Technical Report Documentation Page

1. Report No. FHWA/TX-08/0-5472-1	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle ANALYSIS OF SUCCESSFUL FLEXIBLE PAVEMENT SECTIONS IN TEXAS – INCLUDING DEVELOPMENT OF A WEB SITE AND DATABASE		5. Report Date Published October 2008 6. Performing Organization Code
7. Author(s) Paul Krugler, Carlos Chang-Albitres, Tom Scullion, and Arif Chowdhury		8. Performing Organization Report No. Report 0-5472-1
9. Performing Organization Name and Address Texas Transportation Institute The Texas A&M University System College Station, Texas 77843-3135		10. Work Unit No. (TRAIS) 11. Contract or Grant No. Project 0-5472
12. Sponsoring Agency Name and Address Texas Department of Transportation Research and Technology Implementation Office P.O. Box 5080 Austin, Texas 78763-5080		13. Type of Report and Period Covered Technical Report: September 2005 – August 2007 14. Sponsoring Agency Code

15. Supplementary Notes

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

Project Title: A Database for Successful Pavement Sections in Texas – Including Both Experimental and Non-Experimental Pavements

URL: http://tti.tamu.edu/documents/0-5472-1.pdf

16. Abstract

This report documents a cooperative effort to gather and make available information about flexible pavements which have been identified by the Texas Department of Transportation as superior performers compared to similar pavement structures carrying similar traffic loads. Analyses of available construction records for these pavements and the results of pavement testing performed during this project are provided. A web site was created to store and make available information about successful flexible pavements and also to allow online nomination of additional pavements into the database by field personnel.

17. Key Words Asphalt Concrete, Successful Flexible Pavement Performance, Surface Treatment, Stone-Matrix Asphalt, Coarse-Matrix High-Binder, Superpave, Dense-Graded Hot Mix, Flexible Base, Forensic		18. Distribution Statement No restrictions. This document is available to the public through NTIS: National Technical Information Service Springfield, Virginia 22161 http://www.ntis.gov	
19. Security Classif.(of this report) Unclassified	20. Security Classif.(of this page) Unclassified	21. No. of Pages 154	22. Price

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

ANALYSIS OF SUCCESSFUL FLEXIBLE PAVEMENT SECTIONS IN TEXAS – INCLUDING DEVELOPMENT OF A WEB SITE AND DATABASE

by

Paul Krugler
Research Engineer
Texas Transportation Institute

Carlos Chang-Albitres
Associate Transportation Researcher
Texas Transportation Institute

Tom Scullion
Senior Research Engineer
Texas Transportation Institute

Arif Chowdhury
Assistant Research Engineer
Texas Transportation Institute

Report 0-5472-1
Project 0-5472
Project Title: A Database for Successful Pavement Sections in Texas – Including Both Experimental and Non-Experimental Pavements

Performed in cooperation with the
Texas Department of Transportation
and the
Federal Highway Administration

Published October 2008

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

DISCLAIMER

This research was performed in cooperation with the Texas Department of Transportation (TxDOT) and the Federal Highway Administration (FHWA). The contents of this report reflect the views of the authors, who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official view or policies of the FHWA or TxDOT. This report does not constitute a standard, specification, or regulation. This report is not intended for construction, bidding, or permitting purposes. The engineer in charge of the project was Paul E. Krugler, P.E. #43317. The United States Government and the State of Texas do not endorse products or manufacturers. Trade or manufacturers' names appear herein solely because they are considered essential to the objective of this report.

ACKNOWLEDGMENTS

This project was conducted in cooperation with TxDOT and FHWA. The authors thank the members of TxDOT's Project Monitoring Committee: Bill Brudnick (HOU), Tracy Cumby (LBB), Gary Fitts, (Asphalt Institute), Darlene Goehl (BRY), Joe Leidy (CST), Magdy Mikhail (CST), Michael Murphy (CST), Tammy Sims (MNT), Walter Torres (HOU), and Karen VanHooser (TSD). Special thanks go to the project director, Ahmed Eltahan (CST), and the program coordinator, Darrin Grenfell (FHWA). 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.

TABLE OF CONTENTS

Page

LIST OF FIGURES

Page

LIST OF TABLES

Page

CHAPTER 1: INTRODUCTION

This report documents the development of a web site and database for collecting and making available information about particularly successful flexible pavement sections in Texas. The scope of the project included defining successful flexible pavement performance and identifying the initial group of flexible pavement sections to include in the database. Researchers collected construction information that was still available for the identified pavements, and obtained additional test information from tests on aged-pavement cores and auger samples taken during the project. The gathered information was analyzed to gain insights into pavement characteristics resulting in superior performance. A comparison with current specification requirements was made to assess appropriateness of specification criteria.

ORGANIZATION OF THE REPORT

This introductory chapter includes an overview of the Texas Successful Flexible Pavements web site and database that were developed.

Chapter 2 describes a recommended definition of "successful" flexible pavement performance and how the definition was developed.

Chapter 3 describes the successful pavement nomination process and the methods used to evaluate nominations and select the initial group of pavements to be included in the database.

Chapter 4 describes the web site and database that were developed to make information about particularly successful flexible pavements available to TxDOT pavement engineers as well as a national audience.

Chapter 5 describes the field sampling, field testing, and laboratory evaluations that were performed to evaluate selected pavements.

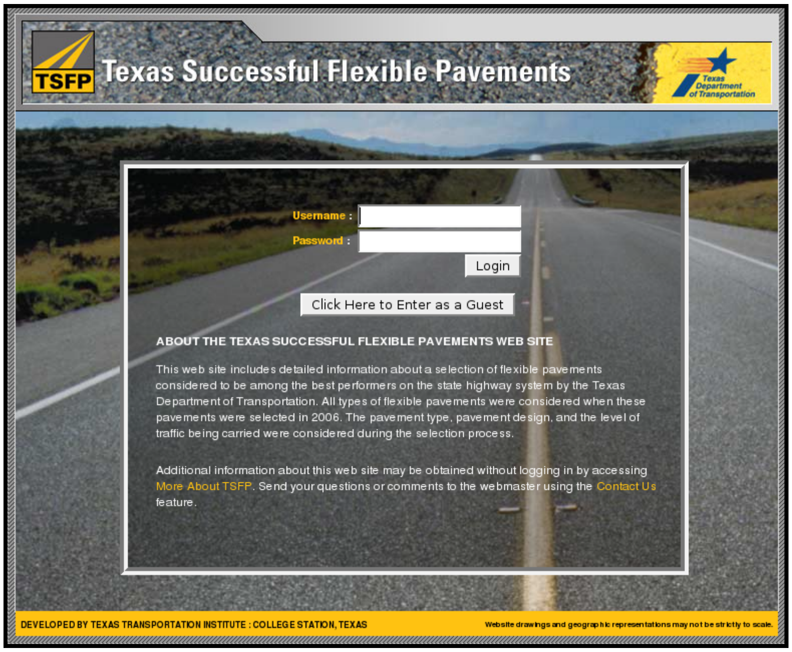
Chapter 6 describes the analyses that were performed on district construction test records as well as on the results from laboratory and on-site pavement testing performed during this project.

Chapter 7 summarizes the findings and recommendations derived from this research project.

OVERVIEW OF THE TEXAS SUCCESSFUL FLEXIBLE PAVEMENTS WEB SITE AND DATABASE

The pavements described in this web site should be considered representative of the many successfully performing flexible pavements in Texas. The process of selecting the initial flexible pavements to include in this web site began with a solicitation of nominations from TxDOT's 25 geographically located district offices. The districts were asked to nominate pavements that their staffs believe have performed in a superior fashion considering all factors involved. Preliminary information was gathered about each nominated pavement section, and the research team visited each nominating district to view and discuss the pavement section's history with district personnel. The final selection of pavements considered the need to represent a wide variety of flexible pavement structure types, asphalt mixture types, and the broad geographical area of the state.

Registered web site users and guests have access to all pavement information included in the database. Three security access levels are provided for registered users, allowing TxDOT's web site administrator broad flexibility during implementation. The web site features online functionality for new pavement nominations by registered users. Web site administration tools are provided to facilitate future TxDOT management of web site content and registered user access. Figure 1 shows the login screen.



ABOUT THE TEXAS SUCCESSFUL FLEXIBLE PAVEMENTS WEB SITE

This web site includes detailed information about a selection of flexible pavements considered to be among the best performers on the state highway system by the Texas Department of Transportation. All types of flexible pavements were considered when these pavements were selected in 2006. The pavement type, pavement design, and the level of traffic being carried were considered during the selection process.

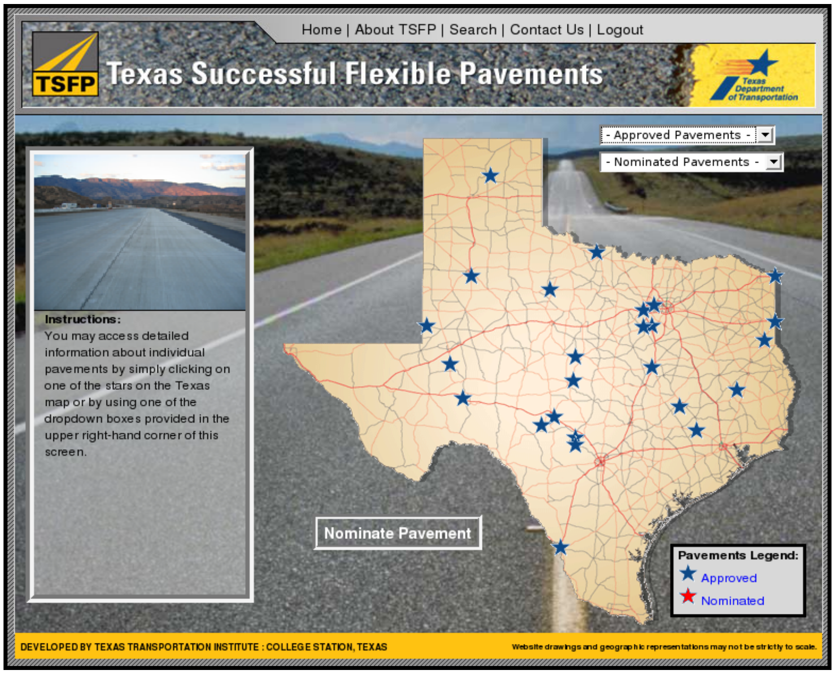
Additional information about this web site may be obtained without logging in by accessing More About TSFP. Send your questions or comments to the webmaster using the Contact Us feature.

DEVELOPED BY TEXAS TRANSPORTATION INSTITUTE : COLLEGE STATION, TEXAS

Website drawings and geographic representations may not be strictly to scale.

Figure 1. Texas Successful Flexible Pavements Web Site Login Screen.

Figure 2 shows the home page for registered users of the web site. Guests observe the same home page, but without the capability to nominate pavement sections. Blue and red stars on the map are links to detailed information about approved pavements and nominated pavements, respectively, at those locations. Separate drop down lists of approved and nominated pavements provide alternative methods of pursuing information about specific pavements.



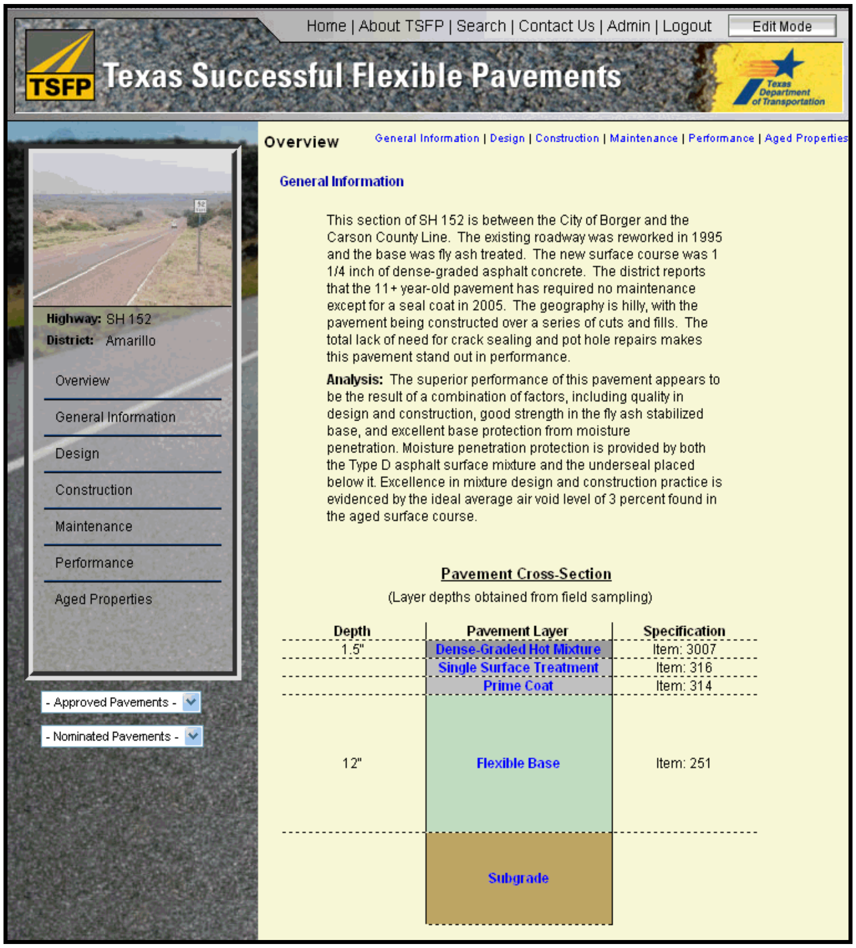
Instructions:
You may access detailed information about individual pavements by simply clicking on one of the stars on the Texas map or by using one of the dropdown boxes provided in the upper right-hand corner of this screen.

Figure 2. Texas Successful Flexible Pavements Web Site Home Page.

The database provides TxDOT area engineers and district pavement engineers with quick access to flexible pavement designs of various types which have been particularly successful. It also provides valuable information for materials engineers to evaluate adequacy of specification criteria on an ongoing basis.

When accessing a pavement's files in the database, the web site first provides the user an overview of information about the pavement section. The overview includes a description of the pavement and lists the factors believed to be instrumental in its particularly successful performance. As shown in Figure 3, a pavement cross-section is also provided to show the type of pavement structure and thicknesses of the various pavement layers. Below the cross-section the overview screen continues and provides the user some of the more frequently desired information items about the pavement. If the user desires to access more detailed information, the navigation options shown under the photograph of the highway in the side bar box are the portals to all additional pavement information contained in the database. The web site divides information into the following major navigation categories:

- General Information,
- Design,
- Construction,
- Maintenance,
- Performance, and
- Aged Properties.



General Information

This section of SH 152 is between the City of Borger and the Carson County Line. The existing roadway was reworked in 1995 and the base was fly ash treated. The new surface course was 1 1/4 inch of dense-graded asphalt concrete. The district reports that the 11+ year-old pavement has required no maintenance except for a seal coat in 2005. The geography is hilly, with the pavement being constructed over a series of cuts and fills. The total lack of need for crack sealing and pot hole repairs makes this pavement stand out in performance.

Analysis: The superior performance of this pavement appears to be the result of a combination of factors, including quality in design and construction, good strength in the fly ash stabilized base, and excellent base protection from moisture penetration. Moisture penetration protection is provided by both the Type D asphalt surface mixture and the underseal placed below it. Excellence in mixture design and construction practice is evidenced by the ideal average air void level of 3 percent found in the aged surface course.

Pavement Cross-Section

(Layer depths obtained from field sampling)

Depth	Pavement Layer	Specification
1.5"	Dense-Graded Hot Mixture	Item: 3007
	Single Surface Treatment	Item: 316
	Prime Coat	Item: 314
12"	Flexible Base	Item: 251
	Subgrade	

Figure 3. Upper Portion of Overview Screen – SH 152, Amarillo District.

CHAPTER 2:
DEFINITION OF SUCCESSFUL FLEXIBLE PAVEMENT PERFORMANCE

The scope of this project included defining successful flexible pavement performance. Researchers used a multifaceted approach in developing this definition.

LITERATURE REVIEW

One of the first steps to developing a definition was performing a literature review to obtain currently available information pertaining to successful flexible pavement performance. The most relevant references to this project were identified, and Table 1 provides those items and a brief description of pertinent information. Definitive information to assist in development of the definition of successful performance was limited.

BRAINSTORMING MEETING WITH TXDOT PAVEMENT ENGINEERS

Shortly after completion of the literature review, a brainstorming meeting was held to discuss definition concepts obtained from the literature and to gather additional thoughts and opinions based on personal experiences in Texas. Table 2 shows those attending the meeting and their areas of experience.

A list of potential factors to consider in the definition of successful flexible pavement performance was developed, and these are categorized in Table 3. Each factor was discussed, and the meeting culminated with the group reaching consensus that:

- a general definition for statewide application should be developed, as opposed to separate definitions for regions of the state;
- the research team should consider the Maintenance Division's level of service definitions shown in Table 4 as a starting place for desired performance; and
- annual roadway maintenance costs were to be included in the definition to offset improved visual distress scores resulting from preventative maintenance work.

The research team proceeded to develop the definition of successful flexible pavement performance with these understandings.

Table 1. Top Reference Items for Pavement Performance.

Reference Item	Title	Author(s) Publisher, Year	Brief Summary
1	LTTP Data Analysis: Influence of Design and Construction Features on the Response and Performance of New Flexible and Rigid Pavements	K. Chatti, N. Buch, S.W. Haider, A.S. Pulipaka, R.W. Lyles, D. Gilliland, P. Desaraju NCHRP, 2005	This research focuses on the relative influence of design and construction features on the response and performance of new flexible and rigid pavements. The effects of hot-mix asphalt (HMA) layer thickness, base type, base thickness, and drainage on pavement performance were investigated. Base type has the greatest influence on the fatigue performance of flexible pavements and roughness. Subgrade soil type and climate also have considerable effects on the influence of the design factors (longitudinal cracking, transverse cracking).
2	Network Performance Profiles	Kieran Sharp and Tim Martin ARRB Group, 2005	Austroroads Project AT 1067 has as an overall objective to establish whether there is a national trend for increased under-performance of pavements over the last 10 years, and the likely reasons for this underperformance. Field inspections were conducted to evaluate the reasons for under-performance of pavements identified by a desk-top review as "underperforming." The criterion was based on roughness and annual pavement maintenance cost. A deterioration rate matrix, based on roughness and rutting, was proposed for each functional class of roads and traffic level. Criteria for classifying a pavement section as good, fair, or poor was developed.
3	Guidance on the Development, Assessment and Maintenance of Long-Life Flexible Pavements	D. Merrill TRL, 2005	This research introduces the concept of robust pavements. Robust pavements are expected to deteriorate in a similar fashion to long-life pavements, provided that these pavements demonstrate similar characteristics to long-life pavements; these pavements can be thinner than long-life pavements. Guidelines to identify existing robust pavements and criteria are provided in the report. Visual distress, rutting, and structural condition are considered in these criteria.

Table 1. Top Reference Items for Pavement Performance (Continued).

Reference Item	Title	Author(s) Publisher, Year	Brief Summary
4	Expected Service Life and Performance Characteristics of HMA Pavements in LTPP	Harold L. Von Quintus, Jan Mallela, Jane Jiang APA, 2005	In this study six distress types were used to determine the average time to various surface conditions or magnitudes of distress. These distress types are: area fatigue cracking, longitudinal cracking in the wheel path area, transverse cracking, rut depth, and smoothness as measured by the International Roughness Index (IRI). Key factors from LTPP database were identified for the analysis such as traffic, climate, roughness, distress types, deflection, drainage, subgrade characteristics, HMA layer properties, and base layer properties.
5	Strategy for Modeling a Pavement Performance Analysis System at WisDOT	Jae-ho Choi, Teresa Adams TRB, 2004	The objective of this study was to design a database model for developing an effective database template and allowing analysis of pavement performance measures based on design and construction information linked by location. Information regarding year of construction, traffic, aggregate source, aggregates and materials properties for each pavement layer, distress data, performance, and maintenance records was considered relevant in the model.
6	Design-Build Pavement Warranties	Washington Department of Transportation (WSDOT) WSDOT, 2003	Washington Department of Transportation threshold criteria for pavement warranties include: ride quality, friction, and pavement surface condition (rutting, alligator cracking, longitudinal cracking, and transverse cracking) for asphalt pavements.
7	Asphaltic Pavement Warranties	Steven Krebs, B. Duckert, S. Shwandt, J. Volker, T. Brokaw, W. Shemwell, G. Waelti WisDOT, 2001	In 1995, the Wisconsin Department of Transportation and the Wisconsin Asphalt Pavement Association developed and began constructing asphaltic pavements with warranty specifications. Distress thresholds were established for alligator cracking, block cracking, edge raveling, flushing, longitudinal cracking, longitudinal distortion, rutting, surface raveling, transverse cracking, transverse distortion patching, and potholes. The International Roughness Index is also considered in the criteria.

Table 1. Top Reference Items for Pavement Performance (Continued).

Reference Item	Title	Author(s) Publisher, Year	Brief Summary
8	Performance-Based Specifications as a Step to Performance-Based Management and Maintenance of Pavement in Japan	Takeshi Yoshida Public Works Research Institute, Japan, 2001	This paper proposes that successful road projects should be defined using performance indicators which should be selected in accordance with the goals and objectives of the project. Skid resistance, durability, evenness, and tire/road noise level are examples of performance indicators.
9	Performance Trends of Rehabilitated AC Pavements	Federal Highway Administration FHWA, 2000	This study documents performance trends of GPS-6 test sections using distress data collected through 1997. Six distress types or performance indicators were used to evaluate performance trends. They include fatigue cracking, longitudinal cracking not in the wheel path, transverse cracking, rutting, and roughness (IRI).
10	Common Characteristics of Good and Poorly Performing AC Pavements	J. B. Rauhut, A. Eltahan, and A.L. Simpson 1999	Data from the Long-Term Pavement Performance (LTPP) test sections were used to identify the site conditions and design/construction features of flexible pavements that lead to good performance and those that lead to poor performance. Four distress types were investigated: performance in roughness (IRI), rutting, transverse cracking, and fatigue cracking.
11	Engineering Application of Washington State's Pavement Management System	Michael J. Baker, Joe P. Mahoney, and Nadarajah "Siva" Sivaneswaran TRB, 1998	The Washington State Department of Transportation (WSDOT) identified pavement sections that were outperforming or underperforming although constructed of similar materials and subjected to similar traffic and environmental considerations. The WSDOT's Pavement Management System was used to select candidate sections for further analysis. The five performance measures considered in the selection criteria included: age of the surface course, a distress-based pavement structural condition score, annual design-lane equivalent single axle loads, roughness (IRI), and rutting.

Table 2. Brainstorming Meeting Attendees.

Last Name	First Name	Organization	Experience
Chang-Albitres	Carlos	Texas Transportation Institute (TTI)	Associate Transportation Researcher
Claros	German	TxDOT, Research and Technology Implementation Office	Pavements Research Engineer
Eltahan	Ahmed	TxDOT, Construction Division	Pavement Engineer
Garrison	Miles	TxDOT, Atlanta District	Pavement and Laboratory Engineer
Graff	Joe	TxDOT, Maintenance Division	Engineer of Maintenance
Graham	Gary	TxDOT, Construction Division	Pavement Design Engineer
Krugler	Paul	Texas Transportation Institute	Research Engineer
Leidy	Joe	TxDOT, Construction Division	Pavement Forensics Engineer
Murphy	Mike	TxDOT, Construction Division	State Pavement Engineer
Pigg	Billy	TxDOT, Waco District	Pavement and Laboratory Engineer
Rmeili	Elias	TxDOT, Brownwood District	District Transportation, Planning and Development Engineer
Scullion	Tom	Texas Transportation Institute	Senior Research Engineer
Smith	Stephen	TxDOT, Odessa District	Construction and Laboratory Engineer
Stampley	Bryan	TxDOT, Construction Division	Pavement Management Engineer
Wimsatt	Andrew	TxDOT, Fort Worth District	Pavement Engineer

Table 3. Potential Factors for Definition of Successful Pavement Performance.

Category	Factor
Pavement Condition	Visual Distress Rating
	Structural Condition – Deflection Test Results
	Should Not Have Structural Failures – No Patching or Base Repairs
	Ride Score and Rate of Increase in Roughness
	Rut Depth and Rate of Increase in Rut Depth
Maintenance	Annual Maintenance Costs
	Date of Last Seal Coat
Climate and Subgrade	Rainfall
	Freeze or Non-Freeze
	Type of Subgrade – Fineness of the Soil
Pavement Design	Pavement Type – Asphalt Concrete, Overlay of Concrete Pavement, Surface Treatment Pavement
	Roadside Drainage
	Lane Width
	Asphalt Concrete Thickness
	Design Equivalent Single Axle Loads (ESALs)
	Percent Trucks
Pavement Longevity	Pavement Age
	Cumulative ESALs
Materials	Type of Base
	Type of Asphalt Additive – Latex, Crumb-Rubber, Others
Construction	Construction Variability

Table 4. Level of Service Definitions for Pavement Maintenance (from TxDOT).

PMIS Distress Type	Traffic Category (ADT)	Level of Service			
		Desirable	Acceptable	Tolerable	Intolerable
RUTTING	Low (0-500)	0% shallow & 0% deep	1-50% shallow & 0% deep	51-100% shallow & 0% deep OR 0-50% shallow & 1-25% deep	51-100% shallow & 1-25% deep OR 26-100% deep
	Medium (501-10,000)	0% shallow & 0% deep	1-50% shallow & 0% deep	51-100% shallow & 0% deep OR 0-50% shallow & 1-25% deep	51-100% shallow & 1-25% deep OR 26-100% deep
	High (over 10,000)	0% shallow & 0% deep	1-25% shallow & 0% deep	26-50% shallow & 0% deep	51-100% shallow & 0% deep OR 1-100% deep
ALLIGATOR CRACKING	All Traffic	0%	1-10%	11-50%	51-100%
RIDE QUALITY	Low (0-500)	2.6-5.0	2.1-2.5	1.6-2.0	0.1-1.5
	Medium (501-10,000)	3.1-5.0	2.6-3.0	2.1-2.5	0.1-2.0
	High (over 10,000)	3.6-5.0	3.1-3.5	2.6-3.0	0.1-2.5

Reference: TxDOT Administrative Circular 5-92, February 13, 1992

EVALUATION OF DATA FROM TXDOT'S PAVEMENT MANAGEMENT INFORMATION SYSTEM (PMIS)

With information from the literature search and brainstorming meeting as a backdrop, the research team reviewed 2006 PMIS records for all of the nominated pavements. Appendix A includes the tabulation of this initial query results. A rather wide range in the performance criteria was observed despite the fact that each of these pavements had been nominated as a particularly successful pavement. This wide range in performance criteria evidenced the difficulty in establishing a single set of criteria that reasonably identifies successful performance under the myriad of climatic, geographic, traffic, and local material factors involved across the state. The insight gained from the 2006 PMIS records led to the creation of a definition that requires compliance with a number of the selected performance criteria, but not all of them, for a pavement's performance to be considered successful. Also, engineering judgment is recognized in the definition as an important element in pavement performance evaluations.

SELECTION AND DISCUSSION OF DEFINITION CRITERIA

As a result of the foregoing efforts, a series of criteria arose as primary candidates for use in the definition of successful flexible pavement performance. These criteria included:

- age of the pavement section,
- drainage conditions,
- design service life,
- environmental factors (geographic location),
- maintenance history and treatment costs,
- material properties,
- pavement distresses,
- safety,
- serviceability (ride quality),
- structural adequacy of the pavement structure,
- subgrade, and
- traffic level (ADTs, ESALS).

As this list of potential criteria was further considered, the research team observed that many of these factors are interrelated. Therefore, it was concluded that not all of them needed to be explicitly included in the minimum criteria defining successful performance. For example, a section without distresses over its service life will more than likely be structurally adequate for the level of traffic and environmental factors acting upon the pavement structure. On the other hand, it is unlikely that a section with poor drainage conditions will have served without manifesting significant distresses over time. An important factor that does need to be included is the level of maintenance expenditures which have been required to adequately maintain the pavement performance being obtained. These discussions and preliminary analysis lead to focusing on only key performance criteria that, together, capture virtually all the factors affecting pavement performance, either directly or indirectly.

Another important consideration in selecting criteria was the ease with which TxDOT might be able to apply them. Not all data and information may be readily available even though they are potentially very valuable in defining successful performance.

From this perspective, the research team determined that the criteria should bear upon measurable and objective parameters for identifying successful pavement performance. Analyzing the factors mentioned as potential parameters, the research team concluded that the following factors should bear upon the determination of successful flexible pavement performance:

- Age of the Pavement,
- Cumulative Design Loading,
- Pavement Condition Score,
- Pavement Distress Score,
- Pavement Ride Score,
- Traffic Level, and
- Maintenance Expenditures (pavement-related).

All of these factors are readily available to TxDOT personnel in PMIS records.

In order to characterize each of these factors, and to establish the criteria for identifying successful flexible pavement sections in Texas, the research team found that the rating methods used in TxDOT's PMIS offer the best and the most practical solutions.

Age of the Pavement: The age of the pavement section is an obvious factor to include in the criteria. While age is only an indirect indicator of the amount of traffic that has been carried, it's a direct indicator of the length of time that the pavement has been exposed to environmental conditions. On less traveled rural roadways, age can become at least as definitive an indicator of superior performance as cumulative traffic loading. Another age-related aspect is that determination of "successful" pavement performance is time-dependent. A pavement section may meet "successful" criteria in its early stage of life but later on rapidly deteriorate and no longer be described as successful. The age categories included in the definition of successful performance are 0-7 years, 8-14 years, and above 14 years.

Cumulative Design Loading: The degree to which a pavement withstands traffic loading in comparison to its design loading is a most important indicator of successful performance. The definition criteria, therefore, must be flexible enough to correctly evaluate a pavement which has already exceeded its service life, regardless of pavement age. A pavement in reasonable condition after surpassing design traffic loadings should be considered successful.

Pavement Condition Score: The condition score provides a single descriptor of the overall pavement condition. This parameter combines ride quality and pavement distress characteristics of the pavement. Table 5 shows condition score classes used by TxDOT.

Table 5. Condition Score Classes (from TxDOT).

Condition Score	Class	Description
90 – 100	A	Very Good
70 – 89	B	Good
50 – 69	C	Fair
35 – 49	D	Poor
1 – 34	F	Very Poor

Reference: Condition of Texas Pavements PMIS Annual Report, FY 2001-2004 (May 2004)

It is expected for a successful pavement to be in either very good or good condition, depending upon its stage of service life. A different minimum value for the condition score is established in the criteria for each of the pavement age categories. The criteria for successful performance also include the requirement for relatively low variability of condition scores within a successful pavement section. The maximum amount of variability allowed increases with increasing pavement age. Uniformity in performance is desirable and believed to be a strong indicator of quality in construction.

Table 6 shows average 2005 pavement condition scores in Texas broken down by geographic district. The degree of variance in these average condition scores, as well as in the standard deviations within each district, is believed to primarily result from the widely varying traffic levels, subgrade characteristics, and climatic conditions across the state.

Table 6. 2005 PMIS Condition Score Averages by District.

	LOW TRAFFIC			MEDIUM TRAFFIC			HIGH TRAFFIC		
District	Average	Standard Dev.	Number of Sections	Average	Standard Dev.	Number of Sections	Average	Standard Dev.	Number of Sections
Abilene	93.2	13.9	4468	92.8	16.1	3924	83.1	23.9	216
Amarillo	94.5	11.6	4247	87.6	18.2	4508	76.6	21.9	204
Atlanta	95.9	9.9	906	94.4	11.7	4308	94.8	14.2	783
Austin	92.5	12.3	1017	90.9	15.4	4192	92.0	15.3	1750
Beaumont	94.1	13.5	694	87.4	21.3	3843	78.2	29.1	990
Brownood	94.4	10.1	2743	93.4	12.5	2823	79.5	25.9	79
Bryan	86.1	22.1	1235	88.3	19.2	4594	94.3	14.5	954
Childress	95.8	10.7	3521	91.4	15.1	1987	76.0	26.5	21
Corpus Christi	85.3	21.4	2022	84.3	21.7	4030	86.0	21.4	545
Dallas	85.1	23.4	882	81.9	27.0	4704	84.5	23.7	3750
El Paso	90.6	18.1	1583	88.7	19.5	2229	77.3	24.2	612
Fort Worth	96.0	10.3	1135	89.2	19.4	4476	85.2	21.7	2350
Houston	88.7	21.4	312	84.5	21.9	3474	81.9	24.2	4076
Laredo	88.1	18.9	2222	87.8	20.8	2394	78.1	27.3	205
Lubbock	94.3	13.5	5665	92.6	16.3	5902	80.9	27.9	184
Lufkin	89.3	16.4	1783	89.4	17.2	3789	95.4	10.4	497
Odessa	97.7	8.3	2848	95.8	12.2	5106	92.0	17.1	169
Paris	89.8	16.1	2073	89.0	17.7	4515	87.2	20.5	518
Pharr	91.6	14.1	523	91.5	14.7	3552	89.1	17.8	932
San Angelo	95.2	11.5	3444	96.5	10.0	3189	91.3	10.8	12
San Antonio	84.5	22.3	1928	87.3	19.5	6041	88.4	19.5	2276
Tyler	90.5	13.5	1174	91.3	14.6	5872	91.4	15.5	1033
Waco	94.0	12.3	1849	93.3	13.5	4365	87.9	20.3	1115
Wichita Falls	94.8	12.2	2768	92.9	15.2	3288	85.4	22.3	268
Yoakum	88.8	17.1	1856	92.3	13.8	4875	94.6	11.8	834

Although the condition score is a good overall indicator of performance, as it combines pavement distress and ride quality characteristics, the research team concluded that this parameter alone would be inadequate to identify successfully performing pavements. It was decided that the criteria in the definition of successful performance should also include independent distress score and ride quality factors, thereby stressing a specific minimum level of quality for each parameter.

<u>Pavement Distress Score:</u> The distress score reflects the degree of visible surface deterioration observed by pavement raters on an annual basis. Table 7 shows distress score classes defined by TxDOT.

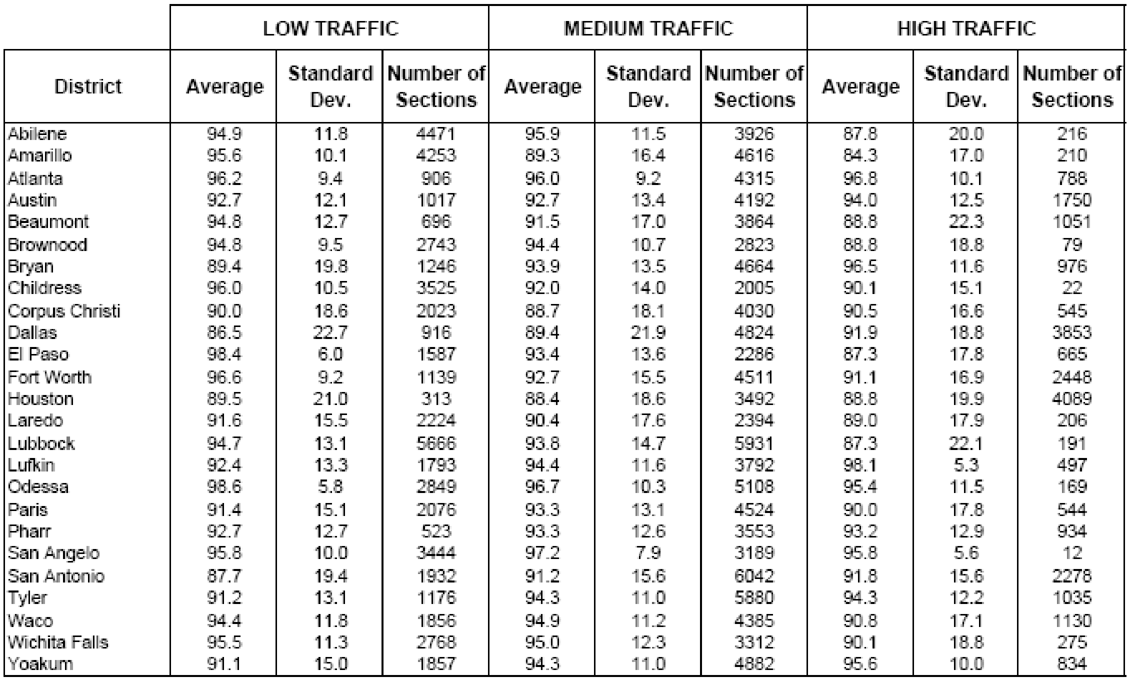
Table 7. Distress Score Classes (from TxDOT).

