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Texas A&M Transportation Institute

Texas Mechanistic-Empirical Flexible Pavement Design and Analysis System (TxME) Student Handbook

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Texas Mechanistic-Empirical Flexible Pavement Design and Analysis System (TxME)
Student Handbook

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INTRODUCTION

This student handbook is to provide basic and advanced training about the use of the Texas M-E Flexible Pavement Design and Analysis System (TxME). It can be used as 1) a TxME user manual and 2) a standalone resource of Mechanistic-Empirical (M-E) flexible pavement design training material. The purposes of the TxME training are to:

- Provide students advanced, in-depth knowledge about the flexible pavement design.
- Help students understand the importance of M-E models in pavement performance prediction.
- Allow students to examine the influence of key input parameters such as climate, traffic, pavement structure, and material property.
- Let students explore different combinations of material design and thickness design and choose the best option.
- Help students to identify the issues that some kind of materials or pavement structures may cause.

At the end of this course, participants will be able to:

- Gain in-depth understanding of performance models and material properties.
- Be familiar with the TxME interfaces, functions, and features.
- Examine the influence of climate, traffic, pavement structure, and material property.
- Use the TxME to conduct flexible performance analysis and design for three types of flexible pavements: thin surface, conventional, and perpetual pavement.
- Connect the TxME with the current Texas Department of Transportation (TxDOT) flexible pavement design system (FPS 21) and select best design option.

TXME OVERVIEW

TxME is comprehensive M-E based software to assist TxDOT engineers to make design decisions. It can be used for:

- Asphalt concrete (AC) mixture design.
- Thickness design, for surface treatment, conventional or thin hot mix asphalt (HMA), or perpetual pavement.
- AC thermal cracking analysis or prediction.
- AC fatigue cracking analysis or prediction.
- Rutting analysis or prediction, including AC rutting, flexible base/subgrade rutting.
- Stabilized base fatigue cracking analysis for surface treatment or thin HMA pavement with stabilized base layer.
- Endurance limit analysis for perpetual pavement.

TxME FEATURES

TxME design system enables TxDOT designers to take full advantage of new materials and to make more economical and reliable designs. The main features of TxME include:

- Mechanistic-empirical modeling.
- Performance based material characterization.
- Traffic load spectrum incorporation.
- Design input variability based reliability methodology.
- Incremental distress prediction.
- Fast running speed.
- Friendly user interface.
- Convenient connection with FPS.

SYSTEM REQUIREMENT AND INSTALLATION

TxME is a Windows-based application, which was developed using C# language and within the visual studio integrated development environment. The system requirements are:

- Running TxME requires Windows XP, or Windows 7®.
- For Windows XP®, .Net framework 4.0 is required before installing the software.
- At least 1.0 GHz processor speed and minimum of 1GB disk space are recommended.
- Microsoft Excel 2003® or later version is required.

The software is provided in an executable setup program which extracts all the needed files into the “C:\Users\Public” folder.

The installation of .Net framework can be done by click the following link and follow the instruction: http://www.microsoft.com/en-us/download/confirmation.aspx?id=24872.

TXME MAIN SCREEN

Figure 1 shows the main screen and the layout of TxME design and analysis software. User inputs the data in four main categories: Structure, Climate, Traffic, and Reliability. After all inputs are provided for the design and analysis program, the user clicks the “run” menu or button to run the analysis. The software predicts AC fatigue cracking, AC rutting, AC thermal cracking, flexible base/subgrade rutting, stabilized base fatigue cracking, endurance limit, etc., based the pavement type and pavement structure. The normal running time is generally less than two minutes for one deterministic analysis. The reliability analysis time depend on the number of variables that have uncertainty. The program automatically creates a summary of all inputs of the design project. It also provides a summary of the distress and performance prediction in both tabular and graphical formats. All charts are plotted in Microsoft Excel® and can be incorporated into documents and reports.

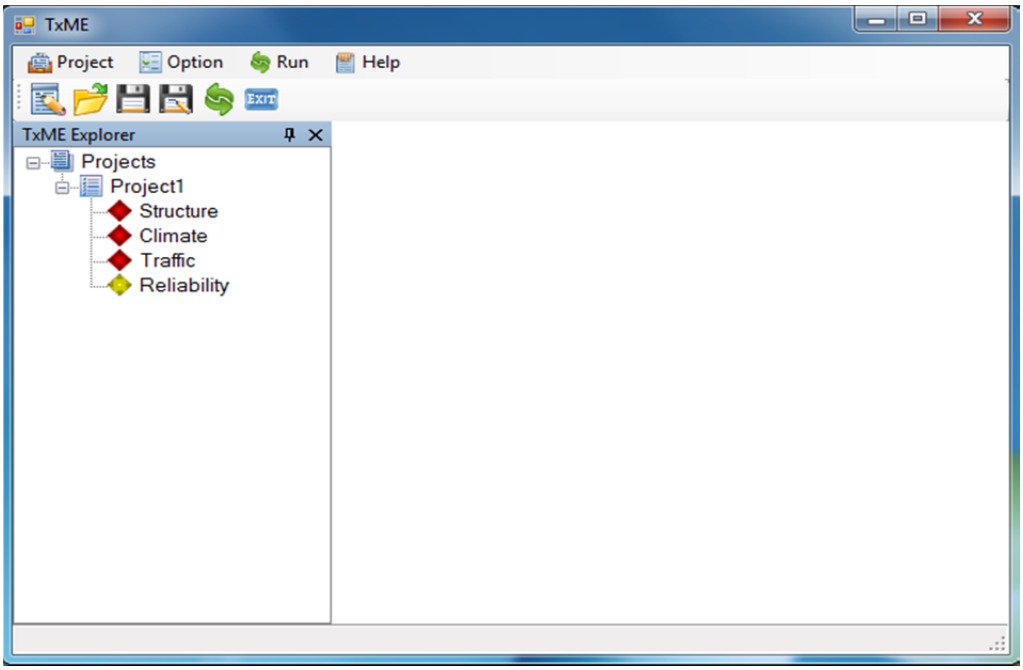


Figure 1. Main Screen of TxME Design and Analysis System.

The following details the screens in the order of structure, traffic, climate, reliability, and output of the TxME design software. After that, the connection with FPS 21 is illustrated.

STRUCTURE INPUT

The structure information includes pavement structure information and material property information for each layer.

PAVEMENT STRUCTURE

Figure 2 presents the pavement structure input screen. On this screen, the upper left window shows the pavement type and location; the upper right window lists available AC layer material, base layer material, and sub-base layer material icons; the lower left window shows the pavement structure; and the lower right window shows the layer material property.

Users can build their own pavement structures by dragging the layer material icons into the pavement structure window. To remove a layer from the pavement structure window, users just need to click the layer and choose “Remove this layer” from the pop-up menu.

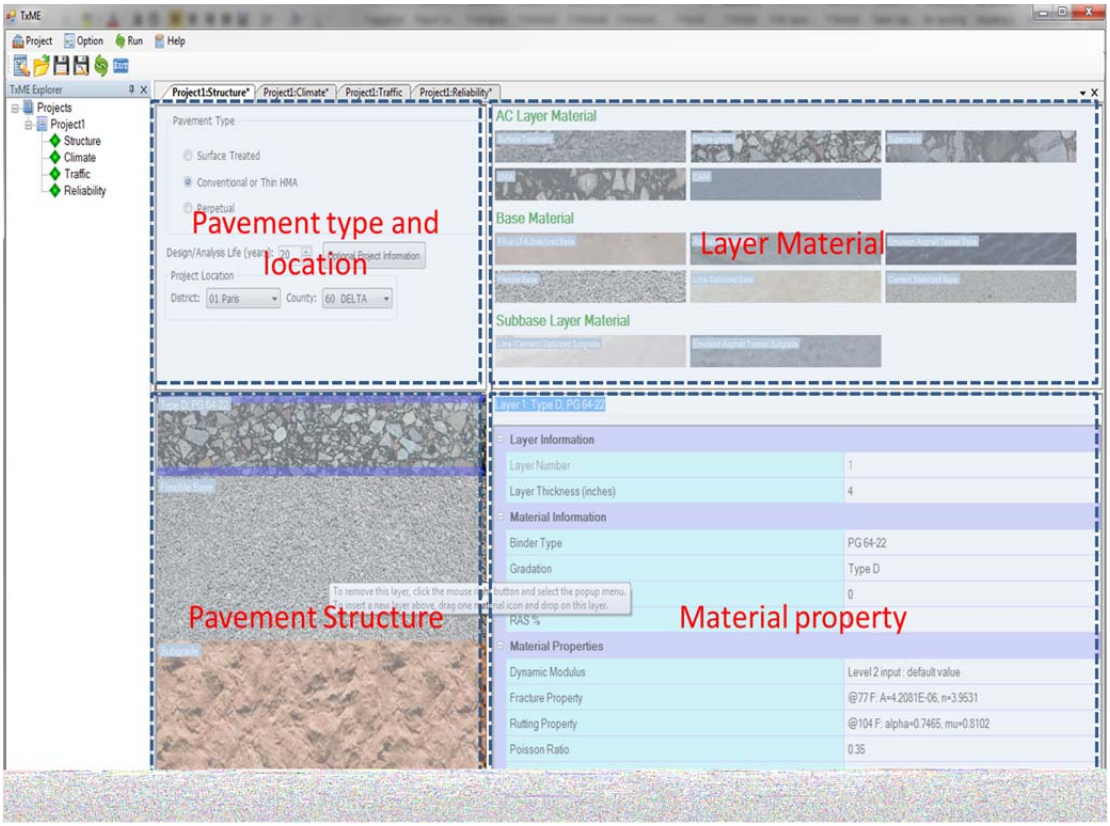


Figure 2. Pavement Structure Information Screen.

