

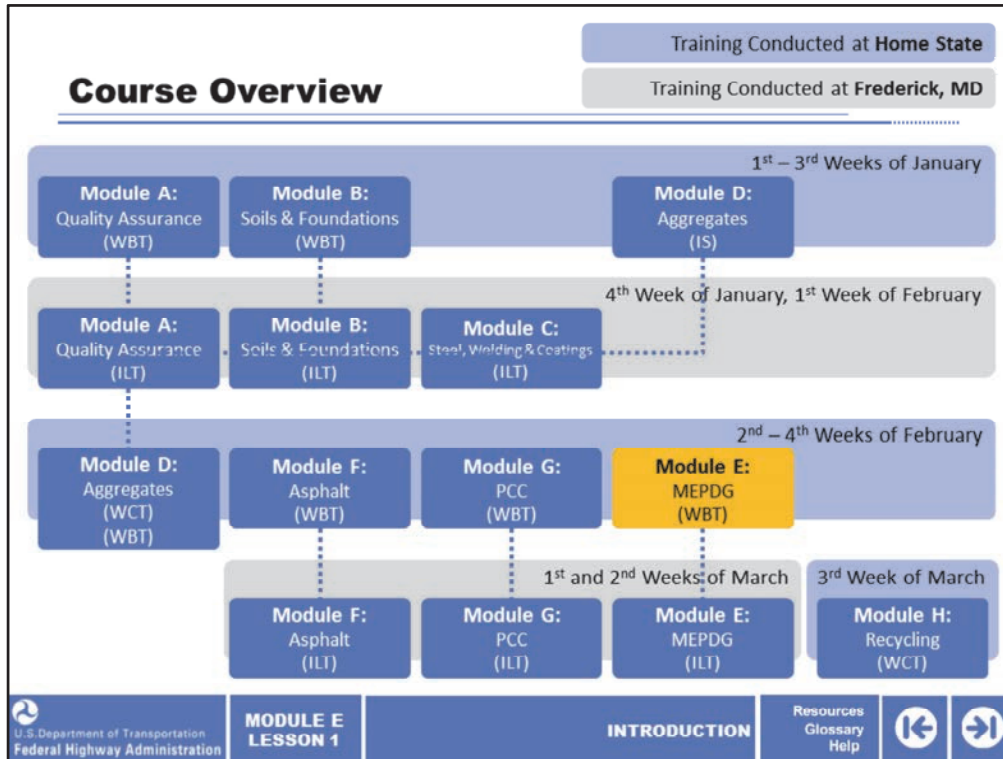


Welcome to the Highway Materials Engineering Course (HMEC) Module E, Lesson 1: Introduction. This lesson will introduce you to the newest approach in pavement design: the AASHTO Pavement Mechanistic Empirical (ME) Design software. The AASHTO Pavement ME Design software carries forth the design procedures developed in the Mechanistic Empirical Pavement Design Guide (MEPDG), which was balloted into practice by AASHTO in 2007. This lesson will provide you with a baseline knowledge in order to prepare you for the more detailed lessons to be covered in the instructor-led portion of this module.

A printer-friendly version of the lesson materials can be downloaded by selecting the paperclip icon. Only the slides for the this lesson are available.

If you need technical assistance during the training, please select the Help link in the upper right-hand corner of the screen.

Image description: People sitting in front of computers in a training setting.



The Highway Materials Engineering Course is a comprehensive, 11-week training event. Module E: Mechanistic Empirical Pavement Design Guide (MEPDG) is the seventh module in the HMEC. Although other modules and workshops are presented on MEPDG, Module E is expected to provide content that is specific to materials engineers.

Participants will be given the information that they need to more proficiently and actively review agency- and consultant-generated pavement designs to ensure their alignment with the appropriate materials designs. Participants who do not normally review pavement design, or only perform a cursory review, will learn how to review pavement design with more knowledge of what they are looking at, and how the material design selected by the designer may impact the ultimate pavement service life. This was not done before the advent of the MEPDG approach.

On the next screen, we'll review the lesson structure of this module.

Training Conducted at Home State
Training Conducted at Frederick, MD

Module E Overview

Web-based Training (WBT) 2nd – 4th Weeks of February

1 Introduction

Instructor-led Training (ILT) 1st and 2nd Weeks of March

2 Project Level,
Traffic, and
Climate Inputs


3 Materials Inputs

4 Flexible
Pavement
Design

5 Rigid Pavement
Design

6 Hot Topics

Review and Final
Assessment





U.S. Department of Transportation
Federal Highway Administration

MODULE E
LESSON 1

INTRODUCTION

Resources
Glossary
Help

Module E consists of six lessons. Lesson 1 is completed in the Web-based training (WBT) portion of the module. Lessons 2–6 are completed in the instructor-led training (ILT) portion of the module, before the review and final assessment.

Learning Outcomes



By the end of this lesson, you will be able to:

- List the basic factors required in designing a pavement structure
- Compare mixture design and pavement design related to materials in terms of predicted pavement performance
- Distinguish between empirical and mechanistic empirical design methods
- List the factors that may affect the predicted performance of pavements in Pavement ME Design
- Describe the steps of a Pavement ME Design analysis
- Describe the iterative design process used with Pavement ME Design software
- Describe the performance parameters analyzed by Pavement ME Design software
- Explain how pavement prediction models from Pavement ME Design are being incorporated into the evaluation of asphalt and concrete paving mixtures
- Using an example, identify important considerations for pavement design



This lesson will take approximately 180 minutes to complete.



By the end of this lesson, you will be able to:

- List the basic factors required in designing a pavement structure;
- Compare mixture design and pavement design related to materials in terms of predicted pavement performance;
- Distinguish between empirical and mechanistic empirical design methods;
- List the factors that may affect the predicted performance of pavements in Pavement ME Design;
- Describe the steps of a Pavement ME Design analysis;
- Describe the iterative design process used with Pavement ME Design software;
- Describe the performance parameters analyzed by Pavement ME Design software;
- Explain how pavement prediction models from Pavement ME Design are being incorporated into the evaluation of asphalt and concrete paving mixtures; and
- Using an example, identify important considerations for pavement design.

During this lesson, knowledge checks are provided to test your understanding of the material presented.

This lesson will take approximately 180 minutes to complete.

Documents Needed For This Lesson



- Take a moment to download and print the Module E, Lesson 1 Exercises PDF document by selecting the paperclip icon
- For this lesson, you will need the following exercises:
 - Module E, Lesson 1 Exercise 1
 - Module E, Lesson 1 Exercise 2
 - Module E, Lesson 1 Exercise 3
 - Module E, Lesson 1 Exercise 4
 - Module E, Lesson 1 Exercise 5




To open the exercises select the paperclip icon.



During this lesson, you will be prompted to reference the lesson exercise document. The documents referenced during this lesson are attached to the lesson in the paperclip icon. Please take a moment to open and print the document.

Review Questions



Question 1: What do the letters “MEPDG” stand for?

Question 2: What is MEPDG?

Question 3: Is MEPDG an approach or a software?

Question 4: What are the functions of the MEPDG?

Question 5: What do the various inputs signify?



Select each question to review your knowledge of MEPDG.

U.S. Department of Transportation
Federal Highway Administration

MODULE E
LESSON 1

INTRODUCTION

Resources
Glossary
Help



Let’s start by reviewing how familiar you are with aspects of the new mechanistic empirical design of new and rehabilitated pavement structures.

Read each of the five questions presented here and consider the answer. Then, select each question to review your knowledge of MEPDG.

Review Questions

Question 1: What do the letters "MEPDG" stand for?

- Mechanistic Empirical Pavement Design Guide

Select each question to

U.S. Department of Transportation
Federal Highway Administration

MO
LE

X CLOSE

MEPDG stands for the Mechanistic Empirical Pavement Design Guide.

Review Questions

Question 2: What is MEPDG?

• MEPDG: A design approach based on mechanistic empirical principles

• Mechanistically:

- Calculates pavement responses (stresses, strains, deflections) due to loading and environmental conditions

• Empirically:

- Relates the cumulative damage to observed pavement distresses
- Uses those responses to compute incremental damage over time

Select each question to

U.S. Department of Transportation
Federal Highway Administration

MO
LE

The MEPDG is a design approach based on mechanistic empirical principles.

Mechanistically, it calculates pavement responses (stresses, strains, and deflections) due to loading and environmental conditions and uses those responses to compute incremental damage over time. Empirically, it relates the cumulative damage to observed pavement distresses.

The empirical model predicts damage, then is calibrated against measured field distress. Although practitioners may reach a point in the future when this relationship can be mechanistically predicted through fracture mechanics or some other means, the current model in the Pavement ME Design software is empirically-based.

Review Questions

Question 3: Is MEPDG an approach or a software?

- The MEPDG is a design approach
- The software based on the MEPDG design approach is the Pavement ME Design version 2.0

U.S. Department of Transportation
Federal Highway Administration

The MEPDG is a design approach. The software based on the MEPDG design approach is the Pavement ME Design version 2.0.

Review Questions

Question 4: What are the functions of the MEPDG?

- Pavement design tool
 - Practical design approach with strategic thickness iterations
- Pavement analysis tool
 - Distress predictions
 - Flexible pavements: rutting, cracking, IRI
 - Rigid pavements: faulting, cracking, punchouts, IRI

Select each question to

U.S. Department of Transportation
Federal Highway Administration

MO
LE

The functions of the MEPDG are as a pavement design tool (for pavement practitioners to design pavement layers with a practical approach at reasonable precision levels by implementing strategic thickness iterations to the process) and a pavement analysis tool (distress predictions that include rutting, cracking, and rideability or International Roughness Index (IRI) for flexible pavements and faulting, cracking, punchouts, and IRI for rigid pavements).

The image shows a screenshot of a quiz interface. On the left, there is a sidebar titled "Review Questions" with a list of questions. The fifth question is selected and highlighted in dark blue, with the text "Question 5: Wh...". Below the sidebar, there is a prompt "Select each question to" and the logo for the U.S. Department of Transportation Federal Highway Administration. The main content area is a dark blue modal window with a white "X CLOSE" button in the top right corner. The question text is "Question 5: What do the various inputs signify?". Below the question, there is a bulleted list: "• Represent different means for obtaining the parameters needed to test the appropriateness of a trial pavement design" and "- The numerically lower level inputs will result in a higher design reliability". At the bottom of the modal, there are three white rectangular buttons labeled "Input Level 1", "Input Level 2", and "Input Level 3".

The various inputs are used to represent different means for obtaining the parameters needed to test the appropriateness of a trial pavement design. Generally the numerically lower level inputs (Levels 1 and 2) will result in a higher design reliability, which means that the design you ultimately end up with will have a greater chance in more of the cases to successfully reach its intended design life.

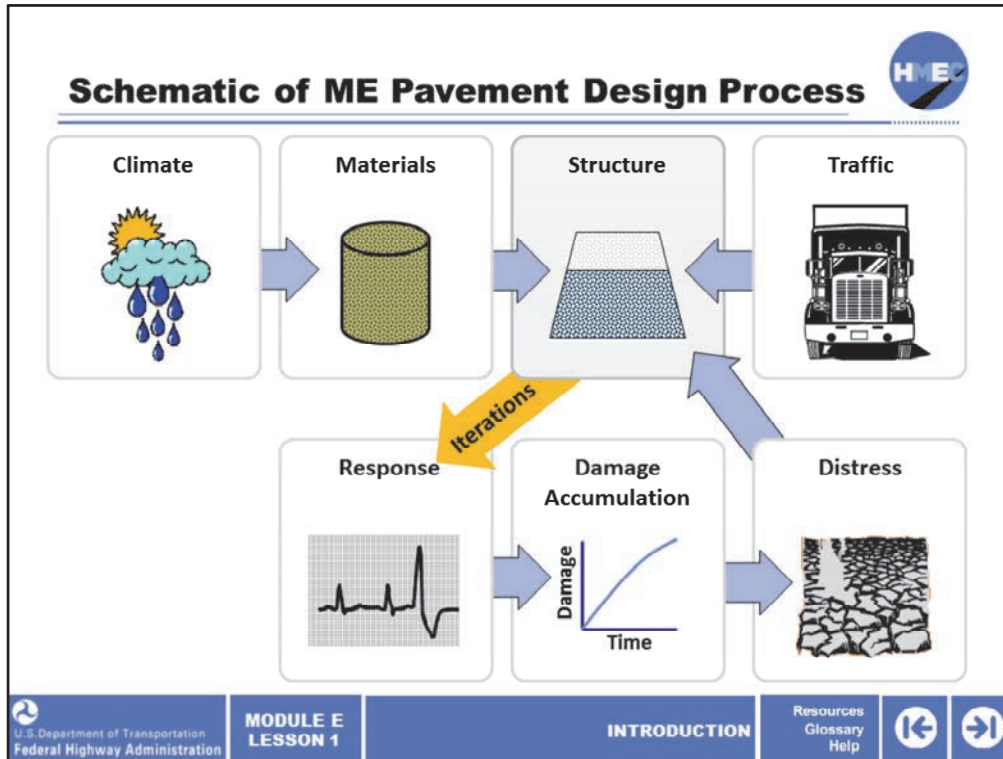
Input Level 1 represents the greatest knowledge about the input parameter for a specific project but has the highest testing and data collection costs to determine the input value. Level 1 is used for pavement designs having unusual site features, materials, or traffic conditions that are outside the inference—space used to develop the correlations and defaults included for input Levels 2 and 3.

Input Level 2 presents the input value that is calculated from other site specific data or parameters that are less costly to measure. Input Level 2 also represents measured regional values that are not project-specific.

Finally, Level 3 inputs are based on global or regional default values—that is, the median value from a group of data with similar characteristics. This input level contains the least detail about the input parameters for the specific project; however, it has the lowest testing and data collection costs.

In this course we will discuss the various input levels as they relate mostly to materials to

gain some information on how input levels can vary across parameters and how much influence the selection of different input levels will ultimately have on the predicted performance of the trial design.




As we just reviewed, there are various types of inputs and among them, there are different levels of specificity with obtaining or selecting the input values. In the past, pavement designers were able to generate the inputs and design pavements with very little need to interact with other units in a transportation organization. This approach did not necessarily end up with pavements that lasted as long as they should, and in many cases, the pavements were not as economical as they could be and were oftentimes over-designed.


These reasons and others like them are some of the motivating factors for how the MEPDG was developed. From the advent of better technology, such as weigh-in-motion sensors embedded in pavements that measure real-time traffic loads to the national implementation of Superpave asphalt mixtures, there was a need for pavement design to align with modern technology, modern traffic, and modern materials. Pavement designers need to consider the influence of traffic, climate, materials, and construction properties.

Image description: Schematic of ME Pavement Design process.

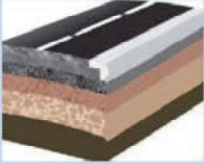
Data Sources




Material Characterization




Pavement Structure



Traffic Conditions



Climate Conditions





Select each data source to learn more.

U.S. Department of Transportation
Federal Highway Administration

MODULE E
LESSON 1

INTRODUCTION

Resources
Glossary
Help



Pavement designers have a lot to consider. But where does all the data come from? Select each data source to learn about different types of data available to assist pavement designers in building better-performing and more economical pavements.


Image 1 description: Asphalt pavement layers.

Image 2 description: Pavement design construction asphalt surfacing.

Image 3 description: Trucks in congested traffic.

Image 4 description: Collage of climate conditions.

Data Sources



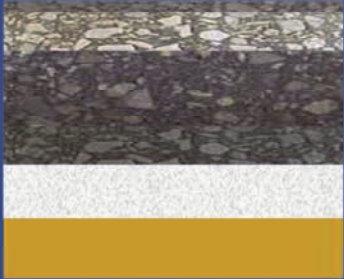
Material
Characterization


Pavement
Structure

Traffic Conditions

Climate Conditions

- Categories:
 - Pavement response model material inputs
 - Material-related pavement distress criteria
 - Other material properties
- Material Parameters:
 - Unit weight
 - Poission's ratio
 - Other thermal properties





There are a number of properties that describe the characterization of the typical materials used in pavement structures. They are generalized into three categories.


Pavement response model material inputs relate to the moduli and Poisson's ratio used to characterize layer behavior within the specific model. Bound materials generally display a linear or nearly linear stress-strain relationship. Unbound materials display stress-dependent properties. Granular materials generally are "stress hardening" and show an increase in modulus with an increase in stress. Fine-grained soils generally are "stress softening" and display a modulus decrease with increased stress.

On the other hand, material-related pavement distress criteria are linked to some measure of material strength (shear strength, compressive strength, modulus of rupture) or to some manifestation of the actual distress effect (repeated load permanent deformation, fatigue failure of Portland cement concrete (PCC) materials).

For all materials used in a pavement structure, the following parameters must be described: Unit weight; Poisson's ratio; and other thermal properties such as thermal conductivity, heat capacity, and surface absorptivity. Additional details on each property will be presented in the instructor-led training lessons of this module.

Image description: Asphalt pavement layers.

Data Sources




Material
Characterization


Pavement
Structure

Traffic Conditions

Climate Conditions

- Resilient modulus
- Classification and volumetric properties
- Moisture-density relationships
- Soil-water characteristic relationship
- Saturated hydraulic conductivity





The unbound layers in a pavement include any granular layers which support the paved surface.

In the Pavement ME Design software, the granular base, subbase, and subgrade layers are defined by primarily their strength (through classification of the aggregate or soil type and the resilient modulus—a measure of stiffness under repeated loading) and their properties in the presence of water (through defining the saturation properties and the effect of moisture on density of these layers).

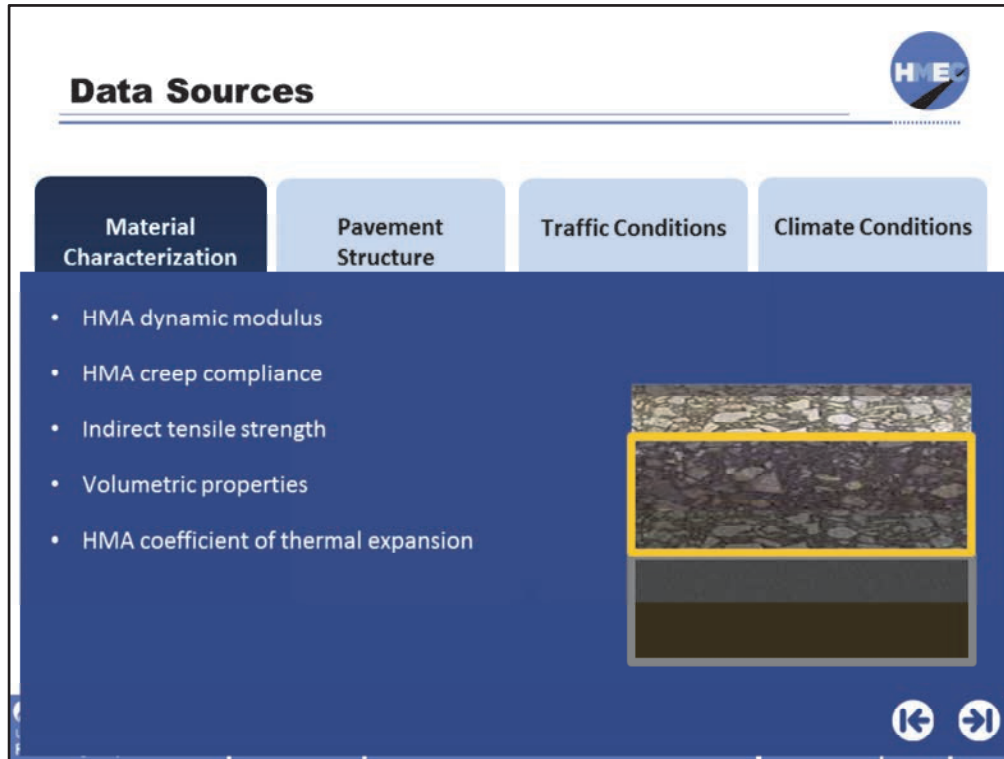
Classification properties measure the gradation and Atterberg limits from bulk sample recovered from the subsurface investigation. Volumetric properties of hot mix asphalt (HMA) mixtures refer to air voids, asphalt content, and aggregate gradation. Whenever this volumetric data is unavailable from construction records, selected cores recovered from the project are used to measure these properties. Volumetric Properties of unbound layers and subgrade measure the moisture content and dry density of undisturbed samples recovered during the subsurface investigation.

Moisture-density and soil-water characteristic relationships are used to characterize the unbound layers and subgrade. The moisture-density relationship focuses on the target density and moisture content of the unbound layers and subgrade. The soil-water characteristic relationship focuses on a specialized set of moisture retention parameters that are fundamental to predicting the moisture content and soil stiffness of the subgrade and unbound pavement layers.

Saturated hydraulic conductivity is required to determine the transient moisture profiles in compacted unbound materials and to compute their drainage characteristics.

The properties listed can be measured in the laboratory, in the field, or by using tools such as the Arizona State University Soil Unit Map tool.

Image description: Asphalt pavement layers.



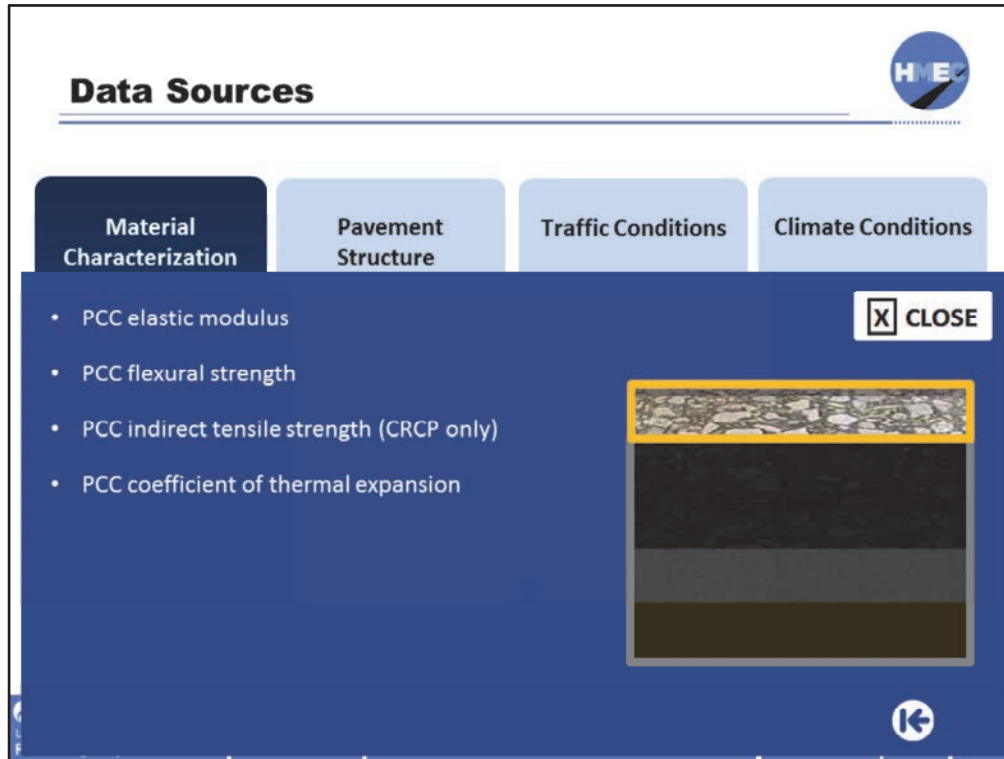
There are a number of inputs that relate to layers constructed HMA. This would include the asphalt concrete surface layers as well as a bituminous-treated base layer.

The inputs required by the Pavement ME Design software include the HMA dynamic modulus (a measure of stiffness with load frequency and temperature), the HMA creep compliance, asphalt concrete indirect tensile strength (at low temperatures), mixture volumetric properties, and the HMA coefficient of thermal expansion. These are only some of the inputs that are most sensitive for asphalt pavements, but are not the only inputs that are or could be used in the Pavement ME Design software.

For these properties, there are three levels of inputs. Level 1 inputs are project-specific and are measured directly from laboratory or field testing. Level 2 inputs are estimated from other material properties using predictive equations. Level 3 inputs are based on global or regional default values.

Therefore, the properties listed can be measured in the laboratory or by using the defaults provided in the software.

Image description: Asphalt pavement layers.




There are a number of inputs that relate to layers constructed with concrete materials. This would include the concrete surface slabs as well as a cement-treated base layer.

The inputs required by the Pavement ME Design software include the Portland cement concrete elastic modulus (a measure of stiffness), the flexural strength (or modulus of rupture), coefficient of thermal expansion, and in the case of continuously-reinforced concrete pavements (CRCP), the indirect tensile strength of the concrete. These inputs were found through a number of research studies to be some of the most sensitive inputs for PCC; however, they are not the only inputs that a designer can use in Pavement ME Design. For example, the concrete's compressive strength is a Level 3 strength input and the coefficient of thermal expansion (CTE) is a thermal input to concrete pavement design.

The properties listed can be measured in the laboratory or by using the defaults provided in the software.

Image description: Concrete pavement layer.

Data Sources



Material Characterization

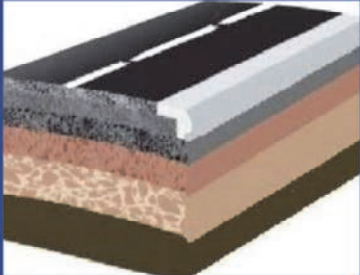
Pavement Structure

Traffic Conditions

Climate Conditions

X CLOSE

- Layer type
- Pavement cross-section
- Layer thickness
- Friction or level of bond between paved layers
- Existing pavement condition
- Endurance limit (flexible pavement only)
- Milling depth (rehabilitation)



The properties of the trial pavement structure are critical to starting a design analysis in Pavement ME Design software. A user must first select the type of, number of, and thickness of each layer. One can also define the level of bond between the paved layers (denoted by an estimate of friction between the paved surfaces and also with the underlying base layer), which is a consideration of conditions during the pavement's construction.


The endurance limit is an input for flexible pavements that is defined as the tensile strain or stress below which no load-related fatigue damage occurs.

In the case of designing a pavement rehabilitation, the existing pavement condition must also be input. The structural condition for concrete pavements is described by input values for the percent of slabs cracked or for the number of punch outs. The structural condition for asphalt pavements is described by input values for amount of surface area that is cracked.

The final input for general pavement structure that considers construction aspects is the milling depth for flexible pavement overlays.

Image description: Pavement design construction asphalt surfacing.


Data Sources



Material Characterization Pavement Structure **Traffic Conditions** Climate Conditions

- Axle load spectra
- Average annual daily truck traffic (AADTT)
- Traffic volume adjustment factors
- Traffic growth
- Number of lanes
- Operational speed
- Lane and directional truck distributions
- Truck classification percentages

CLOSE



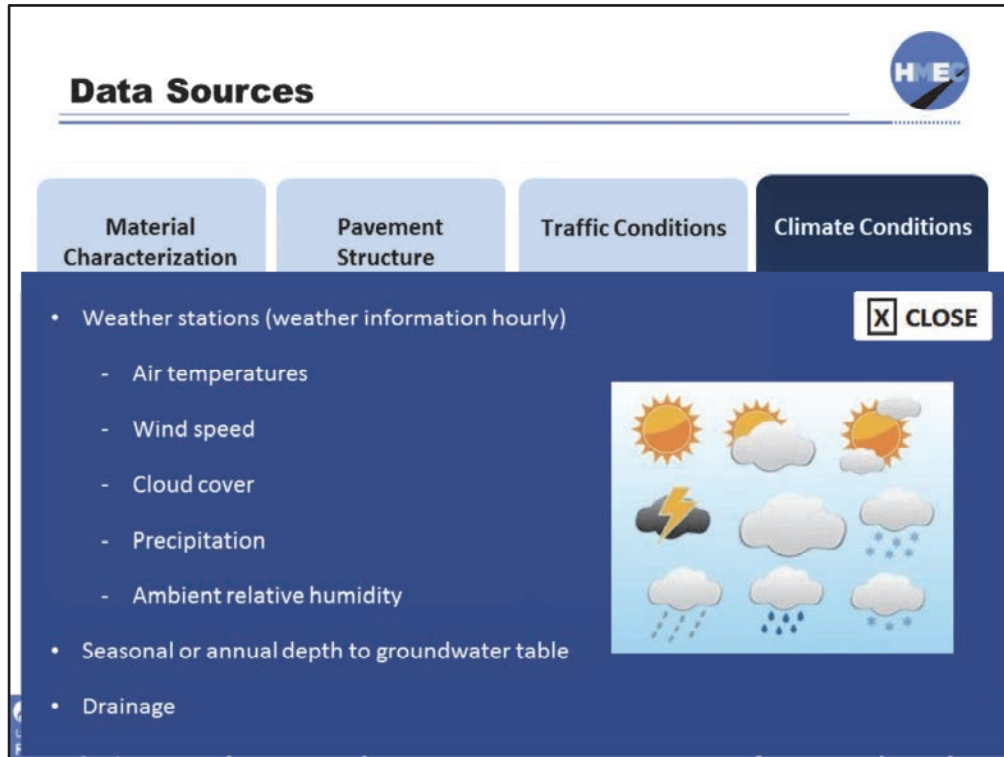
The image shows a screenshot of a software interface titled "Data Sources". At the top right is the HME logo. Below the title are four tabs: "Material Characterization", "Pavement Structure", "Traffic Conditions" (which is selected and highlighted in dark blue), and "Climate Conditions". A list of data sources is displayed under the "Traffic Conditions" tab, including axle load spectra, AADTT, traffic volume adjustment factors, traffic growth, number of lanes, operational speed, lane and directional truck distributions, and truck classification percentages. A "CLOSE" button with an 'X' icon is in the top right of the list area. An inset image on the right side of the list shows several large trucks in a line of traffic on a highway.

There are a number of inputs that relate to traffic that can be relatively straightforward, such as the traffic volumes, heavy vehicle percentages, lane and directional truck distributions, operational (actual speed passengers are expected to travel) speed, and the number of lanes. However, other traffic inputs can be much more complex, such as the truck classification percentages, type and amount of traffic growth, axle load spectra, and the traffic volume adjustment factors.

These are just a summary of the traffic inputs but many more exist in the module for traffic. Data for the traffic inputs can be measured by weigh-in-motion stations in the field or can come from projection data from transportation planners.

In this module, we will introduce the traffic inputs but will not cover them in extensive detail.

Image description: Trucks in congested traffic.



