TEXAS PERPETUAL PAVEMENTS – NEW DESIGN GUIDELINES

by

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LIST OF NOTATIONS AND SYMBOLS

AASHTO	American Association of State Highway and Transportation Officials
ADT	Average daily traffic
BCI	Base curvature index
DM	Dynamic modulus
ESAL	Equivalent single axle load
FDAP	Full-depth asphalt pavement
FPS	Flexible pavement system
FWD	Falling weight deflectometer
GPR	Ground penetrating radar
HDSMA	Heavy-duty stone mastic asphalt
HMA	Hot-mix asphalt
HMAC	Hot-mix asphalt concrete
HWTT	Hamburg wheel tracking test
IR	Infra-red
IRI	International roughness index
MDD	Multi-depth deflectometer
MEPDG	Mechanistic empirical design guide
MTD	Material transfer device
NDT	Non-destructive test (ing)
NMAS	Nominal maximum aggregate size
OT	Overlay tester
PFC	Porous friction course
PG	Performance grade
PI	Plasticity Index
PP	Perpetual pavement
PSI	Pavement Serviceability Index
QA	Quality assurance
QC	Quality control

LIST OF NOTATIONS AND SYMBOLS (CONTINUED)

RBL	Rich-bottom layer
RLPD	Repeated load permanent deformation test
RRL	Rut-resistant layer
SCI	Surface curvature index
SF	Stone-fill or stone filled
SFHMA(C)	Stone-fill hot-mix asphalt (concrete)
Subgrade_{W7}	Subgrade curvature index
SMA	Stone mastic asphalt
SS	Special specification
WIM	Weigh-in-motion
W_i	FWD surface deflection from ith sensor
ε_t	Horizontal tensile strain measured in microns ($\mu\varepsilon$)
ε_v	Vertical compressive strain measured in microns ($\mu\varepsilon$)
ϕ	Symbol phi used to mean diameter

CHAPTER 1

INTRODUCTION

Since 2001, the State of Texas has been designing and constructing perpetual pavements on some of its heavily trafficked highways where the expected 20-year truck-traffic estimate of 18 kip ESALs is in excess of 30 million (TxDOT, 2001). To date, there are 10 in-service perpetual pavement (PP) sections. Based on the TxDOT initial design proposals (see Appendix A), a typical Texas PP structure consists of the following (TxDOT, 2001; Walubita et al., 2009a):

- about 22 inches total thickness of hot-mix asphalt (HMA) layers;
- at least 8 inches thick treated (lime or cement) base material; and
- a well compacted in-situ subgrade soil material.

In 2005, a research study was initiated to validate, among other objectives, the Texas PP design concept and make recommendations for the future design of Texas PP structures (Walubita et al., 2009a). To achieve these objectives, various research tasks were completed including the following:

- construction monitoring and compaction quality measurements;
- extensive laboratory testing and material property characterization;
- traffic and response measurements for structural evaluations;
- field testing and periodic performance evaluations;
- comparative mix-design evaluations; and
- computational modeling and software evaluations.

Based on the findings of the study (Walubita et al., 2009a), this report documents the revised guidelines and recommendations for the future design, construction, and performance evaluation of Texas PP structures. The recommendations include guidelines for structural thickness design, design software, response criteria, mix-design, and layer moduli values.

Recommendations for future PP construction improvements and performance evaluation strategies are also presented in the report. This report consists of seven chapters as follows:

1) Chapter 1 – introduction;
2) Chapter 2 – the general PP design philosophy;
3) Chapter 3 – the general Texas PP design recommendations;
4) Chapter 4 – structural design including software recommendations and the mechanistic-empirical (M-E) response design criteria;
5) Chapter 5 – mix designs and material properties;
6) Chapter 6 – construction and performance evaluation aspects; and
7) Chapter 7 – summary of key points.

Where necessary, reference should also be made to the following technical reports that contain similar work on Texas perpetual pavements:

1) 0-4822-1 (Scullion, 2007),
2) 0-4822-2 (Walubita and Scullion, 2007), and
3) 0-4822-3 (Walubita et al., 2009a).

Additionally, reference can also be made to the companion Texas PP database and the project summary report, respectively (Walubita et al., 2009b; Walubita and Scullion, 2009).

CHAPTER 2

THE GENERAL PERPETUAL PAVEMENT DESIGN PHILOSOPHY

By definition, a perpetual pavement is 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). Its utility is especially appropriate for heavily-trafficked highways and as a direct competitor to rigid pavements. However, they are subject to periodic surface maintenance and/or renewal in response to surface distresses in the upper layers of the pavement (APA, 2002; Timm and Newcomb, 2006). Deep seated structural distresses such as bottom-up fatigue cracking and/or full-depth rutting are considered unlikely, or if present, are very minimal.

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.

THE PERPETUAL PAVEMENT CONCEPT

The PP 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 PP 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; and
- be durable enough to resist damage due to traffic forces (abrasion) and environmental effects (e.g., moisture damage).

The PP mechanistic design principle thus consists of providing enough stiffness in the upper pavement layers to prevent rutting and enough total pavement thickness and flexibility in the lowest HMA layer to avoid bottom-up fatigue cracking.

Like any other pavement structure, extended performance relies on a solid/stable 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).

THE PP MECHANISTIC DESIGN PRINCIPLE

The current PP mechanistic-empirical design principle is based on two response-limiting criteria:

- horizontal tensile strain at the bottom of the lowest HMA layer (ε_t): ≤ 70 με (for bottom-up fatigue cracking), and
- vertical compressive strain on the top of subgrade (ε_v): ≤ 200 με (for full-depth rutting).

A PP structure meeting these strain response criteria is considered to be structurally adequate both in terms of fatigue cracking (bottom-up) and full-depth rutting. Otherwise, the layer thicknesses and material properties would need to be modified.

TYPICAL PP STRUCTURAL SECTION

In general a PP structure consists of, but is 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. The layer thicknesses are generally variable depending on the traffic loading, environmental location, and materials/mix-designs. However, the rut-resistant intermediate layers are often the thickest element, providing sufficient load carrying capability. Appendix A (APA, 2002) includes an example of a typical PP structure based on the Asphalt Institute proposal.

PP TERMINOLOGY

While the terminology (e.g., thick-asphalt pavements, long-lasting asphalt pavements, long-life asphalt pavements, deep-strength asphalt pavements, extended life HMA pavements, and full-depth asphalt pavements) may differ from place to place, the basic concept is the same as described previously (APA, 2002).

Texas uses the term full-depth asphalt pavement (FDAP) for perpetual pavements. Consequently, this term shall be used synonymously with the term PP in this report to refer to perpetual pavements.

BENEFITS AND ADVANTAGES OF PERPETUAL PAVEMENTS

Overall, some of the major benefits derived from perpetual pavements include the following:

- high structural capacity for high traffic volume and heavy truck loads;
- long life and low life-cycle costs with minimal or no major structural rehabilitation activities;
- decreased user costs due to rehab or maintenance delays; and
- competitive option to rigid pavements.

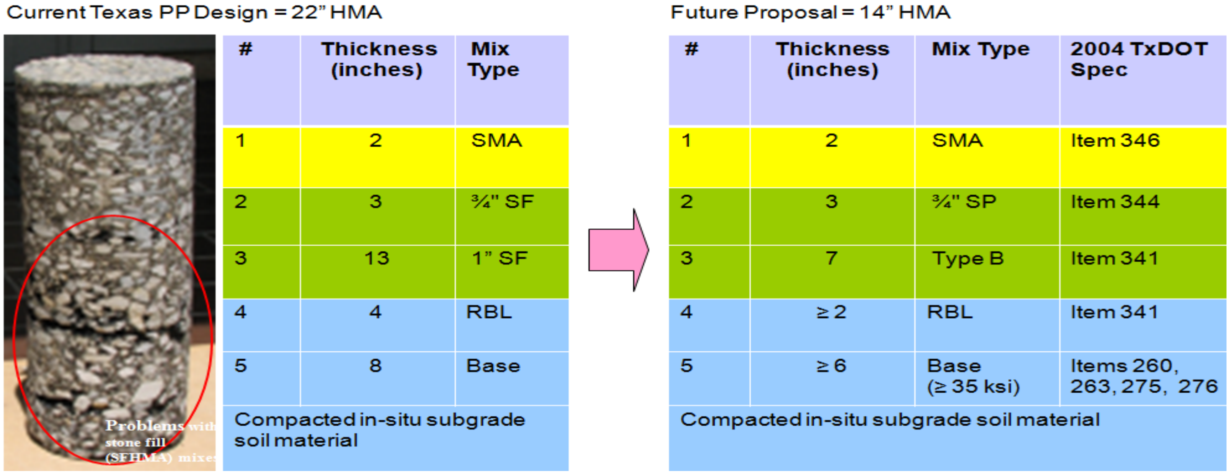
Because of the thicker and/or many HMA layers, the initial construction costs for PPs are often higher than that of conventional HMA pavements by more than 10 percent. However, the above benefits will generally outweigh this effect, particularly in the long-term, thus providing a sustainable solution to the ever growing traffic for the highway agencies. Another concern is the overall complexity, compelling the need for highly competent contractors. The multi-layered nature of these PP structures (often with multiple mix-designs and material types) means that quality control during construction is very critical and thus, the need for competent contractors.

CHAPTER 3

THE TEXAS PERPETUAL PAVEMENT DESIGN RECOMMENDATIONS

In general, the Texas PP design concept that was initially proposed based on the TxDOT 2001 memorandum (see Appendix B) was found to be relatively conservative with the potential for further optimization (TxDOT, 2001; Walubita et al., 2009a). In fact, field structural evaluations and in-situ MDD response measurements of the in-service Texas PP sections indicated that the total structural HMA thickness was reducible from the current average of 22 inches to an optimal of about 14 inches with predicted satisfactory performance (Walubita et al., 2009a).

Computational modeling based on loading projections using actual measured traffic data and material properties (i.e., measured layer moduli values) also indicated that 14-inch total HMA thickness with a 6- to 8-inch thick base was structurally sufficient for an expected traffic level of up to 75 million 18-kip ESALs. Both the M-E design requirements of 70 and 200 microstrains at the bottom of the lowest HMA layer (tensile) and on top of the subgrade (compressive), respectively, were analytically met. Performance life prediction prior to a first surface renewal was greater than 20 years; see Appendix C (Walubita et al., 2009a). On this basis, a transition to a more optimal PP structural design with about a 14-inch total HMA thickness is recommended; see Figure 3-1.



