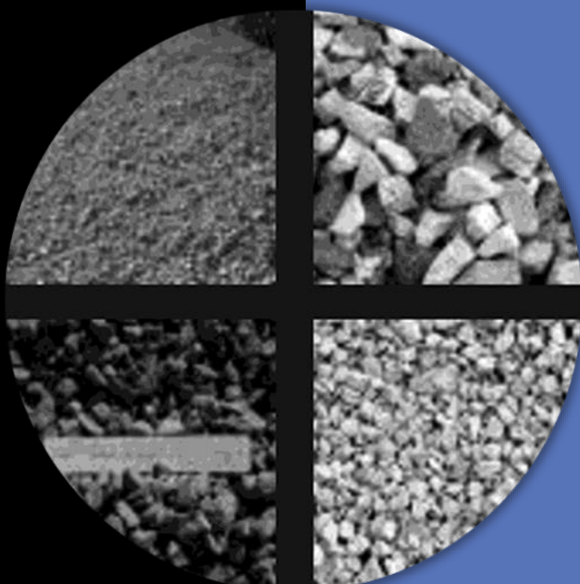
HMEC

Highway Materials Engineering Course

PARTICIPANT WORKBOOK



Aggregates for Transportation Construction Projects

MODULE

D

U.S.Department of Transportation
Federal Highway Administration

Table of Contents

About This Workbook

This workbook has been developed as a resource for participants. This workbook can be used during the training session to follow along with the instructor and take notes, as well as for reference after the module has ended.

Course Overview

The Federal Highway Administration (FHWA) Highway Materials Engineering Course (HMEC) is a comprehensive multi-week training event that consists of eight content “modules” that provide students with the knowledge to develop materials specifications and guidance, make effective acceptance decisions, and design, construct, and maintain assets with a long service life. Modules range in duration for the number of days they take to complete. The modules are:

- Module A: Quality Assurance
- Module B: Soils and Foundations
- Module C: Steel, Welding, and Coatings
- Module D: Aggregates for Transportation Construction Projects
- Module E: Mechanistic Empirical Pavement Design Guide
- Module F: Asphalt Materials and Paving Mixtures
- Module G: Portland Cement Concrete
- Module H: Evaluating Recycled Materials for Beneficial Uses in Transportation

Introduction

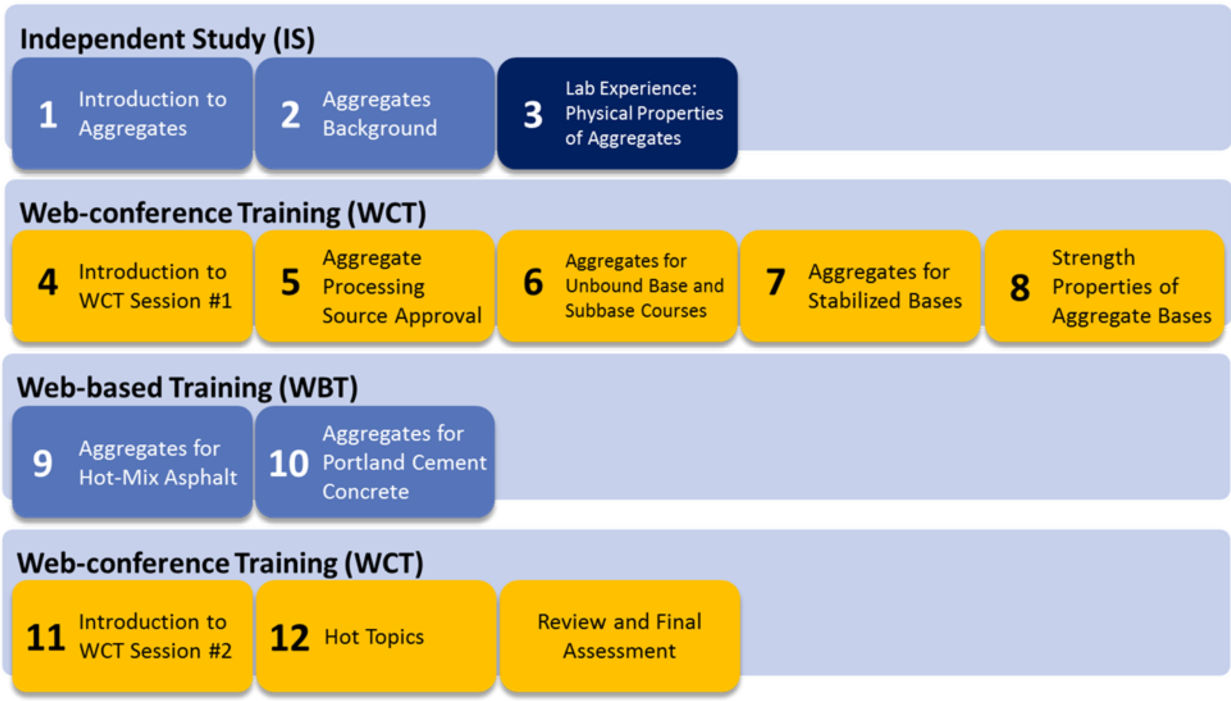
Module D: Aggregates for Transportation Construction Projects is the fourth module in the FHWA HMEC. Module D focuses on the properties of aggregates and the general considerations for their use. Highlighting contractor quality control and agency acceptance practices, the module builds upon Module A: Quality Assurance. The content will form a foundation for subsequent modules, as well, as it forms a foundation of knowledge of aggregate characteristics that are important considerations in hot mix asphalt (HMA) and Portland cement concrete (PCC).

Aggregates are probably the most diverse material in terms of how they are handled in different States or parts of the country. How States define quality is also diverse. This creates a challenge in how this topic is approached in this course.

Module D consists of 12 lessons. Lesson 1–3 are completed in the Independent Study (IS) portion of the module, including a visit to the district or State laboratory facility for an independent laboratory experience. Lessons 4–8 are completed in a scheduled Web-conference Training (WCT) session. Lessons 9 and 10 are completed as a Web-based Training (WBT) before participants reconvene for Lessons 11 and 12 in another scheduled WCT session. Finally, participants complete a brief review/wrap-up, a final assessment, and a module evaluation.

Module D Overview

Below is a visual overview of all of the lessons covered in this module:



Module Goals

The goals for this module are as follows:

- Describe the characteristics and engineering properties of aggregates and their effects on four highway applications (hot mix asphalt, Portland cement concrete, stabilized bases, and unbound aggregate bases)
- Explain the significance of common field and laboratory testing of aggregates
- Apply field and laboratory test results to hot mix asphalt and Portland cement concrete mix designs to the design of stabilized bases and unbound aggregate bases, and to the implementation of materials quality control
- Describe the elements of an effective quality assurance program for aggregates
- Discuss current best practices, emerging issues, technology, and trends that might affect aggregate supply and usage

Learning Outcomes

Lesson 1: Introduction

Lesson 2: General Aggregate Considerations

- LO 2.1: List common uses of aggregates in transportation projects
- LO 2.2: Define common aggregate-related terms
- LO 2.3: Describe the most important aggregate properties for general transportation-related applications
- LO 2.4: Explain the most important aggregate quality characteristics for PCC, asphalt concrete (AC), and pavement support layers
- LO 2.5: Identify standard test methods for evaluating aggregates

Lesson 3: Physical Properties of Aggregates

- LO 3.1: List the most commonly specified gradation parameters and how they are determined in the lab
- LO 3.2: List the most commonly specified cleanliness parameters and how they are determined in the lab
- LO 3.3: List the most commonly specified strength parameters and how they are determined in the lab
- LO 3.4: List the most commonly specified hardness parameters and how they are determined in the lab
- LO 3.5: List the most commonly specified abrasion, wear, and degradation parameters and how they are determined in the lab
- LO 3.6: List the most commonly specified aggregate shape characteristics parameters and how they are determined in the lab
- LO 3.7: List the most commonly specified pore properties parameters and how they are determined in the lab

- LO 3.8: List the most commonly specified volume stability parameters and how they are determined in the lab

Lesson 4: Introduction to Web-conference Training Session #1

Lesson 5: Source Approval

- LO 5.1: Describe how the intended use for aggregates affects the required physical, chemical, and mechanical properties
- LO 5.2: List the most important factors to consider in selecting an aggregate source for a specific application
- LO 5.3: Describe the basic operations required to quarry and process aggregates
- LO 5.4: Describe the process for evaluating aggregates at the point of production
- LO 5.5: Explain your State's process for aggregate source approval
- LO 5.6: Explain your State's quality assurance process for aggregates
- LO 5.7: Explain the aggregate producers' quality control requirements for your State and the ways in which those requirements are monitored

Lesson 6: Aggregates for Unbound Base and Subbase Courses

- LO 6.1: Discuss the reasons why a base or subbase course is required for most pavements
- LO 6.2: List the most important physical properties of coarse aggregates used for an unbound base layer
- LO 6.3: Explain the desirable quality characteristic of fine aggregates in an unbound aggregate base
- LO 6.4: Describe how variations in aggregate gradation can occur during construction operations
- LO 6.5: Explain the importance of density and compactive effort for both dense-graded and permeable bases
- LO 6.6: Describe the process for acceptance of unbound base and subbase layers

Lesson 7: Aggregates for Stabilized Bases

- LO 7.1: Describe the basic selection process for choosing a stabilized base instead of an unbound granular base
- LO 7.2: Describe the three stabilization processes (asphalt, Portland cement, and lime-fly ash), and compare the benefits and drawbacks of each
- LO 7.3: Explain best practices for construction of stabilized bases
- LO 7.4: Describe the process for acceptance of stabilized base items

Lesson 8: Strength and Deformation Properties of Aggregate Bases and Subbases

- LO 8.1: Describe the role of unbound aggregate and stabilized bases and subbases in terms of long-term pavement performance
- LO 8.2: Explain the various test methods used to evaluate the strength and deformation properties of aggregate bases and subbases

Lesson 9: Aggregates for Hot Mixed Asphalt (HMA)

- LO 9.1: Relate the physical properties of aggregates to the performance of HMA
- LO 9.2: List the most important coarse aggregate properties for HMA and the tests used to determine those properties
- LO 9.3: List the most important fine aggregate properties for HMA and the tests used to determine those properties
- LO 9.4: Explain the role of aggregates in providing skid resistance on HMA pavements
- LO 9.5: Explain HMA mix producers' aggregate quality control requirements for your State and the ways in which those requirements are monitored
- LO 9.6: Explain your State's aggregate quality assurance process for HMA mixes

Lesson 10: Aggregates for Portland Cement Concrete (PCC)

- LO 10.1: Relate the physical properties of aggregates to the performance of PCC
- LO 10.2: List the most important coarse aggregate properties for PCC and the tests used to determine those properties
- LO 10.3: List the most important fine aggregate properties for PCC and the tests used to determine those properties
- LO 10.4: Explain the role of aggregates in providing skid resistance on PCC pavements
- LO 10.5: Explain PCC mix producers' aggregate quality control requirements for your State and the ways in which those requirements are monitored

Lesson 11: Introduction to Web-conference Training Session #2

Lesson 12: Hot Topics

- LO 12.1: Share best practices for aggregate production and usage
- LO 12.2: Explain the potential effects of various emerging issues, changes in technology, shrinking aggregate resources, and industry trends
- LO 12.3: Evaluate the benefits of emerging test methods

Adobe Connect Virtual Classroom

The Adobe Connect virtual classroom is open 24 hours per day, 365 days per year. In the classroom, the facilitator and participants may find the following layouts:

Welcome Layout: This layout houses all of the administrative items associated with the module; e.g., file share pods for downloadable files, such as the Participant Workbook and pre-module assignments. This layout will be displayed before and after each session of the module.

Presentation Layout: This layout is used for sharing the slides for each module, keeping track of attendees, and facilitating ongoing chat discussions. It utilizes a variety of pods to perform these functions.

Some example layouts are provided below:

Some example layouts are provided below:

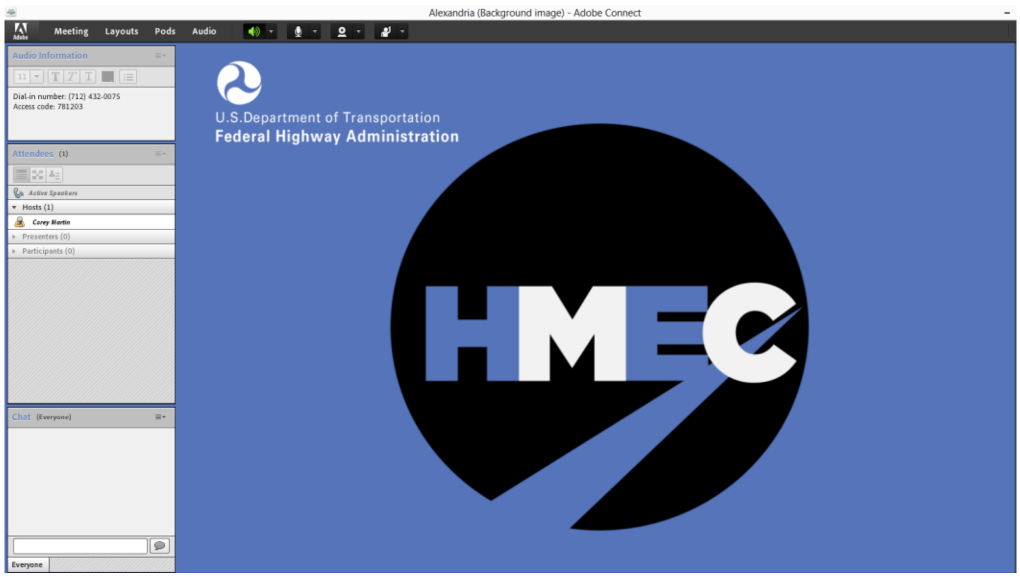


Figure 1: Welcome Layout Screen Shot with Various Pods

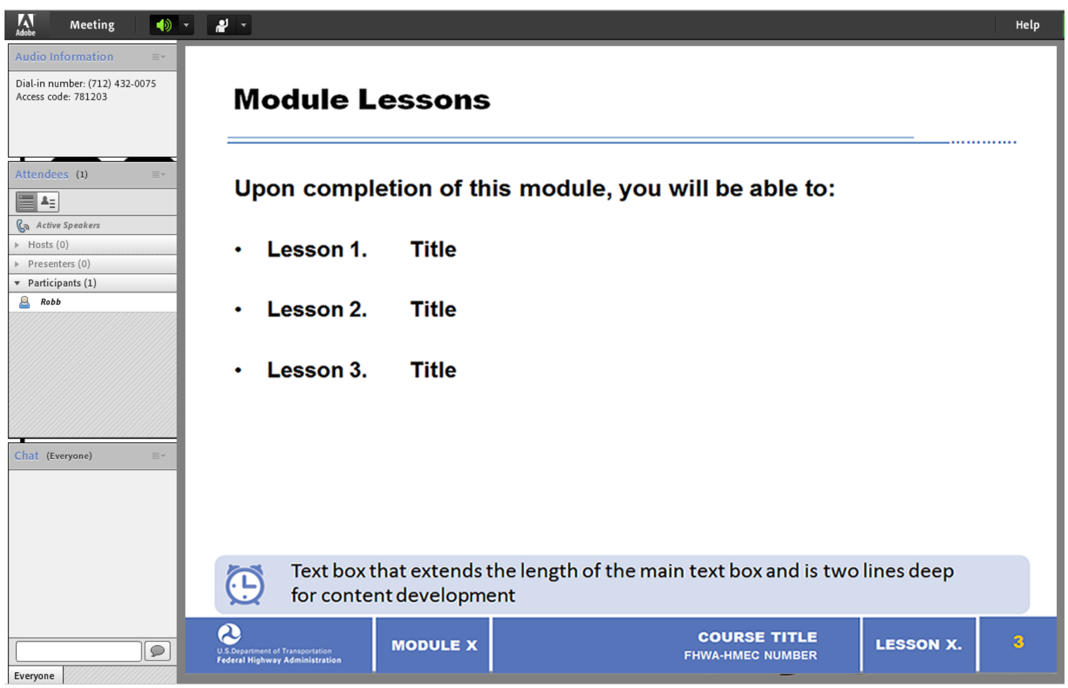


Figure 2: Adobe Connect Presentation Layout

WCT Facilitation Icons

The following icons are used on the slides as a cue to the instructor and participants:

Icon	Icon Name	Typical Use
	Timer	▪ Call out the estimated time for the lesson
	Chat Pod	▪ Ask and answer open-ended question(s). ▪ Post hyperlinks to Web sites. ▪ Provide further information to select attendees. ▪ Encourage attendees to share ideas with each other. ▪ Email contents of the pod.
	Note Pod	▪ Capture discussion points. ▪ Provide a way for small groups to document their results. ▪ Email contents of the pod.
	Whiteboard Tool	▪ Edit illustrations, such as diagrams, charts, documents, maps, and photographs. ▪ Record participant responses. ▪ Create visual examples.
	Poll Pod	▪ Ask multiple-choice questions with one or more correct answers. ▪ Gather opinions, i.e., conduct a survey. ▪ Prioritize a list of text items.
	Web Share Pod	▪ Share new content or resources. ▪ Instruct participants to search for information.

Icon	Icon Name	Typical Use
	Phone Discussion	▪ Facilitate introductions. ▪ Ask and answer verbal questions. ▪ Explain new ideas, concepts, or methods. ▪ Encourage learners to answer each other's questions.
	Breakout Rooms	▪ Assign small-group activities. ▪ Create a customized workspace for each breakout group to differentiate assignments for each group. ▪ Monitor breakout room discussions using chat pod and provide feedback.
	Important Information	▪ Call out important information.
	Q & A	▪ Check for understanding or agreement. ▪ Survey participants. ▪ Solicit feedback.

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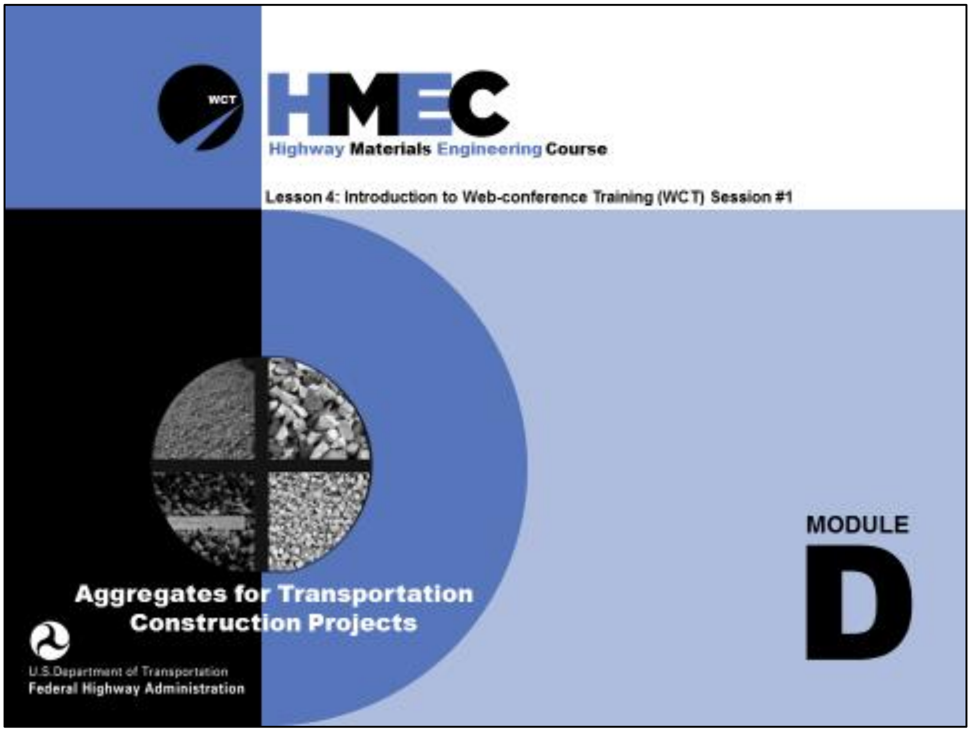
Slide 1


WCT
HMEC
Highway Materials Engineering Course
Lesson 4: Introduction to Web-conference Training (WCT) Session #1
Aggregates for Transportation
Construction Projects
U.S.Department of Transportation
Federal Highway Administration
MODULE
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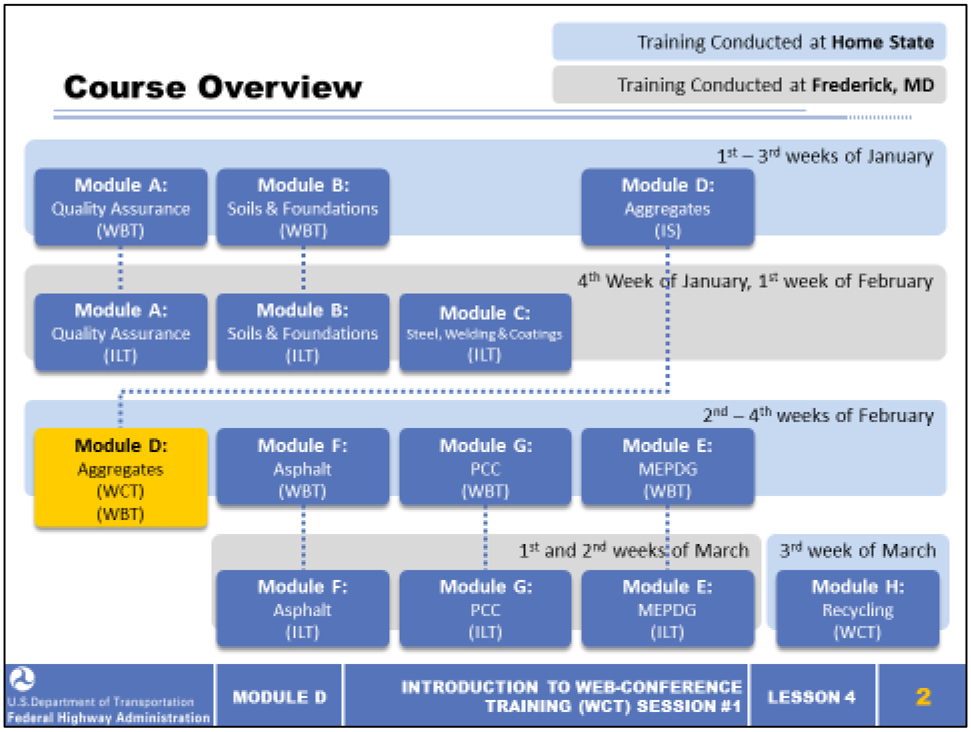
Slide 2


Training Conducted at Home State
Training Conducted at Frederick, MD
Course Overview
1st – 3rd weeks of January
Module A: Quality Assurance (WBT)
Module B: Soils & Foundations (WBT)
Module D: Aggregates (IS)
4th Week of January, 1st week of February
Module A: Quality Assurance (ILT)
Module B: Soils & Foundations (ILT)
Module C: Steel, Welding & Coatings (ILT)
2nd – 4th weeks of February
Module D: Aggregates (WCT) (WBT)
Module F: Asphalt (WBT)
Module G: PCC (WBT)
Module E: MEPDG (WBT)
1st and 2nd weeks of March
3rd week of March
Module F: Asphalt (ILT)
Module G: PCC (ILT)
Module E: MEPDG (ILT)
Module H: Recycling (WCT)
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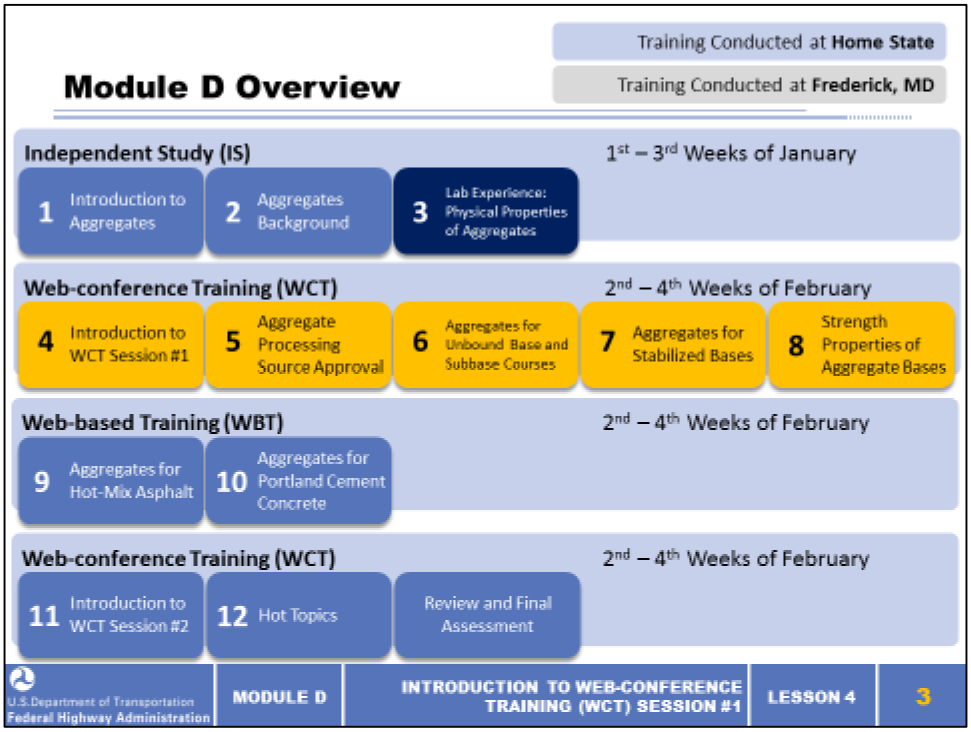
Slide 3


Training Conducted at Home State
Training Conducted at Frederick, MD
Module D Overview
Independent Study (IS)
1st – 3rd Weeks of January
1 Introduction to Aggregates
2 Aggregates Background
3 Lab Experience: Physical Properties of Aggregates
Web-conference Training (WCT)
2nd – 4th Weeks of February
4 Introduction to WCT Session #1
5 Aggregate Processing Source Approval
6 Aggregates for Unbound Base and Subbase Courses
7 Aggregates for Stabilized Bases
8 Strength Properties of Aggregate Bases
Web-based Training (WBT)
2nd – 4th Weeks of February
9 Aggregates for Hot-Mix Asphalt
10 Aggregates for Portland Cement Concrete
Web-conference Training (WCT)
2nd – 4th Weeks of February
11 Introduction to WCT Session #2
12 Hot Topics
Review and Final Assessment
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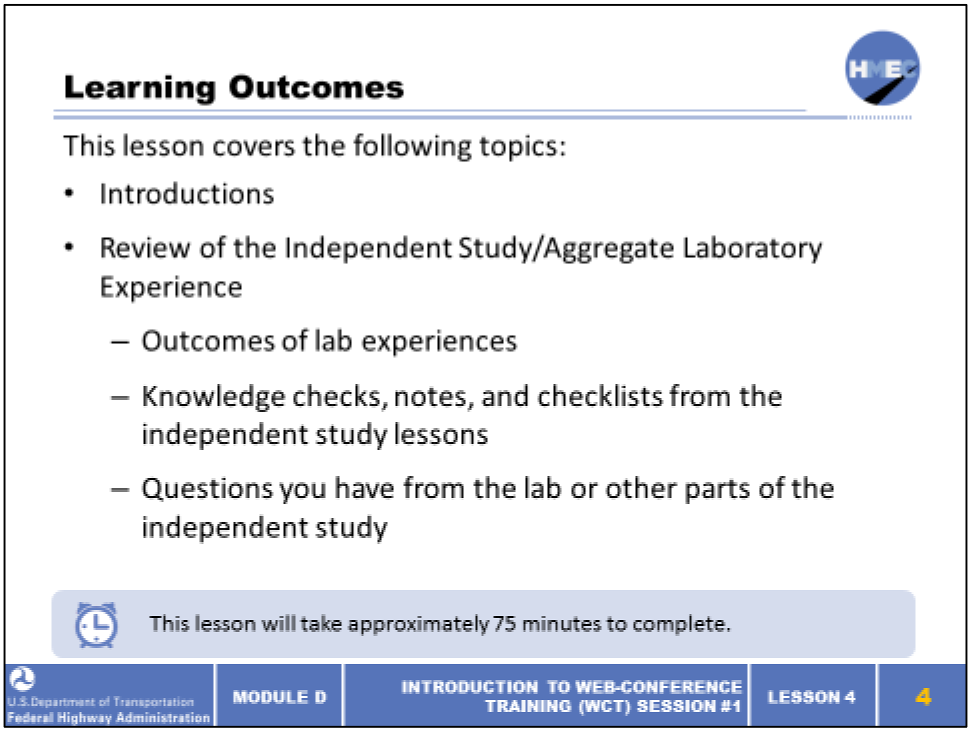
Slide 4


Learning Outcomes
This lesson covers the following topics:
• Introductions
• Review of the Independent Study/Aggregate Laboratory Experience
– Outcomes of lab experiences
– Knowledge checks, notes, and checklists from the independent study lessons
– Questions you have from the lab or other parts of the independent study
This lesson will take approximately 75 minutes to complete.
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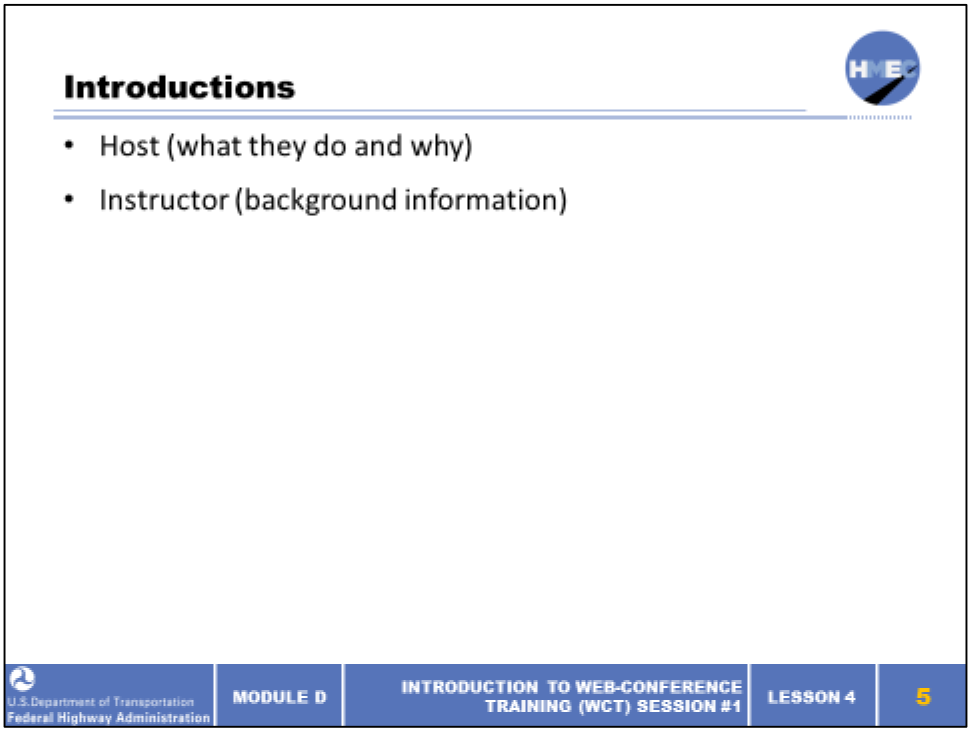
Slide 5


Introductions
• Host (what they do and why)
• Instructor (background information)
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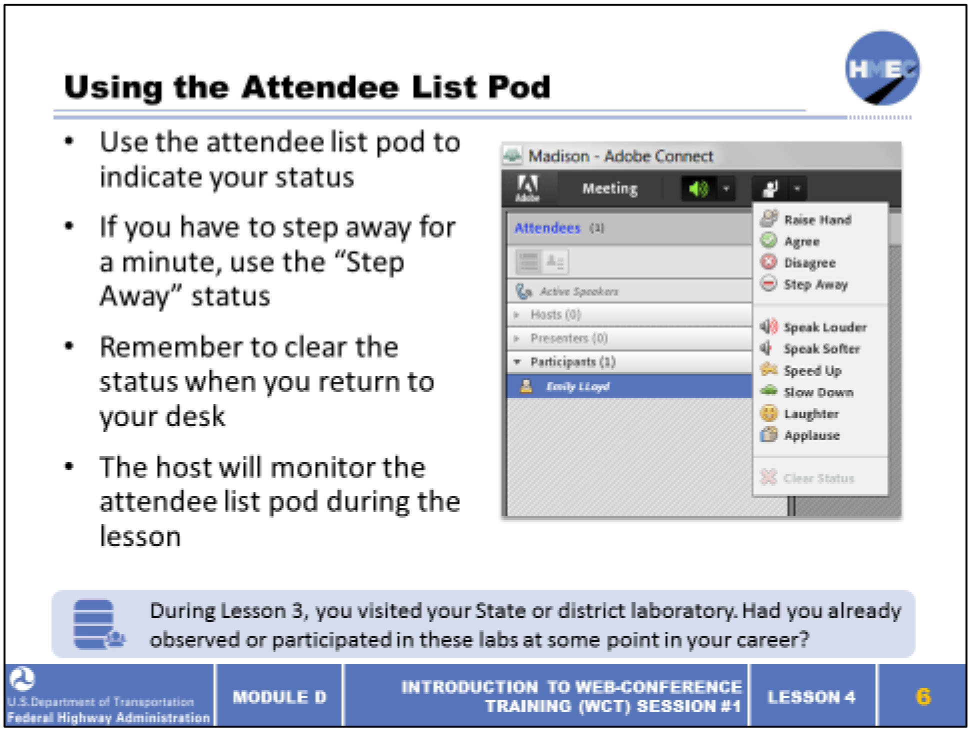
Slide 6



If you need to briefly step away, select the "Set Status" dropdown arrow and choose "Step Away." That way, the instructor will know that you had to step away from your computer. Don't forget to clear your status when you return to your desk.

Periodically throughout the Web-conference lessons, we may ask you to answer a question using the "Agree" or "Disagree" choices in the attendee list pod.

In addition, the host will monitor the attendee list pod during instruction. Your status is one way to communicate your needs during the lesson. The host will bring any status changes to the instructor's attention.

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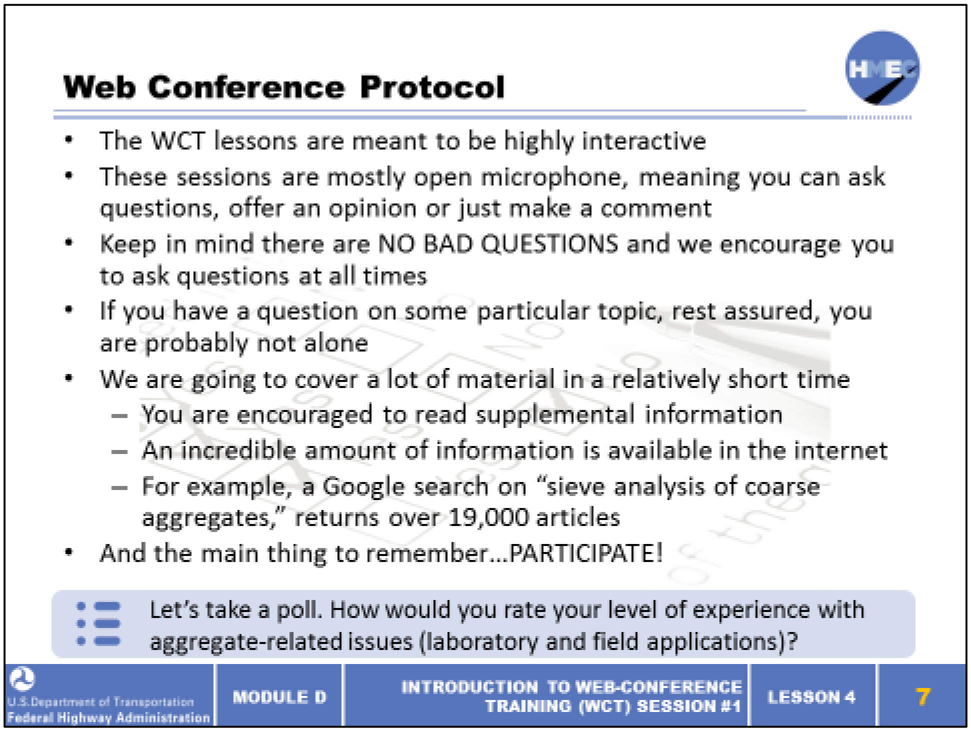
Slide 7



WCT lessons are designed to be very engaging—and, like in a traditional classroom, this only works if you actively participate.

Slide 8

Agency standards typically contain dozens of aggregate-related provisions that were identified in Lesson 1.

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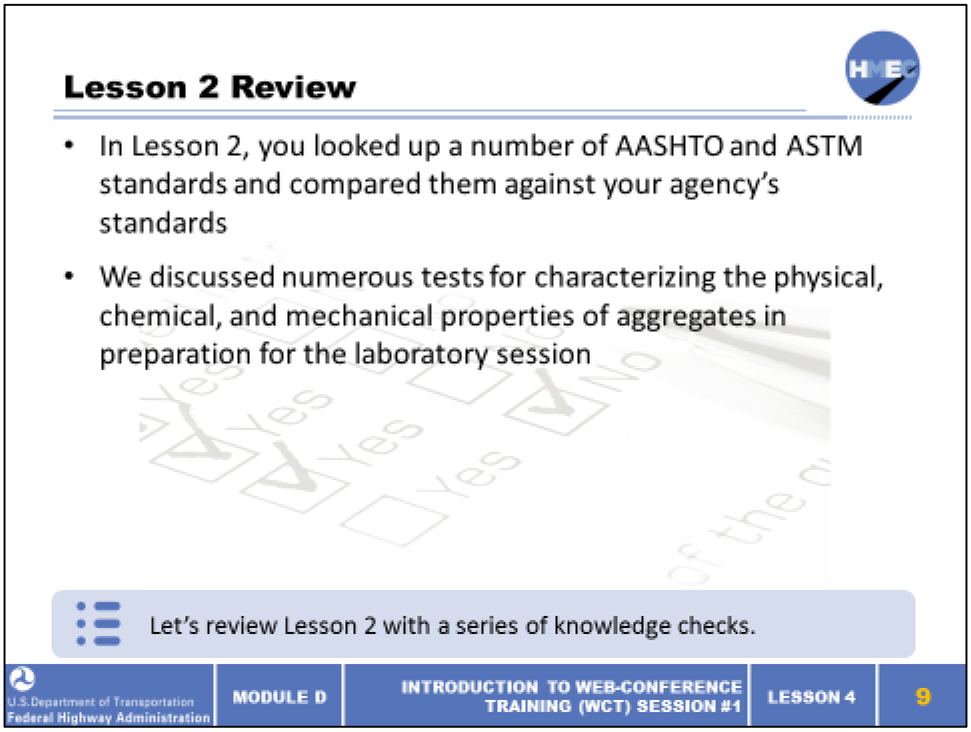
Slide 9



Lesson 2 presented an overview of aggregate uses, terminology, characterization methods, and a comparison between AASHTO/ASTM and agency standards.

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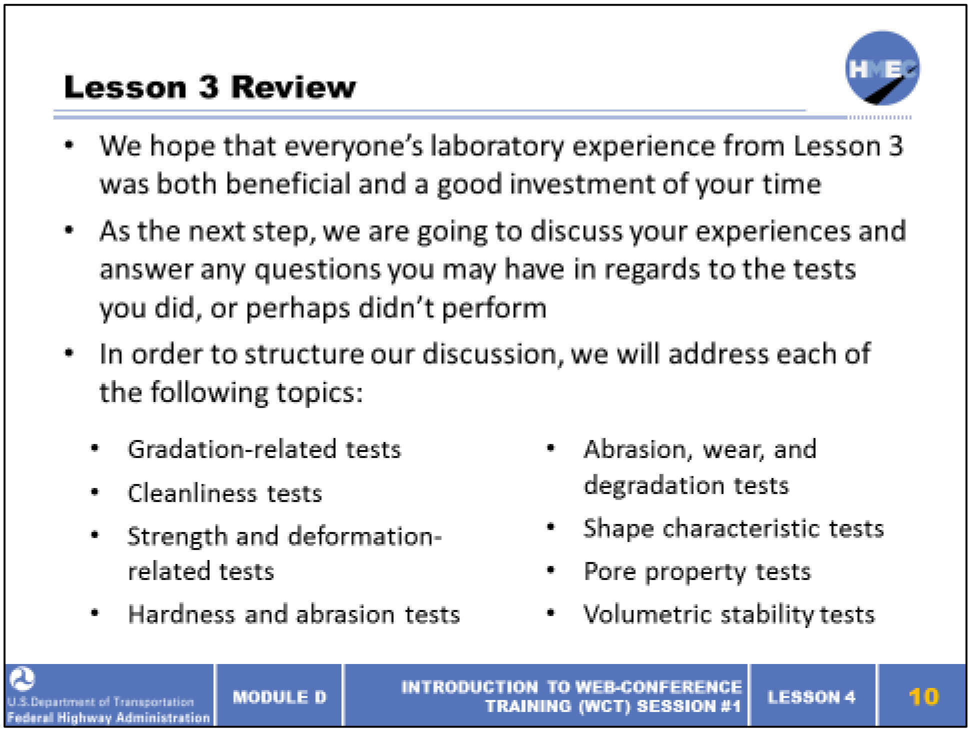
Slide 10


Lesson 3 Review
HMEC
We hope that everyone's laboratory experience from Lesson 3 was both beneficial and a good investment of your time
As the next step, we are going to discuss your experiences and answer any questions you may have in regards to the tests you did, or perhaps didn't perform
In order to structure our discussion, we will address each of the following topics:
Gradation-related tests
Cleanliness tests
Strength and deformation-related tests
Hardness and abrasion tests
Abrasion, wear, and degradation tests
Shape characteristic tests
Pore property tests
Volumetric stability tests
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Gradation-Related Tests

Sieve Analysis	T 27	C 136	Sieve Analysis of Fine and Coarse Aggregates
Wash Loss	T 11	C 117	Materials Finer than 75-µm (#200) Sieve in Mineral Aggregates by Washing
Hydrometer Test	T 88		Particle Size Analysis of Soils: Hydrometer Test

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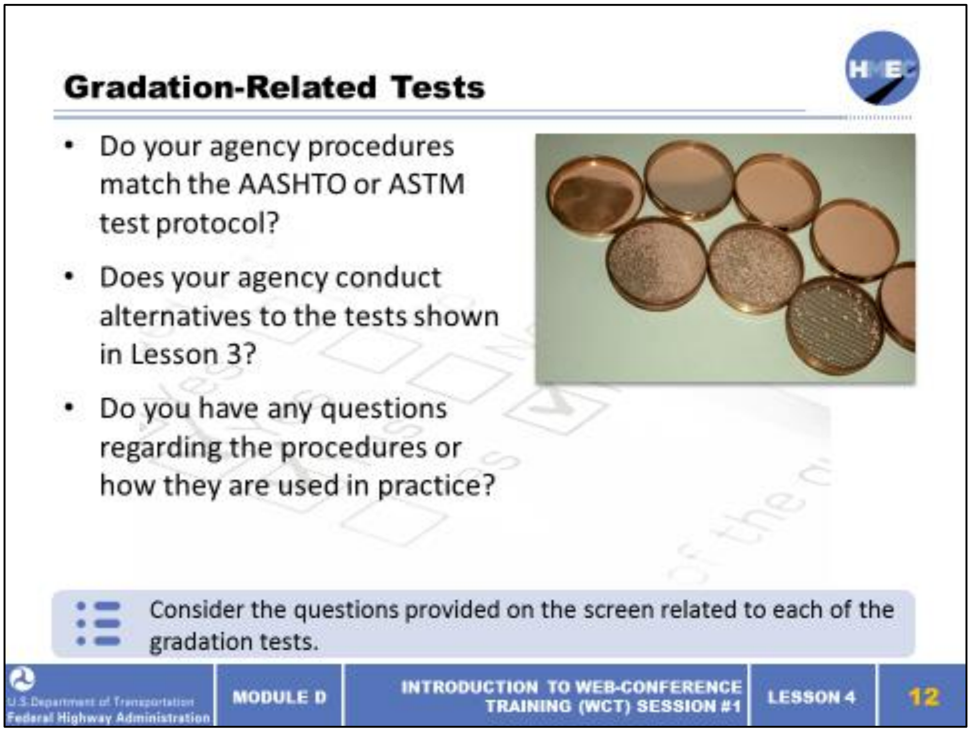
Gradation-Related Tests
Do your agency procedures match the AASHTO or ASTM test protocol?
Does your agency conduct alternatives to the tests shown in Lesson 3?
Do you have any questions regarding the procedures or how they are used in practice?
Consider the questions provided on the screen related to each of the gradation tests.
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Aggregate Cleanliness

T 176	D 2419	Plastic Fines in Graded Aggregates and Soils by Use of the Sand Equivalent Test
T 330		The Qualitative Detection of Harmful Clays of the Smectite Group in Aggregates Using Methylene Blue
T 89 and T 90		Determining the Liquid Limit, Plastic Limit, and Plasticity Index of Soils

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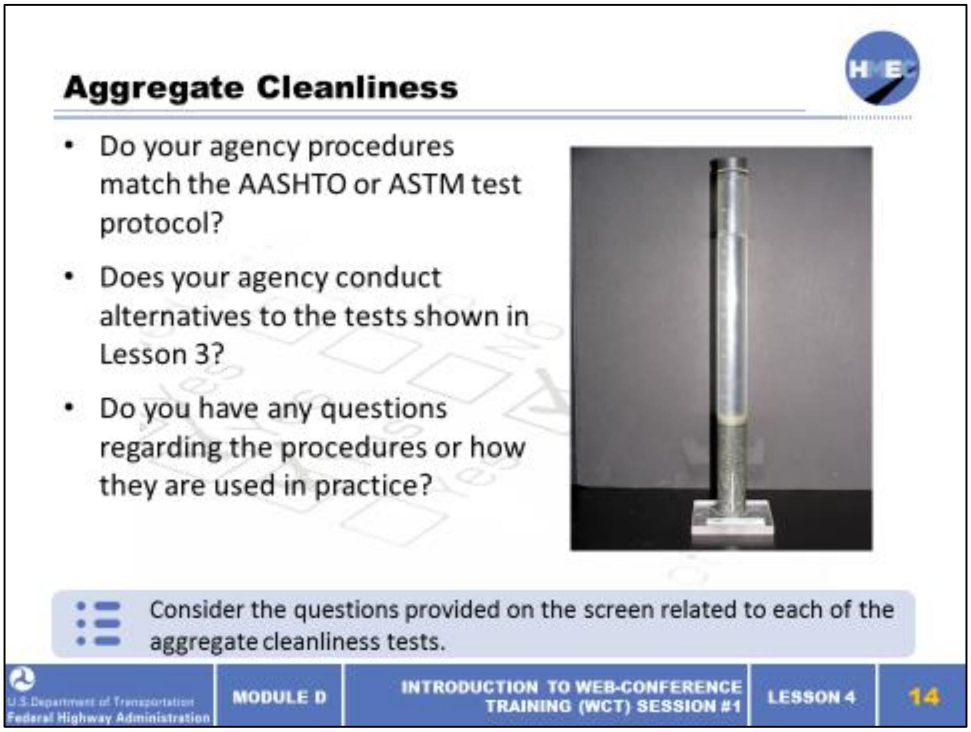
Aggregate Cleanliness
HMEC
Do your agency procedures match the AASHTO or ASTM test protocol?
Does your agency conduct alternatives to the tests shown in Lesson 3?
Do you have any questions regarding the procedures or how they are used in practice?
Consider the questions provided on the screen related to each of the aggregate cleanliness tests.
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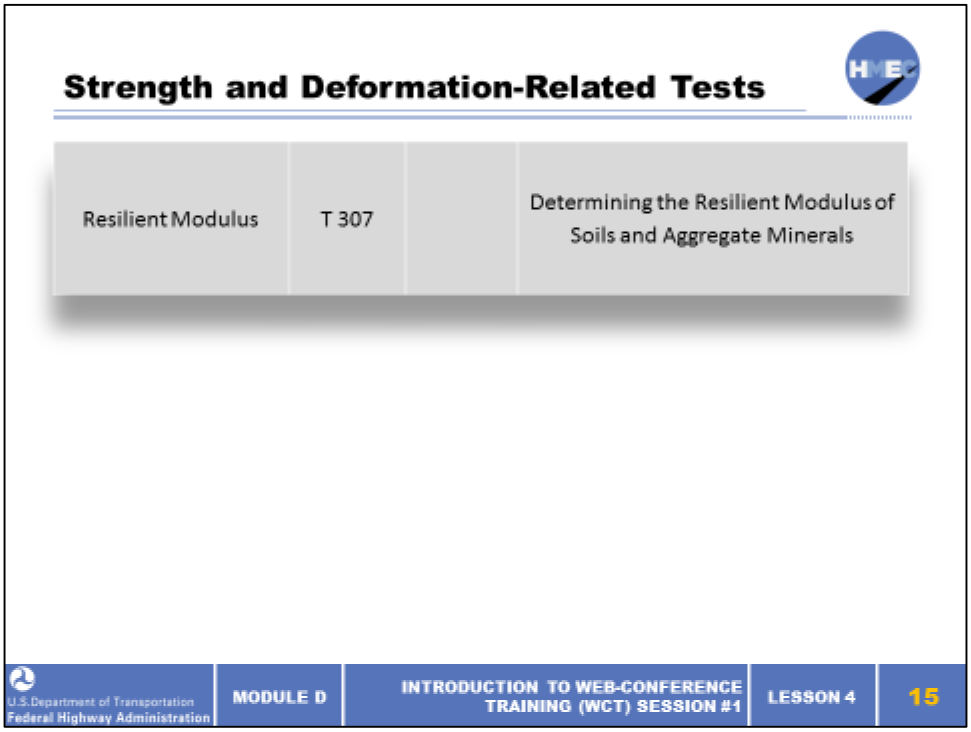
Strength and Deformation-Related Tests
HMEC
Resilient Modulus
T 307
Determining the Resilient Modulus of Soils and Aggregate Minerals
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Federal Highway Administration
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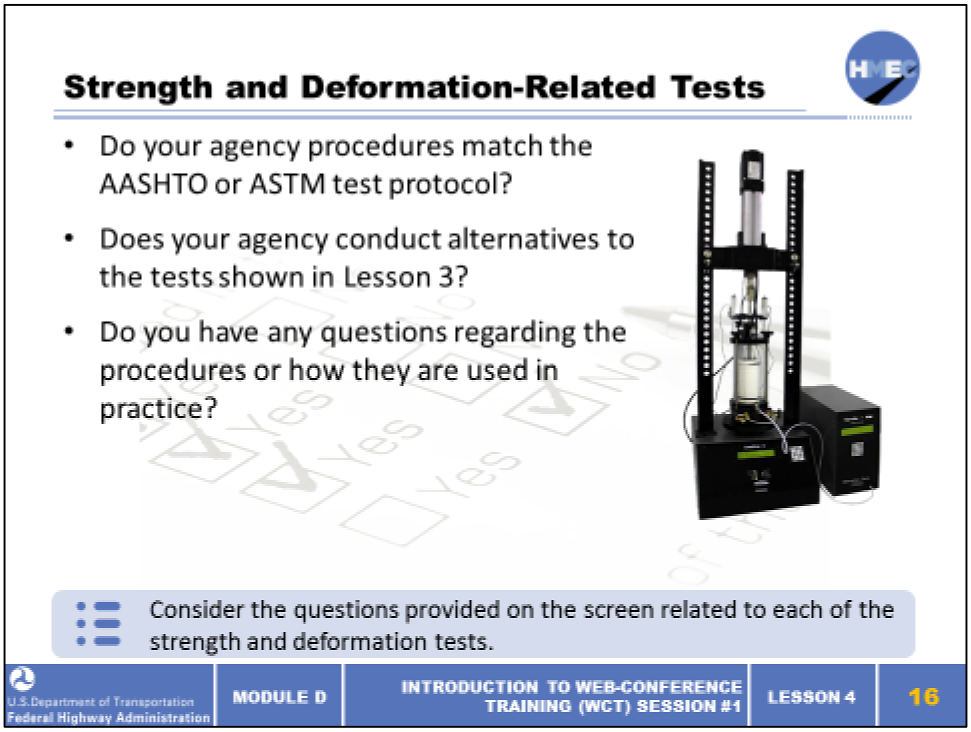
Strength and Deformation-Related Tests
HMEC
• Do your agency procedures match the AASHTO or ASTM test protocol?
• Does your agency conduct alternatives to the tests shown in Lesson 3?
• Do you have any questions regarding the procedures or how they are used in practice?
Consider the questions provided on the screen related to each of the strength and deformation tests.
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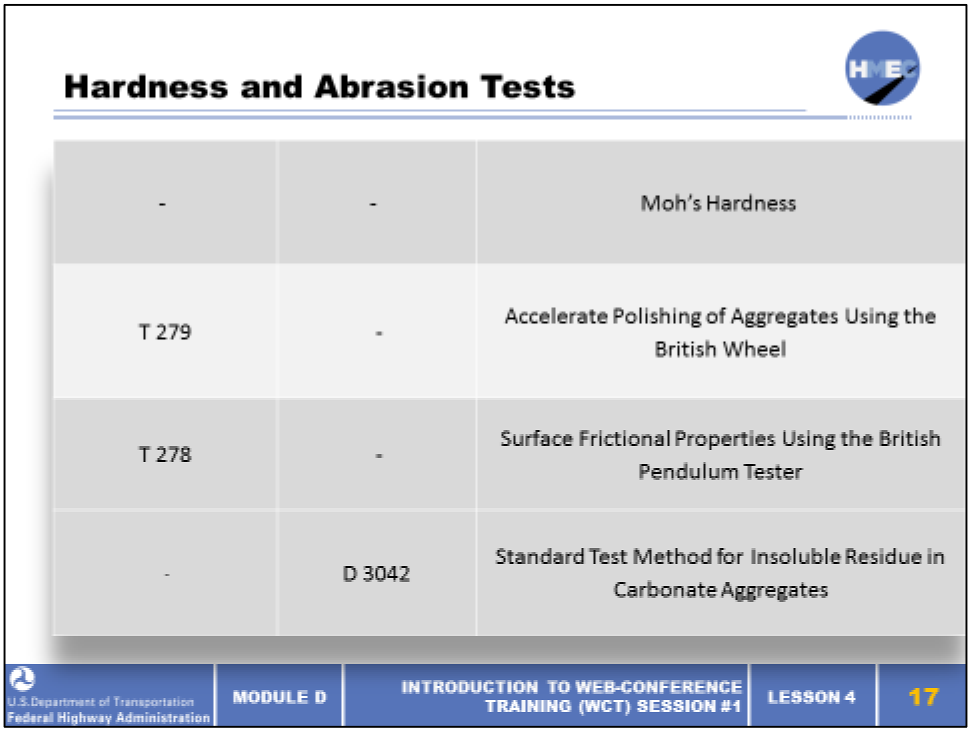
Slide 17



-	-	Moh's Hardness
T 279	-	Accelerate Polishing of Aggregates Using the British Wheel
T 278	-	Surface Frictional Properties Using the British Pendulum Tester
-	D 3042	Standard Test Method for Insoluble Residue in Carbonate Aggregates

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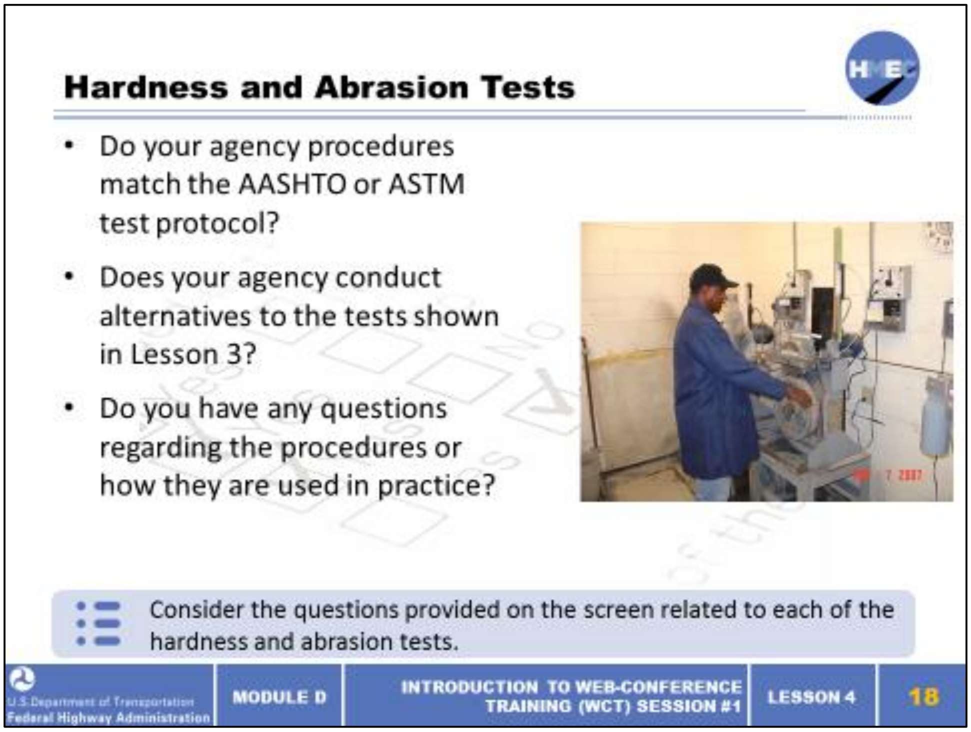
Hardness and Abrasion Tests
HMEC
• Do your agency procedures match the AASHTO or ASTM test protocol?
• Does your agency conduct alternatives to the tests shown in Lesson 3?
• Do you have any questions regarding the procedures or how they are used in practice?
Consider the questions provided on the screen related to each of the hardness and abrasion tests.
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Abrasion, Wear and Degradation Tests

T 96	C 131	Resistance to Degradation of Small-Size Coarse Aggregate by Abrasion and Impact in the Los Angeles Machine
	C 535	Resistance to Degradation of Large-Size Coarse Aggregate by Abrasion and Impact in the Los Angeles Machine
T 327	D 6928	Resistance of Coarse Aggregate to Degradation by Abrasion in the Micro-Deval Apparatus
	D 7428	Resistance of Fine Aggregate to Degradation by Abrasion in the Micro-Deval Apparatus

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Abrasion, Wear and Degradation Tests
Do your agency procedures match the AASHTO or ASTM test protocol?
Does your agency conduct alternatives to the tests shown in Lesson 3?
Do you have any questions regarding the procedures or how they are used in practice?
Consider the questions provided on the screen related to each of the abrasion, wear and degradation tests.
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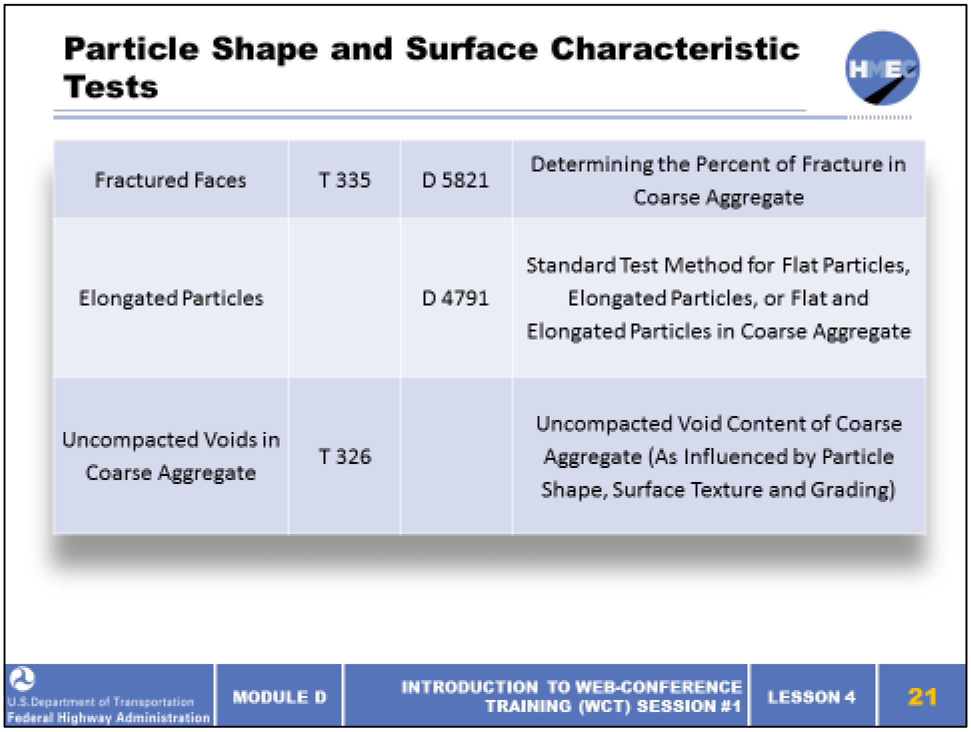
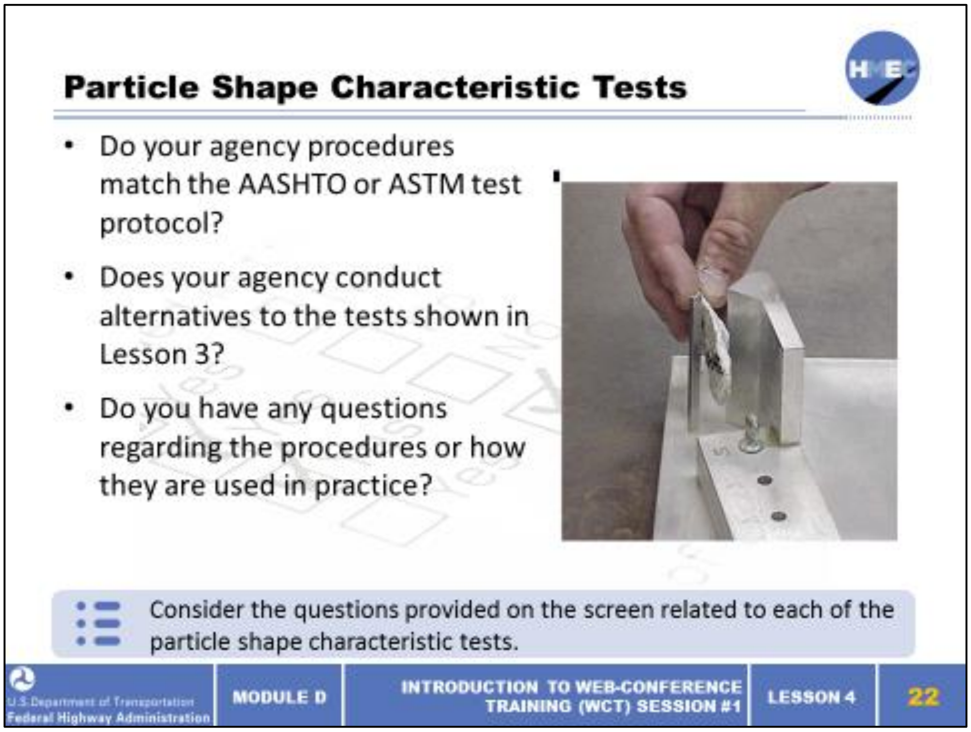


Particle Shape and Surface Characteristic Tests

Fractured Faces	T 335	D 5821	Determining the Percent of Fracture in Coarse Aggregate
Elongated Particles		D 4791	Standard Test Method for Flat Particles, Elongated Particles, or Flat and Elongated Particles in Coarse Aggregate
Uncompacted Voids in Coarse Aggregate	T 326		Uncompacted Void Content of Coarse Aggregate (As Influenced by Particle Shape, Surface Texture and Grading)