MATERIAL PROPERTY

As in Figure 2, by clicking each layer in the pavement structure window, users can browse or edit this layer thickness and layer material property in the material property window. For some

property inputs such as Thickness, Poisson Ratio, etc., the user only needs to input some numbers. For more complicated inputs such as dynamic modulus and fracture/rutting property, the user needs to click the item and the corresponding input screen will pop up. Several material property input screens are illustrated below, including:

- Figure 3, presenting the dynamic modulus inputs for AC layers.
- Figures 4 and 5, presenting AC layers fracture property and rutting property inputs, respectively.
- Figure 6, presenting the stabilized base material property inputs.
- Figure 7 and 8, presenting flexible base or subgrade modulus inputs, including typical modulus and modulus considering moisture impact, respectively.
- Figure 9, presenting the flexible base or subgrade material rutting property inputs, with monthly values.

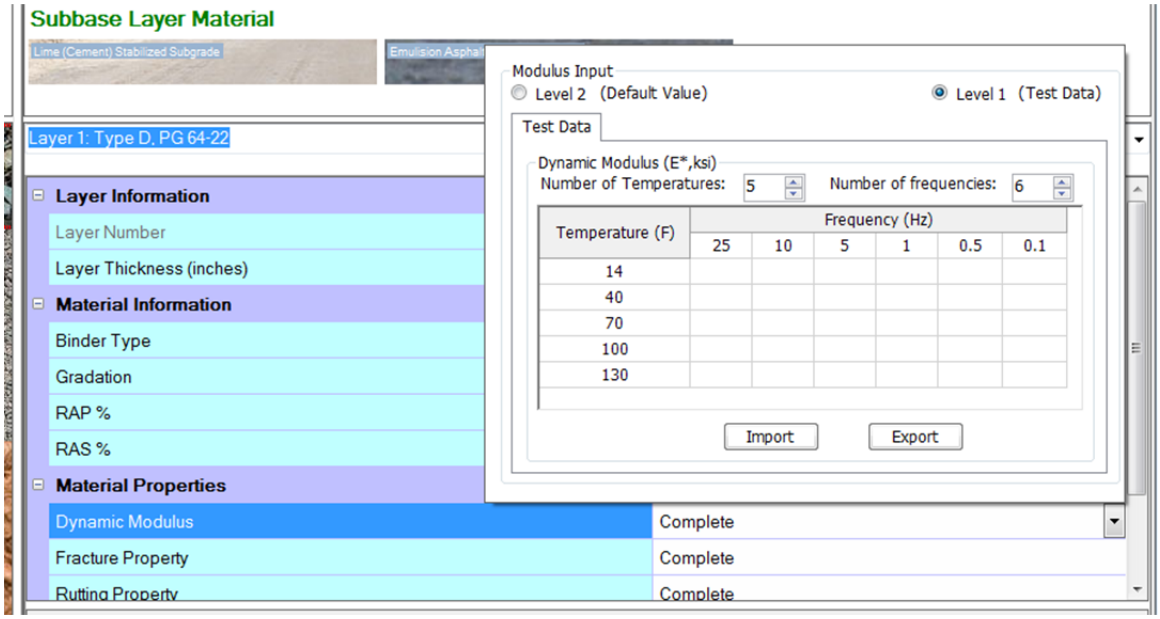


Figure 3. AC Layer Dynamic Modulus Input Screen.

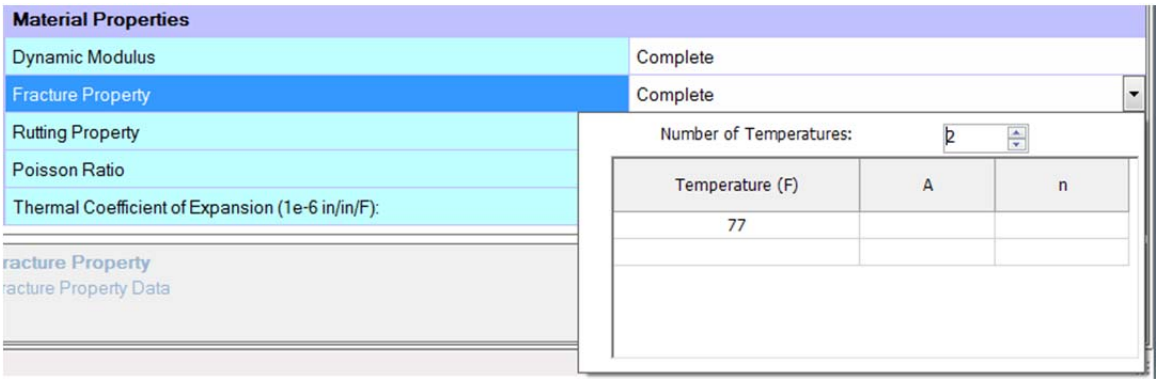


Figure 4. AC Layer Fracture Properties Input Screen.

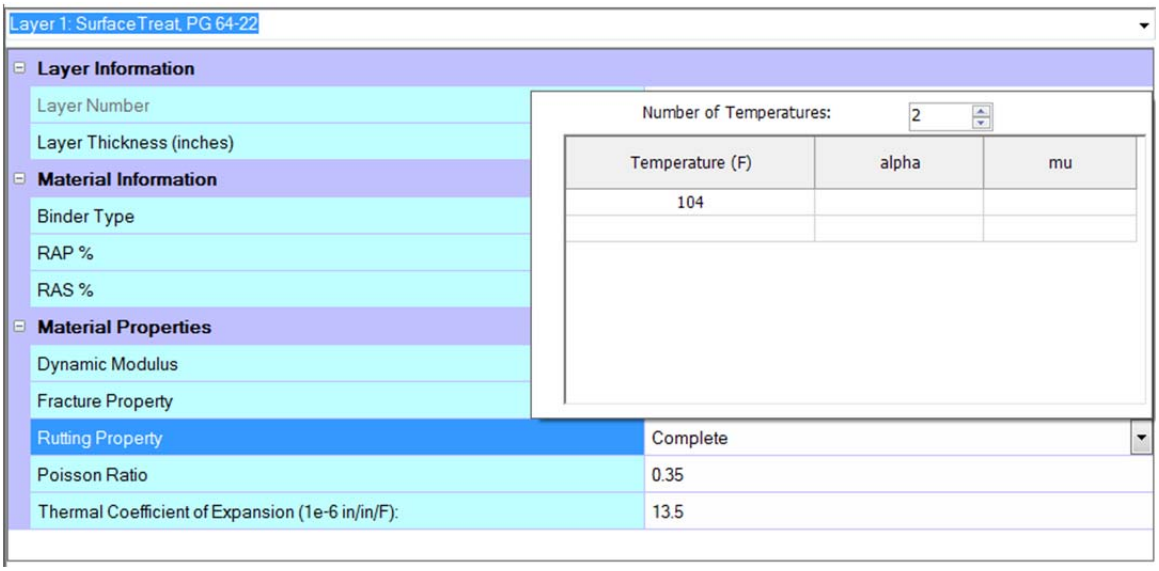


Figure 5. AC Layer Rutting Properties Input Screen.

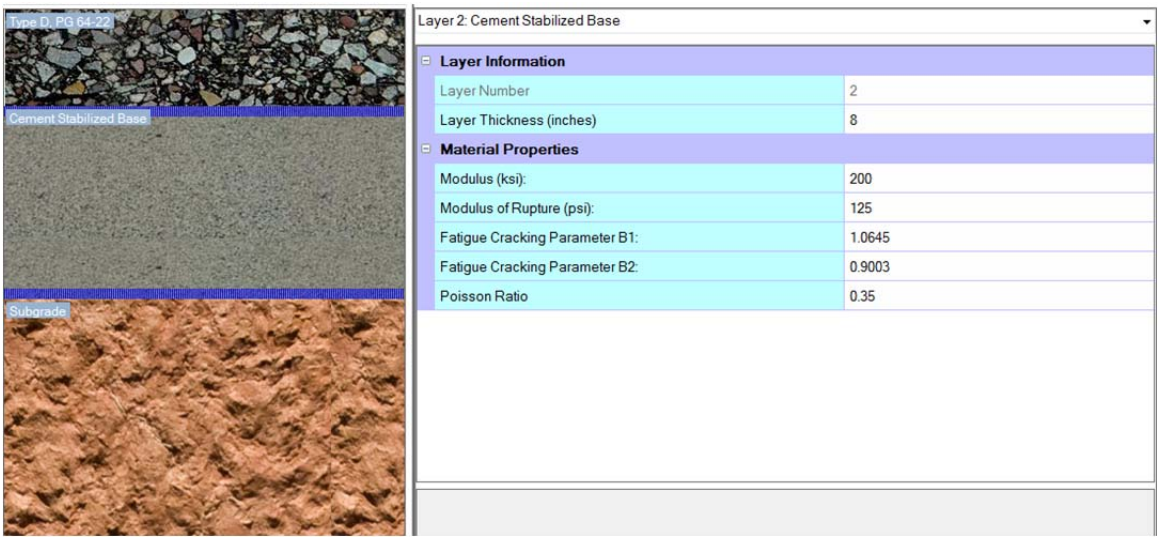


Figure 6. Stabilized Base Material Properties Input Screen.