Current Texas PP Design = 22" HMA

#	Thickness (inches)	Mix Type
1	2	SMA
2	3	¾" SF
3	13	1" SF
4	4	RBL
5	8	Base
Compacted in-situ subgrade soil material		

Future Proposal = 14" HMA

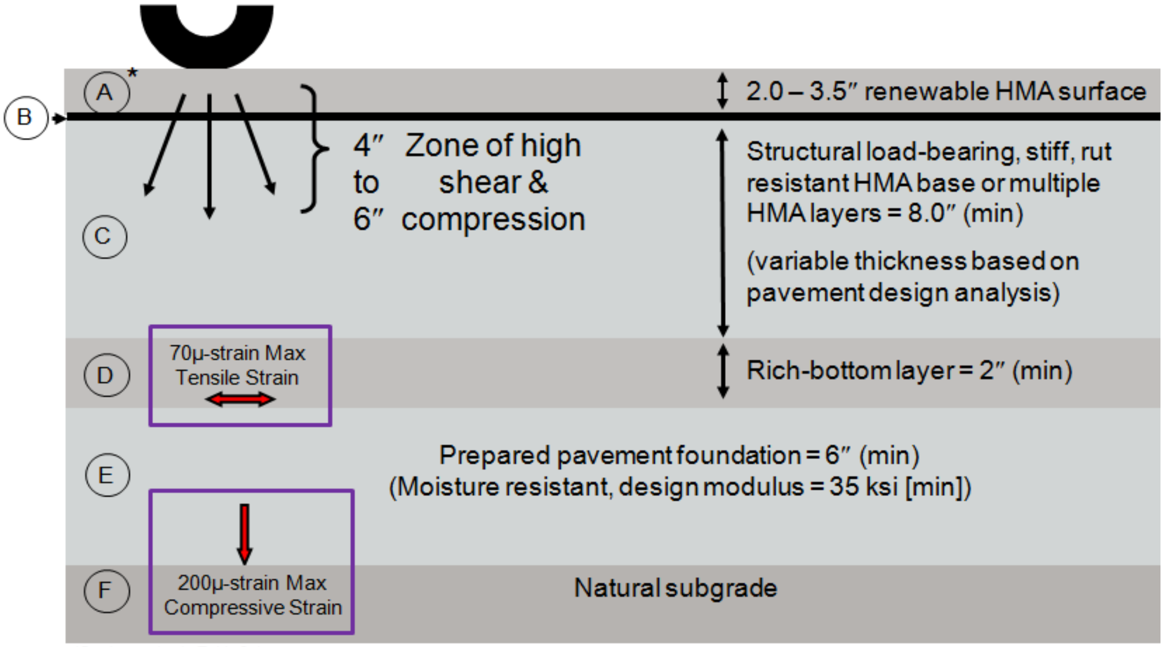
#	Thickness (inches)	Mix Type	2004 TxDOT Spec
1	2	SMA	Item 346
2	3	¾" SP	Item 344
3	7	Type B	Item 341
4	≥ 2	RBL	Item 341
5	≥ 6	Base (≥ 35 ksi)	Items 260, 263, 275, 276
Compacted in-situ subgrade soil material			

Figure 3-1. The Proposed Future Texas PP Structural Design Concept.

In Figure 3-1, SMA stands for stone matrix (or mastic) asphalt, SF for stone-filled (or stone fill), RBL for rich bottom layer, and SP for Superpave. The preceding number in front of SF such as ¾" and 1" refers to the nominal maximum aggregate size (NMAS) in inches, e.g., ¾" ≅ ¾-inch NMAS, 1" ≅ 1-inch NMAS (Walubita et al., 2009a).

THE FUTURE TEXAS PP DESIGN CONCEPT

Based on the proposal in Figure 3-1, a generalized Texas PP design guide was thus developed and is shown in Figure 3-2. Description of the structure details including some layer composition and construction considerations is provided in the subsequent text.



*See key notes in Table 3-1

Figure 3-2. Generalized Texas PP Design Guide.

Based on Figure 3-2, the preferred minimum PP layer thicknesses are 12 inches total HMA and 6 inches base. As was shown in Figure 3-1, 14 inches total HMA thickness was found to be optimal based on the findings of this study.

THE TEXAS PP LAYER COMPOSITION

Table 3-1 is a summary description of the layer composition for the recommended PP structural design concept shown in Figure 3-2.

Table 3-1. Texas PP Layer Composition.

Layer	Layer Composition	Spec Item (TxDOT, 2004)	Preferred Mix Size	Preferred Lift Thickness	PG Grade	N_{des}
Ⓐ	Renewable surface SMA or two layer system with PFC (optional) on top of SMA	Item 342 (PFC) (optional)		1.5″	76-XX	50
		Item 346 (SMA)	SMA-D	2.0″	76-XX	75
Ⓑ	Seal Coat	Item 316 or 318	Grade 4 or Grade 4S		--	--
Ⓒ	Rut-Resistant HMA Base (RRL)	Item 344[a] or Item 341	SP-B Type B	4 × NMAS each lift	70-22[b]	75
Ⓓ	Rich-bottom layer (RBL)	Item 344 or Item 341	SP-D	2.0″	64-22	50
Ⓔ[c]	Prepared Pavement Foundation	1) Item 247		6-12″	--	--
		2) Item 275		6-12″		
		3) Item 260		8.0″		
Ⓕ	Natural subgrade	--	--	--	--	--

Legend:
PFC = porous friction course, SMA stands for stone matrix (or mastic) asphalt, SP for Superpave, NMAS = nominal maximum aggregate size, RRL = rut-resistant, N_{des} = number of laboratory gyrations for mix design at a specified density (TxDOT, 2004)

Notes:
[a] Preference should be given to designing above the reference zone.
[b] Use PG 70-22 or higher grade for all HMA mixes that fall within the top 6.0″ of the finished pavement surface.
[c] See construction considerations in Table 3-2, Layer Ⓔ.

TEXAS PP CONSTRUCTION CONSIDERATIONS

Some construction consideration aspects as related to the PP layers described in Table 3-1 are summarized in Table 3-2. Typical construction aspects for HMA pavements can be found elsewhere (TxDOT, 2004).

Table 3-2. PP Layer Construction Considerations.

Layer Construction	Considerations
Ⓐ	Renewable surface. The renewable surface lift will need periodic (8 to14 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 inches per year. In this case, the PFC will be placed on top of the SMA layer (minimum PFC thickness should 1.5 inches).
Ⓑ	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 also helps in minimizing moisture ingress into the PP structure.
Ⓒ	Structural load-bearing and rut-resistant layers (RRL). The structural load-bearing and rut resistant layer are placed in multiple lifts of a single HMA base layer or multiple HMA layers. All the HMA mix that is within 6 inches of the surface must use a minimum of PG 70-22 binder. The lower lifts or layer may use PG 64-22 binder. Type B and/or ¾″ Superpave (SP-B) mixes meeting the requirements of Item 341 and/or Item 344 are preferred for these layers; see also Figure 3-1. 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 the layers must be promoted through the proper application of tack coats.
Ⓓ	Rich-bottom layer (RBL). The primary purpose of the RBL layer 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 12.0″ total HMA depth. The RBL also serves as a stress relieving layer. Full bond between the RBL and the overlying rut-resistant layers must be promoted through the proper application of tack coat. This layer should be impermeable and highly resistant to intrusion of moisture rising within the substructure. The layer must comply with the RBL requirements under Item 344 or Item 341.
Ⓔ	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 Type A flexible base; 2) Cement treated base (≤ 3% cement); 3) Lime stabilized subgrade (≥ 8.0″), passing Tex-121-E, Part I, with 50 psi retained strength after 10 days capillary rise (≥ 6% lime).
Ⓕ	Natural subgrade. A geotechnical investigation must be performed to determine the composition of the natural subgrade soil and to check for the presence of organics and sulfates. The suitability, type, and depth of stabilization must be established based on these geotechnical tests. For pavement foundation using options 1 or 2 above, stabilize to a minimum 6.0″ depth in cases where the existing subgrade cannot provide sufficient and uniform support. Overall, the prepared foundation and pavement structure should limit the potential vertical rise to no more than 1.5 inch.

CHAPTER 4

THE TEXAS PP DESIGN SOFTWARE AND STRUCTURAL ANALYSIS

This chapter provides some structural design recommendations in terms of the software and M-E response criteria. The recommended design software, FPS and MEPDG, are discussed in this chapter with a focus on structural layer type and thickness.

PP STRUCTURAL DESIGN AND ANALYSES SOFTWARE

The FPS 21W is the proposed and recommended software for computing the structural thickness of the Texas perpetual pavements (Walubita et al., 2009a). If need be, the MEPDG software may optionally be utilized for the PP design verification and performance analysis/predictions.

- FPS 21W – for PP structural thickness design, M-E response analyses, and strain check, and
- MEPDG – for PP design verification and performance analyses/distress predictions (optional).

A brief description of these programs is provided in the subsequent text. Where needed, reference should be made to the Texas PP database for software installation details and demonstration examples (Walubita et al., 2009b).

The FPS (21W) Software

The FPS is a mechanistic-empirical based software routinely used by TxDOT for: (1) pavement structural (thickness) design, (2) overlay design, (3) stress-strain response analysis, and (4) pavement life prediction (rutting and cracking). As of this writing, the version 21W is still under evaluation; it is a modified version of FPS 19W facilitating the multiple layer input and analysis demands of a PP system.

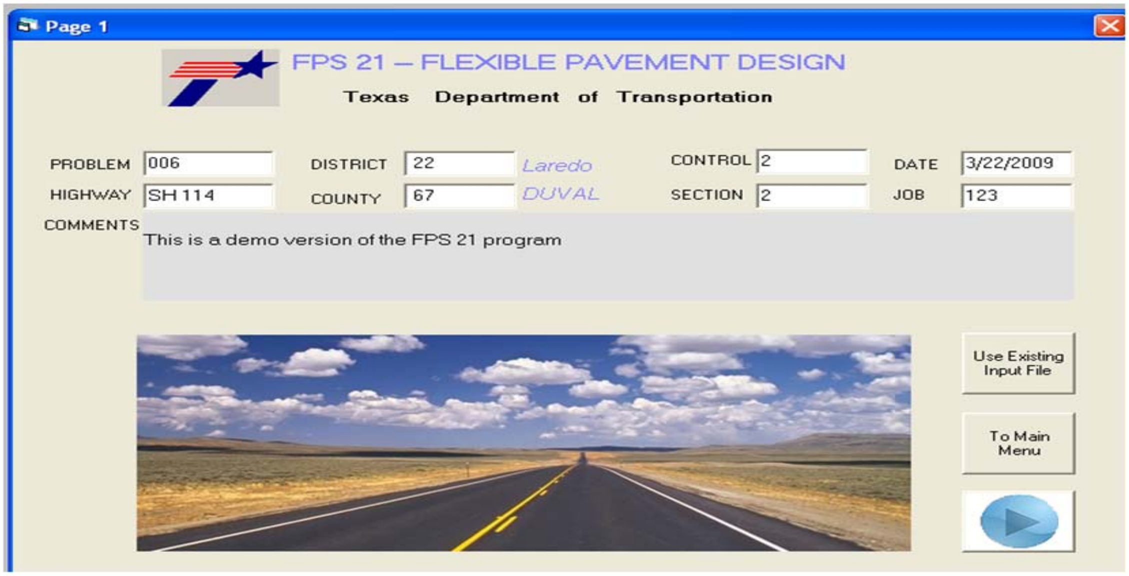
The design approach is based on a linear-elastic analysis system, and the key material characterization input is the back-calculated FWD modulus of the pavement layers. The FPS design system itself is comprised of two fundamental processes: (1) trial pavement structure development and thickness design, and (2) design checks including performance prediction. The FPS system has an embedded performance function relating the computed surface curvature index of the pavement to the loss in ride quality. The design check is principally based on either the mechanistic design concepts or the Texas Triaxial criteria.

