanistic-Empirical Design of New and Rehabilitated Pavements (NCHRP, 2006). To address these objectives, the databases should include:

1) Material properties,
2) Pavement structural characteristics,
3) Traffic information,
4) Environmental conditions, and
5) Pavement performance data.

To some extent these databases are currently available at TxDOT. They have, however, been designed and are maintained with specific objectives not necessarily compatible with their potential use for pavement design.

In summary, the ultimate deliverable of this project is simple: a database for development, validation, and calibration of a flexible pavement design method. The goal was conceived to not be too ambitious, and the scope is limited to address a reduced number of designs and expected trends by limiting the number of sections to be monitored. For this reason, the initial experimental design consisted of sixty-four (64) sections, including sections containing asphalt surface on top of asphalt bases, asphalt surface on top of untreated granular bases (flexbase), and surface treated pavements with at least two replicates and two different traffic volumes and sections from all five different climatic regions in Texas.

1.3 Project Objectives & Scope

The primary objective of the study was the development and initial population of a database comprising flexible pavement sections from different climatic regions in Texas under varying traffic conditions. It was also considered important to include sections with varying structural compositions in terms of layers types and thicknesses. The secondary objective was the application of this database towards determining calibration factors to be used for the design of pavements in Texas using the MEPDG. A central objective of RTI's research program is applied research that can be implemented to address concerns identified by TxDOT. The products and reports of this study will empower TxDOT to make informed decisions about the future of the flexible pavement database. This project was conceived as a four-phase approach:

1) **Phase 1 – Planning:** Assess the current situation, research efforts, and expected trends; identify potentially useful existing databases in Texas and elsewhere; and determine the role of LTPP studies with respect to this project. Develop the database structure to include all necessary fields; and develop quality control methods to ensure the integrity of data.
2) **Phase 2 – Data Collection/Population:** The current scenario and trends were analyzed and discussed with local and out-of-state experts who helped in determining data needs, appropriate standards, and database architecture to be adopted by TxDOT. These recommendations were used to develop an interim Texas Flexible Pavement Database, which was initially populated with the relevant Texas LTPP sections and later with new selected sections in Texas.
3) **Phase 3 – Initial Implementation:** This phase covered the implementation of the research findings. An implementation plan was developed including a plan for the management and maintenance of the FPDB. A web-based front-end was developed to populate and query the database.
4) **Phase 4 – Application:** Because the prime objective of developing the Texas Flexible Pavement Database was to support the calibration of mechanistic-empirical pavement design models, the final phase aimed to test the database's suitability for the desired purpose and to check the applicability of the database to the current needs. The good news is that it indeed successfully delivered what it was designed for. It served as the data warehouse for most of the design inputs for pavement design purposes.

1.4 Outline and Organization of the Report

The report is organized into seven different chapters including this one, which introduces the reader to the objective and goal of the research project. The second chapter gives an overview of Texas Pavement Management Information System (PMIS). The third chapter highlights the development of the database as well as the web interface implemented to access the database, which is indeed the main deliverable or output of this research project. The fourth chapter focuses on the experimental design, the different variables that were considered in the experimental design, an overview on the data collection efforts, and a summary of each of the pavement sections included in the Texas Flexible Pavement Database (TFPD). The fifth and sixth chapters summarize the efforts to develop a methodology for the initial calibration of the Mechanistic Empirical Pavement Design Guide and report the preliminary results. Finally, the last chapter outlines the lessons learned and conclusions drawn from this research project.

Chapter 2. Pavement Management Information System

2.1 Introduction to PMIS

Pavement Management Systems (PMS) are network level applications that facilitate the budget planning and resource allocation in a highway agency. Thus, data collected is typically aggregated into indexes or scores that represent overall condition and make possible comparisons among facilities. The condition of pavement surfaces is an indicator of the overall condition of the pavement infrastructure. It can serve as a means of indicating which pavements require some type of maintenance or rehabilitation. The condition of pavement surfaces can be determined using several types of equipment that measure ride quality, structural adequacy, and skid resistance; however, visual assessment is also required so that the level of distress can be recorded in an orderly and consistent manner. According to TxDOT, the evaluations of the condition of the pavement should be consistent and detailed enough that the pavement can be described across the following geographical areas:

1) Maintenance section
2) County
3) District
4) Statewide

Additionally, the information recorded should help in determining which pavement sections require some sort of intervention or which sections are in greater need of rehabilitation, as well as aiding in the estimation of the funding that will be required to perform the rehabilitations. The annual TxDOT Pavement Management Information System (PMIS) survey consists of three separate surveys:

1) Visual evaluation survey,
2) Rutting and ride quality survey, and
3) Skid resistance.

Additional data, such as structural strength, may be collected; however, it is currently not included in the PMIS analysis procedures. For the sections contained in the Texas Flexible Pavement Database, Falling Weight Deflectometer (FWD) data will be collected on an annual basis. If budget and time constraints allow, some of the section's semiannual data collection will be considered in the winter and in the summer.

TxDOT PMIS contains approximately 190,000 data collection sections, which are usually 0.5 mile in length. Reference marker (RM) numbers are used to identify the different sections in the PMIS data collection.

On an annual basis, one lane from each section is rated, corresponding to the lane that shows the most distress on each roadbed. Consequently, the lane that is being rated can change from section to section, and for a given section, from year to year. However, it most often corresponds to the outside lane. Safety considerations are also taken into account for the selection of the lane being monitored.

Although the TxDOT PMIS is currently being used as a network level application, the data collected (before being processed into the various scores) is detailed enough to meet the requirements of the Texas Flexible Pavement Database. The various scores used by TxDOT are briefly described in the following section.

2.2 PMIS Scores

2.2.1 PMIS Condition Score

The PMIS Condition Score combines ride quality measurements (Ride Score) and pavement distress ratings (Distress Score) into a single description of overall pavement condition. PMIS Condition Score values are generally grouped into descriptive classes as shown in Table 2.1.

Table 2.1: PMIS Condition Scores

Condition Score	Description
90 – 100	Very Good
70 – 89	Good
50 – 69	Fair
35 – 49	Poor
1 – 34	Very Poor

2.2.2 PMIS Distress Score

The PMIS Distress Score describes visible surface deterioration (pavement distress). PMIS Distress Scores are generally grouped into descriptive classes as shown in Table 2.2.

Table 2.2: PMIS Distress Scores

Distress Score	Description
90 – 100	Very Good
70 – 89	Good
50 – 69	Fair
35 – 49	Poor
1 – 34	Very Poor

2.2.3 PMIS Ride Score

The PMIS Ride Score describes pavement ride quality. Ride Score is calculated from pavement roughness measured by calibrated electronic equipment. PMIS Ride Scores are generally grouped into descriptive classes as shown in Table 2.3.

Table 2.3: PMIS Ride Scores

Ride Score	Description
4.0 – 5.0	Very Good
3.0 – 3.9	Good
2.0 – 2.9	Fair
1.0 – 1.9	Poor
0.1 – 0.9	Very Poor

Ride information currently collected is very detailed and can be used to determine average pavement roughness and variability for each PMIS section. Ride information will be collected on an annual basis for all sections contained in the Texas Flexible Pavement Database.

2.2.4 PMIS IRI Score

The PMIS IRI Score describes pavement ride quality. The units are in. (of roughness) per mi. IRI Score is the average of the IRI values measured in the left and right wheelpaths. Although IRI Score is a description of ride quality, it is not one of the factors used when determining the PMIS Condition Score. PMIS IRI Scores are generally grouped into descriptive classes as shown in Table 2.4.

Table 2.4: PMIS IRI Scores

IRI Score	Description
1 – 59	Very Good
60 – 95	Good
96 – 130	Fair
131 – 169	Poor
170 – 950	Very Poor

For the purposes of the Texas Flexible Pavement Database, continuous information will be preferred to discrete (or range) information: this is very important for calibration purposes.

2.3 Visual Evaluation

There are two methods in which the data may be collected: using a laptop (using the VISTARE software), or through automated rating forms (which require that the data be entered afterward on the PMIS Database). On flexible pavements, the following types of distress are identified and rated during the visual inspections:

1) Rutting—Shallow (measured by automated rut-measuring device)
2) Rutting—Deep (measured by automated rut-measuring device)
3) Patching
4) Failures

5) Block cracking
6) Alligator cracking
7) Longitudinal cracking
8) Transverse cracking
9) Raveling
10) Flushing

The rating consists of entering a one-, two- or three-digit number for each of these ten distress types. The ratings indicate either the area or the amount of the distress observed. The definitions and methods of measurement for the different types of distress are described in TxDOT's Pavement Management Information System Rater's Manual (TxDOT, 2005).

2.3.1 Rutting—Shallow

Rutting consists of a longitudinal surface depression in the wheelpath, caused by consolidation or lateral displacement of the pavement materials when loaded. That is, rutting could be associated with volumetric change or shape change, both of which are dictated by the shear resistance of the material. Typically, rutting indicates a structural problem within one or more of the pavement layers.

Shallow Rutting is defined by a rut depth of 0.25 in. to 0.49 in. Rutting measured from 0.5 in. to 0.99 in. is referred to as Deep Rutting. Severe Rutting is measured from 1.0 in. to 1.99 in., and Failure Rutting is higher than 2 in.

Rutting is measured along the wheelpaths. Each wheelpath is measured separately and added together to determine the total feet of rutting. Based on the total feet of rutting and the length of the PMIS section, the percentage of area that presents rutting is reported. For the purposes of the Texas Flexible Pavement Database, average surface rutting will be stored in the database, as well as its variability in terms of the standard deviation of the rutting in each wheel path.

2.3.2 Rutting—Deep

As was the case with Shallow Rutting, Deep Rutting is measured along the wheelpaths. Each wheelpath is measured separately, and added together to determine the total ft of rutting. Based on the total ft of rutting, and the length of the PMIS section, the percentage of area that presents rutting is reported. It should be noted that for the objectives of the database, the actual measured surface rutting will be stored. Rut and Ride are collected as part of PMIS on an annual basis. In addition, Rut and Ride will be collected on the pavement sections corresponding to the Texas Flexible Pavement Database on an annual basis, typically after TxDOT PMIS data collection season concludes (typically in the March-April-May timeframe). This operation is necessary to ensure that the Texas Flexible Pavement Database lane is actually being monitored. When duplication exists (which will be often), both surveys can be compared as a quality control measure.

2.3.3 Patching

Patches are repairs made to correct pavement distress. The presence of patches indicates previous maintenance activities. Patching is rated according to the percentage of the rated lane's total surface area. It is measured throughout the PMIS section and converted to full lane width patching. After determining the total feet of patching, and based on the length of the PMIS section, the percentage of area that presents patching is reported.

2.3.4 Failures

Failures are localized sections of pavement where the surface has been severely eroded, badly cracked, depressed, or severely shoved. These localized sections of pavement identify specific structural deficiencies that may generate safety hazards. Failures are measured in lengths of 40 ft. Only unrepaired areas are rated. If a failed area has been adequately patched, then it is rated a patch.

2.3.5 Block Cracking

Block cracking consists of interconnecting cracks that divide the pavement surface into approximately rectangular pieces, varying in size from 1 ft by 1 ft up to 10 ft by 10 ft. Block cracks are larger than alligator cracks and are not load-associated. Block cracks are commonly caused by shrinkage of the asphalt concrete, or shrinkage of the cement- or lime-stabilized base courses.

Block cracking is measured throughout the PMIS section (and converted to full lane width block cracking). With the measurement of full lane width block cracking and the total length of the section, the percentage of area that presents block cracking is reported.

2.3.6 Alligator Cracking

Alligator cracking consists of interconnecting cracks that form small, irregularly shaped blocks that resemble the patterns found on alligator skin. Blocks formed by alligator cracking are smaller than 1 ft by 1 ft. Alligator cracking is the result of repeated flexural stresses caused by traffic loading. Consequently, they may indicate improper design or weak structural layers.

Alligator cracking is rated on the wheelpath throughout the PMIS section. After determining the total feet of alligator cracking, and based on the length of the PMIS section, the percentage of area that presents alligator cracking is reported.

2.3.7 Longitudinal Cracking

Longitudinal cracking consists of cracks or breaks that run approximately parallel to the pavement centerline. Edge cracks, joint or slab cracks, and reflective cracking on composite pavement may all be rated as longitudinal cracking. Longitudinal cracking is measured in terms of linear ft per station (i.e., average ft of cracking in 100 ft of surface). The longitudinal cracks are measured throughout the length of the PMIS section, and based on the total section length, longitudinal cracking in ft per station is determined.

2.3.8 Transverse Cracking

Transverse cracking consists of cracks or breaks that travel perpendicular to the pavement centerline. Joint cracks and reflective cracks may also be rated as transverse cracking. Transverse cracking may be caused by surface shrinkage due to extreme temperature variations or differential movement beneath the pavement surface.

Transverse cracking is measured in terms of number per station (i.e., average number of cracks in each 100 ft of surface). The transverse cracks are counted throughout the length of the PMIS section, and based on the total section length, transverse cracking in number of cracks per station is determined.

It should be noted that cracking data is currently being collected by means of visual inspection, and consequently all types of cracking are subjected to significant human error and rater subjectivity. This problem is also aggravated by the fact that daylight and moisture conditions affect crack visibility and therefore its rating. As a preliminary measure, crack information contained in PMIS will be assessed to determine its suitability to meet the research objective. In the longer term, however, it is expected that TxDOT will implement an automated crack data collection system, which is currently being debugged and calibrated.

2.3.9 Raveling

Raveling is the progressive disintegration of the surface due to dislodgment of aggregate particles. Raveling is rated according to Table 2.5. The rating code is reported. The rating code indicates the percent of the rated lane's total surface area.

Table 2.5: Rating Codes

Rating Code		Amount (Percent Area)
0	None	0
1	Low	1 – 10
2	Medium	11 – 50
3	High	> 50

2.3.10 Flushing

Flushing is the presence of asphalt on the pavement surface. Flushing is rated according to the previous table. The rating code is reported. The rating code indicates the percent of the rated lane's total surface area that is flushed.

2.3.11 Automated Data Collection

Preliminary analysis of PMIS indicated that data collected by mean of visual evaluations are too variable to be used for pavement design purposes. For this reason, data collected with TxDOT automated systems will be used in the development of the database. These data include: roughness (in IRI), surface rutting (based on 5-point data collection and the wire-line method), and surface cracking (collected with the V-crack equipment). Automatically collected data will be processed consistently with LTPP protocols to be included into the Texas Flexible Pavement Database.

Chapter 3. Website and Database Development Process

This chapter highlights the database and website development for the Texas Flexible Pavement Database. The methodology applied was based on recommendations from TxDOT personnel and other local and out-of-state experts who helped in determining data needs and appropriate standards. The database architecture mirrors that of the LTPP database as well as the PMIS database used in Texas.

3.1 Data Elements

To effectively manage and organize data within a relational database structure, it was first necessary to identify the essential data elements required for successful implementation. Consequently, considerable effort was required to identify those specific data fields necessary to effectively analyze pavement performance and for calibration purposes. The importance of this aspect cannot be over-emphasized. Once data fields have been established and the database has been populated, it is not always possible to modify or add additional fields without disrupting the integrity of the existing data structure. Too many data fields can lead to slow-response and bulky databases, but too few data fields can result in calibration models that are not representative.

In the development of any database system, the definition of data fields, primary keys, and indexes are undoubtedly the most time-consuming effort. Only once these elements have been defined, can the database be populated and used for analysis purposes. Fortunately, the researchers did not have to identify many of these data fields but could lean heavily on the structures of well-defined successful models such as LTPP, MEPDG, and TxDOT's PMIS.

The following is an overview of some data fields identified within LTPP, used for calibration of the AASHTO MEPDG software:

1) Administration fields: Location, Project Type, Pavement Type, Base/Subgrade Construction Completion Date, Asphalt Construction Completion Date, Traffic Opening Date, Design Period.
2) Pavement Lane Properties: Lane Width, Pavement Slope, Initial IRI, Thermal Conductivity, Heat Capacity, Surface Short Wave Absorptivity.
3) Environmental/Climatic: Latitude, Longitude, Elevation, and Groundwater Table Depth.
4) Pavement Structure: Number of Layers, Layer Number, Layer Type, Representative Thickness.
5) Aggregate Gradation for Asphalt Mix: Layer Number, Layer Type, Percentage Retained ¾-in. Sieve, Percentage Retained 3/8-in. Sieve, Percentage Retained #4 Sieve, Percentage Passing #200 Sieve.
6) Effective Binder Content by Volume at Time of Construction: Layer Number, Layer Construction Date, Binder Content by Weight, Specific Gravity of the Binder, Bulk Specific Gravity of the Mix, Maximum Theoretical Specific Gravity of the Mix, Bulk Specific Gravity of the Aggregate, Effective Specific Gravity of the Aggregate, Effective Binder Content by Volume at Time of Construction.

7) Original Air Voids (at Time of Construction) and Total Unit Weight: Layer Number, Layer Type, Air Voids at Age = t, Age = t, Mean Annual Air Temperature, Original Viscosity at 77°F, Original Air Voids, Total Unit Weight.
8) Asphalt Binder Data: Layer Number, Layer Type, Viscosity Grade, Penetration Grade, Penetration at 77°F, Viscosity at 140°F, Viscosity at 275°F.
9) Unbound Materials Data: Layer Number, Layer Type, Dry Thermal Conductivity, Dry Heat Capacity, Liquid Limit, Plastic Limit, Plasticity Index, Percent Passing #200 Sieve, Percent Passing #4 Sieve, Diameter D60, Optimum Moisture Content, Estimated Optimum Moisture Content for Level 3 Analysis, Maximum Dry Unit Weight, Estimated Maximum Dry Unit Weight for Level 3 Analysis, Specific Gravity of Solids, Saturated Hydraulic Conductivity, AASHTO Soil Classification, Unified Soil Classification System (USCS) Classification.

Regarding performance data, identifying which materials test parameters are considered relevant was a critical task. For example, it will not be practical to include each and every result from a Hamburg Wheel Tracking Device (HWTD) test, but only the result at failure, i.e., number of cycles until a 12.5-mm rut is reached or the rut at specific numbers of cycles—5,000; 10,000; 15,000; and 20,000 for example. The same applies to the results of fatigue and flow time/number tests, which typically record measurements at more intervals than required to accurately model response.

During the 1-day workshop conducted in June 2007, a list of agreed data elements was established. It should be noted that it was also agreed that the list was dynamic and new elements could be incorporated and some elements could be removed in the future as the database evolves. A list of the data elements incorporated to date can be found in Appendix B, Definitions of Data Elements. The database can be accessed at http://pavements.ce.utexas.edu/.

3.2 Pavement Types

The Texas Flexible Pavement Database will contain pavement sections that will enable addressing the following variables:

1) Type of pavements. A number of typical pavement designs have been identified and proposed as part of the database. Although pavement type and facility type (e.g., Interstate Highway, U.S Highway, and Farm-to-Market road) are highly correlated, consideration was given to sampling diverse pavement types within each facility type. The database contains pavement sections with (i) an asphalt surface on top of an asphalt base, (ii) an asphalt surface layer of top of a granular base, and (iii) surface treated pavements (typically one-, two- or three-course surface treatments on top of a granular flexible base or flexbase).
2) Traditional and new materials. It is important that not only the most common current materials be selected but a number of "future" materials or "recent" materials that are expected to become popular in Texas also be included. Thus, the sections include conventional dense graded asphalt layers (Item 341) as well as newer mixes, such as the so-called performance mixes.
3) Traffic characterization. Currently state default traffic data has been incorporated into the database. These recommendations are based on the findings of TxDOT

Project 0-4510 and utilize continuous axle load distribution measured by TxDOT WIM system. This was done because of the practical advantages and the reduction of the number of input parameters required characterizing the traffic stream. In addition, when available, actual load distributions measured by SHRP WIM system have been incorporated. Traffic volumes have also been obtained from estimates from Texas TLOG and PMIS database.

4) Performance Monitoring. The types of distresses to be collected and the minimum data collection frequencies, as well as desired accuracies, are recommended. At the very minimum, performance data for calibrating rutting, cracking, and roughness models will be collected on an annual basis for all sections. Cracking data from visual inspection was evaluated for its suitability; however, due to its high variability it was decided to collect cracking data using an automated data collection system, currently being finalized under a concurrent research project.

5) Environmental Conditions. From a pavement performance point of view, five environmental regions have been identified in Texas that are consistent with the LTPP Program. These are (i) wet-warm, (ii) wet-cold, (iii) dry-warm, (iv) dry-cold, and (v) mixed. Pavement sections in each climatic region were identified and recommended for monitoring. Pavement sections have been identified in the following Texas Districts: Amarillo, Austin, Beaumont, Brownwood, Bryan, El Paso, Houston, Lubbock, Lufkin, Paris, Pharr, San Antonio, Tyler, Waco, and Yoakum.

Four types of pavements are considered within the design domain of the MEPDG: (i) full-depth, (ii) deep strength (asphalt base), (iii) conventional (granular base), and (iv) semi-rigid (treated bases). Current research projects are focusing on full-depth pavements; based on feedback from TxDOT personnel, this study will address the first two types plus surface treated pavements. Emphasis was placed on pavement structural sections that are built with materials that are currently used or likely to be used more extensively within Texas in the near future.

Aging of the pavement structure is another design variable to be considered. Two levels of pavement age were addressed: relatively new and older existing pavements. In the case of existing pavements, the selection was limited to those LTPP sections for which the relevant data were available or could be accurately estimated. It should be noted that the current flexible pavement database (http://pavements.ce.utexas.edu/) contains both the LTPP and Texas sections. The selection of the Texas sections has been done such that they will represent the "new" sections while the LTPP section while account for the older aged sections.

Another important design variable is traffic, which, for many, is the most important variable because of its variability. It is the researchers' opinion that traffic may not be the most important variable but it is, traditionally, the most neglected. In order to make optimum use of available data and resources, several pavement sections have been selected on multilane highways. Thus, each pavement section will provide several experimental sections. Most importantly, the outer lanes will experience heavier traffic levels as compared to the inner lanes, thus perfectly fitting into the experimental design giving two different ranges of traffic volumes. The ideal situation would be when both lanes are built at the same time, following the same design, and are subjected to different traffic levels.

3.3 Interim Database

TxDOT has well-established protocols in place for the development and use of databases as part of their relational database management system (RDBMS) (TxDOT, 2005). These protocols ultimately determine the type and structure of applications accessing databases on TxDOT computer servers and infrastructure. Besides existing databases, efforts are underway to develop new information systems and even web-based applications for reporting information using geographic information systems under the GIS Architecture and Infrastructure Project (GAIP). Developments undertaken as part of this study had to consider the broader TxDOT vision. It was necessary that the developments conform to RDBMS protocols and were flexible enough to allow interaction with other TxDOT developments. In an effort to achieve this goal, the database design and development including the naming convention for each of the data elements was done in accordance with the TxDOT Data Architecture Version 3.0. Some of the changes that were made to conform to the standards guidelines were renaming the entities and attributes such that they are in uppercase and do not exceed the size restriction of 28 characters. The character "_" was used as the universal word delimiter for the Texas Flexible Pavement Database. The Data Dictionary was also updated according to the TxDOT Data Architecture Version 3.0 standards and each of the column descriptions included a Definition, Purpose, Example/Valid Value, and a Format. Some of the column descriptions included some other properties like Maximum Allowable Size, Mandatory Field, Data Type, etc.

Ideally, the design and development of pavement-related databases should be coordinated with a common database framework and user interfaces to improve the efficiency, enhance the accessibility, and ensure the long-term maintainability of these databases. To take advantage of state-of-the-art information technologies, these databases should be web-based, GIS-oriented, and integrated. Therefore, the following are the key features contemplated for the final database architecture:

1) Web-Based. The advancement in Internet technologies has made web-based applications a viable choice for pavement-related databases. Major advantages include: (i) databases that can be accessed conveniently not only from TxDOT, but also by TxDOT-authorized personnel from any place, domestically or internationally, where internet services are available; (ii) because the databases are maintained and updated in a central location, every TxDOT-authorized user is able to access the same data that is kept up-to-date; and (iii) problems and data errors that could be introduced with traditional means of data-sharing (such as file transfer and CD distribution) will be eliminated. Examples of web-based applications that were used as models for implementation include LTTP that can be found at http://www.ltpp-products.com/. The web-based version of the Texas Flexible Pavement Database is available at http://pavements.ce.utexas.edu/. In the next five years this database will be upgraded by incorporation several additional section and material properties from in situ testing.

2) GIS-Oriented. The maturity of GIS technology provides a solid basis for the Texas Flexible Pavement Database to be enhanced in a GIS environment where information can be managed, queried, analyzed, and visualized graphically. In particular, when GIS-related technology is combined with the web-based design as discussed earlier, it will significantly enhance the user interfaces and improve the user-friendliness. At the moment, the web-based version of the Texas Flexible

Pavement Database provides only a means to visualize the sections graphically, implemented with the aid of an API provided by Google Maps.

3) Integrated. Even though current (and future) TxDOT pavement-related databases are maintained and updated independently, it is important to recognize and take advantage of any similarities between datasets through integration. This is a long-term vision but must be addressed in the development of the Flexible Pavements Database to ensure future compatibility.

The initial database development follows TxDOT recommendation, but it is taking place outside the TxDOT environment. For the development stage, the database will reside in a server at The University of Texas at Austin, thus avoiding security and protocols that may delay the project. At the conclusion of the project and at the discretion of TxDOT, the application could be moved to a TxDOT Division server as part of the research implementation.

3.4 Database and Website Design

The Flexible Pavements Database is primarily organized into four different sections, namely (i) pavement performance, (ii) traffic, (iii) pavement structure, and (iv) material and inventory information. In addition, the website also has an administration feature built into it with limited capabilities like managing user-roles as well as approving or discarding pavement sections from the Flexible Pavements Database. A high-level conceptual model of the system is given in Figure 3.1.

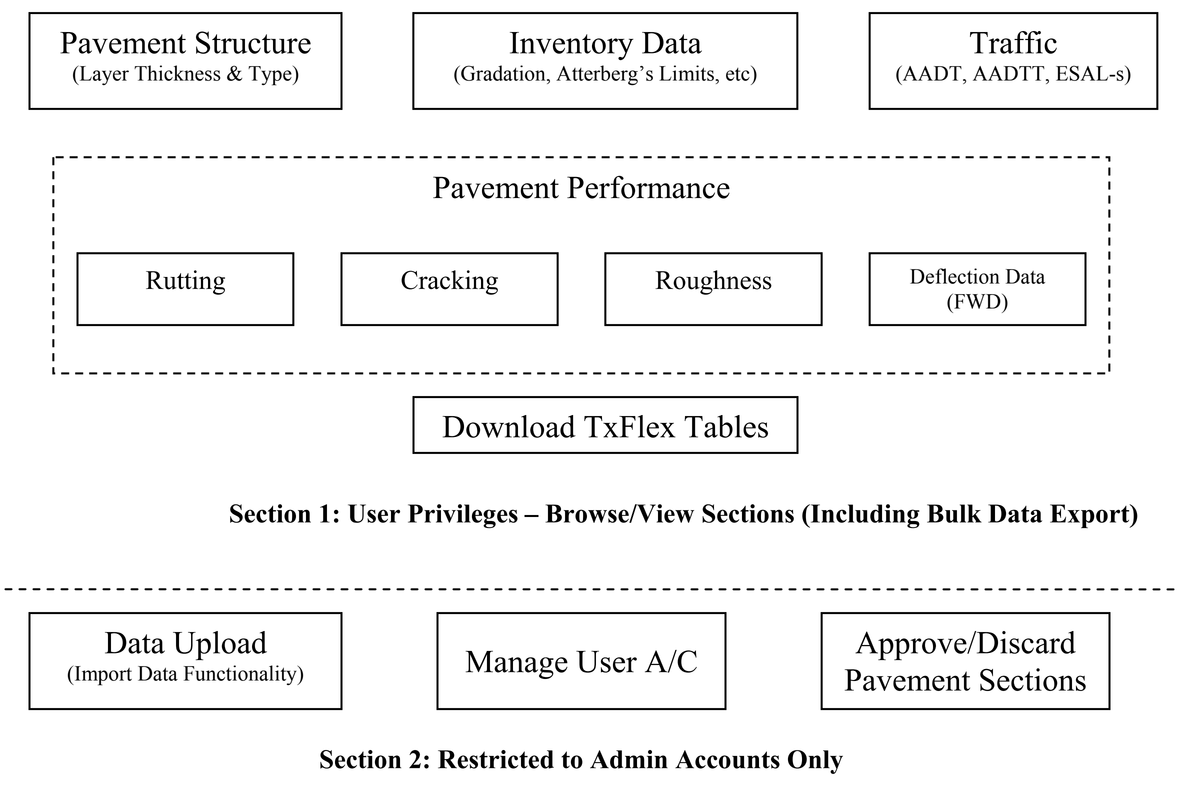


Figure 3.1: High Level Conceptual Data Model for the Texas Flexible Pavements Database

The conceptual model given in Figure 3.1 was the backbone behind developing the different system components. An entity-relationship diagram was charted out after the final database design for the various database components in the Texas Flexible Pavements database was completed. This entity-relationship diagram is as given in Figure 3.2. The data model that was put in place for this system complies as closely as possible with the requirements and guidelines laid down in the TxDOT Data Architecture Version 3.0.

Database architectures of existing pavement-related databases were reviewed as references in the early stages when the database structure was being developed. The databases that were reviewed included the TxDOT Pavement Management Information Systems (PMIS) and the Federal Highway Administration's Long Term Pavement Performance (LTPP) database. The database design finalized for the Texas Flexible Pavement Design was done based on this review, and most of it has been adapted from the LTPP database. The decision on the list of database fields to include was taken after carefully studying the list of inputs that will be essential to run a calibration with Level 1 data for each of the four modules (Traffic, Structure, Materials and Climate) given in the Mechanistic-Empirical Pavement Design Guide (Version 1.0). Comments and recommendations received at several meetings with several TxDOT personnel from the Technology Services Division (TSD) and the Construction Division (CST) were considered in defining the database design.

It should be noted in this context that a sizeable effort was spent to ensure that the naming convention comply with the guidelines laid down in Chapter 3 of "Data Architecture Version 3.0" provided to the research team by TxDOT's Technology Services Division.

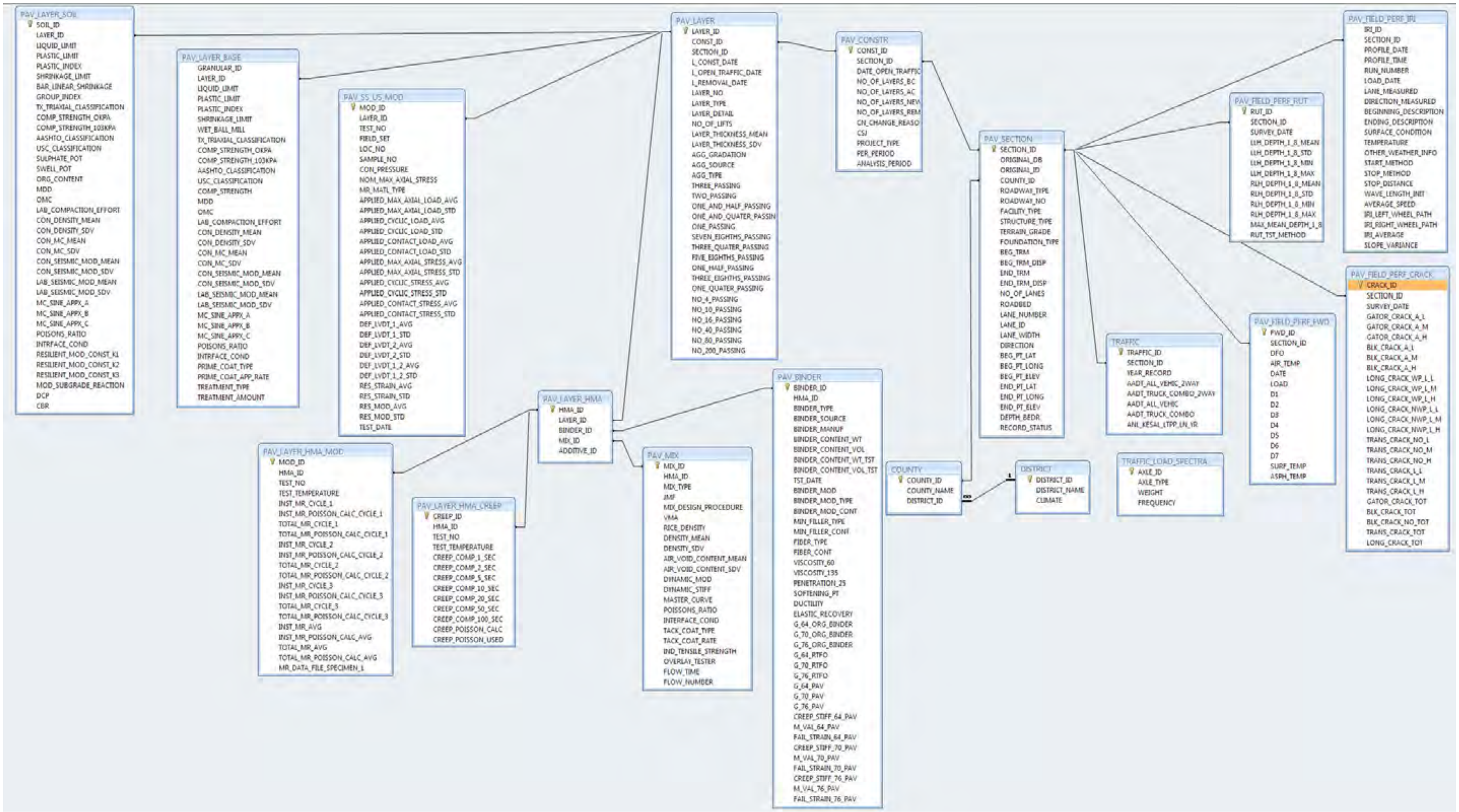


Figure 3.2: Entity-Relationship Diagram for the Database Components in the Texas Flexible Pavements Database

(Refer to Appendix D for a Magnified Image)

3.5 Programming Platform and Software Version

Technical information on the University of Texas server hosting the Texas Flexible Pavements Database is given below.

General Server Information

Windows 2003 server with IIS 6.0

Database Server

Microsoft SQL Server 2000 with SQLXML Bulk Upload Component Installation

Application Server

ASP 3.0 with Microsoft Office 2002 Web Component Support

Information Exchange Protocol

XML Version 1.0

Routine/Scheduled/Server-Side Jobs

VbScript 5.5

Archiving Tool

7-Zip (Uses LZMA compression algorithm)

3.6 Website Access

The website has two groups of users with varying levels of access rights: (i) Users and (ii) Administrators.

3.6.1 User Access

The "Users" access is the default access level offered to anyone who registers/creates an account on the Texas Flexible Pavements Database system. It offers a variety of features including the ability to browse through pavement data on the Flexible Pavements Database website as well as download relevant information for one or many sections as comma separated files. (Should the user choose to download data for multiple sections, he/she may need WinZip or Winrar to extract the *.csv files from the archived files.) It should be noted here that the data download feature has been provided to the user so that he/she may obtain the required information and view it offline or even use the data to run a calibration or validation of mechanistic-empirical pavement design models. For example, a user wishing to calibrate the performance models in the MEPDG for West Texas need only download data from that particular geographical region. The Flexible Pavements Database website also provides the user an option to download data for a particular distress type, a functionality that may be useful if the user is only interested in a specific type of distress type.

3.6.2 Administrator Access

Users with Administrator access have all of the foregoing capabilities, but also have some special privileges such as uploading new pavement data, viewing/editing user account privileges, and the right to approve or rejecting new data. The system is configured such that users with administrator privileges are allowed to navigate to any module whereas users with default access are restricted to specific modules.

3.7 Organization and Retrieval of Database Information

The web site screen designs, the selection of major navigational information areas, and the organization of data on display screens were developed in efforts to provide TxDOT users a logical and familiar experience beginning the first time they access the website. Comments and recommendations received at several meetings with several TxDOT personnel from the Technology Services Division (TSD) and the Construction Division (CST) when the web interface was being developed were implemented.

3.7.1 Website and Database Navigation

To browse through the website or view any kind of pavement data, the user needs to have a registered account on the Texas Flexible Pavement Database system. This is the only pre-requisite on the user's behalf to be able to log into the website. New/registered users can sign up/log in to the Flexible Pavements website by visiting the following link: http://pavements.ce.utexas.edu/. Assuming that the user was successful in logging into the website, he/she will be redirected to the home page. Users with default access will not have the privilege to input data and therefore sections relevant to data insertion will be locked to all such users; while on the other hand users with administrator privileges will have access to this section. To view or download pavement data, the users need to go through the following set of steps:

1. Users should click on the View/Download Data button on the home page to browse through data on the Texas Flexible Pavement Database so that they are redirected to the Search page (http://pavements.ce.utexas.edu/TxFlex3/TxFlex/TxFlex/search.asp).
2. The users are given the option to query the database in terms of 13 different search criteria. It should be remembered here that the search functionality built into the system is an "AND" query, which basically means if the user selects the district as "BRYAN" and facility type and name as "SH" (State Highway), he will obtain results that match both the search criteria—that is, state highways in the Bryan District.
3. After the user has decided on the list of the search criteria, he/she has to hit the Search button and the results are listed below in the same page, sorted in the ascending order of their section identifiers.
4. In case the query returns more than 20 search results, the results are paginated with 20 matching records in each page, with "Previous" and "Next" buttons for the user to browse through the entire record-set.

5. In addition, there's a checkbox against each of the records fetched by the search query. The user can put a "☑" mark against each of the sections for which they want to download entire information.
6. If the user wishes to view detailed information for a particular section, he/she can either click the roadway name or the section identifier and will be redirected to the home page for that particular section (http://pavements.ce.utexas.edu/TxFlex3/TxFlex/TxFlex/sectionInfo.asp?sectionId=TXLT23002). The user can view basic information about a particular section including the location, climatic zone and the structural information for the section.
7. The user will be presented with a left navigation pane having links to different types of information for the pavement section like Traffic, Performance, Material & Inventory Information, etc. The user can click on any of these links to view detailed level information and the trend in the data by visiting each of these links.
8. In addition, the user can visit the Performance webpage (http://pavements.ce.utexas.edu/TxFlex3/TxFlex/TxFlex/test.asp) and can even download data for a particular form of distress type for a given pavement section.
9. For the deflection data collected from Falling Weight Deflectometer (FWD) tests performed in the field, the user is also given an option to download the entire history of the collected data (http://pavements.ce.utexas.edu/TxFlex3/TxFlex/TxFlex/FWD.asp).
10. The Axle Load Spectra for Steering, Single, Tandem, and Tridem axles can be obtained by visiting the following link: http://pavements.ce.utexas.edu/TxFlex3/TxFlex/TxFlex/AxleSpectra.asp. It should be noted here that the Axle Spectra featured on the Texas Flexible Pavements Database are rather the state-wide defaults and not specific to any particular pavement section and these were estimated from Weigh-In-Motion (WIM) stations across Texas.

3.7.2 Input/Upload New Data

The upload new data feature is strictly restricted to users with Administrator rights. The sole purpose of this functionality is to provide users with a means to upload new data or add new test sections to the database. To access the Data Input page, users needs to sign into the website using their login credentials, upon successful completion of which they will be redirected to the home page for the website. Hereafter the user needs to go through the following steps to add/insert new data.

1. Users have to click on the "Data Input" button given on the Home page and they will be redirected to the Data Input webpage (http://pavements.ce.utexas.edu/TxFlex3/TxFlex/TxFlex/dinput.asp).
2. Users will need to download the format file that appears as a hyperlink on the top right-hand corner of the page.
3. The format file is an Excel workbook, with 11 different worksheets each catering to a specific type of data for the pavement section like Construction History,

Layer Information, HMA Mix Properties, and so on. It should be noted here that the user should enable Macros before starting to key in data in the workbook.

4. The user should also follow the instructions given in the workbook like navigating through the worksheets in the same sequence as they are arranged; saving the data by hitting the "SAVE" button at the bottom of each worksheet after changes are made to any data, etc.
5. After the user has punched in all the information in the format file, he should finally export the data by hitting the "EXPORT" button that will then generate an XML file. The details and location of the XML file will appear as a message box on the screen once the file is generated. Users can save the Excel file if they want to work on with the same workbook at a later date or if they wish to complete the workbook at some other time.
6. Once the XML file is generated, the user will need to upload the XML file to the Texas Flexible Pavement Database server through the Upload functionality given on the Data Input page. After the XML file is successfully uploaded to the server, the user will be also notified with a message appearing "File Successfully Uploaded" on the screen.
7. The System Administrator will finally need to run a server job to extract the data from the XML files and upload the data to the MS-SQL Server database (DataUpload.vbs kept at a particular server location (C:\Inetpub\wwwroot\TxFlex3\TxFlex\TxFlex).
8. Once the newly added sections are posted to the database, they need to be approved by qualified personnel (Website Administrators) by visiting the following link: http://pavements.ce.utexas.edu/TxFlex3/TxFlex/TxFlex/sapprove.asp. At this point, the personnel will also have the option to reject/discard a particular data record.
9. Once all the steps from 1 through 8 are completed, the newly added records should now start featuring in the list of Search Results if the Search Criteria are met.

The procedure described above describes the current state of the QC/QA elements incorporated into the TFPD. As the database evolves, further elements should be incorporated.

3.7.3 Miscellaneous Tasks

There are basically two other functionalities that have been provided on the Texas Flexible Pavement Database website. Users with administrator rights are given an option to view all the user accounts registered with the Texas Flexible Pavement database as well as upgrade or downgrade any user account to either an Administrator or a default user. This functionality also maintains some basic login history for every individual user account. The other feature, open to any registered user, is merely a tool that the user can use to download any of the database tables. This feature was provided following recommendations and comments received from the Project Monitoring Committee (PMC) and the Technology Services Division (TSD).

Chapter 4. Pavement Testing and Data Collection Efforts

This chapter outlines the range of pavement testing and data collection that was conducted as part of this research project. It also highlights the experimental design and the variables that were studied and considered while coming up with the experimental design. Finally, the chapter presents a brief summary on each of the pavement sections that have been included in the Texas Flexible Pavement Database.

4.1 Experimental Design

As suggested in Chapter 1, the long-term success of the Texas Flexible Pavement Database will be determined by the balance achieved between the cost allocated for the development and maintenance of the system and the benefits in terms of improved pavement design and performance. It is the development and maintenance cost that constrains the number of sections to be included into the database. To optimize the use of the resources allocated to this project, the following main experimental variables (experimental design) were considered:

Pavement type (3 levels):

- Hot-mix asphalt surface on top of hot-mix asphalt base
- Hot-mix asphalt surface on top of untreated granular base (flexbase)
- Two course surface treatment on top of untreated granular base (flexbase)

Traffic levels (2 levels):

- Heavier traffic (typical of outside lanes)
- Lighter traffic (typical of passing lanes)

Environmental conditions (5 levels):

- Wet-warm
- Wet-cold
- Dry-warm
- Dry-cold
- Mixed

Section replicates (2 levels):

- Whenever available, replicates will be included

Thus, the complete main factorial consists of 60 sections (3 x 2 x 5 x 2). This experiment changed from the original experimental design included in the original proposal based on recommendations from the Project Monitoring Committee (PMC). Although the experimental design warranted 60 sections taking into consideration all the experimental variables, the Texas Flexible Pavement Database actually has close to 200 sections. The research team started its data collection efforts with all 200 sections but later trimmed that down to 73 sections. Of these 73 sections, 32 sections are from the LTPP database and the other 41 are TxDOT-recommended sections. These 73 sections are shown in Appendix A, the details of which could be reviewed online. It should be emphasized again that the database contains close to 200 sections today and this number is expected to increase in the next five years. It should be noted that a few of these pavement sections are still missing significant data elements missing due to unavailability of material test results.

It should be noted that no specific traffic volume level was assigned to define heavy and light traffic. The difference between heavy and light is a relative concept and is given by the data on a section-by-section basis. Having these two levels of traffic is necessary for the statistical analysis of the data. In an ideal situation a section of highway with two-lanes (or more) per direction is selected. Hence, if this highway has the same design for both lanes, it provides the desire effect of having one structure subjected to two different traffic levels (outer lane with heavier traffic and passing lane with lighter traffic).

The LTPP sections were a big addition to the Texas Flexible Pavement Database mostly because they have at least five years of performance data, which was a major requisite for the other objective of this research project: calibrating the Mechanistic Empirical Pavement Design Guide to Texas conditions. This would not have been possible with the use of only the TxDOT-recommended sections (until they are monitored for a period of 8 to 20 years or more).

4.2 Texas LTPP Sections

As initially planned, the LTPP study provided the initial set of sections. There were more than 50 Texas LTPP sections initially considered for the Texas Flexible Pavement Database, but later the number of LTPP sections were cut down to 32 in order have a good balance between older sections (LTPP) and newer sections (TxDOT-recommended). The LTPP sections are very important for capturing longer time series. LTPP was initiated as a part of the Strategic Highway Research Program (SHRP), which was established by the Transportation Research Board (TRB) of the National Research Council in the early 1980s. The program is now sponsored by the Federal Highway Administration (FHWA) with the cooperation of the American Association of State Highway and Transportation Officials (AASHTO).

As is suggested by TRB Special Report 202, *"America's Highways, Accelerating the Search for Innovation,"* there is a need to carry out the LTPP program based on monitoring long-term pavement performance throughout the nation. The motivation for carrying out LTPP-like studies is to better understand pavement performance under the effects of various relevant parameters involving design features, construction quality, material properties, traffic loads, environment, and maintenance activities. Thus, sound performance models can be developed to well capture pavement deterioration processes and accurately forecast their future conditions, which play a central role in both pavement design and system management.

Based on the DataPave Release 20, a total number of 218 sections were identified in Texas. Figure 4.1 indicates the locations of those LTPP sections in Texas, the majority of which are located in the central and east part of Texas as well as in the Panhandle area.

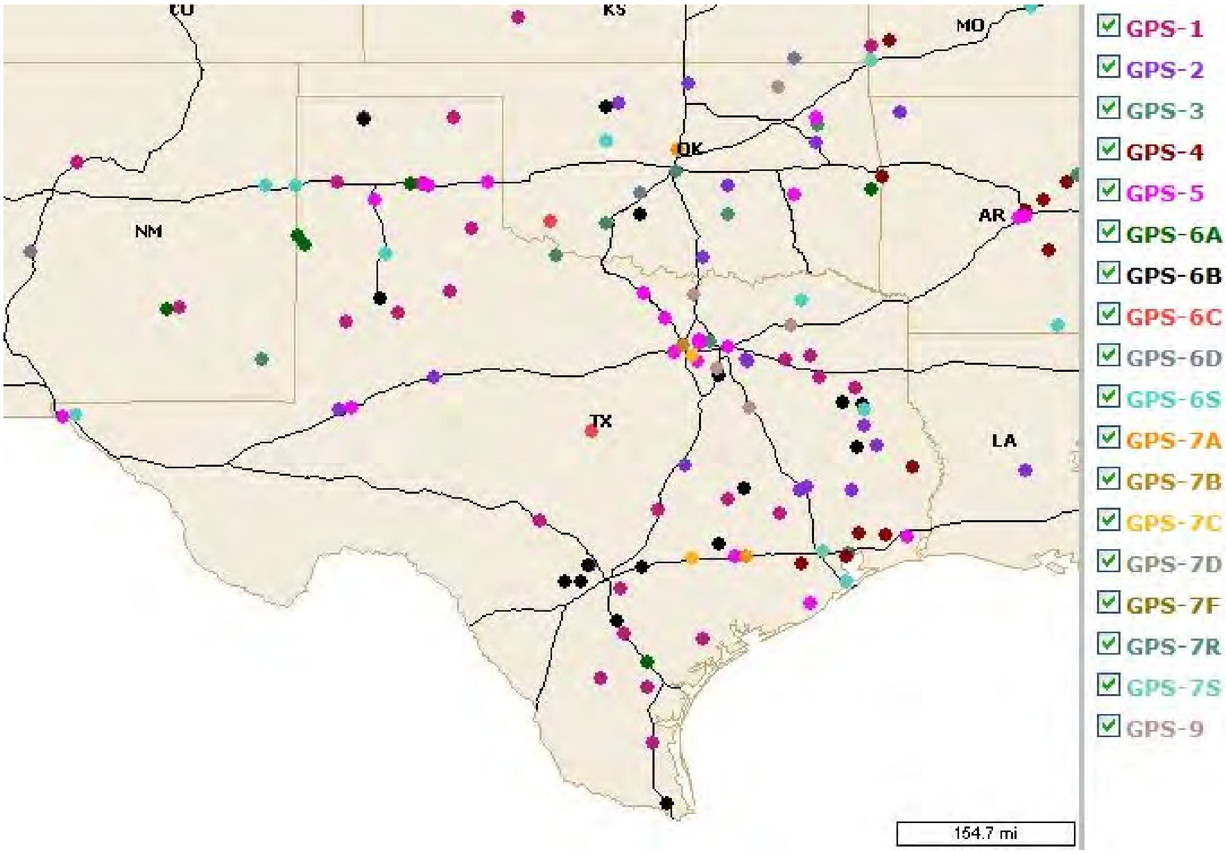


Figure 4.1: LTPP GPS Test Sections across Texas

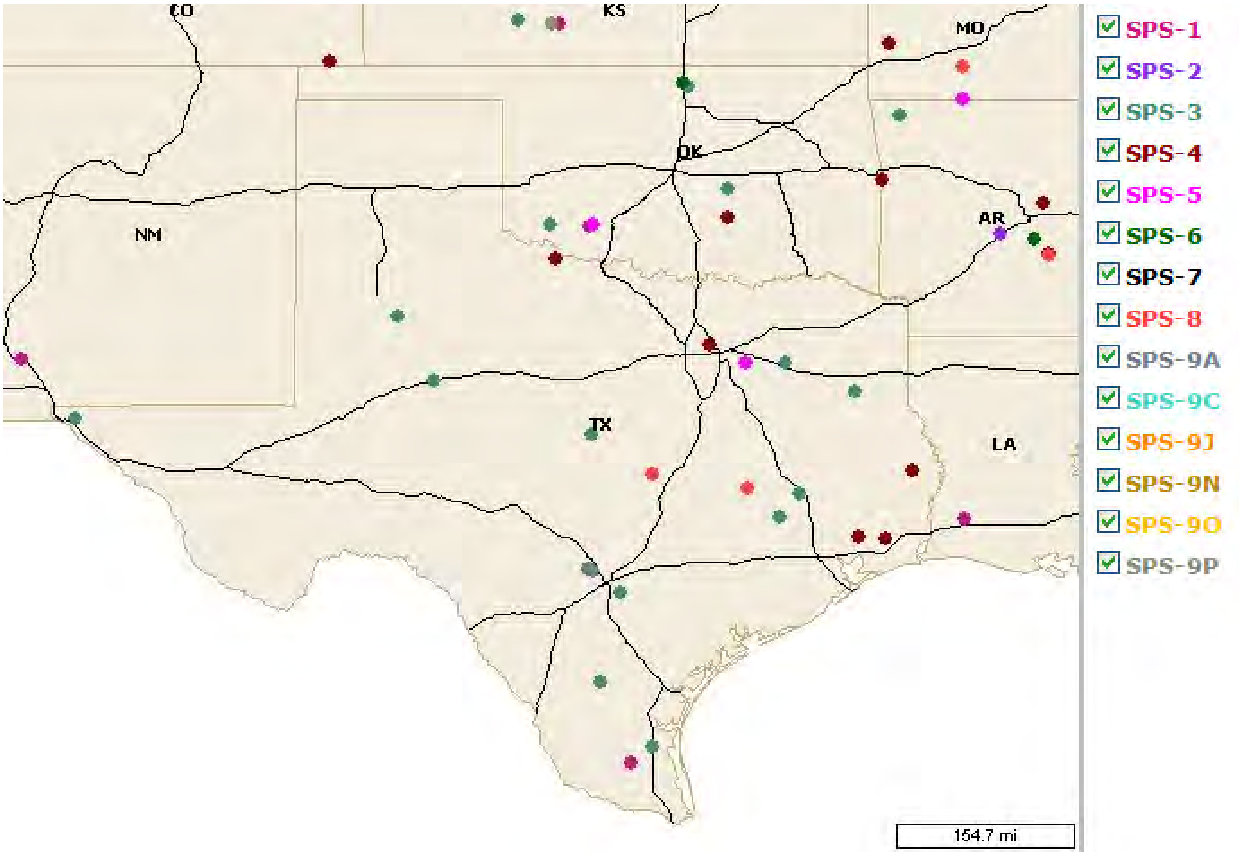


Figure 4.2: LTPP SPS Test Sections across Texas

Figures 4.1 and 4.2 gives a pictorial representation of each of the General Pavement Studies (GPS) test locations in Texas, where each specific GPS and SPS experiment is highlighted using unique color codes. Among the 218 LTPP sections in Texas, 91 sections are GPS (General Pavement Studies), while the remaining 127 sections are SPS (Specific Pavement Studies). Furthermore, according to the definition of the different experiments, there are 58 GPS sections and 127 SPS sections involving flexible pavements. By querying the LTPP database, the general information for the GPS and SPS sections in Texas was obtained. It is indicated that the construction period for an individual section varies due to the numerous maintenance activities that each of these sections have received from time to time. Although the earliest entry in the LTPP database dates back to 1987, many of the GPS sections have construction dates as early as the 1950s because of the fact that most of the GPS sections that were included as part of the study were already in service for quite some time. However on the other hand, the LTPP SPS sections were mostly newly built pavement sections and therefore they will have a construction date after the LTPP database was established in 1987.

4.3 Layout of a Typical LTPP Section

Generally, for both GPS and SPS test sections, the length is around 500 ft (152 m). Figure 4.3 illustrates the overall layout for a typical GPS test section. There are two maintenance control zones before and after the test section, with their lengths of 500 ft (152 m) and 250 ft (76 m), respectively. Figure 4.4 presents the overall layout for a typical SPS test project, which consists of several test sections with their individual lengths of 500 ft (152 m). In addition to maintenance control zones, there are transition zones between each two test sections.

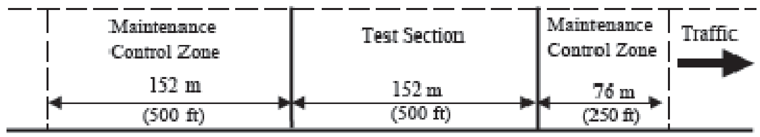


Figure 4.3: Layout of a Generic GPS Test Section

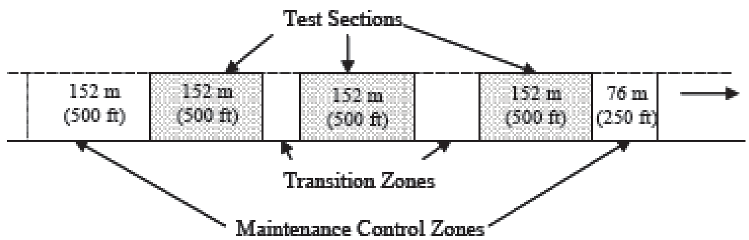


Figure 4.4: Layout of a Generic SPS Test Project

4.4 Summary of Section-wise Information on Texas LTPP Sections

The following section gives a brief summary of each of the LTPP pavement sections included in the Texas Flexible Pavement Database (TFPD). The summary of the section includes its District, County and Location Coordinates. This is followed by the structural design, deflection data for sensors D1 and D7 (Tables 4.1–4.49) obtained from the latest available FWD testing on the pavement section, and finally the IRI for the left and right wheel paths (Figures 4.5–4.53) as a measure of the condition of the pavement over time. However, it should be remembered that the information given in the table and charts given below is just a subset of the data that the TFPD stores for each of the pavement sections. Therefore for all other information that may be of any interest to the reader he/she should refer to the web interface of the TFPD which is available at the following location: http://pavements.ce.utexas.edu/. In addition, it should be noted that the LTPP data currently uploaded onto the TFPD correspond to Standard Data Release 22 (2008). Although only data that passes the highest quality level (Level E) were uploaded, there are some shortcomings. For example, it is apparent that some maintenance and rehabilitation work has not been reported, including seal coats, milling, thin overlay, etc. This is another limitation of the LTPP database that the researchers have no control over; however, it highlighted the importance of integrating construction work with maintenance and rehabilitation activities.

Although the Texas LTPP database has significant limitation, to date it constitutes the most comprehensive data set available for the purpose of calibration and validation of pavement design models. It is therefore, recommended that the Department should consider to continue the monitoring of a set of the remaining LTPP sections. The selected section should be monitored not only to the end of their remaining life but also after rehabilitation or reconstruction. This will provide a subset of sections with a long record.