Slide 22


Particle Shape Characteristic Tests
HMEC
• Do your agency procedures match the AASHTO or ASTM test protocol?
• Does your agency conduct alternatives to the tests shown in Lesson 3?
• Do you have any questions regarding the procedures or how they are used in practice?
Consider the questions provided on the screen related to each of the particle shape characteristic tests.
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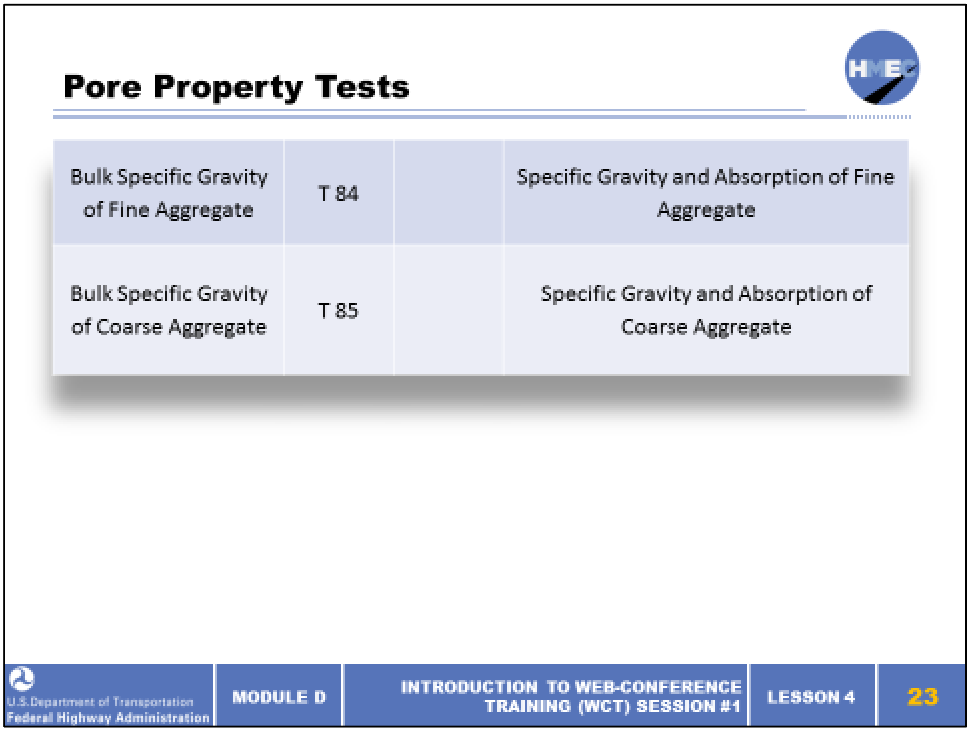
Pore Property Tests
Bulk Specific Gravity of Fine Aggregate
T 84
Specific Gravity and Absorption of Fine Aggregate
Bulk Specific Gravity of Coarse Aggregate
T 85
Specific Gravity and Absorption of Coarse Aggregate
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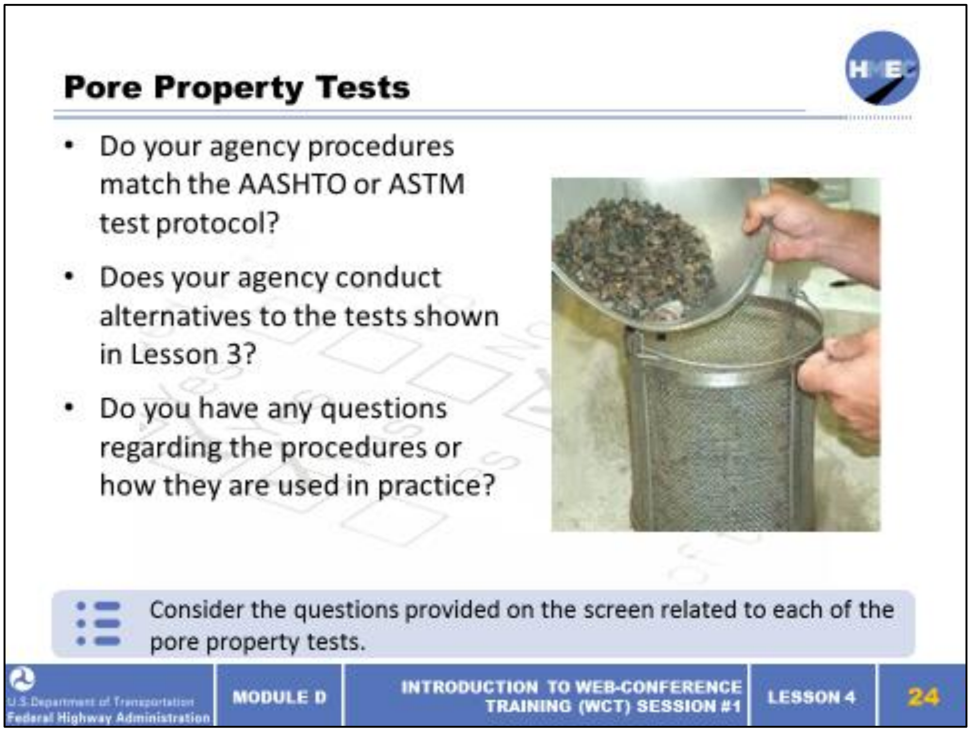
Pore Property Tests
Do your agency procedures match the AASHTO or ASTM test protocol?
Does your agency conduct alternatives to the tests shown in Lesson 3?
Do you have any questions regarding the procedures or how they are used in practice?
Consider the questions provided on the screen related to each of the pore property tests.
U.S. Department of Transportation Federal Highway Administration
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INTRODUCTION TO WEB-CONFERENCE TRAINING (WCT) SESSION #1
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Volumetric Stability Tests

T 336		Coefficient of Thermal Expansion of Hydraulic Cement Concrete
	C 1260	Test Method for Potential Reactivity of Aggregates (Mortar-Bar Test)
	C 295	Standard Guide for Petrographic Examination of Aggregates for Concrete

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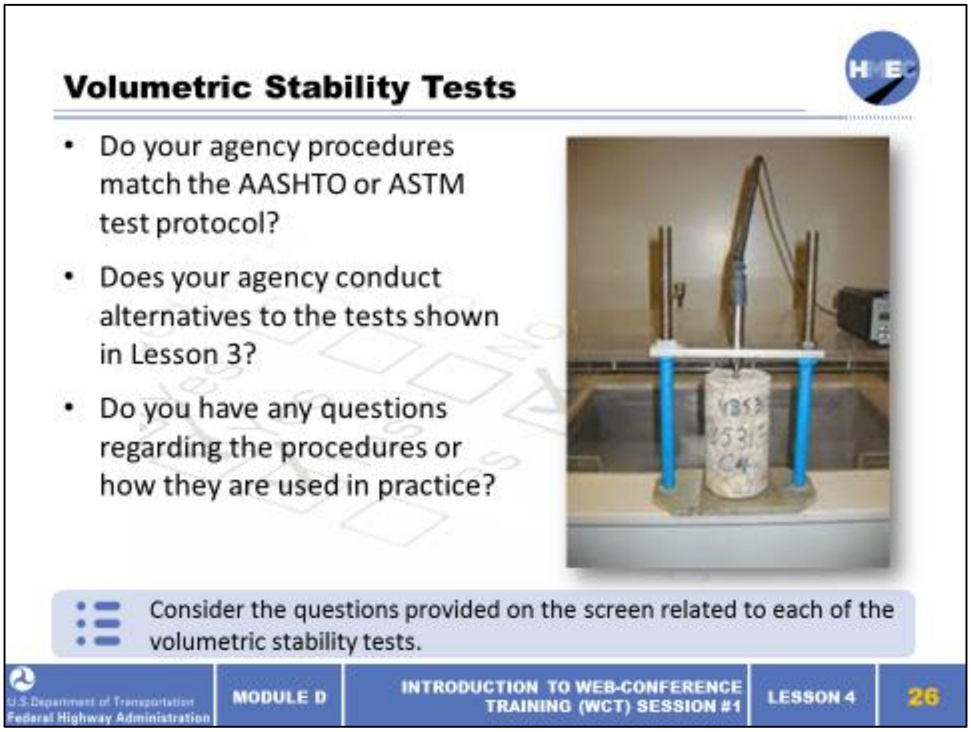
Slide 26


Volumetric Stability Tests
HMEC
• Do your agency procedures match the AASHTO or ASTM test protocol?
• Does your agency conduct alternatives to the tests shown in Lesson 3?
• Do you have any questions regarding the procedures or how they are used in practice?
Consider the questions provided on the screen related to each of the volumetric stability tests.
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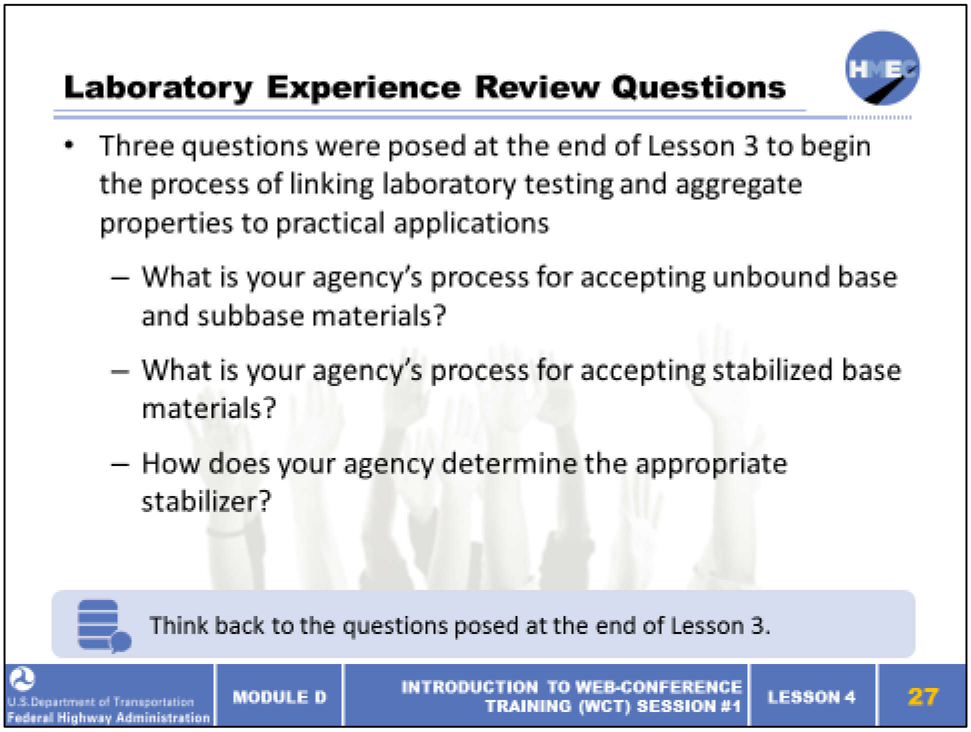
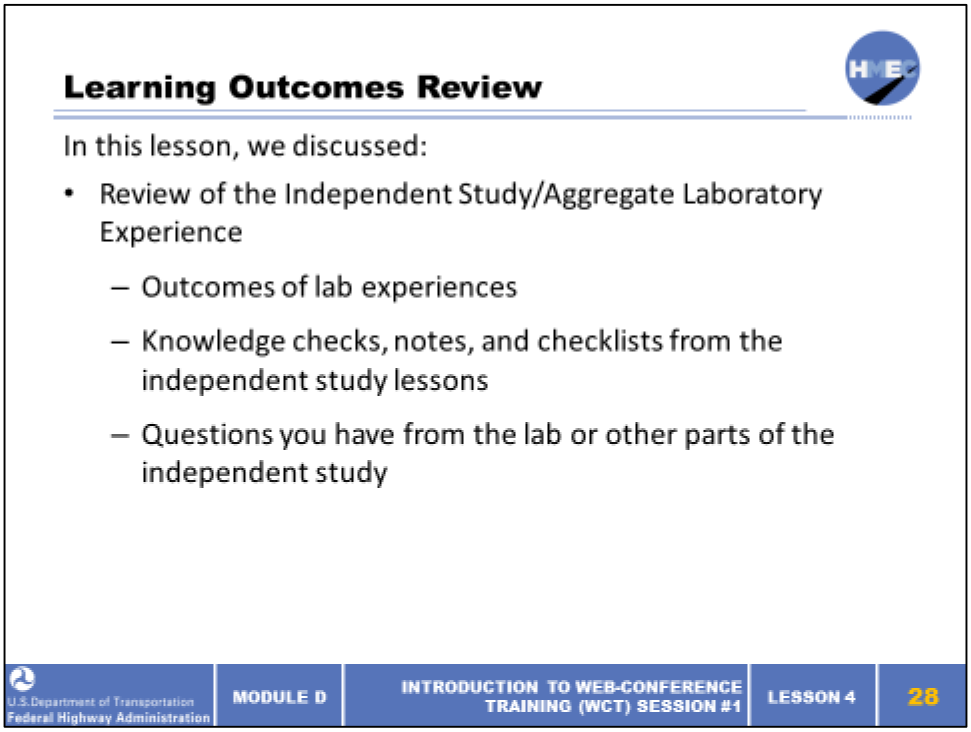
Slide 27



In subsequent lessons, we will provide detailed answers and further discussion of these topics.

Slide 28


Learning Outcomes Review
HMEC
In this lesson, we discussed:
• Review of the Independent Study/Aggregate Laboratory Experience
– Outcomes of lab experiences
– Knowledge checks, notes, and checklists from the independent study lessons
– Questions you have from the lab or other parts of the independent study
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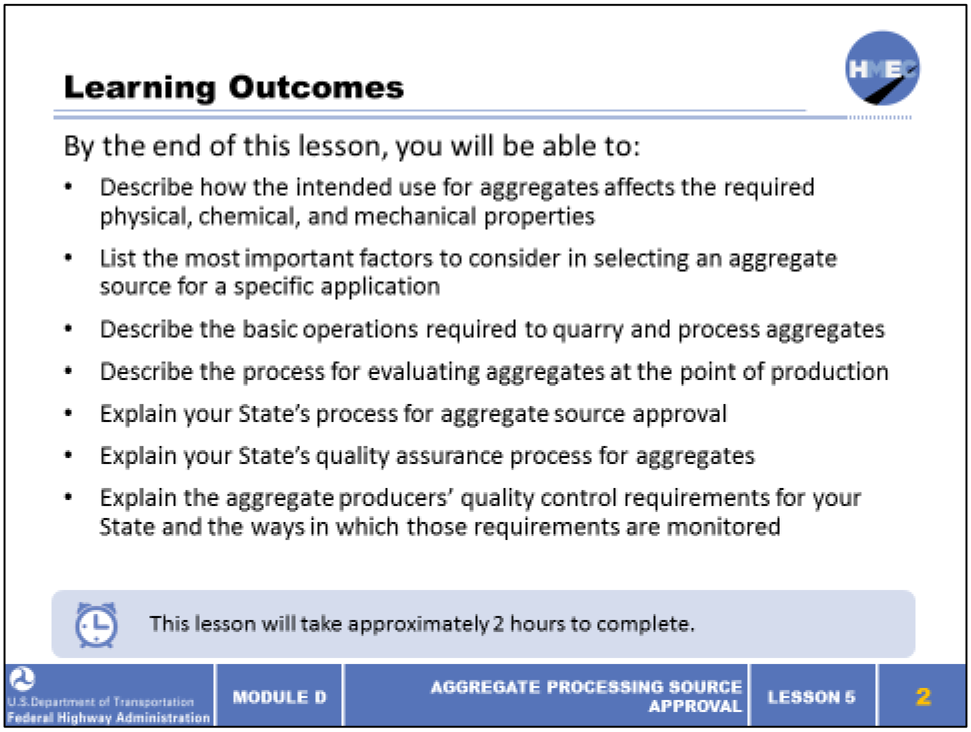
Slide 1


HMEC
Highway Materials Engineering Course
Lesson 5: Aggregate Processing Source Approval
Aggregates for Transportation Construction Projects
U.S.Department of Transportation
Federal Highway Administration
MODULE
D

Slide 2


Learning Outcomes
By the end of this lesson, you will be able to:
Describe how the intended use for aggregates affects the required physical, chemical, and mechanical properties
List the most important factors to consider in selecting an aggregate source for a specific application
Describe the basic operations required to quarry and process aggregates
Describe the process for evaluating aggregates at the point of production
Explain your State's process for aggregate source approval
Explain your State's quality assurance process for aggregates
Explain the aggregate producers' quality control requirements for your State and the ways in which those requirements are monitored
This lesson will take approximately 2 hours to complete.
U.S. Department of Transportation
Federal Highway Administration
MODULE D
AGGREGATE PROCESSING SOURCE APPROVAL
LESSON 5
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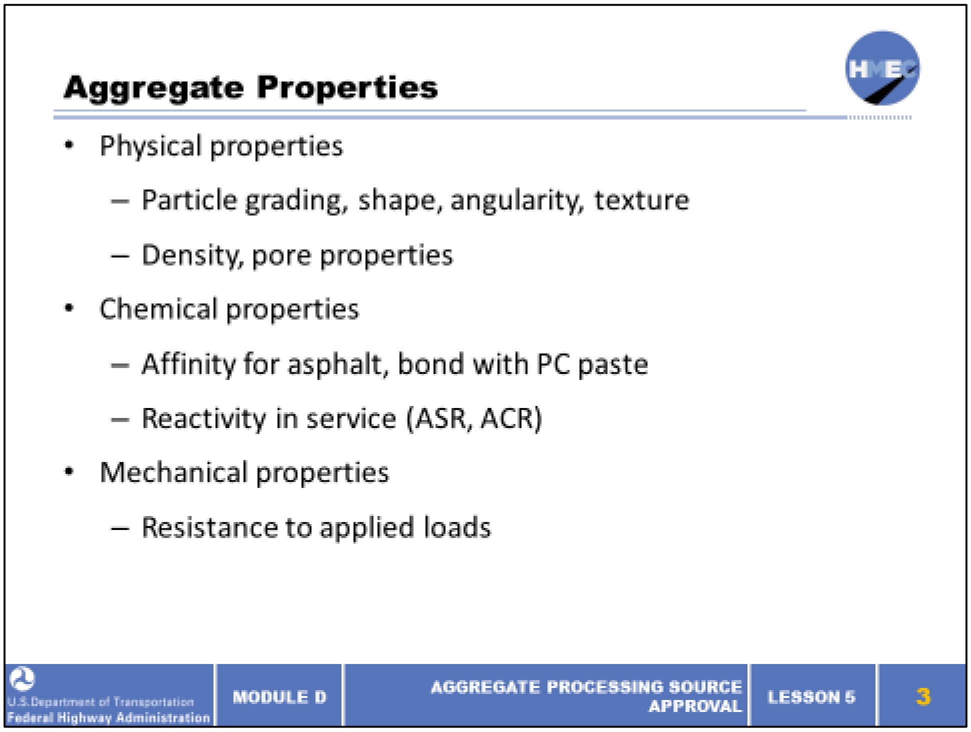
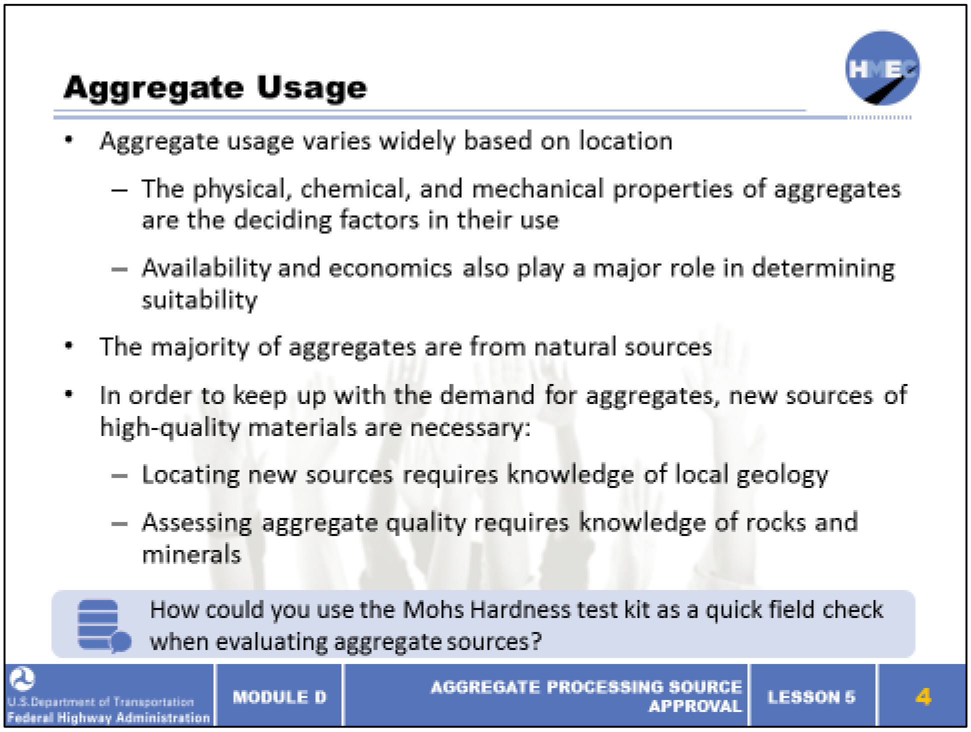
Slide 3



The basic physical, chemical, and mechanical properties of aggregates are very important to determine their overall suitability for a specific application.

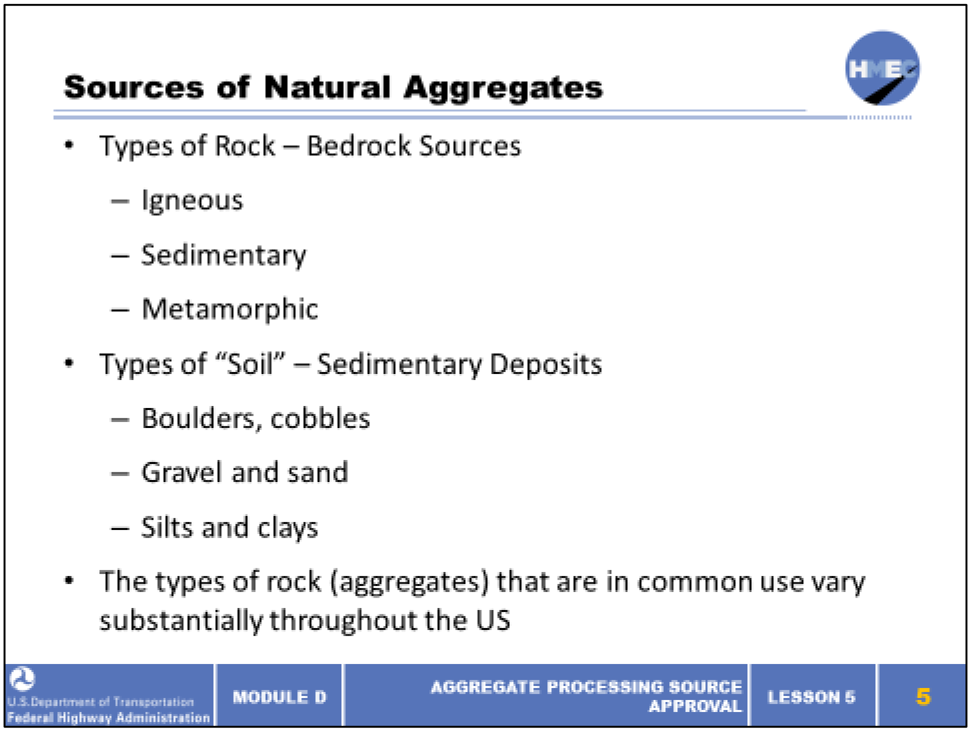
Slide 4



Basic geology deals with the rock and mineral material at or near the Earth's surface. Most aggregates come from natural sources. Rock is mined in quarries and later processed to produce crushed stone. Sand and gravel is dug from land-based pits or dredged from deposits below the water table. Knowledge of rocks and minerals is critical to locating suitable resources and determining the potential quality of the aggregate.

Note that high-quality aggregates may not always be available in a specific region.

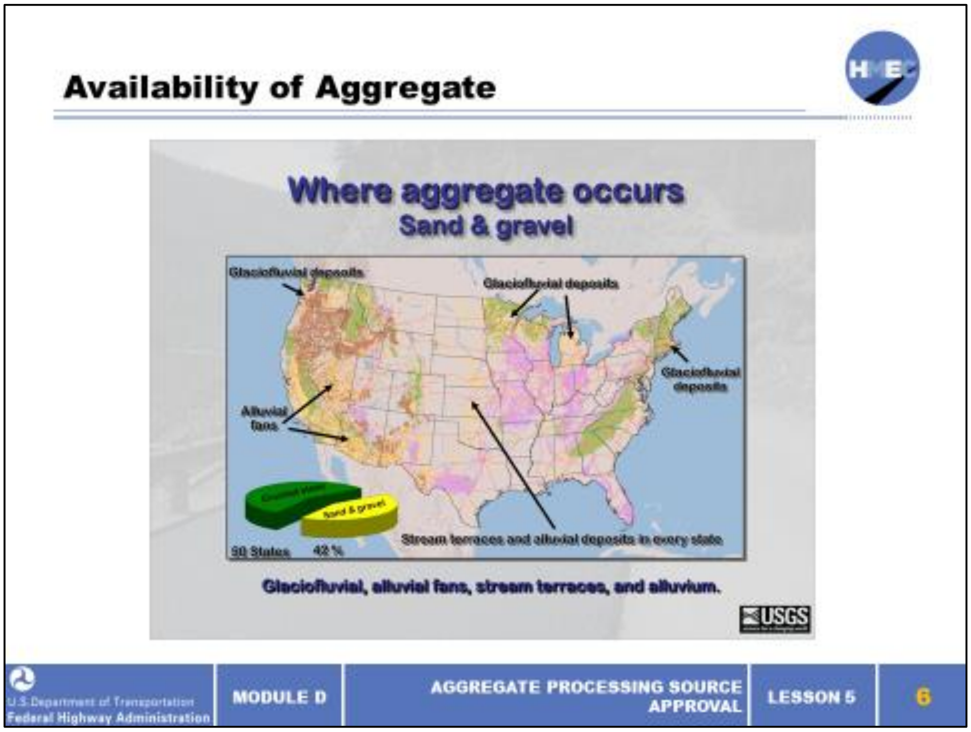
Slide 5



High-quality aggregates can be obtained from any of the three types of rock:

• Igneous: A solid continuous rock mass formed from solidification of molten material from within the Earth.
• Sedimentary: Material transported and deposited during the process of erosion.
• Metamorphic: Rock altered by temperature, pressure, or other factors acting within the Earth's crust

Slide 6

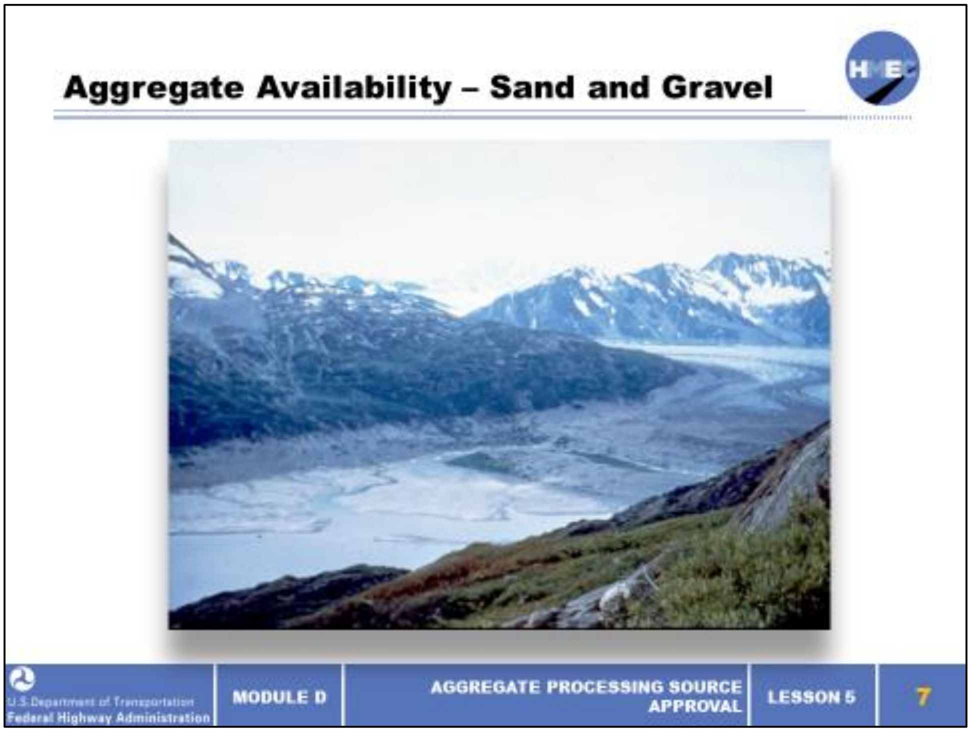


The aggregate industry commonly refers to two general groups of aggregates: sand and gravel and crushed stone. Sand and gravel make up about 42% of the total United States aggregate production. Sand and gravel is produced in every State (Bolen, 2008). Most sand and gravel produced in the United States is of glaciofluvial or alluvial origin. Glaciofluvial deposits are restricted to northern latitudes and high altitudes, and commonly make excellent sources of aggregate. Alluvial fans are typical of arid and semiarid regions and occur primarily in the Great Basin of the western United States. These materials tend to be poorly sorted and require significant processing before use as aggregate.

Alluvial (river or stream) deposits are widespread. Their properties are highly variable and depend in large part on the parent material from which they are derived and the distance from the bedrock source area. Those parts of the United States that have sources of good-quality bedrock also commonly have good quality alluvial gravels. The amount of gravel-sized particles in alluvial deposits commonly decreases the more distant the deposits are from the source area.

Notes: Reference: http://pubs.usgs.gov/of/2011/1119/pdf/OF11-1119_report_508.pdf

Slide 7



Sand and gravel deposits of significance are generally found in glaciated areas, deposits laid down by rivers and streams, and in alluvial fans coming out of mountainous regions.

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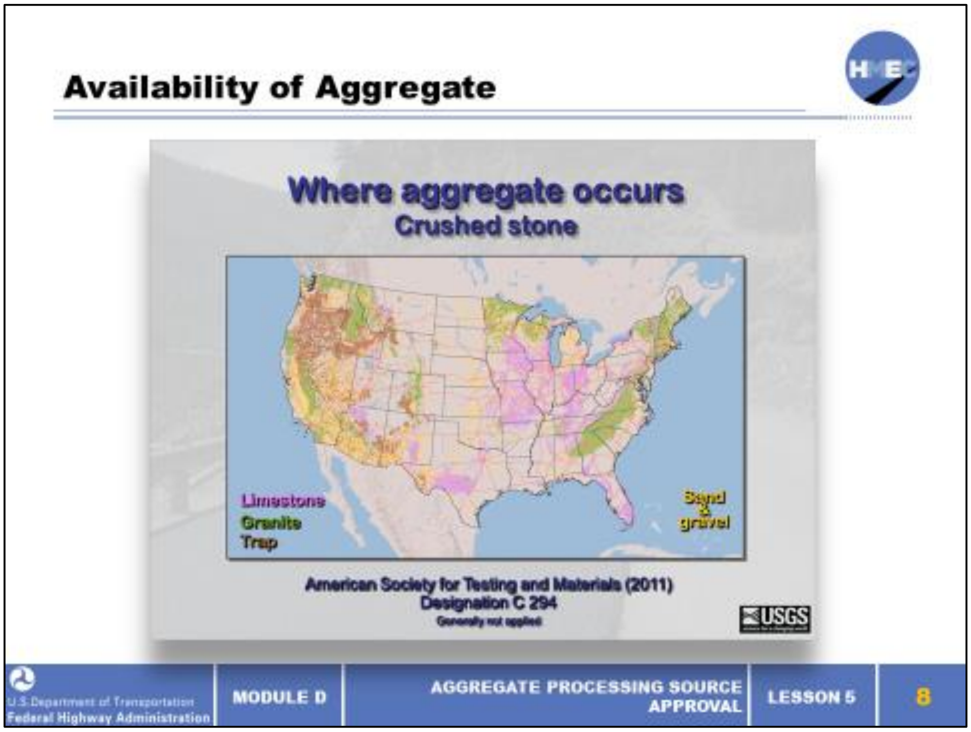

Crushed stone is the product resulting from the artificial crushing of rock and makes up about 58% of total United States aggregate production.

Crushed stone is commonly divided into four general groups that are loosely tied to common petrological classifications: limestone, granite, trap rock, and other rocks.

Notes: Reference: http://pubs.usgs.gov/of/2011/1119/pdf/OF11-1119_report_508.pdf

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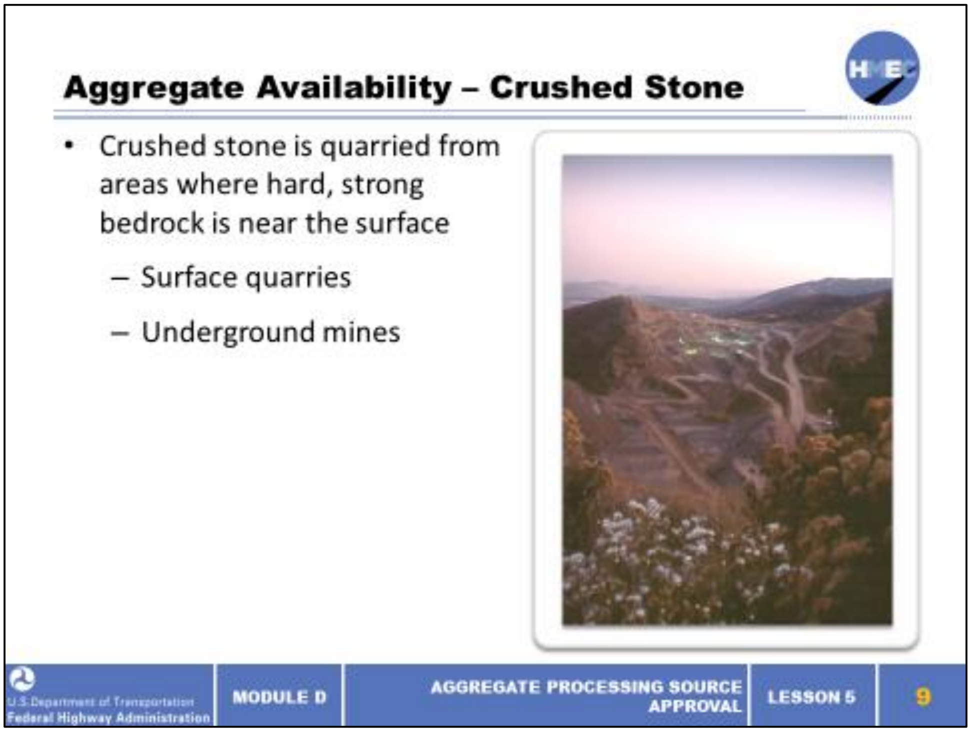
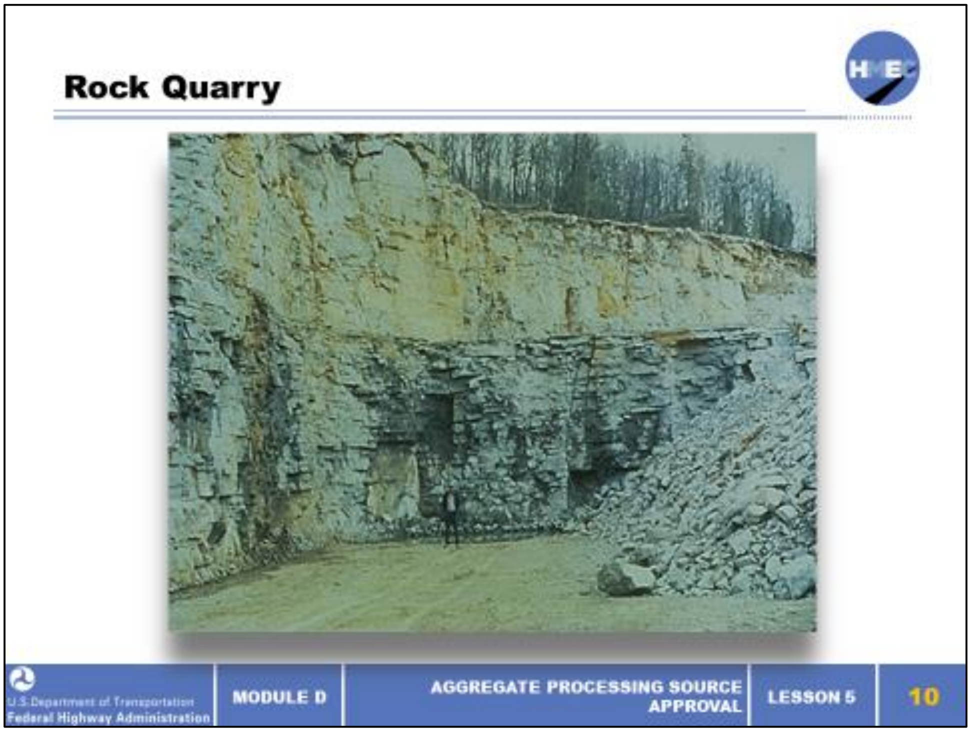


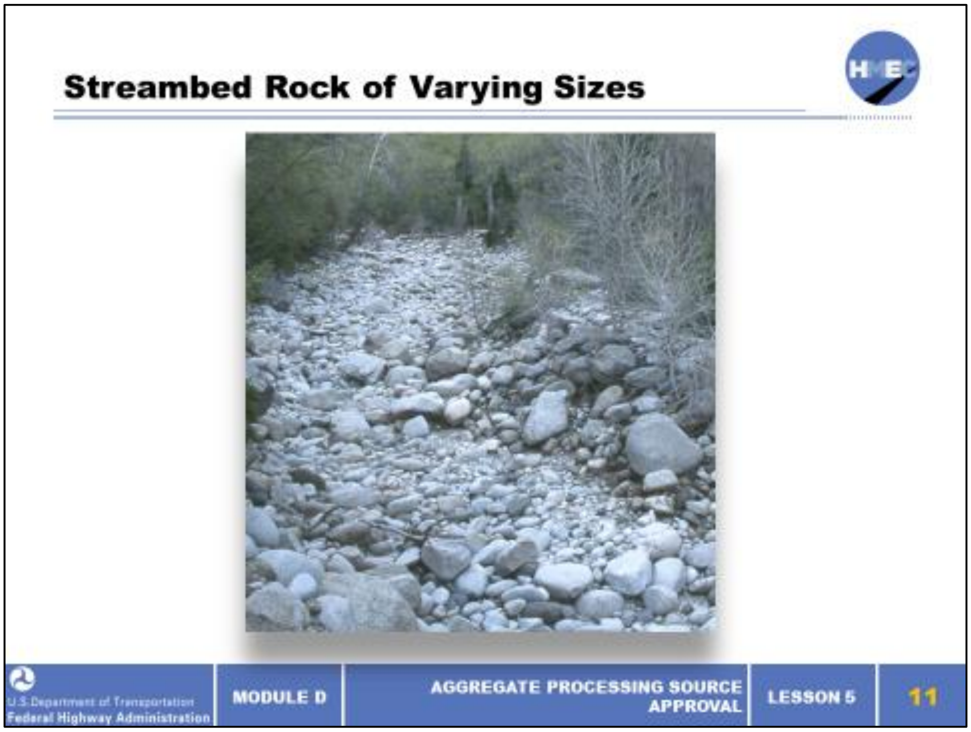
The task of locating suitable deposits of stone or gravel involves highly complex exploration, including but not limited to, the study of topographic and geological maps, air photographs, geophysical investigations using seismic and resistivity apparatus, and ultimately coring and boring to obtain samples for tests. Excellent guidance is found in an Appendix of AASHTO Standard T 2 on sampling aggregates.

Slide 10



Note the various rock strata, each with different properties that may influence its suitability for a specific end use.

Slide 11



Many western sand and gravel deposits include cobbles and boulders that are crushed to produce aggregates. This is in contrast to river laid deposits in flatter areas of the central part of the country; for example, where the top size in gravel and sand deposits is much smaller.

Slide 12

Igneous Rocks

Coarse Grained (Intrusive)	Fine Grained (Extrusive)	Fragmented and Glassy (Volcanic)
Granite	Rhyolite (a Felsite)	Ash, Tuff
Diorite	Andesite (a Felsite)	Pumice (Frothy)
Gabbro, Diabase (Dark, Trap Rock)	Basalt (Dark, Trap Rock)	Obsidian (Glassy)

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General classification of rock: The basic properties of aggregate materials greatly depends upon the mineral constituents present in their parent rock formation. Rocks are grouped in three major classes (igneous, sedimentary, or metamorphic) plus several subclasses, and many individual types within each class. The three main classes, the subclasses, and the types most commonly used for highway purposes are shown.

Igneous rocks are formed by the solidification of molten rock. The grain size of the rock depends on the rate of cooling. Rapid cooling (such as with submarine lava flows) may produce glass; lava flows on land tend to produce fine-grained rocks; rocks cooled within the Earth at slow rates tend to consist of large mineral grains.

Slide 13

Sedimentary Rocks

Mechanically Deposited	Chemically Deposited
Consolidated:	**Calcareous:**
Shale (Clay Particles)	Limestone and Dolomite
Siltstone (Silt Particles)	**Siliceous:**
Sandstone (Sand Grains)	Chert (Dense to Porous)
Conglomerate (Gravel, etc.)	Opal (Coating, Filling)

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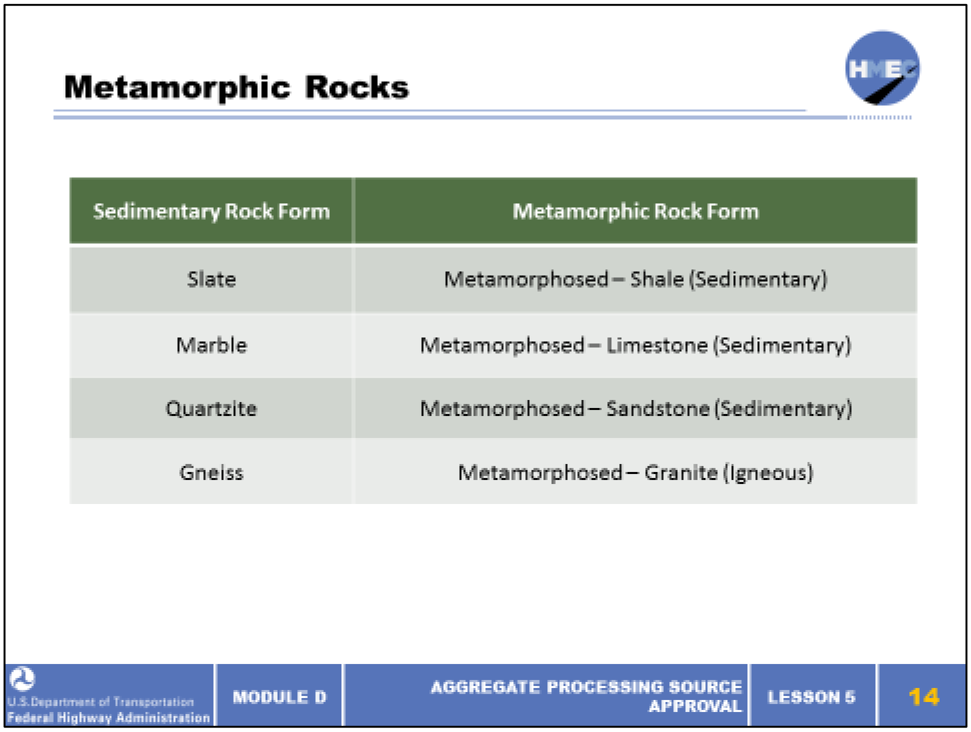
These sedimentary rocks result from the induration of sediments deposited by wind, water, or glaciers, or direct precipitation of material from water. Loose sand and gravel deposits are also sedimentary in nature.

Slide 14

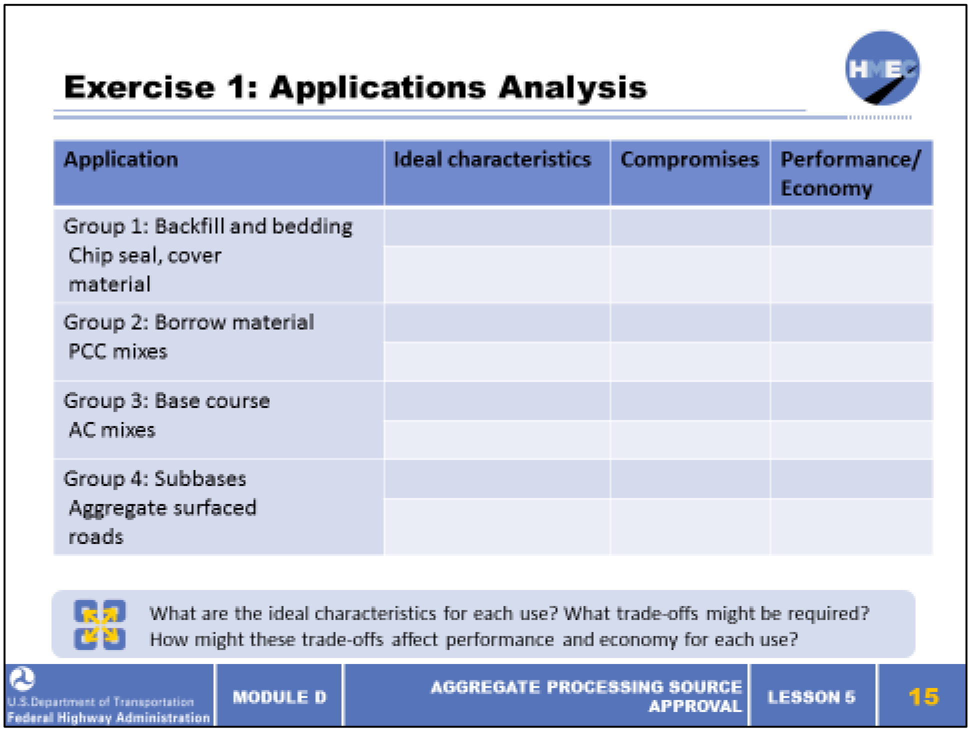

Metamorphic Rocks

Sedimentary Rock Form	Metamorphic Rock Form
Slate	Metamorphosed – Shale (Sedimentary)
Marble	Metamorphosed – Limestone (Sedimentary)
Quartzite	Metamorphosed – Sandstone (Sedimentary)
Gneiss	Metamorphosed – Granite (Igneous)

Metamorphic rocks result from the “re-working” of pre-existing rocks (igneous, sedimentary, or older metamorphic rocks) under the influence of high temperatures and pressures within the Earth.

All three classes of rock have been used successfully as road aggregate. The suitability of aggregate from a given source must be estimated from a combination of tests, supplemented by mineralogical examination. Even the most widely used tests are sometimes misleading due to errors in sampling and lack of precision in the test method itself. The best possible index of aggregate suitability is its known performance in earlier service of the type contemplated.

Slide 15



Application	Ideal characteristics	Compromises	Performance/ Economy
Group 1: Backfill and bedding Chip seal, cover material			
Group 2: Borrow material PCC mixes			
Group 3: Base course AC mixes			
Group 4: Subbases Aggregate surfaced roads			

For optimal performance, the physical, chemical, and mechanical properties of aggregates must be matched to their intended use.

Slide 16

Exercise 1 Solutions: Applications Analysis

Application	Ideal characteristics	Compromises	Performance/ Economy
Group 1: Backfill and bedding			
Chip seal, cover material			
Group 2: Borrow material			
PCC mixes			
Group 3: Base course			
AC mixes			
Group 4: Subbases			
Aggregate surfaced roads			

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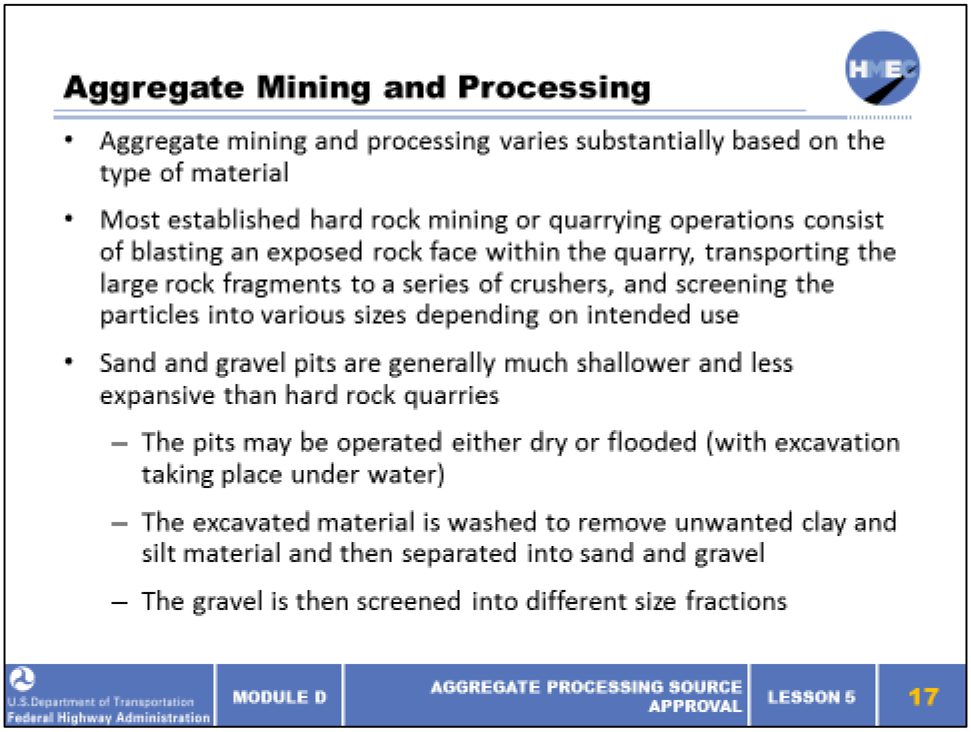
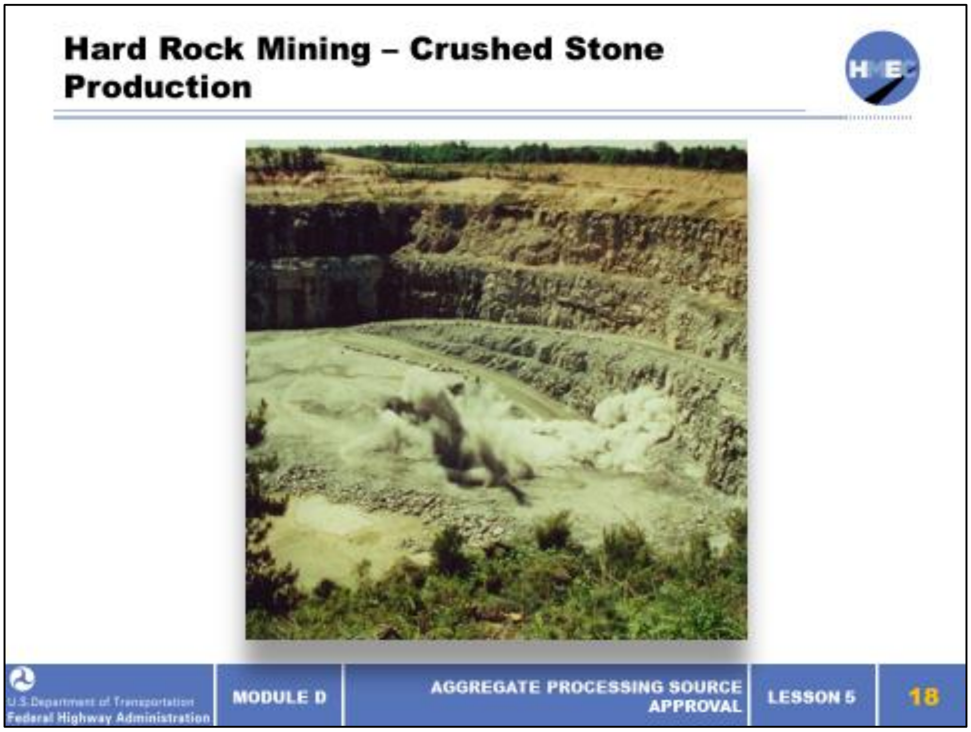


Hard aggregate quarries are typically very large and over time, very deep. Due to the massive scale of these operations, they tend to be in production mode for 30 years or more. Sand and gravel operations on the other hand may be relatively small and have a much shorter production run.

It should be noted that environmental regulations make it very difficult and expensive to open a new quarry.

Slide 18



Crushed stone production is a large-scale operation. Note the different rock ledges and the overburden.

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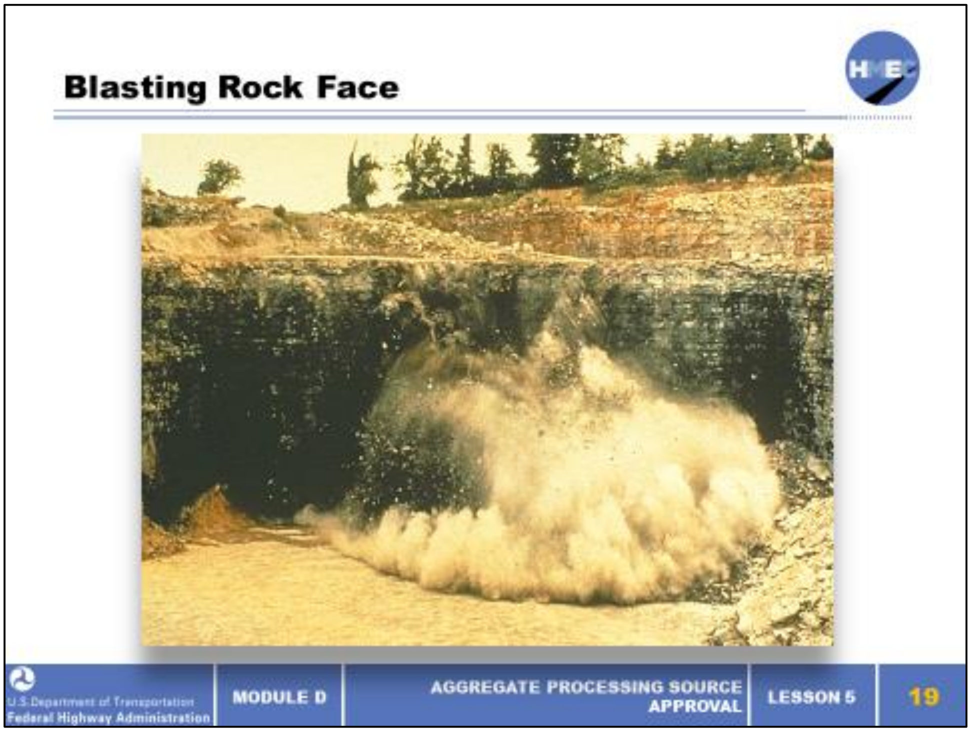

Blasting the face of a rock ledge is done to produce crushed stone. The depth of the rock-blasting zone depends on the geology and the mining plan for the quarry. The pattern for blasting holes and explosive charges is chosen to produce a desirable breakage pattern for the rock, without either excessive fine material or oversize rock that is too large for the primary crusher.

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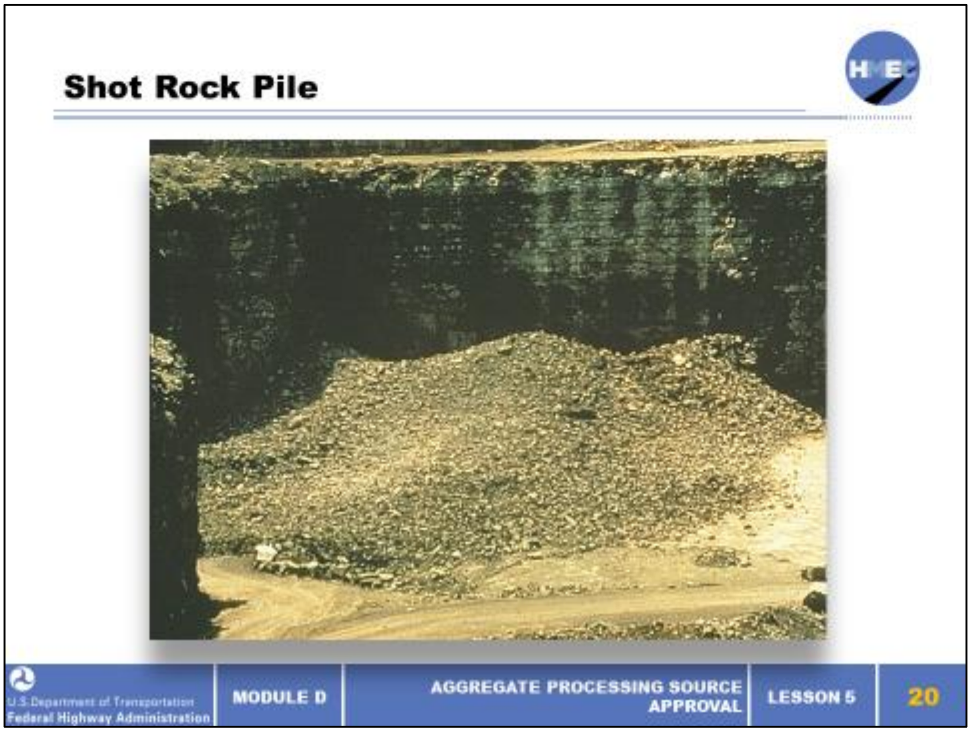
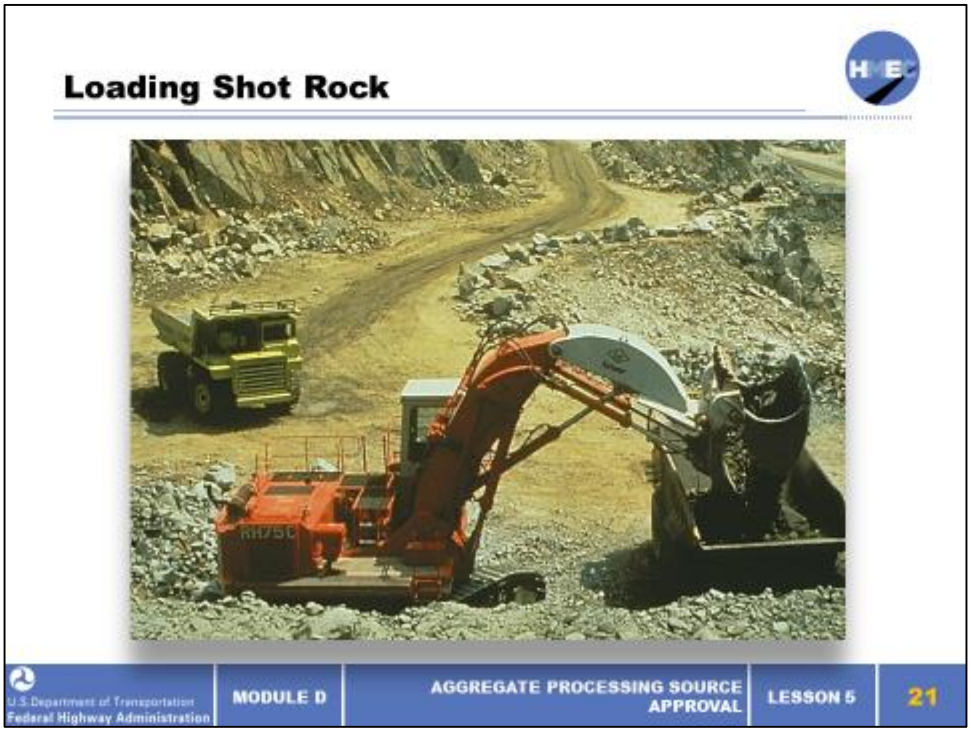
Slide 20



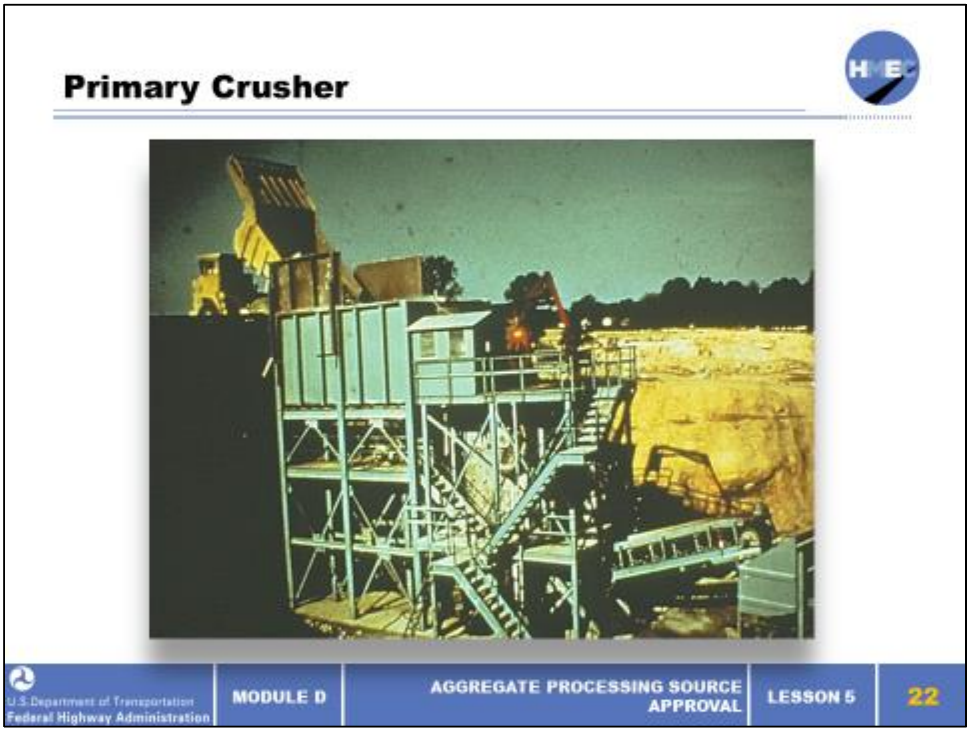
The result of the blasting operation is known as "shot rock." This shot rock pile is now ready for initial processing.

Slide 21



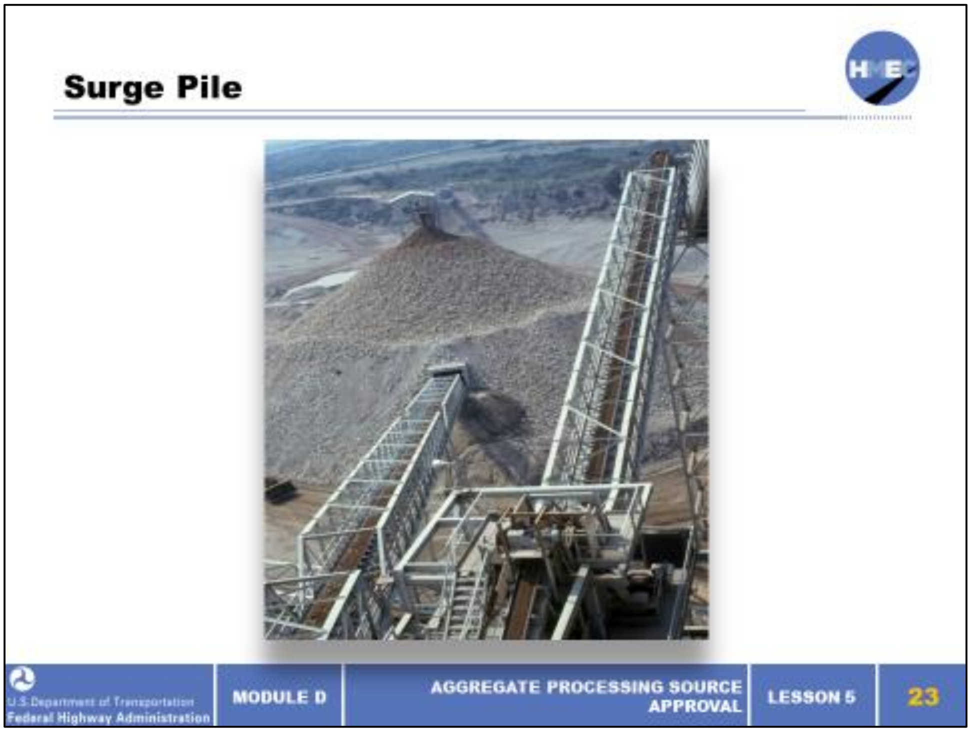
First, the shot rock must be loaded and hauled to the primary crusher (if crushing is necessary). Sometimes a portable primary crusher is located at the face so that the larger pieces are crushed to a size that can be transported to the processing plant by conveyor belt rather than by quarry truck.

Slide 22



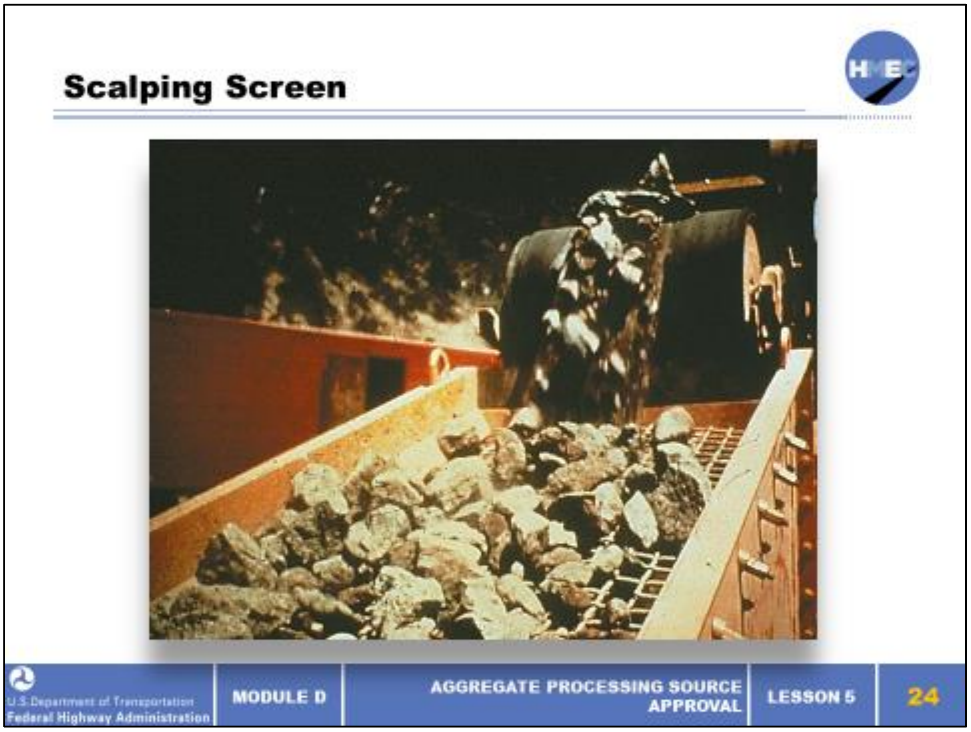
Primary crushing is done to reduce maximum particle size below about 8 to 10 inches.