The climate inputs are obtained from a climate file (weather station data). The Enhanced Integrated Climatic Model (EICM) uses this climate data to model the temperature distribution throughout the pavement layers. The EICM is a tool used to model temperature and moisture within each pavement layer and the foundation soil. This climatic model considers hourly ambient climatic data in the form of temperatures, precipitation, wind speed, cloud cover, and relative humidity from weather stations across the US for estimating pavement layer temperatures and moisture conditions.

The depth to groundwater table must be input by the user. It can be defined as an annual value or can be input seasonally (meaning, one input value per each of the four seasons). The depth to groundwater table can be measured and there are a number of tools to find it, including the FHWA long-term pavement performance (LTPP) database, the ASU Soil Unit Map application, the USGS or other equivalent maps, or by using the default value in the Pavement ME Design software.

Drainage is accounted for in a general sense from the EICM by the inclusion of an infiltration and drainage model. More information on how the pavement materials are adjusted by the EICM will be provided in the instructor-led portion of this module.

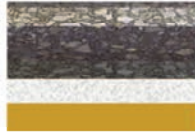
Image description: Collage of climate conditions.

Pavement Management

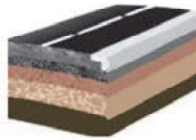


- **Materials characterization, traffic conditions, and pavement structural features are required for defining the pavement management properties in the design of rehabilitation for existing pavements**
- **Pavement existing structural data can be obtained through:**
 - Use of falling weight deflectometer
 - Use of light weight deflectometer
 - Other means of assessing the remaining structure value

Material Characterization



Pavement Structure



Traffic Conditions



In addition to providing data to assist pavement designers in building better-performing and more economical pavements, materials characterization, traffic, and pavement structural features are also required for defining the pavement management properties in the design of rehabilitation for existing pavements.


Pavement existing structural data can be obtained through the evaluation of existing pavements, such as by the use of falling weight deflectometer, light weight deflectometer, or other means of assessing the remaining structural value of the original pavement.

Image 1 description: Asphalt pavement layers.


Image 2 description: Pavement design construction tar surfacing.




Image 3 description: Tail lights from congested traffic.

Select all that apply. Which factors are required in designing a pavement structure?



- a) Layer types and thickness
- b) Project location
- c) Coefficient of thermal expansion
- d) Reliability
- e) Axle load spectra
- f) Depth to groundwater table


 **Knowledge Check** Correct - Click anywhere to continue **Submit** **Clear**

 **MODULE E**
LESSON 1 **INTRODUCTION** Resources
Glossary
Help  


Select all that apply. Which factors are required in designing a pavement structure?




- a) Layer types and thickness;
- b) Project location;
- c) Coefficient of thermal expansion;
- d) Reliability;
- e) Axle load spectra; or
- f) Depth to groundwater table.

Select all that apply. Which factors are required in designing a pavement structure?




- a) Layer types and thickness
- b) Project location
- c) Coefficient of thermal expansion
- d) Reliability
- e) Axle load spectra
- f) Depth to groundwater table

 Knowledge Check Debrief


 **MODULE E**
LESSON 1 **INTRODUCTION** Resources
Glossary
Help  

The correct answers are a) Layer types and thickness, b) Project location, c) Coefficient of thermal expansion, e) Axle load spectra, and f) Depth to groundwater table.


Mixture Design Vs. Pavement Design




Conventional PCC



Roller Compacted Concrete



ANSWER



 Does the MEPDG have a process for mixture design?

U.S. Department of Transportation
Federal Highway Administration

MODULE E
LESSON 1

INTRODUCTION

Resources
Glossary
Help


Let's answer another review question about the function of the MEPDG. Does the MEPDG have a process for mixture design?

Select the answer button the learn more.

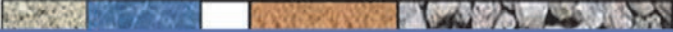
Image description: A series of five images displaying C.M., water, air, fine aggregate, and course aggregate.

Image description: A series of five images displaying C.M., water, air, fine aggregate, and course aggregate.

Mixture Design Vs. Pavement Design



Conventional PCC



X CLOSE

No, MEPDG does not design mixes, but rather indicates if an existing pavement design meets the performance criteria for a certain reliability level.

Mixture durability issues are addressed during the mixture design process or by the material specifications for a project, external to the MEPDG.

ANSWER


Q&A Does the MEPDG have a process for mixture design?

U.S. Department of Transportation
Federal Highway Administration

MODULE E
LESSON 1

INTRODUCTION

Resources
Glossary
Help



The MEPDG approach was not developed in a way that it could effectively be used to design mixes. However, its trial-and-error process can be used to help indicate whether an existing pavement design meets the performance criteria within a certain level of reliability.


The issue of mixture durability and its influence on performance are not modeled in the Pavement ME Design software at this time. The current MEPDG approach assumes that any issues specific to mixtures are dealt with externally in the mixture design or materials specification process.


Image description: A series of five images displaying C.M., water, air, fine aggregate, and course aggregate.




True or false? The MEPDG has the capability to design asphalt mixtures.

a) True

b) False



 **Knowledge Check** Correct - Click anywhere to continue **Submit** **Clear**

 **MODULE E**
LESSON 1 **INTRODUCTION** Resources
Glossary
Help  

Let's pause for another knowledge check.

True or false? The MEPDG has the capability to design asphalt mixtures.

- a) True; or
- b) False.

True or false? The MEPDG has the capability to design asphalt mixtures.



- a) True
- b) False

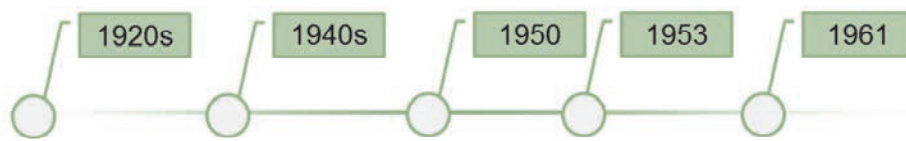


Knowledge Check Debrief



The correct answer is b) False.

History of Design Methodologies



Select each year on the timeline to learn more.



Let's briefly review the history of design methodologies.

Select each year on the timeline to learn more.

Image description: Photo of a construction site along a stretch of road.

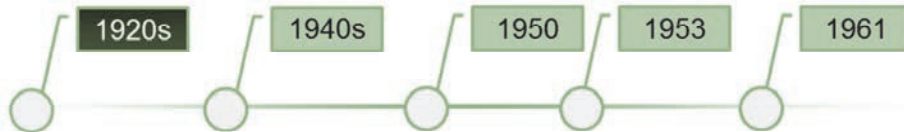
History of Design Methodologies



Pre-Road Test Design (1920s)

X CLOSE

- “Rule of thumb” or precedent
- Traffic, soil, and environmental conditions not considered
- Developed based on geotechnical and/or soil mechanics principles
- These procedures rely on protecting the subgrade by placing sufficient thickness of material above the roadbed




Select each year on the timeline to learn more.



Early on with the advent of paved surface highways and the emergence of automobiles, the typical pavement design did not consider the traffic or environmental loads, nor any consistent attention to soil conditions. The common knowledge at the time of soil mechanics was applied and the basic premises for pavement design (to protect the subgrade) used from the time of the Roman Empire onward was followed.

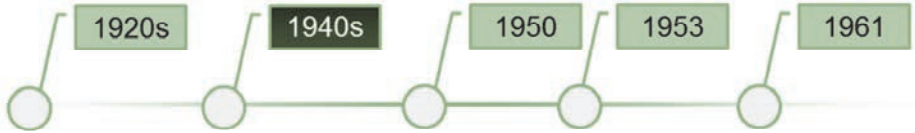
History of Design Methodologies



Equivalent Single Wheel Load (1940s)

CLOSE

- Mechanistic and based on theoretical solution
- Based on fixed traffic




Select each year on the timeline to learn more.

U.S. Department of Transportation
Federal Highway Administration

MODULE E
LESSON 1


INTRODUCTION

Resources
Glossary
Help



During World War II, the equivalent single wheel load (ESWL) was developed by the armed forces for airfield pavements. This mechanistic-based procedure was founded on the idea that the pavement's thickness is governed by a single-wheel load. The design approach was based on fixed traffic and was used for heavy load and low-volume pavements.

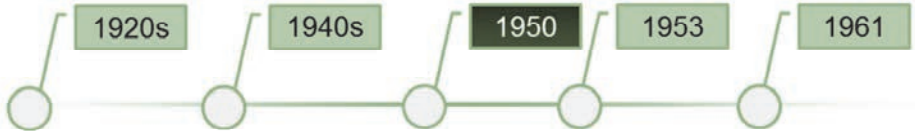
History of Design Methodologies



Maryland Road Test (1950)

X CLOSE

- Conducted on 1.1 mile section of existing US 301
- Significance: Relative effects of four different axle loadings using two vehicle types on a specific concrete pavement design




Select each year on the timeline to learn more.

U.S. Department of Transportation
Federal Highway Administration

MODULE E
LESSON 1

INTRODUCTION

Resources
Glossary
Help



The Maryland Road Test (1950) was conducted on a 1.1-mile section of existing US 301. The principal objective of this road test was to determine the relative effects of four different axle loadings using two vehicle types on a specific concrete pavement design. The loads employed were 18,000 lbs. and 22,400 lbs. on single axles, and 32,000 lbs. and 44,000 lbs. on tandem axles.

History of Design Methodologies

The screenshot shows a digital interface for a history of design methodologies. At the top right is a circular logo with 'HME' and a pencil icon. Below it is the title 'History of Design Methodologies'. A dark green pop-up window is open, titled 'WASHO Road Test (1953)' with a 'CLOSE' button. The pop-up contains two bullet points: 'Conducted on 1 mile of specially built flexible pavement in Idaho' and 'Significance: Carrying the pavement structure across the full roadway width, including shoulders, results in substantial reductions in thickness'. Below the pop-up is a horizontal timeline with five nodes: '1920s', '1940s', '1950', '1953', and '1961'. The '1953' node is highlighted in black. Below the timeline is the text 'Select each year on the timeline to learn more.' At the bottom is a blue navigation bar with the U.S. Department of Transportation Federal Highway Administration logo, 'MODULE E LESSON 1', 'INTRODUCTION', 'Resources Glossary Help', and left/right arrow icons.

WASHO Road Test (1953)

- Conducted on 1 mile of specially built flexible pavement in Idaho
- Significance: Carrying the pavement structure across the full roadway width, including shoulders, results in substantial reductions in thickness

1920s 1940s 1950 1953 1961

Select each year on the timeline to learn more.

U.S. Department of Transportation
Federal Highway Administration

MODULE E
LESSON 1

INTRODUCTION


Resources
Glossary
Help

The WASHO Road Test (1953) was conducted on 1 mile of specially built flexible pavement in Malad, Idaho. Four loops were constructed under carefully controlled conditions; each had a variety of surface and base thicknesses. Loop loadings were similar to those of the Maryland Road Test. Elaborate measurements were taken to determine pavement behavior.

Among the most significant findings of the WASHO test were:

1. The asphalt pavement contributes substantially to the strength of the roadway structure; and
2. By carrying the pavement structure for the full roadway width, including shoulders, substantial reductions in thickness can be realized.

History of Design Methodologies



AASHO Road Test (1961)

X CLOSE

- The test road contained six loops each with two lanes, located about 80 miles southwest of Chicago
- Significance: Basic principles established and validated by the road test still serve as the basis for performance-based design procedures used today




Select each year on the timeline to learn more.

U.S. Department of Transportation
Federal Highway Administration

MODULE E
LESSON 1

INTRODUCTION

Resources
Glossary
Help



Finally, in 1961 the AASHO Road Test was constructed and formed the basis of the AASHO design that was followed until the advent of the MEPDG approach.

The AASHO Road Test was the last of the major road tests in the United States, conducted about 80 miles southwest of Chicago. This site was chosen because the soil within the area is uniform and is representative of that found in large areas of the country.

The basic principles established and validated by the road test still serve as the basis for a large number of performance-based design procedures being used in the US today.

We'll discuss this road test in more detail on the following screens.

AASHO Road Test

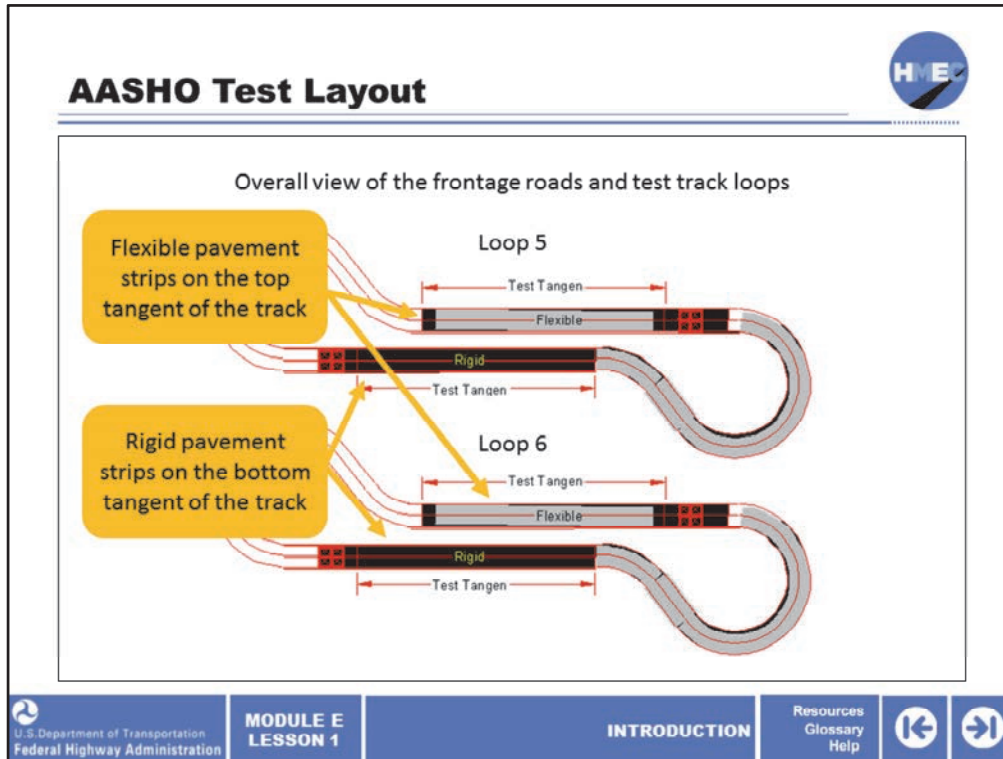


- Ottawa, Illinois (1958–1960)
- Study of performance of highway pavement structures
- Axle loading effects on pavement structure



The AASHO Road Test was constructed in Ottawa, Illinois between 1958 and 1960, and included both new flexible and new rigid pavement test pavements. This test road provided the opportunity to study the field performance of pavements, which could be used to create empirical models for pavement design. The major focus of the study was the effects of axle loading types on pavement structures.

Image description: Photo of the AASHTO Road Test.



Now we'll review the schematic of the AASHO test loops.


This diagram presents the overall view of the frontage roads and test track loops.

This diagram shows the flexible and rigid pavement strips on the top and bottom tangents of the track.



The performance data that was collected included mechanical responses (such as deflections and strains) and roughness measurements. The results from the AASHO Road Test were also used to develop the present serviceability index (PSI), which established a correlation between user assessment (ride experience) and performance indicators (measurable characteristics).

Image description: Series of diagrams of (1) flexible pavement strips on the top tangent of the track; and (2) the rigid pavement strips on the bottom tangent of the track.

AASHO Road Test Achievements




- **Simplified pavement design based in field observations**
 - Empirical process
- **Performance equations for different pavement damage types**
 - Establish the measure of whether a pavement is meeting its intended purpose
 - Calculate whether the pavement is meeting its intended structural capacity

ANSWER

Q&A



How is serviceability defined? What is the structural number (SN)?


U.S. Department of Transportation
Federal Highway Administration

MODULE E
LESSON 1

INTRODUCTION

Resources
Glossary
Help

There were a number of achievements that derived from the AASHO Road Test, but above all it resulted in a simplified pavement design based in field observations (an empirical process), which is why it was in practice for more than 40 years.

The performance equations for different pavement damage types were established. These helped in two ways: 1. To establish the measure of whether a pavement is meeting its intended purpose (through the serviceability concept), and 2. To calculate whether the pavement is meeting its intended structural capacity (through the structural number concept).

How is serviceability defined? What is the structural number (SN)? Select the Answer button to learn more.

Image description: Photo of the AASHO Road Test track.

Image description: Photo of the AASHO Road Test track.

AASHO Road Test Achievements



The serviceability can be defined as the initial user rating of the pavement minus the terminal user rating of the pavement, in which:

- PSI_0 = Initial serviceability after construction
- PSI_T = Terminal serviceability after end of pavement life (damage)
- ΔPSI = Change in serviceability during the life of the pavement



ANSWER



How is serviceability defined? What is the structural number (SN)?



The serviceability can be defined as the initial user rating of the pavement minus the terminal user rating of the pavement, in which:

- PSI_0 = Initial serviceability after construction;
- PSI_T = Terminal serviceability after end of pavement life (damage); and
- ΔPSI = Change in serviceability during the life of the pavement.

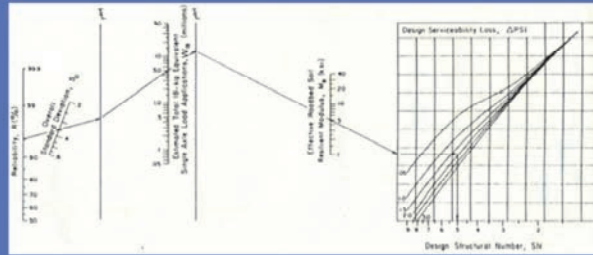
Select the next arrow for the definition of the structural number.

AASHO Road Test Achievements



X CLOSE

The structural number (SN) is used to determine what stiffness and thickness is needed to protect the subgrade and to keep each individual layer from being overstressed in FLEXIBLE PAVEMENTS.



ANSWER




How is serviceability defined? What is the structural number (SN)?



The structural number (SN) is used to determine what stiffness and thickness is needed to protect the subgrade for a FLEXIBLE PAVEMENT design. It is also used to keep each individual layer from being overstressed. The nomographs were developed to get the SN needed to provide adequate protection for Flexible pavements.


Image description: Nomographs.




AASHTO Road Test



- The Serviceability Concept
 - User evaluation of pavement condition was considered as part of the design process
- The ESAL Process
 - Traffic stream was homogenized into a factor that represented damage to the pavement
- The Structural Number (SN)
 - Flexible pavement structure was reduced to a single number
- The Effective Modulus of Subgrade Reaction (k_{eff})
 - Rigid pavement foundation considered as a composite value

ANSWER

 What did the axle load study, conducted through the AASHTO Road Test, accomplish?

 **MODULE E**
LESSON 1 **INTRODUCTION** **Resources**
Glossary
Help  


It is important to recognize that at the time (1950s) when the AASHTO test procedure was developed, this road test marked a significant improvement in the way pavements were built and it was a remarkable effort at that point in time. Four major ideas and advancement came from the AASHTO Road Test:

1. The serviceability concept (user evaluation of pavement condition was considered as part of the design process);
2. The ESAL process (traffic stream was homogenized into a factor that represented damage to the pavement);
3. The structural number (flexible pavement structure was reduced to a single number); and
4. The effective modulus of subgrade reaction (rigid pavement foundation considered as a composite value of all underlying granular layers, including shallow bedrock). The empirical design for rigid pavements was a three-way relationship amongst slab thickness, traffic and loss of serviceability.

These enabled the design procedure to be simplified into a pavement design nomograph for flexible pavements structural number, and a 2-part nomograph for rigid pavement thickness. Pavement design became standardized throughout the US and much of the world.


What did the axle load study, conducted through the AASHTO Road Test, accomplish? Select the answer button to learn more.

AASHO Road Test



X CLOSE

The axle load study conducted through the AASHO Road Test provided a way to relate traffic damage to pavement performance through the equivalent single axle load (ESALs) concept.



ANSWER


Q&A What did the axle load study, conducted through the AASHO Road Test, accomplish?

U.S. Department of Transportation
Federal Highway Administration

MODULE E
LESSON 1

INTRODUCTION

Resources
Glossary
Help



The axle load study conducted through the AASHO Road Test provided a way to relate traffic damage to pavement performance through the equivalent single axle load (ESALs) concept.

The traffic design is based on the total number of passes of the standard axle load and how that translates to damage in the pavement.

In addition, load equivalency factors (LEFs) were established to define the damage per pass to pavement by the axle in question relative to the damage per pass of a standard 18,000-lb. axle load.

Image description: Heavy duty tank transporter used in the AASHO Road Test.

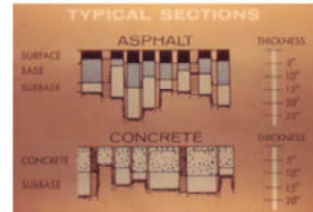
Limitations of Design Procedures Based on the AASHO Road Test



- Models based on only one climate and in situ soil type
- Test only run over two years
- Axle loads applied during the testing were only a fraction of what many high-type pavements experience in modern times
- Vehicles representative of the late 1950s
- Paving materials and mixture designs based on 1950s technology
- Sites constructed for the test were for new roadways

TEST TRAFFIC LOADS

LOOP	3	6	5	2	1	4
LOAD IN POUNDS	31,000	30,000	22,400	2,000	80	18,000
	SINGLE	SINGLE	SINGLE	SINGLE	TRAFFIC	SINGLE
	TANDEM	TANDEM	TANDEM	SINGLE	STEADY	TEST
					TRAFFIC	TANDEM



It is now time for a new design procedure. The old AASHTO design procedure has perhaps outlived its capacity.



U.S. Department of Transportation
Federal Highway Administration

MODULE E
LESSON 1

INTRODUCTION

Resources
Glossary
Help



Considering the advances made in understanding material characterization, the effect of climate on pavement materials and pavement response, and in monitoring of pavement performance, it is now time for a new design procedure. The old AASHTO design procedure has perhaps outlived its capacity.

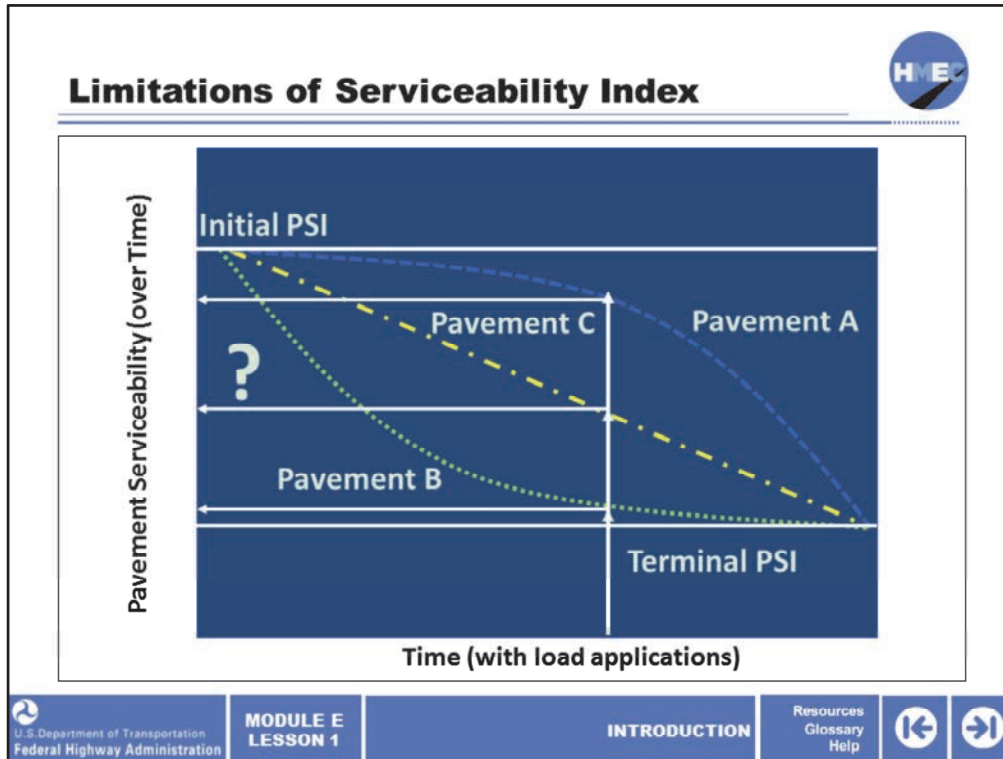
There are a number of pressing reasons why the design procedure based on the results of the AASHO Road Test began to be less effective for today's pavements and these limitations include the following considerations:

- The models generated from the road test data were based on only one climate and in situ soil type;
- The testing itself was run over the course of two years, which means that pavement materials perhaps did not develop the aging properties or other changes in properties with time that a real in-service pavement would exhibit;
- There was a maximum of 2-million axle loads applied during the testing, which is only a fraction of what many high-type pavements experience in modern times;
- The truck suspension systems, tires, and construction equipment were representative of the late 1950s and much has evolved in these areas over the past 60 years;
- Paving materials and mixture designs are reflective of a time when polymer modification, reclaimed asphalt or concrete pavement, widened slabs, tied shoulders, and certain types of base stabilization did not exist; and
- The sites constructed in the road test were for new roadways, whereas the vast majority of roadway construction is currently for rehabilitation consisting of overlays or partial-replacement of an existing pavement.

These and other limitations illustrate the need for moving pavement design procedure to something more reflective of the technological environment that designers are working in today.

Image 1 description: Listing of the load configurations on each of the test track's heavy vehicles' single and tandem axles, given for each test loop.

Image 2 description: Listing of the asphalt and concrete test pavement substructures showing the thickness of each of the test loop typical sections.



Another serious drawback of the AASHO based procedure is the limitation of the serviceability concept. Under the AASHO design process, serviceability was defined by two points: initial and terminal.

Pavement managers have been trying to define the performance between these curves for some time. The most common curve shape is represented by curve A. But, there have been many a pavement which performed in a way such as curve B, and even a few pavements that have shown performance like that of curve C.

So, which is the correct shape? Do we have to wait until after we build pavement to determine how they perform? What does the AASHO data-based procedures tell us about points between initial and terminal?

Image description: Graphic of AASHO design process.

Limitations of Designing with AASHO

Flexible Pavements
Vs.
Rigid Pavements

- **Structural number has less application for Flexible Pavements outside of the road test**
 - Not a fundamental engineering property
 - Cannot be determined in the laboratory
 - Cannot be established for new materials not used at the road test
- **Slab thickness in Rigid Pavement approach is conservative**
 - Doesn't allow for design optimization to build thinner and more cost-effective concrete pavements

Select each type of pavement to learn more.

U.S. Department of Transportation
Federal Highway Administration

MODULE E
LESSON 1

INTRODUCTION

Resources
Glossary
Help

⏪ ⏩

For the design of Flexible Pavements, the Structural number (SN) is the tool which was developed through the AASHO procedure used to determine the pavement structure appropriate for traffic and serviceability. But, this number means very little outside of the road test. The SN was used to approximate the structural bearing capacity of an individual flexible pavement layer, based on its layer properties (layer coefficient) and thickness. The SN was used along with the layer and moisture coefficients to calculate the required thickness of each individual pavement layer above the subgrade. The SN of flexible pavements is not a fundamental engineering property and cannot be determined in the laboratory, nor can it be established for new materials that were not used at the time of the construction of the road test.

In Concrete Pavement design, the basic performance relationship is the $\log(W) = f(D, \Delta PSI)$ where W = cumulative axle loads, D = slab thickness, and ΔPSI = loss of serviceability. The serviceability was based on the observed performance at the AASHO road test and doesn't reflect serviceability of pavements in very different climate locations, different materials performance, or traffic. Therefore, designers are limited in how much they can optimize for thinner pavements and build more cost effectively.

With the lack of a load carrying capacity to relate to a pavement, a crucial element in designing pavements today, one asks themselves the question of whether this is the best approach upon which to base our present-day pavement design process?

Select each type of pavement to learn more.

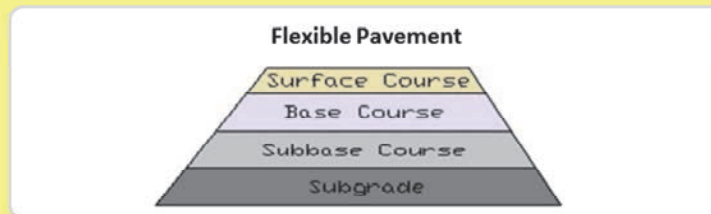
Limitations of Designing with AASHO



Flexible Pavements

CLOSE

- Original AASHO design procedure was not based on fundamental properties of asphalt mixtures
- An estimate of stiffness or layer coefficient were not properties that could be directly measured in a laboratory
- Models are based on the asphalt mixes of 60 years ago and do not include new materials that relate to Superpave binders or other types of asphalt mixtures



Other limitations exist for flexible pavements. The original AASHO design procedure was not based on fundamental properties of asphalt mixtures and an estimate of its stiffness or layer coefficient were not properties that could be directly measured in a laboratory. The models are based on the asphalt mixes of 60 years ago and do not include the new materials that relate to Superpave binders or other types of asphalt mixtures (with RAP, warm mix asphalt, etc.).

Image description: Illustration displaying surface course, base course, sub-base course, and subgrade.

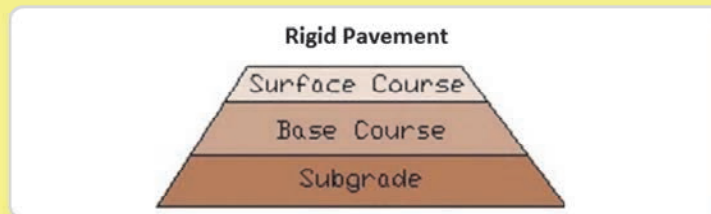
Limitations of Modulus of Subgrade Reaction



Rigid Pavements

X CLOSE

- Modulus of subgrade reaction is not a true engineering property for the foundation soil because it depends not only upon the soil stiffness, but also upon the slab size and stiffness
- Stabilized layers in rigid pavements were represented only by bumping up the stiffness proportionately to the layer thickness of the base
- There was no laboratory testing to determine what the relationship between a stabilized base and the layer thickness of both the concrete layer and the base layer should be



In terms of rigid pavements, there are also a few limitations. The modulus of subgrade reaction (k) is used to estimate the “support” of the PCC slab by the layers below. Usually, an “effective” k (k_{eff}) is calculated, which reflects base, subbase, and subgrade contributions as well as the loss of support that occurs over time due to erosion and stripping of the base, subbase, and subgrade.