Distress Score	Class	Description
90 – 100	A	Very Good
70 – 89	B	Good
50 – 69	C	Fair
35 – 49	D	Poor
1 – 34	F	Very Poor

Reference: Condition of Texas Pavements PMIS Annual Report, FY 2001-2004 (May 2004)

Like the condition score, it is expected that a successful pavement be in either very good or good condition from a distress rating standpoint, depending on the current age and stage of its service life. Relatively low variability is also a requirement. Table 8 shows the average 2005 pavement distress scores in Texas by geographic district.

Table 8. 2005 PMIS Distress Score Averages by District.



	LOW TRAFFIC			MEDIUM TRAFFIC			HIGH TRAFFIC		
District	Average	Standard Dev.	Number of Sections	Average	Standard Dev.	Number of Sections	Average	Standard Dev.	Number of Sections
Abilene	94.9	11.8	4471	95.9	11.5	3926	87.8	20.0	216
Amarillo	95.6	10.1	4253	89.3	16.4	4616	84.3	17.0	210
Atlanta	96.2	9.4	906	96.0	9.2	4315	96.8	10.1	788
Austin	92.7	12.1	1017	92.7	13.4	4192	94.0	12.5	1750
Beaumont	94.8	12.7	696	91.5	17.0	3864	88.8	22.3	1051
Brownood	94.8	9.5	2743	94.4	10.7	2823	88.8	18.8	79
Bryan	89.4	19.8	1246	93.9	13.5	4664	96.5	11.6	976
Childress	96.0	10.5	3525	92.0	14.0	2005	90.1	15.1	22
Corpus Christi	90.0	18.6	2023	88.7	18.1	4030	90.5	16.6	545
Dallas	86.5	22.7	916	89.4	21.9	4824	91.9	18.8	3853
El Paso	98.4	6.0	1587	93.4	13.6	2286	87.3	17.8	665
Fort Worth	96.6	9.2	1139	92.7	15.5	4511	91.1	16.9	2448
Houston	89.5	21.0	313	88.4	18.6	3492	88.8	19.9	4089
Laredo	91.6	15.5	2224	90.4	17.6	2394	89.0	17.9	206
Lubbock	94.7	13.1	5666	93.8	14.7	5931	87.3	22.1	191
Lufkin	92.4	13.3	1793	94.4	11.6	3792	98.1	5.3	497
Odessa	98.6	5.8	2849	96.7	10.3	5108	95.4	11.5	169
Paris	91.4	15.1	2076	93.3	13.1	4524	90.0	17.8	544
Pharr	92.7	12.7	523	93.3	12.6	3553	93.2	12.9	934
San Angelo	95.8	10.0	3444	97.2	7.9	3189	95.8	5.6	12
San Antonio	87.7	19.4	1932	91.2	15.6	6042	91.8	15.6	2278
Tyler	91.2	13.1	1176	94.3	11.0	5880	94.3	12.2	1035
Waco	94.4	11.8	1856	94.9	11.2	4385	90.8	17.1	1130
Wichita Falls	95.5	11.3	2768	95.0	12.3	3312	90.1	18.8	275
Yoakum	91.1	15.0	1857	94.3	11.0	4882	95.6	10.0	834

<u>Pavement Ride Score:</u> The ride score expresses the ride quality on a scale from 0.1 (roughest) to 5.0 (smoothest). Table 9 shows descriptive ride score classes used by TxDOT.

Table 9. Ride Score Classes (from TxDOT).

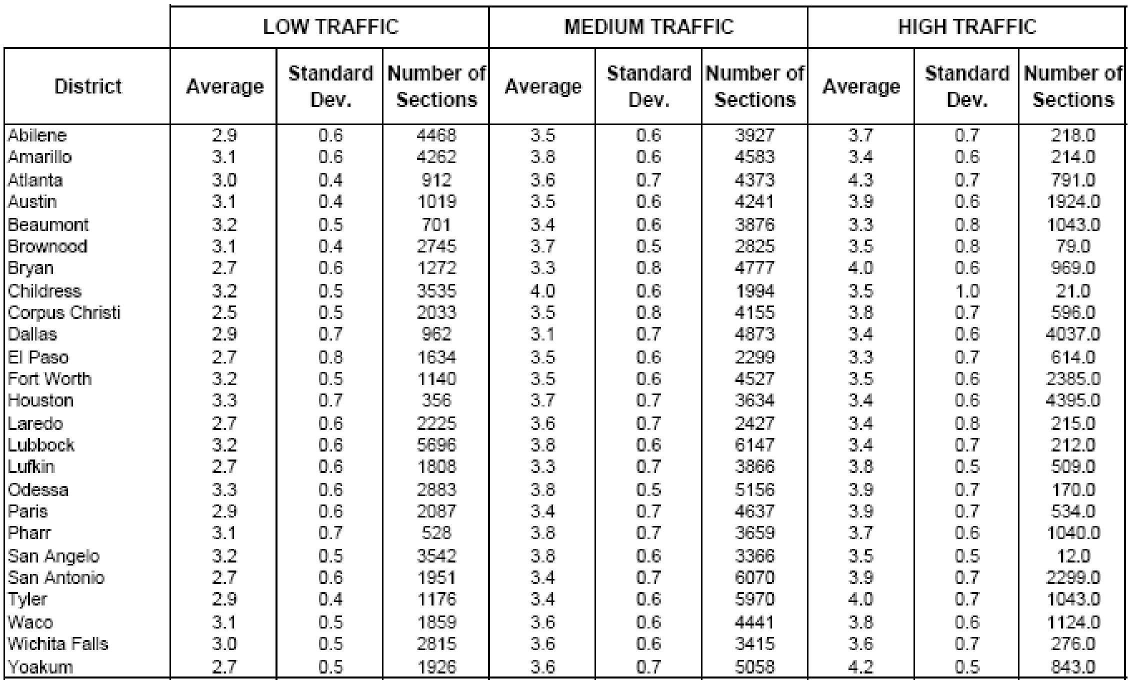
Distress Score	Class	Description
4.0 – 5.0	A	Very Good
3.0 – 3.9	B	Good
2.0 – 2.9	C	Fair
1.0 – 1.9	D	Poor
0.1 - 0.9	F	Very Poor

Reference: Condition of Texas Pavements PMIS Annual Report, FY 2001-2004 (May 2004)

As with other rating criteria, it is expected that a successful pavement be in either very good or good condition for ride quality, depending on the current age and stage of its service life. Relatively low variability is again a requirement.

Table 10 shows the average 2005 pavement ride scores in Texas by geographic district. While the degree of variability is high, as with other pavement rating score types, the average rating for ride quality dips into the fair category in a number of areas.

Table 10. 2005 PMIS Ride Score Averages by District.



	LOW TRAFFIC			MEDIUM TRAFFIC			HIGH TRAFFIC		
District	Average	Standard Dev.	Number of Sections	Average	Standard Dev.	Number of Sections	Average	Standard Dev.	Number of Sections
Abilene	2.9	0.6	4468	3.5	0.6	3927	3.7	0.7	218.0
Amarillo	3.1	0.6	4262	3.8	0.6	4583	3.4	0.6	214.0
Atlanta	3.0	0.4	912	3.6	0.7	4373	4.3	0.7	791.0
Austin	3.1	0.4	1019	3.5	0.6	4241	3.9	0.6	1924.0
Beaumont	3.2	0.5	701	3.4	0.6	3876	3.3	0.8	1043.0
Brownood	3.1	0.4	2745	3.7	0.5	2825	3.5	0.8	79.0
Bryan	2.7	0.6	1272	3.3	0.8	4777	4.0	0.6	969.0
Childress	3.2	0.5	3535	4.0	0.6	1994	3.5	1.0	21.0
Corpus Christi	2.5	0.5	2033	3.5	0.8	4155	3.8	0.7	596.0
Dallas	2.9	0.7	962	3.1	0.7	4873	3.4	0.6	4037.0
El Paso	2.7	0.8	1634	3.5	0.6	2299	3.3	0.7	614.0
Fort Worth	3.2	0.5	1140	3.5	0.6	4527	3.5	0.6	2385.0
Houston	3.3	0.7	356	3.7	0.7	3634	3.4	0.6	4395.0
Laredo	2.7	0.6	2225	3.6	0.7	2427	3.4	0.8	215.0
Lubbock	3.2	0.6	5696	3.8	0.6	6147	3.4	0.7	212.0
Lufkin	2.7	0.6	1808	3.3	0.7	3866	3.8	0.5	509.0
Odessa	3.3	0.6	2883	3.8	0.5	5156	3.9	0.7	170.0
Paris	2.9	0.6	2087	3.4	0.7	4637	3.9	0.7	534.0
Pharr	3.1	0.7	528	3.8	0.7	3659	3.7	0.6	1040.0
San Angelo	3.2	0.5	3542	3.8	0.6	3366	3.5	0.5	12.0
San Antonio	2.7	0.6	1951	3.4	0.7	6070	3.9	0.7	2299.0
Tyler	2.9	0.4	1176	3.4	0.6	5970	4.0	0.7	1043.0
Waco	3.1	0.5	1859	3.6	0.6	4441	3.8	0.6	1124.0
Wichita Falls	3.0	0.5	2815	3.6	0.6	3415	3.6	0.7	276.0
Yoakum	2.7	0.5	1926	3.6	0.7	5058	4.2	0.5	843.0

<u>Traffic Level:</u> The traffic level is currently expressed in terms of average daily traffic for establishing traffic categories within the definition of successful performance. Table 11 shows the traffic categories included in the definition.

Table 11. Traffic Classes (from TxDOT).

ADT	Class	Description
0 – 500	1	Low
501 – 10,000	2	Medium
Over 10,000	3	High

Reference: TxDOT Administrative Circular 5-92 (February 13, 1992)

Maintenance Expenditures: A pavement section in very good condition with a high condition score, high distress score, and high ride score may not actually perform in a successful manner if maintenance treatment costs over its service life are above the average maintenance costs in the area. It is possible that the high pavement scores are the result of excessive maintenance work that has been required. For this reason, pavement-related maintenance costs over a period of years are considered a crucial factor in the criteria for identifying successful flexible pavement sections. The maximum average annual pavement maintenance costs included in the definition vary by traffic level, with $600 per lane-mile allowed for low traffic pavements, $900 per lane-mile allowed for medium traffic pavements, and $800 per lane-mile allowed for high traffic pavements. The selection of a lower allowable dollar rate for high traffic pavements compared to medium traffic pavements was based on demonstrated differences seen in PMIS maintenance cost records for nominated pavements. It is surmised that maintenance needs on high traffic pavements are much more frequently addressed using rehabilitation funding, which PMIS records do not track in Texas.

All of these criteria elements were combined in the definition of successful flexible pavement performance discussed in the next section. A table containing criteria involved with the determination follows the verbal definition. This definition, as with other tools of pavement engineers, should be applied carefully. Engineering judgment is a necessary element.

DEFINITION AND CRITERIA FOR SUCCESSFUL FLEXIBLE PAVEMENT PERFORMANCE

Definition

“A successful flexible pavement is defined as a structure that has met performance expectations over its service life with only normally expected levels of maintenance for its age, materials utilized, traffic loads, and local conditions." Table 12 contains the recommended set of criteria for condition scores, distress scores, ride scores, and annual maintenance expenditures to assist the experienced pavement engineer in categorizing a pavement or experimental project as successful.

Individual Criteria

There are seven criteria recommended to assist in identifying a successful pavement section, as follows:

- annual maintenance expenditure average,
- minimum condition score average,
- standard deviation of condition scores,
- minimum distress score average,
- standard deviation of distress scores,
- minimum ride score average, and
- standard deviation of ride scores.

To be identified as a successful pavement, it is recommended that the pavement section be at least six years old and meet the maintenance expenditure criteria plus at least four of the other individual criteria listed above and in Table 12. If the section does not meet these requirements, but extenuating circumstances exist, engineering judgment should be used in determining if performance is considered successful.

Criteria Table Instructions

To determine if a pavement section meets the definition for successful performance, first calculate average values and standard deviations for the most recent condition, distress, and ride scores available for the pavement section being considered. Condition, distress, and ride scores are available from TxDOT's PMIS database. Determine the average annual pavement maintenance expenditure for the pavement section being considered by averaging expenditure information for each of the segments of the pavement section. Make this determination for each of the last three years and calculate the three-year average maintenance expenditure for the pavement section. Annual pavement maintenance expenditure information is available in TxDOT's Maintenance Management Information System (MMIS) as well as from PMIS. Compare all determined values to the criteria shown in Table 12.

Table 12. Criteria for Identifying Successful Flexible Pavement Sections in Texas.

Parameter	ADT	Age of the Pavement Section							
		From 0 to 7 years		From 8 to 14 years		Above 14 years		Beyond Design Life	
		Minimum	Std. Dev.	Minimum	Std. Dev.	Minimum	Std. Dev.	Minimum	Std. Dev.
Condition Score	0 to 500	90	6	85	6	80	6	70	6
	501 to 10,000	90	8	85	8	80	8	70	8
	Above 10,000	90	10	85	10	80	10	70	10
Distress Score	0 to 500	92	6	88	6	84	6	75	6
	501 to 10,000	92	8	88	8	84	8	75	8
	Above 10,000	92	10	88	10	84	10	75	10
Ride Score	0 to 500	3.2	0.6	3.0	0.6	2.8	0.6	2.5	0.6
	501 to 10,000	3.6	0.7	3.4	0.7	3.2	0.7	2.8	0.7
	Above 10,000	3.8	0.8	3.6	0.8	3.4	0.8	3.0	0.8
3-Year Average Pavement Maintenance Expenditure	0 to 500	Below $ 600 / lane-mile		Below $ 600 / lane-mile		Below $ 600 / lane-mile		Below $ 600 / lane-mile	
	501 to 10,000	Below $ 900 / lane-mile		Below $ 900 / lane-mile		Below $ 900 / lane-mile		Below $ 900 / lane-mile	
	Above 10,000	Below $ 800 / lane-mile		Below $ 800 / lane-mile		Below $ 800 / lane-mile		Below $ 800 / lane-mile	

Notes:

- The average and standard deviation of all score values is to be determined using all scores from within the pavement section being considered.
- Pavement maintenance-related annual expenditures do not include construction programmed seal coats.
- Pavement maintenance costs in the table are based on 2005 cost information.

CHAPTER 3:
SUCCESSFUL FLEXIBLE PAVEMENT NOMINATION AND SELECTION

NOMINATION PROCESS

Identification of particularly successful flexible pavements began by allowing the 25 geographically located districts to nominate sections of pavement which in their opinions warranted evaluation for including them in the database being created. Appendix B includes the nomination solicitation letter and form. Guidance provided in the solicitation was broad and general, as the definition of successful flexible pavement performance discussed in Chapter 2 had not yet been developed. The following three definitions were included in the letter to the districts.

> "Successful – We are seeking excellently performing new pavements or excellent overlays. The new / reconstructed pavement or the rehabilitated pavement must be in its first performance period. Pavement performance, primarily serviceability, should be well above expectations considering the pavement design, traffic and percentage of trucks, materials utilized, and the local environment."
>
> "Flexible Pavement. – A pavement with either surface treatment over base, thin or thick hot mix surfacing, or it may be a composite pavement with a minimum of 2 inches of asphalt mixture over concrete."
>
> "Section – A length of pavement having constant structure and mixture design and that has a minimum length of one mile."

A total of 75 nominations were received from 17 districts. Figure 4 shows locations of nominated pavements. A listing of all nominated pavements and basic descriptive information is included in Appendix C.

SELECTION PROCESS

The selection of the initial 25 pavements to populate the database was based on a number of factors. After receiving all nominations, members of the research team visited each pavement section site, normally accompanied by the nominator. Pavement conditions were visually noted, photographed, and additional information was obtained. Unique subgrade conditions, unusual

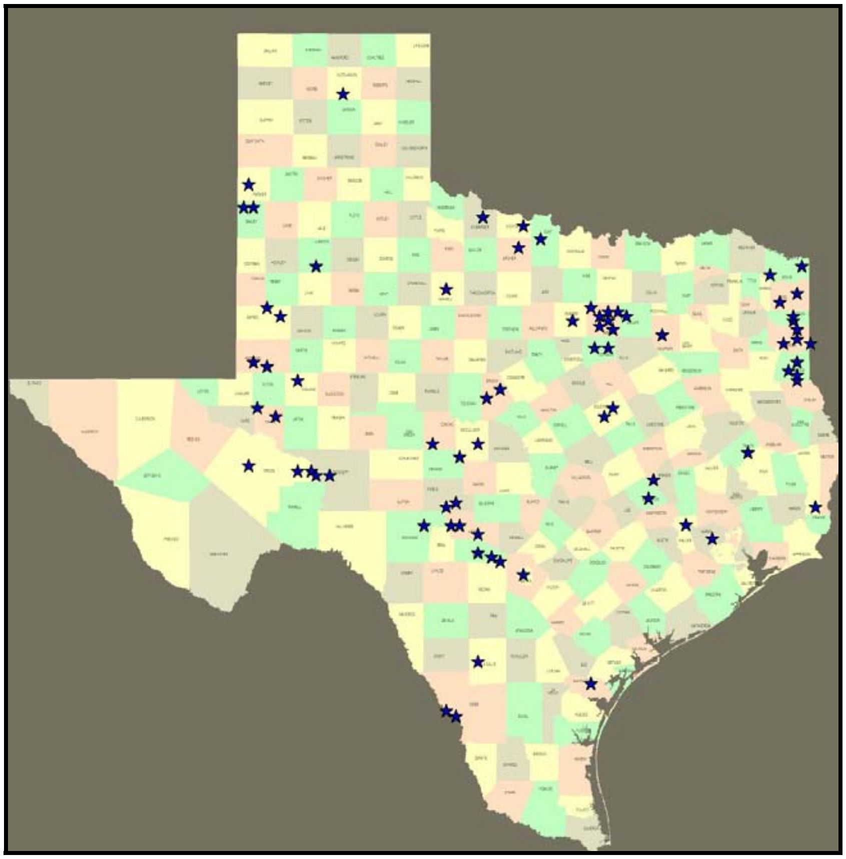


Figure 4. Geographic Locations of Nominated Pavements.

traffic considerations, and any unique aspects of construction and maintenance were discussed during these visits. The research team obtained 2004 and 2005 PMIS pavement information at this time, primarily to allow observation of maintenance expenditures over a three-year period. Maintenance expenditure information was obtained from PMIS instead of MMIS to generally facilitate the information gathering effort. Appendix A includes initial PMIS information obtained for 2004 and 2005 along with the previously gathered 2006 information.

A goal of the selection process was that the initially selected pavements include all commonly used types of flexible pavement structures and that these pavements would be distributed throughout the varied geographic and climatic regions of the state.

Other considerations in the selection process were that the list should include a variety of material types, pavement designs, and levels of traffic. Because of these non-performance related selection factors, and because the database could only include a limited number of pavements during the two-year research project, the selected pavements do not constitute an exclusive list of the best performing Texas flexible pavements. A number of the other nominated pavements provide equally impressive performances.

A proposed list of 25 pavement sites was presented to the research project monitoring committee during the first project milestone meeting, held in June of 2006. Twenty-four pavement sites were approved at the milestone meeting. It was further decided at the meeting that it would be desirable to include two additional pavements, both carrying high traffic levels, and that these pavements should be located in the gulf coast and central Texas areas of the state. After a comprehensive search, one more pavement section was added to the initially approved list of pavements. Figure 5 shows the geographic distribution of the final group of 25 selected flexible pavement sections, and Table 13 provides their descriptive information.

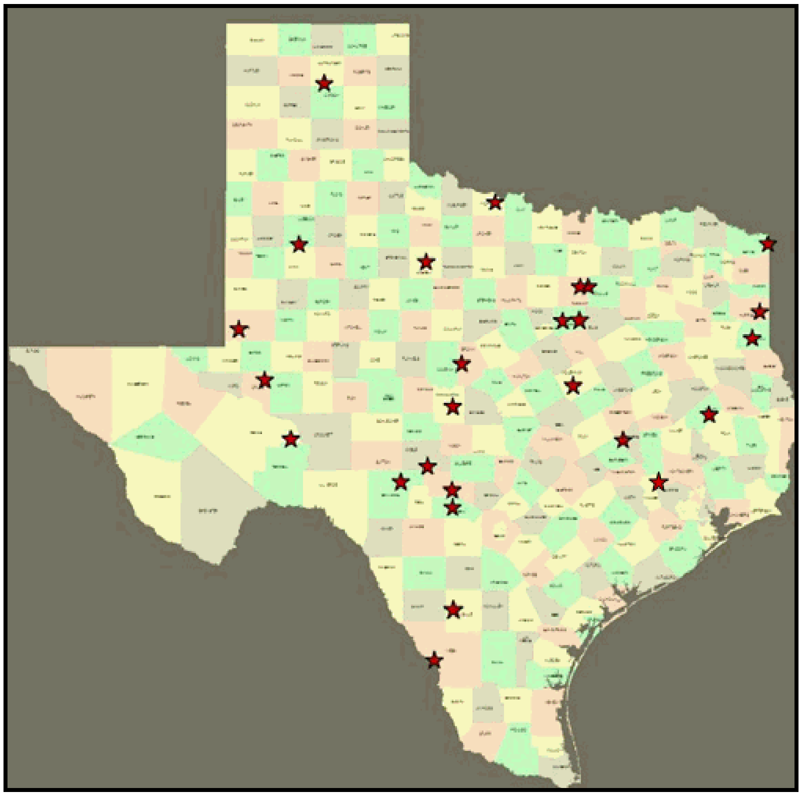


Figure 5. Geographic Locations of Selected Pavements.

Table 14 breaks down the distributions of pavement structure categories and traffic levels among the selected pavements. Approximately two-thirds of the 25 pavements are in the medium traffic category, one was selected from the low traffic category, and the rest were in the high traffic category. The types of pavement structures represented are well distributed except that several additional thin asphalt concrete pavements would have been desirable.

Table 13. Initial Successful Flexible Pavements in the Database.

TxDOT District	Highway Designation	Pavement Structure Type	Pavement Age, Years	2006 Average Daily Traffic	2006 Percent Trucks in ADT
Abilene	US 380	Surface Treatment(s) over Flexible Base	40	1,693	13
Amarillo	SH 152	Thin Asphalt Concrete	11	1,250	9
Atlanta	IH 20 (WB lanes only)	Composite (Asphalt Surfaced Concrete)	10	15,017	39
Atlanta	IH 30	Composite (Asphalt Surfaced Concrete)	10	21,289	28
Atlanta	US 59	Thick Asphalt Concrete	17	5,940	23
Brownwood	US 67	Thick Asphalt Concrete	26	7,140	18
Brownwood	US 190	Surface Treatment(s) over Flexible Base	29	1,450	20
Bryan	SH 21 (EB lanes only)	Medium Asphalt Concrete	14	5,206	15
Fort Worth	BIH 35	Composite (Asphalt Surfaced Concrete)	14	4,800	5
Fort Worth	SH 183	Composite (Asphalt Surfaced Concrete)	21	14,660	10
Fort Worth	SH 121	Composite (Asphalt Surfaced Concrete)	21	73,845	7
Fort Worth	SH 171	Medium Asphalt Concrete	14	6,738	14
Houston	SH 6	Thick Asphalt Concrete	11	8,576	17
Laredo	FM 1472	Thick Asphalt Concrete	5	20,167	17
Lubbock	FM 1585	Surface Treatment(s) over Flexible Base	20	2,442	6
Lufkin	US 287	Thick Asphalt Concrete	37	1,850	35
Odessa	IH 10	Surface Treatment(s) over Flexible Base	28	2,155	55
Odessa	US 385	Medium Asphalt Concrete	8	2,110	16
Odessa	SH 176	Medium Asphalt Concrete	9	2,250	32
San Angelo	IH 10	Medium Asphalt Concrete	37	3,963	29
San Angelo	US 377	Surface Treatment(s) over Flexible Base	57	324	32
San Antonio	FM 2771	Surface Treatment(s) over Flexible Base	42	865	16
San Antonio	RM 2828	Surface Treatment(s) over Flexible Base	37	896	29
Waco	FM 3223	Medium Asphalt Concrete	14	14,820	6
Wichita Falls	FM 3492	Surface Treatment(s) over Flexible Base	10	1,015	11

Table 14. Numbers of Pavements in Structural Categories and Traffic Levels.

Traffic Level	Thick Asphalt Concrete Pavement (ACP)	Medium Asphalt Concrete Pavement (ACP)	Thin Asphalt Concrete Pavement (ACP)	ACP over Concrete Pavement	Surface Treatments over Flexible Base	Total
High >10,000 ADT	1	1	0	4	0	6
Medium 501 – 10,000 ADT	4	5	1	1	7	18
Low < 500 ADT	0	0	0	0	1	1
Totals	**5**	**6**	**1**	**5**	**8**	**25**

Table 15 provides a breakdown of pavement types by district geographic area. Rarely was more than a single pavement of a given structural type selected from one district. However, selecting more than one project in a district was unavoidable in several cases to adequately represent certain pavement types, particularly the ACP overlay of concrete pavement category.

PMIS Data and Information Summaries for Selected Pavements

To facilitate review, researchers summarized PMIS data for years 2004, 2005, and 2006 for the 25 selected pavements. Appendix D displays condition, ride, and distress pavement performance scores for these three years. Appendix E summarizes roadway maintenance expenditure information for these three years. Some of the pavements are noted to fail to meet the criteria established in the definition of successful performance. However, most are considered excellent representatives of successfully performing flexible pavement in Texas.

Table 15. TxDOT Geographic Districts Represented.

TxDOT District	Thick Asphalt Concrete Pavement (ACP)	Thin ACP		ACP over Concrete Pavement	Surface Treatments over Flexible Base	Total
		over Flexible Base	over Cementitious Base			
Abilene	-	-	-	-	1	1
Amarillo	-	-	1	-	-	1
Atlanta	1	-	-	2	-	3
Brownwood	1	-	-	-	1	2
Bryan	-	1	-	-	-	1
Fort Worth	-	1	-	3	-	4
Houston	1	-	-	-	-	1
Laredo	1	-	-	-	-	1
Lubbock	-	-	-	-	1	1
Lufkin	1	-	-	-	-	1
Odessa	1	1	-	-	1	3
San Angelo	-	1	-	-	1	2
San Antonio	-	-	-	-	2	2
Waco	-	1	-	-	-	1
Wichita Falls	-	-	-	-	1	1
Totals	**6**	**5**	**1**	**5**	**8**	**25**

CHAPTER 4:
WEB SITE AND DATABASE DEVELOPMENT

SOFTWARE AND TECHNICAL SPECIFICATIONS

Conceptual Data Modeling

Figure 6 shows a high-level conceptual data model diagram providing a general overview of the major components of the database architecture. Data components are organized into three levels. The first level provides general information about the pavement section, including section inventory information and maintenance data. The second level gives information about pavement performance and aged pavement properties. The third level contains administrative information for managing and accessing the database.

The data model diagram shown in Figure 6 was the basis for developing more-detailed data models included herein. Both conceptual and physical data models were created early in the development process. These data models comply with the requirements of Section 3 of the TxDOT document Data Architecture Version 3.0 *(12)*.

Database architectures of existing pavement-related databases were reviewed as references in the early stages of the data modeling process. Several of the databases that were reviewed included the Pavement Management Information System, Maintenance Management Information System, and the Long-Term Pavement Performance Database. The architecture for the Texas Successful Flexible Pavements database was developed based on this review. Comments and recommendations received at several meetings with TxDOT personnel from the Information Systems Division (ISD) and the Construction Division (CST) were considered in defining which data fields to include.

Figure 7 shows the conceptual data model, which is a business-oriented model also at a high level of understanding. Appendix F includes a glossary for the conceptual data model. The physical data model is described in much more detail in the Entity-Relationship Diagram, included in Appendix A CD-ROM due to its size. The diagram of the physical data model shows the specific requirements of the database management system. The data dictionary for the physical model is also included in the Appendix A CD-ROM.

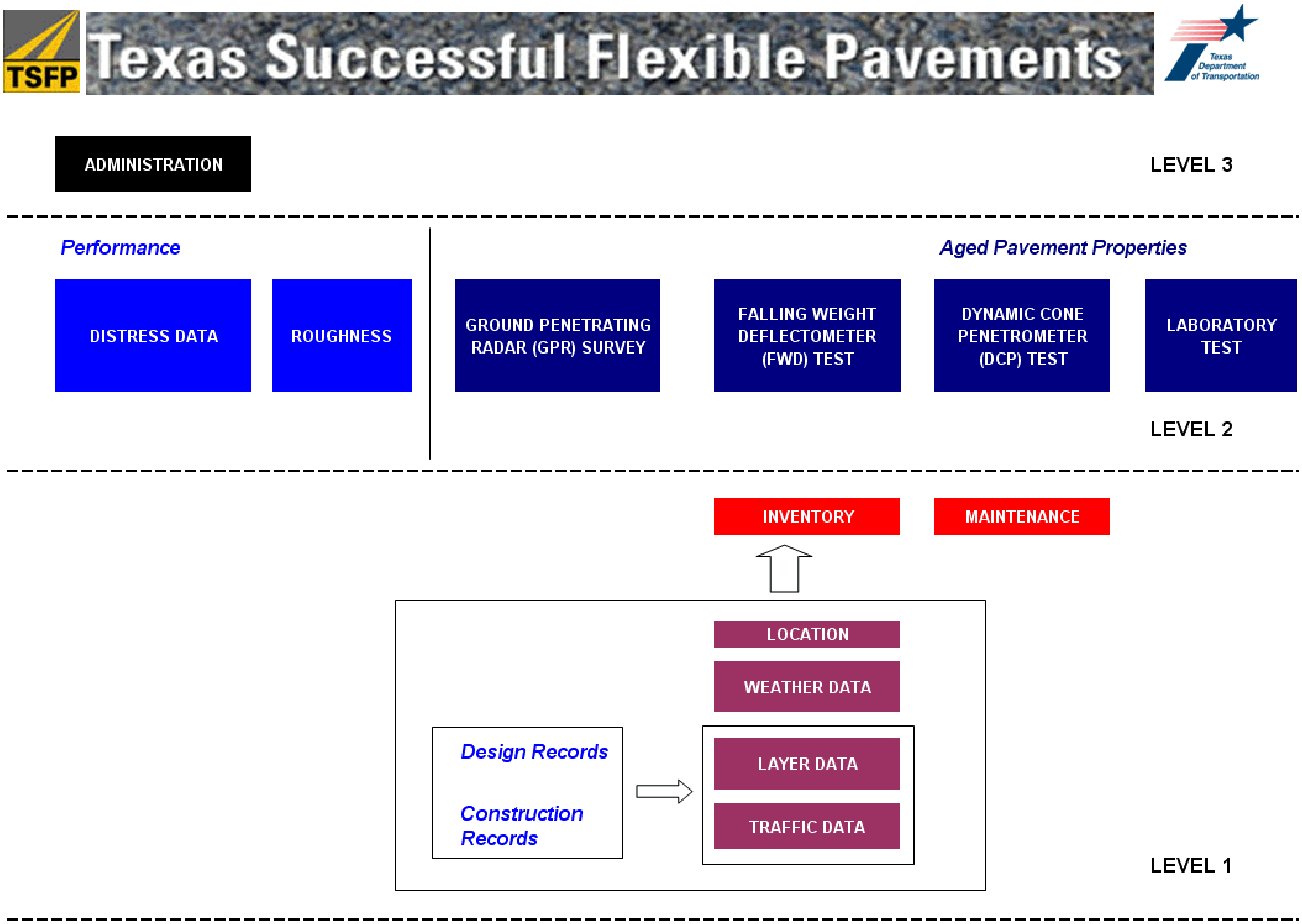


Figure 6. High-Level Conceptual Data Model Diagram for the Texas Successful Flexible Pavements Database.

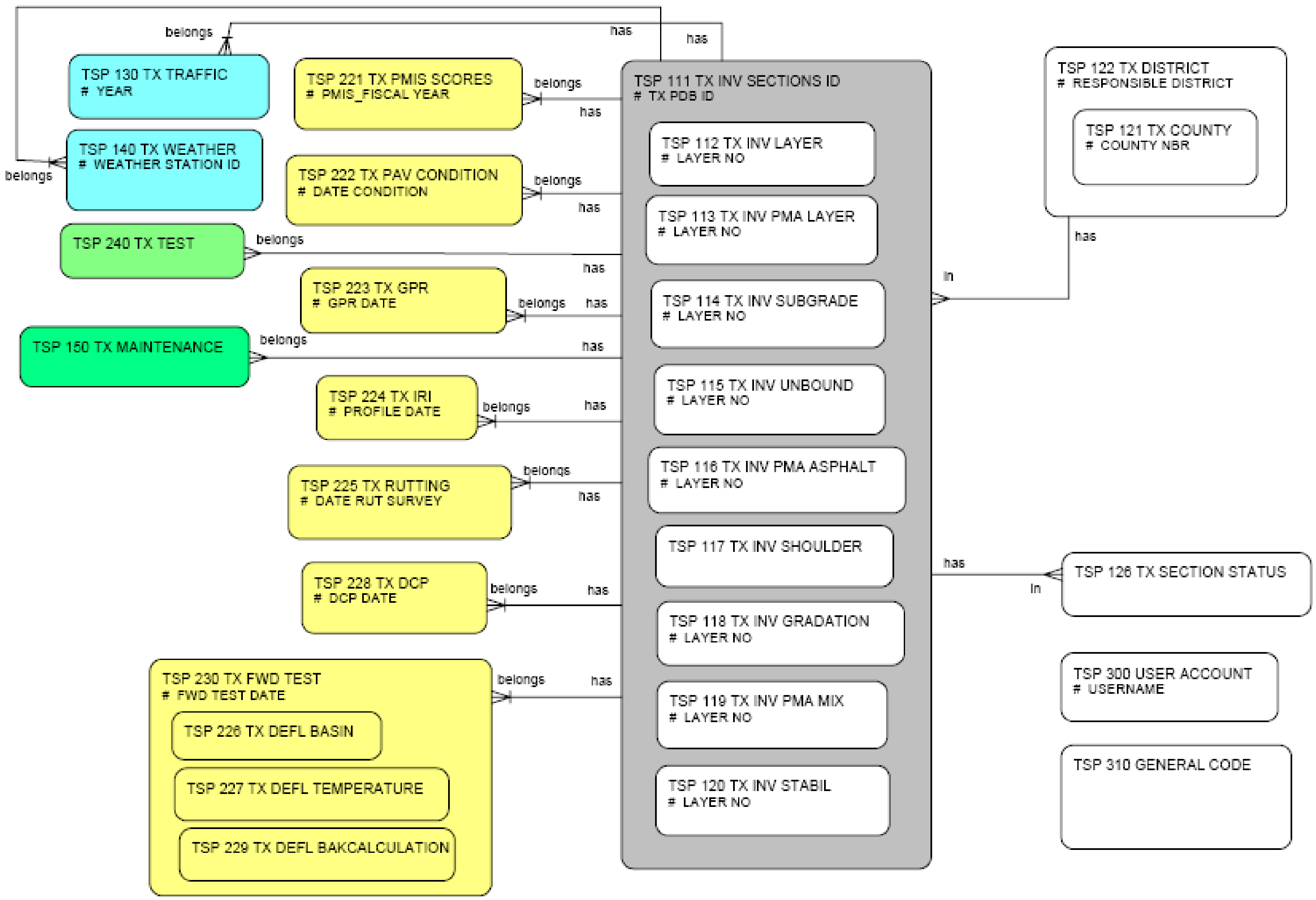


Figure 7. Conceptual Data Model for the Texas Successful Flexible Pavements Database.

As in other areas of development, the diagrams and data dictionary comply with the requirements described in section 4 and section 5 of Chapter 2 of "Data Architecture Version 3.0" provided to the research team by TxDOT's Information Systems Division. The naming convention follows the guidelines presented in Chapter 3 of the same document.

