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TEXAS PERPETUAL PAVEMENT DESIGN AND CONSTRUCTION GUIDELINES

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

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CHAPTER 1. INTRODUCTION

Since 2001, Texas has designed and constructed perpetual pavements on heavily trafficked highways. The perpetual pavement takes into account the increased structural demands due to heavy truck traffic, where cumulative one-direction traffic loading of more than 30 million 18-kip equivalent single axle loads (ESALs) over a 20–30 year design life is projected. By definition and unlike conventional flexible pavements, the perpetual pavements, also commonly known as full-depth asphalt pavements, are pavement structures designed to have a virtually infinite fatigue and full-depth rut life, requiring only periodic surface renewal for at least 50 years. To date, there are 10 perpetual pavement sections in service within Texas. Based on the Texas Department of Transportation (TxDOT) initial design, a typical structure of existing Texas perpetual pavement consists of the following:

- 22 in. total thickness hot mix asphalt (HMA) layers.
- 8 in. thickness of lime or cement treated base layer.
- A well compacted in-situ subgrade layer.

Based on the evaluation of global data related to perpetual pavement design, the Texas perpetual pavements required the thickest HMA layers while the perpetual pavement sections using thinner HMA layers than Texas show good field performance. Thus, the Texas perpetual pavement needs possibly significant improvement in material quality and thickness reduction for cost-effectiveness.

This report documents the revised guidelines and recommendation for the design, construction, and performance evaluation of Texas perpetual pavement structures including structural thickness design, design software, construction practice, and performance evaluation strategies, consisting of:

- Chapter 1 – Introduction.
- Chapter 2 – Overview of Perpetual Pavements.
- Chapter 3 – Texas Perpetual Pavement Design Recommendation.
- Chapter 4 –Design and Structural Analysis of Texas Perpetual Pavement.
- Chapter 5 – Mix Designs and Material Properties.
- Chapter 6 – Perpetual Pavement Construction and Performance Evaluation.
- Chapter 7 – Summary.

CHAPTER 2. OVERVIEW OF TEXAS PERPETUAL PAVEMENT

Perpetual pavement, especially appropriate for heavily trafficked highways, is defined as a long-lasting thick HMA pavement structure with a service life in excess of 50 years without major structural rehabilitation and/or reconstruction activities (in particular the intermediate and bottom layers). Deep seated structural distresses such as bottom-up fatigue cracking and/or full-depth rutting are considered unlikely, or if present, are very minimal. However, they are subject to periodic surface maintenance and/or renewal in response to surface distresses in the upper layers of the pavement (*1*). With these pavement structures, distresses and rehabilitation activities are confined to the easily accessible and replaceable surface portions of the pavement. So, when surface distresses reach undesirable levels, an economical solution is often to replace or simply overlay the top layers. These rehabilitation considerations are especially significant on heavily trafficked highways where lane closures/user-delays may be cost prohibitive.

PERPETUAL PAVEMENT DESIGN CONCEPT

The perpetual pavement concept was derived on a mechanistic principle that thickly designed HMA pavements with the appropriate material combinations, if properly constructed, will structurally outlive traditional design lives while simultaneously sustaining high traffic volumes/loads. The perpetual pavement design philosophy is such that the pavement structure must:

- Have enough structural strength to resist structural distresses such as bottom-up fatigue cracking, permanent deformation, and/or rutting.
- Be durable enough to resist damage due to traffic forces (abrasion) and environmental effects (e.g., moisture damage).

The perpetual pavement mechanistic design principle consists of providing enough total pavement thickness and flexibility in the lowest HMA layer to avoid bottom-up fatigue cracking and enough stiffness in the upper pavement layers to prevent rutting. The principal approach to perpetual pavement design focuses on pavement response related to both distresses (fatigue cracking and rutting), and the following limiting strain criteria are used as mechanistic benchmarks:

- Tensile strain at the bottom of composite HMA layer: $< 70\ \mu\varepsilon$ (for limiting bottom-up fatigue cracking).
- Compressive strain at the top of subgrade: $< 200\ \mu\varepsilon$ (for limiting full-depth rutting).

Also, special attention is required in designing a durable foundation to provide long-term support to the pavement structure/traffic loading and to reduce seasonal support variation due to environmental effects (e.g., freeze-thaw and moisture changes).

TYPICAL PERPETUAL PAVEMENT STRUCTURAL SECTION

In general, a perpetual pavement structure consists of, but not limited to, impermeable, durable, and wear resistant top layers; a stiff, thick rut-resistant intermediate layer for structural strength; and a flexible fatigue-resistant bottom layer resting on a permanent, stable foundation. While the layer thicknesses are generally variable depending on the traffic loading, environmental location, and materials/mix-designs, the rut-resistant intermediate layers are often the thickest element to provide sufficient load carrying capability. Figure 1 illustrates a typical perpetual pavement structure recommended from the Asphalt Pavement Alliance.

Layer 1	**Surface: High quality HMA or OGFC**	**1.5 - 3.0 in.**
Layer 2	**Intermediate: High Modulus rut Resistant Material**	**4.0 - 7.0 in.**
Layer 3	**HMA Base: Durable Fatigue Resistant Material**	**3.0 - 4.0 in.**
Layer 4	**Pavement Foundation**	

Figure 1. Typical Perpetual Pavement Structure (*1*, *2*).

BENEFIT AND ADVANTAGES OF PERPETUAL PAVEMENT

Since the perpetual pavements have thicker and/or more HMA layers, the initial construction costs should be higher than conventional HMA pavements. However, in the long-term and view of life cycle cost, it has been shown that the perpetual pavements have the following benefits:

- High structural capacity for high traffic volume and heavy truck loads areas such as overweight corridors and energy sector zones.
- More efficient design and construction, eliminating costly overlay conservative pavements.
- Lower maintenance/rehabilitation-induced agency and user delay costs.
- Lower energy costs while the pavement is in service.

To provide the advantages above, it is ensured that the perpetual pavement should be designed and constructed adequately.

CHAPTER 3. TEXAS PERPETUAL PAVEMENT DESIGN RECOMMENDATION

The Texas perpetual pavement concept used to build existing perpetual pavement sections was initially proposed based on the TxDOT 2001 memorandum, as presented in Table 1, which is relatively conservative with the potential for further optimization (*3*). Also, based on the field performance evaluations of the in-service Texas perpetual pavement sections and the extensive literatures reviews on perpetual pavement practices at local, national, and international levels, the total structural HMA thickness is cost-effectively and satisfactorily reducible from the current average of 22 in. to an optimal of about 16 in. without compromising the perpetual pavement structural performance (i.e., 36 percent reduction in total HMA layer thickness). The current perpetual pavement structural design of 22 in. total HMA layer thickness is overly conservative and not cost-effective. A 36 percent reduction in HMA layer thickness may also potentially translate into up to 36 percent cost savings.

Table 1. Current Materials and Thickness of Texas Perpetual Pavement.

Layer No.	Mixture/Material	Thickness (in.)	Function
1	SMA	2.0–3.0	Renewable HMA surface
2	¾" SFHMA	2.0–3.0	Load transitional layer
3	1" SFHMA	≥ 8.0	- RRL - Main structural load-carrying layer
4	½" SFHMA	3.0–4.0	- RBL - Fatigue resistant - Impermeable layer
5	Lime treated base	≥ 6.0	Providing stable foundation at the stage of construction
6	Subgrade		

Legend: SMA = Stone matrix asphalt; SFHMA = Stone-filled hot mix asphalt; RRL = Rut resistant layer; RBL = rich bottom layer

Also, it has been found imperative to change the SFHMA mix currently used for the HMA layers including an RRL due to undesirable constructability problems. On this basis, a transition to a more optimal perpetual pavement structural design with about 16 in. total HMA thickness is recommended as presented in Figure 2.

Current Texas PP Design (≈ 22" HMA)

Layer#	Material Type	Thick. (in.)
1	SMA	2.0-3.0
2	¾" SFHMA	2.0-3.0
3	1" SFHMA	8.0-13.0
4	RBL	3.0-4.0
5	Base	≥ 8.0
Compacted in-situ subgrade soil		

Proposed Texas PP Design (≈ 16" HMA)

Layer#	Material Type	Thick. (in.)
1	SMA	2.0-3.0
2	SP-C or Type C	2.0-3.0
3	SP-B or Type B	6.0-8.0
4	SP-C or Type C	2.0-4.0
5	Base	6.0-8.0
Compacted in-situ subgrade soil		

Figure 2. Proposed Future Texas Perpetual Pavement Structural Design.

FUTURE TEXAS PERPETUAL PAVEMENT DESIGN CONCEPT

With the proposed Texas perpetual pavement structural design in Figure 2, a generalized Texas perpetual pavement design guide is recommended in Figure 3. The preferred minimum perpetual pavement layer thicknesses are 12 in. of total HMA layer and 6 in. of base layer.