The mechanistic design check basically computes and checks the sufficiency of the mechanistic responses in terms of maximum horizontal tensile strains at the bottom of the lowest HMA layer and the maximum vertical compressive strains on top of the subgrade not exceeding prescribed limits. The mechanistic design check is recommended for all pavements with HMA surfaces. However, the fatigue analysis is restricted to all pavements where the HMA thickness is greater than 1.5 inches but should be run for informational purposes on all thin-surfaced HMA designs. The Texas Triaxial criterion checks the likelihood of shear failure in the subgrade soil under the heaviest wheel load anticipated for the pavement section.

TxDOT traditionally uses the FPS for conventional flexible HMA pavement design. However, the upgraded FPS 21W is multi-layered and therefore can sufficiently accommodate perpetual pavements. Figures 4-1 through 4-4 show highlights of the FPS 21W main screen, the FPS built-in layer options, and an example of the output data. The screen in Figure 4-2 allows the user to automatically select the materials and moduli of preference, thus making the software very user-friendly.

As an example, the output data in Figure 4-3 shows up to 17 alternative designs, giving the user a very wide range of design options to choose from. However, only the last option pictured follows the recommended layer criteria as depicted in Figure 3-2 and Table 3-1.

The PP example selected in Figure 4-3 and evaluated by the M-E check in Figure 4-4 yielded a performance life of 22 years prior to requirement for a surface renewal or an overlay. The predicted strains at the critical evaluation locations are circled in Figure 4-4; they were 52 and 144 με, lower than the 70 and 200 με thresholds established for fatigue and rut resistance (subgrade), respectively.

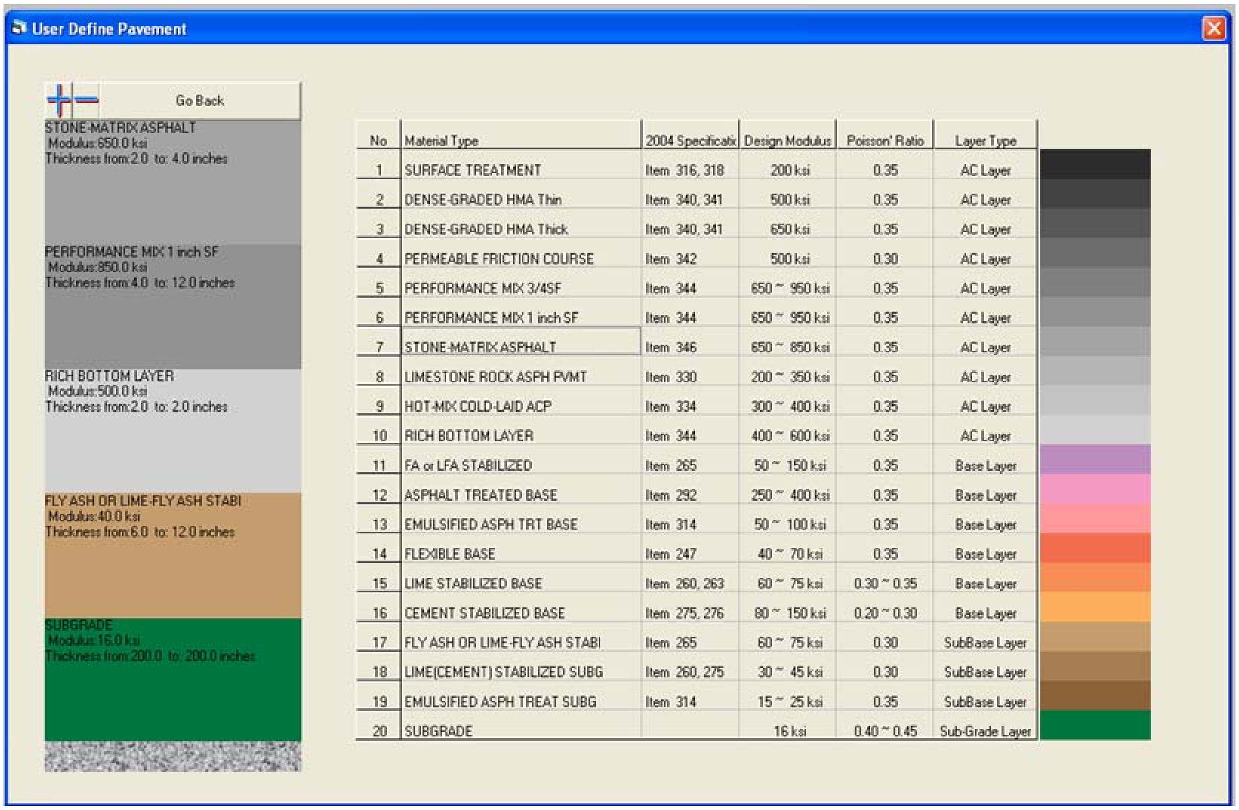


FPS 21 – FLEXIBLE PAVEMENT DESIGN

Texas Department of Transportation

PROBLEM 006
HIGHWAY SH 114
DISTRICT 22 Laredo
COUNTY 67 DUVAL
CONTROL 2
SECTION 2
DATE 3/22/2009
JOB 123
COMMENTS This is a demo version of the FPS 21 program

Figure 4-1. FPS 21W Main Screen.



STONE-MATRIX ASPHALT
Modulus:650.0 ksi
Thickness from:2.0 to: 4.0 inches

PERFORMANCE MIX 1 inch SF
Modulus:850.0 ksi
Thickness from:4.0 to: 12.0 inches

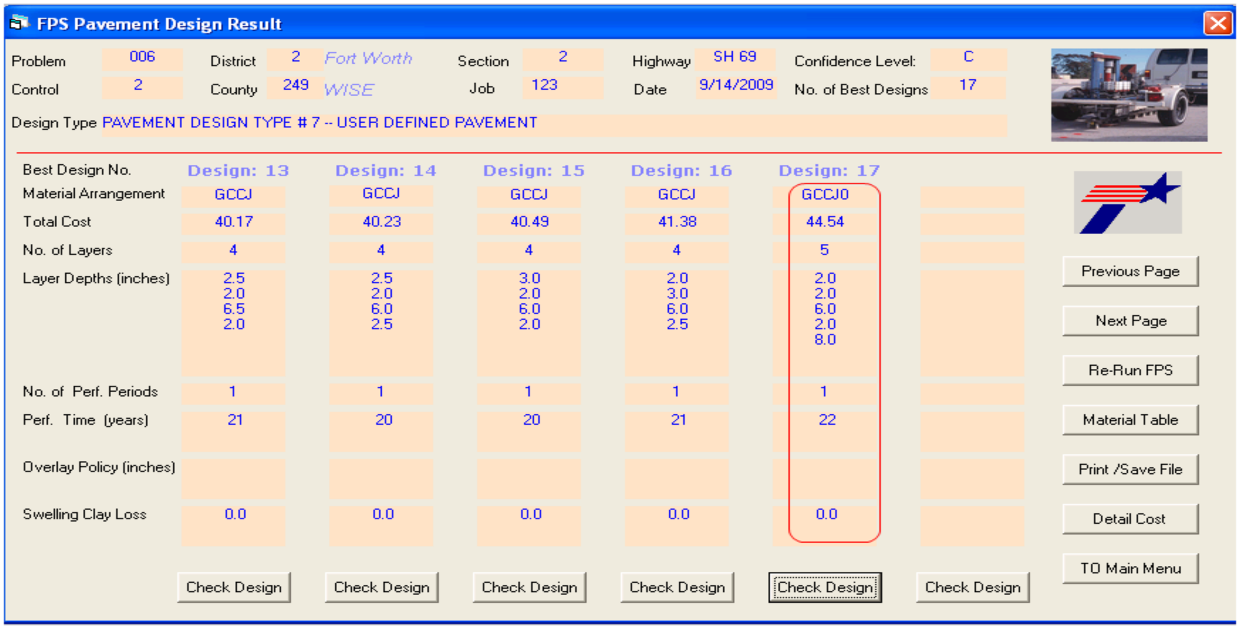
RICH BOTTOM LAYER
Modulus:500.0 ksi
Thickness from:2.0 to: 2.0 inches

FLY ASH OR LIME-FLY ASH STABI
Modulus:40.0 ksi
Thickness from:6.0 to: 12.0 inches

SUBGRADE
Modulus:16.0 ksi
Thickness from:200.0 to: 200.0 inches

No	Material Type	2004 Specificati	Design Modulus	Poisson' Ratio	Layer Type
1	SURFACE TREATMENT	Item 316, 318	200 ksi	0.35	AC Layer
2	DENSE-GRADED HMA Thin	Item 340, 341	500 ksi	0.35	AC Layer
3	DENSE-GRADED HMA Thick	Item 340, 341	650 ksi	0.35	AC Layer
4	PERMEABLE FRICTION COURSE	Item 342	500 ksi	0.30	AC Layer
5	PERFORMANCE MIX 3/4SF	Item 344	650 ~ 950 ksi	0.35	AC Layer
6	PERFORMANCE MIX 1 inch SF	Item 344	650 ~ 950 ksi	0.35	AC Layer
7	STONE-MATRIX ASPHALT	Item 346	650 ~ 850 ksi	0.35	AC Layer
8	LIMESTONE ROCK ASPH PVMT	Item 330	200 ~ 350 ksi	0.35	AC Layer
9	HOT-MIX COLD-LAID ACP	Item 334	300 ~ 400 ksi	0.35	AC Layer
10	RICH BOTTOM LAYER	Item 344	400 ~ 600 ksi	0.35	AC Layer
11	FA or LFA STABILIZED	Item 265	50 ~ 150 ksi	0.35	Base Layer
12	ASPHALT TREATED BASE	Item 292	250 ~ 400 ksi	0.35	Base Layer
13	EMULSIFIED ASPH TRT BASE	Item 314	50 ~ 100 ksi	0.35	Base Layer
14	FLEXIBLE BASE	Item 247	40 ~ 70 ksi	0.35	Base Layer
15	LIME STABILIZED BASE	Item 260, 263	60 ~ 75 ksi	0.30 ~ 0.35	Base Layer
16	CEMENT STABILIZED BASE	Item 275, 276	80 ~ 150 ksi	0.20 ~ 0.30	Base Layer
17	FLY ASH OR LIME-FLY ASH STABI	Item 265	60 ~ 75 ksi	0.30	SubBase Layer
18	LIME(CEMENT) STABILIZED SUBG	Item 260, 275	30 ~ 45 ksi	0.30	SubBase Layer
19	EMULSIFIED ASPH TREAT SUBG	Item 314	15 ~ 25 ksi	0.35	SubBase Layer
20	SUBGRADE		16 ksi	0.40 ~ 0.45	Sub-Grade Layer

Figure 4-2. FPS 21W Built-In Layer Options.