Programming Technical Information and Database Compatibility

Technical information about the Texas Transportation Institute server, web development software, and the database modeling tool are listed below. In addition, because of TxDOT's stated desire for the Texas Successful Flexible Pavements database to be able to exchange information with the database being developed under project 0-5513, "Development of a Flexible Pavements Database," a protocol to exchange information with external databases was also developed. This protocol, along with the entity-relationship (E-R) diagram and data dictionary for the Texas Successful Flexible Pavements database, was provided to researchers developing the Flexible Pavements Database early in their development process.

General Server Technical Information:
Windows 2003 server with .NET framework 2.0 on ISS 6.
Windows 2003 server to host the Oracle 10g database.

Web Development Software:
ASP.NET
Database abstraction layer.

Database Modeling Tool (E-R Diagram and Data Dictionary):
Oracle Designer 10g.

Protocol to Exchange Information:
XML Web services (proposed).
XML file (if web service is not preferred).

The definition of XML (from google.com) is XML is a W3C initiative that allows information and services to be encoded with meaningful structure and semantics that computer and humans can understand. XML is great for information exchange, and can easily be extended to include user-specified and industry-specified tags.

Frequency to Exchange Information:

Every month is the suggested frequency, if XML file type is preferred.

An example of XML from the Texas Successful Flexible Pavements database is shown below.

```
<?xml version=”1.0”?>
<tx_inv_sections>
        <tx_inv_section id=123>
                <district>Bryan</district>
                <county>Brazos</county>
                <highway_system>FM2818</highway_system>
                <pavement_type>flexible</pavement_type>
                …
        </tx_inv_section>
</tx_inv_sections>
```

WEB SITE ACCESS

The web site is designed to allow guest access and includes three registered user access levels. The system security was designed to allow TxDOT maximum flexibility in implementation and future web site use.

Guest Access

Guests visiting the web site have access to all stored pavement information and data. Guests may also export data from the database. Guest access is provided to allow anyone with Internet access to benefit from the information gathered by TxDOT about their more successfully performing flexible pavements.

Read Access

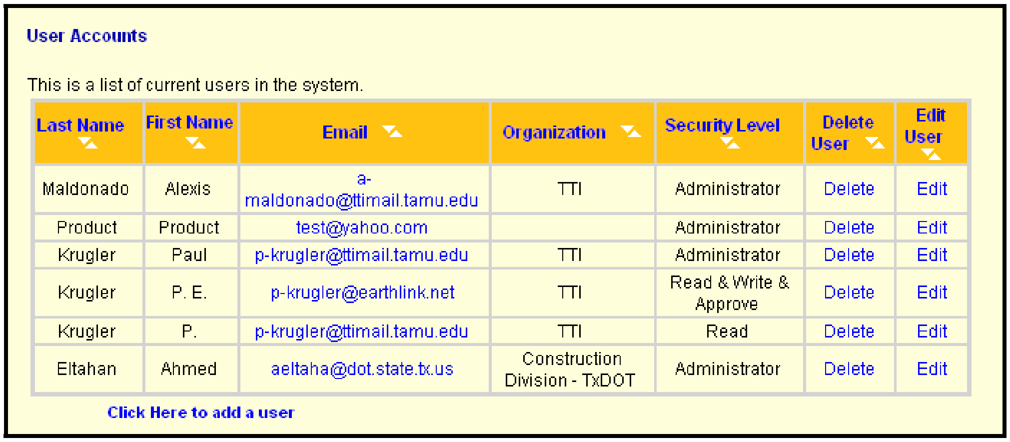
The Read access level allows users access to all data, as is available to guests, but users with Read access may also nominate pavements for inclusion in the database. Once a pavement is nominated, the nominated pavement information is available for viewing by all guests and registered users of the web site. The home page map of Texas displays a red star based on the latitude and longitude supplied by the nominator. Once a user submits a nomination, the web site provides the user with a My Pavement Nominations table located on their personal nomination screen that lists all of that user's nominations, and which also allows the nominator to delete the nomination and remove it from display on the web site.

Read, Write, and Approve Access

Registered users with this access level have the capabilities available to users with Read access, but they may also edit data stored in the database for any pavement. In addition, they may change the status of nominated pavements to approved status and they may remove pavements from either the nominated or approved status and place them into a disabled status, thereby removing the information from display on the web site.

Administrator Access

Users with the Administrator access have all of the foregoing capabilities, and also have the capability to register new users in any of the registered user categories. Administrators are provided a User Accounts table displaying all currently registered user's names, email addresses, organizations, and security access levels. Figure 8 shows an example User Accounts table.



User Accounts

This is a list of current users in the system.

Last Name	First Name	Email	Organization	Security Level	Delete User	Edit User
Maldonado	Alexis	a-maldonado@ttimail.tamu.edu	TTI	Administrator	Delete	Edit
Product	Product	test@yahoo.com		Administrator	Delete	Edit
Krugler	Paul	p-krugler@ttimail.tamu.edu	TTI	Administrator	Delete	Edit
Krugler	P. E.	p-krugler@earthlink.net	TTI	Read & Write & Approve	Delete	Edit
Krugler	P.	p-krugler@ttimail.tamu.edu	TTI	Read	Delete	Edit
Eltahan	Ahmed	aeltaha@dot.state.tx.us	Construction Division - TxDOT	Administrator	Delete	Edit

Click Here to add a user

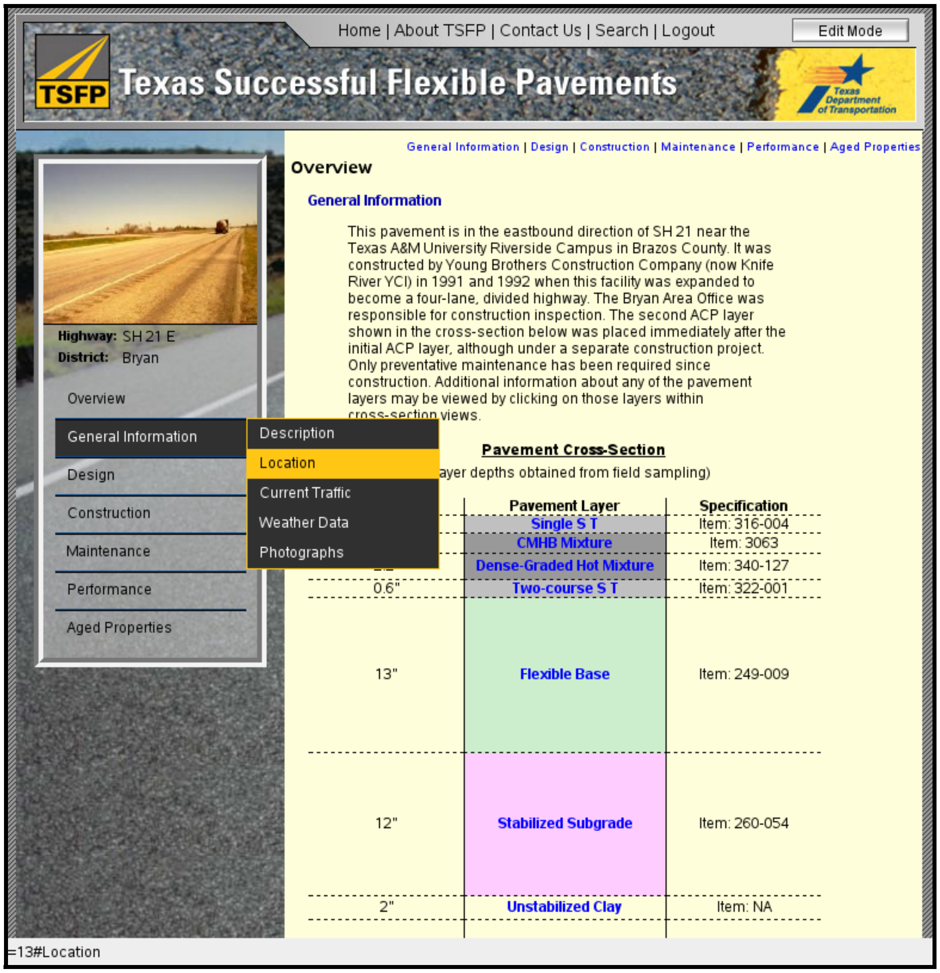
Figure 8. Screen Shot of User Accounts Section of the Administrator Screen.

ORGANIZATION AND RETRIEVAL OF DATABASE INFORMATION

The web site screen designs, the selection of major navigation informational 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 web site.

Database Navigation

Figure 9 shows the major navigation options under the pavement location photograph. The figure also shows mouse-over pop-up minor navigation options under General Information. Table 16 details all major and minor navigation levels for the web site interface to the database. The table also provides a general description of the contents of each minor navigation level.



Overview

General Information

This pavement is in the eastbound direction of SH 21 near the Texas A&M University Riverside Campus in Brazos County. It was constructed by Young Brothers Construction Company (now Knife River YCI) in 1991 and 1992 when this facility was expanded to become a four-lane, divided highway. The Bryan Area Office was responsible for construction inspection. The second ACP layer shown in the cross-section below was placed immediately after the initial ACP layer, although under a separate construction project. Only preventative maintenance has been required since construction. Additional information about any of the pavement layers may be viewed by clicking on those layers within cross-section views.

Pavement Cross-Section

ayer depths obtained from field sampling)

	Pavement Layer	Specification
	Single S T	Item: 316-004
	CMHB Mixture	Item: 3063
	Dense-Graded Hot Mixture	Item: 340-127
0.6"	Two-course S T	Item: 322-001
13"	Flexible Base	Item: 249-009
12"	Stabilized Subgrade	Item: 260-054
2"	Unstabilized Clay	Item: NA

Figure 9. Demonstration of Minor Navigation Availability.

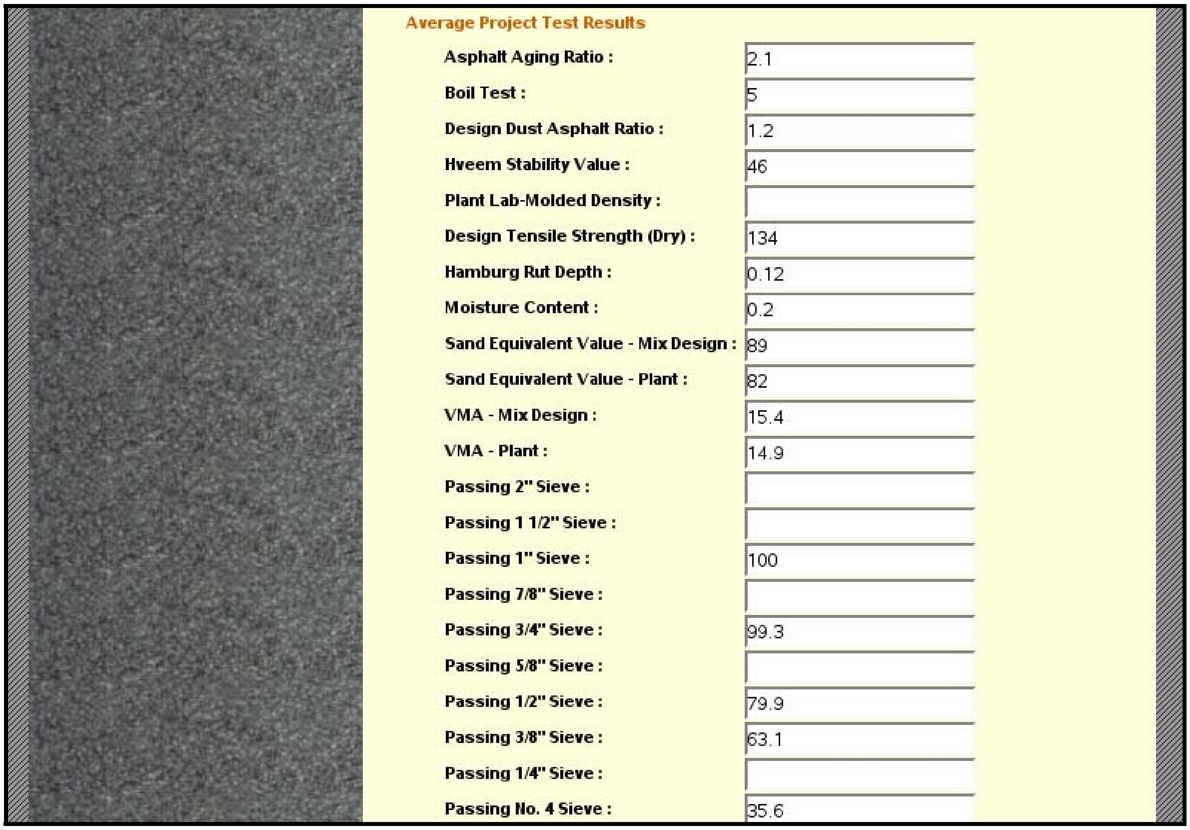
Table 16. Major and Minor Web Site Navigation Levels.

Major Navigation	Minor Navigation	Content Summary
Overview		Key information from each of the other major navigation areas.
General Information	Description	Verbal description of pavement and performance analysis, existing pavement cross-section (portals to detailed layer information), geometric information, and year nominated.
	Location	District, county, latitude-longitude, and Texas reference markers with displacements.
	Current Traffic	Annual average daily traffic, percent trucks, and cumulative traffic.
	Weather Data	Average high temperature for the hottest month, average low temperature for the coldest month, average annual rainfall, and average annual freeze-thaws.
	Photographs	Pictures taken during pavement sampling and in the laboratory.
Design	Layer Information	Cross-section shown on construction plans (portals to detailed design information on layers) and links to online and uploaded construction specifications.
	Shoulder Information	Shoulder structural information and geometrics.
	Design Traffic	Design number of ESALs and design years.
	Pavement Design Reports	Uploaded pavement design reports and information.
Construction	General Information	Contractor, year of construction, control-section-job number, and pavement structure type.
	Layer Information	Existing cross-section (portals to construction and component material information and inspection test results on individual layers) and links to online and uploaded construction specifications.
	Test Reports	Uploaded test reports.
	Mixture Design Reports	Uploaded mixture design reports.
Maintenance	Responsibility	Maintenance office name.
	Expenditures	Roadway maintenance costs for three prior years and the three-year average cost.
	Last Pavement Overlay	Type of last overlay, thickness, and year placed.
	Last Pavement Seal	Type of last seal and year placed.
Performance	Condition Score	Prior ten years of PMIS condition scores.
	Distress Score	Prior ten years of PMIS distress scores, distress survey data from most recent year, and uploaded data table.
	Ride Score	Prior ten years of PMIS ride scores, IRI data for each wheel path, rutting data, and uploaded data table.
Aged Properties	GPR Testing	Uploaded COLORMAP and test date.
	DCP Testing	Elastic modulus, CBR, and mm/blow data for base, and subgrade layers. Uploaded DCP worksheets and data plots.
	FWD Testing	Back-calculated modulus average values and standard deviations for surface, base, subbase, and subgrade layers. Uploaded deflection plot and test date.
	Laboratory Testing	Existing pavement cross-section (portals to all laboratory test results on aged pavement samples).

The web site features pavement cross-sections that serve as hyperlink portals to detailed information about the individual pavement layers. Clicking on any pavement layer in a cross-section view displays the additional information available for that layer.

Information may be entered into the database or may be revised at a later date by registered users utilizing the edit mode of the web site. The Edit Mode button may be seen in Figure 9 in the upper right-hand corner of the screen banner. Figure 10 shows an example screen of the web site in edit mode, with information entered in some of the fields. Figure 11 displays the entered information as it appears to users in the normal view. Note that unused data entry fields are not displayed in the normal view. The "display empty fields" option may be modified on an individual field basis by users having the Administrator access role.

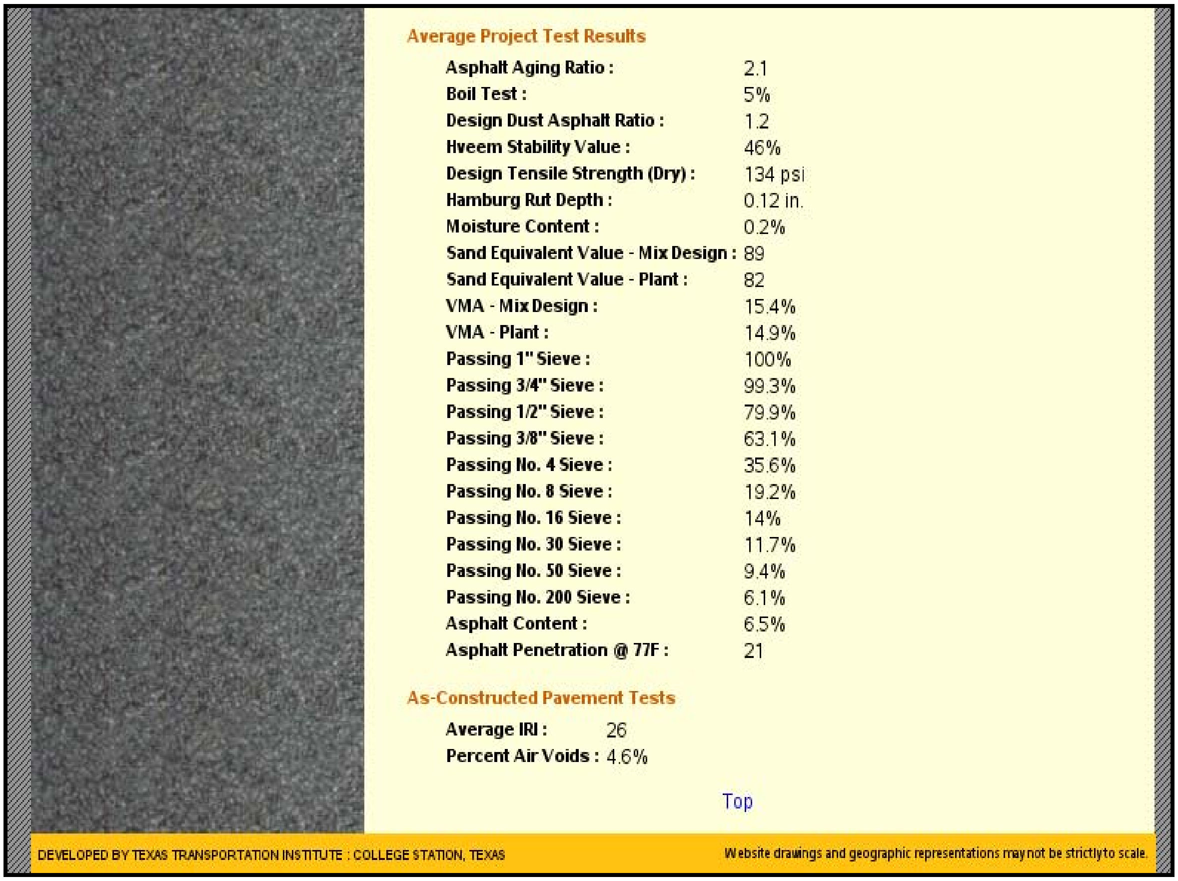
In addition to specific data entry fields for selected information, the web site offers a number of locations for the user to upload files, graphs, tables, and photographs. In this manner, almost any information TxDOT should require or desire in the future may be provided by nominators.



Average Project Test Results

Asphalt Aging Ratio :	2.1
Boil Test :	5
Design Dust Asphalt Ratio :	1.2
Hveem Stability Value :	46
Plant Lab-Molded Density :	
Design Tensile Strength (Dry) :	134
Hamburg Rut Depth :	0.12
Moisture Content :	0.2
Sand Equivalent Value - Mix Design :	89
Sand Equivalent Value - Plant :	82
VMA - Mix Design :	15.4
VMA - Plant :	14.9
Passing 2" Sieve :	
Passing 1 1/2" Sieve :	
Passing 1" Sieve :	100
Passing 7/8" Sieve :	
Passing 3/4" Sieve :	99.3
Passing 5/8" Sieve :	
Passing 1/2" Sieve :	79.9
Passing 3/8" Sieve :	63.1
Passing 1/4" Sieve :	
Passing No. 4 Sieve :	35.6

Figure 10. Portion of Web Site Screen in Edit Mode.



Average Project Test Results

Asphalt Aging Ratio : 2.1
Boil Test : 5%
Design Dust Asphalt Ratio : 1.2
Hveem Stability Value : 46%
Design Tensile Strength (Dry) : 134 psi
Hamburg Rut Depth : 0.12 in.
Moisture Content : 0.2%
Sand Equivalent Value - Mix Design : 89
Sand Equivalent Value - Plant : 82
VMA - Mix Design : 15.4%
VMA - Plant : 14.9%
Passing 1" Sieve : 100%
Passing 3/4" Sieve : 99.3%
Passing 1/2" Sieve : 79.9%
Passing 3/8" Sieve : 63.1%
Passing No. 4 Sieve : 35.6%
Passing No. 8 Sieve : 19.2%
Passing No. 16 Sieve : 14%
Passing No. 30 Sieve : 11.7%
Passing No. 50 Sieve : 9.4%
Passing No. 200 Sieve : 6.1%
Asphalt Content : 6.5%
Asphalt Penetration @ 77F : 21

As-Constructed Pavement Tests

Average IRI : 26
Percent Air Voids : 4.6%

DEVELOPED BY TEXAS TRANSPORTATION INSTITUTE : COLLEGE STATION, TEXAS

Website drawings and geographic representations may not be strictly to scale.

Figure 11. Corresponding Edit Mode Web Site Screen in Normal View.

Web site functionality allows both guests and registered users to search for pavement types of interest by key word, including district, county, road or highway number, pavement and layer type, and other distinguishing features. The search function utilizes the home page map of Texas, shown in Figure 2, to indicate a star in each location of a pavement meeting the search criteria.

The online nomination capability provided to registered users greatly facilitates continued growth of database information and a corresponding increase in database value. Registered users may nominate new pavements online at any time; enter and edit data for pavements being nominated now or in the past; and are also able to create the pavement cross-section views to be displayed for the nominated pavements. The online nomination capability is considered a particularly valuable feature of this product.

Future data analysis is facilitated by an export function, whereby users may download database information on an individual or collective pavement section basis. Export data are placed in an Excel format to facilitate further analysis by the user.

NOMINATED PAVEMENT ADMINISTRATION

In addition to managing registered user access, the web site administrator also has the capability to approve, delete, or disable any pavement nomination included in the database. Figure 12 displays the Nominated Pavements management table, available only to the Administrator(s).

Administration

Nominated Pavements | Nominate a New Section | User Accounts

Nominated Pavements

This is a list of your nominated pavement sections and their approval status. You can click on a section to view or modify the data. To cancel an approved section the section must be disabled first. Click on "Approve" to approve nominated sections or to enable disabled sections.

Highway Name	Status	Nominated by:	Approved by:	Date Nominated	Date Approved	Disable Nomination	Delete Nomination	Approve Nomination
IH 10	APPROVED	admin	megalex		08/22/2007 17:12:16	Disable	Delete	Approve
IH 10	APPROVED	admin	admin		08/17/2007 09:40:01	Disable	Delete	Approve
IH 20 W	APPROVED	admin	admin		08/17/2007 09:40:01	Disable	Delete	Approve
IH 30	APPROVED	admin	admin		08/17/2007 09:40:01	Disable	Delete	Approve
BIH 35	APPROVED	admin	admin		08/17/2007 09:40:01	Disable	Delete	Approve
US 59	APPROVED	admin	admin		08/17/2007 09:40:01	Disable	Delete	Approve
US 67	APPROVED	admin	admin		08/17/2007 09:40:01	Disable	Delete	Approve
US 190	APPROVED	admin	admin		08/17/2007 09:40:01	Disable	Delete	Approve
US 287	APPROVED	admin	admin		08/17/2007 09:40:01	Disable	Delete	Approve
US 377	APPROVED	admin	admin		08/17/2007 09:40:01	Disable	Delete	Approve
US 380	APPROVED	admin	admin		08/17/2007 09:40:01	Disable	Delete	Approve

Figure 12. Administrator's Nominated Pavements Table.

CHAPTER 5:
LABORATORY AND PAVEMENT TESTING OF SUCCESSFUL PAVEMENTS

SCOPE AND OBJECTIVES OF AGED PAVEMENT AND MATERIALS TESTING

The task of sampling and testing the 25 flexible pavements began soon after the pavements were jointly selected by the research team and TxDOT. The objective of the sampling and testing of the aged pavements was to learn as much as possible about why the pavements had performed as well as they had. In some respects, the field work was similar to—but the inverse of—the more typical forensic pavement evaluations for determining why a pavement had failed to adequately perform. A chief difference between typical forensic studies and the pavement studies performed during this project is that typical performance failures usually vary considerably in intensity along the roadway, providing the opportunity for sampling and testing of both good and poor performing locations, which allows the determination of difference in characteristics, a strong indicator of being a causative factor. The pavements in this project tended to be quite uniform in appearance and performance, thereby making determination of causative factors more challenging.

Both in situ pavement testing and laboratory testing were performed. The research team recommended the suite of tests to perform based on the perceived likelihood of capturing information pertinent to the high level of performance being experienced.

A one-mile length of a single lane of each pavement was selected for sampling and field testing. The lane was selected to well represent the entire nominated pavement. When available, GPR data were consulted to help assure that the selected location was representative and uniform below the surface. Traffic control considerations that would arise during sampling and testing were also a factor in selecting the one-mile section. Only one direction of a highway was chosen for field testing and sample collection. In most multilane cases, the outside lane was chosen.

PAVEMENT TESTING PROTOCOLS

A number of nondestructive pavement tests were conducted on the selected pavements. The pavement field tests included ground penetrating radar, falling weight deflectometer, and dynamic cone penetrometer. In most cases, the GPR test run was performed prior to the site visit for obtaining field samples. The FWD and DCP tests were generally conducted at the time of field sampling, with TxDOT personnel performing the FWD tests. Table 17 indicates the field testing and sampling that was performed.

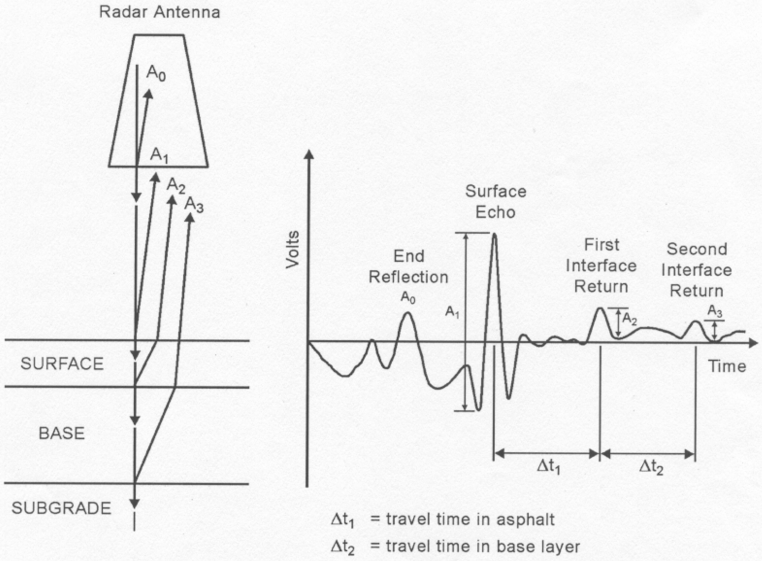
Table 17. Field Sampling and Pavement Tests.

Sect. No.	District	HWY No.	GPR	DCP	Field Sampling
11	Abilene	US 380	√	√	√
16	Amarillo	SH 152	√	√	√
6	Atlanta	US 59	√	√	√
3	Atlanta	IH 20W	√	Concrete	√
4	Atlanta	IH 30	√	Concrete	√
8	Brownwood	US 190	√	√	√
7	Brownwood	US 67/84	√	√	√
13	Bryan	SH 21E	√	√	√
14	Fort Worth	SH 183	√	Concrete	√
15	Fort Worth	SH 121	Pavement Removed		
17	Fort Worth	SH 171	√	√	√
5	Fort Worth	BIH 35	√	Concrete	√
19	Laredo	FM 1472	√	√	√
20	Lubbock	FM 1585	√	√	√
9	Lufkin	US 287	√	√	√
1	Odessa	IH 10	√	√	√
18	Odessa	SH 176	√	√	√
12	Odessa	US 385	√	√	√
10	San Angelo	US 377	√	√	√
2	San Angelo	IH 10	√	√	√
21	San Antonio	FM 2771	√	√	√
24	San Antonio	RM 2828	√	√	√
22	Waco	FM 3223	√	√	√
23	Wichita Falls	FM 3492	√	√	√
25	Houston	SH 6	√	Could Not Penetrate	√

Ground Penetrating Radar

The objective of GPR testing was to investigate subsurface conditions and observe variations in layer thicknesses, if any. TTI's one gigahertz (1 GHz) air-launched ground penetrating radar unit was used and is shown in Figure 13. This system sends discrete pulses of

(a) TTI GPR Equipment



(b) Principles of GPR. The incident wave is reflected at each layer interface and plotted as return voltage against time of arrival in nanoseconds.

Figure 13. GPR Equipment and Principles of Operation.

radar energy into the pavement system and captures the reflections from each layer interface within the structure. Radar is an electromagnetic wave and therefore obeys the laws governing reflection and transmission of these waves in layered media. The GPR unit used during this project can operate at highway speeds (60 mph), transmit and receive 50 pulses per second, and effectively penetrate to a pavement depth of 2 feet.

A typical plot of captured reflected energy versus time for a single radar pulse is also shown in Figure 13. The units are volts versus arrival time in nanoseconds. The reflection A_1 is the energy reflected from the surface of the pavement and A_2 and A_3 are reflections from the top of the base and subgrade, respectively. These are all classified as positive reflections, which indicate interfaces with a transition from a lower to a higher dielectric material. Amplitudes of reflection and the time delays between reflections are used to calculate both layer dielectrics and thicknesses. The dielectric constant of a material is an electrical property that is most influenced by moisture content and density. An increase in moisture will cause an increase in layer dielectric; in contrast an increase in air void content will cause a decrease in layer dielectric.

Typically, GPR data were obtained from the right wheel path of the outside lane of the nominated pavement section. GPR data were usually obtained for the entire length of the nominated pavement section, in one direction, at pulse distance intervals of 1 foot. Pavement video was captured during GPR test runs to assist in evaluating GPR data. Figure 14 shows a typical still picture from the video data.

Figure 14. Still Picture from GPR Video Data – SH 6, Houston.

It is common for GPR testing of a single pavement section to include several thousand GPR traces. In order to conveniently display this information, color-coding schemes are used to convert the traces into line scans and stack them side-by-side so that a subsurface image of the pavement structure can be obtained. This approach is used extensively in Texas. Figure 15 shows a typical display for a thick asphalt concrete pavement. A display of this nature was created for each one-mile test pavement length and was placed in the Texas Successful Flexible Pavements database.

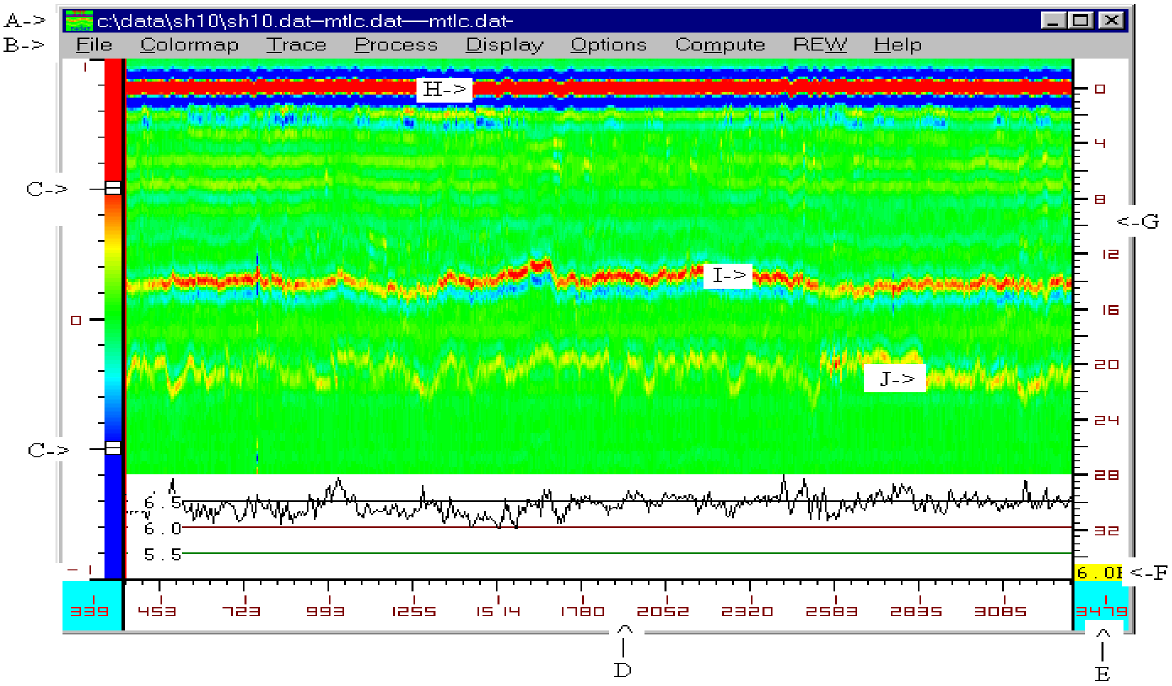


Figure 15. Typical Color-Coded GPR Traces for a Test Section.

Falling Weight Deflectometer

The objective of FWD testing on these sections was to evaluate pavement structural integrity and to measure the modulus of elasticity of the various pavement layers. The research team appreciates the TxDOT districts and Construction Division for their support in providing this testing. All pavement sections were tested with the exception of two, SH 183 – Fort Worth and IH 30 – Atlanta. These two pavements were not tested because the underlying pavement was continuously reinforced concrete pavement, and the experience of TxDOT personnel was that there would be little value gained relative to the expense and difficulty in closing traffic lanes on these heavily traveled highways.

TxDOT’s project level data collection protocol was followed during testing. The tests were conducted in the outer wheel path of the designated lane, and 30 test points were evenly distributed over the one-mile length. In most cases the test load was 9000 lbs, with three test drops being made at each test point. Pavement temperature was measured at the beginning and the end limits of the one-mile test length. Figure 16 shows a typical FWD test in progress on the outer wheel path.

Figure 16. FWD Testing – US 59, Atlanta.

Dynamic Cone Penetrometer

The objective of DCP testing was to measure the in situ stiffness of flexible base and subgrade layer(s). This test was conducted following the general guidelines from ASTM D6951-03 "Standard Test Method for the Use of the Dynamic Cone Penetrometer in Shallow Pavement Applications." An 8 kilogram sliding hammer was used for this testing. Before testing, asphalt concrete layers and surface treatment layers were penetrated with a drill (see Figure 17) so that the tip of the DCP cone rested on the top of the flexible base layer to begin testing. Figure 18 depicts personnel taking DCP measurements at one test location. The number of drops between penetration measurements varied widely depending on the layer stiffness. A smaller number of drops were used for softer layers and a larger number for stiffer layers. In several cases the

Figure 17. Drilling Asphalt Mixture before DCP Testing.

Figure 18. DCP Testing in Outer Wheel Path.

research team drilled somewhat further, into the flexible base layer, prior to beginning testing. This additional drilling was necessary when the depth of penetration was zero or was bouncing after as many as 40 drops. The problem was believed to be caused by a large rock directly beneath the cone tip. The research team took DCP measurements at two locations for each one-mile test length—one near each end of the test section.

PAVEMENT MATERIALS SAMPLING

Samples of the aged pavement were obtained from all pavements to be included in the initial database. Core samples were obtained from asphalt mixture layers and other stabilized layers, and loose samples of flexible base layers and subgrade materials were taken by auger. When the nominated flexible pavement was an overlay of Portland cement concrete, only samples of the asphalt mixture overlays were obtained. TxDOT district personnel graciously provided the necessary traffic control.

Samples were obtained from two locations of each one-mile test length. These locations were generally 500 feet from each end of the section. For pavements including at least one asphalt concrete mixture layer, a total of ten 6-inch diameter cores were obtained; five from between the wheel paths and five from the outer wheel path. These cores were distributed between the two sampling locations as shown in Figure 19, which also shows the typical auger sampling locations and DCP testing locations. For pavements that did not contain an asphalt concrete mixture layer, only four 6-inch diameter cores were taken; two from between wheel paths and two from the outer wheel path, as shown in Figure 20. Pavement cores were marked at the sampling site with paint. Cores were numbered individually, indicating sampling location number and whether it was taken from the wheel path or from between wheel paths. For example, WP 1-2 indicates the second core sample obtained from a wheel path from coring location 1. The samples were also marked with roadway and district identification. Photographs of coring holes were taken before patching.