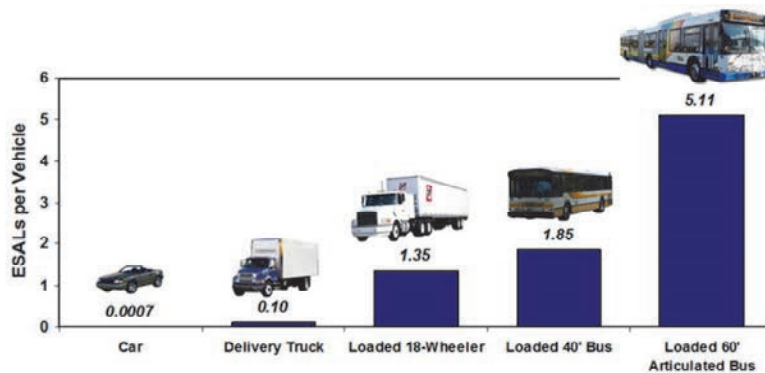
Typically, large changes in k_{eff} have only a modest impact on PCC slab thickness. However, the modulus of subgrade reaction is not a true engineering property for the foundation soil because it depends not only upon the soil stiffness, but also upon the slab (or footing) size and stiffness. In addition, the stabilized layers in rigid pavements were represented only by bumping up the stiffness proportionately to the layer thickness of the base. There was no laboratory testing to really determine what the relationship between a stabilized base and the layer thickness of both the concrete layer and the base layer should be.

Image description: Illustration displaying surface course, base course, sub-base course, and subgrade.

Equivalent Single-Axle Load (ESAL)



- Mixed traffic...loss of PSI equations?
 - Answer: 18-kip equivalent single-axle load (ESAL)
 - How: Using multipliers to convert other axle weights to 18-kip ESALs



The developers of the AASHO method realized the mathematical difficulty in handling mixed traffic in the loss of PSI equations, therefore they decided to apply an equivalent applications approach and came up with the 18-kip equivalent single-axle load or ESAL. Coefficient multipliers are used to convert other axle weights to ESALs.

Image description: Chart the depicts ESALs per vehicle. A car is 0.0007; a delivery truck is 0.10; a loaded 18-wheeler is 1.35; a loaded 40-ft. bus is 1.85; and a loaded 60-ft. articulated bus is 5.11.

Why are Flexible ESALs Different from Rigid ESALs?



- ESAL multiplier based on:
 - Specific flexible layer thickness (SN)
 - Specific rigid slab thickness (D)
 - Specific axle group (single, tandem, or tridem)
 - Specific truck weight range
 - Specific serviceability loss (Δ PSI)



Rigid and flexible ESALs are different because their coefficient multipliers were derived from different empirical pavement experiments.



U.S. Department of Transportation
Federal Highway Administration

MODULE E
LESSON 1

INTRODUCTION

Resources
Glossary
Help

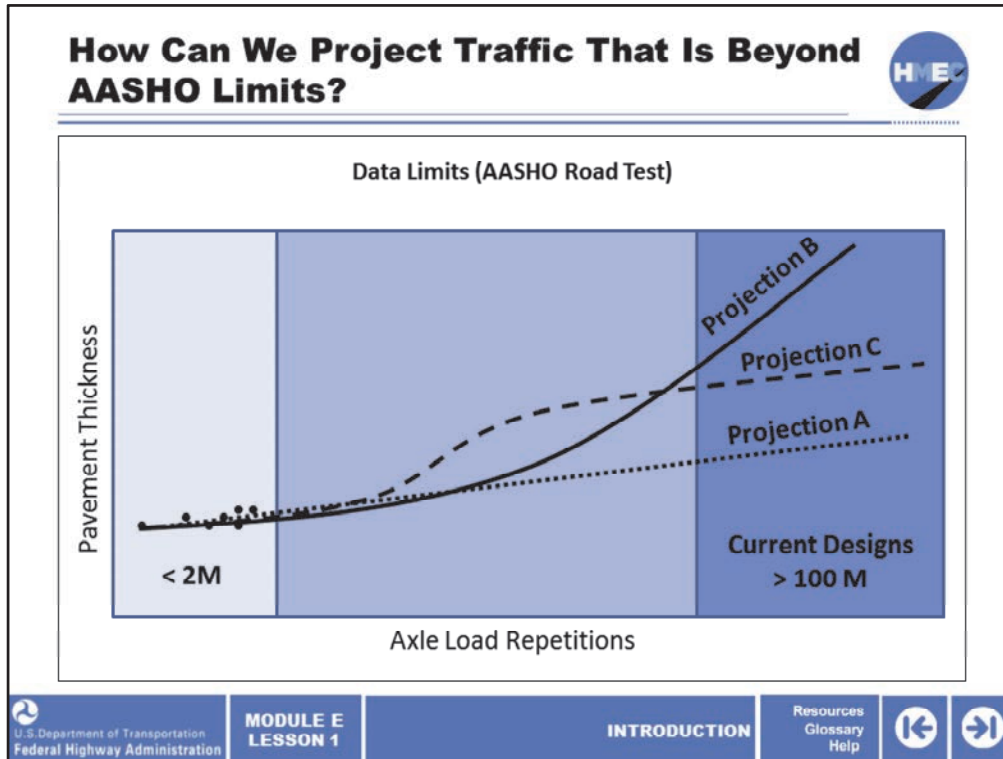


Why are flexible and rigid pavement ESALs different rather than the same value?

Because, the ESAL coefficient multiplier is based on the following factors:

- Specific flexible layer thickness (SN);
- Specific rigid slab thickness (D);
- Specific axle group (single, tandem, or tridem);
- Specific truck weight range; and
- Specific serviceability loss (Δ PSI).

Therefore, rigid and flexible ESALs are different because their coefficient multipliers were derived from different empirical pavement experiments.



This graph demonstrates one of the most serious drawbacks to using the AASHO Road Test as a basis for the pavement design. The AASHO Road Test data was based upon less than 2-million axle applications. This information can be projected several different ways as illustrated by projection A's straight line (the increase in traffic gets a proportional increase in thickness). Or by projection B that says that as the traffic increases, the required thickness required increases at a substantial rate. Or projection C that says the thickness requirement varies with different levels of traffic.

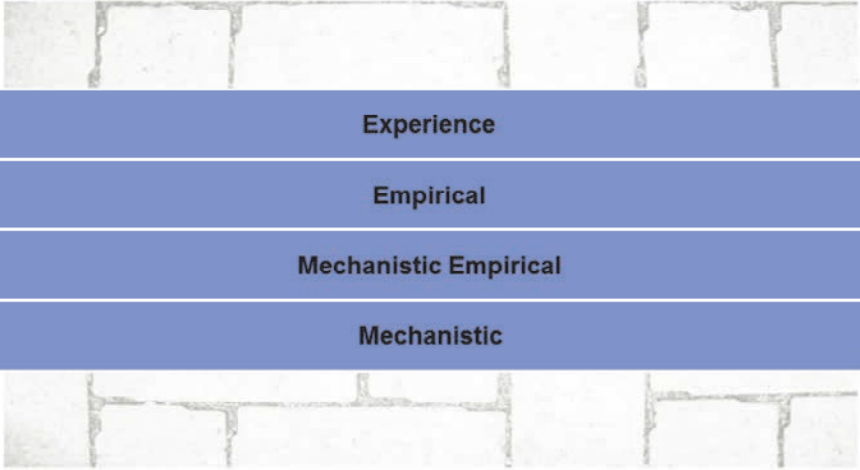

The real answer is that we don't know exactly which way it will go, which is why a more accurate description of traffic (through load spectra) is so important.

Now we are designing some roads approaching 100-million load applications in this area. Which of these projections is correct, based upon the original data produced in the AASHO Road Test?

The bottom line is that we are way beyond the traffic limits represented in the AASHO Road Test.

Image description: Graph demonstrating drawbacks to using the AASHO Road Test as a basis for the pavement design.

Design Methodologies



Experience

Empirical

Mechanistic Empirical

Mechanistic



Select each design methodology to learn more.

U.S. Department of Transportation
Federal Highway Administration

MODULE E
LESSON 1

INTRODUCTION

Resources
Glossary
Help



There are essentially four approaches to pavement design: experience, empirical, mechanistic empirical, and mechanistic. Let's review the differences between these methods of design so that you can understand how the old AASHTO design based on empirical models is different from the new ME design concept. The other two extremes—design based on “experience” and “mechanistic concepts alone”—are provided here to give you the right perspective about where ME design stands in the big picture.

Select each design methodology to learn more.

Image description: Photo of pavement.

Design Method

Experience

- In this methodology, the pavement decision is made based on what is typically done in the area

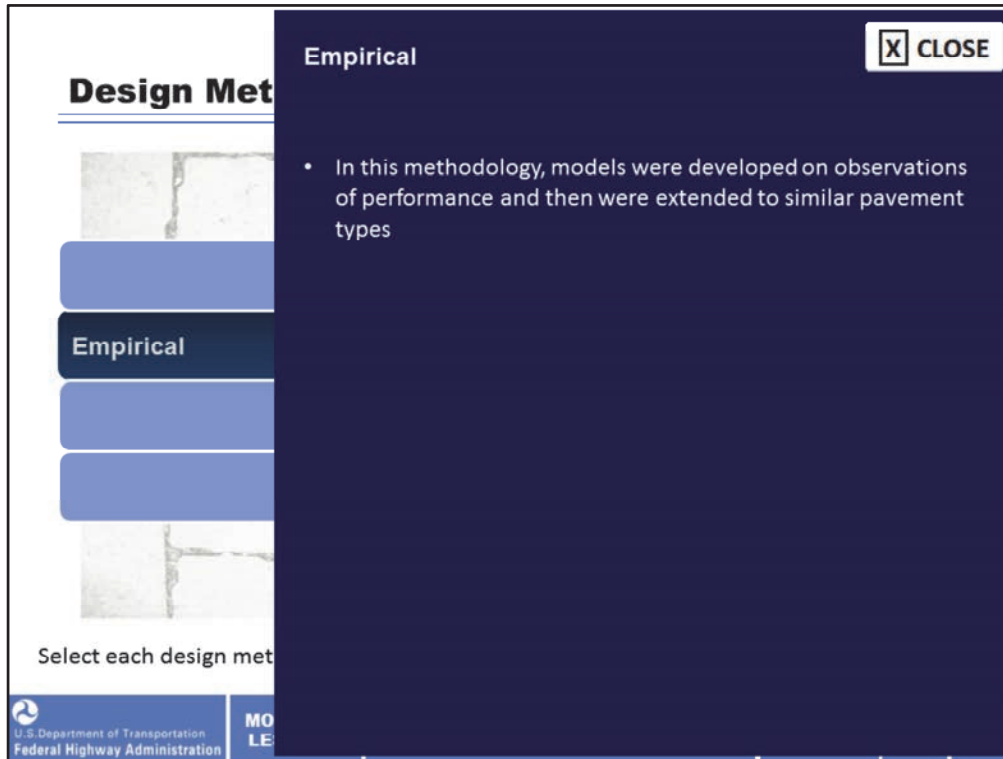
Select each design method

U.S. Department of Transportation
Federal Highway Administration

MO
LE

In the experience methodology, the pavement design decision is made based on what is typically done in the area.

Image description: Photo of pavement.



In the empirical methodology, models were developed based on observations of performance and then were extended to similar pavement types.

Image description: Photo of pavement.

Design Met

Mechanistic Empirical

- In this methodology, mechanistic theory is used to predict the pavement's response to loading, and then empirical models are used to relate these responses to distress levels

Select each design met

U.S. Department of Transportation
Federal Highway Administration

MO
LE

In the mechanistic empirical methodology, mechanistic theory is used to predict the pavement's response to loading, and then empirical models are used to relate these responses to distress levels.

Image description: Photo of pavement.

Design Met

Mechanistic

- In this methodology, distresses are calculated directly from loading by using calculated stresses, strains, and deflections
- Crack propagation theory and particle displacement predictions are used to determine the appropriate pavement design

Select each design met

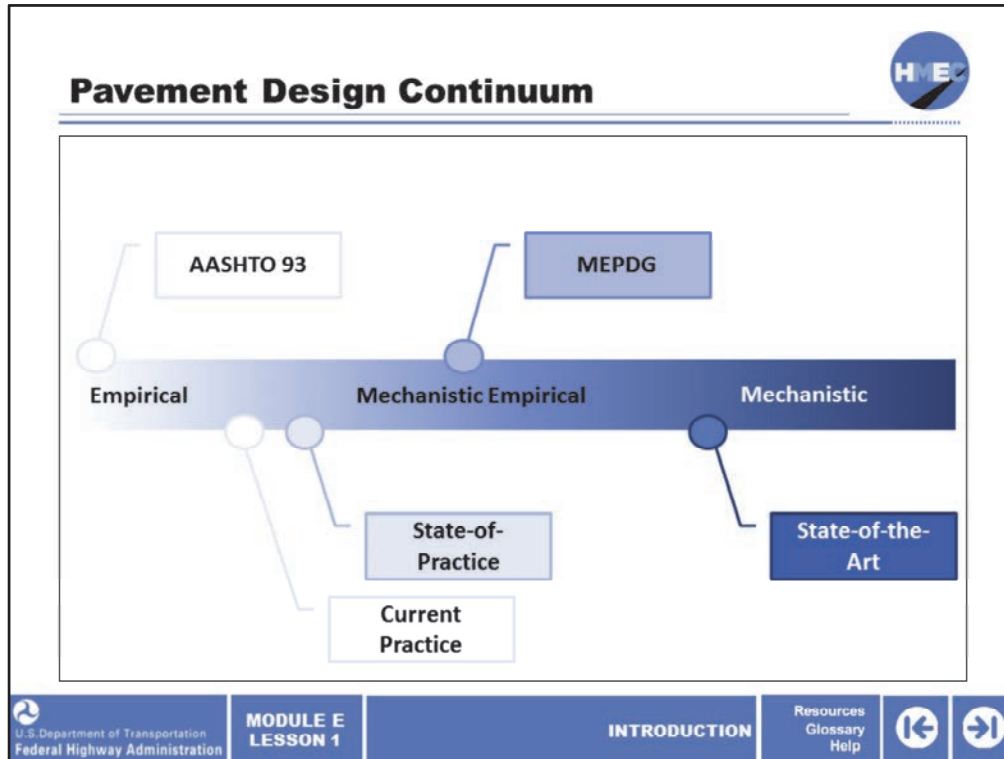
U.S. Department of Transportation
Federal Highway Administration

MO
LE

X CLOSE

In the mechanistic methodology, distresses are calculated directly from loading by using calculated stresses, strains, and deflections. In addition, crack propagation theory and particle displacement predictions are used to determine the appropriate pavement design.

Image description: Photo of pavement.




This continuum qualitatively summarizes pavement design practice as it exists today. Note the distance between the current practice and state-of-practice and between the state-of-practice and state-of-the-art. Most agencies (approximately 90%) currently use AASHTO-based empirical design procedures (72, 86, or 93). The state-of-practice is the most advanced practice being used by DOTs at this point (some use mechanistic empirical design). The state-of-the-art is where current research activities in pavement design are leading us.

Recall the empirical design (such as the AASHTO 1993 version) is based on statistical models from road tests. Then, mechanistic empirical design includes the calculation of stresses/strains combined with empirical pavement performance models, like the MEPDG approach.

Finally, a mechanistic design would include mechanistic-based pavement performance models and is the area in the continuum where researchers are pushing forward toward for the future of pavement design.

Image description: Graphic of the pavement design continuum.

AASHTO Design Versus ME Design



AASHTO 1993 Design **Vs.** **MEPDG Design Approach**

- There are a number of differences between the 1993 AASHTO design and the new ME Design approach

Select each term to learn more.

U.S. Department of Transportation
Federal Highway Administration

MODULE E
LESSON 1

INTRODUCTION

Resources
Glossary
Help

← →

There are a number of differences between the 1993 AASHTO design and the new ME design approach. Let's take a quick look at how the two approaches differ in order to understand why and how pavement designers are changing the way that they do business.

Select each term to learn more.

AASHTO Design Versus ME Design

The screenshot shows a comparison interface. At the top, the title "AASHTO Design Versus ME Design" is displayed. Below the title, there are two boxes: a dark blue box on the left labeled "AASHTO 1993 Design" and a white box on the right labeled "MEPDG Design Approach", with "Vs." between them. Below these is a large dark blue panel with the title "AASHTO 1993 Design" and a "CLOSE" button. The panel contains two bullet points: "Based on default information from the AASHO Road Test" and "Includes statistical models and empirical measurement of pavement performance". At the bottom, there is a navigation bar with the U.S. Department of Transportation Federal Highway Administration logo, "MODULE E LESSON 1", "INTRODUCTION", "Resources Glossary Help", and navigation arrows.

AASHTO 1993 Design

Vs.

MEPDG Design Approach

AASHTO 1993 Design

X CLOSE

- Based on default information from the AASHO Road Test
- Includes statistical models and empirical measurement of pavement performance

U.S. Department of Transportation
Federal Highway Administration

MODULE E
LESSON 1

INTRODUCTION

Resources
Glossary
Help

The AASHTO 1993 design is based on field measurements and observations taken from the AASHO Road Test, which were then used to create empirical models including statistical correlations. The AASHTO 1993 design further refined the statistical models and empirical measurements for use as inputs in the estimation of pavement performance and calculation of required pavement layer thicknesses.

One of the major differences in the two approaches is how the traffic loads are characterized. The AASHTO 1993 design is still founded on the traffic loads originally modeled from the AASHO Road Test.

AASHTO Design Versus ME Design

The slide is titled "AASHTO Design Versus ME Design" and includes the HME logo in the top right corner. A central comparison box shows "AASHTO 1993 Design" on the left and "MEPDG Design Approach" on the right, separated by "Vs.". Below this, a dark blue box titled "MEPDG Design Approach" with a "CLOSE" button lists the following characteristics:

- Only considers FHWA vehicle classes 4 and higher and relies on information such as truck speed, axle configuration, etc.
- Defaults based on measurements from the FHWA long-term pavement performance field sections all across the US
- Mechanistically calculates structural responses
- Uses two types of empirical models

The footer contains the U.S. Department of Transportation Federal Highway Administration logo, "MODULE E LESSON 1", "INTRODUCTION", "Resources Glossary Help", and navigation arrows.

One of the major differences in design approach lies in how traffic loads are characterized. The ME approach only considers FHWA vehicle classes 4 and higher and relies on information such as truck speed, axle configuration, etc.

ME design defaults are based on measurements from the FHWA long-term pavement performance field sections all across the United States.

Structural responses (stresses, strains, and deflections) are mechanistically-calculated in ME design and are based on material properties, environmental conditions, and loading characteristics.

There are two types of empirical models used in the MEPDG. One model predicts the distress directly (e.g., rutting model for flexible pavements, and faulting for rigid pavements). A second model predicts the damage, which is then calibrated against measured field distress (for example, fatigue cracking for flexible pavements and punch outs for continuously reinforced rigid pavements).

Benefits of ME Design Approach



- Improves design reliability
- Improves rehabilitation design
- Includes method for local calibration
- Better evaluates the impacts of traffic and climate



There are a number of benefits to using the MEPDG design approach. One benefit includes the improved potential for designs reaching their intended service life through improved levels of design reliability. The MEPDG allows for better design of rehabilitations for pavements through either flexible or rigid overlays. It has the capability to address unique pavement sections, such as composition pavement structures as well as rehabilitation. The program uses the same principles to analyze existing pavements.

There is a method for locally calibrating the distress models in the Pavement ME Design software to conditions in the State or location where the design will eventually be built. Also, the MEPDG approach permits for better evaluation of the impacts of both loading types (that is, traffic and climate loads) through applying various traffic levels, seasonal traffic, or seasonal drainage effects, and through yearly changes in material properties.

The ME design approach also integrates the effects of current and future loadings, site-specific climate (ICM), and the material changes that occur over time.

Image description: Construction crew applying a cape seal to an existing flexible pavement. Cape seal treatments prevent the occurrence of loose stones in chip seals, used in flexible pavements with high traffic volumes.

State of the Practice in Pavement Design



2003 Survey Results

Vs.

2010 Survey Results

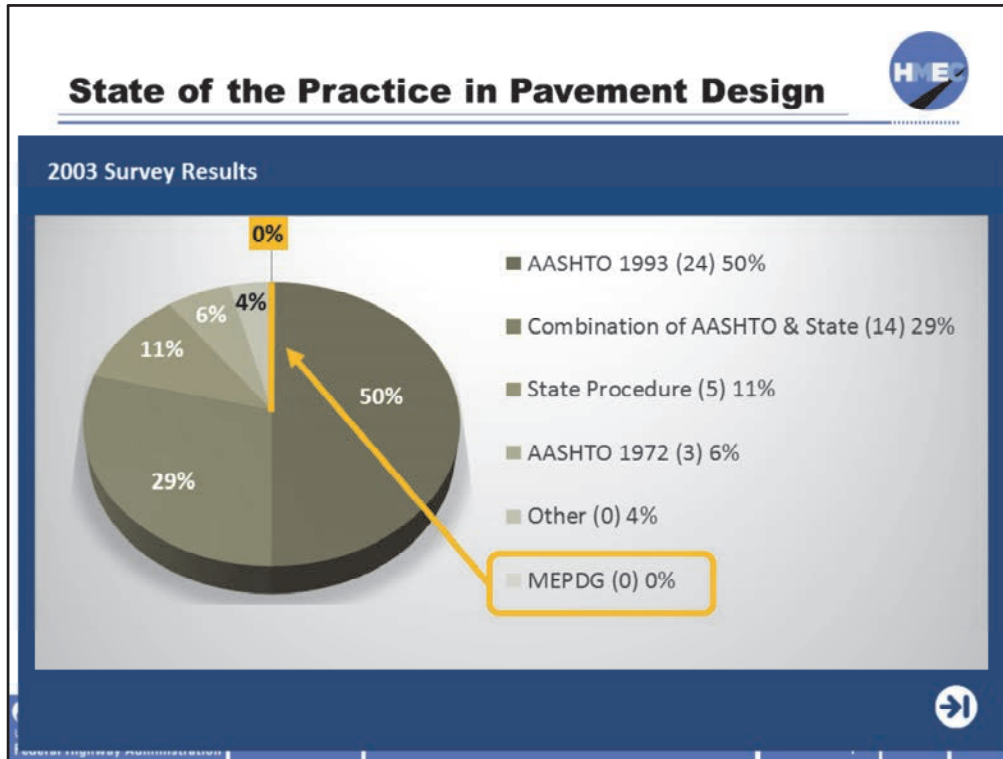
- Two surveys were conducted in the past 10 years to determine the state of the practice of pavement design in the US

Select each survey year to learn more.



Two surveys were conducted in the past 10 years to determine the state of the practice of pavement design in the US, in 2003 and 2010.

Select each survey year to review the survey results.

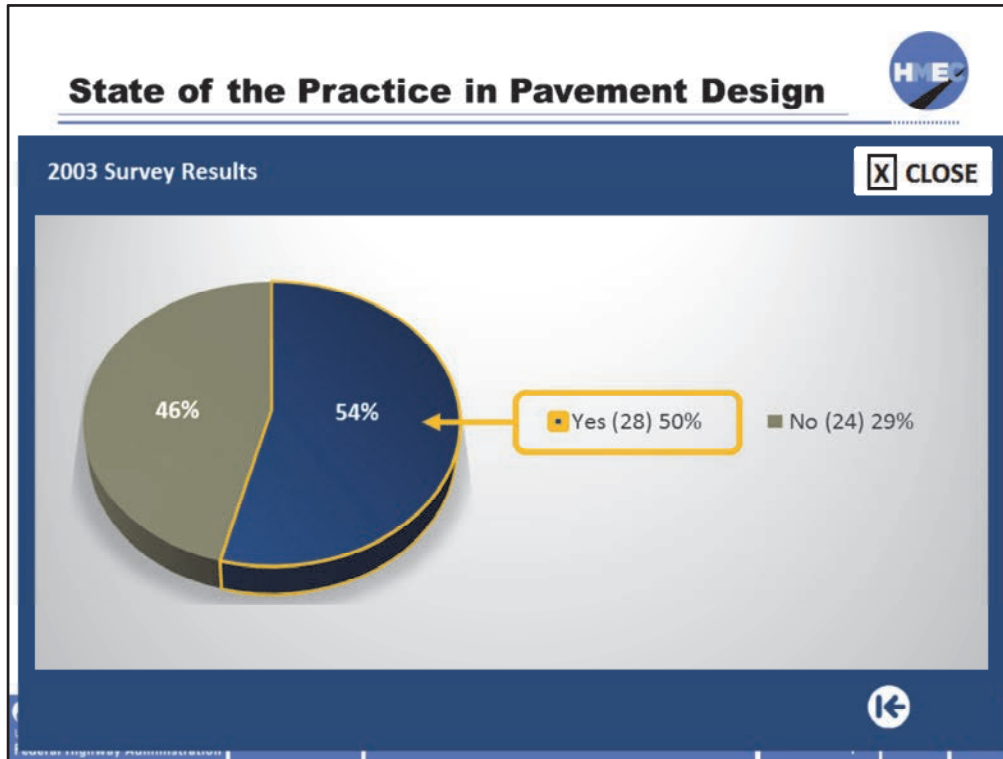


The FHWA first queried its division offices in 2003 as to the practices used by the DOTs for pavement design. It was observed that 0% of the States were using MEPDG approach for their design procedure.

A second question common between the two surveys was related to whether DOTs were pursuing local calibration or implementation of the MEPDG design approach. Select the forward arrow to learn more.

Image description: Pie chart showing the 2003 survey results of the state of the practice in pavement design.

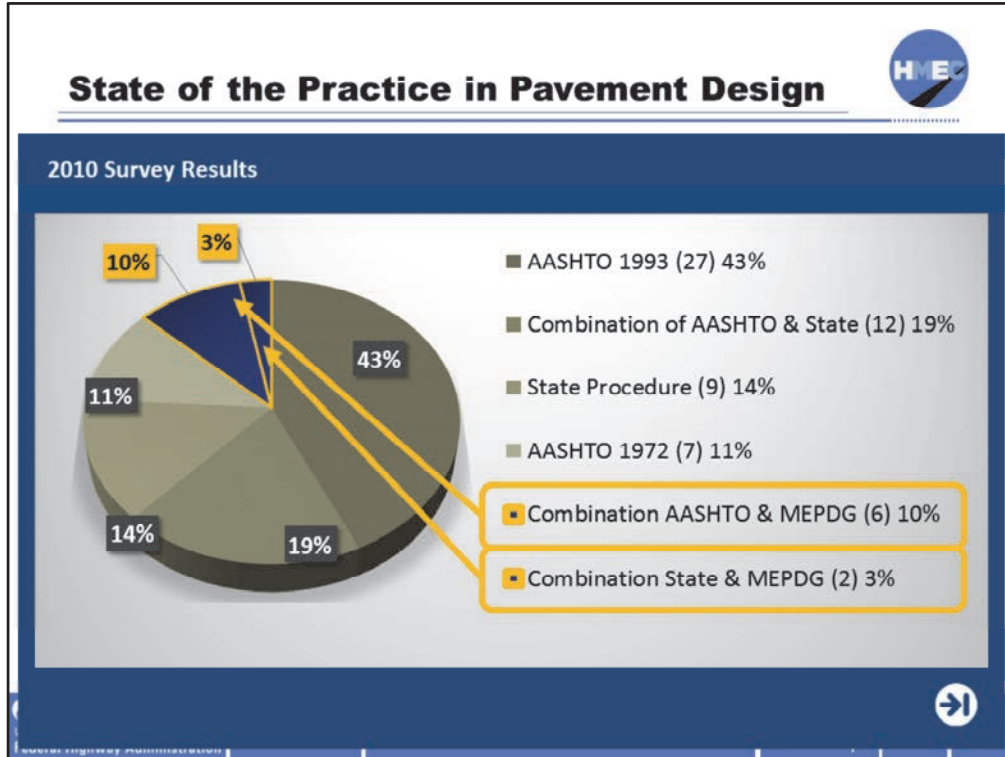
Source: FHWA Design Guide Implementation Survey (2003)



In 2003, there were 28 States who were actively collecting data to be able to support local calibration.

Image description: Pie chart showing the 2003 survey results of the state of the practice in pavement design.

Source: FHWA Design Guide Implementation Survey (2003).

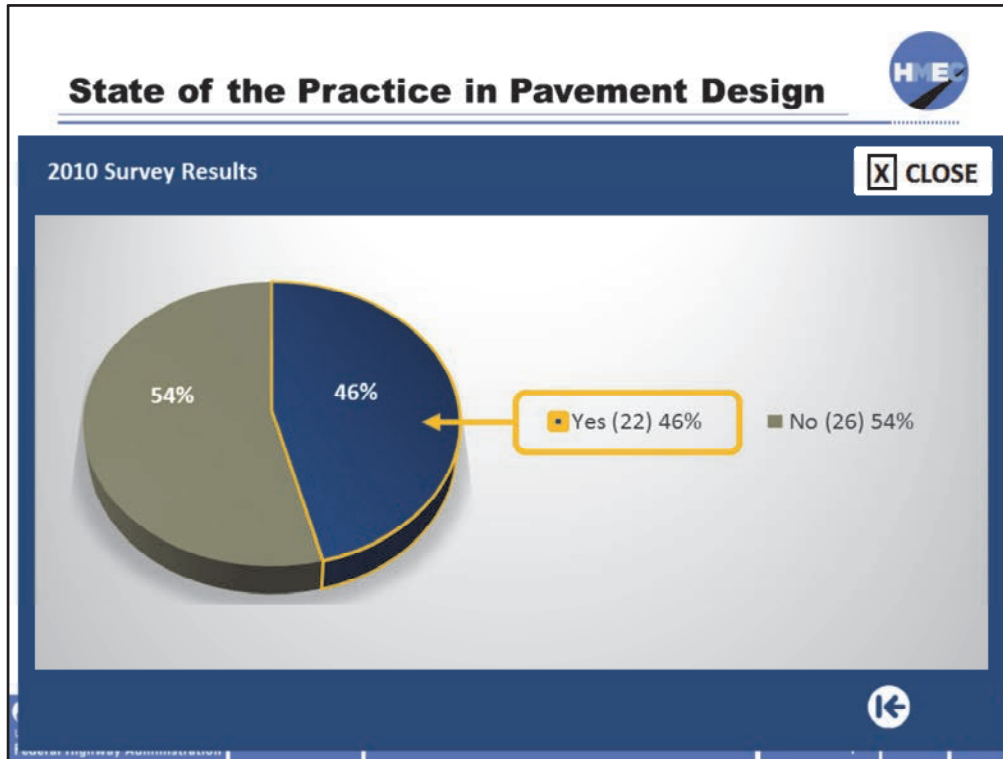


Seven years after the 2003 survey was conducted, FHWA again asked its division offices as to the practices used by the DOTs for pavement design. Two States were using a combination of MEPDG and their DOT design approach, and six States were using a combination of AASHTO 1993 and the MEPDG.