Section: TXLT01001

- District, County [Climatic Region]: Paris, Lamar [Wet-Cold]
- Highway: SH 19 (Lane: L1)
- Starting Coordinates & Elevation: 33.51°N, 95.59°W; 445 feet above MSL

Table 4.1: Structural Details for Section TXLT01001

Section	Layer	Const. Date	Layer Type	Details	Thickness
TXLT01001	10	11/1/2000	HMA Surface		1.5 in.
	9		Surface Treatment		0 in.
	8				
	7				
	6	7/27/1999			
	5	3/1/1987	HMA Surface		3 in.
	4				7 in.
	3		Base/Subbase		6 in.
	2				8 in.
	1		Subgrade	Clayey Soil	semi-infinite

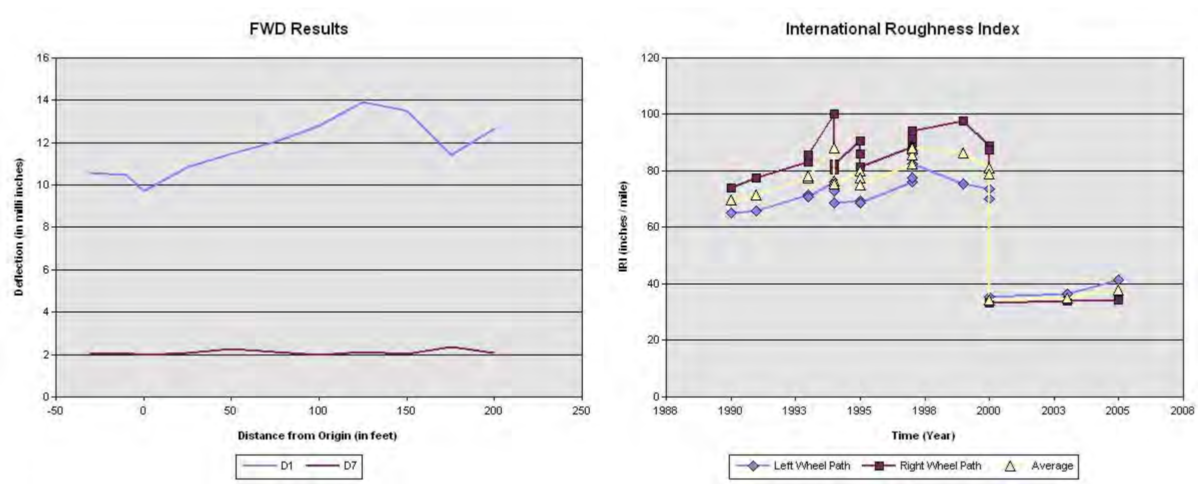


Figure 4.5: FWD and IRI - Section TXLT01001

Section TXLT04001

- District, County [Climatic Region]: Amarillo, Carson [Dry-Cold]
- Highway: SH 40 (Lane: R1)
- Starting Coordinates & Elevation: 35.21°N, 101.34°W; 3432 feet above MSL

Table 4.2: Structural Details for Section TXLT04001

Section	Layer	Const. Date	Layer Type	Details	Thickness
TXLT04001	8	7/1/1956	HMA Surface		1.7 in.
	7				1.9 in.
	6				6.4 in.
	5				1.1 in.
	4				1.3 in.
	3		Base/Subbase		8.4 in.
	2				5.1 in.
	1		Subgrade	Clayey Soil	semi-infinite

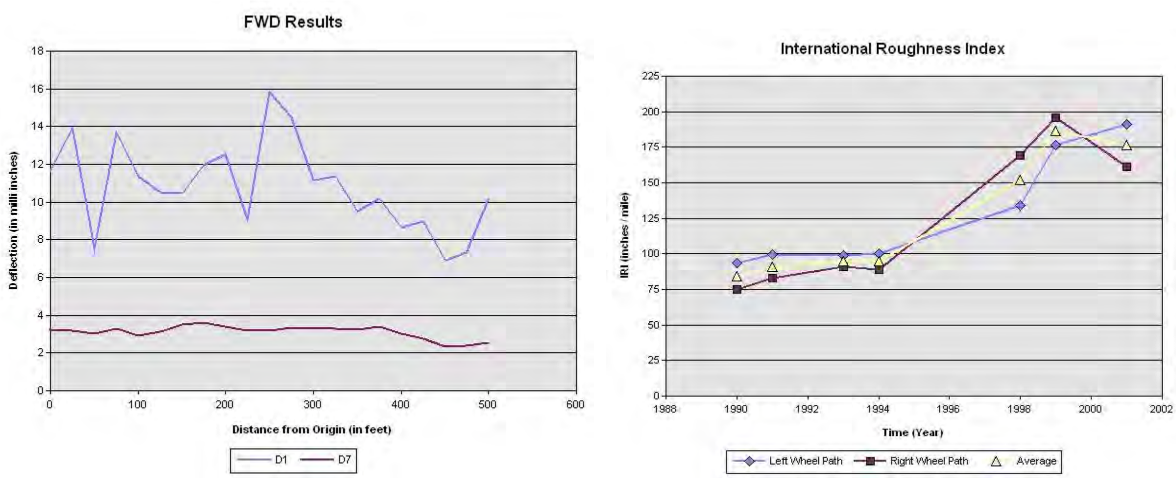


Figure 4.6: FWD and IRI - Section TXLT04001

Section TXLT04002

- District, County [Climatic Region]: Amarillo, Ochiltree [Dry-Cold]
- Highway: US 83 (Lane: K1)
- Starting Coordinates and Elevation: 36.19°N, 100.71°W; 2873 feet

Table 4.3: Structural Details for Section TXLT04002

Section	Layer	Const. Date	Layer Type	Details	Thickness
TXLT04002	9	7/6/2000	Surface Treatment		0 in.
	5	7/1/1988			
	4	6/1/1970	HMA Surface		1.5 in.
	3		Surface Treatment		0.5 in.
	2		Base/Subbase		14 in.
	1		Subgrade	Clayey Soil	semi-infinite

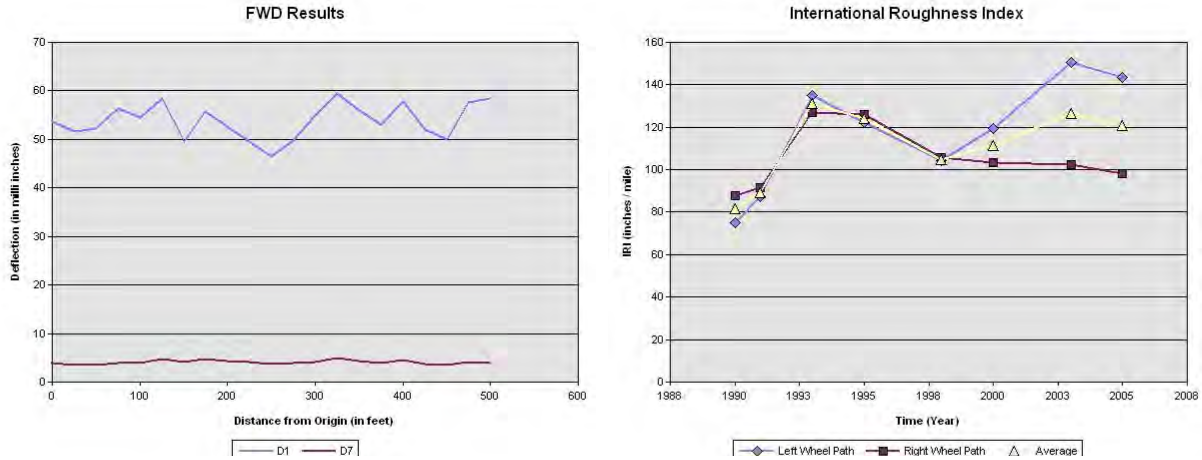


Figure 4.7: FWD and IRI - Section TXLT04002

Section TXLT05001

- District, County [Climatic Region]: Lubbock, Terry [Dry-Cold]
- Highway: SH 62 (Lane: K6)
- Starting Coordinates & Elevation: 33.17°N, 102.28°W; 3018 feet above MSL

Table 4.4: Structural Details for Section TXLT05001

Section	Layer	Const. Date	Layer Type	Details	Thickness
TXLT05001	5	6/13/1999	Surface Treatment		0 in.
	4	11/1/1977	HMA Surface		2 in.
	3				3.5 in.
	2		Base/Subbase		10.5 in.
	1		Subgrade		Semi-infinite

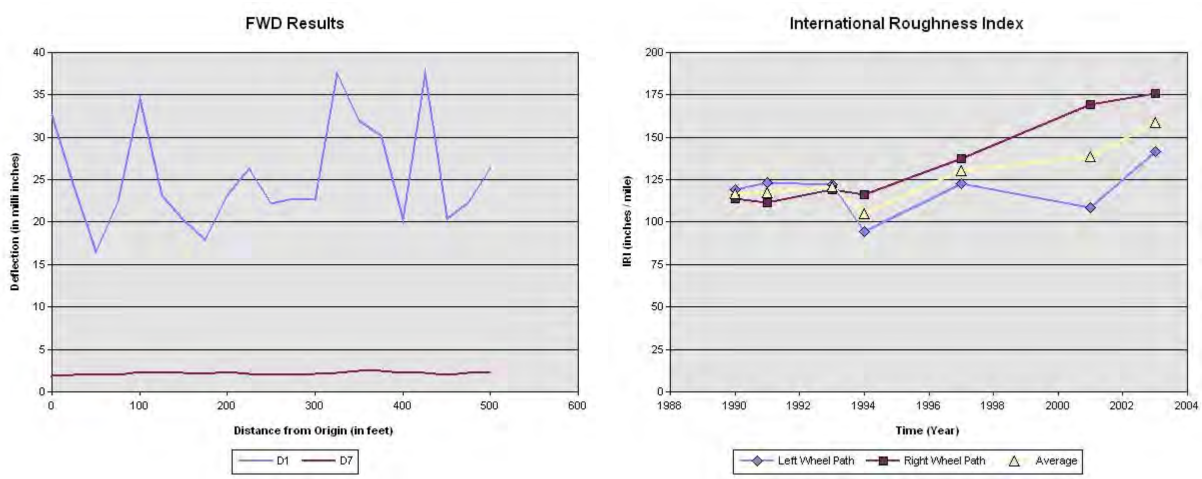


Figure 4.8: FWD and IRI - Section TXLT05001

Section TXLT05002

- District, County [Climatic Region]: Lubbock, Lubbock [Dry-Cold]
- Highway: SH 289 (Lane: R1)
- Starting Coordinates & Elevation: 33.53°N, 101.8°W; 3158 feet above MSL

Table 4.5: Structural Details for Section TXLT05002

Section	Layer	Const. Date	Layer Type	Details	Thickness
TXLT05002	8	8/15/1999	HMA Surface		1.6 in.
	7		Surface Treatment		0 in.
	6	9/1/1972			0.2 in.
	5				0.2 in.
	4		HMA Surface		1.5 in.
	3				5 in.
	2		Base/Subbase		7.5 in.
	1		Subgrade	Clayey Soils	Semi-infinite

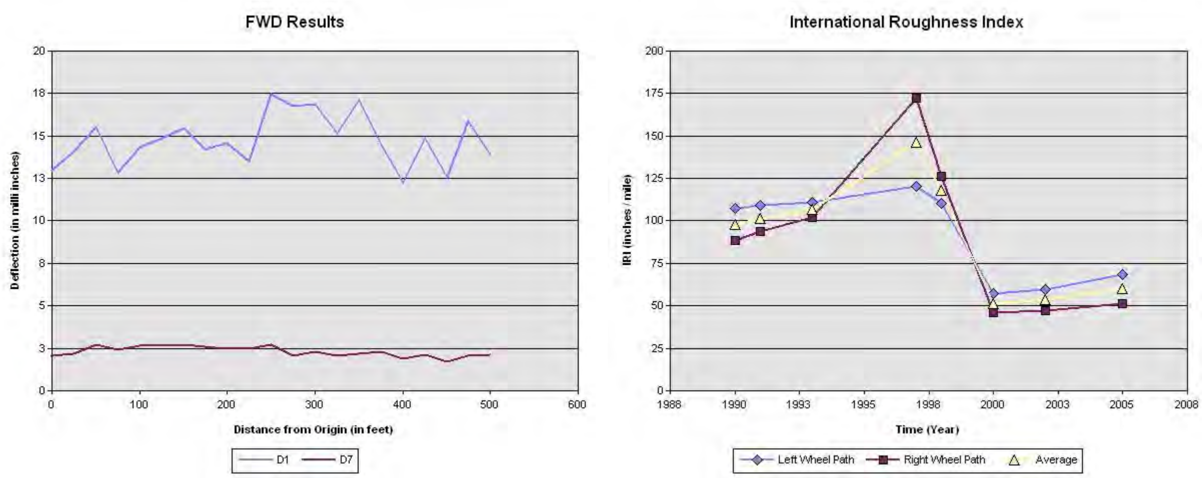


Figure 4.9: FWD and IRI - Section TXLT05002

Section TXLT05003

- District, County [Climatic Region]: Lubbock, Hale [Dry-Cold]
- Highway: FM 445 (Lane: R1)
- Starting Coordinates & Elevation: 34.17°N, 101.71°W; 3369 feet above MSL

Table 4.6: Structural Details for Section TXLT05003

Section	Layer	Const. Date	Layer Type	Details	Thickness
TXLT05003	8	2/22/2001	HMA Surface		1.5 in.
	7		Surface Treatment		0.1 in.
	6	6/26/1997			0.7 in.
	5	7/1/1970	HMA Surface		1 in.
	4				1.5 in.
	3		Base/Subbase		9.8 in.
	2				5 in.
	1		Subgrade	Clayey Soils	Semi-infinite

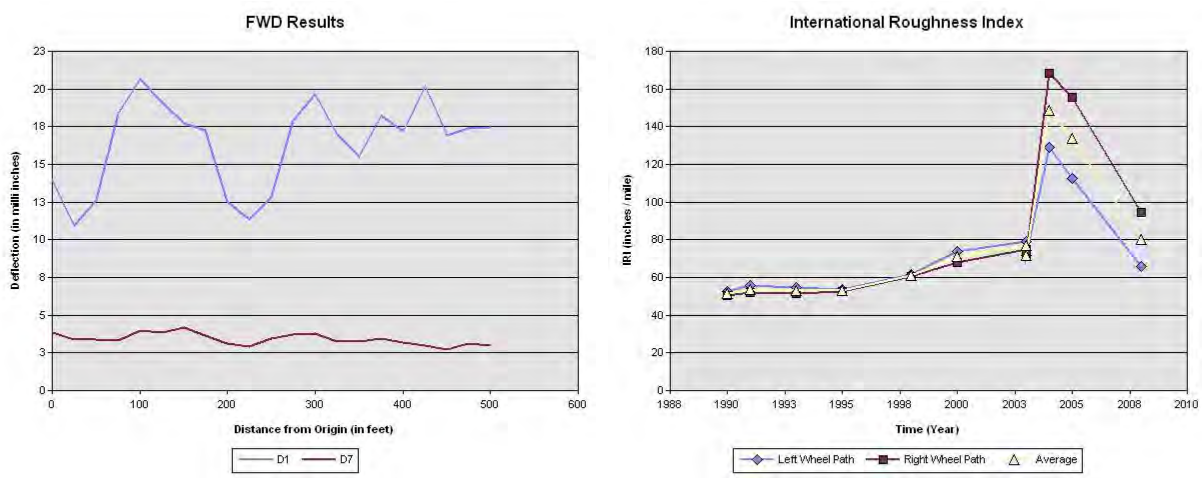


Figure 4.10: FWD and IRI - Section TXLT05003

Section TXLT08001

- District, County [Climatic Region]: Abilene, Mitchell [Dry-Cold]
- Highway: IH 20
- Starting Coordinates & Elevation: 32.36°N, 100.99°W; 2134 feet above MSL

Table 4.7: Structural Details for Section TXLT08001

Section	Layer	Const. Date	Layer Type	Details	Thickness
TXLT08001	7	10/11/1990	HMA Surface	Asphalt Concrete	1.0 in.
	6	1/1/1987			0.9 in.
	5				2.1 in.
	4				7.8 in.
	3		Base/Subbase	Treated Base	6.8 in.
	2				8.8 in.
	1		Subgrade		Semi-infinite

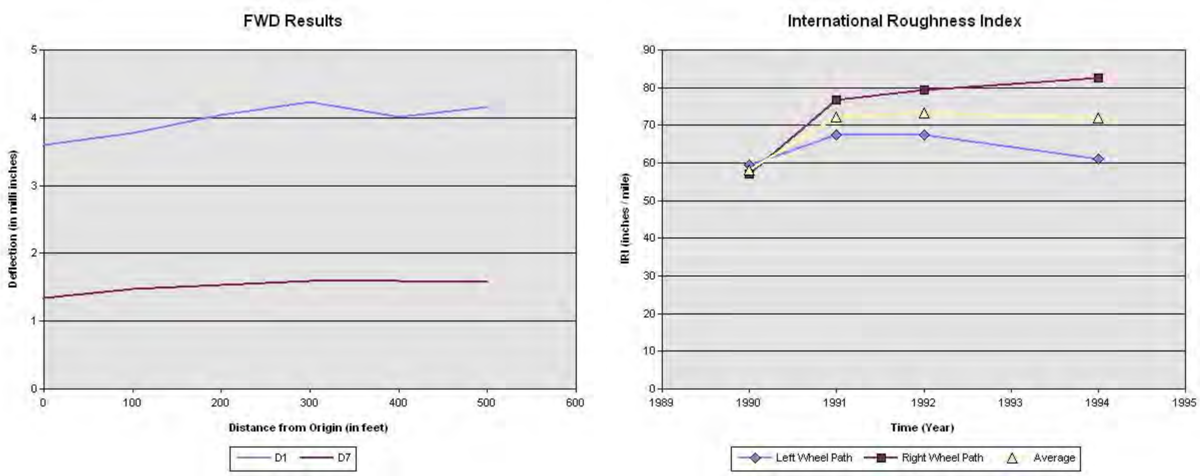


Figure 4.11: FWD and IRI - Section TXLT08001

Section TXLT08002

- District, County [Climatic Region]: Abilene, Mitchell [Dry-Cold]
- Highway: IH 20
- Starting Coordinates & Elevation: 32.36°N, 100.99°W; 2134 feet above MSL

Table 4.8: Structural Details for Section TXLT08002

Section	Layer	Const. Date	Layer Type	Details	Thickness
TXLT08002	7	9/17/1990	Surface Treatment	Asphalt Concrete	0.1 in.
	6	1/1/1987	HMA Surface		1.0 in.
	5				2.2 in.
	4				7.3 in.
	3		Base/Subbase	Treated Base	6.8 in.
	2				8.8 in.
	1		Subgrade		Semi-infinite

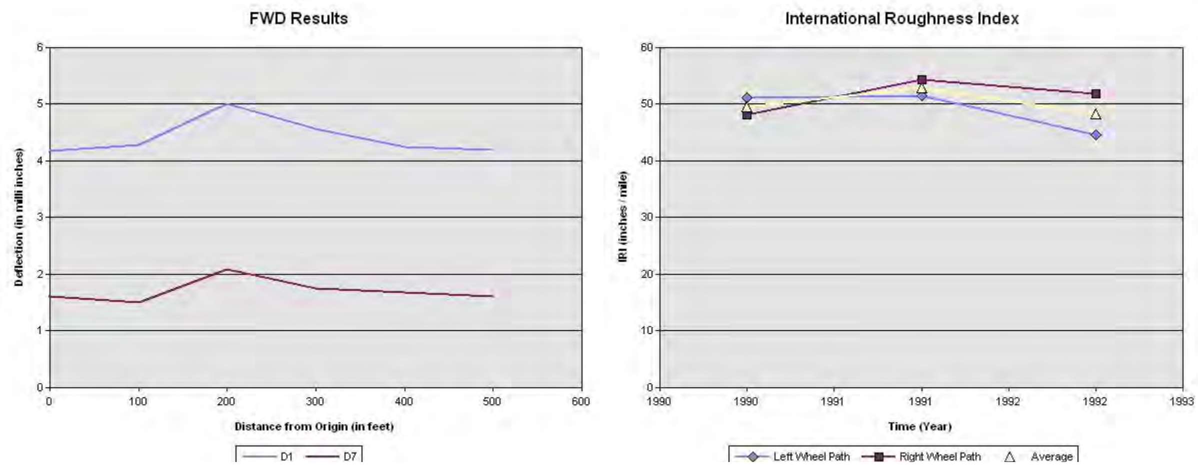


Figure 4.12: FWD and IRI - Section TXLT08002

Section TXLT08003

- District, County [Climatic Region]: Abilene, Mitchell [Dry-Cold]
- Highway: IH 20
- Starting Coordinates & Elevation: 32.36°N, 100.99°W; 2134 feet above MSL

Table 4.9: Structural Details for Section TXLT08003

Section	Layer	Const. Date	Layer Type	Details	Thickness
TXLT08003	7	9/17/1990	Surface Treatment	Asphalt Concrete	0.1 in.
	6	1/1/1987	HMA Surface		0.8 in.
	5				2.5 in.
	4				7.6 in.
	3		Base/Subbase	Treated Base	6.8 in.
	2				8.8 in.
	1		Subgrade		Semi-infinite

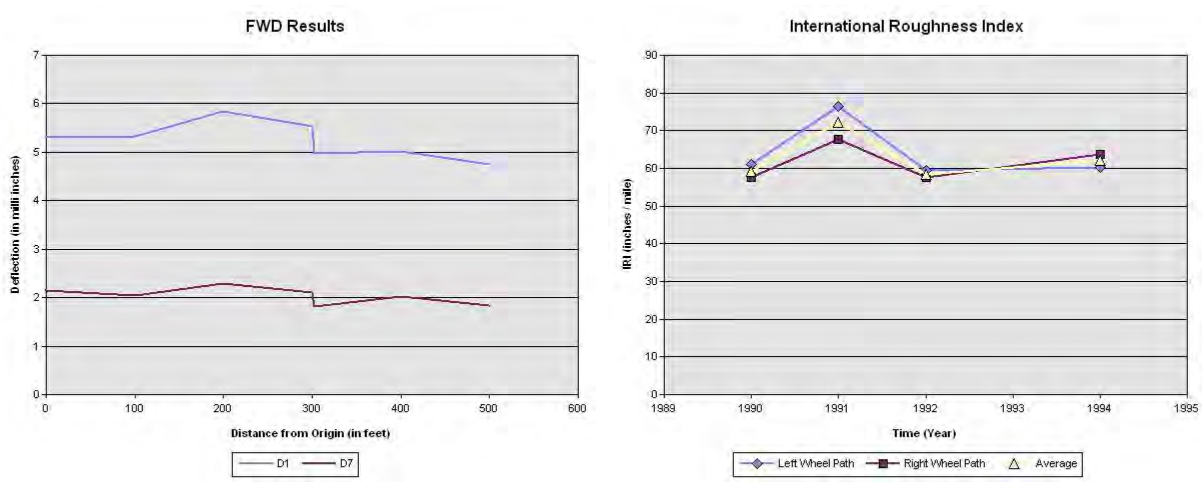


Figure 4.13: FWD and IRI - Section TXLT08003

Section TXLT09037

- District, County [Climatic Region]: Waco, Bell [Mixed]
- Highway: SH 363 (Lane: K1)
- Starting Coordinates & Elevation: 31.08°N, 97.32°W; 599 feet above MSL

Table 4.10: Structural Details for Section TXLT09037

Section	Layer	Const. Date	Layer Type	Details	Thickness
TXLT09037	7	8/3/2000	Surface Treatment		0 in.
	6	10/1/1985	HMA Surface		1.5 in.
	5		Surface Treatment		0.5 in.
	4		Base/Subbase		3 in.
	3				6 in.
	2				12 in.
	1		Subgrade	Clayey Soils	Semi-infinite

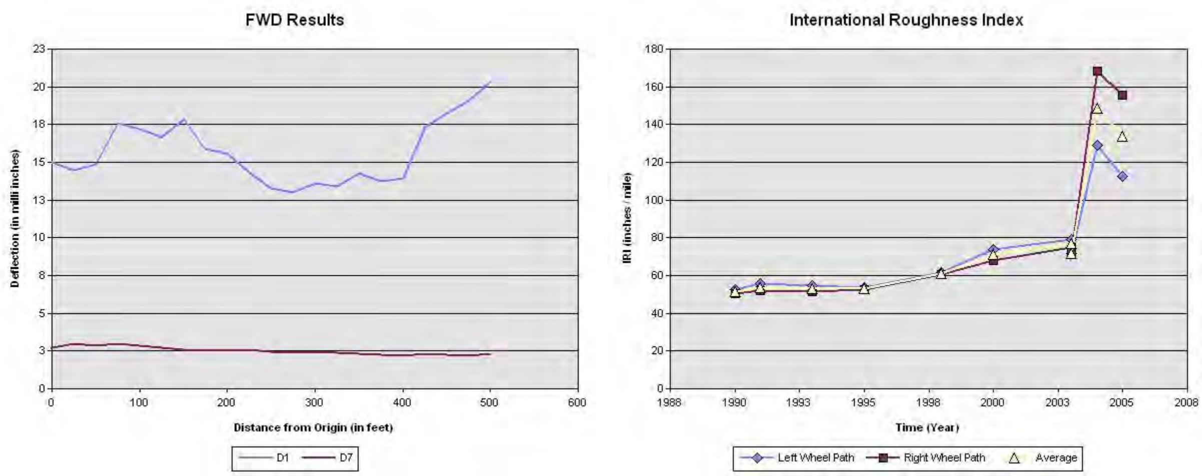


Figure 4.14: FWD and IRI - Section TXLT09037

Section TXLT10001

- District, County [Climatic Region]: Tyler, Smith [Wet-Cold]
- Highway: US 69 (Lane: K6)
- Starting Coordinates & Elevation: 32.37°N, 95.33°W; 545 feet above MSL

Table 4.11: Structural Details for Section TXLT10001

Section	Layer	Const. Date	Layer Type	Details	Thickness
TXLT10001	5	12/1/1973	Surface Treatment		0.3 in.
	4		HMA Surface		1.5 in.
	3				6 in.
	2		Base/Subbase		8 in.
	1		Subgrade		Semi-infinite

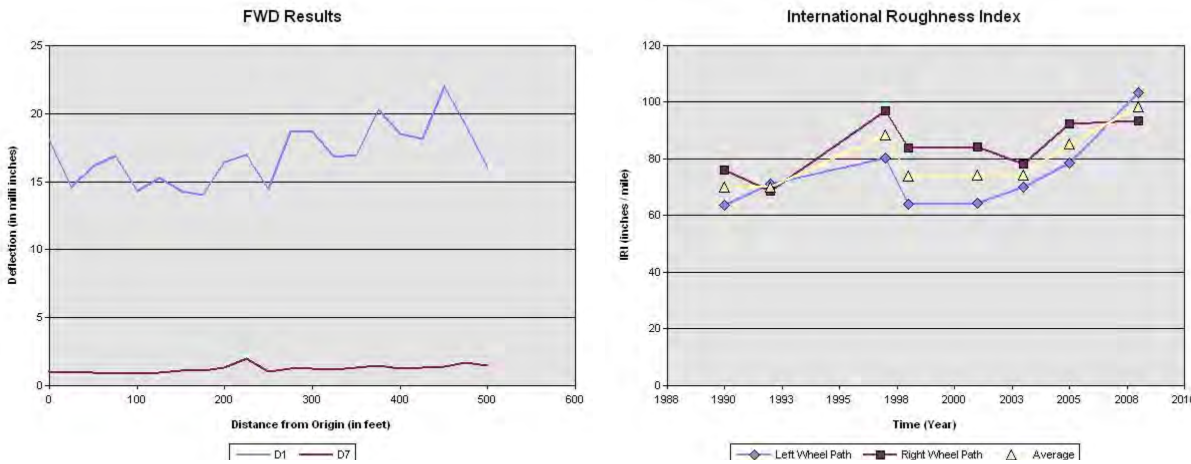


Figure 4.15: FWD and IRI - Section TXLT10001

Section TXLT10002

- District, County [Climatic Region]: Tyler, Wood [Wet-Cold]
- Highway: FM 564 (Lane: K1)
- Starting Coordinates & Elevation: 32.68°N, 95.47°W; 418 feet above MSL

Table 4.12: Structural Details for Section TXLT10002

Section	Layer	Const. Date	Layer Type	Details	Thickness
TXLT10002	5	4/15/2002	Surface Treatment		0 in.
	4	9/1/1985	HMA Surface		1 in.
	3		Surface Treatment		0.5 in.
	2		Base/Subbase		11 in.
	1		Subgrade		Semi-infinite

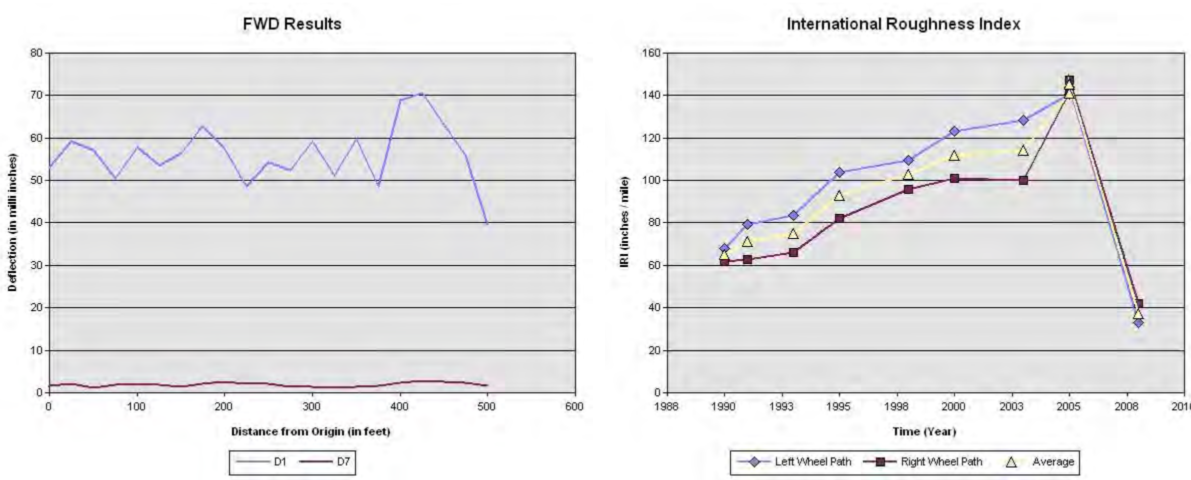


Figure 4.16: FWD and IRI - Section TXLT10002

Section TXLT10003

- District, County [Climatic Region]: Tyler, Rusk [Wet-Cold]
- Highway: SH 322 (Lane: K6)
- Starting Coordinates & Elevation: 32.2°N, 94.8°W; 430 feet above MSL

Table 4.13: Structural Details for Section TXLT10003

Section	Layer	Const. Date	Layer Type	Details	Thickness
TXLT10003	6	8/15/2000	Surface Treatment		0 in.
	5	8/1/1972			0.5 in.
	4		HMA Surface		1.5 in.
	3		Surface Treatment		0.5 in.
	2		Base/Subbase		12 in.
	1		Subgrade		Semi-infinite

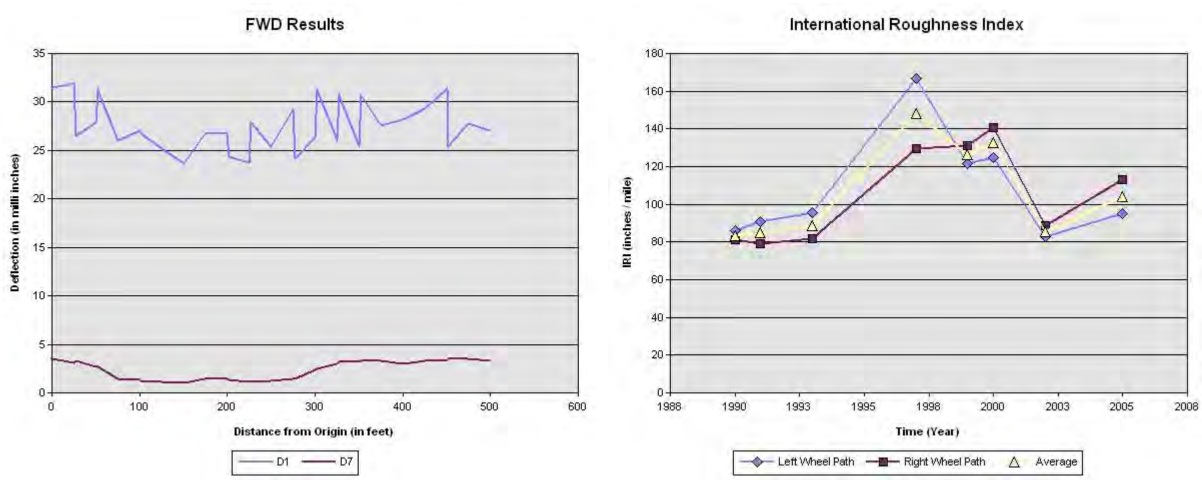


Figure 4.17: FWD and IRI - Section TXLT10003

Section TXLT10026

- District, County [Climatic Region]: Tyler, Rusk [Wet-Cold]
- Highway: SH 322 (Lane: K6)
- Starting Coordinates & Elevation: 32.2°N, 94.8°W; 430 feet above MSL

Table 4.14: Structural Details for Section TXLT10026

Section	Layer	Const. Date	Layer Type	Details	Thickness
TXLT10026	6	10/14/1990	HMA Surface	Asphalt Concrete	1.2 in.
	5	1/1/1987	Surface Treatment		0.5 in.
	4		HMA Surface		1.4 in.
	3		Surface Treatment		0.3 in.
	2		Base/Subbase		11.3 in.
	1		Subgrade		Semi-infinite

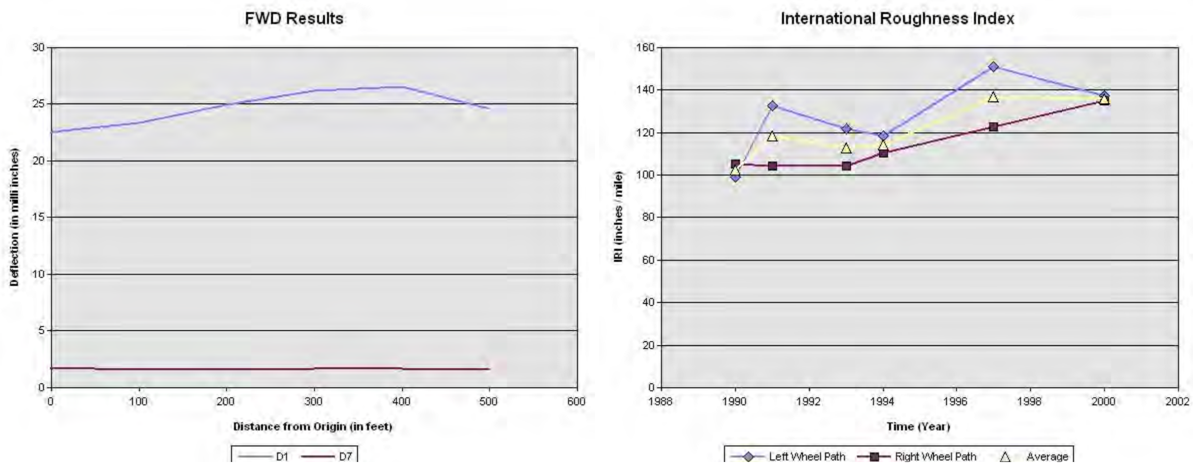


Figure 4.18: FWD and IRI - Section TXLT10026

Section TXLT10027

- District, County [Climatic Region]: Tyler, Rusk [Wet-Cold]
- Highway: SH 322 (Lane: K6)
- Starting Coordinates & Elevation: 32.2°N, 94.8°W; 430 feet above MSL

Table 4.15: Structural Details for Section TXLT10027

Section	Layer	Const. Date	Layer Type	Details	Thickness
TXLT10027	6	10/4/1990	Surface Treatment	Asphalt Concrete	0.1 in.
	5	1/1/1987			0.4 in.
	4		HMA Surface		1.2 in.
	3		Surface Treatment		0.3 in.
	2		Base/Subbase		11.3 in.
	1		Subgrade		Semi-infinite

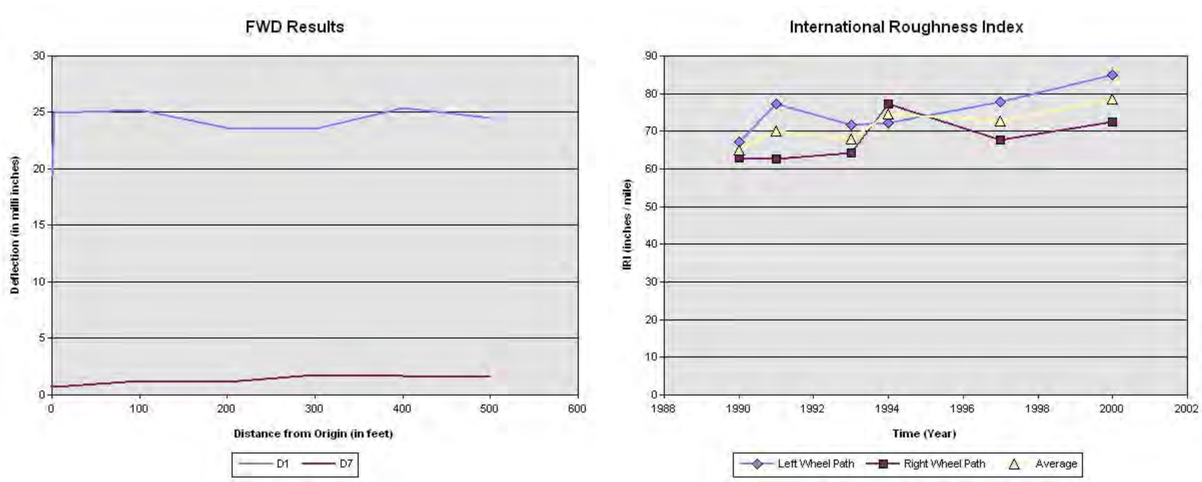


Figure 4.19: FWD and IRI - Section TXLT10027

Section TXLT10028

- District, County [Climatic Region]: Tyler, Rusk [Wet-Cold]
- Highway: SH 322 (Lane: K6)
- Starting Coordinates & Elevation: 32.2°N, 94.8°W; 430 feet above MSL

Table 4.16: Structural Details for Section TXLT10028

Section	Layer	Const. Date	Layer Type	Details	Thickness
TXLT10028	5	1/1/1987	Surface Treatment	Asphalt Concrete	0.5 in.
	4		HMA Surface		1.5 in.
	3		Surface Treatment		0.3 in.
	2		Base/Subbase		11.3 in.
	1		Subgrade		Semi-infinite

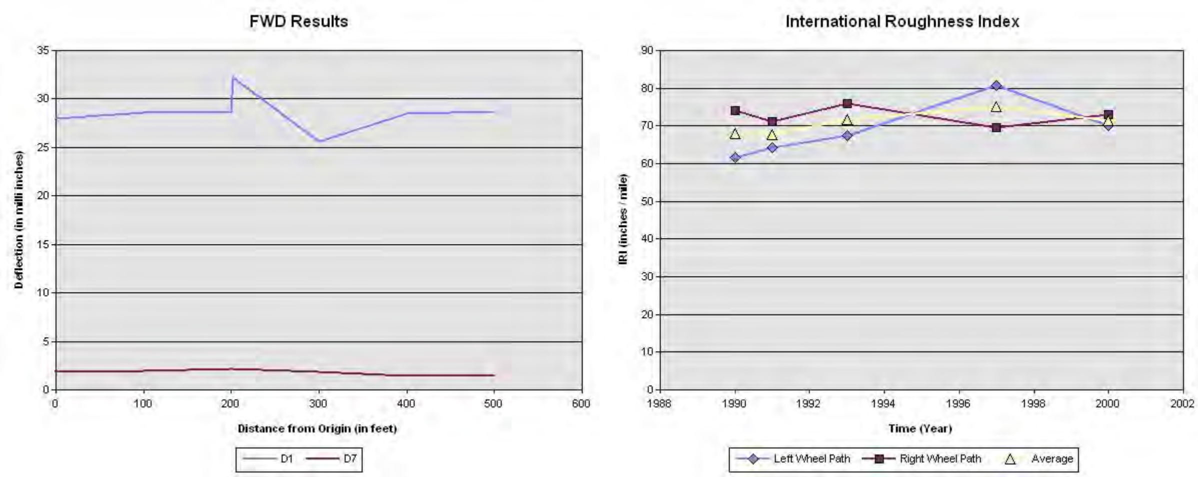


Figure 4.20: FWD and IRI - Section TXLT10028

Section TXLT11001

- District, County [Climatic Region]: Lufkin, Angelina [Wet-Warm]
- Highway: SH 94 (Lane: K1)
- Starting Coordinates & Elevation: 31.33°N, 94.79°W; 315 feet above MSL

Table 4.17: Structural Details for Section TXLT11001

Section	Layer	Const. Date	Layer Type	Details	Thickness
TXLT11001	7	6/11/2003	Surface Treatment		0.3 in.
	6	9/15/2000	HMA Surface		1.6 in.
	5	5/1/1983			1.5 in.
	4				2.7 in.
	3		Base/Subbase		8 in.
	2				7.9 in.
	1		Subgrade	Clayey Soils	Semi-infinite

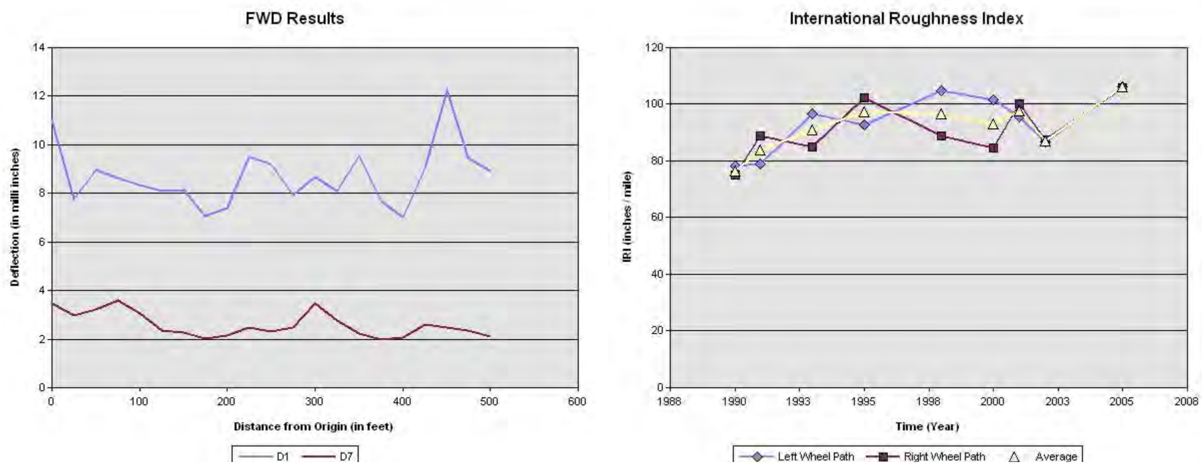


Figure 4.21: FWD and IRI - Section TXLT11001

Section TXLT12001

- District, County [Climatic Region]: Houston, Galveston [Wet-Warm]
- Highway: SH 197 (Lane: L1)
- Starting Coordinates & Elevation: 29.35°N, 94.93°W; 8 feet above MSL

Table 4.18: Structural Details for Section TXLT12001

Section	Layer	Const. Date	Layer Type	Details	Thickness
TXLT12001	8	6/15/2003	HMA Surface		1.2 in.
	7				2 in.
	6		Surface Treatment		0.3 in.
	5		HMA Surface		1.5 in.
	4	6/22/1994			3 in.
	3		Base/Subbase		14 in.
	2				6 in.
	1		Subgrade	Clayey Soils	Semi-infinite

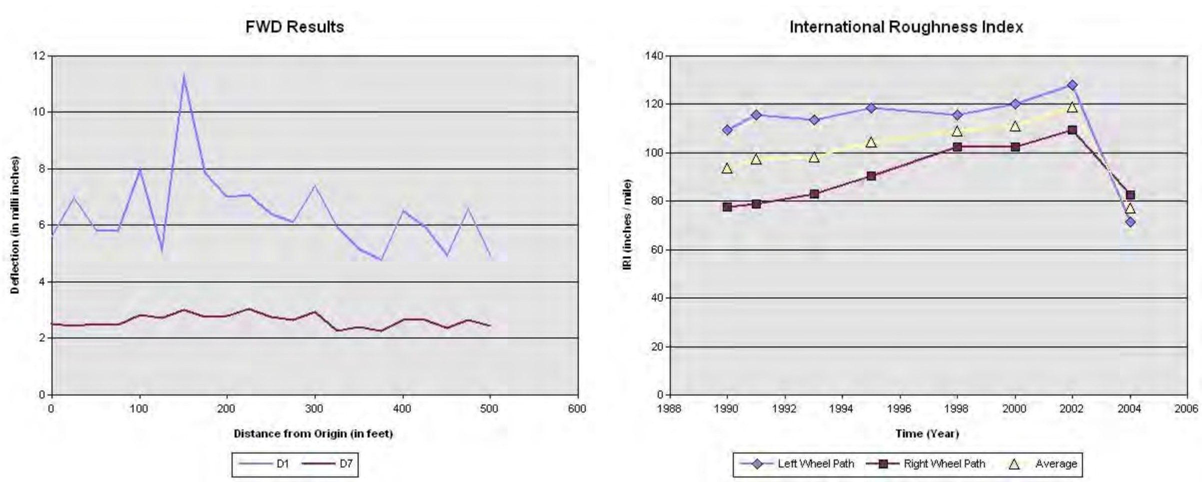


Figure 4.22: FWD and IRI - Section TXLT12001

Section TXLT13001:

- District, County [Climatic Region]: Yoakum, Fayette [Wet-Warm]
- Highway: US 71 (Lane: L1)
- Starting Coordinates & Elevation: 29.9°N, 96.81°W; 320 feet above MSL

Table 4.19: Structural Details for Section TXLT13001

Section	Layer	Const. Date	Layer Type	Details	Thickness
TXLT13001	7	12/14/1998	HMA Surface		1.9 in.
	6	10/1/1979			0.2 in.
	5				0.9 in.
	4				0.3 in.
	3		Base/Subbase		16.8 in.
	2				6 in.
	1		Subgrade	Gravel and Sand	Semi-infinite

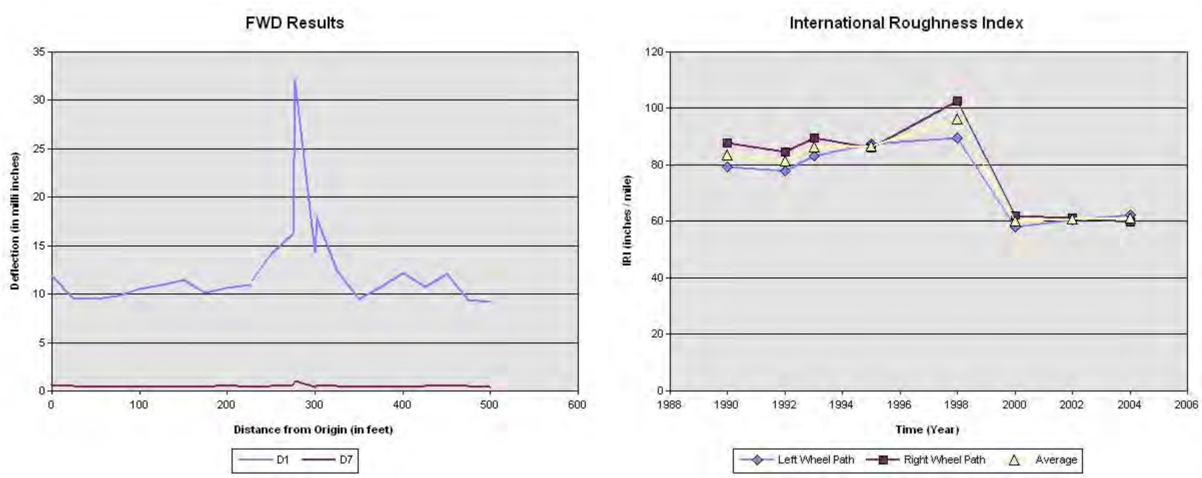


Figure 4.23: FWD and IRI - Section TXLT13001

Section TXLT14001

- District, County [Climatic Region]: Austin, Travis [Mixed]
- Highway: LP 1 (Lane: R1)
- Starting Coordinates & Elevation: 30.41°N, 97.72°W; 771 feet above MSL

Table 4.20: Structural Details for Section TXLT14001

Section	Layer	Const. Date	Layer Type	Details	Thickness
TXLT14001	4	4/1/1989	HMA Surface		1 in.
	3				1.4 in.
	2		Base/Subbase		14.7 in.
	1		Subgrade	Clayey Soils	Semi-infinite

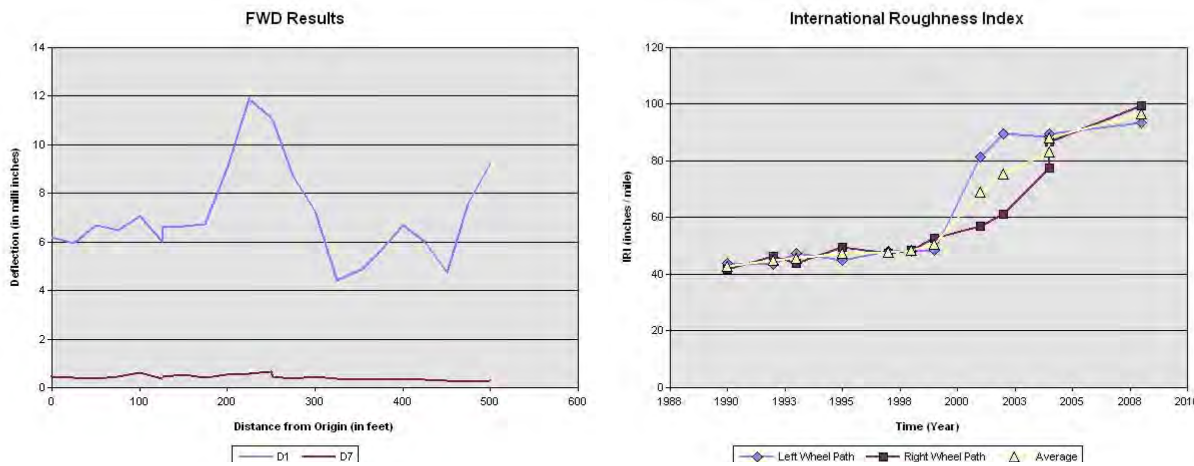


Figure 4.24: FWD and IRI - Section TXLT14001

Section TXLT15001

- District, County [Climatic Region]: San Antonio, Medina [Dry-Warm]
- Highway: US 90 (Lane: L1)
- Starting Coordinates & Elevation: 29.36°N, 98.84°W; 774 feet above MSL

Table 4.21: Structural Details for Section TXLT15001

Section	Layer	Const. Date	Layer Type	Details	Thickness
TXLT15001	10	5/30/2001	HMA Surface		2 in.
	9		Surface Treatment		0.3 in.
	8	7/1/1996			0.3 in.
	7	4/1/1981	HMA Surface		0.6 in.
	6				1.5 in.
	5				5 in.
	4		Surface Treatment		0 in.
	3		Base/Subbase		8.1 in.
	2				6 in.
	1		Subgrade	Clayey Soils	Semi-infinite

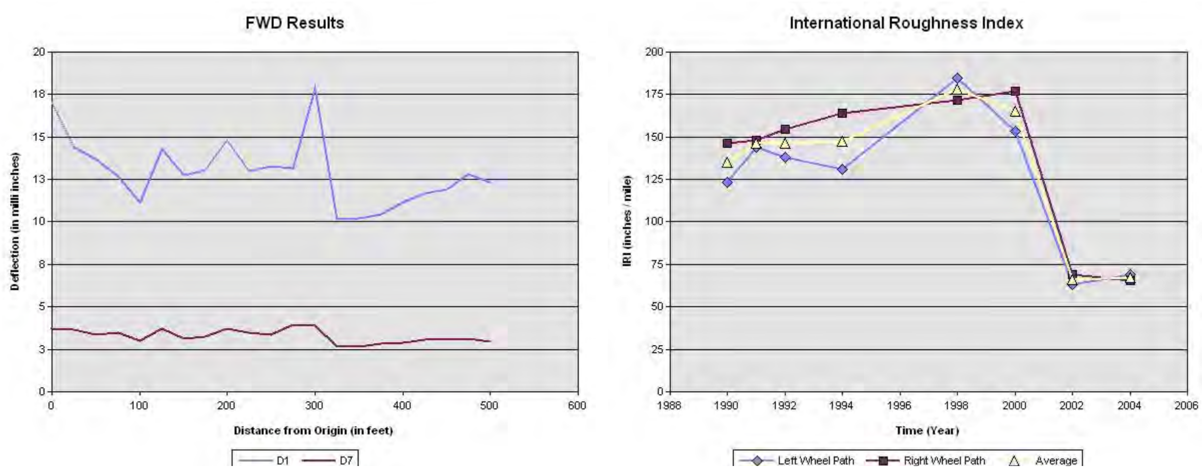


Figure 4.25: FWD and IRI - Section TXLT15001

Section TXLT15002

- District, County [Climatic Region]: San Antonio, Bexar [Dry-Warm]
- Highway: SH 16 (Lane: L1)
- Starting Coordinates & Elevation: 29.6°N, 98.71°W; 1109 feet above MSL

Table 4.22: Structural Details for Section TXLT15002

Section	Layer	Const. Date	Layer Type	Details	Thickness
TXLT15002	6	9/14/1998	Surface Treatment		0 in.
	5	8/1/1976	HMA Surface		0.4 in.
	4				0.7 in.
	3		Surface Treatment		1.2 in.
	2		Base/Subbase		8.4 in.
	1		Subgrade	Clayey Soils	Semi-infinite

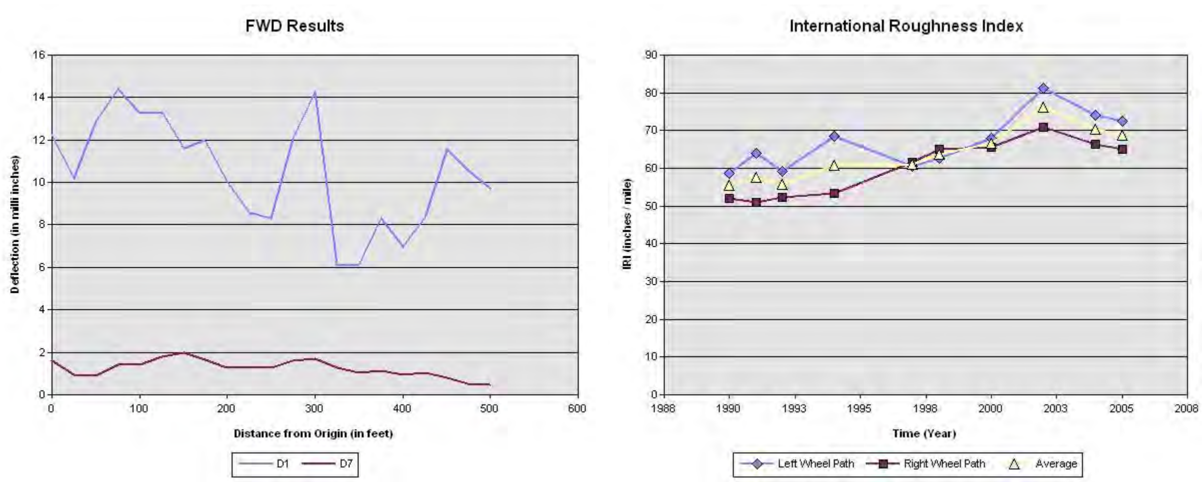


Figure 4.26: FWD and IRI - Section TXLT15002

Section TXLT15003

- District, County [Climatic Region]: San Antonio, Medina [Dry-Warm]
- Highway: SH 90 (Lane: L1)
- Starting Coordinates & Elevation: 29.35°N, 99.07°W; 828 feet above MSL

Table 4.23: Structural Details for Section TXLT15003

Section	Layer	Const. Date	Layer Type	Details	Thickness
TXLT15003	11	9/15/1998	HMA Surface		1.7 in.
	10	7/15/1995	Surface Treatment		0.3 in.
	9	8/27/1991			0.2 in.
	8	9/1/1983	HMA Surface		0.7 in.
	7				1 in.
	6				1 in.
	5		Surface Treatment		0 in.
	4		Base/Subbase		0.4 in.
	3				5.5 in.
	2				7 in.
	1		Subgrade	Clayey Soils	Semi-infinite

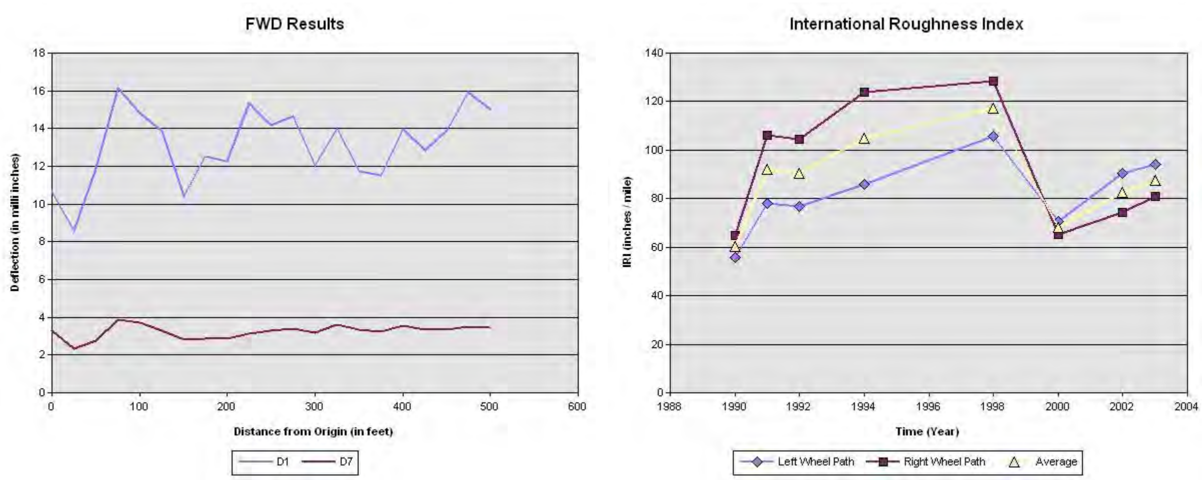


Figure 4.27: FWD and IRI - Section TXLT15003

Section TXLT15004

- District, County [Climatic Region]: San Antonio, Bexar [Dry-Warm]
- Highway: FM 1560 (Lane: K1)
- Starting Coordinates & Elevation: 29.52°N, 98.72°W; 910 feet above MSL

Table 4.24: Structural Details for Section TXLT15004

Section	Layer	Const. Date	Layer Type	Details	Thickness
TXLT15004	6	9/14/1998	HMA Surface		1.9 in.
	5		Surface Treatment		0.3 in.
	4	9/1/1986	HMA Surface		1.2 in.
	3		Surface Treatment		0.4 in.
	2		Base/Subbase		9.4 in.
	1		Subgrade	Clayey Soils	Semi-infinite

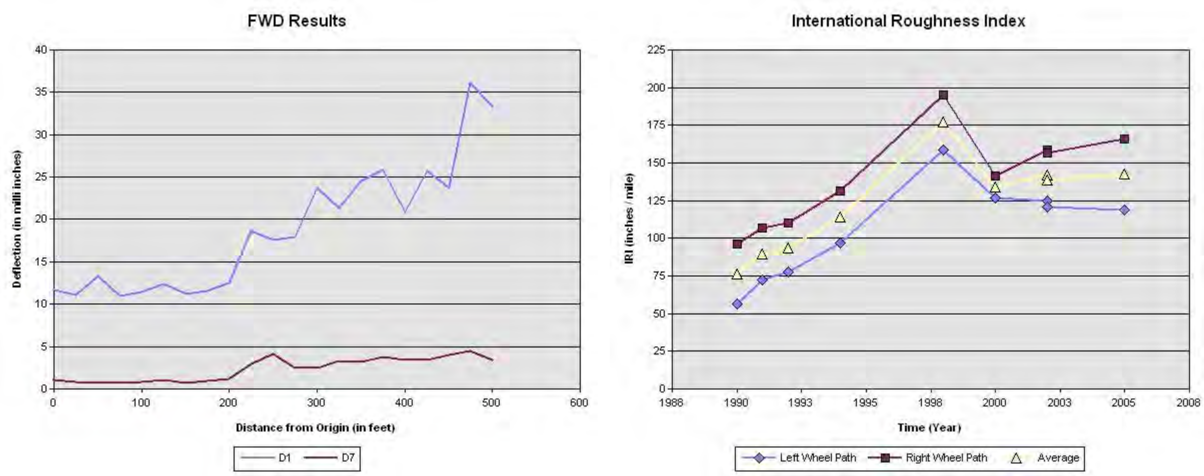


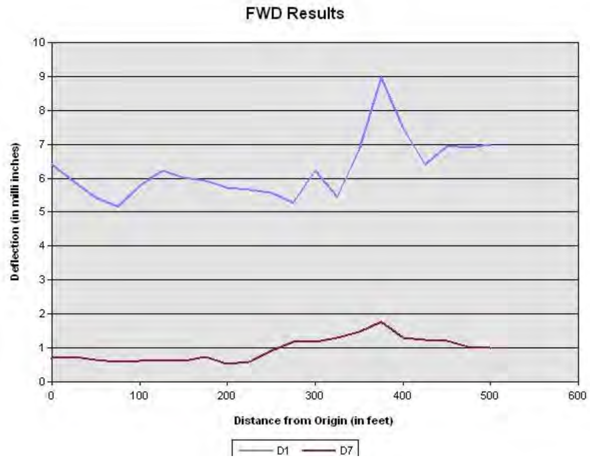
Figure 4.28: FWD and IRI - Section TXLT15004

Section TXLT15005

- District, County [Climatic Region]: San Antonio, Wilson [Dry-Warm]
- Highway: US 181 (Lane: L1)
- Starting Coordinates & Elevation: 29.24°N, 98.25°W; 470 feet above MSL

Table 4.25: Structural Details for Section TXLT15005

Section	Layer	Const. Date	Layer Type	Details	Thickness
TXLT15005	6	2/1/1974	HMA Surface		0.4 in.
	5				1.4 in.
	4				1.6 in.
	3		Base/Subbase		15.6 in.
	2				8.4 in.
	1		Subgrade	Fine Sand	Semi-infinite



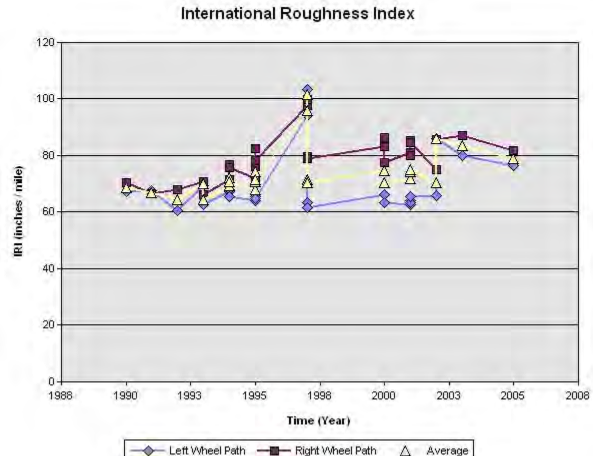


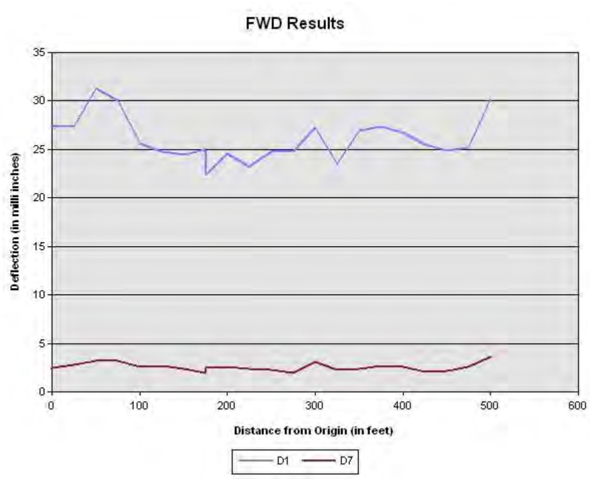
Figure 4.29: FWD and IRI - Section TXLT15005

Section TXLT15006

- District, County [Climatic Region]: San Antonio, Atascosa [Dry-Warm]
- Highway: SH 37 (Lane: L1)
- Starting Coordinates & Elevation: 28.78°N, 98.31°W; 249 feet above MSL

Table 4.26: Structural Details for Section TXLT15006

Section	Layer	Const. Date	Layer Type	Details	Thickness
TXLT15006	6	9/14/1988	HMA Surface		1.9 in.
	5				0.6 in.
	4	4/1/1980			0.5 in.
	3				2.4 in.
	2		Base/Subbase		17.2 in.
	1		Subgrade	Gravel and Sand	Semi-infinite



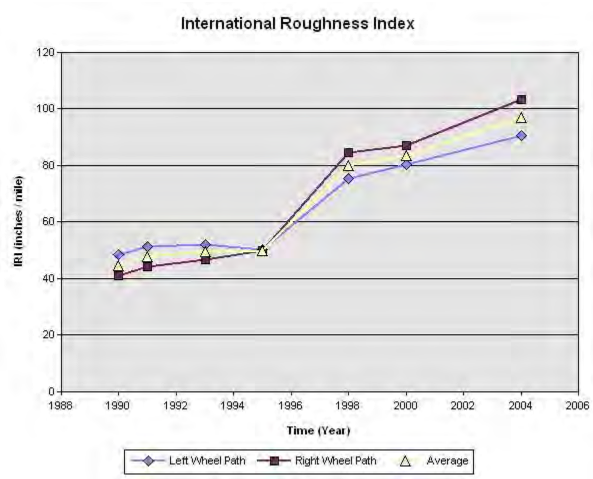


Figure 4.30: FWD and IRI - Section TXLT15006

Section TXLT15007

- District, County [Climatic Region]: San Antonio, Guadalupe [Dry-Warm]
- Highway: SH 123 (Lane: L1)
- Starting Coordinates & Elevation: 29.56°N, 97.94°W; 519 feet above MSL

Table 4.27: Structural Details for Section TXLT15007

Section	Layer	Const. Date	Layer Type	Details	Thickness
TXLT15007	6	10/21/1992	HMA Surface		1.6 in.
	5	10/1/1971			0.4 in.
	4				2.3 in.
	3		Base/Subbase		17.9 in.
	2				8 in.
	1		Subgrade	Clayey Soils	Semi-infinite

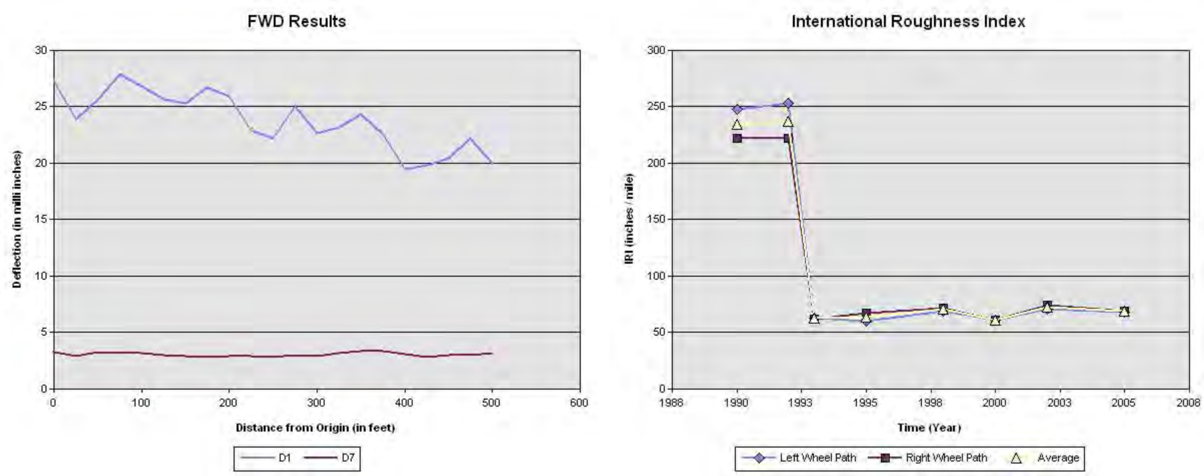


Figure 4.31: FWD and IRI - Section TXLT15007

Section TXLT17016

- District, County [Climatic Region]: Bryan, Robertson [Wet-Warm]
- Highway: SH 6 (Lane: L1)
- Starting Coordinates & Elevation: 30.73°N, 96.43°W; 331 feet above MSL