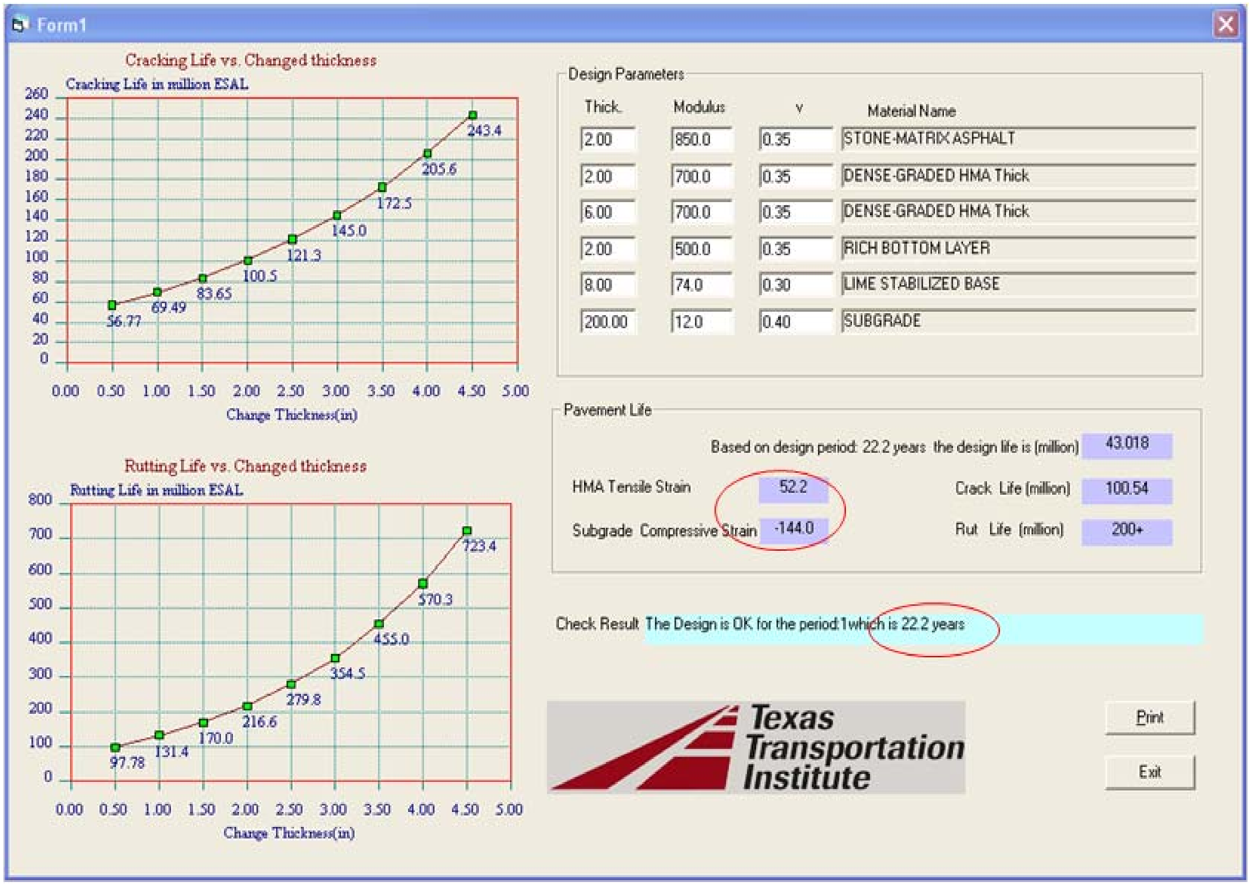
Problem 006 District 2 Fort Worth Section 2 Highway SH 69 Confidence Level: C

Control 2 County 249 WISE Job 123 Date 9/14/2009 No. of Best Designs 17

Design Type PAVEMENT DESIGN TYPE # 7 -- USER DEFINED PAVEMENT

Best Design No.	Design: 13	Design: 14	Design: 15	Design: 16	Design: 17	
Material Arrangement	GCCJ	GCCJ	GCCJ	GCCJ	GCCJ0	
Total Cost	40.17	40.23	40.49	41.38	44.54	
No. of Layers	4	4	4	4	5	
Layer Depths (inches)	2.5 2.0 6.5 2.0	2.5 2.0 6.0 2.5	3.0 2.0 6.0 2.0	2.0 3.0 6.0 2.5	2.0 2.0 6.0 2.0 8.0	
No. of Perf. Periods	1	1	1	1	1	
Perf. Time (years)	21	20	20	21	22	
Overlay Policy (inches)						
Swelling Clay Loss	0.0	0.0	0.0	0.0	0.0	

Figure 4-3. Example FPS 21W Design Output Data.



Design Parameters

Thick.	Modulus	v	Material Name
2.00	850.0	0.35	STONE-MATRIX ASPHALT
2.00	700.0	0.35	DENSE-GRADED HMA Thick
6.00	700.0	0.35	DENSE-GRADED HMA Thick
2.00	500.0	0.35	RICH BOTTOM LAYER
8.00	74.0	0.30	LIME STABILIZED BASE
200.00	12.0	0.40	SUBGRADE

Pavement Life

Based on design period: 22.2 years the design life is (million) 43.018

HMA Tensile Strain 52.2

Subgrade Compressive Strain -144.0

Crack Life (million) 100.54

Rut Life (million) 200+

Check Result The Design is OK for the period:1which is 22.2 years

Figure 4-4. Example FPS 21W Mechanistic Analysis.

The MEPDG Software

The MEPDG is an M-E based analytical software for pavement structural design analysis and performance prediction, within a given service period (AASHTO, 2008). The MEPDG design procedure is primarily based on pavement performance predictions. However, unlike the FPS, the MEPDG does not directly generate pavement layer thickness designs. Instead trial pavement layer thicknesses/combinations are iteratively input into the software and the thicknesses/combinations that meet the prescribed performance criteria are selected as the final designs. The performance predictions include permanent deformation, rutting, cracking (bottom-up and top-down), thermal fracture, and surface roughness (IRI).

The MEPDG adapts two major aspects of M-E based material characterization, pavement response properties and major distress/transfer functions as follows.

- Pavement response properties are required to predict states of stress, strain, and deformation within the pavement structure when subjected to external wheel loads and thermal stresses. The properties for assumed elastic material behavior are the elastic modulus and Poisson's ratio.
- The major MEPDG distress/transfer functions for asphalt pavements are load-related fatigue fracture, permanent deformation, rutting, and thermal cracking.

Because of its comprehensive performance analysis models, the MEPDG software was optionally recommended for the future Texas PP design verification and performance analysis, with the actual PP thickness designs accomplished with the FPS 21W software. However, it is recommended to use the calibration factors listed in Table 4-1 when applying the MEPDG for Texas PP analyses (Walubita et al., 2009a). The MEPDG offers additional advantages over FPS in assessing performance by accounting for environmental impact on material properties and evaluating pavement response based on axle load spectra.

Table 4-1. Recommended MEPDG Calibration Factors for Texas PP Analysis.

Distress Item	Calibration Parameter	Default Value	Recommended Value
AC rutting	β_{r3}	1.0	0.94
Subgrade rutting	β_{s1}	1.0	0.6
AC cracking	C_1 (bottom-up)	1.0	1.2
AC cracking	C_1 (top-down)	7.0	9.0

See Appendix D for some examples of sensitivity analyses and determination of the local calibration factors for Texas PP application. Full details of the sensitivity analyses are documented elsewhere (Walubita et al., 2009a).

Table 4-2 shows a typical summarized output from the MEPDG software at 95 percent reliability level. The table shows satisfactory performance with the IRI barely meeting the 95 percent reliability threshold, suggesting that IRI would likely be the governing failure distress criteria for this PP structure. Fatigue cracking is non-existent while the likelihood of the HMA permanent deformation exceeding the 0.5-inch threshold is only 3.7 percent.

Table 4-2. Example MEPDG Distress Analysis at 95 Percent Reliability Level.

Performance Criteria		Distress Target	Predicted Distress	Reliability Predicted	Pass/ Fail
1	Terminal IRI (in/mi)	≤ 172	118	94.8%	Pass
2	AC Surface Down Cracking (Long. Cracking) (ft/500)	≤ 1000	0.0	99.9%	Pass
3	AC Bottom-Up Cracking (Alligator Cracking) (%)	≤ 25	0.0	99.9%	Pass
4	AC Thermal Fracture (Transverse Cracking) (ft/mi)	≤ 1000	1	99.9%	Pass
5	Permanent Deformation (AC Only) (in)	≤ 0.50	0.21	96.3%	Pass
6	Permanent Deformation (total pavement) (in)	≤ 0.75	0.38	99.9%	Pass
Analysis period =20 yrs, Reliability threshold ≥ 95%					

Interpretatively, Table 4-2 shows that at most there is 5.2 percent chance of the IRI exceeding the threshold at 95 percent reliability. Overall, increasing highway roughness was analytically found to be the most restrictive distress on the Texas PP performance longevity (Walubita et al., 2009a). In general, the MEPDG software displays the distress results as a function of time over the life of the pavement (see examples in Appendix D).

In terms of the input data, the MEPDG utilizes a hierarchical system for both material characterization and analysis (AASHTO, 2008). This system has three material property input levels. Level 1 represents a design philosophy of the highest achievable reliability, and Levels 2 and 3 have successively lower reliability, respectively. In addition to the typical volumetrics, Level 1 input requires laboratory measured asphalt-binder and HMA properties such as the shear and dynamic modulus, respectively; Level 3 input requires only the PG binder grade and aggregate gradation characteristics. Level 2 utilizes laboratory measured asphalt-binder shear modulus properties and aggregate gradation characteristics. For assistance with the MEPDG input data, reference should be made to the Texas PP database (Walubita et al., 2009b).

THE M-E RESPONSE DESIGN CRITERIA

Based on the findings by Walubita et al. (2009a), the recommendation is that the 70 and 200 $\mu\varepsilon$ maximum thresholds be used as the M-E response (strain) design criteria in the future Texas PP designs:

- horizontal tensile strain at the bottom of the lowest HMA layer (ε_t): ≤ 70 $\mu\varepsilon$ (for limiting bottom-up fatigue cracking), and
- vertical compressive strain on the top of subgrade (ε_v): ≤ 200 $\mu\varepsilon$ (for limiting rutting).

A PP structure meeting these M-E strain response criteria is considered to be structurally adequate both in terms of fatigue cracking (bottom-up) and full-depth rutting. Structures not meeting these criteria would need to have one or more layer thicknesses or material properties modified to comply.

PP LAYER THICKNESSES

The recommended minimum PP layer thicknesses are summarized in Table 4-3; see also Figures 3-1 and 3-2.