Select the next arrow to learn about whether DOTs were pursuing local calibration or implementation of the MEPDG design approach.

Image description: Pie chart showing the 2010 survey results of the state of the practice in pavement design.

Source: Transportation Research e-c155 (2010)



By 2010, 22 States reported that they had a complete local calibration plan in place for using MEPDG as their partial or full design approach.

Image description: Pie chart showing the 2010 survey results of the state of the practice in pavement design.

Source: Transportation Research e-c155 (2010)

Exercise 1: Sample Pavement Projects

Select each highlighted State to learn more. : Sample State DOTs

U.S. Department of Transportation
Federal Highway Administration

MODULE E
LESSON 1

INTRODUCTION

Resources
Glossary
Help

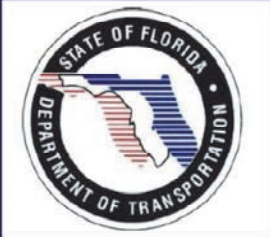
← →

Let's review some real-world examples to help you apply the information presented in this lesson. This screen introduces four different States and corresponding sample pavement design projects (both flexible and rigid), which will be used in this lesson, and the following instructor-led lessons in this module, to illustrate concepts in the Pavement ME Design software.

Select each highlighted State to review the current state of the practice in terms of pavement design for that State.

Image description: Map of the United States with the states of Washington, Utah, Indiana, and Florida highlighted.

Exercise 1: Sample Pavement Projects - Florida X CLOSE



FLEXIBLE PAVEMENT DESIGN VARIABLES

$SN_R = (ESAL_D, M_R, \%R)$

For New Construction

$SN_C = SNR$

Overlay With and Without Milling

$SN_O = SNR - SNE$

Where:

$ESAL_0$ = Accumulated 18-kip Equivalent Single Axle Loads over the life of the project (18-kip ESAL).

SN_0 = Structural number determined as a function of the Design Equivalent Single Axle Loadings (DESAL), Resilient Modulus (M_R) and the Reliability ($\%R$).

SN_C = Structural number of the proposed structural layers in a newly constructed pavement.

SN_O = Structural number of the structural layers needed in the overlay.

SN_E = Structural number of the existing pavement structure after any milling.

REQUIRED DEPTH (D_R) IN INCH FOR 75% RELIABILITY ($\%R$)

ESAL ₀	Modulus Of Subgrade Reaction (K_0), psi/in									
	40	80	110	150	185	200	260	300	330	370
100 000 to 1, 500 000 ESAL Use 8" for all K Values										
2 000 000	8	8	8	8	8	8	8	8	8	8
2 500 000	8½	8	8	8	8	8	8	8	8	8
3 000 000	9	8½	8½	8	8	8	8	8	8	8
3 500 000	9	9	8½	8½	8	8	8	8	8	8
4 000 000	9	9	9	8½	8½	8½	8	8	8	8


A Florida Rigid Design procedure based on the 1.0 version of the MEPPDG has been developed and can be used as an alternate to the AASHTO 1993 and 1998.

To open the exercises, select the paperclip icon.

Review the pavement design information for Florida. This information, and a streamlined version of the entire FDOT standard, can be found in the Module E, Lesson 1 Exercises PDF document. To download this document, select the paperclip icon.

Image description: Documents from sample pavement projects, Florida.

Exercise 1: Sample Pavement Projects - Indiana




X CLOSE

52-8.03(02) Flexible-Pavement-Layer Design

A flexible-pavement system consists of HMA (Surface, Intermediate, and Base) on an unbound base layer or prepared subgrade. A final pavement-structure design in the MEPDG should include all of the layers shown in the Figure [52-13](#) series typical pavement sections. Iterative runs in the MEPDG should be conducted to minimize the HMA Base thickness while satisfying the pavement performance prediction for the design life.

52-8.03(03) Rigid-Pavement-Layer Design

A rigid-pavement system consists of portland cement concrete pavement on granular subbase on prepared subgrade. A final pavement-structure design in the MEPDG should include all the layers described in the Figure [52-13](#) series typical pavement sections. Iterative runs in the MEPDG should be conducted to minimize the structural thicknesses while satisfying the pavement performance prediction for the design life. A new rigid-pavement trial should be started by first creating a template identifying all subgrade and pavement layers.


 To open the exercises, select the paperclip icon.

Review the pavement design information for Indiana. This information, and a streamlined version of the entire Indiana DOT standard, can be found in the Module E, Lesson 1 Exercises PDF document. To download this document, select the paperclip icon.

Image description: Documents from sample pavement projects, Indiana.

Exercise 1: Sample Pavement Projects - Utah

X CLOSE



udot.utah.gov

AASHTO Design Nomograph Method of Flexible Pavement Design

The basic AASHTO design process for flexible pavements begins with the determination of required structural number (SN) based on the level of traffic. Trial pavement designs are then identified by using different layer thicknesses that provide the required structural number, meet minimum layer thickness criteria, and provide adequate protection for underlying materials.

Flexible Pavement Layer Coefficients

Layer	Coefficient (per inch)
Plant Mix Seal (PMS)	0.30
Hot Mix Asphalt (HMA)	0.40
Untreated Base Course(UTBC)	0.10
Granular Borrow (GB)	0.08

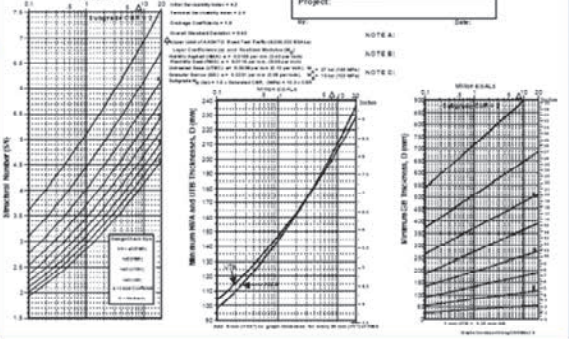
Table 3D-2

Asphalt Pavement Thickness Evaluation (55% reliability)

Project: _____

MINIMUM SN: _____

MINIMUM THICKNESS (inches): _____



NOTE: 1. The AASHTO design process for flexible pavements begins with the determination of required structural number (SN) based on the level of traffic. Trial pavement designs are then identified by using different layer thicknesses that provide the required structural number, meet minimum layer thickness criteria, and provide adequate protection for underlying materials.

NOTE: 2. The AASHTO design process for flexible pavements begins with the determination of required structural number (SN) based on the level of traffic. Trial pavement designs are then identified by using different layer thicknesses that provide the required structural number, meet minimum layer thickness criteria, and provide adequate protection for underlying materials.

NOTE: 3. The AASHTO design process for flexible pavements begins with the determination of required structural number (SN) based on the level of traffic. Trial pavement designs are then identified by using different layer thicknesses that provide the required structural number, meet minimum layer thickness criteria, and provide adequate protection for underlying materials.

To open the exercises, select the paperclip icon.

Review the pavement design information for Utah. This information, a streamlined version of the entire UDOT pavement design policy, and the layer coefficient (a) tables used by the Utah DOT, can be found in the Module E, Lesson 1 Exercises PDF document. To download this document, select the paperclip icon.

Image description: Documents from sample pavement projects, Utah.

Exercise 1: Sample Pavement Projects - Washington

X CLOSE



Washington State Department of Transportation

Table 5.1. Flexible and Rigid Pavement Layer Thicknesses for New or Reconstructed Pavements

Design Period ESALs	Layer Thicknesses, ft				
	Flexible Pavement		Rigid Pavement		
	HMA	CSBC Base	PCC Slab	Base Type and Thickness	
< 5,000,000	0.50	0.50	0.67	CSBC only	0.35
5,000,000 to 10,000,000	0.67	0.50	0.75	HMA over CSBC	0.35 + 0.35
10,000,000 to 25,000,000	0.83	0.50	0.83	HMA over CSBC	0.35 + 0.35
25,000,000 to 50,000,000	0.92	0.58	0.92	HMA over CSBC	0.35 + 0.35
50,000,000 to 100,000,000	1.00	0.67	1.00	HMA over CSBC	0.35 + 0.35
100,000,000 to 200,000,000	1.08	0.75	1.08	HMA over CSBC	0.35 + 0.35

Design Procedures: Two design procedures were used to develop Table 5.1 along with results from national and international studies. The primary procedure used was the AASHTO Guide for Design of Pavement Structures (1993). The secondary procedure was the MEPDG (version 1.0).

Flexible Pavement Assumptions: The thicknesses shown in Table 5.1 are a combination of results largely from AASHTO 93. The results were modified as needed with additional information from the MEPDG 1.0, WSDOT historical pavement performance data and experience. The assumptions used in AASHTO 93 for flexible pavement design included: $\Delta PSI = 1.5$, $S_w = 0.5$, $m = 1.0$, $R_{HMA} = 0.50$, $R_{CSBC} = 0.13$, $M_{R1} = 10,000$ psi, and $E_{sub} = 30,000$ psi. Thicker CSBC layers may be required for frost design.

Rigid Pavement Assumptions: The thicknesses shown in Table 5.1 are a combination of results largely from AASHTO 93. The results were modified as needed with additional information from MEPDG 1.0, WSDOT historical pavement performance data and experience. The assumptions used in AASHTO 93 for rigid pavement design included: $J = 3.2$ (dowels), $S_w = 0.4$, $E_c = 4,000,000$ psi, $C_d = 1.0$, $\Delta PSI = 1.5$, $S_c = 700$ psi, $k = 200$ pci (CSBC is the only base), $k = 400$ pci (HMA base paved over CSBC).

To open the exercises, select the paperclip icon.

Review the pavement design information for Washington. This information, a reduced, streamlined version of the entire WS DOT pavement design method, and the layer coefficient (a) tables used by the Washington DOT, can be found in the Module E, Lesson 1 Exercises PDF document. To download this document, select the paperclip icon.


Image description: Documents from sample pavement projects, Washington.


Select the best answer. Based on your review of the information provided, what type of design methodology do you think Florida DOT is using?




a) AASHTO Guide for Design of Pavement Structures (1993)

b) Mechanistic empirical

c) MEPDG along with FDOT pavement historical data and experience used in the development and validation of the design tables



 Knowledge Check

 **MODULE E**
LESSON 1 **INTRODUCTION** Resources
Glossary
Help  

Now let's answer a series of questions on the information you reviewed related to design methodology in the example States.

Select the best answer. Based on your review of the information provided, what type of design methodology do you think Florida DOT is using?

- a) AASHTO Guide for Design of Pavement Structures (1993);
- b) Mechanistic empirical; or
- c) MEPDG along with FDOT pavement historical data and experience used in the development and validation of the design tables.

Select the best answer. Based on your review of the information provided, what type of design methodology do you think Florida DOT is using?



- a) AASHTO Guide for Design of Pavement Structures (1993)
- b) Mechanisticempirical
- c) MEPDG along with FDOT pavement historical data and experience used in the development and validation of the design tables




Knowledge Check Debrief



The correct answer is a) AASHTO Guide for Design of Pavement Structures (1993).


Select the best answer. Based on your review of the information provided, what type of design methodology do you think Indiana DOT is using?




a) AASHTO Guide for Design of Pavement Structures (1993)

b) Mechanistic empirical

c) MEPDG along with Indiana DOT pavement historical data and experience used in the development and validation of the design tables



 Knowledge Check Try again Submit Clear

 U.S. Department of Transportation
Federal Highway Administration

MODULE E
LESSON 1

INTRODUCTION

Resources
Glossary
Help

Select the best answer. Based on your review of the information provided, what type of design methodology do you think Indiana DOT is using?

- a) AASHTO Guide for Design of Pavement Structures (1993);
b) Mechanistic empirical; or
c) MEPDG along with Indiana DOT pavement historical data and experience used in the development and validation of the design tables.

Select the best answer. Based on your review of the information provided, what type of design methodology do you think Indiana DOT is using?



- a) AASHTO Guide for Design of Pavement Structures (1993)
- b) Mechanistic empirical
- c) MEPDG along with Indiana DOT pavement historical data and experience used in the development and validation of the design tables



Knowledge Check Debrief



U.S. Department of Transportation
Federal Highway Administration

MODULE E
LESSON 1


INTRODUCTION

Resources
Glossary
Help







The correct answer is b) Mechanistic empirical.

Select the best answer. Based on your review of the information provided, what type of design methodology do you think Utah DOT is using?



- a) AASHTO Guide for Design of Pavement Structures (1993)
- b) Mechanistic empirical
- c) MEPDG along with Utah DOT pavement historical data and experience used in the development and validation of the design tables.

 Knowledge Check Try again Submit Clear

 **MODULE E**
LESSON 1 **INTRODUCTION** Resources
Glossary
Help  

Select the best answer. Based on your review of the information provided, what type of design methodology do you think Utah DOT is using?

- a) AASHTO Guide for Design of Pavement Structures (1993);
- b) Mechanistic empirical; or
- c) MEPDG along with Utah DOT pavement historical data and experience used in the development and validation of the design tables.

Select the best answer. Based on your review of the information provided, what type of design methodology do you think Utah DOT is using?



- a) AASHTO Guide for Design of Pavement Structures (1993)
- b) Mechanisticempirical
- c) MEPDG along with Utah DOT pavement historical data and experience used in the development and validation of the design tables.



Knowledge Check Debrief



The correct answer is a) AASHTO Guide for Design of Pavement Structures (1993).

Types of State-Specific Data

Select each highlighted State to learn more. : Sample State DOTs

U.S. Department of Transportation
Federal Highway Administration

MODULE E
LESSON 1

INTRODUCTION

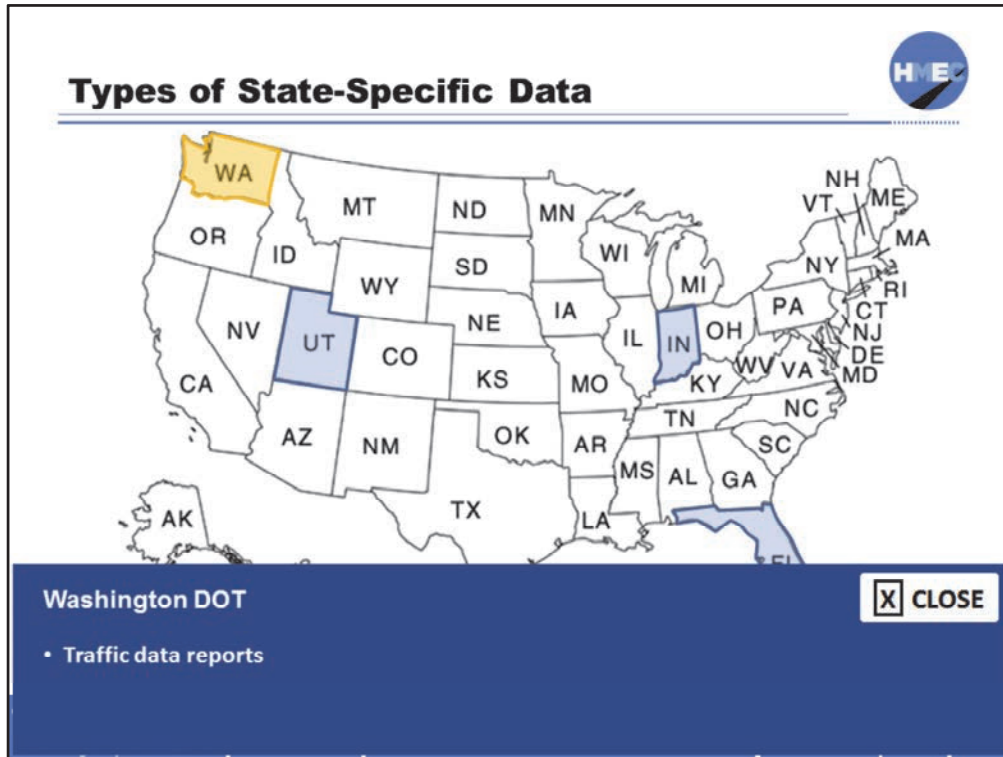
Resources
Glossary
Help

◀ ▶

There are many States deriving their own State-specific data to be used in populating databases that serve to provide inputs to the Pavement ME Design software and thereby “calibrating” the designs more to their particular conditions. Let’s take a look at how these four sample States are doing this.

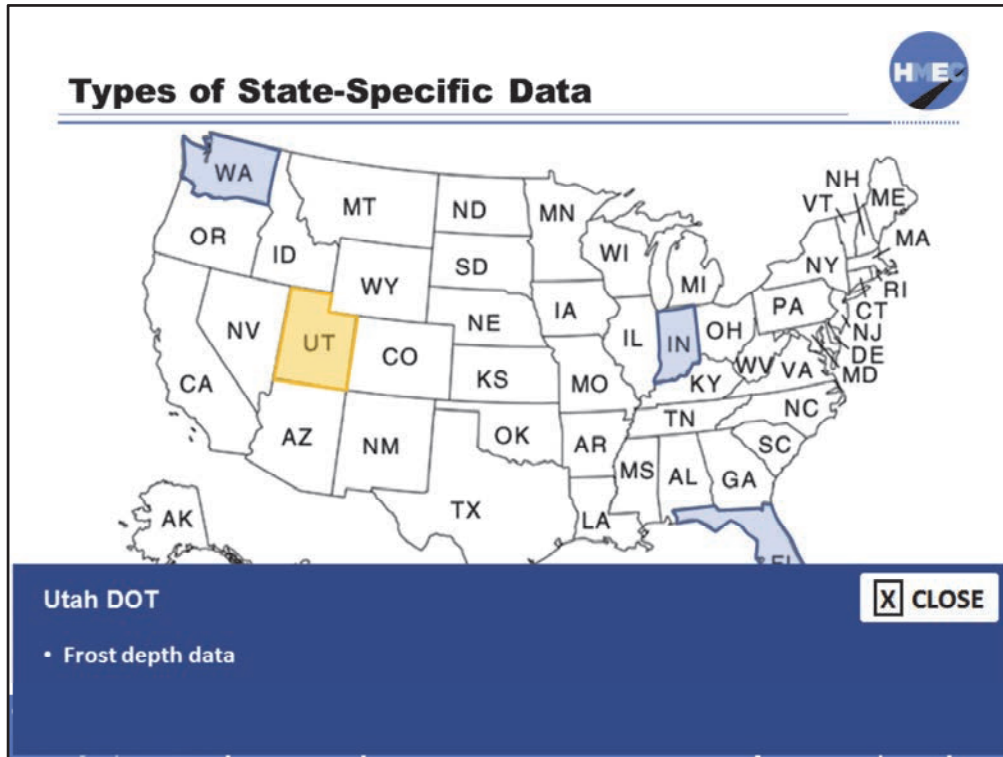
Select each highlighted State to learn more.

Image description: Map of the United States with the states of Washington, Utah, Indiana, and Florida highlighted.



In Washington, there is a traffic input catalog with State-specific traffic reports for different types of roadways in the State.

Image description: Map of the United States with the state of Washington highlighted.



In Utah, there is a materials catalog which contains frost-depth data for soils and aggregates because of the frost-heave issues experienced in much of the State.

Image description: Map of the United States with the state of Utah highlighted.

Types of State-Specific Data

Indiana DOT

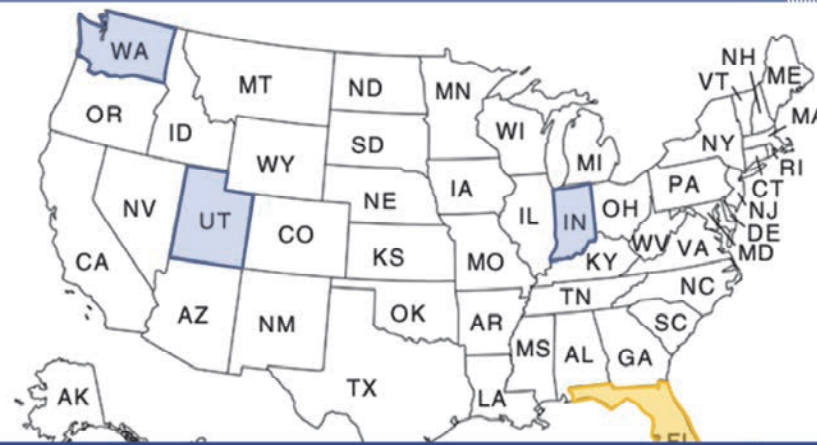
- Material catalog
- Traffic data catalog

X CLOSE

In Indiana, there is a materials catalog with State-specific inputs as well as a traffic input catalog with traffic data for different types of roadways.

Image description: Map of the United States with the state of Indiana highlighted.

Types of State-Specific Data



Florida DOT

- Local calibration database for Florida materials

X CLOSE

In Florida, there is a materials catalog with State-specific inputs.

Image description: Map of the United States with the state of Florida highlighted.

Exercise 2: One Minute Paper



- Which design approach is being used in your State for flexible pavements?
- Which design approach is being used in your State for rigid pavements?
- Where does your State's approach fall within the pavement design continuum?



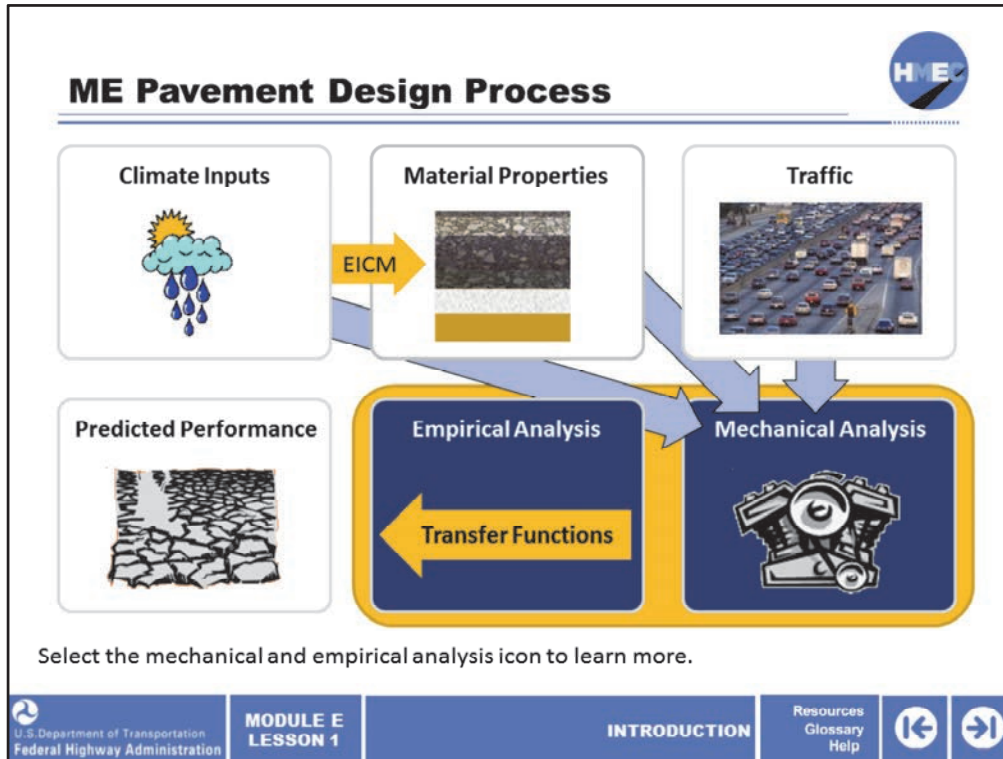
To open the exercises, select the paperclip icon.



Let's take a moment to consider what is being done in terms of pavement design in your State. Please answer the questions on the screen in the Module E, Lesson 1 Exercises PDF.

We'll discuss your answers in the instructor-led portion of this module.

Once you have completed this exercise, advance to the next screen to continue this lesson.



The ME design procedure accounts for all factors that change with time and that affect pavement response. The mechanistic empirical design is much more than thickness design. Structural response models in ME design help determine the critical responses in the pavement structure. These responses are directly used to calculate damage, which is in turn related to individual distress modes.

Select the mechanical and empirical analysis icon to take a peek inside the engine.

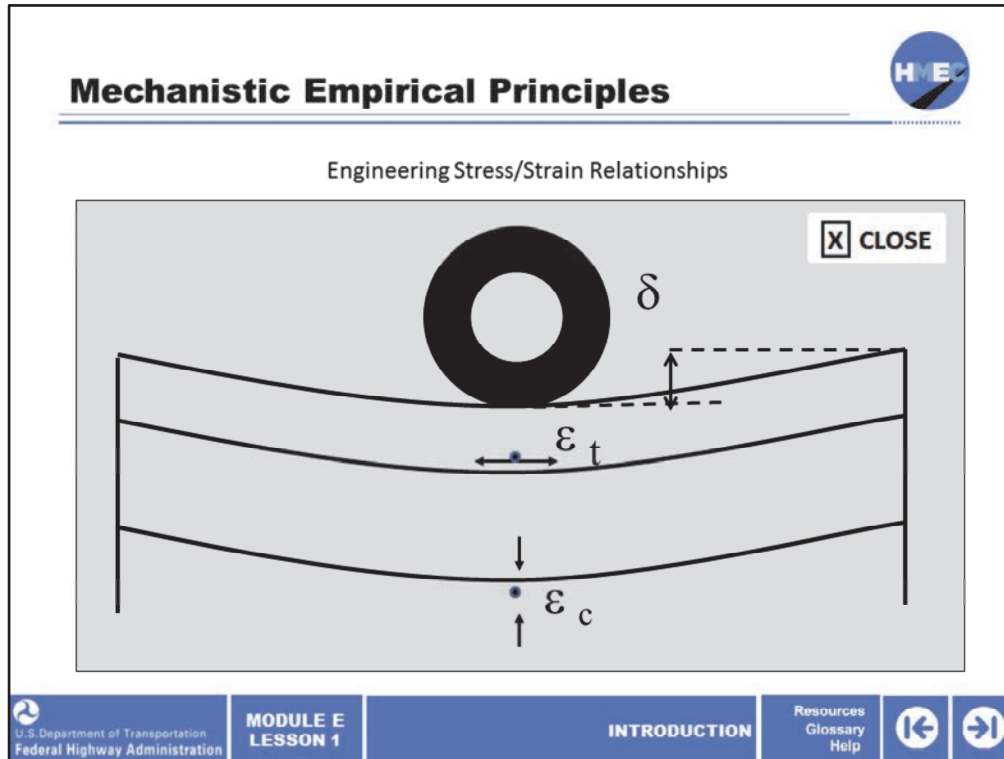
Image description: Illustration of a rain cloud blocking the sun.

Image description: Asphalt pavement layers.

Image description: A highway traffic jam.

Image description: Illustration of cracked soil.

Image description: Illustration of an engine.



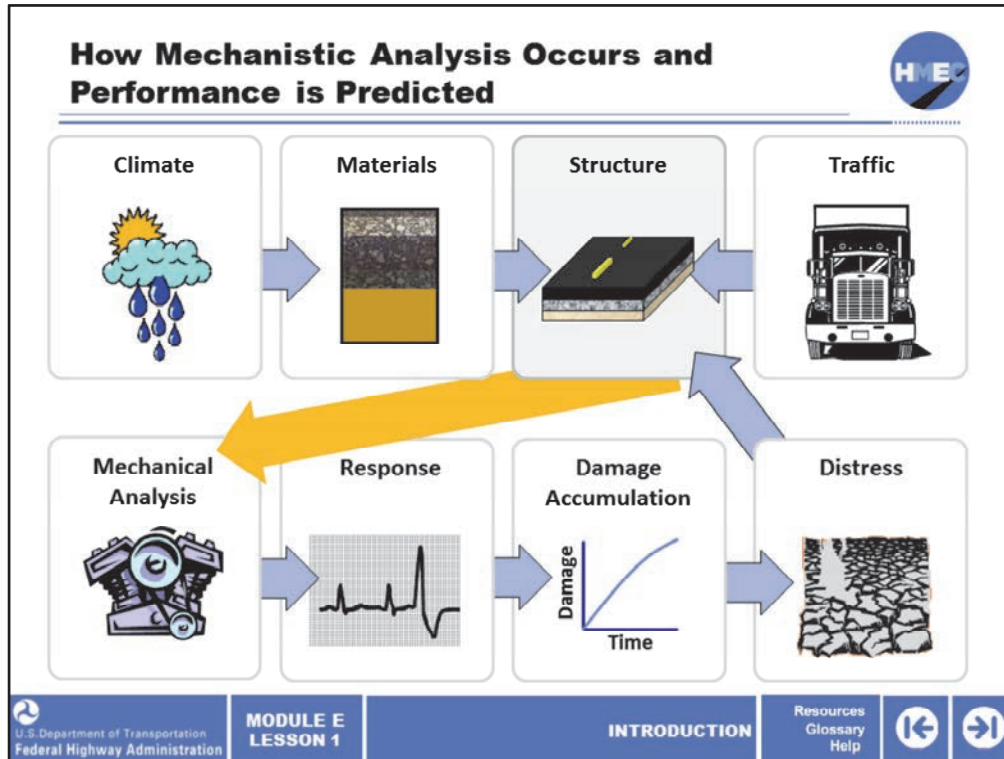
What is meant by mechanistic empirical? This means that for the first time the principles of engineering mechanics will be applied to the pavement design problem on a national basis.

Mechanistic analysis is based on a given material's response to load and environment, through the definition and evaluation of its stress and strain relationships. This figure shows a wheel load being applied to a pavement. The pavement materials will mechanically respond in three ways:

1. The layers will deform when the load passes over a given point in a pavement (represented by the deflection symbol, δ);
2. The compressive strain response at the surface of the subgrade soil will indicate how effective the soil is under the pressure of a heavy vertical load being applied to the system; and
3. The tensile strain at the bottom of the surface layer (e.g., asphalt or concrete) will indicate how effective the material's strength is in reacting to the bending under the vertical load applied.

Empirical analysis is based on field observations and physical measurements of how the pavement materials strengthen (as in the case early on for concrete pavements) or deteriorates over time.