Table 4.28: Structural Details for Section TXLT17016

Section	Layer	Const. Date	Layer Type	Details	Thickness
TXLT17016	8	12/31/1999	HMA Surface		1.8 in.
	7				4.1 in.
	6				0.3 in.
	5	10/1/1991			1.7 in.
	4				6.8 in.
	3		Base/Subbase		13 in.
	2				6 in.
	1		Subgrade		Semi-infinite

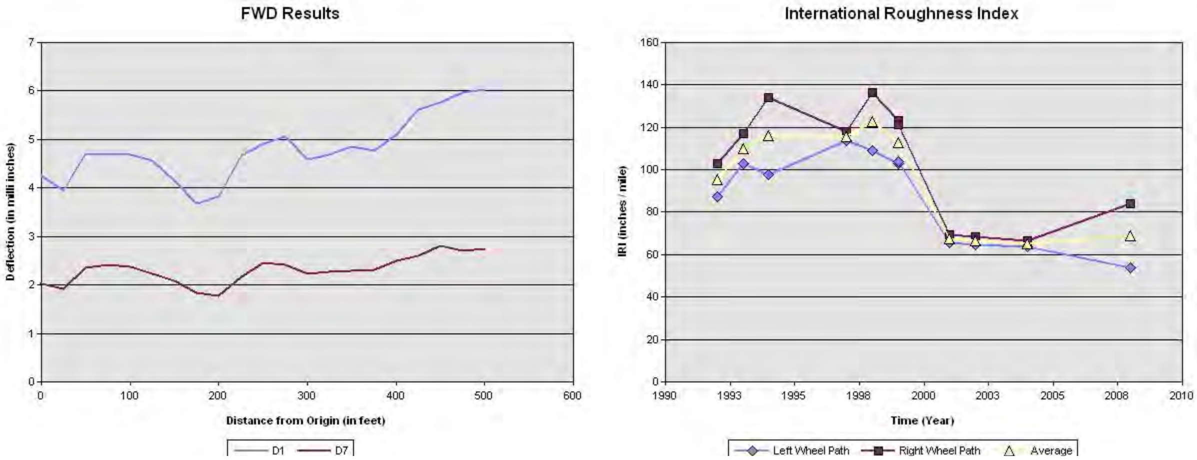


Figure 4.32: FWD and IRI - Section TXLT17016

Section TXLT17017

- District, County [Climatic Region]: Bryan, Brazos [Wet-Warm]
- Highway: FM 2223 (Lane: K1)
- Starting Coordinates & Elevation: 30.77°N, 96.38°W; 331 feet above MSL

Table 4.29: Structural Details for Section TXLT17017

Section	Layer	Const. Date	Layer Type	Details	Thickness
TXLT17017	5	7/1/1996	HMA Surface		2.5 in.
	4				2.5 in.
	3		Base/Subbase		8.5 in.
	2				10 in.
	1		Subgrade	Clayey Soils	Semi-infinite

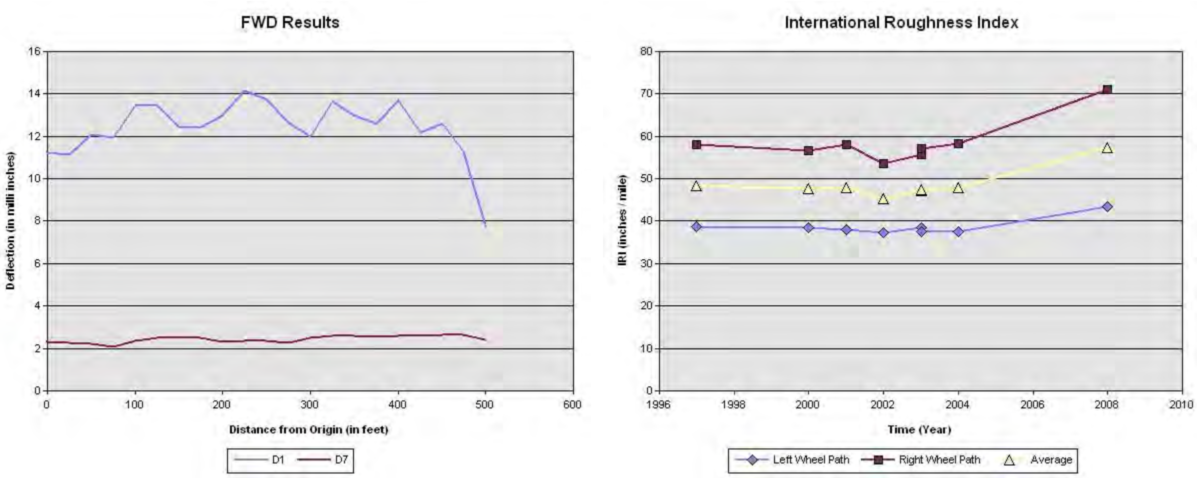


Figure 4.33: FWD and IRI - Section TXLT17017

Section TXLT17018

- District, County [Climatic Region]: Bryan, Brazos [Wet-Warm]
- Highway: FM 2223 (Lane: K1)
- Starting Coordinates & Elevation: 30.77°N, 96.38°W; 331 feet above MSL

Table 4.30: Structural Details for Section TXLT17018

Section	Layer	Const. Date	Layer Type	Details	Thickness
TXLT17018	5	7/1/1996	HMA Surface		2.5 in.
	4				5.5 in.
	3		Base/Subbase		10.7 in.
	2				10 in.
	1		Subgrade	Silty Soil	Semi-infinite

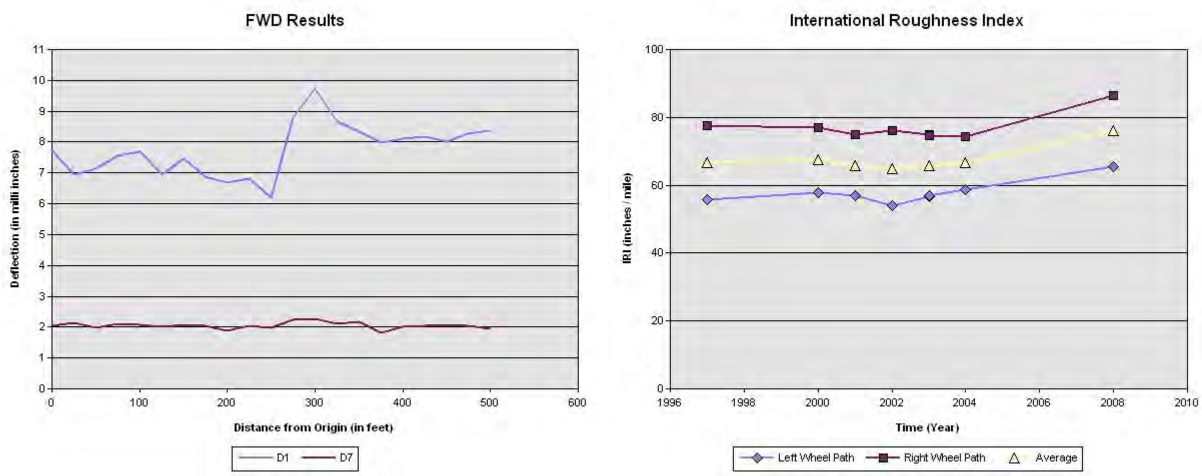


Figure 4.34: FWD and IRI - Section TXLT17018

Section TXLT18001

- District, County [Climatic Region]: Dallas, Kaufman [Wet-Cold]
- Highway: US 175 (Lane: R1)
- Starting Coordinates & Elevation: 32.62°N, 96.43°W; 425 feet above MSL

Table 4.31: Structural Details for Section TXLT18001

Section	Layer	Const. Date	Layer Type	Details	Thickness
TXLT18001	8	7/15/2003	HMA Surface		0.4 in.
	7				2 in.
	6				2 in.
	5	6/1/1977			1.7 in.
	4				7.8 in.
	3		Base/Subbase		15.2 in.
	2				6.5 in.
	1		Subgrade	Clayey Soils	Semi-infinite

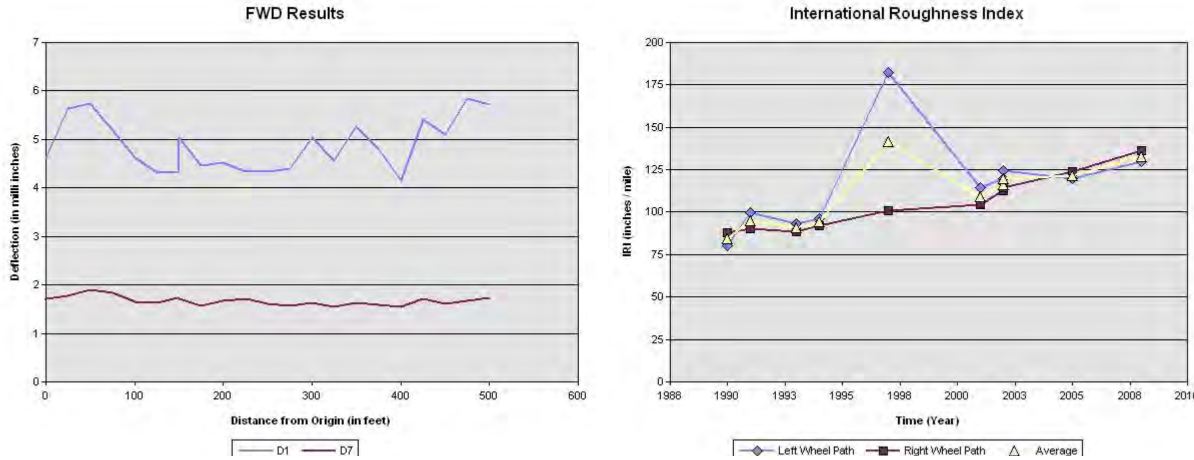


Figure 4.35: FWD and IRI - Section TXLT18001

Section TXLT18002

- District, County [Climatic Region]: Dallas, Kaufman [Wet-Cold]
- Highway: US 175 (Lane: R1)
- Starting Coordinates & Elevation: 32.6°N, 96.38°W; 429 feet above MSL

Table 4.32: Structural Details for Section TXLT18002

Section	Layer	Const. Date	Layer Type	Details	Thickness
TXLT18002	7	7/15/2003	HMA Surface		2 in.
	6				2 in.
	5	1/1/1987			1.2 in.
	4				9.3 in.
	3		Base/Subbase		13.5 in.
	2				10 in.
	1		Subgrade	Clayey Soils	Semi-infinite

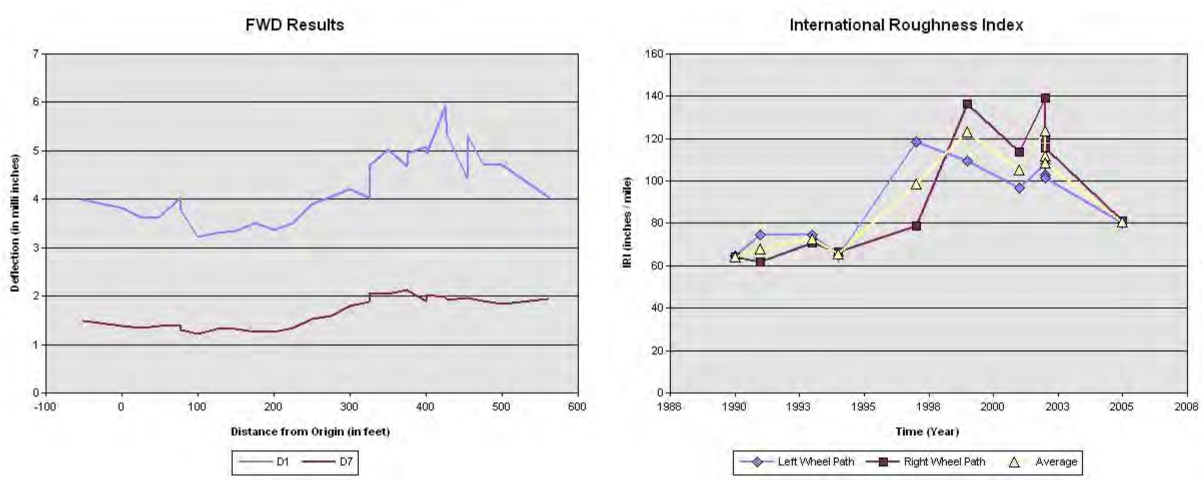


Figure 4.36: FWD and IRI - Section TXLT18002

Section TXLT18003

- District, County [Climatic Region]: Dallas, Ellis [Wet-Cold]
- Highway: US 287 (Lane: K6)
- Starting Coordinates & Elevation: 32.49°N, 96.82°W; 566 feet above MSL

Table 4.33: Structural Details for Section TXLT18003

Section	Layer	Const. Date	Layer Type	Details	Thickness
TXLT18003	8	7/15/2001	HMA Surface		0.2 in.
	7	8/2/1996			1.6 in.
	6	8/1/1996			0.3 in.
	5	6/1/1982			1.2 in.
	4				6.2 in.
	3		Base/Subbase		14 in.
	2				7.8 in.
	1		Subgrade	Clayey Soils	Semi-infinite

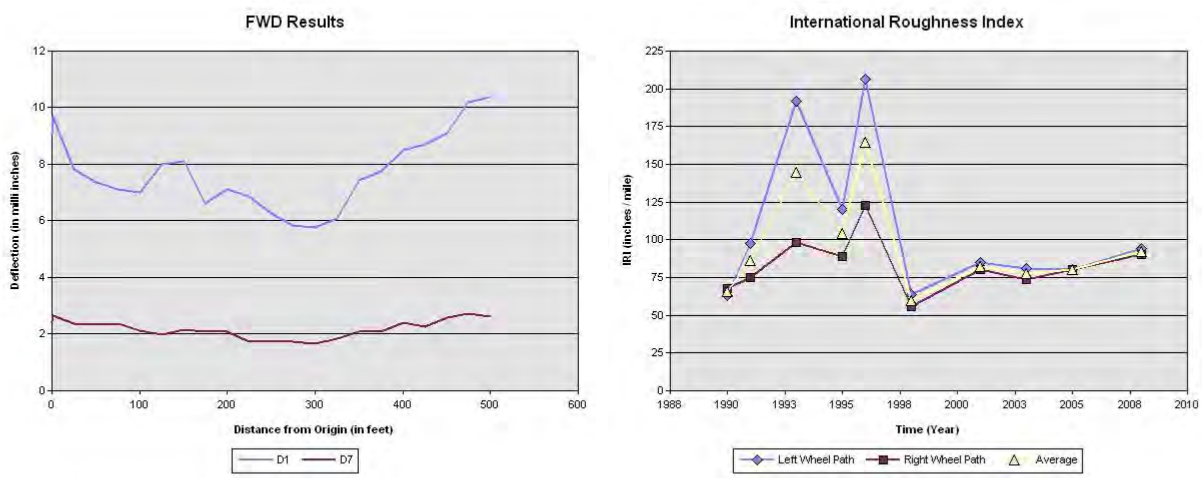


Figure 4.37: FWD and IRI - Section TXLT18003

Section TXLT21001

- District, County [Climatic Region]: Pharr, Kenedy [Dry-Warm]
- Highway: US 77 (Lane: L1)
- Starting Coordinates & Elevation: 26.98°N, 97.8°W; 36 feet above MSL

Table 4.34: Structural Details for Section TXLT21001

Section	Layer	Const. Date	Layer Type	Details	Thickness
TXLT21001	7	4/2/2001	HMA Surface		1 in.
	6	9/26/1994			0.2 in.
	5	5/1/1982			0.3 in.
	4				1.5 in.
	3		Base/Subbase		11.4 in.
	2				7.4 in.
	1		Subgrade		Semi-infinite

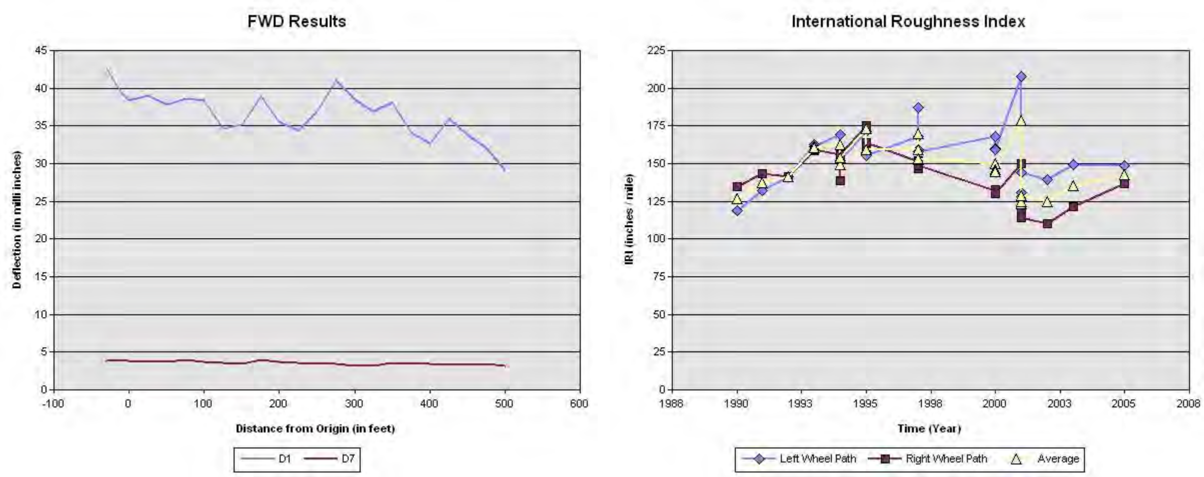


Figure 4.38: FWD and IRI - Section TXLT21001

Section TXLT21002

- District, County [Climatic Region]: Pharr, Hidalgo [Dry-Warm]
- Highway: US 281 (Lane: R1)
- Starting Coordinates & Elevation: 26.74°N, 98.11°W; 84 feet above MSL

Table 4.35: Structural Details for Section TXLT21002

Section	Layer	Const. Date	Layer Type	Details	Thickness
TXLT21002	6	4/29/2002	HMA Surface		0 in.
	5	7/1/1997			1.8 in.
	4				2.0 in.
	3		Base/Subbase		7.8 in.
	2				12 in.
	1		Subgrade		Semi-infinite

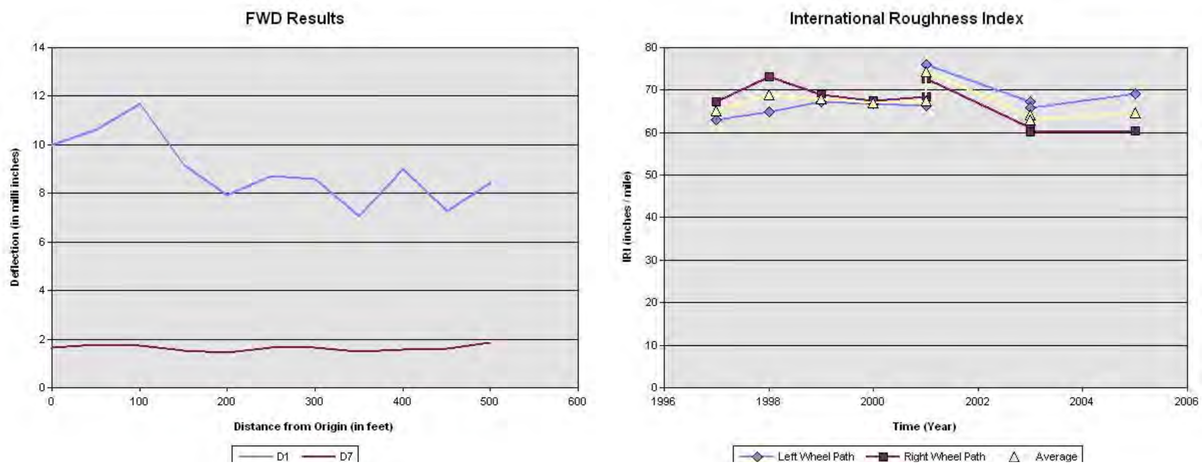


Figure 4.39: FWD and IRI - Section TXLT21002

Section TXLT21003

- District, County [Climatic Region]: Pharr, Hidalgo [Dry-Warm]
- Highway: US 281 (Lane: R1)
- Starting Coordinates & Elevation: 26.74°N, 98.11°W; 84 feet above MSL

Table 4.36: Structural Details for Section TXLT21003

Section	Layer	Const. Date	Layer Type	Details	Thickness
TXLT21003	6	4/29/2002	HMA Surface		0 in.
	5	7/1/1997			2.1 in.
	4				4.4 in.
	3		Base/Subbase		12.3 in.
	2				12 in.
	1		Subgrade		Semi-infinite

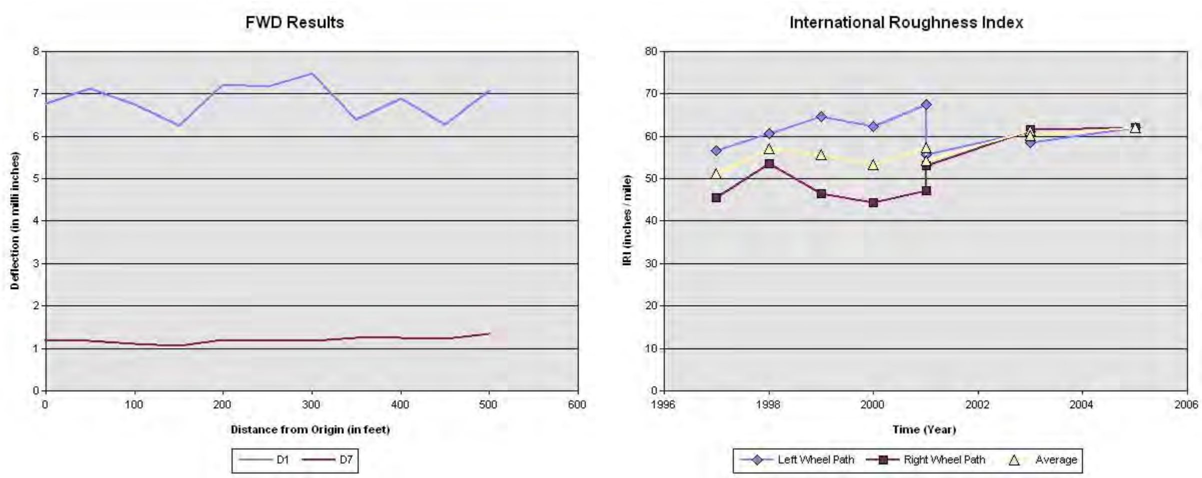


Figure 4.40: FWD and IRI - Section TXLT21003

Section TXLT21006

- District, County [Climatic Region]: Pharr, Hidalgo [Dry-Warm]
- Highway: US 281 (Lane: R1)
- Starting Coordinates & Elevation: 26.74°N, 98.11°W; 84 feet above MSL

Table 4.37: Structural Details for Section TXLT21006

Section	Layer	Const. Date	Layer Type	Details	Thickness
TXLT21006	7	4/29/2002	HMA Surface		0 in.
	6	7/1/1997			2.1 in.
	5				6 in.
	4				4.2 in.
	3		Base/Subbase		2.6 in.
	2				12 in.
	1		Subgrade		Semi-infinite

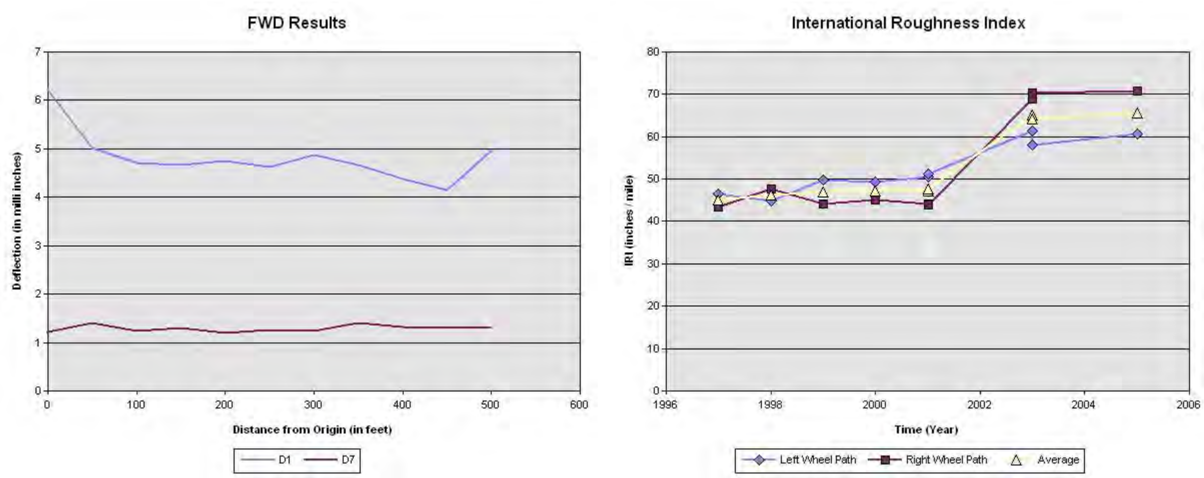


Figure 4.41: FWD and IRI - Section TXLT21006

Section TXLT21007

- District, County [Climatic Region]: Pharr, Hidalgo [Dry-Warm]
- Highway: US 281 (Lane: R1)
- Starting Coordinates & Elevation: 26.74°N, 98.11°W; 84 feet above MSL

Table 4.38: Structural Details for Section TXLT21007

Section	Layer	Const. Date	Layer Type	Details	Thickness
TXLT21007	7	4/29/2002	HMA Surface		0 in.
	6	7/1/1997			2.3 in.
	5				2.3 in.
	4				9.2 in.
	3		Base/Subbase		1.7 in.
	2				12 in.
	1		Subgrade		Semi-infinite

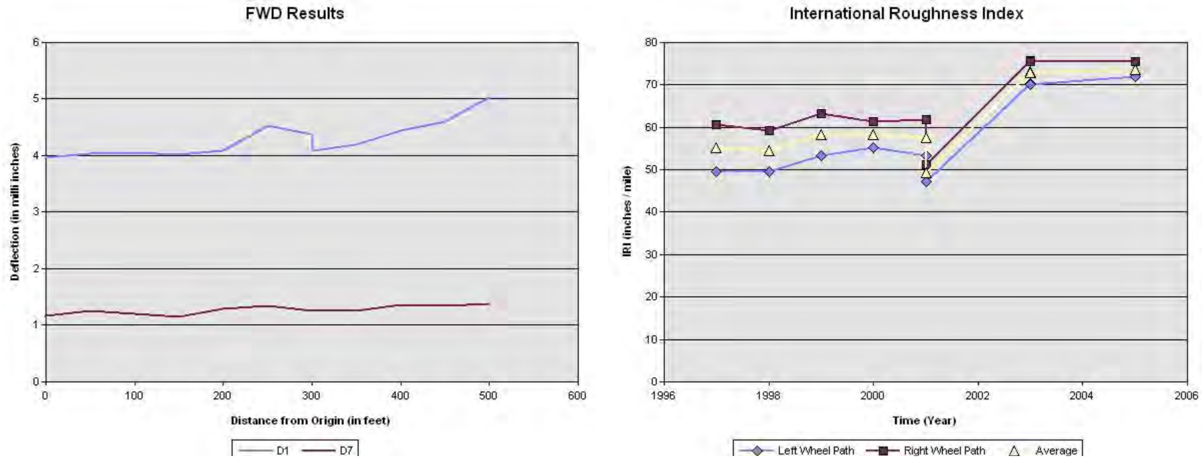


Figure 4.42: FWD and IRI - Section TXLT21007

Section TXLT21009

- District, County [Climatic Region]: Pharr, Hidalgo [Dry-Warm]
- Highway: US 281 (Lane: R1)
- Starting Coordinates & Elevation: 26.74°N, 98.11°W; 84 feet above MSL

Table 4.39: Structural Details for Section TXLT21009

Section	Layer	Const. Date	Layer Type	Details	Thickness
TXLT21009	8	4/29/2002	HMA Surface		0 in.
	7	7/1/1997			2 in.
	6				2.4 in.
	5		Base/Subbase		4 in.
	4		Surface Treatment		0.1 in.
	3		Base/Subbase		7.4 in.
	2				12 in.
	1		Subgrade		Semi-infinite

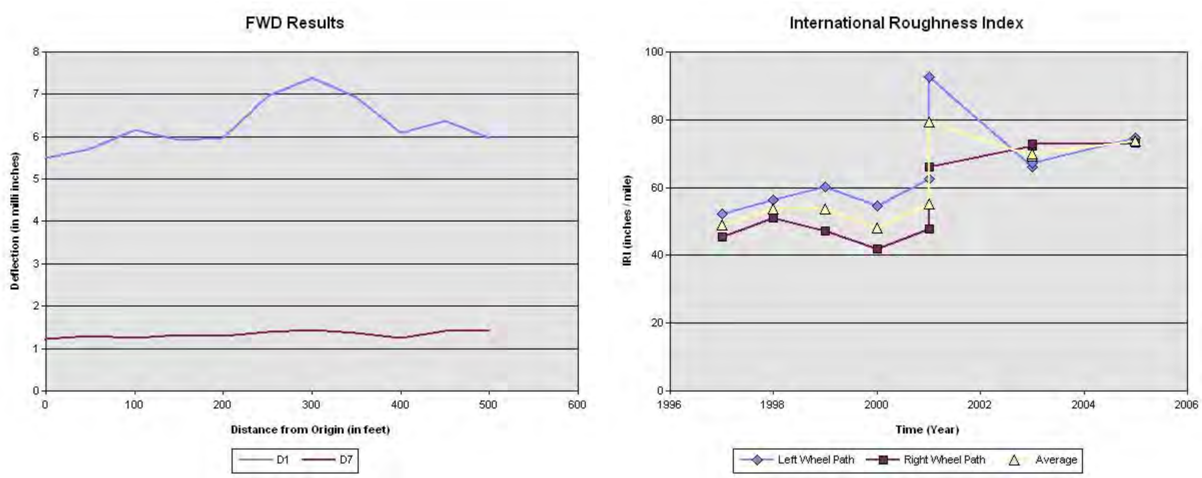


Figure 4.43: FWD and IRI - Section TXLT21009

Section TXLT21015

- District, County [Climatic Region]: Pharr, Hidalgo [Dry-Warm]
- Highway: US 281 (Lane: R1)
- Starting Coordinates & Elevation: 26.74°N, 98.11°W; 84 feet above MSL

Table 4.40: Structural Details for Section TXLT21015

Section	Layer	Const. Date	Layer Type	Details	Thickness
TXLT21015	6	4/29/2002	HMA Surface		0 in.
	5	7/1/1997			2.2 in.
	4				2.1 in.
	3		Base/Subbase		8.3 in.
	2				12 in.
	1		Subgrade		Semi-infinite

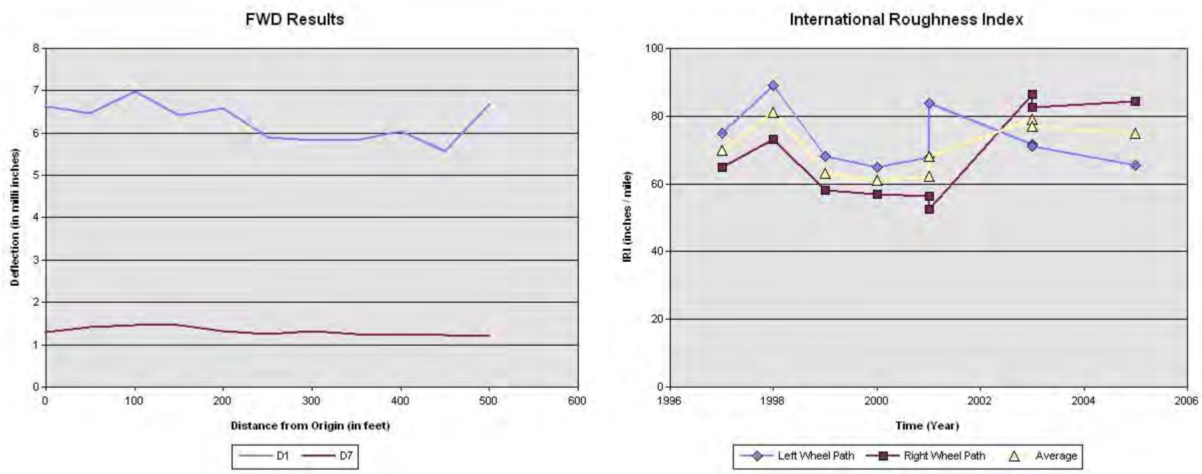


Figure 4.44: FWD and IRI - Section TXLT21015

Section TXLT23001

- District, County [Climatic Region]: Brownwood, Mills [Mixed]
- Highway: US 84 (Lane: K6)
- Starting Coordinates & Elevation: 31.57°N, 98.67°W; 1473 feet above MSL

Table 4.41: Structural Details for Section TXLT23001

Section	Layer	Const. Date	Layer Type	Details	Thickness
TXLT23001	7	7/7/2003	HMA Surface		0 in.
	6	5/18/2001			0.5 in.
	5	7/1/1969			0.3 in.
	4				1.9 in.
	3		Base/Subbase		7.5 in.
	2				10 in.
	1		Subgrade	Silty Soils	Semi-infinite

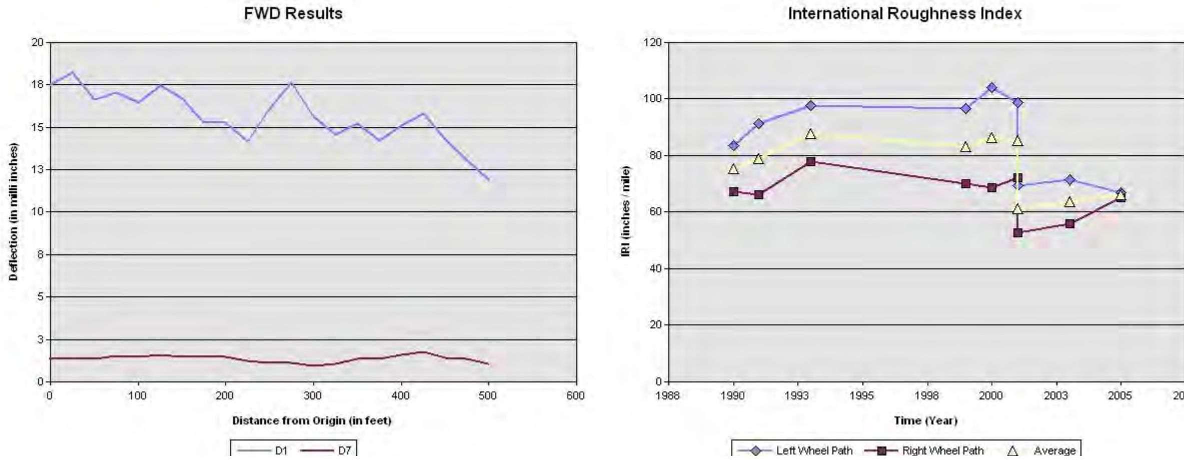


Figure 4.45: FWD and IRI - Section TXLT23001

Section TXLT23002

- District, County [Climatic Region]: Brownwood, Mills [Mixed]
- Highway: US 84 (Lane: K6)
- Starting Coordinates & Elevation: 31.57°N, 98.67°W; 1473 feet above MSL

Table 4.42: Structural Details for Section TXLT23002

Section	Layer	Const. Date	Layer Type	Details	Thickness
TXLT23002	6	9/25/1990	HMA Surface	Asphalt Concrete	0.9 in.
	5	1/1/1987	Surface Treatment		0.3 in.
	4		HMA Surface		1.9 in.
	3		Base/Subbase		7.5 in.
	2				10 in.
	1		Subgrade	Silty Soils	Semi-infinite

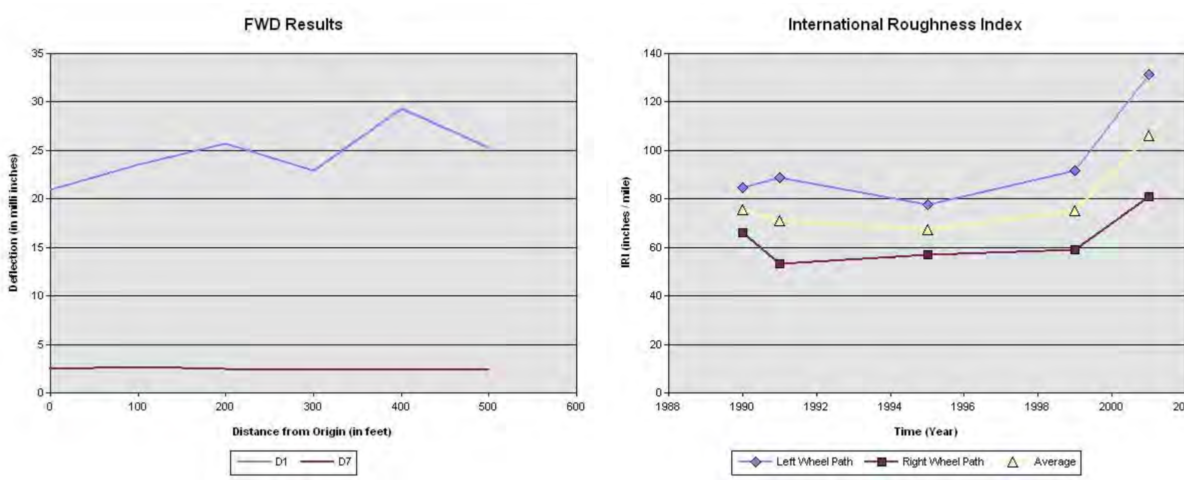


Figure 4.46: FWD and IRI - Section TXLT23002

Section TXLT23003

- District, County [Climatic Region]: Brownwood, Mills [Mixed]
- Highway: US 84 (Lane: K6)
- Starting Coordinates & Elevation: 31.57°N, 98.67°W; 1473 feet above MSL

Table 4.43: Structural Details for Section TXLT23003

Section	Layer	Const. Date	Layer Type	Details	Thickness
TXLT23003	6	9/24/1990	Surface Treatment	Asphalt Concrete	0.1 in.
	5	1/1/1987			0.4 in.
	4		HMA Surface		1.9 in.
	3		Base/Subbase		7.5 in.
	2				10 in.
	1		Subgrade	Silty Soils	Semi-infinite

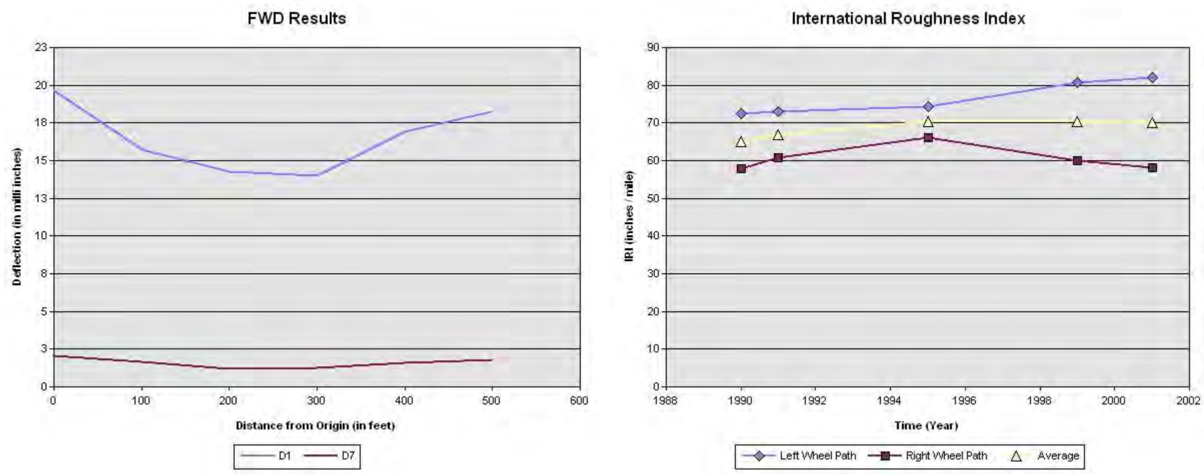


Figure 4.47: FWD and IRI - Section TXLT23003

Section TXLT23004

- District, County [Climatic Region]: Brownwood, Mills [Mixed]
- Highway: US 84 (Lane: K6)
- Starting Coordinates & Elevation: 31.57°N, 98.67°W; 1473 feet above MSL

Table 4.44: Structural Details for Section TXLT23004

Section	Layer	Const. Date	Layer Type	Details	Thickness
TXLT23004	5	1/1/1987	Surface Treatment	Asphalt Concrete	0.4 in.
	4		HMA Surface		1.7 in.
	3		Base/Subbase		7.5 in.
	2				10 in.
	1		Subgrade	Silty Soils	Semi-infinite

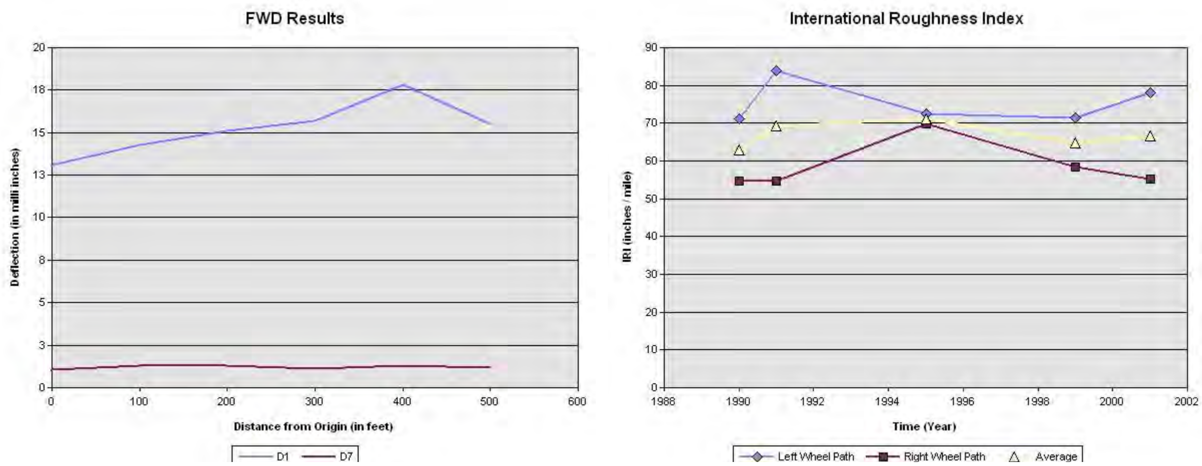


Figure 4.48: FWD and IRI - Section TXLT23004

Section TXLT23005

- District, County [Climatic Region]: Brownwood, Mills [Mixed]
- Highway: US 84 (Lane: K6)
- Starting Coordinates & Elevation: 31.57°N, 98.67°W; 1473 feet above MSL

Table 4.45: Structural Details for Section TXLT23005

Section	Layer	Const. Date	Layer Type	Details	Thickness
TXLT23005	5	1/1/1987	Surface Treatment	Asphalt Concrete	0.4 in.
	4		HMA Surface		1.6 in.
	3		Base/Subbase		7.5 in.
	2				10 in.
	1		Subgrade	Silty Soils	Semi-infinite

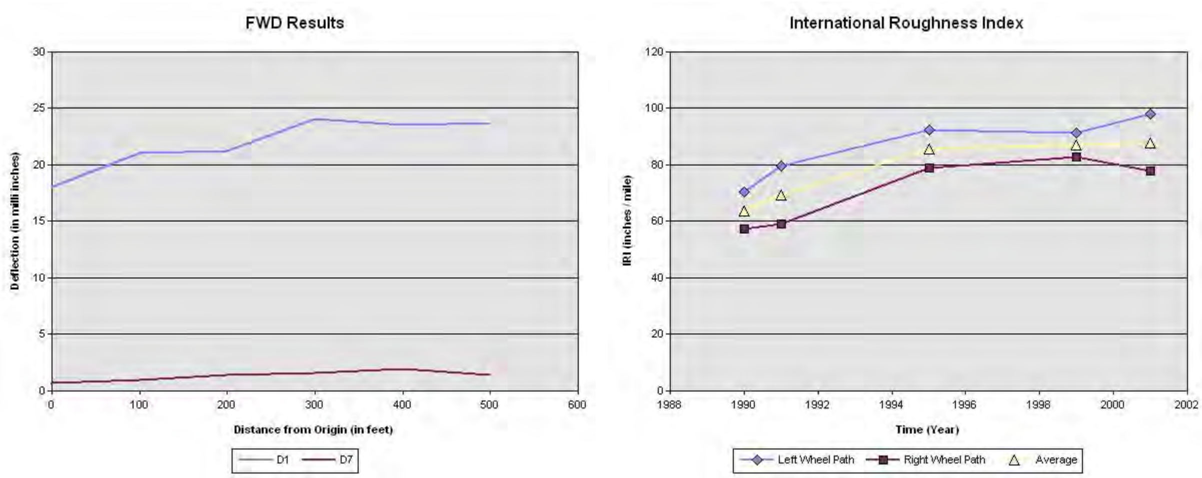


Figure 4.49: FWD and IRI - Section TXLT23005

Section TXLT24042

- District, County [Climatic Region]: El Paso, El Paso [Dry-Warm]
- Highway: US 62 (Lane: R1)
- Starting Coordinates & Elevation: 31.8°N, 106.26°W; 3991 feet above MSL

Table 4.46: Structural Details for Section TXLT24042

Section	Layer	Const. Date	Layer Type	Details	Thickness
TXLT24042	5	5/1/2003	HMA Surface		1.8 in.
	4	6/1/1976			0.4 in.
	3				2 in.
	2		Base/Subbase		8.4 in.
	1		Subgrade	Silty or Clayey Gravel and Sand	Semi-infinite

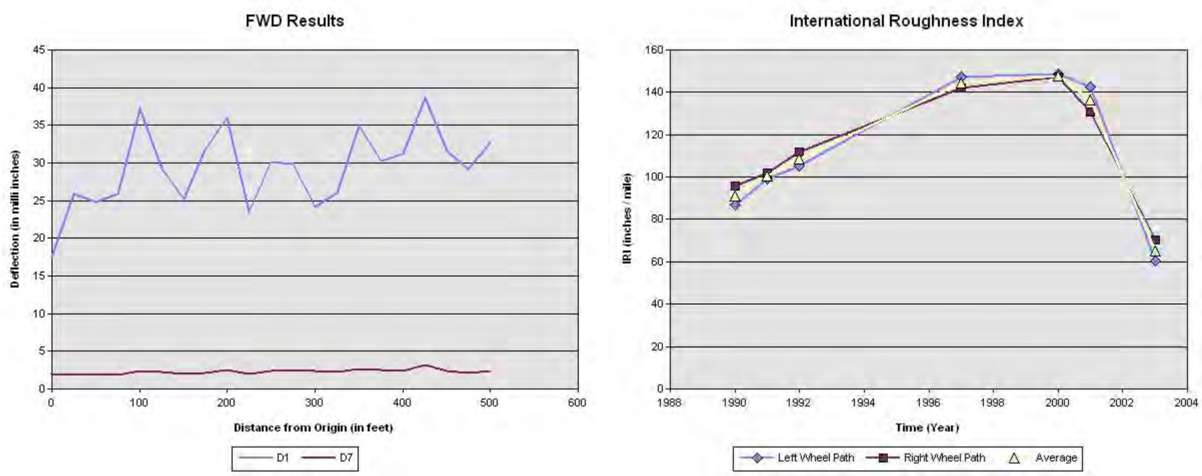


Figure 4.50: FWD and IRI - Section TXLT24042

Section TXLT24043

- District, County [Climatic Region]: El Paso, El Paso [Dry-Warm]
- Highway: US 62 (Lane: R1)
- Starting Coordinates & Elevation: 31.8°N, 106.26°W; 3991 feet above MSL

Table 4.47: Structural Details for Section TXLT24043

Section	Layer	Const. Date	Layer Type	Details	Thickness
TXLT24043	5	4/15/1991	HMA Surface	Asphalt Concrete	1 in.
	4	1/1/1987	Surface Treatment		0.4 in.
	3		HMA Surface		1.7 in.
	2		Base/Subbase	Crushed Stone	8.4 in.
	1		Subgrade	Silty Sand	Semi-infinite

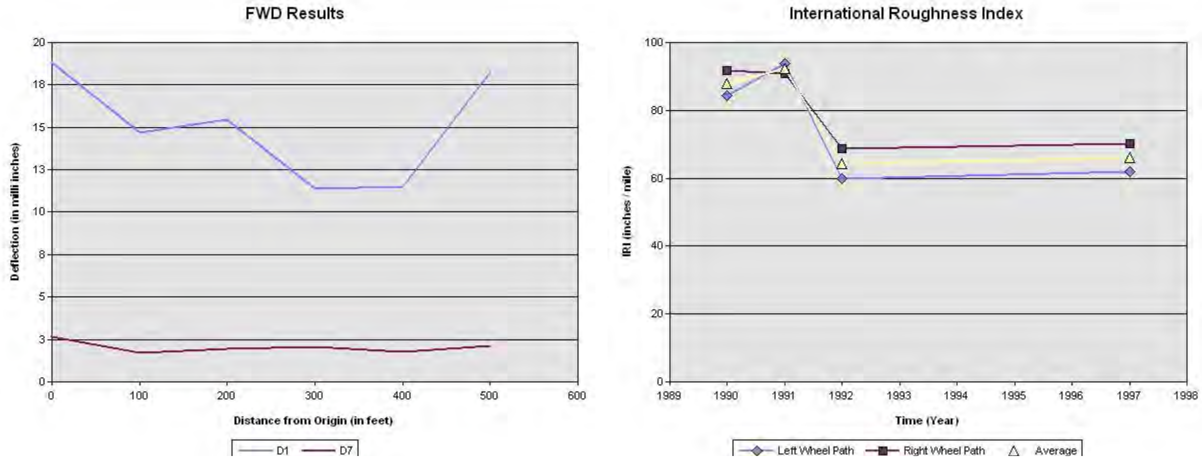


Figure 4.51: FWD and IRI - Section TXLT24043

Section TXLT24044

- District, County [Climatic Region]: El Paso, El Paso [Dry-Warm]
- Highway: US 62 (Lane: R1)
- Starting Coordinates & Elevation: 31.8°N, 106.26°W; 3991 feet above MSL

Table 4.48: Structural Details for Section TXLT24044

Section	Layer	Const. Date	Layer Type	Details	Thickness
TXLT24044	5	9/19/1990	Surface Treatment	Asphalt Concrete	0.1 in.
	4	1/1/1987			0.4 in.
	3		HMA Surface		1.8 in.
	2		Base/Subbase	Crushed Stone	8.4 in.
	1		Subgrade	Silty Sand	Semi-infinite

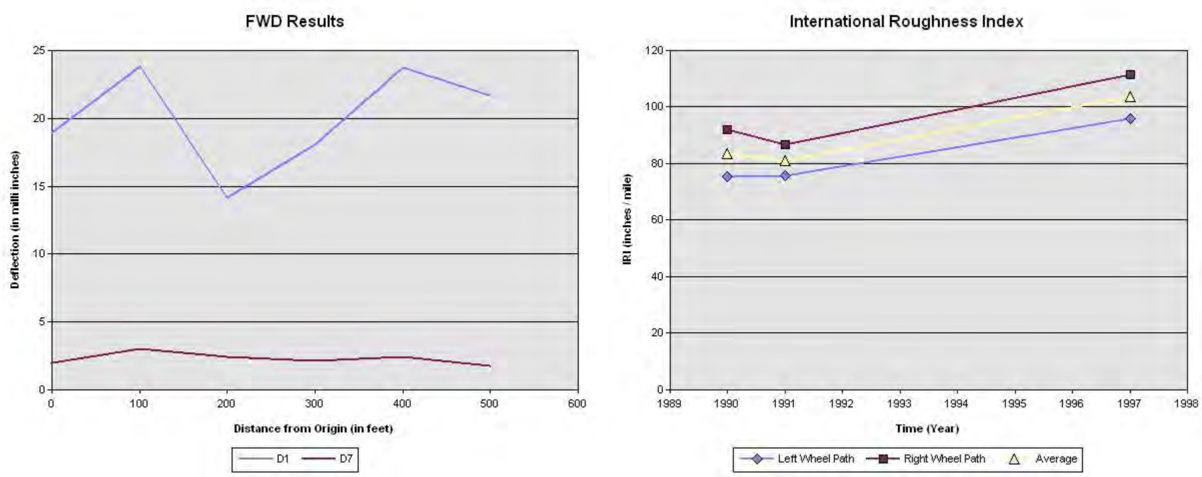


Figure 4.52: FWD and IRI - Section TXLT24044

Section TXLT24045

- District, County [Climatic Region]: El Paso, El Paso [Dry-Warm]
- Highway: US 62 (Lane: R1)
- Starting Coordinates & Elevation: 31.8°N, 106.26°W; 3991 feet above MSL

Table 4.49: Structural Details for Section TXLT24045

Section	Layer	Const. Date	Layer Type	Details	Thickness
TXLT24045	4	1/1/1987	Surface Treatment	Asphalt Concrete	0.3 in.
	3		HMA Surface		1.7 in.
	2		Base/Subbase	Crushed Stone	8.4 in.
	1		Subgrade	Silty Sand	Semi-infinite

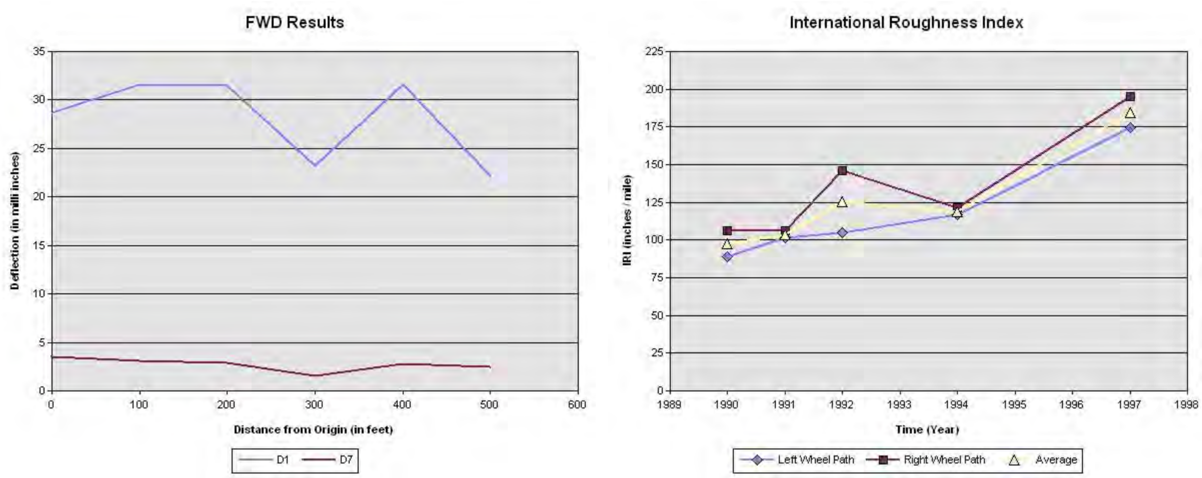


Figure 4.53: FWD and IRI - Section TXLT24045

4.5 Selection of TxDOT Recommended Sections for the Flexible Pavement Database

The selection of the pavement sections was the first step before the data collection process. It was initiated by asking District personnel to nominate flexible pavement sections recently constructed or rehabilitated that belonged to any one of the three pavement categories (HMA on top of HMA base, HMA on top of flexbase, and single course surface treatment on top of flexbase) considered in the experimental design. This was followed by the list of sections received directly from four different districts, namely Bryan, Waco, Tyler, and El Paso. The list of sections was also accompanied by the construction plan and the alignment of the newly built project. The selection of the pavement section from that project was done by the researchers. The decision on the probable pavement section was made after evaluating the road condition, road foundation, alignment of the road and visibility of the chosen section. The factors taken into consideration in coming to this decision were as follows:

- Horizontal alignment of the road and presence of sharp/abrupt turns
- Vertical alignment of the road and presence of sharp valley or summit curves
- Presence of any hydraulic structures like culverts, aqueducts, or viaducts

- Presence or nearness of any road intersection
- Presence of bridges within the section
- Presence of any entry or exit ramps within the section

All these factors were considered to be important from a safe and smooth traffic operation standpoint because some of the pavement tests will need proper traffic control measures to be enforced. Furthermore, sections with extensive fills or cuts were avoided. The initial data collection effort was started on a much larger scale (almost around 100 sections), later narrowed down to a smaller number (41 Texas sections) after paying due attention to the initial experimental plan.

Although no construction dates have been incorporated into the database for TxDOT-recommended sections, it is believed that this information could be obtained by contacting the Districts involved. Construction date is of outmost importance for pavement design and performance so only those sections for which the construction date is available will be kept in the final Texas Flexible Pavement Database.

The volume of data uploaded in the Texas Flexible Pavement Database can be broadly classified into two categories in terms of the source of information. One half of the database contains the LTPP test sections mostly adapted from the LTPP Standard Data Release Version 21 (SDR21). Data collection effort for the other half, containing the Texas road sections, was performed by the research team. In the following section, a summary of the information for each Texas section included in the Texas Flexible Pavement Database will be given.

4.6 Summary of Section-wise Information on Texas Flexible Pavement Sections

The following section gives a brief summary of each of the TxDOT recommended pavement sections included in the Texas Flexible Pavement Database. The summary of the section includes its District, County, and Location Coordinates. This is followed by the structural design, deflection data for sensors D1 and D7 (Tables 4.50–4.90) obtained from FWD testing on the pavement section and finally the IRI for the left and right wheel paths (Figures 4.54–4.94) as a measure of the condition of the pavement over time. For all other information on any specific pavement section, refer to the web interface: http://pavements.ce.utexas.edu/.