Table 4-3. PP Layer Thickness Recommendations.

# Layer	Description	Minimum Thickness (inches)	Comment
1 Ⓐ	Renewable HMA surface (SMA + PFC [optional])	2 – 3.5	Preferably 2 inches SMA + 1.5 inches PFC (optional)
2 Ⓑ	Seal coat	-	Non-structural layer
3 Ⓒ	Main structural load-bearing HMA layers (RRL)	≥ 8	Variable thickness based on structural design
4 Ⓓ	Rich-bottom layer	2 – 4	Stress-relieving layer; impermeable layer. Minimum thickness should be 2 inches, but preferably not to exceed 4 inches
5 Ⓔ	Base or prepared foundation	≥ 6	Lime or cement treated
6 Ⓕ	Subgrade	∞	Natural soil material

Based on Table 4-3, the minimum PP layer thicknesses are 12 inches total HMA and 6 inches base. However, as stated in the previous chapters of this report, 14 inches total HMA thickness was structurally found to be optimal in this study (Walubita et al., 2009a).

CHAPTER 5

HMA MIX-DESIGNS, BASE, SUBGRADE, AND MATERIAL PROPERTIES

Recommendations for mix-designs and material properties for use in future Texas PP structures are provided in this chapter. The materials include the HMA mixes, the base, and subgrade. Recommendations for design layer moduli values are also presented in this chapter.

HMA MIX-DESIGNS AND MATERIALS

As pointed out in Chapter 3, recommendations are to use dense-graded mixes such as the Superpave (i.e., ¾-inch NMAS) and/or Type B mix for the main structural load-carrying and rut-resistant layers; see Figure 3-2 and Table 3-1. As reported elsewhere (Walubita et al., 2009a), previous experience with coarse-graded stone-filled HMA mixes exhibited constructability problems with high potential for moisture entrapment and other forensic defects, which is undesirable. The Type B mix on the other hand was found to be more workable with better compactability and constructability properties, attaining more uniform density with lower potential for moisture problems or forensic defects; see Figure 5-1.

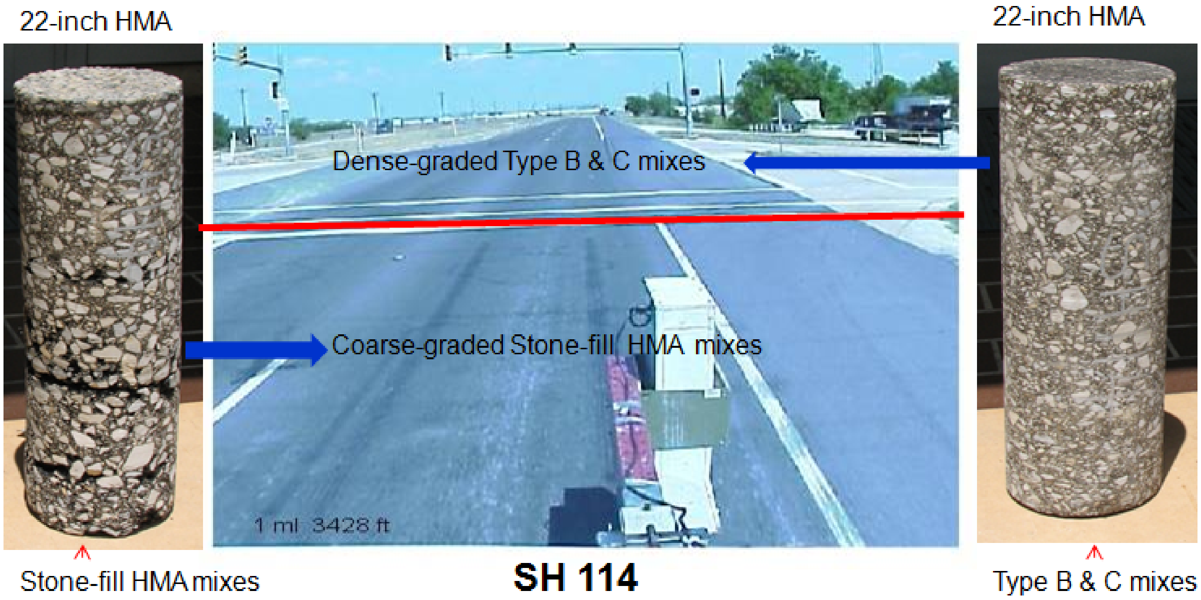


Figure 5-1. HMA Mix-Design Evaluations on SH 114 PP Sections.

Performance wise, the Type B mix was comparable to the stone-filled HMA mixes and even superior in some instances, i.e., in terms of subsurface defects and other anomalies such as localized voiding, vertical segregation, and debonding between HMA lifts. However, rutting tests and the MEPDG performance predictions had indicated potential for HMA permanent deformation, particularly where PG 64-22 was used in the Type B mix (Walubita et al., 2009a). As such, recommendations are for the use of higher PG asphalt-binder grades such as PG 70-22 in the future Texas PP designs; especially if these mixtures are used within 6 inches of the surface (see Table 3-1).

THE BASE AND SUBGRADE MATERIALS

To date, the base and subgrade materials used in existing PP structures have performed satisfactorily, with sufficient stiffness and strength (Walubita et al., 2009a). The measured in-situ FWD moduli values were greater than 30 and 15 ksi, respectively. Seasonal moduli variations were also very marginal, thus, 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 PP structures (see Figure 3-2).

Lime stabilized subgrade soils should be according to test method Tex-121-E, Part 1 and cement treated subgrade or recycled base layers as recommended in test method Tex-120-E. An unconfined compressive strength of 220 psi should be used to select the required cement content. The Bryan District has successfully utilized this criterion. Additionally, the use of 80 percent retained strength on capillary saturation should also be enforced.

As successfully used in the Laredo District, the use of micro-cracking should also be explored on all bases where cement treatment is used. Where lime is used as the stabilization agent, it should be applied in a liquid form as slurry. As indicated in Table 4-3, the minimum base treatment depth (either lime or cement) should be 6 inches.

LAYER DESIGN MODULI VALUES

Based on extensive laboratory dynamic modulus and field FWD tests, the recommended layer design moduli values in future Texas PP designs at 77 °F are listed in Table 5-1 (Walubita et al., 2009a, b).

Table 5-1. Proposed Future Texas PP Design Moduli Values at 77 °F.

Layer/Material	TxDOT 2004 Spec Item	Proposed Design Modulus Value (ksi)	Recommended Design Modulus Range (ksi)	Poisson's Ratio
PFC (optional)	Item 342	350	300 – 450	0.30
SMA	Item 346	600	500 – 850	0.35
RRL – ¾″ Superpave	Item 344	800	600 – 1200	0.35
RRL – Type B	Item 341	800	700 – 1300	0.35
RBL– Type C or ½″ Superpave	Item 341	500	400 – 650	0.35
Base/foundation	Items 247, 260, 263, 275, & 276	Min 35	35 – 150	0.30 – 0.35
Subgrade		Should be back-calculated from existing or adjacent structure	-	0.40 – 0.45
Refer also to the Texas PP database for more moduli data (Walubita et al., 2009b) and the FPS in-built layer moduli values (see Figure 4-2 of this report).				

These proposed moduli values (Table 5-1) are expected to yield optimal PP structural designs, with sufficient consideration for construction and material property variability. For more detailed material properties and moduli data, reference should be made to the Texas PP database; see Appendix D (Walubita et al., 2009b).

CHAPTER 6

TEXAS PP CONSTRUCTION AND PERFORMANCE EVALUATION ASPECTS

The objective of this chapter is to provide some recommendations for the future construction and performance monitoring/evaluation of Texas perpetual pavements. The recommendations include construction quality and performance thresholds.

TEXAS PP CONSTRUCTION

As reported elsewhere (Walubita et al., 2009a), previous experience has indicated the need for improved construction methods and tightening/better enforcement of some of the quality control (QC) test protocols on future Texas PP construction jobs. This is necessary to optimize the construction quality and minimize construction-related defects including subsurface anomalies within the PP structures. In addition to the construction considerations listed in Table 3-2 (Chapter 3), some of the construction measures warranting future improvements include the following:

- improving the compaction rolling patterns,
- tightening/increasing minimum inspection frequency in joint compaction specifications,
- 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 inches,
- use of a tack coat as a bonding agent between all HMA layer lifts, and
- minimizing the job mix formula (JMF) asphalt binder content reductions.

Compacted Lift Thickness

For improved compaction and construction quality, 4 inches is recommended as the maximum compacted lift-thickness for the Type B and ¾-inch Superpave mixes (Walubita et al., 2009). This is particularly critical where the mixes are used as the structural load-bearing layers with an overall thickness greater than 4 inches in the PP structure. As shown in Table 3-1, the preferred compacted lift thickness is 4 × NMAS.

On a comparative note, the 5-inch lift thickness as previously proposed (TxDOT, 2001) did not yield satisfactory compaction results with the stone-fill HMA mixes (Walubita et al., 2009a). Compaction quality in terms of both thickness and density uniformity was often poor where a 5-inch lift thickness was utilized; substandard cores were retrieved as shown in Figure 6-1.

5-inch lift thickness 4-inch lift thickness 3-inch lift thickness

Figure 6-1. Comparison of the Compacted Lift Thickness for Texas PP Structures.

Otherwise, more compactive energy and rolling passes were required for the 5-inch lift-thickness to attain the same level of compaction quality as a 3- or 4-inch lift. On one project using a 5-inch compacted lift thickness, as many as 17 total roller passes were applied to achieve the 96 percent target density (Walubita et al., 2009a).

Material Transfer Device

The use of the belly-dump trucks and a direct windrow pick-up as the material transfer device (MTD) was observed to be less effective than the Roadtec Shuttle Buggy® in eliminating thermal segregation in the HMA mat, in either the cold (winter) or hot (summer) weather placement (Walubita et al., 2009a). The Roadtec was observed to yield a more consistent, uniform temperature mix due to remixing and significant on-board storage (see Appendix E). Thus, the Roadtec or equivalent MTD would be preferred for future jobs.

Infra-Red Thermal Imaging and Ground Penetrating Radar

As discussed elsewhere (Walubita et al., 2009a), infra-red (IR) thermal imaging and ground penetrating radar (GPR) measurements (supplemented with coring) proved very useful in monitoring the construction quality of the Texas PP structures. These non-destructive testing (NDT) tools were successfully utilized for HMA mat temperature measurements, layer thickness uniformity and compaction density measurements, and detection of subsurface anomalies such as density variations, localized voiding, vertical segregation, debonding, and moisture presence.

Results from both IR thermal imaging and GPR measurements aided contractors in implementing construction changes on some projects that ultimately led to improved construction quality. It is therefore recommended that these NDT tools be considered for use in future Texas PP construction projects as additional construction QC test protocols. Examples of IR thermal imaging and GPR applications are included in Appendices E and F, respectively.