Image description: Illustration of engineering stress/strain relationships.



The structural response model should be able to consider a variety of loading situations and material properties in predicting the pavement response. Just as with the inputs, the response models used to analyze pavements can also vary over a wide range of sophistication. Although a sophisticated pavement analysis model is desirable for accurate pavement response calculation, the degree of sophistication should always be weighted against practicality.

Tremendous research has been conducted over the last century in developing suitable structural response models for pavement analysis. Today, this component of the Pavement ME Design process is perhaps the best developed. The process includes:

- Traffic loading characteristics, such as average daily truck traffic (ADTT), growth factors, axle distributions, hourly distribution, wander, and tire pressures.
- Climate loading, such as through measuring hourly temperatures, rainfall, and the water table depth.
- Materials properties through measurement of the layer moduli, master curves, temperature coefficients, and aging of the properties over time and temperature conditions.
- Pavement structure characterization, such as the thickness and existing pavement structural conditions.

Image description: Illustration of a rain cloud blocking the sun.

Image description: Asphalt pavement layers.

Image description: Illustration of a block of road above two layers of sub-base.

Image description: Illustration of the front of a semi truck.

Image description: Illustration of an engine.

Image description: Graphic of a sound wave.

Image description: Graph of Damage/Time.

Image description: Illustration of cracked soil.

Factors That Affect Material Properties



- Load frequency
- Gradation
- Level of compaction
- Time (consolidation and aging)
- Constructed properties
- Temperature



These are some of the factors that affect material properties in Pavement ME Design. These will be discussed in further detail as part of the instructor-led part of this module, but it is important to keep these in mind during this lesson.

The load frequency applied to the pavement will influence the material's response (such as elastic, viscoelastoplastic, etc.), particularly if you are considering a low-volume pavement exposed to low operational speeds as opposed to a freeway pavement that experiences high frequency loading (from high operational speeds).

The gradation of a soil or base material is one factor, or the gradation used as part of an asphalt or concrete pavement mix design, which will impact the material properties.

The level of compaction, constructed properties, consolidation and aging rate are all factors that come from field exposure but can alter how effective the material responses are over time.

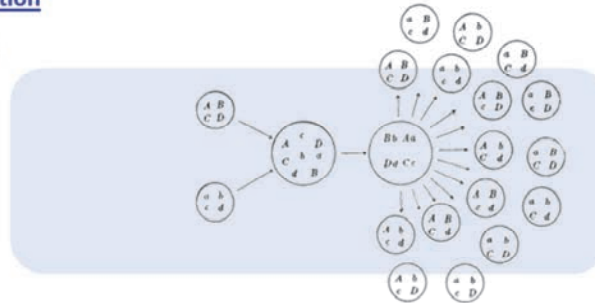
Finally, the temperature (seasonally, monthly, and hourly) can certainly affect the material's strength and resiliency at any given time and traffic load level.

Image description: Interstate with light traffic.

Factors that Affect Predicted Pavement Performance in MEPDG



- Factors:
 - [Traffic Loading](#)
 - [Climate](#)
 - [Material Properties](#)
 - [Design and Construction](#)
 - [Geometric Features](#)



Select each factor to learn more.



The performance of pavements is highly dependent upon several factors. Pavement ME software checks a pavement design to see if it will meet determined criteria at a designated reliability. Understanding the interrelationships of the factors can help be better prepared to adjust a pavement design as needed to obtain the most successful and adequate possible design.

Select each factor to learn more.

Image description: Graphic of a flowchart.

Factors that Affect Predicted Performance in MEPD


- Factors:
 - [Traffic Loading](#)
 - [Climate](#)
 - [Material Properties](#)
 - [Design and Construction](#)
 - [Geometric Features](#)

Select each factor to learn more.

Traffic Loading

CLOSE

- Traffic loading has a significant effect on the predicted pavement performance indicators
- Higher truck traffic volumes may result in higher predicted distresses



U.S. Department of Transportation
Federal Highway Administration

MODULE E
LESSON 1

Traffic loading has a significant effect on the predicted pavement performance indicators. Higher truck traffic volumes may result in higher predicted distresses.

Image description: Static plate load testing on geogrid reinforced base layers.

Factors that Affect Pavement Performance in MEPDC


- Factors:
 - [Traffic Loading](#)
 - [Climate](#) ←
 - [Material Properties](#)
 - [Design and Construction](#)
 - [Geometric Features](#)

Select each factor to learn more.

Climate

CLOSE

- Climate will also affect pavement performance
- High temperatures may cause rutting or permanent deformation in flexible pavements; whereas cold temperatures may cause cracking in flexible pavement



U.S. Department of Transportation
Federal Highway Administration

MODULE E
LESSON 1

Climate will also affect pavement performance. High temperatures may cause rutting or permanent deformation in flexible pavements; whereas cold temperatures may cause cracking in flexible pavement.

Image description: Photo of a stretch of road with very low storm clouds hovering above.

Factors that Affect Pavement Performance in MEPD


- Factors:
 - [Traffic Loading](#)
 - [Climate](#)
 - [Material Properties](#) ←
 - [Design and Construction](#)
 - [Geometric Features](#)

Select each factor to learn more.

Material Properties

CLOSE

- Material properties, foundation, and existing pavement conditions greatly contribute to the longevity of pavements



U.S. Department of Transportation
Federal Highway Administration

MODULE E
LESSON 1

Material properties, foundation, and existing pavement conditions greatly contribute to the longevity of pavements.

Image description: Photo of pavement.


Factors that Affect Pavement Performance in MEPDC

- Factors:
 - [Traffic Loading](#)
 - [Climate](#)
 - [Material Properties](#)
 - [Design and Construction](#)
 - [Geometric Features](#)

Select each factor to learn more.

Design and Construction X CLOSE

- Design and construction factors, such as pavement thickness, maintenance level, and quality of construction have a considerable effect on the pavement performance



U.S. Department of Transportation
Federal Highway Administration

MODULE E
LESSON 1

Design and construction factors, such as pavement thickness, maintenance level, and quality of construction have a considerable effect on the pavement performance.

Image description: Photo of concrete reinforced using grade 60 bars.

Factors that Affect Predicted Performance in MEPD


- Factors:
 - [Traffic Loading](#)
 - [Climate](#)
 - [Material Properties](#)
 - [Design and Construction](#)
 - [Geometric Features](#) ←


Select each factor to learn more.

Geometric Features

X CLOSE

- Other factors that affect the predicted distresses are geometric features, such as the lane width; the width controls the closeness of the edge of the tires traversing the JPCP and CRCP
- The farther away wheel is from the pavement's edge, the lower the fatigue damage, which affects the amount of transverse cracking




U.S. Department of Transportation
Federal Highway Administration

MODULE E
LESSON 1

Other factors that affect the predicted distresses are geometric features, such as the lane width. The width controls the closeness of the edge of the tires traversing the jointed plain concrete pavement (JPCP) and continually reinforced concrete pavement (CRCP).


The further a wheel is from the edge of the pavement the lower the fatigue damage, which affects the amount of transverse cracking. Moving the wheel away from the edge of the pavement will result in reduced fatigue damage.


Image description: Photo of four-lane road with a widened slab width (shown as 2 ft. wider than the 12-ft. lane, so a 14-ft. slab width) indicated.




True or false? Load frequency and temperature affect material properties.

a) True

b) False



 **Knowledge Check** Correct - Click anywhere to continue **Submit** **Clear**

 **MODULE E**
LESSON 1 **INTRODUCTION** Resources
Glossary
Help  

Now let's take a moment to check your knowledge.

True or false? Load frequency and temperature affect material properties.

- a) True; or
- b) False.

True or false? Load frequency and temperature affect material properties.



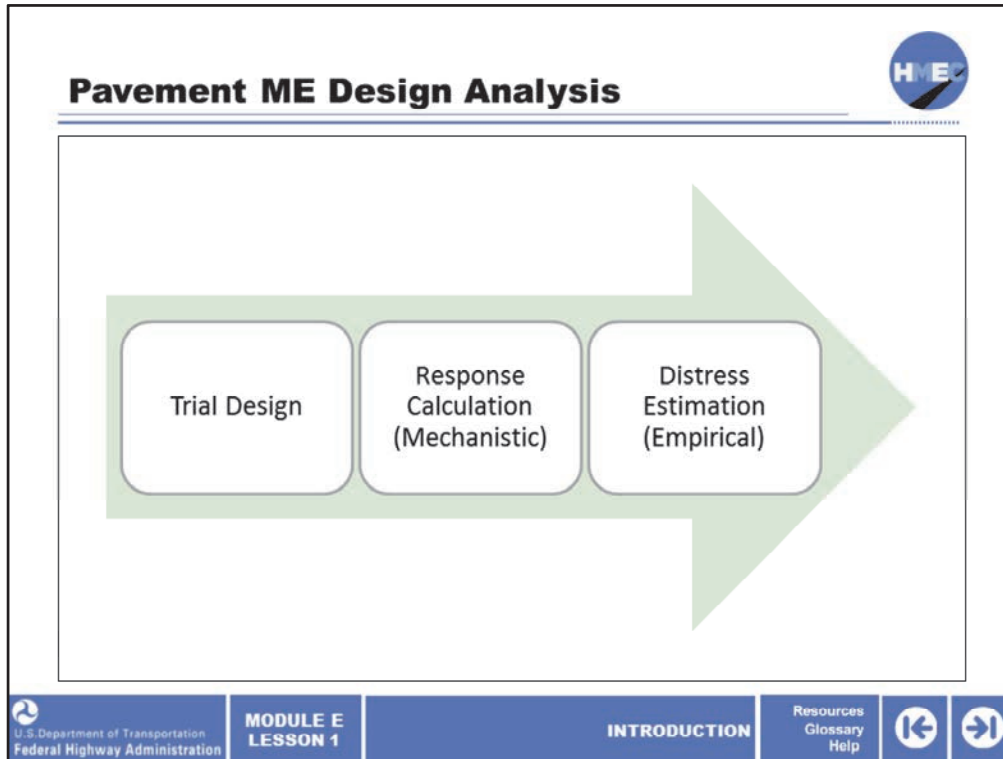
- a) True
- b) False



Knowledge Check Debrief



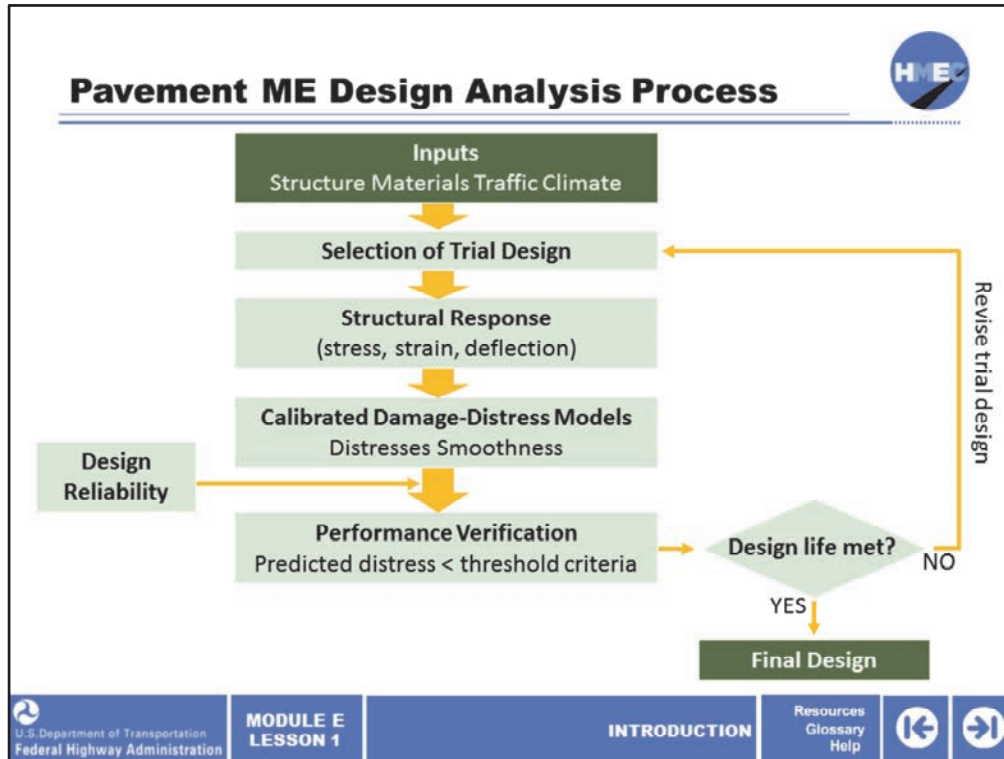
The correct answer is a) True.



The Pavement ME Design analysis consists of three main elements: the selection of a trial design, the mechanistic calculation of structural responses to traffic and climatic loads, and the empirical estimation of resulting pavement distress amounts over the target design life of the pavement.

Once the distress amounts are obtained, the user can compare the trial pavement's predicted distresses to the damage threshold set at a defined reliability level and can decide the best course of action for altering the trial pavement structure for better performance.

Image description: Arrow moving from left to right on screen.



This flowchart illustrates in details the Pavement ME Design analysis process.

The process begins with gathering of user-defined inputs including structure, materials, traffic, and climate.

The user will then select a trial design.

Based on this trial pavement design, the Pavement ME Design software will calculate the structural responses in terms of stress, strain, and deflection.

The calculated mechanical responses will then be incorporated into the calibrated damage-distress models to predict pavement distresses and smoothness at a certain reliability level over the design life.

At this point, the predicted pavement performance will be verified by comparing the predicted distresses to the threshold criteria.


If the predicted distresses are less than the threshold criteria and the design life is met, then the trial design might be considered final.

Otherwise, the trial design will need to be revised and the process will start again.


Image description: Flowchart illustrates in details the Pavement ME Design analysis



process.

Select all that apply. What best describes the MEPDG analysis process?



- a) It calculates pavement responses of trial design to compute incremental damage over time
- b) It addresses mixture durability issues
- c) It is a trial-and-error process

 **Knowledge Check** Try again Submit Clear

 **MODULE E
LESSON 1** **INTRODUCTION** Resources
Glossary
Help 

Let's pause for a knowledge check.

Select all that apply. What best describes the MEPDG analysis process?

- a) It calculates pavement responses of trial design to compute incremental damage over time;
- b) It addresses mixture durability issues; and/or
- c) It is a trial-and-error process.

Select all that apply. What best describes the MEPDG analysis process?




- a) It calculates pavement responses of trial design to compute incremental damage over time
- b) It addresses mixture durability issues
- c) It is a trial-and-error process

 Knowledge Check Debrief

 **MODULE E**
LESSON 1 **INTRODUCTION** Resources
Glossary
Help  

The correct answers are a) It calculates pavement responses of trial design to compute incremental damage over time, and c) It is a trial-and-error process.

Iterative Design Process with Pavement ME Design



Tools to Allow Easy Comparison between Pavement Designs

Step 1: Create a trial design for the project

Step 2: Run the Pavement ME Design

Step 3: Compare the predicted performance of the trial design against performance criteria


If necessary, the user might need to modify the trial design as needed in order to produce a feasible design that satisfies the performance criteria.

U.S. Department of Transportation
Federal Highway Administration

MODULE E
LESSON 1

INTRODUCTION

Resources
Glossary
Help



As mentioned previously, the Pavement ME Design process is iterative and consists of three steps:

1. Create a trial design for the project;
2. Run the Pavement ME Design to predict the key distresses and smoothness for the trial design; and
3. Compare the predicted performance of the trial design against performance criteria. The user must note whether the predicted performance exceeds or is less than the performance life set by the user.

If necessary, the user might need to modify the trial design as needed in order to produce a feasible design that satisfies the performance criteria.

Image description: Interchange on the interstate with the words, “Tools to allow easy comparison between pavement designs.”

Example Scenario: Ohio Pavement Design

Input 1: General Information




Input 2: Traffic Data

Input 3: Climate Station and Climate

Input 4: JPCP Design Properties

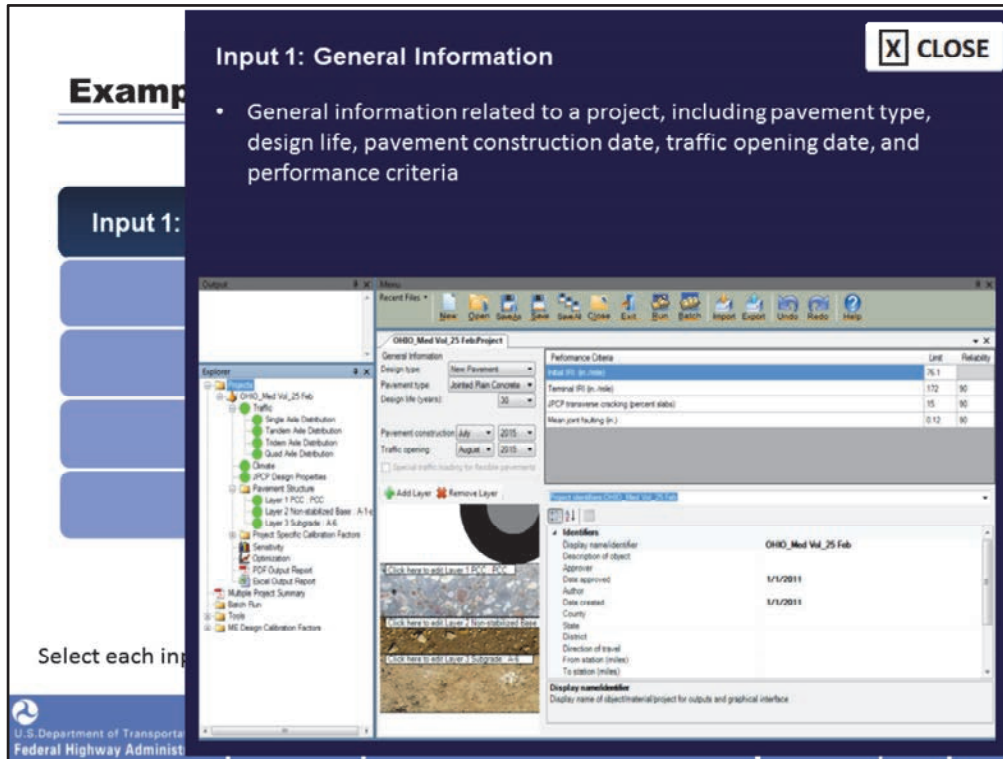
Input 5: Material Properties for Each Pavement Layer

Select each input to learn more.

 **MODULE E**
LESSON 1 **INTRODUCTION** **Resources**
Glossary
Help  

Let's review an example using the Pavement ME Design software. We'll explore the Pavement ME Design analysis process using a JPCP located in Ohio. First, we'll review the information that a user inputs into the software.

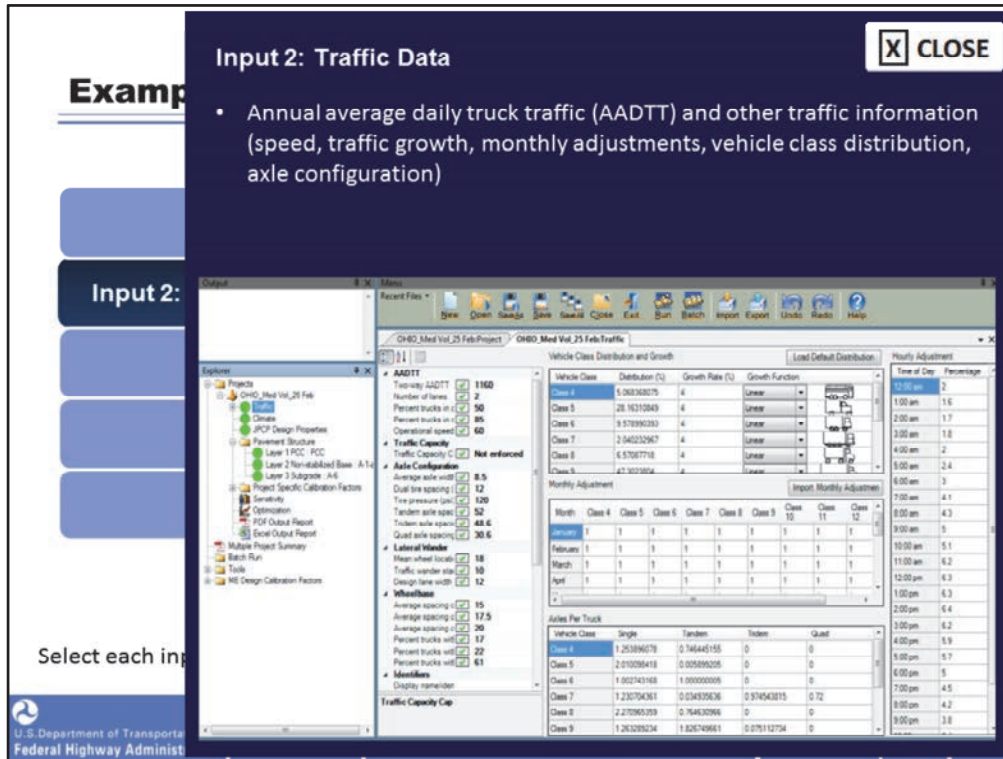
Select each input to learn more.



The user will input the general information related to a project in the first window that appears when the software is launched and a new project is selected. The user will start by selecting the pavement type as well as the design life, pavement construction date, and traffic opening date. The performance criteria and related reliability are also defined in this screen.

Recall that this project consists of a JPCP located in Ohio. After selecting a trial design consisting of 9-in. PCC surface over a 6-in. AASHTO classified A-1-a base on top of an AASHTO classified A-6 subgrade soil, we want to determine if this trial structure performs within the set threshold criteria over a 30-year design life.

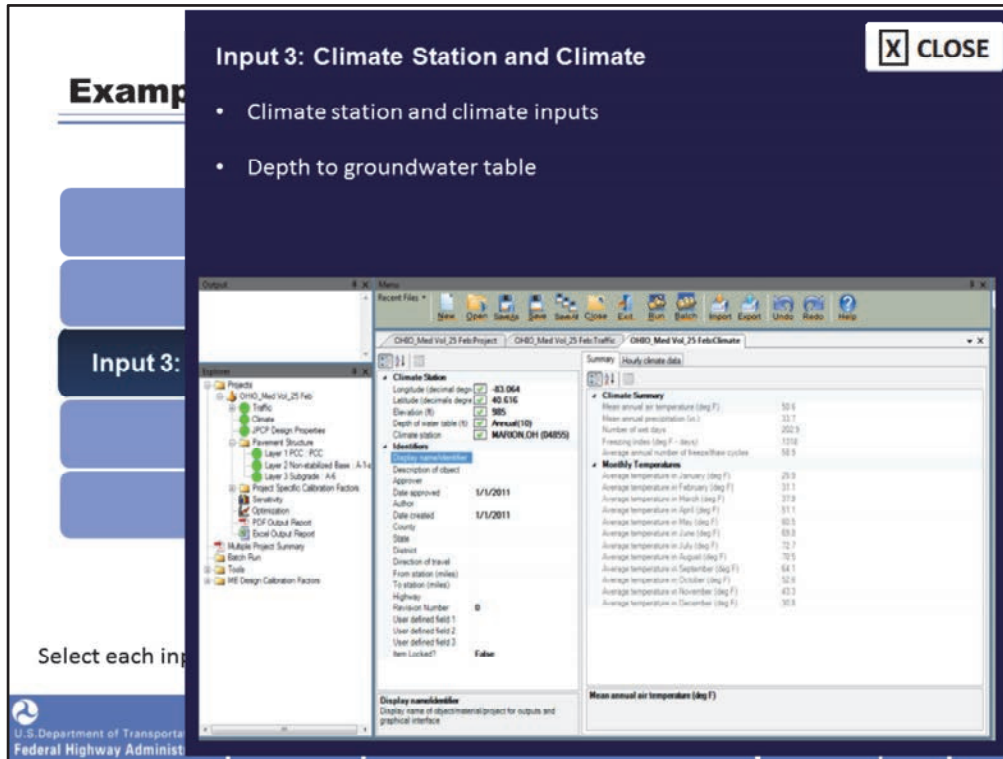
Image description: Screenshot of the general information screen of the Pavement ME Design software.



The next step is to input the traffic data. The software requires the annual average daily truck traffic (AADTT) as an input. The AADTT has a significant effect on the predicted pavement performance indicators and represents a weighted average between weekday and weekend truck traffic. AADTT are obtained from weigh-in-motion (WIM) data, automated vehicle counters, or manual traffic counts.

This window is also where other traffic information such as speed, traffic growth, monthly adjustments, vehicle class distribution, and axle configuration are defined.

Image description: Screenshot of the traffic data screen of the Pavement ME Design software.



From the traffic input screens a user then proceeds to select the climate station and climate inputs. This example project is located in Marion, Ohio. In this window is where the depth to the groundwater table is also defined.

Image description: Screenshot of the climate station and climate screen of the Pavement ME Design software.

Example

Input 4:

Input 4: JPCP Design Properties X CLOSE

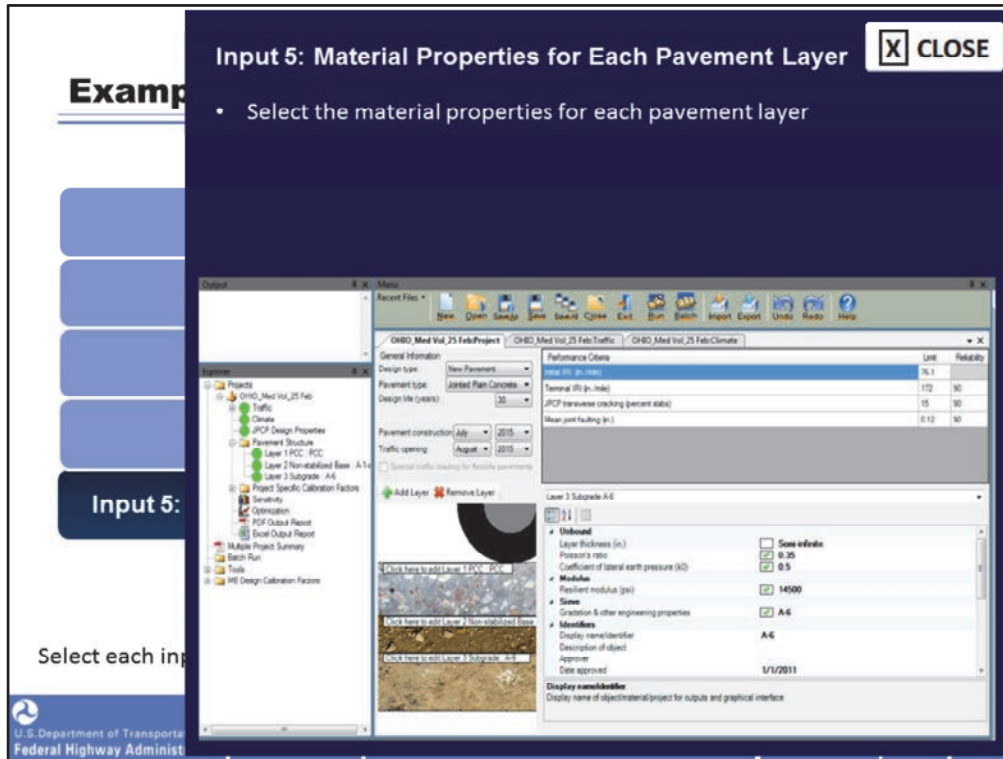
- PCC joint spacing, sealant type, dowel spacing and diameter, and erodibility index

Select each input

U.S. Department of Transportation
Federal Highway Administration

The next step is to input the JPCP design properties, such as the PCC joint spacing, sealant type, dowel spacing and diameter, and erodibility index.

Image description: Screenshot of the JPCP design properties screen of the Pavement ME Design software.



Once the JPCP design properties are defined, the next step consists of selecting the material properties for each pavement layer.

For the surface layer or PCC, the main inputs are layer thickness, unit weight, Poisson's ratio, thermal, and mix properties.


For the unbound A-1-a base layer the main inputs are layer thickness, Poisson's ratio, coefficient of lateral earth pressure, and resilient modulus.

Finally, for the A-6 subgrade layer the main inputs are Poisson's ratio, coefficient of lateral earth pressure, and resilient modulus.

Image 1 description: Screenshot of the PCC inputs screen of the Pavement ME Design software.

Image 2 description: Screenshot of the unbound A-1-a base layer screen of the Pavement ME Design software and screenshot of the A-6 subgrade layer screen of the Pavement ME Design software.

Example Scenario: Ohio Pavement Design



Output 1: PDF Summary File

Output 2: Predicted Pavement Performance Over the Design Life



Select each output to learn more.

U.S. Department of Transportation
Federal Highway Administration

MODULE E
LESSON 1

INTRODUCTION

Resources
Glossary
Help



After the user runs the Pavement ME Design software, several outputs will be available for analysis. Let's review some of the outputs from the example Ohio pavement scenario.

Select each output to learn more.

Image description: Photo of a local street.