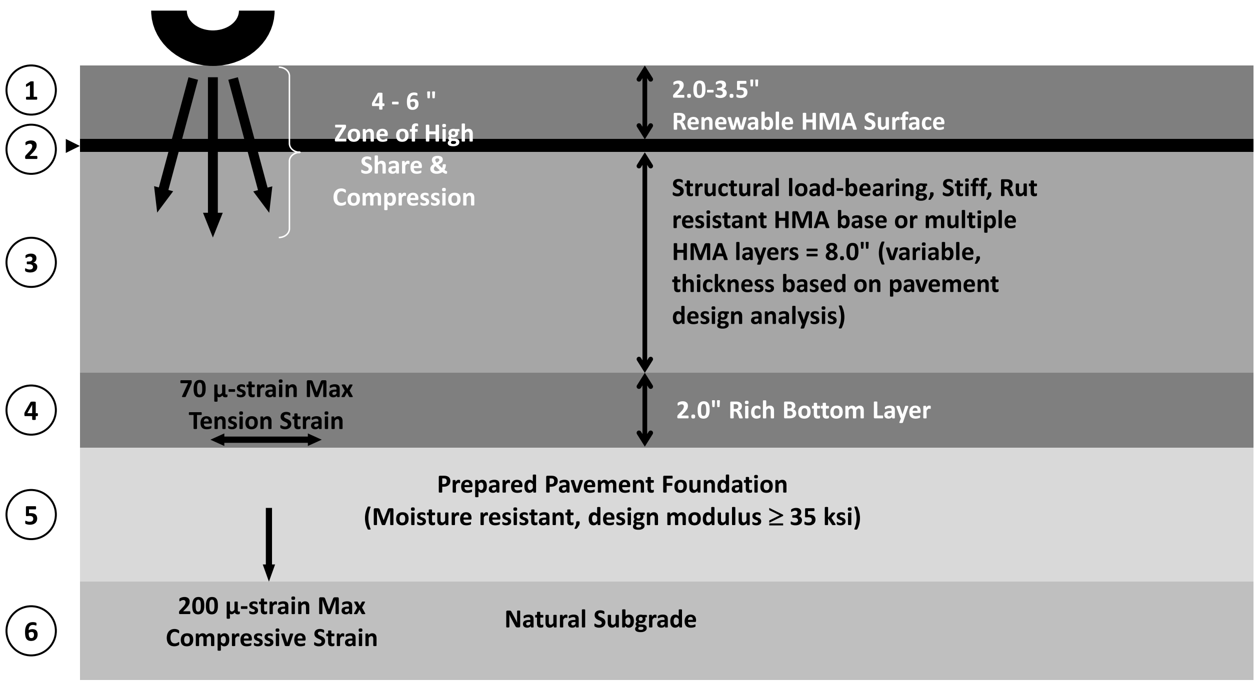


Figure 3. Generalized Texas Perpetual Pavement Design.

TEXAS PERPETUAL PAVEMENT LAYER COMPOSITION

Table 2 summarizes the layer composition for the recommended perpetual pavement structure design concept shown in Figure 3.

Table 2. Texas Perpetual Pavement Layer Composition.

Layer No.	Layer Composition	Spec Item (TxDOT 2014)	Preferred Mix Size	Preferred Thickness	PG Grade	N_{des}
1	Renewable Surface a. SMS or b. PFC on SMA	 Item 342 (PFC) Item 346 (SMA)	 SMA-D	 1.5 in. 2 in.	 76-XX 76-XX	 50 50
2	Seal Coat	Item 316	Grade 4	–	–	
3	Rut-Resistant HMA Base	a. Item 344 b. Item 341	SP-B Type B	4 × NMAS each lift	70-22[a]	50
4	RBL	Item 344	SP-C	2 in.	64-22	50
5	Prepared Pavement Foundation[b]	a. Item 247 b. Item 260 c. Item 275	–	6–12 in. 8 in. 6-12 in.	–	–
6	Natural Subgrade	–	–	–	–	–

Legend: PFC = permeable friction course; SP = Superpave; NMAS = nominal maximum aggregate size; PG = performance grade
Notes: [a]Use PG 70-22 or higher grade for all HMA mixes that fall within the top 6.0 in. if the finished pavement surface; [b]See construction consideration in Table 4

ALTERNATIVE TEXAS PERPETUAL PAVEMENT DESIGN

Based on the new design concept proposed, alternative structural designs also were recommended as a function of three traffic levels, namely: (a) traffic ESALs ≤ 30 million, (b) 30 million < Traffic ESALs ≤ 50 million, and (c) traffic ESALs > 50 million, as listed in Table 3. These alternative perpetual designs are to use dense-graded mixes such as the SP-B or Type B mix for the main structural load-carrying RRL as opposed to the coarse-graded SFHMA mixes in the current Texas perpetual pavement design concept. However, the use of higher PG asphalt-binder grades such as PG 70-22 for RRL is recommended, especially if the mixtures are placed within 6 in. of the surface.

Table 3. Alternative Texas Perpetual Pavement Designs by Traffic Level.

Layer #	Thickness (in.)	Mix Type	Designation	2014 TxDOT Spec. Item	Asphalt-Binder
(a) Traffic ESALs ≤ 30 million					
1	2	SMA	Surfacing	Item 346	PG 70-28 or better
2	2	SP-C or Type C	Load transitional layer	Item 344 or 341	PG 70-22 or better
3	≥ 6	SP-B or Type B	Main structural load carrying rut-resistant layer	Item 344 or 341	PG 64-22 or better
4	2	SP-C or Type C	Rich bottom fatigue-resistant layer (durability & impermeability)	Item 344 or 341	PG 64-22
5	≥ 6	Base	Lime or cement treatment	Item 260, 263, 275, & 276	
6	Subgrade (in-situ soil material)				
Minimum pavement structure thickness = 18 in. (12 in. HMA and 6 in. base)					
(b) 30 million < Traffic ESALs ≤ 50 million					
1	2	SMA	Surfacing	Item 346	PG 70-28 or better
2	3	SP-C or Type C	Load transitional layer	Item 344 or 341	PG 70-22 or better
3	≥ 8	SP-B or Type B	Main structural load carrying rut-resistant layer	Item 344 or 341	PG 64-22 or better
4	2	SP-C or Type C	Rich bottom fatigue-resistant layer (durability & impermeability)	Item 344 or 341	PG 64-22
5	≥ 6	Base	Lime or cement treatment	Item 260, 263, 275, & 276	
6	Subgrade (in-situ soil material)				
Minimum pavement structure thickness = 21 in. (15 in. HMA and 6 in. base)					
(c) Traffic ESALs > 50 million					
1	2-3	SMA	Surfacing	Item 346	PG 70-28 or better
2	≥ 3	SP-C or Type C	Load transitional layer	Item 344 or 341	PG 70-22 or better
3	≥ 8	SP-B or Type B	Main structural load carrying rut-resistant layer	Item 344 or 341	PG 64-22 or better
4	2-4	SP-C or Type C	Rich bottom fatigue-resistant layer (durability & impermeability)	Item 344 or 341	PG 64-22
5	≥ 8	Base	Lime or cement treatment	Item 260, 263, 275, & 276	
6	Subgrade (in-situ soil material)				
Minimum pavement structure thickness = 23 in. (15 in. HMA and 8 in. base)					

TEXAS PERPETUAL PAVEMENT CONSTRUCTION CONSIDERATIONS

Construction consideration aspects as related the perpetual pavement layers described in Table 2 are summarized in Table 4. Typical construction aspects for HMA pavements can be in the TxDOT specification (*4*).

Table 4. Texas Perpetual Pavement Construction Consideration.

Layer No.	Construction Considerations
1	**Renewable Surface.** The renewable surface lift will need periodic (8–14 years) replacement. The SMA surface must have very low permeability. PFCs are highly recommended in locations where overall traffic volume is high and average rainfall is at least 25 in. per year. In this case, the PFC will be placed on top of the SMA layer (minimum PFC thickness should 1.5 in.).
2	**Seal Coat.** The application of a seal coat is strongly recommended for projects that are subject to prolonged exposure to traffic and environmental conditions prior to placement of the SMA mat. This layer also helps in mitigating intrusion of water into the HMA layers.
3	**Rut-Resistant Layer.** The RRL is placed in multiple lifts. All HMA mix that is within 6 in. of the surface must use a minimum PG 70-22 binder. The lower lifts may use PG-64-22 binder. Adjusting or lowering the number of gyrations for these mixes should be considered to improve the workability and impermeability aspects of these mixes. Full bond between layers must be promoted through the proper application of tack coats.
4	**Rich-Bottom Layer.** The primary purpose of the RBL is to establish a fatigue resistant bottom to the overlying HMA composite mass. The functionality of this layer becomes more critical with structures that are composed of less than 12 in. total HMA depth. The RBL also serves as a stress relieving layer. Full bond between the RBL and overlying RRL must be promoted through the proper application of tack coat. The RBL should be highly resistant to intrusion of moisture rising within the substructure. Comply with maximum density requirements under Item 341 or Item 344.
5	**Prepared Foundation.** This stage of construction is crucial to providing a stable foundation. Laboratory tests must be performed to evaluate the moisture susceptibility of the material and selecting the appropriate stabilizer if needed. Possible alternatives for the prepared foundation include: 1. Grade 1-2 Type A Flexible Base. 2. Cement treated base (target 300 psi UCS/80% retained after 10-day capillary rise). 3. Lime stabilized subgrade (≥ 8.0 in.), passing Tex-121-E, Part I, with 50 psi retained strength after 10 days capillary rise (≥ 6% lime).
6	**Natural Subgrade.** A geotechnical investigation must be performed to determine the composition of the natural subgrade and to check for the presence of organics and sulfates. The suitability, type, and depth of stabilization must be established based on the geotechnical tests. For pavement foundation using option 1 or 2 above, stabilize to a minimum 8.0 in. depth in cases where existing subgrade cannot provide sufficient and uniform support. Overall prepared foundation and pavement structure should limit potential vertical rise to no more than 1.5 in.