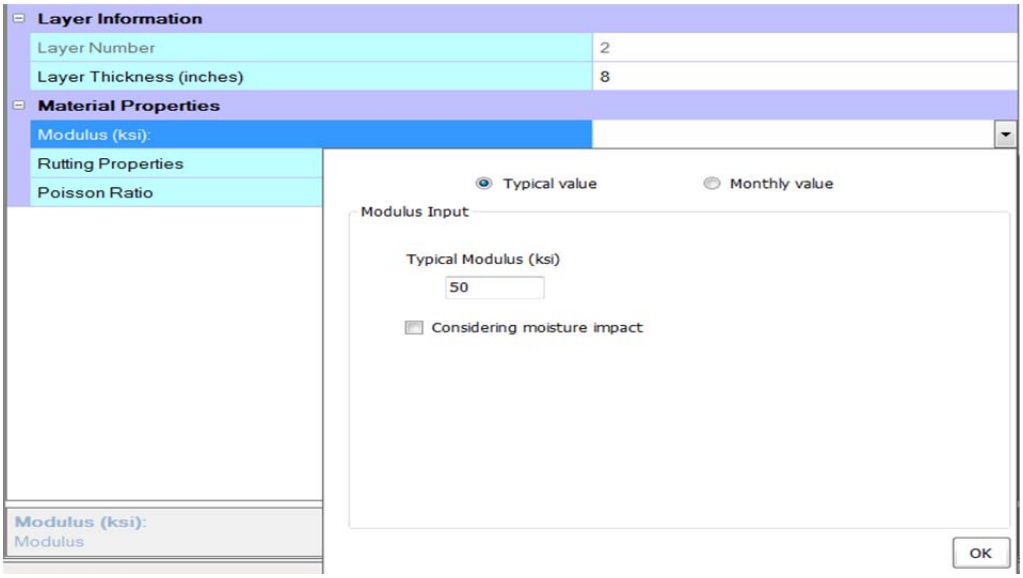


Figure 7. Flexible Base/Subgrade Typical Modulus Input Screen (without Considering Moisture Impact).

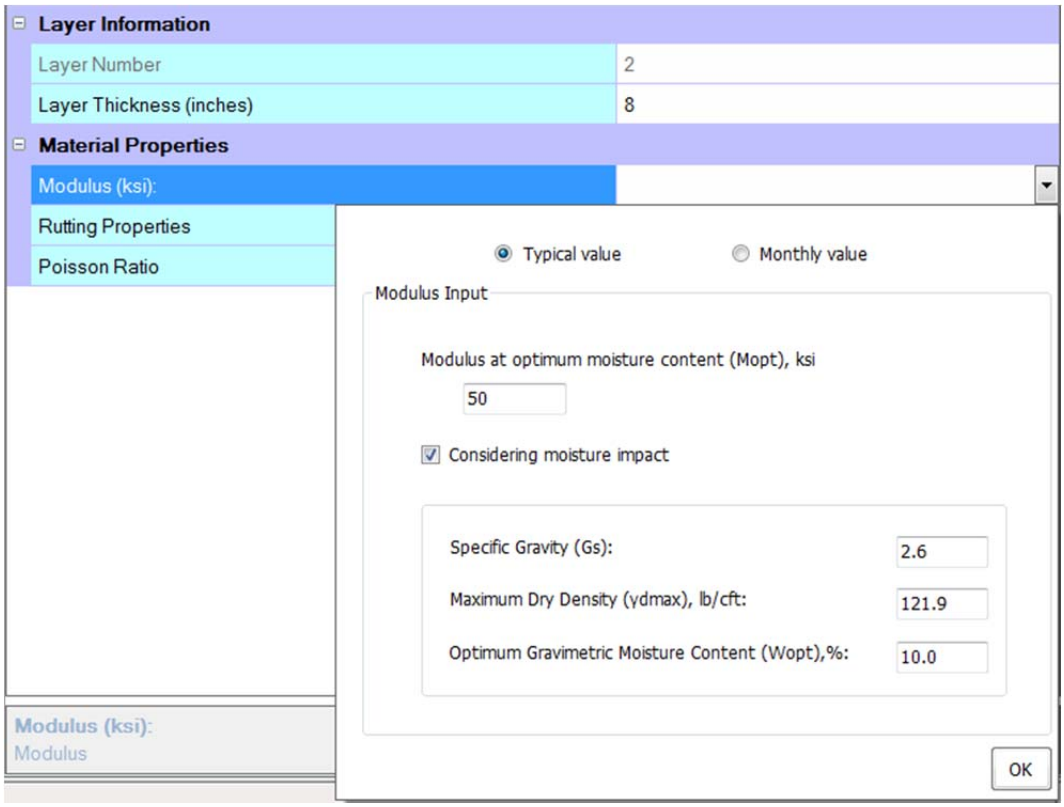


Figure 8. Flexible Base/Subgrade Modulus Input Screen (Considering Moisture Impact).

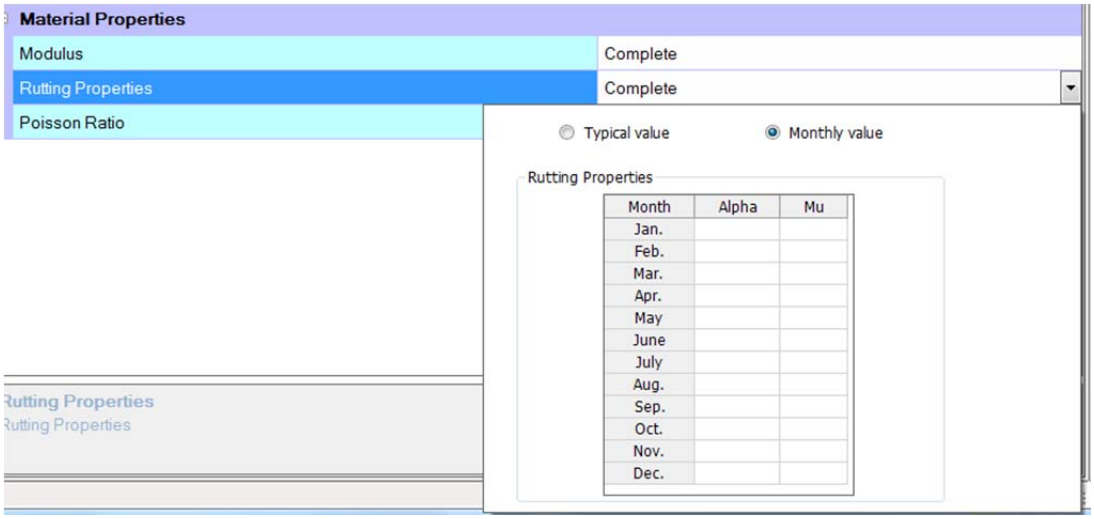


Figure 9. Flexible Base/Subgrade Rutting Properties Input Screen.

TRAFFIC INPUT

There are two levels of traffic inputs in TxME, one is equivalent standard axle loads (ESALs) input and the other is load spectrum input. The following illustrates the difference between these inputs.

TRAFFIC ESALS (LEVEL 2) INPUT

Figure 10 shows the traffic ESALs (Level 2) input screen. The most important input is the total ESAL number during 20 years (one lane and one direction). The ADT-Beginning and ADT-End represent average daily traffic in the beginning and in the end, respectively. These values are used to determine the vehicle growth rate. The tire pressure is used to determine the tire contact area. The operation speed impacts the AC layer modulus since it relates to loading time.

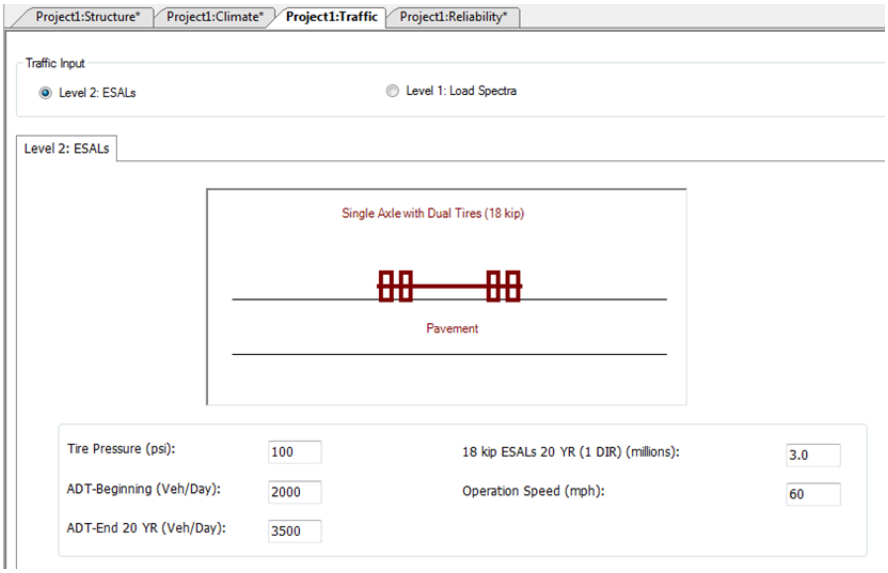


Figure 10. Traffic ESALs (Level 2) Input Screen.