Slide 23



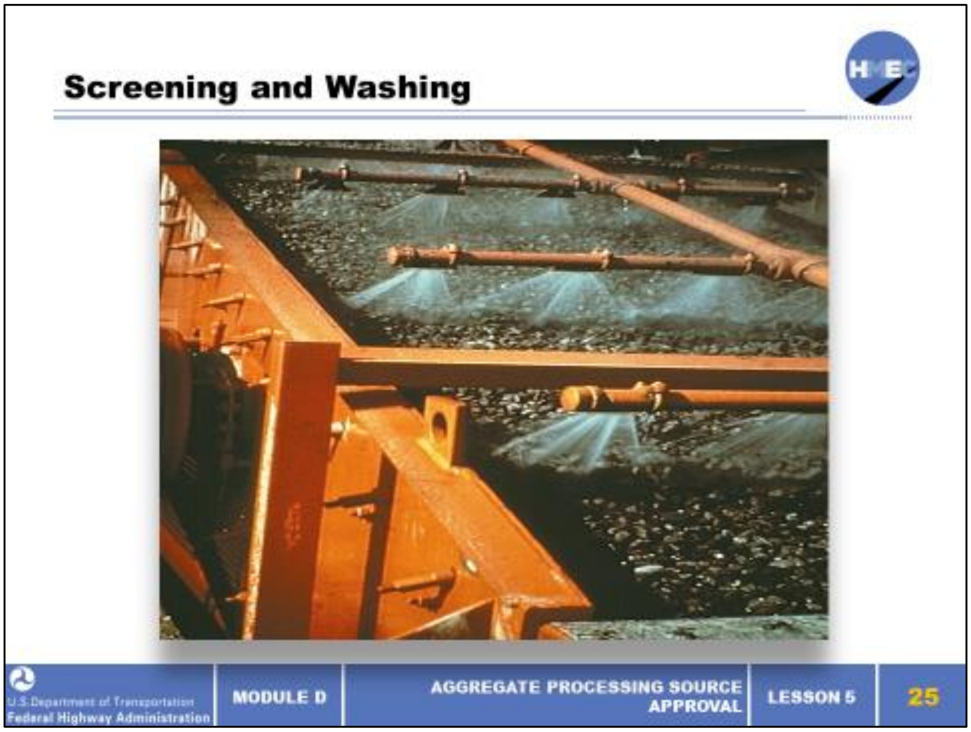
Typically, a surge pile is located after the primary crusher so the remainder of the plant can be fed independently from the primary surge material. Situated in that way, the plant can continue to operate if the primary crusher is down.

Slide 24



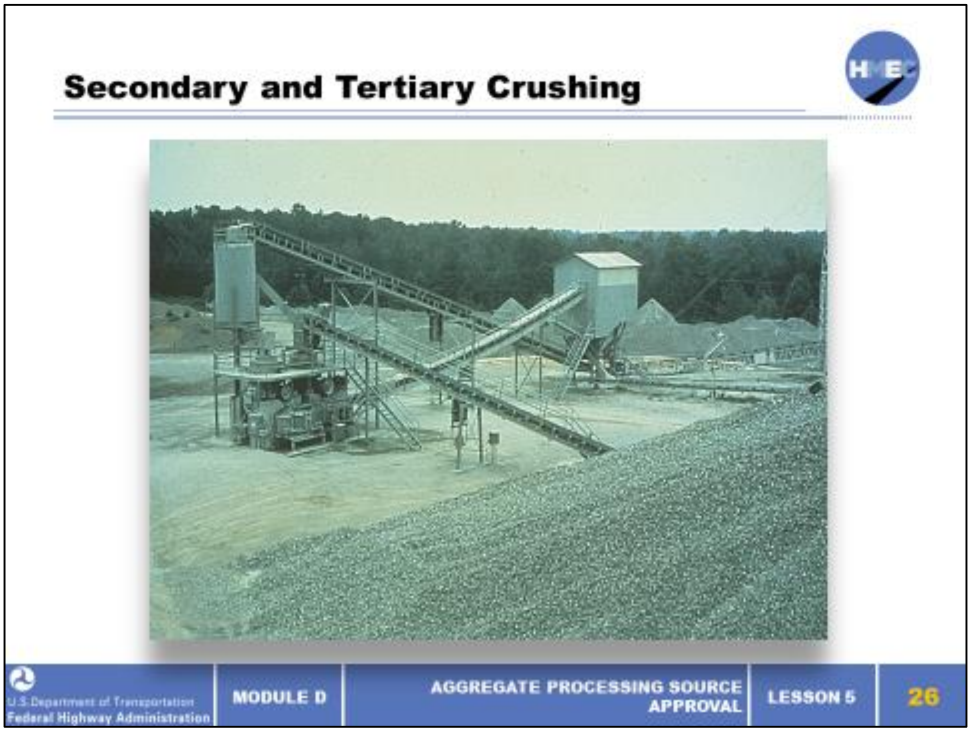
Here we see the scalping screen scalping off larger sizes for further crushing and producing a "crusher run" product passing the screen.

Slide 25



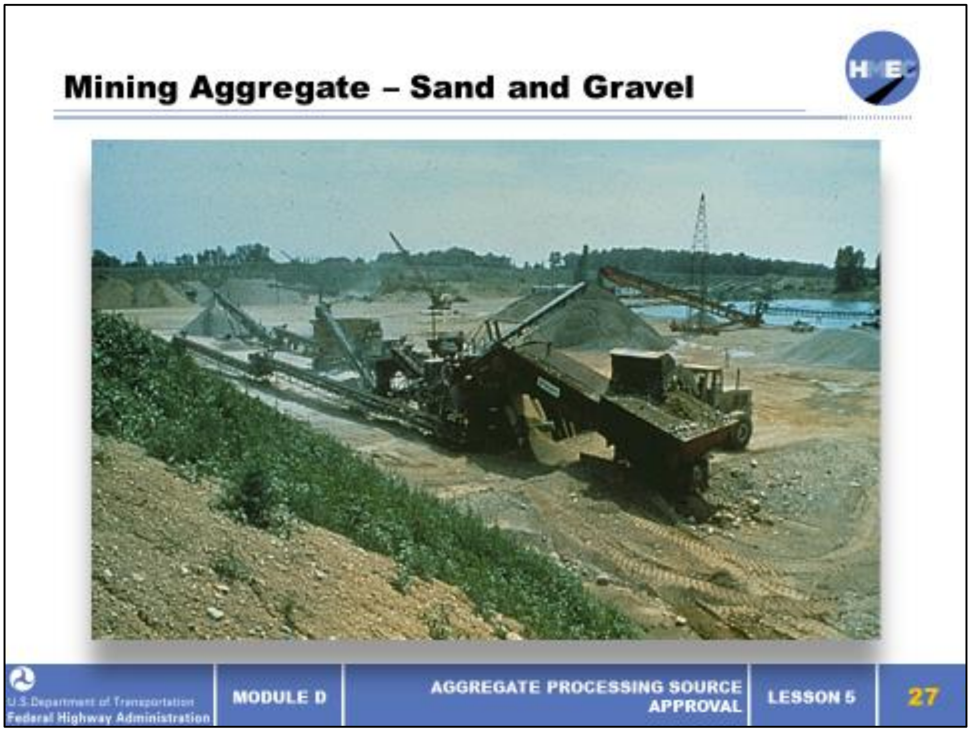
Aggregates are screened over several levels of vibrating wire-cloth screens to separate products into specified size ranges. Washing of fines from the coarse aggregate sizes is accomplished with water spray heads over the screen deck.

Slide 26



Aggregates of intermediate sizes are conveyed to secondary and tertiary crushers for further size reduction (where necessary) and screened into product sizes.

Slide 27



Above-water table deposits of sand and gravel are often mined with conventional earth-moving equipment.

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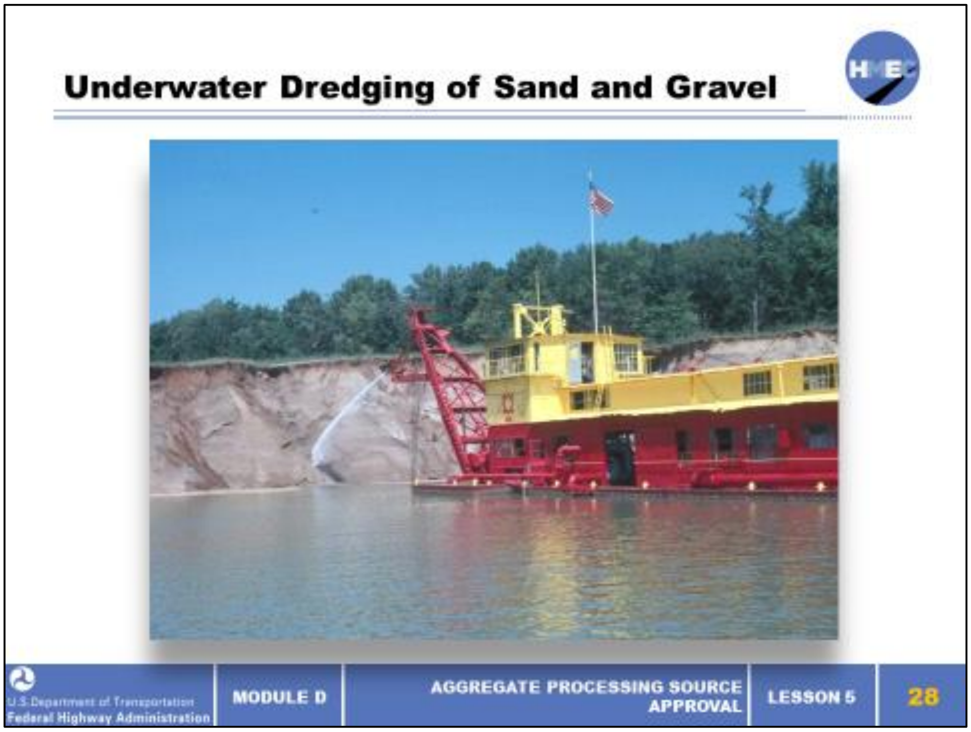

Hydraulic suction dredging can be used to mine below-water table sand and gravel deposits as long as the particle sizes are small enough to be carried through the size of pipe and pump chosen. A rotating cutter head is used to help dislodge the material for pumping. Above-water material can be washed down to the cutter head with a monitor applying a stream of water.

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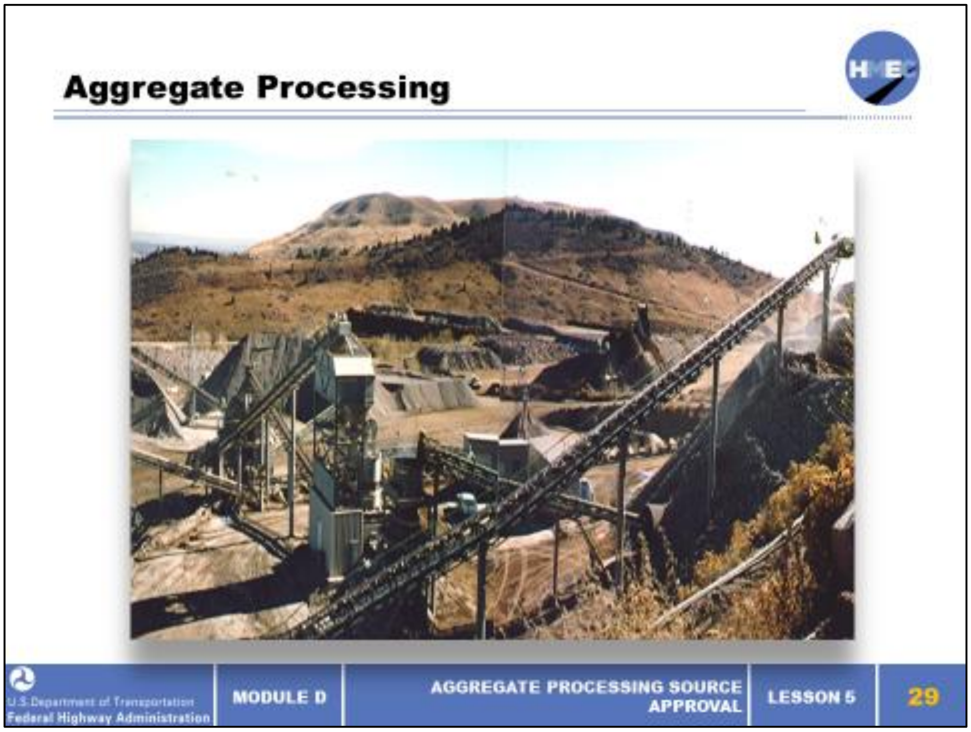

Processing plants for sand and gravel are often set up at the mining site. In some cases, a floating processing plant may be used in conjunction with a dredging operation, with products loaded on barges for delivery to customers.

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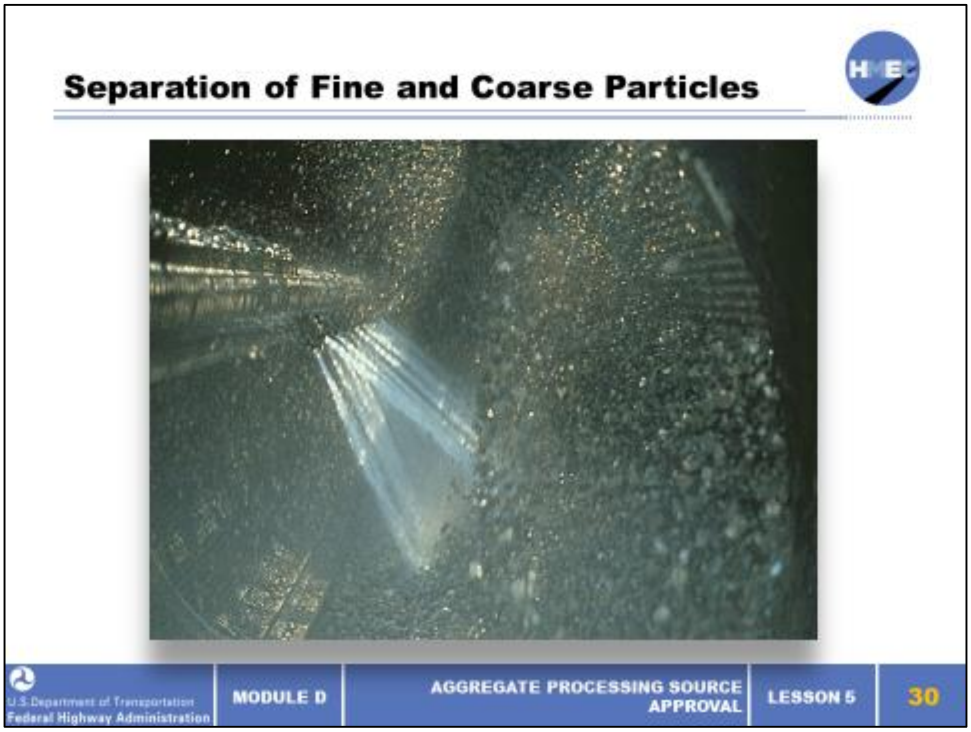
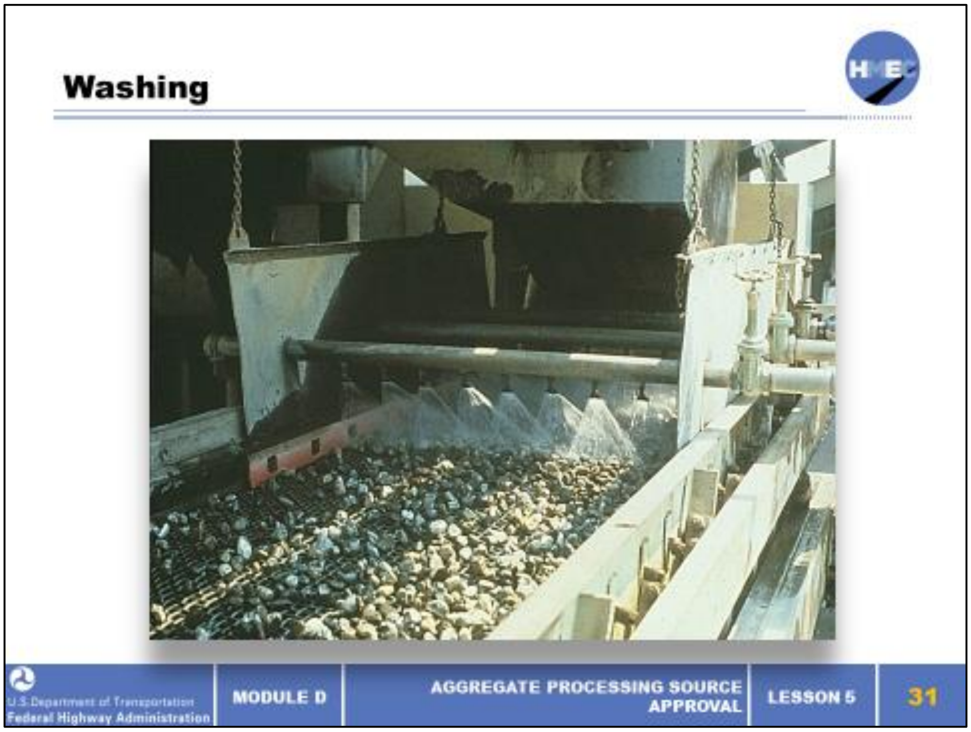


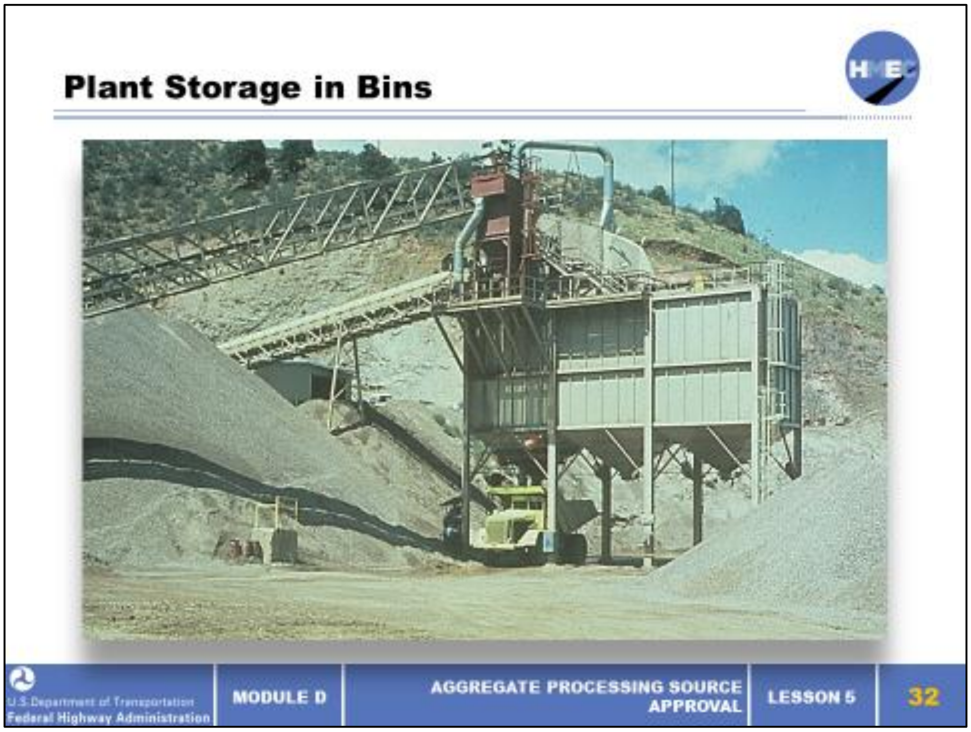
A rotating trommel screen is used to help separate fine from coarse particles in the initial step in the processing of sand and gravel. The washing action also helps to remove silt, clay, and other tenacious coatings. More often, washing is used in the processing of sand and gravel from deposits that contain clay and silt fines. Crushed stone from ledge rock deposits is often processed dry.

Slide 31



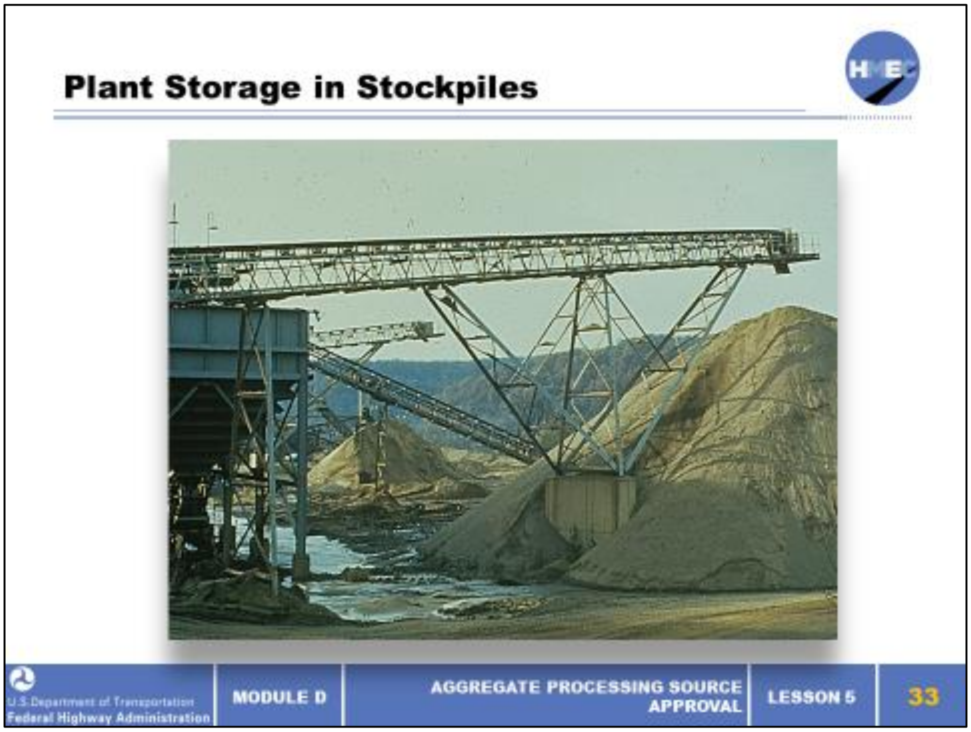
Additional washing of gravel is accomplished on wet screening decks. Processing of clean crushed stone products may also involve washing.

Slide 32



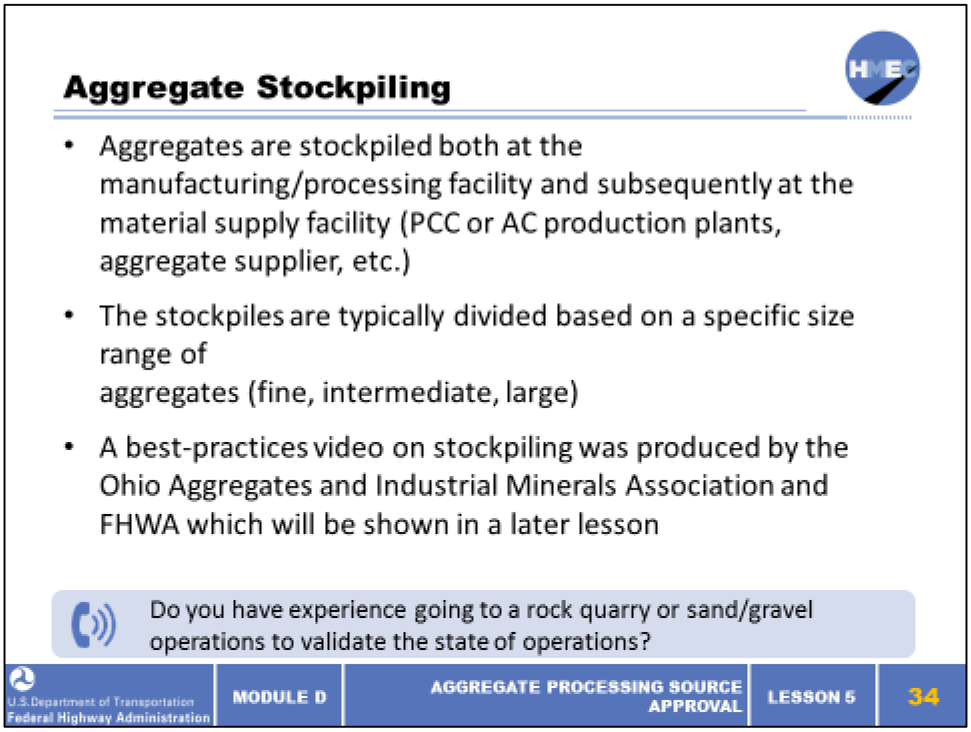
Storing aggregates in overhead bins provides easy access for truck or rail loading for distribution or shipment.

Slide 33



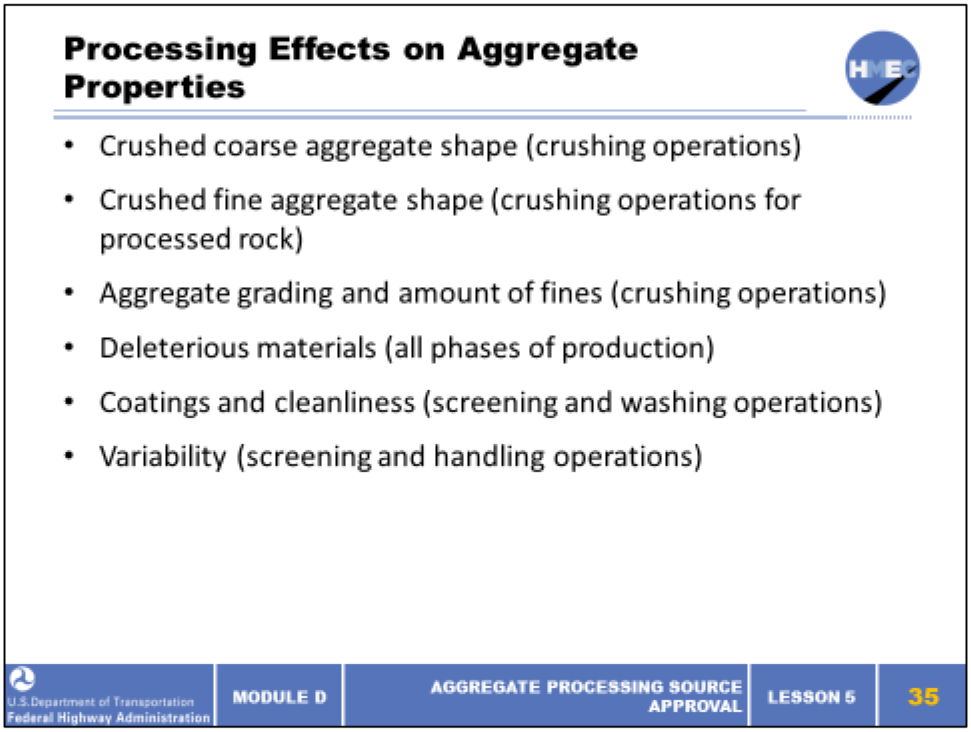
Aggregates are stockpiled for storage at production facilities. Depending on the stage of processing, they may be ready for shipment or they may be awaiting another processing step.

Slide 34



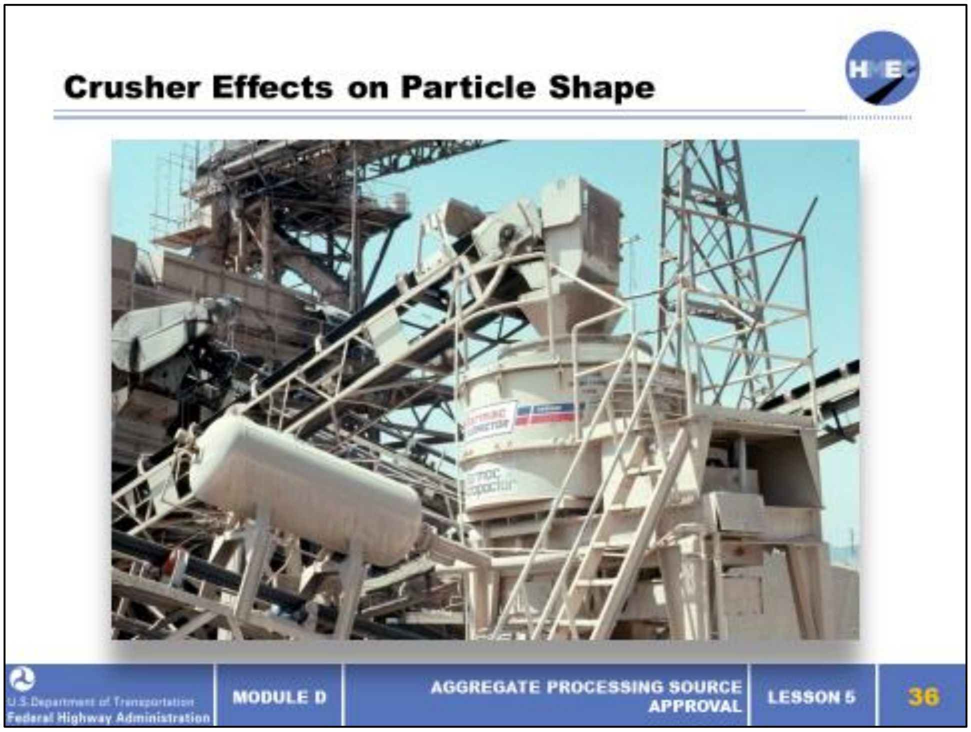
Aggregates are combined into specific, end use-based gradations as required. Stockpiles must be carefully constructed and maintained to avoid segregation and contamination.

Slide 35



Aggregate production methods can affect a number of aggregate properties.

Slide 36



The particle shape of an aggregate is a property that can be regulated to some extent when crushing is employed. This is accomplished by selecting and adjusting crushers and by sizing and blending before and after crushing to achieve the desired objectives.

This is particularly true for crushed stone. The natural shape of gravel in the deposit can vary from rounded to moderately angular to very angular in some natural deposits. It generally depends on the parent rock from which the sand and gravel has come and how far it has been moved in waterborne deposits.

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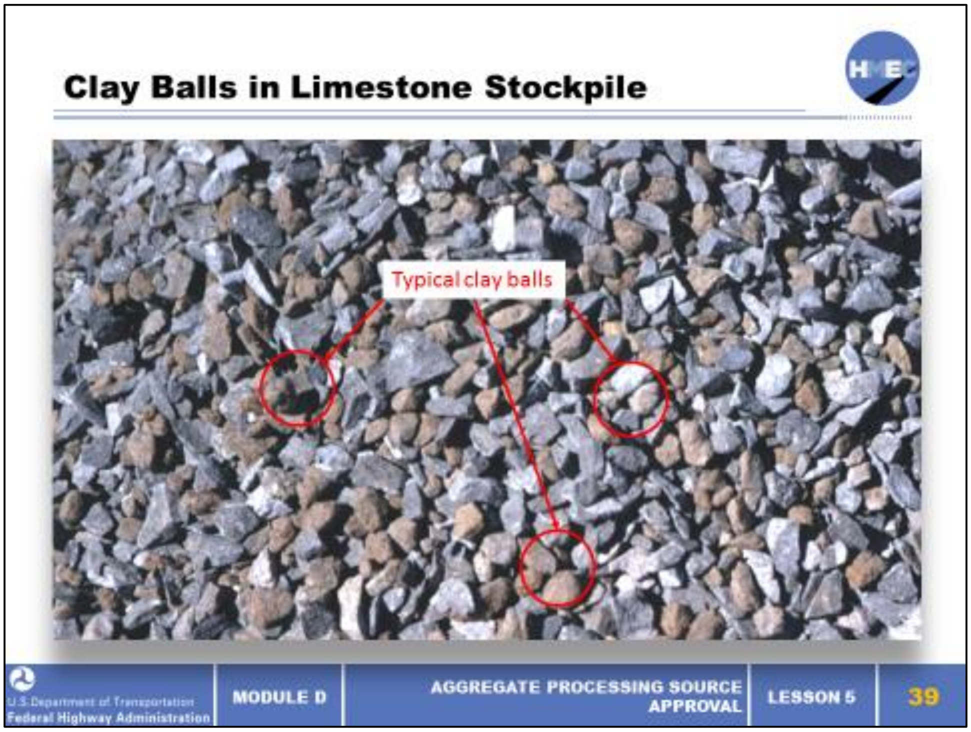
Slide 37

Vertical shaft impact crushers tend to produce a more cubical particle size for both coarse and fine aggregate production, using crushing. These types of crushers may also produce more unwanted fines. Cone crushers can produce more flat and elongated particles with certain rock types.

Slide 38

Loose void content samples of fine aggregates are shown here. For the natural sands, the shape, angularity, and texture of the particles are carried over from what is present in the sand and gravel deposit. When the fine aggregate consists of crushed material, the type of crusher can influence these properties.

Slide 39



Clay from overburden or seams in a limestone deposit has formed into clay balls during dry crushing and screening of the crushed stone product. No wet processing was employed at this Arizona operation.

The photo shows a large number of clay balls arising for the processing on the limestone aggregate. Several of the more typically shaped clay balls are identified, however, virtually all of the brown particles are clay. These friable particles are very detrimental to PCC performance (resulting in pop outs) as well as in AC layers and unbound and stabilized granular bases where they can breakdown either in service or during construction.

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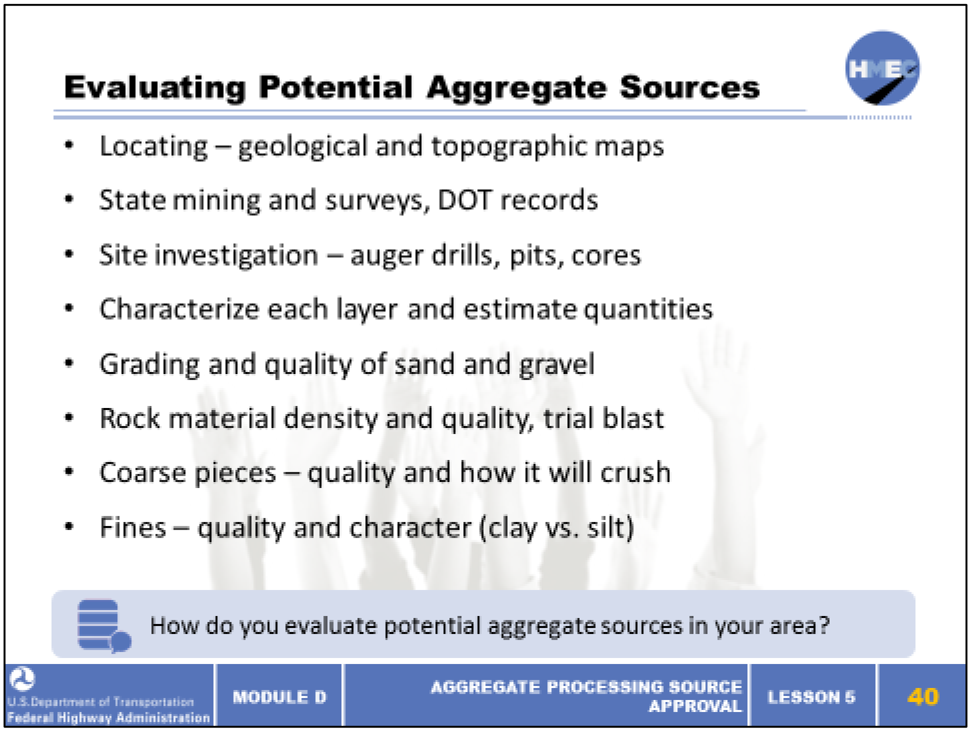
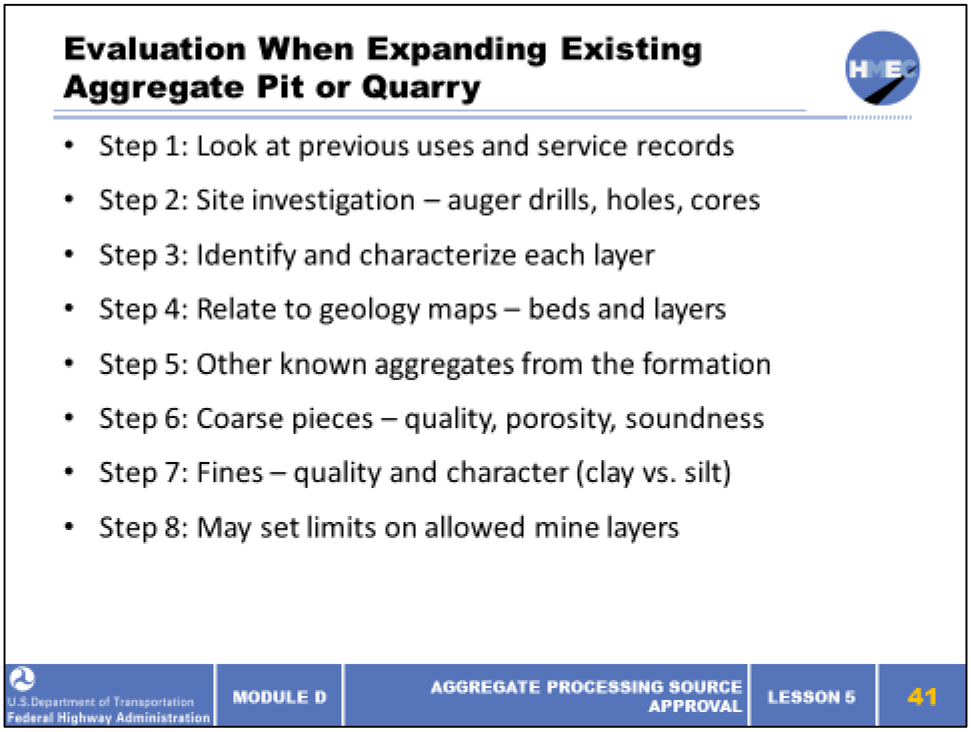
Slide 40



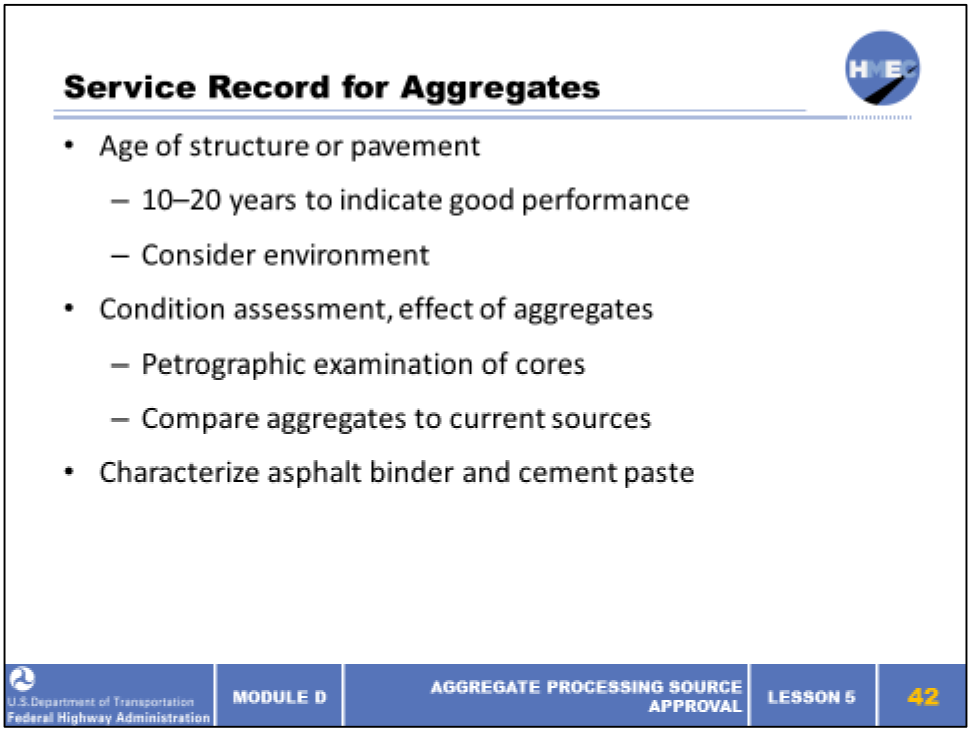
The feasibility of developing a source of aggregates is a commercial decision in most localities. However, large projects away from commercial aggregate sources may require State participation. Some jurisdictions identify aggregate pits or quarries and set them up for use in projects. Occasionally aggregates can be produced from a highway cut area or pit on the project.

Slide 41



Evaluate a source for quality of the larger pieces, the nature and amount of fines, and the gradation of the aggregate using typical production methods. This screen provides the steps in gathering information about a potential aggregate source.

Slide 42



When an aggregate source or geologic layer is being evaluated for service record, it is important to find structures or pavements older than 10 years or preferably older than 20 years. First, it must be verified through petrographic examination of cores that the aggregate in the structure is from the same or very similar source before proceeding.

In evaluating the performance of the aggregate, the nature and properties of the binder, such as the asphalt cement or cement paste, should also be taken into account.

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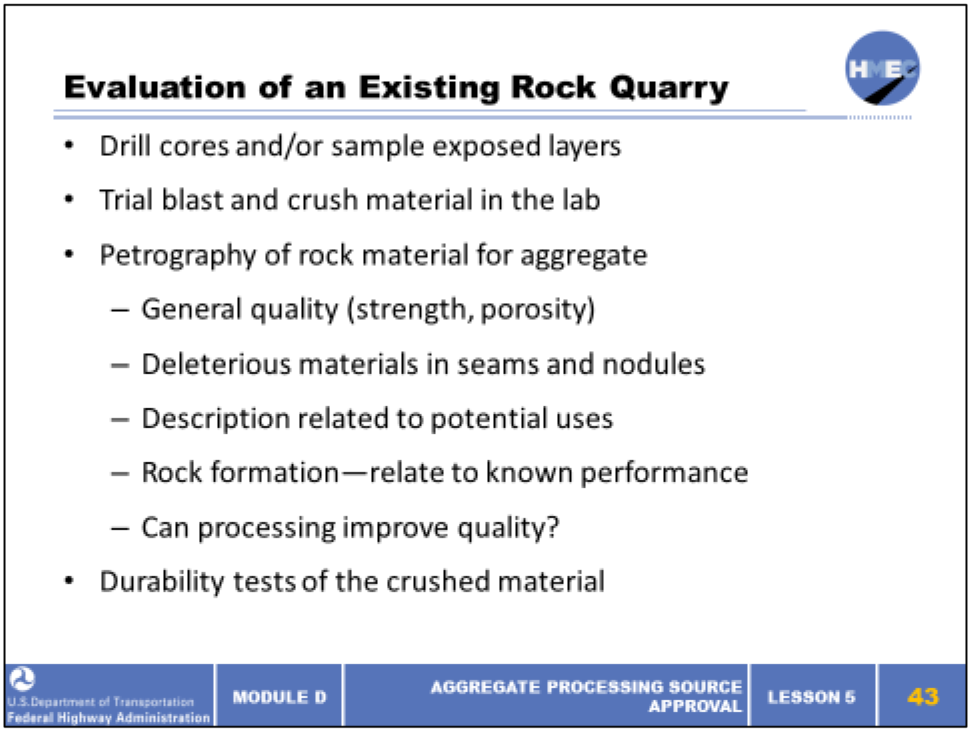
Slide 43



The cores are examined using petrographic methods for general quality, suitability for various potential uses, and the amount of deleterious material in nodules, seams, or layers, which may be undesirable for some applications. Porous, weak rock would limit its use in higher applications. Too much clay fines would require more processing. For example, pure limestone, even though dense, would likely not give good frictional values on high traffic asphalt surface courses.

Some highway agencies will participate in the evaluation of quarry cores and the quality of rock in exposed faces and ledges. Others leave the preliminary investigation to the producer but will require samples of produced aggregate to be tested for source approval, perhaps for several different classes of use.

The extent and quality of rock in a quarry is normally investigated by drilling cores, doing a trial blast or shot to see how the rock breaks, and by crushing some material in the laboratory to evaluate grading, particle shape, soundness, durability, and fines.

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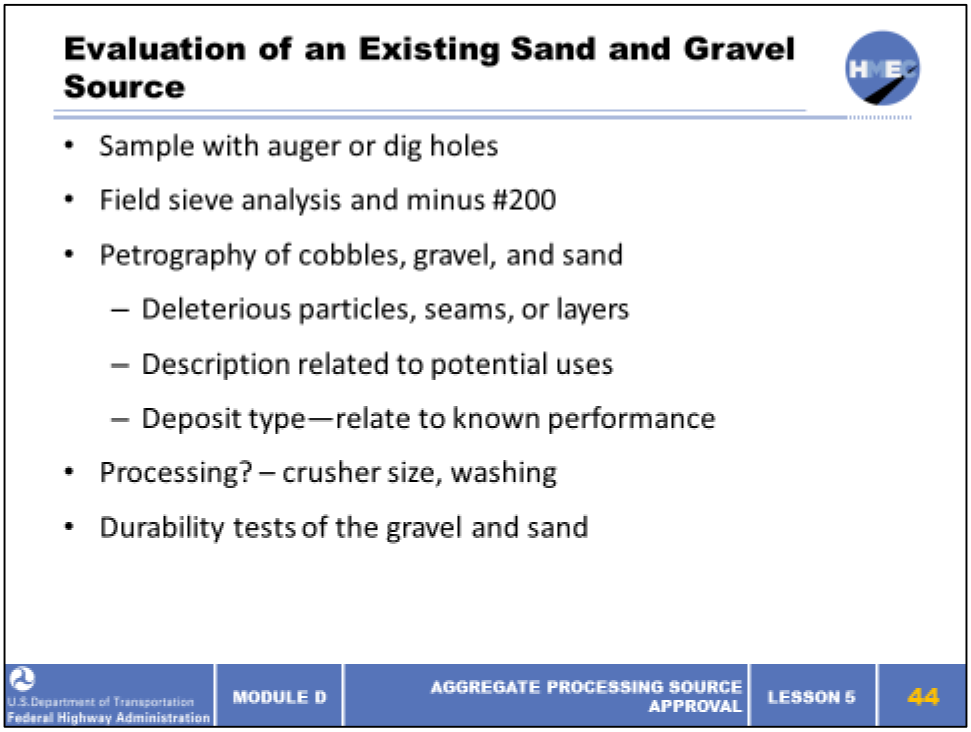
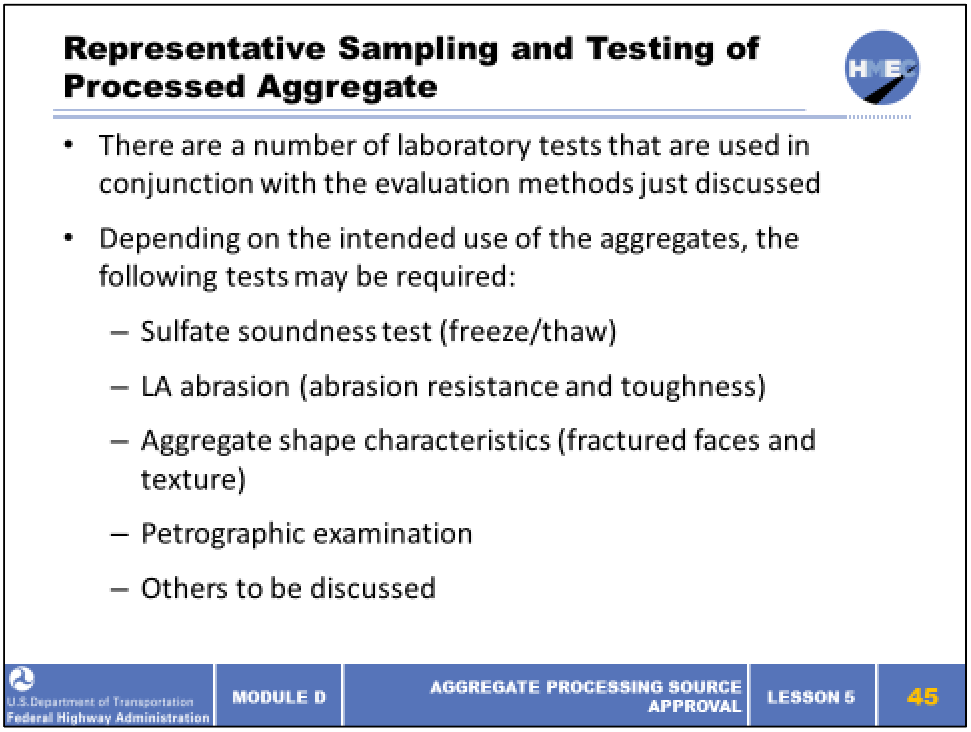
Slide 44



Where larger gravel and cobble sizes are present, the percentage and approximate size is needed to judge the extent and size of crushers needed. Where little crushing is required, the properties of the sand and gravel can be tested directly. Otherwise oversized gravel is crushed and combined with the natural particles for evaluation.

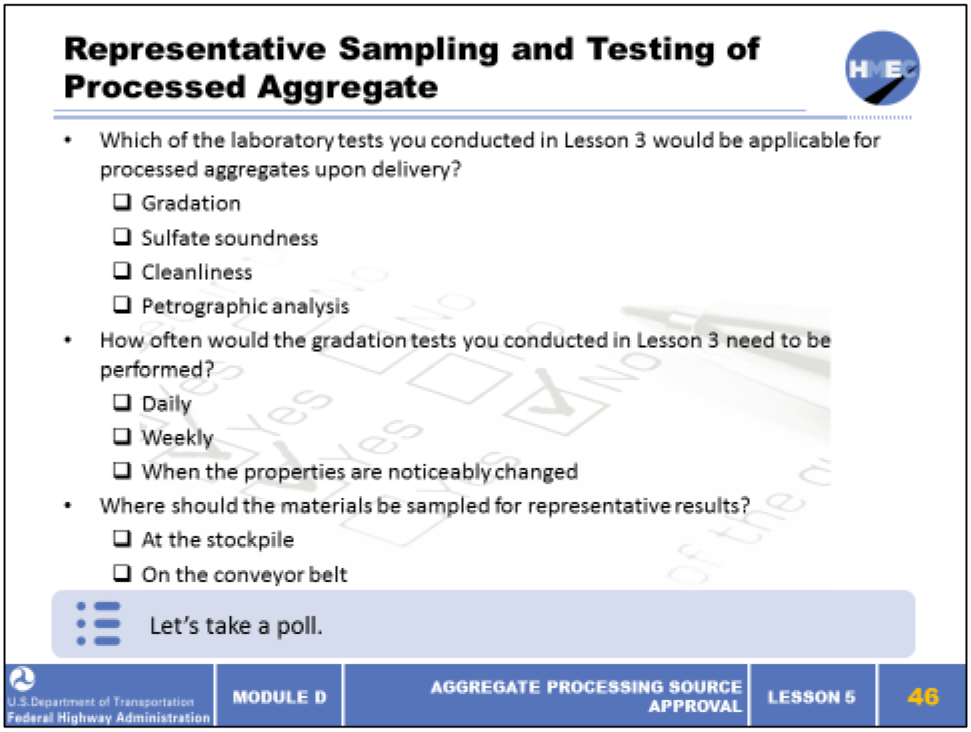
Also, highly crushed gravel products can be made from larger sizes. In this case, the crushed gravel may be produced separately for crushed aggregate applications, and the more rounded natural sand and gravel used for concrete aggregate or other applications.

Slide 45



The aggregate properties required for certain applications may qualify certain sources and not others at the production level. For instance, D-cracking prone aggregates may disqualify a particular quarry from producing Portland cement concrete (PCC) aggregates but not limit its use in other applications.

Slide 46


Representative Sampling and Testing of Processed Aggregate
HMEC
• Which of the laboratory tests you conducted in Lesson 3 would be applicable for processed aggregates upon delivery?
❑ Gradation
❑ Sulfate soundness
❑ Cleanliness
❑ Petrographic analysis
• How often would the gradation tests you conducted in Lesson 3 need to be performed?
❑ Daily
❑ Weekly
❑ When the properties are noticeably changed
• Where should the materials be sampled for representative results?
❑ At the stockpile
❑ On the conveyor belt
Let's take a poll.
U.S. Department of Transportation
Federal Highway Administration
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AGGREGATE PROCESSING SOURCE APPROVAL
LESSON 5
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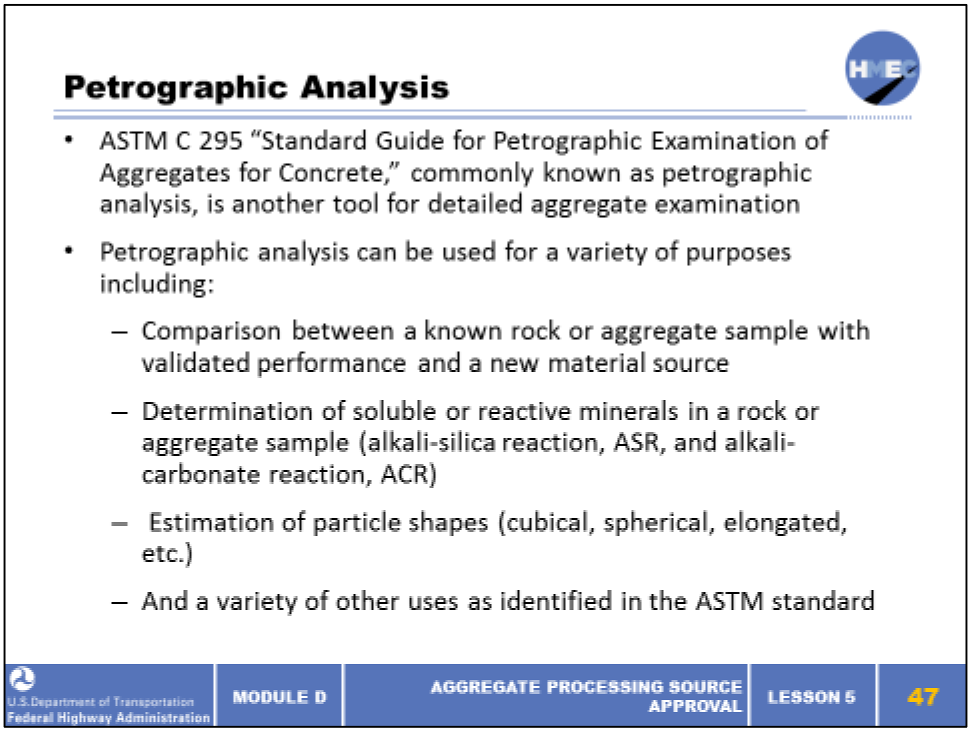
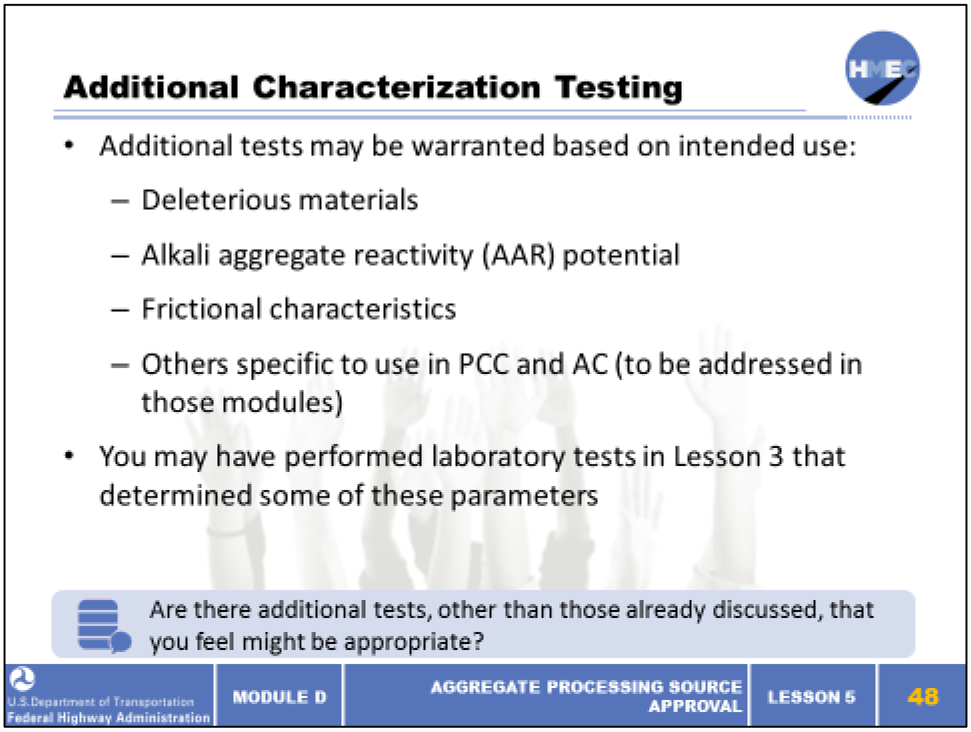
Slide 47



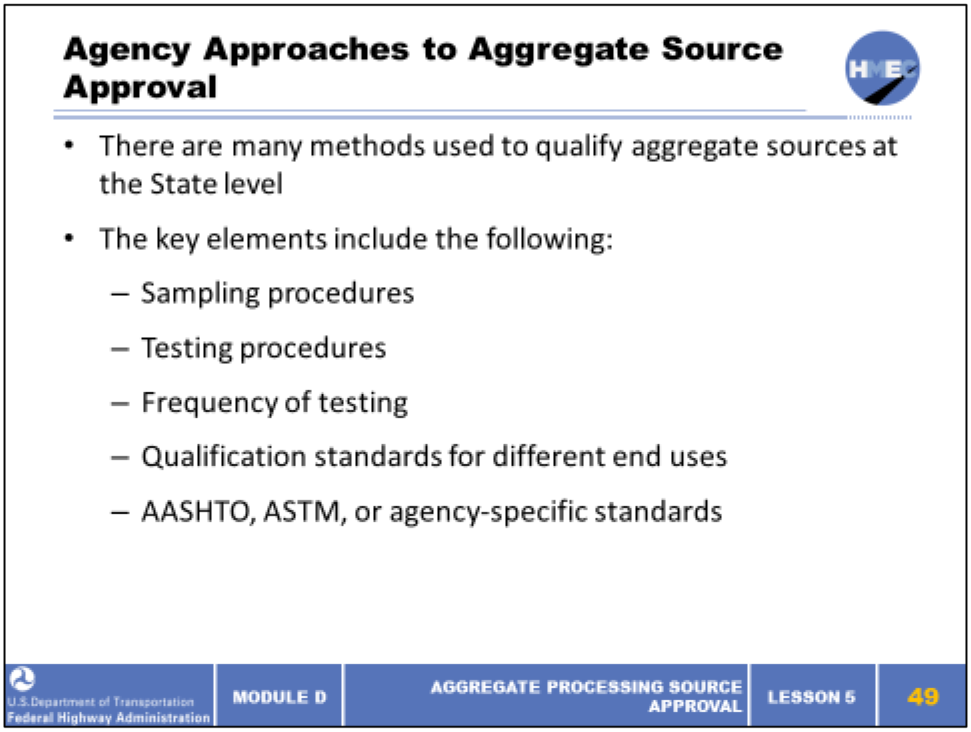
Petrographic analysis generally makes use of high-resolution scanning electron microscope images to evaluate the make-up and structure of rock and aggregate samples. By identifying the mineralogy of the aggregates and the relative proportion of the constituents, it is possible to estimate the potential reactivity, deleterious substances, soluble minerals such as sulfates, and other potential problem areas that may disqualify the use of the specific aggregate for one or more end uses.

Slide 48



There are a number of additional tests that may be performed to determine the suitability of a particular aggregate for a specific use. Generally, the most stringent standards for aggregate characteristics are found in the specifications for PCC and asphalt concrete (AC).

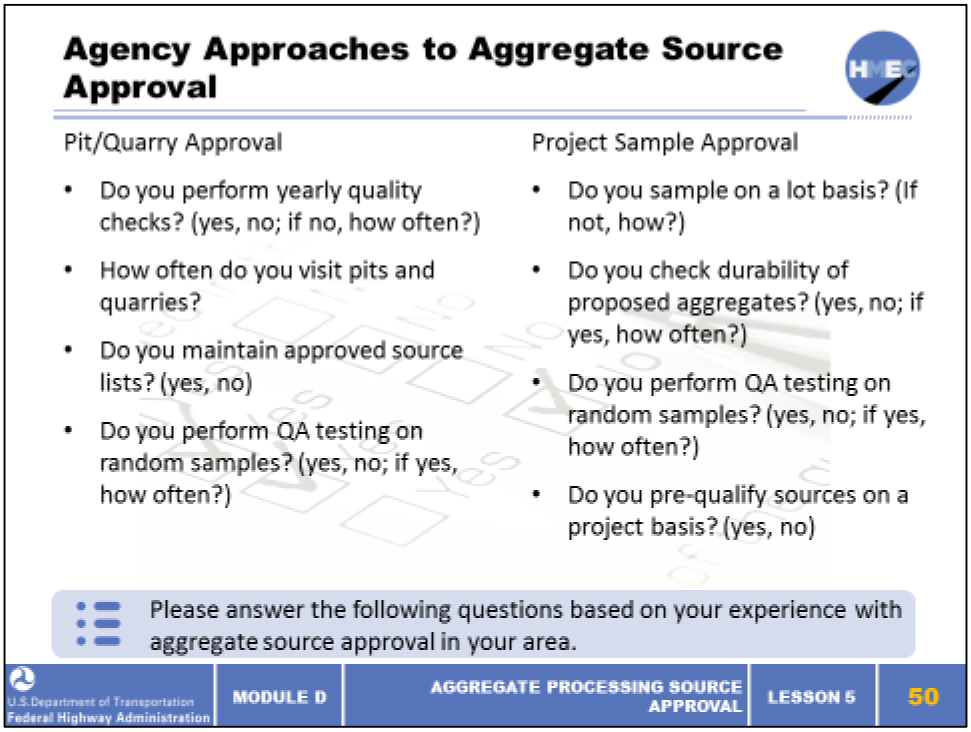
Slide 49



Highway agencies have the option of assessing an aggregate deposit through detailed study of the quality of the material in the pit or quarry. The other option is they can leave that up to the developer of the source and accept or reject the use of an aggregate source on the basis of the properties of the processed aggregate.

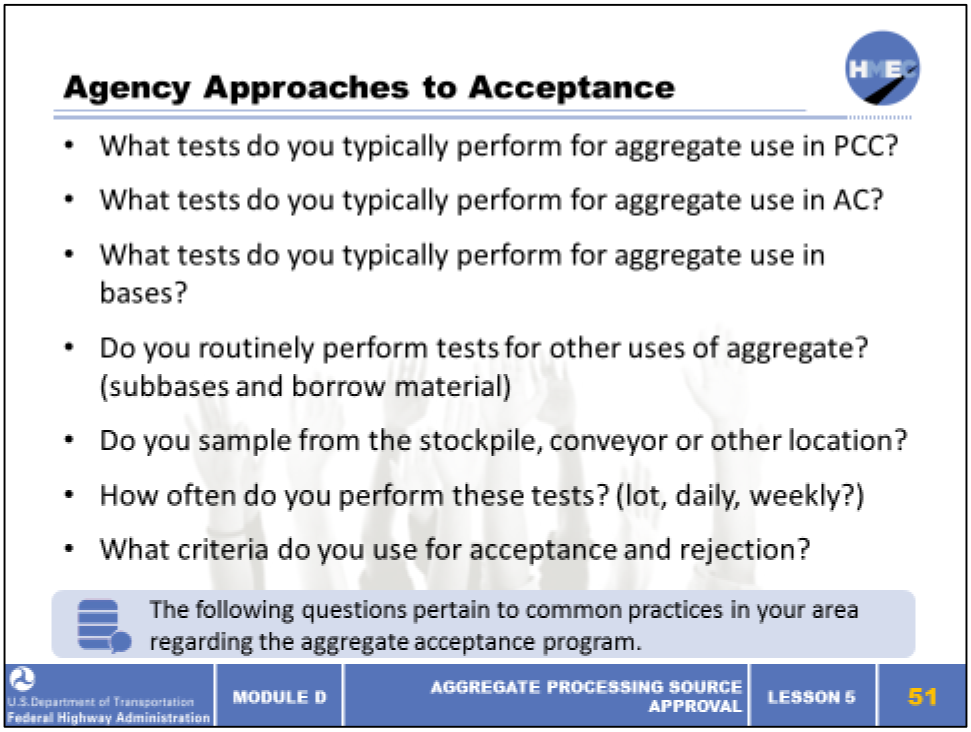
The geology of some States lends itself to the first approach where records are kept of the performance of aggregates from different geologic formations and layers. In that case, geologists can fairly rapidly assess the quality of sources or layers within sources by comparison of the petrographic characteristics with other known deposits. States with extensive limestone resources, or those with glacial sand and gravel regions may use this approach.

Slide 50



Aggregate quarries and sand and gravel pits are generally subjected to yearly evaluations for conformance with agency standards. The agency may rely on their own test results or may use the information provided by the supplier along with spot verification. Project level approval is generally at the stockpile level and requires more detailed testing for QA purposes depending on the intended use of the aggregates.