CHAPTER 4. DESIGN AND STRUCTURAL ANALYSIS OF TEXAS PERPETUAL PAVEMENT

This chapter provides limiting strain criteria as mechanistic benchmarks of perpetual pavement design and recommendation of design software including flexible pavement design system (FPS) (*5*) and Texas mechanistic-empirical flexible pavement design system (TxME) (*6*).

LIMITING STRAIN CRITERIA

The limiting strain criteria used as the thresholds of mechanistic response for bottom-up fatigue cracking and full depth (subgrade failure) rutting for Texas perpetual pavement design are:

- Horizontal tensile strain at the bottom of the lowest HMA layer (εt): < 70 με.
- Vertical compressive strain at the top of subgrade (ε_v): < 200 με.

A perpetual pavement structure meeting these strain response criteria is considered to be structurally adequate both in terms of fatigue cracking (bottom-up) and full-depth rutting. On the other hand, pavement structures not meeting these criteria would need to have one or more layer thicknesses or material properties modified to comply. However, 70 με of horizontal tensile strain, referred to as endurance limit (EL), should be used for initial thickness design and strain check in the FPS 21. In the TxME, more specific EL values determined based on HMA mix types and climatic condition would be used to check the maximum tensile strain at the HMA bottom and verify the perpetual pavement designs from FPS 21.

PERPETUAL PAVEMENT STRUCTURAL DESIGN AND ANALYSIS SOFTWARE

To design perpetual pavement meeting the strain criteria and predict performance during design life, a two-step process would be performed:

1. Run FPS 21 for initial thickness design, response analysis, and strain check.
2. Run TxME for verification of FPS 21 design and performance/distress prediction.

FPS 21

The FPS 21 design system is comprised of the trial pavement structure development and thickness design and the design checks including performance prediction. Since the FPS 21 provides a design check function based on the mechanistic design concept, users can ensure if a perpetual pavement design meets the limiting strain response criteria. Also, the software allows for up to seven layers to be considered and therefore can sufficiently accommodate perpetual pavements. The steps to design perpetual pavement using FPS 21 are as follows.

Step 1

Select a 30-year analysis period. Although the analysis period will not be critical since staying reasonably below the strain criteria is ultimate goal, just meeting the criteria does not ensure adequately reliability. That is, just meeting the 70 με criterion could mean a high probability of failure when a perpetual pavement structure accounts for poor design, material variability, and construction practice.

Step 2

Use a confidence level of C (95 percent). While the confidence level is not tied to the limiting strain criteria, it is useful in ensuring a reasonable beginning thickness to evaluate further.

Step 3

Enter the 20-year cumulative ESALs in the 18 kips ESAL 20 YR (1 DIR) field. When three or more lanes are planned in one direction, adjusted 20-year cumulative ESALs should be calculated using lane distribution factor and entered into the FPS 21. The following distribution factors are used as a multiplier to the one-direction cumulative ESALs to establish the design traffic:

- 1 or 2 lanes in one direction: 1.0.
- 3 lanes in one direction: 0.7.
- More than 4 lanes in one direction: 0.6.

Step 4

Select a minimum time to first overlay of 15 years. The 15 years is recommended because this time frame will usually allow development of a structure of sufficient depth to meet the strain criteria and still ensure a reasonable reliability. The FPS-calculated overlay will not be a structure requirement, but should reasonably mimic an almost certain requirement for surface renewal to mitigate the effect of surface wear, oxidation, top-down cracking, etc.

Step 5

Use Design Type 7 (User defined pavement) for the perpetual pavement design and select a material type required for each pavement layer.

Step 6

Run the design.

Step 7

Conduct a design check of the limiting strain criteria by activating FPS 21 mechanistic check. The horizontal red arrow indicator symbol (for tensile strain) should be placed at the lowest HMA layer by dragging it into the place, as shown in Figure 4. By selecting the run button on the input screen, the mechanistic check output screen shows the strain results. As shown in Figure 5, the HMA tensile strain and subgrade compressive strain should be lower than the limiting strain criteria specified for the design to be valid.

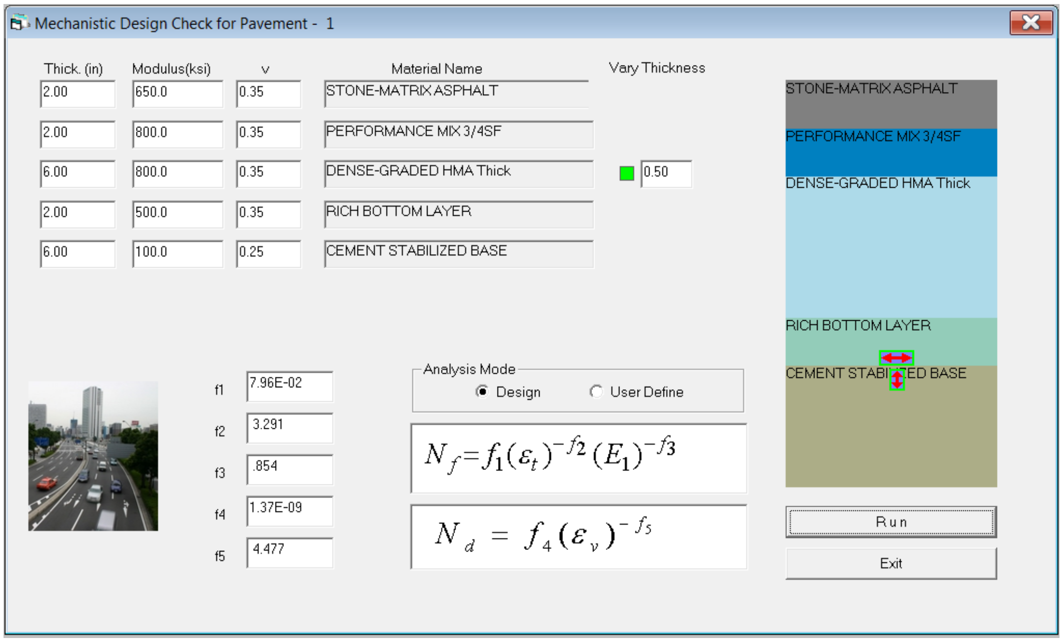


Figure 4. Mechanistic Check Input Screen.

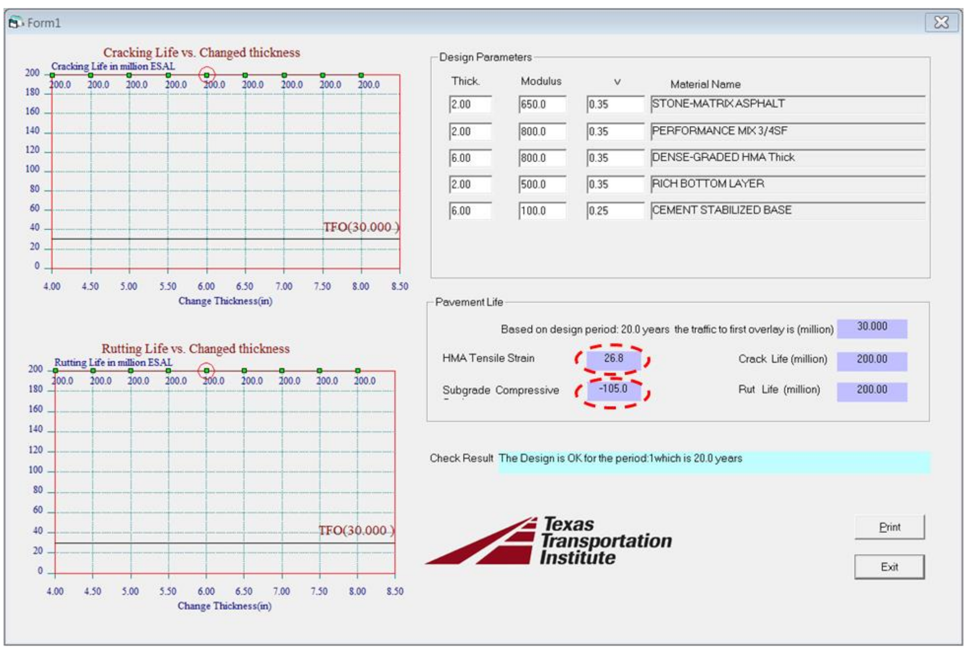


Figure 5. Mechanistic Check Output Screen.