TRAFFIC LOAD SPECTRUM (LEVEL 1) INPUT

Figure 11 is the traffic load spectrum (Level 1) input screen. In this screen, the left windows show the general information and axle configuration information such as average annual daily total truck (AADTT) number, operation speed, tire pressure, axle spacing, etc.; the upper right window shows the vehicle class distribution and growth rate information; and the lower right window shows the axle numbers for each vehicle class. By clicking the “Monthly Adjustment” or “Axle Load Distribution” button in Figure 11, screens such as Figure 12 or Figure 13 pop up. These screens let users define the axle load distributions for each vehicle class and their monthly variations.

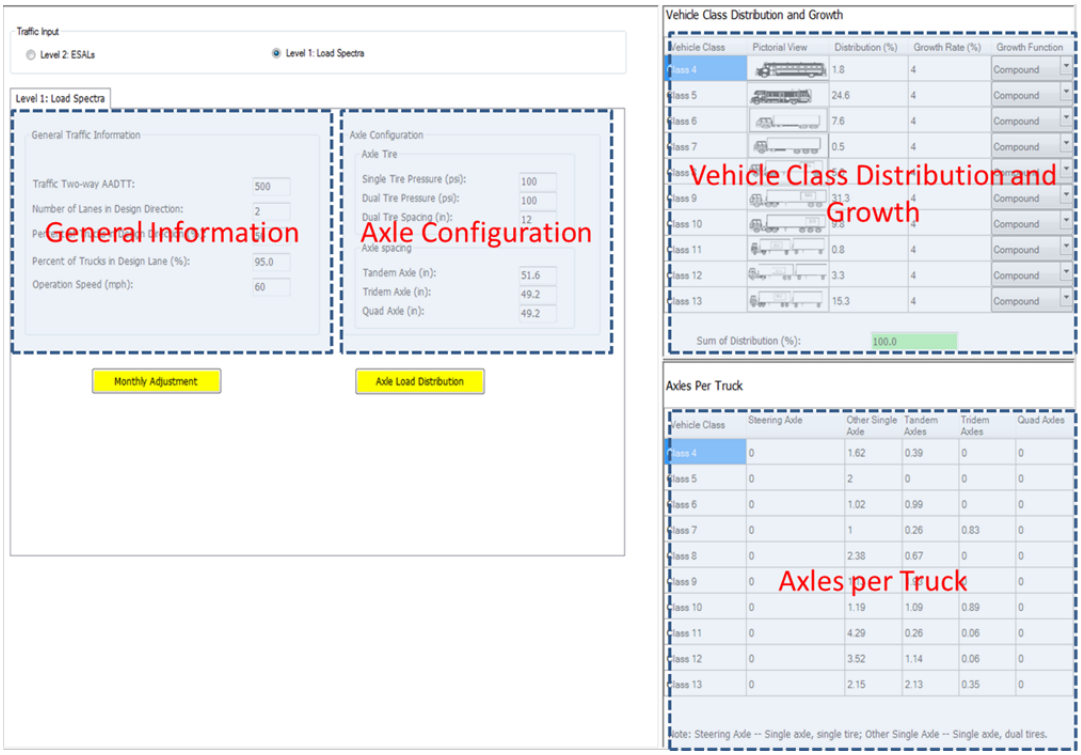


Figure 11. Traffic Load Spectrum (Level 1) Input Screen.

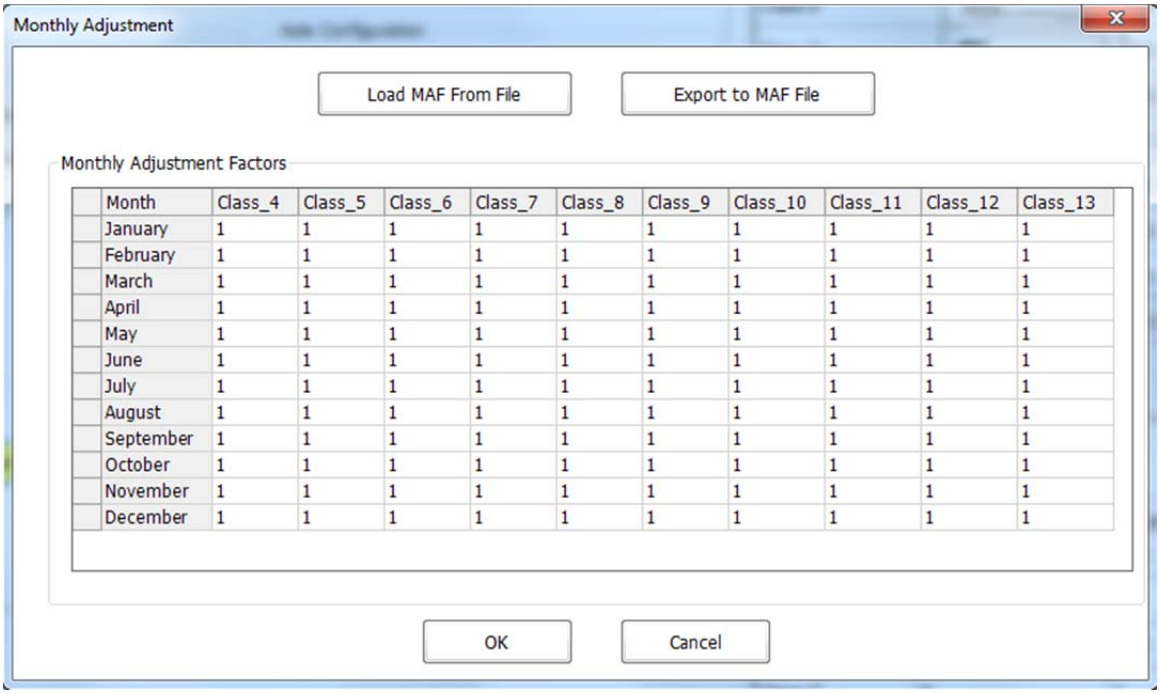
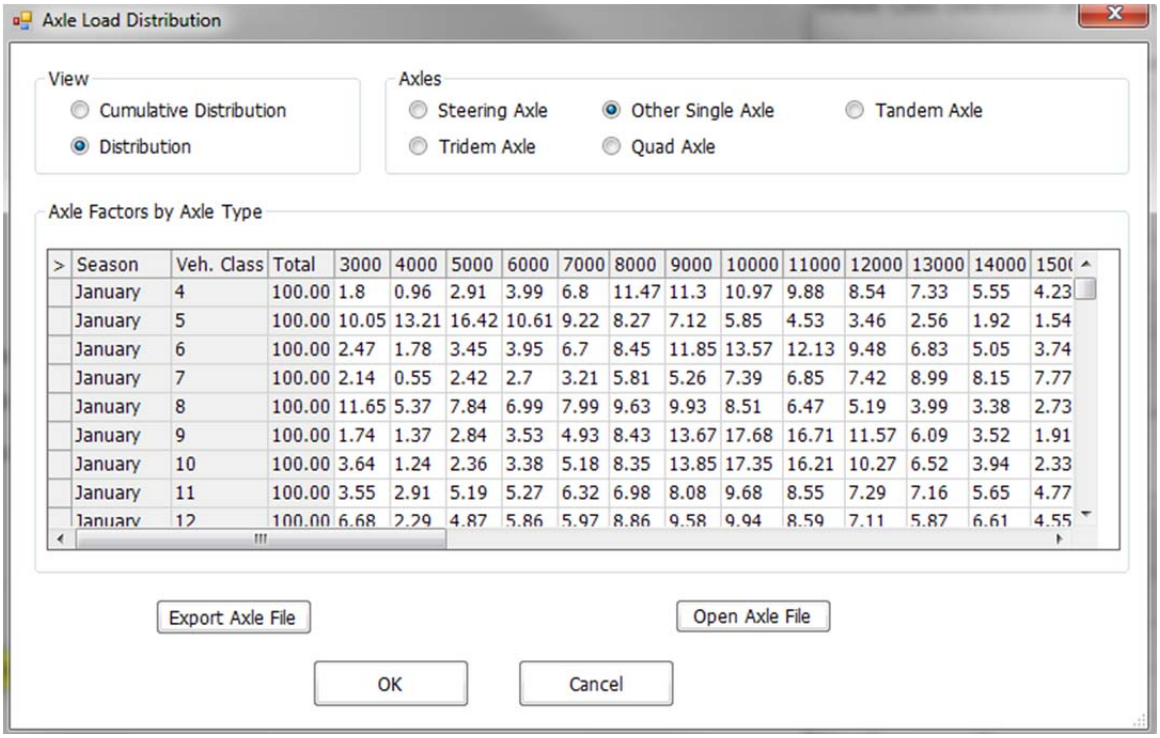


Figure 12. Traffic Monthly Adjustment Input Screen.