Slide 51

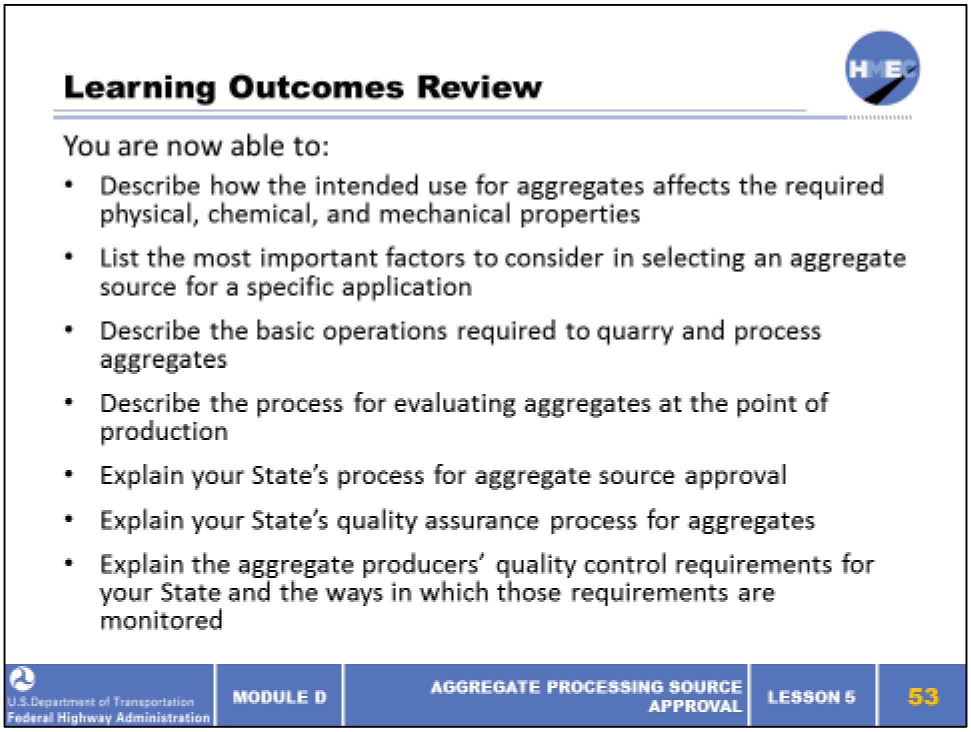


All agencies have established acceptance procedures for aggregates although they can differ significantly. Acceptance standards for aggregates have a common goal: to verify compliance with the appropriate specification. The aggregate specifications vary by the intended use (PCC, AC, bases, other) and are based on performance.

Slide 52

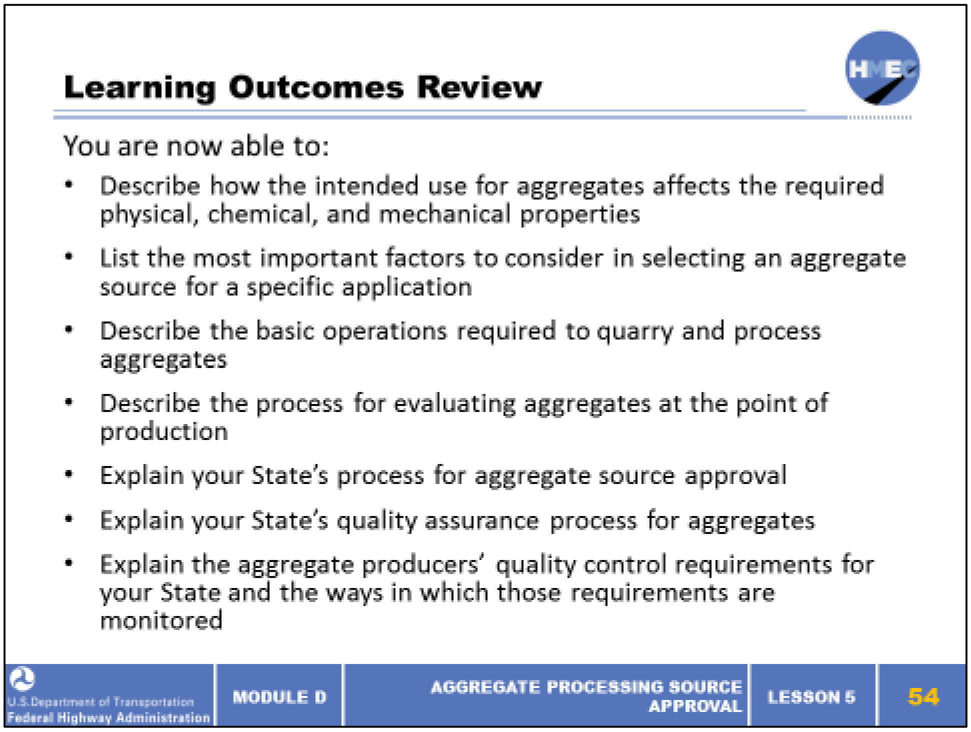
Recall that quality control implies process control and testing on the part of the producer to ensure a product that meets (and is verified) by the owner.

Slide 53



You may not understand the quality control process of the aggregate producers, but here are some main points.

Slide 54


Learning Outcomes Review
HMEC
You are now able to:
• Describe how the intended use for aggregates affects the required physical, chemical, and mechanical properties
• List the most important factors to consider in selecting an aggregate source for a specific application
• Describe the basic operations required to quarry and process aggregates
• Describe the process for evaluating aggregates at the point of production
• Explain your State's process for aggregate source approval
• Explain your State's quality assurance process for aggregates
• Explain the aggregate producers' quality control requirements for your State and the ways in which those requirements are monitored
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AGGREGATE PROCESSING SOURCE APPROVAL
LESSON 5
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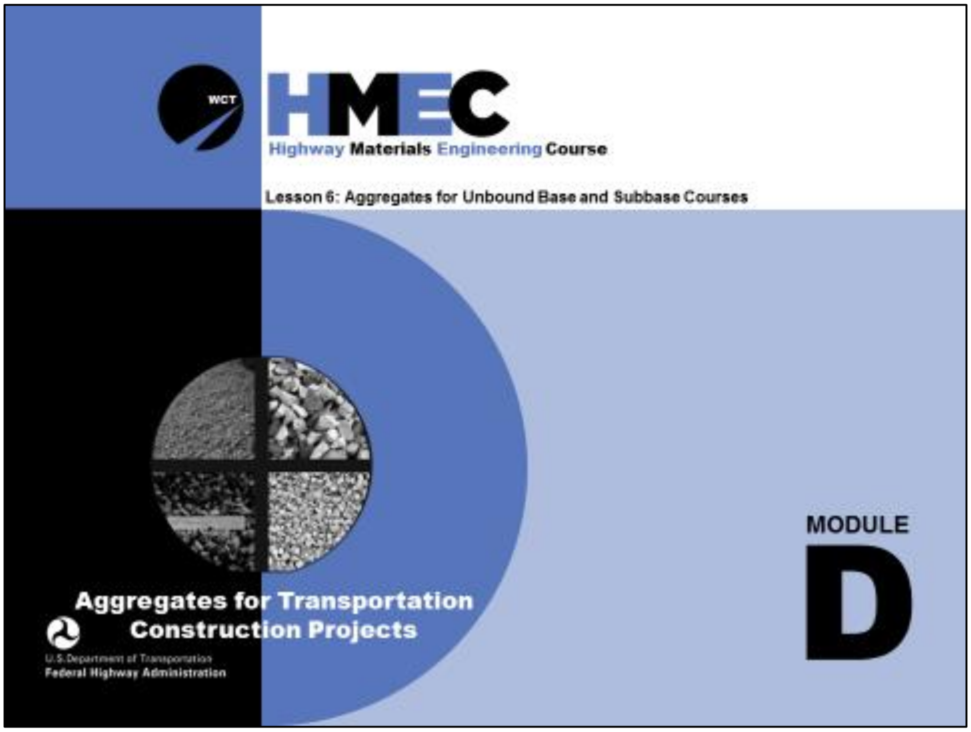
Slide 1


HMEC
Highway Materials Engineering Course
Lesson 6: Aggregates for Unbound Base and Subbase Courses
Aggregates for Transportation Construction Projects
U.S. Department of Transportation
Federal Highway Administration
MODULE
D

Slide 2

Learning Outcomes

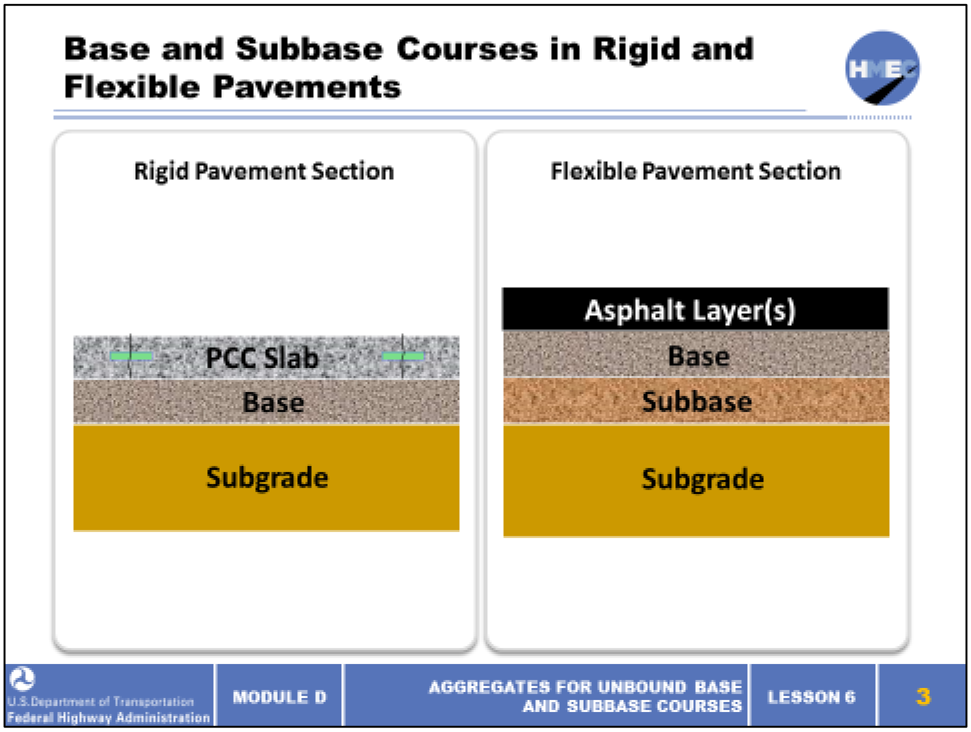
By the end of this lesson, you will be able to:

- Discuss the reasons why a base or subbase course is required for most pavements
- List the most important physical properties of coarse aggregates used for an unbound base layer
- Explain the desirable quality characteristic of fine aggregates in an unbound aggregate base
- Describe how variations in aggregate gradation can occur during construction operations
- Explain the importance of density and compactive effort for both dense-graded and permeable bases
- Describe the process for acceptance of unbound base and subbase layers

This lesson will take approximately 80 minutes to complete.

U.S. Department of Transportation Federal Highway Administration | MODULE D | AGGREGATES FOR UNBOUND BASE AND SUBBASE COURSES | LESSON 6 | 2

Slide 3



Unbound aggregate layers are used to increase the level of support and as a performance enhancement for the majority of rigid pavements. They are an integral part of a flexible pavement structure for all but full-depth asphalt pavements.

Full-depth asphalt pavements utilize a surface course asphalt and an asphalt base on top of a prepared subgrade. The properties of the surface and base asphalt generally differ in terms of aggregate gradation, aggregate size, asphalt grade, and other asphalt concrete (AC) mix parameters.

In a rigid pavement, the layer immediately under the Portland cement concrete (PCC) slab is termed the base. Note that the term subbase is also used to describe this layer in a rigid pavement system in some of the currently available literature (for instance, documents produced by the American Concrete Pavement Association, or ACPA). The function of this support layer differs greatly from the same layer in a flexible pavement structure. An effort was made to rename PCC bases as subbases since the material quality requirements were thought to be roughly equivalent. For purposes of this presentation, the term "base" will be used as the layer immediately under the PCC slab, while flexible pavements will utilize both a base and subbase.

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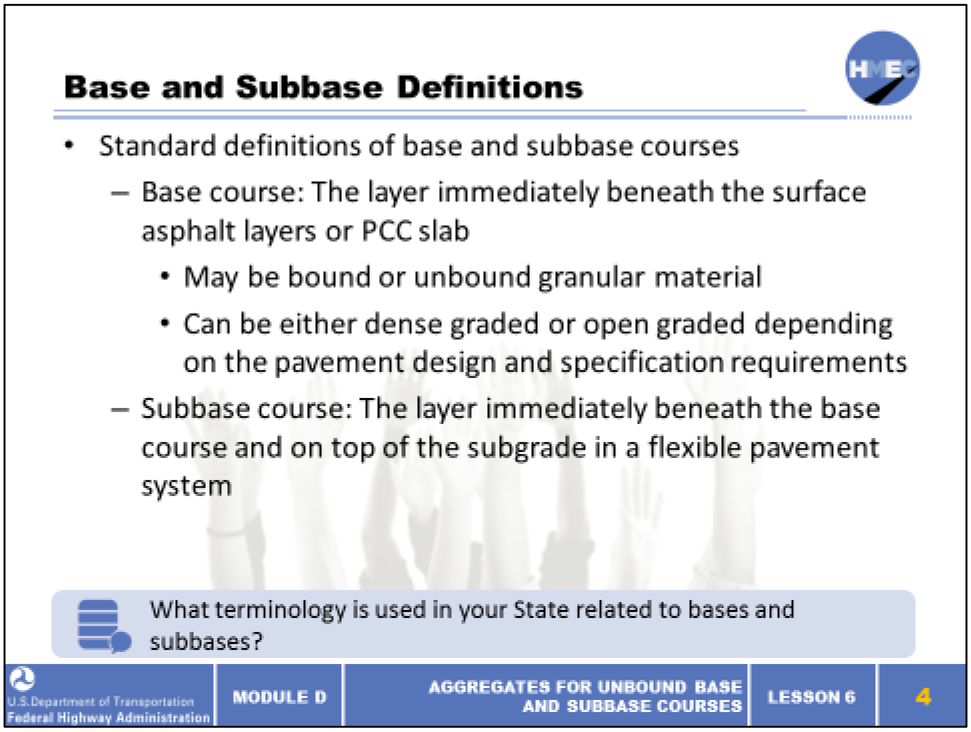
Slide 4



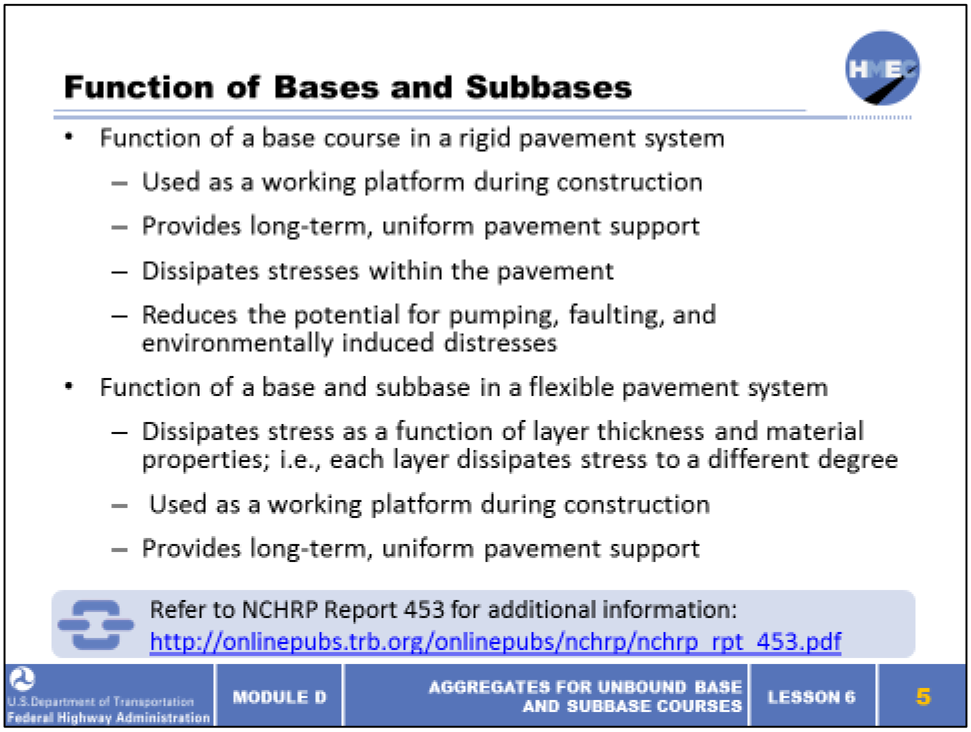
It should be emphasized that we will use "base course" to describe the structural layer in a concrete pavement directly beneath the concrete slab. The idea that subbase or lower-quality materials will suffice as support under a concrete pavement is highly dependent on the material specifications, physical properties, environmental conditions, and so on.

The base course may be either bound or unbound granular material and can be either dense graded or open graded depending on the pavement design and specification requirements. The base and subbase may be a chemically stabilized borrow material or subgrade soil, although those are not specifically discussed in this lesson.

The term subbase is sometimes used interchangeably with the base course in a rigid pavement system. This definition implies that the material requirements are not as stringent as for a true base course.

Flexible pavement systems generally consist of an asphalt layer(s), a base course, and a subbase course overlying a prepared subgrade. Rigid pavement systems are typically comprised of a PCC slab and a base course overlying a prepared subgrade. The requirements for these various base course materials may vary substantially.

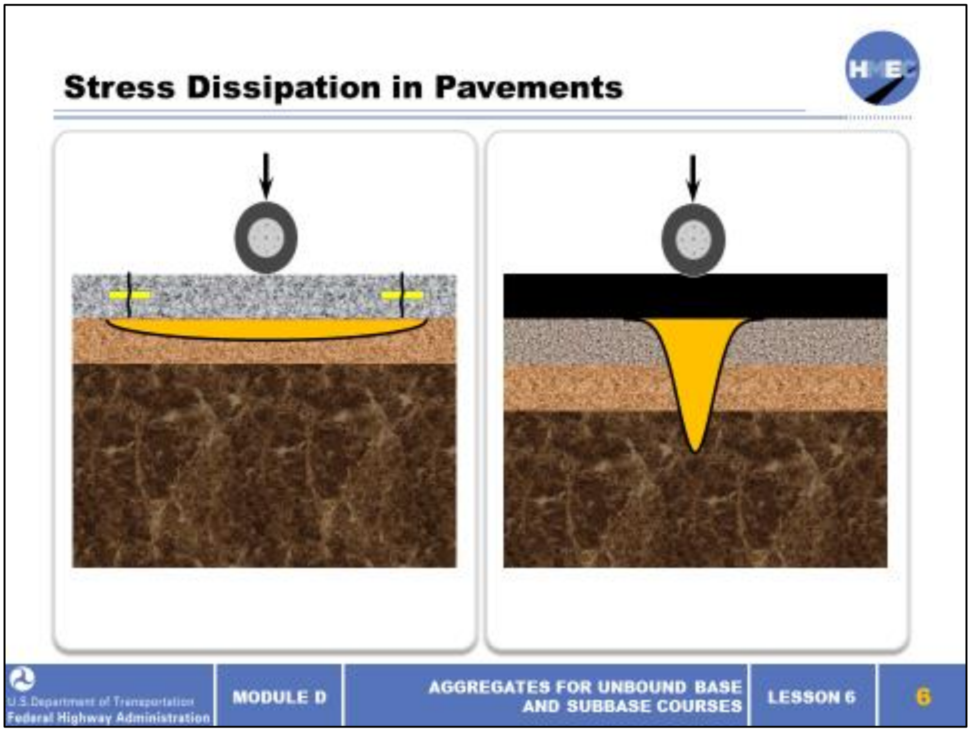
Slide 5



PCC pavements distribute the load over a wide area (slab action) and are not reliant on the base course for any significant level of stress dissipation. Therefore, the purpose of the base on a rigid pavement system is primarily to provide uniform support, act as a construction platform, and minimize pumping potential. While there is a large influence of material properties and layer thicknesses in a flexible pavement design, there is only minimal design implications for rigid pavements. However, research has shown that a correctly designed and constructed base does improve long-term pavement performance.

In order to reduce the thickness of the asphalt layer(s) in a flexible pavement system, bases and subbases are used to dissipate stresses as a function of depth. The base and subbase layers are responsible for reducing the deflection in the asphalt, and thereby the critical tensile stress at the bottom of the lowest asphalt layer. The second critical function in a flexible pavement system is to reduce the contact stress and deflection at the bottom of the subbase and top of subgrade. Reducing the deflection in the asphalt is intended to minimize surface cracking, while the reduction in stress in the subgrade reduces support-related rutting. Since each layer is stressed to a lesser extent as a function of depth, the physical requirements for a subbase are less stringent than for a base.

Slide 6



The key elements of a rigid pavement system are shown on the left, and consist of a PCC slab overlying a granular base course constructed on a prepared subgrade soil. Note that the stress dissipation is over a large area with the actual contact stress on the subgrade—a function primarily of the imposed load and the thickness of the concrete slab. The material properties of the base and the base thickness do not have a significant impact on the stress dissipation but do influence performance both during and after construction. Restate that the base course is intended to minimize pumping, thereby requiring a properly densified, low fines material.

The elements of a typical flexible pavement system are shown on the right, and consist of an asphalt surface and a granular base constructed on a prepared subgrade soil. The stress dissipation in this case is a function of the material properties and layer thicknesses of the asphalt, base, and subbase. The contact stress at the subbase/subgrade interface and the deflection of the asphalt is a function of the entire pavement system. Changes in base or subbase thicknesses and material properties have a very strong impact on pavement performance.

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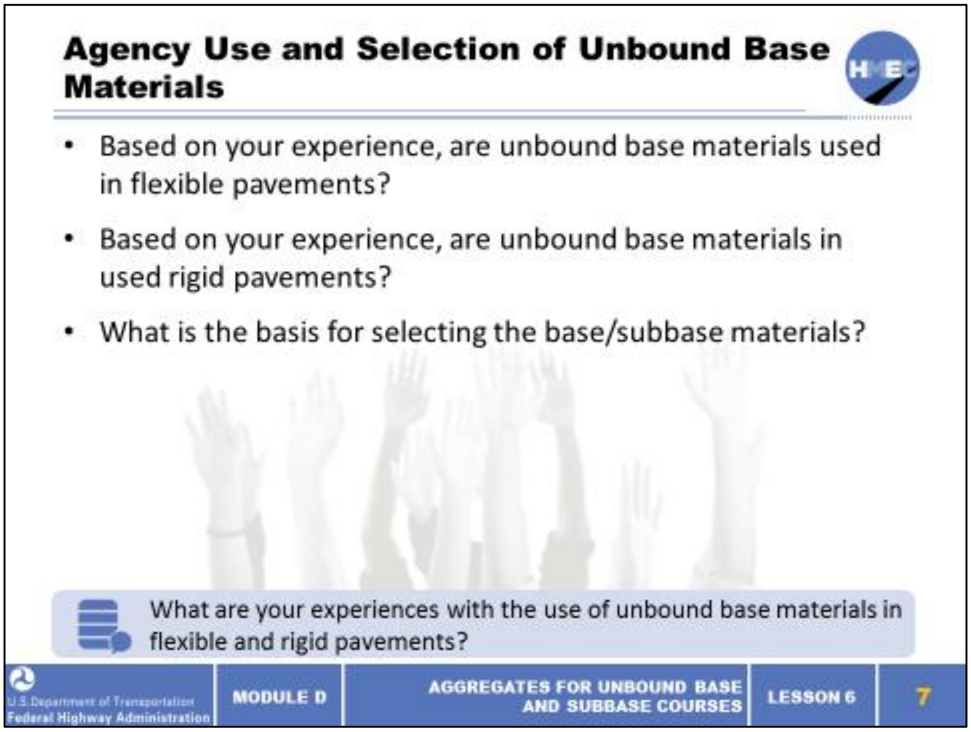
Slide 7



For all except full-depth asphalt pavements, granular bases and subbases are typically used. As the level of traffic increases, the stresses in each of these layers is increased, necessitating higher quality materials and thicker layers. In order to minimize cost, the materials used and the thicknesses should be optimized while still maintaining a threshold level of performance. Generally speaking, the asphalt is the most expensive material followed by the base and finally the subbase.

In the case of rigid pavements, low traffic volume roadways are frequently constructed without a base course to minimize cost. As the level of truck traffic increases to the point where six inches or more of slab thickness is required, bases are typically used as a performance enhancement. The use of bases and subbases in flexible pavement systems has a large effect on the required asphalt thickness. The use of unbound granular bases in concrete pavements has very minimal effect on the required slab thickness. Restate that the purpose of the base and subbase is very different in these different pavement systems.

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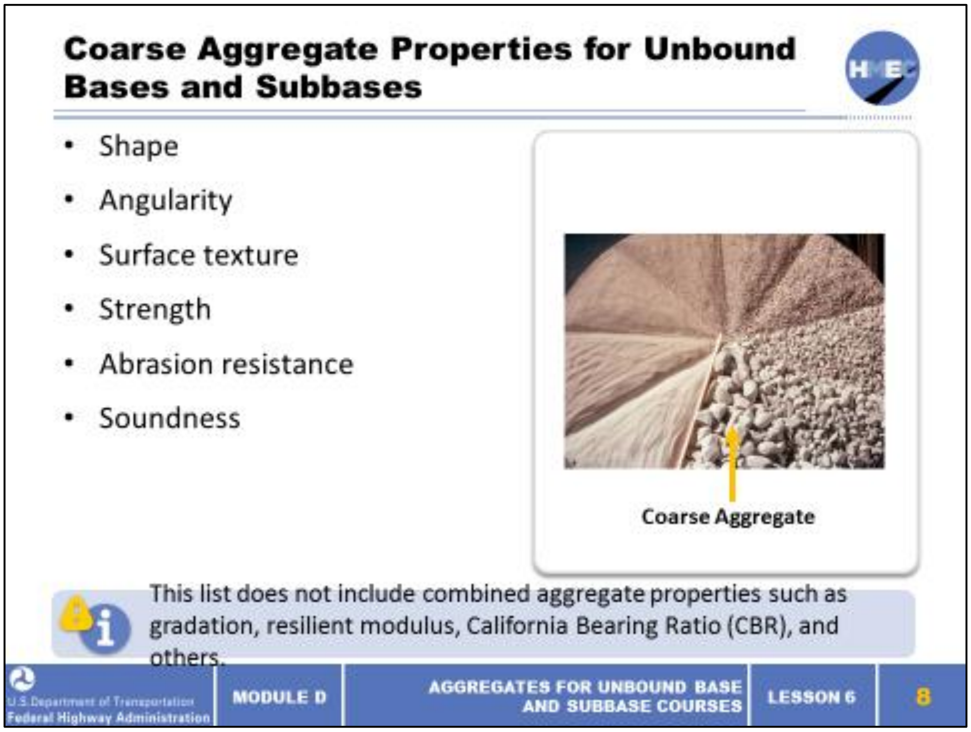
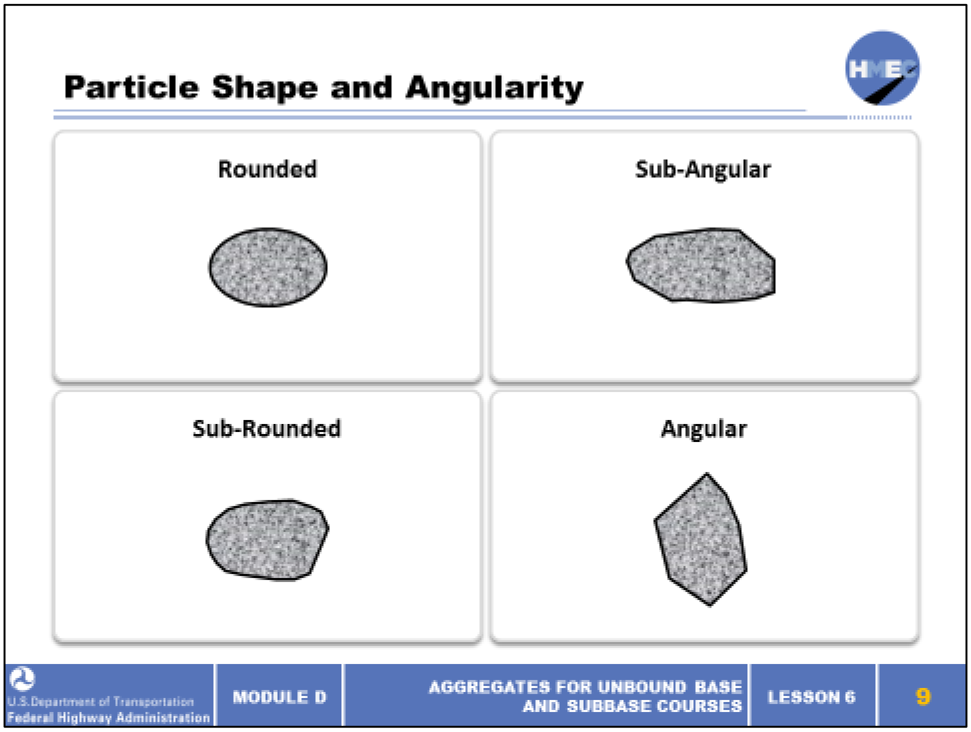
Slide 8



The listed aggregate properties are generally considered the most important for unbound aggregate bases and subbases. The shape, angularity, and surface texture have a significant effect on the particle interaction and effect density, ease of placement, compaction, and associated parameters. The soundness, strength, and abrasion resistance affect the ability of the aggregates to resist breakdown and resulting fines generation and consolidation under repeated traffic loading or harsh environmental conditions. This breakdown may occur in rigid pavement structures, and it is more prevalent in flexible pavements. It should be noted that this list is not all inclusive and represents only a portion of the material properties that could potentially be specified.

Slide 9



Particle shape plays an important role in the ease of placement and compaction, and is largely responsible for particle interaction and stability. The more round-shaped particles have a tendency to displace and reorient under load (primarily during construction operations), while the more angular shapes tend to lock together, resulting in a high degree of stability.

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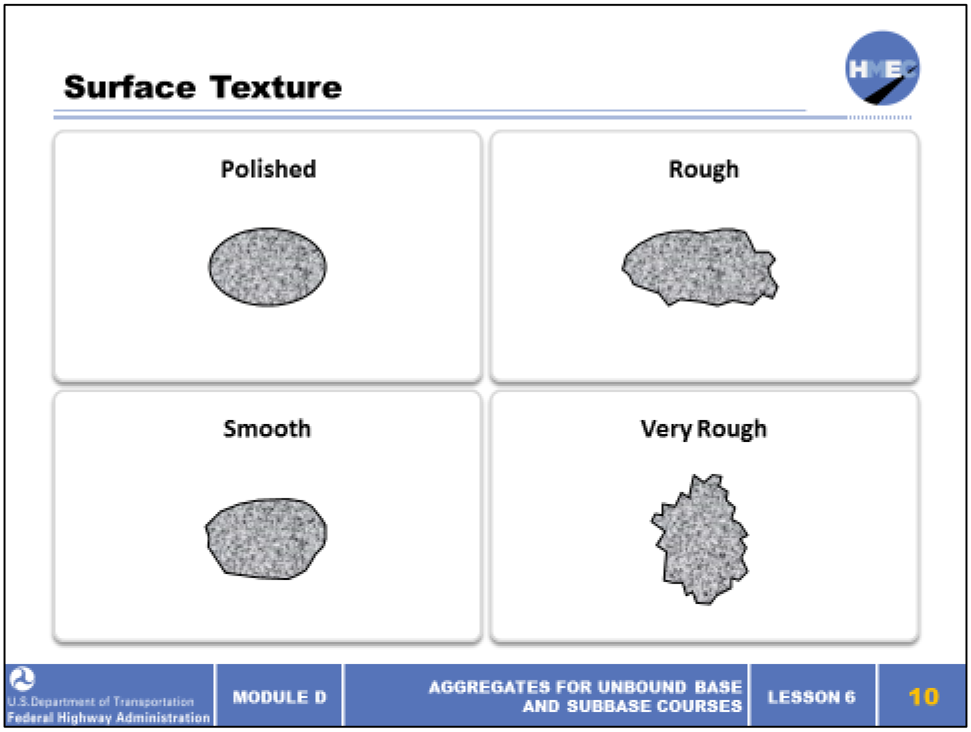
Slide 10



Like particle shape, surface texture plays an important role in the ease of placement and compaction and contributes to particle interaction and stability. Smooth textured aggregates (particularly rounded shapes) tend to displace and reorient easily under load (primarily during construction operations). The presence of fines (minus #200 material) can make this even more problematic, particularly with high plasticity clays.

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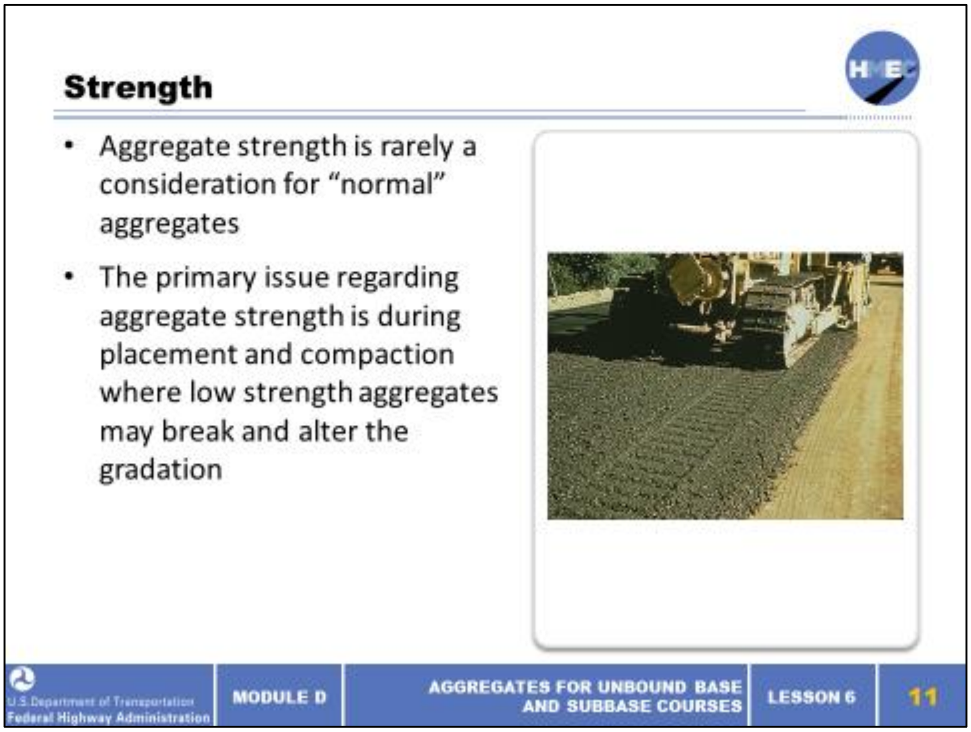
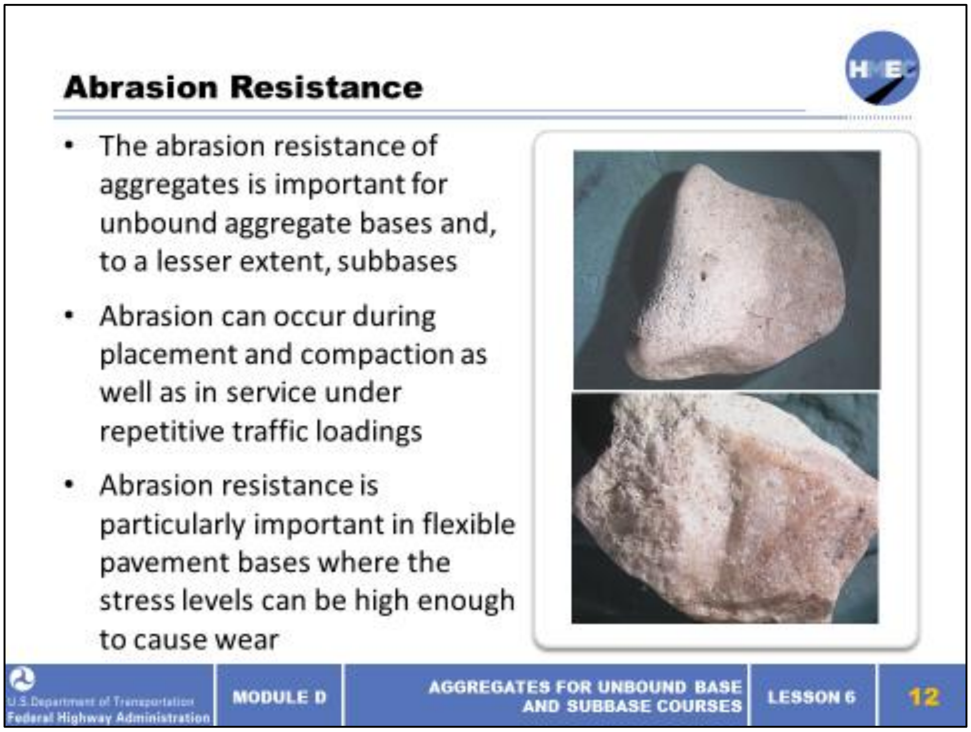
Slide 11



Aggregate strength is generally not a consideration for either bases or subbases unless the material is very weak and friable. The largest effect of strength is during placement and compaction rather than in-service conditions. If the aggregates break down, there is a corresponding change in gradation, which is problematic, particularly if the fines content is increased.

Slide 12



The abrasion resistance of aggregates in unbound bases and subbases is important due to the abrading actions of the aggregate particles during construction as well as in-service. The LA abrasion test and Micro-Deval test are intended to simulate impact resistance and wear under these conditions. The abrading of aggregates leads to the generation of fines and a change in the overall aggregate gradation. A higher fines content frequently leads to lower stability and an increase in the moisture sensitivity of the aggregates.

The photo on the top is prior to abrasion testing, the photo on the bottom is after. Note that not only has the aggregate gradation changed, the particle shape and surface texture is also changed, leading to a lower stability.
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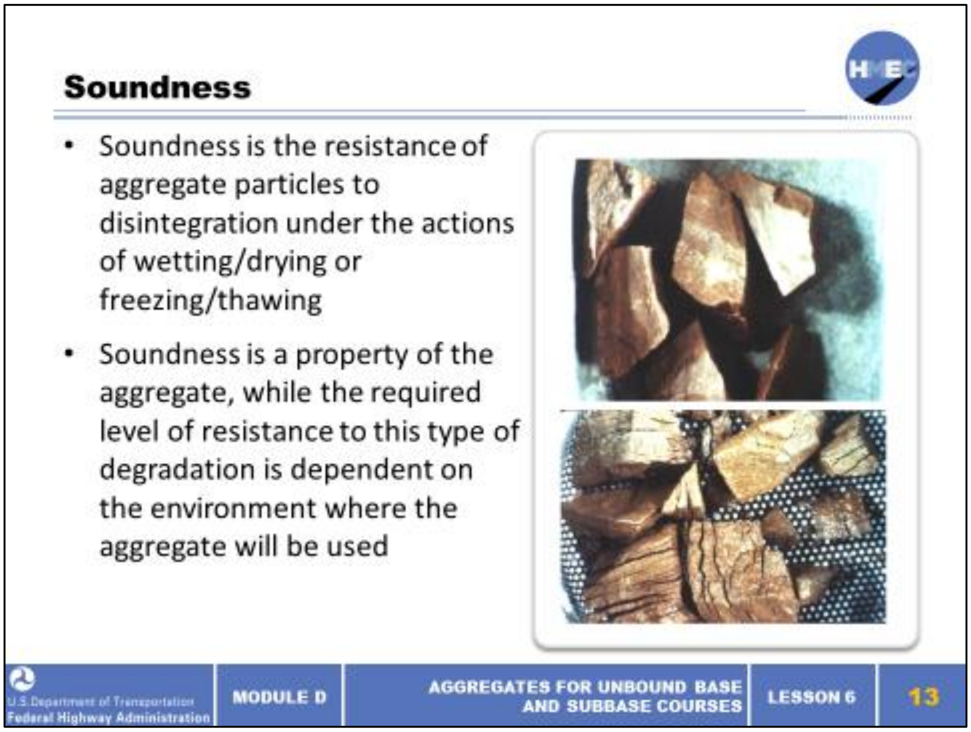
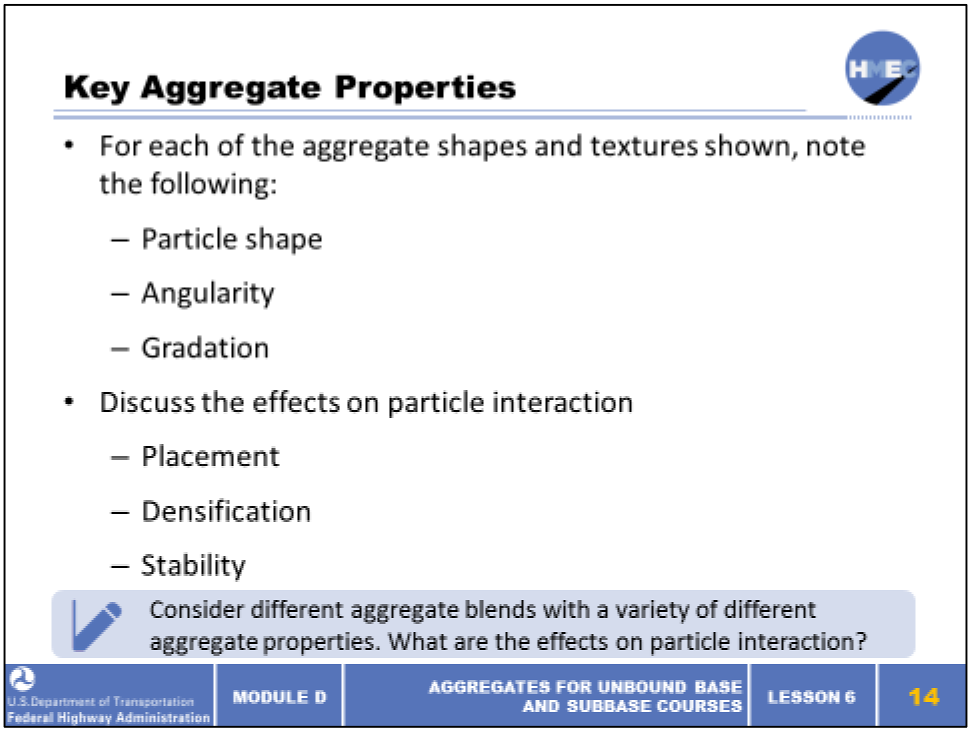
Slide 13



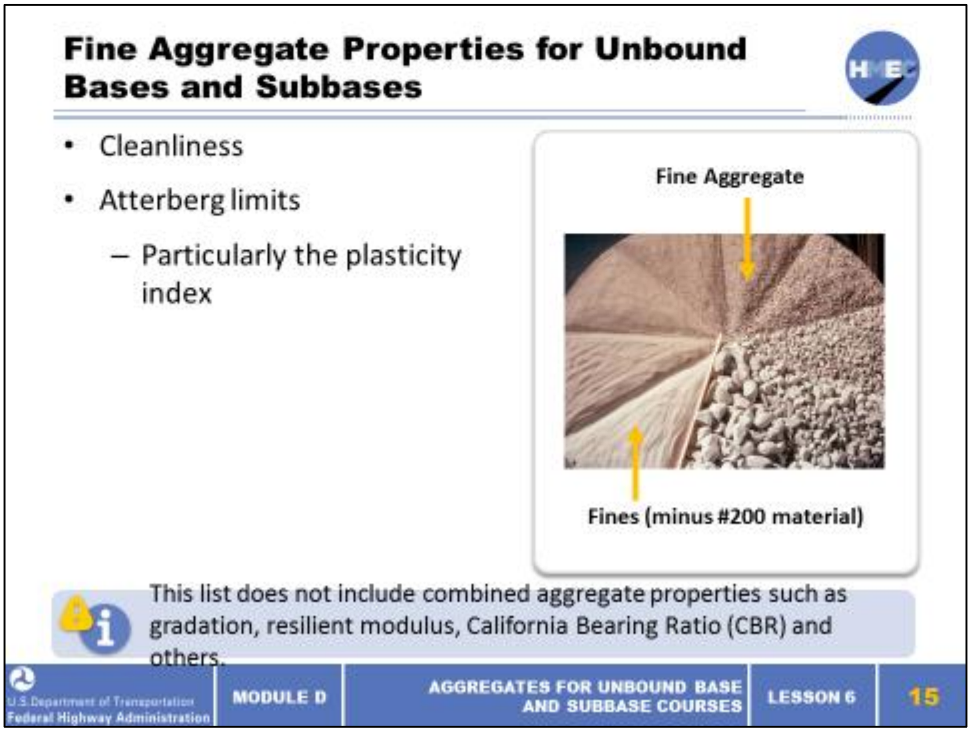
Soundness refers to the resistance of aggregates to break down under repetitive freeze/thaw or wetting and drying cycles. As can be seen in the photos (the sample on the top is the intact sample, the sample on the bottom is after the sulfate soundness test), the aggregates have visible damage as well as a change in gradation. Unsound aggregates will generally continue to degrade in service over a long period of time, thereby reducing the level and uniformity of support.

Slide 14



The properties of the aggregate impact particle interaction.

Slide 15



The fine aggregate content of unbound aggregate bases and subbases is important for a number of reasons, including permeability, stability, ease of placement, compaction, and other related properties. The fine aggregates are generally differentiated by materials passing the #4 sieve (4.75 mm).

Atterberg limit tests (i.e. plastic limit and liquid limit) are performed on the material passing the #40 sieve for the blended aggregate or soil-aggregate mixture. The Plasticity Index (PI) is based on the liquid limit and plastic limit and is very important in assessing the moisture sensitivity of the aggregates. Specifications typically state a maximum value for the PI depending on intended use of the material.

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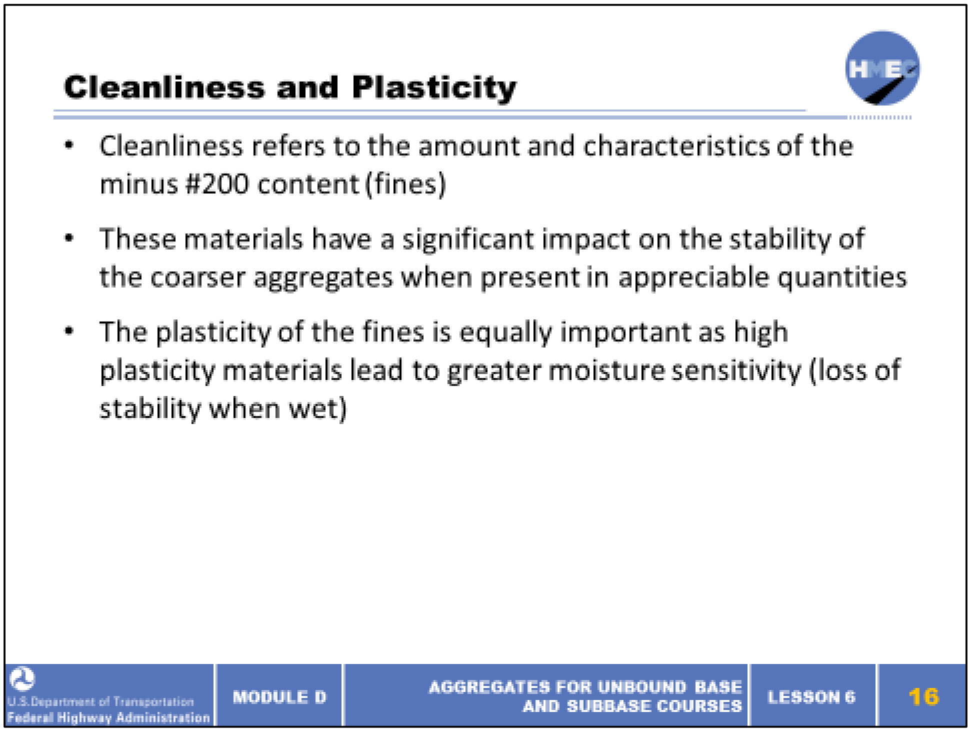
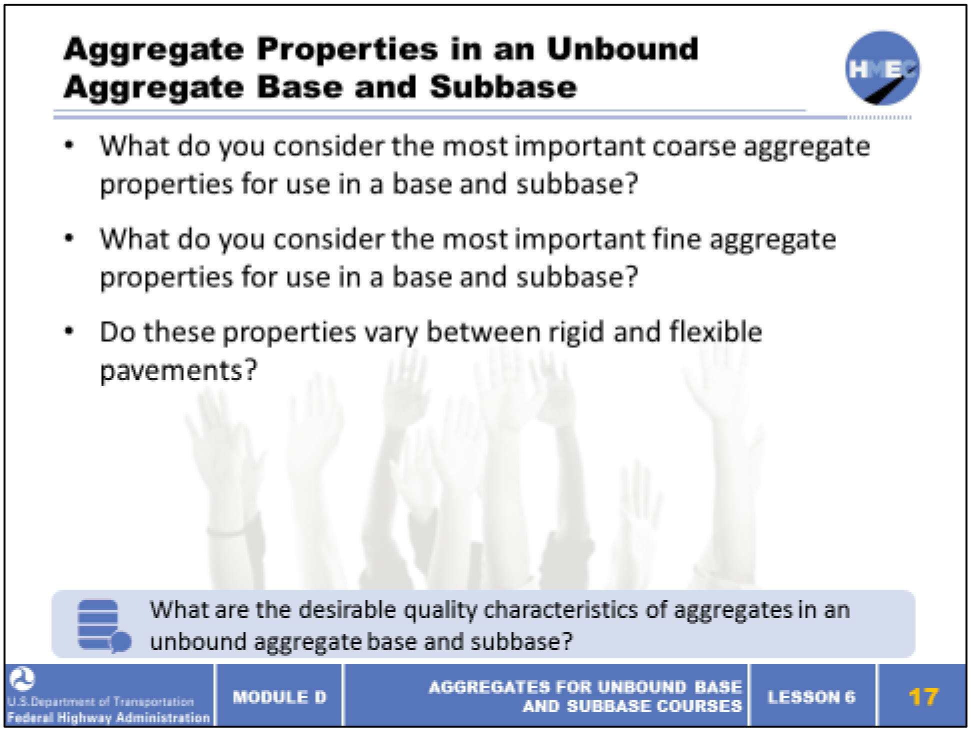
Slide 16



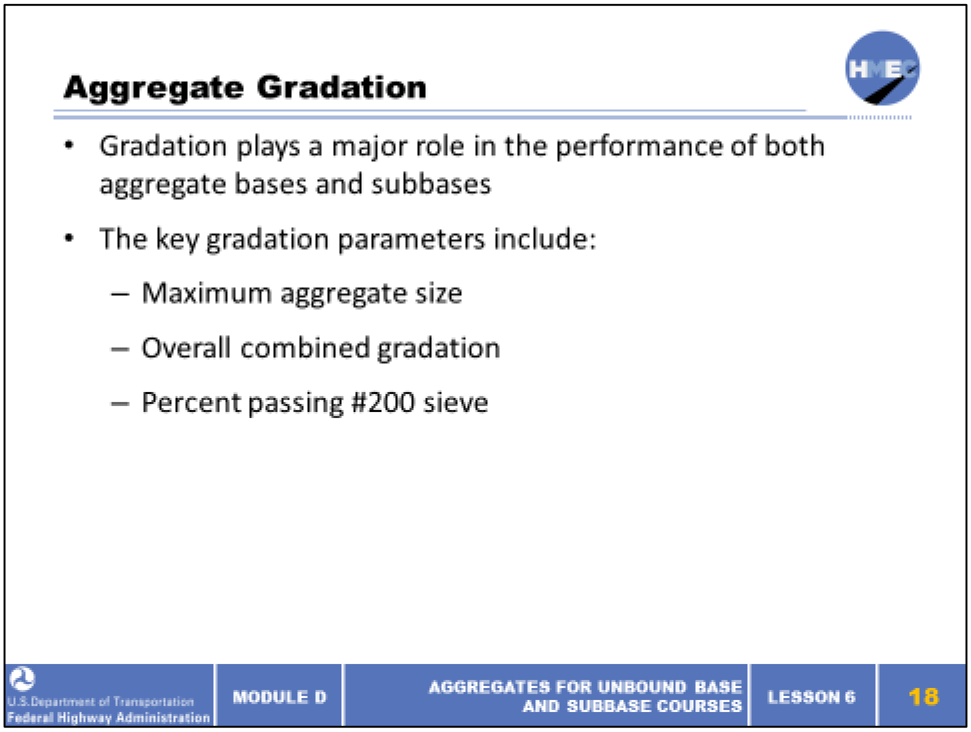
The material passing the #200 sieve (commonly known as fines) can have a significant effect on the properties of the overall fine aggregate. Specifications typically limit the amount of minus #200 material as well as the characteristics; i.e., low plasticity materials are typically specified.

Slide 17



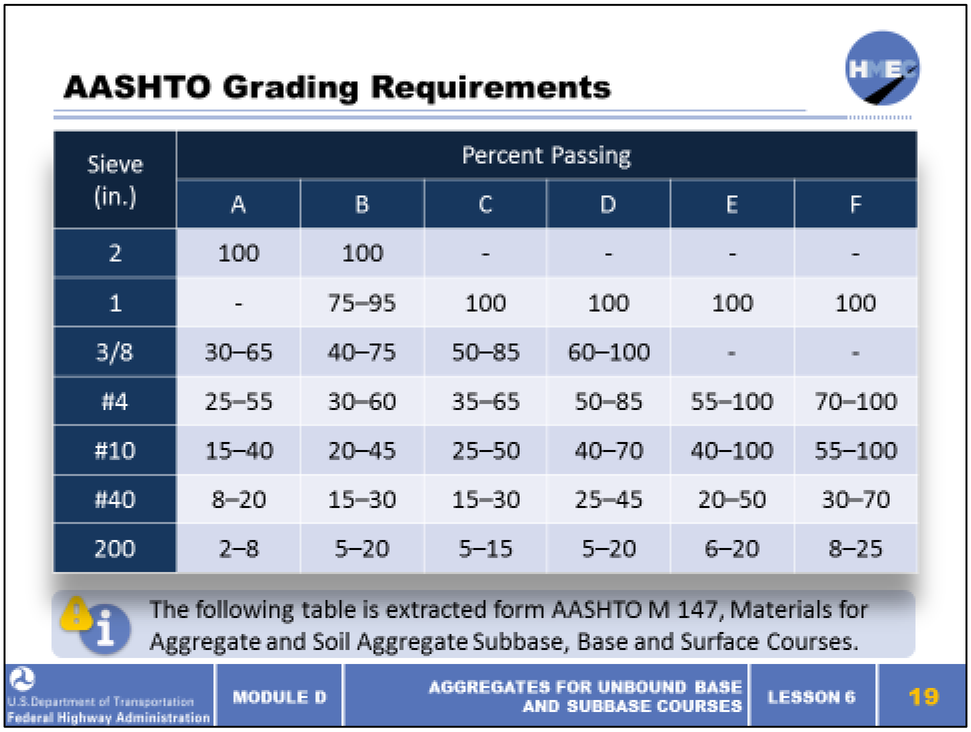
The fine aggregate characteristics appear to be much less stringent than those for the coarse aggregate fraction. However, these characteristics are very important in the overall performance of the combined gradation used for both bases and subbases.

Slide 18



The gradation of the aggregate used in unbound base and subbase courses significantly impacts several properties, including density, stability, permeability, and durability. Density and stability are critical to dense-graded base courses, which are expected to contribute toward the overall structural capacity of the pavement. Permeability is a critical property for drainable bases and durability is always a desired property for all types of base courses.

Slide 19



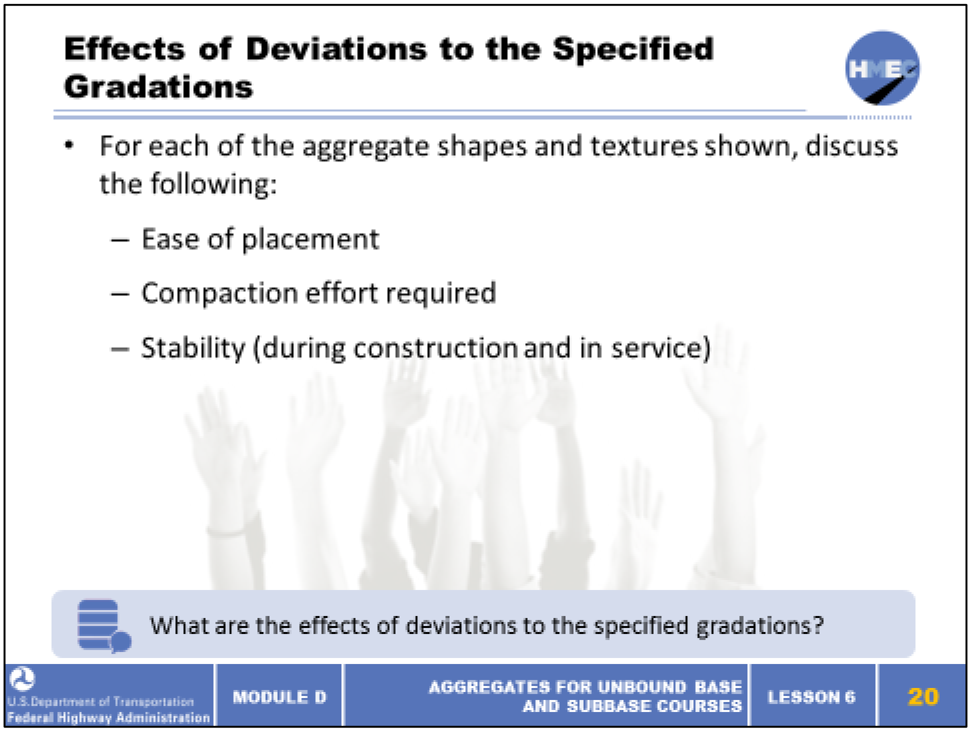
Sieve (in.)	Percent Passing					
	A	B	C	D	E	F
2	100	100	-	-	-	-
1	-	75–95	100	100	100	100
3/8	30–65	40–75	50–85	60–100	-	-
#4	25–55	30–60	35–65	50–85	55–100	70–100
#10	15–40	20–45	25–50	40–70	40–100	55–100
#40	8–20	15–30	15–30	25–45	20–50	30–70
200	2–8	5–20	5–15	5–20	6–20	8–25

The following table is extracted form AASHTO M 147, Materials for Aggregate and Soil Aggregate Subbase, Base and Surface Courses.

The information presented in this table are the grading requirements for soil aggregate materials used for bases, subbases, and aggregate surfaced roads. Additional information contained in the specification have already been addressed in terms of the desirable properties of fine and coarse aggregates.

The gradations specified for bases and subbases include gradings A, B, C, D, E and F. However, if the minus #200 specification has been shown to be problematic in terms of freeze/thaw damage, lower percentages may be specified.

Slide 20


Effects of Deviations to the Specified Gradations
HMEC
For each of the aggregate shapes and textures shown, discuss the following:
– Ease of placement
– Compaction effort required
– Stability (during construction and in service)
What are the effects of deviations to the specified gradations?
U.S. Department of Transportation
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AGGREGATES FOR UNBOUND BASE AND SUBBASE COURSES
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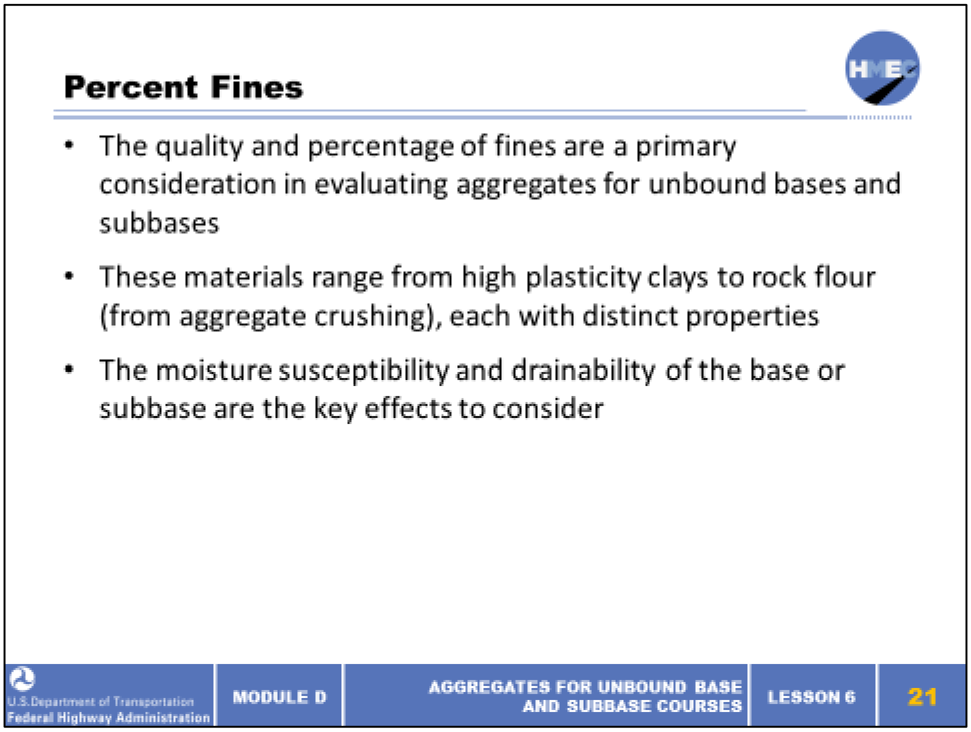
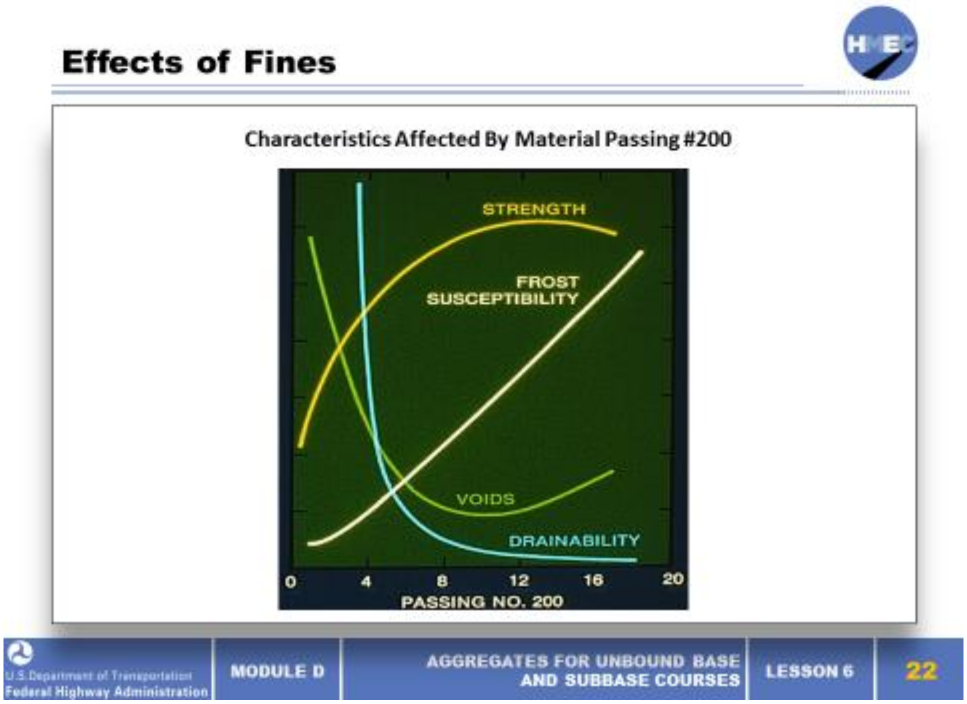
Slide 21



The percentage of fines is a relatively small fraction of the overall gradation but can have a significant effect on performance. Recall that the minus #200 specification in the AASHTO gradations can be reduced if performance issues are noted.

Slide 22



This figure shows the typical relationships between strength, frost susceptibility, voids, and drainability and the percent fines.

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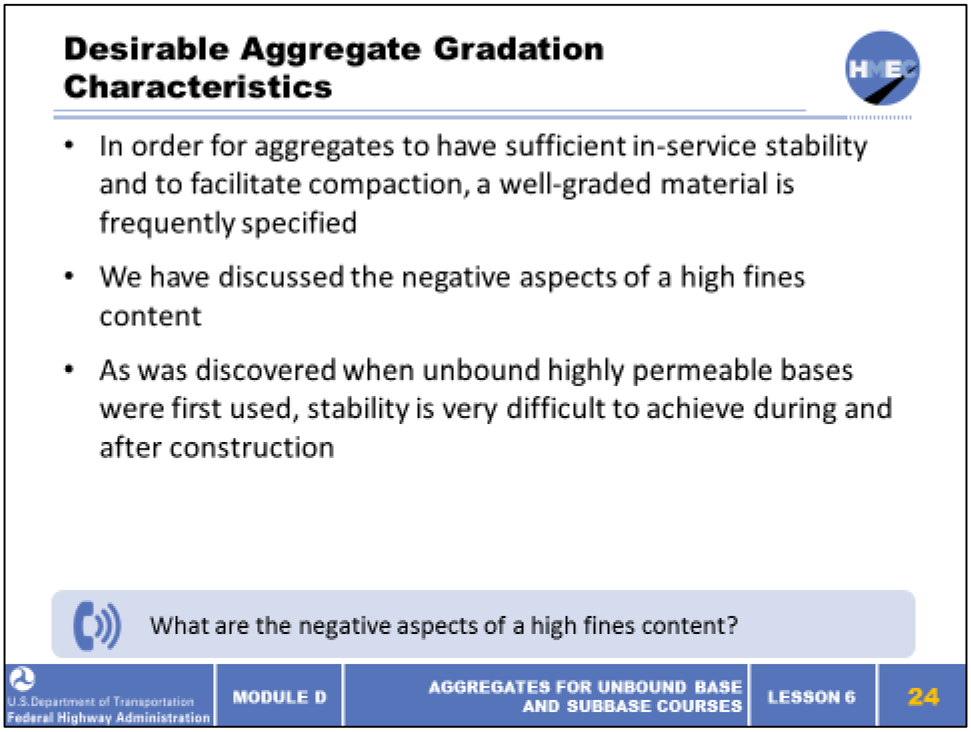
Slide 23

The best aggregates for base courses are those that can provide high stability, high strength, and long-term durability under all anticipated conditions of traffic and environment. In order to achieve these properties, the aggregates must resist deterioration due to traffic stresses and environmental conditions.