Step 8

For each FPS recommended design option, click "TxME" button (Figure 6) to activate TxME program to perform performance prediction. The layer thicknesses, material types, traffic, and location information will be automatically imported into TxME system. The description of how to use TxME to perform performance prediction and verification is described below.

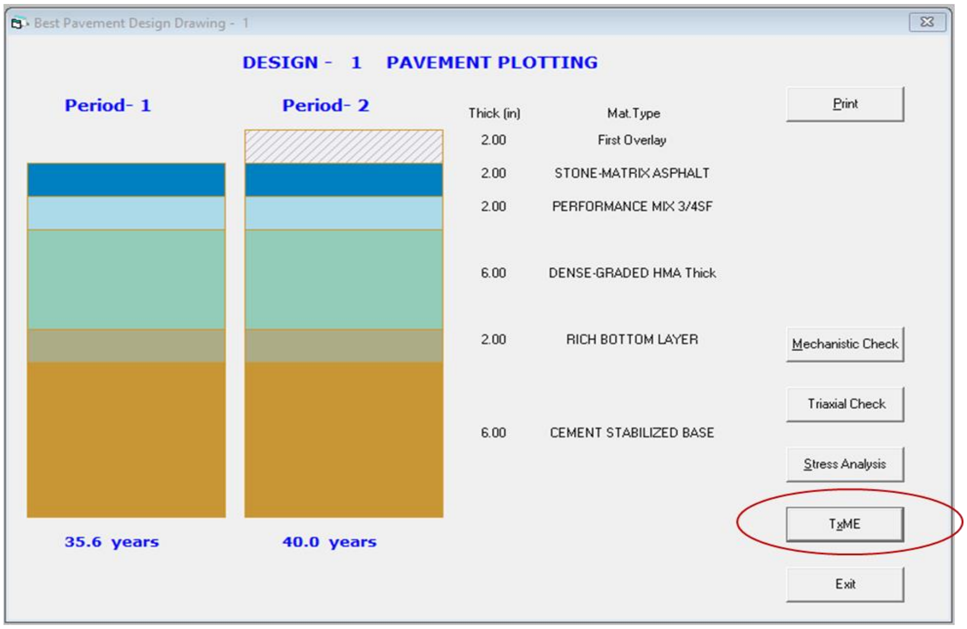


Figure 6. TxME Check Button.

TxME

Figure 7 shows the main input screen of TxME activated by the FPS 21. The project inputs are divided into four categories: Structure, Climate, Traffic, and Reliability. Double-clicking each tree node activates the corresponding input screen.

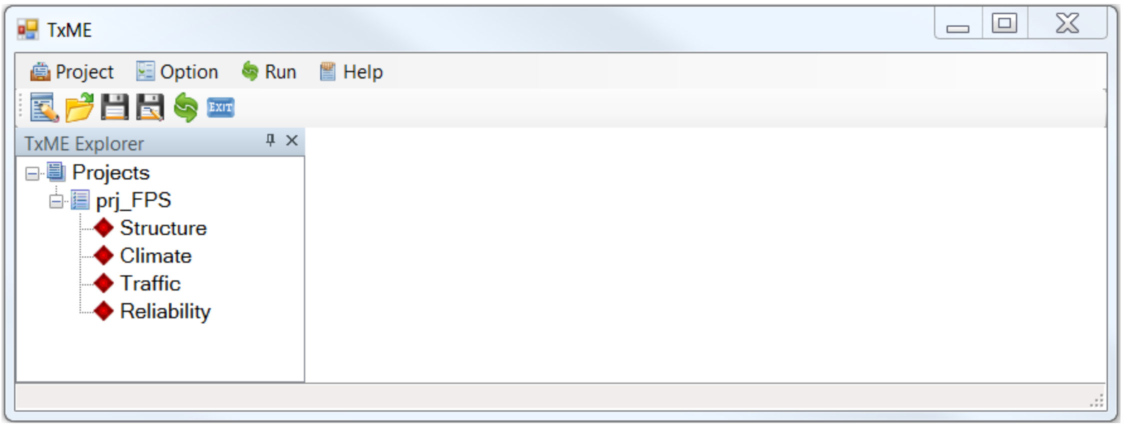


Figure 7 TxME Main Screen.

Step 1

Double click the "Structure" tree node to open the pavement structure input screen. As illustrated in Figure 8, this input screen consists of four windows: Pavement type and project location, Material type for each layer, Pavement structure, and Material properties. Since the pavement layer information was imported from FPS design, the "Pavement Type" radio button shows

“Perpetual” and the corresponding layer thicknesses and material types are the same as those in Figure 6.

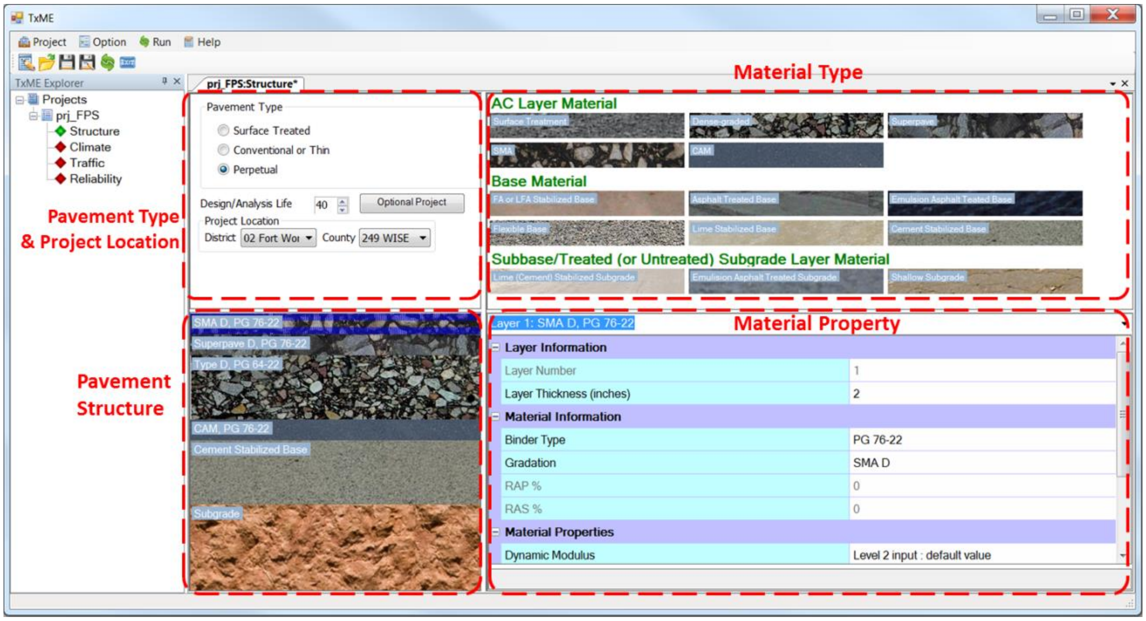
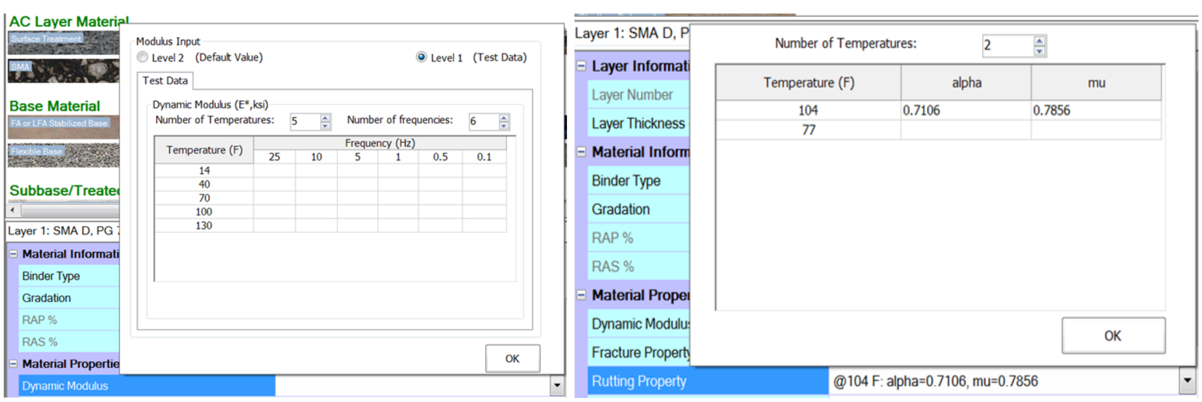


Figure 8. TxME Pavement Structure Input Screen.

Step 2

Click each layer in the Pavement Structure window to browse or edit corresponding layer thickness and material properties in the Material Property window. In this window, user can change layer thickness, binder type, gradation, and material properties, if needed. While the TxME provides the default material properties embedded for each layer, user can enter the material properties obtained from the laboratory or field. Figure 9 shows, as an example, the input screens for dynamic modulus and rutting property of AC layer.



(a) Dynamic Modulus **(b) Rutting Property**

Figure 9. Material Property Input Screens for AC Layer.