Except for samples from FM 1472 and SH 121, the research team used TTI coring equipment to obtain core samples, as shown in Figure 21 after completing coring at a typical location. The Laredo District Laboratory generously obtained their pavement's core samples during the research team visit. The asphalt cores from SH 121 in the Fort Worth District were obtained by district personnel prior to the asphalt overlay being milled. Only four 6-inch diameter cores were available for testing from this pavement.

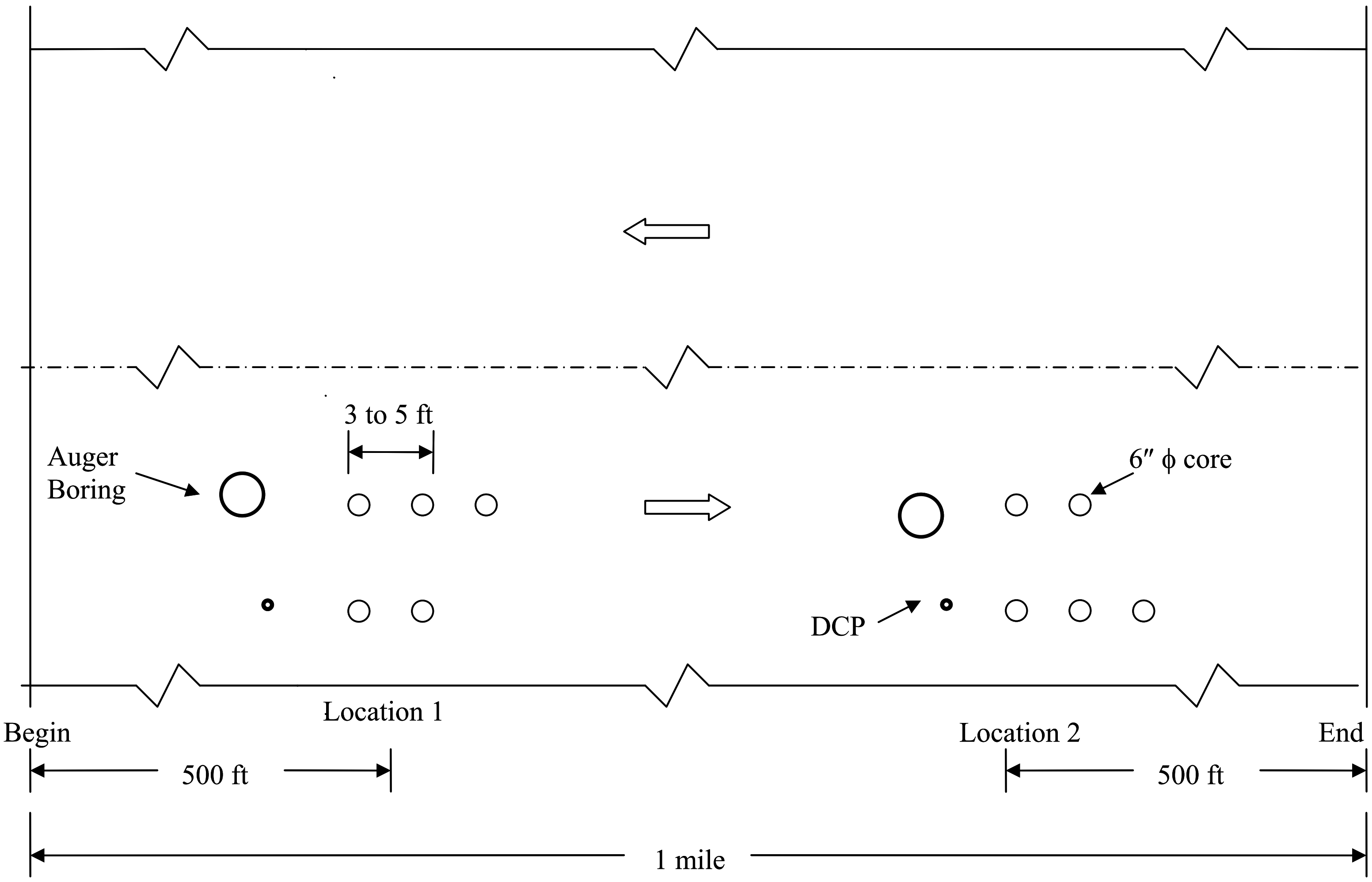


Figure 19.: Typical Sampling Layout –- Pavements with Asphalt Concrete Mixture Layer(s).

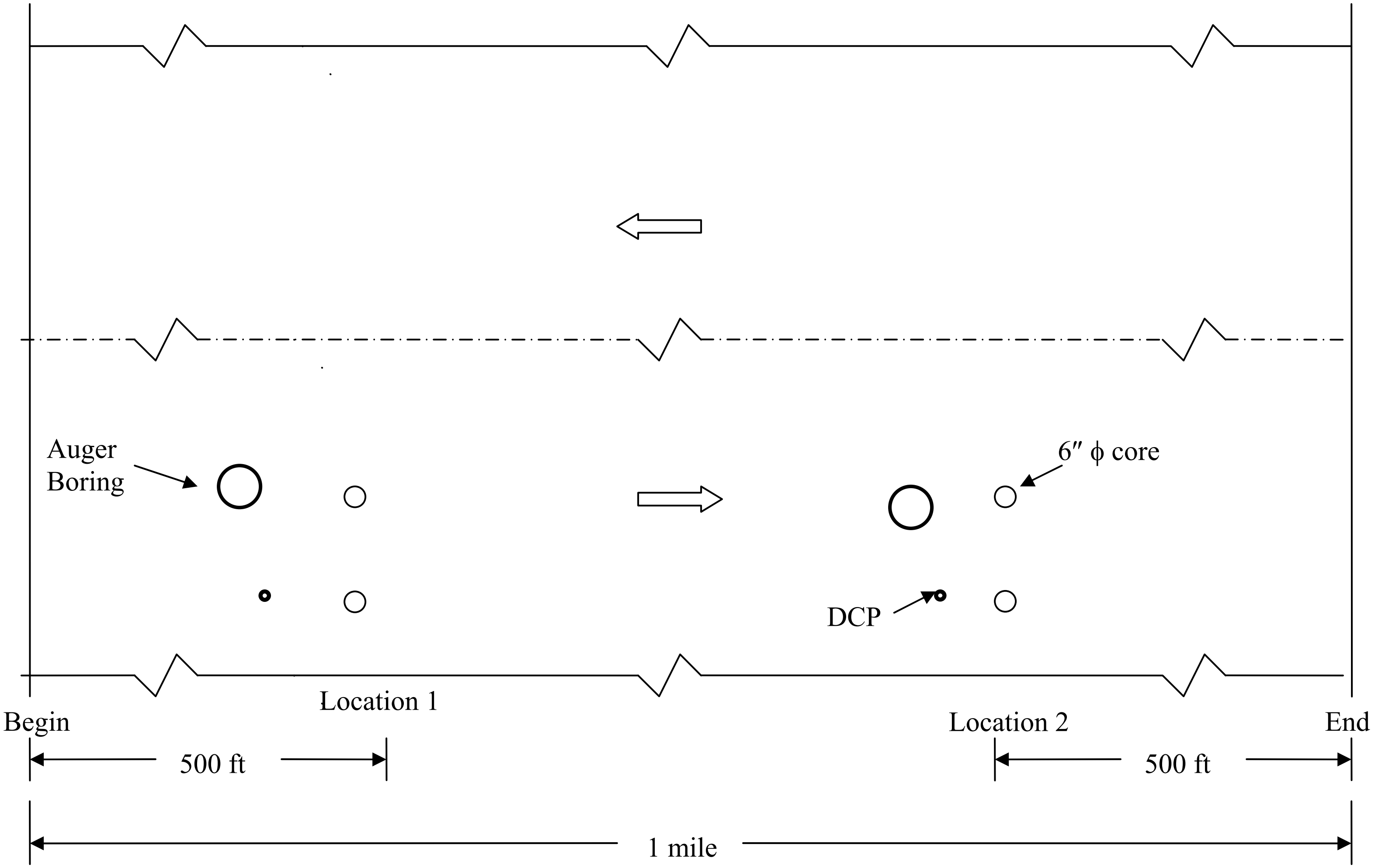


Figure 20. Typical Sampling Layout – Pavements with No Asphalt Concrete Mixture Layer(s).

Figure 21. Typical Coring Layout at Section with HMA Layer (SH 176 in Odessa).

Flexible base and subgrade samples were typically obtained from two 10-inch diameter holes near the coring location. These samples were taken with a TTI auger, shown in Figure 22. These sampling holes were located between the wheel paths in order to minimize the potential for roadway performance damage.

Figure 22. TTI Auger Used to Obtain Flexible Base and Subgrade Samples.

The research team monitored change of sample appearance during operation of the auger so that separate samples could be obtained when materials obviously varied. Samples were stored in plastic bags at the time of sampling to allow moisture determination of these pavement layers. The research team also measured layer thicknesses, as shown in Figure 23. The ultimate depth of auger boring varied depending on the local conditions. Typically, boring continued to 30 inches below the pavement surface. The subgrade samples were taken at least 1 foot below the top of the natural subgrade.

Figure 23. Measurement of Layer Thickness While Auger Sampling.

Besides the collection of pavement samples, the research team recorded global positioning system (GPS) coordinates, pavement temperatures, and any unique aspect of the sampling locations while at the sampling sites. Photographs were taken to record operations and to assist in locating the sampling points in the future, if needed.

LABORATORY TESTING PROTOCOLS

All tests of pavement cores and loose material samples were performed in the TTI materials laboratory on the campus of Texas A&M University in College Station. The laboratory tests and procedures that were performed varied by the type of pavement layer, as follows.

Asphalt Concrete Mixture Layer Testing

The focus of testing asphalt concrete mixture layers was on asphalt binder content, aged asphalt binder properties, aggregate gradation, and the final percent air voids after years of traffic. These were selected for their importance to performance. The asphalt binder content and properties are a major factor in resistance to pavement cracking. The gradation is a major factor in resisting pavement deformation in the wheel paths. And the final percent air voids is a good indicator of the degree of protection that the surface layers are providing underlying moisture susceptible, unstabilized pavement layers.

Core Photography and Measurements

Several cores from each nominated pavement were photographed prior to sawing and separating pavement layers. These photographs were taken to visually document the pavement structure and the appearance of individual pavement layers. These photographs have been uploaded into the Texas Successful Flexible Pavements web site for viewing by users. Figure 24 shows example core photographs. The thickness of each pavement layer was carefully measured at several locations around a given core sample, and an average of the measurements was recorded. A general description of each layer was also logged into laboratory records.

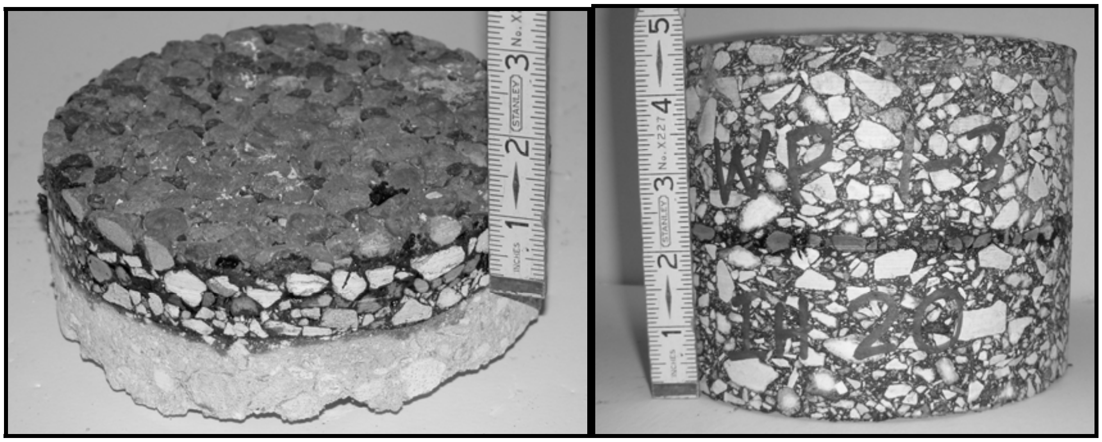


Figure 24. Laboratory Photographs of Pavement Cores.

Specific Gravity and Air Void Determinations

Each asphalt concrete mixture layer of adequate thickness for testing was separated by sawing. Care was taken to exclude any trace of seal coat or microsurfacing materials from the sample to be tested. Individual asphalt layer samples were left in front of a fan at room temperature for several days in order to remove moisture. At least four samples, two taken from the wheel path and two taken from between wheel paths, were bulk specific gravity tested. Bulk specific gravity was measured following Test Method Tex-207-F, Part VI "Bulk Specific Gravity of Compacted Bituminous Mixtures using the Vacuum Method."

Two or more of these layer samples were then melted in a warm oven and mixed together. After cooling to room temperature the sample was carefully split: one half for measuring Rice theoretical maximum specific gravity and the other half for later solvent extraction and recovery of the binder. The Rice specific gravity of the sample was determined following Test Method Tex-227-F, "Theoretical Maximum Specific Gravity of Bituminous Mixtures, Part II."

The percent air voids contained in the individual pavement layers were then calculated using the Rice theoretical maximum specific gravity value and the bulk specific gravities of the core samples.

Asphalt Content and Recovery

Two methods were used to determine the asphalt content of individual pavement mixture layers. Pavement layers that did not include polymers in the asphalt were tested using the solvent extraction procedures in Test Method Tex-210-F, "Determining Asphalt Content of Bituminous Mixtures by Extraction, Part I, Centrifuge Extraction Method Using Chlorinated Solvent." The asphalt washed from these samples was then recovered in accordance with Test Method Tex-211-F, "Recovery of Asphalt from Bituminous Mixtures by the Abson Process." Pavement mixture layers believed to contain polymer modifiers were tested for asphalt content in accordance with Test Method Tex-236-F, "Determining Asphalt Content from Asphalt Paving Mixtures by the Ignition Method." This decision was made because of the high uncertainty that recovered polymer-modified asphalts could be recovered in a manner to adequately determine the binder properties. Therefore, the more efficient ignition test method was used for these samples.

Mixture Aggregate Gradation

Aggregates recovered during both methods of binder content determination were tested in accordance with Test Method Tex-200-F, "Sieve Analysis of Fine and Coarse Aggregate, Part II Washed Sieve Analysis." The set of sieve sizes selected for gradation testing of each pavement layer was based on the sieves required in construction specifications for the pavement mixture type; i.e., Type D, C, etc.

Penetration Testing of Binders

The penetration test was selected for testing recovered binder samples because of this test's historic use in TxDOT during forensic studies of aged pavements. This data history will allow TxDOT to readily compare the binder properties from these particularly successful pavements to test results over the years from a number of other pavements, including a number of pavements which had failed prematurely. The penetration tests were performed at 77° F in accordance with ASTM D5-06, Standard Test Method for "Penetration of Bituminous Materials."

Surface Treatment Layer Testing

Core Photography and Measurements

Cores from pavements consisting of only surface treatments and seal coats above the base were photographed and the total thickness of the combined pavement seals was measured. The research team estimated the number of seal coat applications present from the appearance of the core. No testing was attempted.

Stabilized Base Layer Testing

Core samples were retrieved from three highways containing asphalt stabilized base. These were SH 6, US 287, and US 67/84. Figure 25 shows the asphalt stabilized base samples obtained from US 287 in the Lufkin District and from SH 6 in the Houston District. Note that the US 287 asphalt stabilized base is a sand asphalt mixture.

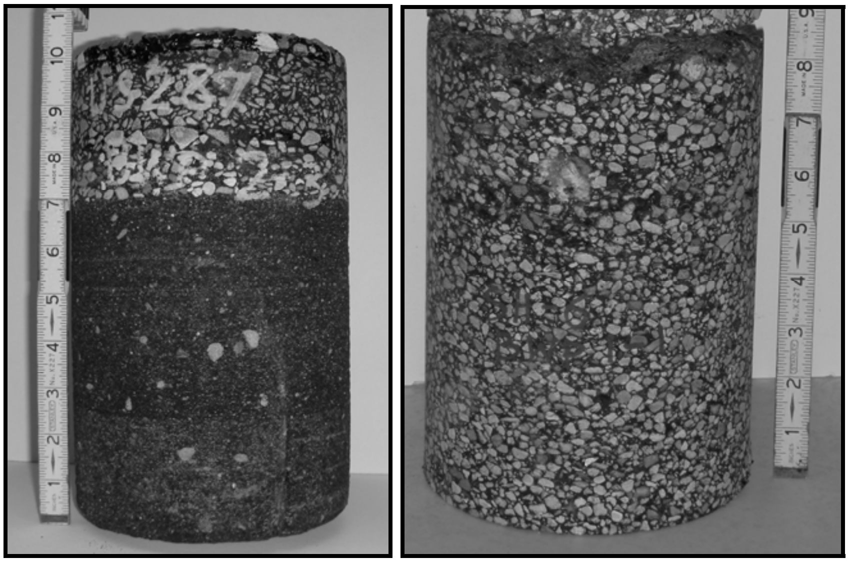


Figure 25. Asphalt Stabilized Base Cores from US 287 and SH 6.

SH 171 in the Fort Worth District included a cement stabilized base, for which a test-worthy sample could not be obtained by either coring or auger boring.

Asphalt stabilized base layers were documented and tested in the laboratory in the same manner as asphalt concrete mixture layers.

Flexible Base Layer and Subgrade Testing

Flexible base materials were obtained from 17 pavement test sections. The remaining eight selected pavements either had underlying concrete pavement or did not have flexible base in the pavement structure. Sampling and testing of flexible base and subgrade focused on determining Atterberg limits, moisture content at time of sampling, and mineral type. In addition, the gradation of each flexible base sample was determined.

Field Moisture Content

A moisture sample was typically obtained at about the midpoint of flexible base layers and from the upper foot of the subgrade. These samples were immediately sealed in a plastic bag. Moisture determinations were performed according to Test Method Tex-103-E, "Determining Moisture Content in Soil Materials."

Atterberg Limits

The liquid limit, plastic limit, and plasticity index were determined for both flexible base layer and subgrade samples. Samples were prepared following the standard procedures found in Test Method Tex-101-E, "Preparing Soil and Flexible base Materials for Testing (Part I)," and testing was performed in accordance with Test Methods Tex-104-E, "Determining Liquid Limits of Soils"; Tex-105-E, "Determining Plastic Limit of Soils"; and Tex-106-E, "Calculating the Plasticity Index of Soils."

When these samples were obtained from two different locations on a given pavement section, they were tested individually. Both results are reported in the web site when significantly different properties were found. Atterberg limits of subgrade samples were measured separately with samples from two separate auger holes for each test section.

Flexible Base Gradation

The gradation of flexible base materials was determined following the standard procedure in Test Method Tex-110-E, "Particle Size Analysis of Soil (Part I)." This procedure allows measuring the gradation of particles larger than 0.425 mm (No. 40 sieve). Before performing this gradation test, the percentage of passing No. 200 sieve material was determined by washing in accordance with Test Method Tex-111-E, "Determining the Amount of Material in Soils Finer than 75 µm (No. 200 sieve)." Since TxDOT construction specifications control flexible base gradation as percent retained by sieve size, these test results are included in the web site in those units.

Mineral Identification

Dr. Pat Harris, a TTI geologist, assisted the research team in mineral identification of flexible base samples. Flexible base samples were washed to remove fines from the coarse aggregate to facilitate mineral identification. Fifteen to twenty coarse aggregate particles were then randomly selected for identification. Samples were first examined microscopically using a Meiji binocular microscope. Most samples were identified by this visual examination, but hydrochloric acid was added to some samples to assist in gauging calcite content. A steel biological pick was also used to determine the hardness of some samples to further aide in mineral identification. Reasonable identifications of coarse aggregate mineral composition were possible in this manner.

CHAPTER 6:
ANALYSIS OF INFORMATION

A number of analyses were performed on construction inspection test data, PMIS data, and aged pavement test data obtained from the successful flexible pavements included in the database. The primary objective of these analyses was to expand knowledge about the correlation of construction specification requirements and aged pavement test results to long-term successful performance of flexible pavements in Texas.

IMPACTS OF SPECIFICATION AND TEST METHOD EVOLUTION

The earliest construction year for pavements included in the Texas Successful Flexible Pavements database is 1949. The most recent construction year is 2001. TxDOT construction specifications and testing procedures have been revised on numerous occasions over the decades to keep pace with knowledge and technology concerning flexible pavements. These changes complicate analyses of information for the purpose of increasing understanding of the impacts of specification requirements on pavement performance. The most significant challenge is in the area of changes to testing procedures, as these have a largely unknown and sometimes variable affect on test results. Analyses of test results are reported herein and compared over time even though a direct comparison is potentially flawed by changes in the testing techniques used.

Another challenge to the research team was that several of the flexible pavements included in the project were constructed using metric units of measure. As TxDOT currently uses English units of measure, all metric information has been converted to English units prior to data analysis and loading into the Texas Successful Flexible Pavements database.

SPECIFICATION ANALYSIS METHODOLOGY

The systematic methodology developed and employed to analyze construction specification criteria included data collection, data refinement, and data analyses processes.

Data Collection

Historic data that were collected included information found in construction plans and also in construction inspection testing records, whenever this information had been retained by the district. Construction plans were located for 24 of the 25 pavements included in the project. Because of record retention policies within TxDOT, only nine of the pavements to be included in the database had construction inspection testing records available. Construction records existed in hard copy in most instances, on microfilm for two projects, and on a CD for one project. The collected construction test results are tabulated in Appendix A on the CD-ROM. The lack of construction inspection test results limited the depth and nature of conclusions related to specification requirement analyses contained herein. However, the web site and database that have been created provide the means for more precise future evaluations as additional project data are included in the database.

Following the procedures described in Chapter 5, field pavement tests and laboratory testing of aged pavement samples were performed to determine current pavement and material characteristics. The results of all aged pavement laboratory test results are also included in Appendix A on the CD-ROM. While aged pavement laboratory test results provide insight for the analysis of construction specification requirements, this information must be carefully evaluated as it does not usually represent the characteristics of the pavement and materials at the time of construction. Degradation of aggregate during construction, traffic densification of pavement layers, and oxidation of asphalt binders will all have significant affects on test results. Although not particularly an objective of this research project, the aged pavement test results provide a particularly valuable contribution toward better understanding of desirable long-term properties of flexible pavement layers.

Construction Data Refinement

In large measure, historic construction data could be included for analysis without refinement. The most notable exception was that test results were deleted from the analyses when they did not meet specification requirements and, thereby, resulted in the materials being rejected at the plant or removed from the roadway at the time of construction.

Data refinement was also required in several instances to allow proper analyses and comparison to current specification criteria. For instance, TxDOT has used percent-passing, percent-retained, and percent-passing-and-retained gradation documentation methods in various material specifications over the decades. When pavements were constructed under specifications using different gradation documentation methods than TxDOT specifications currently use, the test results were converted to the gradation documentation method currently being used. Another common refinement of data was conversion of metric units of measure to English units, when necessary.

Data Analysis Methods

Construction inspection test results that were available are primarily compared to specification criteria in graphical format. Discussions of particular findings are included later in this chapter. A comprehensive series of gradation charts and test result frequency diagrams displaying individual pavement layer data are included in Appendix A on the CD-ROM. Examples of the graphical displays of individual project construction inspection test results are seen in Figures 26, 27, and 28. Data analyses also included determination of mean and standard deviation for each set of pavement layer test results for each pavement. Appendix A provides these statistics along with the individual daily inspection test information.

Aged pavement test results were evaluated using similar graphical means whenever adequate data quantities allowed. Discussions of findings are also included later in this chapter.

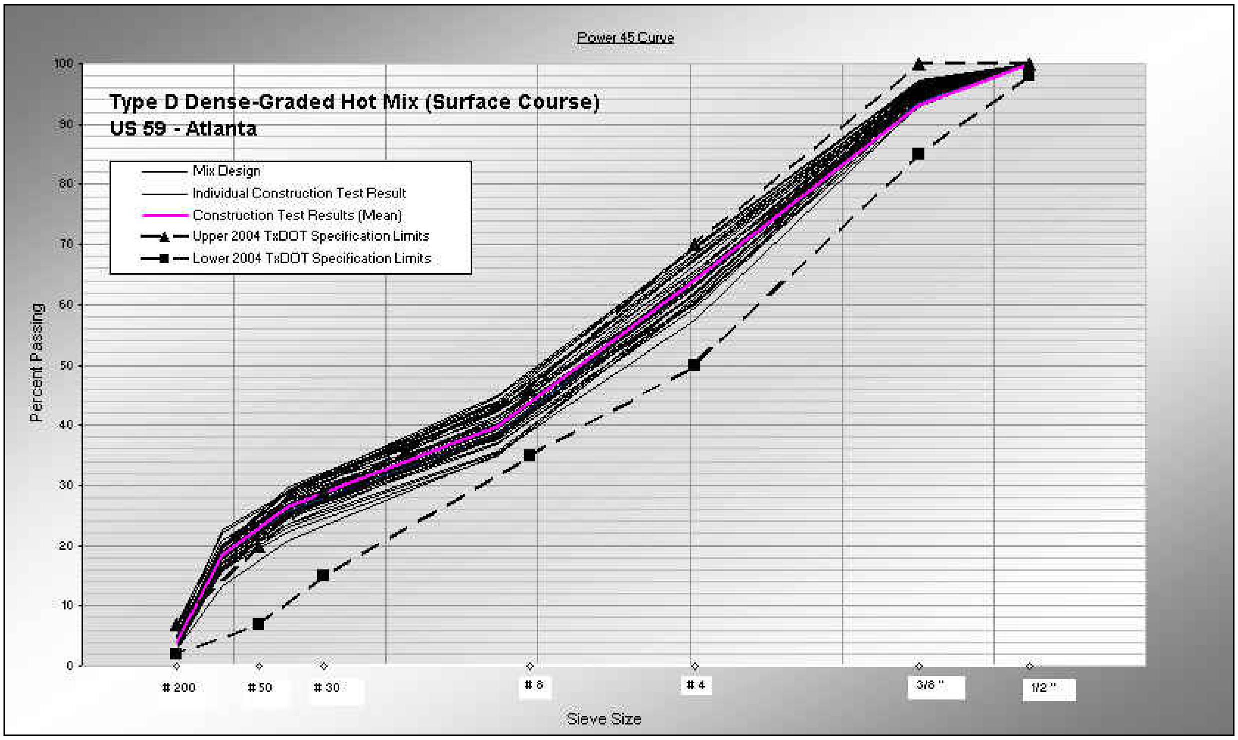


Figure 26. Power 45 Plots of Daily Job Control Gradation Test Results - US 59, Houston.

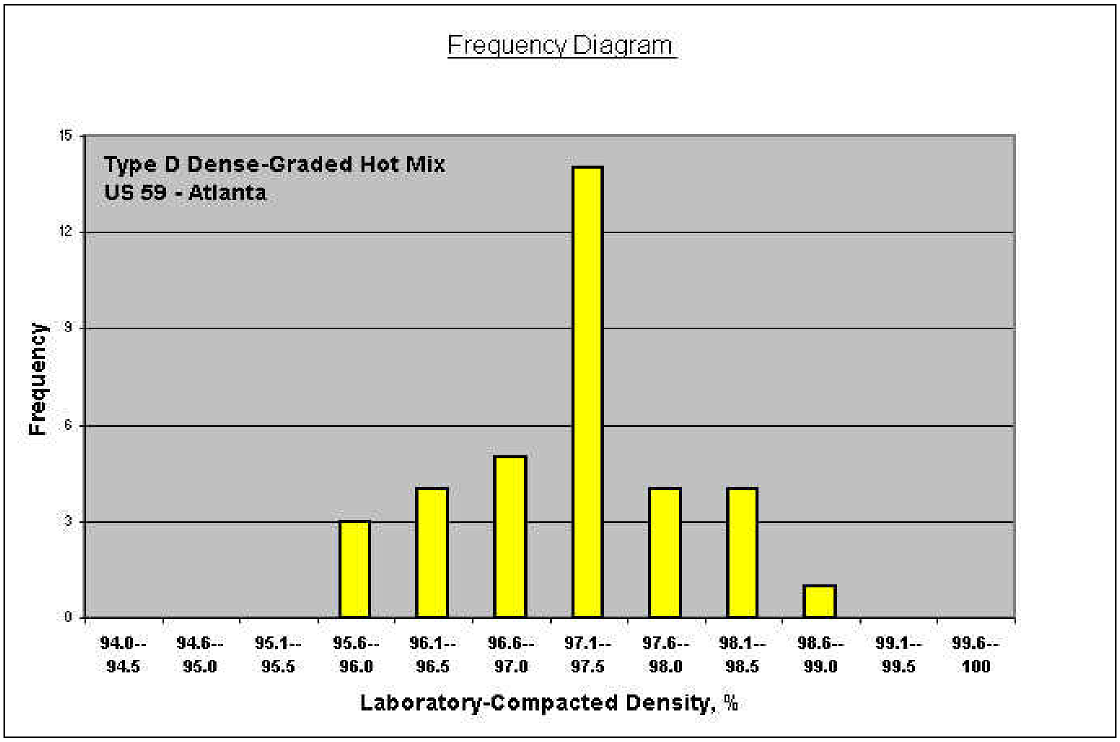


Figure 27. Frequency Diagram of Daily Laboratory-Compacted Densities - US 59, Atlanta.

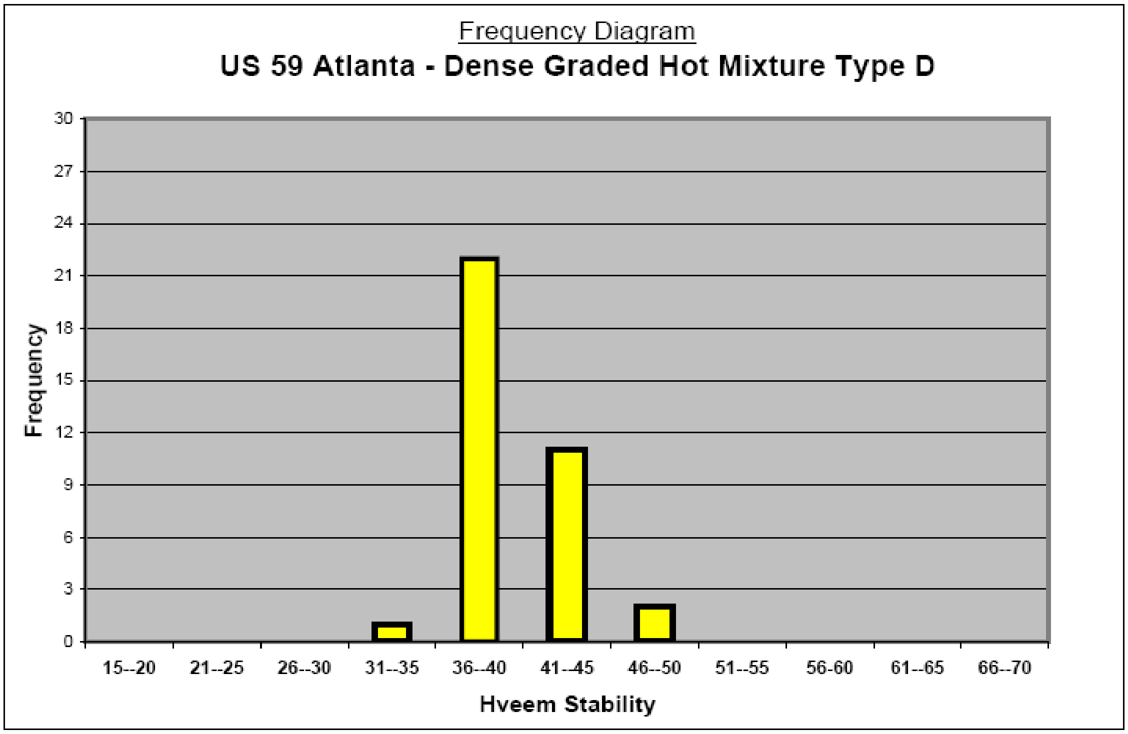


Figure 28. Frequency Diagram of Daily Hveem Stability Test Results - US 59, Atlanta.

INDIVIDUAL PAVEMENT DESCRIPTIONS AND ANALYSES

The amount and types of construction information that could be located for the selected pavements varied. Not surprisingly, the older the pavement, the less likely it was that complete construction or design information remained available in department records. Laboratory testing of aged pavement samples and on-site pavement testing provided information on all pavements included in the database.

All collected information was initially evaluated on an individual pavement basis. Each pavement included in the web site is described in the section that follows. Each description includes the type of pavement structure, some of the more pertinent laboratory test results, commentary on the in-situ pavement testing performed during this project, and a statement of probable factors contributing to the particularly successful pavement performance. In addition to the frequent mention of pavement asphalt contents and air voids, because of their bearing on cracking resistance and layer permeability and aging resistance, the percentages of fines in various layers are also mentioned. The amount of passing No. 200 sieve material is a major limiting factor to VMA and asphalt content, and the amounts of coarser aggregate contribute to stability and deformation resistance.

The detailed test data from individual pavements and graphical displays of individual project construction inspection test results, when available, are included in Appendix A on the CD-ROM.

IH 10 – Odessa District

Both the original construction of this surface treatment pavement in 1978 and the hot rubber asphalt seal coat placed in 1999 are considered extraordinary performers. When built as new location interstate in 1978, the construction plans called for a total of 11 inches of flexible base and a two-course surface treatment. These were considered to be the first stage of "staged construction." The second stage was to include 5 inches of asphalt stabilized base and 3 inches of asphalt concrete. The second stage had not been constructed as of 2007. Instead, only preventative maintenance measures have been taken, most recently being the 1999 placement of a hot rubber asphalt seal coat. Strain Brothers, Inc. was the contractor for the original pavement construction, and J. H. Strain & Sons placed the hot rubber asphalt seal coat.

The GPR colormap from the recent survey shows a uniform profile, without any anomalies, which is indicative of a good pavement structure. The back-calculated modulus for the flexible base from FWD data is 117 ksi, which is above the typical range (40-70 ksi) for this type of base. The back-calculated modulus for the subgrade is 73 ksi, which indicates a strong subgrade and reflects the presence of rock in the soil as observed during pavement sampling.

The superior performance of this pavement appears to be the combined result of good construction practice, high quality flexible base material, and the excellent local subgrade. The relatively dry climate in this area of Texas is also probably a factor. This pavement clearly demonstrates that properly designed and constructed surface treatment pavements can be used in interstate highway construction under certain climate and subgrade conditions.

IH 10 – San Angelo District

This section of pavement on IH 10 is near Junction. The originally constructed pavement section consisted of two 1 ½ inch dense-graded hot asphalt mixture layers on top of two layers of flexible base. The lower flexible base layer was specified to be grade 2 while the upper layer was specified to be grade 1. A mill and fill inlay of coarse-matrix high-binder type C (CMHB-C) was placed in 2000 to correct some areas of rutting. Overall, this 38-year old pavement has held up well.

Pavement design and construction testing and inspection records for the original construction of this IH 10 pavement section were no longer available. Pavement cores revealed that there is now 5 inches of asphalt mixture above the flexible base. Testing of the cores found 3 percent, 6 percent, and 3 percent air voids in the three asphalt mixture layers, top to bottom, when averaging all tests from each layer. The air void levels in all three layers were markedly lower in wheel path cores than in cores taken from between wheel paths. This low air void content in the wheel path is consistent with the report that the mill and inlay had been performed to correct some areas of rutting. Asphalt recovered from the top two mixture layers had penetration values in the 40s and 50s, indicating that the asphalt still has considerable life remaining.

Testing of flexible base and subgrade samples found plasticity indices (PIs) of 5 and 4, respectively. Moisture contents were found to be 4 and 13 percent, respectively. The flexible base was crushed limestone and contained 12.5 percent passing No. 200 sieve material at the point of field sampling.

The GPR colormap from the recent survey shows a uniform profile, without anomalies, which is indicative of a good pavement structure. The back-calculated modulus for the hot asphalt mix from FWD data is 760 ksi, which is within the typical range for CMHB mixes and above that for dense-grade hot mix asphalt. The back-calculated modulus for the flexible base from FWD data is 137 ksi, which is above the typical range (40-70 ksi) for this type of base. The back-calculated modulus for the subgrade is 45 ksi, which indicates a strong subgrade and reflects the presence of rock in the soil that was observed during coring.