Section TXTF09001

- District, County [Climatic Region]: Waco, Bell [Mixed]
- Highway: SH 195 (Lane: R1)
- Starting Coordinates: 31.02°N, 97.75°W
- Ending Coordinates: 31.01°N, 97.75°W

Table 4.50: Structural Details for Section TXTF09001

Section	Layer	Const. Date	Layer Type	Details	Thickness
TXTF09001	5		HMA Surface	Type C	2 in.
	4			Type B	5 in.
	3		Surface Treatment	CST	0 in.
	2		Base/Subbase	Flexbase	7.5 in.
	1		Subgrade	Lime Treated	Semi-infinite

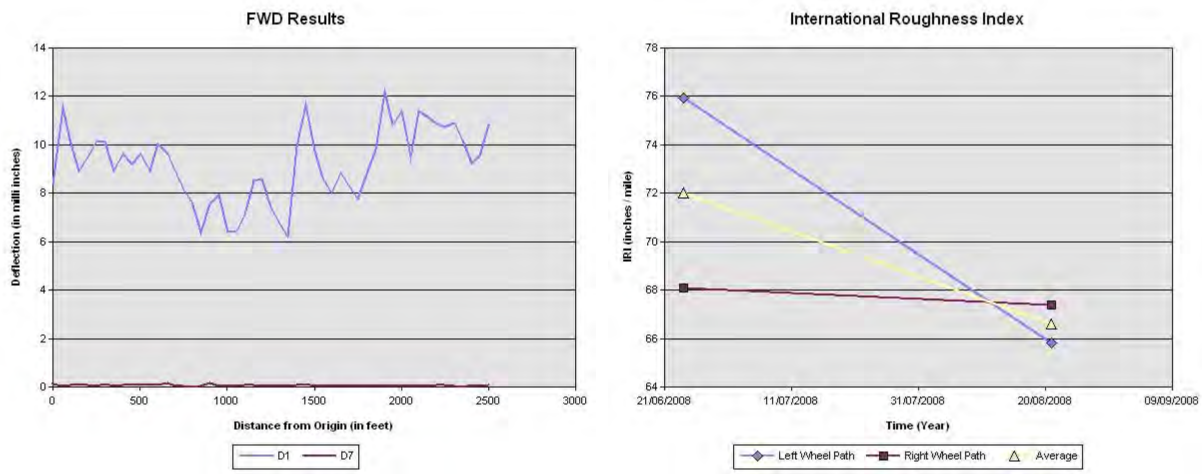


Figure 4.54: FWD and IRI - Section TXTF09001

Section TXTF09002

- District, County [Climatic Region]: Waco, Bell [Mixed]
- Highway: SH 195 (Lane: R2)
- Starting Coordinates: 31.02°N, 97.75°W
- Ending Coordinates: 31.01°N, 97.75°W

Table 4.51: Structural Details for Section TXTF09002

Section	Layer	Const. Date	Layer Type	Details	Thickness
TXTF09002	5		HMA Surface	Type C	2 in.
	4			Type B	5 in.
	3		Surface Treatment	CST	0 in.
	2		Base/Subbase	Flexbase	7.5 in.
	1		Subgrade	Lime Treated	Semi-infinite

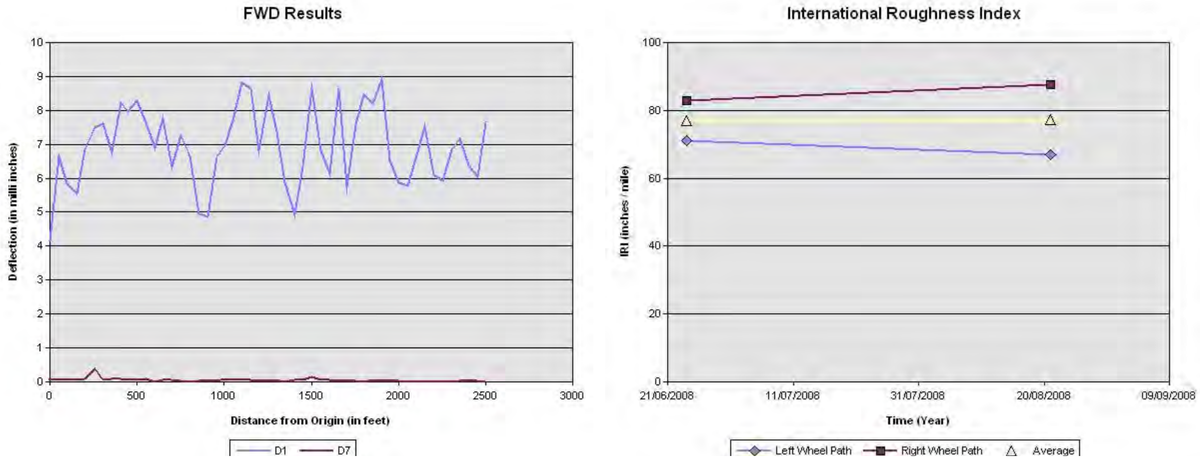


Figure 4.55: FWD and IRI - Section TXTF09002

Section TXTF09003

- District, County [Climatic Region]: Waco, Bell [Mixed]
- Highway: SH 195 (Lane: L1)
- Starting Coordinates: 31.03°N, 97.76°W
- Ending Coordinates: 31.04°N, 97.76°W

Table 4.52: Structural Details for Section TXTF09003

Section	Layer	Const. Date	Layer Type	Details	Thickness
TXTF09003	5		HMA Surface	Type C	2 in.
	4			Type B	5 in.
	3		Surface Treatment	CST	0 in.
	2		Base/Subbase	Flexbase	7.5 in.
	1		Subgrade	Lime Treated	Semi-infinite

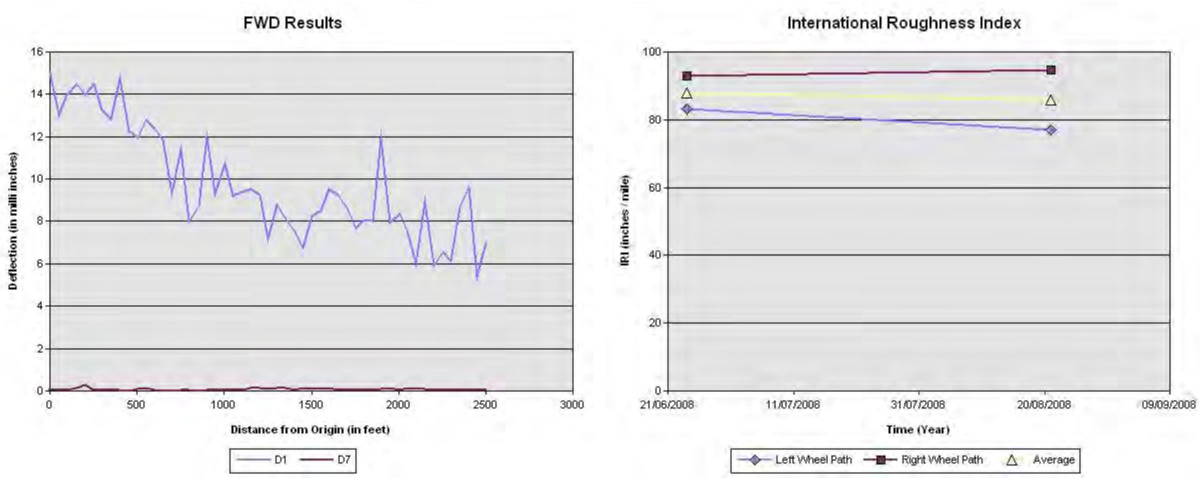


Figure 4.56: FWD and IRI - Section TXTF09003

Section TXTF09004

- District, County [Climatic Region]: Waco, Bell [Mixed]
- Highway: SH 195 (Lane: L2)
- Starting Coordinates: 31.03°N, 97.76°W
- Ending Coordinates: 31.04°N, 97.76°W

Table 4.53: Structural Details for Section TXTF09004

Section	Layer	Const. Date	Layer Type	Details	Thickness
TXTF09004	5		HMA Surface	Type C	2 in.
	4			Type B	5 in.
	3		Surface Treatment	CST	0 in.
	2		Base/Subbase	Flexbase	7.5 in.
	1		Subgrade	Lime Treated	Semi-infinite

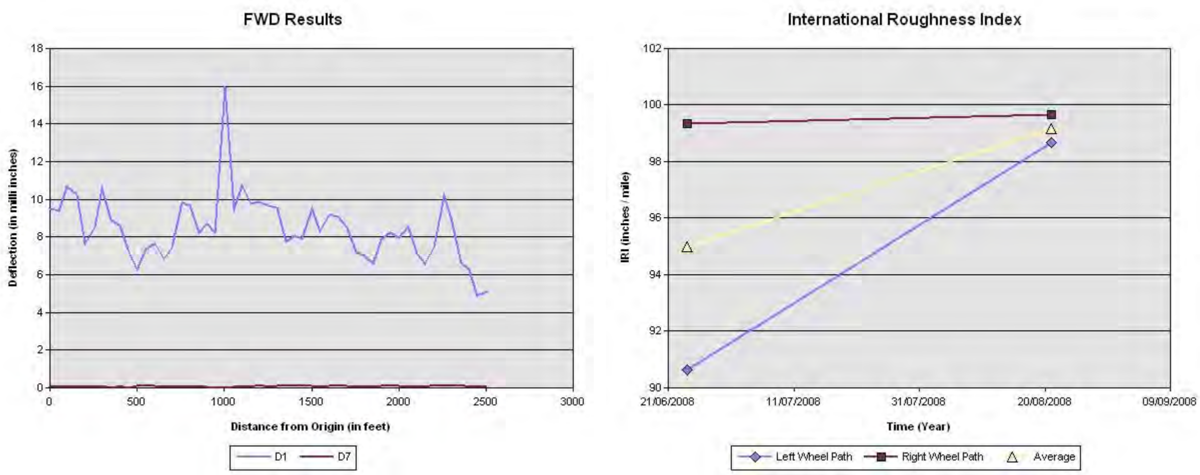


Figure 4.57: FWD and IRI - Section TXTF09004

Section TXTF09007

- District, County [Climatic Region]: Waco, Falls [Mixed]
- Highway: SH 6 (Lane: R1)
- Starting Coordinates: 31.29°N, 96.87°W
- Ending Coordinates: 31.29°N, 96.87°W

Table 4.54: Structural Details for Section TXTF09007

Section	Layer	Const. Date	Layer Type	Details	Thickness
TXTF09007	6		HMA Surface	SMA D	2 in.
	5			Type C	2 in.
	4			Type B	3 in.
	3		Surface Treatment	CST	0 in.
	2		Base/Subbase	Flexbase	15 in.
	1		Subgrade	Lime Treated	Semi-infinite

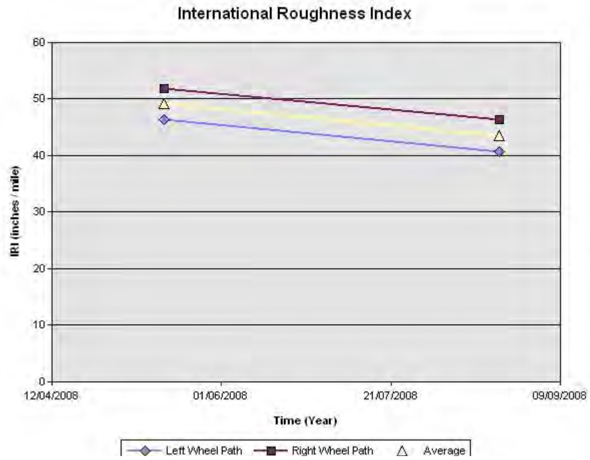


Figure 4.58: IRI - Section TXTF09007

Section TXTF09008

- District, County [Climatic Region]: Waco, Falls [Mixed]
- Highway: SH 6 (Lane: R2)
- Starting Coordinates: 31.29°N, 96.87°W
- Ending Coordinates: 31.29°N, 96.87°W

Table 4.55: Structural Details for Section TXTF09008

Section	Layer	Const. Date	Layer Type	Details	Thickness
TXTF09008	6		HMA Surface	SMA D	2 in.
	5			Type C	2 in.
	4			Type B	3 in.
	3		Surface Treatment	CST	0 in.
	2		Base/Subbase	Flexbase	15 in.
	1		Subgrade	Lime Treated	Semi-infinite

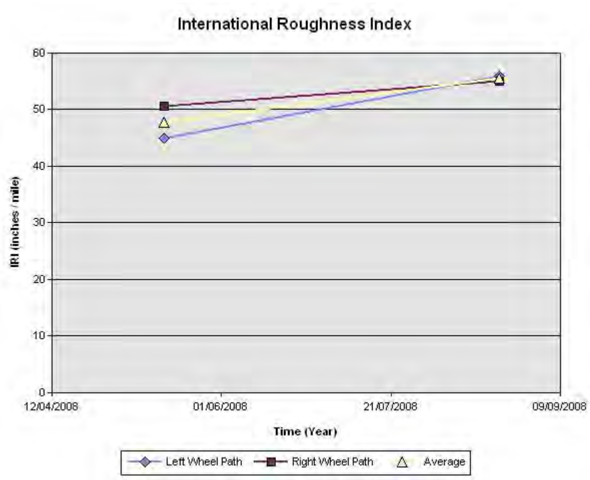


Figure 4.59: IRI - Section TXTF09008

Section TXTF09009

- District, County [Climatic Region]: Waco, Hill [Mixed]
- Highway: FM 1304 (Lane: K1)
- Starting Coordinates: 31.89°N, 97.11°W
- Ending Coordinates: 31.89°N, 97.1°W

Table 4.56: Structural Details for Section TXTF09009

Section	Layer	Const. Date	Layer Type	Details	Thickness
TXTF09009	5		HMA Surface	Type D	1 in.
	4		Surface Treatment	CST	0 in.
	3				0 in.
	2		Base/Subbase	Flexbase	12 in.
	1		Subgrade		Semi-infinite

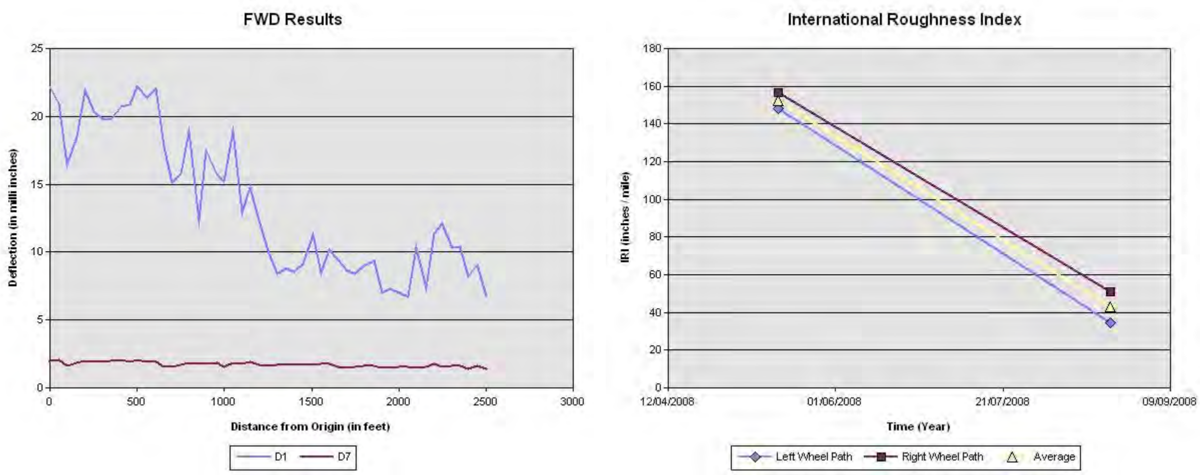


Figure 4.60: FWD and IRI - Section TXTF09009

Section TXTF09010

- District, County [Climatic Region]: Waco, Hill [Mixed]
- Highway: FM 1304 (Lane: K6)
- Starting Coordinates: 31.89°N, 97.10°W
- Ending Coordinates: 31.89°N, 97.11°W

Table 4.57: Structural Details for Section TXTF09010

Section	Layer	Const. Date	Layer Type	Details	Thickness
TXTF09010	5		HMA Surface	Type D	1 in.
	4		Surface Treatment	CST	0 in.
	3			CST	0 in.
	2		Base/Subbase	Flexbase	12 in.
	1		Subgrade		Semi-infinite

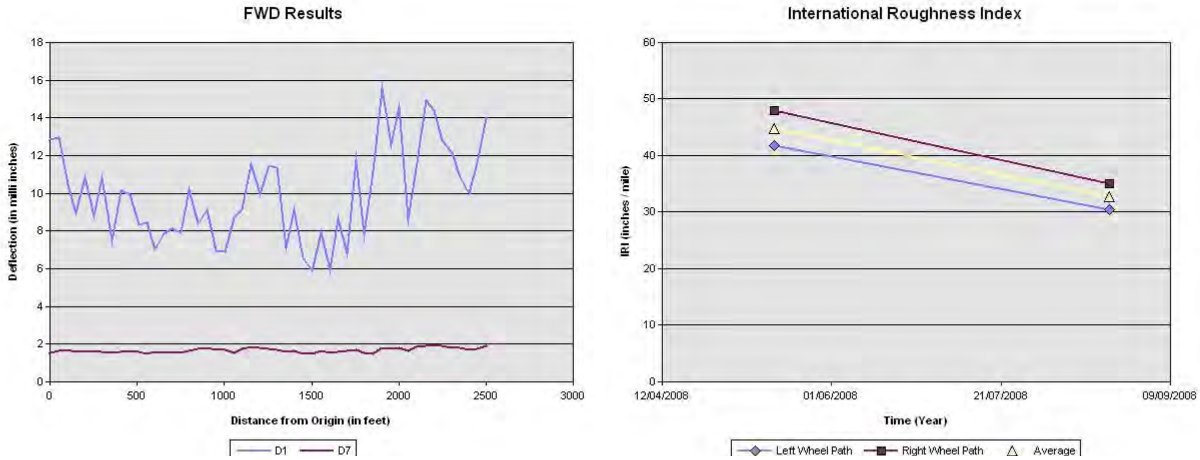


Figure 4.61: FWD and IRI - Section TXTF09010

Section TXTF09011

- District, County [Climatic Region]: Waco, McLennan [Mixed]
- Highway: SH 6 (Lane: R1)
- Starting Coordinates: 31.46°N, 96.92°W
- Ending Coordinates: 31.45°N, 96.92°W

Table 4.58: Structural Details for Section TXTF09011

Section	Layer	Const. Date	Layer Type	Details	Thickness
TXTF09011	4		Surface Treatment	Chip Seal AC-20 – 5TR	0 in.
	3			Tack Coat PG64-22	0 in.
	2		Base/Subbase	Flexbase	12 in.
	1		Subgrade		Semi-infinite

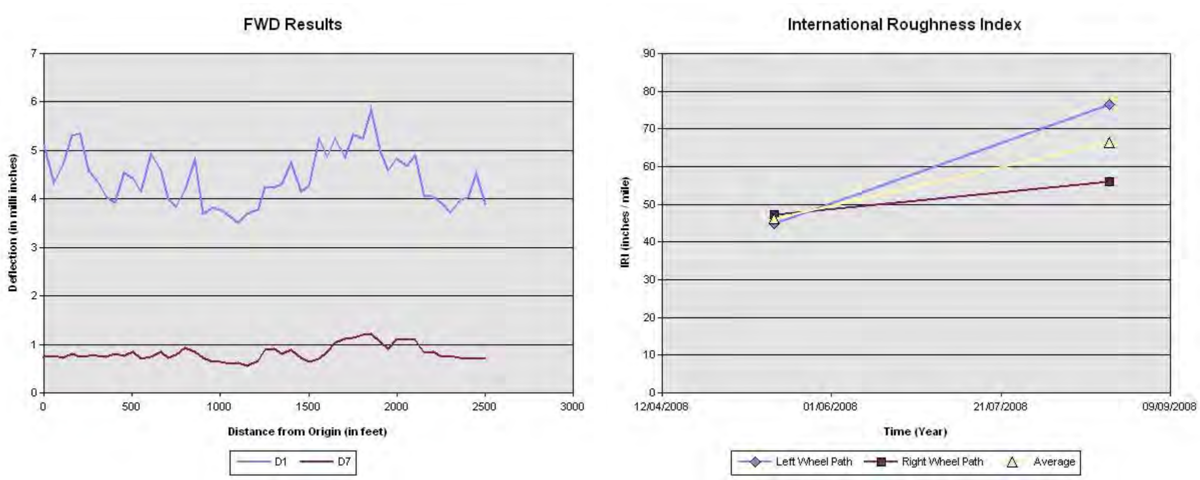


Figure 4.62: FWD and IRI - Section TXTF09011

Section TXTF09012

- District, County [Climatic Region]: Waco, McLennan [Mixed]
- Highway: SH 6 (Lane: R2)
- Starting Coordinates: 31.46°N, 96.92°W
- Ending Coordinates: 31.45°N, 96.92°W

Table 4.59: Structural Details for Section TXTF09012

Section	Layer	Const. Date	Layer Type	Details	Thickness
TXTF09012	5		Surface Treatment	Chip Seal AC-20 – 5TR	0 in.
	4			Tack Coat PG64-22	0 in.
	3		HMA Surface	HMA	0 in.
	2		Base/Subbase	Flexbase	12 in.
	1		Subgrade		Semi-infinite

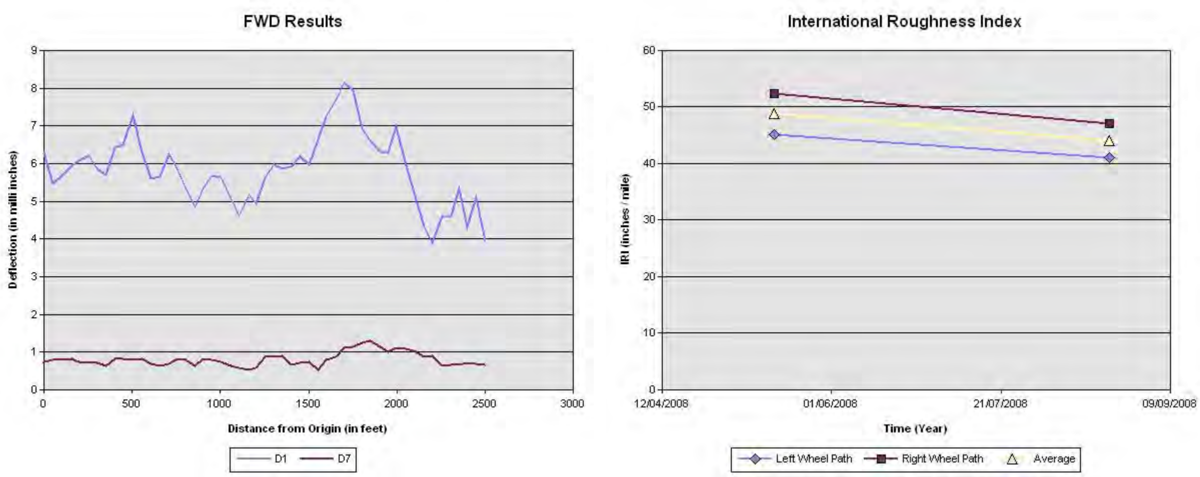


Figure 4.63: FWD and IRI - Section TXTF09012

Section TXTF09013

- District, County [Climatic Region]: Waco, McLennan [Mixed]
- Highway: US 77 (Lane: R1)
- Starting Coordinates: 31.45°N, 97.11°W
- Ending Coordinates: 31.44°N, 97.11°W

Table 4.60: Structural Details for Section TXTF09013

Section	Layer	Const. Date	Layer Type	Details	Thickness
TXTF09013	4		HMA Surface	Type C	2 in.
	3		Surface Treatment	CST	0 in.
	2		Base/Subbase	Flexbase	12 in.
	1		Subgrade		Semi-infinite

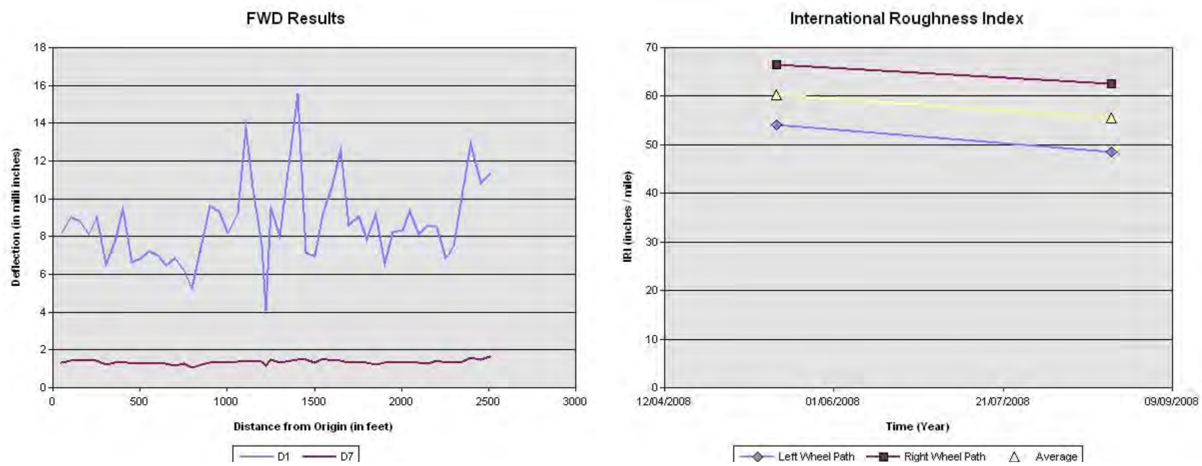


Figure 4.64: FWD and IRI - Section TXTF09013

Section TXTF09014

- District, County [Climatic Region]: Waco, McLennan [Mixed]
- Highway: US 77 (Lane: R2)
- Starting Coordinates: 31.45°N, 97.11°W
- Ending Coordinates: 31.44°N, 97.11°W

Table 4.61: Structural Details for Section TXTF09014

Section	Layer	Const. Date	Layer Type	Details	Thickness
TXTF09014	4		HMA Surface	Type C	2 in.
	3		Surface Treatment	CST	0 in.
	2		Base/Subbase	Flexbase	12 in.
	1		Subgrade		Semi-infinite

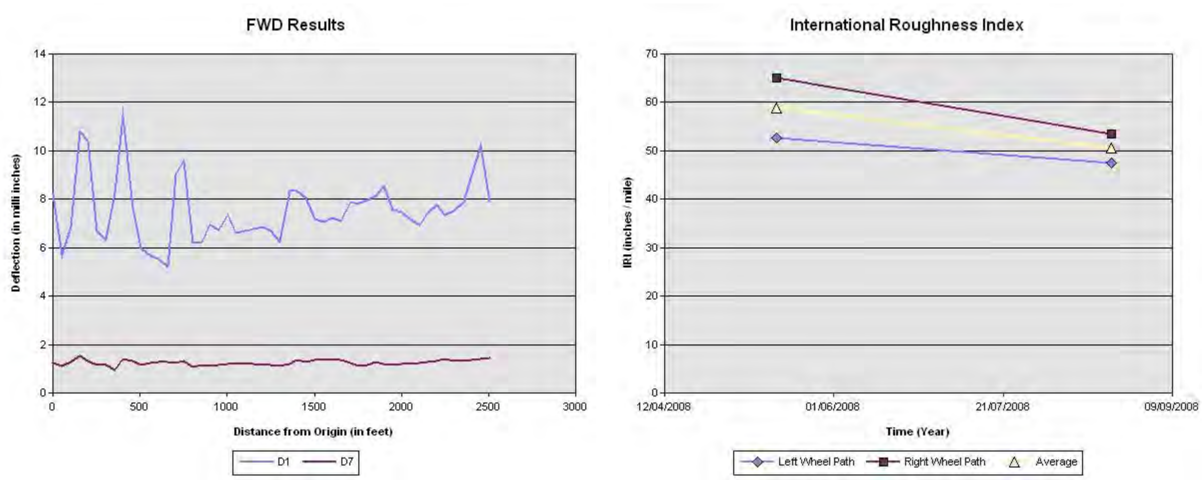


Figure 4.65: FWD and IRI - Section TXTF09014

Section TXTF10004

- District, County [Climatic Region]: Tyler, Anderson [Wet-Cold]
- Highway: FM 645 (Lane: K1)
- Starting Coordinates: 31.7°N, 95.74°W
- Ending Coordinates: 31.69°N, 95.74°W

Table 4.62: Structural Details for Section TXTF10004

Section	Layer	Const. Date	Layer Type	Details	Thickness
TXTF10004	5		HMA Surface	Type C	2.04 in.
	4		Surface Treatment	CST	0 in.
	3		HMA Surface		3.59 in.
	2		Base/Subbase	Flexbase	3.06 in.
	1		Subgrade		Semi-infinite

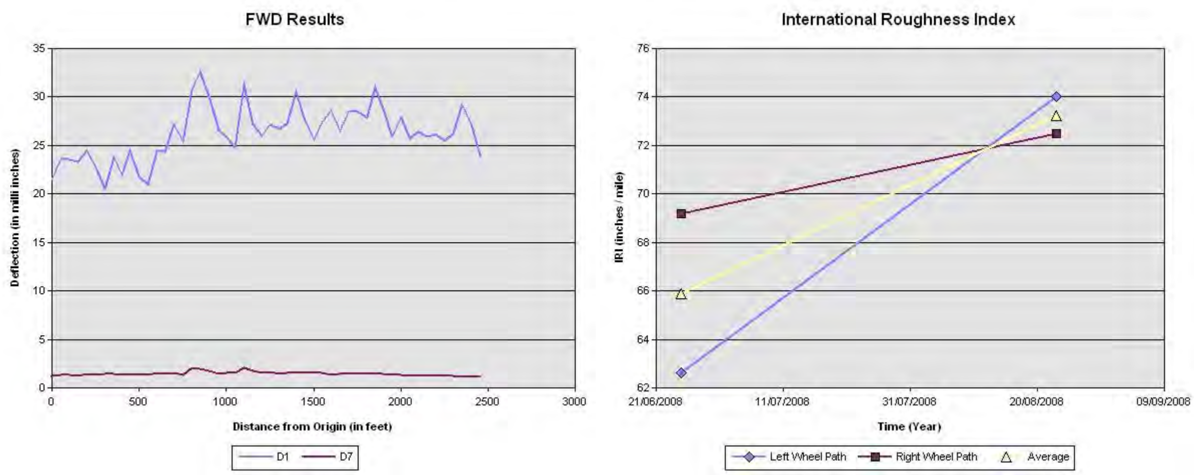


Figure 4.66: FWD and IRI - Section TXTF10004

Section TXTF10005

- District, County [Climatic Region]: Tyler, Anderson [Wet-Cold]
- Highway: FM 645 (Lane: K6)
- Starting Coordinates: 31.69°N, 95.74°W
- Ending Coordinates: 31.7°N, 95.74°W

Table 4.63: Structural Details for Section TXTF10005

Section	Layer	Const. Date	Layer Type	Details	Thickness
TXTF10005	5		HMA Surface	Type C	2.04 in.
	4		Surface Treatment	CST	0 in.
	3		HMA Surface		3.59 in.
	2		Base/Subbase	Flexbase	3.06 in.
	1		Subgrade		Semi-infinite

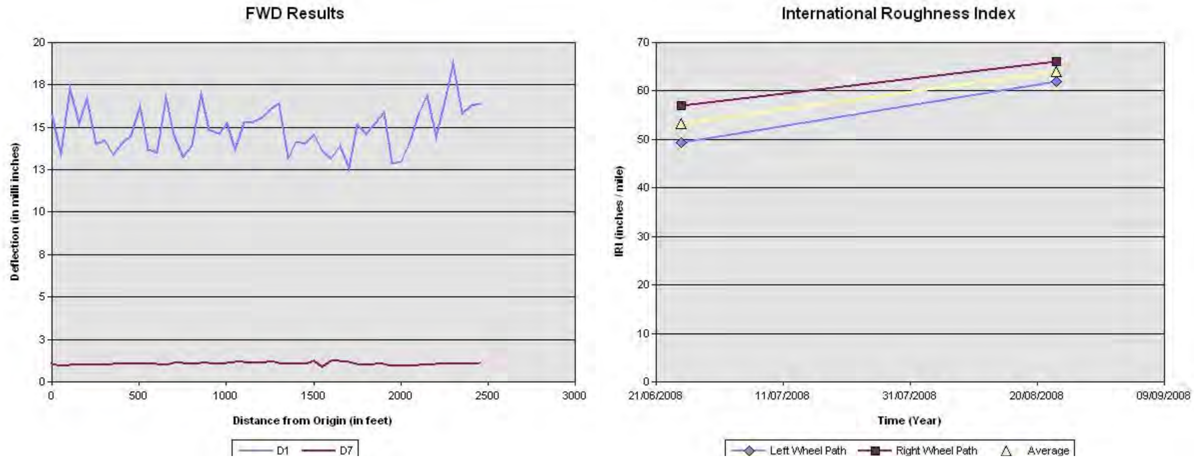


Figure 4.67: FWD and IRI - Section TXTF10005

Section TXTF10006

- District, County [Climatic Region]: Tyler, Anderson [Wet-Cold]
- Highway: FM 321 (Lane: K1)
- Starting Coordinates: 31.87°N, 95.93°W
- Ending Coordinates: 31.87°N, 95.92°W

Table 4.64: Structural Details for Section TXTF10006

Section	Layer	Const. Date	Layer Type	Details	Thickness
TXTF10006	6		Surface Treatment	CST	0 in.
	5		Prime Coat	Prime Coat	0 in.
	4		Base/Subbase	Type D	6 in.
	3		Geogrids	Geogrid Type I	0 in.
	2		Base/Subbase	Type D	6 in.
	1		Subgrade		Semi-infinite

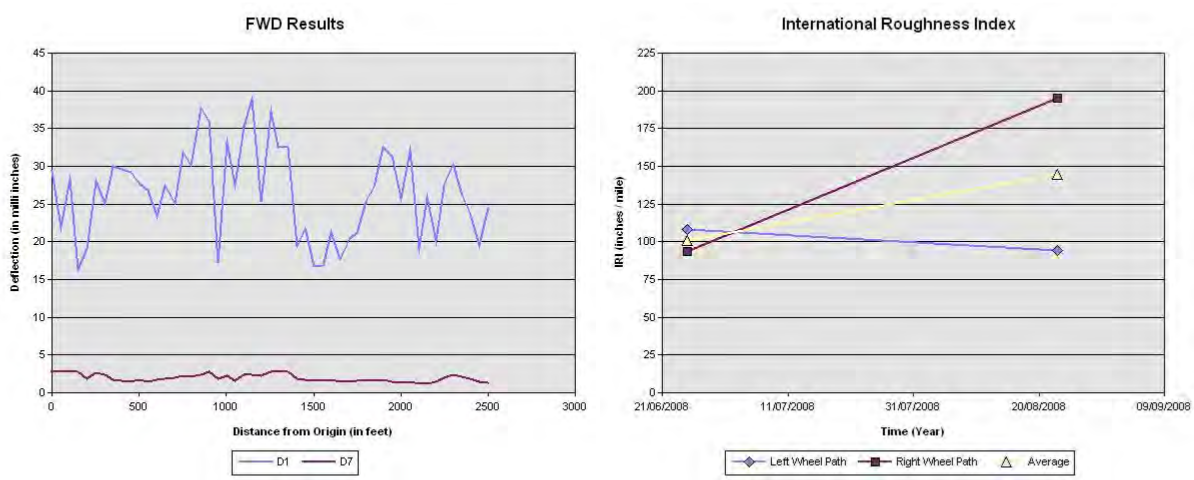


Figure 4.68: FWD and IRI - Section TXTF10006

Section TXTF10007

- District, County [Climatic Region]: Tyler, Anderson [Wet-Cold]
- Highway: FM 321 (Lane: K6)
- Starting Coordinates: 31.87°N, 95.92°W
- Ending Coordinates: 31.87°N, 95.93°W

Table 4.65: Structural Details for Section TXTF10007

Section	Layer	Const. Date	Layer Type	Details	Thickness
TXTF10007	6		Surface Treatment	CST	0 in.
	5		Prime Coat	Prime Coat	0 in.
	4		Base/Subbase	Type D	6 in.
	3		Geogrids	Geogrid Type I	0 in.
	2		Base/Subbase	Type D	6 in.
	1		Subgrade		Semi-infinite

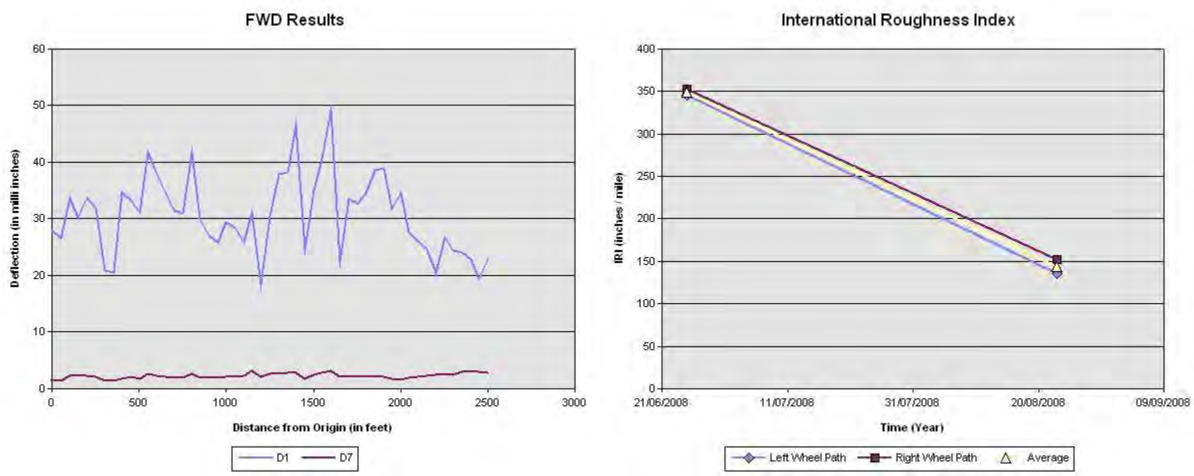


Figure 4.69: FWD and IRI - Section TXTF10007

Section TXTF10020

- District, County [Climatic Region]: Tyler, Rusk [Wet-Cold]
- Highway: FM 3231 (Lane: K1)
- Starting Coordinates: 32.21°N, 94.58°W
- Ending Coordinates: 32.2°N, 94.59°W

Table 4.66: Structural Details for Section TXTF10020

Section	Layer	Const. Date	Layer Type	Details	Thickness
TXTF10020	4		Surface Treatment	CST	0 in.
	3		Prime Coat	Prime Coat	0 in.
	2		Base/Subbase	Flexbase	12 in.
	1		Subgrade		Semi-infinite

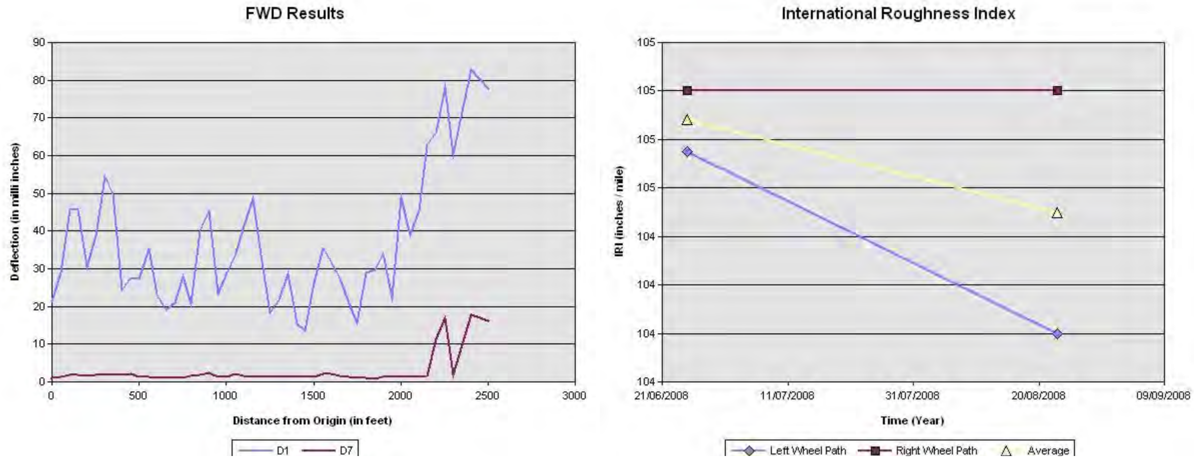


Figure 4.70: FWD and IRI - Section TXTF10020

Section TXTF10021

- District, County [Climatic Region]: Tyler, Rusk [Wet-Cold]
- Highway: FM 3231 (Lane: K6)
- Starting Coordinates: 32.2°N, 94.59°W
- Ending Coordinates: 32.21°N, 94.58°W

Table 4.67: Structural Details for Section TXTF10021

Section	Layer	Const. Date	Layer Type	Details	Thickness
TXTF10021	4		Surface Treatment	CST	0 in.
	3		Prime Coat	Prime Coat	0 in.
	2		Base/Subbase	Flexbase	12 in.
	1		Subgrade		Semi-infinite

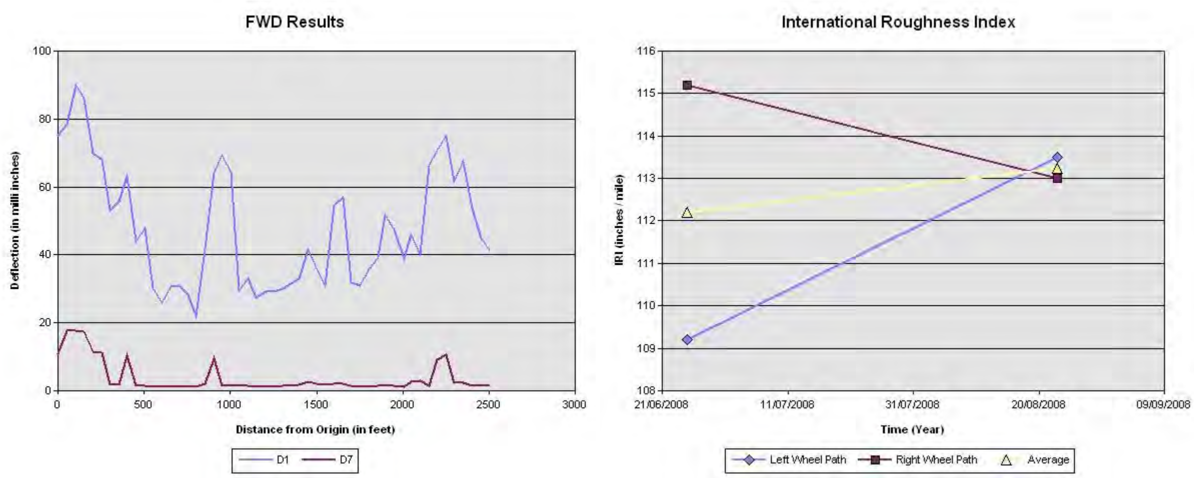


Figure 4.71: FWD and IRI - Section TXTF10021

Section TXTF17001

- District, County [Climatic Region]: Bryan, Brazos [Wet-Warm]
- Highway: SH 21 (Lane: R1)
- Starting Coordinates: 30.76°N, 96.3°W
- Ending Coordinates: 30.76°N, 96.29°W

Table 4.68: Structural Details for Section TXTF17001

Section	Layer	Const. Date	Layer Type	Details	Thickness
TXTF17001	5		HMA Surface	Type C	2 in.
	4		Base/Subbase	HMA Type C	3.9 in.
	3		Surface Treatment	CST	0 in.
	2		Base/Subbase	Flexbase	11.8 in.
	1		Subgrade	Lime Treated	Semi-infinite

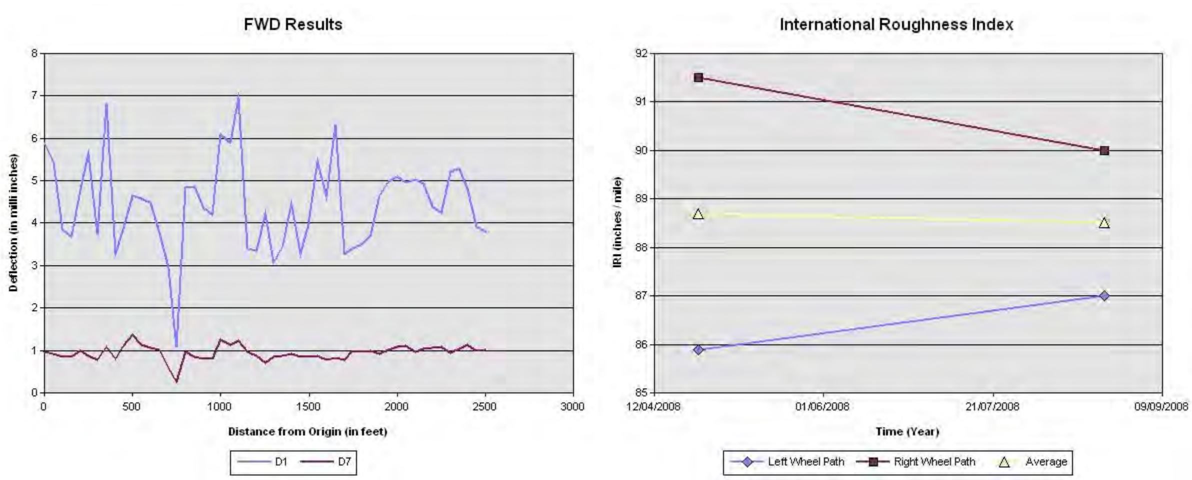


Figure 4.72: FWD and IRI - Section TXTF17001

Section TXTF17002

- District, County [Climatic Region]: Bryan, Brazos [Wet-Warm]
- Highway: SH 21 (Lane: R2)
- Starting Coordinates: 30.76°N, 96.3°W
- Ending Coordinates: 30.76°N, 96.29°W

Table 4.69: Structural Details for Section TXTF17002

Section	Layer	Const. Date	Layer Type	Details	Thickness
TXTF17002	5		HMA Surface	Type C	2 in.
	4		Base/Subbase	HMA Type C	9.3 in.
	3		Surface Treatment	CST	0 in.
	2		Base/Subbase	Flexbase	11.8 in.
	1		Subgrade	Lime Treated	Semi-infinite

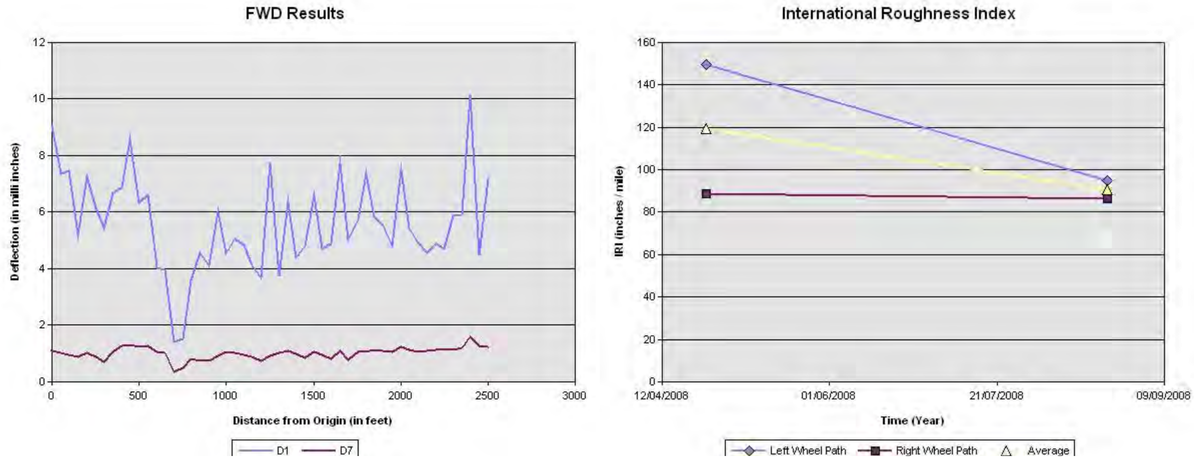


Figure 4.73: FWD and IRI - Section TXTF17002

Section TXTF17003

- District, County [Climatic Region]: Bryan, Burleson [Wet-Warm]
- Highway: SH 40 (Lane: L1)
- Starting Coordinates: 30.55°N, 96.27°W
- Ending Coordinates: 30.55°N, 96.28°W

Table 4.70: Structural Details for Section TXTF17003

Section	Layer	Const. Date	Layer Type	Details	Thickness
TXTF17003	4		HMA Surface	CMHB C	6.5 in.
	3		Surface Treatment	CST	0 in.
	2		Base/Subbase	Flexbase	17.7 in.
	1		Subgrade	Lime Treated	Semi-infinite

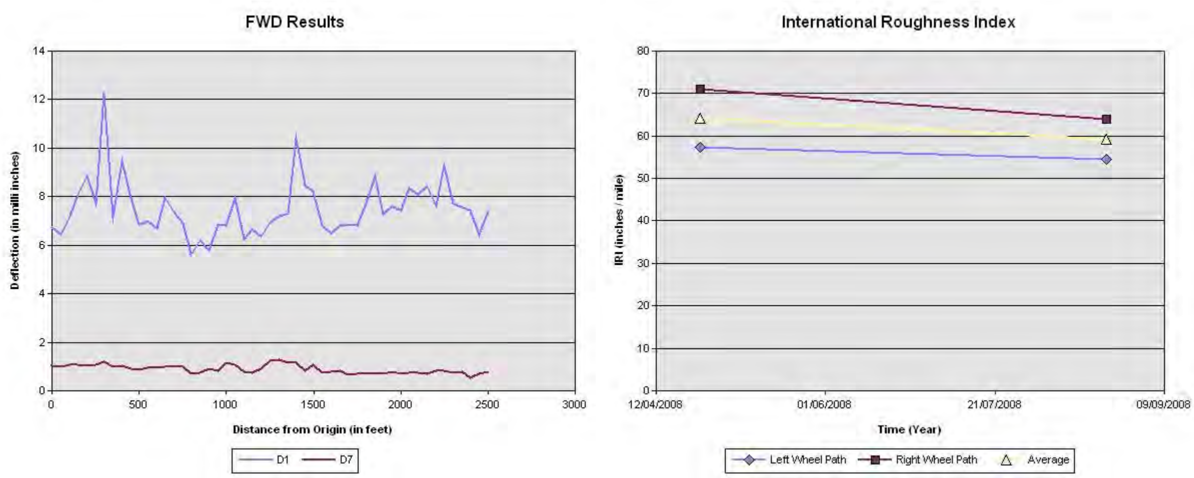


Figure 4.74: FWD and IRI - Section TXTF17003

Section TXTF17004

- District, County [Climatic Region]: Bryan, Burleson [Wet-Warm]
- Highway: SH 40 (Lane: L2)
- Starting Coordinates: 30.55°N, 96.27°W
- Ending Coordinates: 30.55°N, 96.28°W

Table 4.71: Structural Details for Section TXTF17004

Section	Layer	Const. Date	Layer Type	Details	Thickness
TXTF17004	4		HMA Surface	CMHB C	6.5 in.
	3		Surface Treatment	CST	0 in.
	2		Base/Subbase	Flexbase	17.7 in.
	1		Subgrade	Lime Treated	Semi-infinite

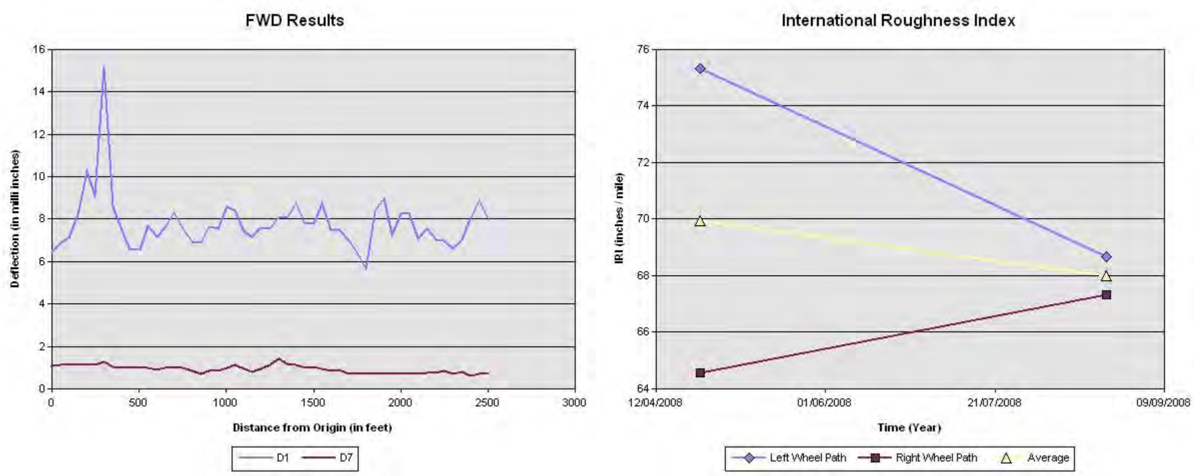


Figure 4.75: FWD and IRI - Section TXTF17004

Section TXTF17007

- District, County [Climatic Region]: Bryan, Robertson [Wet-Warm]
- Highway: FM 2096 (Lane: K1)
- Starting Coordinates: 31.11°N, 96.38°W
- Ending Coordinates: 31.11°N, 96.38°W

Table 4.72: Structural Details for Section TXTF17007

Section	Layer	Const. Date	Layer Type	Details	Thickness
TXTF17007	5		Surface Treatment	CST	0 in.
	4				0 in.
	3				0 in.
	2		Base/Subbase	Flexbase	7 in.
	1		Subgrade	S/R Existing Material	Semi-infinite

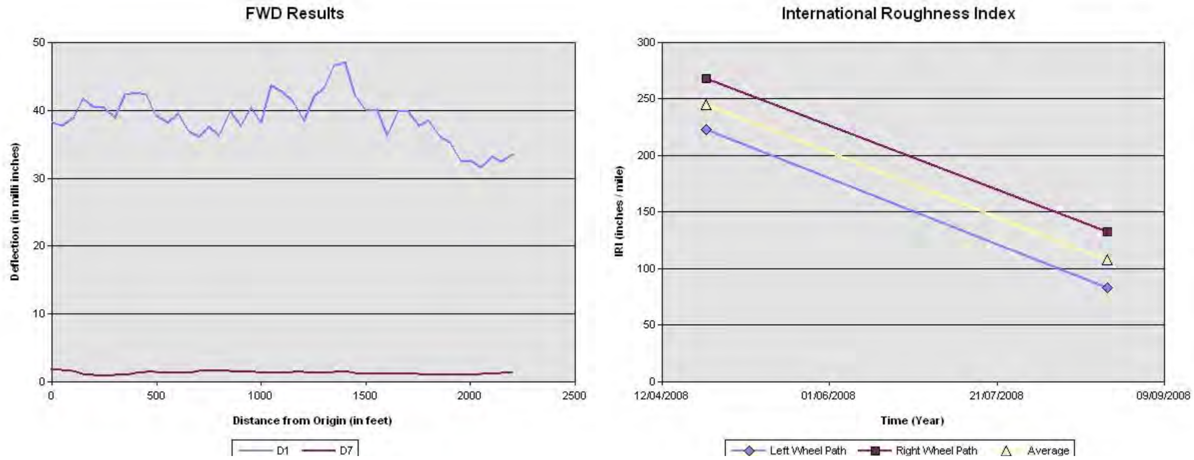


Figure 4.76: FWD and IRI - Section TXTF17007

Section TXTF17008

- District, County [Climatic Region]: Bryan, Robertson [Wet-Warm]
- Highway: FM 2096 (Lane: K6)
- Starting Coordinates: 31.11°N, 96.38°W
- Ending Coordinates: 31.11°N, 96.38°W

Table 4.73: Structural Details for Section TXTF17008

Section	Layer	Const. Date	Layer Type	Details	Thickness
TXTF17008	5		Surface Treatment	CST	0 in.
	4				0 in.
	3				0 in.
	2		Base/Subbase	Flexbase	7 in.
	1		Subgrade	S/R Existing Material	Semi-infinite

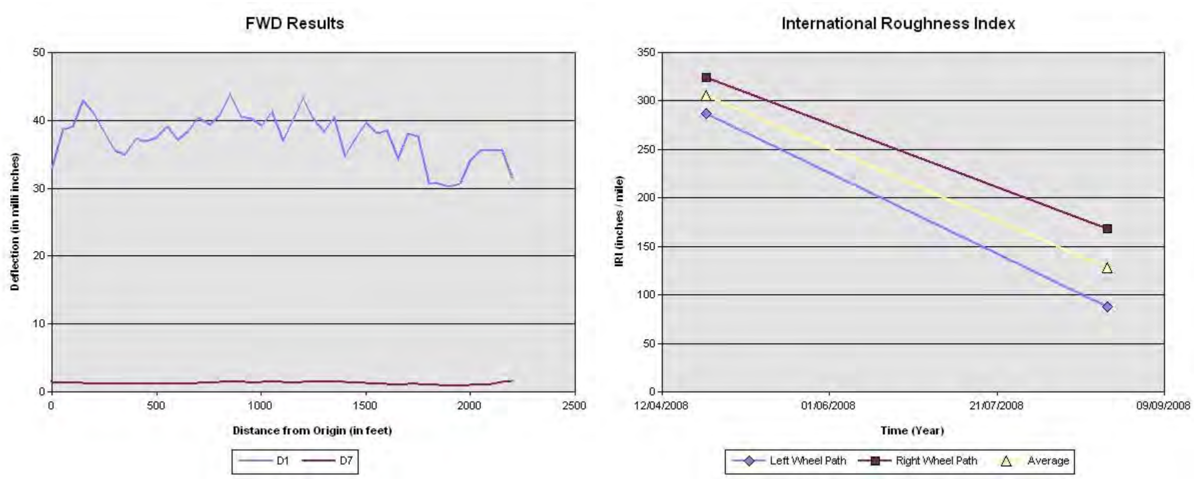


Figure 4.77: FWD and IRI - Section TXTF17008

Section TXTF17009

- District, County [Climatic Region]: Bryan, Leon [Wet-Warm]
- Highway: SH 7 (Lane: K1)
- Starting Coordinates: 31.25°N, 96.19°W
- Ending Coordinates: 31.25°N, 96.19°W

Table 4.74: Structural Details for Section TXTF17009

Section	Layer	Const. Date	Layer Type	Details	Thickness
TXTF17009	4		HMA Surface	Type C	2.5 in.
	3		Surface Treatment	CST	0 in.
	2				0 in.
	1		Subgrade	Cement Treated	Semi-infinite

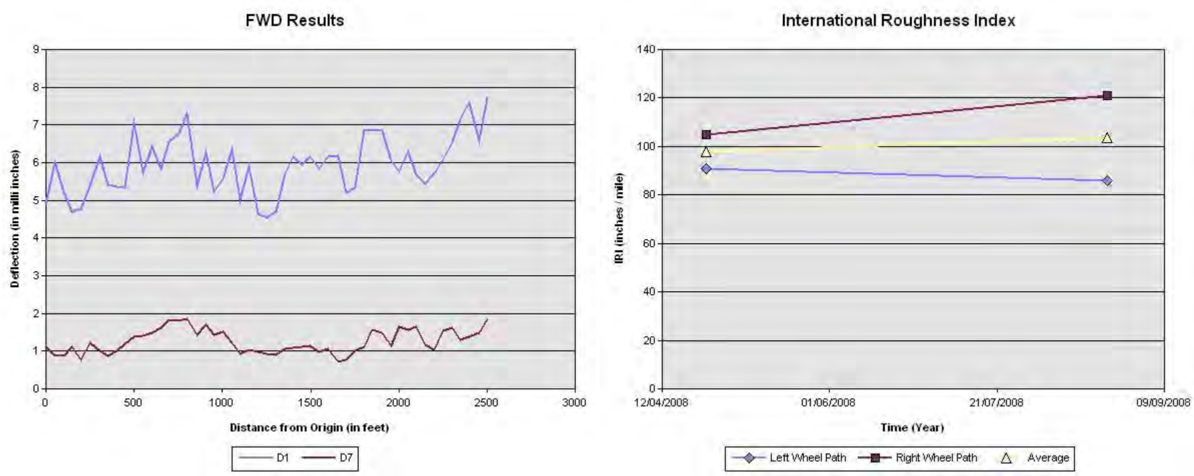


Figure 4.78: FWD and IRI - Section TXTF17009

Section TXTF17010

- District, County [Climatic Region]: Bryan, Freestone [Wet-Warm]
- Highway: FM 80 (Lane: K1)
- Starting Coordinates: 31.55°N, 96.27°W
- Ending Coordinates: 31.55°N, 96.26°W

Table 4.75: Structural Details for Section TXTF17010

Section	Layer	Const. Date	Layer Type	Details	Thickness
TXTF17010	4		HMA Surface	Type C	2 in.
	3		Surface Treatment	CST	0 in.
	2				0 in.
	1		Subgrade	Cement Treated	Semi-infinite

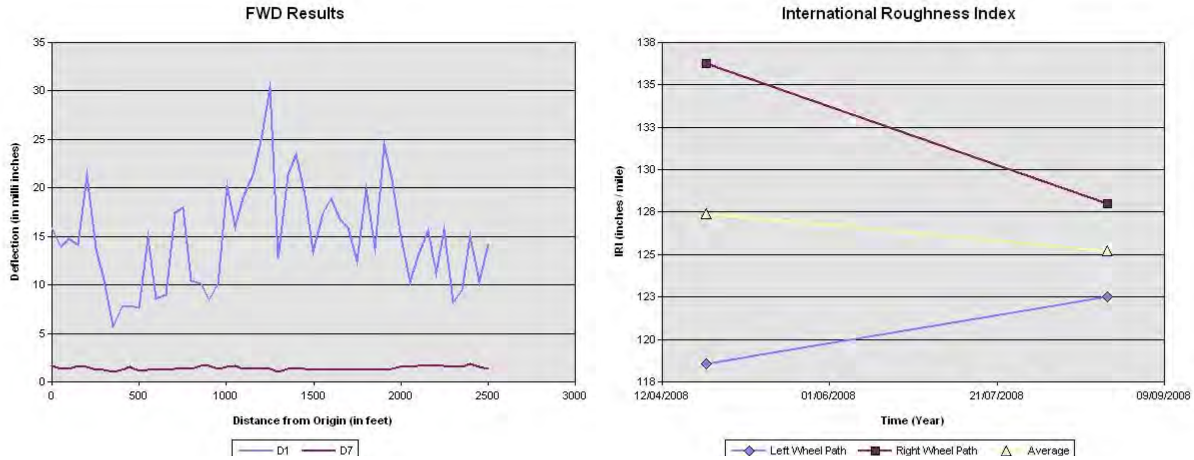


Figure 4.79: FWD and IRI - Section TXTF17010

Section TXTF17011

- District, County [Climatic Region]: Bryan, Freestone [Wet-Warm]
- Highway: FM 80 (Lane: K6)
- Starting Coordinates: 31.55°N, 96.26°W
- Ending Coordinates: 31.55°N, 96.27°W

Table 4.76: Structural Details for Section TXTF17011

Section	Layer	Const. Date	Layer Type	Details	Thickness
TXTF17011	4		HMA Surface	Type C	2 in.
	3		Surface Treatment	CST	0 in.
	2				0 in.
	1		Subgrade	Cement Treated	Semi-infinite

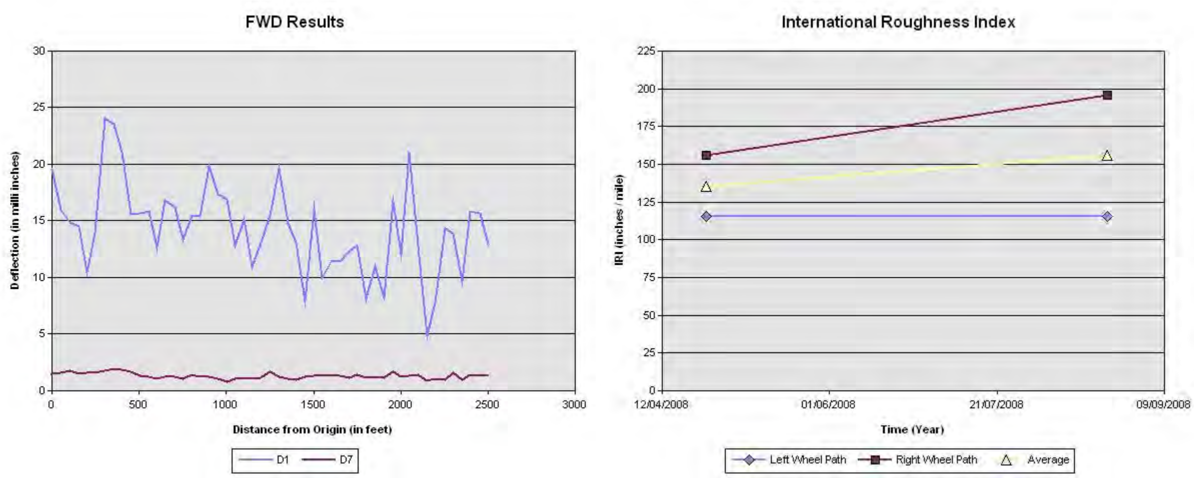


Figure 4.80: FWD and IRI - Section TXTF17011

Section TXTF17014

- District, County [Climatic Region]: Bryan, Freestone [Wet-Warm]
- Highway: FM 2777 (Lane: K1)
- Starting Coordinates: 31.64°N, 96.34°W
- Ending Coordinates: 31.63°N, 96.34°W

Table 4.77: Structural Details for Section TXTF17014

Section	Layer	Const. Date	Layer Type	Details	Thickness
TXTF17014	5		Surface Treatment	CST	0 in.
	4				0 in.
	3				0 in.
	2		Base/Subbase	Flexbase	8 in.
	1		Subgrade	S/R Existing Material	Semi-infinite

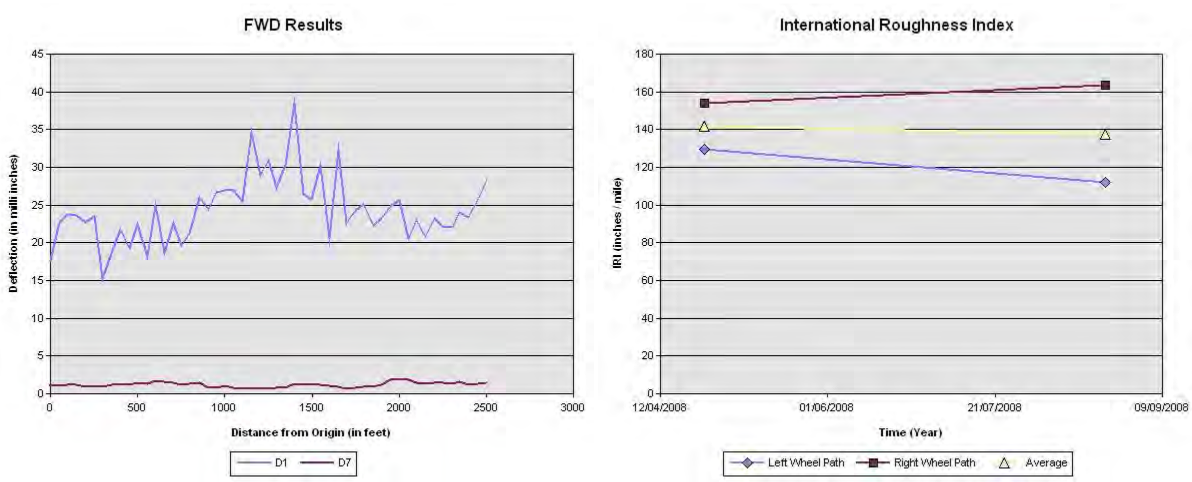


Figure 4.81: FWD and IRI - Section TXTF17014

Section TXTF17015

- District, County [Climatic Region]: Bryan, Freestone [Wet-Warm]
- Highway: FM 2777 (Lane: K6)
- Starting Coordinates: 31.63°N, 96.34°W
- Ending Coordinates: 31.64°N, 96.34°W