Step 3

Double click the “Climate” tree node to open the climate input screen as shown in Figure 10. There are two ways to attach the climatic information as:

- To assign a specific weather station when a dedicated weather station is located for a project.
- To interpolate climatic data by averaging climate information of weather stations near the project location. For this, the user should enter the coordinate of project and select weather stations provided by relative distance from the project location.

The user can look into the weather data at the right part of the screen.

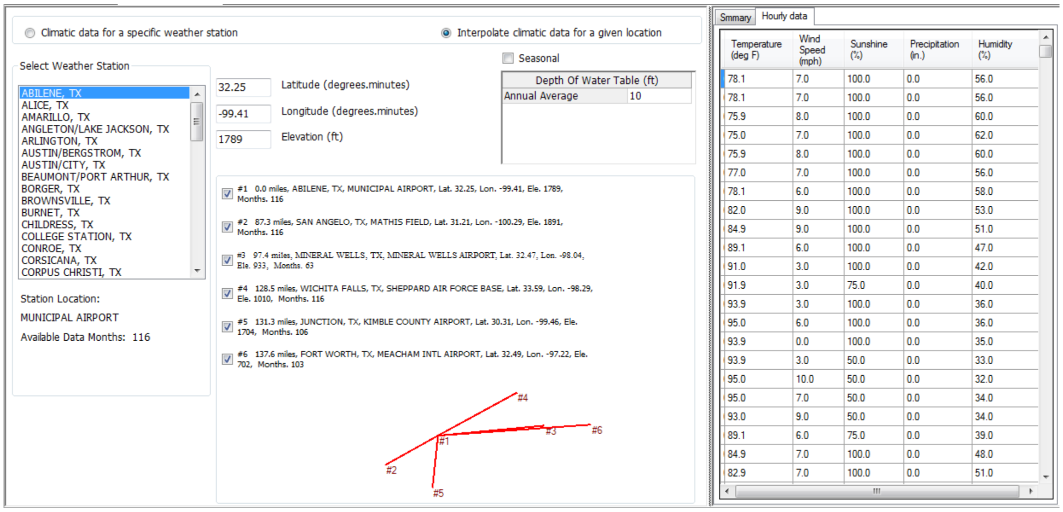


Figure 10. Climatic Data Interpolation Input Screen.

Step 4

Double click the “Traffic” tree node to open the traffic input screen. There are two levels of traffic inputs in TxME: ESALs (Level 2) and axle load spectrum (Level 1). For Level 2, the average daily traffic (ADT)-Beginning, ADT-End 20 years, and total 18-kip ESALs during 20 years (one lane and one direction) were imported directly from FPS 21 program (Figure 11).

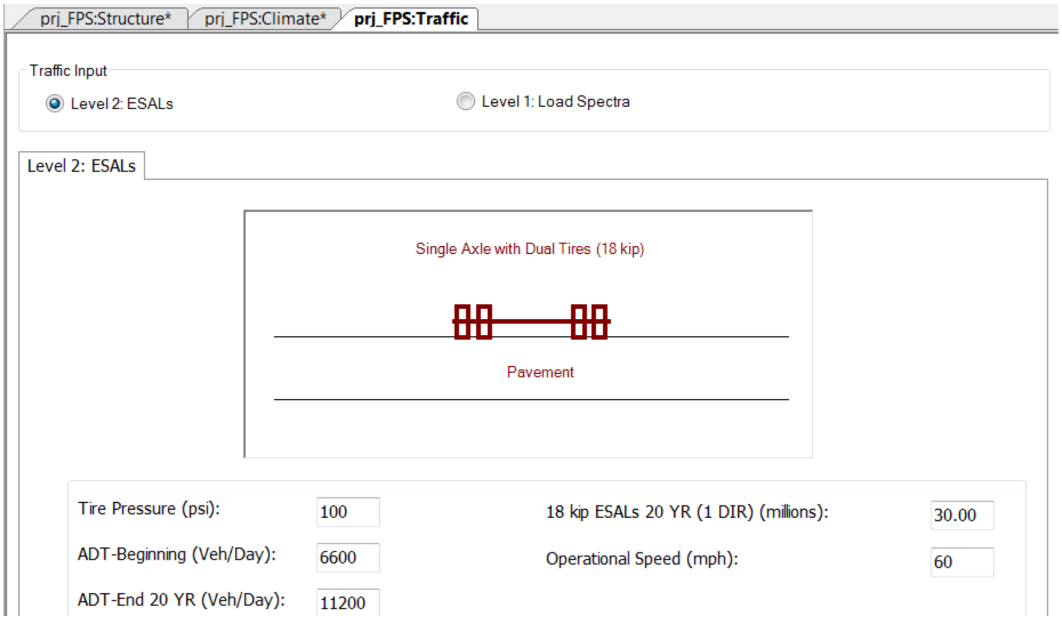


Figure 11. Traffic ESALs (Level 2) Input Screen.

As shown in Figure 12, Level 1 requires more detailed traffic data including annual average daily truck traffic, monthly adjustment, axle load distribution, and vehicle class distribution and growth rate. For the monthly adjustment and axle load distribution, the user can either enter the data directly or load input files that were already generated, as shown in Figure 13.

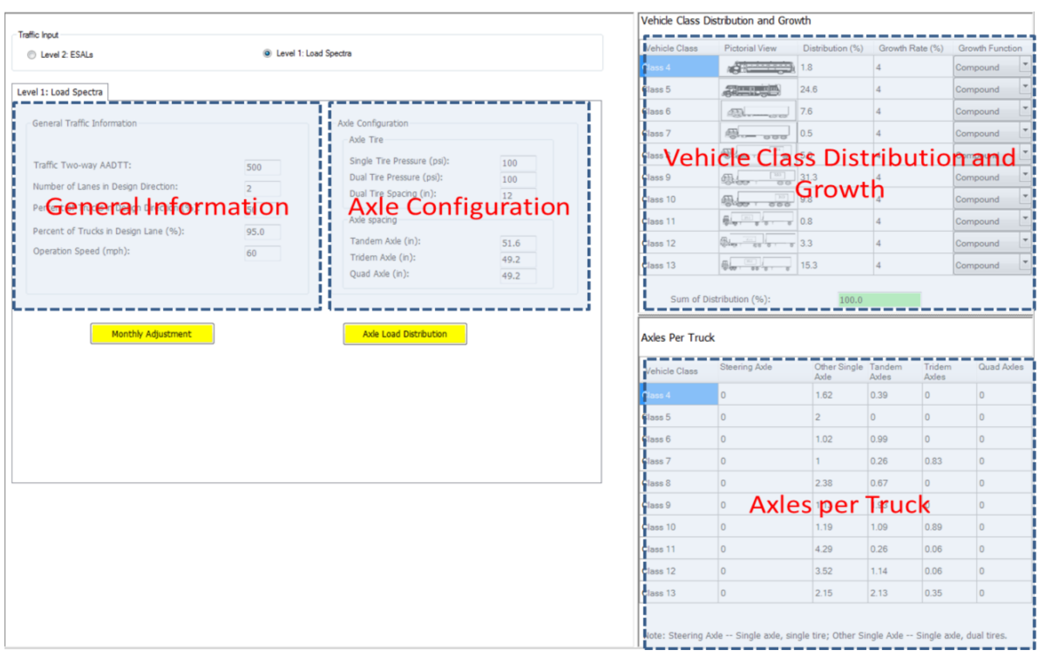
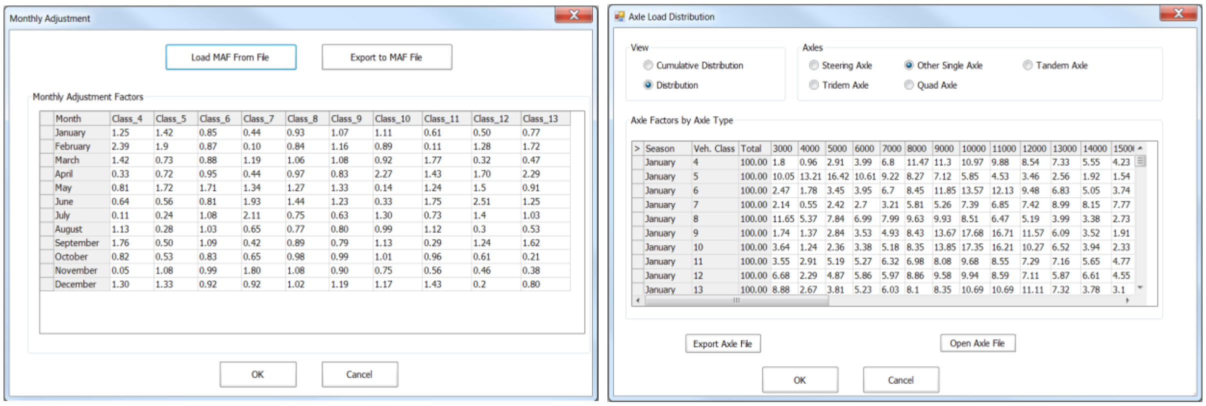


Figure 12. Traffic Load Spectrum (Level 1) Input Screen.



(a) Monthly Adjustment **(b) Axle Load Distribution**

Figure 13. Traffic Data (Level 1) Input Screen.