Factors likely to contribute to performance excellence include the low PI and stiffness of the subgrade, excellent quality flexible base material, and the presence of paved shoulders to impede lateral moisture migration from the pavement edges. Considering the relatively low pavement air voids and the current life remaining in the asphalt cement, this pavement could perform very well for many more years barring an abnormally hot summer, which could possibly cause the reappearance of rutting.

IH 20W – Atlanta District

This section of IH 20 is the westbound roadbed beginning at the Louisiana state line and extending to US 80. The pavement layers of interest are the two dense-graded asphalt concrete mixtures overlaying an existing continuously reinforced concrete pavement. The Type C surface course includes latex-rubber asphalt modification. Pipe edge drains were installed in 1996 at the time of overlay placement.

Construction records indicate that both asphalt mixtures were composed of limestone from Bridgeport area quarries, included liquid antistripping agent, averaged Hveem stabilities in the high 50s, and the surface course included 3 percent latex rubber. Construction in-place air voids averaged 6.9 percent for the Type C surface course. No air void data were available for the underlying Type B layer.

Extraction testing of aged pavement cores from the Type C surface course found an average asphalt content of 4.2 percent, a passing No. 10 sieve average of 31.9 percent, and a passing No. 200 sieve average of 3.4 percent. The average air void content in the Type C pavement layer was 5.1 percent after approximately 10 years of service.

Extraction testing of the underlying Type B aged pavement layer found the asphalt content to average 3.4 percent, the passing No. 10 sieve to average 33.1 percent, and the passing No. 200

sieve to average 4.2 percent. The average air void content found in the Type B course was 5.3 percent.

The GPR colormap from the recent survey shows a uniform profile, without anomalies, which is indicative of a good pavement. The back-calculated modulus for the hot asphalt mix from FWD data is 456 ksi, which is within the typical rage for dense-graded hot mix asphalt layers. The back-calculated modulus for the reinforced concrete pavement is 4,432 ksi, which is within the typical range (2000 – 7000 ksi) for this type of layer. The back-calculated modulus for the subgrade is 25 ksi, which is an indication of a good subgrade.

Factors contributing to the superior performance of this concrete pavement overlay appear to include the use of high quality materials, an abnormally high stability mixture, and the use of latex-rubber asphalt to maintain a degree of crack resistance in an otherwise tough, rut-resistant mixture. The placement of an AC-15-5TR lightweight grade 4 single surface treatment between the two mixture layers may also be playing an important role in maintaining adequate pavement flexibility and crack resistance. Lastly, the use of pavement edge drains to facilitate moisture drainage from the pavement should be mentioned as a possible factor contributing to superior performance.

IH 30 – Atlanta District

This section of IH 30 is between the Arkansas state line and FM 989. The pavement layer of interest is the dense-graded asphalt concrete overlay that was placed in 1996 over an existing asphalt concrete overlay and continuously reinforced concrete pavement. The 1996 overlay is Type C and includes crushed gravel aggregate, lime, and latex-rubber asphalt modification.

Construction records indicate the asphalt overlay was composed of siliceous aggregate, included 1.5 percent lime antistripping agent, averaged Hveem stability of 44 percent for the project, and included 3 percent latex-rubber. Construction in-place air voids averaged a rather high 9.6 percent. A grade 4 lightweight surface treatment was placed under the new overlay. The surface treatment asphalt contained 5 percent tire rubber.

Extraction testing of aged pavement cores from the Type C overlay found an average asphalt content of 5.7 percent, a passing No. 10 sieve average of 34.0 percent, and a passing

No. 200 sieve average of 4.8 percent. The average air void content in the Type C pavement layer was 3.9 percent after approximately 10 years of service.

The GPR colormap from the recent survey shows a uniform profile, without anomalies, which is indicative of a good pavement. FWD testing was not conducted in this section since the underlying layer was continuously reinforced Portland cement concrete.

Factors contributing to the superior performance of this overlay appear to include the use of high quality materials and the use of latex-rubber asphalt to maintain an additional degree of crack resistance. The placement of the lightweight grade 4 single surface treatment below the Type C overlay may also play an important role in maintaining adequate pavement flexibility and crack resistance.

BIH 35 – Fort Worth District

This pavement is the business route for IH 35 through the small town of Alvarado, Texas. The pavement structure of interest is the stone-matrix asphalt (SMA) overlay of existing asphalt mixture and jointed concrete pavement. One-inch of the existing asphalt concrete surface was planed prior to placing the SMA overlay. This project was the first placement of SMA paving mixture in Texas. David Bass, the Fort Worth District Laboratory Engineer, and Carl Utley, the Fort Worth District Construction Engineer, showed early interest in SMA and were instrumental in bringing this new mixture type to Texas. Joe Fossett was the area engineer. The SMA mixture produced on this project was also placed on a rural portion of SH 171, overlaying existing asphalt mixture and flexible base.

Construction records no longer exist for this pavement. However, the research supervisor on this project was employed by TxDOT and was involved with this project in 1992. It is recalled that the SMA mixture is composed of limestone aggregate, agricultural lime mineral filler, latex-rubber modified asphalt cement, and cellulose fiber.

Cores taken at each end of the project revealed an additional inch of existing asphalt concrete above the concrete pavement at one end of the project.

Laboratory testing of the cores taken from the aged pavement found the SMA asphalt content to average 6.4 percent, the passing No. 8 sieve to average 24.6 percent, and the passing No. 200 sieve to average 11.3 percent. The average SMA pavement air void content was 3.7 percent.

The GPR colormap from the recent survey shows a uniform profile, without anomalies, which is an indication of a good pavement. FWD testing was conducted but the back-calculated modulus values are not reliable because of the thin SMA (1.5 inch) and HMA (1.75 inch) layers on top of the thick jointed concrete pavement (15.5 inch).

Factors influencing the excellent performance of this pavement are believed to be the air void level, which would serve to limit water penetration and slow asphalt oxidation; the relatively high asphalt content compared to that used in dense-graded mixtures produced in 1992; the lack of any sign of moisture damage in the existing and SMA pavement layers; and the stone skeleton of the SMA mixture design providing good rut resistance.

US 59 – Atlanta District

This section of US 59 is between FM 2517 and FM 999 just south of Carthage, Texas. The expansion of this roadway to four lanes and two roadbeds was completed in 1989. The pavement structure is somewhat unique in that it includes 16 inches of lime-fly ash stabilized subgrade. That was followed by three layers of Type C asphalt concrete, totaling 8.5 inches in thickness, and then 2 inches of Type D asphalt concrete on the surface.

Construction records indicate that both asphalt mixtures were composed of siliceous aggregate, included liquid antistripping agent in the AC-20 asphalt cement, and averaged Hveem stabilities in the low 40s. The surface course included a premium liquid antistripping agent, while the underlying layers included a standard grade agent. Construction in-place air voids averaged 6.6 percent for the Type D surface course and 6.1 percent for the Type C pavement layers.

Extraction testing of aged pavement cores from the Type D surface course found an average asphalt content of 4.4 percent, having a penetration value of 40; a passing No. 10 sieve average of 33.1 percent; and a passing No. 200 sieve average of 4.4 percent. The average air void content in the Type D pavement layer was found to average 9.6 percent at the two coring locations after approximately 10 years of service. This is significantly more than the average air void test results during construction and may not be representative of the majority of the current pavement length.

Extraction testing of the underlying Type C aged pavement layer found the asphalt content to also average 4.4 percent, the passing No. 10 to average 35.9 percent, and the passing No. 200 sieve to average 9.8 percent. The pavement air void content could not be determined for the Type C layers because of apparent stripping in the uppermost Type C layer.

The GPR colormap from the recent survey shows a uniform profile except for a short length at the end of the section that indicates moisture presence in the uppermost asphalt layer. The back-calculated modulus for the hot asphalt mix from FWD data is 210 ksi, while the back-calculated modulus for the fly ash stabilized subgrade is 242 ksi.

Factors contributing to the ongoing performance of this flexible pavement appear to include substantial pavement design, including lime-fly ash stabilized subgrade and a deep asphalt pavement section. The moisture damage in the uppermost layer of the Type C paving material may warrant additional investigation even though it is not affecting performance at this time. The use of standard grade liquid antistripping agent in the Type C layers may be a factor in the degree of stripping occurring.

US 67 – Brownwood District

This pavement section runs through the small town of Bangs. The pavement structure is composed of 1.5 inches of dense-graded hot asphalt mixture over 4.5 inches of asphalt stabilized base over 6 inches of flexible base. The Brown County Area Office was responsible for design and project inspection, and Charles W. Heald was the area engineer. The district engineer was Lawrence Schulz. This pavement replaced an old stone Macadam pavement which had three inches of hot mix on the surface.

A review of construction inspection testing records showed that the average in-place air voids of the surface paving mixture was 4.6 percent and the average density achieved in the flexible base was 101.4 percent.

Aged pavement testing found the air void content of the surface paving mixture to be 3.4 percent and the air void content of the asphalt stabilized base to be 1.0 percent at the point of field sampling. Penetration tests of recovered asphalt found the surface course asphalt too soft for a penetration test and the asphalt stabilized base asphalt to be 184. It is surmised that the pavement at the point of sampling may have been contaminated in some manner.

The flexible base and the subgrade were sampled and tested and found to have PIs of 10 and 6, respectively. Field moisture contents were 3 and 10 percent, respectively. The flexible base was crushed limestone and averaged 4.7 percent passing the No. 200 sieve at the locations of field sampling.

The GPR colormap from the recent survey shows a uniform profile except for a short length at the end of the section that indicates potential presence of moisture at the interface between the surface treatment and the asphalt stabilized base. The back-calculated modulus for the asphalt stabilized base from FWD data is 560 ksi, which is above the typical range for asphalt treated bases (250 – 400 ksi). The back-calculated modulus for the flexible base is 139 ksi, which is also above the typical range (40 – 70 ksi) for this type of layer. The back-calculated modulus for the subgrade is 39 ksi, which is indicative of good subgrade.

Factors likely to be contributing to performance excellence include high quality flexible base material, quality construction, the robust pavement structure, and good protection of the base from moisture intrusion resulting from low air void contents in both pavement mixture layers.

US 190 – Brownwood District

This flexible base and surface treatment pavement is somewhat unique in that it was constructed on top of an existing asphalt concrete pavement. The plans called for 8 inches of flexible base to be placed on top of the existing pavement, followed by two single surface treatments. The McCulloch County Area Office was responsible for design and project inspection of this rural pavement section. Ben E. Dillon was the area engineer. The district engineer was Lawrence Schulz. The plan notes required that asphalt surface treatment spray nozzles over the wheel paths be one size smaller than the rest of the nozzles. There was no evidence of wheel path flushing noted during site visits.

A review of construction testing records showed that the average density achieved in the flexible base was 106.0 percent. It is likely that the underlying pavement structure provided greater resistance than is normally available under a flexible base during construction and thereby allowed particularly effective compaction of the new flexible base.

Pavement cores indicated that two or perhaps three preventative maintenance seal coats have been placed since pavement construction in 1977. The area office reported that the last seal coat was placed in 2000. The cores also indicated excellent prime coat penetration into the flexible base.

The upper flexible base, lower existing flexible base, and the subgrade were sampled and tested and found to have PIs of 7, 15, and 29, respectively. Moisture contents were 6, 9 and 28 percent, respectively. The upper flexible base was crushed limestone and had 6.5 percent passing the No. 200 sieve at the location of field sampling. The lower, original flexible base was also crushed limestone and had 4.6 percent passing the No. 200 sieve at the location of field sampling.

The GPR colormap from the recent survey shows a uniform profile except for a short length at the end of the section that indicates potential presence of moisture at the interface between the 2–inch asphalt concrete beneath the 4” flexible base. The back-calculated modulus for the subgrade is 29 ksi, which is an indication of a good subgrade.

Factors likely to be contributing to performance excellence include high quality flexible base material, the presence of the underlying asphalt mixture layer, quality in construction, and timely preventative maintenance over the decades, resulting in approximately an inch of asphalt-rich and impervious asphalt surfacing.

US 287 – Lufkin District

This section of US 287 is between the city of Groveton and the Polk County line. This pavement structure is somewhat unique in this district in that it includes asphalt stabilized base. Further, the 8 inches of base is a sand-asphalt used from time to time in the Lufkin District during this time. The asphalt stabilized base layer is covered with a little over 1 inch of dense-graded asphalt surface course. Constructed in 1969, this pavement has required minimal maintenance while holding up very well carrying the logging traffic in the area for over 35 years.

Construction records no longer exist for this pavement. Cores taken from the aged pavement were laboratory tested to determine possible contributors to the successful performance of this pavement.

Extraction testing of the cores from the originally placed Type D surface course found an average asphalt content of 4.2 percent. The recovered asphalt cement was extremely hard, registering a penetration value of 0. The passing No. 10 sieve amount averaged 38.1 percent, and the passing No. 200 sieve averaged 6.5 percent. The average air void content in this Type D pavement layer was 8.7 percent. This layer was found to be stripping in some of the coring locations.

Testing of the underlying asphalt stabilized base, a sand-asphalt mixture, found the asphalt content to average 5.5 percent and have a penetration value of 43. The average air void content found in this sand-asphalt base was 16.4 percent.

The GPR colormap from the recent survey shows a uniform profile, without anomalies, which is indicative of a good pavement. The back-calculated modulus for the hot asphalt mix layer from FWD data is 760 ksi, which is above normally expected modulus values for dense hot mix asphalt layers. The back-calculated modulus for the asphalt stabilized layer is 64 ksi, which is below typical values for this type of layer. These results are influenced by the thickness of the layers and should be considered as indicative of a robust overall pavement structure rather than as individual, isolated values. The back-calculated modulus is 45 ksi for the subbase and 10 ksi for the subgrade.

No core test results particularly stand out as obvious contributors to the long and successful performance of this pavement. It is theorized that the use of sand-asphalt base, which allowed a considerably greater depth of asphalt stabilization than normal, provided additional strength as well as moisture protection of underlying layers.

US 377 – San Angelo District

This section was built in about 1949 when Kimble County was part of the old Del Rio District. The resident engineer was M. N. Blakaney, and the district engineer was J. A. Waller. While this pavement structure benefits from good quality subgrade, this section of pavement has outperformed similar pavements in this area of the state.

No construction testing or pavement design records were still available for this pavement. The plans were based upon 1938 Texas Highway Department standard specifications. The plans called for 3 inches of flexible base, and 4.5 inches was found during field sampling. That was the entire pavement structure under a two-course surface treatment.

While the subgrade was found to be rocky, bedrock was not reached at the three foot sampling depth at either location that was sampled. The PI of the subgrade was 14 and the field moisture content was 10 percent. The flexible base layer was found to have a PI of 11 and a moisture content of 6 percent. The flexible base gradation had 11 percent passing the No. 200 sieve.

The GPR colormap from the recent survey shows a uniform profile. The back-calculated. modulus for the flexible base layer is 110 ksi, which is higher than typical values for this type of layer. The back-calculated modulus for the subgrade is 15 ksi, which is considered good.

Considering the thin pavement structure, a primary factor contributing to performance excellence is the very stable subgrade conditions in the area. Other factors are probably quality flexible base material, quality in construction, and timely preventative maintenance over the decades.

US 380 – Abilene District

This section of US 380 is between the cities of Rule and Haskell. The current pavement structure is the reconstruction of old SH 24 which was completed in 1966. The pavement structure includes a 4-inch foundation course followed by 8 inches of flexible base. The wearing surface placed in 1966 was a two course surface treatment. This pavement has required little maintenance over the decades. It carries several hundred trucks per day.

Pavement design and construction testing and inspection records no longer exist for this pavement. However, the area engineer contacted the retired inspector for the project, who recalled that they had processed the flexible base very wet of its optimum. This was a common and successful practice at that time.

Pavement cores indicated that four or perhaps five preventative maintenance seal coats have been placed since pavement construction in 1966. The area office reported that the last seal coat was placed in 2004 and was grade 3 precoated limestone and AC-15-5TR.

Testing of flexible base and subgrade samples found PIs of 9 and 24, respectively. Moisture contents were 6 and 14 percent, respectively. The flexible base was crushed limestone and banded calcite and had a low percentage passing the No. 200 sieve.

The GPR colormap from the recent survey shows a uniform profile. The back-calculated. modulus for the flexible base layer is 99 ksi, which is higher than typical values for this type of layer. The back-calculated modulus for the subgrade is 17 ksi, which is considered good.

Factors likely to be contributing to performance excellence include high quality flexible base material, quality in construction, and timely preventative maintenance over the decades, resulting in approximately 1.5 inches of asphalt-rich and impervious asphalt surfacing.

US 385 – Odessa District

This pavement demonstrates the excellent performance that is obtainable using rubber asphalt for pavement rehabilitation. The rehabilitation of US 385 included an asphalt-rubber seal coat followed by 1 ¾ inches of crumb-rubber asphalt concrete mixture. This pavement is in outstanding condition after nine years, and it has won a National Quality Award. It was one of the best appearing pavements seen by the research team even though it had not yet received a preventative maintenance surface treatment. This project was designed and constructed by the Odessa Area Office. Dan Dalager was the area engineer.

The GPR colormap from the recent survey shows a uniform profile, without anomalies, which is indicative of a good pavement. The back-calculated modulus for the flexible base layer is 111 ksi, which is a little higher than typical values for this type of layer. The back-calculated modulus for the subgrade is 32 ksi, which is an indication of good subgrade.

This pavement appears to owe its length of distress-free service in large measure to its high content of asphalt-rubber binder. The CMHB-F mixture design VMA was 20.8, creating an optimum asphalt-rubber content of 8.3 percent at 97 percent design density. The paving mixture also averaged a low 20.2 percent passing No. 10 sieve aggregate during production, creating exceptional stone-on-stone contact. This heavy asphalt content would provide increased resistance to oxidative aging and pavement cracking, while the stone skeleton would provide strength. Another factor is believed to be the impervious layer of surface treatments, including an asphalt-rubber surface treatment, immediately below the CMHB-F pavement layer. The flexible base and subgrade are exceptionally well-protected from moisture intrusion. A final note concerning this pavement is its extraordinarily smooth ride for a pavement of this age, with a 2006 average IRI of 58 and a ride score of 4.5.

SH 21E – Bryan District

This pavement is in the eastbound direction of SH 21 near the Texas A&M University Riverside Campus in Brazos County. It was constructed by Young Brothers Construction Company (now Knife River YCI) in 1991 and 1992 when this facility was expanded to become a four-lane, divided highway. The pavement structure is composed of 8 inches of lime stabilized subgrade, 15 inches of flexible base, a two-course surface treatment, 1.5 inches of Type D dense-graded mixture, and 1.5 inches of CMHB surface course. The Bryan Area Office was responsible for construction inspection. Only preventative maintenance has been required since construction.

Construction records no longer exist for this pavement. Laboratory testing of the cores taken from the aged pavement found the CMHB asphalt content to average 6.8 percent and have a penetration value of 36, the passing No. 10 sieve to average 25.7 percent, and the passing No. 200 sieve to average 9.9 percent. The average air void content in the aged CMHB pavement layer was 2.6 percent. Testing of the underlying Type D aged pavement layer found the asphalt content to average 7.0 percent and have a penetration value of 41, the passing No. 10 to average 39.0 percent, and the passing No. 200 sieve to average 7.0 percent. The average air void content found in the Type D cores was 3.6 percent.

The GPR colormap from the recent survey shows a uniform profile except for a short length at the end of the section that indicates potential presence of moisture in the interface between the 2.2-inch dense-graded hot mix layer and the flexible base. The back-calculated modulus for the CMHB layer from FWD data is 868 ksi, which is slightly above the typical range for this type of material (650 – 850 ksi). The back-calculated modulus for the flexible base layer is 52 ksi, which is within the range of typical values (40 – 70 ksi) for this type of layer. The back-calculated modulus for the stabilized subgrade is 219 ksi, which is above typical modulus values for this type of layer. The back-calculated modulus for the subgrade is very low, 2 ksi, but this value can not be interpreted independently from the overall analysis, which indicates a sound pavement structure.

Factors influencing the superior performance of this pavement are believed to be the high optimum asphalt contents of the mixture designs and excellent pavement air void levels found in both of the mixture layers. These factors would together limit water penetration and slow asphalt oxidation, as indicated by the penetration values of recovered asphalt samples. The stone skeleton of the CMHB mixture design is undoubtedly a factor in providing long term rut resistance. The result was an almost impervious pavement that would maintain flexibility over an extended period of time and yet have good resistance to rutting.

SH 121 – Fort Worth District

This 2 inch thickness of Type D asphalt concrete overlay was located on SH 121 between Loop 820 and SH 183. It was placed in 1986 and removed after lengthy successful performance, at about the time of its nomination by the district. The underlying pavement is continuously reinforced concrete. The asphalt overlay mixture contained 3 percent latex-rubber. A fabric underseal with AC-10 had been placed between the concrete pavement and the overlay. The area engineer on this project was Robert Julian, and the district engineer was J. R. Stone.

Construction inspection and testing records for this pavement were no longer available. Although the overlay had been removed, the research team was provided a set of cores taken by the Fort Worth district just prior to its removal. These were tested by the research team to determine factors likely to be contributing to the overlay's successful and lengthy performance.

Visual inspection of the cores found the Type D asphalt concrete to be a lightweight synthetic aggregate mixture. It was also noted that the fabric underseal on the bottom of the cores appears to have plenty of asphalt cement to render it completely impermeable.

Ignition testing of the cores found 8.5 percent by weight asphalt cement, 7.4 percent passing the No. 200 sieve, and 41.7 percent passing the No. 10 sieve. The average percent air voids was 3.8 percent after nearly 20 years of service.

The GPR colormap from the recent survey shows a uniform profile without any anomalies. FWD testing was not conducted on this section since the underlying layer was continuously reinforced Portland cement concrete.

Factors appearing to contribute to the superior performance obtained from this concrete pavement overlay are the substantial optimum asphalt content of the mixture design, providing resistance to cracking and oxidative aging; the latex additive, providing resistance to reflective cracking from the concrete below; and the presence of an excellent underseal.

SH 152 – Amarillo District

This section of SH 152 is between the City of Borger and the Carson County Line. The existing roadway was reworked in 1995 and placed again as 10 inches of fly ash treated flexible base. The new surface course was 1.25 inches of dense-graded asphalt concrete. The district reports that the 11 year-old pavement has required no maintenance except for a seal coat in 2005. The geography in the area is hilly, with the pavement being constructed over a series of cuts and fills. The total lack of need for crack sealing and pothole repairs makes this pavement stand out in performance.

The GPR colormap from the recent survey shows a uniform profile, without anomalies, which is indicative of a good pavement. The back-calculated modulus for the fly ash stabilized layer is 116 ksi, which is above typical values for this type of layer (60 – 75 ksi). The back-calculated modulus for the subgrade is 18 ksi.

The superior performance of this pavement appears to be the result of a combination of factors, including quality in design and construction, good strength in the fly ash stabilized base, and excellent base protection from moisture penetration. Moisture penetration protection is provided by both the Type D asphalt surface mixture and the underseal placed below it. Excellence in mixture design and construction practice is evidenced by the ideal average air void level of 3 percent found in the aged surface course.

SH 171 – Fort Worth District

This pavement section and a section of BIH-35 in Alvarado are the first sections of stone-matrix asphalt (SMA) placed in the State of Texas. While the Alvarado section placed SMA over concrete pavement, this SH 171 section placed 1.25 inches of SMA over an existing 10 inches of cement-treated flexible base. David Bass, the Fort Worth District Laboratory Engineer, and Carl Utley, the Fort Worth District Construction Engineer, showed early interest in SMA and were instrumental in bringing this new paving mixture type to Texas. Joe Fossett was the area engineer.

Construction records no longer exist for this pavement. However, the research supervisor was employed by TxDOT and was involved with this project in 1992. It is recalled that the SMA mixture is composed of limestone aggregate, agricultural lime mineral filler, latex-rubber modified asphalt cement, and cellulose fiber.

Laboratory testing of the cores taken from the aged pavement found the SMA asphalt content to average 7.8 percent, the passing No. 8 sieve to average only 18.7 percent, and the passing No. 200 sieve to average 9.2 percent. The average air void content was 3.9 percent after 14 years of service. The subgrade PI was found to be 5.

The GPR colormap from the recent survey shows a uniform profile. The back-calculated modulus for the SMA layer from FWD data is 511 ksi, which is typical for this type of material (500 ksi). The back-calculated modulus for the cement-treated base is 210 ksi, which is typical for this type of layer. The back-calculated modulus for the subgrade is 20 ksi, which is considered good.

Factors influencing the excellent performance of this pavement are believed to be the high optimum asphalt content of the SMA mixture design and the relatively low pavement air void level, which would together serve to limit water penetration and slow asphalt oxidation; a strong base layer; low PI subgrade; and the stone skeleton of the SMA mixture design providing good resistance to rutting.

SH 176 – Odessa District

The nominated pavement overlay is on a rural stretch of SH 176 leading up to the New Mexico state line. Placed in 1997, this two-inch CMHB-F overlay was one of the first latex-modified asphalt projects in this district. The asphalt was believed to have been produced from

Brazilian crude by Koch Asphalt Materials. The underlying pavement had 1.5 inches of dense-graded mixture over 8.5 inches of flexible base.

The CMHB-F mixture design gradation provided a VMA of 18, well above the required 15, and demanded 6.9 percent design asphalt content. The asphalt content dropped off very little during construction, averaging 6.6 percent for the project according to the construction inspection records which were obtained.

While CMHB-F construction test results averaged 7.5 percent pavement air voids, aged pavement cores found that traffic compaction had reduced pavement air voids to an average of 2.6 percent, with very little variation between that found in wheel paths and between wheel paths. In addition, the air void level found in the asphalt mixture layer that had been overlaid in 1997 was 3.8 percent air voids, also near ideal for pavement longevity.

Testing of flexible base and subgrade samples found PIs of 16 and 8, respectively. The flexible base was a combination of limestone and caliche.

The GPR colormap from the recent survey shows a uniform profile. The back-calculated modulus for the asphalt layers from FWD data is 277 ksi, which is considered low. It is possible that the back-calculation analysis may be influenced by the presence of the 1-inch layer of multiple surface treatments between the 1.8 inches of CMHB and the 1.8 inches of dense-graded hot mix layer. The back-calculated modulus for flexible base is 98 ksi, which is above typical values for this type of layer. The back-calculated modulus for the subgrade is 12 ksi.

Factors likely to contribute to performance excellence include the ideal level of air voids in both of the asphalt mixture layers, the high optimum asphalt content of the CMHB-F mixture, latex modification of the asphalt cement, the low PI subgrade, and the presence of paved shoulders to impede lateral moisture migration from the pavement edges.

SH 183 – Fort Worth District

This relatively short section of SH 183 in Tarrant County runs between US 80 and IH 30 on the west side of the city of Fort Worth. Construction was completed in 1987, at which time the existing ACP overlay was removed, a new 8-inch CRCP was placed under the outside lane, and both lanes of concrete pavement were overlaid with a fabric underseal and 2 inches of a fine, dense-graded asphalt concrete surface course. The asphalt concrete contained 3 percent latex-rubber. Harold Oppermann was the area engineer for this project. The district engineer was J. R. Stone.

Construction inspection and testing records for this pavement were no longer available. Visual inspection of the cores found the Type D asphalt concrete to be a crushed stone aggregate mixture. It was also noted that the fabric underseal on the bottom of the cores appears to be well-bonded and has plenty of asphalt cement to render it completely impermeable.

Ignition testing of the cores found 6.2 percent asphalt cement, 5.1 percent passing the No. 200 sieve, and 35.7 percent passing the No. 10 sieve. The average percent air voids was 7.3 percent after nearly 20 years of service, which is higher than normally expected.

The GPR colormap from the recent survey shows a uniform profile, without anomalies. FWD testing was not conducted on this section since the underlying layer was continuously reinforced Portland cement concrete.

Factors appearing to contribute to the superior performance obtained from this concrete pavement overlay are the rather high optimum asphalt content, providing resistance to cracking and oxidative aging; the latex additive, providing resistance to reflective cracking from the concrete below; and the presence of a good underseal.

FM 1472 – Laredo District

This pavement carries extremely heavy truck traffic due to proximity to a large warehousing area and an international border crossing on the outskirts of the City of Laredo. It has required lane expansion and structural capacity increases on numerous occasions over the past 20 years. The two-inch Superpave overlay was placed in 2001 over a pavement composed of 5 inches of dense-graded asphalt mixture, 12 inches of flexible base, and 8 inches of lime stabilized subgrade. The overlay has withstood the extreme truck traffic and high temperature environment very well.

The Superpave mixture design showed a VMA of 17.5, well above the specified 15 percent minimum. The optimum asphalt content was shown to be 5.2 percent. Construction records indicate that the asphalt content during construction averaged 5.2 percent, right on the mixture design amount. Tests of aged pavement cores found 5.4 percent asphalt content. The closeness of these results is an indication of quality in plant production and construction.

Construction test results averaged 6.6 percent pavement air voids. The several locations which were cored during this study averaged 7.3 percent air voids. This indicates that the mixture is abnormally resistant to increased densification under traffic. The openness and toughness of this mixture, after six years of extremely heavy truck traffic, is indication that the design asphalt content may have been somewhat under the ideal optimum for the gradation being provided. However, while this layer is likely to be somewhat pervious, that characteristic may be of minimal importance considering the dryness of the local climate. The long term resistance of the pavement to cracking, stemming in part from oxidative hardening of the asphalt cement, remains to be seen.

The GPR colormap from the recent survey shows a uniform profile. The back-calculated modulus for the asphalt layer from FWD data is 1,033 ksi, which is very high when compared to typical modulus values. The back-calculated modulus for the flexible base is 105 ksi, which is also above typical values for this type of layer. The back-calculated modulus for the lime-stabilized sub-base is 221 ksi, which is above typical modulus values for this type of layer. The back-calculated modulus for the subgrade is 31 ksi.

Factors likely to be contributing to performance excellence include the toughness of the pavement mixture, stemming from the stone on stone contact provided by the Superpave mixture design, and quality in construction.

FM 1585 – Lubbock District

This section of FM 1585 is between US 87 and US 84 just south of the City of Lubbock. It has been in service since reconstruction in 1986. The pavement structure includes the use of salvaged flexible base from the old pavement, followed by 5.5 inches of new flexible base. The pavement was surfaced with a two-course surface treatment when reconstructed.

As an older pavement, pavement design and construction testing and inspection records were no longer available. Pavement cores indicate that only two preventative maintenance seal coats have been placed since original construction. District maintenance records show that an AC-20-5TR seal coat was placed in 2005.

Testing of flexible base and subgrade samples found PIs of 20 and 10, respectively. Moisture contents were found to be 6 and 10 percent, respectively. The flexible base was caliche. The lower PI of the subgrade appears due to its sandy composition.

The GPR colormap from the recent survey shows a uniform profile. The back-calculated modulus from FWD data for the flexible base is 47 ksi, which is within the range of typical modulus values for this type of layer (40-70 ksi). The back-calculated modulus for the subgrade is 15 ksi.

Factors likely to contribute to performance excellence include the low PI subgrade, quality in construction, and the presence of paved shoulders to impede lateral moisture migration from the pavement edges.

FM 2771 – San Antonio District

This thin rural pavement has performed extraordinarily well for over 40 years. The 6-inch flexible base was treated with EA-HVMS prior to placement of the one-course surface treatment.

Pavement design and construction testing and inspection records no longer exist. Pavement cores indicated that about a half dozen preventative maintenance seal coats have been placed since construction. The area office reported that the last seal coat was placed in 2002.

Testing of flexible base and subgrade samples found PIs to be 7 for both materials. Moisture contents were 4 and 10 percent, respectively. The flexible base was predominantly crushed limestone river gravel and had only 4 percent passing the No. 200 sieve at the location sampled.

The GPR colormap from the recent survey shows a uniform profile. The back-calculated modulus from FWD data for the flexible base is 57 ksi, which is within the range of typical modulus values for this type of layer (40-70 ksi). The back-calculated modulus for the subgrade is 12 ksi.

Factors likely to contribute to performance excellence include high quality flexible base material, quality in construction, stable subgrade, and timely preventative maintenance over the decades, resulting in approximately 1.5 inches of asphalt-rich and impervious asphalt surfacing.

FM 2828 – San Antonio District

This thin rural pavement has performed extraordinarily well for over 37 years. It is composed of approximately 6 inches of flexible base and was originally surfaced with a two course surface treatment. The surface of the flexible base was treated with EA-HVMS prior to placement of the two-course surface treatment.

Being constructed in 1969, pavement design and construction testing and inspection records no longer exist. Pavement cores indicated that three or four preventative maintenance seal coats have been placed since construction. The area office reported that the last seal coat was placed in 2003.

Testing of flexible base and subgrade samples found PIs of 11 and 10, respectively. Moisture contents were 5 and 16 percent, respectively. The flexible base was crushed limestone river gravel and had only 5 percent passing the No. 200 sieve at the location sampled.

The GPR colormap from the recent survey shows a uniform profile. The back-calculated modulus from FWD data for the flexible base is 47 ksi, which is within the range of typical modulus values for this type of layer (40-70 ksi). The back-calculated modulus for the subgrade is 18 ksi.

Factors likely to contribute to performance excellence include high quality flexible base material, quality in construction, and timely preventative maintenance over the years, resulting in approximately 1.25 inches of asphalt-rich and impervious asphalt surfacing.

FM 3223 – Waco District

This section of FM 3223 serves the industrial area of Waco. Truck traffic is moderate to heavy, with considerable stopping, starting, and turning at several signalized intersections. The 1.25 inches of Type D overlay placed in 1992 has performed far beyond normal expectations under these traffic conditions. It was placed over an existing 1.25 inch thick dense-graded mixture and 10 inches of flexible base.

Construction records no longer exist for this pavement. Laboratory testing of the cores taken from the aged pavement found the Type D overlay asphalt content to average 5.7 percent with a penetration value of 56, the passing No. 10 sieve to average 45.6 percent, and the passing No. 200 sieve to average a low 1.6 percent. The average air void content in the aged overlay was 4.8 percent.

The older, underlying pavement layer was also cored and tested. It was found to be a Type D mixture with 5.4 percent asphalt content, and the asphalt was still at a surprisingly good penetration value of 61.

The relatively high asphalt content, apparently made possible by the low amount of passing No. 200 sieve aggregate in the mixture, appears to be a factor influencing the superior performance of this pavement overlay. Beyond the uncharacteristically low passing No. 200 percentage and healthy asphalt content, this pavement layer appears pretty average.

The GPR colormap from the recent survey shows a uniform profile. The back-calculated modulus for the flexible base is 39 ksi, which is slightly below the lower limit of expected modulus values for this type of layer (40-70 ksi). The back-calculated modulus for the subgrade is 15 ksi.

Timely maintenance sealing over the years is likely also a factor in this pavement's resistance to oxidative hardening of the asphalt cement. However, for whatever the reasons it has occurred, the lack of oxidation of the asphalt cement and the pavement's successful resistance to rutting bode well for continued service despite the overlay's 16 year age.

FM 3492 – Wichita Falls District

In 1996, the existing flexible pavement was reworked, spread to cover the expanded roadway width, and compacted to form a 2-inch flexible base layer. Ten inches of new flexible base and a two-course surface treatment followed. This reconstructed rural pavement section was designed and constructed by the Wichita Falls Area Office.

Construction testing and inspection records were no longer available for this pavement. District maintenance records show that a preventative maintenance seal coat was placed in 2001.

Testing of flexible base and subgrade samples found PIs of 11 and 12, respectively. Moisture contents were found to be 4 and 10 percent, respectively. The flexible base was crushed fossiliferous limestone and contained less than 5 percent passing No. 200 sieve material at the location of field sampling.

The GPR colormap from the recent survey shows a uniform profile. The back-calculated modulus from FWD data for the flexible base is 48 ksi, which is within the range of typical modulus values for this type of layer (40-70 ksi). The back-calculated modulus for the subgrade is 9 ksi.

Factors likely to contribute to performance excellence include high quality flexible base material, quality in construction, and timely preventative maintenance.