Output 1: PDF Summary File X CLOSE

- Software will determine if each criterion was satisfied

Design Inputs

Design Life: 30 years Existing construction: - Climate Data: 40.023, -82.463
Design Type: Jointed Plain Concrete Pavement (JPCP) Pavement construction: July, 2015 Sources (Lat/Lon)
Traffic opening: August, 2015

Design Structure

Layer type	Material Type	Thickness (in.)	Joint Design:	
PCC	PCC	9.0	Joint spacing (ft)	15.0
NonStabilized	A-1-a	6.0	Dowel diameter (in.)	1.50
Subgrade	A-6	Semi-infinite	Slab width (ft)	12.0

Traffic

Age (year)	Heavy Trucks (cumulative)
2015 (initial)	1,160
2030 (15 years)	3,253,940
2045 (30 years)	8,033,160

Design Outputs

Distress Prediction Summary

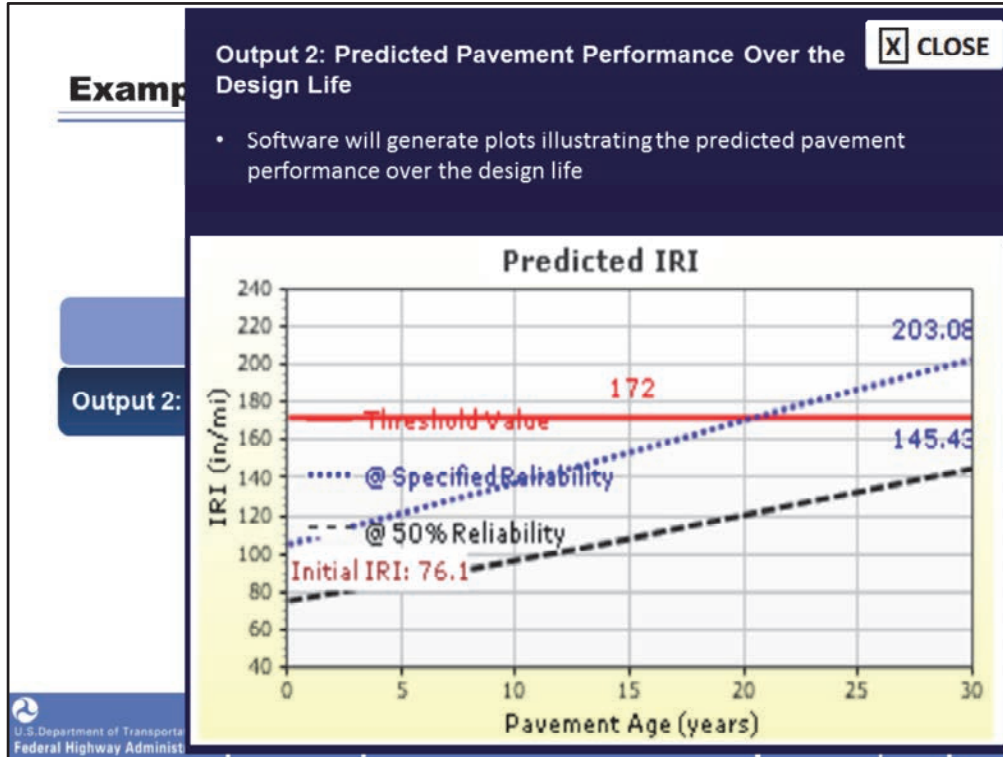
Distress Type	Distress @ Specified Reliability		Reliability (%)		Criterion Satisfied?
	Target	Predicted	Target	Achieved	
Terminal IRI (in./mile)	172.00	203.08	90.00	72.26	Fail
Mean joint faulting (in.)	0.12	0.10	90.00	97.55	Pass
JPCP transverse cracking (percent slabs)	15.00	4.12	90.00	100.00	Pass

U.S. Department of Transportation
Federal Highway Administration

A PDF file summarizing the user-defined inputs (including design structure and traffic) and the predicted distresses is automatically generated when the Pavement ME Design software is run.

Based on the set performance thresholds and reliability, the software will determine if each criterion was satisfied. As noted in the “Distress Prediction Summary”, the only criterion that failed in the terminal IRI. The predicted IRI was estimated to be higher than the target threshold.

Image description: Pavement ME Design PDF file summarizing the user-defined inputs and the predicted distresses.



The Pavement ME Design software will also generate plots illustrating the predicted pavement performance over the design life.

For all plots, the red line represents the performance criteria threshold, the blue dotted line represents the predicted distress at the specified reliability, and the black dashed line represents the predicted distress at 50% reliability.

In this case, in the “predicted IRI” plot you can see that the predicted IRI surpassed the threshold value at approximately 20 years out of the intended 30-year design life.

Image description: Pavement ME Design PDF screenshot of Predicted IRI graph.

Research on Pavement ME Design Models



- NCHRP Project 1-47: Sensitivity Evaluation of MEPDG Performance Prediction
- Sensitivity study conducted on MEPDG software version 1.0
- Design inputs evaluated included:
 - Traffic volume
 - Layer thicknesses
 - Material properties
 - Groundwater depth
 - Geometric parameters



The NCHRP Project 1-47 sensitivity study is available at:
http://onlinepubs.trb.org/onlinepubs/nchrp/docs/NCHRP01-47_FR.pdf


Recently the NCHRP has published the NCHRP Project 1-47: Sensitivity Evaluation of MEPDG Performance Prediction. The sensitivity study was conducted on MEPDG software version 1.0 for flexible pavements, JPCP, and CRCP.

This report documents and presents the results of a study to evaluate the sensitivity of pavement performance predicted by the Mechanistic Empirical Pavement Design Guide to the values of the design inputs. Global sensitivity analyses were performed for five pavement types under five climate conditions and three traffic levels. Design inputs evaluated in the analyses included traffic volume, layer thicknesses, material properties (e.g., stiffness, strength, HMA and PCC mixture characteristics, subgrade type), groundwater depth, geometric parameters (e.g., lane width), and others.

The NCHRP Project 1-47 sensitivity study is available at:
http://onlinepubs.trb.org/onlinepubs/nchrp/docs/NCHRP01-47_FR.pdf.

Image description: Screenshot of Research Results Digest 372.

NCHRP Project 1-47 Ranking System



- Sensitivity categories include:

Very Sensitive (VS)

Sensitive (S)

Not Sensitive (NS)


Select each sensitivity category to learn more.

U.S. Department of Transportation
Federal Highway Administration

MODULE E
LESSON 1

INTRODUCTION

Resources
Glossary
Help



A normalized sensitivity index (NSI) was adopted as the quantitative metric. The NSI is defined as the percentage change of predicted distress relative to its design limit caused by a given percentage change in the design input.

The “mean plus/minus two standard deviations” value of NSI was adopted as the best and most robust ranking measure because it incorporates both the mean sensitivity and the variability of sensitivity across the problem domain. Based on this, design input sensitivity categories were defined.

Select each sensitivity category to learn more.

NCHRP Project 1-47 Ranking System



- Sensitivity categories include

Very Sensitive (VS)

Sensitive (S)

Not Sensitive (NS)

Very Sensitive (VS)

CLOSE

- Those that have very significant effect on one or more outputs
- It roughly corresponds to a mean-normalized sensitivity index greater than 0.5

Very sensitive (VS): those that have very significant effect on one or more outputs; it roughly corresponds to a mean-normalized sensitivity index > 0.5 .

NCHRP Project 1-47 Ranking System



- Sensitivity categories include:

Very Sensitive (VS)

Sensitive (S)

Not Sensitive (NS)

Sensitive (S)

CLOSE

- Those that have a moderate effect on one or more outputs
- It roughly corresponds to a mean-normalized sensitivity index in the range of 0.1–0.5

Sensitive (S): those that have a moderate effect on one or more outputs; it roughly corresponds to a mean-normalized sensitivity index in the range of 0.1–0.5.

NCHRP Project 1-47 Ranking System



- Sensitivity categories include:

Very Sensitive (VS)

Sensitive (S)

Not Sensitive (NS)

Not Sensitive (NS)

CLOSE

- Those that have only minor effect on one or more outputs
- It roughly corresponds to a mean-normalized sensitivity index of less than 0.1

Not sensitive (NS): those that have only minor effect on one or more outputs; it roughly corresponds to a mean-normalized sensitivity index < 0.1 .

Exercise 3: Critical Thinking Questions



- What are some of the factors that you would expect to affect JPCP performance?
- What are some of the factors that you think would most affect flexible pavement performance?
- What are some of the factors that you think would most affect CRCP performance?



To open the exercises, select the paperclip icon.



Let's take a few moments for you to consider some critical thinking questions related to pavement performance. In the Module E, Lesson 1 Exercises PDF, complete Exercise 3. When you have finished, return to the training to advance to the next screen and review the questions you have answered.

Input Affecting JPCP Performance



- What are some of the factors that you would expect to affect JPCP performance?

JPCP Inputs		Sensitivity Rating for JPCP Distresses	
Groups	Parameters	Faulting	Cracking
Traffic	Initial top layer AADTT	VS	VS
	Design lane width	NS	S
Climate	Climate	VS	S
	Permanent cur/warp effective temp difference	VS	VS
Design Feature	Joint spacing	NS	NS
	Sealant type	S	NS
	Dowel diameter	NS	NS
	Dowel spacing	VS	S
	Edge Support	S	NS
	Erodibility Index	NS	NS
	PCC Base Interlock	VS	VS
Layer/General	Surface shrinkive absorptivity	VS	VS
	PCC layer thickness	VS	VS
	Unit weight	S	S
	Poisson's ratio	S	S
	Coefficient of thermal expansion	VS	VS
	Thermal conductivity	S	VS
	Heat opacity	NS	NS
	Cement type	NS	NS
	Cementitious material content	S	NS
	Water/cement ratio	S	NS
	Aggregate type	NS	NS
	PCC set/cure/finish temperature	S	NS
	Reversible shrinkage	NS	NS
	Time to develop 50% of ultimate shrinkage	NS	NS
	Curing method	NS	NS
28-day PCC modulus of rupture	S	VS	
28-day PCC compressive strength	NS	VS	
Layer/Subbase (base)	Granular base material/stiffness	VS	S
	Granular base thickness	S	S
	Poisson's ratio	NS	NS
Layer/Subgrade	Subgrade material/stiffness	S	S
	Poisson's ratio	NS	NS
	Compacted or uncompacted	NS	NS
JPCP/HMA (rehab)	HMA milled thickness	NS	NS
	Pavement rating	S	S
	Monthly modulus of subgrade reaction measured	S	S
	Month for measuring modulus	S	S

Select the graph to view its sensitivity rating.

Table 2.2



The factors affecting JPCP performance include traffic, climate, design feature, layer/general, layer/PCC, layer/subbase (base), layer/subgrade, and JPCP/HMA (rehab).

Select each factor to view its sensitivity rating from the triage summary for JPCP pavements resulting from the NCHRP 1-47 research project.

Image description: JPCP inputs graph.

Table 2.2 Part 1

JPCP Inputs		Level of Sensitivity for JPCP Distresses	
Groups	Parameters	Faulting	Cracking
Traffic	Initial two-way AADITT	VS	VS
	Design lane width	NS	S
Climate	Climate	VS	S
Design Feature	Permanent curl/warp effective temp difference	VS	VS
	Joint spacing	VS	VS
	Sealant type	NS	NS
	Dowel diameter	S	NS
	Dowel spacing	NS	NS
	Edge Support	VS	S
	Erodibility index	S	NS
	PCC Base Interface	NS	NS
Layer/General	Surface shortwave absorptivity	VS	VS



Image description: JPCP inputs graph.

Table 2.2 Part 2

JPCP Inputs		Level of Sensitivity for JPCP Distresses	
Groups	Parameters	Faulting	Cracking
Layer/PCC	PCC layer thickness	VS	VS
	Unit weight	S	S
	Poisson's ratio	S	S
	Coefficient of thermal expansion	VS	VS
	Thermal conductivity	S	VS
	Heat capacity	NS	NS
	Cement type	NS	NS
	Cementitious material content	S	NS
	Water/cement ratio	S	NS
	Aggregate type	NS	NS
	PCC zero-stress temperature	S	NS
	Reversible shrinkage	NS	NS
	Time to develop 50% of ultimate shrinkage	NS	NS
	Curing method	NS	NS
	28-day PCC modulus of rupture	S	VS
28-day PCC compressive strength	NS	VS	



Image description: JPCP inputs graph.

Table 2.2 Part 3

X CLOSE

JPCP Inputs		Level of Sensitivity for JPCP Distresses	
Groups	Parameters	Faulting	Cracking
Layer/Subbase (Base)	Granular base material/stiffness	VS	S
	Granular base thickness	S	S
	Poisson's ratio	NS	NS
Layer/Subgrade	Subgrade material/stiffness	S	S
	Poisson's ratio	NS	NS
	Compacted or uncompacted	NS	NS
JPCP/HMA (Rehab)	HMA milled thickness	NS	NS
	Pavement rating	S	S
	Monthly modulus of subgrade reaction measured	S	S
	Month for measuring modulus	S	S



Image description: JPCP inputs graph.

Inputs Affecting HMA Pavements



- What are some of the factors that you think would most affect flexible pavement performance?

HMA Pavement Inputs		Level of Sensitivity for Flexible Pavement Outputs				
Group	Parameter	HMA Ruting	Total Ruting	Alligator Cracking	Long Cracking	Thermal Cracking
General	Traffic open month	N5	N5	N5	N5	N5
	Traffic					
Traffic	Volume	V5	V5	V5	V5	N5
	Speed	V5	V5	5	5	N5
Climate	Location	N5	N5	N5	N5	N5
	Depth to groundwater table	N5	5	N5	N5	N5
Layer/General	Surface drainage absorbivity	V5	V5	5	V5	N5
Layer/HMA	Thickness	V5	V5	V5	5	N5
	Dynamic modulus	5	5	5	5	N5
	Stiffness coefficient	V5	5	5	5	5
	Poisson's ratio	N5	N5	N5	N5	N5
	Thermal conductivity	N5	N5	N5	N5	5
	Moisture	N5	N5	N5	N5	5
	Creep compliance	N5	N5	N5	N5	V5
	Tensile strength at LUTC	N5	N5	N5	N5	V5
Aggregate coefficient of thermal contraction	N5	N5	N5	N5	V5	
Layer/Base (Subbase)	Thickness	5	5	5	5	N5
	Resilient modulus	5	5	5	V5	N5
	Poisson's ratio	N5	N5	N5	N5	N5
	Soil-water characteristic curve	N5	N5	N5	N5	N5
Layer/Subgrade	Permeability	N5	N5	N5	N5	N5
	Compaction (vibroimpact)	N5	N5	N5	N5	N5
	Resilient modulus	N5	V5	5	5	N5
HMA/HMA (Rehab)	Poisson's ratio	N5	N5	N5	N5	N5
	Soil-water characteristic curve	5	5	5	5	N5
	Permeability	N5	N5	N5	N5	N5
	Compaction (vibroimpact)	N5	N5	N5	N5	N5
HMA/JCPC (Rehab)	Initial AC thickness	N5	N5	N5	N5	N5
	Binding AC thickness (after milling)	5	5	5	5	N5
	Binding AC binder grade	5	5	5	5	N5
	Pavement depth	V5	5	V5	V5	N5
HMA/JCPC (Rehab)	Total ruting	V5	V5	N5	N5	N5
	Binding PCC modulus of rupture	N5	N5	N5	N5	N5
	Pavement max (initial) moisture	N5	N5	N5	N5	N5
	Stiffness modulus of subgrade reaction	N5	N5	N5	N5	N5
HMA/JCPC (Rehab)	Moisture for measuring modulus	N5	N5	N5	N5	N5

Select the graph to view its sensitivity rating.

Table 2.1



The factors affecting HMA, or flexible, pavement performance include general, traffic, climate, layer/general, layer/HMA, layer/subbase (base), layer/subgrade, HMA/HMA (rehab), and HMA/JCPC (rehab).

Select each factor to view its sensitivity rating from the triage summary for flexible pavements resulting from the NCHRP 1-47 research project.

Image description: HMA pavement Inputs graph.

Table 2.1 Part 1

HMA Pavement Inputs		Level of Sensitivity for Flexible Pavement Outputs				
Group	Parameters	HMA Rutting	Total Rutting	Alligator Cracking	Long Cracking	Thermal Cracking
General	Traffic open mouth	NS	NS	NS	NS	NS
Traffic	Volume Speed	VS	VS	VS	VS	NS
		VS	VS	S	S	NS
Climate	Location Depth to groundwater table	VS	S	S	S	S
		NS	S	NS	NS	NS
Layer/General	Surface shortwave absorptivity	VS	VS	S	VS	NS



Image description: HMA pavement Inputs graph.

Table 2.1 Part 2

HMA Pavement Inputs		Level of Sensitivity for Flexible Pavement Outputs				
Group	Parameters	HMA Rutting	Total Rutting	Alligator Cracking	Long Cracking	Thermal Cracking
Layer/HMA	Thickness	VS	VS	VS	S	NS
	Dynamic modulus	S	S	S	S	NS
	Binder grade/stiffness	VS	S	S	S	S
	Poisson's ratio	NS	NS	NS	NS	NS
	Thermal conductivity	NS	NS	NS	NS	S
	Heat capacity	NS	NS	NS	NS	S
	Creep compliance	NS	NS	NS	NS	VS
	Tensile strength at 14°C	NS	NS	NS	NS	VS
	Aggregate coefficient of thermal contraction	NS	NS	NS	NS	VS



Image description: HMA pavement Inputs graph.

Table 2.1 Part 3

HMA Pavement Inputs		Level of Sensitivity for Flexible Pavement Outputs				
Group	Parameters	HMA Rutting	Total Rutting	Alligator Cracking	Long Cracking	Thermal Cracking
Layer/Base (Subbase)	Thickness	S	S	S	S	NS
	Resilient modulus	S	S	S	VS	NS
	Poisson's ratio	NS	NS	NS	NS	NS
	Soil-water characteristic curve	NS	NS	NS	NS	NS
	Permeability	NS	NS	NS	NS	NS
	Compacted / uncompactd	NS	NS	NS	NS	NS
Layer/Subgrade	Resilient modulus	NS	VS	S	S	NS
	Poisson's ratio	NS	NS	NS	NS	NS
	Soil-water characteristic curve	S	S	S	S	NS
	Permeability	NS	NS	NS	NS	NS
	Compacted / uncompactd	NS	NS	NS	NS	NS



Image description: HMA pavement Inputs graph.

Table 2.1 Part 4

X CLOSE

HMA Pavement Inputs		Level of Sensitivity for Flexible Pavement Outputs				
Group	Parameters	HMA Rutting	Total Rutting	Alligator Cracking	Long Cracking	Thermal Cracking
HMA/HMA (Rehab)	Milled AC thickness	NS	NS	NS	NS	NS
	Existing AC thickness (after milling)	S	S	S	S	NS
	Existing AC binder grade	S	S	S	S	NS
	Pavement rating	VS	S	VS	VS	NS
	Total rutting	VS	VS	NS	NS	NS
HMA/JPCP (Rehab)	Existing PCC modulus of rupture	NS	NS	NS	NS	NS
	Percent slabs cracked/repared	NS	NS	NS	NS	NS
	Monthly modulus of subgrade reaction	NS	NS	NS	NS	NS
	Month for measuring modulus	NS	NS	NS	NS	NS



Image description: HMA pavement Inputs graph.

Inputs Affecting CRCP Performance



- What are some of the factors that you think would most affect CRCP performance?

Groups	CRCP Inputs Parameters	Level of Sensitivity for CRCP Distresses		
		Punch-out	Maximum Crack Width	Minimum LTE
Traffic	Initial two-way AADTT	VS	S	S
Climate	Climate	S	S	S
Design Feature	Permanent curl/warp effective temperature difference	VS	NS	NS
	Shoulder type	S	NS	S
	Percent steel	VS	VS	VS
	Bar diameter	NS	S	S
	Steel depth	NS	S	NS
	Base/lab friction coefficient			
Layer/General	Surface shortwave absorptivity	NS	NS	NS
Layer/PCC	PCC layer thickness	VS	S	VS
	Unit weight	S	NS	NS
	Poisson's ratio	S	NS	NS
	Coefficient of thermal expansion	VS	S	S
	Thermal conductivity	NS	NS	NS
	Heat capacity	NS	NS	NS
	Cement type	NS	NS	NS
	Cementitious material content	S	S	S
	Water/cement ratio	NS	S	S
	Aggregate type	NS	NS	NS
	Reversible shrinkage	NS	NS	NS
Curing method	NS	NS	NS	
Layer/Subbase (base)	Granular base material/stiffness	S	NS	NS
	Granular base thickness	S	NS	NS
	Poisson's ratio	NS	NS	NS
	Compacted or uncompacted	NS	NS	NS
Layer/Subgrade	Subgrade material/stiffness	S	NS	NS
	Poisson's ratio	NS	NS	NS
	Compacted or uncompacted	NS	NS	NS

Select the graph to view its sensitivity rating.

Table 2.3



The factors affecting CRCP performance include traffic, climate, design feature, layer/general, layer/PCC, layer/subbase (base), and layer/subgrade.

Select each factor to view its sensitivity rating from the triage summary for flexible pavements resulting from the NCHRP 1-47 research project.

Image description: CRCP inputs graph.

Table 2.3 Part 1

CRCP Inputs		Level of Sensitivity for CRCP Distresses		
Groups	Parameters	Punch-out	Maximum Crack Width	Minimum LTE
Traffic	Initial two-way AADTT	VS	S	S
Climate	Climate	S	S	S
Design Feature	Permanent curl/warp effective temperature difference	VS	NS	NS
	Shoulder type	S	NS	S
	Percent steel	VS	VS	VS
	Bar diameter	VS	VS	VS
	Steel depth	NS	S	S
	Base/slab friction coefficient	NS	S	NS
Layer / General	Surface shortwave absorptivity	NS	NS	NS



Image description: CRCP inputs graph.

Table 2.3 Part 2

CRCP Inputs		Level of Sensitivity for CRCP Distresses		
Groups	Parameters	Punch-out	Maximum Crack Width	Minimum LTE
Layer / PCC	PCC layer thickness	VS	S	VS
	Unit weight	S	NS	NS
	Poisson's ratio	S	NS	NS
	Coefficient of thermal expansion	VS	S	S
	Thermal conductivity	NS	NS	NS
	Heat capacity	NS	NS	NS
	Cement type	NS	NS	NS
	Cementitious material content	S	S	S
	Water/cement ratio	NS	S	S
	Aggregate type	NS	NS	NS
	Reversible shrinkage	NS	NS	NS
	Curing method	NS	NS	NS
	28-day PCC modulus of rupture	VS	VS	VS



Image description: CRCP inputs graph.

Table 2.3 Part 3 X CLOSE

CRCP Inputs		Level of Sensitivity for CRCP Distresses		
Groups	Parameters	Punch-out	Maximum Crack Width	Minimum LTE
Layer / Subbase (Base)	Granular base material/stiffness	S	NS	NS
	Granular base thickness	S	NS	NS
	Poisson's ratio	NS	NS	NS
	Compacted or uncompacted	NS	NS	NS
Layer / Subgrade	Subgrade material/stiffness	S	NS	NS
	Poisson's ratio	NS	NS	NS
	Compacted or uncompacted	NS	NS	NS

←

Image description: CRCP inputs graph.

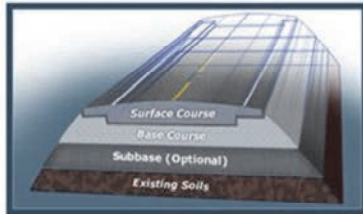
Sensitivity of the Input Parameters



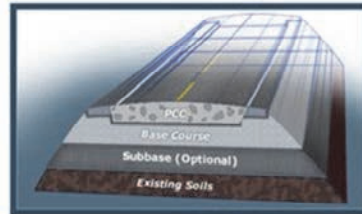
Flexible Pavement

Rigid Pavement
(JPCP)

Rigid Pavement
(CRCP)



Typical Flexible Pavement



Typical Rigid Pavement

Select each type of pavement to learn more.




Let's review the most sensitive parameters for each pavement type.

Select each type of pavement to learn more.

Image description: Diagrams of typical flexible and rigid pavements.

Sensitivity of the Input Parameters



Flexible Pavement

Rigid Pavement (JPCP)

Rigid Pavement (CRCP)

Flexible Pavements

CLOSE


- Traffic volume
- HMA thickness
- Surface shortwave absorptivity

U.S. Department of Transportation
Federal Highway Administration

MODULE E
LESSON 1

INTRODUCTION


Resources
Glossary
Help



According to the findings from the NCHRP 1-47 project, the most sensitive parameters for flexible pavements are:

- Traffic volume;
- HMA thickness; and
- Surface shortwave absorptivity.


Sensitivity of the Input Parameters



Flexible Pavement
Rigid Pavement
(JPCP)
Rigid Pavement
(CRCP)

Rigid Pavements (JPCP) X CLOSE



- Initial two-way AADTT
- Climate
- Permanent curl/warp effective temp difference
- Joint spacing
- Edge support
- Surface shortwave absorptivity
- PCC layer thickness
- Coefficient of thermal expansion
- Granular base material/stiffness


 U.S. Department of Transportation
Federal Highway Administration

MODULE E
LESSON 1

INTRODUCTION


Resources
Glossary
Help

The most sensitive parameters for JPCP are:

- Initial two-way AADTT;
- Climate;
- Permanent curl/warp effective temperature difference;
- Joint spacing;
- Edge support;
- Surface shortwave absorptivity;
- PCC layer thickness;
- Coefficient of thermal expansion; and
- Granular base material/stiffness.

Sensitivity of the Input Parameters



Flexible Pavement Rigid Pavement (JPCP) **Rigid Pavement (CRCP)**

Rigid Pavements (CRCP) X CLOSE


- Initial two-way AADTT
- Coefficient of thermal expansion
- PCC layer thickness
- 28-day PCC modulus of rupture
- Percent steel
- Bar diameter

U.S. Department of Transportation
Federal Highway Administration

MODULE E
LESSON 1


INTRODUCTION

Resources
Glossary
Help



The most sensitive parameters for CRCP are:


- Initial two-way AADTT;
- Coefficient of thermal expansion;
- PCC layer thickness;
- 28-day PCC modulus of rupture;
- Percent steel; and
- Bar diameter.


Select the best answer. What do engineers need to adjust if the predicted distress is significantly less than the threshold criteria? 

a) Reliability level

b) Trial design

c) Distress criteria thresholds



 Knowledge Check Try again Submit Clear

 U.S. Department of Transportation
Federal Highway Administration

MODULE E
LESSON 1

INTRODUCTION

Resources
Glossary
Help

Select the best answer. What do engineers need to adjust if the predicted distress is significantly less than the threshold criteria?

- a) Reliability level;
- b) Trial design; or
- c) Distress criteria thresholds.

Select the best answer. What do engineers need to adjust if the predicted distress is significantly less than the threshold criteria?



- a) Reliability level
- b) Trial design
- c) Distress criteria thresholds




Knowledge Check Debrief




The correct answer is b) Trial design.




True or false? The final step in the iterative design process with Pavement ME Design is comparing the predicted performance of the trial design against the performance criteria.



a) True

b) False

 **Knowledge Check** Correct - Click anywhere to continue **Submit** **Clear**

 **MODULE E**
LESSON 1 **INTRODUCTION** Resources
Glossary
Help  

True or false? The final step in the iterative design process with Pavement ME Design is comparing the predicted performance of the trial design against the performance criteria.

- a) True; or
b) False.

True or false? The final step in the iterative design process with Pavement ME Design is comparing the predicted performance of the trial design against the performance criteria.



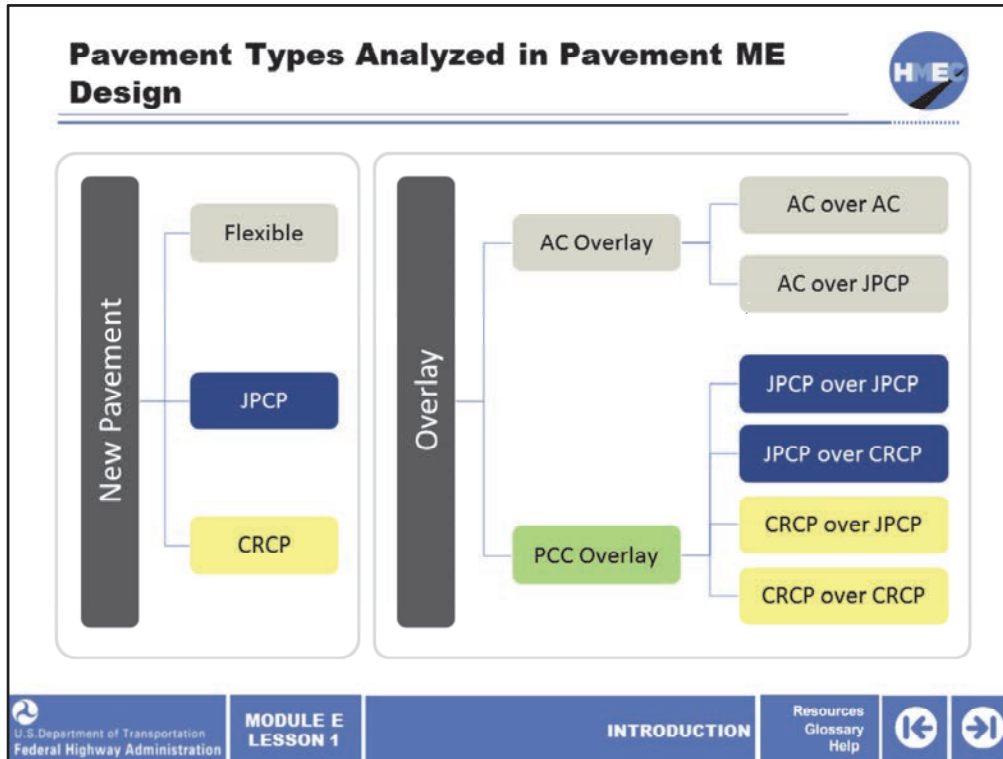
- a) True
- b) False



Knowledge Check Debrief



The correct answer is a) True.



The Pavement ME Design software can be used to analyze the expected performance of new pavements or rehabilitated pavements. New pavements can be flexible pavements, jointed plain concrete pavements, or continuously reinforced concrete pavements.

Rehabilitated pavements can feature either asphalt concrete (AC) or Portland cement concrete (PCC) overlays.

AC overlays can be paved on existing AC or JPCP overlays.

PCC overlays can be constructed on top of JPCP or CRCP.

Image description: Diagram displaying pavement types analyzed in Pavement ME Design.

Pavement Distresses and Smoothness



- Flexible pavement distresses:

- [Rutting](#)
- [Transverse Cracking](#)
- [Alligator Cracking](#)
- [Longitudinal Cracking](#)
- [Smoothness \(IRI\)](#)



Select each of the distresses that flexible pavements may experience to learn more.



Flexible and rigid pavements are subjected to a number of distresses throughout their design life. The ability to predict key distresses makes it possible to control them to reasonable levels over the life of the pavement. This aspect makes the MEPDG extremely valuable.

Select each of the distresses that pavements may experience to learn more.

Image description: Photo of a crack running across a road.


Pavement Distresses

- Flexible pavement distresses:
 - Rutting** ←
 - Transverse Cracking
 - Alligator Cracking
 - Longitudinal Cracking
 - Smoothness (IRI)

Select each of the distresses that flexi

Rutting

- Surface depression in the wheel path resulting from plastic or permanent deformation in each pavement layer
- Could be a result of structural consolidation rutting or by result of instability rutting



U.S. Department of Transportation
Federal Highway Administration

MODULE E
LESSON 1

X CLOSE

Rutting is a surface depression in the wheel path resulting from plastic or permanent deformation in each pavement layer. It could be a result of structural consolidation rutting (which initiates at the surface of the subgrade layer or unbound base layer) or by result of instability rutting (which initiates at the surface of the asphalt mixture layer).