>	Season	Veh. Class	Total	3000	4000	5000	6000	7000	8000	9000	10000	11000	12000	13000	14000	150(
	January	4	100.00	1.8	0.96	2.91	3.99	6.8	11.47	11.3	10.97	9.88	8.54	7.33	5.55	4.23
	January	5	100.00	10.05	13.21	16.42	10.61	9.22	8.27	7.12	5.85	4.53	3.46	2.56	1.92	1.54
	January	6	100.00	2.47	1.78	3.45	3.95	6.7	8.45	11.85	13.57	12.13	9.48	6.83	5.05	3.74
	January	7	100.00	2.14	0.55	2.42	2.7	3.21	5.81	5.26	7.39	6.85	7.42	8.99	8.15	7.77
	January	8	100.00	11.65	5.37	7.84	6.99	7.99	9.63	9.93	8.51	6.47	5.19	3.99	3.38	2.73
	January	9	100.00	1.74	1.37	2.84	3.53	4.93	8.43	13.67	17.68	16.71	11.57	6.09	3.52	1.91
	January	10	100.00	3.64	1.24	2.36	3.38	5.18	8.35	13.85	17.35	16.21	10.27	6.52	3.94	2.33
	January	11	100.00	3.55	2.91	5.19	5.27	6.32	6.98	8.08	9.68	8.55	7.29	7.16	5.65	4.77
	January	12	100.00	6.68	2.29	4.87	5.86	5.97	8.86	9.58	9.94	8.59	7.11	5.87	6.61	4.55

Figure 13. Traffic Axle Load Distribution Input Screen.

CLIMATE INPUT

There are two ways to attach the climatic information to a given project location: users can either assign a specific weather station or use interpolated climatic data based on the coordinates of the location.

Figure 14 presents the climate input screen when users choose a specific weather station. Generally, the left part of screen lets the user select a weather station, and the right part shows the summary of the weather data, such as average temperature or precipitation. The user can look into more detailed information like hourly data by clicking the “Hourly data” tab on the upper right.

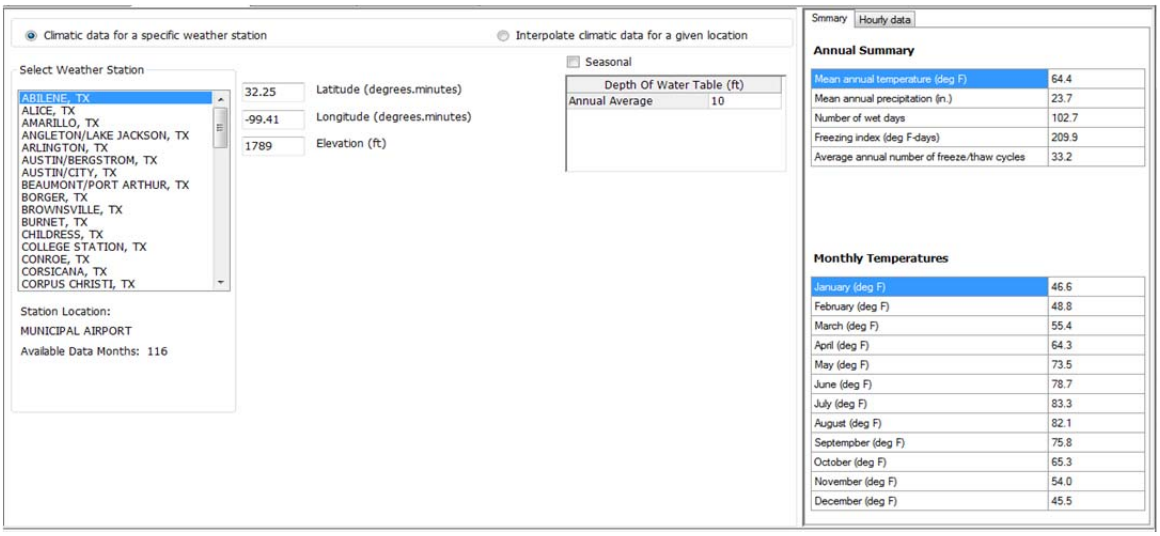


Figure 14. Climate for a Specific Weather Station Input Screen.

For a project location without a dedicated weather station, users can choose the radio button “Interpolate climatic data for a given location,” and the application will provide six weather stations nearby for the user to select for interpolation. Figure 15 presents the user input screen for climate data interpolation. The lines and numbers such as “#1, #2…” in the graph show the relative positions and distances from the location defined by the coordinates. The interpolated hourly data information is listed in the right part of the screen.

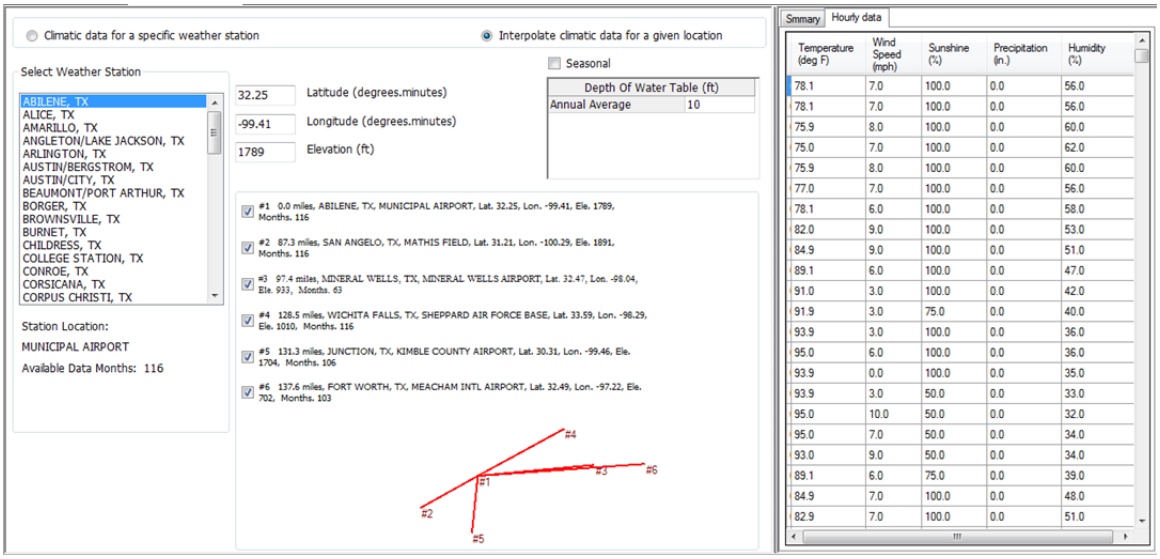


Figure 15. Climatic Data Interpolation Input Screen.

RELIABILITY RELATED INPUT

Figure 16 presents the reliability related input screen for a three-layer conventional pavement. Two input categories are displayed in this screen. On the left side are the performance criteria inputs, and on the right side are the variability inputs. For the performance criteria inputs, the user supplies the analysis stop criteria (performance limit) and reliability level in terms of percentage. For variability inputs, the user checks the applicable checkboxes and modifies the coefficient of variation value.

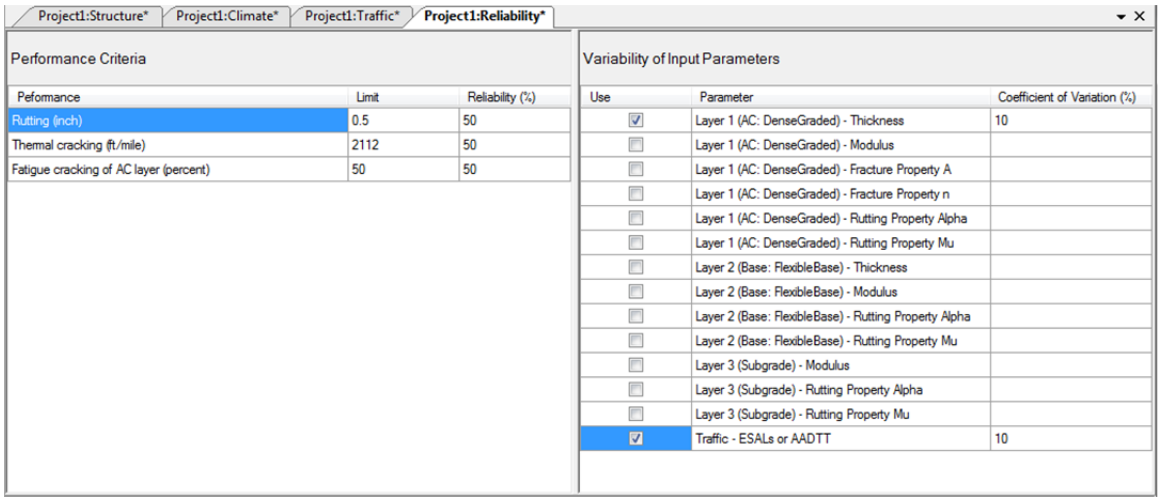


Figure 16. Reliability Related Input Screen for a Three-Layer Conventional Pavement.

Both performance criteria and variability parameters are related to pavement structure and pavement type. Whenever the pavement structure or pavement type changes, these parameters are changed accordingly. For example, Figure 17 shows the reliability related input screen for a

four-layer perpetual pavement. As can be seen in this figure, the endurance limit entry appears on the left side and more parameters are listed on the right side.