Slide 24

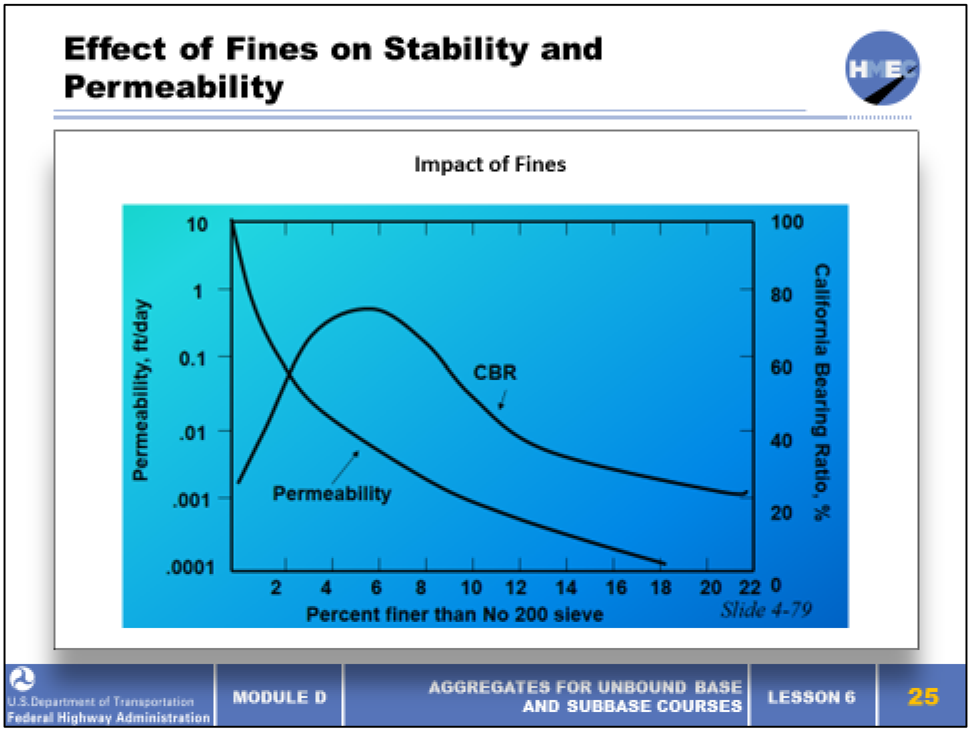


There is a tradeoff between the amount of fines and the ability to compact an aggregate base or subbase to a target density and permeability (drainability). In order for aggregates to have sufficient in-service stability and to facilitate compaction, a well-graded material is frequently specified.

Recall the negative aspects of a high fines content.

As was discovered when unbound highly permeable bases were first used, stability is very difficult to achieve during and after construction.

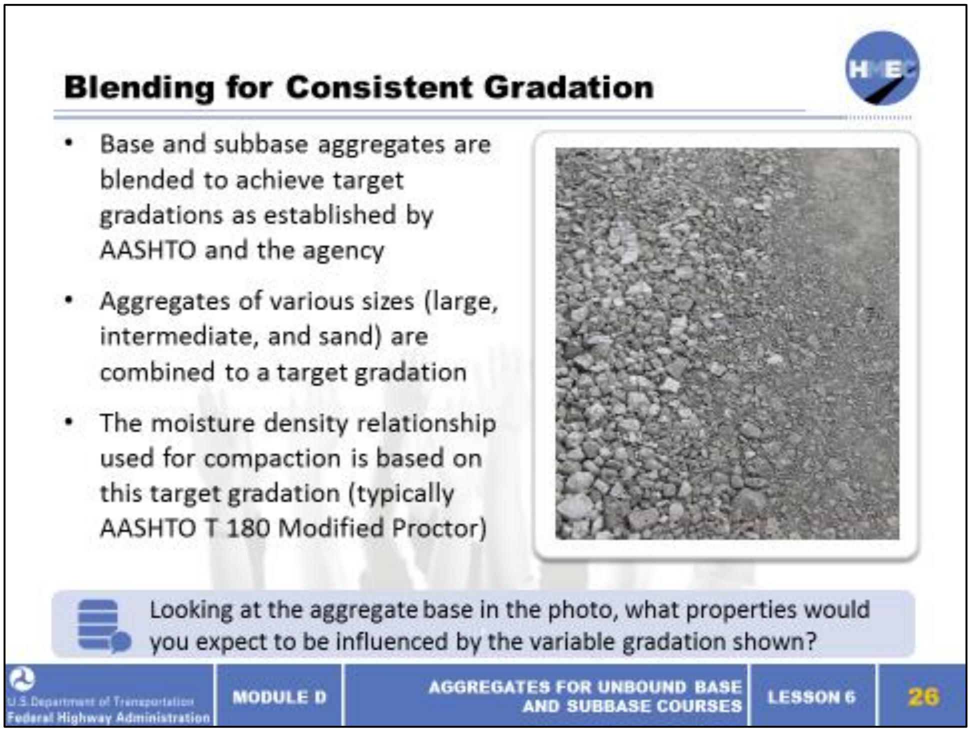
Slide 25



This figure shows that a base designed for maximum strength may not provide good permeability and vice versa. The data show that permeability decreases with increased fines and going from poor permeability to excellent permeability causes a significant drop in stability (CBR).

Although not shown directly on this slide, there is a narrow range of percent fines over which both maximum stability and maximum density can be achieved. As the percent fines increases, the stability (as shown by CBR in the graph) increases as the voids are filled with the fines. There is also a corresponding increase in density since the void space is now occupied by solid material. After a certain point (dependent on other gradation parameters), the fines begin to separate the larger aggregate particles thereby reducing aggregate to aggregate contact. The result of this separation is lower stability and lower density.

Slide 26



The material being sent to the project should be consistent in gradation and other important characteristics. A consistent gradation is essential for good compaction control, for development of true target densities, and for accurate measurement of density in the field. Compaction is the key to good base construction. Compaction provides pre-confinement of the unbound base course.

Base and subbase aggregates are blended to achieve target gradations as established by AASHTO and the agency. The AASHTO M 147 aggregate gradations are sufficiently broad to allow for significant deviations on most sieve sizes.

In order to provide the most consistent gradations, aggregates of various sizes (large, intermediate, and sand) are combined to a target gradation. The moisture density relationship used for compaction is based on this target gradation (typically AASHTO T 180 Modified Proctor).

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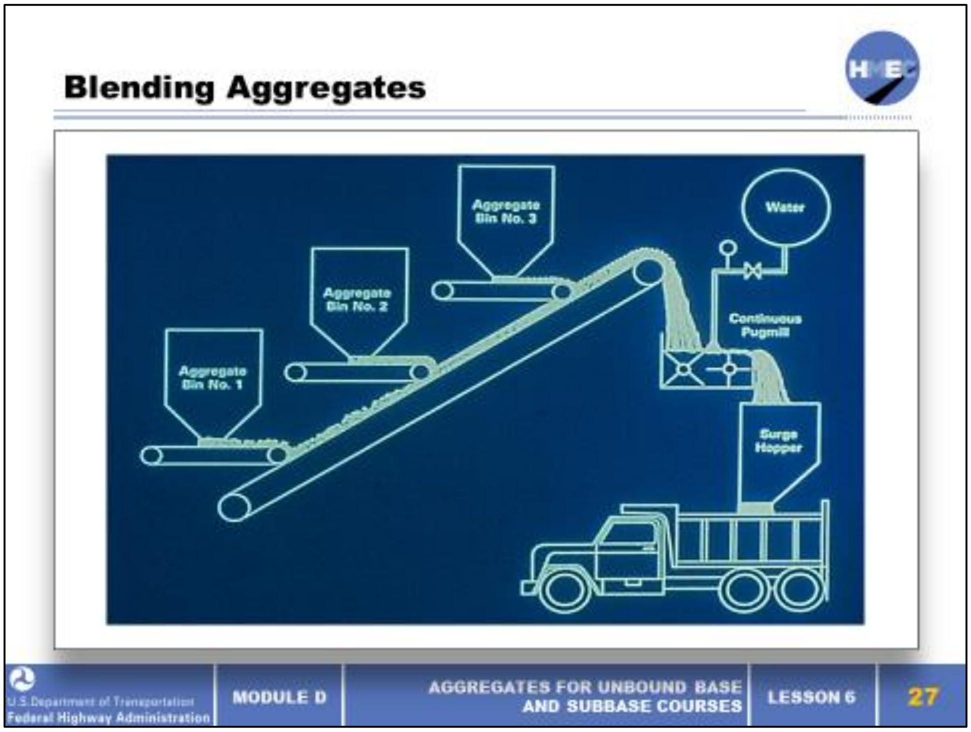
Slide 27



The aggregate bins shown are different size fractions corresponding to coarse, intermediate, and sand. The sizes of these stockpiled materials corresponds to the tendency to segregate during handling. The materials are charged onto the conveyor according to the target gradation and then combined in the pugmill for blending prior to discharge into the haul vehicle.

Slide 28

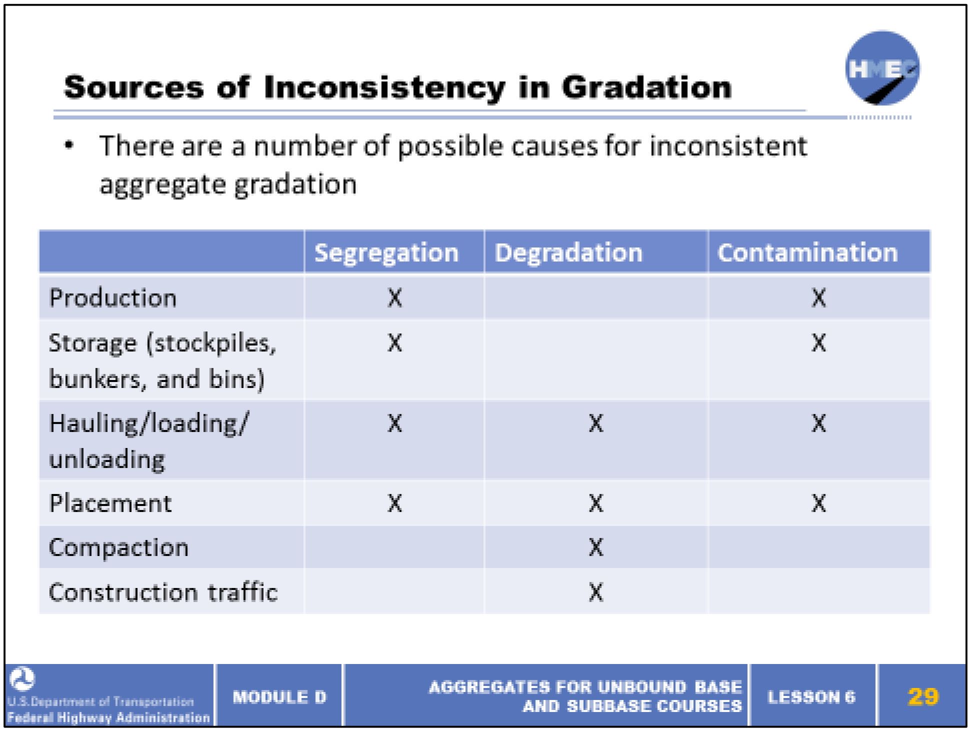
The goal of aggregate blending is to produce a uniform distribution of particles based on a target gradation.

To achieve this, stockpiles are blended at the production facility to produce standard gradations. Note that aggregates may also be blended at the point of use.

Stockpiled materials are blended by intermixing in the proper proportions for a specific overall gradation.

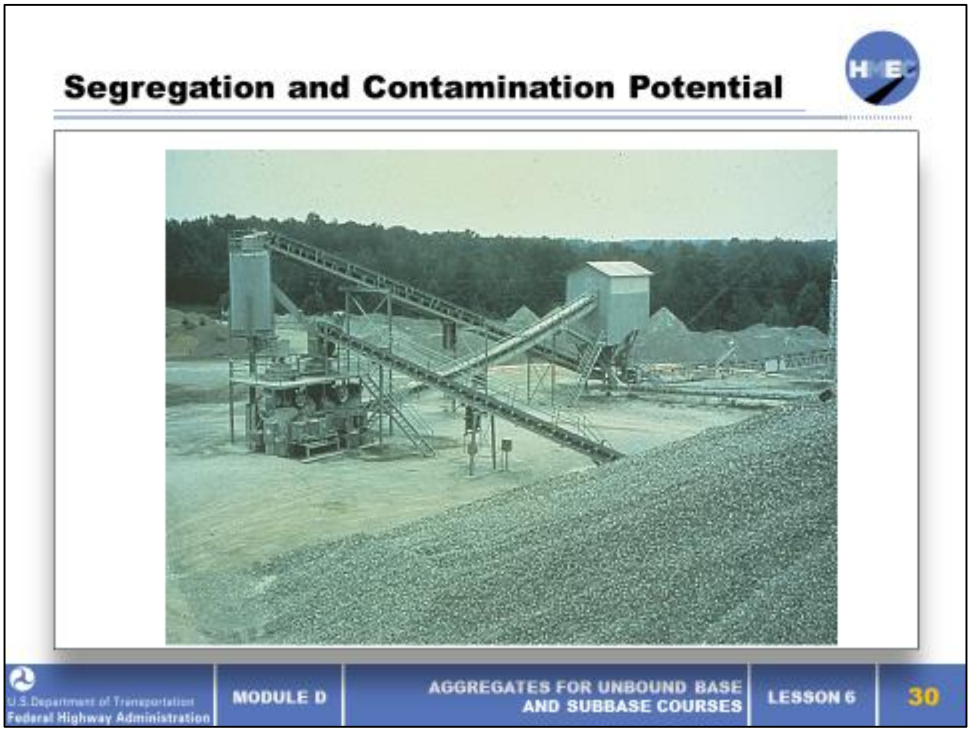
In order to minimize dusting and to reduce segregation (particularly separation of fines), the stockpiles are generally misted, as shown in the photo.

Slide 29



There are a number of possible causes for inconsistent aggregate gradation. The table on this slide illustrates the most common issues related to gradation control at each stage, from production through to construction. Note that degradation refers to the potential breakdown of the aggregates (thereby generating fines), while contamination refers to external sources of materials (typically fine material).

Slide 30



Control over variability must be maintained all the way from the production plant to the project. If possible, the material should be hauled directly to the grade and should be spread and compacted promptly, while its gradation and moisture content are within tolerances. Stockpiling of the blended aggregates is not recommended since the material is more likely to segregate or become contaminated.

The potential for segregation increases as the particle size distribution becomes greater. In other words, a stockpile containing materials ranging from the #4 to 1½-in. is much more likely to segregate during handling than a stockpile comprised only of ¾ and 1½-in. material. It is important to note that aggregates can segregate any time they are moved or transported. This can occur during stockpile construction when the conveyor freefall is excessive; loading if the aggregates are dropped from excessive height; transportation if the haul distance is relatively long and rough; and placement if the truck discharge and grading is improper.

Contamination is the introduction of external materials to the graded aggregates. Contamination can arise from multiple sources, including windblown dust and debris or foundation material being introduced during loading operations. Contamination may also occur during placement and grading operations where multiple lifts of materials may be inadvertently mixed.

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Slide 31

Rolling is necessary to compact the aggregate base or subbase to a predetermined target density. Friable aggregates or soft aggregates are not desirable materials, as previously mentioned. These aggregates can deteriorate during compaction, resulting in a changed gradation and an increased fines content.

Note that degradation can also occur after placement and compaction if construction traffic is allowed to drive on the unbound aggregate for an extended period of time.

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Slide 32

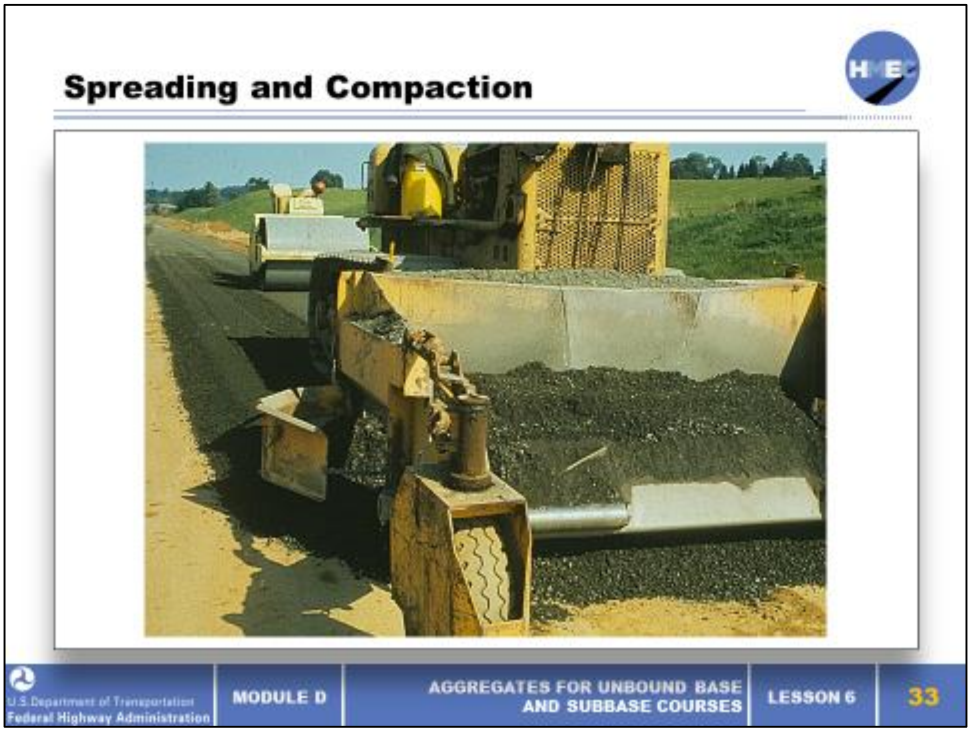
There are many methods of placement of unbound aggregate bases and subbases. Spreading blended aggregates while minimizing segregation or contamination is an important step in assuring uniform support in the pavement structure. As previously mentioned, the larger the particle size distribution, the higher the opportunity for segregation.

The blended aggregates are generally wetted so that the fines adhere to the larger aggregate particles to minimize segregation. Wetting is also required to achieve adequate compaction based on the Proctor moisture-density relationship.

The photo on the left shows a skid-steer loader being used to place the aggregate base. This method of placement is not recommended due to the chance for segregation, contamination for the subbase or subgrade, and poor thickness control.

The photo on the right illustrates a spreader box being used to place the aggregate base. This practice reduces the opportunity for segregation and results in more uniform placement.

Slide 33



Compaction should follow immediately so the material doesn't dry out, and therefore require additional water. Note the relatively uniform appearance of the blended aggregates in the hopper and as placed. Prior testing of the aggregates should have limited the amount of friable and soft particles. However, it is a good idea to test a sample of the compacted material in order to determine if excessive degradation is present.

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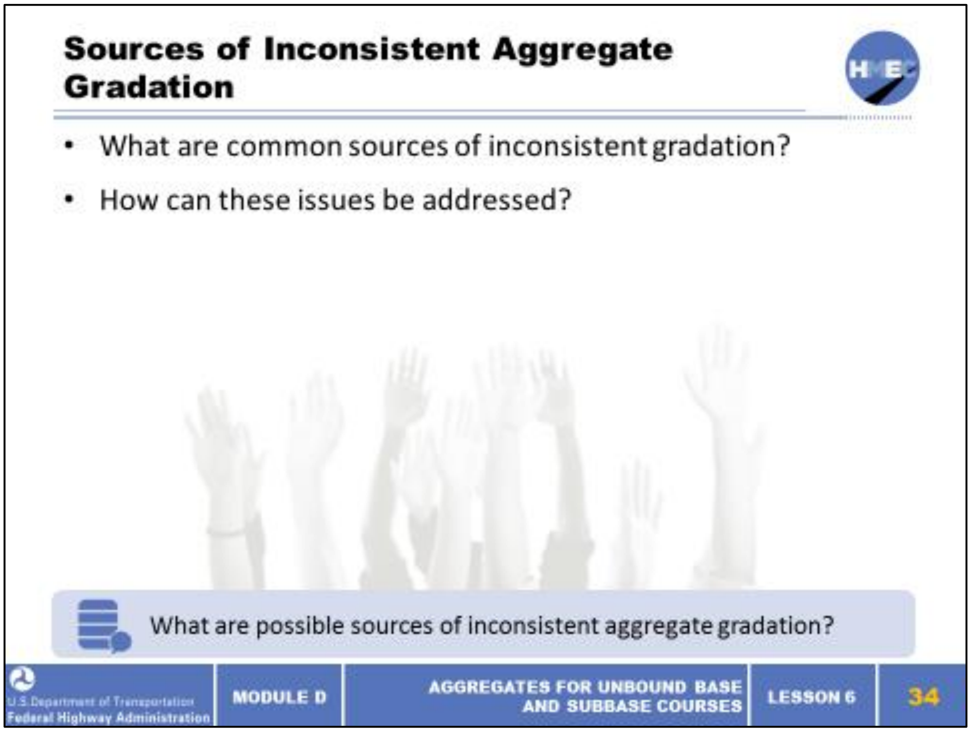
Slide 34


Sources of Inconsistent Aggregate Gradation
• What are common sources of inconsistent gradation?
• How can these issues be addressed?
What are possible sources of inconsistent aggregate gradation?
U.S. Department of Transportation
Federal Highway Administration
MODULE D
AGGREGATES FOR UNBOUND BASE AND SUBBASE COURSES
LESSON 6
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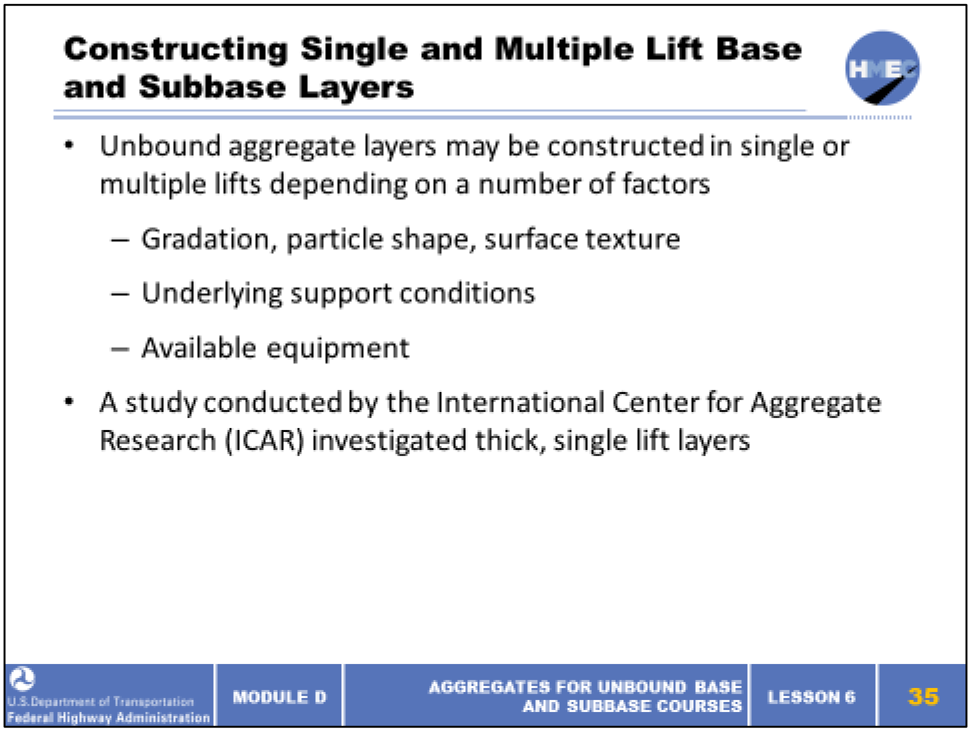
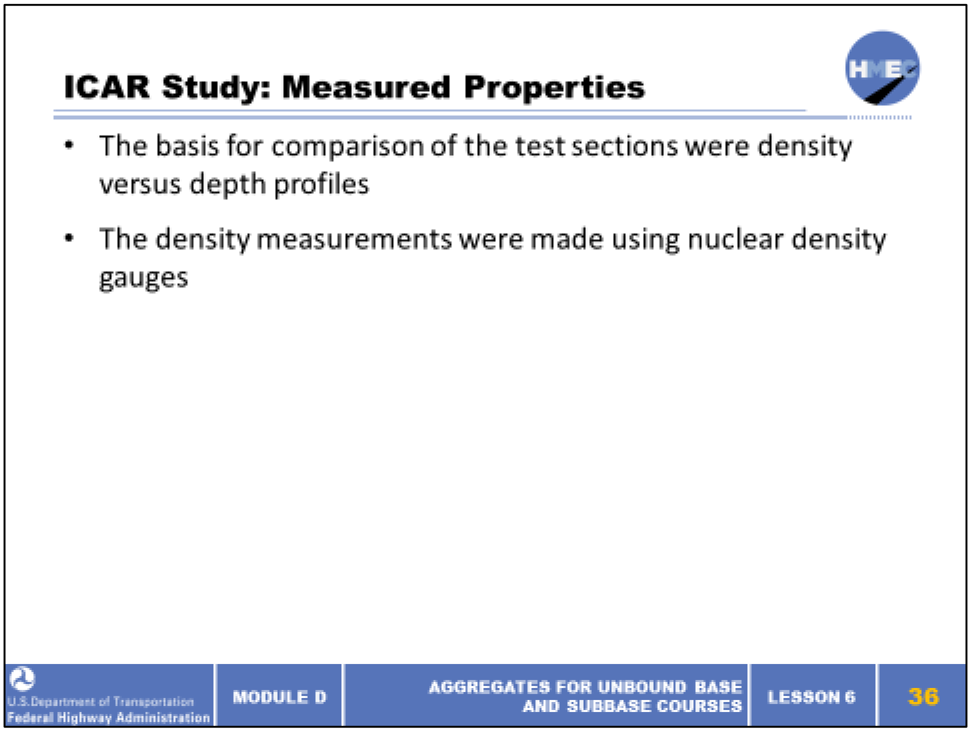
Slide 35



Unbound aggregate layers may be constructed in single or multiple lifts depending on a number of factors, including gradation, particle shape, and surface texture, underlying support conditions, and available equipment.

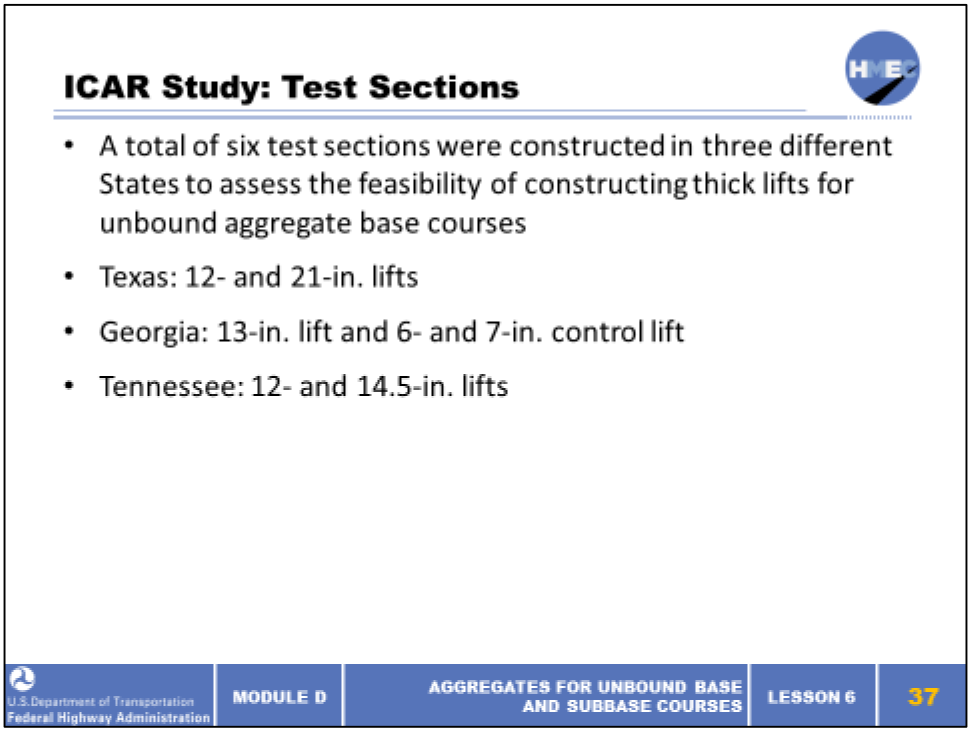
In 1998, the International Center for Aggregate Research (ICAR) conducted an extensive study to evaluate the feasibility of constructing thick single lift base layers. A summary report, entitled "Increased Single-Lift Thickness for Unbound Aggregate Base Courses," Research Report ICAR-501-5 is available from ICAR.

Slide 36



A comparison between the different placement and compaction options was based on density measurements. The field sections were evaluated in terms of their density profile (nuclear density gage) to evaluate if acceptable densities are achieved when thicker lifts are constructed. All sections were compacted with the same roller (45,000–55,000 lbs. vibratory roller).

Slide 37



The Texas sections were constructed at an aggregate quarry using dense-graded crushed limestone.

The Georgia sections were constructed on Hwy 29 using dense-graded crushed granite.

The Tennessee sections were constructed at an aggregate quarry using gap-graded uncrushed and partially crushed gravels with low fines.

Slide 38

ICAR Study: Texas and Tennessee Sections

Depth into Base (in.)	Texas Sections % Compaction	Tennessee Sections % Compaction
2	93	103
4	95	104
6	97	102
8	98	102
10	99	101
12	101	100

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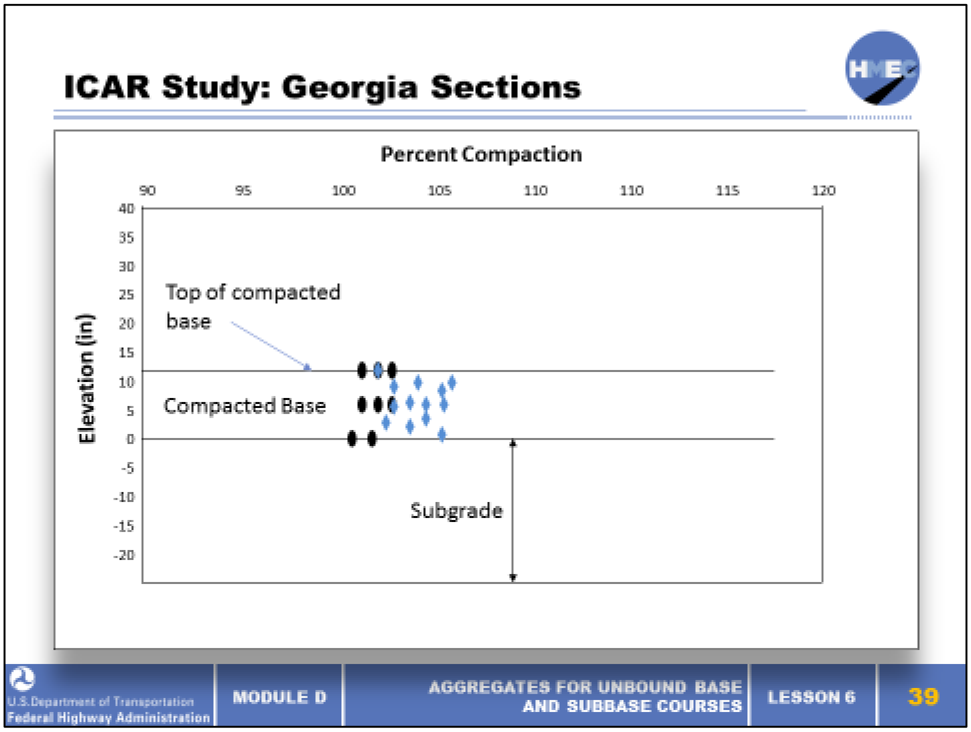
The nuclear density gauge used in this study was equipped with a 12-in. probe, so density data were only measured down to 12 in. into the lift.

The Texas data represents tests in the upper 12 in. of a 21-in. lift. The data shows that all densities are in excess of 93% of AASHTO T 180, which represent compaction above most State specifications.

The Tennessee data represents tests in the upper 12 in. of a 12-in. lift. The density data from the Tennessee section show percent compaction in excess of 100% throughout the depth of the base layer.

Slide 39

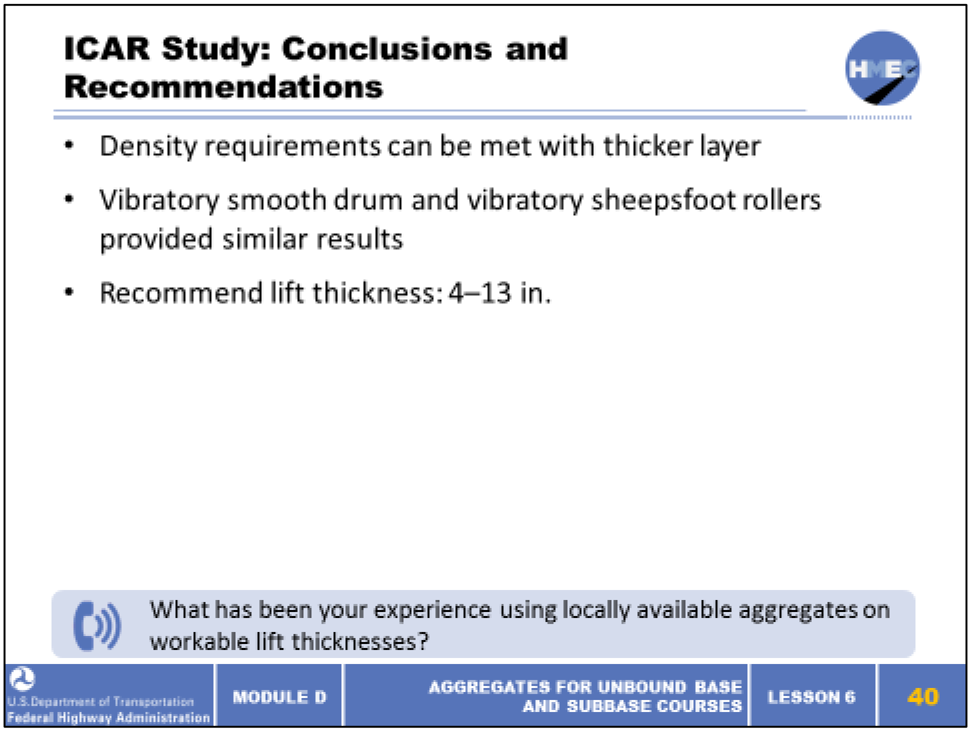


The control section consisted of 7-in. and 6-in. lifts, represented by the black data points on the graph. Each of these lifts was placed and compacted independently. Note that the level of compaction exceeds 100% in all cases and that the upper lift has essentially uniform compaction with depth.

The data points shown on the graph in blue represent a single lift placement, 13 in. thick. The Georgia data show that average densities for the sections with the 13-in. single lift are slightly greater than those for the control strip, which was placed in one 6- and one 7-in. lift.

Note that the data points at elevation 0 correspond to the density of the compacted base at the base/subgrade interface. The other data points correspond to the densities at different elevations within the single or two lifts.

Slide 40

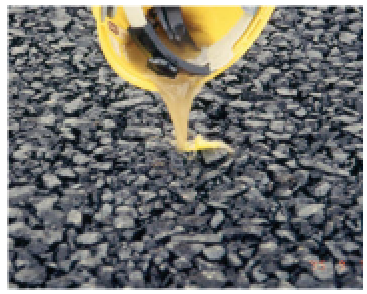


Based on the data generated from the sections in Texas, Georgia, and Tennessee, the ICAR research concluded that thicker lift base courses can be effectively compacted to achieve density requirements. In addition, the type of vibratory roller did not make any appreciable difference in in-place density.

Slide 41

Permeable Bases

- Used to drain water that infiltrates into the pavement from rainfall, snow melt, and other surface/near surface sources
- Typically used in conjunction with a comprehensive drainage system or by daylighting to a ditch or median
- Must be designed and constructed carefully to avoid instability or too low permeability



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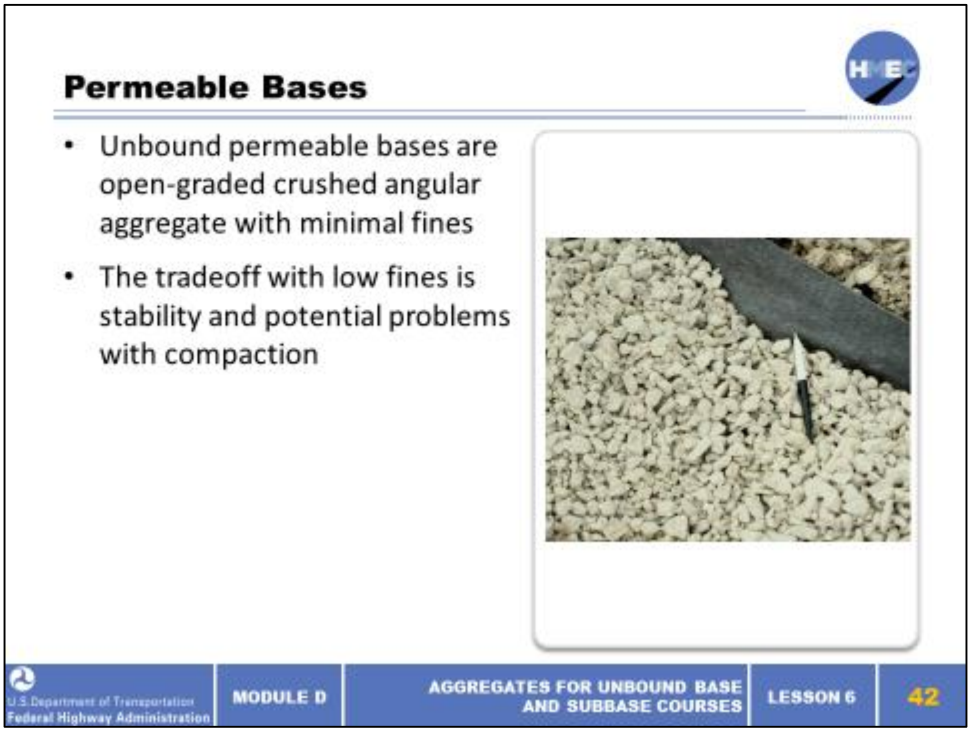
Permeable bases have a varied history, ranging from providing a measureable benefit to pavement performance to causing premature failure. In order for a permeable base to function correctly and provide the desired benefit, it must have adequate stability and permeability.

Permeable bases require a way for the water to drain from the structure. This generally entails a well-maintained, comprehensive drainage system or a well-maintained, day lighted system. Permeable bases should only be used if there is a commitment for long-term maintenance.

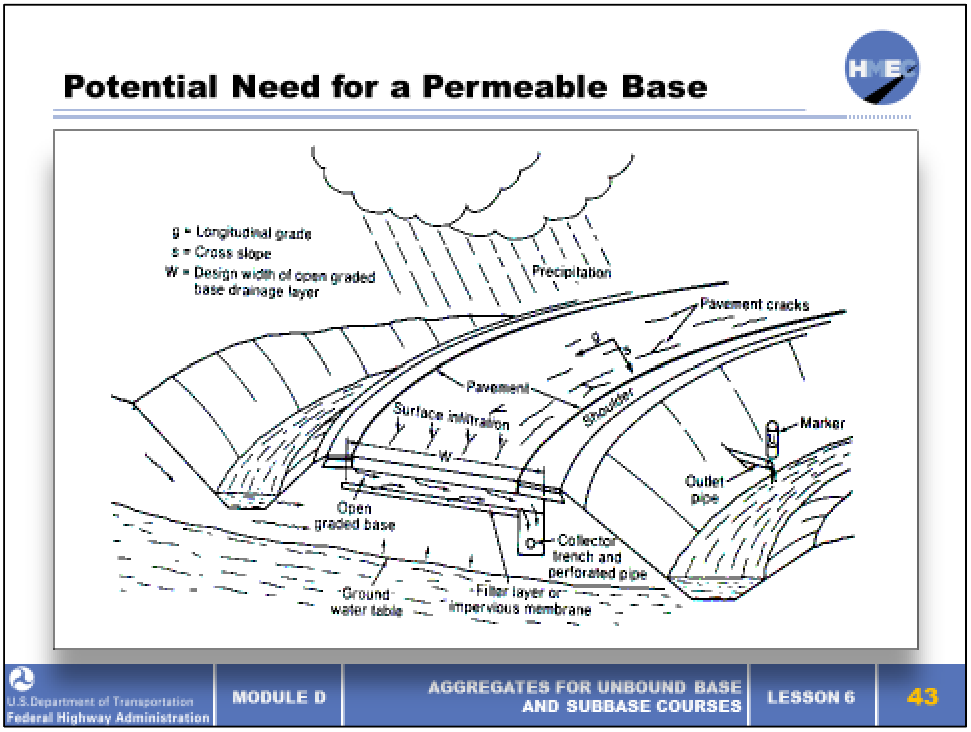
Slide 42



The main objective of permeable bases is to drain water that infiltrates into the pavement structure without damaging the underlying subgrade. Therefore, the key property in permeable bases is drainability, which represents the ability of a base course to drain water as a function of time.

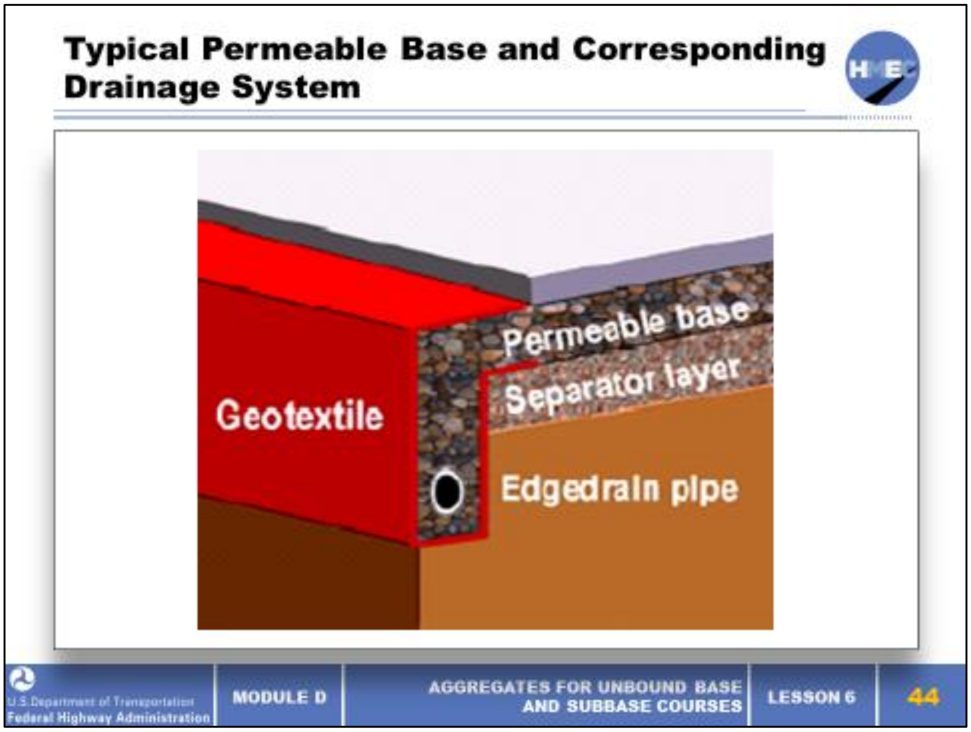
Unbound permeable bases are open-graded crushed angular aggregate with minimal fines. This slide shows typical aggregate for an open-graded base course. The aggregates are usually very clean and single size, allowing for high air voids and high permeability. Open-graded aggregates are required for adequate drainage but can be difficult to compact and may lack stability.

Slide 43



Water enters the pavement structure from various sources. It is the job of the designer to drain the water away from the pavement structure as quickly as possible to reduce its potential of damaging the various layers. Virtually all pavement layers are susceptible to moisture and its existence will greatly reduce the useful life of both flexible and rigid pavements.

Slide 44



Permeable bases are effective if they function correctly and they are very damaging if they do not function correctly. They must be kept open and be protected from contamination throughout the life of the pavement.

If the open-graded base or the drainage pipe get clogged, the moisture will accumulate in the base and seep through to the subgrade causing extensive damage to the entire pavement structure.

In summary, the use of open-graded bases should come with a long–term commitment to keep the drainage system operational at all times.

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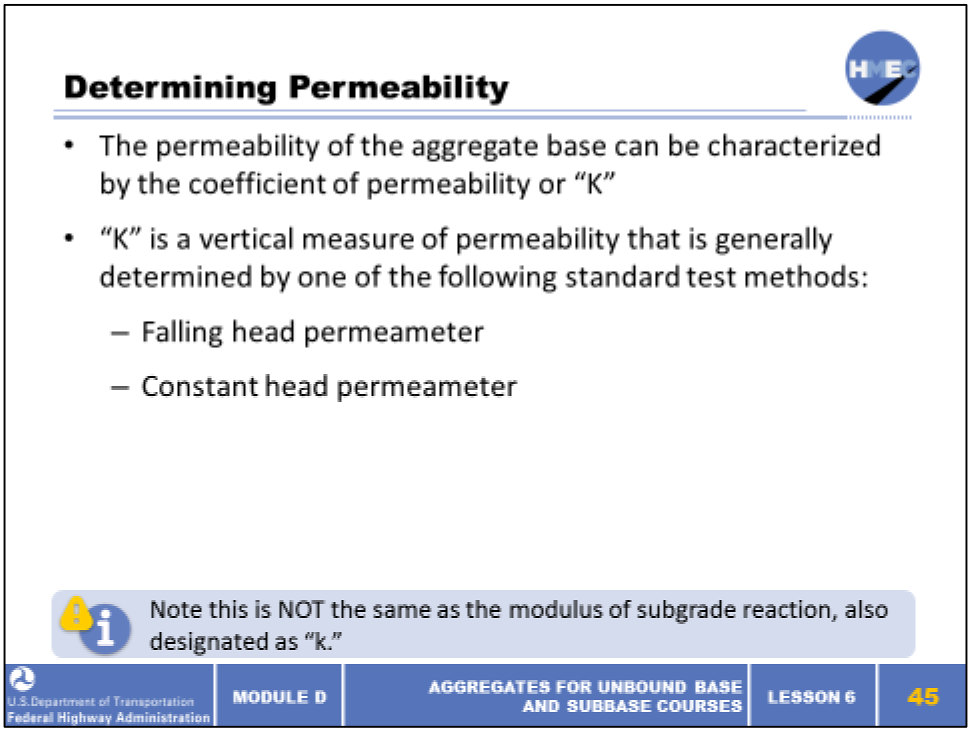
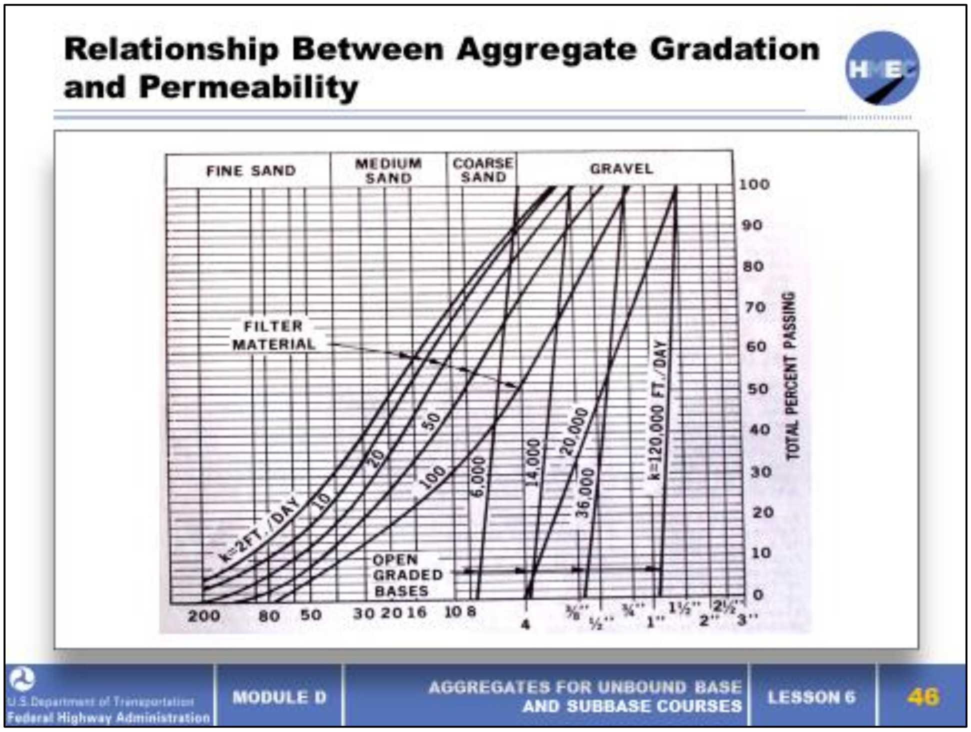
Slide 45



Drainability is expressed in terms of a coefficient of permeability, K, in feet per day or centimeters per second. K is generally measured by a laboratory test, such as AASHTO T 215 on disturbed samples of granular material containing no more than 10% soil passing the 0.075 mm sieve. More often it is estimated from empirically derived graphs indicating relative permeability for various open-graded aggregates.

Slide 46



This figure shows the direct relationship between permeability and aggregate gradation. The lower the percent passing the 0.075 mm sieve, the higher the permeability will be. Note that open gradations (single size) result in higher permeability.

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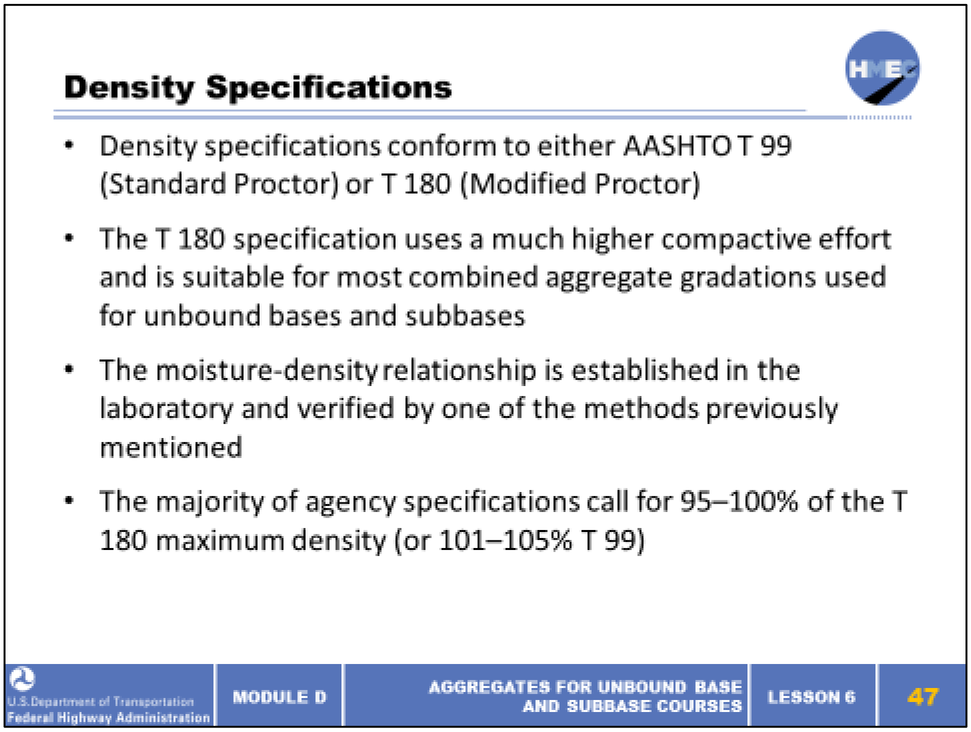
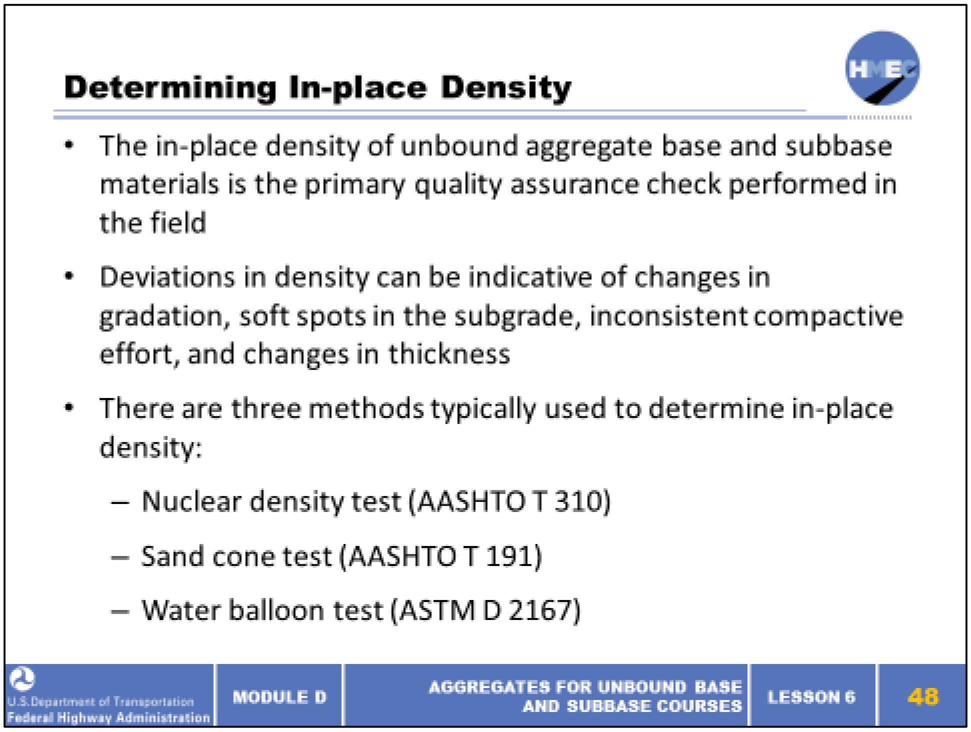
Slide 47



The selection of T 99 or T 180 specifications is dependent on agency preference. It is important to note that the T 180 specification will result in significantly higher density than T 99 for the same target value (i.e., both compacted at 95%).

In-place density represents the final quality check for base courses. It is used by almost all States to check the effectiveness of the entire construction process. Relative density expressed as a percentage of the maximum density is used by all States.

Slide 48



There are three primary means to determine the in-place density of granular materials. Of these, the nuclear density gauge is preferred due to its ease of use and repeatability. However, the regulations governing its use are fairly stringent due to the presence of radioactive material.

In-place densities are measured during the compaction process and at the end of compaction. Measurements during the compaction process are used to guide the contractor while final measurements are used to accept/reject the in-place product.

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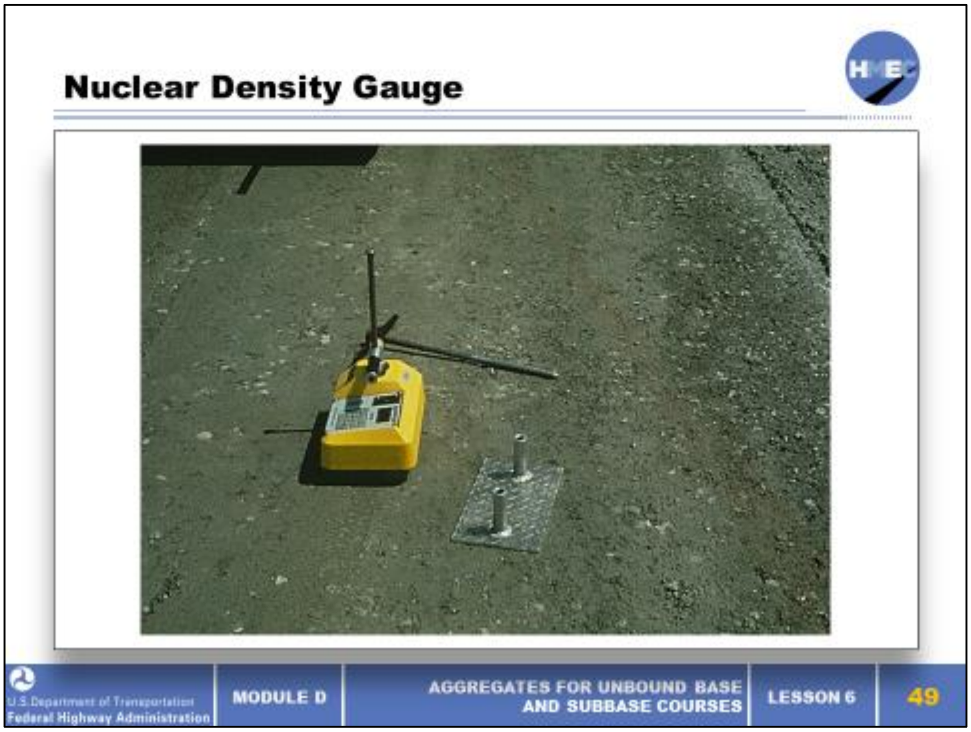
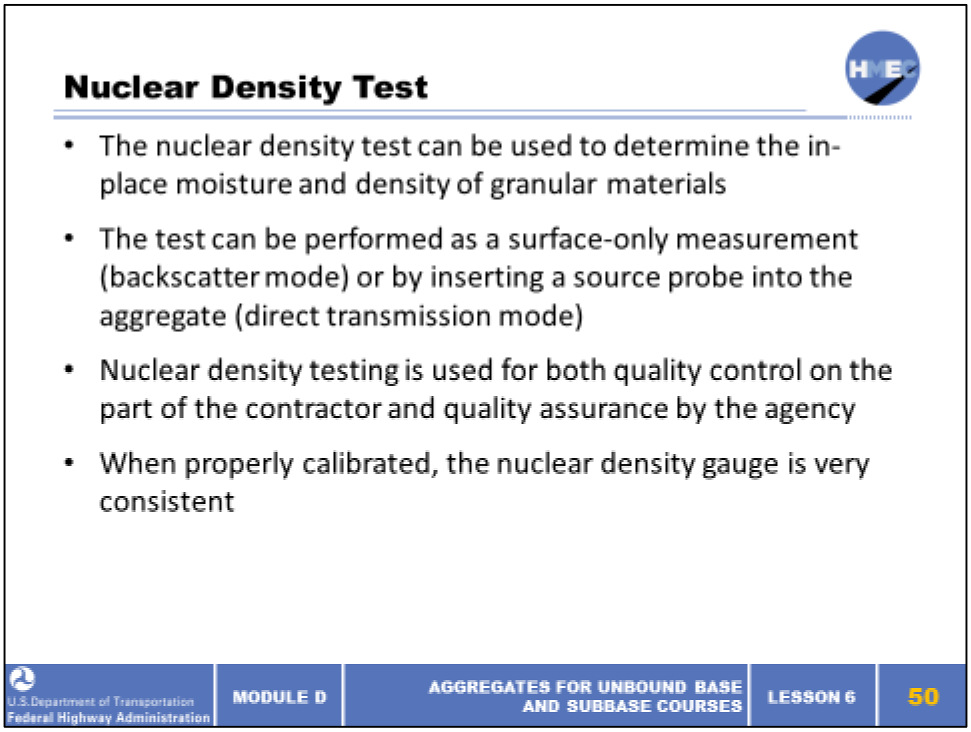


Operators of the nuclear density gauges are trained both on appropriate safety procedures for handling of the gauge as well as the technical operation of the gauge to achieve accurate test results. These devices are regulated in terms of use, storage, disposal, etc.

Slide 50



This method can be used for virtually all unbound base and subbase materials. The nuclear density test can be used to determine the in-place moisture and density of granular materials.

The test can be performed as a surface-only measurement (backscatter mode) or by inserting a source probe into the aggregate (direct transmission mode).

Nuclear density testing is used for both quality control on the part of the contractor and quality assurance by the agency.

When properly calibrated, the nuclear density gauge is very consistent.

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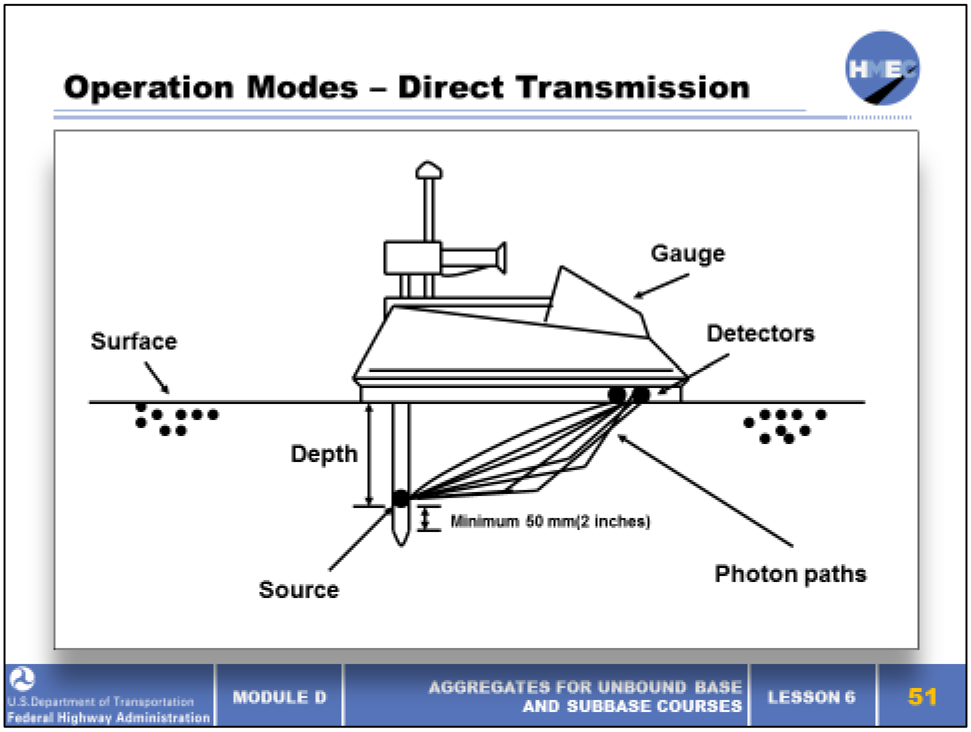

The direct transmission mode is commonly used for unbound base and subbase courses. This mode is preferred for more accurate results whenever the material to be tested lends itself to the direct transmission mode.

The nuclear density gauge can be used with a source probe as shown.