Image description: Photo of a stretch of road with rutting.

Pavement Distresses


- Flexible pavement distresses:
 - [Rutting](#)
 - [Transverse Cracking](#)
 - [Alligator Cracking](#)
 - [Longitudinal Cracking](#)
 - [Smoothness \(IRI\)](#)

Select each of the distresses that flexi

Transverse Cracking

CLOSE

- A non wheel load-related cracking that is predominately perpendicular to the pavement centerline
- Caused by low temperatures or thermal cycling



U.S. Department of Transportation
Federal Highway Administration

MODULE E
LESSON 1

Transverse cracking is a non-wheel load related cracking that is predominately perpendicular to the pavement centerline and caused by low temperatures or thermal cycling.

Image description: Photo of a stretch of road showing transverse cracking.



Pavement Distresses

- Flexible pavement distresses:
 - [Rutting](#)
 - [Transverse Cracking](#)
 - [Alligator Cracking](#) ←
 - [Longitudinal Cracking](#)
 - [Smoothness \(IRI\)](#)

Select each of the distresses that flexi

Alligator Cracking

- A form of fatigue or wheel load-related bottom-up cracking
- Defined as a series of interconnected cracks



U.S. Department of Transportation
Federal Highway Administration

MODULE E
LESSON 1

X CLOSE

Alligator cracking is a form of fatigue or wheel load-related bottom-up cracking and is defined as a series of interconnected cracks (characteristically with an “alligator” pattern) that initiate at the bottom of the HMA layers.

Image description: Close up photo of alligator cracking.

Image description: Photo of alligator cracking on the road.

Pavement Distresses


- Flexible pavement distresses:
 - [Rutting](#)
 - [Transverse Cracking](#)
 - [Alligator Cracking](#)
 - [Longitudinal Cracking](#)
 - [Smoothness \(IRI\)](#)

Select each of the distresses that flexi

Longitudinal Cracking

CLOSE

- A form of fatigue or wheel load-related top-down cracking that occurs within the wheel path
- Defined as cracks predominantly parallel to the pavement centerline



U.S. Department of Transportation
Federal Highway Administration

MODULE E
LESSON 1

Longitudinal cracking is a form of fatigue or wheel load-related top-down cracking that occurs within the wheel path and is defined as cracks predominantly parallel to the pavement centerline.

Image description: Collage of photos of longitudinal cracking.


Pavement Distresses

- Flexible pavement distresses:
 - [Rutting](#)
 - [Transverse Cracking](#)
 - [Alligator Cracking](#)
 - [Longitudinal Cracking](#)
 - [Smoothness \(IRI\)](#) ←

Select each of the distresses that flexi

Smoothness (IRI)

- A parameter used to define pavement smoothness and derived from the simulation of a “quarter-car” traveling along the longitudinal profile of the road
- Calculated from the mean of the longitudinal profiles in each wheel path



The image collage consists of two photographs of roadways. The top photograph shows a long, straight asphalt road with a white center line, stretching into the distance under a clear sky. The bottom photograph shows a similar road, but with a visible crack running across the width of the road in the foreground. The background of the slide is dark blue with white text.

U.S. Department of Transportation
Federal Highway Administration

MODULE E
LESSON 1

X CLOSE

IRI is a parameter used to define pavement smoothness and derived from the simulation of a “quarter-car” traveling along the longitudinal profile of the road. IRI is calculated from the mean of the longitudinal profiles in each wheel path.

Image description: Collage of photos of roadway smoothness.

Pavement Distresses and Smoothness



- Rigid pavement distresses
 - [Mean Transverse Joint Faulting \(JPCP\)](#)
 - [Bottom-up Transverse Cracking \(JPCP\)](#)
 - [Top-down Transverse Cracking \(JPCP\)](#)
 - [Load Transfer Efficiency \(LTE\)](#)
 - [CRCP Punchouts](#)
 - [Smoothness \(IRI\)](#)



Select each of the distresses that rigid pavements may experience to learn more.



Now let's review some of the distresses that rigid pavements are subjected to throughout their design life.

Select each of the distresses that rigid pavements may experience to learn more.

Image description: Photo of a stretch of road with pavement distresses.


Pavement Distresses

- Rigid pavement distresses:
 - [Mean Transverse Joint Faulting](#)
 - [Bottom-up Transverse Cracking](#)
 - [Top-down Transverse Cracking](#)
 - [Load Transfer Efficiency \(LTE\)](#)
 - [CRCP Punchouts](#)
 - [Smoothness \(IRI\)](#)

Select each of the distresses that rigid

Mean Transverse Joint Faulting
X CLOSE

- Differential elevation across joints or cracks
- Caused by loose material under trailing slab near the joint or crack plus the depression of the leading slab
- Loose material caused by pumping due to heavy loading



U.S. Department of Transportation
Federal Highway Administration

MODULE E
LESSON 1

Mean transverse joint faulting is the differential elevation across the joint measured approximately 1 ft. from the slab's edge (longitudinal joint for a conventional lane width), or from the right-most lane paint stripe for a widened slab.

Image description: Photo of mean transverse joint faulting.

Pavement Distresses

- Rigid pavement distresses:
 - [Mean Transverse Joint Faulting](#)
 - [Bottom-up Transverse Cracking](#)
 - [Top-down Transverse Cracking](#)
 - [Load Transfer Efficiency \(LTE\)](#)
 - [CRCP Punchouts](#)
 - [Smoothness \(IRI\)](#)

Select each of the distresses that rigid pavement experiences.


U.S. Department of Transportation
Federal Highway Administration

MODULE E
LESSON 1

Bottom-up Transverse Cracking (JPCP)

X CLOSE

- Occurs when a critical tensile bending stress occurs at the bottom of the slab under the wheel load



Bottom-up transverse cracking occurs when the truck axles are near the longitudinal edge of the slab, midway between the transverse joints, and a critical tensile bending stress occurs at the bottom of the slab under the wheel load.

Image description: Photo of bottom-up transverse cracking.

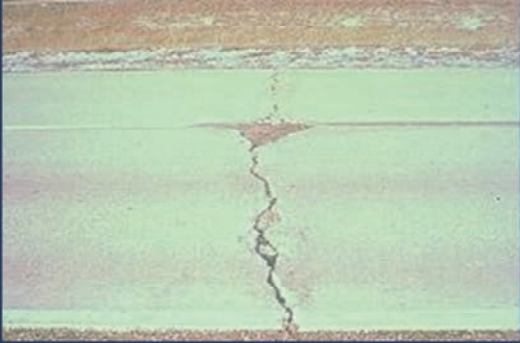
Pavement Distresses

- Rigid pavement distresses:
 - [Mean Transverse Joint Fault](#)
 - [Bottom-up Transverse Cracking](#)
 - [Top-down Transverse Cracking](#)
 - [Load Transfer Efficiency \(LTE\)](#)
 - [CRCP Punchouts](#)
 - [Smoothness \(IRI\)](#)

Select each of the distresses that rigid

Top-down Transverse Cracking (JPCP)

- Fatigue damage resulting in transverse or diagonal cracking
- Starts at the surface of the slab



U.S. Department of Transportation
Federal Highway Administration

MODULE E
LESSON 1

X CLOSE

Top-down transverse cracking is a fatigue damage at the top of the slab, which eventually results in a transverse or diagonal crack that is initiated on the surface of the pavement. It occurs when a repeated loading by heavy truck tractors with certain axle spacing is applied when the pavement is exposed to high negative temperature gradients.

Image description: Photo of top-down transverse cracking.

Pavement Distresses

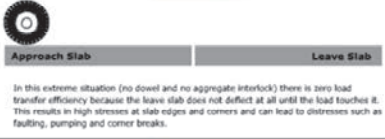
- Rigid pavement distresses:
 - [Mean Transverse Joint Fault](#)
 - [Bottom-up Transverse Crack](#)
 - [Top-down Transverse Crack](#)
 - [Load Transfer Efficiency \(LTE\)](#)
 - [CRCP Punchouts](#)
 - [Smoothness \(IRI\)](#)

Select each of the distresses that rigid

Load Transfer Efficiency (LTE)
X CLOSE

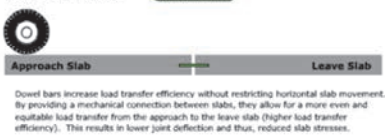
- Load transfer efficiency
- Transverse crack close to transverse joint at dowel ends
- <http://www.pavementinteractive.org/article/load-transfer/> for more information

Zero Load Transfer
Run Animation



In this extreme situation (no dowel and no aggregate interlock) there is zero load transfer efficiency because the leave slab does not deflect at all until the load touches it. This results in high stresses at slab edges and corners and can lead to distresses such as faulting, pumping and corner breaks.

100% Load Transfer
Run Animation



Dowel bars increase load transfer efficiency without restricting horizontal slab movement. By providing a mechanical connection between slabs, they allow for a more even and equitable load transfer from the approach to the leave slab (higher load transfer efficiency). This results in lower joint deflection and thus, reduced slab stresses.

© 2003 Steve Muench
Figure 1. Load Transfer Efficiency Across a PCC Surface Course Joint

The load transfer efficiency (LTE) is defined as the ratio of deflection of the unloaded side to the loaded side of the joint multiplied by 100. When crack LTE is reduced the potential for punch outs to develop increases greatly.

In joint load transfer deterioration, a transverse crack happens at a short distance from a transverse joint, usually at the end of joint load transfer dowels.

The joint deterioration is due to extensive corrosion or misalignment of dowel system.

Image description: Screenshot of the pavementinteractive.org article regarding joint load transfer deterioration.

Hyperlink description: <http://www.pavementinteractive.org/article/load-transfer/>


Pavement Distresses


- Rigid pavement distresses:
 - [Mean Transverse Joint Fault](#)
 - [Bottom-up Transverse Crack](#)
 - [Top-down Transverse Crack](#)
 - [Load Transfer Efficiency \(LTE\)](#)
 - [CRCP Punchouts](#) ←
 - [Smoothness \(IRI\)](#)

Select each of the distresses that rigid

CRCP Punchouts
X CLOSE

- Occurs transversely across at the top of CRCP slab within a distance of 48 in. from the edge





MODULE E
LESSON 1

In CRCP pavements, a punch out occurs when truck axles pass near the longitudinal edge of the slab between two closely-spaced transverse cracks, and a high-tensile stress occurs transversely across the pavement at the top of the slab within a distance of 48 in. from the edge.

Image description: Collage of photos of CRCP punch outs.


Pavement Distresses

- Rigid pavement distresses:
 - [Mean Transverse Joint Fault](#)
 - [Bottom-up Transverse Crack](#)
 - [Top-down Transverse Crack](#)
 - [Load Transfer Efficiency \(LTE\)](#)
 - [CRCP Punchouts](#)
 - [Smoothness \(IRI\)](#) ←

Select each of the distresses that rigid pavement can experience.

Smoothness (IRI)

- A parameter used to define pavement smoothness and derived from the simulation of a “quarter-car” traveling along the longitudinal profile of the road
- Calculated from the mean of the longitudinal profiles in each wheel path



The image collage consists of three photographs of roadways. The top-left photo shows a long, straight road with a white center line and a clear horizon. The bottom-left photo shows a road with a white center line and a visible crack in the pavement. The right-side photo shows a road with a white center line and a car in the distance.

U.S. Department of Transportation
Federal Highway Administration

MODULE E
LESSON 1

X CLOSE

Just as with flexible pavement distresses, IRI is a parameter used to define pavement smoothness and derived from the simulation of a “quarter-car” traveling along the longitudinal profile of the road. IRI is calculated from the mean of the longitudinal profiles in each wheel path.

Image description: Collage of photos of roadway smoothness.

Performance Threshold Values Recommended for Pavement ME Design



Pavement Type	Performance Criteria	Threshold Value at End of Design Life
HMA pavement & overlays	Alligator cracking (HMA bottom up cracking)	Interstate: 10% lane area Primary: 20% lane area Secondary: 35% lane area
	Rut depth (permanent deformation in wheel paths)	Interstate: 0.40 in. Primary: 0.50 in. Others (<45 mph): 0.65 in.
	Transverse cracking length (thermal cracks)	Interstate: 500 ft./mi Primary: 700 ft./mi Secondary: 700 ft./mi
	IRI (smoothness)	Interstate: 160 in./mi Primary: 200 in./mi Secondary: 200 in./mi
JPCP new, CPR, and overlays	Mean joint faulting	Interstate: 0.15 in. Primary: 0.20 in. Secondary: 0.25 in.
	Percent transverse slab cracking	Interstate: 10% Primary: 15% Secondary: 20%
	IRI (smoothness)	Interstate: 160 in./mi Primary: 200 in./mi Secondary: 200 in./mi



This table summarizes the recommended performance threshold values for Pavement ME Design. The threshold values change at the end of the design life depending on the functional classification of the roadway. These are design target thresholds and do not consider the scheduling of preventative or routine maintenance activities.

Table of Suggested Reliability Values



Functional Classification	Level of Reliability (%)	
	Urban	Rural
Interstate/Freeways	95	95
Principal Arterials	90	85
Collectors	80	75
Local	75	70



Design performance criteria and design reliability greatly affect the determination of an adequately performing pavement. Reliability is the probability that the predicted performance indicator of the trial design will not exceed the design criteria within the design-analysis period. The design criteria and design reliability levels could be selected in balance with each other. A low level of distress should not be selected in conjunction with a high level of reliability because this may make it impossible or costly to obtain an adequate design. A designer may specify the desired level of reliability for each distress type and smoothness.

Demonstration



The next series of slides are included to provide you with a demonstration of the Pavement ME Design software. These are built around a jointed plain rigid pavement design in Ohio, which is based on the LTPP Section Site 39-0263.

The purpose of this activity is to show how a selected number of factors affect the predicted pavement performance. We want to observe what happens to the predicted pavement performance when few parameters are changed.

Image description: PvD AASHTOWare Pavement ME Design logo banner.

Pavement ME Example for Rigid Pavement in Ohio: Baseline Information

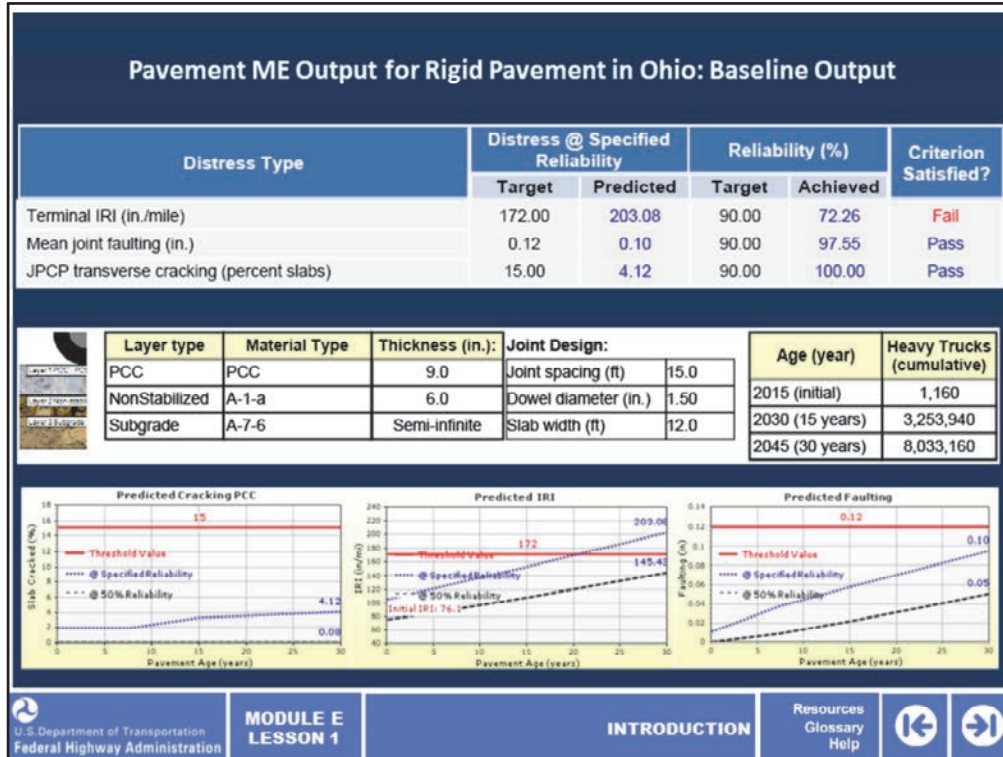
Layer type	Material Type	Thickness (in.):	Joint Design:		Age (year)	Heavy Trucks (cumulative)
PCC	PCC	9.0	Joint spacing (ft)	15.0	2015 (initial)	1,160
NonStabilized	A-1-a	6.0	Dowel diameter (in.)	1.50	2030 (15 years)	3,253,940
Subgrade	A-7-6	Semi-infinite	Slab width (ft)	12.0	2045 (30 years)	8,033,160



We will now change one parameter at a time from the 9-inch baseline rigid pavement thickness and then compare the predicted performance of the modified structure to the predicted performance of the baseline.

This slide shows some of the basic inputs for the design of the example rigid pavement.

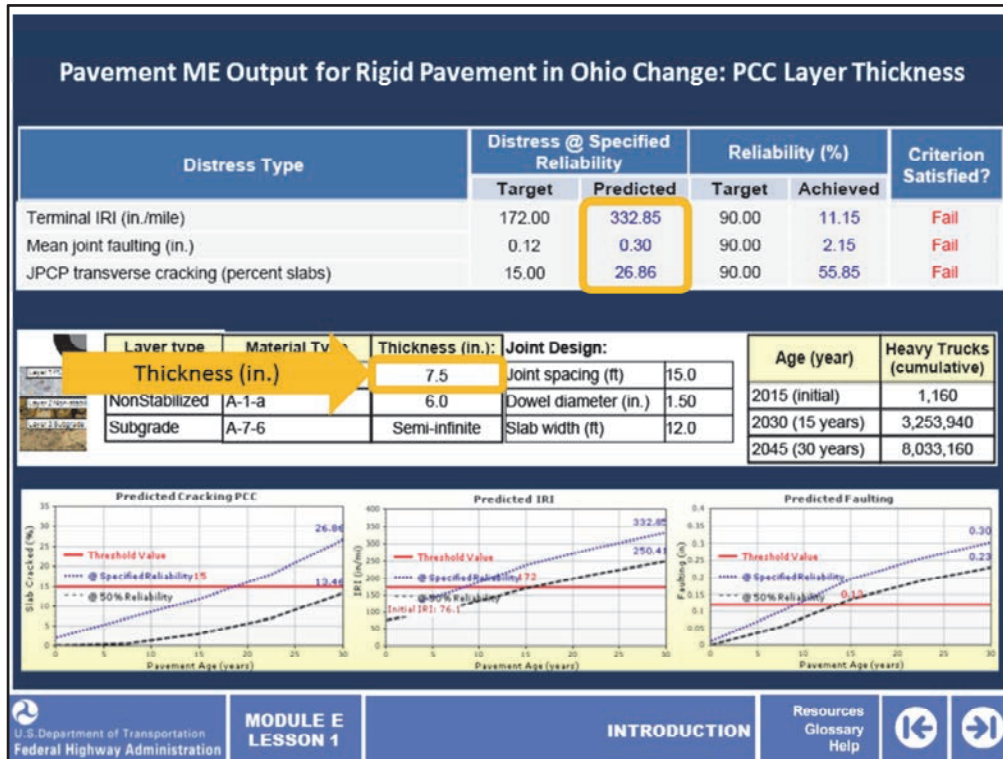
Image description: Pavement ME Example for Rigid Pavement in Ohio: Baseline Information.



This slide shows the predicted performance of the original pavement in the example. The IRI was predicted to fail in terms of pavement smoothness prior to its target value of 172 inches per mile at the 90% reliability. The design performed sufficiently in terms of faulting at the joints and transverse cracking.

Assuming the Ohio DOT desired to optimize the design for costs, let's see what would happen if we attempted a design that is 1.5" thinner, so a 7.5-inch rigid pavement instead.

Image description: Pavement ME Output example for Rigid Pavement in Ohio: Baseline Information.



We will now change one parameter at a time from the 9-inch baseline rigid pavement thickness and then compare the predicted performance of the modified structure to the predicted performance of the baseline.

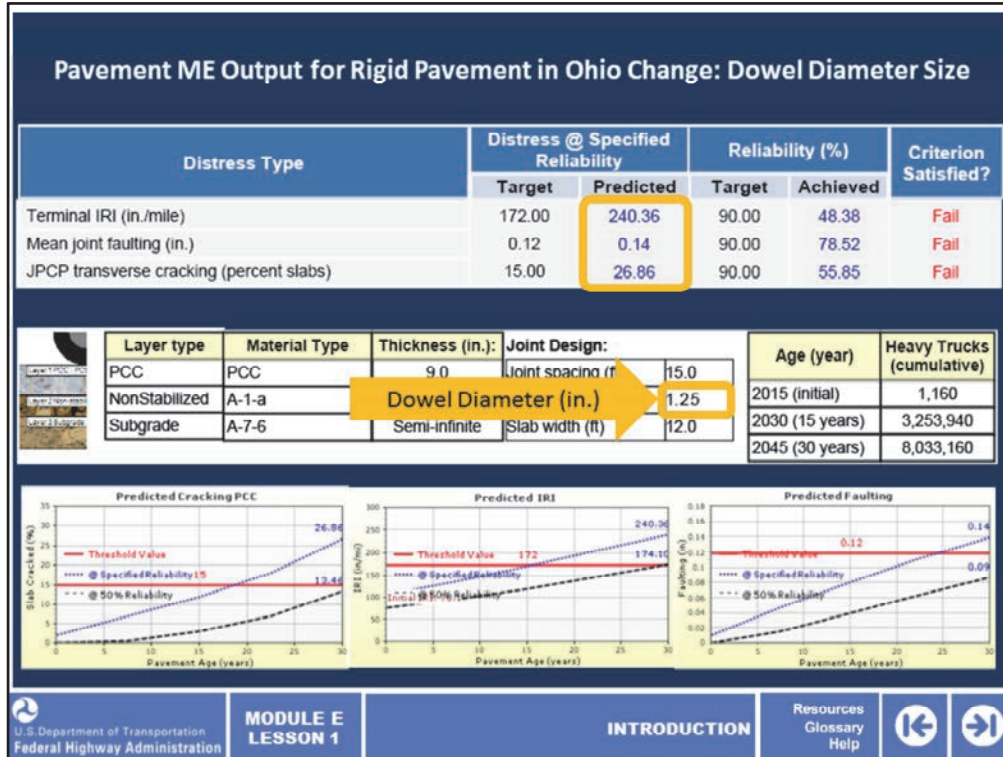
When we decrease the PCC layer thickness from 9 in. to 7.5 in., we notice an increase in all distresses and smoothness.

As can be seen in the plots at the bottom, the IRI fails after approximately 8 years, which is 12 years before this failure was observed in the baseline structure.

In addition, cracking and faulting were observed to exceed their respective threshold values after approximately 18 and 9 years, respectively.

In comparison, the baseline structure doesn't experience any cracking and faulting within the 30 years of design life.

Image description: Pavement ME Output example for Rigid Pavement in Ohio: Baseline Information.



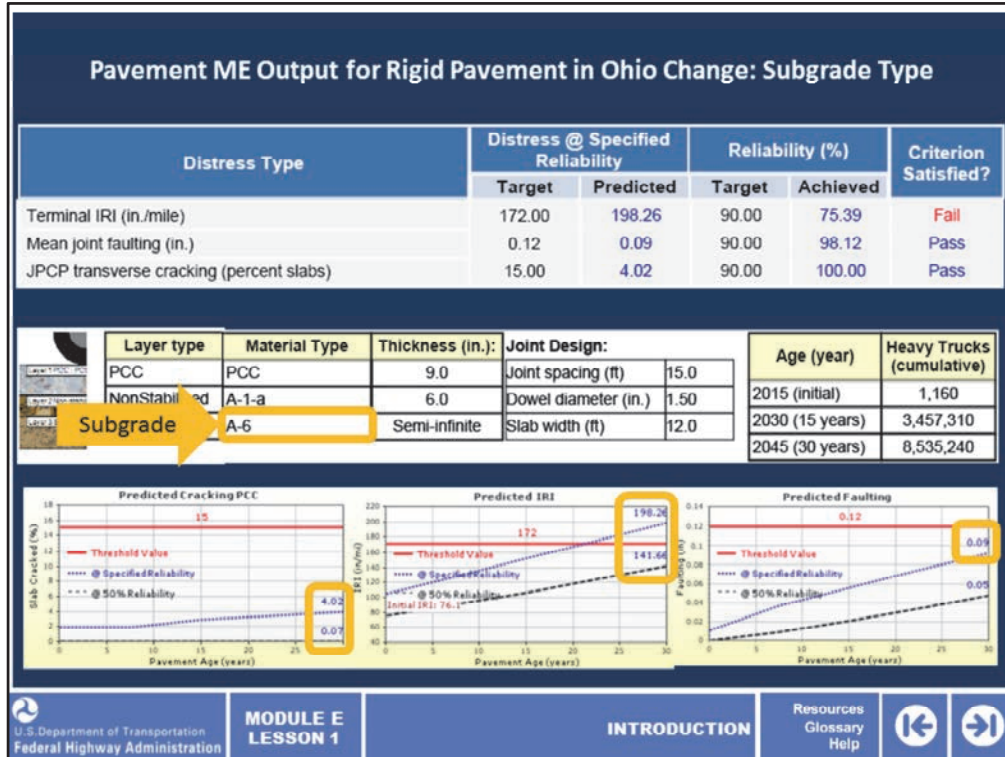
When we decrease the dowel diameter from 1.5 in. to 1.25 in., we notice an increase in all distresses and smoothness.

The IRI fails after approximately 15 years. The IRI of the baseline structure surpasses the threshold after approximately 20 years.

The cracking and faulting fail after approximately 18 and 24 years, respectively.

On the other hand, the baseline structure doesn't experience any cracking and faulting within the 30 years of design life.


Image description: Pavement ME Output example for Rigid Pavement in Ohio: Baseline Information.



In this case, we changed the subgrade type from A-7-6 (with a resilient modulus of 13,000 psi) to A-6 (with a resilient modulus of 14,000 psi), through the application of a cut/fill with more superior soil.


When we increase the subgrade strength, we notice a slight decrease in cracking, IRI, and faulting compared to the baseline structure.

Image description: Pavement ME Output for Rigid Pavement in Ohio: Baseline Information.



Summary of Demonstration

Distress Type	Baseline	Change subgrade (from A-7-6 to A-6)	Change dowel diameter (from 1.5" to 1.25")	Change PCC thickness (from 9" to 7.5")
Terminal IRI (in./mile)	203	198	240	332
Joint Faulting (in.)	0.10	0.09	0.12	0.30
Transverse Cracking (% slab cracked)	4.12	4.02	15.00	26.86

U.S. Department of Transportation Federal Highway Administration | MODULE E LESSON 1 | INTRODUCTION | Resources Glossary Help | 

This table summarizes the results from the four analyzed pavement structures.


As you can see, changing subgrade strength, dowel size, and PCC thickness affected the predicted pavement performance of this particular pavement structure.

Increasing subgrade stiffness resulted in slightly lower terminal IRI, joint faulting, and transverse cracking as compared to the predicted distresses of the baseline pavement structure.


Decreasing the dowel bar diameter size resulted in higher predicted distresses and smoothness (compared to the baseline pavement structure).




Decreasing the PCC thickness resulted in even higher levels of distresses predicted and a reduction in smoothness.

Select all that apply. Which performance parameters are not analyzed by Pavement ME Design software?



- a) Permanent deformation
- b) Surface disintegration distresses
- c) Faulting
- d) Skid resistance
- e) Fatigue cracking
- f) IRI

 **Knowledge Check** Try again Submit Clear

 **MODULE E**
LESSON 1 **INTRODUCTION** Resources Glossary Help  

Let's pause to check your understanding of performance parameters and the Pavement ME Design software.

Select all that apply. Which performance parameters are not analyzed by Pavement ME Design software?

- a) Pavement deformation;
- b) Surface disintegration distresses;
- c) Faulting;
- d) Skid resistance;
- e) Fatigue cracking; or
- f) IRI.

Select all that apply. Which performance parameters are not analyzed by Pavement ME Design software?



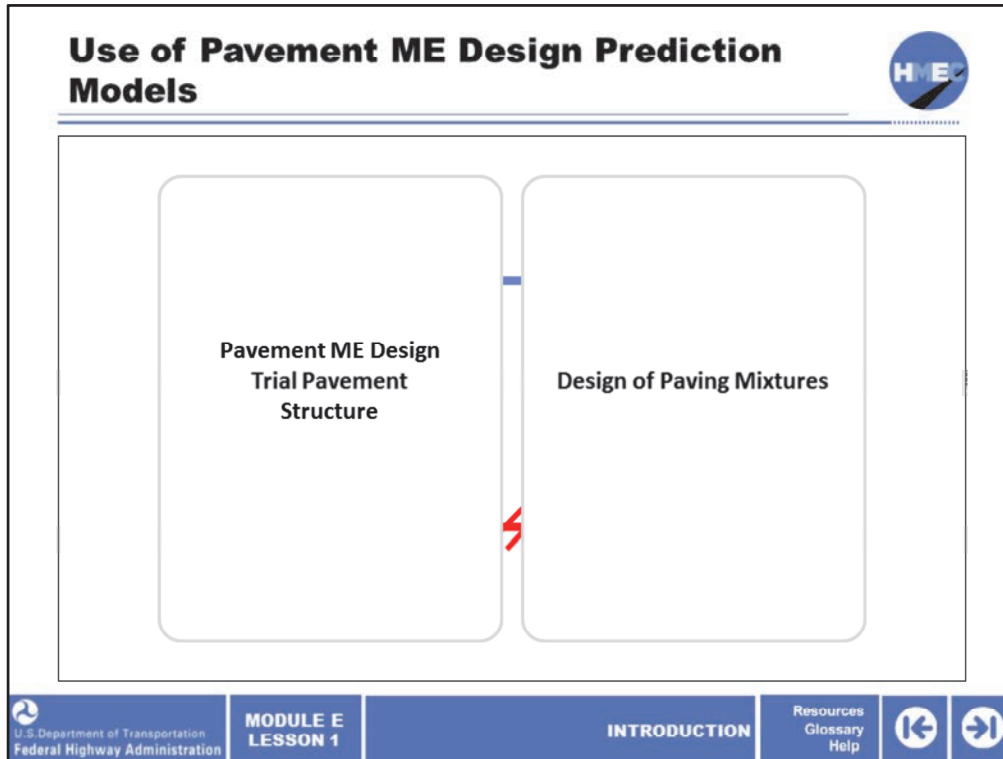
- a) Permanent deformation
- b) Surface disintegration distresses
- c) Faulting
- d) Skid resistance
- e) Fatigue cracking
- f) IRI



Knowledge Check Debrief



The correct answers are b) Surface disintegration distresses and d) Skid resistance.