SH 6 – Houston District

This section of SH 6 is located immediately north of Hempstead. It was constructed in 1985 in the process of expanding the highway to a divided four-lane facility. The new roadbed is composed of two 1.5 inch dense-graded mixture layers above 12 inches of asphalt stabilized base above 6 inches of flexible base. This new roadbed has performed exceptionally well. A single surface treatment and porous friction course were placed in 2005 to restore skid properties.

Construction records no longer exist for this pavement. Cores taken from the aged pavement were laboratory tested to determine possible contributors to the successful performance of this pavement.

Extraction testing of the cores from the top layer of Type D asphalt concrete found an average asphalt content of 5.7 percent and a penetration value for the recovered asphalt of 64. The passing No. 10 sieve amount averaged 34.9 percent, and the passing No. 200 sieve averaged 3.3 percent. The average air void content in the upper Type D pavement layer was 6.4 percent.

Testing of the underlying Type D aged pavement layer found the asphalt content to average 5.1 percent and have a penetration value of 111, the passing No. 10 to average 45.9 percent, and the passing No. 200 sieve to average 4.4 percent. The average air void content found in the Type D lower course was 6.6 percent.

The asphalt stabilized base had an asphalt content of 4.3 percent, and the penetration value of the recovered asphalt was 84.

The GPR colormap from the recent survey shows a uniform profile. A blue trace was noted at a depth of approximately six inches, which coincides with the depth where the cores tended to break during the coring operation. However, no stripping was noted during the core examination in the laboratory. The back-calculated modulus for the asphalt layers from FWD data is 165 ksi, which is below the typical value. The back-calculated modulus for the asphalt stabilized base layer is 829 ksi, which is higher than typical values (250-400 ksi). The back-calculation analysis may be influenced by the pavement structure, which in addition to the stabilized base, has a cement-treated subgrade below. Also, the presence of the porous friction riding course may be factor as well. Considering the porous friction course, asphalt dense layers, and asphalt stabilized base as a whole, we think that the back-calculated modulus reflects a sound structural layer. The back-calculated modulus for the cement-treated stabilized layer is 67 ksi, which is considered above the typical range for this type of layer (30 – 45 ksi). The back-calculated modulus for the subgrade is 21 ksi, which is considered good.

The only test results which particularly stand out are the high penetration values of the asphalt cement in each of the pavement layers placed in 1985. The asphalt cement is seen to have resisted oxidative hardening, thereby keeping the layers flexible enough to resist the pavement cracking that would have otherwise been expected.

ANALYSES OF GROUPS OF SIMILAR PAVEMENTS

The research team evaluated test results from groups of the same and similar pavement layer types whenever adequate data existed. While an inadequate number of replicates of any given pavement type exists to support specification change recommendations at this time, the evaluations of aggregated test results from groups of same and similar pavement types do provide valuable indications of specification performance as well as generally increase knowledge about desirable characteristics in flexible pavements.

The evaluation methods below also establish an approach and framework for continued, more intensive and more conclusive evaluations of specification requirements in the future, when additional pavement data sets should be available in the database.

Pavement Air Voids in All Types of Dense Asphalt Paving Mixtures

The cored pavements for this project contained 30 different asphalt pavement layers designed to have optimally low air voids throughout their service lives. Of these, 7 were of unconfirmed mix type, although very likely dense-graded mixes; 17 were dense-graded mixes; 3 were CMHB mixes; 2 were SMA mixes; and there was 1 Superpave mix. Several of these layers are below particularly successful overlays, which were the primary focus of the evaluations being performed. However, basic testing was performed on these underlying layers in hopes of further enhancing project findings.

Several interesting observations may be made about the levels of air voids found in these successfully performing pavement layers after years of traffic compaction. Figure 29 shows the frequency distribution of pavement air void average values as found in the 30 dense asphalt pavement layers that were cored and tested. The data show an apparent skew toward the 3 to 4 percent air void levels. It is noteworthy that this has been the targeted design air void level in Texas for many decades. However, there also appears to be a secondary factor involved with the data distribution, as a second peak in the distribution curve is noted in the 6 to 7 percent air void range.

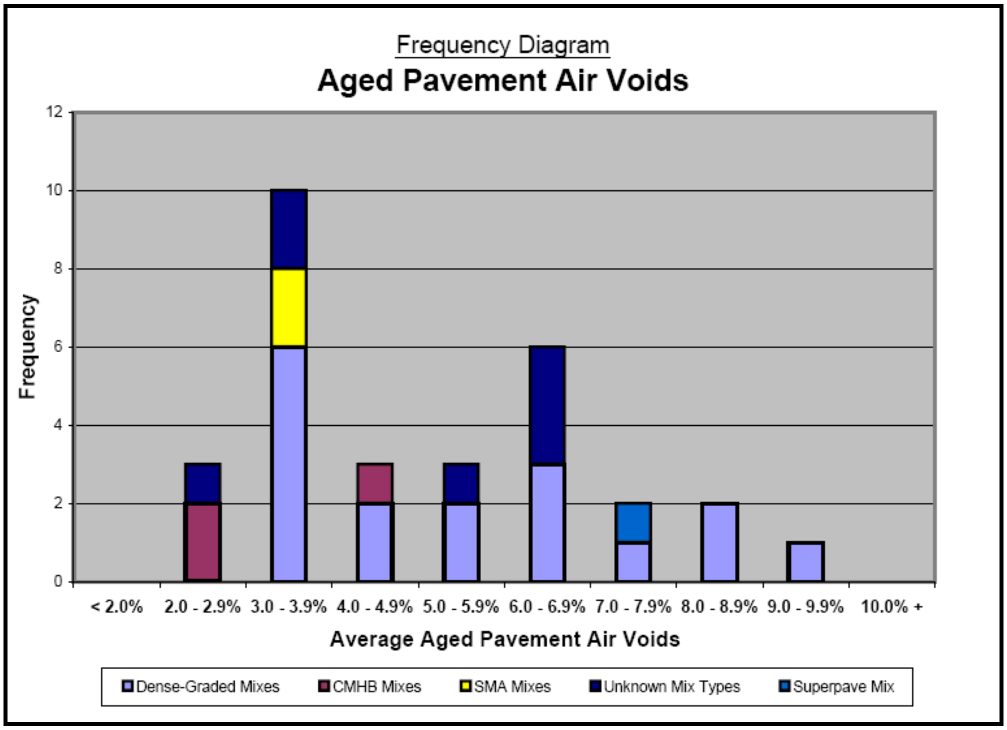


Figure 29. Frequency Diagram of Air Voids in Aged Pavement Layers – All Asphalt Concrete Mix Types.

Researchers investigated two possible causes for the secondary peak in the distribution curve. First, the data distributions were separately plotted based on each pavement layer's vertical position in the pavement structure. Figure 30 shows test results from only the surface layers, while Figure 31 shows the results from underlying layers. The apparent difference in the skew of these two data distribution indicates the likelihood that vertical location of the layer in the pavement structure is a contributing factor toward the secondary data distribution peak seen in Figure 29. While difference in the data skew stood out, the average air void levels did not differ substantially. The average air void level found in the surface courses was 4.9 percent, while the average air void level found in the underlying layers was 5.5 percent. Additional data would help clarify these relationships. A greater difference may in fact be found with a larger data set, possibly much closer to the approximate 3 percent difference between the two data peaks seen in Figure 29.

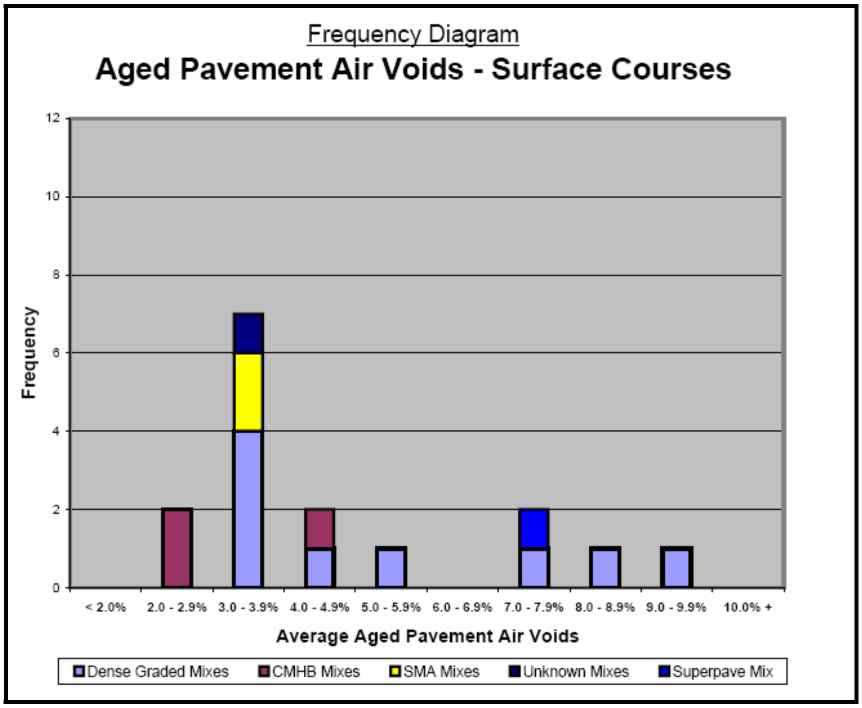


Figure 30. Frequency Diagram of Air Voids in Asphalt Concrete Pavement Surface Layers.

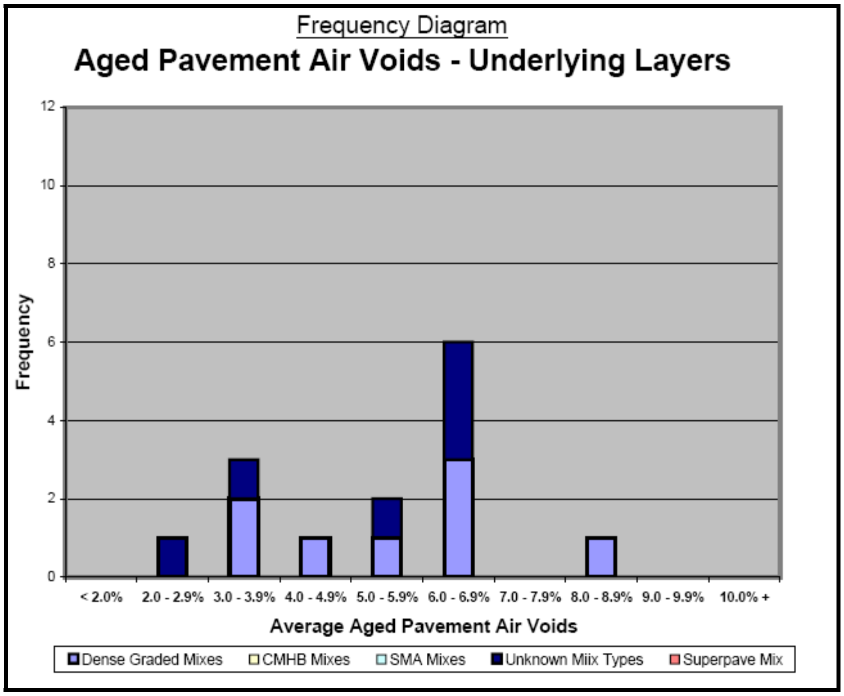


Figure 31. Frequency Diagram of Air Voids in Underlying Asphalt Concrete Pavement Layers.

The difference in air void levels between surface courses and underlying layers was not surprising, as temperatures in underlying layers will have been lower over the lives of these aged pavements, thereby keeping the viscosity of the asphalt binder higher in the lower layers, which in turn increases their resistance to densification under traffic.

This difference does, though, raise the question if the department would benefit by increasing the target mix design density by a small amount, perhaps 0.5 percent, to pavement layers at least 2 or 3 inches below the riding surface. The potential gain in that specification adjustment would be to increase cracking resistance while slightly decreasing porosity in underlying pavement layers. The data in this project are inadequate by itself to justify that recommendation, however. A much larger data set, and that data set composed of randomly selected pavements, should be evaluated to better assess the likelihood that the additional asphalt binder that would go into underlying layers might push these pavement layers, as a group, too close to the point of instability, thereby allowing normal mix plant production variation in asphalt content to cause performance problems.

The second possible cause for the secondary peak in the data distribution that was investigated was the variation in transverse coring location on the pavement. Test results from cores located in the wheel path and test results from cores located between wheel paths, at the same pavement locations, are shown in Figure 32 and Figure 33, respectively. While the cores taken between wheel paths were expected to have higher air voids than the cores taken from the wheel path at the same pavement location, the difference was rather small, with the wheel path cores from all pavements averaging 4.9 percent air voids and between wheel path cores from all pavements averaging 5.8 percent air voids. This difference is enough to indicate that transverse coring location may be a minor contributing factor toward the dual data distribution peaks seen in Figure 29. It is noted that this difference is considerably less than the difference often found in pavements performing poorly enough to be the subject of a forensic pavement study. The lack of difference is seen as a mark of good laboratory mixture design, plant production, and pavement construction practices in this group of particularly successful flexible pavements.

With the secondary peak in the data distribution explained to a reasonable degree of assurance, the skew toward the 3 to 4 percent air void range becomes more notable as evidence

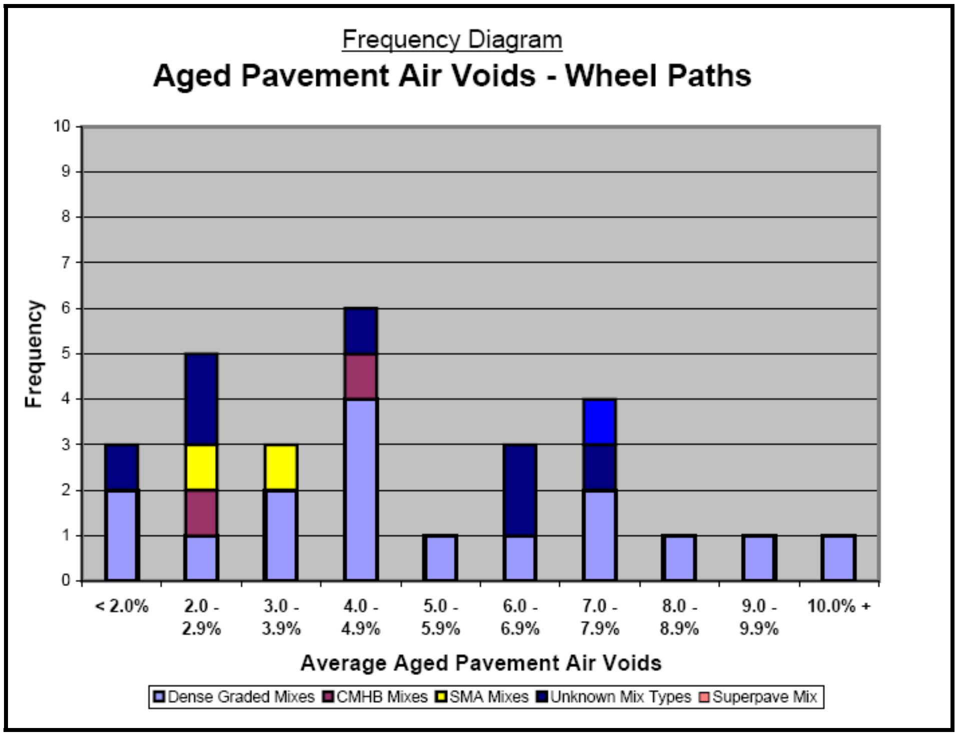


Figure 32. Frequency Diagram of Air Voids in Asphalt Concrete Pavement in Wheel Paths.

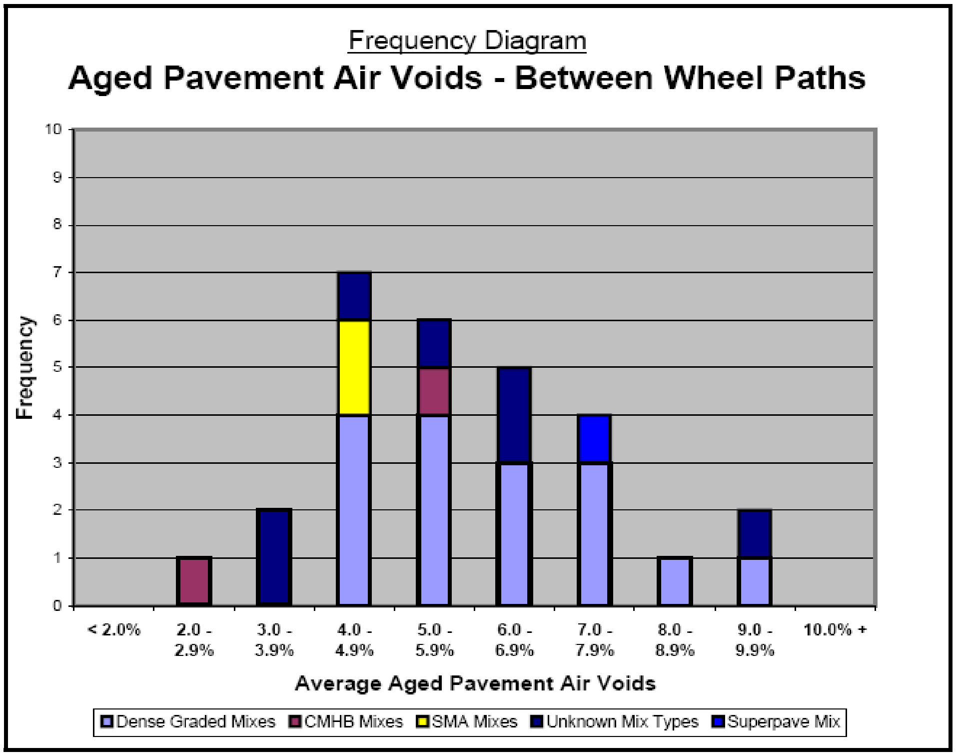


Figure 33. Frequency Diagram of Air Voids in Asphalt Concrete Pavement between Wheel Paths.

that department mixture design and job control laboratory compaction methods over the decades, with the Texas gyratory compactor, has provided an excellent approximation of ultimate traffic densification of pavement layers, particularly in surface courses.

Dense-Graded Asphalt Paving Mixtures

Construction inspection gradation test results were located for two Type D and three Type C dense-graded asphalt pavements. The average job control gradations determined at the mix plants during production on these projects are shown on Figure 34 and Figure 35, which also display current specification upper and lower gradation requirements for these two mixture types. It is apparent that specification requirements have changed over the years, as occasionally these average gradations are outside of current specification requirements.

Gradation data from a considerably higher number of pavements would be necessary to allow identification of frequently occurring gradation characteristics, which in turn could lend insight for future specification revisions. The Texas Successful Flexible Pavements web site and

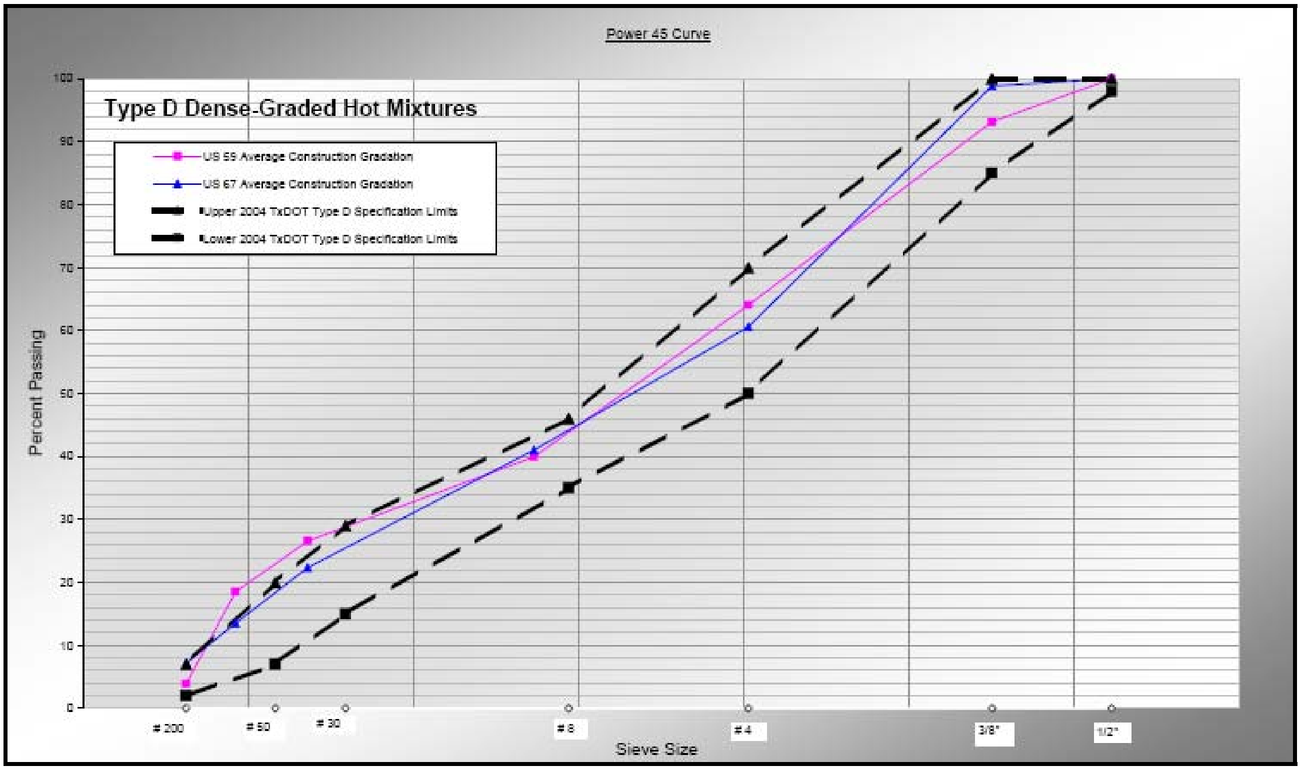


Figure 34. Power 45 Average Construction Job Control Gradations – Type D Mixes.

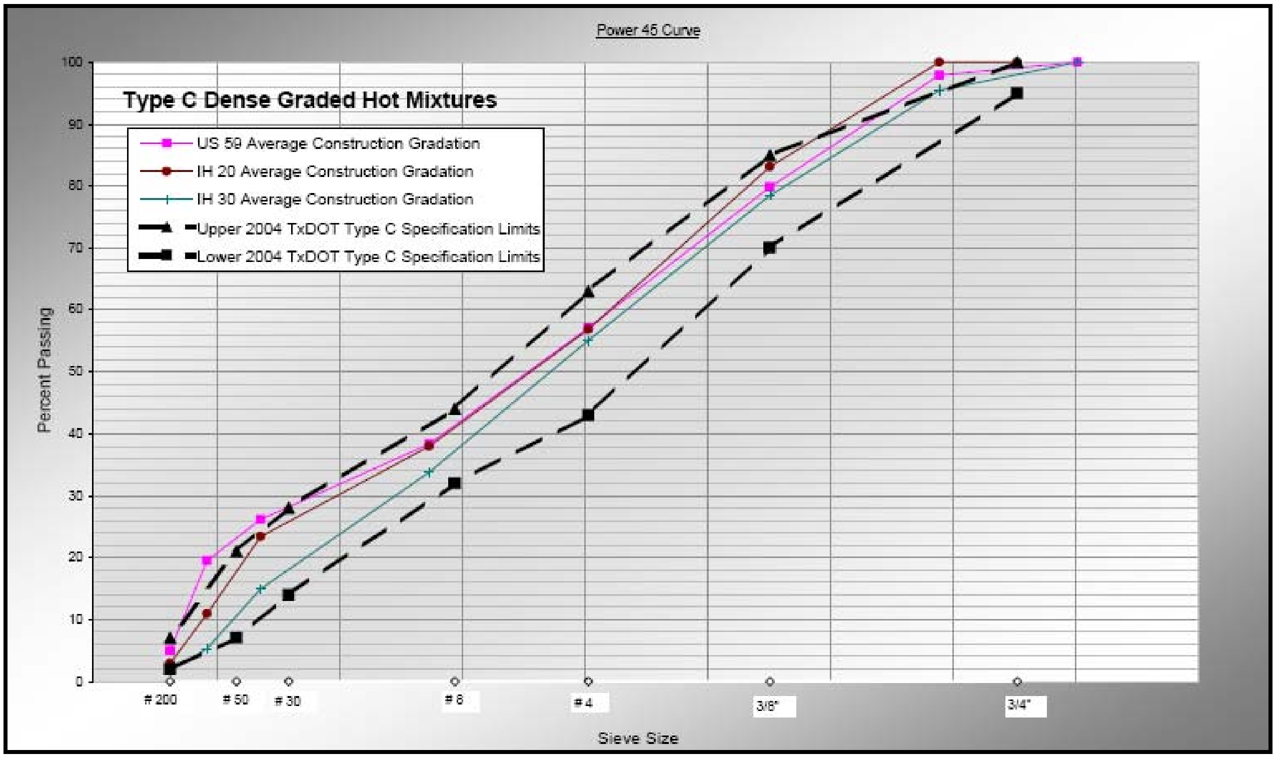


Figure 35. Power 45 Average Construction Job Control Gradations – Type C Mixes.

database will facilitate the gathering of the additional data needed to better evaluate gradation and numerous other flexible pavement construction specification requirements.

Historically, TxDOT had utilized a minimum asphalt requirement to assure adequate binder and film thickness in asphalt paving mixtures. Since about 1992, minimum requirements for voids-in-the-mineral-aggregate have indirectly established the minimum amounts of asphalt binder to include in asphalt paving mixtures.

As older pavements tended to provide the best examples of particularly well-performing flexible pavements, most of the dense-graded pavement layers selected for evaluation were constructed prior to VMA specification requirements. However, the average asphalt contents found by extraction or ignition oven testing of pavement cores indicate that selected pavements generally had asphalt contents well above the minimum asphalt contents in specifications, thereby indicating generally higher VMAs as well. Unfortunately, specifically corresponding VMAs for these older pavement mixtures cannot be determined from core tests. Table 18 shows asphalt contents as measured in core samples of Type D and Type C dense-graded pavement layers. Table 19 includes mixture design VMA results for the two pavements where that information was available. The core asphalt content of 5.7 percent and mix design VMA value of 14 for the Type C mixture placed on IH 30 do not appear to correlate. A review of the construction records found that indeed the mix design asphalt content had been 4.7 percent, which is more in line with the mix design VMA of 14.

Table 18. Asphalt Contents from Cores – Dense-Graded Mixes.

Highway Designation	Asphalt Content, % by Weight	
	Type D	Type C
IH 20 (WB lanes only)	-	4.2
IH 30	-	5.7
US 59	4.4	4.4
US 67	6.1	-
SH 21 (EB lanes only)	7.0	-
SH 183	6.2	-
SH 6	5.7 & 5.1	-
US 287	4.2	-
IH 10	7.0	-
FM 3223	5.7 & 5.4	-
Average	**5.7**	**4.8**
1982 Spec Minimum %	**4.0**	**3.5**

Table 19. VMAs from Construction Records – Dense-Graded Mixes.

Highway Designation	Mix Design VMA
	Type C
IH 20 (WB lanes only)	15
IH 30	14

Coarse-Matrix High-Binder Paving Mixtures

Construction inspection gradation test results were located for two CMHB asphalt pavement mixtures, both of them being CMHB-F mixture types. Figure 36 shows the average job control gradations determined at the mix plants during production on these projects, which also displays current specification upper and lower gradation requirements for CMHB-F mixtures.

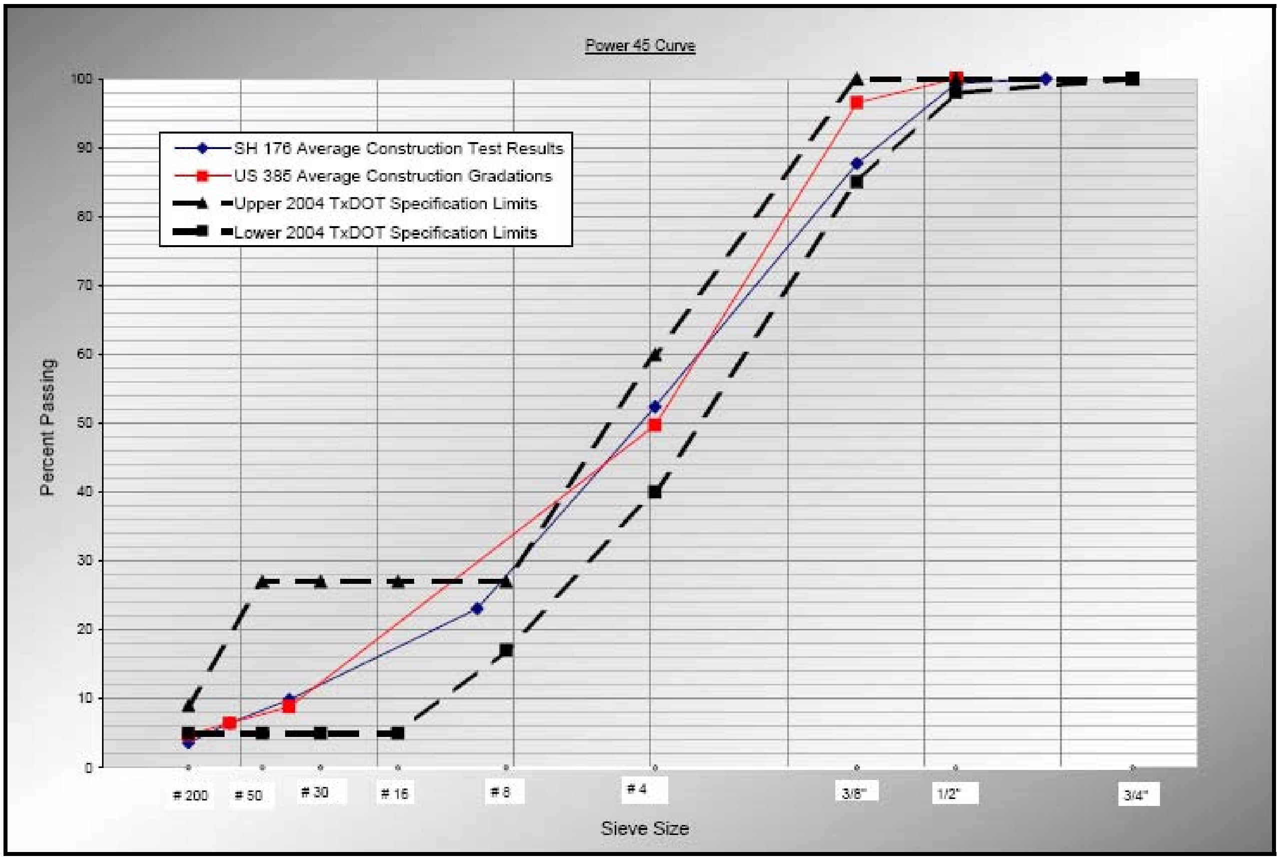


Figure 36. Power 45 Average Construction Job Control Gradations – CMHB-F Mixes.

Stone-Matrix Asphalt Paving Mixtures

No construction inspection records were still available for the two SMA pavements included in the database. It is recommended that a number of well-performing SMA pavements be identified for which construction records exist so that trends in data can be analyzed and compared to current construction specification criteria for this mixture type.

Figure 30 shows that both SMA pavements included in the database were found to have near ideal air void levels after approximately 14 years of service. It should also be mentioned that these two pavements were constructed on the same project, but on different highways with widely varying underlying pavement types.

Surface Treatments

Construction inspection gradation test results were located for five projects with Grade 4 surface treatments. Aggregate types represented were limestone, rhyolite, and lightweight. The average job control gradations on these projects are shown on Figure 37, which also displays current specification upper and lower gradation requirements for Grade 4 surface treatment aggregate.

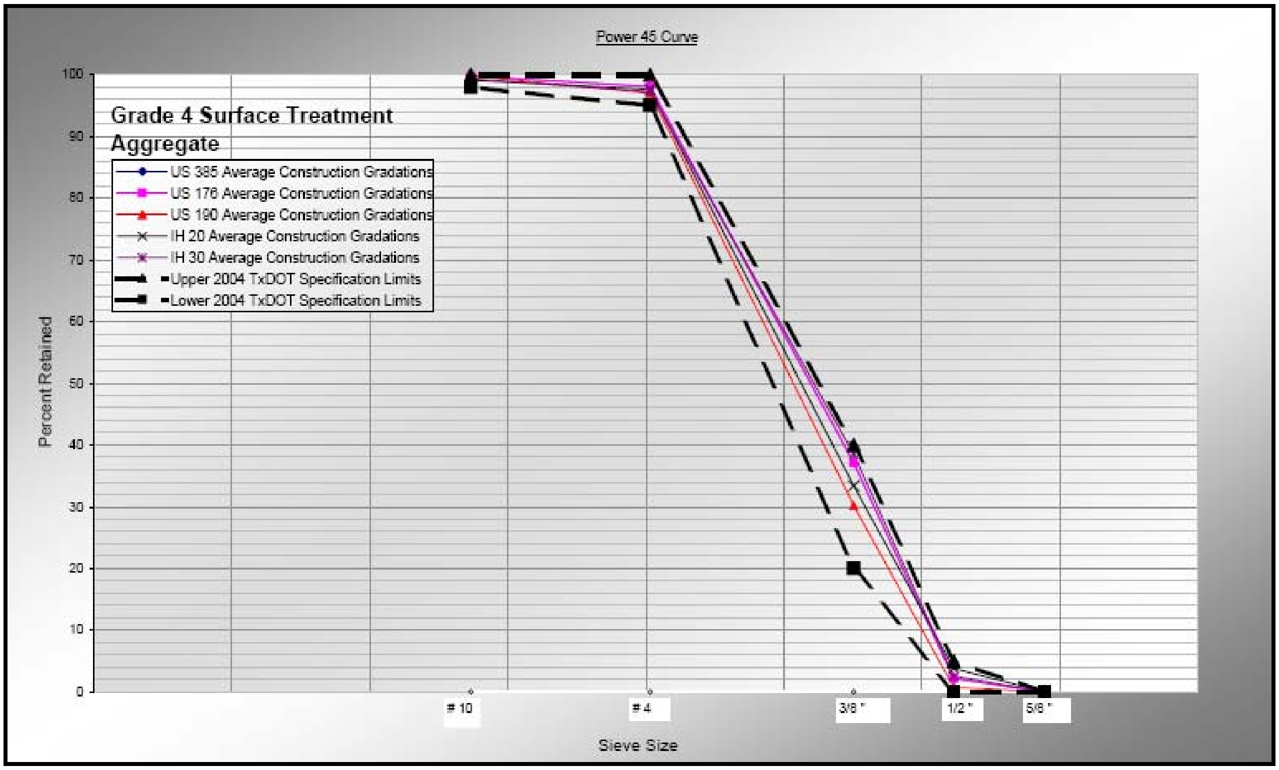


Figure 37. Power 45 Average Construction Job Control Gradations – Grade 4 Surface Treatment Aggregate.

Flexible Bases

Construction inspection gradation test results were located for two flexible base projects, both of them composed of Grade 4 limestone in the Brownwood District. The average job control gradations from these two projects are shown on Figure 38, which also displays current specification upper and lower gradation requirements for Grade 1 flexible base. Similarly, Figure 39 displays the gradations found in flexible base field samples from all sampled pavements.