Step 5

Double click the "Reliability" tree node to open the reliability input screen, as shown in Figure 14. In this screen, users can modify the performance limits and coefficients of variation. Both performance criteria and variability parameters are related to pavement structure and pavement type. Thus, whenever the pavement structure or pavement type changes, these parameters are changed accordingly. Also, since the EL depends on the climate condition and AC mix types, the default EL value will change by location of weather station and binder grade/gradation type of the bottom AC layer.

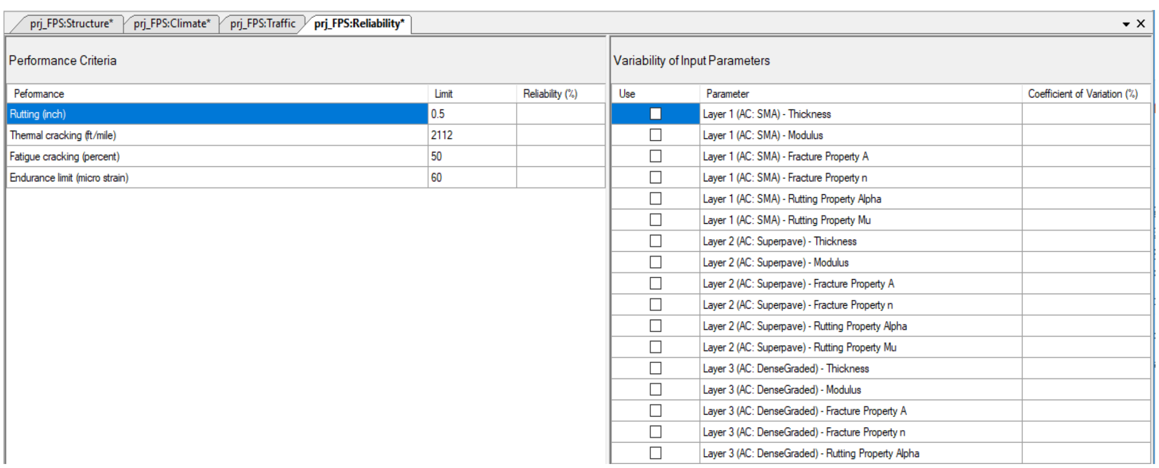
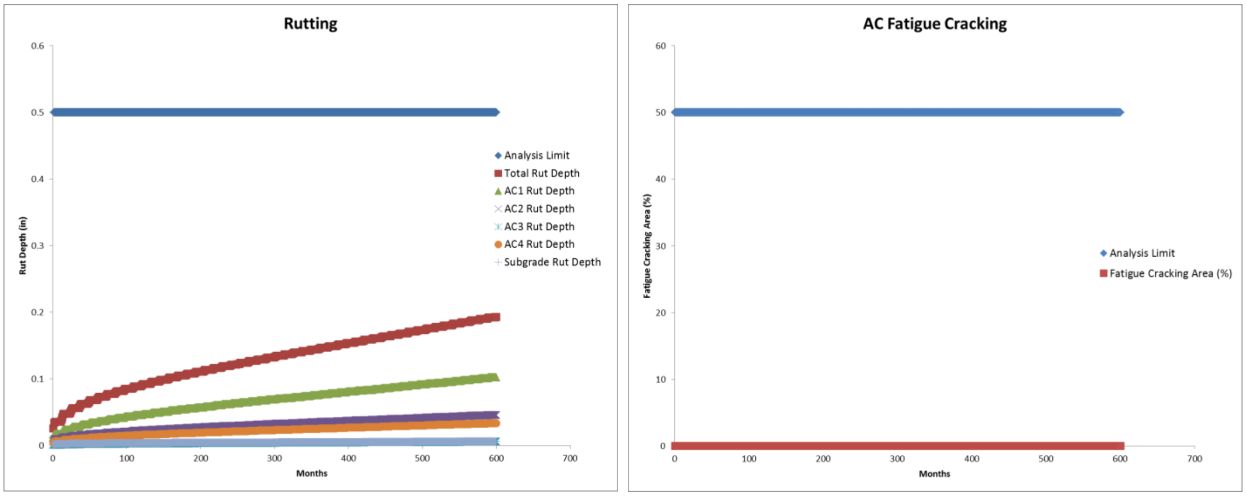


Figure 14. Reliability Related Input Screen.

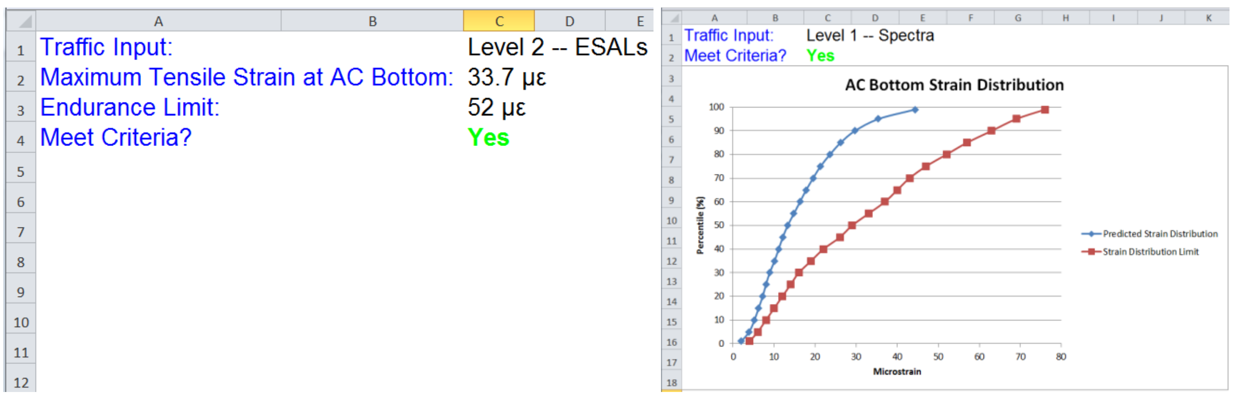
Step 6

Run TxME to start the performance analysis. The analysis results are organized into an Excel file consisting of three parts: input summary, analysis result table, and distress plots. Figure 15 shows the rutting and AC fatigue cracking plots generated from the TxME. The EL at the bottom of AC layers is defined as the maximum strain at the traffic input level 2 (ESALs) and the strain distribution at traffic level input 1 (Load spectrum), as shown in Figure 16, respectively.



(a) Rutting Plot **(b) AC Fatigue Cracking Plot**

Figure 15. Output of TxME in Excel File Format.



(a) Traffic Level 2: ESALs **(b) Traffic Level 1: Load Spectra**

Figure 16. EL of TxME Design.

Step 7

Compare the distress prediction with the performance criteria. Users can modify the layer thicknesses or material types until all the performance meet the criteria.

PERPETUAL PAVEMENT LAYER THICKNESS

Table 5 summarizes the recommend minimum perpetual pavement layer thicknesses.

Table 5. Texas Perpetual Pavement Layer Thickness Recommendation.

Layer No.	Layer Description	Thickness (in.)	Comment
1	Renewable surface	2–3.5	1.5 in. PFC (optional) + 2 in. SMA
2	Seal coat	–	Non-structural layer
3	Main structural load-bearing HMA layer (Rut-resistant layer)	≥ 8	Variable thickness based on structural design
4	RBL	2–4	Stress-relieving and impermeable layer.
5	Prepared Pavement Foundation	≥ 6	Lime or cement treated
6	Subgrade	-	Natural soil material

While the minimum total thickness of HMA layers is 12 in., 16 in. total HMA thickness was structurally found to be optimal from the study (*7*).

CHAPTER 5. MIX DESIGNS AND MATERIAL PROPERTIES

Since the perpetual pavement consists of different functional asphalt layers, it is important to select proper materials based on the function of each layer. The selection of structurally strong, stable foundation material is also important to support traffic loadings and compaction efforts during construction process. In this chapter, recommendation for mix-design and material properties for the Texas perpetual pavement structures are provided, including laboratory testing protocol and design layer moduli values.

HMA MATERIALS

It has been found imperative to change the SFHMA mix used for existing Texas perpetual pavement pavements including an RRL due to undesirable constructability and compactability problems (*7*, *8*). Thus, recommendations are to use dense-graded mix such as the SP or Type B mix for the main structural load-carrying and RRL, as seen in Figure 2 and Table 2. As for field performance, the dense-graded mix such as Type B was found to be comparable to the SFHMA mixes and even superior in some instances, in terms of subsurface defects and other anomalies such as localized voiding, vertical segregation, and de-bonding between HMA lifts. For selecting asphalt-binder grade, use of higher PG such as PG 70-22 is recommended to eliminate potential for HMA permanent deformation, especially the HMA mixes in this layer fall within the top 6.0 in. of the finished pavement surface.

To ensure perpetual pavement structural integrity and adequate performance, a proper testing method should be applied to characterize HMA mix properties required to meet the functional requirements of each layer. Also, as the design method of perpetual pavement moves forward to the mechanistic-empirical (M-E) design, additional laboratory testing should be performed to obtain typical inputs required to run the M-E design software. Table 6 lists recommended HMA test protocol to provide typical material inputs required to run the M-E software such as the TxME.