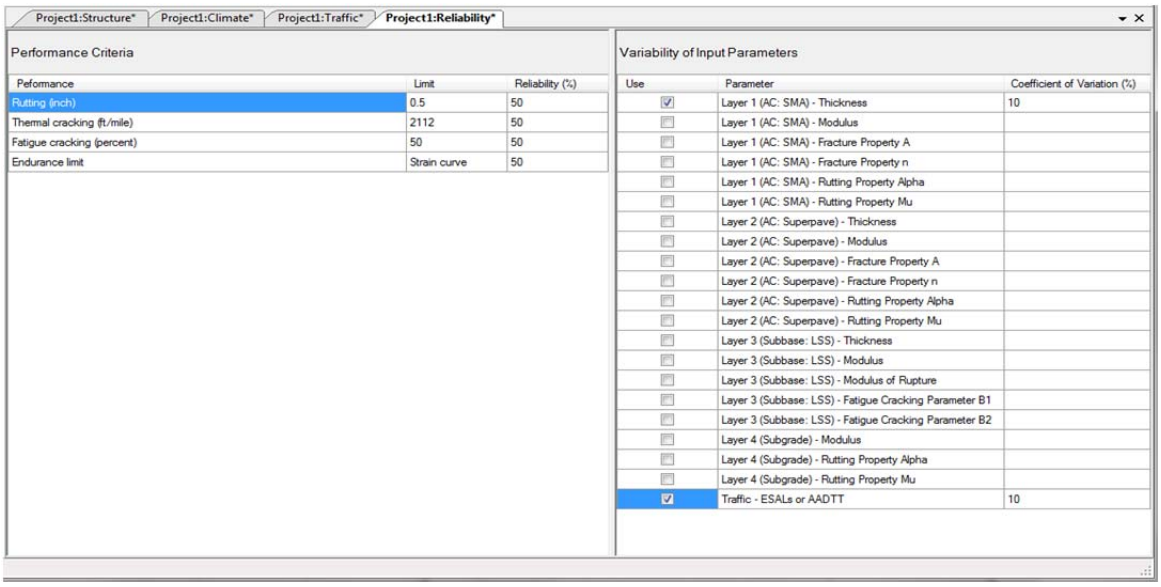


Figure 17. Reliability Related Input Screen for a Four-Layer Perpetual Pavement.

OUTPUT

The output of TxME is organized into an Excel file that is mainly composed of three parts: the summary of user's inputs, the analysis result table, and the distress plots. See Figure 18. The predicted distresses are different depending on pavement structure and pavement type. The following discusses and illustrates the output for each pavement type.

Figure 18. Output of TxME in Excel File Format.

OUTPUT OF SURFACE TREATED PAVEMENT

For surface treated pavement with flexible base, only rutting result is predicted and plotted. See Figure 19.

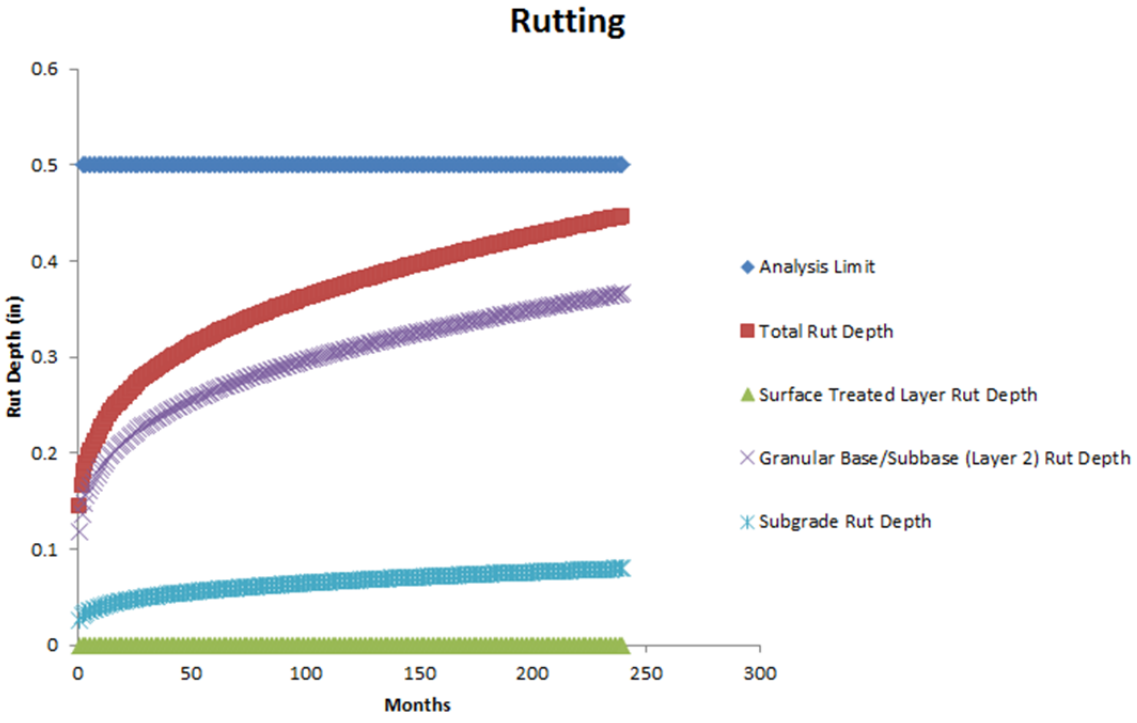


Figure 19. Output of Surface Treated Pavement with Flexible Base.

For surface treated pavement with stabilized base, both rutting and stabilized fatigue cracking are predicted and plotted. See Figure 20; note that the rut depth of stabilized base is ignored.

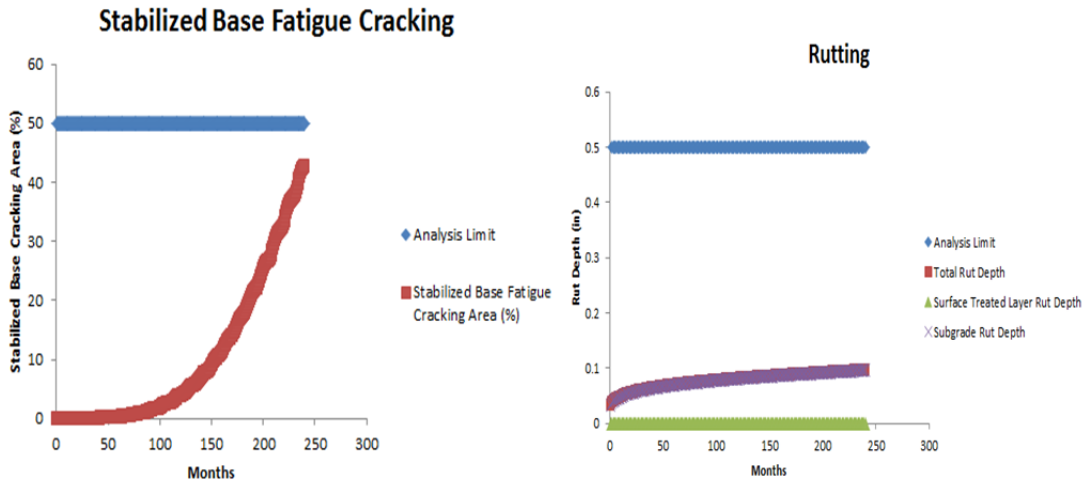


Figure 20. Output of Surface Treated Pavement with Stabilized Base.

If there are more than two base or subbase layers, of which some are flexible and the others are stabilized, TxME will predict the stabilized fatigue cracking only if the stabilized base layer is just under the AC layer. The rut depth of flexible base layer is always predicted no matter where the layer is.

OUTPUT OF CONVENTIONAL OR THIN HMA PAVEMENT

Figure 21 shows the typical output of conventional or thin HMA pavement with flexible base. Rutting, AC fatigue cracking, and AC thermal cracking are predicted in the analysis.

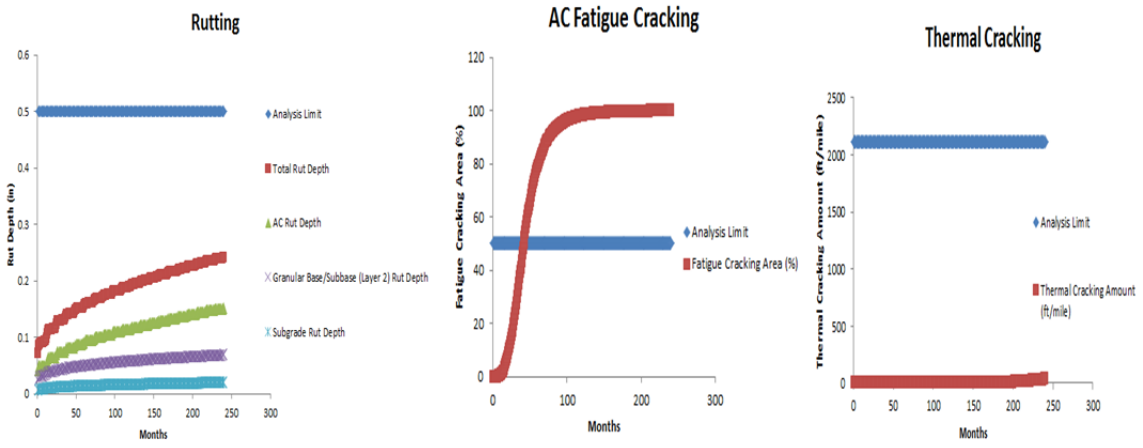


Figure 21. Output of Conventional or Thin HMA with Flexible Base.