FIELD TESTING AND PERFORMANCE EVALUATION

In addition to the traditional performance monitoring and evaluation tests of flexible HMA pavements such as deflection tests using the FWD, it is recommended herein to consider incorporating GPR measurements on all future PP projects for forensics and structural evaluations. In this research study, the GPR was found to be a very useful NDT tool for the structural evaluation of the perpetual pavements in terms of detecting subsurface defects (Walubita et al., 2009a).

The GPR has the potential to detect subsurface defects and anomalies such as localized voiding, debonding, and moisture entrapment within the PP structures. This is particularly very critical in pavement maintenance programs for PP structures and can beneficially lead to timely pre-treatment of the defects prior to severe deterioration. Appendix F includes an application example of the GPR.

Because of their unique HMA layer composition and structural thickness with postulated superior performance compared to conventional flexible HMA pavements, modified performance thresholds should be considered. These proposals are listed in Table 6-1 (Walubita et al., 2009a).

Table 6-1. Comparison of Some Performance Thresholds.

Item	Thresholds for Good Performance	Proposal
PP surface roughness		
1)QC IRI	30 – 65 in/mi	30 – 65 in/mi
2)IRI after 20 yrs	≤ 172 in/mi	≤ 150 in/mi
PP surface rutting after 20 yrs	≤ 0.75 inches	≤ 0.60 inches
Cracking after 20 yrs	≤ 25%	≤ 25%

The proposed thresholds in Table 6-1 are largely based on the field results and extrapolative analyses (Walubita et al., 2009a). Therefore, the values proposed should be treated as preliminary. Given that most of the Texas PP sections had barely been in service for 5 years at the time of this report, long-term performance evaluations are still necessary to validate these proposals. In particular, periodic summer and winter performance monitoring is strongly recommended to evaluate hot- and cold-weather related distresses.

CHAPTER 7

SUMMARY OF KEY POINTS

This chapter summarizes recommendations for the design, construction, and performance evaluation of future Texas PP structures.

- The optimal PP structural thickness should be around 14 inches total HMA thickness. A permanent foundation consisting of treated subgrade or other base material is needed for long-term performance.
- The FPS 21W software should be utilized for structural thickness design and strain response analysis. The MEPDG can optionally be utilized for design verification and performance prediction/evaluation of distress progression.
- The M-E response design criteria should be 70 and 200 microstrain at the bottom of the lowest HMA lift (tensile) and on top of the subgrade (compressive), respectively.
- A dense-graded Superpave and/or Type B HMA should be utilized as the main structural load-bearing layers for rut-resistance. While the minimum thickness should be 8 inches, the actual thickness of these layers should be determined based on structural design with the FPS 21W software and subsequent verification with the MEPDG (optional). The recommended design moduli should at least be 800 ksi.
- A PG 70-22 or higher PG asphalt-binder grade should be utilized for the main structural load-bearing layers, i.e., Superpave and/or Type B mixes.
- Seal coating, after placement of the main structural load-bearing layers, is strongly recommended for projects that are subject to prolonged exposure to traffic and environmental conditions prior to placement of the top SMA mat. The intent is to minimize moisture ingress into the PP structure.
- The minimum base or foundation thickness should be 6 inches 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.

- A minimum 2-inch thickness is recommended for the rich-bottom layer. This layer should also be impermeable and highly resistant to capillary moisture intrusion from the substructure.
- For larger stone RRL HMA mixes, 3- to 4-inch compacted lift thickness yielded better compaction results than 5-inch lifts. Future jobs should consider limiting the compacted lift thickness to 4 inches, or preferably use the following criteria: 3 to 4 times the NMAS.
- The Roadtec MTD exhibited less thermal segregation in the HMA mat temperature compared to the direct windrow pick-up process. Where possible, the Roadtec or equivalent MTD should be given preference in future Texas PP jobs.
- The following construction aspects need to be given due cognizance in future Texas PP jobs: (1) staggering of construction joints at every HMA lift, (2) better enforcement/increased inspection frequency of joint compaction, (3) tightening/better enforcement of the QC test protocols, (4) promoting interface layer bonding with tack coat at all HMA lift interfaces, and (5) eliminating trench construction where possible.
- The GPR and IR thermal imaging (supplemented with coring) were found to be ideal and effective NDT tools for construction QC monitoring and performance evaluation. These NDT tools should be considered for incorporation in future Texas PP construction jobs.

REFERENCES

AASHTO. *Pocket Facts*: MEPDG Version 1.0, *NCHRP 1-37A, Guide for Mechanistic-Empirical Design of New and Rehabilitated Pavement Structures,* http://www.trb.org/mepdg, Accessed October 2008.

APA. *Asphalt Pavement Alliance: Perpetual Pavements – A Synthesis, APA 101*. 2002.

Timm, D. H., and Newcomb, D. E. Perpetual Pavement Design for Flexible Pavements in US, *International Journal of Pavement Engineering (IJPE*), Vol. 7. No. 2, pp. 111-119. June 2006.

Scullion, T. “Perpetual Pavements in Texas: The State of the Practice,” Report FHWA/TX-05/0-4822-1, Texas Transportation Institute, College Station, Texas, 2007.

TxDOT. “Memorandum on Full-depth Asphalt Pavements, Flexible Pavement Design Task Force Implementation,” Texas Department of Transportation, Austin, Texas, April 23, 2001.

TxDOT. *Standard Specifications for Construction and Maintenance of Highways, Streets, and Bridges*, Austin, Texas, US. 2004.

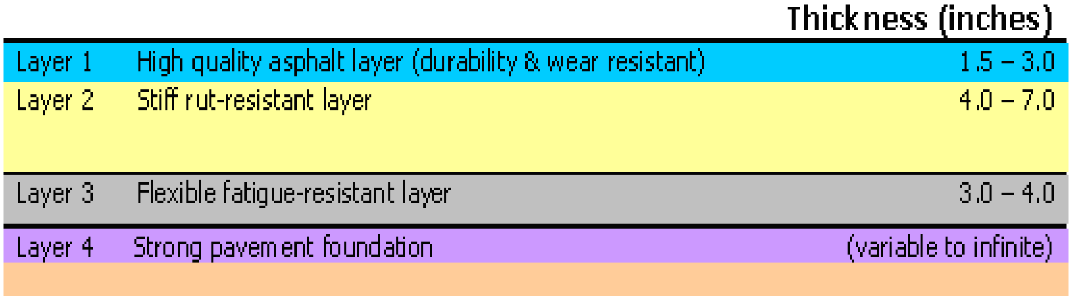
Walubita, L. F., Liu, W., and Scullion T. “Texas Perpetual Pavements - Experience Overview and the Way Forward,” *Technical Report 0-4822-3*, TTI, College Station, 2009a.

Walubita, L. F., Hu, S., and Scullion T. “The Texas Perpetual Pavement Database – Users’ Manual,” *Technical Report 0-4822-4*, TTI, College Station, 2009b.

Walubita, L. F., and Scullion, T. Perpetual Pavements in Texas: The Fort Worth SH 114 Perpetual Pavement in Wise County, Technical Report FHWA/TX-05/0-4822-2, TTI, TX, US, 2007.

Walubita, L. F., and Scullion, T. “Perpetual Pavements in Texas,” *Project Summary Report 0-4822-PSR*, TTI, College Station, 2009.

APPENDIX A: TYPICAL PP STRUCTURE BASED ON THE ASPHALT INSTITUTE PROPOSAL



		Thickness (inches)
Layer 1	High quality asphalt layer (durability & wear resistant)	1.5 – 3.0
Layer 2	Stiff rut-resistant layer	4.0 – 7.0
Layer 3	Flexible fatigue-resistant layer	3.0 – 4.0
Layer 4	Strong pavement foundation	(variable to infinite)

Figure A-1. A Typical Perpetual Pavement Structure Based on the Asphalt Institute Proposal (APA, 2002).

APPENDIX B: INITIAL TEXAS PP DESIGN CONCEPT

	Layer Designation, Materials, and Functions				Thickness (inches)
Layer 1	PFC (SS3231)	Porous Friction Course		Sacrificial layer	1.0 – 1.5
Layer 2	HDSMA (SS3248)	Heavy-Duty SMA	1/2″ Aggregate + PG 76-XX	Impermeable load carrying layer	2.0 – 3.0
Layer 3	SFHMAC (SS3249)	Stone-Filled HMAC	3/4″ Aggregate + PG 76-XX	Transitional layer	2.0 – 3.0
Layer 4	SFHMAC (SS3248)	Stone-Filled HMAC	1.0-1.5″ Aggregate + PG 76-XX	Stiff load carrying layer	8.0 - Variable
Layer 5	Superpave (SS3248)	Superpave (RBL)	1/2″ Aggregate + PG 64-XX (Target lab density=98%)	Stress relieving impermeable layer	2.0 – 4.0
Layer 6	Stiff base or stabilized subgrade		Construction working table or compaction platform for succeeding layers		6.0-8.0
Subgrade					∞

Figure B-1. Typical Texas PP Structural Section Based on the 2001 TxDOT Design Proposals (TxDOT, 2001).

In Figure B-1, SMA stands for stone matrix (or mastic) asphalt, HMAC for hot-mix asphalt concrete, RBL for rich bottom layer, and PG for performance grade. SF, HD, SS, and PFC stand for stone-filled, heavy-duty, special specification, and permeable friction course, respectively. The preceding number in front of the term aggregate such as ½″, ¾″, 1″, and 1.5″ refers to the NMAS in inches. For the PG asphalt-binder, the double X (i.e., XX) refers to the lower PG temperature grade of the asphalt-binder, e.g., -22, -28, etc. in °C.

APPENDIX C: THE FUTURE TEXAS PP DESIGN PROPOSALS

Table C-1. Future Texas PP Design Proposals.

Layer#	Thickness (inches)	Mix Type	Designation	2004 TxDOT Spec Item	Material
(a) Traffic ESALs ≤ 30 million					
1	2	SMA	Surfacing	Item 346	PG 70-28 or better
2	2	¾-inch Superpave	Load transitional layer	Item 344	PG 70-22 or better
3	≥ 6	Type B	Main structural load-carrying rut-resistant layer	Item 341	PG 64-22 or better
4	2	Type C or ½-inch Superpave	Rich bottom fatigue-resistant layer (durability & impermeability	Item 341	PG 64-22
5	≥ 6	Base	Lime or cement treatment	Items 260, 263, 275, & 276	
Subgrade (in-situ soil material)					
Minimum PP structure thickness = 18 inches (12 inches HMA and 6 inches base)					
(b) 30 million < Traffic ESALs ≤ 50 million					
1	2	SMA	Surfacing	Item 346	PG 70-28 or better
2	3	¾-inch Superpave	Load transitional layer	Item 344	PG 70-22 or better
3	≥ 8	Type B	Main structural load-carrying rut-resistant layer	Item 341	PG 64-22 or better
4	2	Type C or ½-inch Superpave	Rich bottom fatigue-resistant layer (durability & impermeability	Item 341	PG 64-22
5	≥ 6	Base	Lime or cement treatment	Items 260, 263, 275, & 276	
Subgrade (in-situ soil material)					
Minimum PP structure thickness = 21 inches (15 inches HMA and 6 inches base)					
(c) Traffic ESALs > 50 million					
1	2-3	SMA	Surfacing	Item 346	PG 70-28 or better
2	≥ 3	¾-inch Superpave	Load transitional layer	Item 344	PG 70-22 or better
3	≥ 8	Type B	Main structural load-carrying rut-resistant layer	Item 341	PG 70-22 or better
4	2-4	Type C or ½-inch Superpave	Rich bottom fatigue-resistant layer (durability & impermeability	Item 341	PG 64-22
5	≥ 8	Base	Lime or cement treatment	Items 260, 263, 275, & 276	
Subgrade (in-situ soil material)					
Minimum PP structure thickness = 23 inches (15 inches HMA and 8 inches base)					

*On top of the SMA, a PFC (TxDOT 2004 spec item 342) can be added as an “optional” surface promoting drainage, splash/spray reduction, noise-reduction, and skid-resistance. Preferably, the PFC layer thickness should be 1.5 inches.