Table 6. Laboratory Testing Protocol for Texas Perpetual Pavement.

Test	Material Properties	Test parameter/output	Test Method/Specification
M-E design input	Dynamic modulus	Dynamic modulus: - Temp.: 14–130°F - Freq.: 0.1–25 Hz	AASHTO TP 62-03
	Fracture property	*A* and *n* at 77°F	Overlay Tester Fracture Test
	Rutting property	α and μ at 104°F and 122°F	Repeated loading permanent deformation test
	EL	Strains at different temperature	AASHTO TP107-14
Screening test	Hamburg Wheel Tracking Test	Rut depth at 20,000 wheel load passing at 122°F	Tex-242-F
	Indirect tensile strength test	Tensile strength	Tex-226-F

Legend: AASHTO = American Association of State Highway and Transportation Officials

BASE AND SUBGRADE MATERIALS

The base and subgrade materials used in existing perpetual pavement structures have performed satisfactorily, with sufficient stiffness and strength (*7*, *8*). The measured in-situ falling weight deflectometer (FWD) moduli values were greater than 35 and 15 ksi, respectively. Seasonal moduli variations were also very marginal, substantiating that both the base and subgrade materials are relatively non-moisture susceptible. Therefore, the current TxDOT specifications of base and subgrade treatment should continue to be used, with emphasis on achieving a minimum base or foundation strength above the natural subgrade of 35 ksi for perpetual pavement structures.

For the cement treated base layer, an unconfined compressive strength of 300 psi should be used to select the required cement content and the use of 80 percent retained strength on capillary saturation should be enforced. The lime stabilized subgrade is recommended to pass test method Tex-121-E with 50 psi retained strength after 10-day capillary saturation.

RECOMMENDED LAYER DESIGN MODULI VALUES

Based on laboratory dynamic modulus and field FWD tests, the recommended layer design moduli values in the Texas perpetual pavement designs at 77°F are listed in Table 7. The recommended moduli values are expected to yield optimal perpetual pavement structural designs, with sufficient consideration for construction and material property variability.

Table 7. Recommended Texas Perpetual Pavement Design Moduli Values at 77°F.

Layer	Material	Spec Item (TxDOT 2014)	Typical Design Modulus Value	Recommended Design Modulus Value	Poisson's Ratio
Surface	PFC (optional)	Item 342	350	300–450	0.30
	SMA	Item 346	600	500–850	0.35
RRL	SP-B	Item 344	800	600–1200	0.35
	Type B	Item 341	800	700–1300	0.35
RBL	SP-C	Item 344	500	400–650	0.35
	Type C	Item 341	500	400–650	0.35
Base		Item 247, 260, 275	≥ 35	35–150	0.30–0.35
Subgrade			Back-calculated from existing or adjacent structure		0.40–0.45

CHAPTER 6. TEXAS PERPETUAL PAVEMENT CONSTRUCTION AND PERFORMANCE EVALUATION

This chapter is to provide recommendations for best practice for construction and performance evaluation of Texas perpetual pavement. The recommendation includes performance threshold that can be used as an indicator for rehabilitation and maintenance requirements.

BEST-PRACTICE TEXAS PERPETUAL PAVEMENT CONSTRUCTION

As reported in some reports, previous experience has indicated the need for improved construction methods and better enforcement of the innovative quality control/quality assurance (QC/QA) protocols for the implementation of new Texas perpetual pavement construction procedures (*7*, *8*). This is necessary to optimize the construction quality and minimize construction-related defects including subsurface anomalies within the perpetual pavement structures. Some of the construction measures warranting future improvements include, but not limited to the following:

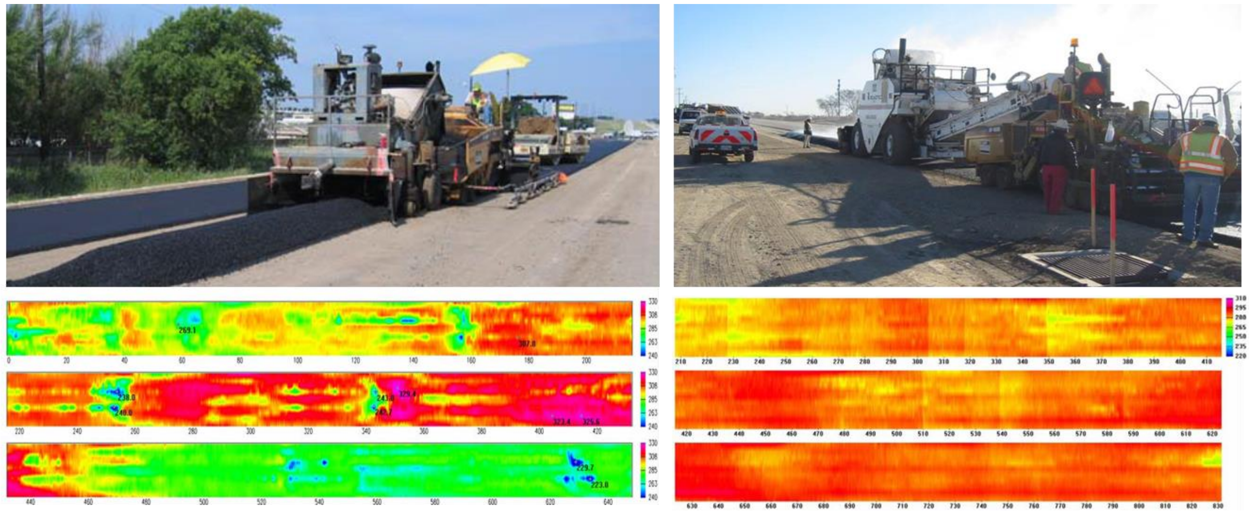
- Improving the compaction rolling patterns.
- Tightening/increasing the minimum inspection frequency in joint compaction specification.
- Eliminating trench construction (where possible).
- Enforcing joint staggering at all mat levels.
- Better transitioning techniques between concrete and HMA pavements.
- Optimizing the compacted lift thickness (RRL) to between 3 and 4 in.
- Applying tack coat as a bonding agent between all the HMA layer lifts.
- Minimizing the job mix formula asphalt binder content reductions.

Compacting Lift Thickness of HMA Layer

Compacting at a higher lift thickness tended to cause the HMA mixes to segregate vertically, creating highly localized voided areas capable of determining trapping moisture. So, for improved compaction and construction quality, 4 in. is recommended as the maximum compacted lift-thickness for the SP-B and Type B mixes. This is particularly critical where the mixes are used as the structural load-bearing layers with an overall thickness greater than 6–8 in. in the perpetual pavement structures. A 4 in. lift thickness is expected to significantly improve the compaction and construction quality of the mix/layer including density uniformity.

Use of Material Transfer Device

For the material transfer device (MTD), the combination of belly-dump trucks and windrow elevator (windrow pick-up system) was observed to be less effective and caused more thermal segregation in the HMA mat during either the cold or hot weather placement. From Figure 17(a) that is showing the comparative infrared thermal profiles for a target HMA mat placement temperature of 300°F, the placement temperature of the windrow pick-up MTDsystem was hardly attained nor was it uniform (*8*). Instead, use of the Roadtec® MTD with its internal remixing capability is recommended to yield a more consistent, uniform temperature mix due to remixing and significant on-board storage uniformity as shown in Figure 17(b). The thermal segregation caused by lower HMA mat placement temperature observed in the infrared thermal profiles coincided with the end of HMA delivery truck loads and paver stoppages. Thus, it is important to ensure pavers are supplied with sufficient HMA mix material at uniform temperatures to allow continuous, uninterrupted operations.



(a) Windrow pick-up MTD **(b) Roadtec MTD**

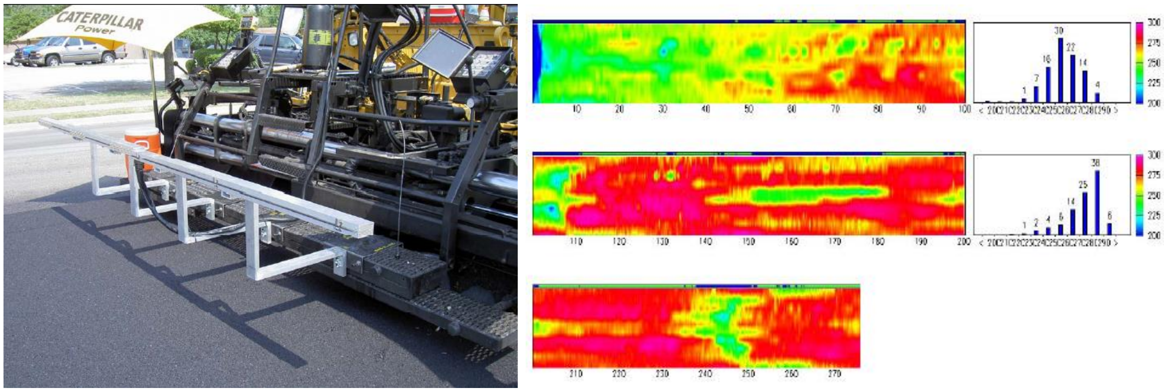
Figure 17. Comparison of MTDs and HMA Mat Temperature Profiles.