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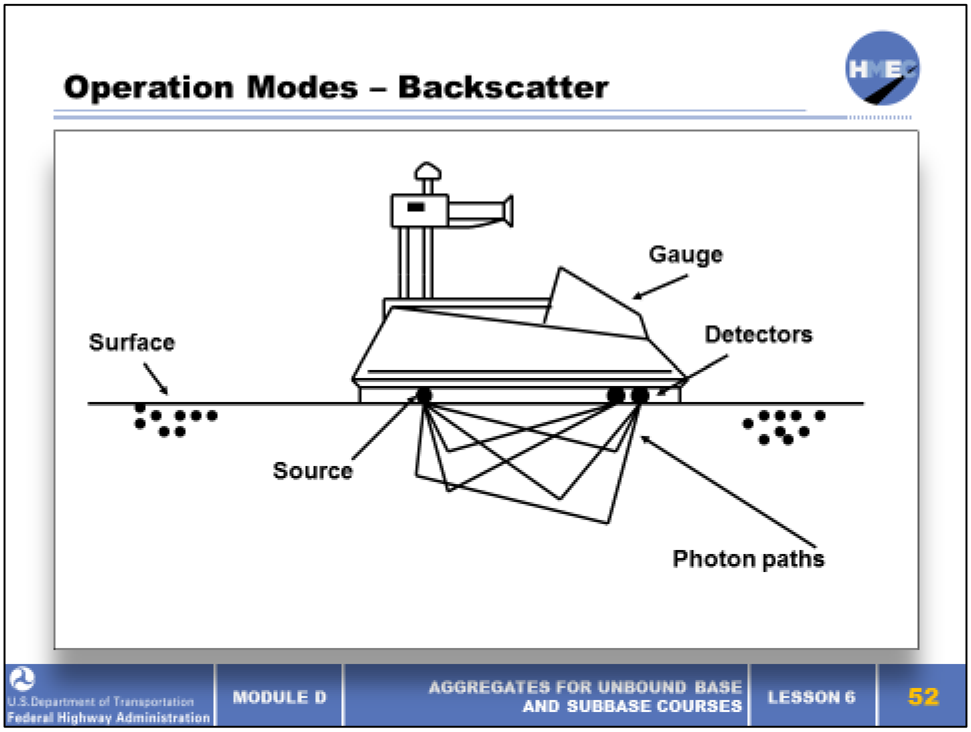
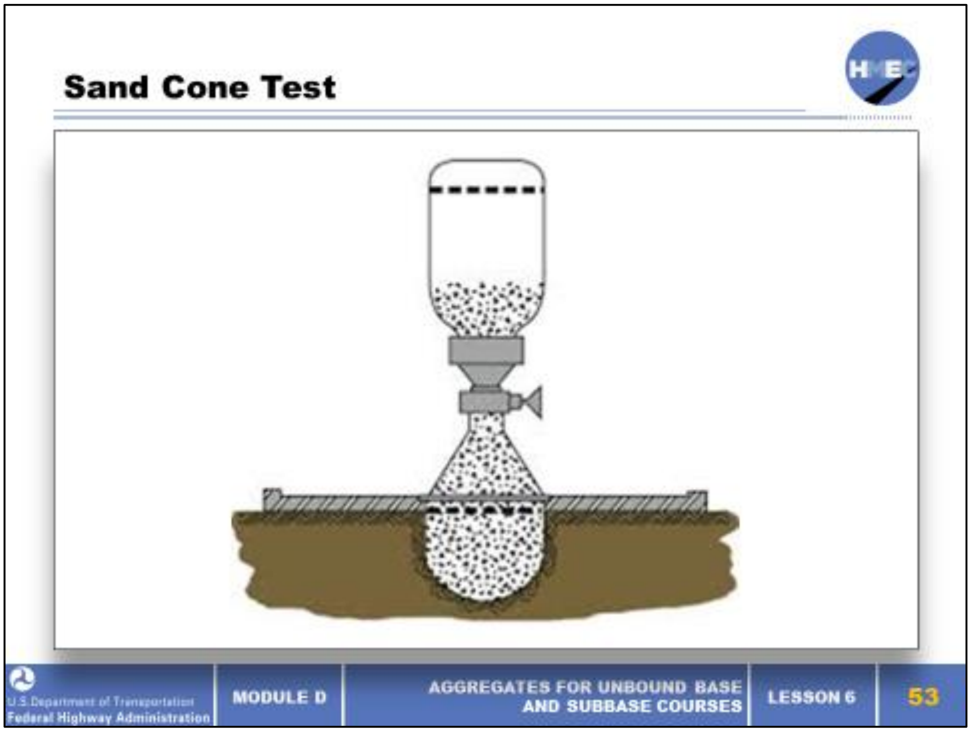


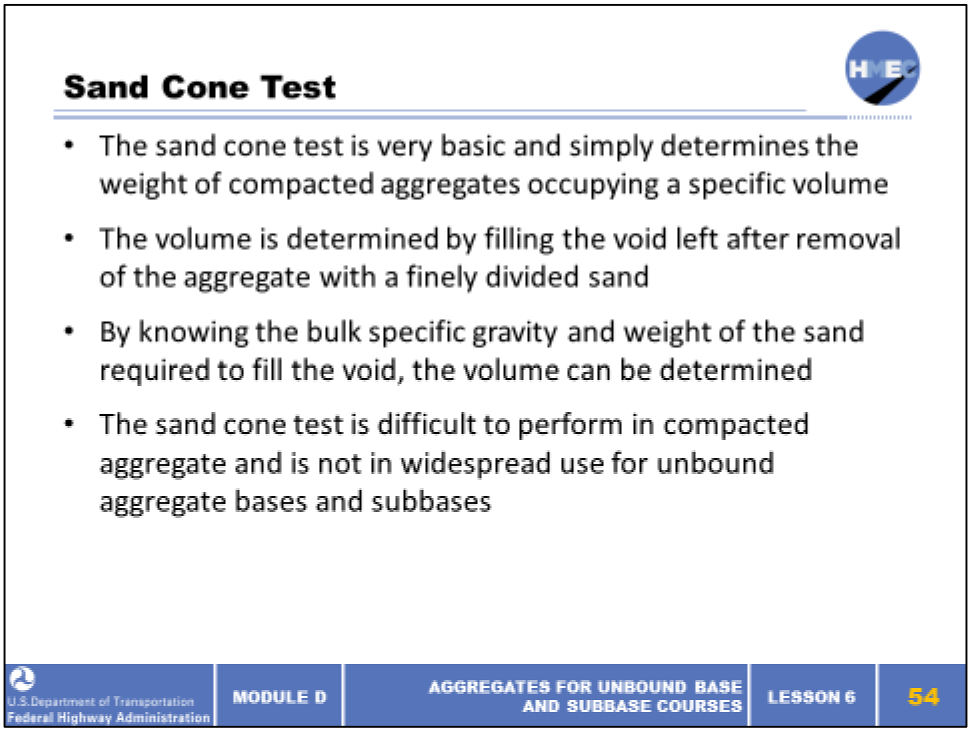
The nuclear density gauge can be used as a surface-only device as pictured here.
The backscatter mode is commonly used for bound (stabilized) base and subbase courses.

Slide 53



In addition to the sand cone device, plate, and sand, tools for excavation and an accurate scale are required.

Slide 54


Sand Cone Test
HMEC
• The sand cone test is very basic and simply determines the weight of compacted aggregates occupying a specific volume
• The volume is determined by filling the void left after removal of the aggregate with a finely divided sand
• By knowing the bulk specific gravity and weight of the sand required to fill the void, the volume can be determined
• The sand cone test is difficult to perform in compacted aggregate and is not in widespread use for unbound aggregate bases and subbases
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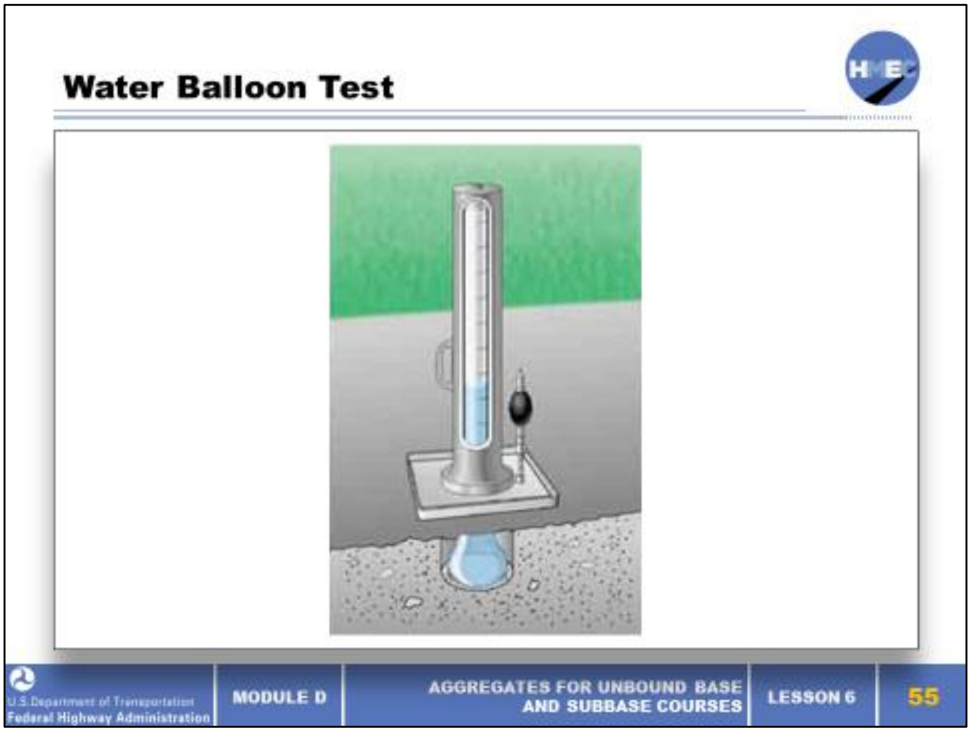

The water balloon or volume replacement method uses a relatively simple approach as pictured here. The operation of the device is very similar to the sand cone method in that an accurately measured volume of water is used to determine the volume occupied by a sample of compacted aggregate. By knowing the weight of the aggregate removed and the volume, density can be determined.

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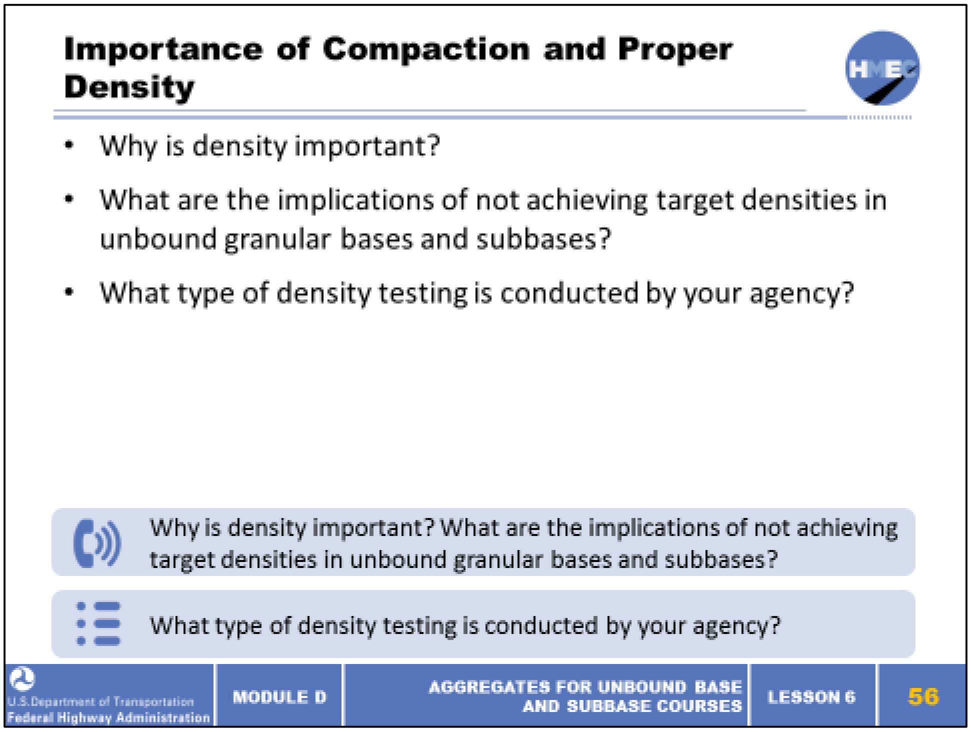
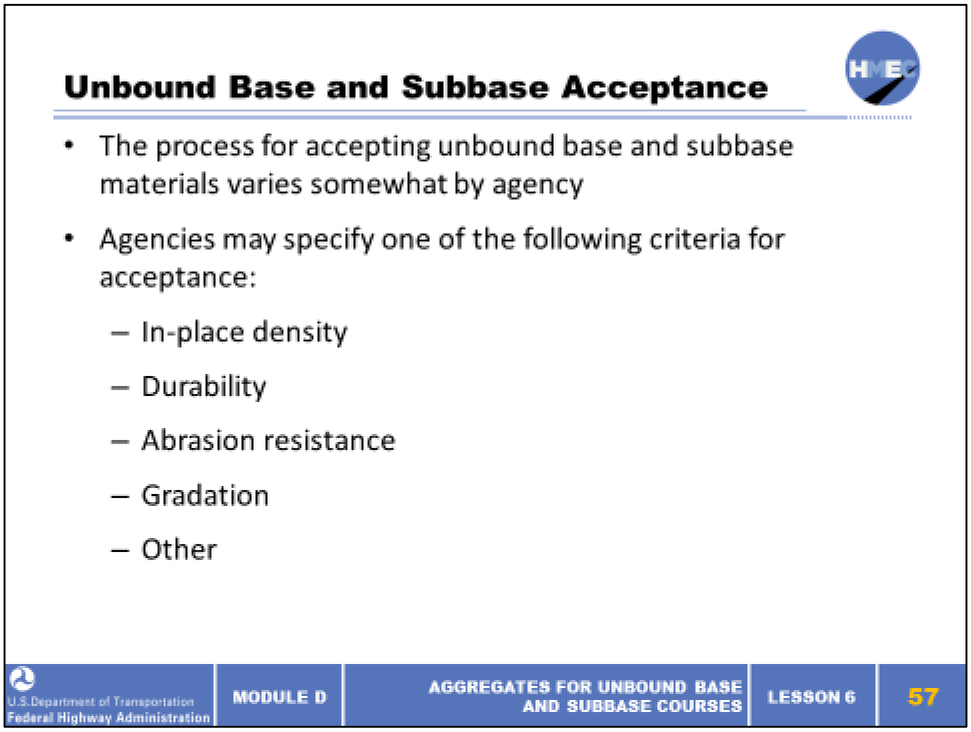


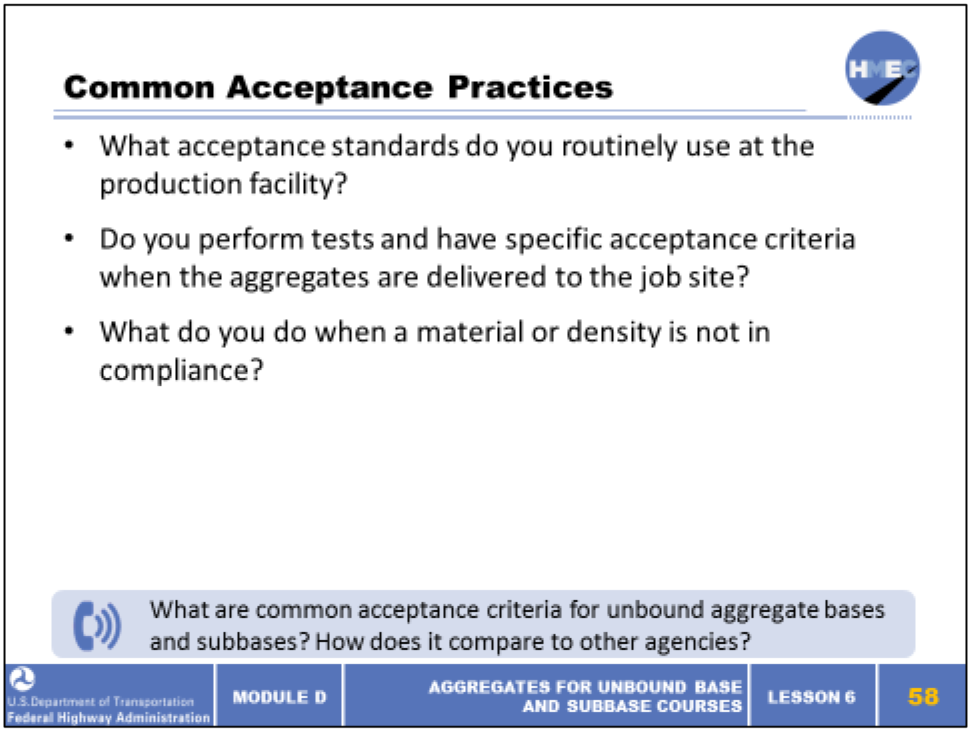
Compaction and density play a very important role in the uniformity and level of support for roadways. Differential density can lead to premature pavement distress.

Slide 57



The acceptance criteria for unbound bases and subbases are as described in this lesson. Although all of the physical properties of aggregates we have discussed are important, the primary acceptance criteria is in-place density.

Slide 58



The acceptance criteria for unbound bases and subbases differ between agencies.

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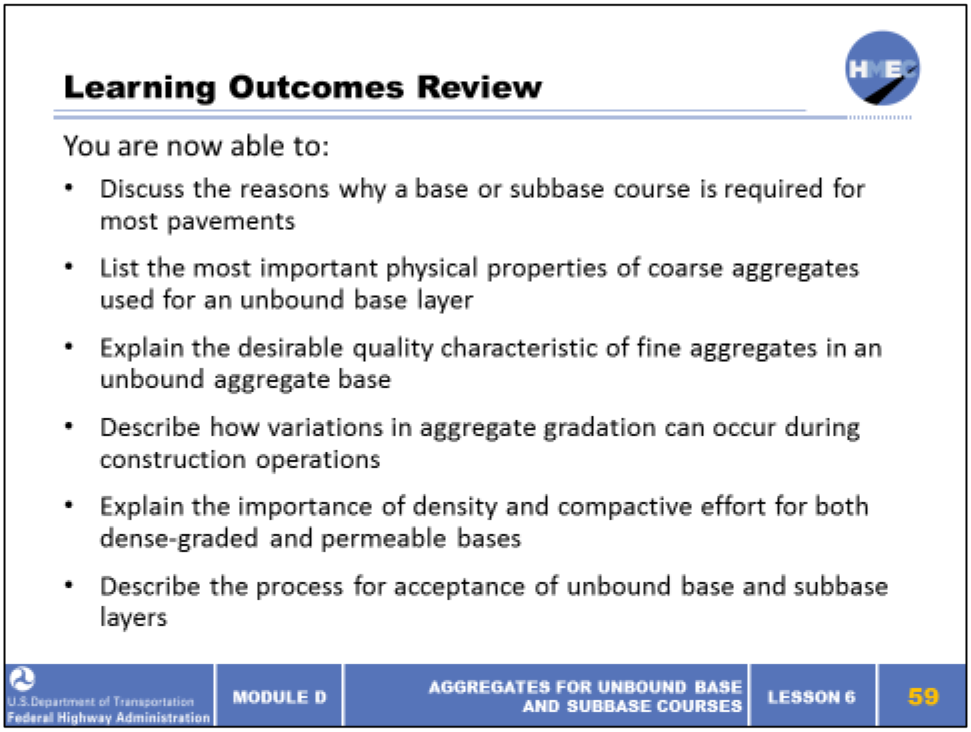
Learning Outcomes Review
You are now able to:
• Discuss the reasons why a base or subbase course is required for most pavements
• List the most important physical properties of coarse aggregates used for an unbound base layer
• Explain the desirable quality characteristic of fine aggregates in an unbound aggregate base
• Describe how variations in aggregate gradation can occur during construction operations
• Explain the importance of density and compactive effort for both dense-graded and permeable bases
• Describe the process for acceptance of unbound base and subbase layers
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Slide 1


HMEC
Highway Materials Engineering Course
Lesson 7: Aggregates for Stabilized Bases
Aggregates for Transportation Construction Projects
U.S.Department of Transportation
Federal Highway Administration
MODULE
D

Slide 2

Learning Outcomes

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

- Describe the basic selection process for choosing a stabilized base instead of an unbound granular base
- Describe the three stabilization processes (asphalt, Portland cement, and lime-fly ash), and compare the benefits and drawbacks of each
- Explain best practices for construction of stabilized bases
- Describe the process for acceptance of stabilized base items

This lesson will take approximately 70 minutes to complete.

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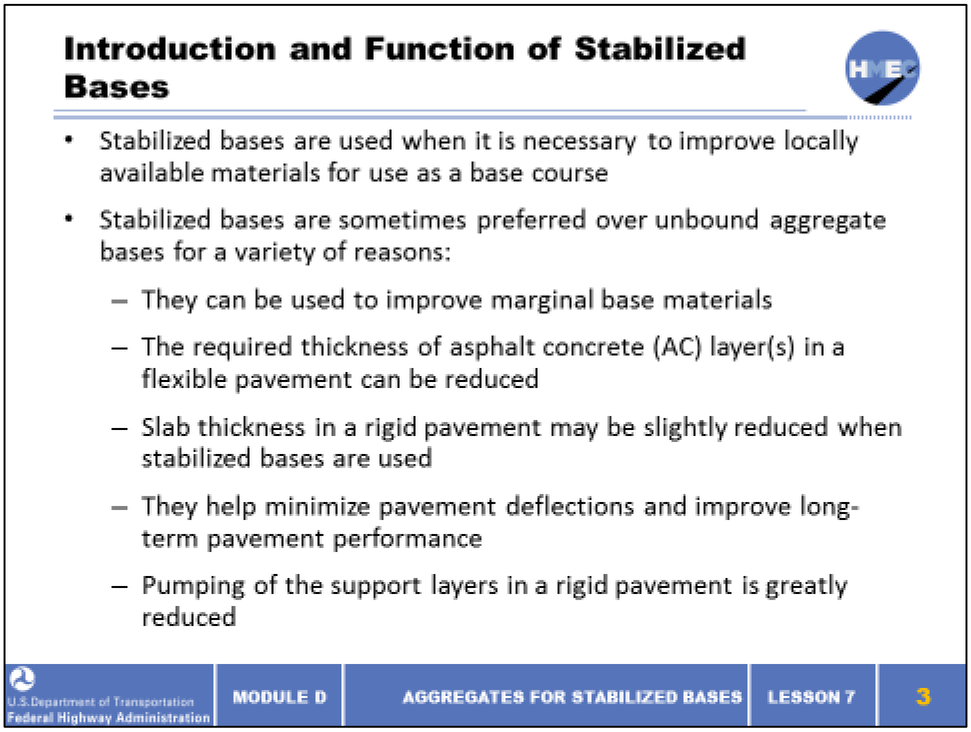
Slide 3



Stabilization of granular materials is a widely used practice when it is necessary to improve locally available materials for use as a base course under either flexible or rigid pavements.

Stabilization can also be used to reduce the design thickness of the pavement layers. Through stabilization, the stiffness/strength of the base course is increased, which in turn reduces the required thickness to carry the projected traffic volumes (i.e. reduced deflections and stresses in the surface layers).

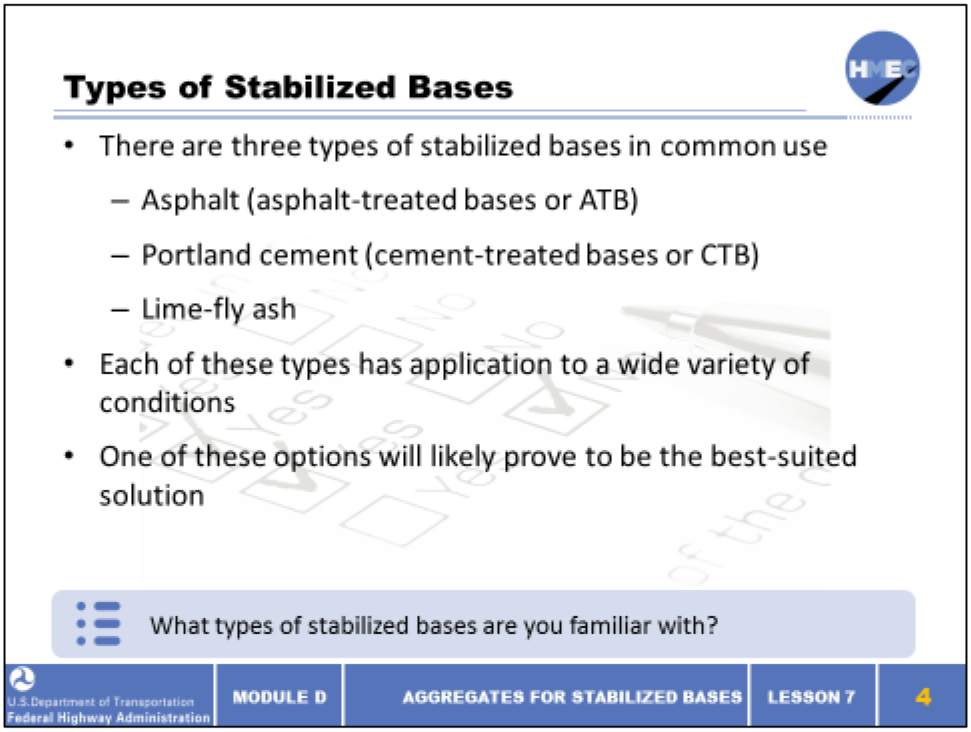
Reducing the moisture sensitivity of granular materials through stabilization can be highly beneficial in cases where protection of the subgrade from moisture is desired or the use of the stabilized material will be used as a driving surface (typically short term).

Stabilized bases can be compared to unbound bases and may be preferred for a variety of reasons, including:

• They can be used to improve marginal base materials;
• The required thickness of asphalt concrete (AC) layer(s) in a flexible pavement can be reduced;
• Slab thickness in a rigid pavement may be slightly reduced when stabilized bases are used;

- They help minimize pavement deflections and improve long-term pavement performance; and
- Pumping of the support layers in a rigid pavement is greatly reduced.

Slide 4

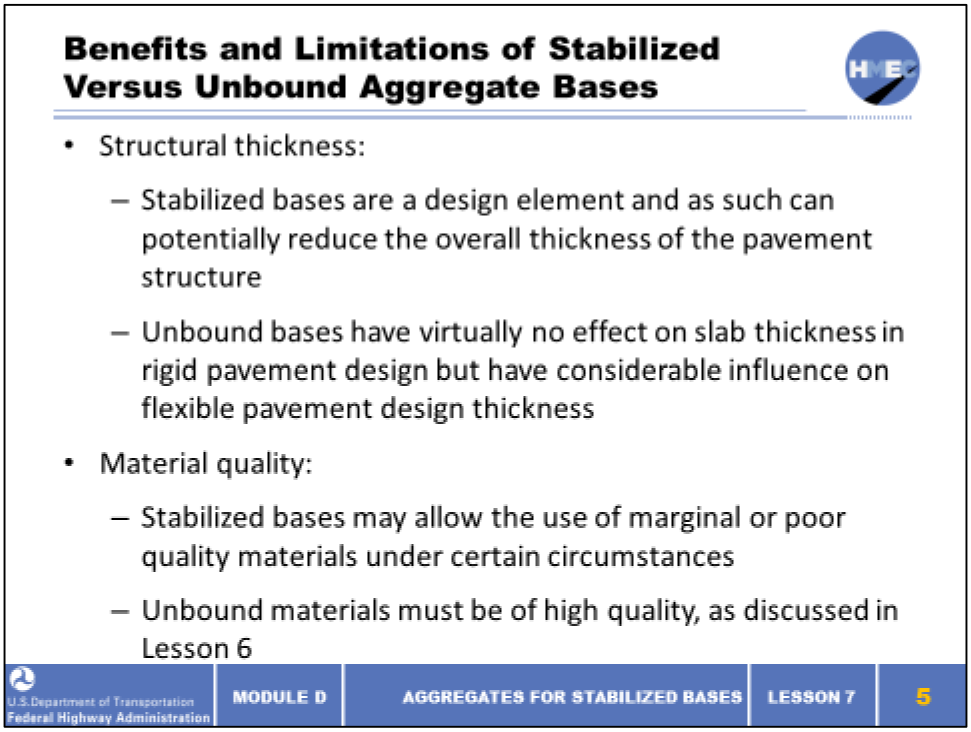


Stabilization is intended to provide an agent which binds the granular materials and gives it internal stability.

Three classes of stabilizing agents can be used: asphalt, Portland cement, and lime-fly ash (LFA).

It should be noted that the main difference between stabilization and the production of hot mixed asphalt (HMA) mixtures and Portland cement concrete (PCC) is the relatively low percent of binders used.

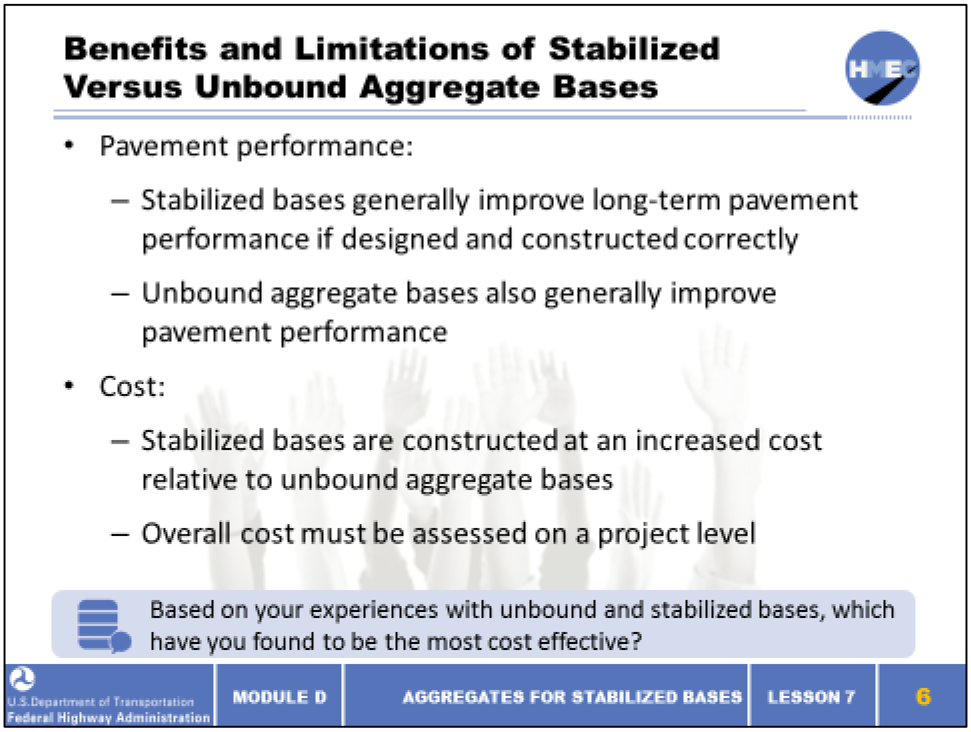
Slide 5



The structural differences between these materials has always been evident but is much more pronounced with use of the Mechanistic Empirical Pavement Design Guide (MEPDG).

As we discussed in Lesson 6, the requirements for unbound aggregate bases are relatively strict (by specification). The requirements for stabilized bases are still important but allow for more leeway in properties. Stabilization improves the properties of the overall blended aggregate and is the primary reason that the standards are slightly less stringent.

Slide 6



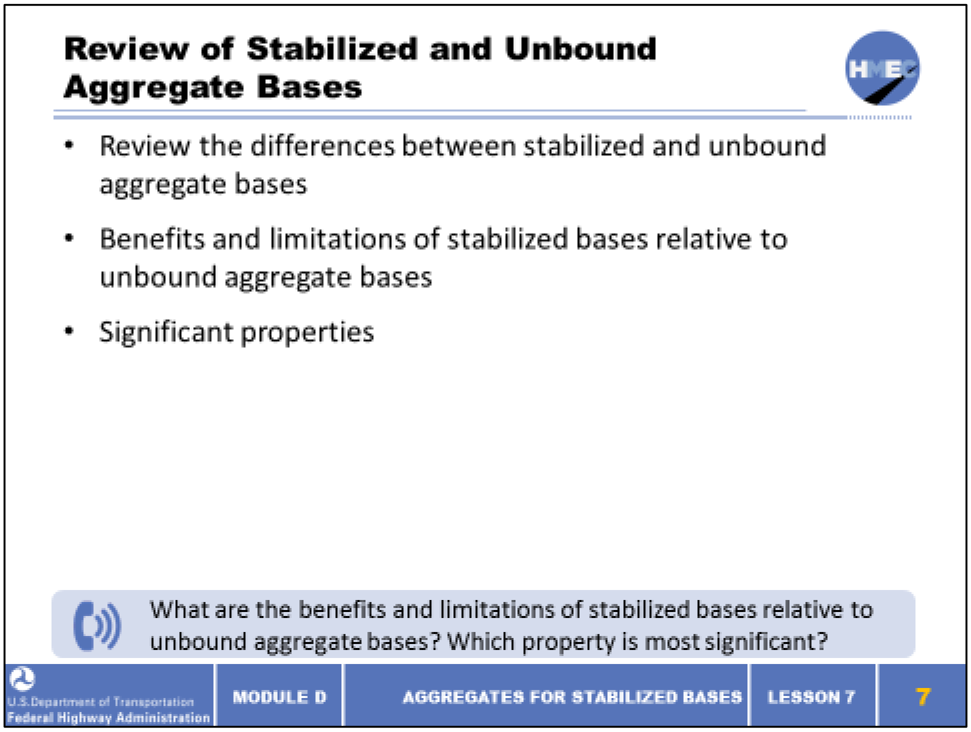
Pavement performance is typically enhanced with stabilized bases.

The exception to this is a too-strong base underlying a PCC slab. While a strong and non-deforming base is generally desirable, the curling of the PCC slab in a rigid pavement system can lead to high stresses in the slab as the corners lift due to a high temperature gradient. If the stabilized base (typically a lean PCC base) is sufficiently strong and a separation layer between the base and slab is not present, cracks that develop in the base can propagate through the PCC slab.

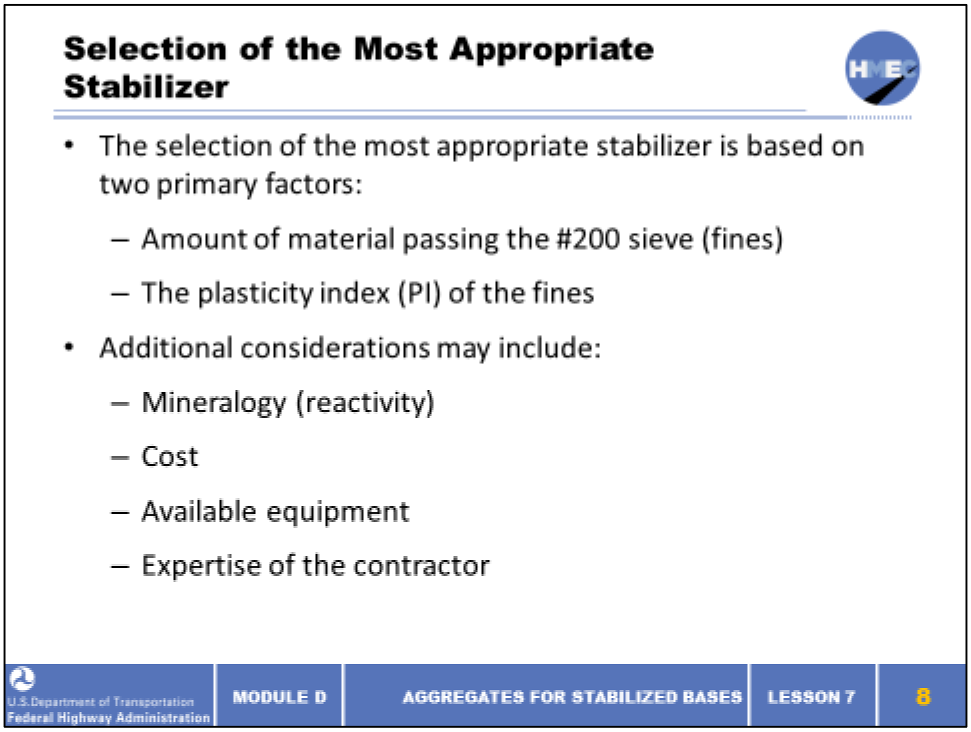
It should be noted that unbound bases also improve performance but to a different extent.

A general cost comparison is not possible since each project has different conditions that must be accounted for. For instance, haul distance, material quality, cost per ton, etc.

Slide 7

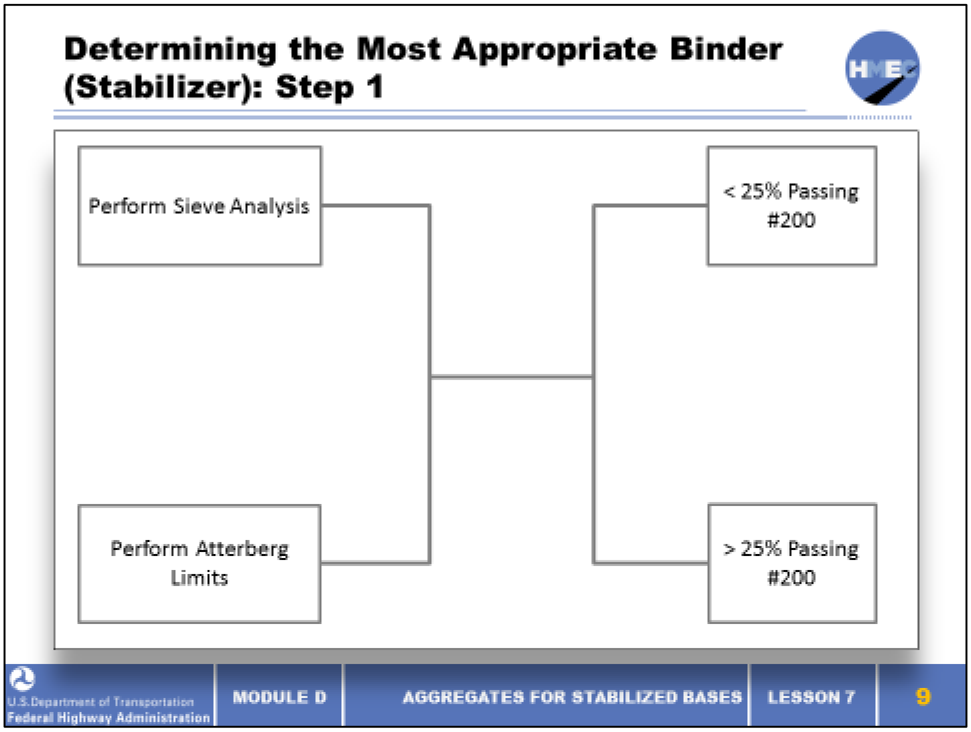

Review of Stabilized and Unbound Aggregate Bases
Review the differences between stabilized and unbound aggregate bases
Benefits and limitations of stabilized bases relative to unbound aggregate bases
Significant properties
What are the benefits and limitations of stabilized bases relative to unbound aggregate bases? Which property is most significant?
U.S. Department of Transportation
Federal Highway Administration
MODULE D
AGGREGATES FOR STABILIZED BASES
LESSON 7
7

Slide 8



Selection of the most appropriate binder is based on relatively simple concepts but requires laboratory testing to assess key properties.

Slide 9



The proposed base course material (combined gradation) must be accurately sieved to determine the minus #200 material content (fines) using the AASHTO T 27 dry sieve analysis procedure. Atterberg limits are then established for the minus #40 portion of the combined sample.

Depending on the percentage passing the #200 sieve, one of the charts on the following two slides is used.

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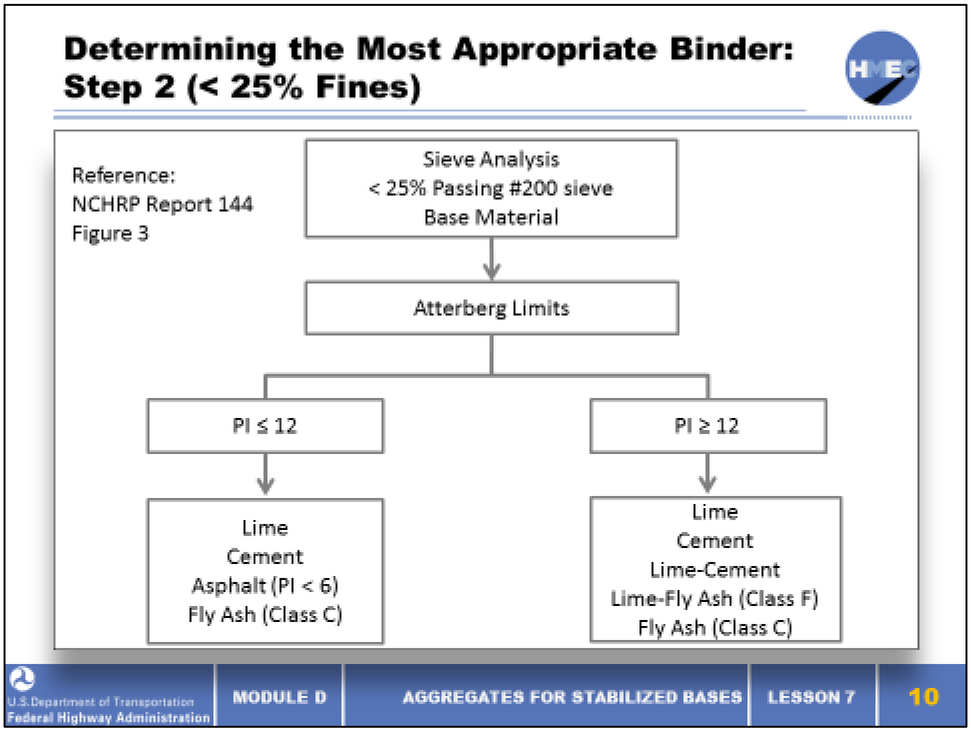
Slide 10



If the minus #200 material is less than 25%, this flow chart should be used to determine the best choice of binder. The differentiation in the recommended stabilizer is at a PI of 12. Lime, Portland cement, or Class C fly ash may be used regardless of the PI while asphalt is suitable for materials with a PI less than 6. Lime-cement and Class F lime-fly ash are suited to materials with a PI greater than 12. Note that a reduction in the PI due to these binders essentially makes them non-plastic.

Note also that the soil-aggregate mixture should be evaluated for the presence of high sulfates which may lead to adverse reaction products (ettringite formation) if Portland cement is used as a binder.

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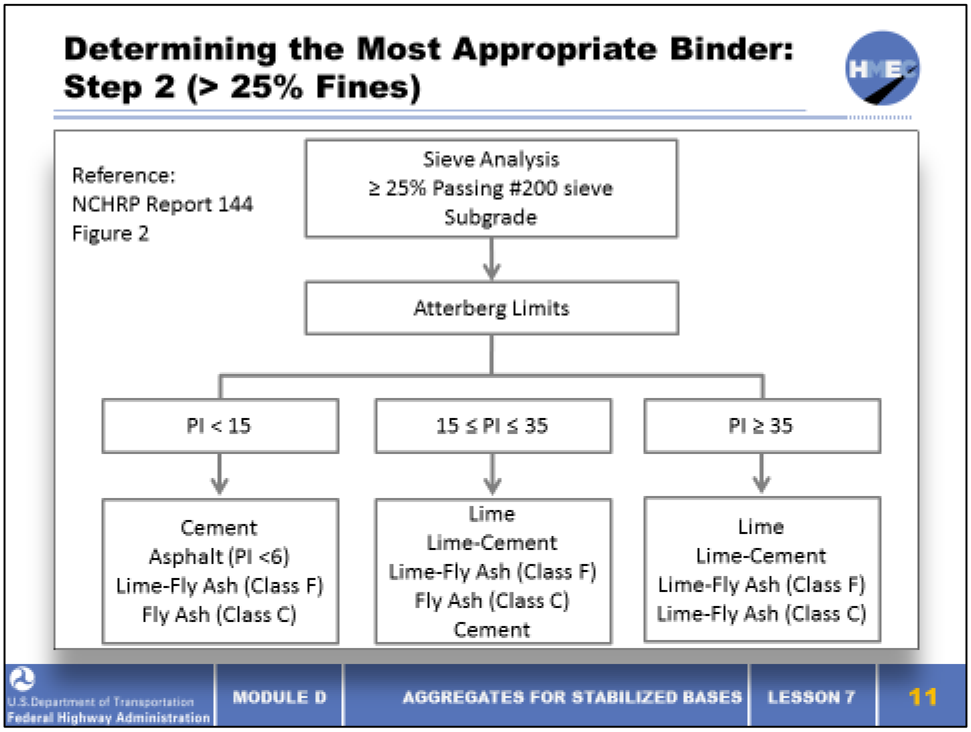
Slide 11



If the minus #200 material is greater than 25%, this flow chart should be used to determine the best choice of binder.

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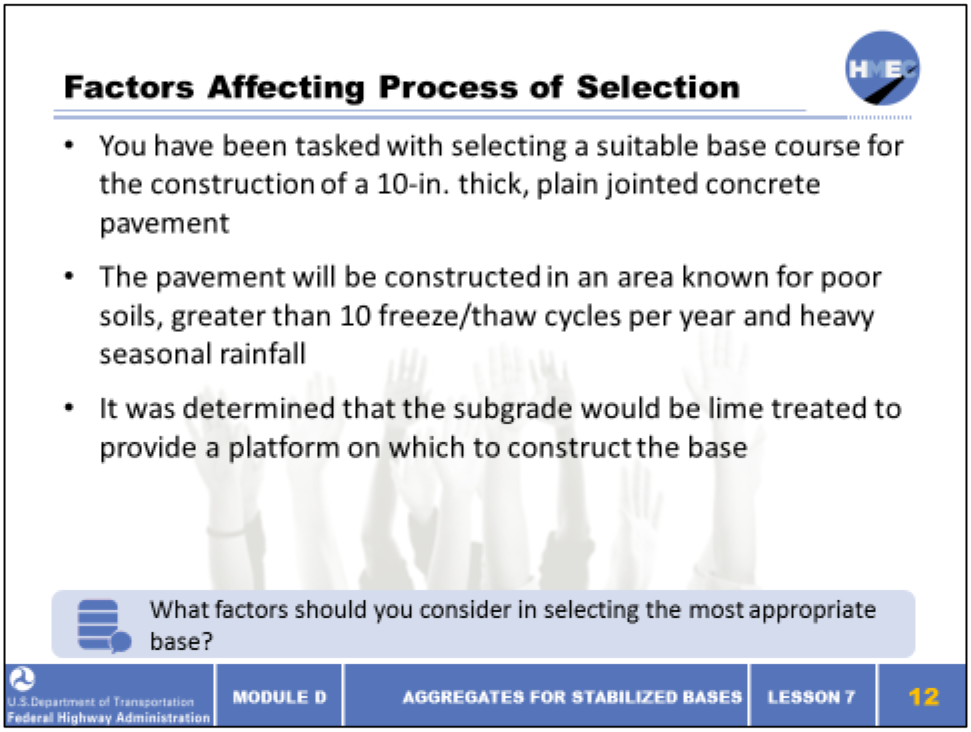
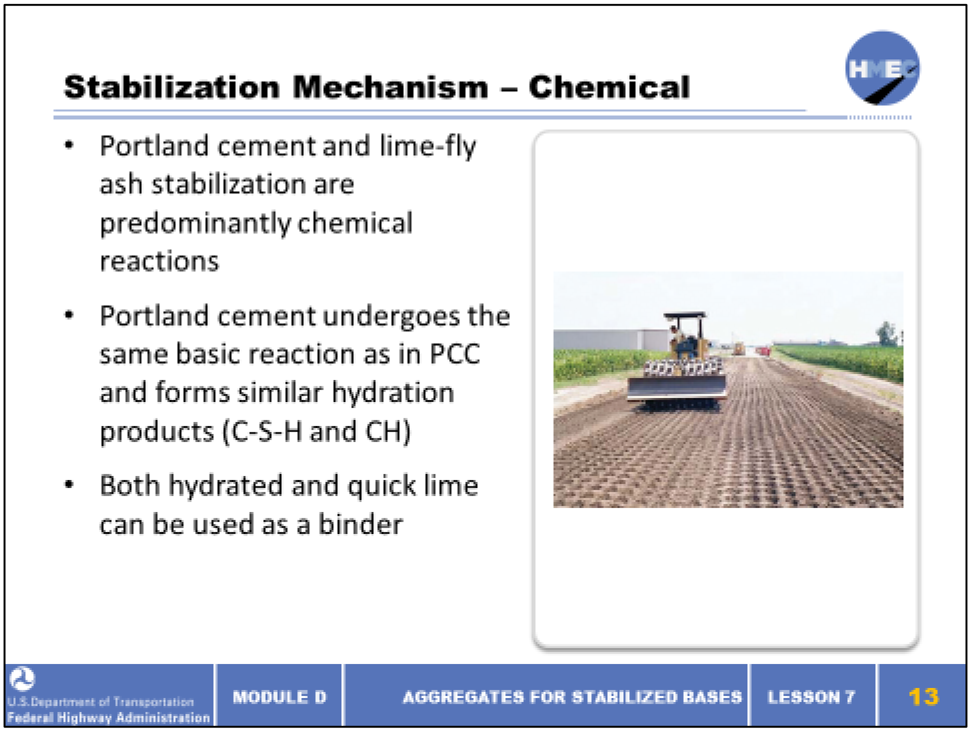
Slide 12


Factors Affecting Process of Selection
HMEC
You have been tasked with selecting a suitable base course for the construction of a 10-in. thick, plain jointed concrete pavement
The pavement will be constructed in an area known for poor soils, greater than 10 freeze/thaw cycles per year and heavy seasonal rainfall
It was determined that the subgrade would be lime treated to provide a platform on which to construct the base
What factors should you consider in selecting the most appropriate base?
U.S. Department of Transportation
Federal Highway Administration
MODULE D
AGGREGATES FOR STABILIZED BASES
LESSON 7
12

Slide 13



Portland cement and lime-fly ash stabilization are predominantly chemical reactions.

In cement-stabilized bases, the stabilization process is a result of the hydration mechanism that occurs as the Portland cement and water are combined. Portland cement undergoes the same basic reaction as in PCC and forms similar hydration products (calcium-silicate-hydrate, or C-S-H, and calcium hydroxide, or CH). These reaction products cement the soil particles together in a combined chemical and mechanical stabilization process. The amount of cement varies within the range of 5–13% by weight of soil.

A minimum amount of water must be added in order to ensure full hydration of the Portland cement. Too much water causes reduction in strength. Therefore, like in the case of Portland cement concrete, water quantity must be adjusted according to in-situ moisture content.

Both hydrated and quick limes have been successfully used to stabilize base courses. Fly ash is needed to produce the necessary lime-silica reaction. Lime alone is very effective with clays having high PI > 10. Fly ash is necessary for materials that have less clay and lower PI. Lime is typically added in the range of 4–6% by weight of aggregate while Class C fly ash is generally in the range of 8–16%. Note that the percentages for all materials are based on the dry weight of aggregate.

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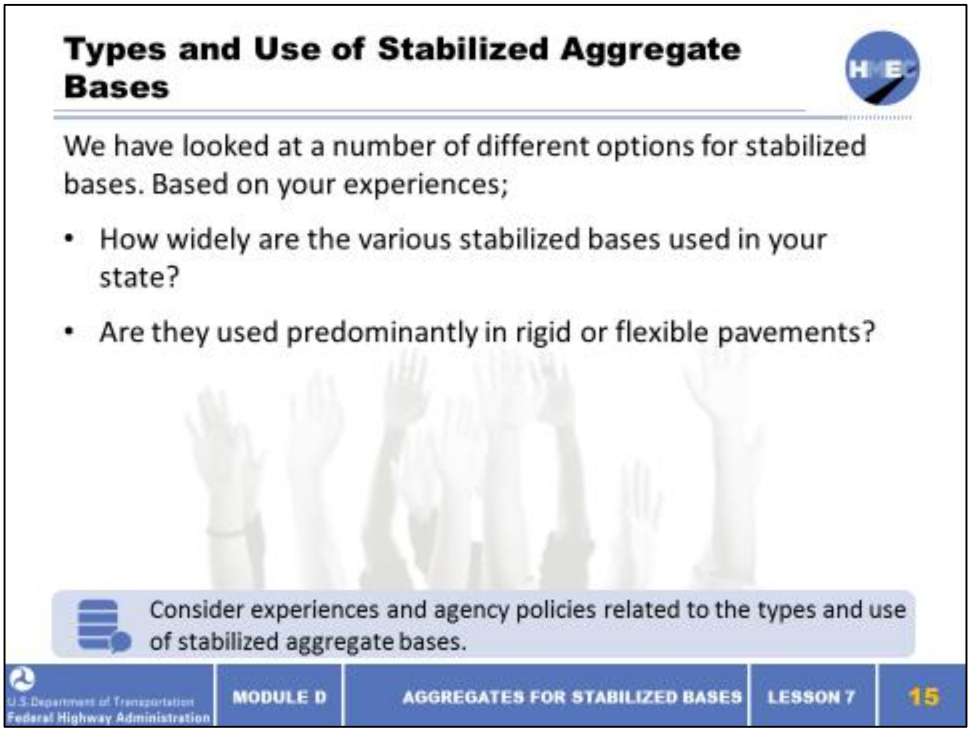
Slide 14

Asphalt stabilization does not involve any chemical or physical reactions. Stabilization is achieved through the cohesive properties of the asphalt binder, which physically binds the aggregate mass together. This adhesion-cohesion process creates a waterproof stable mass.

The percent of asphalt binder required for stabilization is relatively low (2–3%) as compared to HMA mixtures, which require 4.5–6.5%. With this low percentage of asphalt, there is not enough asphalt binder to coat a large surface area. Therefore, asphalt stabilization is most effective on low PI granular material with minimum amount of fines (passing #200). The presence of fines significantly increases the surface area, which makes coating a problem.

Slide 15



Differing geologic zones, varying material properties, and agency policies often dictate the type and extent of stabilized base course use.

Slide 16

Keep in mind that a best practice is a relative term and is subject to change as materials or processes evolve.

This section pertains to current practices regarding asphalt, Portland cement, and lime-fly ash stabilization.

We will not discuss construction techniques in detail but will look at the following:

- Overall stabilization process;
- Desirable engineering properties;
- Expected performance; and
- Design criteria.

Slide 17

Regardless of the specific binder type used, asphalt-stabilized bases are essentially the same in that the asphalt binds the aggregates through a mechanical process. These materials do not require a cure time (emulsions must have time to break) and can be opened to low levels of traffic soon after final compaction.

Two types of asphalt-stabilized bases are commonly used: asphalt-treated base (ATB) and emulsified asphalt-treated base (EATB). Asphalt-treated bases using asphalt cement are plant mixed materials that are placed and compacted on the roadway, usually in multiple lifts.

Emulsified asphalt-treated bases using liquid asphalt can be either road mixed materials that are mixed and compacted on the roadway or plant mixed materials that are placed and compacted on the roadway.

Uniform placement prior to compaction is required to achieve uniform depth, typically 3-in. or less compacted lifts.

A motor grader can be used to spread the first lift of material but mechanical spreaders are typically required for subsequent lifts.

Compaction is typically done with vibratory rollers but other compaction methods are also acceptable.

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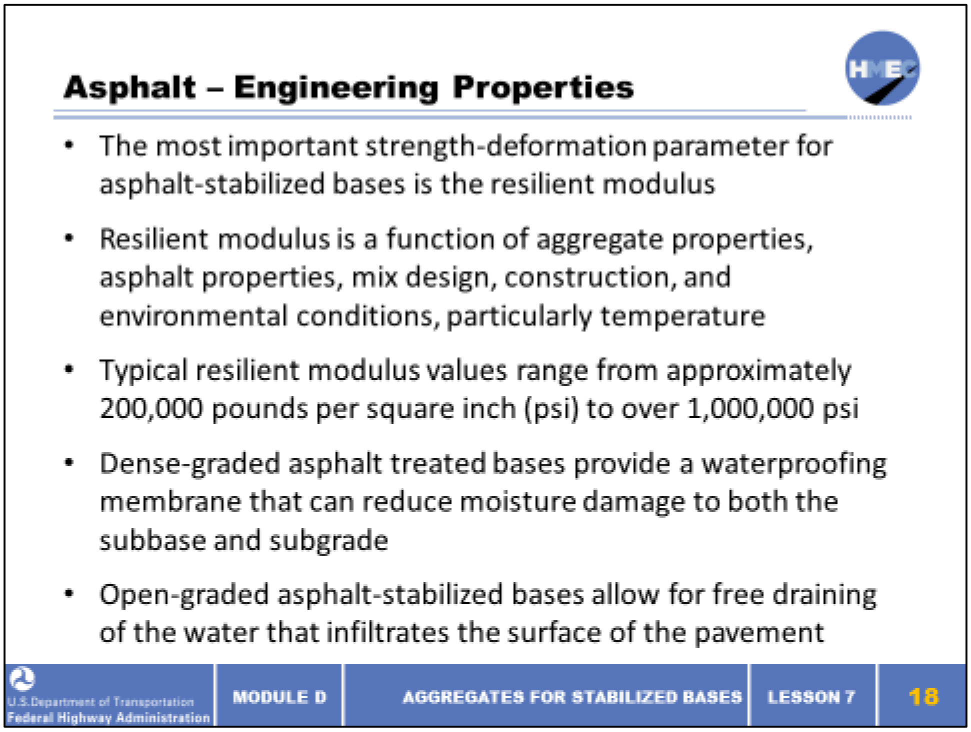
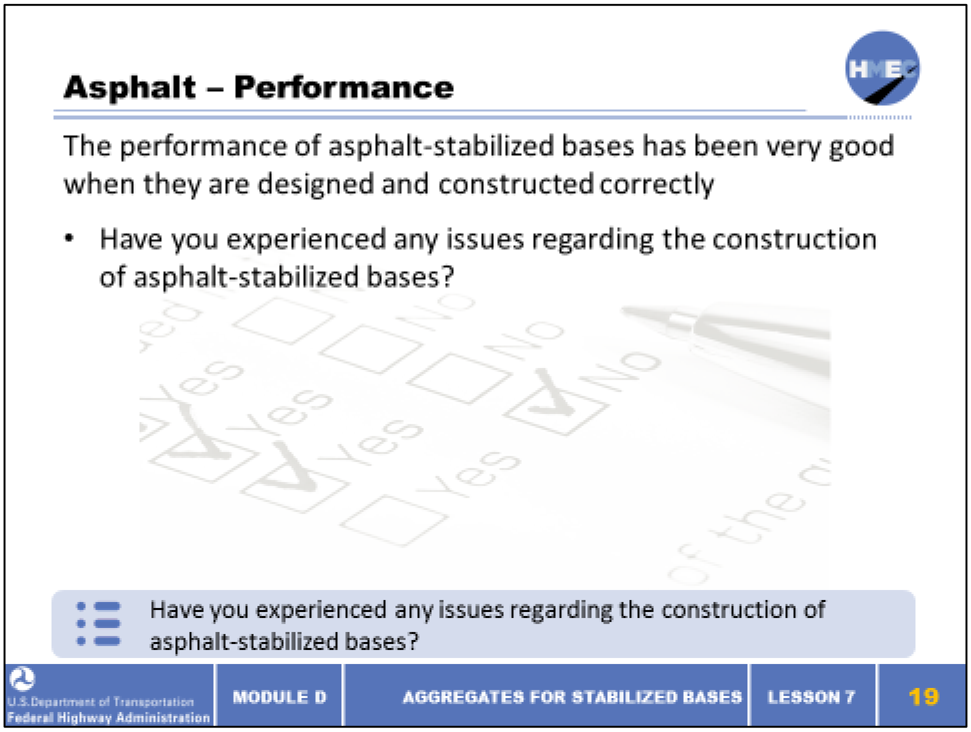
Slide 18



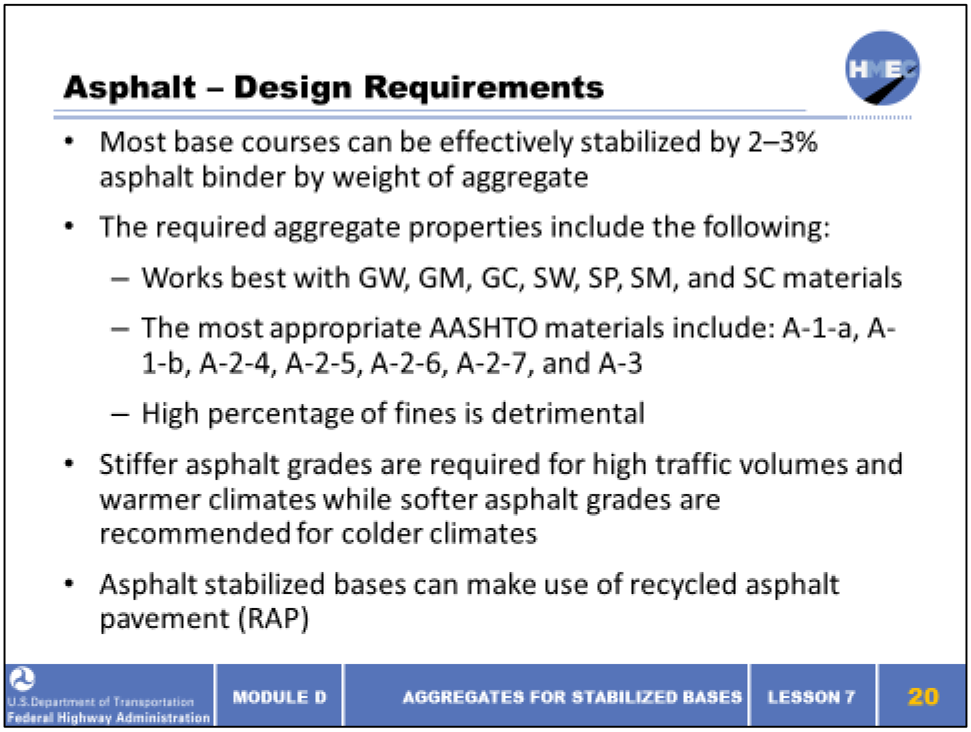
Asphalt stabilization waterproofs the material being stabilized (i.e. base course) and prevents water penetration into the subgrade. Therefore, moisture damage is reduced in both the stabilized base and the subgrade. Also, through cohesion, the shear and tensile strength of the stabilized base layer are increased, which improves its resistance to permanent deformation and fatigue failures. This is highly important when stabilized bases are used as surface layers.

Slide 19



The performance of ATBs under rigid pavements has been excellent and is beneficial both as a construction platform and to enhance long-term pavement performance. Similar results have been shown for ATB use in flexible pavements.

Slide 20



The percent of asphalt binder required for stabilization is relatively low (2–3%) as compared to HMA mixtures which require 4.5–6.5%. With this low percentage of asphalt, there is not enough asphalt binder to coat a large surface area. Therefore, asphalt stabilization is most effective on low PI granular material with minimum amount of fines (passing #200). The presence of fines significantly increases the surface area, which makes coating a problem.

The selection of asphalt type (asphalt cement versus emulsion or cutback) and grade involves considerations of materials gradation, traffic volume, and environment. Liquid asphalt offers longer mixing time, which allows better coating for dense-graded materials having high surface areas.

Asphalt stabilization of granular materials can be achieved either by asphalt cement, emulsions or cutbacks. Asphalt cement is solid at room temperature, which requires the stabilization process to be conducted at elevated temperatures (250–300° F). Emulsions or cutbacks are liquid at room temperature and can be placed at ambient temperatures.

Slide 21

Cement-stabilized bases or cement-treated bases can be constructed on the grade by placing a uniform layer of properly blended aggregate and adding the correct amount of cement and water. The materials are then thoroughly blended and compacted. However, mixing the CTB in a pug mill or central batch plant and then hauling to the job site for placement and compaction is the preferred method.

In cement stabilized bases, the stabilization process is a result of the hydration mechanism that occurs as the Portland cement and water are combined. A minimum amount of water must be added in order to ensure full hydration of the Portland cement. Too much water causes a reduction in strength. Therefore, as is the case with PCC, water quantity must be adjusted according to in-situ moisture content.

Uniform distribution of the cement and the proper moisture content are key to consistent properties and optimized pavement performance.

Since CTB undergoes the same basic hydration reaction as PCC, it is necessary to maintain the moisture content during curing.

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Slide 22

The strength of the CTB is controlled by the aggregate properties, the cement content and the water content, efficiency of mixing, placement, compaction, and curing. The strength of the CTB reduces pavement deflection and, in the case of flexible pavements, leads to a reduction in subgrade stress and tensile stress in the asphalt.

In rigid pavements, the strength of the CTB should be limited so as not to create too strong a platform underlying the PCC slab, which can lead to increased stresses due to curling and warping.

CTBs are susceptible to expansion and contraction due to temperature and moisture variations. Cracks resulting from drying shrinkage or thermal movement may reflect through asphalt surface courses but generally not PCC. Cement and water should be minimized to reduce cracking.

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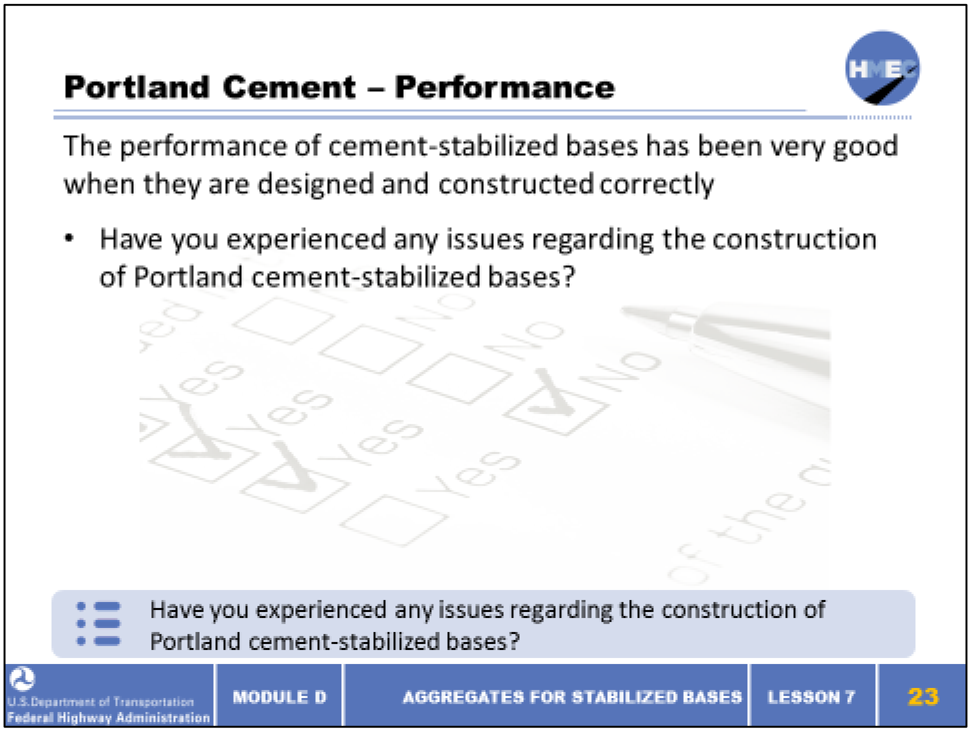
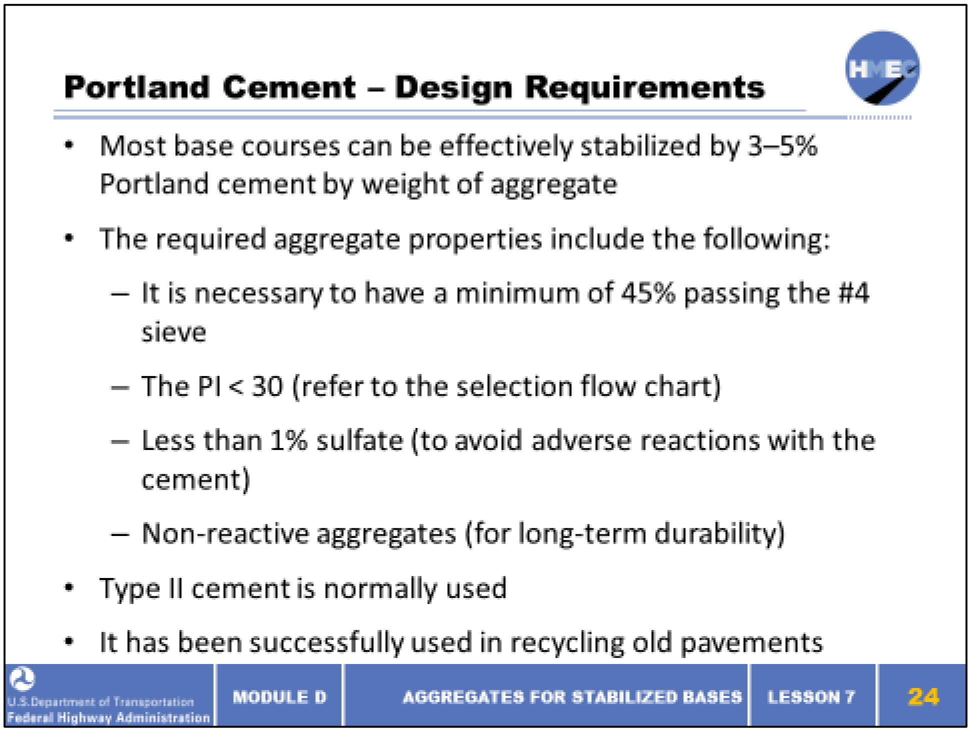
Slide 23



The performance of CTBs under rigid pavements has been excellent and is beneficial both as a construction platform and to enhance long-term pavement performance. The key issue when placing a CTB as a flexible pavement layer is the potential for reflective cracking. This issue can be minimized by the use of a bond breaker, which is also commonly used in rigid pavements.