Similar to surface treated pavement, if the first base layer (counted from top to bottom) is stabilized layer, the stabilized base fatigue cracking is also predicted and plotted.

OUTPUT OF PERPETUAL PAVEMENT

For perpetual pavement analysis, endurance limit is determined according to the traffic input level. For ESALs input (Level 2), the endurance limit is actually the maximum bottom strain of the AC layer under the standard 18 kip single axle dual tire load. For load spectrum input (Level 1), the endurance limit is the frequency of AC layer bottom strain distribution under different axle load levels. Figure 22 shows the endurance limit output under the traffic load spectrum.

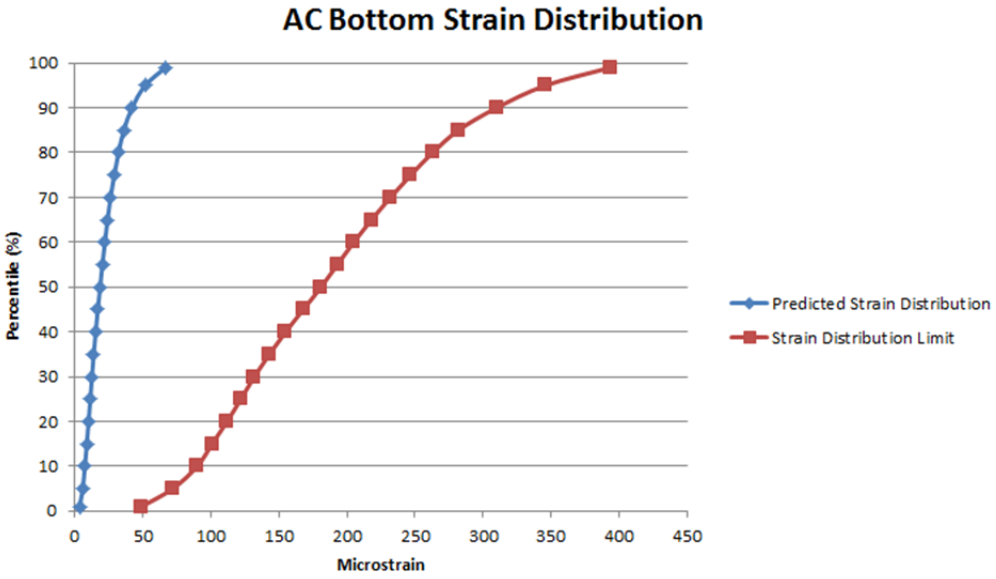


Figure 22. Output of Endurance Limit of Perpetual Pavement under Load Spectrum.

Other typical outputs of perpetual pavement are similar to conventional pavement, which includes rutting, AC fatigue cracking, and AC thermal cracking. There is no stabilized fatigue cracking analysis for perpetual pavement since normally the AC layers are thick enough to prevent fatigue cracking in the stabilized base layer.

CONNECTION WITH FPS 21

FPS 21 is the flexible pavement design system currently used by TxDOT. Figure 23 shows the program start screen.

Figure 23. Start Screen of FPS 21.

The users input of FPS 21 includes pavement location, traffic ESALs, Falling Weight Deflectometer (FWD) modulus of each layer, maximum and minimum thickness of each layer, etc. The output of FPS 21 is available layer thickness combinations. Note that FPS 21 only uses FWD modulus to represent each layer's property; it does not use any lab testing data, so it is impossible to determine benefits from improved base materials or superior asphalt mixes. To determine these benefits, TxME is designed to import the input and output information from FPS21, plus some specific test results such as rutting property or fracture property, to conduct the performance check. Figure 24 shows the connection concept.

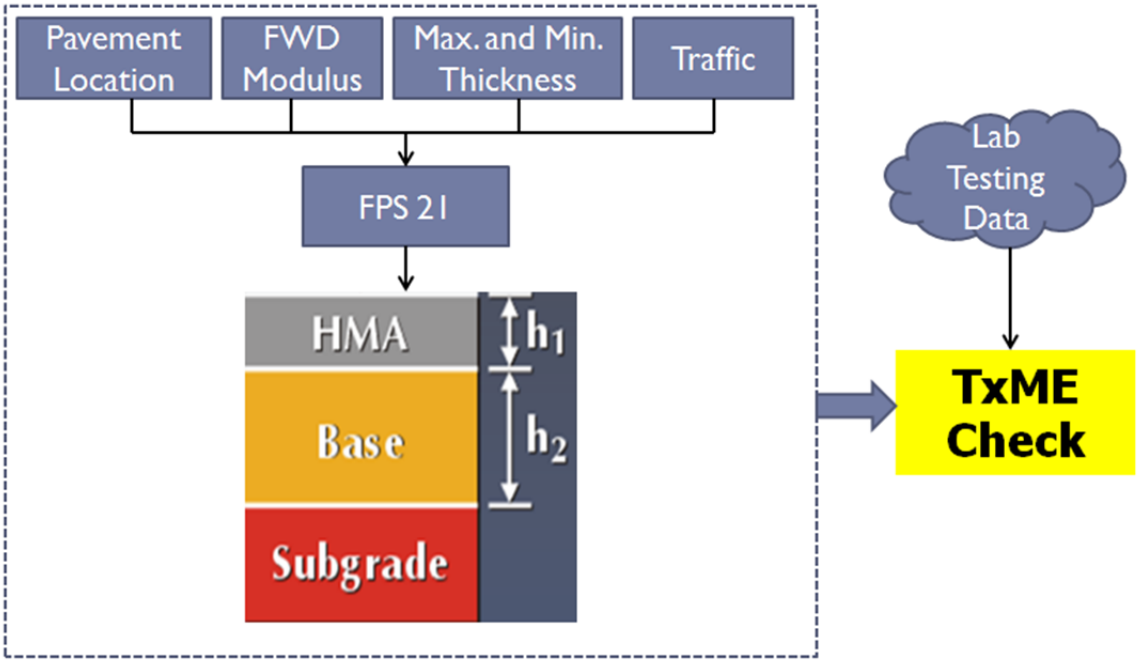


Figure 24. Connection Concept between FPS 21 and TxME.

Figure 25 shows an example of TxME pavement structure imported from FPS 21. By clicking the button “TxME Check” in the FPS 21 screen, the TxME will be launched and automatically import the related information, such as pavement location, layer type, layer thickness, ESALs, and so on. The left part of Figure 25 is the FPS 21 recommended design option, and the right part is the TxME pavement structure after importation. TxME also searches the embedded database and provides default values for lab testing data. Users can edit these values if specific lab test results are available.

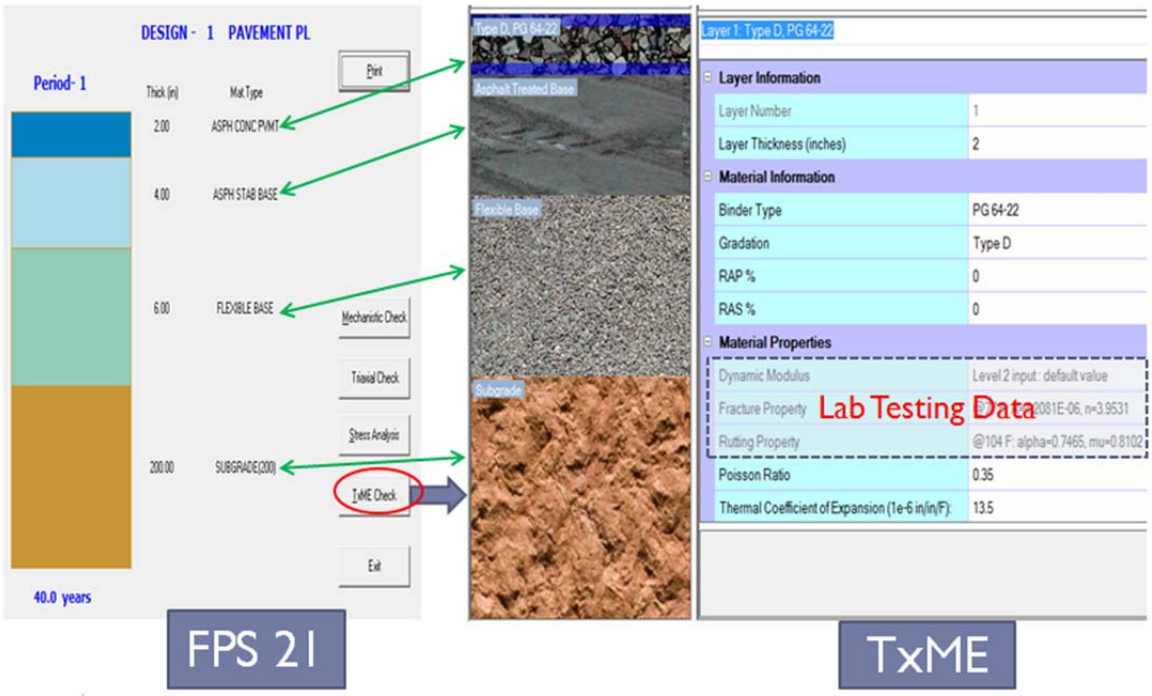


Figure 25. An Example of TxME Pavement Structure Imported from FPS 21.