QC/QA TOOLS FOR TEXAS PERPETUAL PAVEMENT CONSTRUCTION

Along with improving the construction methods and operations, it is required to formulate QC/QA protocols consisting of effective tools and equipment to check the Texas perpetual pavement construction quality and layer uniformity during and post placement. The following tools and non-destructive testing (NDT) methods are suggested for the QC/QA monitoring of perpetual pavement construction.

Infrared Thermal Imaging System

An infrared temperature monitoring system is used to detect the temperature segregation in HMA and evaluates the uniformity and the overall quality of paving construction (Tex-244-F). This system employs a bar with an array of infrared sensors that are mounted onto the rear end of a paver. As the paver moves forward, the sensors measure the surface temperature of the uncompacted HMA mix. Figure 18 displays the paver-mounted thermal imaging system and an example of thermal infrared data collected in real time.

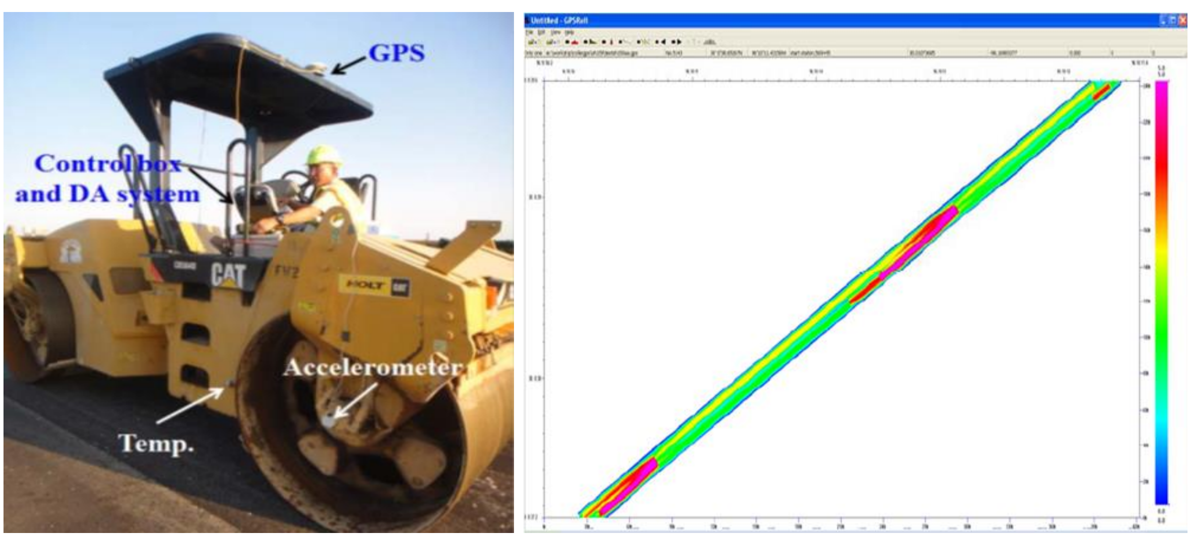


(a) Infrared System Installed on Paver **(b) Data Displayed in Real Time**

Figure 18. Infrared System and Thermal Data.

Compaction Monitoring System

For monitoring the quality of compaction in real time, the compaction monitoring system can be used to check the perpetual pavement construction quality and layer uniformity. The system consists of a global positioning system unit for tracking the location, temperature sensors for recording the mat surface temperature, and accelerometer sensors for determining the mode of operation (static or vibratory) on the roller, as shown in Figure 19(a). The system monitors the location of the roller on the HMA mat and the number of passes across the mat. Each pass is multiplied by the effectiveness factor across the roller's width to produce the compaction index distribution. Since the distribution is converted to color maps in real time as displayed in Figure 19(b), the roller operator can use it to adjust the compaction patterns (by changing the number of passes, overlapping, and overhanging) needed to achieve the required density uniformly across the HMA mat. Using known reference compaction curves, these maps can be converted to predict the density distributions (*9*, *10*).



(a) Compaction Monitoring System **(b) Real-time Compaction Effort Map**

Figure 19 Compaction Monitoring System and Display.

Ground Penetrating Radar

The ground penetrating radar (GPR) using electromagnetic wave principles and dielectric characteristics is being used to characterize pavement layer densities (air void), pavement layer thickness, and presence of free moisture both during and after construction. This unit can be used for both construction quality monitoring (density, layer thickness uniformity, segregation, etc.) and performance evaluation (i.e., forensic defects such as localized voiding, moisture presence) of perpetual pavement structures.

Coring Pavement Samples

Cored samples extracted from the field after construction are routinely used to assess the construction quality by measuring the thickness and air void (density) and to characterize the material properties by performing laboratory tests. While this method provides the most accurate detection of forensic defects and construction quality, it is a destructive test method damaging the pavement surface. Nonetheless, this is one of the cheapest, oldest, and simplest conventional methods for construction quality control assessment of HMA including perpetual pavement structures; it is also an invaluable method for forensic evaluation during performance monitoring/evaluation of in-service pavement structures including perpetual pavements.

FIELD TESTING AND PERFORMANCE EVALUATION

To monitor and evaluate the performance of Texas perpetual pavement, the following pavement response and performance data should be collected as:

- Pavement distress (rutting, cracking, etc.) by visual and/or automated distress surveys.
- Subsurface defects and anomalies by GPR.
- Deflection data by FWD.
- Surface roughness (International Roughness Index [IRI]) by high-speed profiler.
- Traffic data (permanent and/or portable weigh-in-motion).

Periodic summer and wither performance monitoring is recommended to evaluate hot and cold weather-related distresses. The performance data collected are applicable to long-term calibration of the M-E perpetual pavement design method (i.e., TxME).

Since the perpetual pavement has a different HMA structure and superior performance compared to conventional flexible HMA pavements, its own indicators and thresholds should be established to be used as metrics of rehabilitation and maintenance requirement. Table 8 lists the recommended performance thresholds for Texas perpetual pavement.

Table 8. Recommended Performance Thresholds for Texas Perpetual Pavement.

Item		Thresholds for Good Performance
Surface roughness	QC/QA IRI	65 in./mile
	IRI after 20 years	172 in./mile
Surface rutting after 20 years		0.5 in.
Fatigue cracking after 20 years		25%

CHAPTER 7. SUMMARY

This chapter summarizes recommendations for the design, construction, and performance evaluation of Texas perpetual pavement structures:

- The recommended optimal thickness of perpetual pavement HMA layers are around 14 to 16 in. Special attention is required in designing a durable foundation with a high quality granular base, cement or lime-treated base, or other engineered foundation for long-term performance.
- The perpetual pavement structure should be designed to meet the following limiting strain criteria for bottom-up fatigue cracking and full-depth rutting, respectively:
    - Tensile strain at the bottom of composite HMA layer: < 70 $\mu\varepsilon$.
    - Compressive strain at the top of subgrade: < 200 $\mu\varepsilon$.

  However, 70 $\mu\varepsilon$ of horizontal tensile strain, referred to as EL, should be used for initial thickness design and strain check in the FPS 21. In the enhanced TxME, more specific EL values determined based on HMA mix types and climatic conditions would be used to check the maximum tensile strains at the bottom HMA and verify the perpetual pavement designs of FPS 21.
- The renewable surface layer should be constructed with SMA having very low permeability. The PFC placed on the SMA layer is recommended for high traffic volume and rainfall locations.
- SP-B or dense-graded Type B should be used for the main structural load-carrying and RRL with a minimum thickness of 8 in. PG 70-22 or higher PG asphalt-binder grade should be used for the main structural load-bearing layers (i.e., SP and/or Type B mixes).
- The RBL, a minimum 2 in. thickness, should be constructed with a material to be highly resistant to intrusion of moisture rising within the substructure.
- The minimum base or foundation thickness should be 6 in. with a minimum strength of 35 ksi. Where needed, cement treatment should not be more than 3 percent. Lime treatment, on the other hand, should not be below 6 percent and should be applied in a liquid form as slurry.
- The FPS 21 software should be used for structural thickness design and strain analysis. Then, the enhanced TxME would be run for design verification and performance prediction and analysis.
- A 4-in. lift thickness is expected to significantly improve the compaction and construction quality of the mix/layer including density uniformity.
- Use of the Roadtec® MTD with its internal remixing capability is recommended to yield a more consistent, uniform temperature mix due to remixing and significant on-board storage uniformity.
- The NDT tools including the infrared thermal imaging and GPR measurements (supplemented with coring) proved very useful in monitoring the construction quality of the perpetual pavement structures. Also, for monitoring the quality of compaction in real

time, the compaction monitoring system can be used to check the perpetual pavement construction quality and layer uniformity.

- The pavement response and performance data including surface distress, FWD deflection, IRI should be collected to monitor and evaluate the Texas perpetual pavement performance. The performance data collected are applicable to long-term calibration of the M-E perpetual pavement design method.

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