Slide 24

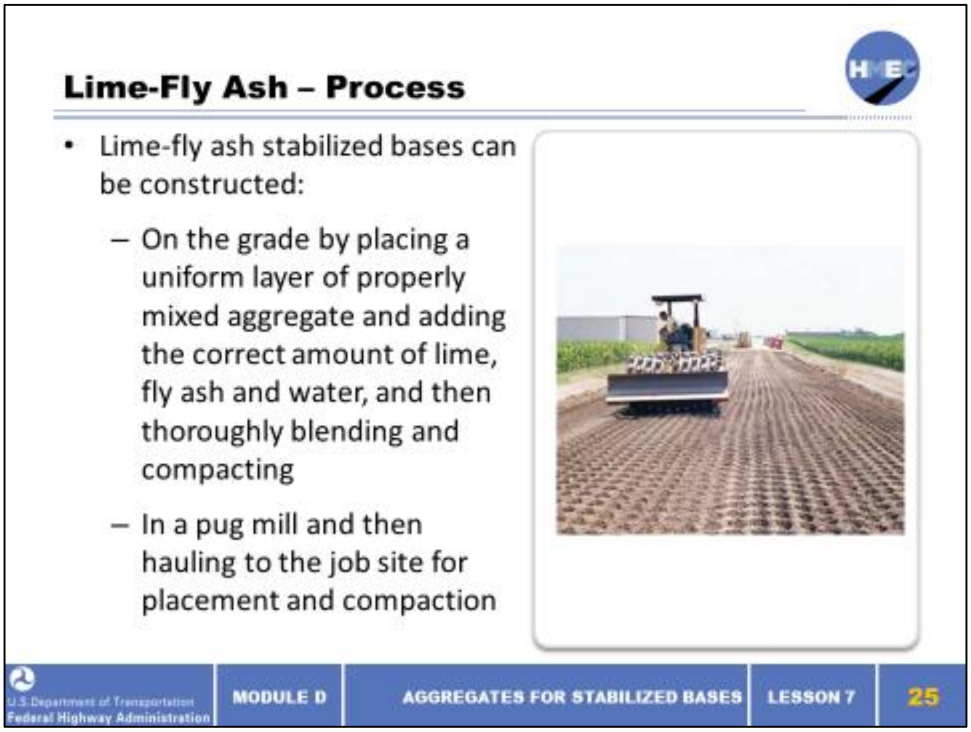


The percent of Portland cement to stabilize base courses is relatively low, around 3–5% by weight of aggregate. Too much Portland cement would generate a stiff base course, which would cause reflective cracking problems. The durability of cement stabilized base courses is measured through the ASTM D560 freeze/thaw test. The durability of the stabilized base greatly affects its resistance to pumping, which is critical to both flexible and rigid pavements.

Suitable materials for cement-stabilized base courses are very similar to Portland cement concrete since Portland cement is the main binding agent in both cases. A minimum amount of sand is required to ensure continuous grading. The maximum sulfate content is specified to reduce the potential of sulfate attack and the aggregates should not be reactive to eliminate the possibility of alkali silica reactivity between aggregates and Portland cement.

Type II Portland cement is used when no special properties are required. Cement stabilization has been successfully used in recycling old pavements since it provides early strength and improves resistance to moisture damage.

Slide 25



Lime-fly ash stabilized bases can be constructed on the grade by placing a uniform layer of properly aggregate and adding the correct amount of lime, fly ash and water. The materials are then thoroughly blended and compacted. Lime-fly ash stabilized bases are ideally produced by thorough mixing of the materials in a pug mill and then hauling to the job site for placement and compaction.

Uniform distribution of the lime and fly ash and the proper moisture content are key to consistent properties and optimized pavement performance.

In LFA-stabilized bases, the stabilization process is a result of the hydration mechanism that occurs when the lime (calcium), fly ash (silica), and water are combined. A minimum amount of water must be added in order to ensure complete hydration of the lime-fly ash mix. LFA undergoes the same basic hydration reaction as PCC; it is necessary to maintain the moisture content during curing.

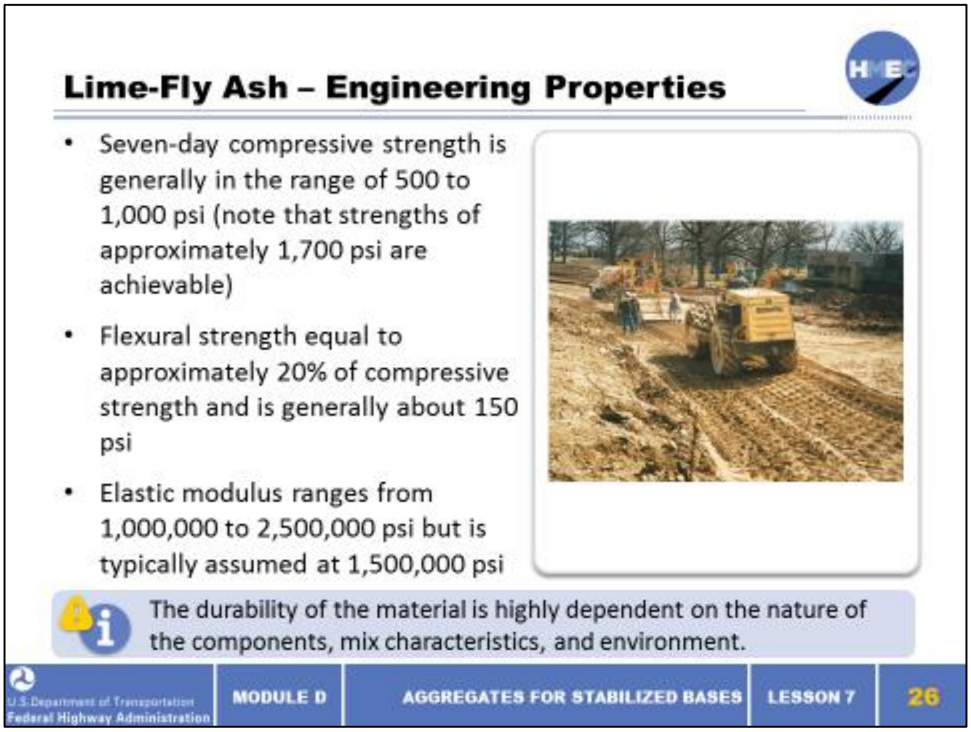
Note that class C fly ash may be used as a standalone material where “F ash” always requires lime (or cement) for the hydration reaction to occur.

Also note that Portland cement, cement kiln dust, or lime kiln dust may be substituted for lime although generally at a higher cost.

Both hydrated and quick limes have been successfully used to stabilize base courses. Fly ash is needed to produce the necessary lime-silica reaction. Lime alone is very effective with clays having high PI > 10. Fly ash is necessary for materials that have less clay and lower PI.

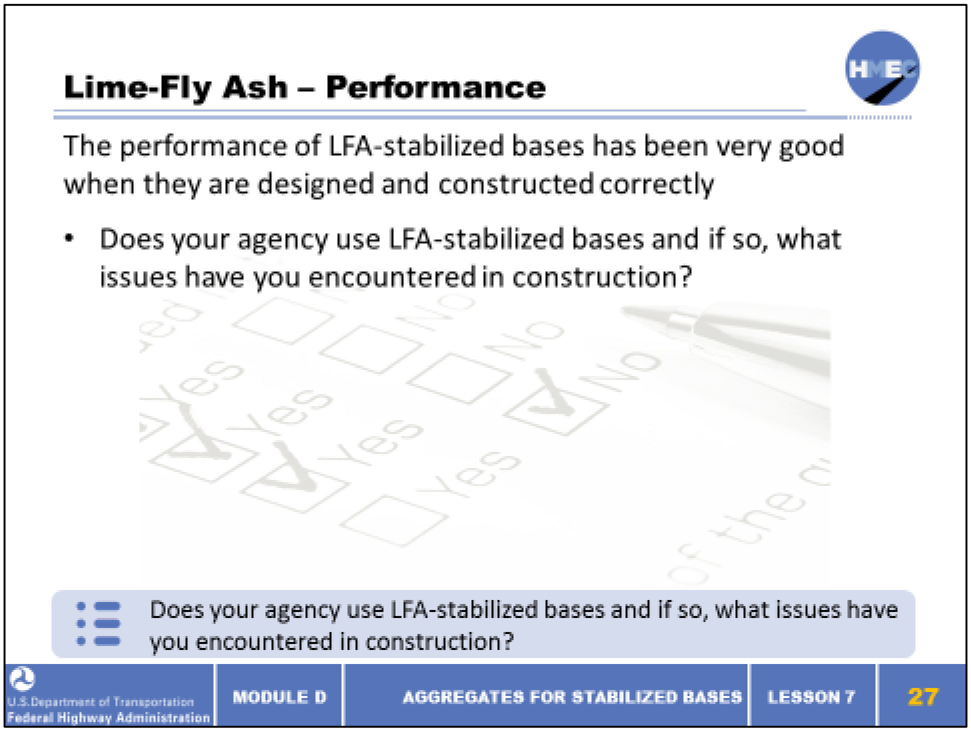
Curing conditions and time have a significant impact on the properties of lime-fly ash stabilized bases. The higher the curing temperature, the higher the compressive strength achieved by the stabilized materials.

Slide 26



The strength of the LFA mix is primarily controlled by the aggregate properties, lime, fly ash, and water content, efficiency of mixing, placement, compaction, and curing. The characteristics of the mix are highly dependent on the material properties, particularly the fly ash and the aggregates.

Slide 27

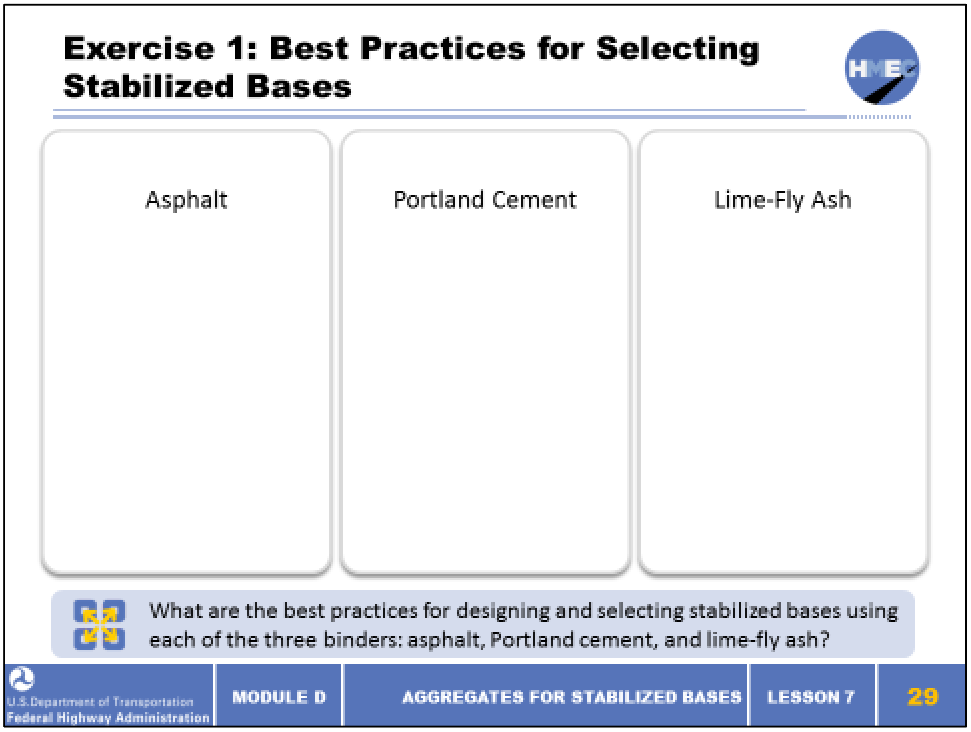


The performance of LFA-stabilized bases under both rigid and flexible pavements has been very good. These bases are used as a construction platform and to enhance long-term pavement performance. Although not as high strength as CTB, the issue of reflective cracking may still occur in flexible pavements and the use of a bond breaker may be required for the higher end of the typical strengths.

Slide 28

Additional requirements for aggregates to be used in lime stabilized base courses cover the durability and toughness properties of the aggregates. The sodium sulfate test evaluates the resistance of aggregates to damage due to wetting and drying while the LA abrasion test measures the resistance of the aggregate to degradation by abrasion and impact.

Slide 29


Exercise 1: Best Practices for Selecting Stabilized Bases
Asphalt
Portland Cement
Lime-Fly Ash
What are the best practices for designing and selecting stabilized bases using each of the three binders: asphalt, Portland cement, and lime-fly ash?
U.S. Department of Transportation Federal Highway Administration
MODULE D
AGGREGATES FOR STABILIZED BASES
LESSON 7
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Slide 30


Exercise 1 Solution: Best Practices for Selecting Stabilized Bases
HMEC
Asphalt
Portland Cement
Lime-Fly Ash
U.S.Department of Transportation
Federal Highway Administration
MODULE D
AGGREGATES FOR STABILIZED BASES
LESSON 7
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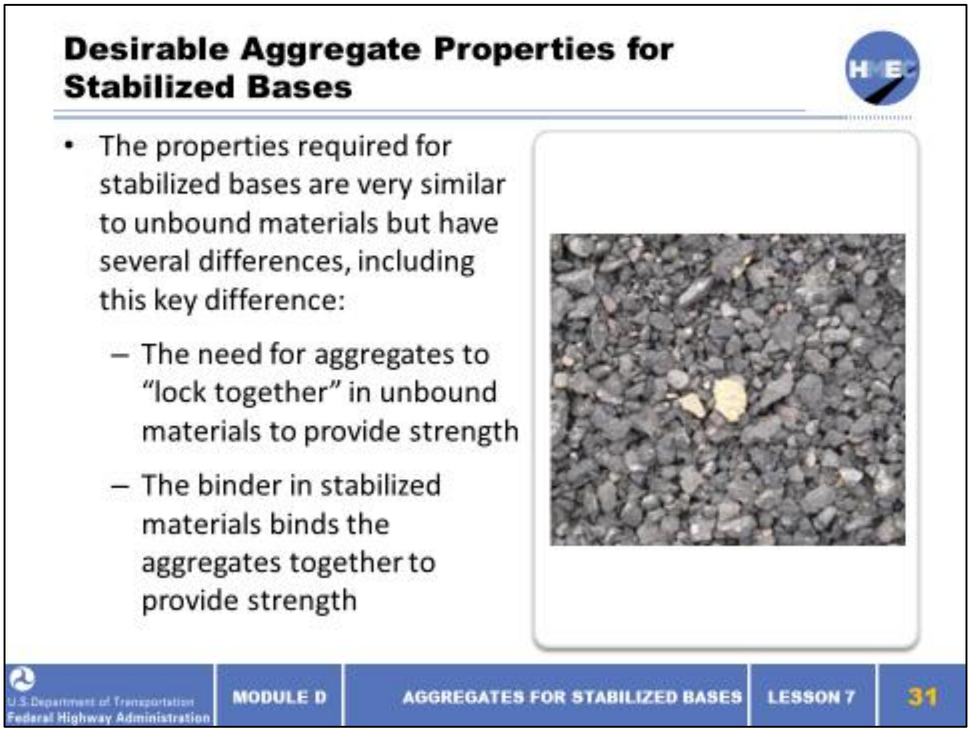
Slide 31



Most of the desirable properties for aggregates used in unbound aggregate bases are applicable to stabilized bases as well. The primary difference lies in the gradation, particularly the amount and nature of the fines. With unbound aggregate bases, the stability was negatively impacted with high fines. With stabilized materials, the fines impact the ability to bind the materials together.

Slide 32

Gradations Suited to Asphalt Stabilization

Sieve Size	Sand-Bitumen	Soil-Bitumen	Sand-Gravel-Bitumen
1.5 in.			100
1 in.	100		
0.75 in.			60–100
#4	50–100	50–100	35–100
#10	40–100		
#40		35–100	13–50
#100			8–35
#200	5–12	**Good:** 3–20 **Fair:** 0–3 and 20–30 **Poor:** > 30	
Liquid Limit		**Good:** < 20 **Fair:** 20–30 **Poor:** 30–40 **Unusable:** > 40	
Plasticity Index	< 10	**Good:** < 5 **Fair:** 5–9 **Poor:** 9–15 **Unusable:** > 12–15	< 10

U.S. Department of Transportation Federal Highway Administration | MODULE D | AGGREGATES FOR STABILIZED BASES | LESSON 7 | 32

In order for the gradation used for asphalt stabilization to be considered good, the fines content must be less than 10% and have a PI of less than 5. Fines contents exceeding 30% and PI values greater than 12 are not suitable for asphalt stabilization.

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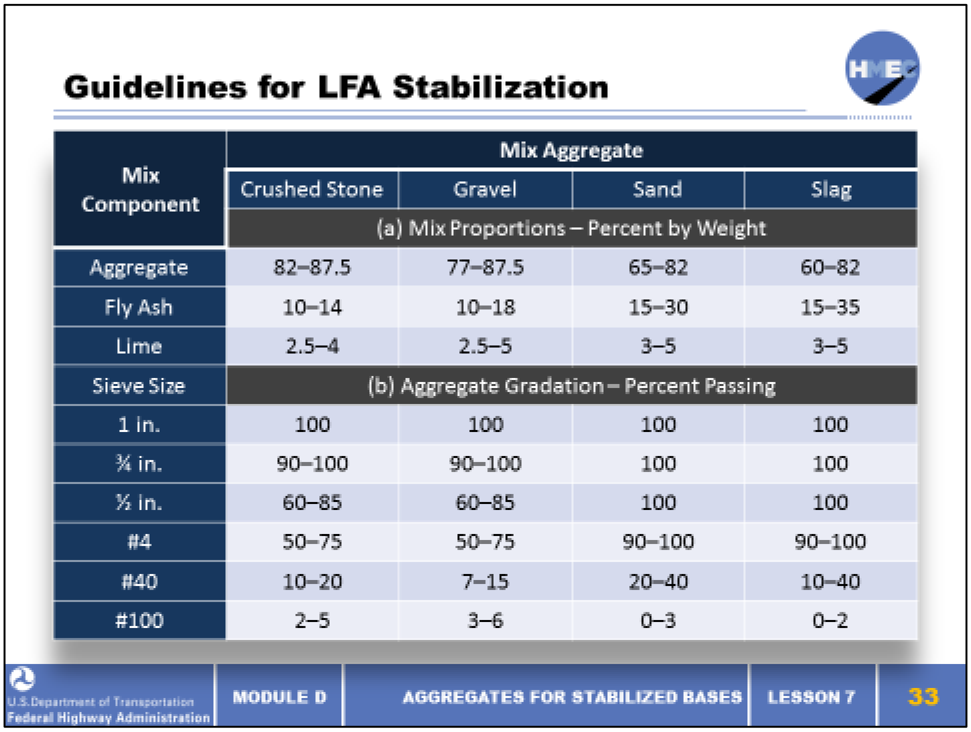
Slide 33


Guidelines for LFA Stabilization

Mix Component	Mix Aggregate			
	Crushed Stone	Gravel	Sand	Slag
	(a) Mix Proportions – Percent by Weight			
Aggregate	82–87.5	77–87.5	65–82	60–82
Fly Ash	10–14	10–18	15–30	15–35
Lime	2.5–4	2.5–5	3–5	3–5
Sieve Size	(b) Aggregate Gradation – Percent Passing			
1 in.	100	100	100	100
¾ in.	90–100	90–100	100	100
½ in.	60–85	60–85	100	100
#4	50–75	50–75	90–100	90–100
#40	10–20	7–15	20–40	10–40
#100	2–5	3–6	0–3	0–2

The relatively low fines content is due to the nature of the stabilization mechanism. That is the hydration products from the LFA reaction fill the void space rather than fines. A high fines content implies a high surface area that increases water demand.

Note that the values presented in this table are only intended as a range of appropriate percentages. The actual selection of the appropriate gradation should be based on material availability, cost, and the LFA needed to reach the target strength for the project.

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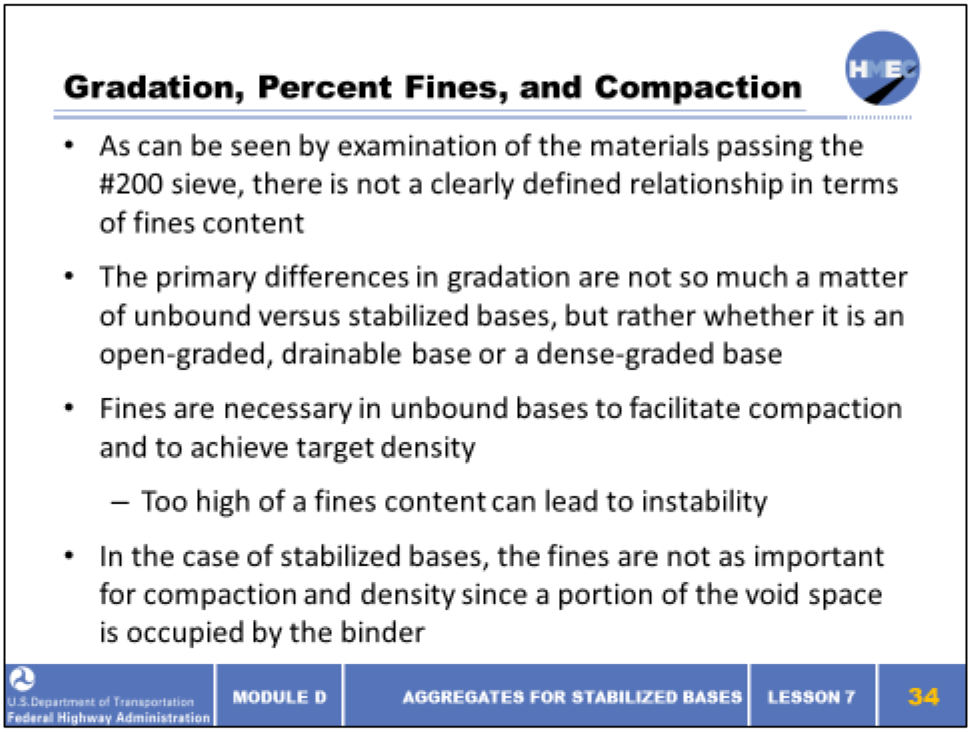
Slide 34



There are not clearly defined differences for aggregate gradation requirements as will be seen in the following slides. However, a number of generalizations can be made as shown on the slide.

The following three slides illustrate the basic gradation criteria for unbound aggregate bases, asphalt-stabilized bases, and LFA-stabilized bases.

Slide 35


Exercise 2: Best Practices for Constructing Stabilized Bases
Asphalt
Portland Cement
Lime-Fly Ash
What are the best practices for constructing stabilized bases using each of the three binders: asphalt, Portland cement, and lime-fly ash?
U.S. Department of Transportation
Federal Highway Administration
MODULE D
AGGREGATES FOR STABILIZED BASES
LESSON 7
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Slide 36


Exercise 2 Solution: Best Practices for Constructing Stabilized Bases
HMEC
Asphalt
Portland Cement
Lime-Fly Ash
U.S. Department of Transportation
Federal Highway Administration
MODULE D
AGGREGATES FOR STABILIZED BASES
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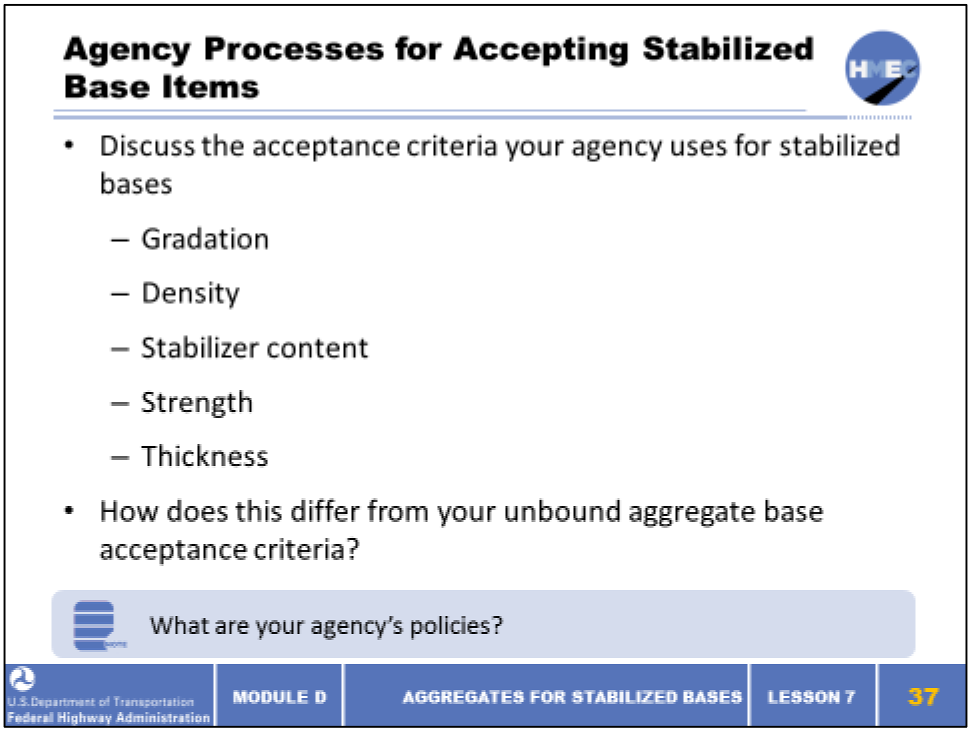
Slide 37


Agency Processes for Accepting Stabilized Base Items
HMEC
• Discuss the acceptance criteria your agency uses for stabilized bases
– Gradation
– Density
– Stabilizer content
– Strength
– Thickness
• How does this differ from your unbound aggregate base acceptance criteria?
What are your agency's policies?
U.S. Department of Transportation
Federal Highway Administration
MODULE D
AGGREGATES FOR STABILIZED BASES
LESSON 7
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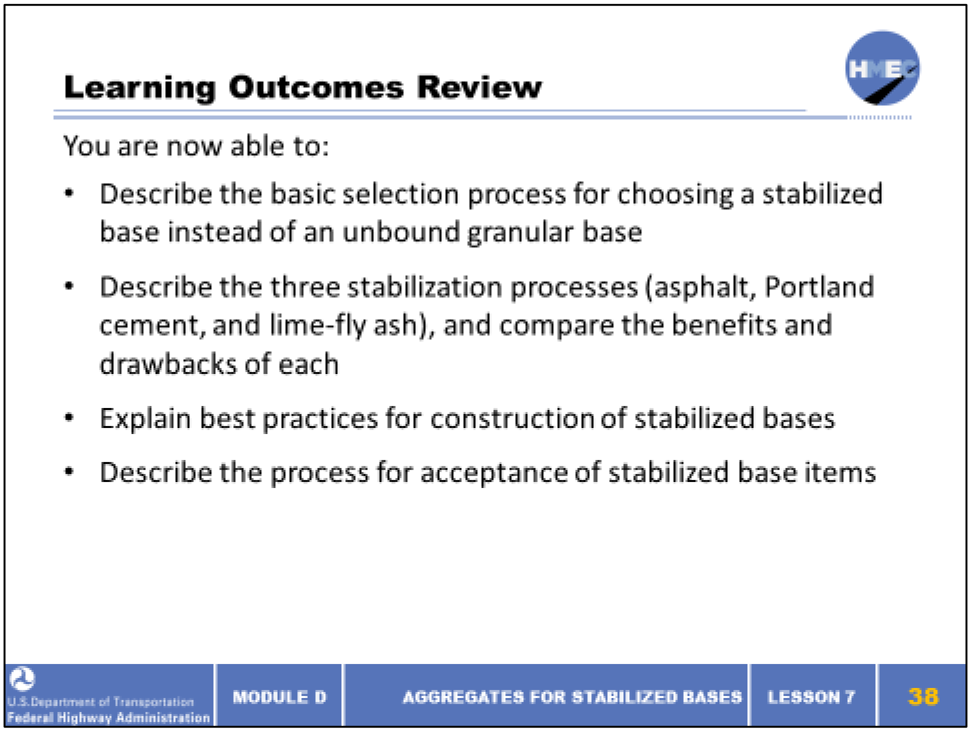
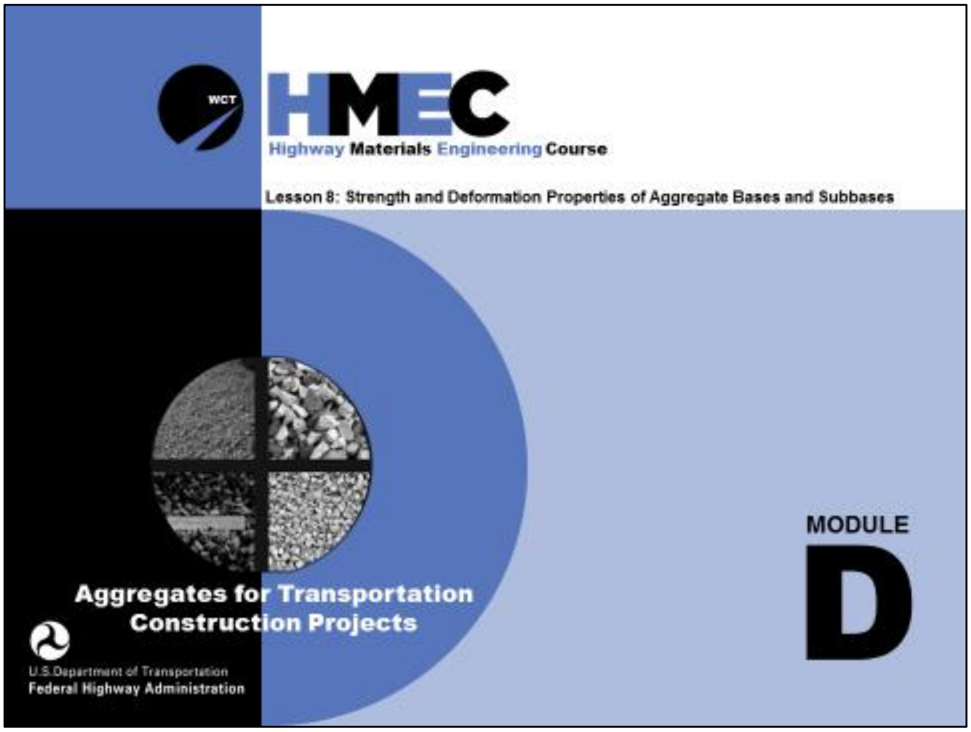
Slide 38


Learning Outcomes Review
HMEC
You are now able to:
• Describe the basic selection process for choosing a stabilized base instead of an unbound granular base
• Describe the three stabilization processes (asphalt, Portland cement, and lime-fly ash), and compare the benefits and drawbacks of each
• Explain best practices for construction of stabilized bases
• Describe the process for acceptance of stabilized base items
U.S. Department of Transportation
Federal Highway Administration
MODULE D
AGGREGATES FOR STABILIZED BASES
LESSON 7
38

Slide 1


HMEC
Highway Materials Engineering Course
Lesson 8: Strength and Deformation Properties of Aggregate Bases and Subbases
Aggregates for Transportation Construction Projects
U.S.Department of Transportation
Federal Highway Administration
MODULE
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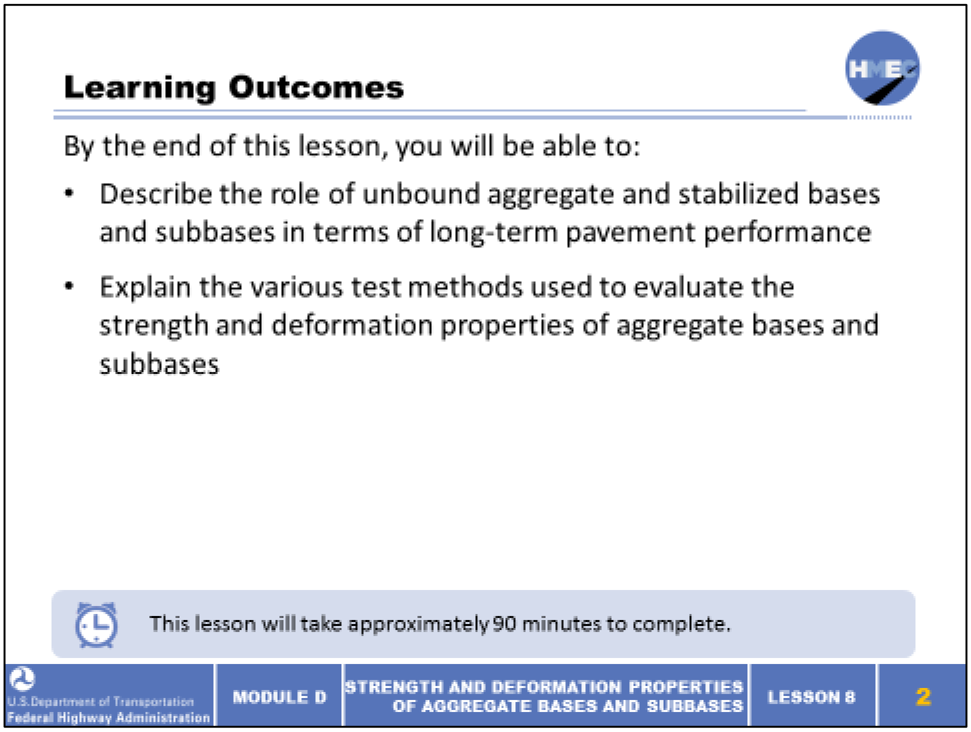
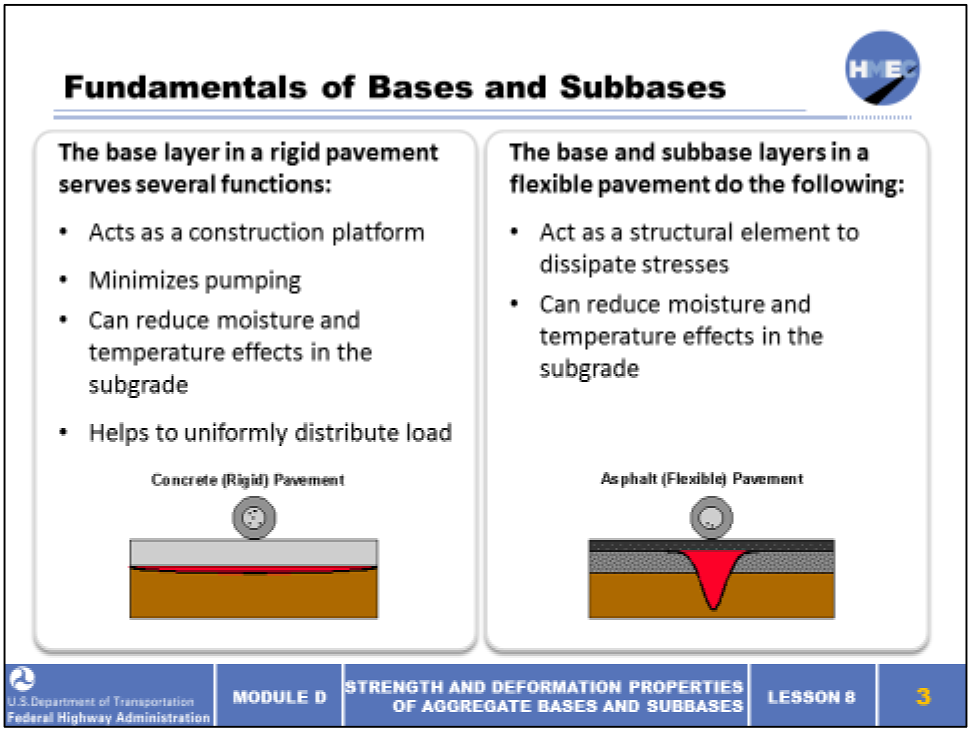
Slide 2

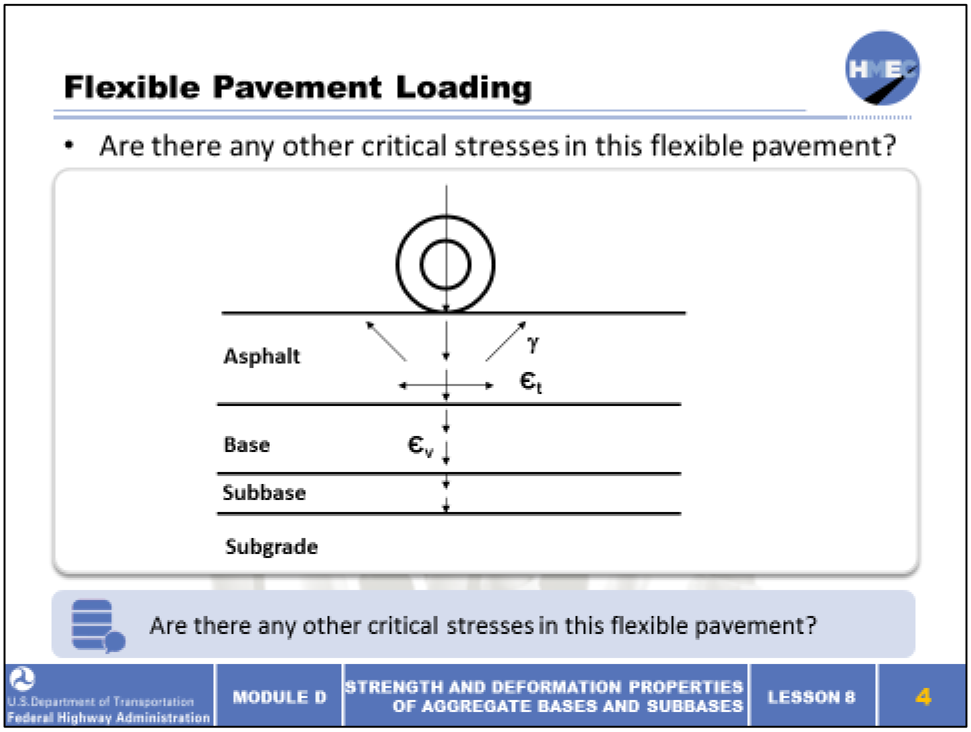

Learning Outcomes
By the end of this lesson, you will be able to:
• Describe the role of unbound aggregate and stabilized bases and subbases in terms of long-term pavement performance
• Explain the various test methods used to evaluate the strength and deformation properties of aggregate bases and subbases
This lesson will take approximately 90 minutes to complete.
U.S. Department of Transportation
Federal Highway Administration
MODULE D
STRENGTH AND DEFORMATION PROPERTIES OF AGGREGATE BASES AND SUBBASES
LESSON 8
2

Slide 3



The role of the base course differs from flexible pavement to rigid pavement.

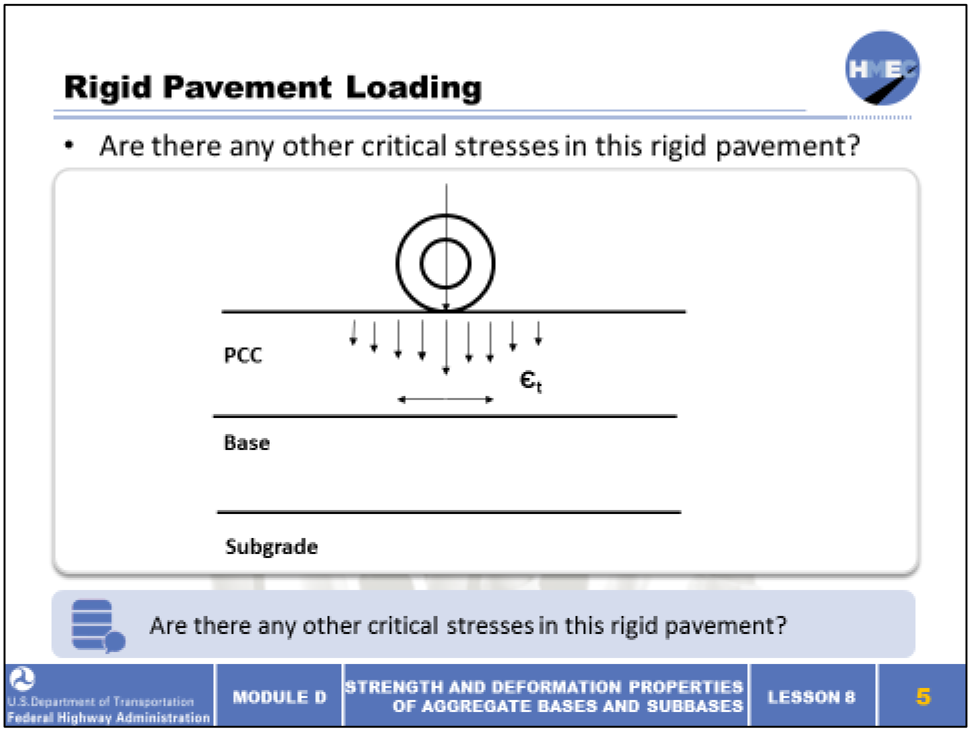
Slide 4



As the flexible pavement is loaded, stresses, strains, and deflections are generated throughout the various layers. The magnitudes of these responses control the development of rutting and fatigue failure of the flexible pavement.

The strength and quality of the base and subbase materials control the dissipation of stresses within the structure. The critical points are the vertical stress at the top of the subgrade and the tensile stress at the bottom of the lowest bound layer.

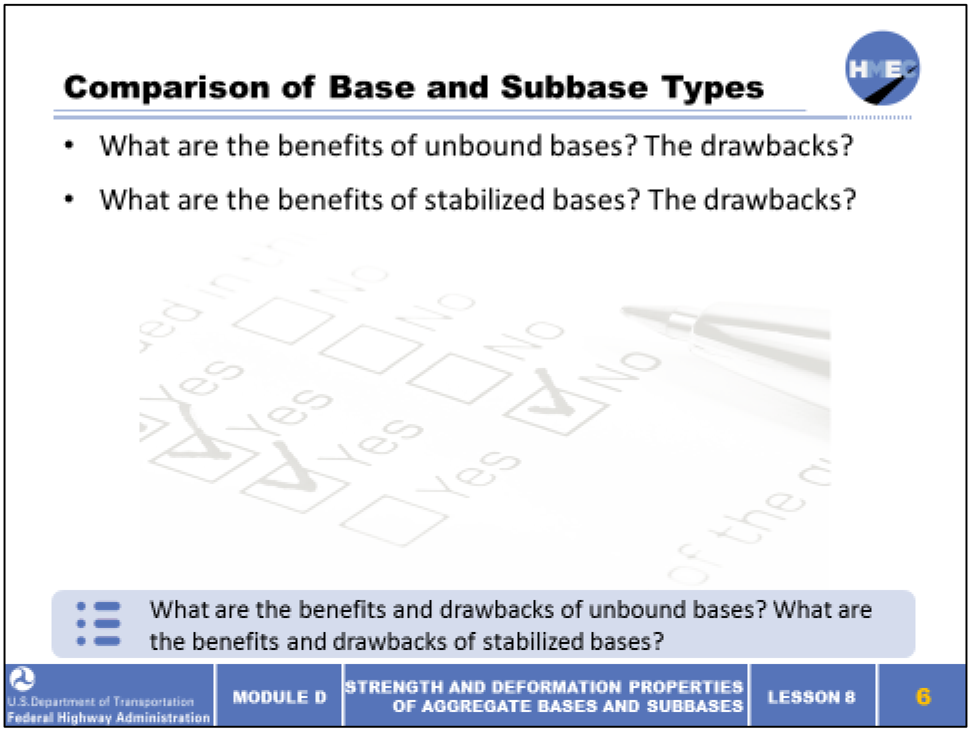
Slide 5



As the rigid pavement is subjected to traffic, the loads are distributed throughout the slab via slab action. The thickness and stiffness of the slab controls the degree of stress dissipation.

The base course plays a role in the structural response of the pavement system but to a far lesser degree than in a flexible pavement. The critical point is the tensile stress at the bottom of the slab.

Slide 6



Due to differences in the function of bases and subbases in rigid and flexible pavements, selection of unbound versus stabilized bases can be very important.

Slide 7

Desirable Properties of Bases and Subbases

- In order for bases and subbases to achieve the desired goal of enhancing long-term pavement performance, the following properties are key:
  - Durable and resist chemical and mechanical breakdown
  - Sufficiently strong and deformation resistant to fulfill their design function
  - Affordable

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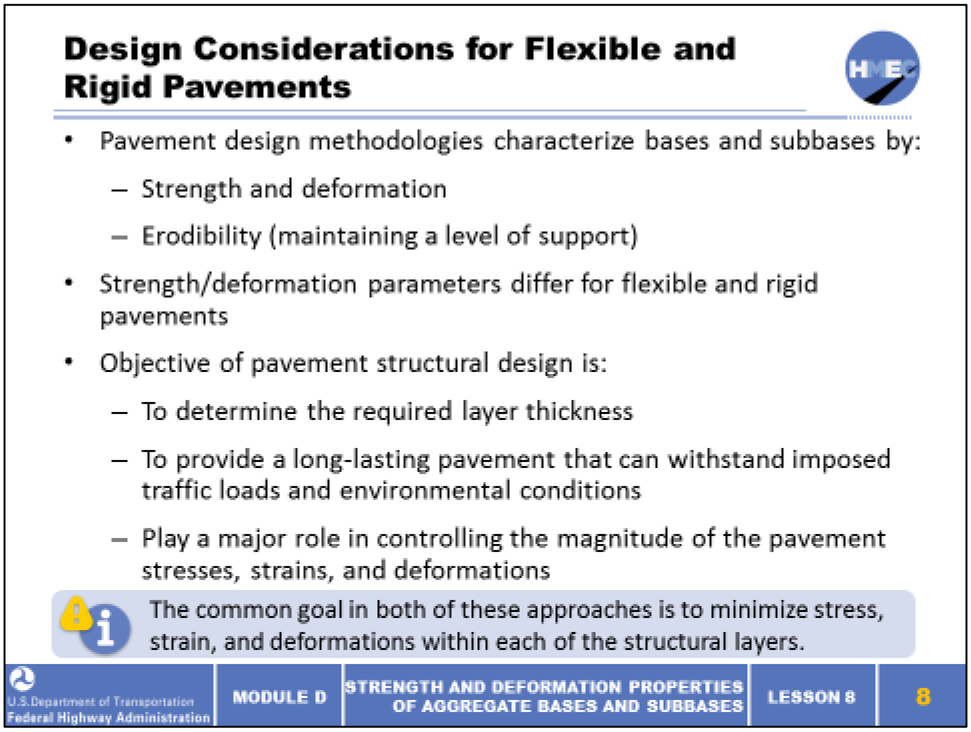
Slide 8



Pavement design methodologies ranging from the older AASHTO 1993 procedure to the new Mechanistic Empirical Pavement Design Guide (MEPDG) characterize bases and subbases in two ways:

- Strength and deformation; and
- Erodibility (maintaining a level of support).

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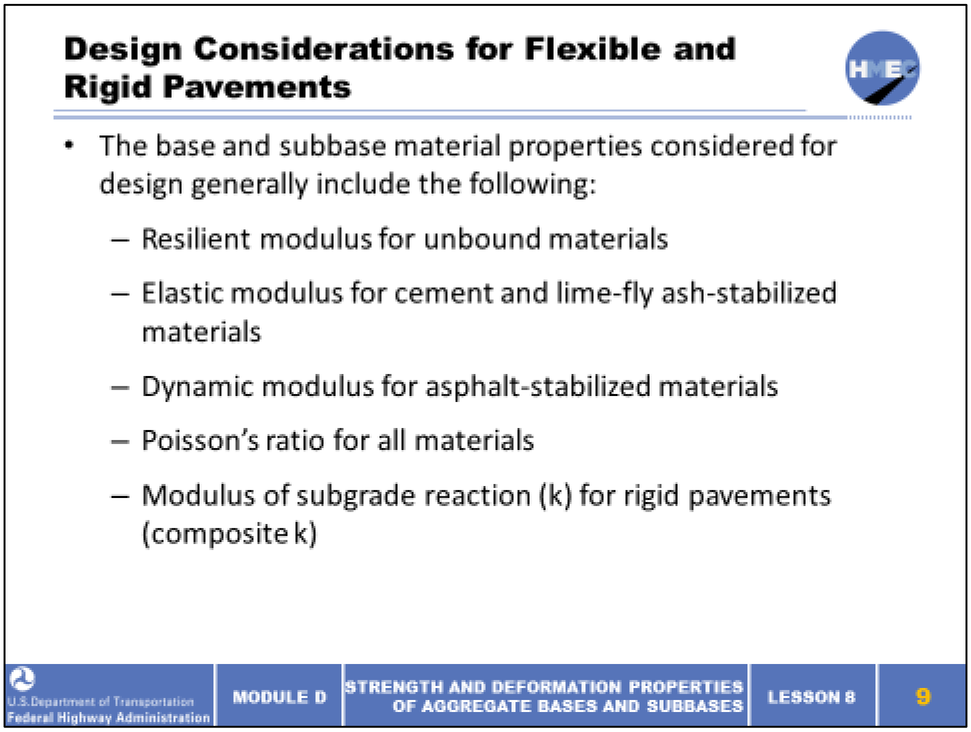
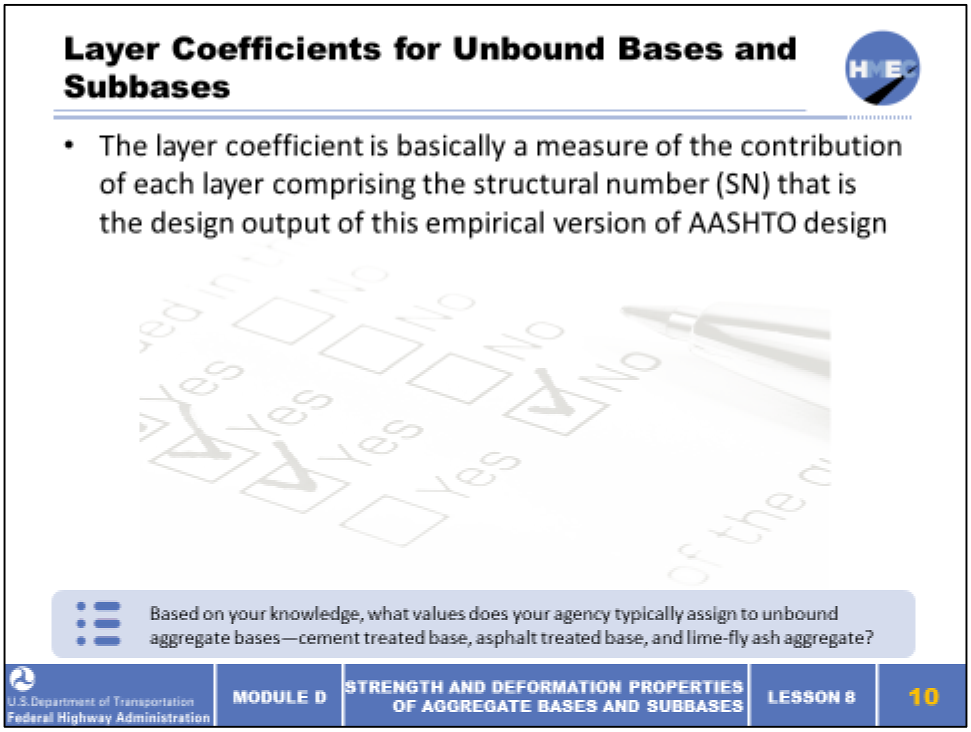
Slide 9



The modulus of the base or subbase depends on the type of material used. The term modulus is used to describe the stress-strain relationship but its magnitude and methods of testing varies depending on the type of materials. Unbound materials are non-linear elastic, the cement/lime stabilized materials are linear elastic, while the asphalt stabilized materials are linear visco-elastic.

Slide 10



Older versions of the AASHTO pavement design method (1972, 1986, and 1993) used the concept of structural layer coefficients (ai) for flexible pavement design. The structural layer coefficient concept is being phased out as the MEPDG is adopted. However, a number of agencies still use it at present.

Layer coefficients continue to be used since the adoption of the MEPDG is not universal, particularly for lower volume roadways.

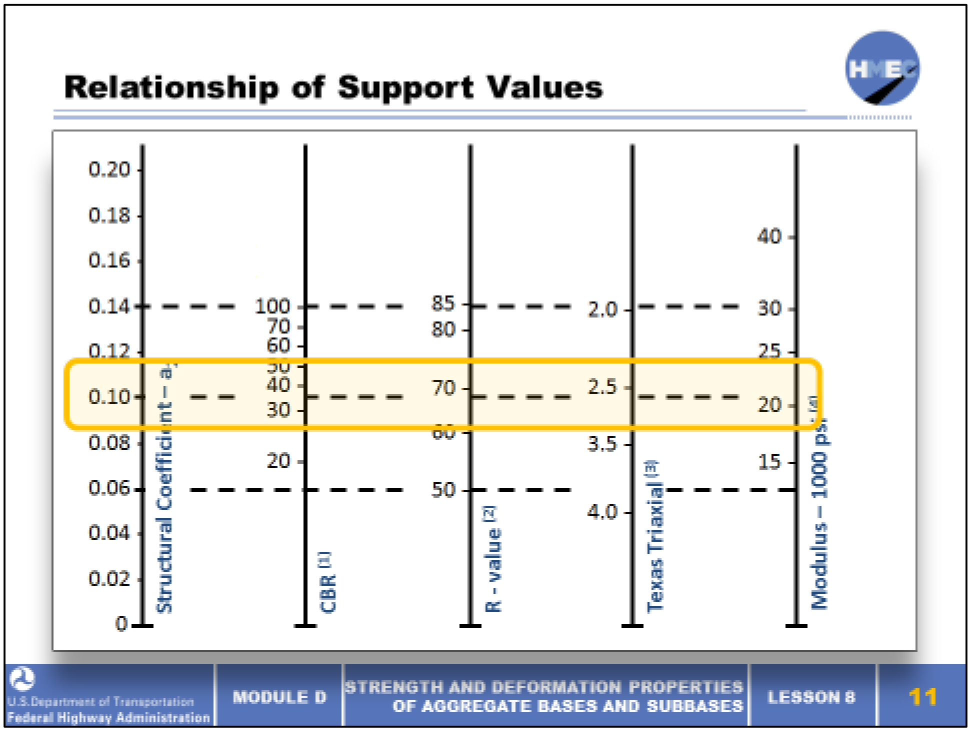
The layer coefficient is an easy concept to grasp and it has become part of many pavement designer's toolboxes in characterizing different materials. The layer coefficient is based on the modulus of the layer being considered in the design (surface, base, and subbase). It is basically is a measure of the contribution of each layer comprising the structural number (SN) that is the design output of this empirical version of AASHTO design.

Common values for unbound granular bases typically range from 0.10 to 0.12 for high quality crushed stone.

There are distinctly better methods of characterization (resilient modulus for instance) that will eventually eliminate this method of looking at relative support values.

Note that we will discuss the MEPDG approach and how the AASHTO Pavement ME Design software implements that approach in more detail in Module E.

Slide 11


Relationship of Support Values
HMEC
0.20
0.18
0.16
0.14
0.12
0.10
0.08
0.06
0.04
0.02
0
Structural Coefficient – a
100
70
60
40
30
20
CBR [1]
85
80
70
50
R - value [2]
2.0
2.5
3.5
4.0
Texas Triaxial [3]
40
30
25
20
15
Modulus – 1000 psi [4]
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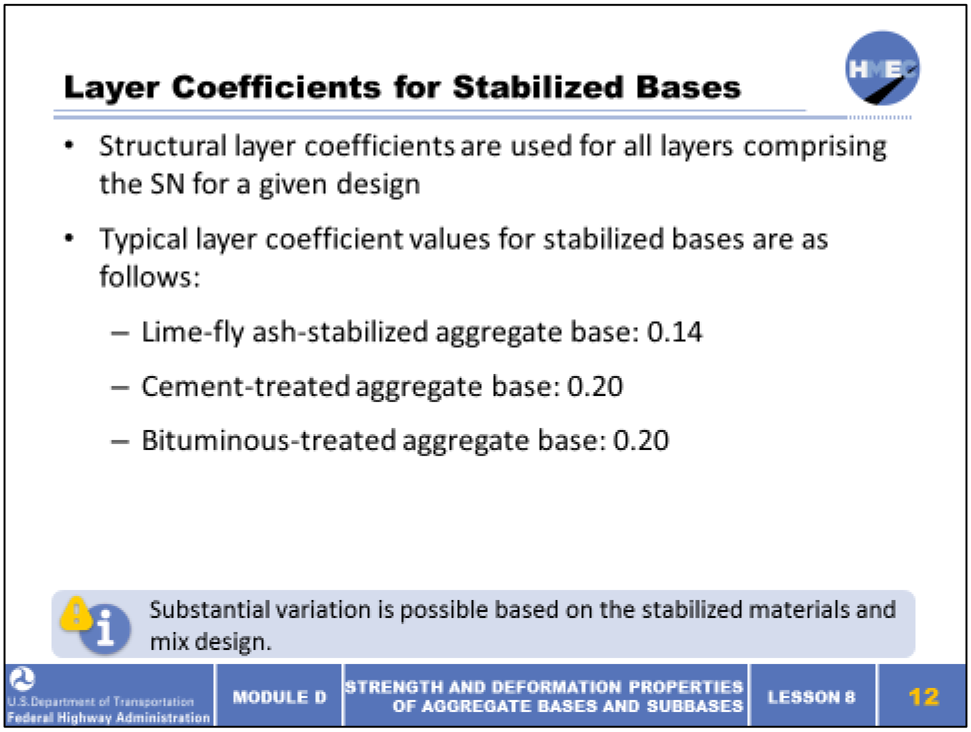
Slide 12

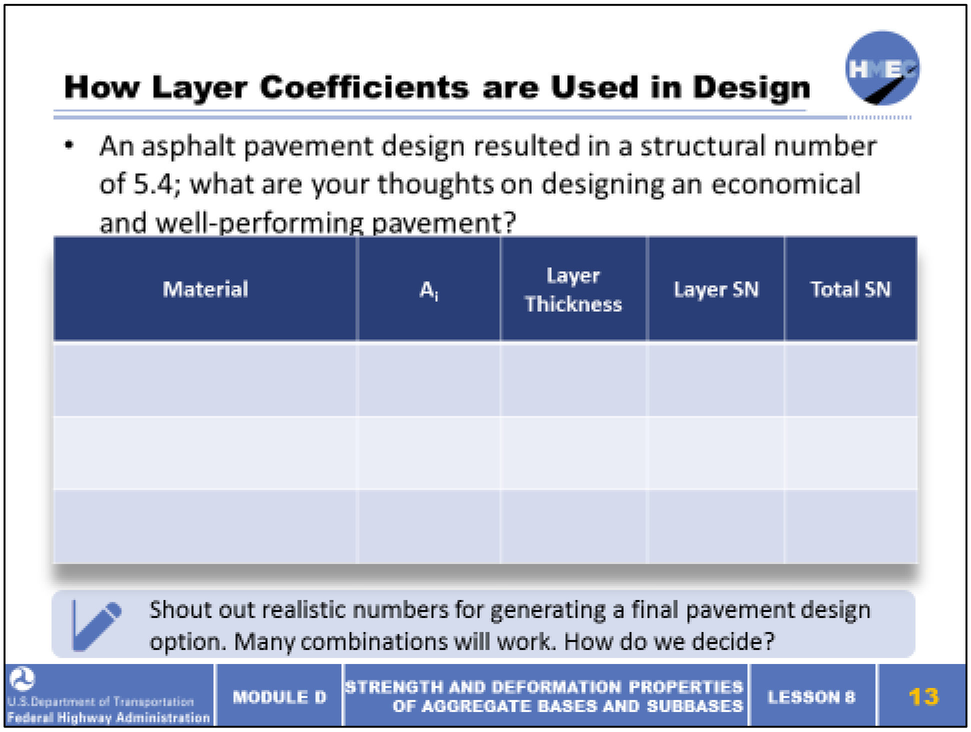


The typical values shown in this slide are average values for the various materials listed.

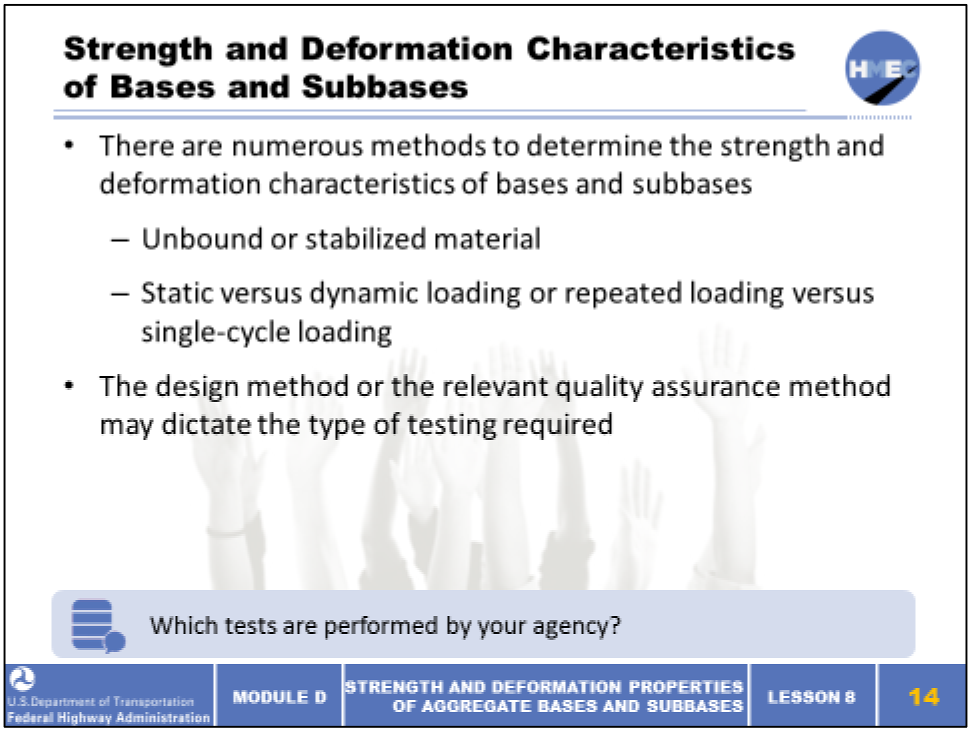
Typical hot mix asphalt (HMA) has a layer coefficient of approximately 0.44, as opposed to unbound granular material which averages about 0.11. In other words, in terms of structural capacity, 4 in. of crushed stone base is roughly equivalent to 1 in. of HMA.

Keep in mind that substantial variation is possible based on the stabilized materials and mix design.

Slide 13


How Layer Coefficients are Used in Design
HMEC
An asphalt pavement design resulted in a structural number of 5.4; what are your thoughts on designing an economical and well-performing pavement?
Material
A_i
Layer Thickness
Layer SN
Total SN
Shout out realistic numbers for generating a final pavement design option. Many combinations will work. How do we decide?
U.S. Department of Transportation
Federal Highway Administration
MODULE D
STRENGTH AND DEFORMATION PROPERTIES OF AGGREGATE BASES AND SUBBASES
LESSON 8
13

Slide 14



Numerous options are available for characterizing base and subbase materials depending on whether they are unbound or stabilized.

Further differentiation can be made in terms of static versus dynamic loading or repeated loading versus single-cycle loading.

The design method or the relevant quality assurance method may dictate the type of testing required. You should consult the design methodology you will be using to select the most appropriate procedure.

In this section, we will look at both laboratory testing and in-situ (in-place) testing and characterization methods.