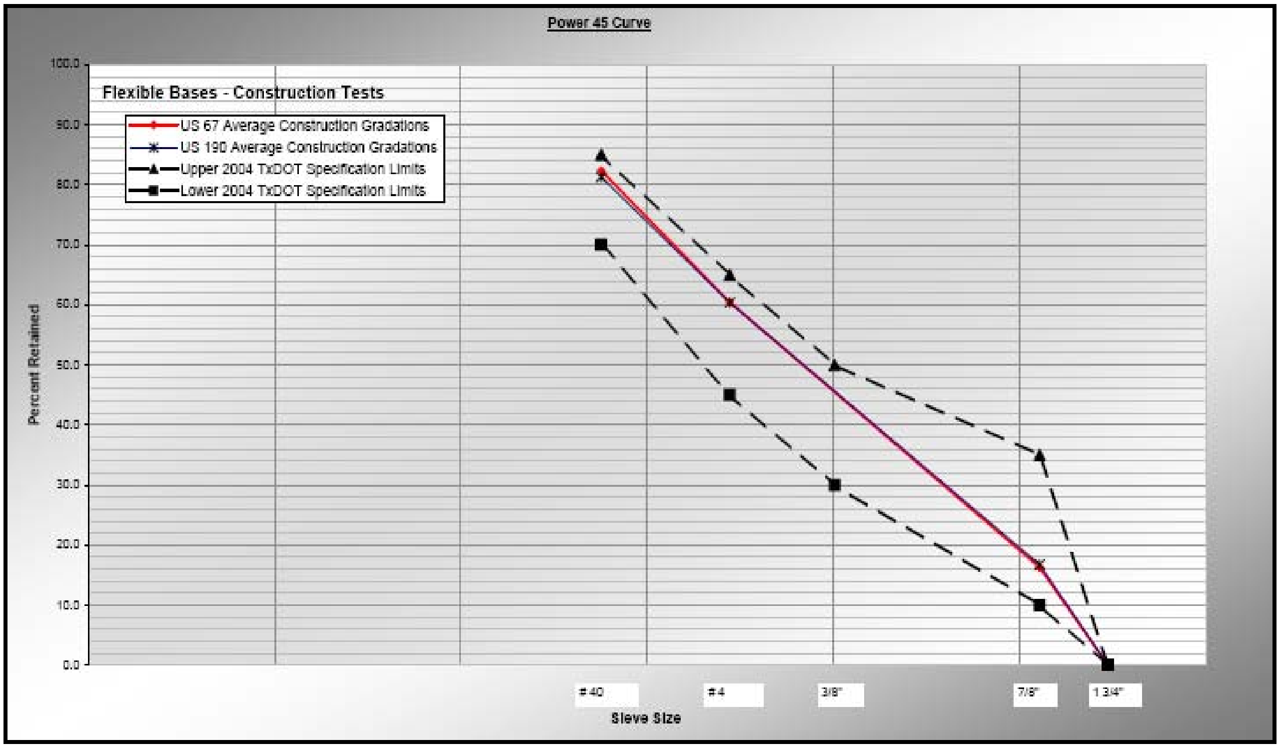


Figure 38. Power 45 Average Construction Job Control Gradations – Flexible Bases.

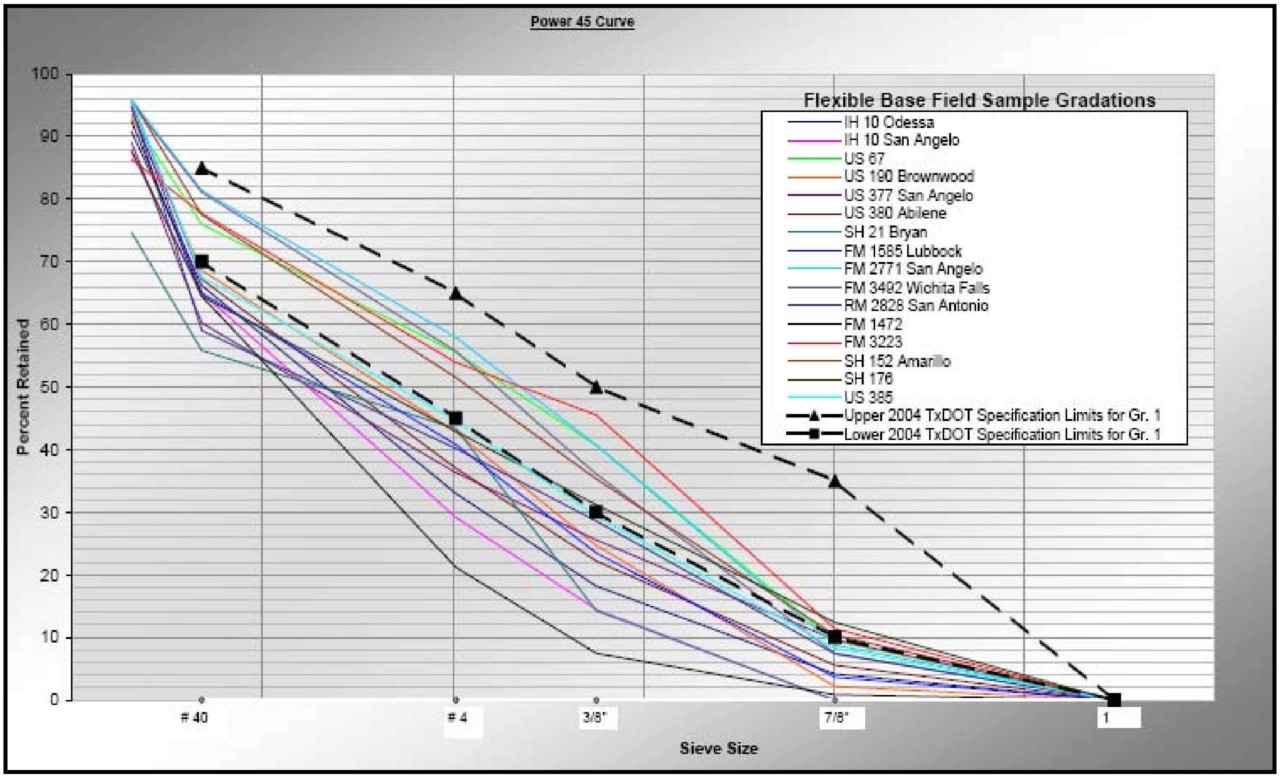


Figure 39. Power 45 Average Field Sample Gradations – Flexible Bases.

Asphalt Pavement Layers Containing Tire Rubber

Particular mention of this category of pavement is warranted. Five of the selected 25 pavements included tire rubber in either a surface treatment or paving mixture. This selection level is believed to be disproportionately high compared to the ratio of use of this material type in Texas over the past several decades.

Three pavements included Type II crumb rubber blended into the surface treatment asphalt cement by the contractor and two pavements used AC-15-5TR in the underseal being placed below the new asphalt paving mixture layers. The single pavement mixture containing tire rubber was a CMHB-F with Type II crumb rubber. This is the pavement on US 385 in the Odessa District. The researcher visiting this pavement site found it to be one of the very best appearing pavement sections seen among all nominations, despite the fact that it was eight years old at that time and had not yet received any type of preventative maintenance seal application. A review of PMIS performance data also shows it clearly among top performers at this point in its service life. Figure 40 is a photograph of this pavement at the time of field sampling, and Figure 41 clearly shows the binder-rich nature and yet excellent macro-texture after eight years of service.

Figure 40. CMHB-F Pavement Containing Type II Tire Rubber – US 385, Odessa.

Figure 41. CMHB-F Pavement Macro-Texture – US 385, Odessa.

PAVEMENT MODULUS DATA COLLECTION

Modulus values associated with most of the 25 pavements were obtained through field testing. Researchers performed DCP testing of pavements that did not include underlying Portland cement concrete, and TxDOT performed FWD testing in support of this project on 23 of the pavements. Table 20, below, shows average modulus values determined from all dense-graded asphalt mixture pavement layers, all flexible base layers, and all of the subgrades, as determined by both field test methods. These average values are compared to the ranges and typical values for these layer types found in the TxDOT Pavement Design Guide. Table 21 includes modulus values back-calculated from FWD test results for all tested pavements. Table 22 includes modulus values determined from DCP testing for all tested pavements.

Table 20. Average Field Test Moduli Compared to Typical Design Moduli.

Pavement Layer Type	Typical Design Modulus, ksi *	Average FWD Modulus, ksi	Average DCP Modulus, ksi
Dense-Graded Hot Asphalt Mixture	500	478	-
Flexible Base	40 - 70	86	41
Subgrade	8 - 20	23	27

* From Pavement Design Guide, Texas Department of Transportation.

Table 21. FWD Back-Calculated Modulus Values.

TxDOT District	Highway Designation	FWD Back-Calculated Modulus, ksi			
		Surface	Base	Subbase	Subgrade
Abilene	US 380	-	99	-	17
Amarillo	SH 152	-	116	-	18
Atlanta	IH 20 (WB only)	456	4432	-	25
Atlanta	US 59	210	242	-	27
Brownwood	US 67	-	-	-	39
Brownwood	US 190	-	-	-	29
Bryan	SH 21 (EB only)	868	52	219	2
Fort Worth	BIH 35	66	2050	-	9
Fort Worth	SH 183	-	-	-	-
Fort Worth	SH 171	511	210	-	20
Houston	SH 6	165	829	67	21
Laredo	FM 1472	1033	105	221	31
Lubbock	FM 1585	-	47	-	15
Lufkin	US 287	760	64	45	10
Odessa	IH 10	-	117	-	73
Odessa	US 385	-	111	-	32
Odessa	SH 176	-	98	-	12
San Angelo	IH 10	-	137	-	45
San Angelo	US 377	-	110	-	15
San Antonio	FM 2771	-	57	-	12
San Antonio	RM 2828	-	47	-	18
Waco	FM 3223	-	39	-	15
Wichita Falls	FM 3492	-	48	-	9

Table 22. DCP Modulus Values.

TxDOT District	Highway Designation	DCP Modulus, ksi	
		Flexible Base	Subgrade
Abilene	US 380	47	9
Amarillo	SH 152	12	16
Atlanta	US 59	-	49
Brownwood	US 67	26	18
Brownwood	US 190	74	20
Bryan	SH 21 (EB only)	-	37
Fort Worth	SH 171	24	23
Laredo	FM 1472	-	38
Lubbock	FM 1585	43	24
Lufkin	US 287	41	40
Odessa	IH 10	24	42
Odessa	US 385	47	9
Odessa	SH 176	42	47
San Angelo	US 377	-	31
San Antonio	FM 2771	48	18
San Antonio	RM 2828	46	22
Waco	FM 3223	49	16
Wichita Falls	FM 3492	47	18

A graphical display showing individual layer FWD back-calculated modulus values in surface treatment pavements may be seen in Figure 42. This information is provided for thin and thick asphalt concrete pavements in Figure 43 and Figure 44, respectively.

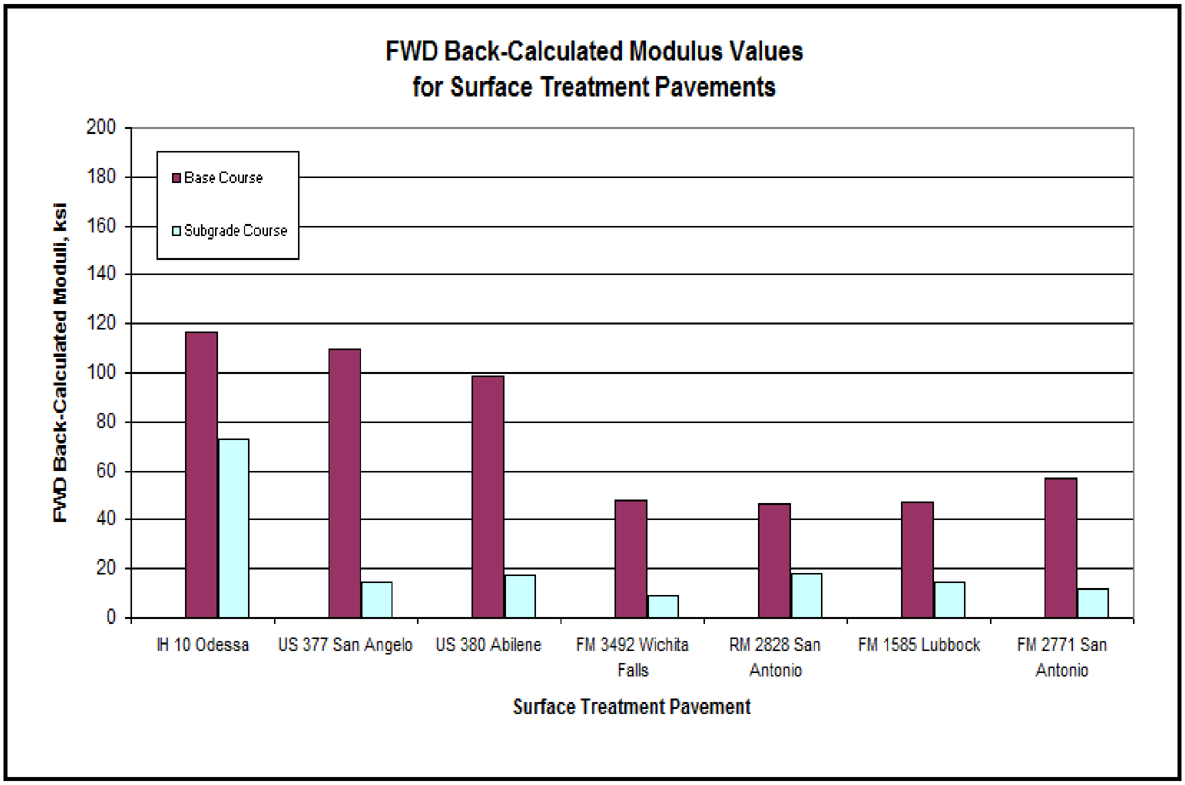


Figure 42. FWD Moduli in Surface Treatment Pavements.

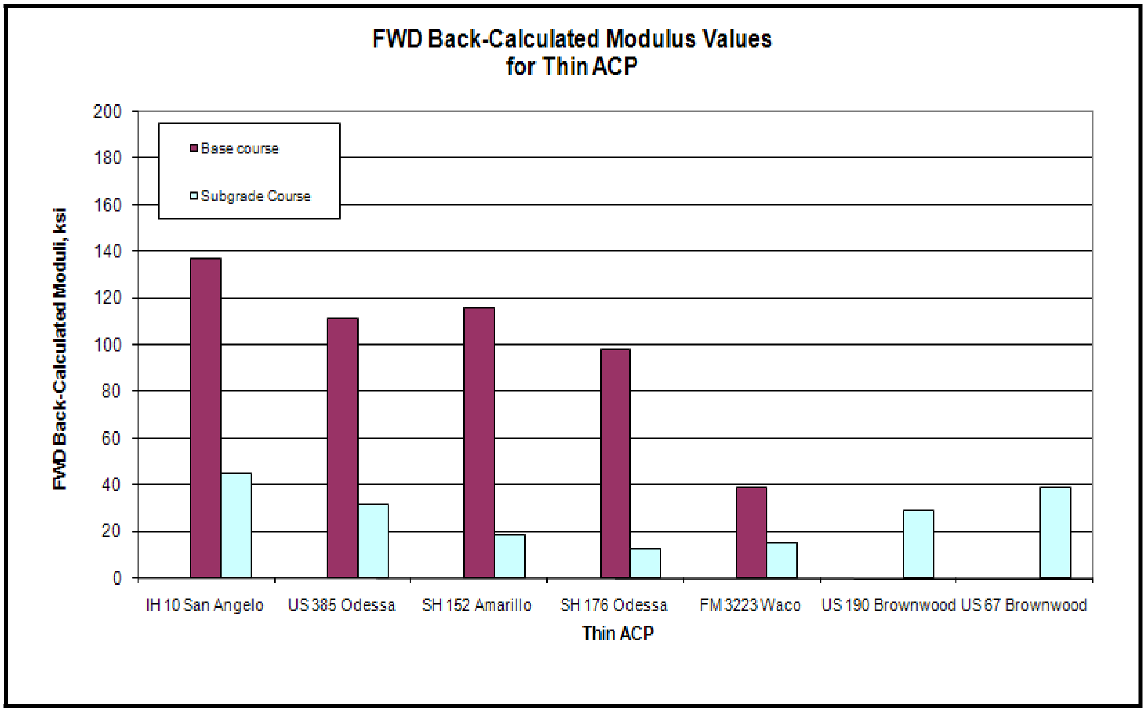


Figure 43. FWD Moduli in Thin Asphalt Concrete Pavements.

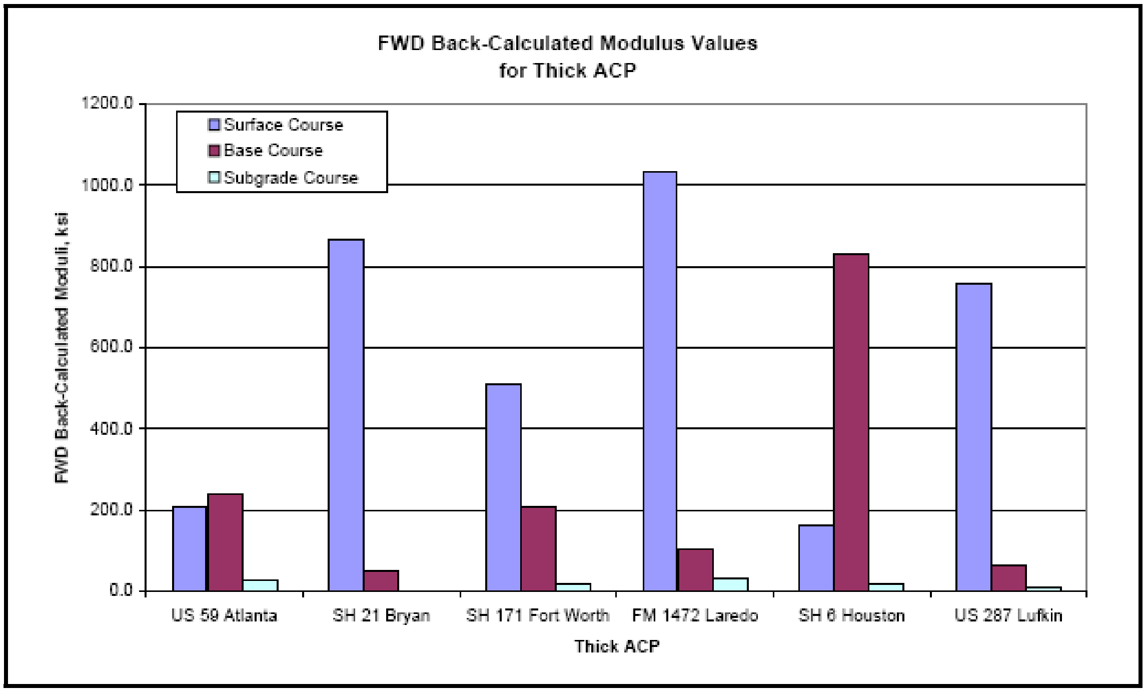


Figure 44. FWD Moduli in Thick Asphalt Concrete Pavements.

Most of the back-calculated modulus values are within or above the range of expected typical values for the types of materials composing each layer. However, interpretation of back-calculated modulus values should consider the whole of the pavement structure rather than focusing on the individual values for each layer. Results are influenced by the ratio of layer thicknesses between pavement layers and the types of materials. An overall analysis of the back-calculated layer modulus provides an indication of the structural soundness of the entire pavement structure.

HISTORICAL PMIS DATA COLLECTION AND ANALYSIS

Analysis of PMIS data from the 25 pavement sections is summarized in Tables 23, 24, and 25. Table 23 summarizes the analysis for the condition score and shows the average and standard deviation for each section from data available from 1998 through 2006. It is observed that except for two sections (Brownwood US 67 and Fort Worth SH 183) all of the sections have an average condition score above 90, which is considered to indicate very good pavement condition. The overall average condition score from all data collected over nine years is 95.7 with a standard deviation of 8.11.

Table 23. Average Condition Scores from 1998-2006 PMIS Data.

TxDOT District	Highway Designation	Condition Score	
		Average	Stand. Dev
Abilene	US 380	98.6	1.84
Amarillo	SH 152	97.9	2.17
Atlanta	IH 20	97.7	3.65
Atlanta	IH 30	98.2	2.47
Atlanta	US 59	95.9	4.59
Brownwood	US 67	84.6	20.02
Brownwood	US 190	96.9	2.97
Bryan	SH 21	99.7	0.75
Fort Worth	BIH 35	91.1	7.71
Fort Worth	SH 183	68.2	10.74
Fort Worth	SH 121	93.7	5.12
Fort Worth	SH 171	99.6	0.50
Houston	SH 6	94.6	10.62
Laredo	FM 1472	96.7	3.11
Lubbock	FM 1585	99.2	0.56
Lufkin	US 287	94.0	9.57
Odessa	IH 10	99.9	0.22
Odessa	US 385	99.6	1.13
Odessa	SH 176	99.7	0.66
San Angelo	IH 10	97.0	3.31
San Angelo	US 377	97.2	3.30
San Antonio	FM 2771	93.4	6.23
San Antonio	RM 2828	96.9	3.17
Waco	FM 3223	95.1	6.65
Wichita Falls	FM 3492	100.0	0.00

Table 24 summarizes the analysis for the distress score and shows the average and standard deviation for each section from data available from 1998 through 2006. It is observed that except for two sections (Brownwood US 59 and Fort Worth SH 183) all the sections have an average above 90, which is considered to indicate pavements with very low distress. The overall average distress score from all data collected over nine years is 96.7 with a standard deviation of 6.66

Table 25 summarizes the analysis for the ride summary score and shows the average and standard deviation for each section from data available from 1998 through 2006. It is observed that except for three sections (Fort Worth SH 183, San Angelo IH 10, and San Antonio FM 2771) all the sections have an average above 3.0, which is considered to indicate good smoothness. The overall ride score average from all data collected over nine years is 3.9 with a standard deviation of 0.57.

Table 24. Average Distress Scores from 1998-2006 PMIS Data

TxDOT District	Highway Designation	Distress Score	
		Average	Stand. Dev.
Abilene	US 380	98.6	1.84
Amarillo	SH 152	97.9	2.17
Atlanta	IH 20	97.7	3.65
Atlanta	IH 30	98.2	2.47
Atlanta	US 59	97.6	3.21
Brownwood	US 67	85.7	20.74
Brownwood	US 190	96.9	2.97
Bryan	SH 21	99.7	0.75
Fort Worth	BIH 35	98.5	1.43
Fort Worth	SH 183	82.2	9.79
Fort Worth	SH 121	94.4	5.08
Fort Worth	SH 171	99.6	0.50
Houston	SH 6	95.0	10.78
Laredo	FM 1472	98.7	2.73
Lubbock	FM 1585	99.2	0.56
Lufkin	US 287	94.0	9.57
Odessa	IH 10	99.9	0.22
Odessa	US 385	99.6	1.13
Odessa	SH 176	99.7	0.66
San Angelo	IH 10	97.0	3.31
San Angelo	US 377	97.4	3.30
San Antonio	FM 2771	94.1	5.88
San Antonio	RM 2828	97.0	3.12
Waco	FM 3223	95.1	6.69
Wichita Falls	FM 3492	100.0	0.00

These PMIS scores are consistent with the selection of these 25 pavements as a group to initially populate the database. The pavements selected for the Texas Successful Flexible Pavements database are likely candidates to be included in the Texas Flexible Pavements database being developed at the time of this writing by the Center of Transportation Research under TxDOT research project 0-5513. As that database will be used for pavement model validation purposes, additional PMIS data has been obtained for these 25 pavements and is tabulated in Appendix A on

Table 25. Average Ride Summary Scores from 1998-2006 PMIS Data

TxDOT District	Highway Designation	Ride Summary	
		Average	Stand. Dev.
Abilene	US 380	3.6	0.17
Amarillo	SH 152	4.6	0.05
Atlanta	IH 20	4.4	0.17
Atlanta	IH 30	4.4	0.10
Atlanta	US 59	4.1	0.40
Brownwood	US 67	3.6	0.08
Brownwood	US 190	4.1	0.20
Bryan	SH 21	4.2	0.19
Fort Worth	BIH 35	3.3	0.20
Fort Worth	SH 183	2.9	0.11
Fort Worth	SH 121	3.7	0.18
Fort Worth	SH 171	4.1	0.09
Houston	SH 6	4.1	0.28
Laredo	FM 1472	3.8	0.38
Lubbock	FM 1585	4.5	0.10
Lufkin	US 287	3.3	0.23
Odessa	IH 10	4.3	0.05
Odessa	US 385	4.4	0.28
Odessa	SH 176	4.4	0.09
San Angelo	IH 10	4.3	0.17
San Angelo	US 377	2.9	0.11
San Antonio	FM 2771	2.8	0.07
San Antonio	RM 2828	3.3	0.05
Waco	FM 3223	4.2	0.30
Wichita Falls	FM 3492	4.3	0.16

the CD-ROM. The desire had been to collect and provide a total of 10 year's of PMIS information. However, only nine year's of data were available to the researchers. Nevertheless, the database and web site are designed to allow entry and storage of up to 10 year's of PMIS performance score information.

STRATEGIES FOR DATABASE INFORMATION UPDATE CAPABILITIES

One of the designated products of this project was for the research team to investigate and report strategies for updating or adding new information to the database on an ongoing basis.

The research team concluded that by far the greatest ongoing need for data in the Texas Successful Flexible Pavements database is the nomination and inclusion of additional pavements. This need soon became the focus of strategizing for updating capabilities. Once possibilities to provide this capability were explored, the research team determined that it might be feasible to include this capability within this project's budget and time limit. That effort was successful, and a straightforward and easy means has been provided for registered users to nominate additional pavements. Further, a truly easy means of managing nominated pavements, including approving or removing information from display, was provided for the TxDOT administrator of the web site.

The research team also weighed the value of automatic transfer of updated PMIS performance data into the Texas Successful Flexible Pavements database for the 25 initially loaded pavements as well as for pavements to include later. The recommendation provided to TxDOT is that uploaded PMIS information could be misleading as often as helpful and should not be pursued. As pavements included in the database are rehabilitated and reconstructed, the most recent PMIS data that would be uploaded, replacing older PMIS data, would no longer be reflective of the pavement structure that is described within the database. It is believed much more valuable and practical for users to always be able to see the PMIS data that were available to the nominator at the time of pavement nomination. These are the data that were the basis of the pavement's nomination.

RECOMMENDATIONS ON CHANGES TO TESTING TECHNIQUES TO IMPROVE PAVEMENT EVALUATION

Another designated product of this project was for the research team to provide TxDOT any recommendations for improving pavement evaluation testing techniques which became evident during the course of this project. While no needs for change were observed, a couple of recommendations can be provided based on experiences during this project.

The field testing and sampling plan developed and used during this project, described in Chapter 5, was found efficient and effective for the purpose of evaluating pavements that were not experiencing performance difficulties. Future use of this plan for similar information gathering needs is recommended.

A possibly significant improvement in pavement evaluation technique is being developed by Tom Scullion, a member of our project research team. The rest of the research team observed a prototype of a system that integrates pavement evaluation video with *PaveCheck* data representations. The prototype allowed the user to access video for any specific roadbed location by clicking on the *PaveCheck* figure at the desired point. In this manner, an evaluator can look for telltale surface signs of subsurface conditions, greatly facilitating improved analyses made from GPR test results. The user may also quickly and accurately determine physical location on the roadway where a subsurface condition has been noted. Further development and evaluation of this capability is strongly recommended.

CHAPTER 7:
FINDINGS AND RECOMMENDATIONS

FINDINGS

This project resulted in the following findings.

- The web site and database programmers were able to develop a product within the scope of this project that allows online nomination of additional pavements by users possessing the appropriate security access level. The web site also features several web site administration tools to facilitate ongoing web site management by TxDOT.
- While the success of each pavement appears to have somewhat differing factors involved, in general, superior performance may be attributed to the combined result of good construction practice, high-quality materials, and timely maintenance.
- Analysis of PMIS data from the 25 pavement sections reflects superior pavement performance over time. Average condition scores, distress scores, and ride scores from data available from 1998 through 2006 indicate very good performance and substantiate the selections of these pavements by the districts.
- GPR colormaps display uniform pavement profiles for the selected pavements, an indication of uniformity in materials production, materials quality, and use of good pavement construction practices. Colormaps were consistent with observations of layer depths and occasional anomalies made in the field during pavement sampling.
- Most pavement layer back-calculated modulus values were within or above the range of expected typical values for the types of materials involved.
- Current record retention policies for construction inspection test results severely limited availability of construction inspection test results for pavements older than six or seven years in age. However, potentially valuable observations were made regarding test results and specification criteria that warrant further evaluation. Additional quantities of construction inspection test results will be required to adequately evaluate these specification improvement opportunities. Recommendations concerning these observations are included below.

RECOMMENDATIONS

The following recommendations are made.

- Availability of the Texas Successful Flexible Pavements web site and database should be advertised to all potential department users to gain immediate and maximum benefit from the information now available.
- District pavement engineers should be provided security access and be encouraged to nominate additional flexible pavements that they find to be clearly performing beyond normal expectations.
- Once a number of additional pavements have been included in the database, TxDOT should consider more closely evaluating benefits and other possible effects from a small increase in the laboratory design density for pavement layers below the surface course.
- The voids-in-the-mineral-aggregate criteria in current specifications should be evaluated beyond that possible during this project, specifically to validate the current specification criteria or to support increased minimum values, should that be found appropriate for this most important mixture composition characteristic.
- Implementing a sister web site and database, using the same basic web site and database structure developed in this project, should be considered for the sole purpose of capturing and tracking information about experimental pavement sections placed under construction and maintenance oversight. This additional use appears an excellent means to leverage the value of the programming already provided, as development costs for the sister web site would be a small fraction of original development costs. This work may meet the criteria for implementation program funding, or other funding outside of the research program.
- Similarly, implementing a sister web site and database solely for collecting information about Superpave, SMA, and CMHB mixtures should be considered to expedite department ability to evaluate current specification criteria unique to these mixtures and to increase general understanding of these pavement types. A separate database is recommended to allow the random selection of pavements, selected from throughout the state, to assure statewide applicability of findings. This approach also assures adequate numbers of pavement data sets for statistical evaluations. The gathering and

loading of this information into the database may appropriately fall under TxDOT's Implementation Program or other non-research funding should department human resources not be readily available. If the current web site and database require only superficial changes, such as naming conventions, the cost would be extremely small to provide this additional tool to TxDOT.

- The 25 pavement data sets created during this project should be included in the database being developed under TxDOT research project 0-5513. Nominated pavements that were not selected for full evaluation under this project should also be considered by the project 0-5513 team, as they provide additional good candidates to populate that database with upper-end performing pavements.
- TxDOT should continue to pursue coordination of protocols between the database provided by this project and the database being developed under research project 0-5513, ultimately allowing either database to transfer data to or from the other database. It is believed that the protocol developed for that purpose under this project provides a solid framework to achieve that goal.
- Current record retention policies for construction inspection test result records should be reviewed to determine if adjustments might be practical that would facilitate future review of important construction specification criteria.
- The prototype system observed by the research team that integrates pavement evaluation video with *PaveCheck* data representations should be further developed, evaluated, and strongly considered for incorporation into the standard pavement evaluation testing protocol.

REFERENCES

1. Chatti, K., N. Buch, S.W. Haider, A.S. Pulipaka, R.W. Lyles, D. Gilliland, and P. Desaraju. *LTPP Data Analysis: Influence of Design and Construction Features on the Response and Performance of New Flexible and Rigid Pavements.* National Cooperative Highway Research Program (NCHRP), Michigan State University, Michigan, 2005.
2. Sharp, K., and T. Martin. *Network Performance Profiles.* www.arrb.com.au. Road System and Engineering Technology Forum, August 2005.
3. Merrill, D. *Guidance on the Development, Assessment and Maintenance of Long-Life Flexible Pavements*. Report TRL 639. Highways Agency, Quarry Products Association and Refined Bitumen Association.
4. Von Quintus, H., J. Mallela, and J. Jiang. *Expected Service Life and Performance Characteristics of HMA Pavements in LTPP.* Eres Consultants Division, Texas, 2005.
5. Choi, J., and T.M. Adams. *Strategy for Modeling a Pavement Performance Analysis System at WisDOT.* Transportation Research Board, Washington D.C., 2004.
6. *Design Build Pavement Warranties.* Washington Department of Transportation, Washington, 2006.
7. Krebs, S.W., B. Duckert, S. Schwandt, J. Volker, T. Brokaw, W. Shemwell, and G. Waelti. *Asphaltic Pavement Warranties, Five-Year Progress Report.* WisDOT, FHA, WAPA, Wisconsin, 2001.
8. Yoshida, T. *Performance-Based Specifications as a Step to Performance-Step Management and Maintenance of Pavement in Japan.* Public Works Research Institute, Japan, 2001.
9. Richter, C.. *Performance Trends of Rehabilitated AC Pavements*. Publication Number: FHWA -RD-99-193, US DOT, FHA, Virginia, 2000.
10. Rauhut, J.B., A. Eltahan, and A.L. Simpson. *Common Characteristics of Good and Poorly Performing AC Pavement.* Publication Number: FHWA-RD-99-193, US DOT, FHA, Virginia, 1999.
11. Baker, M.J., J.P. Mahoney, and N. Sivaneswaran. *Engineering Application of Washington State's Pavement Management System.* Research Record 1643, WSDOT, Washington, 1998.
12. Information Systems Division, *TxDOT Data Architecture - Version 3.0*, Texas Department of Transportation, Austin, Texas, 2006.

APPENDIX A:
(SEE COMPACT DISC ATTACHED TO BACK COVER)

The following information is provided on CD-ROM due to the length and size of these documents:

- **Initial 2004-2006 PMIS Information - All Nominated Pavements**
- **Database Entity-Relationship Diagram**
- **Database Data Dictionary**
- **Construction Inspection Test Results**
- **Laboratory Test Results on Samples of Aged Pavements**
- **Graphical Display of Individual Pavement Layer Test Results**
- **1998-2006 PMIS Pavement Scores – Selected Pavements**

APPENDIX B: PAVEMENT NOMINATION SOLICITATION DOCUMENTS

Texas Transportation Institute
The Texas A&M University System
1106 Clayton Lane, Suite 300E
Austin, TX 78723

512-467-0952
Fax: 512-467-8971
http://tti.tamu.edu

October X, 2005

Subject: Request for Nominations - Extraordinarily Performing Flexible Pavements

District Engineer
Address
Address

Dear M________:

The department has historically done an excellent job of studying and learning from pavement sections which have failed to perform as expected. Forensic investigations have recorded and provided knowledge that has been of great value as specification requirements were reviewed. Up to this point, little has been done to identify and learn from pavement sections which have performed well above expectations for considerable lengths of time. Research Project 0-5472 was recently initiated to identify and study a selection of flexible pavement sections that have performed extremely well over time. Your assistance is requested in identifying potential pavement sections to be studied by the research team during this project.

The attached form is provided to assist in nominating pavement sections. Very minimal information is being requested to facilitate the nomination process. At a later date, your district pavement engineer will be contacted to arrange a date for someone from the research team to visit the site(s) in your district. After these visits, approximately 25 of the nominated sections will be selected for detailed investigation to determine the factors contributing most heavily in their extraordinary performance.

There are three definitions below which will guide your district in nominating successful flexible pavement sections.

> Successful – We are seeking excellently performing new pavements or excellent overlays. The new / reconstructed pavement or the rehabilitated pavement must be in its first performance period. Pavement performance, primarily serviceability, should be well above expectations considering the pavement design, traffic and percentage of trucks, materials utilized, and the local environment.
>
> Flexible Pavement. – A pavement with either surface treatment over base, thin or thick hot mix surfacing, or it may be a composite pavement with a minimum of 2 inches of asphalt mixture over concrete.

Section – A length of pavement having constant structure and mixture design and that has a minimum length of one mile.

Thank you for your assistance in this research project. We would appreciate receiving your pavement section nominations by December 30, 2005. They may be forwarded electronically or submitted by mail to one of the addresses shown below.

Mailing Address:	Email Submission:
Paul E. Krugler Texas Transportation Institute 1106 Clayton Lane, Suite 300E Austin, TX 78723	p-krugler@ttimail.tamu.edu

The findings should prove to be quite interesting and helpful to all. Should one or more sections be selected from your nominations, your district pavement engineer will have the opportunity to be personally involved with all activities pertinent to their further evaluation. Should you have questions about this request, please contact either Dr. Ahmed Eltahan, the TxDOT research project director, at 512-467-3993 or aeltaha@dot.state.tx.us, or you may contact me at 512-467-0952 or the email address above.

Sincerely yours,

Paul E. Krugler, P.E.
Research Engineer & Manager of
Research Implementation
Texas Transportation Institute

Enclosure

cc: Amadeo Saenz Jr., AED, Engineering Operations
Thomas R. Bohuslav, CST
Ahmed Eltahan, CST, Project Director

Flexible Pavement Section Nomination Form

TxDOT Research Project 0-5472 will closely evaluate a number of selected pavement sections which have been found to have performed extraordinarily well considering their structural design, traffic type and level, and their age. Valuable information is anticipated from these forensic-type investigations. Please provide the requested information below to nominate pavement sections from your district.