EXAMPLE 1

Project Input

- Pavement Structure: Conventional Pavement; AC/Flexible base/Subgrade
- Design or Analysis Life: 20 years
- District: Austin; County: Bastrop
- Analysis Parameters & Criteria:
  - Fatigue Cracking Limit: 50%
  - Total Rutting Limit: 0.5 inch
- Traffic:
  - ADT-Beginning: 20000; ADT-End: 35000; ESALs: 3.0 million; Speed: 60 mph
- Weather Station: Austin/City, Tx
- Layer thickness
  - AC layer: 4 inches
  - Flexible base layer: 8 inches
- AC layer material property
  - Mix type: Type D; Binder type: PG 64-22
  - Modulus Input Level: Level 3-default values
  - Fracture properties and Rutting properties: default values
- Flexible base layer property
  - Modulus: 50 ksi
  - Rutting properties: default values
- Subgrade
  - Modulus: 4 ksi
  - Rutting properties: default values
- Reliability
  - Deterministic

Analysis Result

After 92 months, Fatigue Cracking Area reaches 50%.

Rut depth reaches 0.316 inches after 20 years (240 months).

EXAMPLE 2

Project Input

- Pavement Structure: Conventional Pavement; AC/Flexible base/Subgrade
- Design or Analysis Life: 20 years
- District: Austin; County: Bastrop
- Analysis Parameters & Criteria:
  - Fatigue Cracking Limit: 50%
  - Total Rutting Limit: 0.5 inch
- Traffic:
  - Level 1 Input (Load Spectrum)
  - AADTT: 500
  - Other traffic input parameters: default values
- Weather Station: Austin/City, Tx
- Layer thickness
  - AC layer: 4 inches
  - Flexible base layer: 8 inches
- AC layer material property
  - Mix type: Type D; Binder type: PG 64-22
  - Modulus Input Level: Level 3-default values
  - Fracture properties and Rutting properties: default values
- Flexible base layer property
  - Modulus: 50 ksi
  - Rutting properties: default values
- Subgrade
  - Modulus: 4 ksi
  - Rutting properties: default values
- Reliability
  - Deterministic

Note that the difference between Example 1 and Example 2 is traffic input.

Analysis Result

After 111 months, Fatigue Cracking Area reaches 50%.

Rut depth reaches 0.337 inches after 20 years (240 months).

EXAMPLE 3

Project Input

- Pavement Structure: Conventional Pavement; AC/Flexible base/Subgrade
- Design or Analysis Life: 20 years
- District: Austin; County: Bastrop
- Analysis Parameters & Criteria:
  - Fatigue Cracking Limit: 50%
  - Total Rutting Limit: 0.5 inch
- Traffic:
  - ADT-Beginning: 20000; ADT-End: 35000; ESALs: 3.0 million; Speed: 60 mph
- Weather Station: Austin/City, Tx
- Layer thickness
  - AC layer: 4 inches
  - Flexible base layer: 8 inches
- AC layer material property
  - Mix type: Type D; Binder type: PG 64-22
  - Modulus Input Level: Level 3-default values
  - Fracture properties and Rutting properties: default values
- Flexible base layer property
  - Modulus: 50 ksi
  - Rutting properties: default values
- Subgrade
  - Modulus: 4 ksi
  - Rutting properties: default values
- Reliability
  - AC Thickness CV: 15%
  - Flexible base modulus CV: 20%
  - Reliability Level: 95%

Note that the difference between Example 1 and Example 2 is reliability input.

Analysis Result

After 46 months, Fatigue Cracking Area reaches 50% at 95% reliability.

Rut depth reaches 0.321 inches after 20 years (240 months) at 95% reliability.

EXERCISE 1

Project Input

- Pavement Structure: Conventional Pavement; AC/Flexible base/Subgrade
- Design or Analysis Life: 20 years
- District: Austin; County: Bastrop
- Analysis Parameters & Criteria:
  - Fatigue Cracking Limit: 50%
  - Total Rutting Limit: 0.5 inch
- Traffic:
  - Level 1 Input (Load Spectrum)
  - AADTT: 500
  - Other traffic input parameters: default values
- Weather Station: Austin/City, Tx
- Layer thickness
  - AC layer: 4 inches
  - Flexible base layer: 8 inches
- AC layer material property
  - Mix type: Type D; Binder type: PG 64-22
  - Modulus Input Level: Level 3-default values
  - Fracture properties and Rutting properties: default values
- Flexible base layer property
  - Modulus: 50 ksi
  - Rutting properties: default values
- Subgrade
  - Modulus: 4 ksi
  - Rutting properties: default values
- Reliability
  - AC Thickness CV: 15%
  - Flexible base modulus CV: 20%
  - Reliability Level: 95%

The purposes of this exercise are to practice the load spectrum plus reliability inputs and to compare the result with that of Example 3.

Analysis Result

After ? months, Fatigue Cracking Area reaches 50% at 95% reliability.

Rut depth reaches ? inches after 20 years (240 months) at 95% reliability.

EXERCISE 2

Project Input

- Pavement Structure: Conventional Pavement; AC/Flexible base/Subgrade
- Design or Analysis Life: 20 years
- District: Austin; County: Bastrop
- Analysis Parameters & Criteria:
  - Fatigue Cracking Limit: 50%
  - Total Rutting Limit: 0.5 inch
- Traffic:
  - Level 1 Input (Load Spectrum)
  - AADTT: 500
  - Other traffic input parameters: default values
- Weather Station: Austin/City, Tx
- Layer thickness
  - AC layer: 4 inches
  - Flexible base layer: 8 inches
- AC layer material property
  - Mix type: SMA D; Binder type: PG 76-22
  - Modulus Input Level: Level 3-default values
  - Fracture properties and Rutting properties: default values
- Flexible base layer property
  - Modulus: 50 ksi
  - Rutting properties: default values
- Subgrade
  - Modulus: 4 ksi
  - Rutting properties: default values
- Reliability
  - AC Thickness CV: 15%
  - Flexible base modulus CV: 20%
  - Reliability Level: 95%

The purpose of this exercise is to change the AC layer material (SMA, PG 76-22) and to compare the result with that of Exercise 1.

Analysis Result

After ? months, Fatigue Cracking Area reaches 50% at 95% reliability.

Rut depth reaches ? inches after 20 years (240 months) at 95% reliability.

EXAMPLE 4

FPS 21 Input

- Design type: Surface Treatment
- Pavement Structure: Surface Treatment/Flexible base/Subgrade
- Design Life: 15 years
- District: Austin; County: Bastrop
- Traffic:
  - ADT-Beginning: 1500; ADT-End: 3000; ESALs: 0.3 million

FPS 21 Output

- Design Option 1: Surface Treatment + 9.5 inches flexible base+Subgrade
- Design Option 2: Surface Treatment +13.5 inches flexible base

TxME Check

- Analysis Parameters & Criteria:
  - Total Rutting Limit: 0.5 inch
- Design 1: 0.4188 inches
- Design 2: 0.4752 inches

EXAMPLE 5

FPS 21 Input

- Design type: Conventional Pavement
- Pavement Structure: AC Layer/Asphalt Stabilized Base/Flexible Base/Subgrade
- Design Life: 15 years
- District: Austin; County: Bastrop
- Traffic:
  - ADT-Beginning: 1500; ADT-End: 3000; ESALs: 3 million

FPS 21 Output

Pavement Structure	Thickness (inches)			
	Design 1	Design 2	Design 3	Design 4
AC Layer	2	2	2	2
Asphalt Stabilized Base	5.5	7.0	5.0	6.5
Flexible Base	6	6.0	9.5	9.5

TxME Check

Since the pavement type is conventional, TxME performs fatigue cracking, thermal cracking, and rutting analysis. The fatigue cracking and thermal cracking area are very small for all the design options. Figure 26 illustrates the rutting comparison result among these design options.

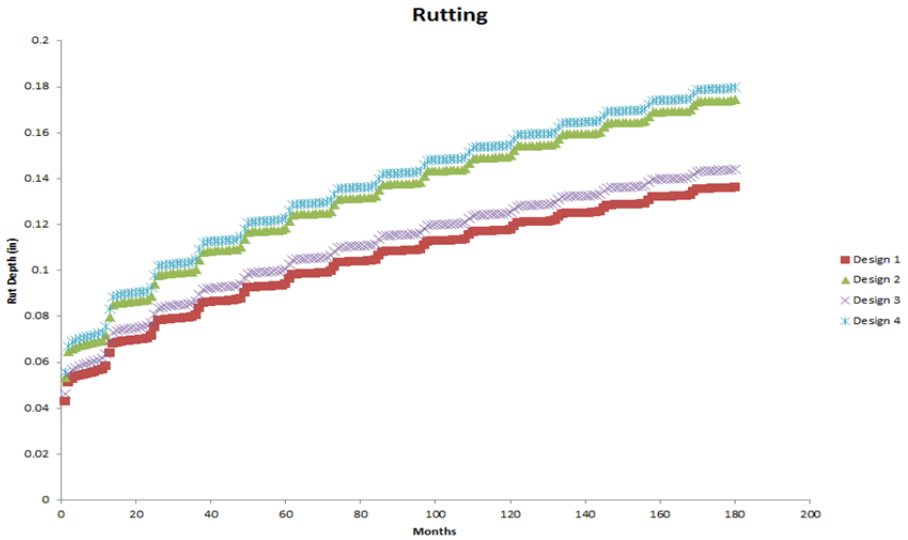


Figure 26. Rut Depth Comparison among FPS 21 Design Options.