Table 4.78: Structural Details for Section TXTF17015

Section	Layer	Const. Date	Layer Type	Details	Thickness
TXTF17015	5		Surface Treatment	CST	0 in.
	4				0 in.
	3				0 in.
	2		Base/Subbase	Flexbase	8 in.
	1		Subgrade	S/R Existing Material	Semi-infinite

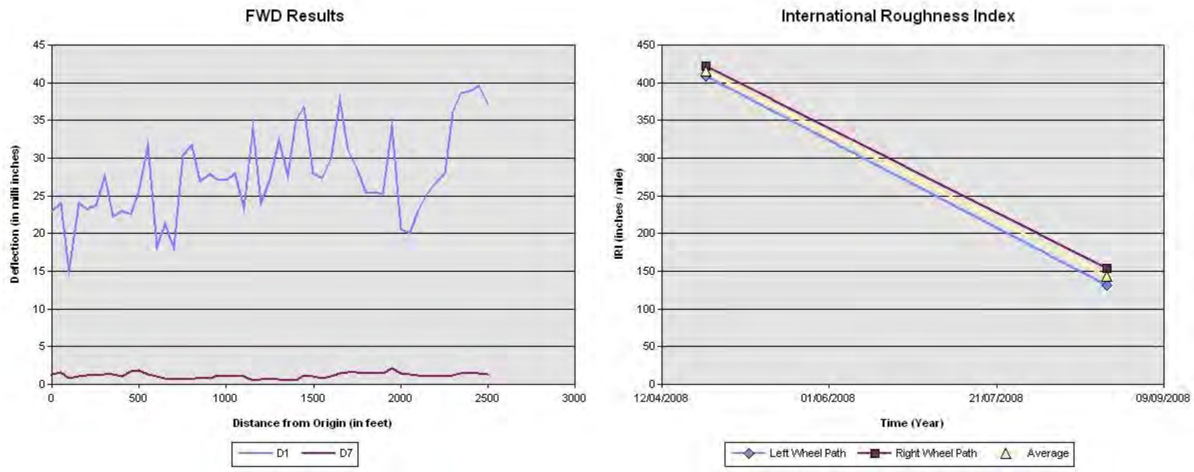


Figure 4.82: FWD and IRI - Section TXTF17015

Section TXTF24001

- District, County [Climatic Region]: El Paso, Culberson [Dry-Warm]
- Highway: IH 10 (Lane: R1)
- Starting Coordinates: 31.04°N, 104.81°W
- Ending Coordinates: 31.04°N, 104.8°W

Table 4.79: Structural Details for Section TXTF24001

Section	Layer	Const. Date	Layer Type	Details	Thickness
TXTF24001	3		HMA Surface	Type C	2 in.
	2			Type B	6 in.
	1		Subgrade	Lime Treated	Semi-infinite

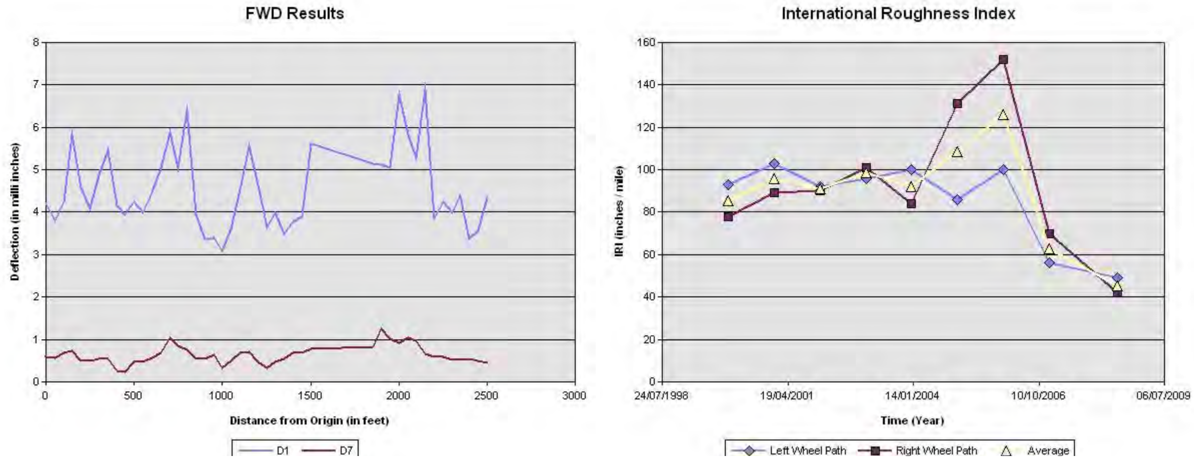


Figure 4.83: FWD and IRI - Section TXTF24001

Section TXTF24002

- District, County [Climatic Region]: El Paso, Culberson [Dry-Warm]
- Highway: IH 10 (Lane: R1)
- Starting Coordinates: 31.04°N, 104.81°W
- Ending Coordinates: 31.04°N, 104.8°W

Table 4.80: Structural Details for Section TXTF24002

Section	Layer	Const. Date	Layer Type	Details	Thickness
TXTF24002	3		HMA Surface	Type C	2 in.
	2			Type B	6 in.
	1		Subgrade	Lime Treated	Semi-infinite

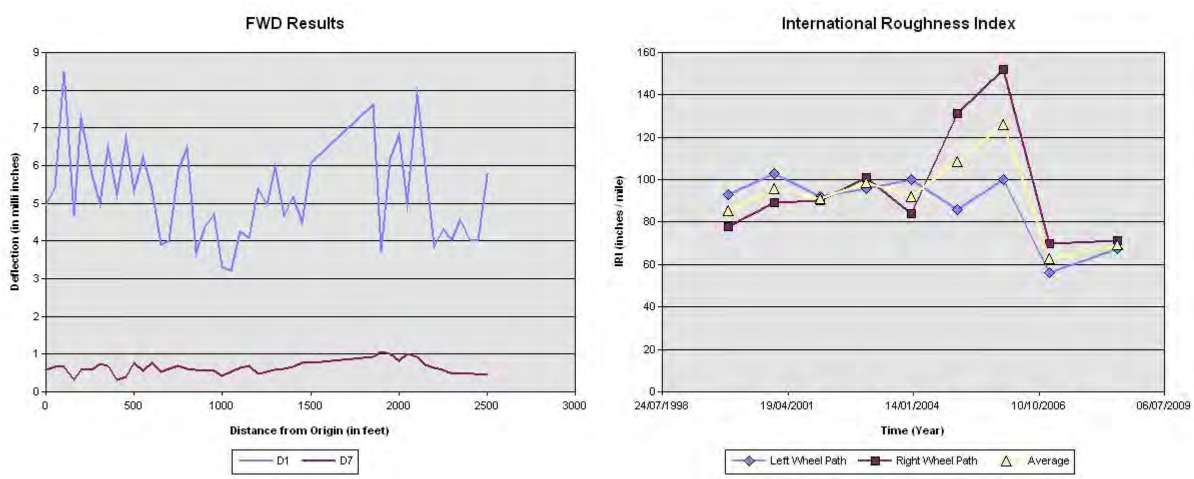


Figure 4.84: FWD and IRI - Section TXTF24002

Section TXTF24020

- District, County [Climatic Region]: El Paso, Hudspeth [Dry-Warm]
- Highway: US 62 (Lane: K1)
- Starting Coordinates: 31.83°N, 105.93°W
- Ending Coordinates: 31.83°N, 105.92°W

Table 4.81: Structural Details for Section TXTF24020

Section	Layer	Const. Date	Layer Type	Details	Thickness
TXTF24020	4		Surface Treatment	CST	0 in.
	3				0 in.
	2		Base/Subbase	Flexbase	12 in.
	1		Subgrade		Semi-infinite

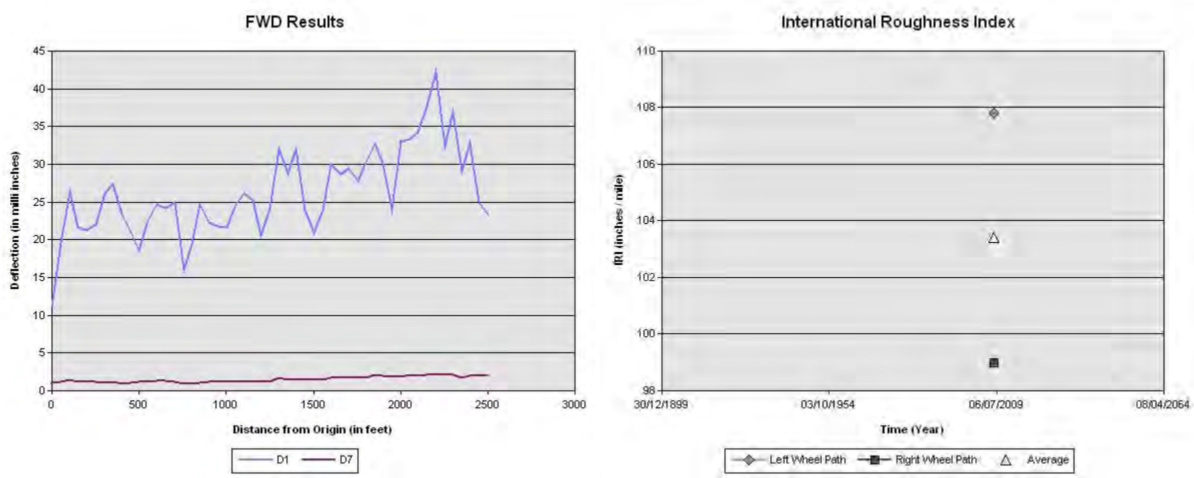


Figure 4.85: FWD and IRI - Section TXTF24020

Section TXTF24021

- District, County [Climatic Region]: El Paso, Hudspeth [Dry-Warm]
- Highway: US 62 (Lane: K6)
- Starting Coordinates: 31.83°N, 105.92°W
- Ending Coordinates: 31.83°N, 105.93°W

Table 4.82: Structural Details for Section TXTF24021

Section	Layer	Const. Date	Layer Type	Details	Thickness
TXTF24021	4		Surface Treatment	CST	0 in.
	3				0 in.
	2		Base/Subbase	Flexbase	12 in.
	1		Subgrade		Semi-infinite

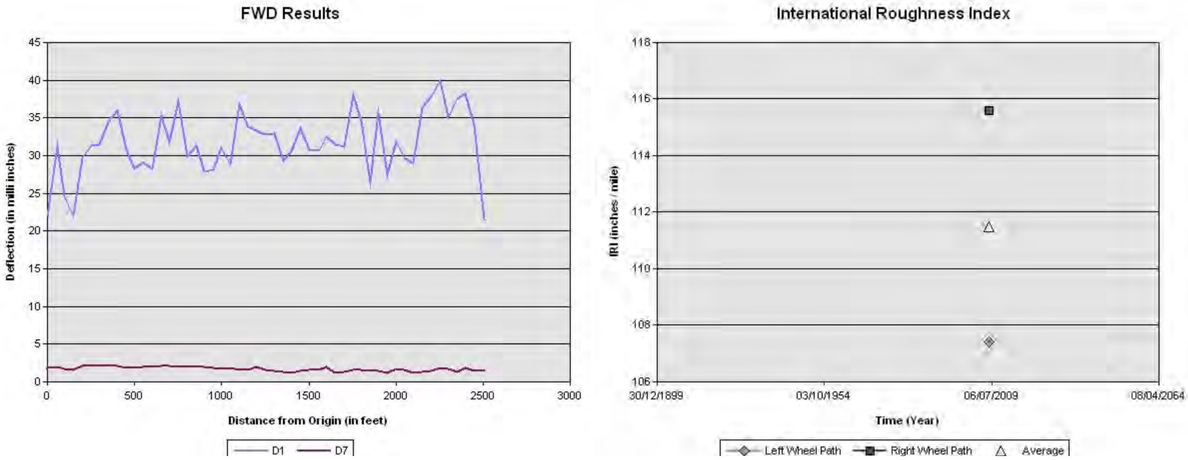


Figure 4.86: FWD and IRI - Section TXTF24021

Section TXTF24022

- District, County [Climatic Region]: El Paso, Hudspeth [Dry-Warm]
- Highway: US 62 (Lane: K1)
- Starting Coordinates: 31.83°N, 105.74°W
- Ending Coordinates: 31.83°N, 105.74°W

Table 4.83: Structural Details for Section TXTF24022

Section	Layer	Const. Date	Layer Type	Details	Thickness
TXTF24022	4		Surface Treatment	CST	0 in.
	3				0 in.
	2		Base/Subbase	Flexbase	12 in.
	1		Subgrade		Semi-infinite

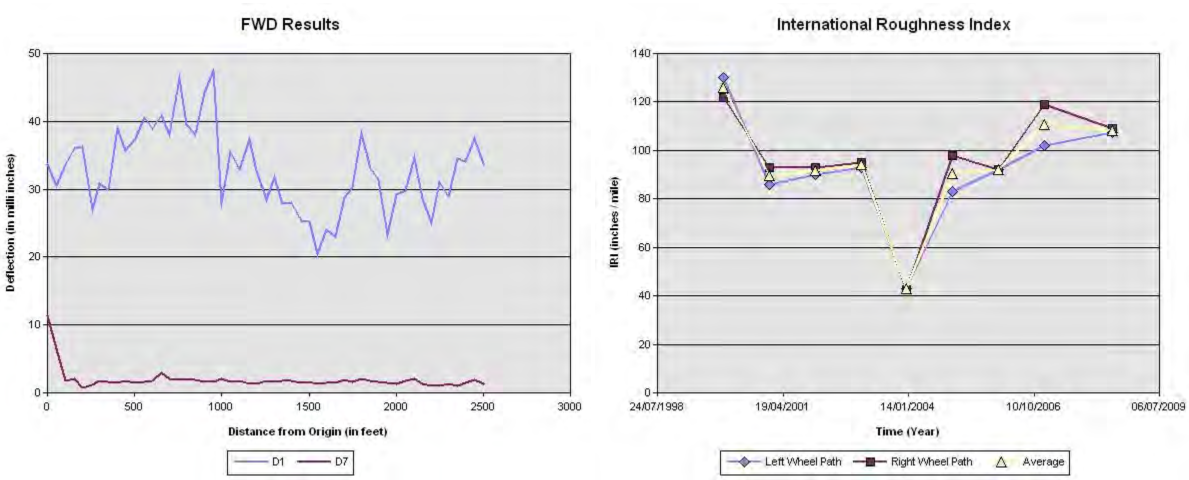


Figure 4.87: FWD and IRI - Section TXTF24022

Section TXTF24023

- District, County [Climatic Region]: El Paso, Hudspeth [Dry-Warm]
- Highway: US 62 (Lane: K6)
- Starting Coordinates: 31.83°N, 105.74°W
- Ending Coordinates: 31.83°N, 105.74°W

Table 4.84: Structural Details for Section TXTF24023

Section	Layer	Const. Date	Layer Type	Details	Thickness
TXTF24023	4		Surface Treatment	CST	0 in.
	3				0 in.
	2		Base/Subbase	Flexbase	12 in.
	1		Subgrade		Semi-infinite

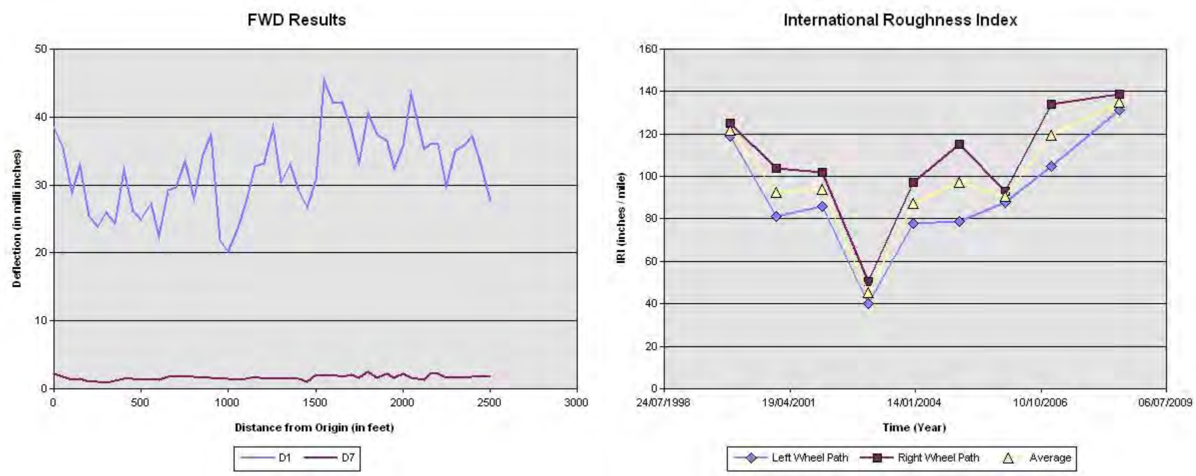


Figure 4.88: FWD and IRI - Section TXTF24023

Section TXTF24030

- District, County [Climatic Region]: El Paso, El Paso [Dry-Warm]
- Highway: FM 1110 (Lane: K1)
- Starting Coordinates: 31.59°N, 106.23°W
- Ending Coordinates: 31.59°N, 106.24°W

Table 4.85: Structural Details for Section TXTF24030

Section	Layer	Const. Date	Layer Type	Details	Thickness
TXTF24030	3		HMA Surface	CMHB F	2 in.
	2			Type B	6 in.
	1		Subgrade	Lime Treated	Semi-infinite

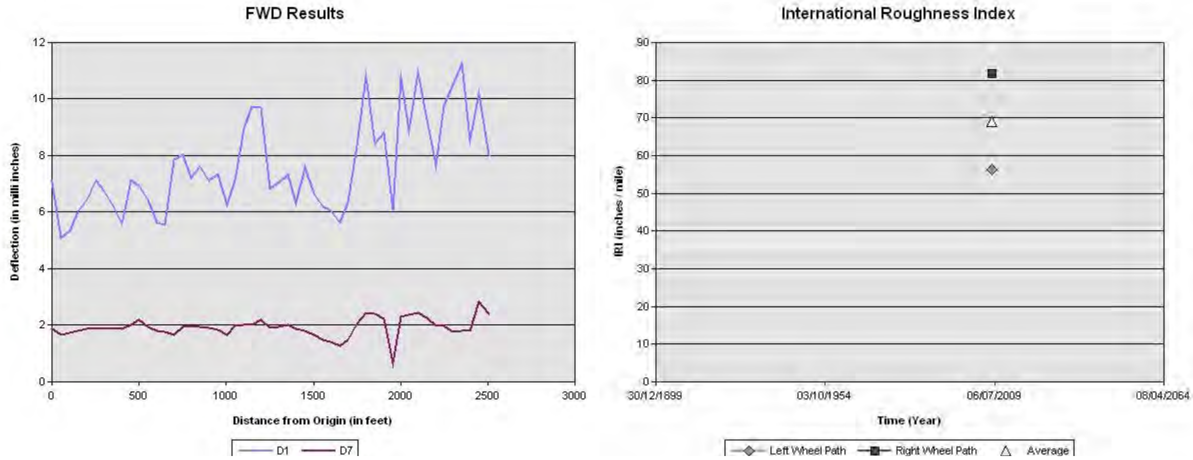


Figure 4.89: FWD and IRI - Section TXTF24030

Section TXTF24031

- District, County [Climatic Region]: El Paso, El Paso [Dry-Warm]
- Highway: FM 1110 (Lane: K6)
- Starting Coordinates: 31.59°N, 106.24°W
- Ending Coordinates: 31.59°N, 106.23°W

Table 4.86: Structural Details for Section TXTF24031

Section	Layer	Const. Date	Layer Type	Details	Thickness
TXTF24031	3		HMA Surface	CMHB F	2 in.
	2			Type B	6 in.
	1		Subgrade	Lime Treated	Semi-infinite

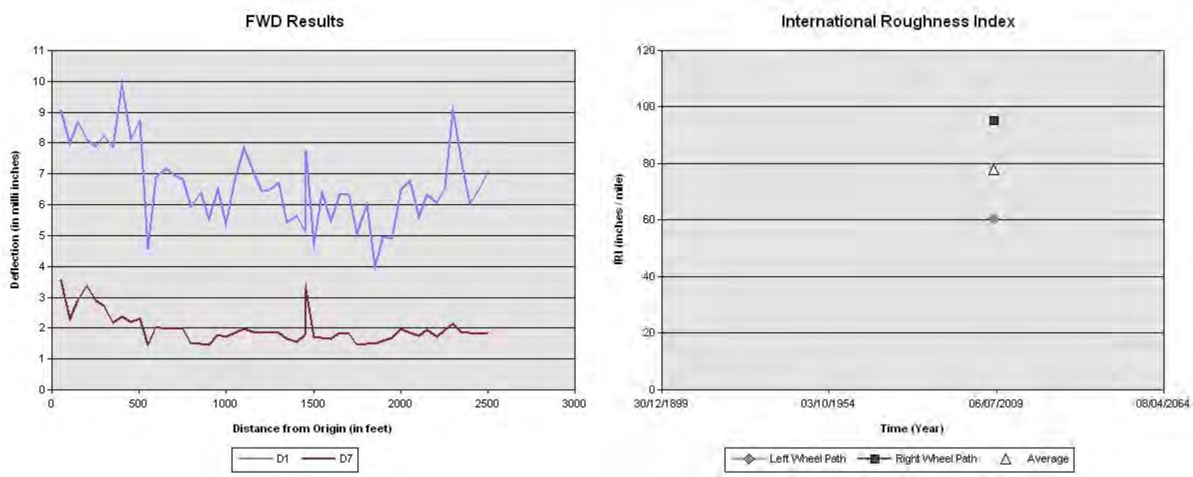


Figure 4.90: FWD and IRI - Section TXTF24031

Section TXTF24036

- District, County [Climatic Region]: El Paso, Culberson [Dry-Warm]
- Highway: IH 10 (Lane: R1)
- Starting Coordinates: 31.05°N, 104.6°W
- Ending Coordinates: 31.06°N, 104.59°W

Table 4.87: Structural Details for Section TXTF24036

Section	Layer	Const. Date	Layer Type	Details	Thickness
TXTF24036	3		HMA Surface	Type C	2 in.
	2			Type B	6 in.
	1		Subgrade	Lime Treated	Semi-infinite

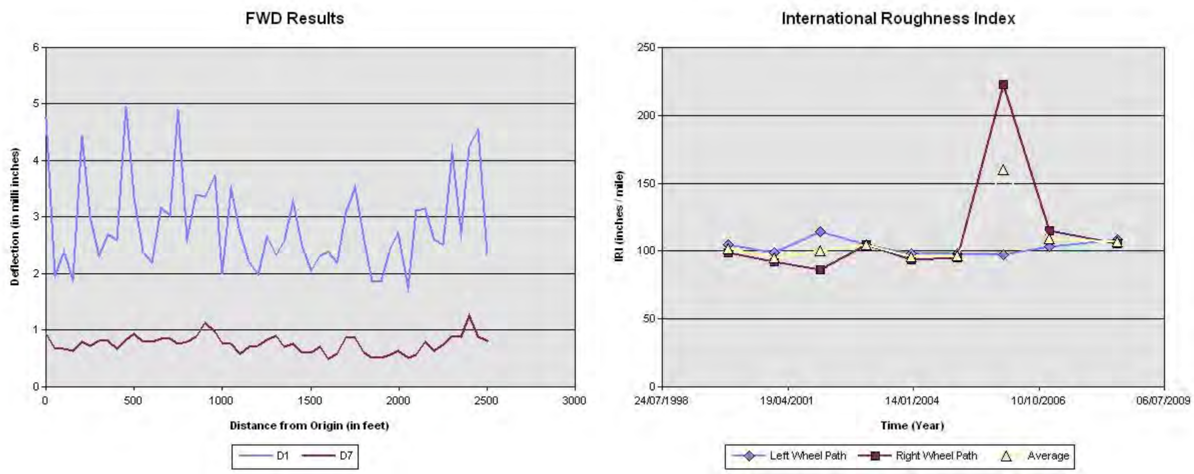


Figure 4.91: FWD and IRI - Section TXTF24036

Section TXTF24037

- District, County [Climatic Region]: El Paso, Culberson [Dry-Warm]
- Highway: IH 10 (Lane: R2)
- Starting Coordinates: 31.05°N, 104.6°W
- Ending Coordinates: 31.06°N, 104.59°W

Table 4.88: Structural Details for Section TXTF24037

Section	Layer	Const. Date	Layer Type	Details	Thickness
TXTF24037	3		HMA Surface	Type C	2 in.
	2			Type B	6 in.
	1		Subgrade	Lime Treated	Semi-infinite

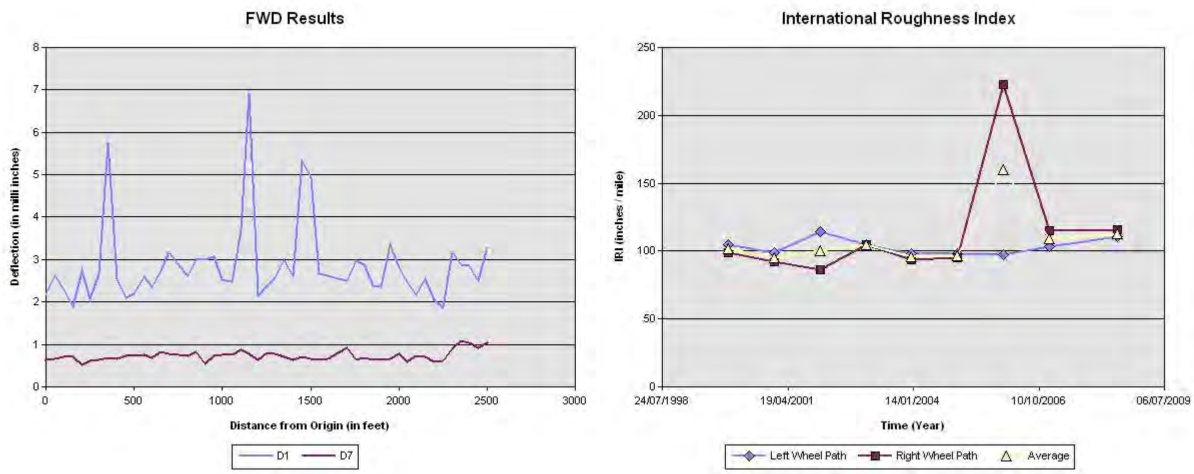


Figure 4.92: FWD and IRI - Section TXTF24037

Section TXTF24040

- District, County [Climatic Region]: El Paso, Jeff Davis [Dry-Warm]
- Highway: SH 17 (Lane: K1)
- Starting Coordinates: 30.77°N, 103.76°W
- Ending Coordinates: 30.76°N, 103.76°W

Table 4.89: Structural Details for Section TXTF24040

Section	Layer	Const. Date	Layer Type	Details	Thickness
TXTF24040	4		Surface Treatment	CST	0 in.
	3				0 in.
	2		Base/Subbase	Flexbase	12 in.
	1		Subgrade		Semi-infinite

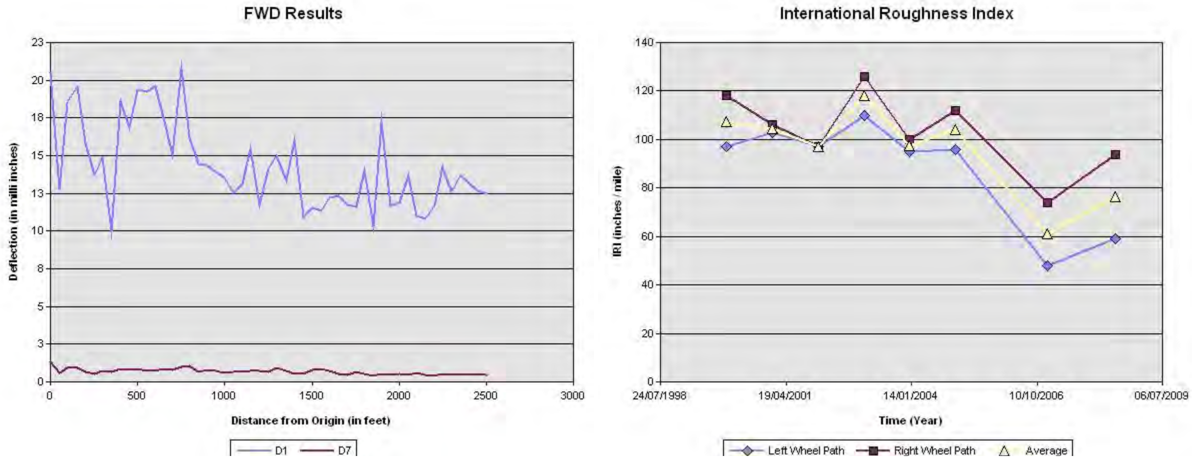


Figure 4.93: FWD and IRI - Section TXTF24040

Section TXTF24041

- District, County [Climatic Region]: El Paso, Jeff Davis [Dry-Warm]
- Highway: SH 17 (Lane: K6)
- Starting Coordinates: 30.76°N, 103.76°W
- Ending Coordinates: 30.77°N, 103.76°W

Table 4.90: Structural Details for Section TXTF24041

Section	Layer	Const. Date	Layer Type	Details	Thickness
TXTF24041	4		Surface Treatment	CST	0 in.
	3				0 in.
	2		Base/Subbase	Flexbase	12 in.
	1		Subgrade		Semi-infinite

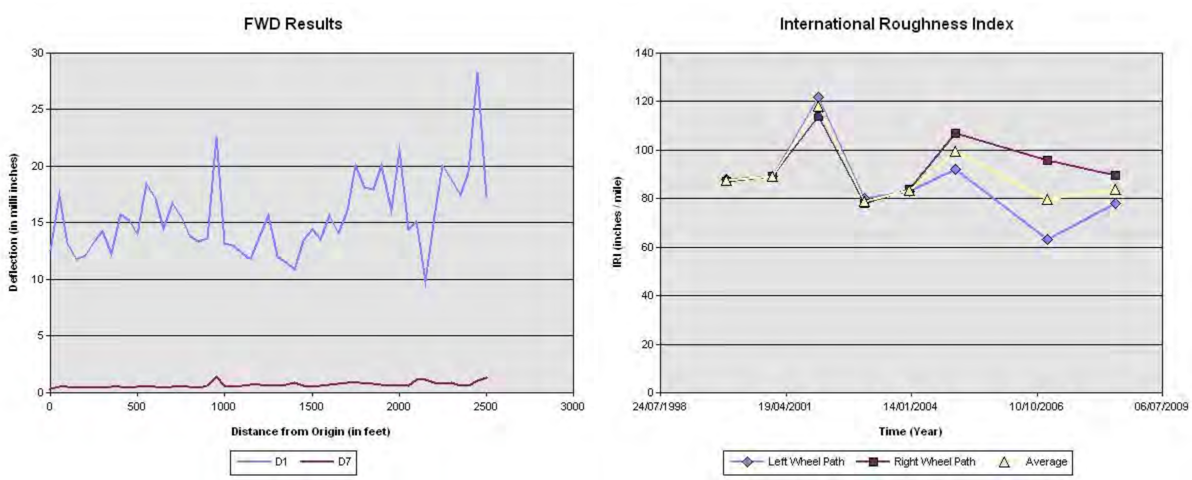


Figure 4.94: FWD and IRI - Section TXTF24041

The above results are only a subset of what is contained in the Texas Flexible Pavement Database for each of the pavement sections listed above. In addition to these characteristics, the database also has information on material, traffic, and other forms of distresses like rutting and cracking that can be viewed by any registered user. For the FWD, it was decided to show the deflection for sensors D1 and D7 after consulting with the Project Monitoring Committee (PMC). It should be noted that the deflections at the other sensors as well as their history are also available to the user on the Texas Flexible Pavement Database website (http://pavements.ce.utexas.edu/) and can be downloaded for any kind of post-processing.

4.7 Comparison of Distress Measurements with PMIS

A comparison of the distress data was made between the data collected by the research team and the data contained in the PMIS database to check for consistency and correctness of the information. It was observed that the data collected with the TxDOT Profiler by the research team is indeed quite close to the distress values reported in the PMIS database. This is the case when the specific lane of PMIS data collection is known. The case study was run with six sections from the El Paso district. It was observed that the distress values reported in both cases (PMIS and Texas Database) are quite close with the only exception being longitudinal cracking. For longitudinal cracking, there seems to be some differences in the values reported by PMIS and the data collected by the researchers. Figures 4.95 through 4.96 show a side-by-side comparison between the distress measurements as reported in the Texas Flexible Pavement Database and the PMIS databases.

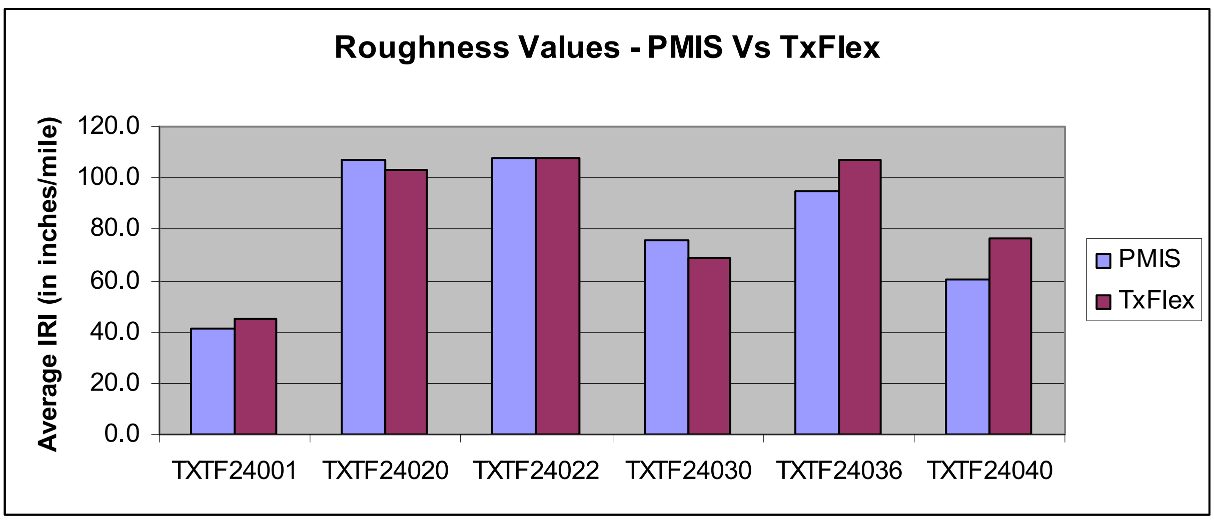


Figure 4.95: Roughness Values as reported in PMIS & TxFlex database

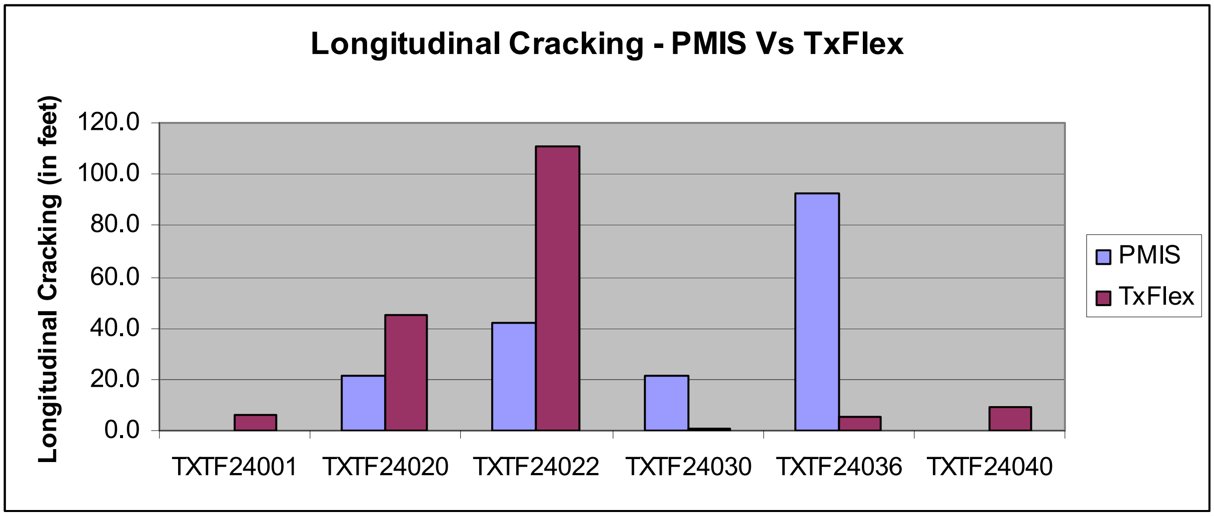


Figure 4.96: Longitudinal Cracking as reported in PMIS & TxFlex database

For the other forms of distresses, the values reported in both the databases for each of the sections were equal to zero. A statistical analysis was run on this dataset and the results as obtained from the analysis are given in Table 4.91. The standard deviation of the error term was observed to be quite large in the case of longitudinal cracking as compared to the roughness values. The good thing that was also observed that on an average the errors almost cancel out each other in case of longitudinal cracks.

Table 4.91: Statistical Analysis of the Error Term Due to Difference in Values Between PMIS & TxFlex Databases

	Difference in Average IRI (in/mile)	Difference in Alligator Cracking (sq. ft.)	Difference in No. of Block Cracks	Difference in No. of Transverse Cracks	Difference in Length of Longitudinal Cracks (ft.)
Mean (μ)	3.9	0.00	0.00	0.00	0.02
Std. Dev. (σ)	8.89	0.00	0.00	0.00	51.88

Chapter 5. Local Calibration of the MEPDG Performance Models for Texas

This chapter describes the methodology followed to calibrate the permanent deformation models (rutting models) used in the MEPDG. After each section is calibrated individually (Level 1), Level 2 calibration factors are used applying joint optimization principles. Finally, Level 3 factors are obtained by simple arithmetic average. The chapter also provides a set of Level 2 and Level 3 bias correction factors that can, in the interim, be used for design or analysis purposes within the state of Texas. As more data is collected, calibration factors are expected to change and become more reliable.

5.1 Introduction

The term calibration refers to the mathematical process through which the total error or difference between the observed and the predicted values for any quantity is minimized. It is a systematic process to eliminate the bias and minimize the difference between observed or measured performance from the actual pavements and predicted results from an empirical or mechanistic model (von Quintus et al., 2007). Bias is a term used when the average statistic systematically misses the parameter it is estimating. That is, a consistent error that arises when estimating a quantity. Errors from chance will cancel each other out in the long run (random errors), while those from bias will not. For example, the Mechanistic Empirical Pavement Design Guide (MEPDG) was nationally calibrated taking into consideration the various climatic regions across the country. If the MEPDG with the exact same calibration coefficients were used for pavement design in Texas, the design would be either over-estimate or under-estimate the pavement structure because materials, environmental conditions, and construction practices in Texas differ from the national average. The same will apply to any other state or country. The resulting error will be either always positive or negative, meaning that it will never cancel out, thus, contributing to the bias in the prediction model. To correct these biases (systematic errors) in the model, the bias correction factors are introduced (also known as the calibration coefficients). For the current study, the objective consisted of calibrating the asphalt concrete (AC) rutting model predicted with the current MEPDG to actual in-field performance observations of pavement sections in Texas.

The national calibration of the design guide was based on a wide spectrum of conditions that are too general and different from those normally seen in Texas. For example, materials or weather conditions in Texas are quite different from those found in the northern states of the U.S. Calibrating the MEPDG on a national level implies the performance predicted by the MEPDG will not be accurate enough for a specific region or locality. National calibration reproduces the behavior of a theoretical average American pavement, not any specific one. The prime reason for this is the fundamental differences in the various design parameters such as climate and materials, because the materials or construction practices used in any given region may differ significantly from the national average, as will regional weather patterns and climate conditions. As a result, predictions will tend to systematically miss the actual in-field observations and the errors so observed will be biased in nature. The calibration of the model will, therefore, consist of determining a set of bias correction factors that will eliminate the biases in the predictions. For this study, bias correction factors were established by minimizing the sum of squared errors between observed and predicted pavement distresses from specific sections. That is, calibration is done first following a Level 1, section specific, analysis. In turn, Level 1 analysis is used to determine Level 2 calibration factors, which are then averaged to determine Level 3 factors.

5.2 Objective

This chapter reports the research results obtained from an extensive local calibration effort that was undertaken to calibrate the permanent deformation performance model in the MEPDG for five different regions in Texas, and for Texas in general. The study focused on finding two bias correction factors for the AC rutting transfer function, per region, that are consistent with Level 2 design. The definitions of each of the design levels as interpreted by the authors are:

1) Level 1: The highest level of accuracy and reliability, implies determination of a specific set of calibration factors best suited to a given test site. Level 1 calibration factors can be very accurate while predicting pavement distresses for a specific section, but they cannot be relied upon for distress predictions at a regional or state level. These calibration factors will fit the data the best but cannot be used for future designs unless the conditions and location are exactly the same.
2) Level 2: The intermediate level or regional level, proposes determining bias correction factors at a regional level. Calibration factors that conform to Level 2 design may not be very accurate for site specific distress predictions, but can be fairly accurate while predicting distresses for sections belonging to a specific region.
3) Level 3: It refers to lowest accuracy and reliability while predicting distresses for a specific site because they are most suited for predicting pavement distresses at a state level.

As indicated above, Level 1 calibration factors were determined using section specific data. In an effort to determine the Level 2 calibration factors, a joint optimization approach was adopted while minimizing the sum of the squared residuals between the predicted and observed distresses. Another approach could have been determining Level 1 calibration parameters for each of the sections within a given region and then averaging them to obtain a set of Level 2 calibration parameters. The former was preferred because of its soundness from a theoretical and statistical point of view. On the other hand, while trying to calculate the Level 3 calibration parameters, the latter approach was preferred because of the enormous level of computation effort that would be required. Recent studies also suggest that the results are similar for either approach, though the former has a slight edge in terms of accuracy over the latter (Banerjee and Aguiar-Moya, 2008).

5.3 MEPDG Design Philosophy

The MEPDG represents a major change from the way pavement design had been done in the past. The designer first considers site conditions (traffic, climate, subgrade, existing pavement conditions for rehabilitation) and construction conditions in proposing a trial design for a new pavement or rehabilitation. The trial design is then evaluated for adequacy through the prediction of key distresses (cracking, and rutting) and smoothness (roughness in IRI). If the design does not meet desired performance criteria, it is revised by changing structural and material properties and the evaluation process is repeated as necessary (Figure 5.1). Thus, the designer has the flexibility to consider different design features and materials for the prevailing site conditions. As such, the MEPDG is not a design tool but a very powerful and comprehensive pavement analysis tool.

> "The MEPDG allows the designer to calibrate the performance prediction models depending on local factors such as traffic and climate. Well-calibrated prediction models result in reliable pavement design for state highway agencies. Local pavement performance data can be used to validate and adjust calibration factors integrated in the MEPDG. The procedure empirically relates damage over time to pavement distress" (Kang and Adams, 2007).

5.4 Calibration Data

In this chapter, the data used in the calibration process was taken from the TFPD, which was developed at The University of Texas at Austin to support Level 1 calibration for the various geographical regions within Texas as well as Texas in general. Although the data was adapted from the TFPD database, the pavement sections used for this section specifically belongs to the LTPP database (Elkins et al., 2006). The idea of using the LTPP sections for the calibration purpose was because of a lack of Texas sections having time-series data for a period of at least four years. The pavement sections included are from the Specific Pavement Studies (SPS-1 & SPS-3) experiments within the state of Texas. The SPS-1 experiment examines the effects of climatic region, subgrade soil, and traffic rate on pavement sections incorporating different levels of structural factors. These factors include drainage, asphalt concrete (AC) surface thickness, base type, and base thickness. The SPS-3 experiment compares the effectiveness and mechanisms by which the selected maintenance treatments preserve and extend pavement service life, safety and ride quality. The study factors for flexible pavements include: climatic zone, subgrade type, traffic loading, initial condition, and structural adequacy. The dataset included sections from five different regions in Texas, the details of which can be found in Table 5.1.

It is known that Texas can be classified into five distinct climatic zones, namely wet-warm, wet-cold, dry-warm, dry-cold, and mixed. The selection of the locations for the calibration process was done keeping in mind that there are representatives from each of these geographical zones so that the differences in climatic conditions are not neglected while doing a Level 3 calibration. Unfortunately, the experimental design included sections from each of these geographical regions except for the Wet-warm zone because of lack of adequate data (at least four distress surveys). The geographical classification of each of the locations is also given in Table 5.1.

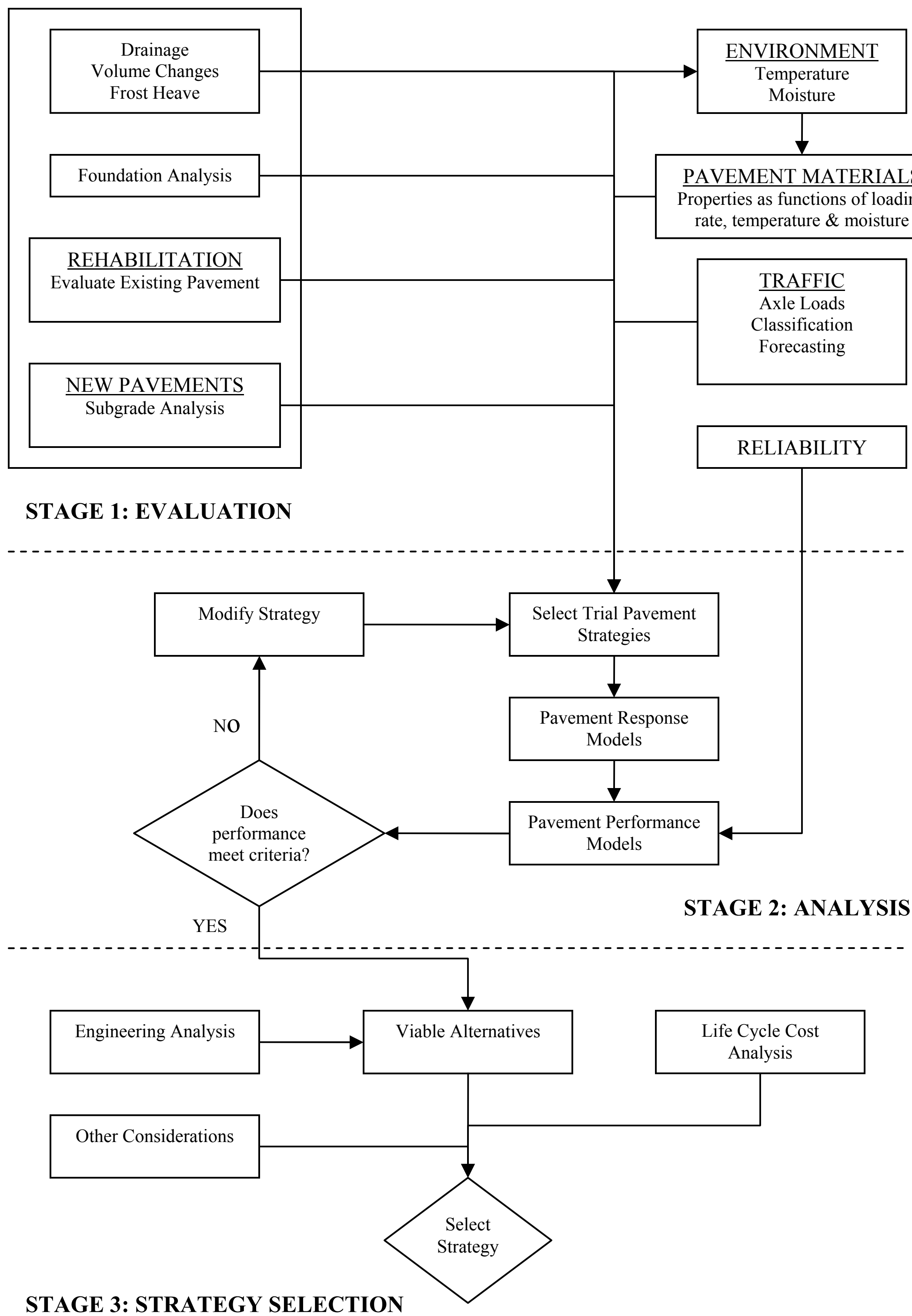


Figure 5.1: MEPDG Design Procedure (ARA, 2004)

Most of the calibration data were obtained from the Texas Flexible Pavement Database, except for a few that had to be adapted from the LTPP database. Appendix B lists all the data elements and the type of information that is being stored in each of those data elements. Information on gradation, hot-mix asphalt (HMA) layers, subgrade and unbound layers was collected from the *PAV_LAYER, PAV_LAYER_BASE, PAV_LAYER_SOIL, PAV_MIX, PAV_BINDER* and *PAV_LAYER_HMA* tables as established in the Texas Flexible Pavement Database. Data related to rutting distress in the pavement section was obtained from the *PAV_FIELD_PERF_RUT* table. Details related to axle load distribution and vehicle classification were obtained from the *Traffic* dataset of the LTPP database (http://www.datapave.com) and the rest were obtained from the Texas Flexible Pavement database (http://pavements.ce.utexas.edu/).

5.4.2 Layer Information

Table 5.1: SPS-1 & SPS-3 Experimental Test Sections

Section Information					Thickness (inches)				
Location (County, District)	**Climatic Region**	**Region**	**Section**	**Const. Date**	**Sub-Base**	**Base**	**Binder Layer (Asphalt Concrete)**	**Surface Course (Asphalt Concrete)**	**Overlay (Asphalt Concrete)**
El Paso, El Paso	Dry-warm	West Texas	TXLT24043	April, 1991		8.4”		3.1”	
			TXLT24044	Sept, 1990		8.4”		2.3”	
			TXLT24045			8.8”		2.0”	
Hidalgo, Pharr	Dry-warm	Texas Valley	TXLT21002	April, 1997	24.0”	7.8”	2.8”	1.8”	
			TXLT21003		24.0”	12.2”	4.7”	2.1”	
			TXLT21006		24.0”	7.3”	5.2”	2.2”	
			TXLT21007		24.0”	10.3”	3.1”	1.7”	
			TXLT21009		24.0”	11.4”	2.7”	2.0”	
Rusk, Tyler	Wet-cold	East Texas	TXLT10026	Oct, 1990		11.3”		3.4”	
			TXLT10027			11.3”		2.0”	
			TXLT10028	Jan, 1987		11.3”		2.3”	
Mitchell, Abilene	Dry-cold	High Plains	TXLT08001	Oct, 1990	8.8”	6.8”	7.8”	2.1”	1.9”
			TXLT08002	Sept, 1990	8.8”	6.8”	7.3”	2.2”	1.1”
			TXLT08003		8.8”	6.8”	7.6”	2.4”	1.0”
Mills, Brownwood	Mixed	Hill Country	TXLT23002	Sept, 1990	10.0”	7.5”		1.9”	1.2”
			TXLT23003		10.0”	7.5”		2.4”	
			TXLT23004	Jan, 1987	10.0”	7.5”		2.1”	
			TXLT23005		10.0”	7.5”		2.0”	

5.4.3 Traffic Data

The traffic growth rate and related necessary information were obtained from the TRAFFIC table of the TFPD database. A minimum of four and a maximum of eight years of traffic data were available for the sections under study. It was assumed that the traffic growth rate is linear during the survey period. The initial traffic volume and the growth rate for the five locations under study are given in Table 5.2.

Table 5.2: Initial Traffic Volume & Growth Rate

Location	Roadway Type & Name	Initial Traffic Volume (AADTT – Annual Average Daily Truck Traffic)	Traffic Growth Type	Traffic Growth Rate
El Paso	US 62	170	Linear	5.5%
Tyler	SH 322	54	Linear	21.5%
Pharr	US 281	942	Linear	3.7%
Abilene	IH 20	1425	NA	Nil
Brownwood	US 84	197	Linear	3.1%

It can be observed that the traffic growth rates as well as the initial truck traffic volumes are quite different for the five different locations evaluated. It can also be observed that the traffic growth rate is higher for sections with lower initial traffic and vice versa.

The vehicle classification data was obtained from the *TRF_HIST_CLASS_DATA* table in the *Traffic* dataset of the LTPP database, the details of which can be seen in Figure 5.2.

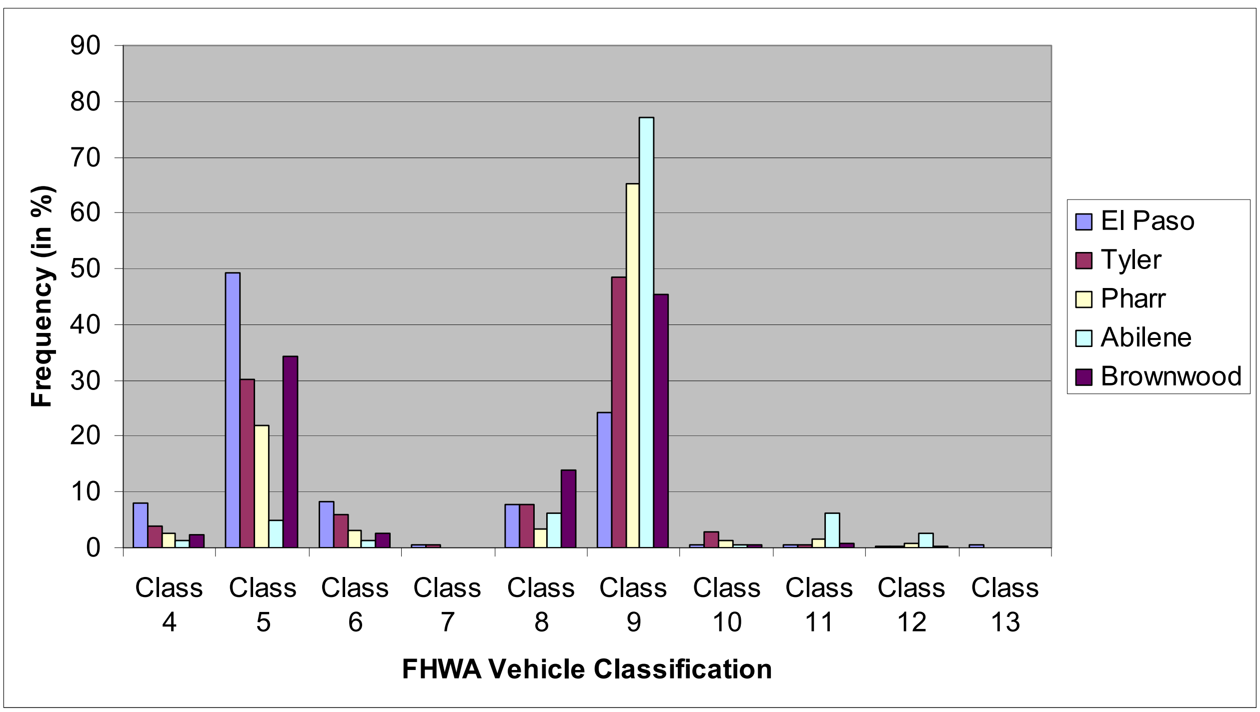


Figure 5.2: FHWA Vehicle Classification

The axle load distribution, which is another key design input, was obtained from the *TRF_MONITOR_AXLE_DISTRIB* table of the *Traffic* dataset in the LTPP database. Axle spectra were estimated for single, tandem, and tridem axles for the sections under analysis for each of the AASHTO vehicle classes. In the figures 5.3 through 5.17, the Axle Spectra has been only listed for Vehicle Classes 5 and 9 because it was observed that these were the two classes that constituted the bulk of the truck traffic. However, it should not be misunderstood that the calibration of the MEPDG was only done with Vehicle Classes 5 and 9; calibration included all the 10 different vehicle classes (Class 4 through Class 13).