Table C-2. Computational Validation of the Proposed PP Structural Designs.

Item (a)	Traffic ESALs ≤ 30 million	(b) 30 million < Traffic ESALs ≤ 50 million	(c) Traffic ESALs > 50 million
Actual traffic loading used in analysis	30 million	40 million	75 million
Design life	20 yrs	20 yrs	20 yrs
Environment	Fort Worth	Fort Worth	Fort Worth
PP structure	2-inch SMA + 2-inch (¾-inch) Superpave + 6-inch Type B + 2-inch RBL + 6-inch base + subgrade	2-inch SMA + 3-inch (¾-inch) Superpave + 8-inch Type B + 2-inch RBL + 6-inch base + subgrade	2-inch SMA + 3-inch (¾-inch) Superpave + 8-inch Type B + 2-inch RBL + 8-inch base + subgrade
FPS tensile strains at bottom of lowest HMA layer (≤ 70με)	47 με	55 με	63 με
FPS compressive strains on top of subgrade (≤ 200 με)	128 με	146 με	168 με
FPS performance life prediction (≥ 20 yrs)	21 yrs	23 yrs	19.6 yrs
MEPDG IRI (≤ 172 in/mi)	151 in/mi	138 in/mi	157 in/mi
MEPDG rutting (≤ 0.75 inches)	0.59 inches	0.53 inches	0.6 inches
MEPDG cracking (should be 0 percent)	0.00%	0.00%	0.00%
MEPDG performance life prediction (≥ 20 yrs)	18.5 yrs base on IRI	20 yrs based on IRI	18.1 yrs based on IRI

APPENDIX D: DESIGN SOFTWARE EVALUATION

Table D-1. Example of Sensitivity Analysis for MEPDG Rutting.

Station Id	**Measured (inch)**	**Rut Depth (inch) Predicted by the MEPDG with**	
		β_{s1}=0.6, β_{r1}=0.7, and β_{r3}=1.0	β_{s1}=0.6, β_{r1}=1.0, and β_{r3}=0.94
481060	0.35	0.37	0.36
481109	0.40	0.51	0.43
481169	0.45	0.47	0.46
481174	0.60	0.55	0.54
484749	0.50	0.51	0.49

Refer to Walubita et al. (2009a) for more details.

Following this sensitivity analyses, the calibration factors in the MEPDG should be modified as follows for Texas PP analyses:

▪ AC rutting:	β_{r3}=	from 1.0 to 0.94.
▪ Subgrade rutting:	β_{s1}=	from 1.0 to 0.6.
▪ AC cracking:	C_1 (bottom-up) =	from 1.0 to 1.2.
▪ AC cracking:	C_1 (top-down) =	from 7.0 to 9.0.

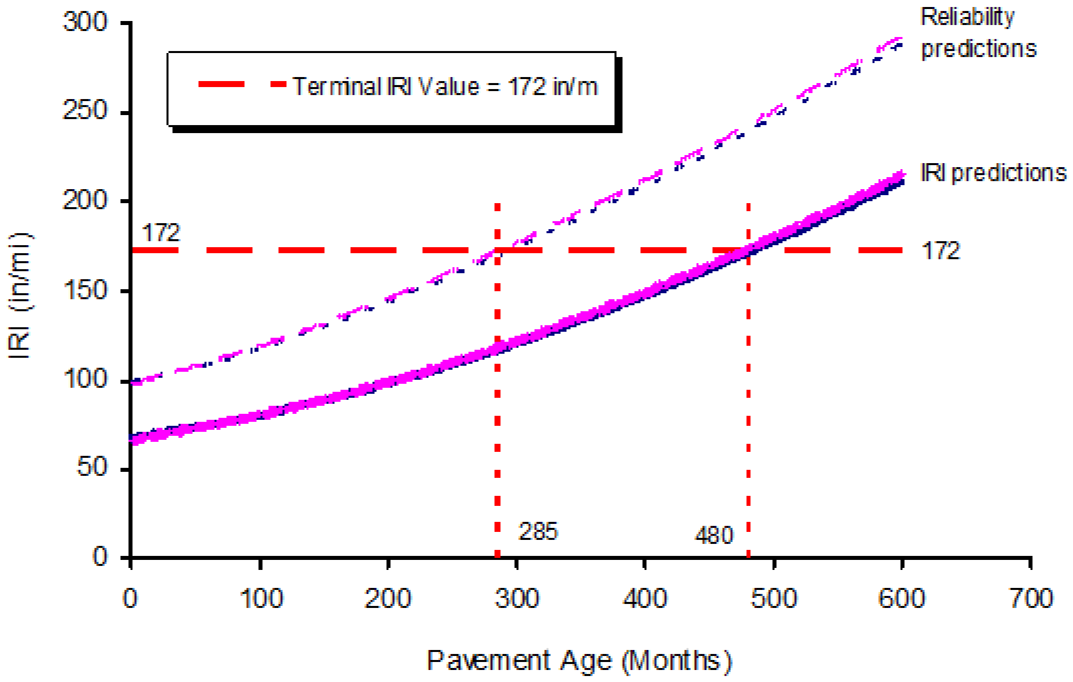


Figure D-1. Example of MEPDG-IRI Plots.

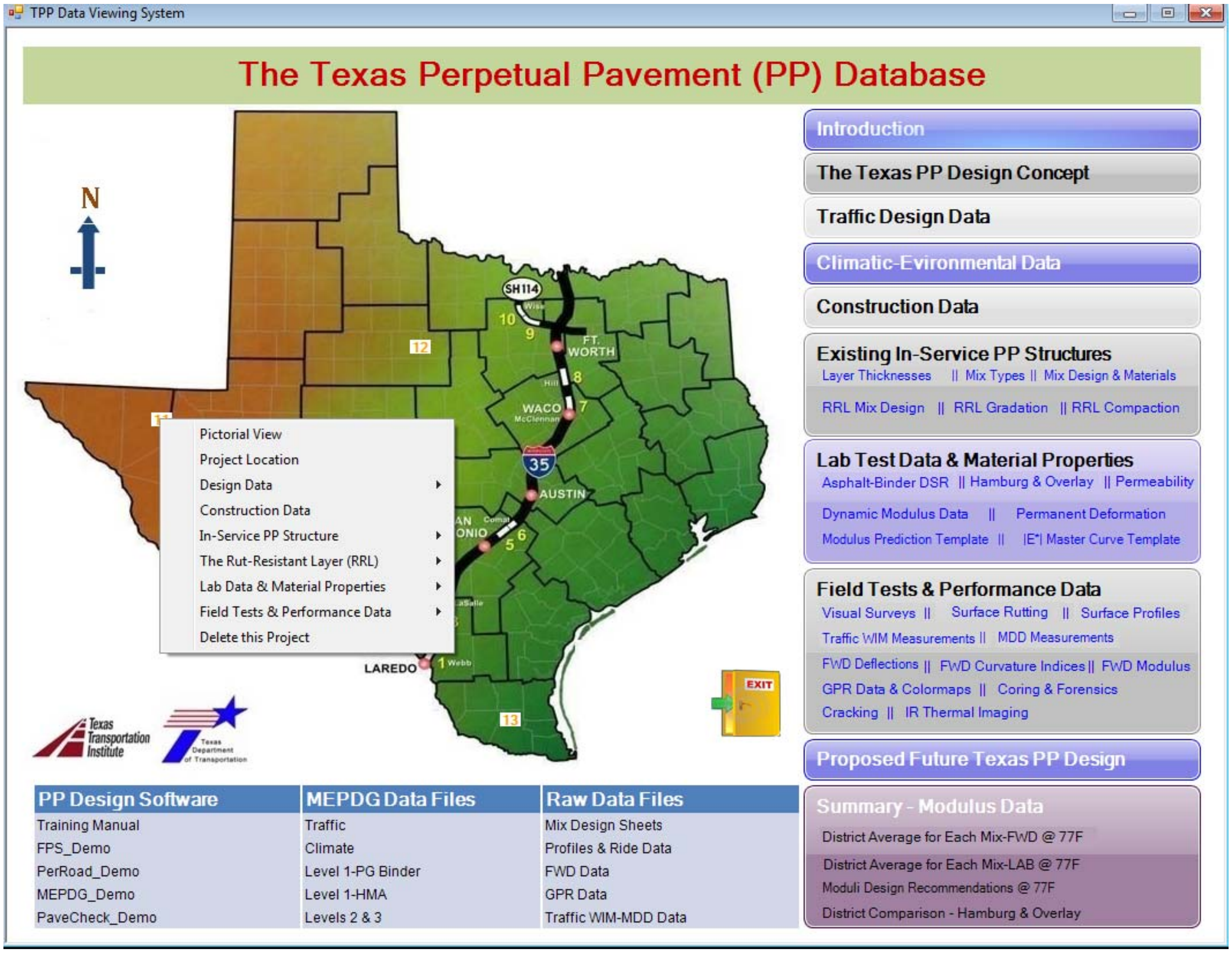


Figure D-2. Main Screen Shot for the Texas Perpetual Pavement Database (Walubita et al, 2009b).

APPENDIX E: INFRA-RED THERMAL IMAGING AND COMPARISON OF MATERIAL TRANSFER DEVICES

Figure E-1 shows an example of the comparative infra-red thermal profiles on SH 114 for a target HMA mat temperature of 300 °F.