Minimum Requirements for Nominated Sections

1. Minimum length of one mile.
2. Must be a flexible pavement with either surface treatment over base, thin or thick hot mix surfacing, or it may be a composite pavement with a minimum of 2 inches of asphalt mixture over concrete.
3. The new / reconstructed pavement or the rehabilitated pavement must be in its first performance period. We are seeking excellently performing new pavements or excellent overlays.
4. The nominated sections should have already distinctly outperformed normal serviceability expectations. Most nominated new pavement sections are expected to be at least 15 years old and most overlays are expected to have been in service at least 10 years. These minimum pavement ages are guidelines only.

Nominator:	Nominator's Email:	Nominator's Phone No.:

District:	Highway No.:	Beginning Reference Marker:
County:	Approx. Year of Construction:	Ending Reference Marker:

Surface Type:	(Optional) Surface Course Comments:
Base Type:	(Optional) Base Course Comments:
Best Description of Traffic Loading During Performance Period: (Check One) ☐ High ☐ Medium ☐ Low	
Comments about Extraordinary Performance:	

APPENDIX C: NOMINATED SUCCESSFUL FLEXIBLE PAVEMENTS

Nominated Successful Flexible Pavements

TxDOT District	Nominators	Highway Identification	Year Constructed	Last Treatment	Traffic Level	Pavement Structure & Comments
Abilene	Joe Higgins	US 380	1966	Seal Coat	Medium	2-course Surface Treatment over 8-inches flex base over 4-inches of existing flex base.
Amarillo	Tom Nagel Kenneth Corse	SH 152	1995	Seal in 2005	Medium	1.5 " Type D ACP over 10" sand & gravel fly ash base. All material sources are known.
Atlanta	Miles Garrison Mike Anderson	US 59	1989	Microsurface & Seal in ~ 2000	Medium	2" Type D ACP over 8.5" Type C ACP over 16-inch LFA Subgrade. ADT = 11,100. Some slight wheel path flushing in outside lane. All mix design materials and pavement design info on plan sheets.
Atlanta	Miles Garrison Mike Anderson	US 59	1991	Seal Coat, Micro, & Overlay in 2002	Medium	2" Type D ACP over 8" Type G ACP over 16-inch LFA Subgrade. 2004 ADT = 12,700. Looks very good.
Atlanta	Miles Garrison	IH 20	1995	Fog & Microsurface	High	2" CMHB-C over 4" ACP over CRCP. One of first CMHBs in state. They were loosing fines from the CMHB and so fog sealed it and microsurfaced it. I would imagine that the mix had been a little too dry, and if so, the performance won't be as would normally be expected from this structure.
Atlanta	Miles Garrison	US 59	1995	Microsurface ~ 2003	Medium	2" Type C ACP over 8.5" Item 292 over 16-inch LFA Subgrade. 2004 ADT = 11,100.
Atlanta	Miles Garrison	IH 20 (WB lanes only)	1996	Microsurface in 1997 or 1998 to improve skid values	High	2" Type C ACP over 2" Type B over CRCP. They had some problems with some of the microsurfacing and have milled some of it up. ADT ~ 30,000 with ~ 40% trucks.
Atlanta	Miles Garrison	US 59	1997	Seal Coat	Medium	2" Type C (Latex) ACP over 10" Type A ACP (AC-20) over 16" LFA subgrade.
Atlanta	Miles Garrison	SH 155	1997	Seal Coat	Low	2" Type C ACP over 1CST (constructed in 1997) over 2CST over 10" LFA flex base (constructed in 1980). Two different Type C mix designs, different screenings.
Atlanta	Miles Garrison	US 59 (thru Atlanta)	1997	Seal Coat	Medium	INSIDE LANE: 5" Type C ACP over 1CST over 12" flex base (constructed in 1997). OUTSIDE LANE: 2" Type C ACP over 13" ACP Base
Atlanta	Miles Garrison	IH 30	1998	-	High	1.6" Type D ACP over 1CST (AC-15-5TR) over 2.4" Type B ACP over 8" CRCP over 8" CT subbase over 8" Lime treated subgrade. Cracking - needs some attention pretty quickly.
Atlanta	Miles Garrison	IH 30	1996	Microsurface in 2002 or 2003	High	2" Type C ACP (constructed in 1996) over 4" ACP over 8" CRCP over 8" cement treated sub-base over 6" select material.
Atlanta	Miles Garrison	US 59	1998	Seal Coat	Medium	ACP Dense graded overlay. To be removed for placement of CRCP later in 2006.
Atlanta	Miles Garrison	US 59 (SB lanes only)	2001	Seal Coat	Medium	2" 12.5 mm Superpave over 4" 25 mm Superpave over 11" of existing ACP over 16" LFA treated subgrade. Total section length is about 0.35 mile.
Atlanta	Miles Garrison	US 59 (SB lanes only)	2001	Seal Coat	Medium	2" 12.5 mm Superpave over 4" 25 mm Superpave over 6" of existing ACP over 16" LFA treated subgrade. This section is showing some flushing in the wheel paths. Miles thought it is from the last seal coat. I wasn't as sure. Total section length is about 0.3.
Atlanta	Miles Garrison Mike Anderson	US 79	1988	Overlay in 2001 was first thing done to it. Seal Coat more recently.	Low	1.5" Type D ACP over 8" Type B or C ACP over 10" LFA treated existing base (may have crushed concrete in it). This section overlaid 5-6 years ago & still excellent. 2004 ADT = 8,100.
Beaumont	John Barton (email)	SH 62	1988	Unknown	Medium	Mr. Barton said it was last overlaid in 1988.
Brownwood	Elias Rmeili	US 190	1977	3 seals since 1977	Medium	2-course Surface Treatment over 8 inches Type A Gr 2 flex base.
Brownwood	Elias Rmeili	US 183	1981	2 seals since 1981	Medium	2-course Surface Treatment over 10 inches Type A Gr 2 flex base.
Brownwood	Elias Rmeili	US 190	1986	2 seals since 1986	Medium	2-course Surface Treatment over 10 inches Type A Gr 2 flex base.
Brownwood	Elias Rmeili	US 67/84 in Bangs	1980	Seal Coat 2003	Medium	1.5" Type D ACP over 4.5" ASB over 6" flex base. Current ADT is 9,000 with 17% trucks.
Bryan	Darlene Goehl	FM 3058	1990	-	Low	Seal Coat, 12" Limestone base, scarified and reshaped roadway.
Bryan	Darlene Goehl	SH 21 (EB only)	1992	Recent seal coat	Medium	1.5" Hot Mix, 15" limestone base, 8" lime-treated subgrade.

Nominated Successful Flexible Pavements (Continued)

TxDOT District	Nominators	Highway Identification	Year Constructed	Last Treatment	Traffic Level	Pavement Structure & Comments
Corpus Christi	Peter Stricker	US 181	2004	-	Medium	2” Type C with PG 76-22, 6” Type B, 17” flex base, geogrid. Too new.
Dallas	G.Moonshower	IH 635	2005	-	High	SMA, Type C level-up, CRCP. Too new.
Dallas	A. Mehdibeigi	US 175	1991-1995	-		SPS-5 Section.
Fort Worth	A. Wimsatt	SH 183	1985	-	Medium	2” Type D ACP w/ AC-10 & 3% SBR, JCP
Fort Worth	A. Wimsatt	SH 183	1985	-	Medium	2” Type D ACP w/ AC-10 & 3% SBR, JCP
Fort Worth	A. Wimsatt	SH 121	1985	Microsurface 1997	High	2” Type D ACP w/ AC-10 & 3% SBR, CRCP
Fort Worth	A. Wimsatt	SH 121	1985	Microsurface 1997	High	2” Type D ACP w/ AC-10 & 3% SBR, CRCP
Fort Worth	A. Wimsatt	SH 183	1985	Microsurface 1997	High	2” Type D ACP w/ AC-10 & 3% SBR, CRCP
Fort Worth	A. Wimsatt	FM 157	1986	-	High	2” Type D ACP w/ AC-10 & 3% SBR, asphaltic concrete.
Fort Worth	A. Wimsatt	SH 171	1992	-	High	2” SMA, old ACP, flex base (oldest SMA in Texas).
Fort Worth	A. Wimsatt	BIH 35	1992	-	High	2” SMA, JCP (oldest SMA in Texas).
Fort Worth	A. Wimsatt	FM 51	1994	-	High	2” Type D ACP w/ AC-10 & 3% SBR, asphaltic concrete.
Fort Worth	A. Wimsatt	FM 730	1996	-	Medium	2” Type D ACP w/ AC-10 & 3% SBR, asphaltic concrete.
Houston	Tony Yrigoyen	SH 6	1986	New PFC overlay 2005		PFC, ASB, excellent rating from construction.
Houston	Eliza Paul	IH 10	2000	-	High	This section overlaid 5-6 years ago & still excellent.
Laredo	Rosa Trevino Rene Soto	FM 1472	1995	Resurfaced in Feb 2001	High	2” Type D ACP (placed in 2001) over 5” Type B ACP w/ 12” lime-treated Flex Base over 8” lime-treated Subgrade. In 2005, ADT = 21,100 and % Trucks = 27.7%. One lane is currently barricaded, so now would be an excellent time to sample and test.
Laredo	Rosa Trevino Rene Soto	FM 1472	1995	Resurfaced in Feb 2001	High	2” SMA (placed in 2001) over 5” Type B ACP w/ 12” lime-treated Flex Base over 8” lime-treated Subgrade. In 2005, ADT = 21,100 and % Trucks = 27.7%. SMA moving a little at a stop light under terrific truck pounding, otherwise it looks excellent.
Laredo	Rosa Trevino Rene Soto	IH 35	2001	-	High	Perpetual Pavement. 3” of ¾” SMA over 3” Stone-Filled ACP over 8” Stone-filled ACP over 2” of ½” Superpave over 8” lime-treated Subgrade (3% lime). 2001 ADT = 12,400. Pavement Design and mix designs available.
Lubbock	Stacy Young	FM 303	1970	Sealed 1986, 1991, 1999	Low	2-course surface treatment over 6” new flex base over 4” salvage flex base (caliche/limestone base). This section has a current job to add shoulders. Will be sealed again afterward.
Lubbock	Stacy Young	SH 83	1975	Sealed 1979, 1989, 2005	Medium	2-course surface treatment over 6” new flex base over 6” salvage flex base (caliche/limestone bases).
Lubbock	Stacy Young	FM 1585	1986	Seal coat 2000	Medium	2-course surface treatment over 5.5” new flex base over 2.5” salvage flex base (caliche/limestone bases).
Lubbock	Stacy Young	SH 86	1987	Sealed 1982, 1991, 2000	Low	3-course surface treatment over 7” new flex base over 3” to 5” salvage flex base (caliche/limestone bases).
Lubbock	Stacy Young	FM 1760	1973	Sealed 1992 & 2002	Low	2-course surface treatment over 6” caliche/limestone base.
Lubbock	Stacy Young	FM 1760	1987	Sealed 1992 & 2002	Low	2-course surface treatment over 6.25” new caliche/limestone base over 3.75” salvage flex base.
Lufkin	Paul Montgomery	US 287	1969	Seal coat some time	Medium	1” HMAC, 8” asphalt treated base, 6” lime-treated subgrade (15#/SY). 2004 ADT = 1,850.
Odessa	S. Smith N. Brito III Ciro Baeza	IH 10	1978	Rubber seal 1999	Medium	2-course surface treatment w/ rubber chip seal over 5” Gr 1 flex base over 6” Gr 4 flex base.
Odessa	S. Smith N. Brito III Ciro Baeza	IH 10	1978	Rubber seal 1999	Medium	2-course surface treatment w/ rubber chip seal over 8” Gr 1 flex base over 6” Gr 4 flex base.

Nominated Successful Flexible Pavements (Continued)

TxDOT District	Nominators	Highway Identification	Year Constructed	Last Treatment	Traffic Level	Pavement Structure & Comments
Odessa	S. Smith N. Brito III Ciro Baeza	IH 10	1979	Rubber seal 1999	Medium	2-course surface treatment w/ rubber chip seal over 8" Gr 1 flex base over 6" Gr 4 flex base
Odessa	S. Smith N. Brito III Ciro Baeza	IH 10	1983	Rubber seal 2000	Medium	2-course surface treatment w/ rubber chip seal over 10" Gr 1 flex base over 6" Gr 4 flex base
Odessa	S. Smith N. Brito III Ciro Baeza	SH 176	1997	-	Medium	2" CMHB-F over asphalt-rubber seal coat over existing 1.5" ACP over ~8" flex base
Odessa	S. Smith N. Brito III Ciro Baeza	US 385	1998	-	Medium	1.75" CRM-CMHB over hot rubber SC (constructed in 1998) over existing 2.5" ACP over 10" flex base (constructed in 1979)
Odessa	S. Smith N. Brito III Ciro Baeza	FM 181		-		Series of SMRP sections.
Odessa	S. Smith N. Brito III Ciro Baeza	B158 (Wall Street)	1973	1.5" ACP milled in 1986 and 2" ACP placed		Curb and getter urban pavement in city of Midland. Concrete pavement under inside lanes from Pecos Street to O Street. Outside lanes - 1.5" ACP surface over 8" ASB placed in 1973.
Odessa	S. Smith N. Brito III Ciro Baeza	IH 20	1999	-	High	2" CMHB-F over 2" Superpave in WB lanes only over 1CST (hot rubber) over about 7" existing ACP over 14" flex base.
San Angelo	Karl Bednarz	US 377	1949	Seal coats, most recent in 2005	Low	2-course surface treatment over 5" limestone flex base.
San Angelo	Karl Bednarz	US 377	1970	Seal coats, most recent in 2005	Low	1-course surface treatment over 75#/SY Type DD Limestone Rock Asphalt over 9" limestone flex base.
San Angelo	Karl Bednarz	IH 10	1969	Seals and Overlays	Medium	1" ACP surface course over 1.7" ACP base course over ~10" limestone flex base.
San Angelo	Karl Bednarz	IH 10	1980	Seals and Overlays	Medium	1.25" ACP surface over 1.5" ACP level-up (constructed in 1993) over 2-course surface treatment and 14" limestone flex base (constructed in 1980).
San Angelo	Karl Bednarz	US 87	1972	Seal in 2003 because of some problem areas in ACP	Medium	2" CMHB-C over petromat (constructed in 2002) over 3CST over 12" flex base (constructed in 1972). ADT 4,400. Section may be built on top of rock.
San Antonio	Mike Coward	SH 173	1956	Seals	Medium	2-course surface treatment over 5" flex base. Medina River to Medina County line.
San Antonio	Mike Coward	FM 1340	1966-1969	Seals	Low	2-course surface treatment over 6" flex base. SH 41 to Mo Ranch.
San Antonio	Mike Coward	FM 2771	1964	Seals	Low	2-course surface treatment over 5" flex base. SH 16 to SH 173.
San Antonio	Mike Coward	SH 41	1958-1962	Seals	Low	2-course surface treatment over 8" flex base. Real County line to SH 27.
San Antonio	Mike Coward	FM 1283	1987	Seal Coat 2000	Medium	2-course surface treatment over 8" flex base or 3" old base and surface plus 6" flex base. Only minor maintenance other than seal coat in 2000.
San Antonio	Mike Coward D. Cranford	RM 2828	1969	Seals	Low	2-course ST over 6" flex base. NAPA Award winner. SH 16 to SH 173.
San Antonio	Patrick Downey	Loop 1604		-		SPS-9 series of short sections.
Waco	D. Schwarz	IH 35	1972	Mill/overlay 1983	High	Mill 3" and replace in 1991 (current condition), 7" ASB, 6" gravel base, 6" lime-treated subgrade.
Waco	D. Schwarz	FM 3223	1985	Overlaid 1992	Medium	Original 2-course ST over 10" gravel base, widened and 1.5" Type D ACP in 1985, 1.25" Type D ACP in 1992.
Wichita Falls	Ralph Self	FM 1134	1996	-	Low	2-course ST, 6-inch limestone flex base, fly ash (6%) treated subgrade.
Wichita Falls	Ralph Self	FM 3492	1996	-	Low	2-course ST, 10-inch limestone flex base, 2 inches salvaged asphalt & sandstone base from old county road.
Wichita Falls	Ralph Self	FM 440	1999	-	Low	2-course ST, 8" limestone flex base.
Wichita Falls	Ralph Self	US 287	2002	-	High	1.25" PFC, 2.5-3.9" stone filled HMAC (PG 76-22), existing ACP over JRCP & existing ACP over CRCP. Won NAPA Award. Shown in D. Rand presentations. No winter maintenance problems to date.

APPENDIX D: SUMMARY OF 2004-2006 PMIS PERFORMANCE SCORES – SELECTED PAVEMENTS

2004 PMIS Pavement Performance Scores – Selected Pavements

TxDOT District	Highway Designation	Year Constructed	Annual Average Daily Traffic (AADT)	Percent Trucks	Distress Score		Ride Score		Condition Score	
					Average	Std. Dev.	Average	Std. Dev.	Average	Std. Dev.
Abilene	US 380	1966	1,643	12	92	18.76	3.7	0.31	92	20.11
Amarillo	SH 152	1995	1,354	10	98	4.83	4.6	0.24	98	4.83
Atlanta	IH 20 (WB lanes only)	1996 Overlay	14,643	35	70	46.31	4.6	0.17	70	46.31
Atlanta	IH 30	1996 Overlay	21,275	28	92	27.81	4.14	1.27	92	27.81
Atlanta	US 59	1989	7,569	23	99	1.28	4.3	0.31	99	1.28
Brownwood	US 67/84	1980	7,350	15	100	0	3.8	0.13	100	0
Brownwood	US 190	1977	1,400	24	99	4.73	4.3	0.23	99	4.73
Bryan	SH 21 (EB lanes only)	1992	5,450	14	100	1.25	4.1	0.29	100	1.25
Fort Worth	BIH 35	1992 Overlay	6,300	4	99	1	3.2	0.33	93	12.76
Fort Worth	SH 183	1985 Overlay	14,528	10	86	11.96	3	0.28	74	17.11
Fort Worth	SH 121	1985 Overlay	76,306	7	93	8.78	3.6	0.31	92	8.76
Fort Worth	SH 171	1992 Overlay	6,713	16	90	27.88	4.2	0.1	90	27.88
Houston	SH 6	1985	8,576	17	97	6.4	3.8	0.30	96	10.96
Laredo	FM 1472	2001 Overlay	19,022	26	100	0	2.7	1.37	72	42.33
Lubbock	FM 1585	1986	2,230	6	98	5.68	4.5	0.29	98	5.68
Lufkin	US 287	1969	1,850	38	68	46.33	2.5	1.72	68	46.33
Odessa	IH 10	1978	2,340	50	100	1.56	4.3	0.19	100	1.56
Odessa	US 385	1998 Overlay	2,144	19	100	0.24	4.5	0.24	100	0.24
Odessa	SH 176	1997 Overlay	1,750	35	100	0.85	4.3	0.45	100	0.85
San Angelo	IH 10	1969	4,320	28	97	7.84	4.3	0.19	97	7.84
San Angelo	US 377	1949	295	26	91	12.92	2.9	0.31	91	12.92
San Antonio	FM 2771	1964	892	15	97	5.3	2.9	0.24	97	5.18
San Antonio	RM 2828	1969	980	15	99	3.23	3.3	0.12	99	3.23
Waco	FM 3223	1992 Overlay	15,280	6	100	0	3.5	0.45	97	7.06
Wichita Falls	FM 3492	1996	790	11	100	0	4	0.54	100	0

2005 PMIS Pavement Performance Scores – Selected Pavements

TxDOT District	Highway Designation	Year Constructed	Annual Average Daily Traffic (AADT)	Percent Trucks	Distress Score		Ride Score		Condition Score	
					Average	Std. Dev.	Average	Std. Dev.	Average	Std. Dev.
Abilene	US 380	1966	1,675	14	96	14.23	3.5	0.24	95	15.94
Amarillo	SH 152	1995	1,304	14	95	11.71	4.6	0.2	95	11.71
Atlanta	IH 20 (WB lanes only)	1996 Overlay	15,566	35	100	1.48	4.5	0.19	100	1.48
Atlanta	IH 30	1996 Overlay	20,455	27	100	1.32	4.5	0.21	100	1.32
Atlanta	US 59	1989	5,698	24	100	0	4.3	0.31	100	0
Brownwood	US 67/84	1980	7,300	16	98	1.64	3.8	0.25	98	1.64
Brownwood	US 190	1977	1,500	25	99	4.72	4.1	0.26	99	4.72
Bryan	SH 21 (EB lanes only)	1992	5,375	14	97	12.49	4.1	0.28	97	12.49
Fort Worth	BIH 35	1992 Overlay	4,840	6	97	3.83	2.9	0.65	75	27.21
Fort Worth	SH 183	1985 Overlay	14,229	10	82	9.14	3	0.35	71	15.43
Fort Worth	SH 121	1985 Overlay	74,441	7	94	8.2	3.6	0.39	91	10.14
Fort Worth	SH 171	1992 Overlay	6,788	13	99	2.1	4.1	0.19	99	2.1
Houston	SH 6	1985	8,576	17	96	11.4	3.7	0.36	95	14.6
Laredo	FM 1472	2001 Overlay	19,567	27	100	0	3.6	0.58	96	5.79
Lubbock	FM 1585	1986	2,525	7	97	8.09	4.4	0.31	97	8.09
Lufkin	US 287	1969	1,900	39	69	11.9	3.7	0.36	68	12.7
Odessa	IH 10	1978	2,215	52	100	0.13	4.3	0.24	100	0.13
Odessa	US 385	1998 Overlay	1,971	20	100	0	4.5	0.23	100	0
Odessa	SH 176	1997 Overlay	2,000	32	100	0	4.2	0.4	100	0
San Angelo	IH 10	1969	4,045	29	100	1.39	4.4	0.19	100	1.39
San Angelo	US 377	1949	288	28	100	0.54	3	0.22	100	0.54
San Antonio	FM 2771	1964	899	15	97	6.42	2.8	0.23	95	6.3
San Antonio	RM 2828	1969	951	29	99	3.21	3.2	0.17	99	3.2
Waco	FM 3223	1992 Overlay	14,320	6	100	0	4	0.22	100	0
Wichita Falls	FM 3492	1996	938	11	100	0	4.2	0.32	100	0

2006 PMIS Pavement Performance Scores – Selected Pavements

TxDOT District	Highway Designation	Year Constructed	Annual Average Daily Traffic (AADT)	Percent Trucks	Distress Score		Ride Score		Condition Score	
					Average	Std. Dev.	Average	Std. Dev.	Average	Std. Dev.
Abilene	US 380	1966	1,693	13	96	14.00	3.4	0.38	94	19.68
Amarillo	SH 152	1995	1,250	9	95	4.23	4.5	0.20	95	4.23
Atlanta	IH 20 (WB lanes only)	1996 Overlay	15,017	39	98	5.83	4.4	0.30	98	5.83
Atlanta	IH 30	1996 Overlay	21,289	28	96	12.25	4.5	0.58	96	12.25
Atlanta	US 59	1989	5,940	23	85	19.33	4.3	0.34	85	19.33
Brownwood	US 67/84	1980	7,140	18	97	4.24	3.8	0.27	97	4.24
Brownwood	US 190	1977	1,450	20	91	6.13	4.1	0.17	91	6.13
Bryan	SH 21 (EB lanes only)	1992	5,206	15	99	2.24	4.1	0.30	99	2.24
Fort Worth	BIH 35	1992 Overlay	4,800	5	97	3.65	3.4	0.23	95	5.86
Fort Worth	SH 183	1985 Overlay	14,660	10	83	11.82	3.0	0.35	69	16.47
Fort Worth	SH 121	1985 Overlay	73,845	7	93	10.80	3.4	0.43	88	14.08
Fort Worth	SH 171	1992 Overlay	6,738	14	99	2.10	3.9	0.52	96	8.01
Houston	SH 6	1985	8,576	17	99	6.5	4.5	0.4	98	10.3
Laredo	FM 1472	2001 Overlay	20,167	17	100	0.00	3.3	0.33	96	5.06
Lubbock	FM 1585	1986	2,442	6	100	0.24	4.3	0.34	100	0.24
Lufkin	US 287	1969	1,850	35	98	7.76	3.6	0.37	98	7.99
Odessa	IH 10	1978	2,155	55	100	0.23	4.2	0.33	100	0.23
Odessa	US 385	1998 Overlay	2,110	16	97	5.17	4.5	0.24	97	5.17
Odessa	SH 176	1997 Overlay	2,250	32	98	1.83	4.2	0.44	98	1.92
San Angelo	IH 10	1969	3,963	30	95	7.27	4.4	0.24	95	7.27
San Angelo	US 377	1949	324	32	98	1.36	3.0	0.25	98	1.36
San Antonio	FM 2771	1964	865	16	99	3.57	2.9	0.20	98	3.61
San Antonio	RM 2828	1969	896	29	100	0.51	3.3	0.15	100	0.51
Waco	FM 3223	1992 Overlay	14,820	6	90	7.04	4.3	0.15	90	7.04
Wichita Falls	FM 3492	1996	1,015	11	100	0.00	4.1	0.17	100	0.00

APPENDIX E: SUMMARY OF 2004-2006 PMIS PAVEMENT MAINTENANCE COSTS – SELECTED PAVEMENTS

2004-2006 Annual Pavement Maintenance Costs – Selected Pavements

TxDOT District	Highway Designation	Year Constructed	Annual Average Daily Traffic (AADT)	Percent Trucks	Average Roadway Maintenance Expenditures per Lane-Mile (from PMIS)			
					2004	2005	2006	Three-Year Average
Abilene	US 380	1966	1,693	13	$24	$98	$3	$42
Amarillo	SH 152	1995	1,250	9	$1,042	$28	$219	$430
Atlanta	IH 20 (WB lanes only)	1996 Overlay	15,017	39	$3,611	$365	$2,927	$2,301
Atlanta	IH 30	1996 Overlay	21,289	28	$3,604	$1,214	$1,113	$1,977
Atlanta	US 59	1989	5,940	23	$854	$7,413	$86	$2,784
Brownwood	US 67/84	1980	7,140	18	$827	$61	$26	$305
Brownwood	US 190	1977	1,450	20	$213	$102	$9	$108
Bryan	SH 21 (EB lanes only)	1992	5,206	15	$6	$111	$289	$135
Fort Worth	BIH 35	1992 Overlay	4,800	5	$27	$740	$0	$256
Fort Worth	SH 183	1985 Overlay	14,660	10	$2,825	$59	$172	$1,019
Fort Worth	SH 121	1985 Overlay	73,845	7	$628	$1,037	$1,187	$951
Fort Worth	SH 171	1992 Overlay	6,738	14	$237	$619	$905	$587
Houston	SH 6	1985	8,576	17	$91	$3056	$96	$1,081
Laredo	FM 1472	2001 Overlay	20,167	17	$360	$19	$185	$188
Lubbock	FM 1585	1986	2,442	6	$378	$38	$604	$340
Lufkin	US 287	1969	1,850	35	$257	$9,046	$923	$3,409
Odessa	IH 10	1978	2,155	55	$22	$41	$25	$29
Odessa	US 385	1998 Overlay	2,110	16	$1	$48	$2	$17
Odessa	SH 176	1997 Overlay	2,250	32	$9	$35	$0	$15
San Angelo	IH 10	1969	3,963	30	$27	$0	$5	$11
San Angelo	US 377	1949	324	32	$955	$2,162	$11	$1,043
San Antonio	FM 2771	1964	865	16	$0	$58	$108	$55
San Antonio	RM 2828	1969	896	29	$0	$0	$108	$36
Waco	FM 3223	1992 Overlay	14,820	6	$1,460	$7	$113	$527
Wichita Falls	FM 3492	1996	1,015	11	$0	$0	$0	$0

APPENDIX F: DATABASE CONCEPTUAL DATA MODEL GLOSSARY

Texas Successful Flexible Pavement Glossary

ENTITY: **TSP 111 TX INV SECTIONS ID**
DEFINITION: This entity documents basic information about the successful flexible pavement, primarily the highway type and number, the geographic location, and geometric data.

ENTITY: **TSP 112 TX INV LAYER**
DEFINITION: This entity describes individual pavement layers within the pavement structure. A pavement structure is normally composed of a number of different pavement layers.

ENTITY: **TSP 113 TX INV PMA LAYER**
DEFINITION: This entity provides basic information about the individual materials composing a specific pavement layer.

ENTITY: **TSP 114 TX INV SUBGRADE**
DEFINITION: This entity identifies physical characteristics of the subgrade upon which the pavement structure is placed.

ENTITY: **TSP 115 TX INV UNBOUND**
DEFINITION: This entity provides physical characteristics of unbound pavement layers within the pavement structure. Unbound pavement layers are those which do not include asphalt, cement, lime, or fly ash.

ENTITY: **TSP 116 TX INV PMA ASPHALT**
DEFINITION: This entity documents the classification, source, and the physical characteristics of the asphalt binder contained in a pavement layer.

ENTITY: **TSP 117 TX INV SHOULDER**
DEFINITION: This entity identifies the roadway's shoulder type, layers, and geometric characteristics.

ENTITY: **TSP 118 TX INV GRADATION**
DEFINITION: This entity provides the gradation of the aggregate contained in a pavement layer.

ENTITY: **TSP 119 TX INV PMA MIX**
DEFINITION: This entity provides basic asphalt layer mixture design information, including asphalt additives and volumetric data.

ENTITY: **TSP 120 TX INV STABIL**
DEFINITION: This entity documents the type, class, and amount of stabilizer used in an individual pavement base layer.

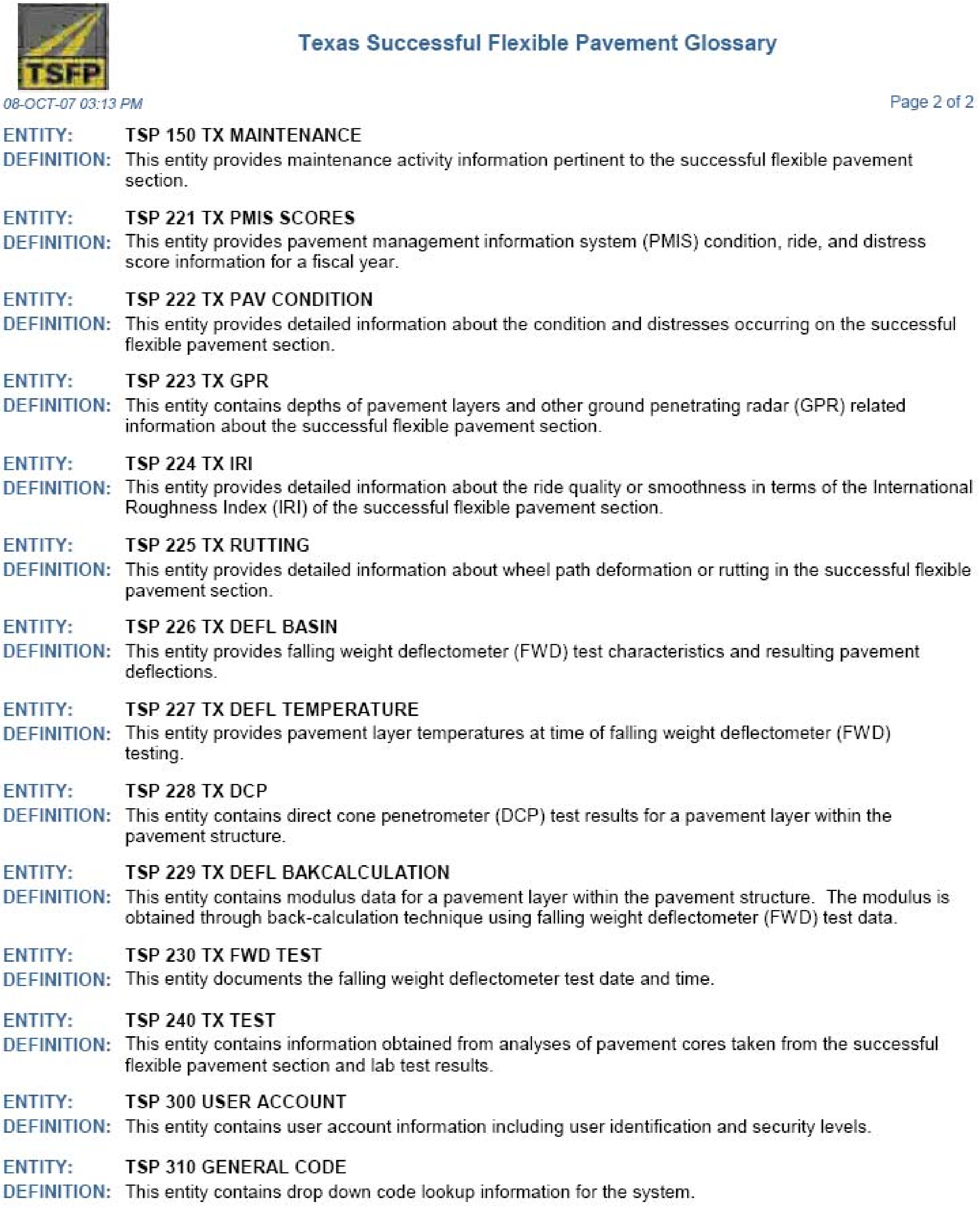
ENTITY: **TSP 121 TX COUNTY**
DEFINITION: This entity contains the TxDOT county location of the successful flexible pavement section. A list of Texas counties is the domain of this entity.

ENTITY: **TSP 122 TX DISTRICT**
DEFINITION: This entity contains the TxDOT district location of the successful flexible pavement section. A list of Texas districts is the domain of this entity.

ENTITY: **TSP 126 TX SECTION STATUS**
DEFINITION: This entity provides identifier information for status of pavement section records within the pavement database (PDB). A section can be labeled either as Nominated or Validated.

ENTITY: **TSP 130 TX TRAFFIC**
DEFINITION: This entity provides traffic data and corresponding data sources pertinent to the successful flexible pavement section.

ENTITY: **TSP 140 TX WEATHER**
DEFINITION: This entity provides weather information for the location of the successful flexible pavement section.



Texas Successful Flexible Pavement Glossary

08-OCT-07 03:13 PM

Page 2 of 2

ENTITY: **TSP 150 TX MAINTENANCE**
DEFINITION: This entity provides maintenance activity information pertinent to the successful flexible pavement section.

ENTITY: **TSP 221 TX PMIS SCORES**
DEFINITION: This entity provides pavement management information system (PMIS) condition, ride, and distress score information for a fiscal year.

ENTITY: **TSP 222 TX PAV CONDITION**
DEFINITION: This entity provides detailed information about the condition and distresses occurring on the successful flexible pavement section.

ENTITY: **TSP 223 TX GPR**
DEFINITION: This entity contains depths of pavement layers and other ground penetrating radar (GPR) related information about the successful flexible pavement section.

ENTITY: **TSP 224 TX IRI**
DEFINITION: This entity provides detailed information about the ride quality or smoothness in terms of the International Roughness Index (IRI) of the successful flexible pavement section.

ENTITY: **TSP 225 TX RUTTING**
DEFINITION: This entity provides detailed information about wheel path deformation or rutting in the successful flexible pavement section.

ENTITY: **TSP 226 TX DEFL BASIN**
DEFINITION: This entity provides falling weight deflectometer (FWD) test characteristics and resulting pavement deflections.

ENTITY: **TSP 227 TX DEFL TEMPERATURE**
DEFINITION: This entity provides pavement layer temperatures at time of falling weight deflectometer (FWD) testing.

ENTITY: **TSP 228 TX DCP**
DEFINITION: This entity contains direct cone penetrometer (DCP) test results for a pavement layer within the pavement structure.

ENTITY: **TSP 229 TX DEFL BAKCALCULATION**
DEFINITION: This entity contains modulus data for a pavement layer within the pavement structure. The modulus is obtained through back-calculation technique using falling weight deflectometer (FWD) test data.

ENTITY: **TSP 230 TX FWD TEST**
DEFINITION: This entity documents the falling weight deflectometer test date and time.

ENTITY: **TSP 240 TX TEST**
DEFINITION: This entity contains information obtained from analyses of pavement cores taken from the successful flexible pavement section and lab test results.

ENTITY: **TSP 300 USER ACCOUNT**
DEFINITION: This entity contains user account information including user identification and security levels.

ENTITY: **TSP 310 GENERAL CODE**
DEFINITION: This entity contains drop down code lookup information for the system.