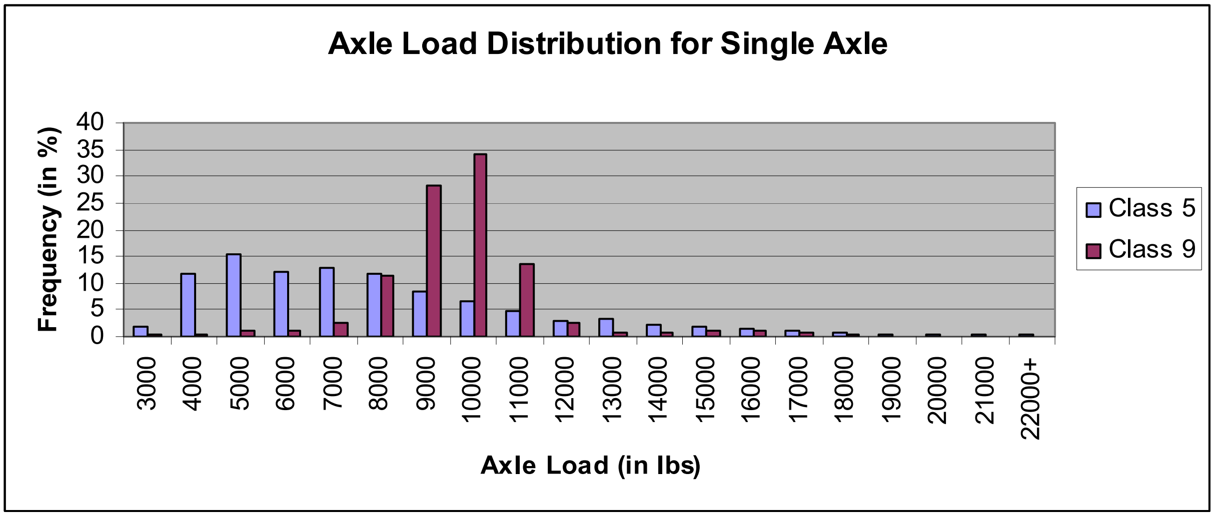


Figure 5.3: Axle Load Distribution for Single Axle (Location: IH 20, Abilene)

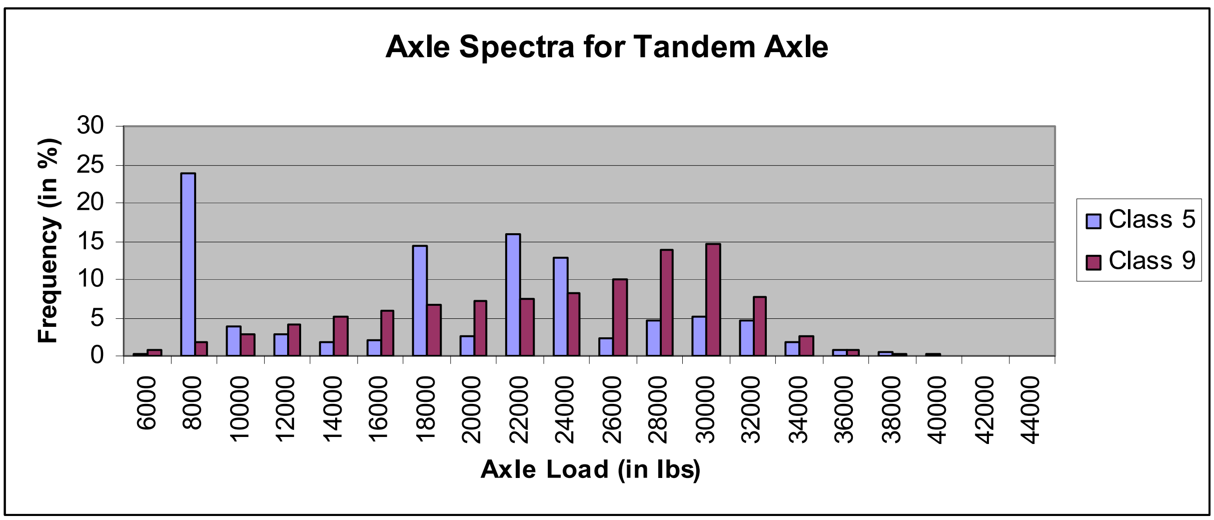


Figure 5.4: Axle Load Distribution for Tandem Axle (Location: IH 20, Abilene)

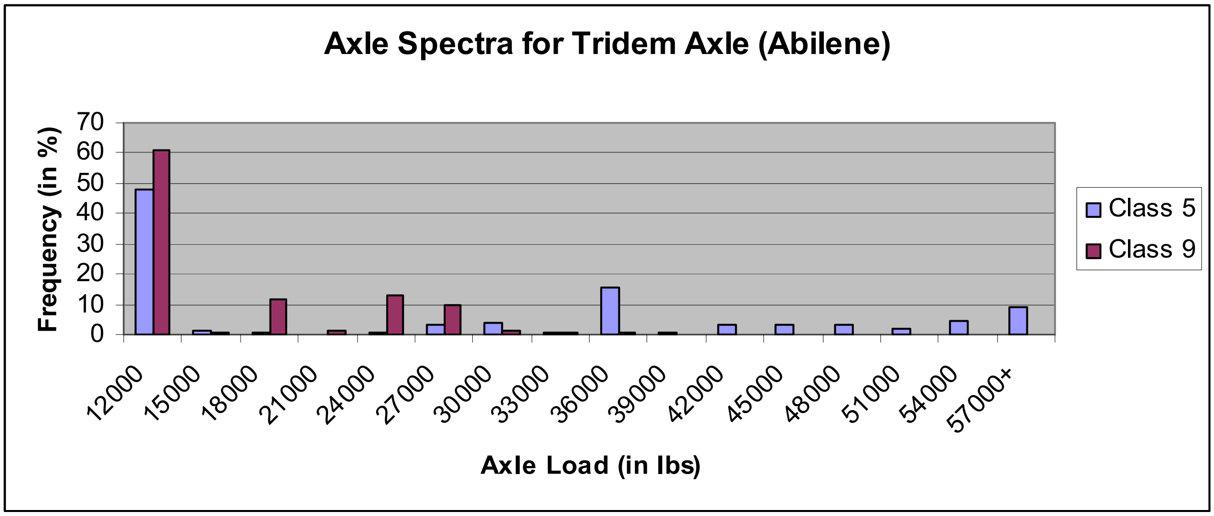


Figure 5.5: Axle Load Distribution for Tridem Axle (Location: IH 20, Abilene)

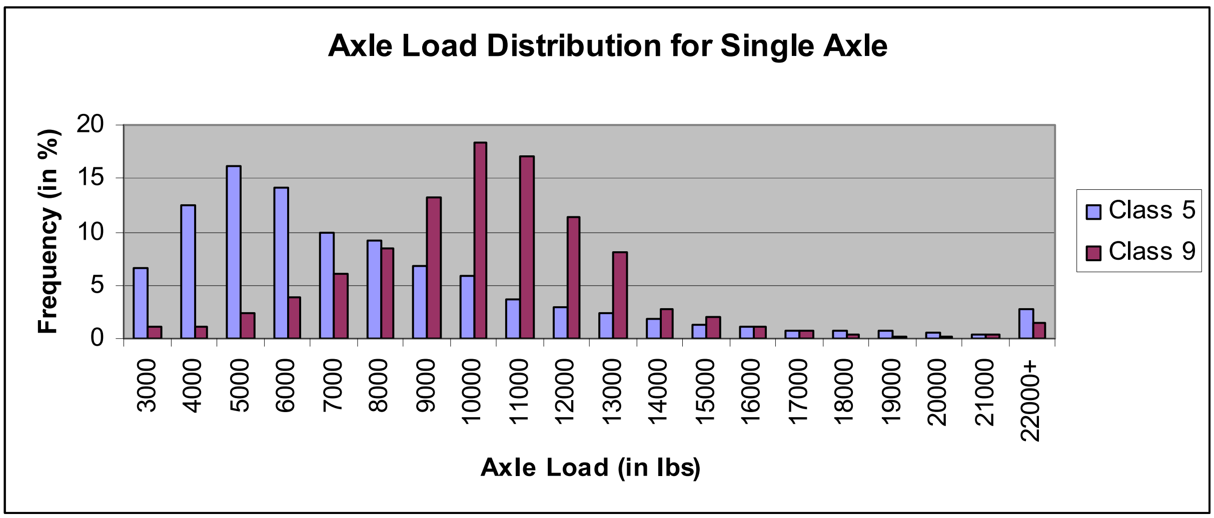


Figure 5.6: Axle Load Distribution for Single Axle (Location: US 62, El Paso)

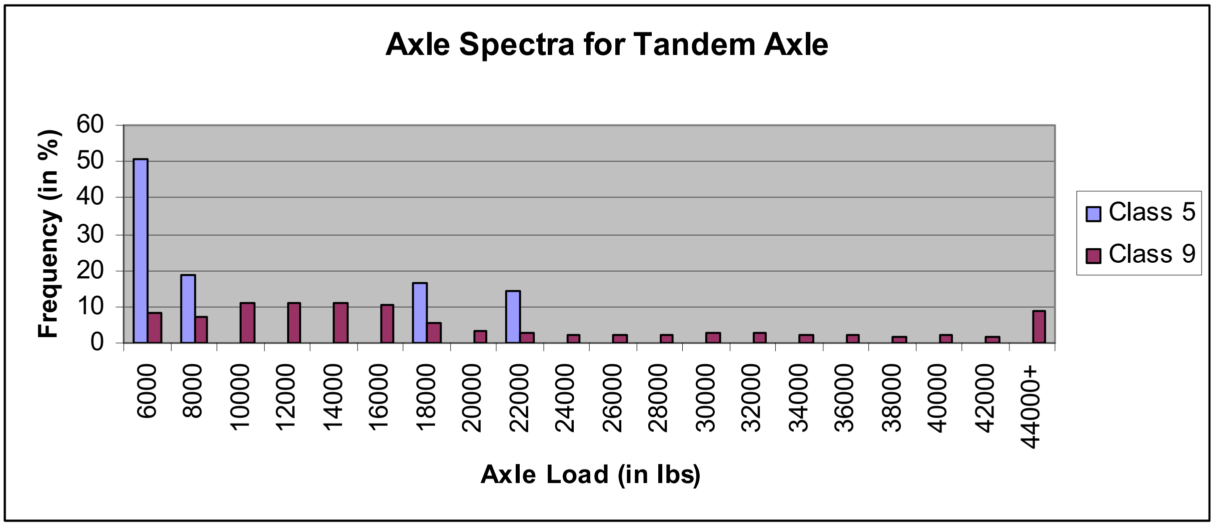


Figure 5.7: Axle Load Distribution for Tandem Axle (Location: US 62, El Paso)

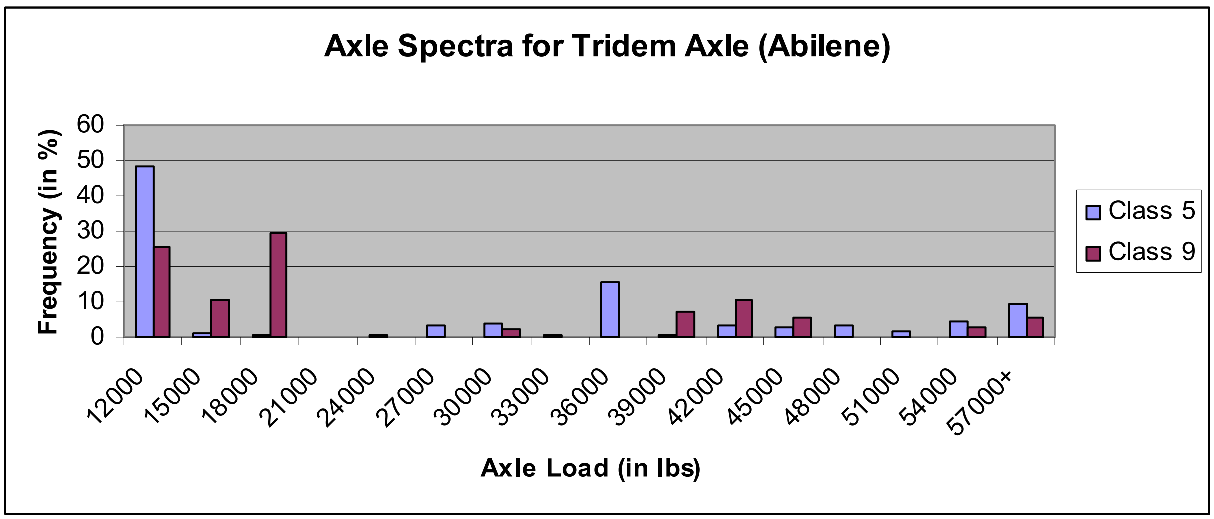


Figure 5.8: Axle Load Distribution for Tridem Axle (Location: US 62, El Paso)

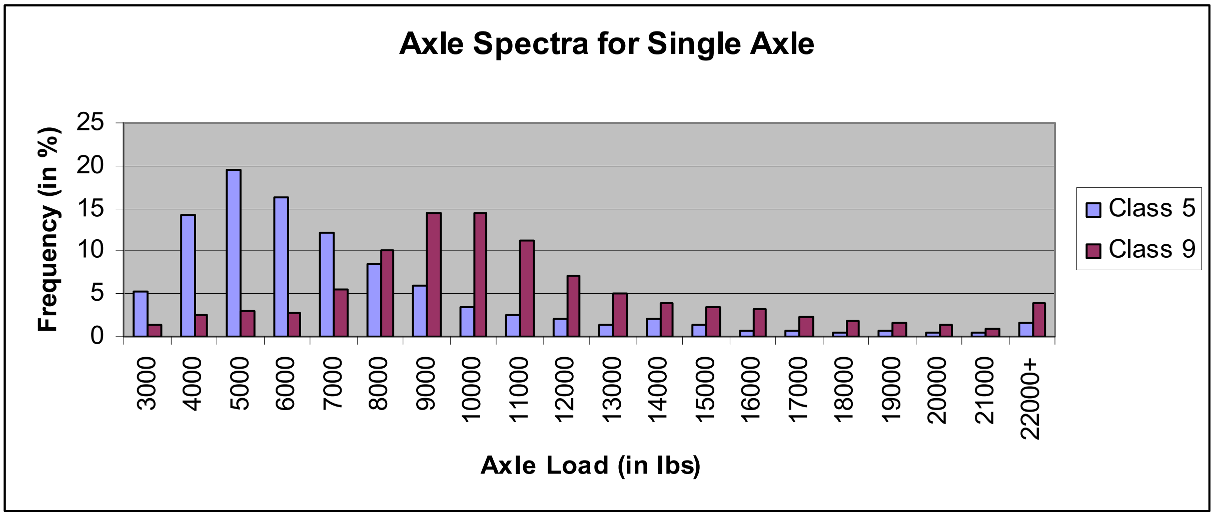


Figure 5.9: Axle Load Distribution for Single Axle (Location: SH 322, Tyler)

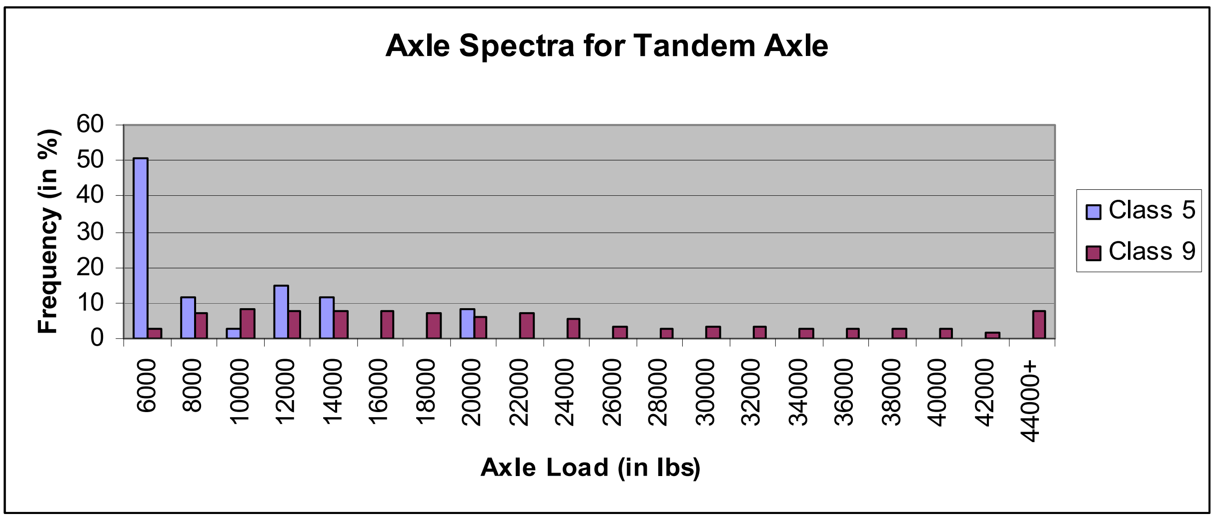


Figure 5.10: Axle Load Distribution for Tandem Axle (Location: SH 322, Tyler)

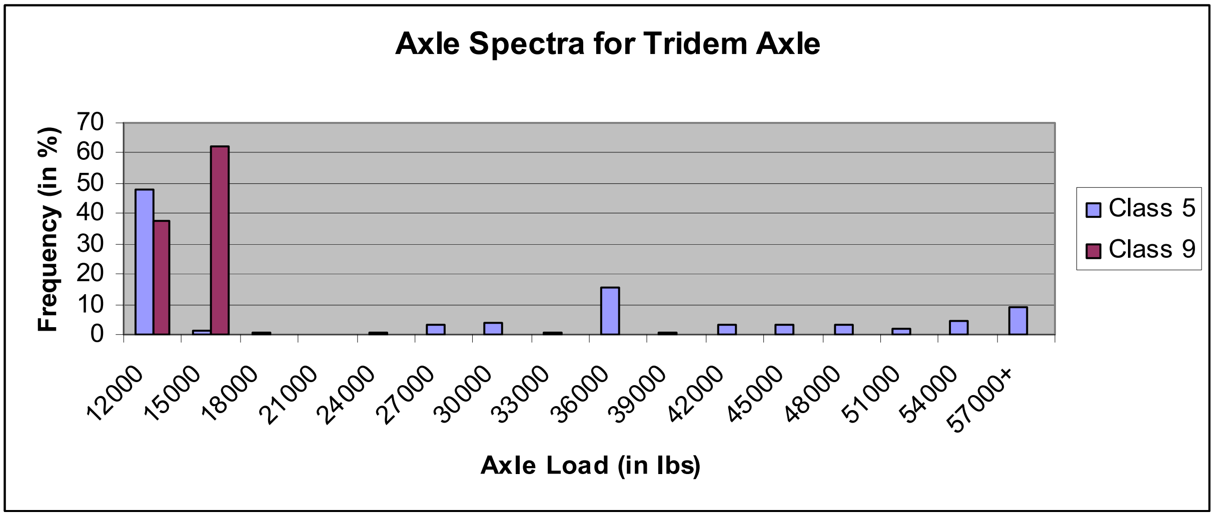


Figure 5.11: Axle Load Distribution for Tridem Axle (Location: SH 322, Tyler)

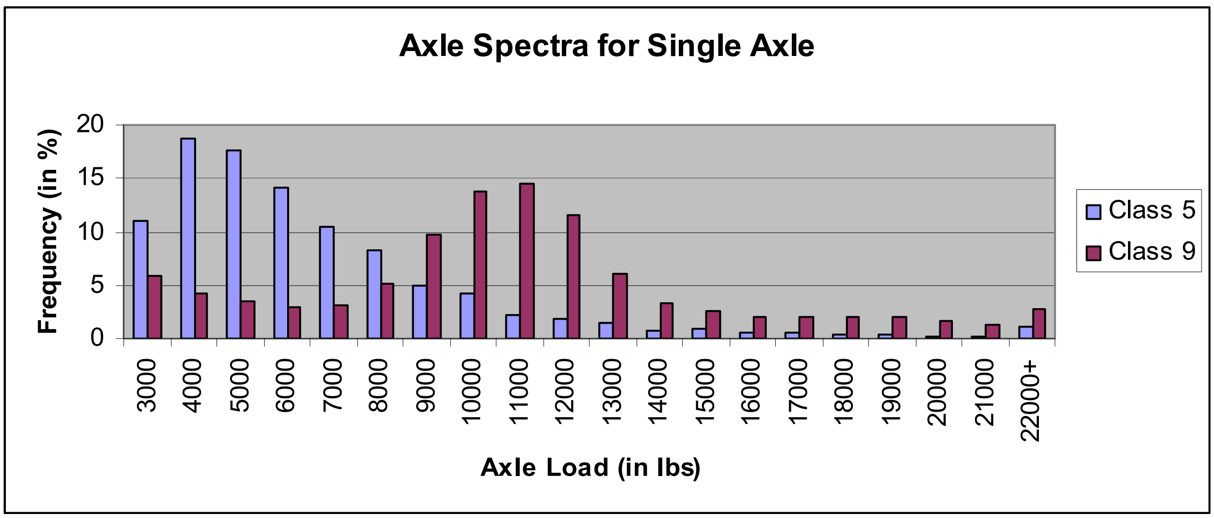


Figure 5.12: Axle Load Distribution for Single Axle (Location: US 84, Brownwood)

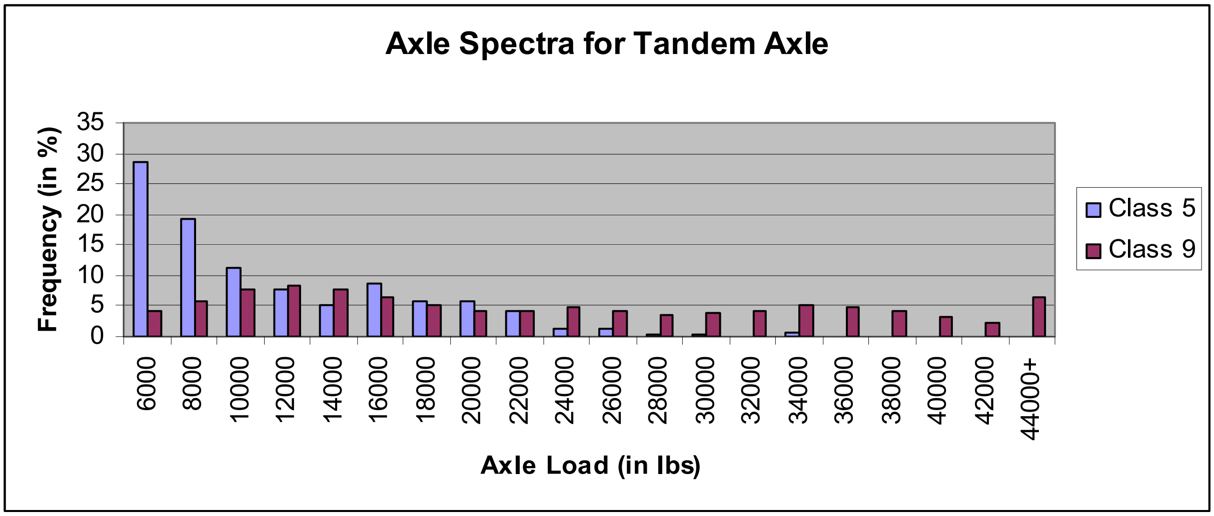


Figure 5.13: Axle Load Distribution for Tandem Axle (Location: US 84, Brownwood)

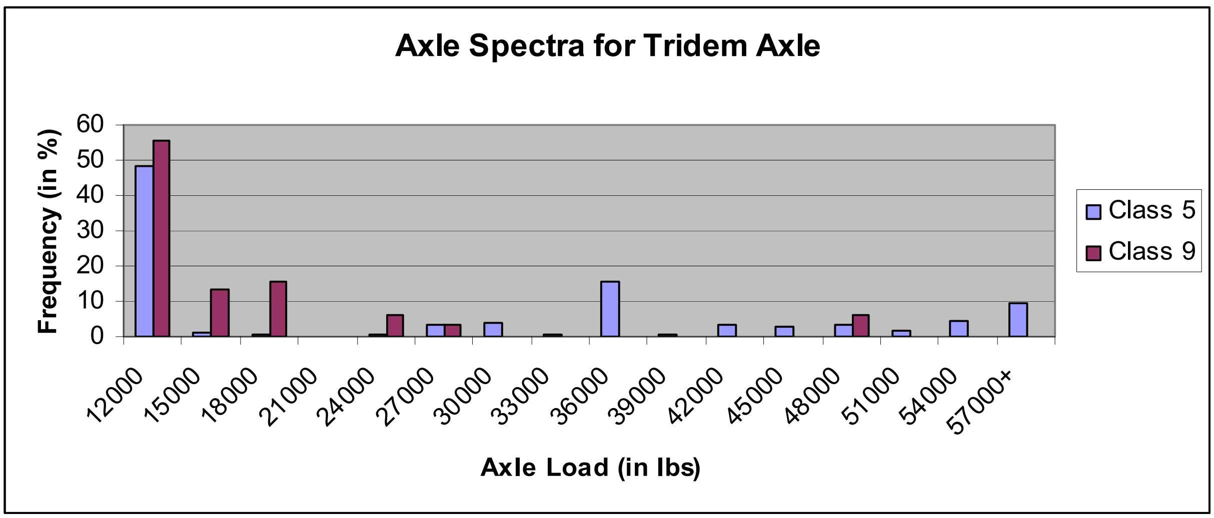


Figure 5.14: Axle Load Distribution for Tridem Axle (Location: US 84, Brownwood)

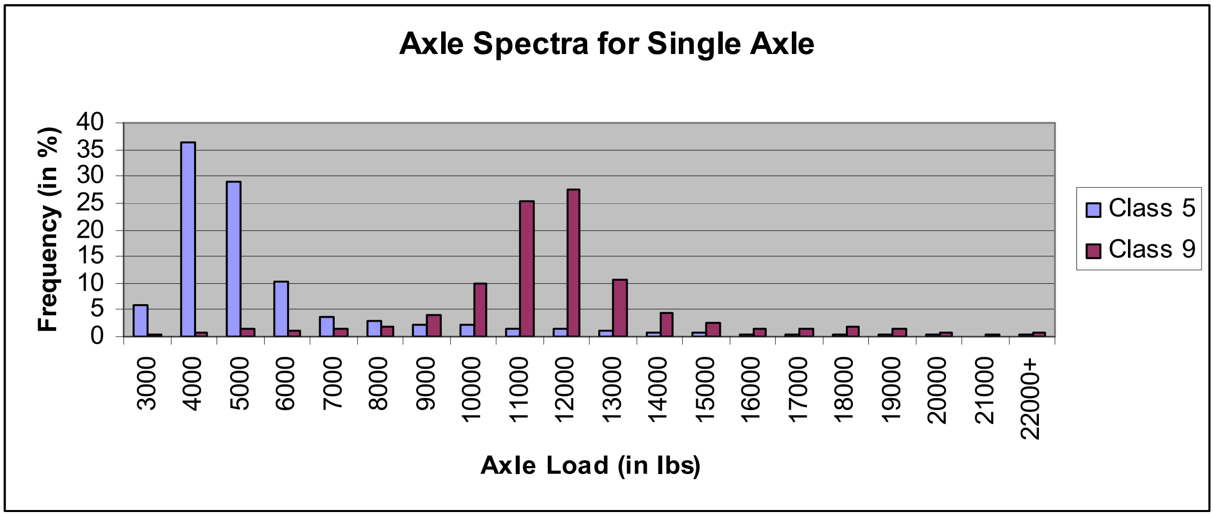


Figure 5.15: Axle Load Distribution for Single Axle (Location: US 281, Pharr)

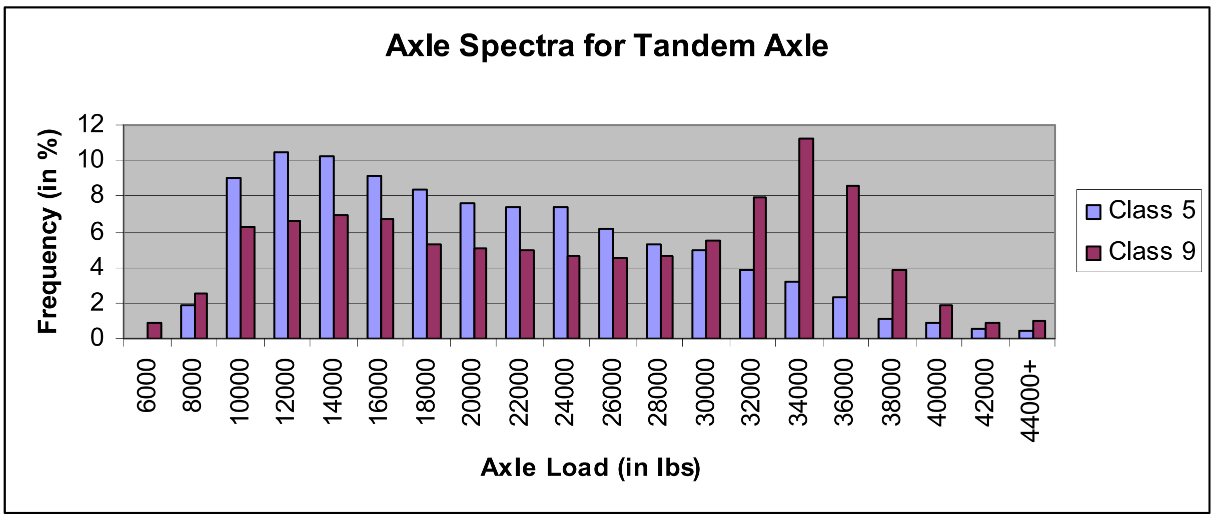


Figure 5.16: Axle Load Distribution for Tandem Axle (Location: US 281, Pharr)

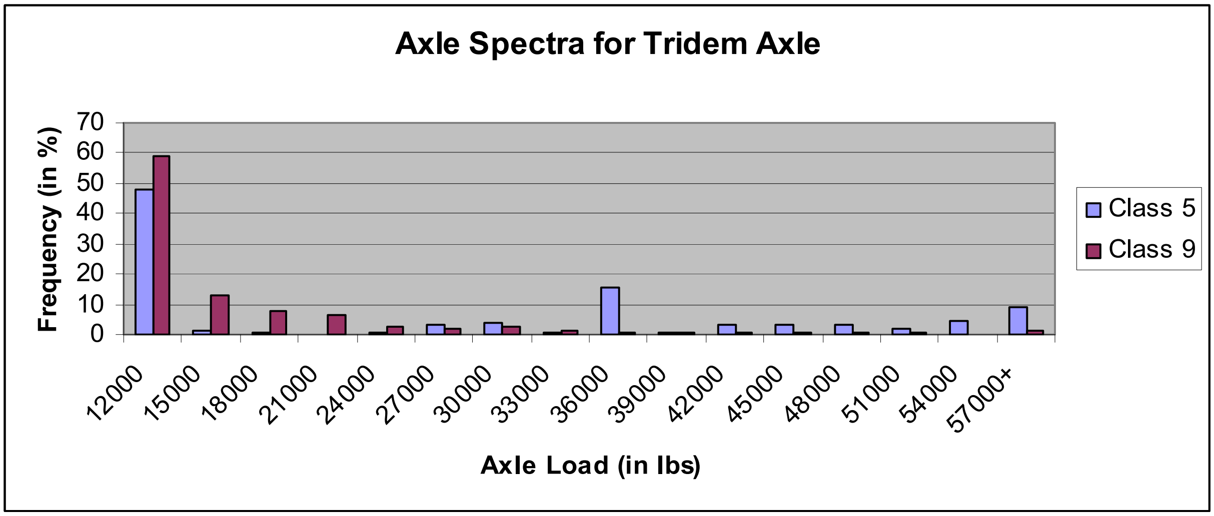


Figure 5.17: Axle Load Distribution for Tridem Axle (Location: US 281, Pharr)

5.4.4 Climate Data

For climatic data, the Enhanced Integrated Climate Module (EICM) that is incorporated into the MEPDG was used. As far as inputs to the program are concerned, it only needs the GPS location for each of the test sections. Information on starting and ending GPS locations for each of the test sections can be obtained from the PAV_SECTION table in the TFPD (for details on table design and field definition, refer to Appendix B); the details are given in Table 5.3. The other important design input to the EICM was the depth of the water table, which was restricted to a depth of 20 feet across projects. The depth of the water table was not a concern for the selected sections and it is known that the MEPDG overlooks the effect of moisture when the water table is at a depth of 20 feet or more from the pavement surface.

Table 5.3: GPS Coordinates of Test Sections

Section Id	District	County	Latitude	Longitude
TXLT24043	El Paso	El Paso	31.79963889°N	106.2595556°W
TXLT24044				
TXLT24045				
TXLT21002	Pharr	Hidalgo	26.7374166666667°N	98.1076666666667°W
TXLT21003				
TXLT21006				
TXLT21007				
TXLT21009				
TXLT10026	Tyler	Rusk	32.19627778°N	94.80327778°W
TXLT10027				
TXLT10028				
TXLT08001	Abilene	Mitchell	32.36478°N	100.99378°W
TXLT08002				
TXLT08003				
TXLT23002	Brownwood	Mills	31.56588889°N	98.66877778°W
TXLT23003				
TXLT23004				
TXLT23005				

5.4.5 Material Information

A number of key construction material parameters were obtained from the *PAV_LAYER, PAV_LAYER_HMA, PAV_BINDER, PAV_MIX,* and *PAV_LAYER_SOIL* of the Texas Flexible Pavement Database (for details on table design and field definition, refer to Appendix B). The list of parameters that were obtained is given in Table 5.4. For the calibration analyses done as part of the study, the MEPDG default values were accepted for design parameters for which information was not available.

Table 5.4: List of Material Properties obtained from the TFPD

Material Property	Table Name, Database
HMA Layer	
Binder Grade (Viscosity Grade)	PAV_BINDER
% Retained on 3/4" sieve	PAV_LAYER
% Retained on 3/8" sieve	
% Retained on #4 sieve	
% Passing #200 sieve	
Air Voids	PAV_MIX
Asphalt Content (by Wt.)	PAV_MIX
Unbound Layers	
% Passing 3" sieve	PAV_LAYER
% Passing 2" sieve	
% Passing 1 1/2" sieve	
% Passing 3/4" sieve	
% Passing 1/2" sieve	
% Passing 3/8" sieve	
% Passing #4 sieve	
% Passing #10 sieve	
% Passing #40 sieve	
% Passing #80 sieve	
% Passing #200 sieve	
AASHTO Soil Class	PAV_LAYER_SOIL
Liquid Limit	PAV_LAYER_SOIL
Plasticity Index	
Optimum Moisture Content	PAV_LAYER_SOIL
Maximum Dry Unit Weight	

Table 5.5: Material Information on HMA Layers

Section	Layer No.	Aggregate Gradation				Binder Type	Binder Content (% by Weight)	Air Voids (%)
		% retained on ¾" sieve	% retained on 3/8" sieve	% retained on #4 sieve	% passing #200 sieve			
TXLT24043	1	0	20	49.5	4.95	AC-20	6.5	6.9
	2	0	20	49.5	4.95	AC-20	6.1	6.9
TXLT24044	1	0	20	49.5	4.95	AC-20	6.5	6.9
TXLT24045	1	0	20	49.5	4.95	AC-20	6.5	6.9
TXLT08001	1	0	1.5	36.5	9.45	AC-20	5.1	2.0
	2	0	1.5	36.5	9.45	AC-10	5.1	2.0
	3	12.5	28.5	46.5	13.75	AC-10	4.25	6.0
TXLT08002	1	0	1.5	36.5	9.45	AC-20	5.1	2.0
	2	0	1.5	36.5	9.45	AC-10	5.1	2.0
	3	12.5	28.5	46.5	13.75	AC-10	4.25	6.0
TXLT08003	1	0	1.5	36.5	9.45	AC-20	5.1	2.0
	2	0	1.5	36.5	9.45	AC-10	5.1	2.0
	3	12.5	28.5	46.5	13.75	AC-10	4.25	6.0
TXLT10026	1	3.9	18.2	43.6	6	AC-20	5.2	5.2
	2	3.9	18.2	43.6	6	AC-20	5.2	5.2
TXLT10027	1	3.9	18.2	43.6	6	AC-20	5.2	5.2
TXLT10028	1	3.9	18.2	43.6	6	AC-20	5.2	5.2
TXLT23002	1	0	0	36.5	5.75	AC-10	4.925	9.6
	2	0	0	36.5	5.75	AC-10	4.925	9.6
TXLT23003	1	0	0	36.5	5.75	AC-10	4.925	9.6
TXLT23004	1	0	0	36.5	5.75	AC-10	4.925	9.6
TXLT23005	1	0	0	36.5	5.75	AC-10	4.925	9.6
TXLT21002	1	0	7	36	6.8	AC-20	4.7	2.7
	2	0	7	36	6.8	AC-20	4.7	3.2
TXLT21003	1	0	7	36	6.8	AC-20	4.7	3.1
	2	0	7	36	6.8	AC-20	4.7	4.1
TXLT21006	1	2	29	56	6.7	AC-20	4.2	4.3
	2	8	38	55	8.3	AC-20	4.9	4.2
TXLT21007	1	2	29	56	6.7	AC-20	4.2	2.2
	2	8	38	55	8.3	AC-20	4.9	5.4
TXLT21009	1	0	10	41	5.9	AC-20	4.7	2.8
	2	0	10	41	5.9	AC-20	4.7	1.5

Table 5.6: Material Information on Unbound Layers

Section	Layer No.	Sieve Analysis – Percent Passing												Atterberg's Limits	
		3"	2"	1 ½"	1"	¾"	½"	3/8"	#4	#10	#40	#80	#200	Liquid Limit	Plasticity Index
TXLT24043	3	100	100	100	97.5	95	90	84	74.5	62	50	45.5	41.5	25	9
	4	97	96.5	95.5	92	89.5	86	84	80	78	73	69.5	63.7	57.5	31
TXLT24044	2	100	100	100	97.5	95	90	84	74.5	62	50	45.5	41.5	25	9
	3	97	96.5	95.5	92	89.5	86	84	80	78	73	69.5	63.7	57.5	31
TXLT24045	2	100	100	100	97.5	95	90	84	74.5	62	50	45.5	41.5	25	9
	3	97	96.5	95.5	92	89.5	86	84	80	78	73	69.5	63.7	57.5	31
TXLT08001	4	100	100	100	97	93.5	88	85	77	64	48.5	38.5	30	23.5	4
	5	100	100	100	97	93.5	88	85	77	64	48.5	38.5	30	23.5	4
	6	100	100	100	99	99	97	95	88	85	82	77	58	27	15
TXLT08002	4	100	100	100	97	93.5	88	85	77	64	48.5	38.5	30	23.5	4
	5	100	100	100	97	93.5	88	85	77	64	48.5	38.5	30	23.5	4
	6	100	100	100	99	99	97	95	88	85	82	77	58	27	15
TXLT08003	4	100	100	100	97	93.5	88	85	77	64	48.5	38.5	30	23.5	4
	5	100	100	100	97	93.5	88	85	77	64	48.5	38.5	30	23.5	4
	6	100	100	100	99	99	97	95	88	85	82	77	58	27	15
TXLT10026	3	100	100	100	100	98.5	96.5	93.5	83	72.5	64	53	26.75	0	NP
	4	100	100	100	100	100	100	100	100	94.5	85	55	2.65	0	NP
TXLT10027	2	100	100	100	100	98.5	96.5	93.5	83	72.5	64	53	26.75	0	NP
	3	100	100	100	100	100	100	100	100	94.5	85	55	2.65	0	NP
TXLT10028	2	100	100	100	100	98.5	96.5	93.5	83	72.5	64	53	26.75	0	NP
	3	100	100	100	100	100	100	100	100	94.5	85	55	2.65	0	NP

Section	Layer No.	Sieve Analysis – Percent Passing												Atterberg's Limits	
		3"	2"	1 ½"	1"	¾"	½"	3/8"	#4	#10	#40	#80	#200	Liquid Limit	Plasticity Index
TXLT23002	3	100	100	100	97	93	86	81	69	57	42	36	28.9	19	4
	4	100	100	100	96	91	79	72	58	47	33	28	23.1	18	1
	5	100	99.5	99	97.5	96	93.5	90	83.5	76.5	67.5	63.5	56.7	21	6.5
TXLT23003	2	100	100	100	97	93	86	81	69	57	42	36	28.9	19	4
	3	100	100	100	96	91	79	72	58	47	33	28	23.1	18	1
	4	100	99.5	99	97.5	96	93.5	90	83.5	76.5	67.5	63.5	56.7	21	6.5
TXLT23004	2	100	100	100	97	93	86	81	69	57	42	36	28.9	19	4
	3	100	100	100	96	91	79	72	58	47	33	28	23.1	18	1
	4	100	99.5	99	97.5	96	93.5	90	83.5	76.5	67.5	63.5	56.7	21	6.5
TXLT23005	2	100	100	100	97	93	86	81	69	57	42	36	28.9	19	4
	3	100	100	100	96	91	79	72	58	47	33	28	23.1	18	1
	4	100	99.5	99	97.5	96	93.5	90	83.5	76.5	67.5	63.5	56.7	21	6.5
TXLT21002	3	100	100	99.7	95.8	86	71.1	63.8	51.1	32.3	26.3	17.5	7.1	0	NP
	4	100	100	99.7	95.8	86	71.1	63.8	51.1	32.3	26.3	17.5	7.1	0	NP
	5	100	100	100	100	100	100	100	99.9	99.8	99.7	62	6.4	0	NP
TXLT21003	3	100	100	99.7	95.8	86	71.1	63.8	51.1	32.3	26.3	17.5	7.1	0	NP
	4	100	100	99.7	95.8	86	71.1	63.8	51.1	32.3	26.3	17.5	7.1	0	NP
	5	100	100	100	100	100	100	100	99.9	99.8	99.7	62	6.4	0	NP
TXLT21006	3	100	99.4	98.9	88.8	72.2	56	50.6	40.6	26.5	19.8	11.1	5.9	0	NP
	4	100	99.4	98.9	88.8	72.2	56	50.6	40.6	26.5	19.8	11.1	5.9	0	NP
	5	100	99.4	98.9	88.8	72.2	56	50.6	40.6	26.5	19.8	11.1	5.9	0	NP
	6	100	100	100	100	100	100	99.4	99.3	99.1	98.7	53.3	7.8	0	NP
TXLT21007	3	100	99.4	98.9	88.8	72.2	56	50.6	40.6	26.5	19.8	11.1	5.9	0	NP
	4	100	99.4	98.9	88.8	72.2	56	50.6	40.6	26.5	19.8	11.1	5.9	0	NP

Section	Layer No.	Sieve Analysis – Percent Passing												Atterberg's Limits	
		3"	2"	1 ½"	1"	¾"	½"	3/8"	#4	#10	#40	#80	#200	Liquid Limit	Plasticity Index
	5	100	99.4	98.9	88.8	72.2	56	50.6	40.6	26.5	19.8	11.1	5.9	0	NP
	6	100	100	100	100	100	100	99.4	99.3	99.1	98.7	53.3	7.8	0	NP
TXLT21009	3	100	99.4	98.9	88.8	72.2	56	50.6	40.6	26.5	19.8	11.1	5.9	0	NP
	4	100	99.4	98.9	88.8	72.2	56	50.6	40.6	26.5	19.8	11.1	5.9	0	NP
	5	100	99.4	98.9	88.8	72.2	56	50.6	40.6	26.5	19.8	11.1	5.9	0	NP
	6	100	100	100	100	100	100	99.4	99.3	99.1	98.7	53.3	7.8	0	NP

5.4.6 Distress Data

The chapter focused on local calibration of the permanent deformation performance model of the MEPDG. Therefore, information on rutting distresses was obtained from the *PAV_FIELD_PERF_RUT* in the TFPD database.

5.5 Calibration of the Permanent Deformation Performance Model in the MEPDG

The constitutive relationship used in the MEPDG for the rutting model is based on the statistical regression analysis of laboratory repeated load permanent deformation tests. The calibration parameters can be determined by analyzing in-service pavement sections and are, therefore, adjustable and known to depend upon local conditions. The calibration is done by comparing the observed pavement performance with the predicted pavement performance over time.

For the design of flexible pavements, the MEPDG makes uses of a multi-layer liner-elastic routine for estimating stresses and strains. The estimation of stresses and strains is done every two-week period for the entire life of the pavement. The estimated stresses or strains are then used in the transfer functions (described below) for estimating pavement life and relative damage. The relative damage is then accumulated for the life of the pavement.

The design guide software was initiated with the default calibration parameters and then adjusted such that the difference between the observed and the predicted performance values are reduced progressively. The best fit minimizes the difference between the observed and the MEPDG predictions. The empirical models (transfer functions) for the asphalt concrete layer and subgrade rutting, as used in the MEPDG are as follows:

AC Rutting Transfer Function

$$\frac{\varepsilon_p}{\varepsilon_r} = k_z \beta_{r_1} 10^{k_1} T^{k_2 \beta_{r2}} N^{k_3 \beta_{r3}}$$

$$k_z = (C_1 + C_2 * depth) * 0.328196^{depth}$$

$$C_1 = -0.1039 * H_{ac}^2 + 2.4868 * H_{ac} - 17.342$$

$$C_2 = 0.0172 * H_{ac}^2 - 1.7331 * H_{ac} + 27.428$$

Where,
H_{ac} = Total AC Thickness (inches)
ε_p = Plastic Strain (inch/inch)
ε_r = Resilient Strain (inch/inch)
T = Layer Temperature (°F)
N = Number of Load Repetitions
k_1, k_2, k_3 = Regression Coefficients Determined in the Laboratory
β_{r1}, β_{r2}, β_{r3} = Calibration Coefficients

Subgrade Rutting Transfer Function

$$\delta_a(N) = \beta_{s_1} k_1 \varepsilon_v h \left(\frac{\varepsilon_0}{\varepsilon_r} \right) \left| e^{-\left(\frac{\rho}{N}\right)^{\beta}} \right|$$

Where,
δ_a = Permanent Deformation for the Layer
N = Number of Load Repetitions
ε_v = Average Vertical Strain (inch/inch)
h = Thickness of the layer (inches)
ε_0, β, ρ = Material Properties
ε_r = Resilient Strain (inch/inch)
k_1 = Regression Coefficient Determined in the Laboratory
β_{s1} = Calibration Coefficient

For the hot-mix asphalt rutting model, β_{r2} was kept constant for the analysis that was conducted under the assumption that the temperature dependency of the specific material should be determined in the laboratory for a given mix. Following along the same lines as the national calibration of the MEPDG, it was decided that a range of β_{r1} and β_{r3} would be chosen for the local calibration exercise. The calibration coefficient β_{r1} is a shift factor that modifies the intercept term of the rutting model. This factor primarily captures differences in the distress predictions due to varying thicknesses of the HMA layers and other initial conditions. β_{r3} captures the differences arising out of the number of load repetitions, thus, it represents the rate of rutting progression.

In the case of subgrade rutting, the calibration coefficient β_{s1} captures the deviation in predictions from the observed distresses that may arise due to differences in the material properties. For the current study, the β_{s1} was preset to regional defaults. The defaults were chosen as 0.3 for West Texas (Abilene and El Paso) and 0.7 for East Texas (Tyler and Pharr). These regional defaults were selected on the basis of average moisture content for the subgrade soil, which was previously also done for other similar studies (von Quintus and Moulthrop, 2007).

Trial runs were conducted with several possible combinations of the calibration coefficients for the sections included in this study. It was observed that the distress predictions were highly sensitive to β_{r3} and less to β_{r1}. For this reason, a higher precision (iteration step) was chosen for β_{r3} (i.e., 0.002) than for β_{r1} (i.e., 0.1).

The model output and best fit were estimated in terms of the Sum of Squared Errors (SSE). The SSE represents the squared sum of the differences between the observed and the predicted distress values. It can be expressed as,

$$(\text{SSE}) = \sum_{i=1}^{N} \left(\text{Output from the MEPDG - Observed Distress Value as obtained from LTPP database}\right)^2$$

where,
N = Number of observed data points/distress measurements
SSE = Sum of Squared Errors

5.5.1 Final Calibration Coefficients

The intent of this whole exercise was to determine a set of bias correction factors for each of the regions (Level 2 calibration coefficients). The regional HMA rutting calibration coefficients as obtained after minimizing the sum of squared errors is given for one of the regions in Figure 5.18. The calibration factors shown in the figures were obtained after running the MEPDG between 200 and 600 times per pavement section with each run taking almost 20 minutes to execute on a Pentium 4 computer. Therefore, there is a high level of confidence that the values given represent the global optima. However, it is possible that the absolute minima may be somewhere outside the bounded region. This will always be the case for multi-dimension non-linear problems such as this one. Therefore, further efforts in this direction are recommended, though the benefit of such an exercise may be less due to the amount of time it will require.

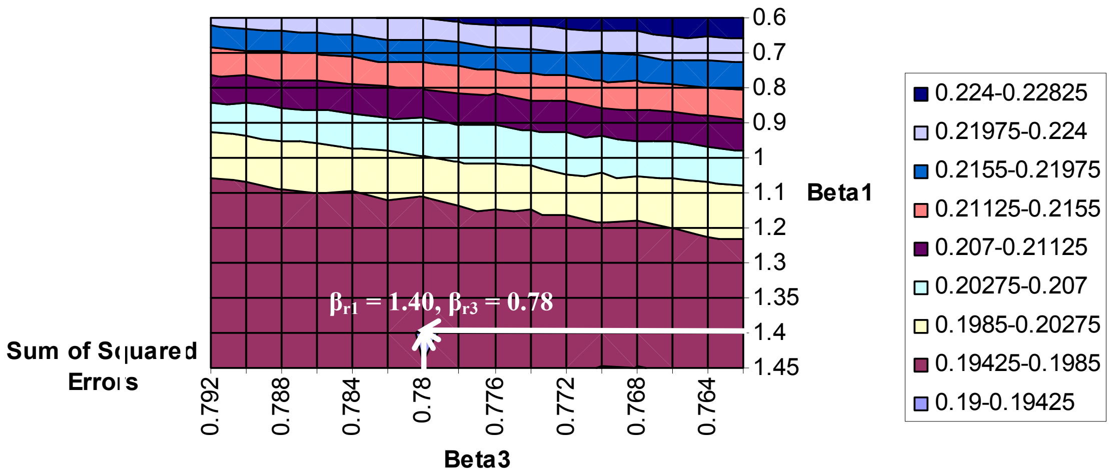


Figure 5.18: Calibrated AC Rutting Coefficients for Texas Hill Country (βr1 = 1.4 and βr3 = 0.78)

5.5.2 Comparison of Calibrated Versus Uncalibrated MEPDG Predictions

Figures 5.19 through 5.22 show the predictions as obtained from the permanent deformation prediction model in the MEPDG before and after the calibration exercise was performed for one of the regions under study (Hill Country/Central Texas). It could be argued that, for Level 1 purposes, it is possible to obtain a better fit between the predictions and observations for the cases included in this study. However, it should be remembered that because it is a Level 2 calibration, the sum of squared errors were minimized jointly for all the sections in that specific location. It has been observed during this exercise that there are often scenarios where the reduction in the sum of squared errors for one section is compensated by the gain in the sum of squared for another, subject to both sections belonging to the same region. The results of the analysis are discussed in more detail in the following section.

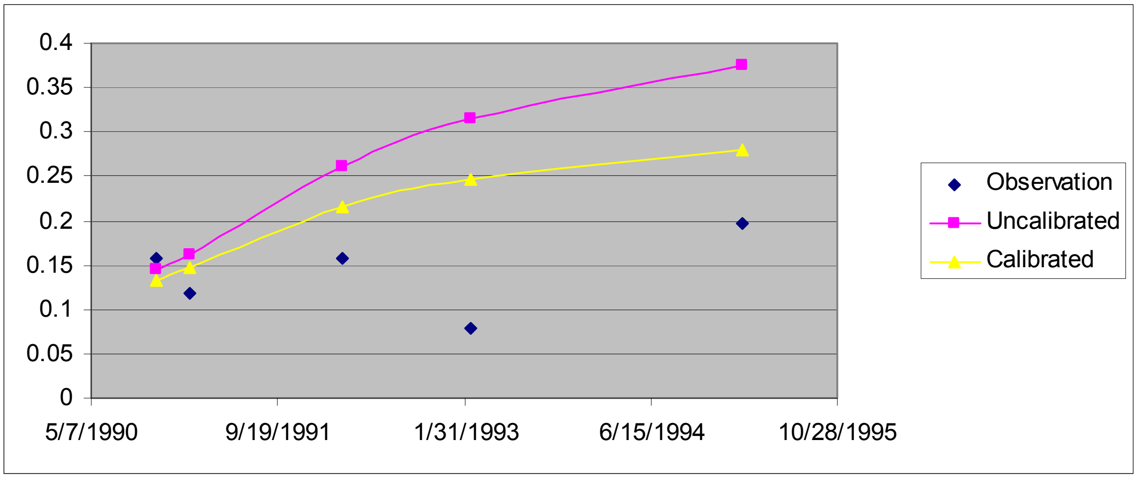


Figure 5.19: Calibrated V/s Uncalibrated Predictions for Section 48-Q310 (Brownwood)

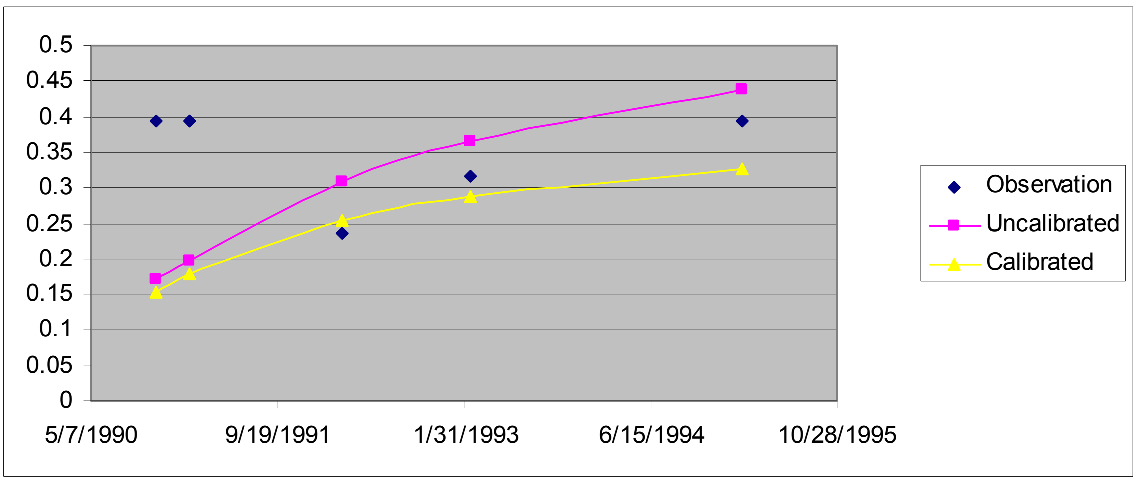


Figure 5.20: Calibrated V/s Uncalibrated Predictions for Section 48-Q320 (Brownwood)

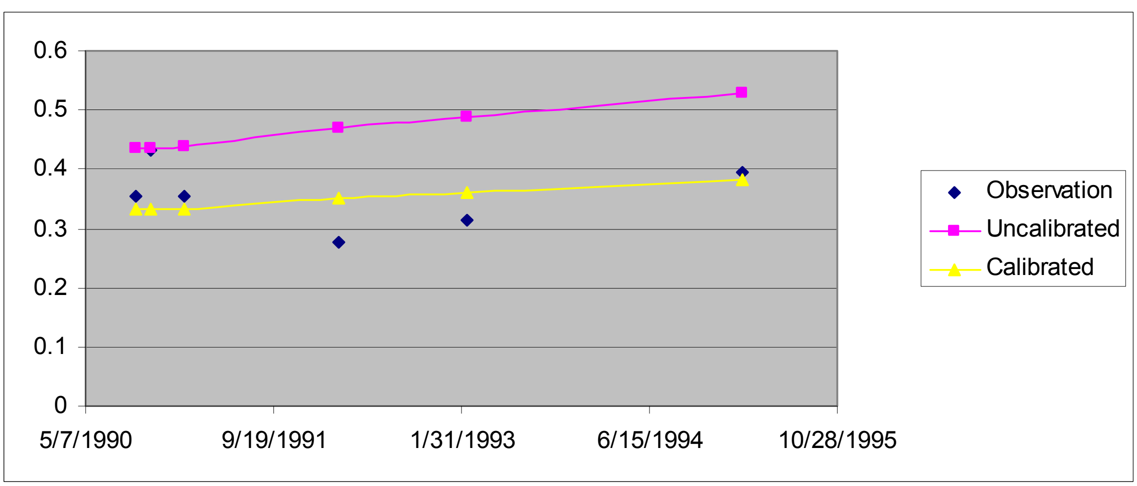


Figure 5.21: Calibrated V/s Uncalibrated Predictions for Section 48-Q330 (Brownwood)

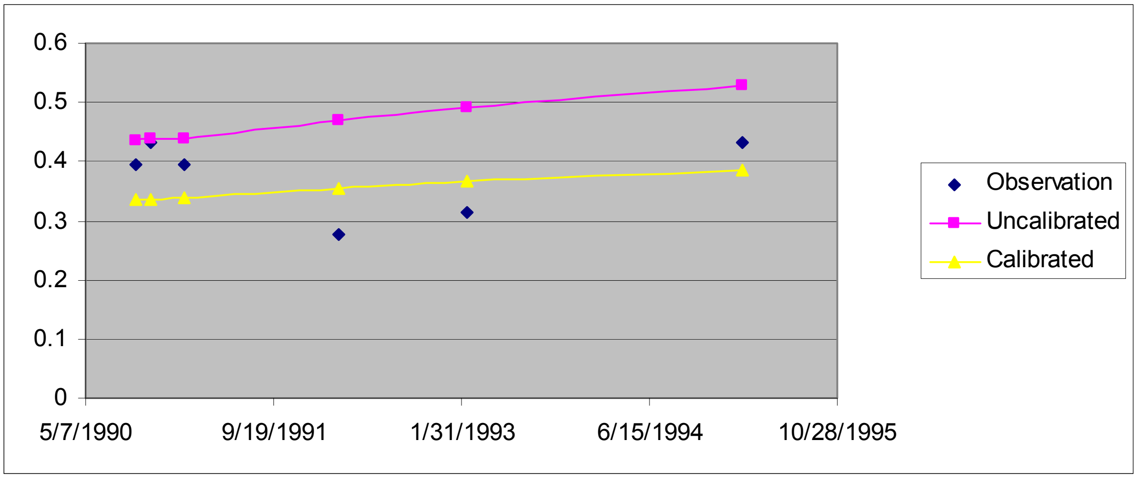


Figure 5.22: Calibrated V/s Uncalibrated Predictions for Section 48-Q340 (Brownwood)

5.6 Results

As stated previously, the purpose of the calibration exercise was to obtain a set of Level 1 calibration factors (section specific). Then, using the section-specific factors for a given region, to develop Level 2, regional, calibration coefficients for the HMA rutting for each of the regions and at the same time obtain a set of Level 3, state default, calibration coefficients for Texas. The Level 2 calibration that was conducted for each of the five regions involved determining a set of calibration coefficients that jointly minimizes the sum of squared errors for all the sections (within a specific region) taken together. Although this method is mathematically sounder, it requires a significant amount of computation effort when the number of sections increases. Following a similar methodology to obtain the Level 3 calibration parameters would have meant running a joint minimization routine with 18 sections together—a process that would have been extremely time-consuming. Therefore an average of the Level 2 calibration coefficients was computed to obtain the Level 3 calibration parameters for Texas for the permanent deformation performance model as given in the MEPDG. The results as obtained are summarized in Figure 5.40.

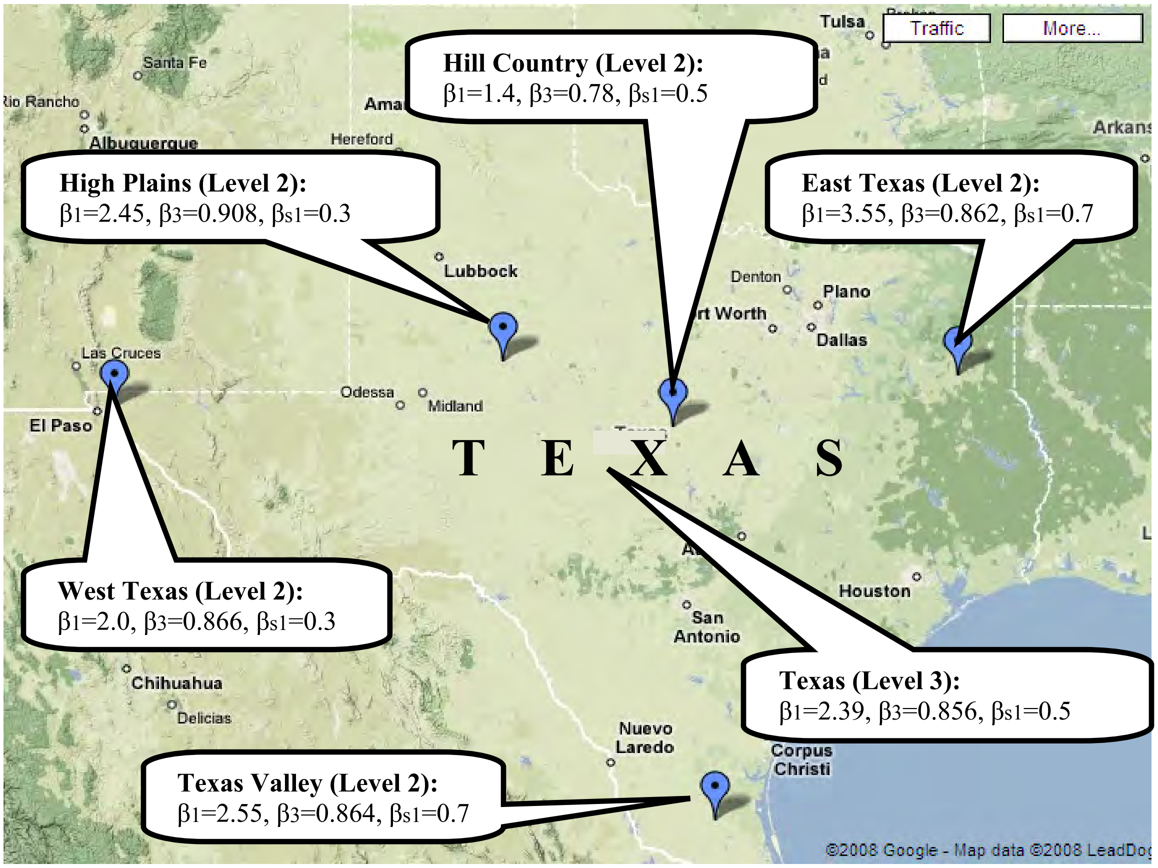


Figure 5.23: Regional and State Level Calibration Coefficients for the Permanent Deformation Performance Model in MEPDG

Since, the primary focus of this research work was towards obtaining a pair of calibration coefficients for the AC permanent deformation model, it will be worthwhile to report the standard error of the predictions obtained from the MEPDG at a regional level (given in Table 4).

Table 5.7: Standard Error of the MEPDG Permanent Deformation Performance Model for each of the Calibrated Regions

Serial No.	County	District	Region	Standard Error of Predicted Permanent Deformations – Before Calibration	Standard Error of Predicted Permanent Deformations – After Calibration
1	El Paso	El Paso	West Texas	0.059413911	0.057594087
2	Mitchell	Abilene	High Plains	0.092022113	0.081416146
3	Mills	Brownwood	Hill Country	0.130935368	0.093925462
4	Rusk	Tyler	East Texas	0.12468411	0.111007265
5	Hidalgo	Pharr	Texas Valley	0.095821401	0.094396415

5.7 Summary of Rutting Model Calibration

This chapter summarized the research results obtained from the study conducted to calibrate the MEPDG permanent deformation performance model for the State of Texas. It is well known that to propose a set of calibration coefficients for a state or a region, the minimization of residual error should be done jointly for all the sections included in that region. Because the simulation matrix included a large number of sections, the amount of time required to run the MEPDG increased significantly, and minimizing the sum of squared errors seemed to be impractical. Therefore, it was decided to run a joint optimization for the regional calibration coefficients and average them out to obtain a Level 3 calibration coefficient for Texas. It is important to note the possibility that the set of bias correction factors proposed in the present study may not be optimal because the point that gives the least SSE may not be the global minima for the entire search space due to the multi-dimensional non-linear nature of the optimization process. However, no method can guarantee the later. Finally, although there is room for further adjustments, the set of correction factors proposed in this study may be safely used for the regions and locations discussed in the study instead of the default values, which correspond to a national average.

Chapter 6. Proposed Modifications of the MEPDG Roughness Models for Texas

6.1 Background on the Roughness Model

As opposed to the rutting and cracking models, the roughness model incorporated into the MEPDG is a purely empirical model. Therefore, before embarking in the calibration of the roughness model, it is necessary to evaluate its validity. The smoothness prediction models (in IRI) currently incorporated into the MEPDG have been developed by means of Ordinary Least Squares (OLS). However, some of the variables that are used in predicting future IRI were previously estimated by means of separate performance models, which could cause bias because of the correlation between the previously estimated distress types and the unobserved components on the IRI model. The bias in this case can be corrected by considering additional variables that are correlated with the distress types causing the bias, thus eliminating the correlation to the unobserved terms in the model.

There can also be bias in the IRI model that is generated by unobserved factors that are not included in the model. If these factors are section-specific, the bias can be removed by taking into consideration performance time history data from several pavement sections.

The researchers have used updated LTPP data that are consistent with the dataset originally used to fit the current MEPDG IRI model for flexible pavements over granular bases. The data were then used in modeling IRI by means of OLS and Instrumental Variable Regressions analyzing the data as pooled, and as a panel dataset (by a fixed-effects and a random-effects approach) to check for possible bias in the model. The preferred IRI model was determined to be the random effects approach and, therefore, the model parameters were estimated correcting for the omitted variable bias and simultaneous equation bias.

The concept of smoothness was first included in a design procedure as a result of the American Association of State Highway Officials (AASHO) Road Test through the concept of serviceability (AASHO, 1962). Serviceability, which is a qualitative measure of how a panel of users of a given pavement section perceive the quality of the pavement, was then related to several distress types, which were found to play a major role in reducing the level of serviceability of the pavement. This is known as the American Association of State Highway and Transportation Officials (AASHTO) Serviceability Equation,

$$\mathrm{PSR} = 5.03 - 1.91 \cdot \log(1+\mathrm{SV}) - 0.01 \cdot (\mathrm{C}+\mathrm{P})^{0.5} - 1.38 \cdot \mathrm{RD}^2 \qquad (1)$$

where PSR is known as the present serviceability rating (mean panel serviceability rating), SV is the slope variance, C is major cracking in ft per 1000 sq ft area, P represents patching in sq ft per 1000 sq ft area, and RD is the average rut depth of both wheel paths in inches measured at the center of a 4-ft span in the most deeply rutted part of the wheel path.

Additional models were later developed to predict PSR by Darter and Barenberg (1976) and Al-Omari and Darter (1992), where additional variables were proposed to account for PSR, such as rut depth variance and depressions.

An important observation regarding pavement serviceability is that it was identified to be highly related to pavement performance and roughness (Carey, 1960). Serviceability was later correlated to smoothness, measured in terms of the International Roughness Index (IRI), which was developed by The World Bank during the 1980s. The IRI measures the roughness in in/mi or an equivalent unit. Several relationships have been developed by analyzing IRI and PSR data. One such example analyzed data from Louisiana, Michigan, New Jersey, New Mexico, Ohio, and Indiana (Al-Omari and Darter, 1992). The model that was developed was a direct nonlinear relationship as shown next (IRI measured in in/mi),

$$\mathrm{PSR} = 5 \cdot \exp(-0.26 \cdot \mathrm{IRI}) \tag{2}$$

A similar model was calibrated by Paterson (1986),

$$\mathrm{PSR} = 5 \cdot \exp(-0.18 \cdot \mathrm{IRI}) \tag{3}$$

More recently, because of the availability of profilers that can measure pavement profile at highway speeds, the focus has shifted to developing and calibrating equations that directly predict IRI. This is the case with the recently developed MEPDG, which includes such a model, and is expected to become widespread in terms of use in the following years. Therefore, it is important that an efficient and calibrated model be readily available.