The concept to be taken from this schematic is that one can use the performance prediction models (with adjustments) from the Pavement ME Design software to assist in the design of paving mixtures and possibly tie performance into the mixture design process. However, you cannot tie the design of paving mixtures into the Pavement ME Design trial pavement process. The software tool can be used to provide a different perspective for materials engineers in predicting the quality of materials in a performance-based sense, prior to final mixture design occurring.

Use of Pavement ME Design Prediction Models

Proof of Concept 1:
Rigid Pavement

Proof of Concept 2:
Flexible Pavements

Select each proof of concept to learn more.

U.S. Department of Transportation
Federal Highway Administration

MODULE E
LESSON 1

INTRODUCTION

Resources
Glossary
Help

The procedures used in the analysis are based upon fundamental engineering properties and behavior based upon ME principles to predict specific pavement distress. The models can also be used as a forensic tool for evaluating changes in specification and/or legal load limits that we are periodically asked by legislators and lobbyists to assess.

However, when it comes to materials design there are some specifics with the capabilities of the Pavement ME Design software to be aware of. In order to help participants visualize the use of Pavement ME Design software prediction models for materials design, two examples or “proofs of concept” are provided: one for rigid pavements and one for flexible pavements. The concept to be proved is that sensitivity to the pavement performance is not stemming from the materials or mixture design.

Use of Pavement ME Design Prediction Models



Proof of Concept 1: Rigid Pavement

Proof of Concept 1: Rigid Pavement

CLOSE

- Concrete coefficient of thermal expansion
- Average value that is averaged over all sublots and all lots and entered into Pavement ME Design



For example, in rigid pavements, there is a section of the design software that allows for the input of the concrete's coefficient of thermal expansion (or CTE). However, the value that is input by the user is an average CTE or in other words, a value that is averaged over all sublots and lots that would be placed in a given pavement project.

Image description: Photo showing paving operation on Interstate 80 with dowel bar baskets.

Use of Pavement ME Design Prediction Models



Proof of Concept 2: Flexible Pavements

Proof of Concept 2: Flexible Pavements

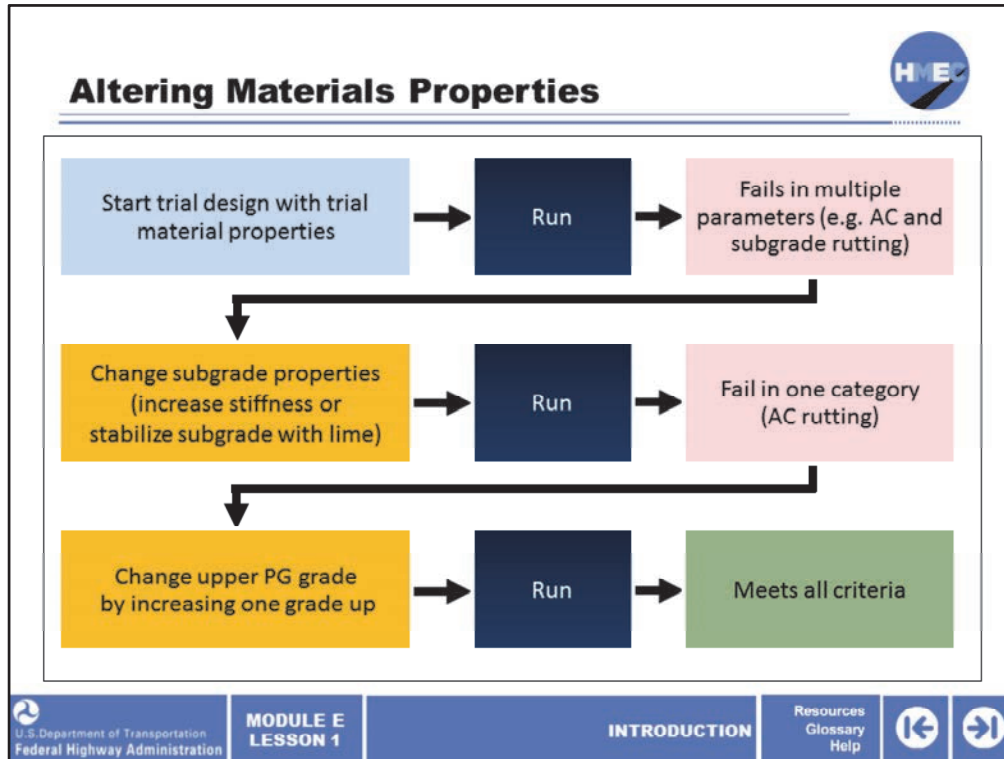
CLOSE

- Dynamic modulus ($|E^*|$) of asphalt concrete
- Average $|E^*|$ entered into pavement ME design for each temperature and frequency combination
- Averaged over all lots and sublots



Another example comes from looking at flexible pavements, in which the dynamic modulus stiffness, or E-star, can be input for the Level 1 section of the asphalt layer's definition. However, the value that is input by the user is an average E-star for each temperature and load frequency combination. In addition, it is a value that is averaged over all sublots and lots that would be paved in a given pavement project.

Image description: Photo of flexible pavement rehabilitation.



This schematic presents the process of altering materials properties in order to take a trial pavement design that fails to one that meets all performance criteria and can advance to the final design and construction phase.

At the top you start with a trial pavement design and trial mixture and material properties for an example flexible pavement.

The analysis is then run in the Pavement ME Design software.

Results from the distress prediction models show that the design fails in multiple distress modes, for example rutting in both the asphalt surface and in the subgrade.

Therefore, the designer elects to change the subgrade properties by increasing its stiffness through stabilization of the subgrade with lime.

The analysis is then run again and the results show that now the pavement only exceeds the threshold value for surface rutting.

The designer then elects to attempt to stiffen the surface layer by bumping up the binder by one PG grade.

The analysis is run one more time.

And finally in this case, the pavement structure now passes all for the given traffic and environmental loads.

Image description: Schematic showing the process of altering materials properties in order to take a trial pavement design that fails to one that meets all performance criteria and can advance to the final design and construction phase.

Performance-Related Specification Quality-Related Standard Specification



NCHRP Project 9-22

NCHRP Project 9-22A

FHWA PaveSpec 4.0

Select each tool to learn more.



There are three recent tools developed either through the National Cooperative Highway Research Program and the Federal Highway Administration that have been based on using the Pavement ME Design performance models to provide a different perspective on how materials engineers can predict the quality of materials in a performance-based sense prior to final mixture design occurring.

Select each tool to learn more about it.

Performance-Related Quality-Related Standards

NCHRP Project 9-22

- NCHRP Project 9-22 beta testing and validation of HMA PRS
- Flexible pavements

Select each tool to learn more.

U.S. Department of Transportation
Federal Highway Administration

**MODULE E
LESSON 1**

X CLOSE

In the NCHRP 9-22 project, entitled the concept of quality-related standard specifications (QRSS) for flexible pavements, was enhanced through the development of a stand-alone program that calculates the predicted performance of an HMA pavement from the volumetric and materials properties of the as-designed HMA and compares it with that of the as-built pavement calculated from the contractor's lot or subplot quality control data. The QRSS accounts for the climate, traffic, pavement structure, and desired or expected service life.

Reference: Moulthrop, J., James, M., Witzak, M., Jeong, M., McCarthy, L., and D. Mensching, Evaluation of the Quality Related Specification Software (QRSS) Version 1.0. NCHRP Project No. 9-22A Final Report, Transportation Research Board, National Research Council, 2012, http://onlinepubs.trb.org/onlinepubs/nchrp/docs/NCHRP09-22A_FR.pdf.

The image shows a presentation slide with a dark blue overlay box. The slide title is "Performance-Related Quality-Related Standards". The overlay box is titled "NCHRP Project 9-22A" and contains a list of bullet points: "NCHRP Project 9-22A Evaluation of the Quality-Related Specification Software (QRSS) Version 1.0" and "Flexible pavements". A "CLOSE" button is in the top right of the overlay. The slide also features a navigation bar with "MODULE E LESSON 1" and the "U.S. Department of Transportation Federal Highway Administration" logo. A "Select each tool to learn more." instruction is at the bottom of the slide content area.

Performance-Related Quality-Related Standards

NCHRP Project 9-22A

- NCHRP Project 9-22A Evaluation of the Quality-Related Specification Software (QRSS) Version 1.0
- Flexible pavements

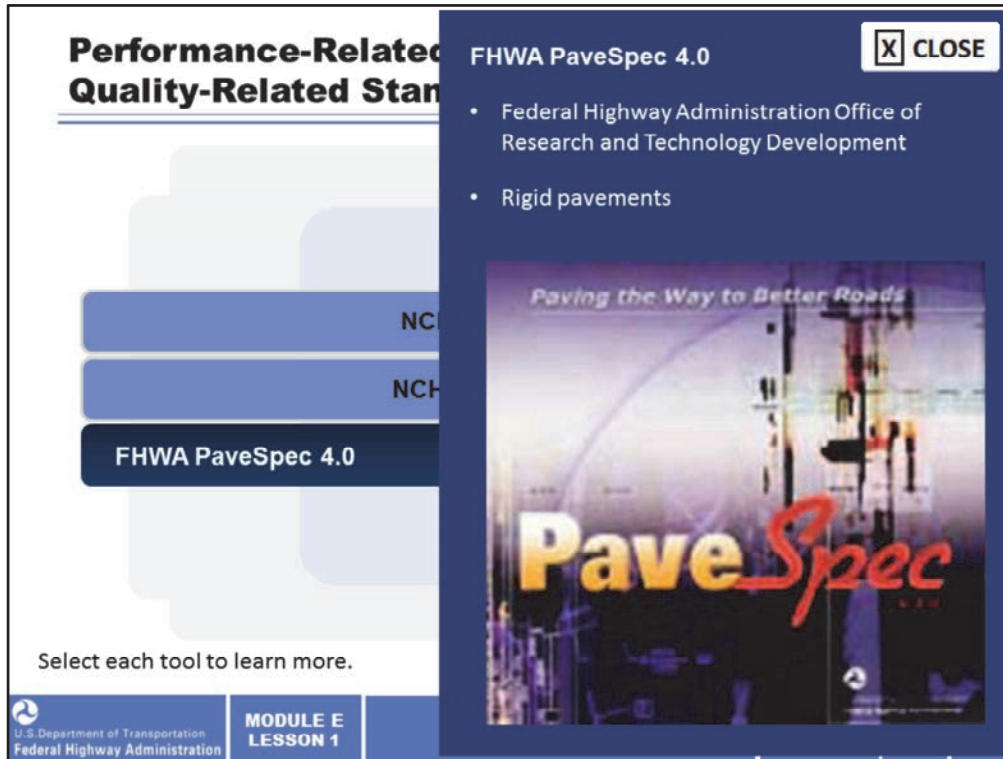
Select each tool to learn more.

U.S. Department of Transportation
Federal Highway Administration

MODULE E
LESSON 1

As a follow up to the previously discussed project, a second effort entitled “Evaluation of the Quality-Related Specification Software (QRSS) Version 1.0” was conducted (known as NCHRP Project 9-22A) to evaluate the QRSS Version 1.0 with quality assurance (QA) data obtained from State DOTs in three parts of the nation (southern Midwest, west, and northeast). In this project, the QRSS results that were obtained were compared with various levels and types of measured mix volumetric and performance data.

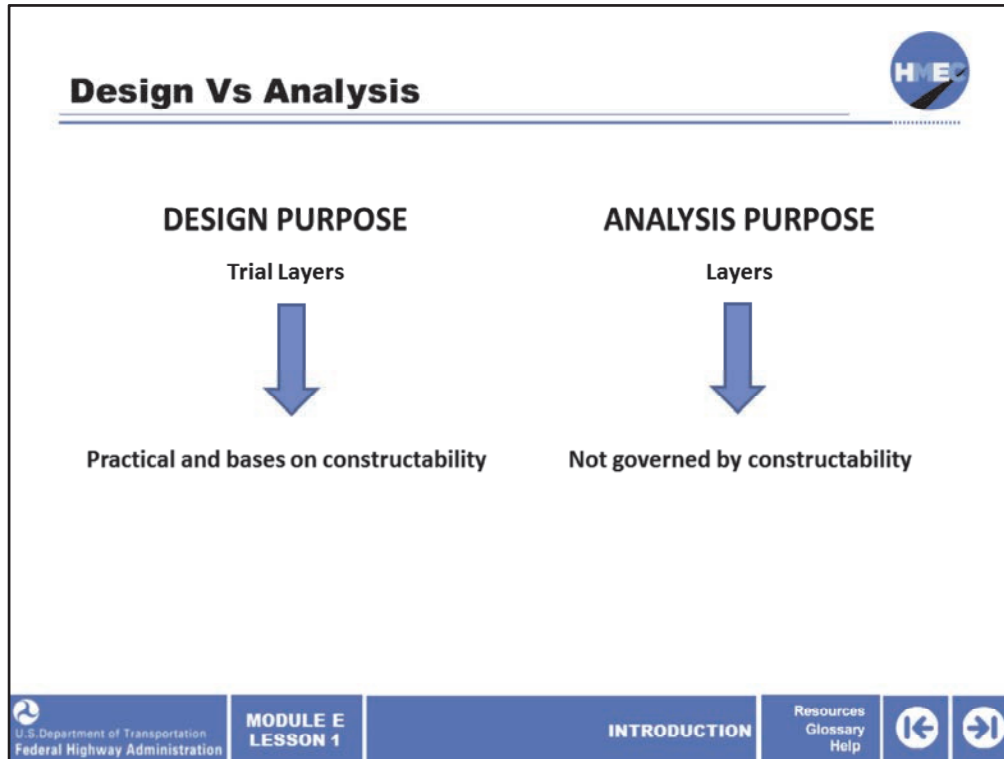
Reference: National Cooperative Highway Research Program (NCHRP), Quality-Related Specification Software (QRSS), 2010,
<http://apps.trb.org/cmsfeed/TRBNetProjectDisplay.asp?ProjectID=958>.



For rigid pavements, the Federal Highway Administration Office of Research and Technology Development has developed the PavSpec software tool. This tool is anticipated for release in Summer 2014 and incorporates the distress prediction models from the Pavement ME Design into JPCP performance-related specifications (PRS). The concept is that this tool can be applied in the development of a plan for the State-wide implementation of PRS.

Reference: Federal Highway Administration PavSpec 3.0 (need to update this Reference once PavSpec 4.0 is released in Summer 2014),
<http://www.fhwa.dot.gov/publications/research/infrastructure/pavements/pccp/pavespec/>

Image description: PavSpec software screenshot.



It is important to make a clear distinction between the design and the analysis purposes when using the AASHTO Pavement ME Design software. When the software is used as a pavement design tool, the trial pavement layers have to be practical and based on constructability. Practitioners will design the pavement layers with a realistic approach at reasonable accuracy levels by implementing strategic thickness iterations to the process. A designer should design what the contractors can construct, especially the pavement layer thickness.

When the software is used for pavement analysis purposes and academic exercises, the layers thicknesses are not governed by constructability. This tool can be used for forensic or exploratory analysis purposes. As a pavement analysis tool, the AASHTO Pavement ME Design software will predict pavement distresses predictions for either flexible or rigid pavements.

How Will I Benefit From ME Design Approach?



- More integrated approach based on field performance criteria
 - Designing the whole pavement system
 - Not just designing the pavement based on thickness of the upper layers
- Making sure that the design criteria have been met or exceeded

Agency/Owner



Contractor/Supplier



For materials engineers, one of the major benefits of the MEPDG will be its ability to tie all the design elements and stakeholders together in one integrated package. For example, in earlier guides HMA mix design and structural capacity were only indirectly related. Through the use of the mechanistic approach, that connection becomes direct and directly related to performance of the pavement.


The most important is the way we design pavement now is a "more integrated" approach that is based on performance criteria. We are not designing based on the thickness of the upper layers anymore. We are designing the whole system.

The ME analysis procedures allows an agency to compare the expected performance of their as-constructed pavements to the expected performance under assumed design conditions. This enables an agency to rationally set the pay factors on their construction specifications and to determine the effectiveness of their warranty and performance-related specifications.

Image description: Photo of two men in suits wearing hard hats observing a construction site.


Image description: Photo of Heavy equipment on a construction site.

Example Pavement Projects for Instructor-Led Training



<p>New HMA (Low Traffic Volume) Washington</p>	<p>New HMA (High Traffic Volume) Florida</p>	<p>New JPCP (High Traffic Volume) Utah</p>
<p>Rehab HMA over HMA (High Traffic Volume) Washington</p>	<p>Rehab HMA over JPCP (High Traffic Volume) Indiana</p>	



Select each example project for a project overview.

 U.S. Department of Transportation
Federal Highway Administration

MODULE E
LESSON 1

INTRODUCTION

[Resources](#)
[Glossary](#)
[Help](#)

As previously mentioned, there are five sample pavement projects that we will use to help illustrate different MEPDG concepts. These five pavement projects will serve as the recurring theme throughout the instructor-led session. They include a new flexible pavement in an area with low truck traffic volumes, a new flexible pavement in an area with high truck traffic volumes, a new jointed plain concrete pavement in an area with high truck traffic volumes (a CRCP study will also be included in the Lesson 5 of the instructor-led training session), a flexible pavement overlay over an existing flexible pavement in an area with high truck traffic volumes, and a flexible pavement overlay over an existing JPCP pavement in an area with high truck traffic volumes (a CRCP study will also be included in the Lesson 5 of the instructor-led training session).



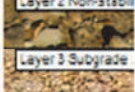
These sample pavement projects are being used to illustrate the important factors to consider as part of forming a pavement design with the Pavement ME Design, with a particular emphasis on materials.

The details of the pavement sections that are used were extracted from real long-term pavement performance sections that are in the same climatic region as the four States used for illustration purposes in this training.

Select each example project for a project overview.

Sample Pavement Design #1 X CLOSE

New HMA low-volume: Washington

	Layer type	Material Type	Thickness (in.):
	Flexible	AC	7.5
	NonStabilized	A-1-b	10.0
	Subgrade	A-1-b	Semi-infinite


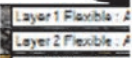


Age (year)	Heavy Trucks (cumulative)	Volumetric at Construction:	
2014 (initial)	230	Effective binder content (%)	11.0
2024 (10 years)	433,373	Air voids (%)	10.5
2034 (20 years)	1,015,790		

New HMA (Low Traffic Volume): The first sample pavement section is a new flexible pavement in an area with low truck traffic volumes and based in the State of Washington.

Image description: Sample of pavement design.

Sample Pavement Design #2 X CLOSE

New HMA high volume: Florida

	Layer type	Material Type	Thickness (in.):
	Flexible	AC 1	4.0
	Flexible	AC 2	4.0
	NonStabilized	A-1-b	8.0
	Subgrade	A-6	Semi-infinite


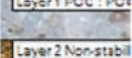
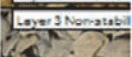

Age (year)	Heavy Trucks (cumulative)	Volumetric at Construction:	
2014 (initial)	5,890	Effective binder content (%)	9.9
2024 (10 years)	11,098,100	Air voids (%)	5.0
2034 (20 years)	26,013,100		

New HMA (High Traffic Volume): The second sample pavement section is a new flexible pavement in an area with high truck traffic volumes and based in the State of Florida.

Image description: Sample of pavement design.

Sample Pavement Design #3 X CLOSE

New JPCP high-volume: Utah

	Layer type	Material Type	Thickness (in.):
	PCC	PCC	11.0
	NonStabilized	A-1-b	6.0
	NonStabilized	A-1-b	12.0
	Subgrade	A-2-4	Semi-infinite


Age (year)	Heavy Trucks (cumulative)	Joint Design:	
2015 (initial)	3,670	Joint spacing (ft)	15.0
2030 (15 years)	10,948,300	Dowel diameter (in.)	1.50
2045 (30 years)	25,968,200	Slab width (ft)	12.0

New JPCP (High Traffic Volume): The third sample pavement section is a new jointed plain concrete pavement in an area with high truck traffic volumes and based in the State of Utah. It should be noted that in Lesson 5, a CRCP pavement will also be substituted in the place of the JPCP to demonstrate the design properties and performance predictions for CRCP pavements.

Image description: Sample of pavement design.

Sample Pavement Design #4 X CLOSE

Rehab HMA over HMA high-volume: Washington



Layer type	Material Type	Thickness (in.):
Flexible	Default asphalt concrete	3.0
Flexible	Default asphalt concrete	9.0
NonStabilized	Crushed stone	8.0
NonStabilized	A-1-b	10.0
Subgrade	A-1-b	Semi-infinite

Age (year)	Heavy Trucks (cumulative)
2016 (initial)	2,250
2026 (10 years)	4,197,410
2036 (20 years)	9,504,260

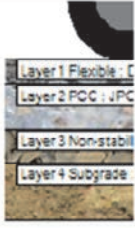
Volumetric at Construction:	
Effective binder content (%)	11.0
Air voids (%)	10.5

Rehab HMA over HMA (High Traffic Volume): The fourth sample pavement section is a flexible pavement overlay over an existing flexible pavement in an area with high truck traffic volumes and based in the State of Washington.

Image description: Sample of pavement design.

Sample Pavement Design #5 [X] CLOSE

Rehab HMA over JPCP high-volume: Indiana



Layer type	Material Type	Thickness (in.):
Flexible	Default asphalt concrete	4.5
PCC	JPCP Default	8.0
NonStabilized	A-1-a	6.0
Subgrade	A-6	Semi-infinite

Age (year)	Heavy Trucks (cumulative)	Volumetric at Construction:	
2016 (initial)	6,500	Effective binder content (%)	11.0
2026 (10 years)	11,452,200	Air voids (%)	8.5
2036 (20 years)	25,931,400		

Rehab HMA over JPCP (High Traffic Volume): The fifth sample pavement section is a flexible pavement overlay over an existing JPCP pavement in an area with high truck traffic volumes and based in the State of Indiana. It should be noted that in Lesson 5, a CRCP pavement will also be substituted in the place of the JPCP to demonstrate the design properties and performance predictions for asphalt overlays of CRCP pavements.

Image description: Sample of pavement design.

Exercise 4: Review and Comparison

- Review the pavement design and materials specifications handouts and compare to those of your own home State

Review Factor	My State DOT	Indiana DOT	Comments on Comparison
Pavement design procedure			

To open the exercises, select the paperclip icon.

U.S. Department of Transportation
Federal Highway Administration

MODULE E
LESSON 1

INTRODUCTION

Resources
Glossary
Help

← →


Before you attend the instructor-led portion of this module, complete Exercise 4: Review and Comparison. In this exercise, you will search for, identify, and consult the pavement design manual, asphalt, and concrete mixture specifications, and other information as applicable one (in this case, review those of Indiana DOT only) of the four States, and your own local area.

Use the exercises that were provided from the paperclip icon. There you will find the steps to complete this exercise.

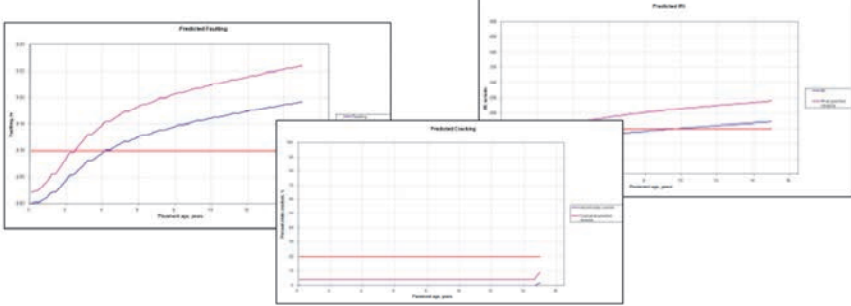
Again, make sure you have completed this exercise in advance of Lesson 2. Be ready to discuss your findings with other participants and the instructor when you attend the instructor-led portion of this module.

Image description: Sample of the pavement design and materials specifications handout.

Exercise 5: Case Study



- Review the Johnstown, Pennsylvania case study information and answer the related questions in the Module E, Lesson 1 Exercises PDF
- These questions will help you identify important considerations for pavement design




To open the exercises, select the paperclip icon.

U.S. Department of Transportation
Federal Highway Administration

MODULE E
LESSON 1

INTRODUCTION

Resources
Glossary
Help

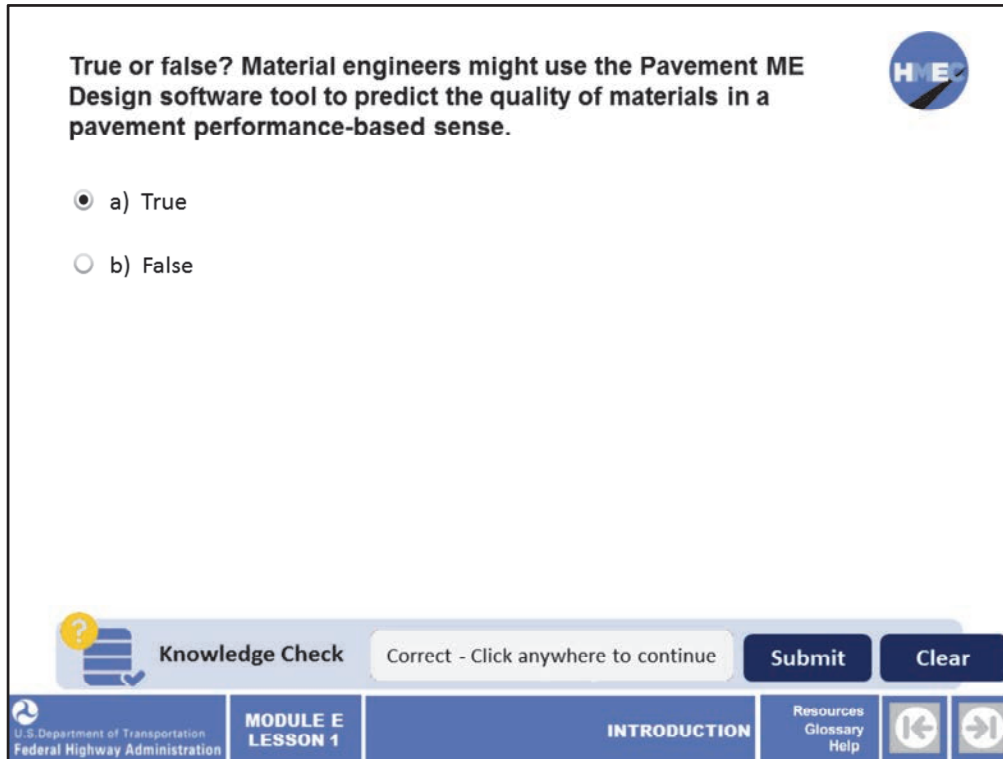


Before you attend the instructor-led portion of this module, complete Exercise 5: Case Study. Read the handout of a case study of a pavement design planned near Johnstown, Pennsylvania and complete the related questions. Identify the important considerations for pavement design and comment on the traffic levels, climate considerations, and types of critical materials properties that should be considered in improving this fictional pavement section's performance.

Use the exercises that were provided from the paperclip icon. There you will find the steps to complete this exercise.

You should complete this exercise in advance of the instructor-led session of this module.

Image description: Collage of images of predicted faulting, predicted cracking, and predicted IRI for the Johnstown, PA case study.



The screenshot shows a knowledge check question in a software interface. The question is: "True or false? Material engineers might use the Pavement ME Design software tool to predict the quality of materials in a pavement performance-based sense." There are two radio button options: "a) True" (which is selected) and "b) False". The interface includes a "Knowledge Check" header, a "Correct - Click anywhere to continue" message, and "Submit" and "Clear" buttons. The footer contains the U.S. Department of Transportation Federal Highway Administration logo, "MODULE E LESSON 1", "INTRODUCTION", and navigation icons for "Resources", "Glossary", and "Help".

True or false? Material engineers might use the Pavement ME Design software tool to predict the quality of materials in a pavement performance-based sense.

a) True

b) False

Knowledge Check Correct - Click anywhere to continue **Submit** **Clear**

U.S. Department of Transportation
Federal Highway Administration

**MODULE E
LESSON 1**

INTRODUCTION

Resources
Glossary
Help

Now we'll answer one last knowledge check before completing this lesson.

True or false? Material engineers might use the Pavement ME Design software tool to predict the quality of materials in a pavement performance-based sense.

- a) True; or
- b) False.

True or false? Material engineers might use the Pavement ME Design software tool to predict the quality of materials in a pavement performance-based sense.



- a) True
- b) False



Knowledge Check Debrief



The correct answer is a) True.

Learning Outcomes Review



You are now able to:

- List the basic factors required in designing a pavement structure
- Compare mixture design and pavement design related to materials in terms of predicted pavement performance
- Distinguish between empirical and mechanistic empirical design methods
- List the factors that may affect the predicted performance of pavements in MEPDG
- Describe the steps of a MEPDG analysis
- Describe the iterative design process used with Pavement ME Design software
- Describe the performance parameters analyzed by Pavement ME Design software
- Explain how pavement prediction models from MEPDG are being incorporated into the evaluation of asphalt and concrete paving mixtures
- Using an example, identify important considerations for pavement design

Return to the module curriculum to select the next lesson. To close this window, select the "X" in the upper right-hand corner of your screen.



U.S. Department of Transportation
Federal Highway Administration

MODULE E
LESSON 1

INTRODUCTION

Resources
Glossary
Help



You have completed Module E, Lesson 1: Introduction. You are now able to:

- List the basic factors required in designing a pavement structure;
- Compare mixture design and pavement design related to materials in terms of predicted pavement performance;
- Distinguish between empirical and mechanistic empirical design methods;
- List the factors that may affect the predicted performance of pavements in MEPDG;
- Describe the steps of a MEPDG analysis;
- Describe the iterative design process used with Pavement ME Design software;
- Describe the performance parameters analyzed by Pavement ME Design software;
- Explain how pavement prediction models from MEPDG are being incorporated into the evaluation of asphalt and concrete paving mixtures; and
- Using an example, identify important considerations for pavement design.

Close this lesson, and return to the module curriculum. To close this window, select the "X" in the upper right-hand corner of your screen.