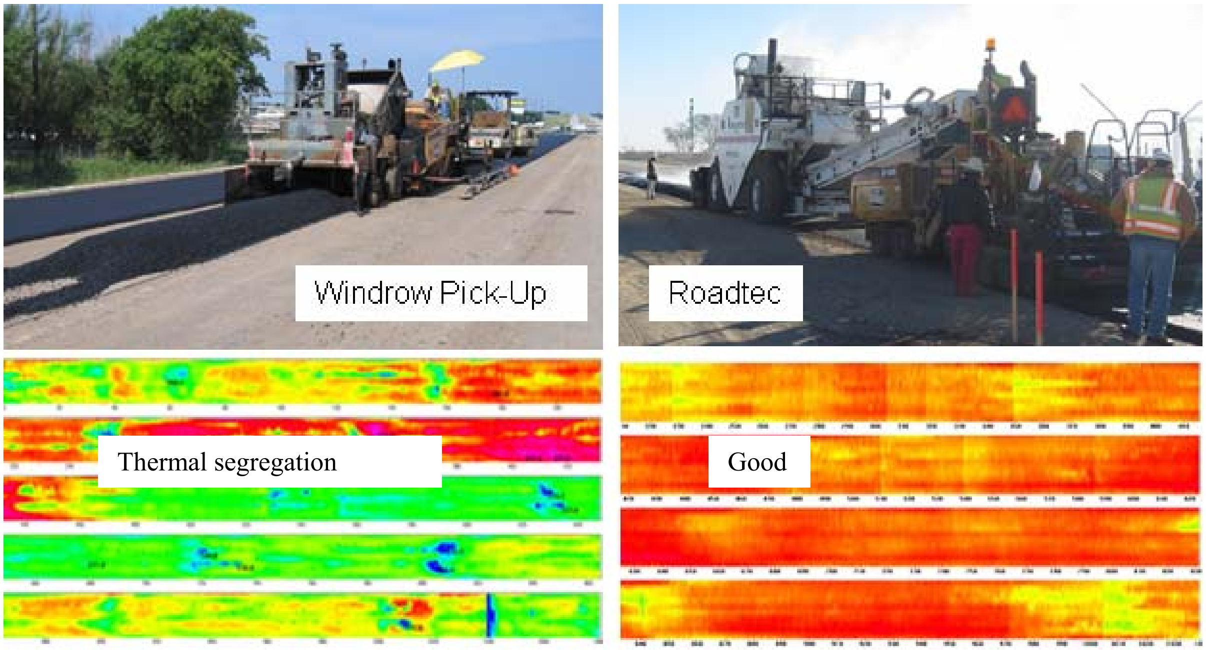


Figure E-1. Comparison of MTDs and HMA Mat Temperature Profiles on SH 114.

Figure E-1 is an example of surface temperature profiles for the full lane width (12 ft) of new HMA mats. With respect to the thermal color coding scheme, red represents HMA mat temperatures around 300 °F, which is the target mat temperature; green represents mat temperatures between 235 and 270 °F, and blue represents mat temperatures less than 235 °F. Blue is generally an undesired color as it represents cold spots with below optimum compaction characteristics in the HMA mat. Solid red throughout is the ideal and desired color, representing high temperature uniformity in the HMA mat with optimum compaction characteristics.

As shown in Figure E-1, the target mat temperature was hardly attained or uniform when using the direct windrow pick-up MTD. There are intermittent sections of green coloring and blue spots representing thermal segregation with mat temperatures below 270 °F. Clearly, the Roadtec MTD system exhibits a more uniform mat consistency at ideal temperature.

APPENDIX F: APPLICATION OF GPR FOR BOTH CONSTRUCTION MONITORING AND PERFORMANCE EVALUATION

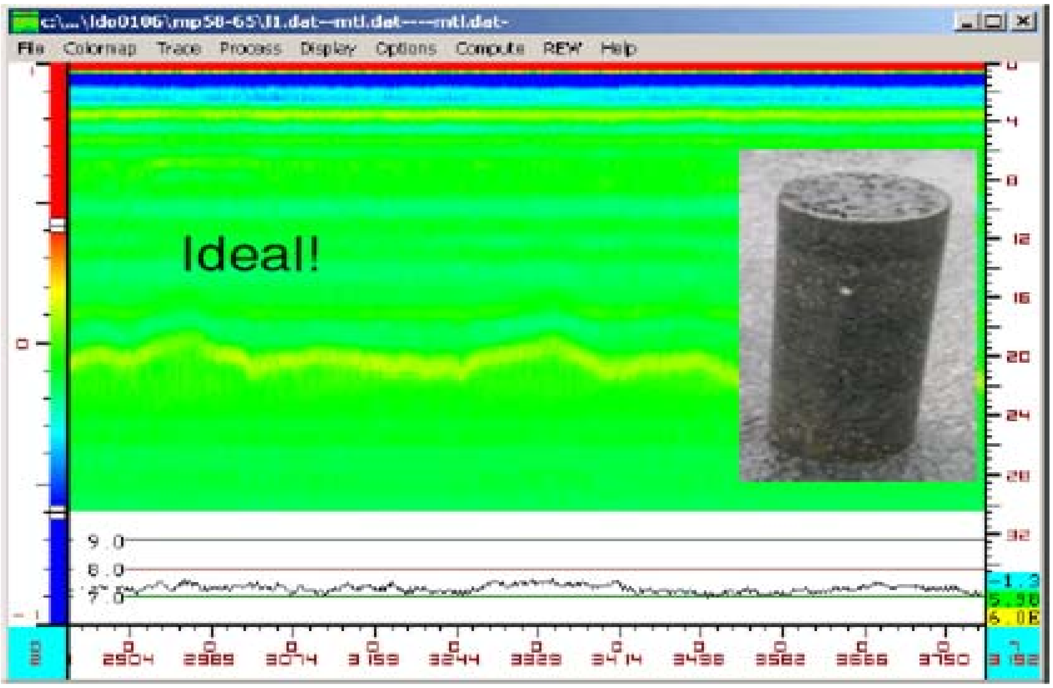


Figure F-1. Example of Ideal GPR Readings.

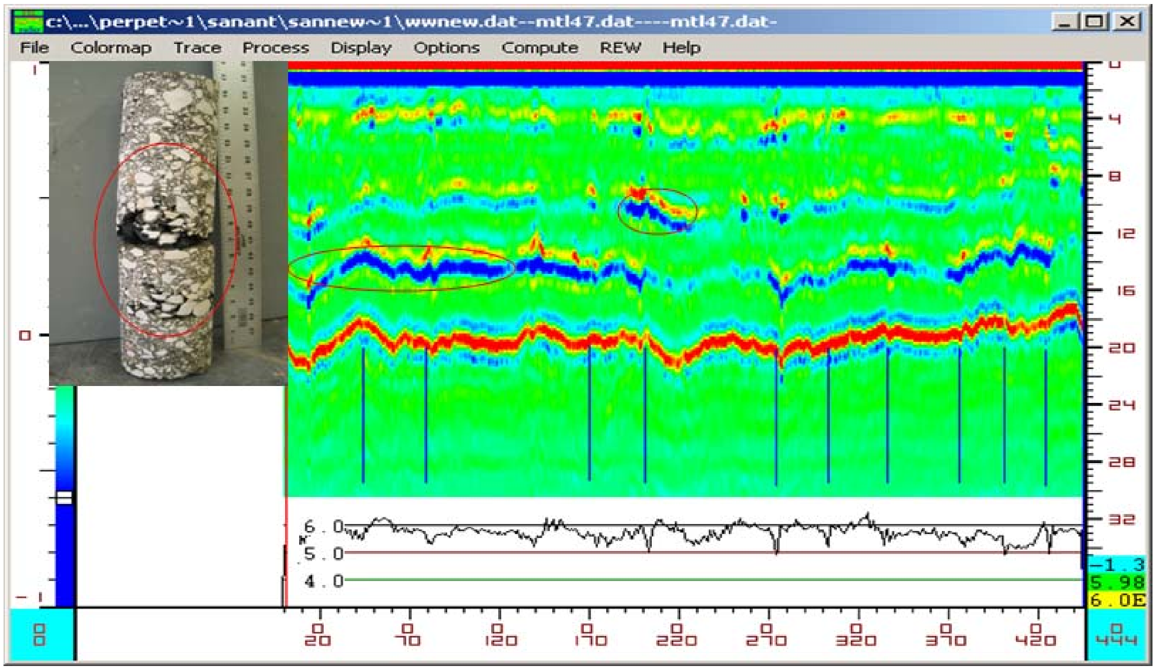


Figure F-2. Example of Non-Ideal GPR Readings.

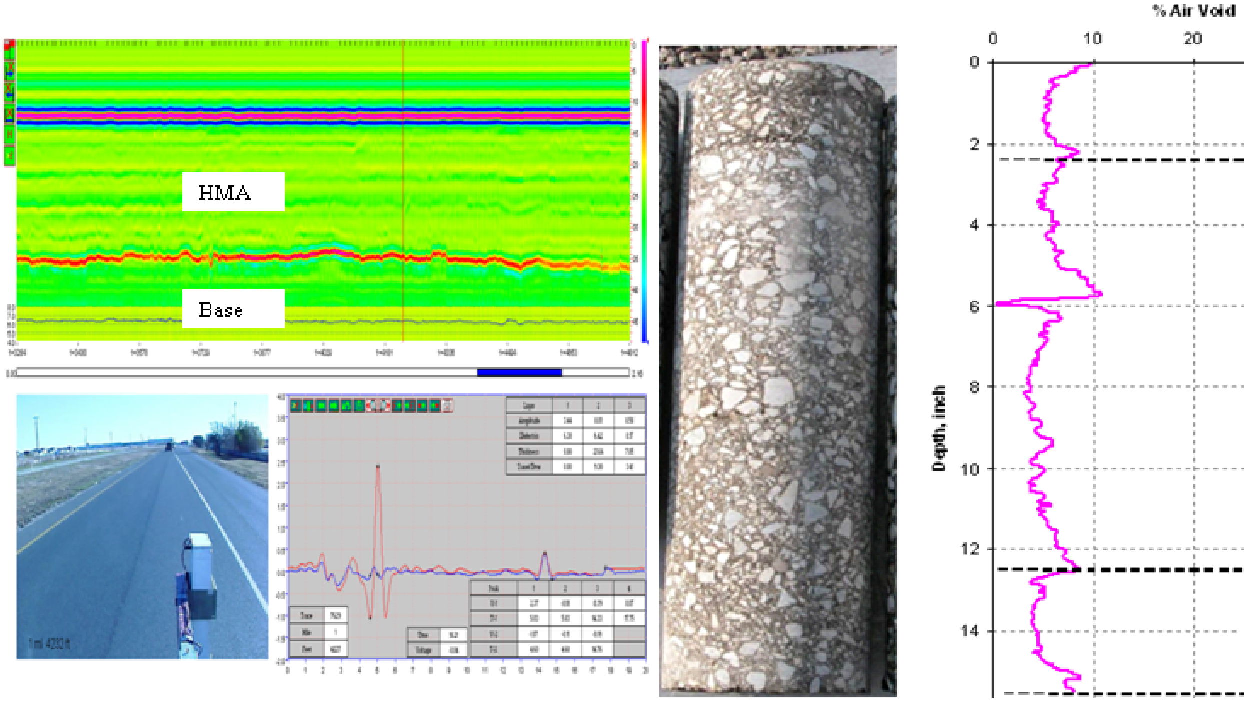


Figure F-3. Example Application of GPR for Construction QC Monitoring.