6.2 The MEPDG IRI Model

As is the case with previous PSR models, the MEPDG IRI model has been defined as a linear function of different distress types and subgrade properties. The initial functional form that was selected for the model was as follows (Von Quintus et al., 2001a, 2001b),

$$\mathrm{IRI} = \mathrm{IRI}_0 + \Delta\mathrm{IRI}_D + \Delta\mathrm{IRI}_F + \Delta\mathrm{IRI}_S \tag{4}$$

where IRI is a function of the initial IRI (IRI_0), the effect of various distresses ($\Delta\mathrm{IRI}_D$), the subgrade frost heave potential ($\Delta\mathrm{IRI}_F$), and the subgrade swelling potential ($\Delta\mathrm{IRI}_S$) on IRI. By means of "stepwise" Ordinary Least Squares (OLS) regression (Von Quintus et al., 2001a, 2001b) variables that had a significant effect on change in IRI were identified. The final model for flexible pavements with unbound aggregate bases and subbases follows (Von Quintus and Yau, 2001c) (Mirza and Zapata, 2003),

$$\begin{aligned}\mathrm{IRI} = {} & \mathrm{IRI}_0 + 0.0463 \cdot \left[\mathrm{SF} \cdot \left(\exp\left(\frac{\mathrm{age}}{20}\right) - 1\right)\right] + 0.00119(\mathrm{TC}_L)_T \\ & + 0.1834(\mathrm{COV}_{RD}) + 0.00384(\mathrm{FC})_T + 0.00736(\mathrm{BC})_T + 0.00155(\mathrm{LC}_{SNWP})_{MH}\end{aligned} \tag{5}$$

From Equation 5 it can be observed that IRI is a function of the initial IRI (which recent research indicates to be one of the major components in determining the change in roughness), a site factor (SF) that encompasses subgrade and environmental properties, the age of the pavement structure after initial construction, and the following types of pavement distress,

$(\mathrm{TC}_L)_T$: total length of low, medium, and high severity transverse cracks in m/km.

(COV_{RD}): rut depth coefficient of variation in percent.

$(\mathrm{FC})_T$: total area of low, medium, and high severity fatigue cracking in percentage of wheel path area.

$(BC)_T$: total area of low, medium, and high severity block cracking in percentage of total lane area.

$(LC_{SNWP})_{MH}$: medium and high severity sealed longitudinal cracks outside the wheel path in m/km.

As was previously mentioned, the model includes a site factor that captures the effect of general subgrade and environmental conditions. More specifically, the SF term is defined as follows,

$$SF = \left[\frac{(R_{SD})\cdot(P_{0.075}+1)\cdot(PI)}{2x10^4}\right] + \left[\frac{\ln(FI+1)\cdot(P_{0.02}+1)\cdot\ln(R_m+1)}{10}\right] \quad (6)$$

where R_{SD} is the standard deviation in monthly rainfall (mm), R_m is the average annual rainfall (mm), FI is the average annual freezing index, $P_{0.075}$ is the percent material passing the 0.075 sieve, $P_{0.02}$ is the percent material passing the 0.02 sieve, and PI is the plasticity index of the subgrade soil.

An initial observation of the IRI model shows that the model does not include a constant term: the initial change in IRI is being forced to zero. Although the previous is intuitive, a constant term should be included to account for possible omitted-variable bias in the model. If after fitting the model that includes a constant term there is statistical evidence that the constant term is not significantly different from zero, only then should the constant term be dropped from the model.

A potential problem of the initial IRI term that is included in the model is how it was determined. From Von Quintus et al. (2001a), the initial IRI was estimated by linearly regressing the available IRI data for each of the pavement sections individually, and then using the estimated slope and intercept for each section to extrapolate the IRI at the time of construction. This original approach can be improved in a number of ways. The initial IRI was extrapolated based on an average of three time series observations for each pavement section that were recorded approximately 15 years after the pavement section was originally constructed (and that might have undergone several maintenance and rehabilitation procedures along the way). Additionally, because the dates on which cracking and rutting were measured do not necessarily match the dates on which IRI was observed, the same individual linear models for each pavement section were used to estimate IRI at the time that the other distress types were measured. Therefore, the M-E PDG IRI model is being estimated by means of previous linear predictions of IRI that have a prediction error associated with them, instead of using the actual observed IRI data.

The researchers believe that the unobserved initial IRI should be captured through the intercept term in the model, removing the need for extrapolating over such a long period of time and uncertainty. Also, there are methods to fit the IRI model that will take advantage of the type of data that are being used to fit the model, and that account for correlation between the different distress types that are being used as independent variables in the model and the unobserved factors that have been unaccounted for. Additionally, the data will allow for eliminating the bias that is due to omitted variables that are constant for the different pavement sections used in estimating the IRI model. A brief overview of these modeling techniques and their advantages is provided in the following section.

6.3 Instrumental Variable Regression

The most common estimation technique and the one used to estimate the MEPDG IRI performance model is OLS. The OLS model for IRI can theoretically be represented as follows,

$$IRI = \beta_0 + \beta_1\left[SF \cdot \left(\exp\left(\frac{age}{20}\right) - 1\right)\right] + \beta_2(TC_L)_T + \beta_3(COV_{RD}) + \beta_4(FC)_T + \beta_5(BC)_T + \beta_6(LC_{SNWP})_{MH} + \varepsilon \qquad (7)$$

where the β_i represent the parameters to be estimated and ε represents the error term, which accounts for all the unobserved factors that have not been included in the model but that have an effect on change in IRI.

OLS assumes that the predicted IRI is a linear combination of the estimated parameters, which are found by minimizing the square difference between the measured observations and the predicted values. This would ensure that the estimated parameters are the "best" in terms of being unbiased and having the minimum variance, given the IRI, distress and site specific information meet the OLS model assumptions. Nonetheless, the previous statement can only be shown to be true if the following conditions are met (Greene, 2008):

1. Nonautocorrelation: the error terms ε_i are uncorrelated among themselves.
2. Exogeneity of independent variables: there is no correlation between the error term ε_i and the independent variables

Unfortunately, in the M-E PDG the IRI model is not used independently: estimating IRI at a future time depends on previous estimations of other performance prediction models, mainly rutting, fatigue cracking, and other types of fracture. In this sense, the IRI predictions are simultaneously being estimated along with rutting and fatigue cracking, which can conceptually be expressed as follows,

$$\begin{aligned} IRI &= \beta_0 + \beta_1\left[SF \cdot \left(\exp\left(\frac{age}{20}\right) - 1\right)\right] + \beta_2(TC_L)_T + \beta_3[E(COV_{RD}) + \varepsilon_{COV}] \\ &\quad + \beta_4[E(FC)_T + \varepsilon_{FC}] + \beta_5(BC)_T + \beta_6(LC_{SNWP})_{MH} + \varepsilon_{unobserved\ \ variables} \\ &= \beta_0 + \beta_1\left[SF \cdot \left(\exp\left(\frac{age}{20}\right) - 1\right)\right] + \beta_2(TC_L)_T + \beta_3[E(COV_{RD})] \\ &\quad + \beta_4[E(FC)_T] + \beta_5(BC)_T + \beta_6(LC_{SNWP})_{MH} + \varepsilon_{total} \end{aligned} \qquad (8)$$

where instead of an observed rutting coefficient of variation and fatigue cracking, the expected value that is determined using the adequate MEPDG models, $E(COV_{RD})$ and $E(FC)_T$ are used. The previous expectations, however, have an error term that is associated with their respective prediction models: ε_{COV} and ε_{FC}, which needs to be considered. Consequently, the "total" error term or disturbance associated with predicting IRI is,

$$\varepsilon_{total} = \varepsilon_{unobserved\ variables} + \beta_3\ \varepsilon_{COV} + \beta_4\ \varepsilon_{FC} \qquad (9)$$

Then, the total error will be correlated with the "independent" variables $E(COV_{RD})$ and $E(FC)_T$. Therefore the exogeneity assumption that would ensure that the OLS estimation is the "best" is not satisfied—the previous variables are endogenous. Failing to meet this assumption and using the OLS estimates will produce biased estimates. In order to address the simultaneous equations bias, an instrumental variable estimator can be used. The instrumental variable estimator estimates the parameters of interest not only using the independent variables in the M-E PDG IRI model, Equation 7, but also introduces a set of "instrumental" regressors that are correlated with the endogenous variables in an effort to absorb the correlation between the endogenous variables and the error term. In doing so, the new set of regressors becomes exogenous and the estimates unbiased.

The instrumental variable estimates can be obtained by means of 2 Stage Least Squares (2SLS), which is obtained, as the name suggests, in two steps: 1) project the new set of regressors on the original set of regressors, and 2) run least squares regression using the projections calculated in step 1.

6.4 Instrumental Variable Regression with Panel Data

Up to this point, an attempt has been made to correct for bias in the IRI model due to correlation between the regressors (independent variables) and the error term; however, better predictions of IRI can be obtained if the type of data that are being used in modeling IRI are taken into account. In estimating the previous IRI models, all the time series data (performance information for a given pavement section through time) and the cross-sectional data (different pavement sections at any given time) have been combined or pooled together. The data consist of a panel data set: cross-sectional and time series data (Prozzi and Madanat, 2003).

Because in a panel dataset several pavement sections are monitored through time, the bias in the model can be further reduced by accounting for unobserved variables that differ from one section to the next, such as additional weather phenomena, drainage conditions, or subgrade properties that are site specific variables, but that do not change over time: this is known as heterogeneity. In the current study, this type of omitted variable bias is dealt with by means of both the fixed-effects approach and the random-effects approach (while still using instruments for some of the independent variables to account for endogeneity).

Both the fixed effects approach and the random effects approach assume that the differences between pavement sections can be captured by differences in the intercept term (Prozzi and Madanat, 2003). This is achieved in the fixed-effects approach by estimating an intercept for each of the pavement sections included in fitting the model, while the random-effects model makes the assumption that the intercept is randomly distributed through the pavement population. Both of these approaches differ from OLS in the assumption that the intercept is not constant for the pavement sections. The fixed effect model for IRI can be represented as follows,

$$IRI = D_i\alpha_i + \beta_1\left[SF \cdot \left(\exp\left(\frac{age}{20}\right) - 1\right)\right] + \beta_2(TC_L)_T + \beta_3(COV_{RD}) + \beta_4(FC)_T + \beta_5(BC)_T + \beta_6(LC_{SNWP})_{MH} + \varepsilon \quad (10)$$

where all the parameters are defined as previously, α_i is a pavement section specific intercept, and D_i is a dummy variable that is 1 for pavement section "i" and 0 elsewhere. The disadvantage of the model is that, depending on the number of pavement sections included in the modeling process, numerous intercept terms will have to be determined at the cost of losing degrees of freedom. Also, the intercepts are specific to each pavement section that was sampled to fit the IRI model, but not necessarily applicable to the entire pavement population in the country.

Instead of eliminating heterogeneity by means of the fixed effects approach, the random effects approach may be used. The random effects model for IRI is as follows,

$$IRI = \beta_1 + \mu_i + \beta_1\left[SF \cdot \left(\exp\left(\frac{age}{20}\right) - 1\right)\right] + \beta_2 (TC_L)_T + \beta_3 (COV_{RD}) + \beta_4 (FC)_T + \beta_5 (BC)_T + \beta_6 (LC_{SNWP})_{MH} + \varepsilon \quad (11)$$

where the μ_i term is the random component of the intercept intended to capture omitted variable bias that is constant over time for each specific pavement section. The structural form of the model allows for testing whether there is heterogeneity in the model by testing if the variance in the μ_i term is significantly different from zero. This is done by means of a Lagrange multiplier test. There is a slight disadvantage to the random-effects model in the sense that in order to estimate it, the assumption that the pavement section specific effects are uncorrelated with the remaining regressors has to be made.

Both models have been estimated and both have inherent advantages and disadvantages. In order to compare the models, the Hausman Test (Greene, 2008) can be applied to test the hypothesis of no correlation between the pavement specific effects and the remaining regressors (random-effects model assumption). Based on the conclusion of the test a preferred model can be chosen.

6.5 Extending the TFPD for the IRI Model Estimation

For estimating the enhanced MEPDG IRI model for flexible pavements over thick granular bases, the researchers chose to use section contained in the TFPD and additional LTPP sections not contained in the TFPD. This was necessary because a large database was required. In addition, this is consistent with the data used to estimate the original model, but the data have been significantly updated. Specifically, the data were collected from pavement sections belonging to the General Pavement Studies 1 (GPS-1) experiment as of Standard Data Release 22. The GPS-1 pavement sections consist mostly of asphalt concrete pavements over granular bases. The 95 GPS-1 pavement sections included in the current study span the entire country. The geographical distribution of the pavement sections is shown in Figure 6.1.

The pavement sections were selected based on the availability of the pavement section specific information as required by the MEPDG IRI model, and some additional information that was considered by the authors to be relevant in performance of pavement structures. The additional information has been used as instrumental variables in an effort to eliminate exogeneity in the IRI model. The endogeneity in the model was assumed to be due to fatigue cracking and rutting (as measured by rutting coefficient of variation—CoV).

The variables selected as instrumental variables for fatigue cracking, $(FC)_T$, and for rutting, (COV_{RD}), are thickness of the asphalt layer (h_{AC}) and thickness of the granular base (h_{GB}), air voids (V_a) and binder content (P_b) for the surface HMA layer, and truck traffic (AADTT). The previous instrumental variables were chosen as they represent the bulk of the independent variables in the M-E PDG fatigue cracking and rutting performance models and, as such, are expected to be highly correlated with the variables for which they act as instruments.

Because truck traffic is recorded only for a given number of years in the LTPP database, and it is not necessarily available for the dates on which IRI, cracking, or rutting evaluations were carried out, a linear regression on the traffic history for each of the included pavement sections was performed. The linear estimates for each of the pavement sections were used to interpolate the expected traffic at the time of the distress observations.

Figure 6.1: Location of pavement sections included in the current study

The performance data contained in the LTPP database for each of the pavement sections is not recorded simultaneously for the different distress types. In other words, the IRI is not measured at the same time that cracking and rutting surveys are performed. However, in order to fit the IRI model, simultaneous observations of IRI, cracking, and rutting were required.

Performing a linear regression on profile data, and using such a regression to predict IRI at the time of the available cracking and rutting observations is the most efficient approach. If the predicted IRI data are used to fit an IRI model, this should be done by means of a joint regression, not individually. Therefore, a different method to match the performance data was selected.

A detailed observation of the data shows that, while the IRI, cracking, and rutting measurement dates do not generally match, there is a high percentage of the different performance observations that differ by less than two years. Therefore, and while being slightly conservative, the authors have defined that observations that overlap by a time span of less than one year constitute a time series observation of the performance for a given pavement section. The previous assumption is further restricted in the sense that it was only considered to hold true if there were no maintenance or rehabilitation activities within the given year. Based on the previous assumption, the dataset used consists of 3,123 data observations for the 95 pavement sections included in this study.

6.6 Model Estimation Results

The IRI model parameters were estimated using OLS (same method as that of the current M-E PDG IRI Model), and instrumental variable regression using instruments to account for endogeneity present in the OLS regression by means of 2SLS while pooling the dataset. Additionally, the IRI model was estimated taking advantage of the panel dataset that is being used by means of a random-effects approach and a fixed-effects approach, with instrumental variables to correct for omitted variable bias due to factors that are specific to each pavement section, but do not change over time.

The parameter estimates, as well as the asymptotic t-values for the regressions with the pooled dataset are shown in Table 6.1, while the panel data regression estimates and their associated t-values are given in Table 6.2. The variance estimates for the four different models are shown in Table 6.3.

Table 6.1: Estimated Parameters for IRI Model while Pooling the Dataset

Parameter	OLS			2SLS (*)		
	Estimates	Std. Err.	t-value	Estimates	Std. Err.	t-value
Intercept	1.0458	0.0211	49.3	0.6847	0.0387	17.6
$SF \cdot (\exp(age/20) - 1)$	0.0006	0.0001	5.9	0.0012	0.0001	9.9
$(TC_L)_T$	0.0025	0.0001	13.6	0.0016	0.0002	7.5
(COV_{RD})	0.7092	0.0651	10.8	2.1838	0.1363	16.0
$(FC)_T$	0.0055	0.0008	6.9	0.0180	0.0018	9.6
$(BC)_T$	0.0056	0.0007	7.7	0.0061	0.0007	7.7
$(LC_{SNWP})_{MH}$	-0.0027	0.0003	-7.0	-0.0003	0.0004	-0.116

(*) Using the 5 instrumental variables: h_{AC}, h_{GB}, V_a, P_b, and AADTT as instruments for (COV_{RD}) and $(FC)_T$.

Table 6.2: Estimated Parameters for IRI Model with Panel Dataset

Parameter	Fixed Effects (*)			Random Effects (*)		
	Estimates	Std. Err.	t-value	Estimates	Std. Err.	t-value
Intercept	1.0747	0.0250	42.8	0.8410	0.4148	2.0
$SF \cdot (\exp(age/20) - 1)$	0.0006	0.0003	1.8	0.0006	0.0003	1.9
$(TC_L)_T$	0.0004	0.0005	0.8	0.0006	0.0005	1.2
(COV_{RD})	-	-	-	1.7735	2.0787	0.8
$(FC)_T$	0.0393	0.0048	8.1	0.0389	0.0050	7.6
$(BC)_T$	0.0113	0.0053	2.1	0.0071	0.0028	2.4
$(LC_{SNWP})_{MH}$	0.0019	0.0004	4.2	0.0018	0.0004	3.9

(*) Using the 5 instrumental variables: h_{AC}, h_{GB}, V_a, P_b, and AADTT as instruments for (COV_{RD}) and $(FC)_T$.

Table 6.3: Estimates of Variance Components for All the Models

Estimate	OLS	Instrumental Variable Regression		
		Pooled	Fixed Effects	Random Effects
σ_ε^2	0.358	0.390	0.210	0.210
σ_u^2	-	-	0.656	0.513
$\sigma_w^2 = \sigma_\varepsilon^2 + \sigma_u^2$	-	-	0.866	0.723

The instrumental variable regression has similar fit to the data as compared to the OLS model when the data is pooled together. This is measured by comparable R-squared values, as well as $\chi 2$ test statistics for the joint test that all the model parameters are significantly different from zero (584.7 vs. 521.8). An interesting observation is the difference in the model parameters between the two models. A small difference would indicate that the fatigue cracking and rutting variables are heterogeneous. There are, however, significant differences between the values of the parameter estimates. This indicates that the assumption of endogeneity was correct, and that not considering it would produce biased estimates.

The standard deviation for the error term between the pooled models is similar. However, the standard deviation for the panel data model increases because of the variance of the unobserved section specific attributes that are constant through time (which is not captured by the pooled data models). This component of the model variance explains a high percentage of the total model variance: 85.6% for the random effect approach and 90.7% for the fixed effects approach.

Consequently, the panel data models should eliminate the omitted variable bias. A Lagrange multiplier was used on the random effects model to test the hypothesis that $\sigma_u = 0$, or that the pooled data models are indeed correct. The resulting LM was 82,985, which is significantly larger than the 5% significance level of 3.84. Therefore, the null hypothesis that there is no omitted variable bias due to pavement section specific unobserved variables can be confidently rejected. This indicates conclusively that the pooled data models are inappropriate for predicting IRI.

One question remains: which of the panel data models is more appropriate? A Hausman test was performed to test the assumption of no correlation between the observed regressors and the unobserved variables. The test statistic was determined to be 8.03, which is smaller than the 5% significance level of 11.07 (for the correspondent number of degrees of freedom). As a result, it is not feasible to reject the null hypothesis and conclude that the random effects model is more appropriate.

6.7 Summary of Roughness Model Calibration

The results of the analysis carried in this chapter show that by applying more sophisticated data analysis techniques, the MEPDG, in its current formulation (as estimated by OLS) is biased due to endogeneity of some of the regressors, which can be corrected by using instrumental variables that are correlated to the endogenous variables and therefore removing the correlation to the error term associated with the model.

The estimation method used on the MEPDG IRI model produced estimates that also exhibit omitted variable bias because of heterogeneity in the data that is present because of unobserved pavement section specific variables. It was statistically demonstrated that for the LTPP GPS-1 pavement sections that were used in modeling IRI, the random effects approach is the most appropriate in predicting profile.

The issue of the random effects approach being preferred over the OLS approach is important from a theoretical standpoint. The change in modeling technique has produced some considerable changes in the effects of several of the independent variables included in the model indicating that there are significant differences in how each of these factors affects IRI over time. The effect of an increase of 1 m (3.3 ft) in the length of transverse cracks has decreased by 75%, while an increase of 1 m^2 (3.3 ft^2) in the area of block cracking has increased by 26%. Moreover, the effect of one additional meter in medium and high severity sealed longitudinal cracks outside the wheelpath has increased its effect on IRI by 167%. The two remaining distress types that were considered for estimating IRI, which were instrumented to eliminate bias, were found to have a significantly higher effect than that previously indicated by OLS. An increase in the rutting coefficient of variation of 1% is associated with a 1.5% increase in IRI, relative to the OLS estimates, and an increase in fatigue cracking under the wheelpath of 1 m2 has increased the effect on IRI by 600%. Therefore, based on the random effects model, fatigue cracking is the type of cracking that has largest effect on profile as opposed to the current MEPDG IRI model, which suggests that block cracking is more important in determining future profile. The large effect of rutting over profile remains unchanged between the models, as was expected.

Because IRI and other performance models have been developed empirically, it is important that adequate methodologies that account for the type of information that is readily available in attempt to eliminate the bias in the predictions be used. The random effects approach with instrumental variables was so intended. The next step in the MEPDG performance model development should be to also eliminate possible bias in the estimates of the cracking and the rutting prediction models. This can be achieved by simultaneously estimating the IRI model, along with the fatigue cracking and rutting performance models by means of a Seemingly Unrelated Regression: a Generalized Least Squares application for estimating the parameters in a system of equations in order to eliminate the correlation between the error terms (or endogeneity in some of the regressors).

Chapter 7. Conclusions and Recommendations

This chapter focuses on the conclusions that were derived from this research study as well as some guidelines or recommendations for the future.

7.1 Conclusions and Summary of the Work Done

The aim of this research project was basically centered on two prime objectives. The first was to develop and populate a Texas Flexible Pavement Database (TFPD) for TxDOT with a user-friendly interface so that users can browse the database, query sections, and download data with ease. Although the database was initially suppose to contain data from some 64 sections, as of summer 2008, the TFPD contains data of approximately 200 sections, which is well beyond what was initially expected. Unfortunately due to time and budget constraints, information on material was not collected during the course of this project and this is a major shortcoming of the TFPD to date. It should be noted that although the experimental design for the TFPD included only 73 test sections originally, it was later found that to run a calibration with the MEPDG consistent with Level 2 or Level 3 design inputs, only 5 of these sections got qualified. The criteria was the sections had to be relatively in a pristine state with at least 5 year of distress data and no less than 4 distress surveys. So it was felt by the research team that another 13 test sections from the SPS-3 experiments of the LTPP database need to be imported into the TFPD so that the data needs are met. It is because of this reason that the experimental design of the TFPD was expanded from 73 to 86 test sections.

The second objective of this study was to develop a calibration methodology for mechanistic-empirical pavement design models. The developed methodology was based on the calibration of the recently developed Mechanistic-Empirical Pavement Design Guide (MEPDG). Two different methodologies were actually developed and applied in this study. The first methodology deals with the calibration of mechanistic models. This methodology was successfully applied to calibrate the rutting models incorporated into the MEPDG (Chapter 5). The second methodology was empirical in nature because the roughness model contained in the MEPDG is an empirical one. The roughness model was not only calibrated but corrected and improved based on advanced econometrics modeling (Chapter 6). The new model developed in Chapter 6 can now be applied to Texas data.

In order to achieve these two goals, the research team followed a four-step approach. The first step consisted of the planning phase, which included an assessment of status-quo and a review of other relevant projects whose research findings may prove to beneficial for the current study. The second phase was directed towards data collection requirements for this study and also populating the database. It should be noted here that this was a continuous effort that started very early in the project and continued until the end of the project and beyond. The third phase focused on initial implementation of the project goals and even development of a web-based interface for querying/populating the database, which has been already discussed in detail. Finally there was an application phase, which was mostly focused on checking how well the Flexible Pavement Database is able to meet the requirements for which it has been developed—that is, to support the calibration procedure of mechanistic-empirical pavement design models.

The TFPD was developed after carefully evaluating similar pavement databases such as the LTPP database and the Texas PMIS database. The database was designed with the TxDOT guidelines on developing Relational Databases in mind. The two most important characteristics of the Texas Flexible Pavement Database (TFPD) are that it is “open to all” and that it is “one-stop shopping” for pavement design data. The TFPD has the ability to store information on material, structure, traffic, and performance for any section with no restriction on the number of years or the number of layers or any other data element.

Before embarking on an assessment of data collection needs for the current study, one very important aspect needed a lot of attention. It was the list of experimental variables that had to be considered for this study. As discussed earlier, the experimental design included two different levels of traffic, three different pavement types, five different climatic regions and two replicates wherever possible—thus bringing the total number of sections required to satisfy the factorial to 60. Of these 60 sections, it was decided that almost 50% will be existing pavement sections and the other half will be relatively new pavement sections. This was done in order to be able to develop and test the calibration methodology because (due to the duration of the project) new sections only contain one, two, or three years of performance data. Existing LTPP sections in Texas proved to be the obvious choice for the initial calibration exercise. As the project continues to monitor the so-called newer sections, the TxDOT-recommended sections will become the primary source for validation and calibration of pavement design and performance models.

The TFPD currently houses 86 pavement sections, of which 45 are LTPP sections. The importance of the LTPP sections was that they had long-term performance data. This long time-series information was necessary for initial calibration. Each LTPP section contained in the Texas Flexible Pavement Database has information on traffic, materials, structure, and performance history.

The other half of the Texas Flexible Pavement Database consists of the TxDOT-recommended sections, which are the relatively new sections. Information on structure, traffic, and performance is included in the Texas Flexible Pavement Database for each of these sections. For the performance data, there were two surveys conducted at each of these locations with the exception of the El Paso sections.

As part of the second objective of this study (development of calibration methodology), a set of calibration parameters for the different performance models in the Mechanistic-Empirical Pavement Design Guide were also obtained. It should be emphasized that these calibration factors should be used in the interim until new data becomes available. As already discussed, the methodology that has been adopted is a joint optimization with all the representative sections from a given region within Texas; the objective being minimization of the sum of squared errors (Error = Prediction of the Distress – Actual In-field Distress Measurements). This being said, the emphasis was placed on calibrating the permanent deformation performance model. The data currently available was not of the necessary quality for calibrating the cracking models. The initial results as obtained from this study are listed below.

- Level 2 Calibration coefficients:
    - West Texas: β_1=2.0, β_3=0.866, β_{s1}=0.3
    - East Texas: β_1=3.55, β_3=0.862, β_{s1}=0.7
    - South Texas: β_1=2.55, β_3=0.864, β_{s1}=0.7
    - North Texas: β_1=2.45, β_3=0.908, β_{s1}=0.3
    - Hill Country: β_1=1.4, β_3=0.78, β_{s1}=0.5
- Level 3 calibration parameters for Texas:

- β_1=1.76, β_3=0.9982, β_{s1}=0.5

Please note that β_1 and β_3 represent the AC calibration coefficients for thickness of the HMA layer and the number of axle repetitions in the HMA rutting transfer function and β_{s1} represents the calibration coefficients for fine and coarse grained soils in the subgrade rutting transfer function.

It is important to note the possibility that the set of bias correction factors proposed in the present study may not be optimal because the point that gives the least SSE may not be the global minima for the entire search space due to the multi-dimensional non-linear nature of the optimization process. However, no method can guarantee the last. Therefore, engineering judgment and expert opinion have been used to make sure that the optimization region (range of possible calibration factors) is consistent with previous studies and reflects the state-of-practice to date.

Finally, although there is room for further adjustments, the set of correction factors proposed in this study may be safely used for the regions and locations discussed in the study instead of the default values, which correspond to a national average. There is no doubt that the interim calibration factors recommended in this are more accurate for predicting pavement performance in Texas than the default national values.

In addition to the methodology for calibrating the mechanistic models, a statistically sound and advance methodology was applied to improve and calibrate the roughness models. To date, there are no accurate mechanistic models for predicting roughness so the methodology presented in this study represents the state-of-the-art in this respect.

7.2 Recommendations

This report and the corresponding database (http://pavements.ce.utexas.edu/) represent the end product of a three-year effort into the development and deployment of a sustainable flexible pavement database. What was achieved during these three years is not faultless and it is expected to evolve and change. However, it constitutes the platform for what could become one of the most important sources of data for the purposes of validating and calibrating data-intensive pavement design models—undoubtedly, the most important in the state of Texas.

Based on the results obtained from this study, it is strongly recommended that TxDOT continues to monitor the sections contained in the TFPD on an annual basis for at least the next ten years. The performance monitoring should consist of collecting roughness, rutting and cracking data buy means of automated systems to avoid human interpretation and subjectivity.

In addition, as new materials become popular in the state of Texas [such as warm-mix asphalt (WMA) and the increased use of recycled asphalt pavements (RAP)] the original experimental design should be periodically reviewed and new sections should be incorporated accordingly.

One of the shortcomings of the current TFPD is the lack of a representative number of sections in North Texas (Panhandle region) and in East Texas. The continuation of the database effort should look into this. As the database starts becoming more popular in the state, more extensive and intensive interaction and cooperation with the Districts are expected.

As already suggested, the calibration methodologies that have been developed should be carried forward and applied to new data as they become available. This will increase the confidence in the results and will produce more reliable calibration factors and, in general, more robust pavement performance models.

At the same time, a few more enhancements should also be targeted on the database side. Some of them could include site-specific data on traffic and materials, an interface for users to run user-specified queries, a feature that allows users to download raw data and, in general, anything else that could facilitate the implementation of mechanistic-empirical design principles in Texas.

If the use and interest in the TFPD could be seen as a measure of success of the project, the TFPD is already a success. Even before it has been officially completed and launched, there are more than 30 registered users. The list of users includes TxDOT personnel from the Divisions and District Offices, researchers from The University of Texas, Texas A&M University, the University of New Mexico, and users from the private sector: Dynatest Consulting, The Transtec Group, and Pavetex Engineering and Testing.

References

1. AASHTO (1962). The AASHO Road Test. Special Report 61E. American Association of State Highway Officials, Highway Research Board. Washington, DC, 1962.

2. AASHTO (1993), Guide for the Design of Pavement Structures, American Association of State Highway and Transportation Officials, Washington, DC.

3. AASHTO (2002), SiteManager Construction Management System User Reference Manual, Release 3.1a, American Association of State Highway and Transportation Officials, Prepared by InfoTech, Gainesville, Florida.

4. Al-Omari, B., and Darter M. I. Relationships between IRI and PSR, Interim Report. Publication No. UILU-ENG-92-2013, Illinois Department of Transportation, 1992.

5. Carey, W. N. Jr., and Irick, P. E. The Pavement Serviceability-Performance Concept. Highway Research Board Bulletin 250. Washington, DC, 1960.

6. Darter, M. I., and Barenberg E. J. Zero-Maintenance Pavements: Results of Field Studies on the Performance Requirements and Capabilities of Conventional Pavement. Report No. Federal Highway Administration FHWA-RD-76-105. Washington, DC, 1976.

7. FHWA (2004), DataPave Online, Release 22, July 2004, www.datapave.com. Federal Highway Administration, Washington, DC.

8. Greene, W. H. Econometric Analysis, Sixth Edition. Pearson Prentice Hall. New Jersey, 2008.

9. Mirza, M. W., and Zapata, C. Appendix OO-3: Addendum — Estimation of Distress Quantities for Smoothness Models For HMA-Surface Pavements. Guide for Mechanistic-Empirical Design of New and Rehabilitated Pavement Structures. National Cooperative Highway Research Program, Transportation Research Board. Washington, DC, 2003.

10. NCHRP (2006), Mechanistic-Empirical Design of New and Rehabilitated Pavements, National Cooperative Highway Research Program, www.trb.org/mepdg/, accesses in August 2006.

11. Paterson, W. D. (1986). International Roughness Index: Relationship to Other Measures of Roughness and Riding Quality. Transportation Research Record 1084. Washington, DC, 1986.

12. Prozzi, J. A., and Madanat, S. M. (2003) Incremental Nonlinear Model for Predicting Pavement Serviceability. Journal of Transportation Engineering, ASCE. November/December, 2003, pp. 635 – 641.

13. Prozzi, J.A. and F. Hong, "Hierarchical Axle-Load Data for Mechanistic-Empirical Design," CD-ROM Proceedings of the 84th Annual Meeting of the Transportation Research Board, Washington, DC, January 9-13, 2005.

14. Prozzi, J.A., V. Gossain and L. Manuel, "Reliability of Pavement Structures Using Empirical-Mechanistic Models," CD-ROM Proceedings of the 84th Annual Meeting of the Transportation Research Board, Washington, DC, January 9-13, 2005.

15. Prozzi, J.A. and R. Luo, "Quantification of Joint Effect of Wheel Load and Tire Inflation Pressure on Pavement Response," Transportation Research Record: Journal of the Transportation Research Board, No. 1919, pp. 134-141, 2005.

16. Prozzi, J.A. and F. Hong, "Seasonal Time Series Models for Supporting Traffic Input Data for the Mechanistic-Empirical Design Guide," Transportation Research Record: Journal of the Transportation Research Board, No. 1947, pp. 175-184, 2006.

17. Prozzi, J.A., F. Hong and J. Leidy, "Optimum Statistical Characterization of WIM Data Based on Pavement Impact," CD ROM Proceedings of the 85th Annual Meeting of the Transportation Research Board, Washington, DC, January 22-26, 2006.

18. Prozzi, J.A., F. Hong and J. Leidy, "Implementation Aspects of Highway Traffic Characterization by Means of Axle Load Spectra in the NCHRP Mechanistic Empirical Design Guide," Proceedings of the 10th International Conference on Asphalt Pavements, Quebec City, Canada, August 12-17, 2006.

19. Prozzi, J.A. and F. Hong, "Effect of Weigh-in-Motion System Measurement Errors on Load-Pavement Impact Estimation," Journal of Transportation Engineering, Vol. 133, Number 1, pp. 1-10, January 2007.

20. Prozzi, J.A. and F. Hong, "Equivalent Damage Factors Based on Mechanistic-Empirical Pavement Design," CD ROM Proceedings of the 86th Annual Meeting of the Transportation Research Board, Washington, D.C., January 21-25, 2007.

21. Simpson, A. L. and J. F. Daleiden (2003), Distress Data Consolidation – Final Report, Report FHWA-RD-01-143, prepared by Fugro BRE for Federal Highway Administration, October 2003.

22. Smit, A. d. F. and G. Cleveland (2004), Towards Tracking the Performance of Superpave in Texas- The Development of Software and Database Structures to Relate Superpave Mixture Letting and Performance Information, Center for Transportation Research, The University of Texas at Austin, Austin, Texas.

23. TxDOT (2005). Pavement Management Information System. Rater's Manual. Texas Department of Transportation. Construction Division, Materials and Pavements Section. May 2005.

24. TxDOT (2005). Condition of Texas Pavements. Pavement Management Information System (PMIS) Annual Report FY 2002-2005. Texas Department of Transportation. Construction Division, Materials and Pavements Section. June 2005.

25. TxDOT (2005). Condition of Texas Pavements. Pavement Management Information System (PMIS) Executive Summary FY 2002-2005. Texas Department of Transportation. Construction Division, Materials and Pavements Section. June 2005.

26. Von Quintus, H. L., Eltahan, A., and Yau, A. Smoothness Models for Hot-Mix Asphalt-Surfaced Pavements – Developed from Long-Term Pavement Performance Program Data. Transportation Research Record 1764. Washington, DC, 2001a, pp. 139 – 156.

27. Von Quintus, H. L., Yau, A., Witczak, M. W., Andrei, D., and Houston, W. N. Appendix OO-1: Background and Preliminary Smoothness Prediction Models for Flexible Pavements. Guide for Mechanistic-Empirical Design of New and Rehabilitated Pavement Structures. National Cooperative Highway Research Program, Transportation Research Board. Washington, DC, 2001b.

28. Von Quintus, H. L., and Yau, A. Appendix OO-2: Revised Smoothness Prediction Models For Flexible Pavement. Guide for Mechanistic-Empirical Design of New and Rehabilitated Pavement Structures. National Cooperative Highway Research Program, Transportation Research Board. Washington, DC, 2001c.

29. Zhang, Z. (1996), Development of a GIS Based and Multimedia Integrated Infrastructure Management System, Doctoral Dissertation, The University of Texas at Austin, Austin, Texas.

30. Zhang, Z., M. R. Rechtien, D. W. Fowler and W. R. Hudson (1999a), A Summary of Pavement and Material-related Databases within the Texas Department of Transportation, Report FHWA/TX-00/1785-1, Center for Transportation Research, The University of Texas at Austin, Austin, Texas.

31. Kang, M. and T. Adams. "Local Calibration for Fatigue Cracking Models Used in the Mechanistic-Empirical Pavement Design Guide." CDROM Proceedings of the 2007 Annual Meeting of the Transportation Research Board, Paper #08-1102, January 2007.

32. Elkins, G. , P. Schmalzer, T. Thompson, and A. Simpson. Long-Term Pavement Performance Information Management System: Pavement Performance Database User Reference Guide. Publication FHWA-RD-03-088. FHWA, U.S. Department of Transportation, December 2006.

33. ARA (2004), "Guide for Mechanistic-Empirical Design of New and Rehabilitated Pavement Structures, National Cooperative Highway Research Program," Final Report, Champaign, IL.

34. Von Quintus, H. L., M. I. Darter, and J. Mallela. Recommended Practice for Local Calibration of the M E Pavement Design Guide. Applied Research Associates, Inc. – Transportation Sector, 2007.

35. Banerjee, A. and J. P. Aguiar-Moya. Local Calibration of the M-EPDG Asphalt Concrete Rutting Model for East Texas. Submitted for International Contest on LTPP Data Analysis, 2008.

36. Von Quintus, H. and J. S. Moulthrop. Mechanistic-Empirical Pavement Design Guide Flexible Pavement Performance Prediction Models for Montana: Volume I Reference Manual. Publication FHWA/MT-07-008/8158-1. FHWA, U.S. Department of Transportation, August 2007.

37. Scullion, T., and Michalak, C., "Flexible Pavement Design System (FPS) 19W: User's Manual," Research Report 1987-2, Texas Transportation Institute, Texas A&M University, College Station, Texas, 1997.

38. "Flexible Pavement Designers Manual, Part I," Texas State Department of Highway and Public Transportation, Highway Design Division, 1972.

Appendix A: Experimental Design

						Hot-mix asphalt surface on top of hot-mix asphalt base										Hot-mix asphalt surface on top of untreated granular base										One course surface treatment on top of untreated granular base									
						Heavy Traffic					Light Traffic					Heavy Traffic					Light Traffic					Heavy Traffic					Light Traffic				
Section ID	District	Lane	Latitude	Longitude	Pavement Structure	Wet-Warm	Wet-Cold	Dry-Warm	Dry-Cold	Mixed	Wet-Warm	Wet-Cold	Dry-Warm	Dry-Cold	Mixed	Wet-Warm	Wet-Cold	Dry-Warm	Dry-Cold	Mixed	Wet-Warm	Wet-Cold	Dry-Warm	Dry-Cold	Mixed	Wet-Warm	Wet-Cold	Dry-Warm	Dry-Cold	Mixed	Wet-Warm	Wet-Cold	Dry-Warm	Dry-Cold	Mixed
TXTF17001	Bryan	R1	30.75788	96.29709	Type C surface - 50 mm / HMA Ty C (base) - 100 mm / 1 CST / Flex Base - 300 mm	X																													
TXTF17002	Bryan	R2	30.75788	96.29709	Type C surface - 50 mm / HMA Ty C (base) - 100 mm / 1 CST / Flex Base - 300 mm						X																								
TXTF17003	Bryan	L1	30.55349	96.26873	CMHB-C - 165 mm / 1 CST / Flex Base - 450 mm / LTSG - 250 mm											X																			
TXTF17004	Bryan	L2	30.55349	96.26873	CMHB-C - 165 mm / 1 CST / Flex Base - 450 mm / LTSG - 250 mm																X														
TXTF17007	Bryan	K1	31.11269	96.38423	3 CST / Flex Base - 7" / S/R Existing Mat'l - 5"																					X									
TXTF17008	Bryan	K6	31.10761	96.38067	3 CST / Flex Base - 7" / S/R Existing Mat'l - 5"																					X									
TXTF17009	Bryan	K1	31.24883	96.19458	HMA Type C - 2.5" / 2 CST / CTSG - 10"											**X**																			
TXTF17010	Bryan	K1	31.55443	96.26705	HMA Type C - 2" / 2 CST / CT Existing Mat'l - 10"																										X				
TXTF17011	Bryan	K6	31.55357	96.25848	HMA Type C - 2" / 2 CST / CT Existing Mat'l - 10"																										X				
TXTF17014	Bryan	K1	31.63508	96.34431	3 CST / Flex Base - 6-10" / S/R Existing Mat'l - 7-7.5"																										X				
TXTF17015	Bryan	K6	31.62848	96.34422	3 CST / Flex Base - 6-10" / S/R Existing Mat'l - 7-7.5"																										X				
TXTF09001	Waco	R1	31.02100	97.75323	C Mix - 2" / B Mix - 5" / 1 CST / Flex Base - 7.5" / Lime Treated Subgrade - 6"					X																									
TXTF09002	Waco	R2	31.02100	97.75323	C Mix - 2" / B Mix - 5" / 1 CST / Flex Base - 7.5" / Lime Treated Subgrade - 6"										X																				
TXTF09003	Waco	L1	31.02958	97.75569	C Mix - 2" / B Mix - 5" / 1 CST / Flex Base - 7.5" / Lime Treated Subgrade - 6"					X																									
TXTF09004	Waco	L2	31.02958	97.75569	C Mix - 2" / B Mix - 5" / 1 CST / Flex Base - 7.5" / Lime Treated Subgrade - 6"										X																				
TXTF09007	Waco	R1	31.29450	96.87440	SMA D - 2" / C Mix - 2" / B Mix - 3" / 1 CST / Flex Base - 15" /Lime Treated Subgrade					X																									
TXTF09008	Waco	R2	31.29450	96.87440	SMA D - 2" / C Mix - 2" / B Mix - 3" / 1 CST / Flex Base - 15" /Lime Treated Subgrade										X																				
TXTF09009	Waco	K1	31.89026	97.11119	D Mix - 1" / 2 CST / Flex Base - 12"												X																		
TXTF09010	Waco	K6	31.89374	97.10375	D Mix - 1" / 2 CST / Flex Base - 12"												X																		
TXTF09011	Waco	R1	31.46149	96.92415	2 CST / Flex Base - 12"																									X					
TXTF09012	Waco	R2	31.46149	96.92415	2 CST / Flex Base - 12"																														X
TXTF09013	Waco	R1	31.45004	97.10851	C Mix - 2" / 1 CST / Flex Base - 12"															X															
TXTF09014	Waco	R2	31.45004	97.10851	C Mix - 2" / 1 CST / Flex Base - 12"																				X										
TXTF24001	El Paso	R1	31.04167	104.80787	C Mix - 2" / Type B HMAC - 6" / Lime Treated Subgrade - 6"			X																											
TXTF24002	El Paso	R2	31.04167	104.80787	C Mix - 2" / Type B HMAC - 6" / Lime Treated Subgrade - 6"								X																						
TXTF24020	El Paso	K1	31.82822	105.93298	2 CST / Flex Base - 12"																							X							
TXTF24021	El Paso	K6	31.82798	105.92346	2 CST / Flex Base - 12"																							X							
TXTF24022	El Paso	K1	31.83495	105.74331	2 CST / Flex Base - 12"																							X							
TXTF24023	El Paso	K6	31.83176	105.73553	2 CST / Flex Base - 12"																							X							
TXTF24030	El Paso	K1	31.58649	106.23409	CMHB-F w/ AR - 2" / Type B HMAC (PG 76-22) - 6" / Lime Treated Subgrade - 6"								X																						
TXTF24031	El Paso	K6	31.58546	106.24266	CMHB-F w/ AR - 2" / Type B HMAC (PG 76-22) - 6" / Lime Treated Subgrade - 6"								X																						
TXTF24036	El Paso	R1	31.05424	104.59654	C Mix - 2" / Type B HMAC - 6" / Lime Treated Subgrade - 6"			X																											
TXTF24037	El Paso	R2	31.05424	104.59654	C Mix - 2" / Type B HMAC - 6" / Lime Treated Subgrade - 6"								X																						
TXTF24040	El Paso	K1	30.77004	103.75568	2 CST / Flex Base - 12"																												X		
TXTF24041	El Paso	K6	30.76356	103.76047	2 CST / Flex Base - 12"																												X		
TXLT14001	Austin	R1	30.39167	97.72500	HMA Mix - 2.4" / Flexbase - 14.7" / Subgrade - 36"															X															

Experimental Design (Cont.)

						Hot-mix asphalt surface on top of hot-mix asphalt base										Hot-mix asphalt surface on top of untreated granular base										One course surface treatment on top of untreated granular base									
						Heavy Traffic					Light Traffic					Heavy Traffic					Light Traffic					Heavy Traffic					Light Traffic				
Section ID	District	Lane	Latitude	Longitude	Pavement Structure	Wet-Warm	Wet-Cold	Dry-Warm	Dry-Cold	Mixed	Wet-Warm	Wet-Cold	Dry-Warm	Dry-Cold	Mixed	Wet-Warm	Wet-Cold	Dry-Warm	Dry-Cold	Mixed	Wet-Warm	Wet-Cold	Dry-Warm	Dry-Cold	Mixed	Wet-Warm	Wet-Cold	Dry-Warm	Dry-Cold	Mixed	Wet-Warm	Wet-Cold	Dry-Warm	Dry-Cold	Mixed
TXLT15001	San Antonio	L1	29.35614	98.83519	HMA Mix - 2" / 2 CST / HMA Mix - 7.1" / 1 CST / Flexbase - 14.1"			X																											
TXLT15002	San Antonio	L1	29.60233	98.70764	1 CST / HMA Mix - 1.1" / 1 CST / Flexbase - 8.4" / Subgrade - 48"													X																	
TXLT15003	San Antonio	L1	29.35061	99.06794	HMA Mix - 1.7" / 2 CST / HMA Mix - 2.7" / 1 CST / Flexbase - 12.5"			X																											
TXLT04001	Amarillo	R1	35.20775	101.34453	HMA Mix - 3.6" / HMA Mix - 6.4" / HMA Mix - 2.4" / Flexbase - 13.5"				X																										
TXLT11001	Lufkin	K1	31.32797	94.78661	1 CST / HMA Mix - 5.8" / Flexbase - 15.9"																X														
TXLT15004	San Antonio	K1	29.51681	98.72050	HMA Mix - 1.9" / 1 CST / HMA Mix - 1.2" / 1 CST / Flexbase - 9.4"								X																						
TXLT01001	Paris	L1	33.50606	95.58928	HMA Mix - 1.5" / 4 CST / HMA Mix - 10" / Flexbase - 14"		X																												
TXLT04002	Amarillo	K1	36.19447	100.71078	2 CST / HMA Mix - 1.5" / 1 CST / Flexbase - 14"																			X											
TXLT05001	Lubbock	K6	33.16648	102.28278	1 CST / HMA Mix - 5.5" / Flexbase - 10.5"																			X											
TXLT05002	Lubbock	R1	33.53178	101.80394	HMA Mix - 1.6" / 3 CST / HMA Mix - 6.5" / Flexbase - 7.5"				X																										
TXLT05003	Lubbock	R1	34.16539	101.70975	HMA Mix - 1.5" / 2 CST / HMA Mix - 2.5" / Flexbase - 14.8"				X																										
TXLT09037	Waco	K1	31.07625	97.31528	1 CST / HMA Mix - 1.5" / 1 CST / Flexbase - 21"																				X										
TXLT10001	Tyler	K6	32.36922	95.33103	1 CST / HMA Mix - 7.5" / Flexbase - 8"																	X													
TXLT10002	Tyler	K1	32.67956	95.46619	1 CST / HMA Mix - 1" / 1 CST / Flexbase - 11"																	X													
TXLT10003	Tyler	K6	32.19628	94.80328	2 CST / HMA Mix - 1.5" / 1 CST / Flexbase - 12"																	X													
TXLT12001	Houston	L1	29.34753	94.92758	HMA Mix - 3.2" / 1 CST / 4.5" / Flexbase - 20"											X																			
TXLT13001	Yoakum	L1	29.89975	96.80706	HMA Mix - 3.3" / Flexbase - 22.8"											X																			
TXLT15005	San Antonio	L1	29.23594	98.25367	HMA Mix - 3.4" / Flexbase - 24"													X																	
TXLT15006	San Antonio	L1	28.77725	98.30828	HMA Mix - 5.4" / Flexbase - 17.2"													X																	
TXLT15007	San Antonio	L1	29.56014	97.94436	HMA Mix - 4.3" / Flexbase - 25.9"													X																	
TXLT17016	Bryan	L1	30.73406	96.43411	HMA Mix - 5.9" / HMA Mix - 8.8" / Flexbase - 19"	X																													
TXLT18001	Dallas	R1	32.61728	96.42569	HMA Mix - 4.4" / HMA Mix - 9.5" / Flexbase - 21.7"		X																												
TXLT18002	Dallas	R1	32.59886	96.38192	HMA Mix - 5.2" / HMA Mix - 9.3" / Flexbase - 23.5"		X																												
TXLT18003	Dallas	K6	32.49381	96.81556	HMA Mix - 3.3" / HMA Mix - 6.2" / Flexbase - 21.8"							X																							
TXLT21001	Pharr	L1	26.98386	97.79547	HMA Mix - 4" / Flexbase - 18.8"													X																	
TXLT23001	Brownwood	K6	31.56589	98.66878	1 CST / HMA Mix - 2.7" / Flexbase - 17.5"																				X										
TXLT24042	El Paso	R1	31.79964	106.25956	HMA Mix - 4.2" / Flexbase - 8.4"													X																	
TXLT17017	Bryan	K1	30.77153	96.38386	HMA Mix - 2.5" / HMA Mix - 2.5" / Flexbase - 18.5"						X																								
TXLT17018	Bryan	K1	30.77153	96.38386	HMA Mix - 2.5" / HMA Mix - 5" / Flexbase - 20.7"						X																								
TXLT21006	Pharr	R1	26.73742	98.10767	1 CST / HMA Mix - 2.1" / HMA Mix - 6" / HMA Mix - 4.2" / Flexbase - 14.6"			X																											
TXLT21015	Pharr	R1	26.73742	98.10767	1 CST / HMA Mix - 2.2" / HMA Mix - 2.1" / Flexbase - 20.3"			X																											
TXTF10004	Tyler	K1	31.69887	95.74041	HMA Type C - 2" / 1 CST / HMA Mix - 3.6" / Flexbase - 3.1"																	X													
TXTF10005	Tyler	K6	31.69216	95.73894	HMA Type C - 2" / 1 CST / HMA Mix - 3.6" / Flexbase - 3.1"																	X													
TXTF10006	Tyler	K1	31.87121	95.93058	1 CST / Prime Coat / Base Type D - 6" / Geogrid Type 1 / Base Type D - 6"																											X			
TXTF10007	Tyler	K6	31.86939	95.92285	1 CST / Prime Coat / Base Type D - 6" / Geogrid Type 1 / Base Type D - 6"																											X			
TXTF10020	Tyler	K1	32.20902	94.58275	1 CST / Prime Coat / Flexbase - 12"																											X			
TXTF10021	Tyler	K6	32.20335	94.58708	1 CST / Prime Coat / Flexbase - 12"																											X			

Appendix B: Definitions of Data Element (as of August 2008)

COUNTY	The COUNTY entity contains all the counties of Texas, and to what district to they belong. A COUNTY is one of 254 geographical areas within the state of Texas where the Texas Department of Transportation conducts its work activities.
COUNTY_ID	The COUNTY_ID is a unique identifier to represent every County in the State of Texas, as defined by TxDOT
COUNTY_NAME	A COUNTY_NAME is a word or phrase that provides a distinctive designation for a COUNTY
DISTRICT_ID	The DISTRICT_ID is a unique identifier to represent every District in the State of Texas, as defined by TxDOT
DISTRICT	The DISTRICT entity contains all the districts of Texas, and a general climatic classification per district. A DISTRICT is one of 25 geographical areas within the state of Texas where the Texas Department of Transportation conducts its primary work activities.
CLIMATE	The CLIMATE is a PMIS Climate Classification for each DISTRICT
DISTRICT_ID	The DISTRICT_ID is a unique identifier to represent every District in the State of Texas, as defined by TxDOT
DISTRICT_NAME	A DISTRICT_NAME is a word or phrase that provides a distinctive designation for a DISTRICT
PAV_BINDER	The PAV_BINDER entity contains specific rheological and physical information on the asphalt binders used on the different asphalt layers of the different pavement sections included in the database.
BINDER_CONTENT_VOL	The BINDER_CONTENT_VOL represents the BINDER CONTENT in percentage by volume, for field extracted samples
BINDER_CONTENT_VOL_TST	The BINDER_CONTENT_VOL_TST represents the BINDER CONTENT in percentage by volume, for laboratory molded samples at TxDOT or research entity
BINDER_CONTENT_WT	The BINDER_CONTENT_WT represents the BINDER CONTENT in percentage by weight, for field extracted samples
BINDER_CONTENT_WT_TST	The BINDER_CONTENT_WT_TST represents the BINDER CONTENT in percentage by weight, for laboratory molded samples
BINDER_ID	The BINDER_ID is a system generated unique identifier to represent each binder type included in the database
BINDER_MANUF	The BINDER_MANUF is a word or phrase that provides the name of the BINDER MANUFACTURER

BINDER_MOD	The BINDER_MOD is a indicator of whether the BINDER is modified or not
BINDER_MOD_CONT	The BINDER_MOD_CONT is a indicator of the amount of MODIFIER included in a BINDER, in percentage
BINDER_MOD_TYPE	The BINDER_MOD_TYPE is a indicator of the type (brand, chemical composition) of MODIFIER included in a BINDER
BINDER_SOURCE	The BINDER_SOURCE is a word or phrase that provides the source (origin) of the BINDER
BINDER_TYPE	The BINDER_TYPE is an indicator of the type of BINDER
CREEP_STIFF_64_PAV	The CREEP_STIFF_64_PAV is a indicator of the CREEP STIFFNESS at 64°C on PAV BINDER
CREEP_STIFF_70_PAV	The CREEP_STIFF_70_PAV is a indicator of the CREEP STIFFNESS at 70°C on PAV BINDER
CREEP_STIFF_76_PAV	The CREEP_STIFF_76_PAV is a indicator of the CREEP STIFFNESS at 76°C on PAV BINDER
DUCTILITY	The DUCTILITY is a indicator of the DUCTILITY of the BINDER in cm measured at a rate of 5 cm/min
ELASTIC_RECOVERY	The ELASTIC_RECOVERY is a indicator of the ELASTIC RECOVERY of the BINDER when elongated to 100 mm and cut immediately at 25°C
FAIL_STRAIN_64_PAV	The FAIL_STRAIN_64_PAV is a indicator of the failure strain of the BINDER in direct tension at 64°C on PAV aged BINDER
FAIL_STRAIN_70_PAV	The FAIL_STRAIN_70_PAV is a indicator of the failure strain of the BINDER in direct tension at 70°C on PAV aged BINDER
FAIL_STRAIN_76_PAV	The FAIL_STRAIN_76_PAV is a indicator of the failure strain of the BINDER in direct tension at 76°C on PAV aged BINDER
FIBER_CONT	The FIBER_CONT is a indicator of the amount of FIBER included in a BINDER by weight of mix, in percentage
FIBER_TYPE	The FIBER_TYPE is a indicator of the type of FIBER included in a BINDER
G_64_ORG_BINDER	The G_64_ORG_BINDER represents G*/sin d at 64°C on BINDER in original state, in kPa
G_64_PAV	The G_64_PAV represents G*/sin d at 64°C 0n BINDER in PAV aged state, in kPa
G_64_RTFO	The G_64_RTFO represents G*/sin d at 64°C on BINDER in RTFO aged state, in kPa
G_70_ORG_BINDER	The G_70_ORG_BINDER represents G*/sin d at 70°C on BINDER in original state, in kPa
G_70_PAV	The G_70_PAV represents G*/sin d at 70°C on BINDER in PAV aged state, in kPa
G_70_RTFO	The G_70_RTFO represents G*/sin d at 70°C on BINDER in RTFO aged state, in kPa
G_76_ORG_BINDER	The G_76_ORG_BINDER represents G*/sin d at 76°C on BINDER in original state, in kPa
G_76_PAV	The G_76_PAV represents G*/sin d at 76°C on BINDER in PAV aged state, in kPa
G_76_RTFO	The G_76_RTFO represents G*/sin d at 76°C on BINDER in RTFO aged state, in kPa
HMA_ID	The HMA_ID is a system generated unique identifier to represent each HMA layer included in the database
M_VAL_64_PAV	The M_VAL_64_PAV represents m-value obtained from the BBR at 64°C on BINDER in original state
M_VAL_70_PAV	The M_VAL_70_PAV represents m-value obtained from the BBR at 70°C on BINDER in original state

M_VAL_76_PAV	The M_VAL_76_PAV represents m-value obtained from the BBR at 76°C on BINDER in original state
MIN_FILLER_CONT	The MIN_FILLER_CONT is a indicator of the amount of MINERAL FILLER included in a BINDER by weight of mix, in percentage
MIN_FILLER_TYPE	The MIN_FILLER_TYPE is a indicator of the type of MINERAL FILLER included in a BINDER
PENETRATION_25	The PENETRATION_25 is a indicator of the PENETRATION to the BINDER in mm measured at 25°C
SOFTENING_PT	The SOFTENING_PT is a indicator of the SOFTENING POINT of the BINDER measured by R&B or T800 Method
TST_DATE	The TST_DATE is a indicator of the DATE the testing was performed on the BINDER
VISCOSITY_135, Pa s	The VISCOSITY_135 is a indicator of the VISCOSITY to the BINDER in Pa s measured at 135°C
VISCOSITY_60, Pa s	The VISCOSITY_60 is a indicator of the VISCOSITY to the BINDER in Pa s measured at 60°C
PAV_CONSTR	The PAV_CONSTR entity contains information on the initial construction and maintenance and rehabilitation activities that have been performed on the pavement sections included in the database.
CONSTR_ANALYSIS_PERIOD	The CONSTR_ANALYSIS_PERIOD is a indicator of when the date when a pavement was visited to check for new construction is any is reported
CN_CHANGE_REASON	The CN_CHANGE_REASON is the construction CHANGE REASON. It indicates why additional construction was needed. For sections belonging to LTPP sections, the reason is entered as a code that can be checked on the LTPP database on the CODES table.
CONST_ID	The CONST_ID is a system generated unique identifier to represent each CONSTRUCTION activity on a particular PAVEMENT SECTION included in the database
CSJ	The CSJ is the construction CONTROL SECTION JOB NUMBER
DATE_OPEN_TRAFFIC	The DATE_OPEN_TRAFFIC is the date the PAVEMENT SECTION was originally opened to TRAFFIC
NO_OF_LAYERS_AC	The NO_OF_LAYERS_AC represents the number of existing layers after a specific CONSTRUCTION activity
NO_OF_LAYERS_BC	The NO_OF_LAYERS_BC represents the number of existing layers before a specific CONSTRUCTION activity
NO_OF_LAYERS_NEW	The NO_OF_LAYERS_NEW represents the number of new layers that have been constructed after a specific CONSTRUCTION activity
NO_OF_LAYERS_REMOVE	The NO_OF_LAYERS_REMOVE represents the number of new layers that have been removed after a specific CONSTRUCTION activity
CONSTR_PER_PERIOD	The CONSTR_PER_PERIOD is a indicator of what performance period was observed before the design of the PAVEMENT SECTION
PROJECT_TYPE	The PROJECT_TYPE represents what type of CONSTRUCTION was performed on the PAVEMENT SECTION

SECTION_ID	The SECTION_ID is a system generated unique identifier for each PAVEMENT SECTION included in the database
PAV_FIELD_PERF_CRACK	The PAV_FIELD_PERF_CRACK entity includes information on cracking initiation and development of the pavement sections included in the database.
BLK_CRACK_A_H	The BLK_CRACK_A_H is the area of high severity block cracking (mean crack width greater than 19 mm or under 19 mm with moderate to high severity random cracking.)
BLK_CRACK_A_L	The BLK_CRACK_A_L is the area of low severity block cracking (cracks of unknown width well sealed or with mean width of 6 mm or less.)
BLK_CRACK_A_M	The BLK_CRACK_A_M is the area of medium severity block cracking (mean crack width from 6 to 19 mm or under 19 mm with adjacent low severity random cracking.)
BLK_CRACK_NO_TOT	The BLK_CRACK_NO_TOT is the total number of block cracks that a given pavement section exhibits.
BLK_CRACK_TOT	The BLK_CRACK_TOT is the total area of block cracking that a given pavement section exhibits.
CRACK_ID	The CRACK_ID is a system assigned variable to keep track of cracking surveys performed on the different PAVEMENT SECTIONS included in the database.
GATOR_CRACK_A_H	The GATOR_CRACK_A_H is the area of alligator (fatigue) cracking of high severity (moderately or severely spalled interconnected cracks, may be sealed, pumping may be evident.)
GATOR_CRACK_A_L	The GATOR_CRACK_A_L is the area of alligator (fatigue) cracking of low severity (no or few connecting cracks, not spalled or sealed, no pumping evident.)
GATOR_CRACK_A_M	The GATOR_CRACK_A_M is the area of alligator (fatigue) cracking of high severity (moderately or severely spalled interconnected cracks, may be sealed, pumping may be evident.)
GATOR_CRACK_TOT	The GATOR_CRACK_TOT is the total area of alligator (fatigue) cracking along the pavement section
LONG_CRACK_NWP_L_H	The LONG_CRACK_NWP_L_H is the length of high severity, well sealed non-wheel path longitudinal cracking (mean crack width greater than 19 mm or under 19 mm with adjacent moderate to high severity random cracking.)
LONG_CRACK_NWP_L_L	The LONG_CRACK_NWP_L_L is the length of low severity, non-wheel path longitudinal cracking (cracks of unknown width well sealed or with mean width of 6 mm or less.)
LONG_CRACK_NWP_L_M	The LONG_CRACK_NWP_L_M is the length of moderate severity, non-wheel path longitudinal cracking (mean crack width from 6 to 19 mm or under 19 mm with adjacent low severity random cracking.)
LONG_CRACK_TOT	The LONG_CRACK_TOT is the total length of wheel path longitudinal cracking along a specific pavement section.
LONG_CRACK_WP_L_H	The LONG_CRACK_WP_L_H is the length of high severity, well sealed wheel path longitudinal cracking (mean crack width greater than 19 mm or under 19 mm with adjacent moderate to high severity random cracking.)
LONG_CRACK_WP_L_L	The LONG_CRACK_WP_L_L is the length of low severity, wheel path longitudinal cracking (cracks of unknown width well sealed or with mean width of 6 mm or less.)

LONG_CRACK_WP_L_M	The LONG_CRACK_WP_L_M is the length of moderate severity, wheel path longitudinal cracking (mean crack width from 6 to 19 mm or under 19 mm with adjacent low severity random cracking.)
SECTION_ID	The SECTION_ID is a system generated unique identifier for each PAVEMENT SECTION included in the database
CRACK_SURVEY_DATE	The CRACK_SURVEY_DATE is a indicator of the DATE the cracking data was collected
TRANS_CRACK_L_H	The TRANS_CRACK_L_H is the length of high severity transverse cracking (crack mean width greater than 19 mm or under 19 mm with adjacent moderate to high severity random cracking.)
TRANS_CRACK_L_L	The TRANS_CRACK_L_L is the length of low severity transverse cracking (cracks of unknown width well sealed or with mean width of 6 mm or less.)
TRANS_CRACK_L_M	The TRANS_CRACK_L_M is the length of moderate severity transverse cracks. (Mean crack width from 6 to 19 mm or under 19 mm with adjacent low severity random cracking.)
TRANS_CRACK_NO_H	The TRANS_CRACK_NO_H is the number of high severity transverse cracking (crack mean width greater than 19 mm or under 19 mm with adjacent moderate to high severity random cracking.)
TRANS_CRACK_NO_L	The TRANS_CRACK_NO_L is the number of low severity transverse cracking (cracks of unknown width well sealed or with mean width of 6 mm or less.)
TRANS_CRACK_NO_M	The TRANS_CRACK_NO_M is the number of moderate severity transverse cracks. (Mean crack width from 6 to 19 mm or under 19 mm with adjacent low severity random cracking.)
TRANS_CRACK_TOT	The TRANS_CRACK_TOT is the total number of transverse cracks in a particular pavement section
PAV_FIELD_PERF_FWD	The PAV_FIELD_PERF_FWD entity includes information on FWD measurements along the pavement sections included in the database.
AIR_TEMP	The AIR_TEMP is a measurement of the ambient air temperature in °F
ASPH_TEMP	The ASPH_TEMP is a measurement of the HMA mix temperature 1" below the surface in °F
D1	The D1 is a measurement of the deflection under geophone D1, in mils.
D2	The D2 is a measurement of the deflection under geophone D2, in mils.
D3	The D3 is a measurement of the deflection under geophone D3, in mils.
D4	The D4 is a measurement of the deflection under geophone D4, in mils.
D5	The D5 is a measurement of the deflection under geophone D5, in mils.
D6	The D6 is a measurement of the deflection under geophone D6, in mils.
D7	The D7 is a measurement of the deflection under geophone D7, in mils.
FWD_DFO	The FWD_DFO is an indicator of the location of testing relative to the beginning of the PAVEMENT SECTION, as measured by the FWD equipment in ft.
FWD_DATE	The FWD_DATE is a indicator of the DATE the FWD data was collected
LOAD	The LOAD is a measurement of the contact load used at a given drop of the FWD equipment
SECTION_ID	The SECTION_ID is a system generated unique identifier for each PAVEMENT SECTION included in the database
SURF_TEMP	The SURF_TEMP is a measurement of the HMA mix temperature on the surface in °F

PAV_FIELD_PERF_IRI	The PAV_FIELD_PERF_IRI entity includes IRI roughness information for the pavement sections included in the database.
AVERAGE_SPEED	The AVERAGE_SPEED is the AVERAGE SPEED the profilometer was running when collecting data, in mph
BEGINNING_DESCRIPTION	The BEGINNING_DESCRIPTION is description of the conditions when initiating the profilometer run over a specific PAVEMENT SECTION
DIRECTION_MEASURED	The DIRECTION_MEASURED is description the cardinal direction the profilometer was running towards
ENDING_DESCRIPTION	The ENDING_DESCRIPTION is description of the conditions when FINALIZING the profilometer run over a specific PAVEMENT SECTION
IRI_AVERAGE	The IRI_AVERAGE is average International Roughness Index (IRI) value along the PAVEMENT SECTION, in in/mi.
IRI_ID	The IRI_ID is a inspection ID for IRI. It is a system assigned variable to keep track of IRI measurements performed on the different PAVEMENT SECTIONS included in the database.
IRI_LEFT_WHEEL_PATH	The IRI_LEFT_WHEEL_PATH is the IRI value for left wheel path value along the PAVEMENT SECTION, in in/mi.
IRI_RIGHT_WHEEL_PATH	The IRI_RIGHT_WHEEL_PATH is the IRI value for right wheel path value along the PAVEMENT SECTION, in in/mi.
LANE_MEASURED	The LANE_MEASURED is description of the lane over which the profiler was run on a PAVEMENT SECTION
LOAD_DATE	The LOAD_DATE is a description of the DATE on which the data was loaded into the database
OTHER_WEATHER_INFO	The OTHER_WEATHER_INFO is description of the weather conditions when the profiler was used over a particular PAVEMENT SECTION
PROFILE_DATE	The PROFILE_DATE is a indicator of the DATE the profile data was collected
PROFILE_TIME	The PROFILE_TIME is a indicator of the TIME the profile data was collected
RUN_NUMBER	The RUN_NUMBER is the RUN NUMBER that the profiler was driven over a specific PAVEMENT SECTION
SECTION_ID	The SECTION_ID is a system generated unique identifier for each PAVEMENT SECTION included in the database
SLOPE_VARIANCE	The SLOPE_VARIANCE is an estimate of the SLOPE VARIANCE over a particular PAVEMENT SECTION
START_METHOD	The START_METHOD is a description to designate the START METHOD for data recording. For LTPP sections refer to CODE table in the LTPP database.
STOP_DISTANCE	The STOP_DISTANCE is the length of profile run as measured by profilometer DMI, in mi.
STOP_METHOD	The STOP_METHOD is a description to designate the STOP METHOD for data recording. For LTPP sections refer to CODE table in the LTPP database.
SURFACE_CONDITION	The SURFACE_CONDITION is a visual description of the SURFACE CONDITION when data was

	collected
TEMPERATURE	The TEMPERATURE is a measurement of the ambient air temperature in °C
WAVE_LENGTH_INIT	The WAVE_LENGTH_INIT is a code indicating if the wave length initialization was disabled or enabled.
PAV_FIELD_PERF_RUT	The PAV_FIELD_PERF_RUT entity contains rutting information for the pavement sections included in the database.
LLH_DEPTH_1_8_MAX	The LLH_DEPTH_1_8_MAX is the maximum left lane depth, measured in inches, according to the method specified in RUT_TST_METHOD
LLH_DEPTH_1_8_MEAN	The LLH_DEPTH_1_8_MEAN is the mean left lane depth, measured in inches, according to the method specified in RUT_TST_METHOD
LLH_DEPTH_1_8_MIN	The LLH_DEPTH_1_8_MIN is the minimum left lane depth, measured in inches, according to the method specified in RUT_TST_METHOD
LLH_DEPTH_1_8_STD	The LLH_DEPTH_1_8_STD is the standard deviation associated with the left lane depth, measured in inches, according to the method specified in RUT_TST_METHOD
MAX_MEAN_DEPTH_1_8	The MAX_MEAN_DEPTH_1_8 is the maximum value associated with the left lane or right lane depth, measured in inches, according to the method specified in RUT_TST_METHOD
RLH_DEPTH_1_8_MAX	The RLH_DEPTH_1_8_MAX is the maximum right lane depth, measured in inches, according to the method specified in RUT_TST_METHOD
RLH_DEPTH_1_8_MEAN	The RLH_DEPTH_1_8_MEAN is the mean right lane depth, measured in inches, according to the method specified in RUT_TST_METHOD
RLH_DEPTH_1_8_MIN	The RLH_DEPTH_1_8_MIN is the minimum right lane depth, measured in inches, according to the method specified in RUT_TST_METHOD
RLH_DEPTH_1_8_STD	The RLH_DEPTH_1_8_STD is the standard deviation associated with the right lane depth, measured in inches, according to the method specified in RUT_TST_METHOD
RUT_ID	The RUT_ID is a unique identifier of rutting information. It is a system assigned variable to keep track of rutting measurements performed on the different pavement sections included in the database.
RUT_TST_METHOD	The RUT_TST_METHOD is intended to indicate what method has been used in the measurement of rutting at a given time for a specific pavement section
SECTION_ID	The SECTION_ID is a system generated unique identifier for each PAVEMENT SECTION included in the database
RUT_SURVEY_DATE	The RUT_SURVEY_DATE is a indicator of the DATE the cracking data was collected
PAV_LAYER	The PAV_LAYER entity includes specific layer information for the different pavement sections that are included in the database. It also includes the aggregate gradation that was used on the diferent layers.

AGG_GRADATION	The AGG_GRADATION represents the AGGREGATE GRADATION according to TxDOT Specifications
AGG_SOURCE	the AGG_SOURCE represents the AGGREGATE SOURCE of material from current LAYER of PAVEMENT SECTION
AGG_TYPE	The AGG_TYPE represents the AGGREGATE TYPE from current LAYER of PAVEMENT SECTION
CONST_ID	The CONST_ID is a system generated unique identifier to represent each CONSTRUCTION to a particular PAVEMENT SECTION included in the database
L_CONST_DATE	The L_CONST_DATE represents the DATE on which the current LAYER was constructed
L_OPEN_TRAFFIC_DATE	The L_OPEN_TRAFFIC_DATE represents the DATE on which the current LAYER was opened to TRAFFIC
L_REMOVAL_DATE	The L_REMOVAL_DATE represents the DATE on which the current LAYER was removed
LAYER_ID	The LAYER_ID is a system generated unique identifier to represent each LAYER for a particular PAVEMENT SECTION in the database
LAYER_NO	The LAYER_NO is used to represent each LAYER NUMBER. Layers are identified from 1 on, where 1 corresponds to subgrade (or bottom-most layer), 2 corresponds to subbase/base (layer on top of layer 1), and so forth.
LAYER_THICKNESS_MEAN	The LAYER_THICKNESS_MEAN is used to represent the MEAN LAYER THICKNESS for a particular LAYER within a given PAVEMENT SECTION, in inches
LAYER_THICKNESS_SDV	The LAYER_THICKNESS_SDV is used to represent the LAYER THICKNESS STANDARD DEVIATION for a particular LAYER within a given PAVEMENT SECTION, in inches
LAYER_TYPE	The LAYER_TYPE is used to represent the LAYER TYPE (type of material that makes up current layer). Can be one of the following: HMA layer=A, Base/subbase layer=B (includes treated/untreated materials), Subgrade=G (includes treated/untreated materials), Other=O
NO_10_PASSING	The NO_10_PASSING is used to represent the amount of material passing the #10 sieve
NO_16_PASSING	The NO_16_PASSING is used to represent the amount of material passing the #16 sieve
NO_200_PASSING	The NO_200_PASSING is used to represent the amount of material passing the #200 sieve
NO_4_PASSING	The NO_4_PASSING is used to represent the amount of material passing the #4 sieve
NO_40_PASSING	The NO_40_PASSING is used to represent the amount of material passing the #40 sieve
NO_80_PASSING	The NO_80_PASSING is used to represent the amount of material passing the #80 sieve
NO_OF_LIFTS	The NO_OF_LIFTS is used to represent the NUMBER OF LIFTS that were required to place the current LAYER
ONE_AND_HALF_PASSING	The ONE_AND_HALF_PASSING is used to represent the amount of material passing the 1 1/2" sieve
ONE_AND_QUATER_PASSING	The ONE_AND_QUATER_PASSING is used to represent the amount of material passing the 1 1/4" sieve
FIVE_EIGHTHS_PASSING	The FIVE_EIGHTHS_PASSING is used to represent the amount of material passing the 5/8" sieve
ONE_HALF_PASSING	The ONE_HALF_PASSING is used to represent the amount of material passing the 1/2" sieve
ONE_PASSING	The ONE_PASSING is used to represent the amount of material passing the 1" sieve

ONE_QUATER_PASSING	The ONE_QUATER_PASSING is used to represent the amount of material passing the 1/4" sieve
SEVEN_EIGHTHS_PASSING	The SEVEN_EIGHTHS_PASSING is used to represent the amount of material passing the 7/8" sieve
THREE_EIGHTHS_PASSING	The THREE_EIGHTHS_PASSING is used to represent the amount of material passing the 3/8" sieve
THREE_PASSING	The THREE_PASSING is used to represent the amount of material passing the 3" sieve
THREE_QUATER_PASSING	The THREE_QUATER_PASSING is used to represent the amount of material passing the 3/4" sieve
TWO_PASSING	The TWO_PASSING is used to represent the amount of material passing the 2" sieve
PAV_LAYER_BASE	The PAV_LAYER_BASE contains general and material subbase/base information on the different pavement sections included in the database.
AASHTO_CLASSIFICATION	The AASHTO_CLASSIFICATION represents the AASHTO SOIL CLASSIFICATION of the current material
COMP_STRENGTH	The COMP_STRENGTH is used to represent the compressive strength of the aggregate corresponding to the given LAYER
COMP_STRENGTH_103KPA	The COMP_STRENGTH_103KPA is used to represent the compressive strength of the aggregate corresponding to the given LAYER, under a confining pressure of 103 kPa
COMP_STRENGTH_0KPA	The COMP_STRENGTH_0KPA is used to represent the compressive strength of the aggregate corresponding to the given LAYER, under no confining pressure
CON_DENSITY_MEAN	The CON_DENSITY_MEAN is used to represent the mean construction density of the aggregate corresponding to the given LAYER, in percentage
CON_DENSITY_SDV	The CON_DENSITY_SDV is used to represent the construction density standard deviation of the aggregate corresponding to the given LAYER, in percentage
CON_MC_MEAN	The CON_MC_MEAN is used to represent the mean construction moisture content in the aggregate corresponding to the given LAYER, in percentage
CON_MC_SDV	The CON_MC_SDV is used to represent the standard deviation of construction moisture content in the aggregate corresponding to the given LAYER, in percentage
CON_SEISMIC_MOD_MEAN	The CON_SEISMIC_MOD_MEAN is used to represent the mean construction seismic modulus corresponding to the given LAYER, in ksi
CON_SEISMIC_MOD_SDV	The CON_SEISMIC_MOD_SDV is used to represent the construction seismic modulus standard deviation of the aggregate corresponding to the given LAYER, in ksi
GRANULAR_ID	The GRANULAR_ID is a system generated unique identifier to represent each GRANULAR material used in a given LAYER for a particular PAVEMENT SECTION in the database. It includes Base, Subbase, treated materials, etc
INTRFACE_COND	The INTRFACE_COND is used to represent the INTERFACE CONDITION between LAYERS in contact with the current GRANULAR LAYER present in the field
LAB_COMPACTION_EFFORT	The LAB_COMPACTION_EFFORT is used to represent the LABORATORY COMPACTION

	EFFORT required to achieve adequate density, in percentage
LAB_SEISMIC_MOD_MEAN	The LAB_SEISMIC_MOD_MEAN is used to represent the MEAN LABORATORY SEISMIC MODULUS under controlled conditions, in ksi
LAB_SEISMIC_MOD_SDV	The LAB_SEISMIC_MOD_SDV is used to represent the LABORATORY SEISMIC MODULUS STANDARD DEVIATION under controlled conditions, in ksi
LAYER_ID	The LAYER_ID is a system generated unique identifier to represent each LAYER for a particular PAVEMENT SECTION in the database
LIQUID_LIMIT	The LIQUID_LIMIT is used to represent the LIQUID LIMIT according to Atterberg's Limits
MC_SINE_APPX_A	The MC_SINE_APPX_A is used to represent the MOISTURE CONTENT SINUSOIDAL APPROXIMATION: Constant A
MC_SINE_APPX_B	The MC_SINE_APPX_B is used to represent the MOISTURE CONTENT SINUSOIDAL APPROXIMATION: Constant B
MC_SINE_APPX_C	The MC_SINE_APPX_C is used to represent the MOISTURE CONTENT SINUSOIDAL APPROXIMATION: Constant C
MDD	The MDD is used to represent the MAXIMUM DRY DENSITY for a corresponding aggregate, in pcf
OMC	The OMC is used to represent the OPTIMAL MOISTURE CONTENT for a corresponding aggregate, in percentage
PLASTIC_INDEX	The PLASTIC_INDEX is used to represent the PLASTIC INDEX according to Atterberg's Limits
PLASTIC_LIMIT	The PLASTIC_LIMIT is used to represent the PLASTIC LIMIT according to Atterberg's Limits
POISONS_RATIO	The POISONS_RATIO is used to represent the POISSONS RATIO for a given material
PRIME_COAT_APP_RATE	The PRIME_COAT_APP_RATE is used to represent the PRIME COAT APPLICATION RATE used to ensure adequate bond between LAYERS
PRIME_COAT_TYPE	The PRIME_COAT_TYPE is used to represent the PRIME COAT TYPE used to ensure adequate bond between LAYERS
SHRINKAGE_LIMIT	The SHRINKAGE_LIMIT is used to represent the SHRINKAGE LIMIT according to Atterberg's Limits
TREATMENT_AMOUNT	The TREATMENT_AMOUNT is used to represent the AMOUNT OF TREATMENT used to stabilize a given LAYER
TREATMENT_TYPE	The TREATMENT_TYPE is used to represent the TYPE OF TREATMENT used to stabilize a given LAYER
TX_TRIAXIAL_CLASSIFICATION	The TX_TRIAXIAL_CLASSIFICATION represents the TEXAS TRIAXIAL CLASSIFICATION of the current material
USC_CLASSIFICATION	The USC_CLASSIFICATION represents the UNIFIED SOIL CLASSIFICATION of the current material
WET_BALL_MILL	The WET_BALL_MILL represents loss of material under the given test specification, in percentage
PAV_LAYER_HMA	The PAV_LAYER_HMA entity is a link entity between the different asphalt layers, and the additives, binder, HMA, and mix information for the layers.

ADDITIVE_ID	The ADDITIVE_ID is a system generated unique identifier to represent the different types of additives included in the database
BINDER_ID	The BINDER_ID is a system generated unique identifier to represent each asphalt binder included in the database
HMA_ID	The HMA_ID is a system generated unique identifier to represent each HMA layer included in the database
LAYER_ID	The LAYER_ID is a system generated unique identifier to represent each LAYER for a particular PAVEMENT SECTION in the database
MIX_ID	The MIX_ID is a system generated unique identifier to represent each individual asphalt mixture used in an HMA LAYER for a particular PAVEMENT SECTION in the database

PAV_LAYER_HMA_CREEP	The PAV_LAYER_HMA_CREEP entity contains creep results on samples from the different asphalt layers.
CREEP_COMP_1_SEC	The CREEP_COMP_1_SEC represents the CREEP COMPLIANCE measured at 1 s
CREEP_COMP_10_SEC	The CREEP_COMP_10_SEC represents the CREEP COMPLIANCE measured at 10 s
CREEP_COMP_100_SEC	The CREEP_COMP_100_SEC represents the CREEP COMPLIANCE measured at 100 s
CREEP_COMP_2_SEC	The CREEP_COMP_2_SEC represents the CREEP COMPLIANCE measured at 2 s
CREEP_COMP_20_SEC	The CREEP_COMP_20_SEC represents the CREEP COMPLIANCE measured at 20 s
CREEP_COMP_5_SEC	The CREEP_COMP_5_SEC represents the CREEP COMPLIANCE measured at 5 s
CREEP_COMP_50_SEC	The CREEP_COMP_50_SEC represents the CREEP COMPLIANCE measured at 50 s
CREEP_ID	The CREEP_ID is a system generated unique identifier for creep compliance results for each specific test specimen from a given HMA LAYER
CREEP_POISSON_CALC	The CREEP_POISSON_CALC is used to represent the POISSONS RATIO calculated from load/deformation time histories
CREEP_POISSON_USED	The CREEP_POISSON_USED is used to represent the POISSONS RATIO used as input to the creep compliance test
HMA_ID	The HMA_ID is a system generated unique identifier to represent each HMA layer included in the database
CREEP_TEST_NO	The CREEP_TEST_NO is a code used in identifying the sample number from a particular HMA LAYER
TEST_TEMPERATURE	The TEST_TEMPERATURE represents the temperature at which the creep compliance test was run, in °C

PAV_LAYER_HMA_MOD	The PAV_LAYER_HMA_MOD entity provides resilient modulus results for the asphalt layer included in the database.
HMA_ID	The HMA_ID is a system generated unique identifier to represent each HMA layer included in the database

INST_MR_AVG	The INST_MR_AVG represents the average instantaneous resilient modulus determined by averaging results from cycles 1, 2, and 3
INST_MR_CYCLE_1	The INST_MR_CYCLE_1 represents the instantaneous resilient modulus determined by from cycles 1, in ksi
INST_MR_CYCLE_2	The INST_MR_CYCLE_2 represents the instantaneous resilient modulus determined by from cycles 2, in ksi
INST_MR_CYCLE_3	The INST_MR_CYCLE_3 represents the instantaneous resilient modulus determined by from cycles 3, in ksi
INST_MR_POISSON_CALC_AVG	The INST_MR_POISSON_CALC_AVG represents the average instantaneous calculated Poisson's ratio determined by averaging results from cycles 1, 2 and 3
INST_MR_POISSON_CALC_CYCLE_1	The INST_MR_POISSON_CALC_CYCLE_1 represents the instantaneous POISSONS ratio for load cycle 1. Calculated from raw load/deformation time histories
INST_MR_POISSON_CALC_CYCLE_2	The INST_MR_POISSON_CALC_CYCLE_2 represents the instantaneous POISSONS ratio for load cycle 2. Calculated from raw load/deformation time histories
INST_MR_POISSON_CALC_CYCLE_3	The INST_MR_POISSON_CALC_CYCLE_3 represents the instantaneous POISSONS ratio for load cycle 3. Calculated from raw load/deformation time histories
MOD_ID	The MOD_ID is a system generated unique identifier to represent each test sample that has been used to run the resilient modulus test
MR_DATA_FILE_SPECIMEN_1	The MR_DATA_FILE_SPECIMEN_1 represents the name of file that contains load/deformation time histories used in calculation of resilient modulus for a given test temperature for specimen 1.
MOD_TEST_NO	The MOD_TEST_NO is a code used in identifying the sample number from a particular HMA LAYER
TEST_TEMPERATURE	The TEST_TEMPERATURE represents the temperature at which the creep compliance test was run, in °C
TOTAL_MR_AVG	The TOTAL_MR_AVG represents the average total resilient modulus determined by averaging results from cycles 1, 2, and 3
TOTAL_MR_CYCLE_1	The TOTAL_MR_CYCLE_1 represents the total resilient modulus determined by from cycles 1, in ksi
TOTAL_MR_CYCLE_2	The TOTAL_MR_CYCLE_2 represents the total resilient modulus determined by from cycles 2, in ksi
TOTAL_MR_CYCLE_3	The TOTAL_MR_CYCLE_3 represents the total resilient modulus determined by from cycles 3, in ksi
TOTAL_MR_POISSON_CALC_AVG	The TOTAL_MR_POISSON_CALC_AVG represents the average total calculated Poisson's ratio determined by averaging results from cycles 1, 2 and 3
TOTAL_MR_POISSON_CALC_CYCLE_1	The TOTAL_MR_POISSON_CALC_CYCLE_1 represents the total POISSONS ratio for load cycle 1. Calculated from raw load/deformation time histories
TOTAL_MR_POISSON_CALC_CYCLE_2	The TOTAL_MR_POISSON_CALC_CYCLE_2 represents the total POISSONS ratio for load cycle 2. Calculated from raw load/deformation time histories
TOTAL_MR_POISSON_CALC_CYCLE_3	The TOTAL_MR_POISSON_CALC_CYCLE_3 represents the total POISSONS ratio for load cycle 3. Calculated from raw load/deformation time histories

PAV_LAYER_SOIL	The PAV_LAYER_SOIL entity contains soil properties of the subgrades of the different pavement sections included in the database.
AASHTO_CLASSIFICATION	The AASHTO_CLASSIFICATION represents the AASHTO SOIL CLASSIFICATION of the current material
BAR_LINEAR_SHRINKAGE	The BAR_LINEAR_SHRINKAGE represents the BAR LINEAR SHRINKAGE of a soil
CBR	The CBR represents the CALIFORNIA BEARING RATIO of a soil
COMP_STRENGTH_103KPA	The COMP_STRENGTH_103KPA is used to represent the compressive strength of the aggregate corresponding to the given LAYER, under a confining pressure of 103 kPa
COMP_STRENGTH_0KPA	the COMP_STRENGTH_0KPA is used to represent the compressive strength of the aggregate corresponding to the given LAYER, under no confining pressure
CON_DENSITY_MEAN	The CON_DENSITY_MEAN is used to represent the mean construction density of the aggregate corresponding to the given LAYER, in percentage
CON_DENSITY_SDV	The CON_DENSITY_SDV is used to represent the construction density standard deviation of the aggregate corresponding to the given LAYER, in percentage
CON_MC_MEAN	The CON_MC_MEAN is used to represent the mean construction moisture content in the aggregate corresponding to the given LAYER, in percentage
CON_MC_SDV	The CON_MC_SDV is used to represent the standard deviation of construction moisture content in the aggregate corresponding to the given LAYER, in percentage
CON_SEISMIC_MOD_MEAN	The CON_SEISMIC_MOD_MEAN is used to represent the mean construction seismic modulus corresponding to the given LAYER, in ksi
CON_SEISMIC_MOD_SDV	The CON_SEISMIC_MOD_SDV is used to represent the construction seismic modulus standard deviation of the aggregate corresponding to the given LAYER, in ksi
DCP	The DCP represents the DYNAMIC CONE PENETROMETER results for a soil
GROUP_INDEX	The GROUP_INDEX is used to identify the type soil according to AASHTO
INTRFACE_COND	The INTRFACE_COND is used to represent the INTERFACE CONDITION between LAYERS in contact with the current GRANULAR LAYER present in the field
LAB_COMPACTION_EFFORT	The LAB_COMPACTION_EFFORT is used to represent the LABORATORY COMPACTION EFFORT required to achieve adequate density, in percentage
LAB_SEISMIC_MOD_MEAN	The LAB_SEISMIC_MOD_MEAN is used to represent the MEAN LABORATORY SEISMIC MODULUS under controlled conditions, in ksi
LAB_SEISMIC_MOD_SDV	The LAB_SEISMIC_MOD_SDV is used to represent the LABORATORY SEISMIC MODULUS STANDARD DEVIATION under controlled conditions, in ksi
LAYER_ID	The LAYER_ID is a system generated unique identifier to represent each LAYER for a particular PAVEMENT SECTION in the database
LIQUID_LIMIT	The LIQUID_LIMIT is used to represent the LIQUID LIMIT according to Atterberg's Limits
MC_SINE_APPX_A	The MC_SINE_APPX_A is used to represent the MOISTURE CONTENT SINUSOIDAL APPROXIMATION: Constant A

MC_SINE_APPX_B	The MC_SINE_APPX_B is used to represent the MOISTURE CONTENT SINUSOIDAL APPROXIMATION: Constant B
MC_SINE_APPX_C	The MC_SINE_APPX_C is used to represent the MOISTURE CONTENT SINUSOIDAL APPROXIMATION: Constant C
MDD	The MDD is used to represent the MAXIMUM DRY DENSITY for a corresponding aggregate, in pcf
MOD_SUBGRADE_REACTION	The MOD_SUBGRADE_REACTION is used to represent the MODULUS OF SUBGRADE REACTION for a corresponding aggregate, in ksi
OMC	The OMC is used to represent the OPTIMAL MOISTURE CONTENT for a corresponding aggregate, in percentage
ORG_CONTENT	The ORG_CONTENT is used to represent the ORGANIC CONTENT present in a soil, in percentage
PLASTIC_INDEX	The PLASTIC_INDEX is used to represent the PLASTIC INDEX according to Atterberg's Limits
PLASTIC_LIMIT	The PLASTIC_LIMIT is used to represent the PLASTIC LIMIT according to Atterberg's Limits
POISONS_RATIO	The POISONS_RATIO is used to represent the POISSONS RATIO for a given material
RESILIENT_MOD_CONST_K1	The RESILIENT_MOD_CONST_K1 is used to represent the RESILIENT MODULUS Function: CONSTANT k1
RESILIENT_MOD_CONST_K2	The RESILIENT_MOD_CONST_K2 is used to represent the RESILIENT MODULUS Function: CONSTANT k2
RESILIENT_MOD_CONST_K3	The RESILIENT_MOD_CONST_K3 is used to represent the RESILIENT MODULUS Function: CONSTANT k3
SHRINKAGE_LIMIT	The SHRINKAGE_LIMIT is used to represent the SHRINKAGE LIMIT according to Atterberg's Limits
SOIL_ID	The SOIL_ID is a system generated unique identifier to represent each subgrade SOIL material used in a given LAYER for a particular PAVEMENT SECTION in the database.
SULPHATE_POT	The SULPHATE_POT is used to represent the sulfate potential of a particular SOIL
SWELL_POT	The SWELL_POT is used to represent the swell potential of a particular SOIL
TX_TRIAXIAL_CLASSIFICATION	The TX_TRIAXIAL_CLASSIFICATION represents the TEXAS TRIAXIAL CLASSIFICATION of the current material
USC_CLASSIFICATION	The USC_CLASSIFICATION represents the UNIFIED SOIL CLASSIFICATION of the current material
PAV_MIX	The PAV_MIX entity contains asphalt mixture information for the different asphalt layers of the pavement sections included in the database.
AIR_VOID_CONTENT_MEAN	The AIR_VOID_CONTENT_MEAN is used to represent the MEAN AIR VOID CONTENT of a particular HMA mix used in an HMA LAYER, in percentage
AIR_VOID_CONTENT_SDV	The AIR_VOID_CONTENT_SDV is used to represent the AIR VOID CONTENT STANDARD DEVIATION of a particular HMA mix used in an HMA LAYER, in percentage
DENSITY_MEAN	The DENSITY_MEAN is used to represent the in-situ mean density of HMA MIX corresponding to

	the given HMA LAYER, in percentage
DENSITY_SDV	The DENSITY_SDV is used to represent the in-situ standard deviation of density of HMA MIX corresponding to the given HMA LAYER, in percentage
DYNAMIC_MOD	The DYNAMIC_MOD is used to represent the DYNAMIC MODULUS of HMA MIX corresponding to the given HMA LAYER, in ksi
DYNAMIC_STIFF	The DYNAMIC_STIFF is used to represent the DYNAMIC STIFFNESS of HMA MIX corresponding to the given HMA LAYER, in ksi
FLOW_NUMBER	The FLOW_NUMBER is used to represent the FLOW NUMBER according to the Marshall Method
FLOW_TIME	The FLOW_TIME is used to represent the FLOW TIME according to the Marshall Method
HMA_ID	The HMA_ID is a system generated unique identifier to represent each HMA layer included in the database
IND_TENSILE_STRENGTH	The IND_TENSILE_STRENGTH is used to represent the INDIRECT TENSILE STRENGHT of an HMA MIX
INTERFACE_COND	The INTERFACE_COND is used to represent the INTERFACE CONDITION between LAYERS in contact with the current HMA LAYER present in the field
JMF	The JMF is used to represent the JOB MIX FORMULA for a given HMA MIX
MASTER_CURVE	The MASTER_CURVE is used to represent the MASTER CURVE or estimate of the same
MIX_DESIGN_PROCEDURE	The MIX_DESIGN_PROCEDURE is used to represent the MIX DESIGN PROCEDURE
MIX_ID	The MIX_ID is a system generated unique identifier to represent each individual asphalt mixture used in an HMA LAYER for a particular PAVEMENT SECTION in the database
MIX_TYPE	The MIX_TYPE is used to represent the MIX TYPE according to TxDOT Item number (340=DENSE, 341=DENSE QCQA, 342=PFC, 344=SUPERPAVE&CMHB, 346=SMA, OTHER, UNKNOWN)
OVERLAY_TESTER	The OVERLAY_TESTER is used to show the OVERLAY TESTER results for a particular HMA MIX
POISSONS_RATIO	The POISSONS_RATIO is used to represent the POISSONS RATIO for a given material
RICE_DENSITY	The RICE_DENSITY is used to represent the maximum theoretical density or RICE DENSITY, in pcf
TACK_COAT_RATE	The TACK_COAT_RATE is used to represent the TACK COAT APPLICATION RATE used to ensure adequate bond between LAYERS
TACK_COAT_TYPE	The TACK_COAT_TYPE is used to represent the TACK COAT TYPE used to ensure adequate bond between LAYERS
VMA	The VMA is used to represent the VOIDS in the MINERAL AGGREGATE, in percentage
PAV_SECTION	The PAV_SECTION entity is the main entity in the database. Each PAVEMENT SECTION contains specific location, climate, and geographical information for the pavement sections included in the database.
BEG_PT_ELEV	The BEG_PT_ELEV is used to represent the ELEVATION of pavement section beginning point, as measured using GPS equipment.

BEG_PT_LAT	The BEG_PT_LAT is used to represent the LATITUDE of pavement section beginning point, as measured using GPS equipment.
BEG_PT_LONG	The BEG_PT_LONG is used to represent the LONGITUDE of pavement section beginning point, as measured using GPS equipment.
BEG_TRM	The BEG_TRM is used to represent the reference marker number closest to the beginning of the pavement section
BEG_TRM_DISP	The BEG_TRM_DISP is used to represent the displacement to the reference marker number closest to the beginning of the pavement section
COUNTY_ID	The COUNTY_ID is a unique identifier to represent every County in the State of Texas, as defined by TxDOT
DEPTH_BEDR	The DEPTH_BEDR is used to represent the DEPTH to BEDROCK of a particular PAVEMENT SECTION, in feet
DIRECTION	The DIRECTION is used to indicate the travel direction of traffic. Can be classified as one of the following: East=1, West=2, North=3, South=4
END_PT_ELEV	The END_PT_ELEV is used to represent the ELEVATION of pavement section ending point, as measured using GPS equipment.
END_PT_LAT	The END_PT_LAT is used to represent the LATITUDE of pavement section ending point, as measured using GPS equipment.
END_PT_LONG	The END_PT_LONG is used to represent the LONGITUDE of pavement section ending point, as measured using GPS equipment.
END_TRM	The END_TRM is used to represent the reference marker number closest to the ending of the pavement section
END_TRM_DISP	The END_TRM_DISP is used to represent the displacement to the reference marker number closest to the ending of the pavement section
FACILITY_TYPE	The FACILITY_TYPE is used to indicate the PMIS facility ranking
FOUNDATION_TYPE	The FOUNDATION_TYPE is used to represent the type of foundation to support roadway structure.
LANE_NUMBER	The LANE_NUMBER is used to represent the lane number on pavement roadway that corresponds to pavement section
LANE_WIDTH	The LANE_WIDTH is used to represent the lane width that corresponds to the PAVEMENT SECTION, in feet
NO_OF_LANES	The NO_OF_LANES is used to represent the number of lanes that corresponds to the PAVEMENT SECTION
ORIGINAL_DB	The ORIGINAL_DB is used to indicate the database from which data was originally acquired from
ORIGINAL_ID	The ORIGINAL_ID is used to indicate the database from which data was originally acquired from
ROADBED	The ROADBED is used to indicate the ROADBED type according to PMIS
ROADWAY_NO	The ROADWAY_NO is used to indicate the Texas ROADWAY NUMBER, which correspond to the TxDOT highway number or route number from PMIS
ROADWAY_TYPE	The ROADWAY_TYPE is used to indicate the ROADWAY TYPE Classification. Can be classified as one of the following: IH=1, US=2, SH=3, Loop=4, FM=5
SECTION_ID	The SECTION_ID is a system generated unique identifier for each PAVEMENT SECTION included

	in the database
TERRAIN_GRADE	The TERRAIN_GRADE is used to indicate the TERRAIN GRADE / slope. Can be classified as one of the following: flat=1, downhill=2, uphill=3
PAV_SS_US_MOD	The PAV_SS_US_MOD entity contains modulus information for the granular materials and soils used on the different layers of the sections included in the database.
APPLIED_CONTACT_LOAD_AVG	The APPLIED_CONTACT_LOAD_AVG is used to indicate the AVERAGE APPLIED CONTACT LOAD
APPLIED_CONTACT_LOAD_STD	The APPLIED_CONTACT_LOAD_STD is used to indicate the APPLIED CONTACT LOAD STANDARD DEVIATION
APPLIED_CONTACT_STRESS_AVG	The APPLIED_CONTACT_STRESS_AVG is used to indicate the AVERAGE APPLIED CONTACT STRESS
APPLIED_CONTACT_STRESS_STD	The APPLIED_CONTACT_STRESS_STD is used to indicate the APPLIED CONTACT STRESS STANDARD DEVIATION
APPLIED_CYCLIC_LOAD_AVG	The APPLIED_CYCLIC_LOAD_AVG is used to indicate the AVERAGE APPLIED CYCLIC LOAD
APPLIED_CYCLIC_LOAD_STD	The APPLIED_CYCLIC_LOAD_STD is used to indicate the APPLIED CYCLIC LOAD STANDARD DEVIATION
APPLIED_CYCLIC_STRESS_AVG	The APPLIED_CYCLIC_STRESS_AVG is used to indicate the AVERAGE APPLIED CYCLIC STRESS
APPLIED_CYCLIC_STRESS_STD	The APPLIED_CYCLIC_STRESS_STD is used to indicate the APPLIED CYCLIC STRESS STANDARD DEVIATION
APPLIED_MAX_AXIAL_LOAD_AVG	The APPLIED_MAX_AXIAL_LOAD_AVG is used to indicate the AVERAGE APPLIED MAXIMUM AXIAL LOAD
APPLIED_MAX_AXIAL_LOAD_STD	The APPLIED_MAX_AXIAL_LOAD_STD is used to indicate the APPLIED MAXIMUM AXIAL LOAD STANDARD DEVIATION
APPLIED_MAX_AXIAL_STRESS_AVG	The APPLIED_MAX_AXIAL_STRESS_AVG is used to indicate the AVERAGE APPLIED MAXIMUM AXIAL STRESS
APPLIED_MAX_AXIAL_STRESS_STD	The APPLIED_MAX_AXIAL_STRESS_STD is used to indicate the APPLIED MAXIMUM AXIAL STRESS STANDARD DEVIATION
CON_PRESSURE	The CON_PRESSURE is used to indicate the chamber CONFINING PRESSURE
DEF_LVDT_1_2_AVG	The DEF_LVDT_1_2_AVG is used to indicate the AVERAGE LVDT deflection across cycles of the average recoverable axial deformations
DEF_LVDT_1_2_STD	The DEF_LVDT_1_2_STD is used to indicate the LVDT deflection STANDARD DEVIATION across cycles of the average recoverable axial deformations
DEF_LVDT_1_AVG	The DEF_LVDT_1_AVG is used to indicate the AVERAGE LVDT deflection across cycles of the recoverable axial deformation of the sample for each LVDT
DEF_LVDT_1_STD	The DEF_LVDT_1_STD is used to indicate the LVDT deflection STANDARD DEVIATION across cycles of the recoverable axial deformation of the sample for each LVDT

DEF_LVDT_2_AVG	The DEF_LVDT_2_AVG is used to indicate the AVERAGE LVDT deflection across cycles of the recoverable axial deformation of the sample for each LVDT
DEF_LVDT_2_STD	The DEF_LVDT_2_STD is used to indicate the LVDT deflection STANDARD DEVIATION across cycles of the recoverable axial deformation of the sample for each LVDT
FIELD_SET	The FIELD_SET is used to indicate the sequential number indicating the field sampling event. Assigned 1 for first sample event and incremented by 1 for subsequent events
LAYER_ID	The LAYER_ID is a system generated unique identifier to represent each LAYER for a particular PAVEMENT SECTION in the database
LOC_NO	The LOC_NO is a unique code number assigned to each sampling location indicating the sample type. The single character prefix indicates the sample type. The numeric suffix is the unique project location for the sample type.
MOD_ID	The MOD_ID is a system generated unique identifier of modulus information for granular layers in a specific pavement section in the database
MR_MATL_TYPE	The MR_MATL_TYPE is a code designating whether the material was coarse
NOM_MAX_AXIAL_STRESS	The NOM_MAX_AXIAL_STRESS is used to indicate the NOMINAL MAXIMUM AXIAL STRESS
RES_MOD_AVG	The RES_MOD_AVG is used to indicate the AVERAGE RESILIENT MODULUS across cycles
RES_MOD_STD	The RES_MOD_STD is used to indicate the RESILIENT MODULUS STANDARD DEVIATION across cycles
RES_STRAIN_AVG	The RES_STRAIN_AVG is used to indicate the AVERAGE RESILIENT STRAIN across cycles
RES_STRAIN_STD	The RES_STRAIN_STD is used to indicate the RESILIENT STRAIN STANDARD DEVIATION across cycles
S_MOD_SAMPLE_NO	The S_MOD_SAMPLE_NO is a code used in identifying the sample number from a particular LAYER
S_MOD_TEST_DATE	The S_MOD_TEST_DATE is a indicator of the DATE the testing was performed on the sample
S_MOD_TEST_NO	The S_MOD_TEST_NO is a code used in identifying the sample number from a particular LAYER
TRAFFIC	The TRAFFIC entity contains general traffic information regarding the pavement sections included in the database.
AADT_ALL_VEHIC_2WAY	The AADT_ALL_VEHIC_2WAY is used for indicating the estimated AVERAGE ANNUAL DAILY TRAFFIC (AADT) in all lanes, two directions, for year indicated
AADT_TRUCK_COMBO_2WAY	The AADT_TRUCK_COMBO_2WAY is used for indicating the estimated AVERAGE ANNUAL DAILY TRUCK TRAFFIC (AADTT) in all lanes, two directions, for year indicated
AADT_ALL_VEHIC	The AADT_ALL_VEHIC is used for indicating the estimated or monitored AVERAGE ANNUAL DAILY TRAFFIC (AADT) per lane for the indicated year
AADT_TRUCK_COMBO	The AADT_TRUCK_COMBO is used for indicating the estimated or monitored AVERAGE ANNUAL DAILY TRUCK TRAFFIC (AADTT) per lane for the indicated year
ANL_KESAL_LTPP_LN_YR	The ANL_KESAL_LTPP_LN_YR is used for indicating the estimated or monitored ANNUAL KILO-EQUIVALENT SINGLE AXLE LOADS (kESALs), for the indicated year

SECTION_ID	The SECTION_ID is a system generated unique identifier for each PAVEMENT SECTION included in the database
TRAFFIC_ID	The TRAFFIC_ID is a system generated unique identifier for each TRAFFIC record or estimation for a PAVEMENT SECTION included in the database
TRAFFIC_YEAR_RECORD	The TRAFFIC_YEAR_RECORD is a indicator of the YEAR for which the traffic data is estimated/monitored for the pavement section
TRAFFIC_LOAD_SPECTRA	The TRAFFIC_LOAD_SPECTRA entity contains information on the axle load spectra for different axle types, as well as default axle load spectras.
AXLE_ID	The AXLE_ID is a system generated unique identifier for different axle types. Axle load spectrum (or distribution) for a given type of axle (such as single axle, single axle with dual wheels, tandem, and tridem…) is composed of two elements: axle load bins and frequency for each interval.
AXLE_TYPE	The AXLE_TYPE is used for indicating the type of axle that the frequency and weight data correspond to
WEIGHT	The WEIGHT is used for indicating the weight of the axle. The weights are classified in bins that represent the intervals of axle load weight. For steering axle and single axle with dual wheels the bins have an interval width of 1 kip; for tandem axle, 2 kip; and for tridem axle, 3 kip.
FREQUENCY	The FREQUENCY is used for indicating the normalized frequency for each axle load bin or weight range

Appendix C: Select Observations about the TxDOT Profiler

Observation 1: Cracking statistics can be collected with the Profiler only at very low speeds, preferably less than 35 mph.

Observation 2: The VCrack program running on the Roborater crashes almost every time after the Cracking statistics are collected. When the program crashes, the computer sometimes needs to be hard-booted because the entire system freezes and comes to a standstill. Therefore, it is advisable to restart the Roborater each time a Cracking survey is done on any pavement section.

Observation 3: The laser beam provided for conducting Cracking surveys even after dark doesn't work. The software fails to collect any data in such circumstances and continuously reports "TOO DARK" instead of fetching/collecting any data.

Observation 4: Rut data cannot be collected on wet surfaces or during rain; if tried the software reports as "DATA ERROR" in the BA file.

Observation 5: The ultrasonic sensors that collect the rutting information sometimes stop working. It is advisable to restart all three computers (Vamos, Roborater and the R683) to resolve such problems.

Observation 6: In some case, the Header is sometimes not recorded. If such problems are encountered, it is suggested that the user should delete the existing Header that was created for the section under consideration and recreate the same Header with the same name and try using it.

Observation 7: If in any case it's required that both the Cracking Video and Summary be collected, then they have to be done separately because the two cannot be done simultaneously. In that case, the user will need to run twice on each section and collect each separately in each of the two runs.

Observation 8: While starting the VCrack program, the user should wait on the Roborater instead of flipping it to some other computer until the number of active connections is 5 and the word "CINF0" can be seen on the VCrack screen. If this precaution is not exercised, there may be a fair chance that the Roborater will freeze and can be only brought to action by hard booting the computer.

Observation 9: When the VCVIEW program is started, the user should check on the VCrack running on the Roborater that the number of active connections now equal to 12.

Observation 10: While the VCrack program is active, it is suggested that the speed of the van should not be too high or else the VCrack may crash and the Roborater may also freeze (even when data is not being collected). Therefore, it is advised that when the van is cruising at high speeds or when data is not being collected, the VCrack program should be closed.

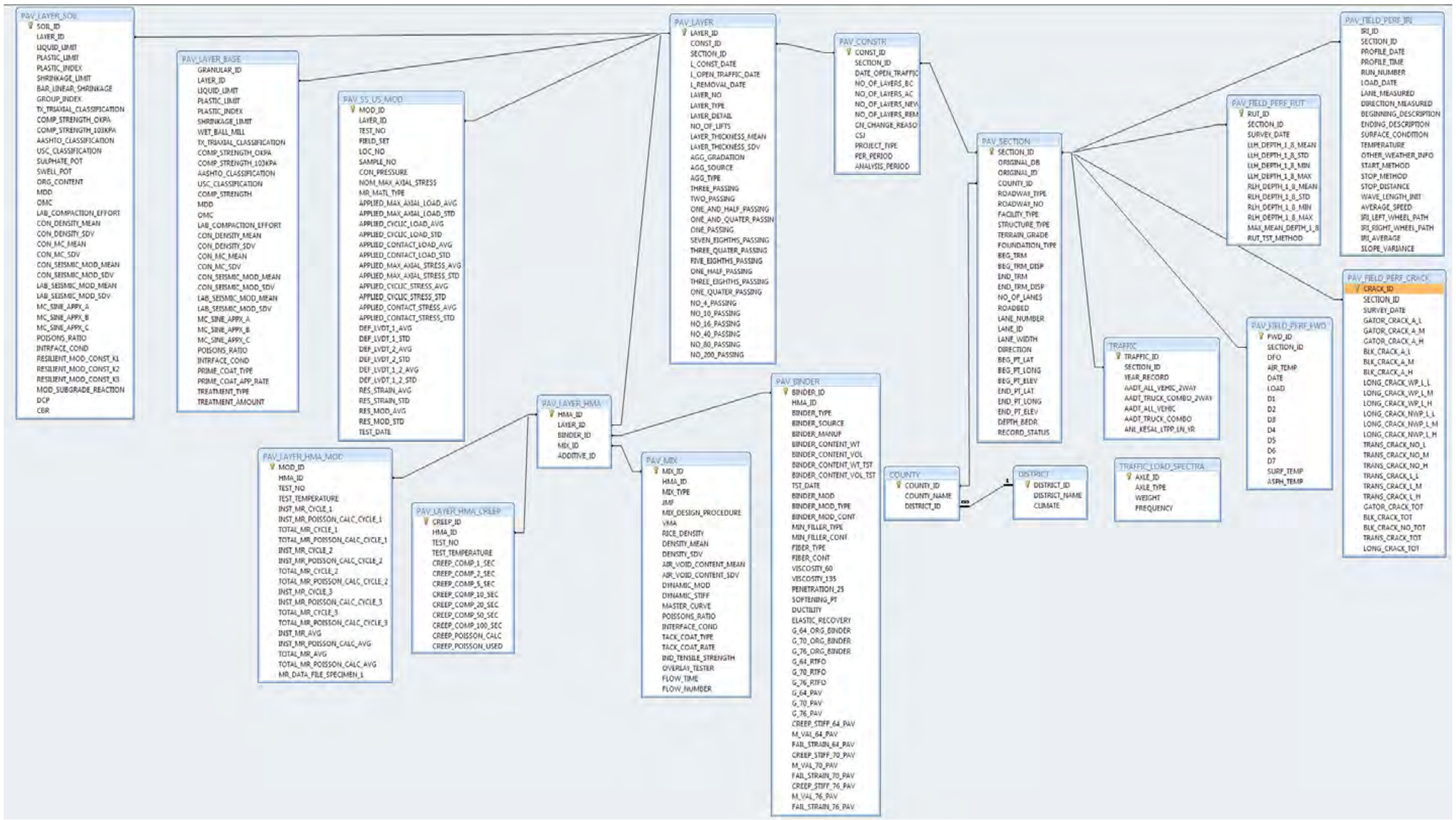
Observation 11: Sometimes the R683 starts malfunctioning and the IRI gets reported as 999 continuously. Therefore, if such a scenario is encountered, all three computers (Vamos, Roborater, and the R683) need to be restarted.

Observation 12: To ensure the DMI is working properly, the user should check that the speeds reported on the Header screen, the Profil screen, and the VCrack screen on Roborater are approximately equal. There may be a variation of +/- 2 miles because of any kind of time lag.

Observation 13: When the VCrack and the VCVIEW are both active and running and data is not being collected, the user/operator should see that new image files with a BMP (Bitmap) extension are getting generated and being reported on the VCVIEW screen. If this is not happening, it will imply that the DMI is having some problems.

Observation 14: Finally, the user should check that the data is actually getting saved into the BA file each time a data collection cycle is collected on any section. In general the physical location of the BA file is C:\Vamos\BA99\. The user should open the BA file with the most current date and look for the data cluster of interest. For the Cracking Video, the user should look into the following location on the Roborater: D:\PaveImage\.

Appendix D: Entity-Relationship Diagram for the TFPD



Appendix E: The Present and Future of the Texas Flexible Pavement Database

E.1. Introduction

For the development, validation and calibration of a method for the structural design of new and rehabilitated pavements, complete, reliable and accessible databases are essential. These databases should include material properties, pavement structural characteristics, highway traffic information, environmental conditions, and performance data in terms of as cracking, rutting, and roughness.

In principle, these databases have been implemented Texas for many years. However, the existing databases have been designed and maintained with specific objectives, not necessarily consistent with their potential use for structural pavement design. These databases include (but are not limited to): Design and Construction Information System (DCIS), Pavement Management Information Systems (PMIS), Maintenance Management Information System (MMIS), Highway Performance Monitoring System (HPMS), Vehicle Tracking Recording Information System (VTRIS), Laboratory Information Management System (LIMS), SiteManager, etc. Specifically some of these databases have been designed for network level applications and planning purposes, not to calibrate data-intensive performance models such as those typical of mechanistic-empirical pavement design models.

The University of Texas at Austin conducted TxDOT Research Project 0-5513, *"The Development of the Texas Flexible Pavement Database,"* with the objectives of providing a "one-stop shopping" database to house all necessary information to develop, validate and calibrate flexible pavement performance models. Based on lessons learned during previous attempts to develop such databases in Texas, it was decided to follow an "open-for-all" approach. That is, the database is user-friendly, easily and freely accessible to anyone that has internet access and chooses to register as a user. This approach ensures a transparent and sustainable system. Any user can download any type of data as he/she requires. Currently the access to the data is open but the Department can, at its discretion, implement any type of access control at any time.

The database can be accessed at http://pavements.ce.utexas.edu/ (select Texas Flexible Pavement Database). As of October 2008, there are 65 registered users from the most diverse geographical locations and organization including State DOTs, FHWA, universities, consultants, research centers, etc. Within the United States, users from the following states have already registered: Arizona, California, Illinois, Minnesota, New Mexico, and Texas. In addition, the database has attracted interest from different countries including: Argentina, Australia, Canada, Chile, Denmark, France, Mexico, South Africa and the United Kingdom. It should also be noted that the database has been officially launched during summer 2008.

To date, the database contains information on 164 sections divided into two main groups and six subsets of sections:

1) ***Texas Flexible Pavement Database*** (90 sections): this group contains the main sections of the database created and selected as part of Research Project 0-5513. Within this group, there are three subsets of sections: (a) TxFlex 0-5513, which consists of 41 sections that have been selected by personnel from TxDOT's Districts and Divisions, (b)

LTPP 0-5513, which consists of 31 sections that have been incorporated from the LTPP database in order to complete the experimental design and provide long-term performance information, and (c) LTPP Calibration, which consists of 18 sections whose data have been used to estimate interim calibration factors for using in conjunction with the Mechanistic-Empirical Pavement Design Guide (MEPDG) in Texas.

2) ***Additional Sections*** (74 sections): this group contains additional sections that were not part of the original experimental design but could provide valuable additional information in the near future. Within this group, there are also three subsets: (a) FHWA, which consists of 25 sections that monitor the performance of fabric underseals in Texas, (b) TxFlex Miscellaneous, which consists of additional 32 sections provided by TxDOT personnel but did not fill in any particular cell of the original experimental design or were just a repeat of existing information, and (c) LTPP Miscellaneous, which consists of 17 additional LTPP sections that were not selected for one of the reason above-mentioned but could still provide valuable additional data for calibration and validation.

E.2. Database Size and Funding Levels

The unprecedented interest in the Texas Flexible Pavement Database (TFPD), demonstrated by many states and countries, is not surprising. Many state highway agencies (SHAs) in the U.S. and around the world are in the process of validating or calibrating empirical and mechanistic-empirical pavement design methods. All of these efforts have been confronted with the same challenge: the lack of comprehensive and reliable pavement design and performance data. Many agencies have followed a similar path as Texas. First, they attempt to use data from the Long-Term Pavement Performance (LTPP) Studies. Then, they attempt to use their own pavement construction and design information as contained in the agency Pavement Management System (PMS). Finally, those agencies that can afford the necessary resources opted for developing local databases. In this case, one of the first decisions to be made is the necessary number of sections that such database should contain. Unfortunately, there is no unique answer or rule for such question because the number of sections will depend of the particular conditions and objectives of the agency and the desired level of accuracy required. For a state such as Texas, subjected to quite diverse environmental conditions, it is recommended that a minimum of 100 sections should be included in the database to address the main design variables at the minimum required level of accuracy. These sections should be at least 500-feet in length; however, when conditions are adequate, performance data before and after the experimental sections should be collected. As the number of variables of interest and the desired accuracy increase, the number of sections could easily increase to 250, 500 or beyond. The resources necessary for development and maintenance would increase almost linearly with the number of sections.

To place this particular requirement in perspective, it is essential to refer to FHWA's LTPP Studies. The LTPP Studies are a set of operational activities consisting of gathering and analyzing data that are being collected in more than 2,500 in-service pavement sections in the United States and Canada. The main goal of the data collection and analysis effort is to improve the understanding of why and how pavements deteriorate when subjected to highway traffic under varied environmental conditions. This goal is consistent with the objectives of the TFPD. Data collection and analysis began in 1987 and will continue until 2009. From there on, the future of LTPP is uncertain.

The total federal investment in LTPP is estimated to be in the order of $260 million and the state and local investment in about two to three times as much. Thus, the total investment in the program can be estimated to be in the order of $800 million or approximately $320,000 per section or $16,000 per section per year for 20 years. Thus, the development and maintenance of 100 sections could easily amount to $1.6 million annually.

The localized nature of a state program and the cooperative nature of TxDOT's Research and Technology Implementation Program (RTI) could easily bring this amount down to one-third or one-quarter of the value above-mentioned, depending on objectives, expected deliverables, and the level of cooperation. However, it is not the intention of this document to set up a budget but to place the task at hand in perspective using actual realistic figures.

E.3. Proposed Plan for the Flexible Pavement Database

There is no doubt that the development and long-term maintenance and management of a Texas Flexible Pavement Database (TFPD) are essential for the Department and for the State of Texas. The availability of a TFPD has the potential to deliver significant savings to the state by better understanding the effects of traffic, materials, and environmental conditions of pavement design and performance. This improved understanding will result in optimal structural designs, use of adequate materials, and the ability to better predict pavement deterioration. By predicting pavement deterioration more accurately, the Department can improve planning and programming activities and allocate annual budgets more effectively and efficiently.

E.3.1. Experiment and Data Collection

To optimize the use of the resources allocated to this project, at a minimum, the following main experimental variables (experimental design) should be considered:

1) Pavement type (4 levels): (a) hot-mix asphalt surface on top of hot-mix asphalt base; (b) hot-mix asphalt surface on top of untreated granular base (flexbase); (c) two course surface treatment on top of untreated granular base (flexbase); and (d) pavement structures contained treated layers (e.g. cement, lime, fly-ash).
2) Traffic levels (3 levels): (a) heavier traffic (typical of outside lanes); (b) lighter traffic (typical of passing lanes); and medium traffic levels.
3) Environmental conditions (5 levels): (a) wet-warm; (b) wet-cold, (c) dry-warm, (d) dry-cold, and (a) mixed.
4) Section replicates (2 levels): whenever possible two, and preferably three, section replicates should be incorporated into the database.

Other important variables that were considered included: highway system, subgrade type, and mix type. However, these variables are highly correlated to some of the variables listed above, therefore, they are implicitly considered.

Traffic is a continuous variable so the specification of light, medium and heavy traffic volumes is merely done so a wider range of traffic level is considered. The ideal situation would consist of including multi-lane pavement sections built to the same specification and subjected to different traffic levels. Traffic is also another variable that is highly correlated to pavement type and highway system, therefore, the experimental design proposed above may not be feasible and will depend on the section that are actually available and that will be built in the next years.

Although a lot of design and construction material information is already available, layer material from each section should be characterized in the laboratory. For pavement sections consisting of thicker asphalt layers, asphalt cores should be extracted and subjected to testing to characterize its dynamic properties. For pavements consisting of thin asphalt layers, base and subgrade material should be collected and subjected to resilient modulus testing for characterizing material properties.

The experimental design proposed above consists of 60 different combinations with a minimum of two replicates. It is recommended that in the next five years, this experiment is completed by filling in the missing cells from Project 0-5513. To this effect, it is proposed that the 41 sections already incorporated into TxFlex 0-5513 be used as the basis and new sections be added in the next five years so as to develop a basic database consisting of 100 sections that are fully characterized. These new sections should be recommended by TxDOT personnel and should not include sections from LTPP. The LTPP sections should, however, remain in the TFPD because they do provide additional validation and calibration data.

Performance data collection should be done on an annual basis because it is not disruptive to traffic and can be collected in a very inexpensive and manner. Performance data collecting should be performed during the spring and summer seasons so as to avoid disruption of TxDOT PMIS data collection process. To avoid subjectivity and unnecessary variability, automated data collection is recommended. This annual data collection exercise should include cracking, rutting and ride (roughness). On the other hand, deflection data collection by means of the Falling Weight Deflectometer (FWD) should be done in two- or, preferably, three-year intervals. Additional FWD surveys should be carried out within the first month the project is opened to traffic and before a major maintenance or rehabilitation activity is planned.

E.3.2. Interaction with Other TxDOT Databases

Although the Texas Flexible Pavement database should be autonomous and independent from any other TxDOT database, it is essential to establish some degree of interaction with other database. This interaction could translate into several benefits which will increase the reliability and completeness of the data. Some of the databases that the TFPD should interact with include: Pavement Management Information System (PMIS), Design and Construction Information System (DCIS), SiteManager, Laboratory Information Management System (LIMS), and, ideally, Maintenance Management Information System (MMIS). The incorporation of MMIS information cannot be understated. The lack of information on the timing of maintenance activities is often one of the main and most generalized shortcomings of pavement performance databases.

It is important to note that the objective of this interaction is not to obtain data for the TFPD but to verify and enhance the quality and quantity of the data. For example, interaction with PMIS could be carried out on an annual basis after data collection is completed. During this exercise that data collected on the same sections should be compared and statistically analyzed. This analysis could be used to determine equipment variability, to assess measurement error and to determine potential seasonal variability.

E.3.3. Software and Hardware

The development of the TFPD proved to be quite challenging in several aspects and additional challenges will have to be faced as the TFPD evolves and incorporates more data and more sections. One of the main challenges will be to decide on the platform that would be most suitable for this database. After considering various alternatives through interaction with TxDOT personnel, adequate review of TxDOT standards and consideration of the volume of data to be handled, it was decided that Microsoft SQL Server 2000 would be the most suitable. In an effort to cater to TxDOT's Microsoft-oriented business architecture, the programming platform chosen was Active Server Pages (ASP) which can be hosted on any Windows NT 4.0 (and upwards) with the Internet Information Services (IIS) up and running. It is therefore recommended that for the next five-year phase of the Texas Flexible Pavement Database that same software platform be maintained and emphasis should be placed on data collection and population. Currently the database resides on a dedicated Dell PowerEdge Server, which allows rapid access to the data to anyone with internet access. The School of Engineering maintains the server and takes care of its security, which is a significant benefit to the research team and to the Department. This arrangement has served well for the initial three-year development phase and it is recommended that this same arrangement be continued. The researcher team periodically backs up the database and provides the Department with a complete back-up copy of the database on an annual basis. Hence, at any time, the Department is in possession of the entire data set.

E.3.4. TxDOT Assistance

TxDOT's Transportation Programming and Planning Division (TPP) performs traffic data collection as part of their regular activities. Some of the data that are collected include: (1) automatic traffic recorder (ATR) volume data; (2) accumulative count recorder (ACR) traffic data; and (3) vehicle classification data using automatic vehicle classifier (AVC) equipment. While these data are collected for supporting the planning, design, and programming functions of TxDOT, MPOs, and local government agencies, it is envisioned that the Construction Division and the RTI Office could help in coordinating counts and classification at the sites selected for the Texas Pavement Flexible Database. This coordination will ensure that the 100 sites proposed as part of the TDPD should be included into these programs. The research team could help in facilitating the details of this coordination.

Further assistance from TxDOT's Construction Division will be required for automatic collection of pavement performance data. This will include the collection of the following data: (1) rutting with the ultrasonic rut-bar, (2) cracking with the V-Crack equipment (this should be run twice per section in order to collect the images and the summary statistics), and (3) riding in terms of the International Roughness Index (IRI) by means of the ride-van. All member of the research team have been trained by TxDOT personnel and are authorized to run the equipment and process the data. In order to avoid any disruption to the normal operation of the Department during the data collection season fro PMIS, the data for the Texas Flexible Pavement database should be collected in the spring and summer (right after PMIS data collection).