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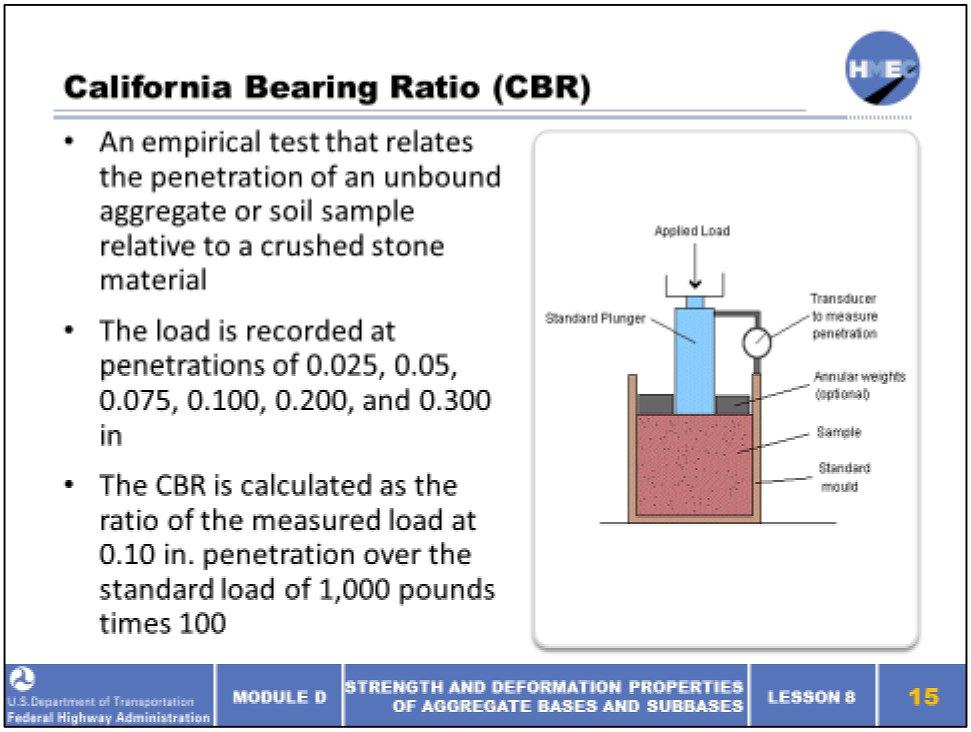
Slide 15



California Bearing Ratio (CBR) is an empirical test that relates the penetration of an unbound aggregate or soil sample relative to a crushed stone material. The penetration of a standard piston with a cross sectional area of 3 in^2 travelling at a rate of 0.05 in. /min is used in the test.

The CBR is calculated as the ratio of the measured load at 0.10-inch penetration over the standard load of 1,000 pounds times 100. For example, if the measured load required to achieve a 0.10-in. penetration was 600 pounds, the CBR value would be [(600/1000) x100] or 60. The standard load represents the load required to achieve 0.10-in. penetration in a crushed limestone material.

CBR is a widely used characterization test for unbound granular materials and soils. Many materials and pavement engineers as well as contractors routinely describe in-situ and as-constructed material properties in terms of CBR. Although it is a uniaxial static test, its widespread use makes it an important characterization method.

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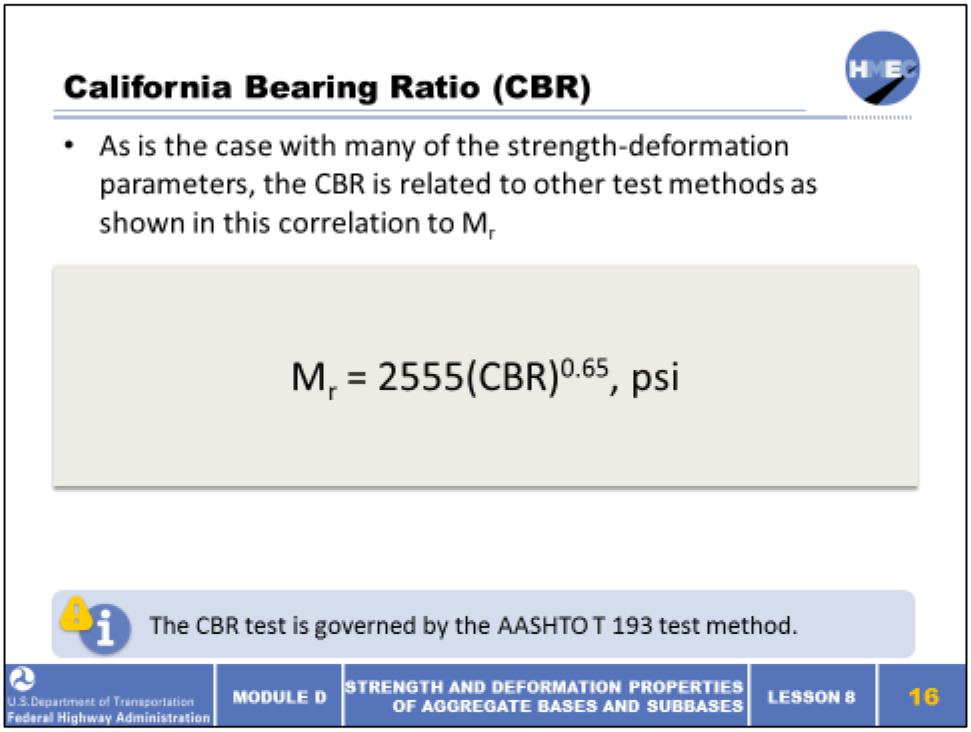
Slide 16



The CBR test is a standard test protocol that has been used for many years to characterize these types of materials. The correlation is one of many relating CBR to modulus.

Slide 17

Note the surcharge weights to simulate the dead weight of the layers above the materials being tested. The surcharge weight is selected to distribute similar stress on top of the materials being tested as the ones in the field.

Slide 18

CBR can also be conducted in the field to determine in-place values that are very representative of actual service conditions.

Slide 19

Rigid pavement design requires the modulus of subgrade reaction (k) which can be determined using a plate load test, as pictured here. Due to the time and expense involved in performing this test, the k value is frequently determined from correlation with other soil support values.

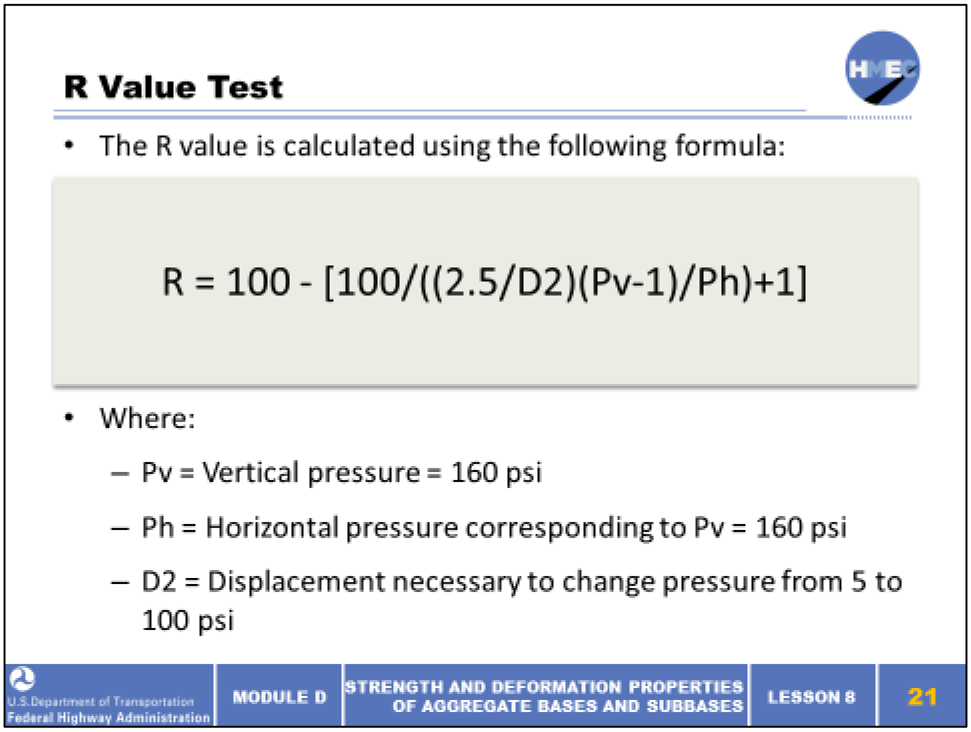
Slide 20

The R value test uses the Hveem stabilometer similar to the one used in the Hveem mix design for asphalt mixtures.

The sample sits inside a rubber diaphragm surrounded by hydraulic fluid. As the sample is loaded in the vertical direction, it expands in the lateral direction and mobilizes the confining pressure exerted by the incompressible hydraulic fluid.

The large dial gauge in the front measures the generated confining pressure. The turning handle pushes the hydraulic fluid around the diaphragm to generate a desired level of confining pressure around the sample.

Slide 21



The R value is an empirical test to measure the internal friction of the unbound granular material under three-dimensional stress conditions. It measures the response of a compacted sample of soil or aggregate to a vertically applied pressure under specified test conditions. It is essentially a static test that does not allow for cyclic loading to simulate traffic loadings.

The R value was developed by Caltrans to provide input to their pavement design procedure.

It is not as commonly used as CBR and will likely have limited application following widespread adoption of the MEPDG and expanded resilient modulus testing capabilities in agency laboratories.

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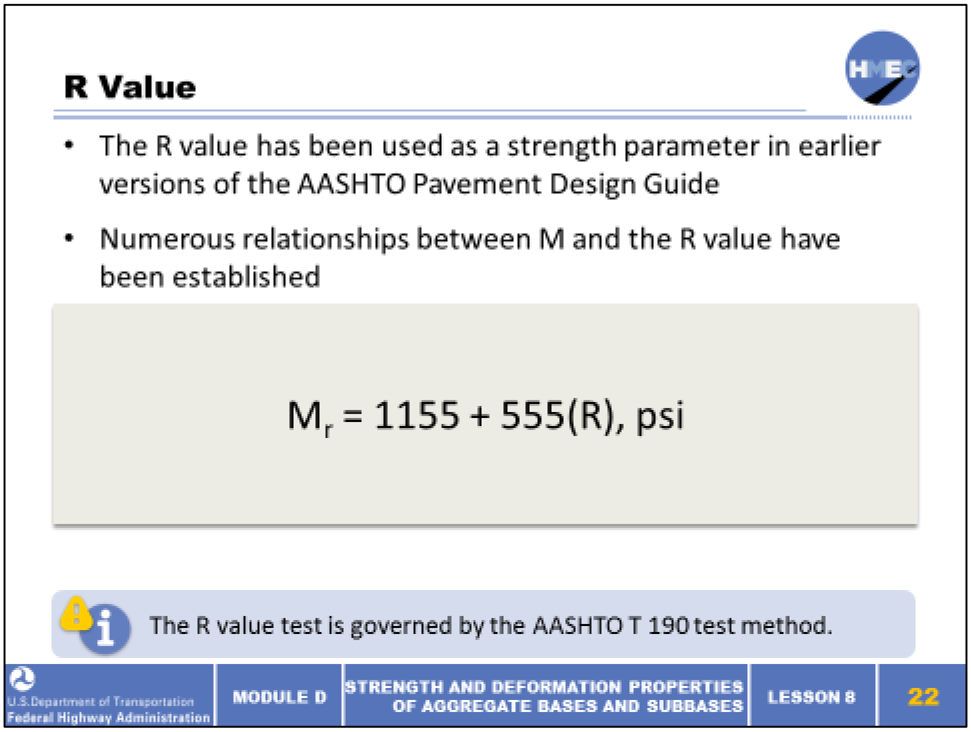
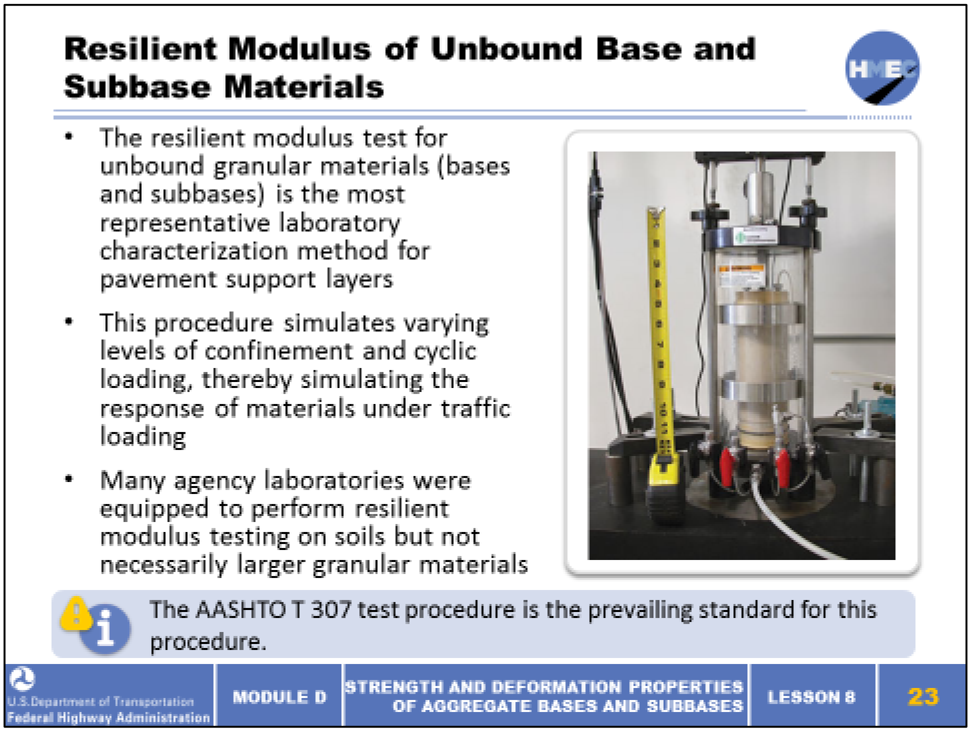
Slide 22



The R value was developed as a replacement for the CBR by Caltrans and has been used as a pavement design input for those that have adopted the Caltrans method of pavement design.

Slide 23

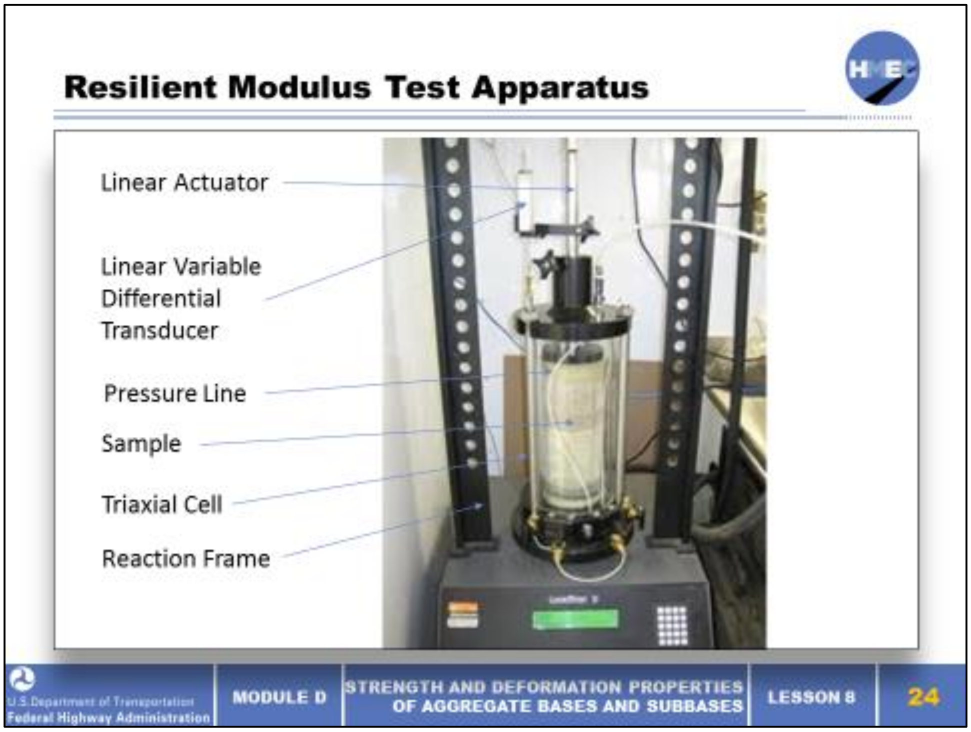


The resilient modulus test for unbound granular materials (bases and subbases) is the most representative laboratory characterization method for pavement support layers.

It is a significant improvement over other characterization methods. Of the available laboratory-based test procedures, this is the only test that allows simulation of in-service conditions.

The resilient modulus test uses triaxial repeated load testing to simulate the dynamic stresses generated by traffic loads moving at highway speed. The term triaxial means the sample is subjected to three-dimensional stresses to simulate the confining conditions in the field.

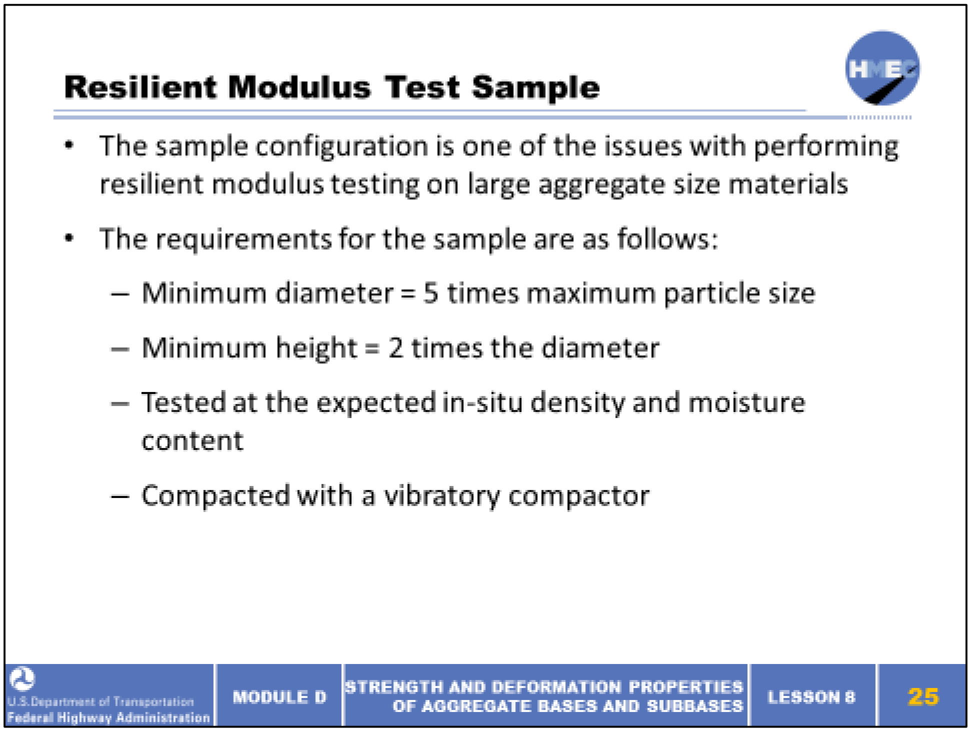
Slide 24



The triaxial chamber shown allows wide variations in testing conditions. Both the repeated vertical stress and the confining pressure can be varied to simulate different loading conditions.

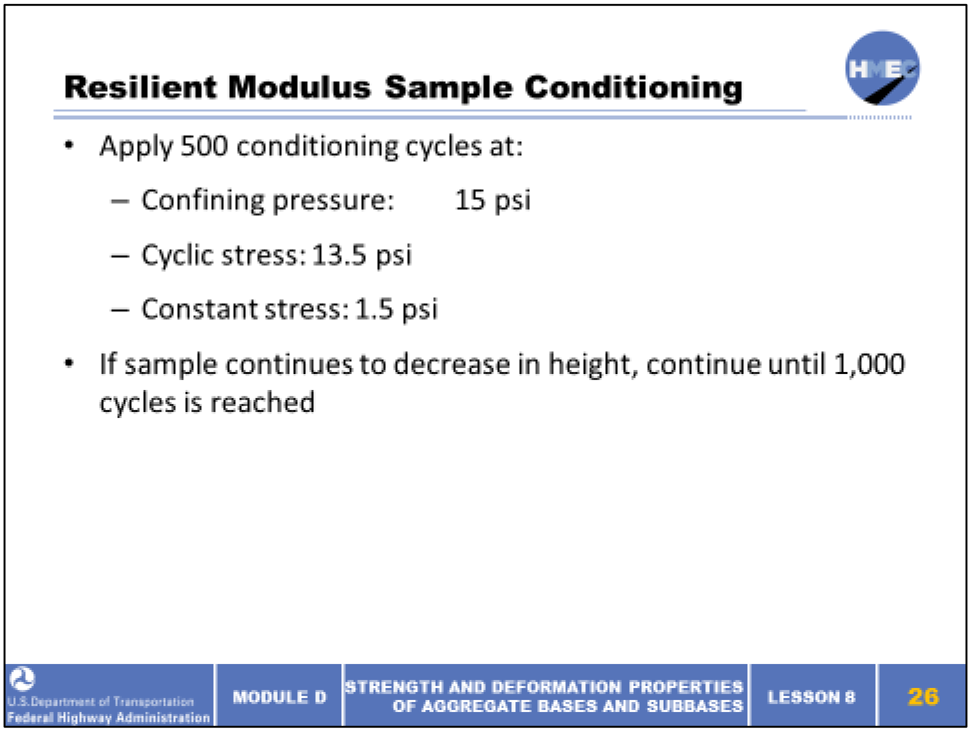
Testing materials that will be placed close to the pavement surface will require higher vertical and confining stresses than testing materials that will be placed deeper into the pavement structure.

Slide 25



The objective of the test is to evaluate a representative sample from the field in terms of moisture content and density. Certain geometric relativity must be maintained to ensure that the measured responses are not greatly influenced by the boundary conditions.

Slide 26



Sample conditioning is a necessary step to ensure that any irregularity in the sample set-up is eliminated prior to actual testing.

For example, a small gap between the top of the sample and the loading platen would lead to large deformations that are not truly representative of the behavior of the material.

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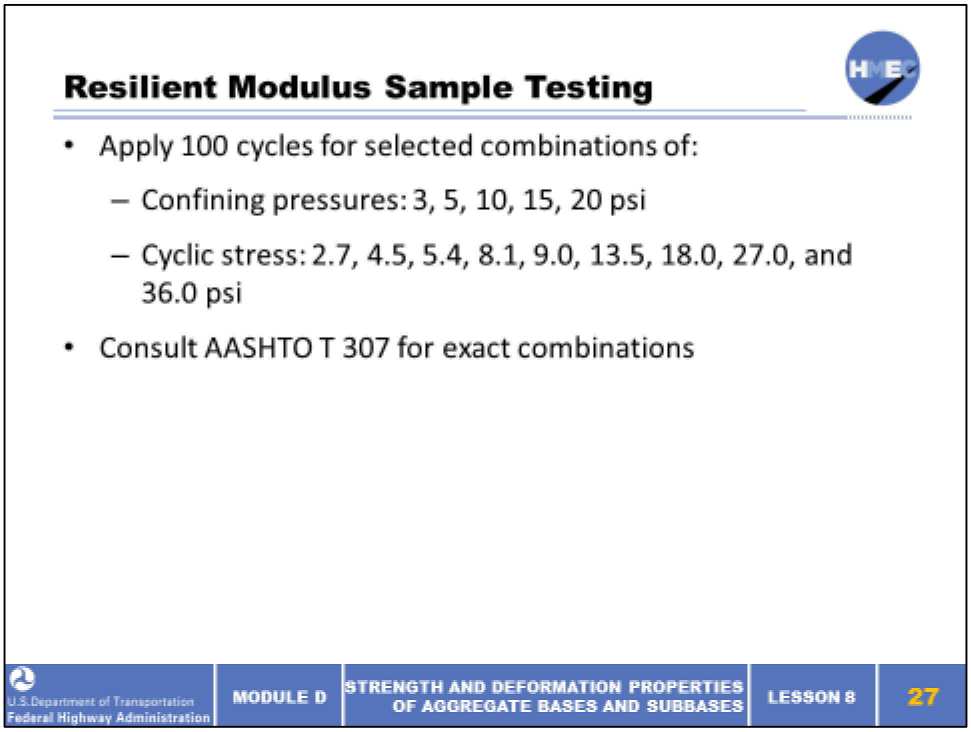
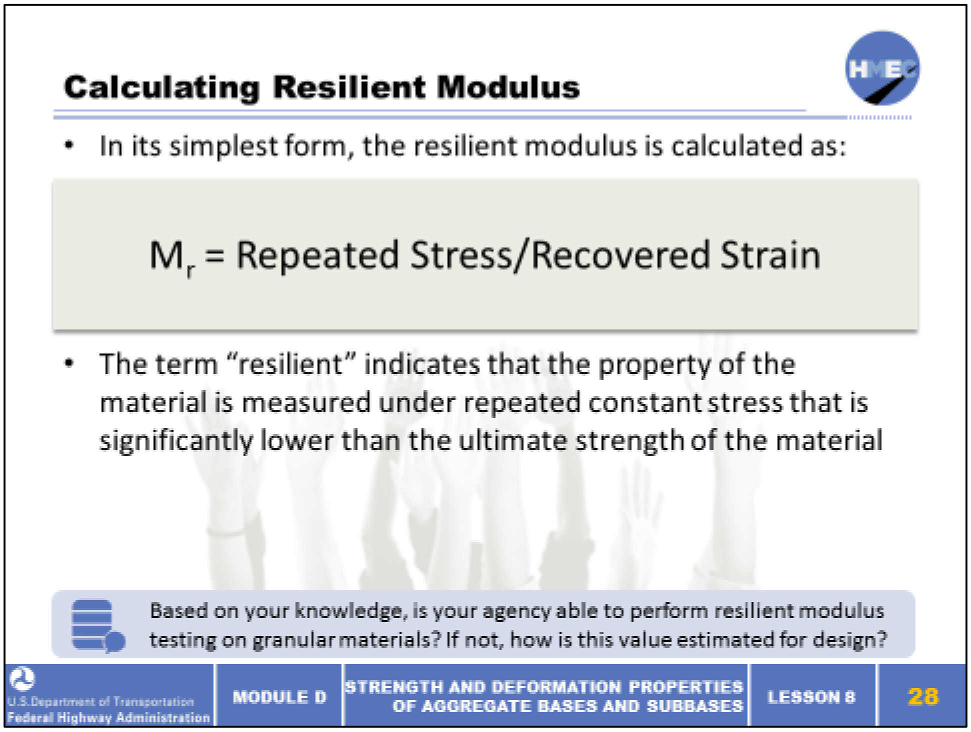
Slide 27



Unbound base materials behave in a non-linear fashion. Therefore, it is necessary that the modulus property is measured at various stress levels.

The testing sequence is typically set up to cover all possible combinations of the repeated stress and confining pressure. The magnitudes of the stresses are determined to simulate various field conditions in terms of load levels and materials locations within the pavement structure.

Slide 28

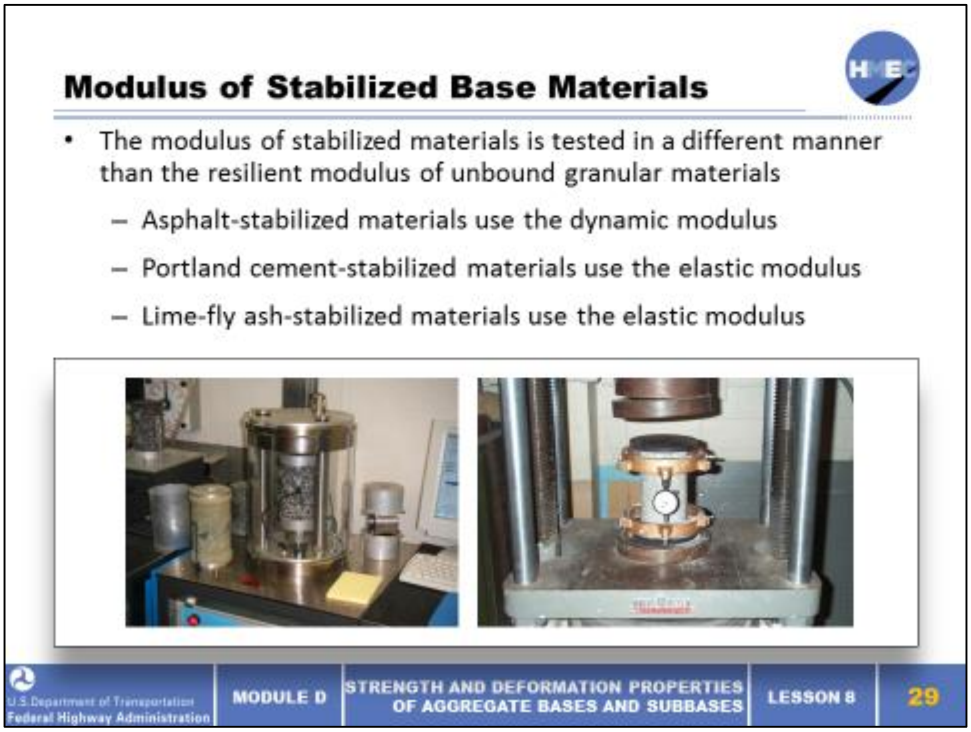


In practical terms, a different resilient modulus value is measured under each combination of repeated axial stress and confining pressure. A constitutive model is a mathematical equation that describes the relationship between the measured resilient modulus and the state of stresses within the sample. Each base material will have its unique constitutive model represented by the appropriate set of constants k_1, k_2, and k_3.

Due to time limitations, we will not go into the details of the constitutive models.

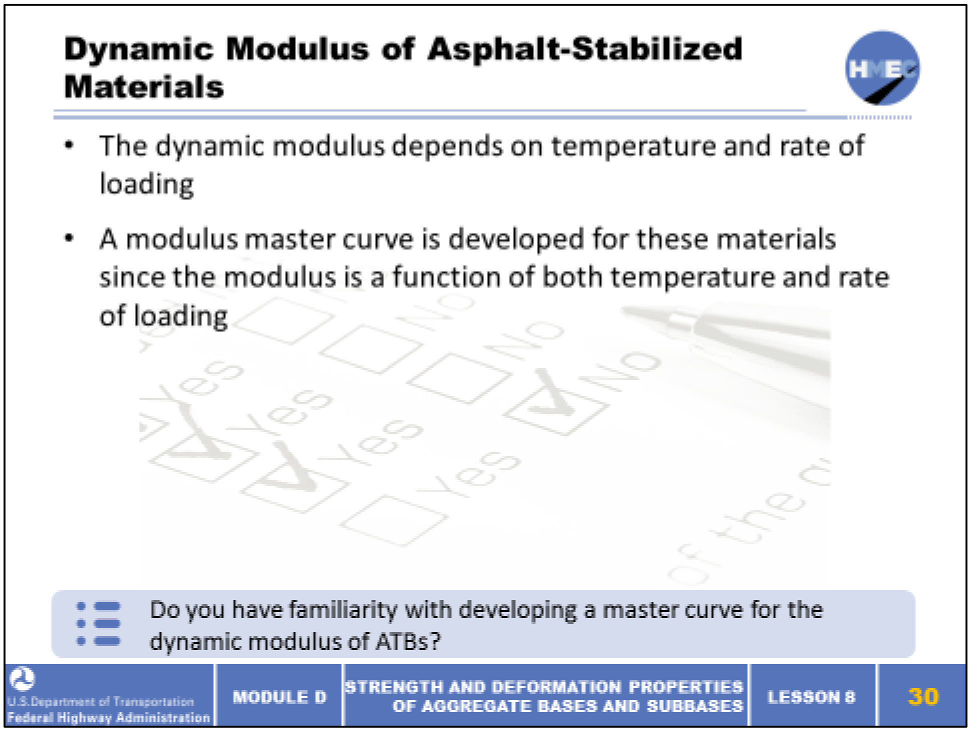
Refer to AASHTO T 307, Determining the Resilient Modulus of Soils and Aggregate Materials, for complete details on this procedure.

Slide 29



Due to the fundamental differences in material behavior, the modulus of stabilized materials differs from that for unbound aggregates. The dynamic modulus and elastic modulus will be briefly reviewed in this section.

Slide 30

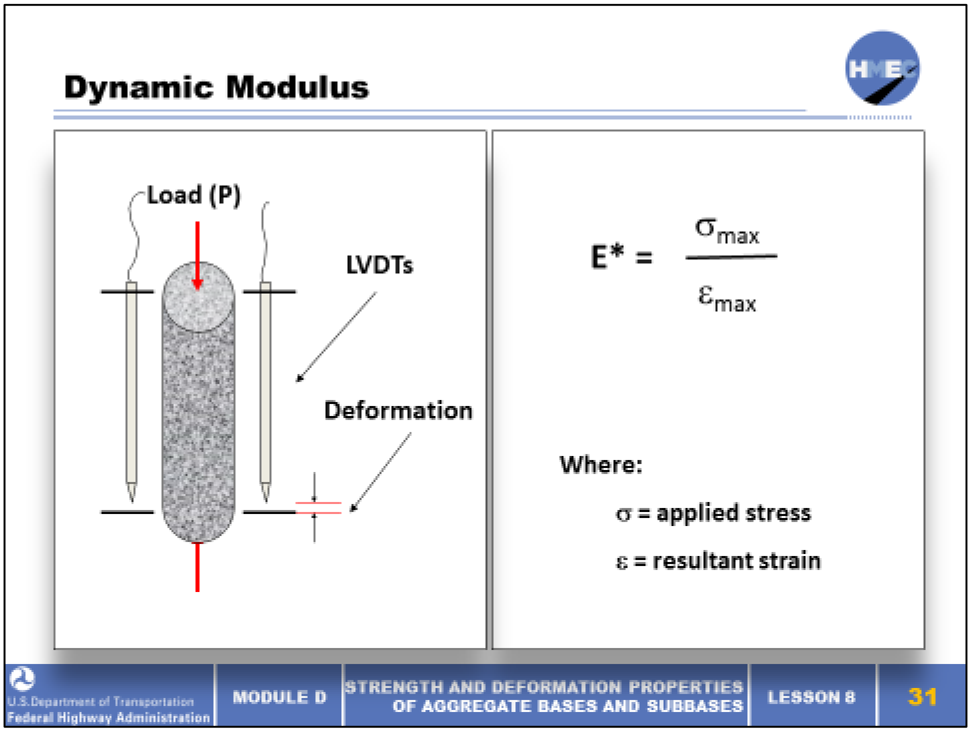


In the case of asphalt-stabilized bases, the visco-elastic properties of the asphalt binder greatly influence the magnitude of the modulus.

In order to capture the visco-elastic behavior, the dynamic modulus is evaluated under various conditions of temperatures and loading rates. Using the time-temperature superposition technique, the modulus master curve is developed to cover the entire range of temperatures and loading rates that will be anticipated in the field.

The temperature range is controlled by the location of the project while the range of loading rates depends on the traffic flow on the pavement (i.e. freeway or signalized street).

Slide 31



The dynamic modulus test is a uniaxial test that uses a cylindrical sample with a 4-in. diameter by 6-in. height.

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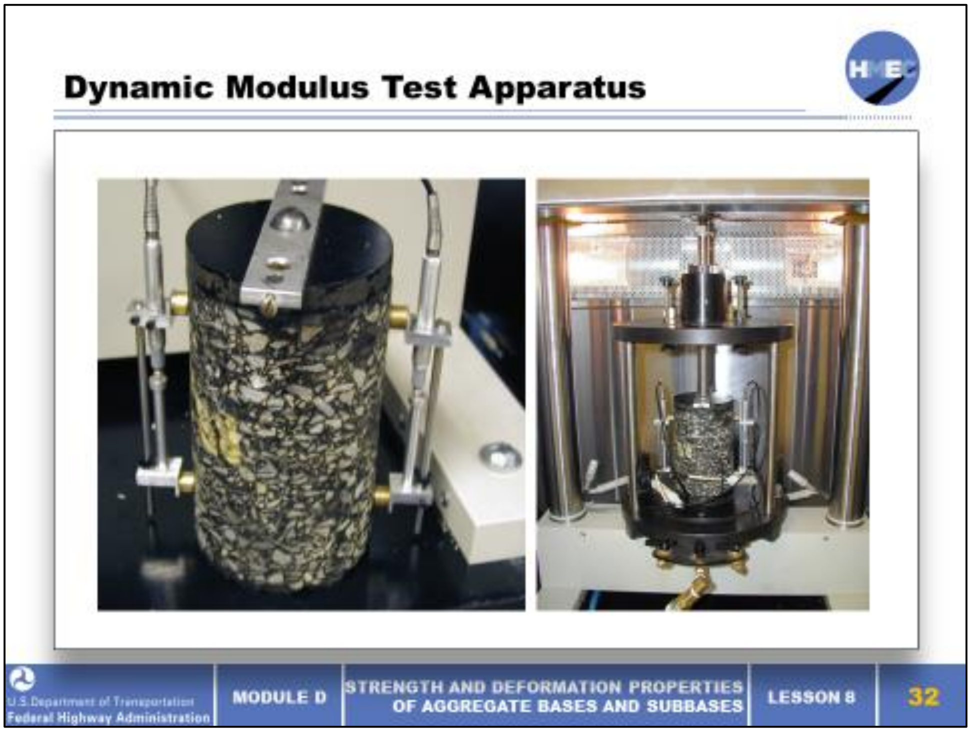
Slide 32



The dynamic modulus apparatus and sample is shown in the photo on the left. The sample is shown in the testing cell on the right.

The linear variable differential transformers are connected to the sample to measure the dynamic vertical deformation generated by the dynamic applied stress.

The instrumented sample is located inside the testing cell. The testing cell shown is triaxial; however, the use of a triaxial cell is not necessary since the test is uniaxial.

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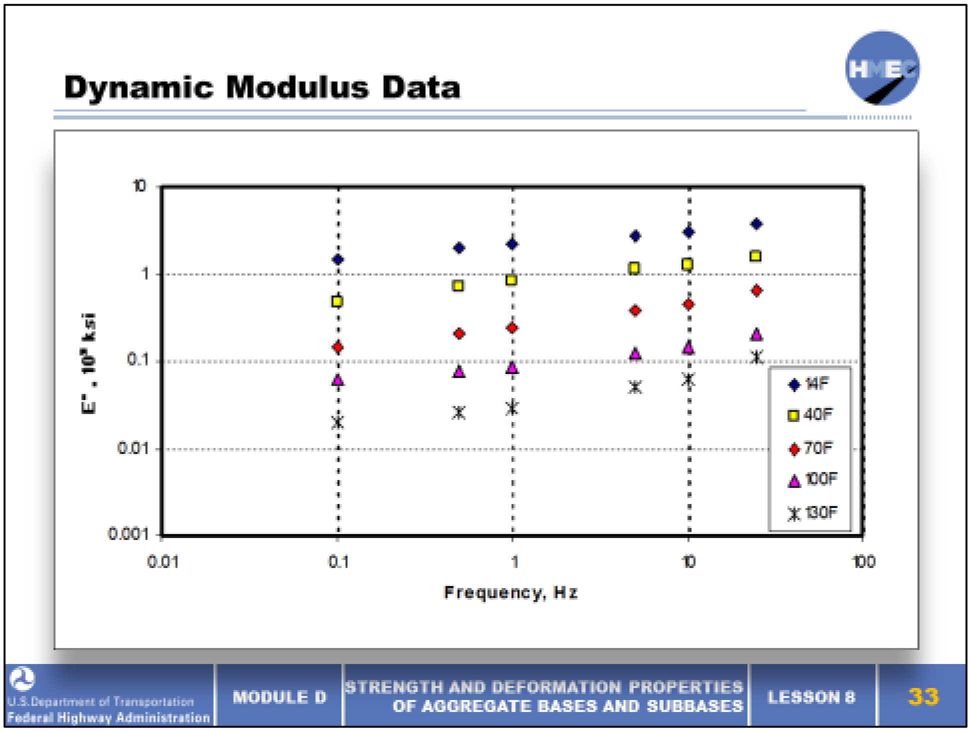
Slide 33



The figure shows typical dynamic modulus (E*) data for a specific sample. The individual points of like designation represent the dynamic modulus at various temperatures. As the temperature increases, the dynamic modulus decreases and as the loading frequency increases (i.e. loading rate decreases), the dynamic modulus increases.

This behavior is typical for visco-elastic material such as asphalt-stabilized base courses.

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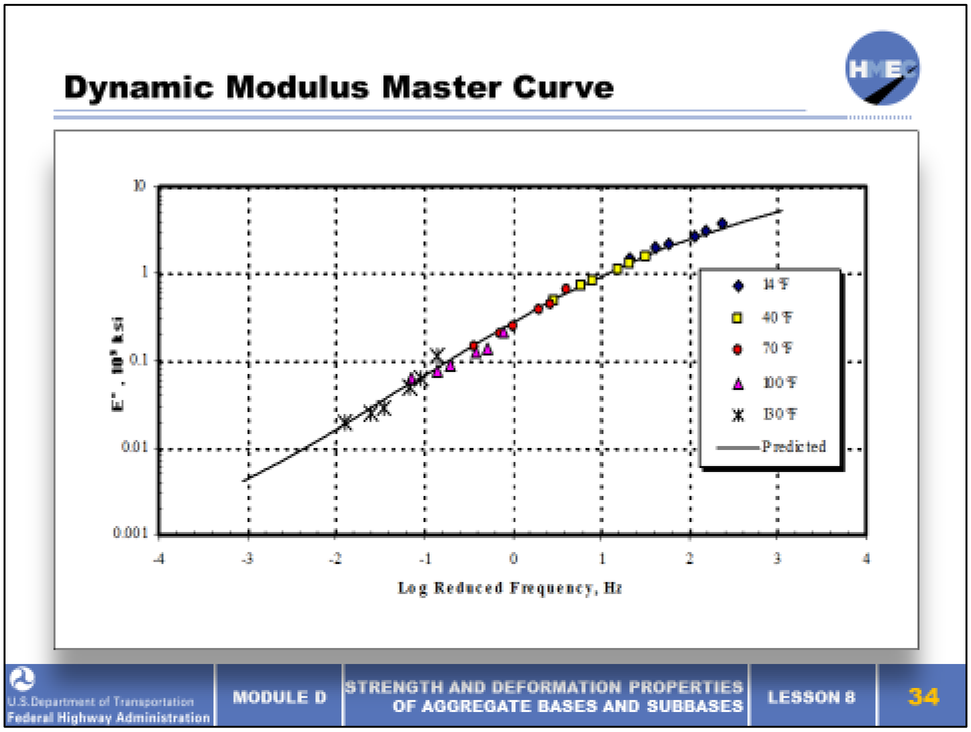
Slide 34



The dynamic modulus master curve is made up of the individual curves generated at various temperatures and shifted horizontally to produce a continuous curve. The ability to shift the individual curves to make the master curve lies in the fact that asphalt-stabilized materials are visco-elastic and their behavior under temperature and rate of loading are interchangeable.

This slide shows a dynamic modulus master curve as a function of the reduced loading frequency. The phrase “reduced loading frequency” indicates that the data has been horizontally shifted to fit the master curve.

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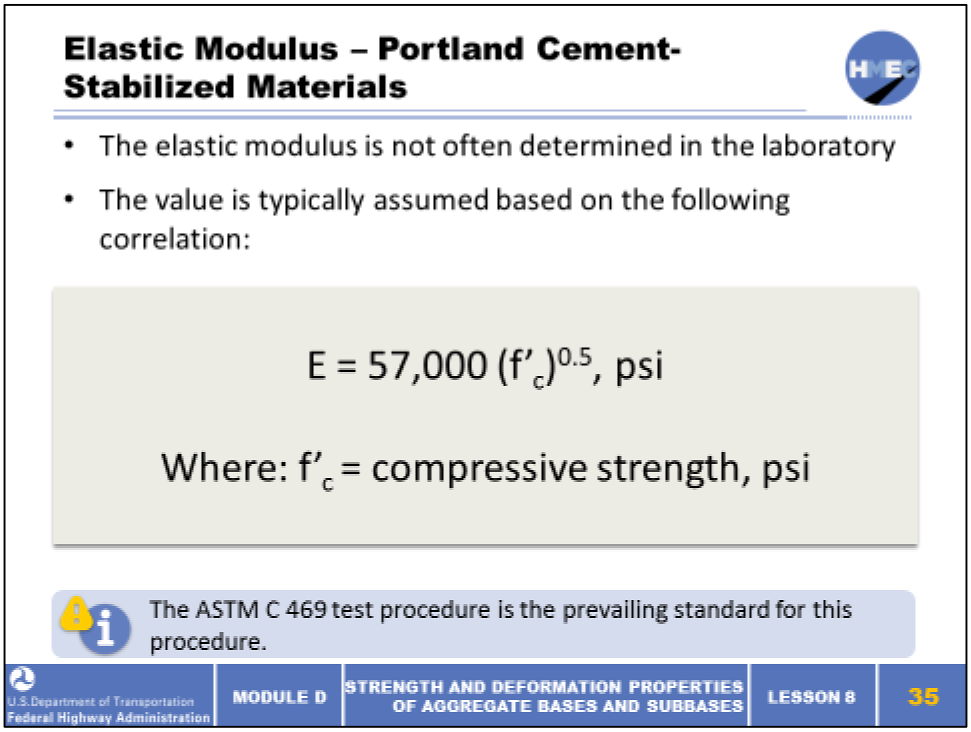
Slide 35

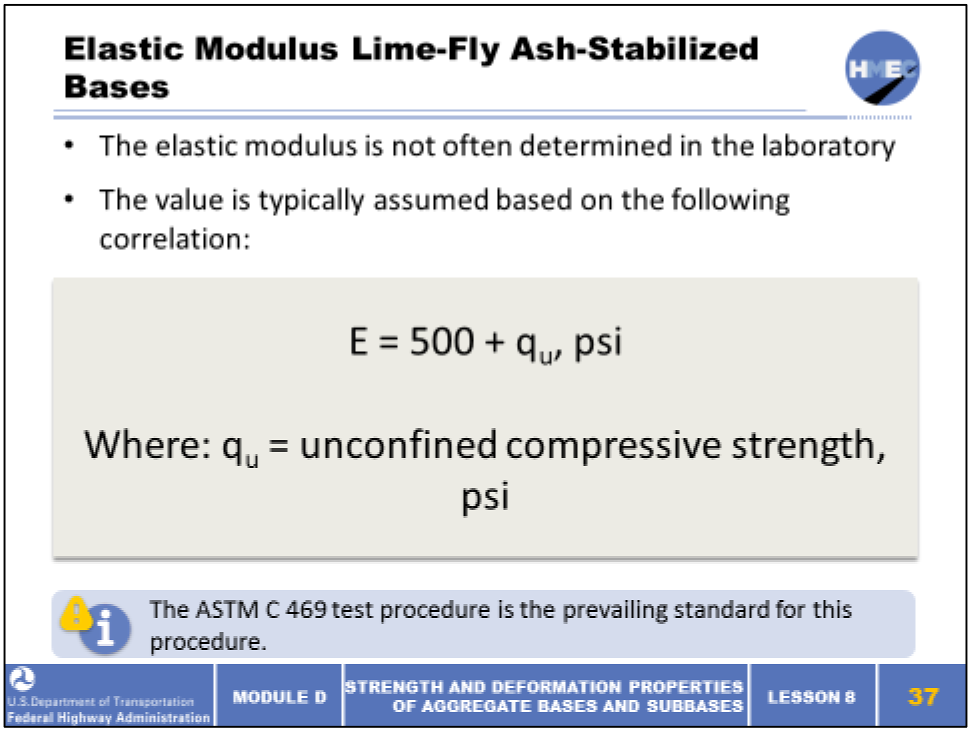


Cement-stabilized base courses behave similarly to Portland cement concrete mixtures, except that they are weaker. The elastic modulus property is used to represent the cement-stabilized base course materials. The elastic modulus can be either directly measured in the lab or estimated from the unconfined compressive strength of the material.

Slide 36

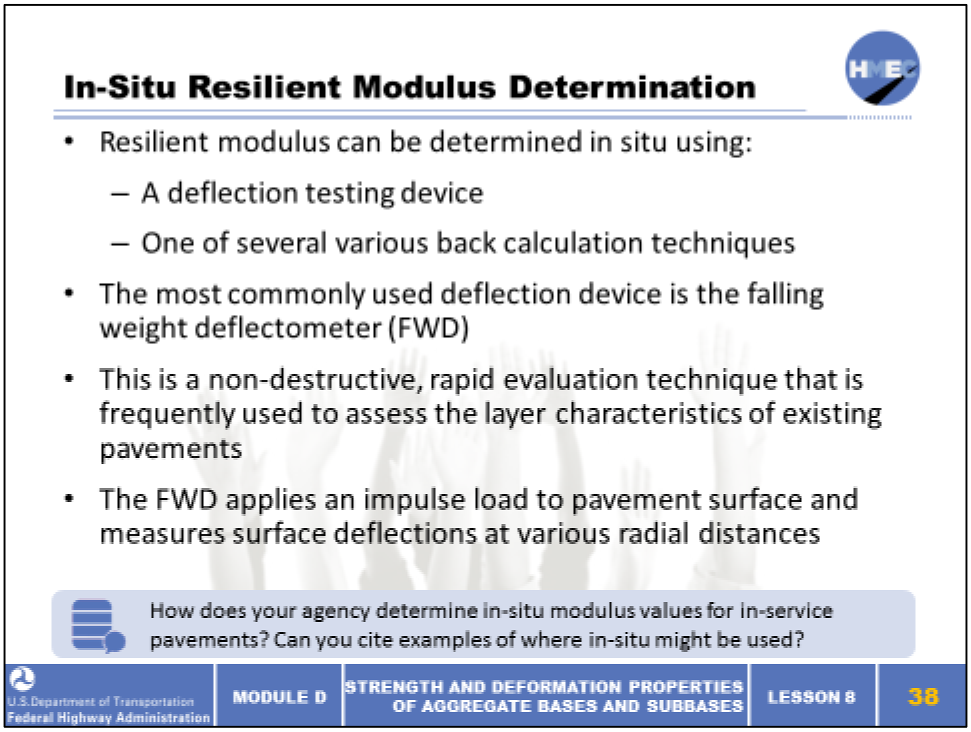
The laboratory test for determining the elastic modulus is a simple one where the vertical deformation of the sample is measured during the uniaxial compressive strength test. The elastic modulus is defined as the ratio of the compressive stress over the compressive strain measured within the linear range of the test.

Slide 37



Lime-fly ash cement-stabilized base materials are evaluated similar to the cement-stabilized materials.

Slide 38



Deflection testing is the most common non-destructive field testing technique used to evaluate the in-situ modulus of the pavement layers. The technique measures the surface deflection response of the pavement as it is subjected to surface loading. The load level is selected to represent the actual axle load and therefore will not damage the pavement.

Slide 39

The falling weight deflectometer is the most commonly used deflection device to evaluate pavements. Variations of these devices can be used to test everything from gravel surfaced roads to airfield pavements. The photo shows a heavyweight deflectometer evaluating an airfield's thick pavement. Through the use of back calculation techniques, the modulus of the support layers can be estimated.

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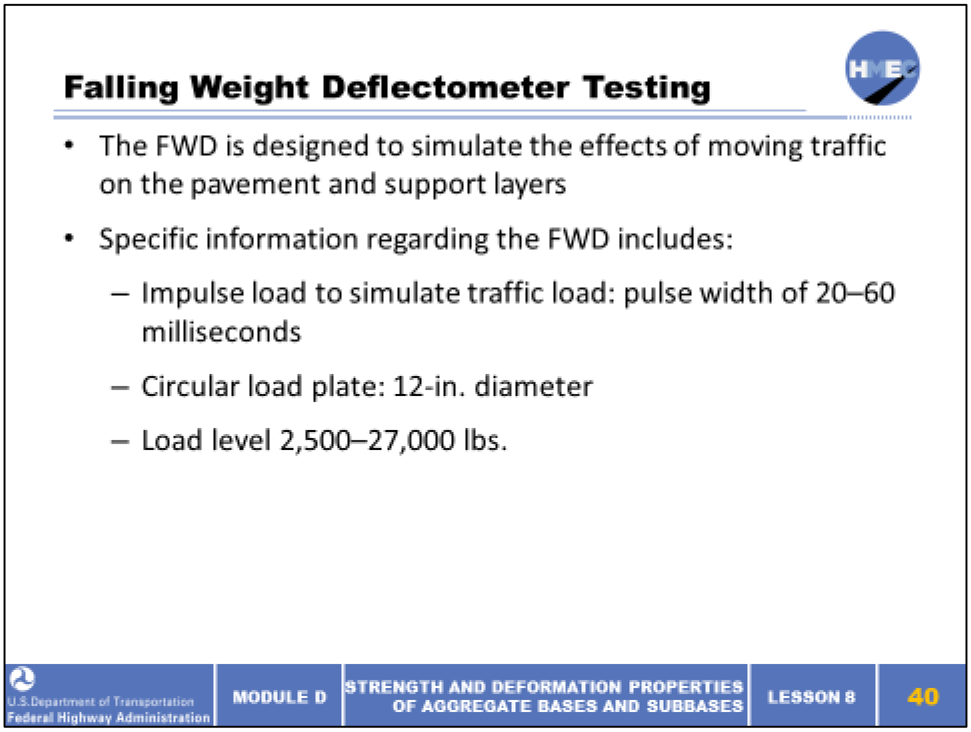
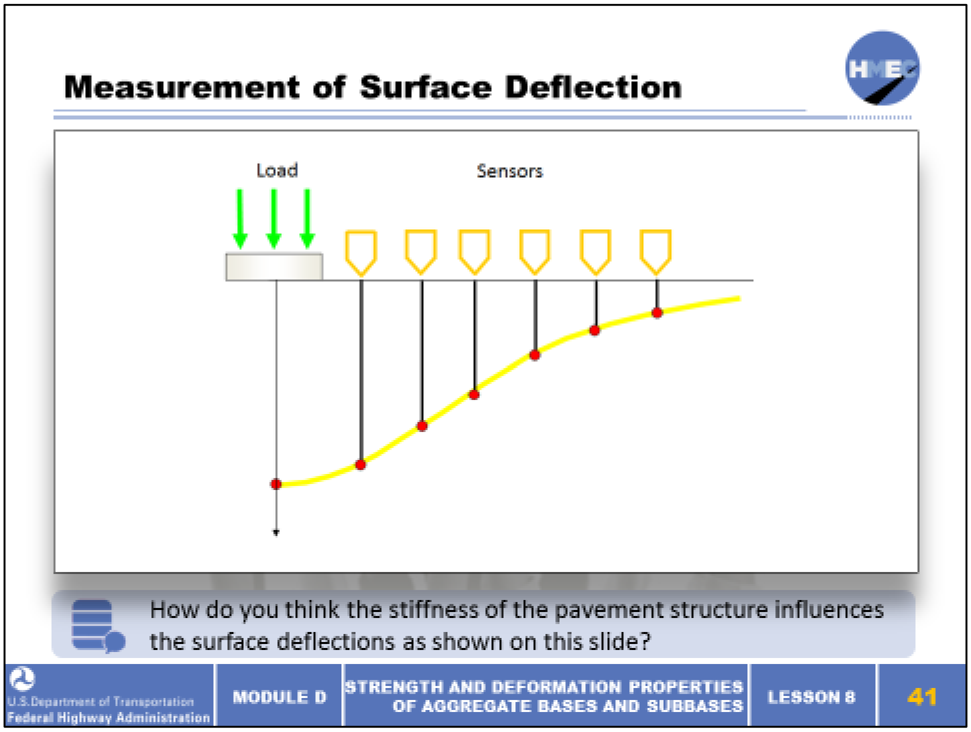
Slide 40



The FWD delivers an impulse load to the pavement surface and measures the resulting surface deflections at various locations. The pulse duration is adjusted to closely simulate the loads imparted by traffic loads. The FWD tests one side of the pavement, therefore, its load magnitude is selected the represent half of the design axle. For example, if an agency uses a 22,000 lb. single axle for design, the FWD load should be adjusted to 11,000 lbs.

Slide 41



Surface deflections are typically measured using seismic style geophones or accelerometers spaced at select intervals starting from the load plate (r = 0) on out to 2 m (6.6 ft.) (r = 200 mm [8 in.]). Depending on the type of non-destructive testing (NDT) device, deflections can be measured with loads ranging from 4 to 14 kN (1,000 to 60,000 lbs.).

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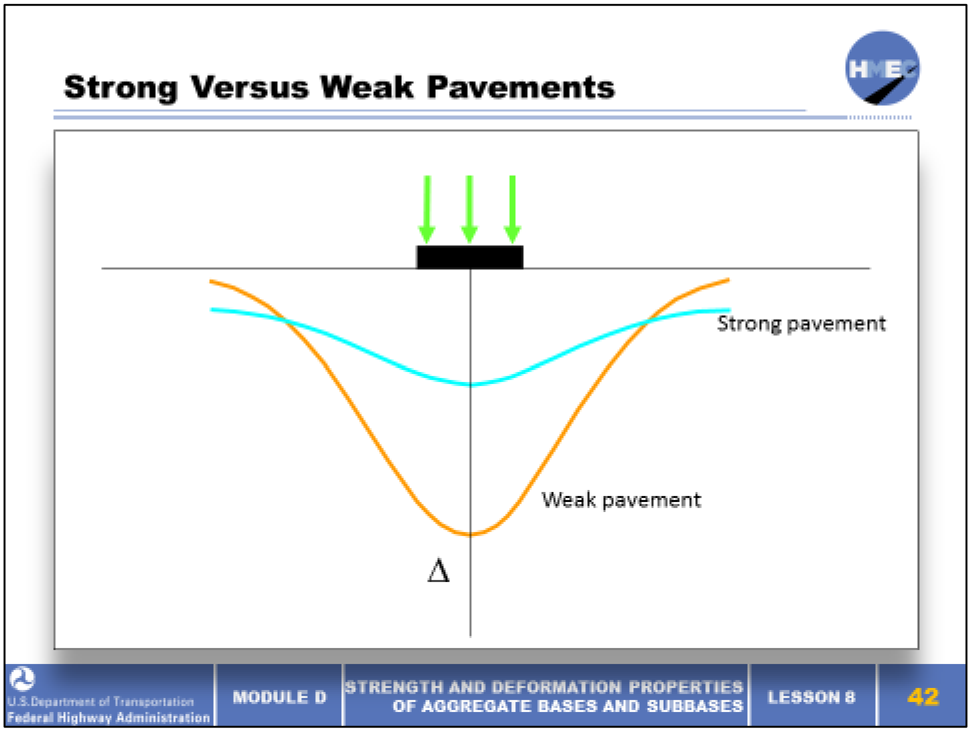
Slide 42



This diagram illustrates the basic relationship between a pavement's structural capacity and pavement surface deflection. Obviously, weak pavements exhibit greater deflection beneath the load than strong pavements.

In many cases, however, the surface deflection at distances away from the load (greater than 1 m [3.28 ft.]) is greater for the strong pavement. This is indicative of the ability of the strong pavement to distribute the load. However, it is also indicative of a weak subgrade soil beneath the strong pavement.

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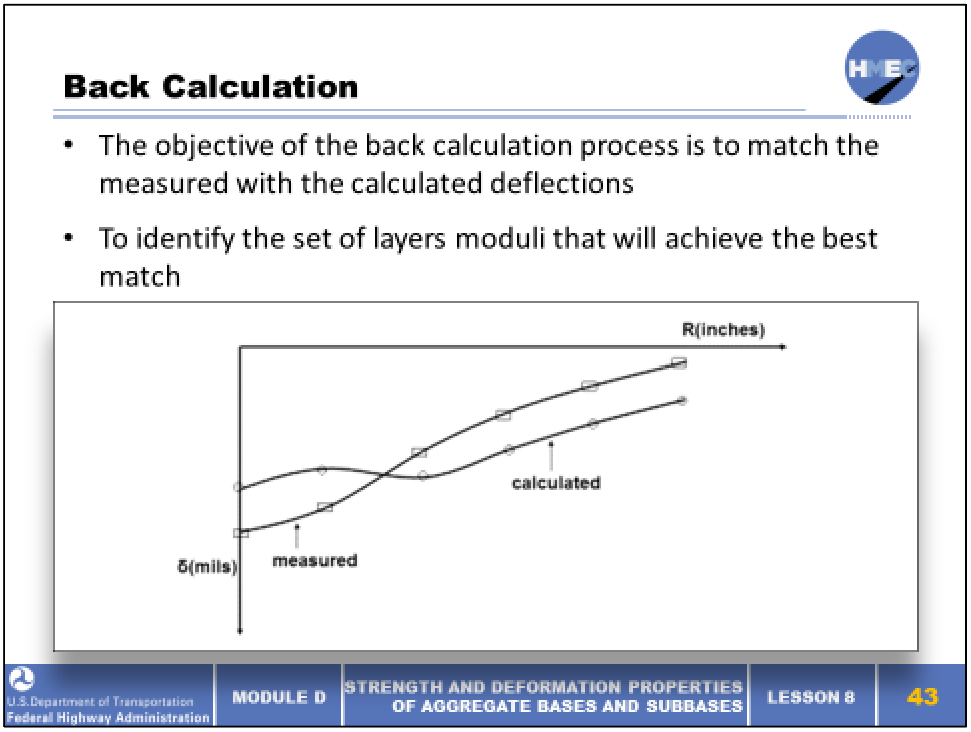
Slide 43



The FWD load and layer thickness are used as inputs to the structural model. Initial estimates for the layers moduli are also used as an input and the surface deflections are generated at the radial distances similar to the ones used in the FWD test. This process generates a calculated deflection basin.

Initial estimates of the layer's moduli are adjusted in order to minimize the differences between the measured and calculated deflection basins.

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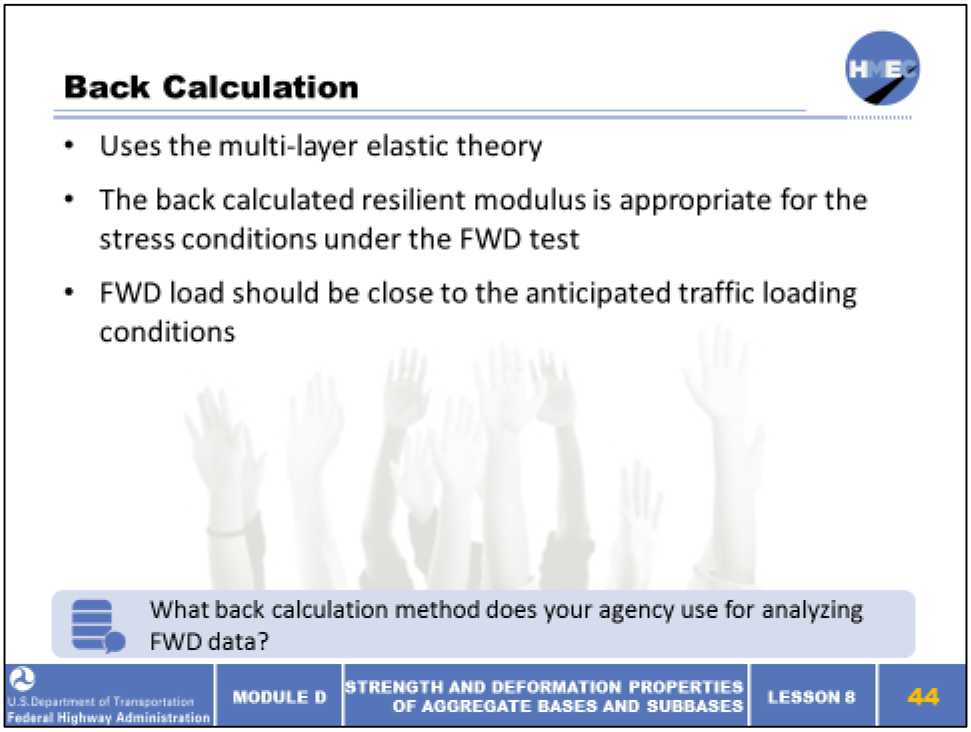
Slide 44

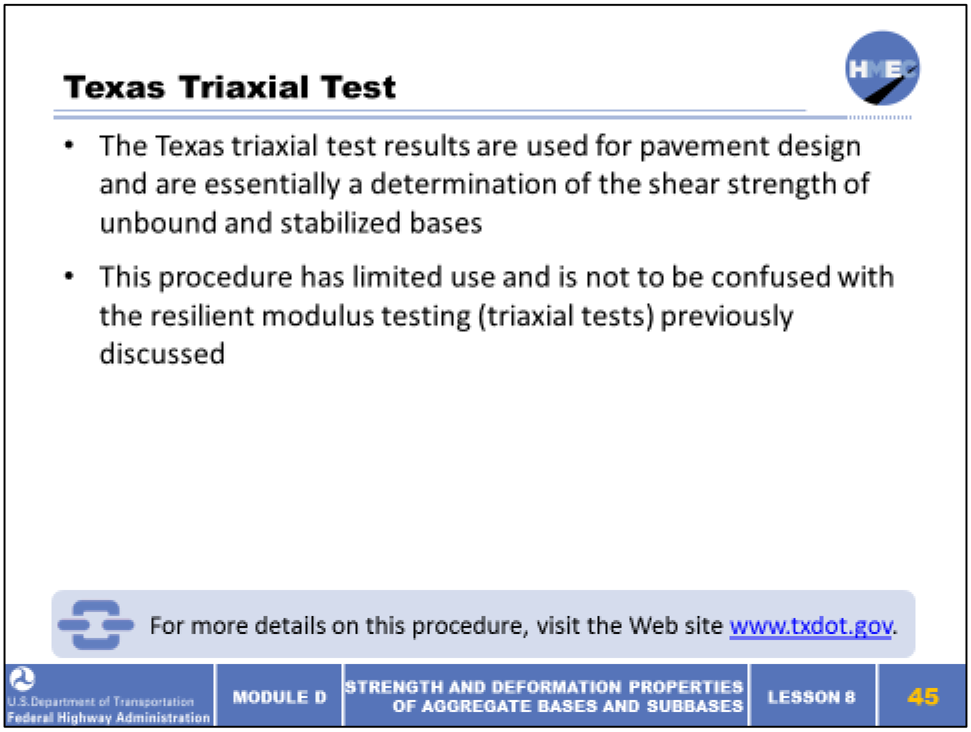


The multi-layer elastic theory is used to model the pavement structure. The pavement is idealized as a multi-layer elastic system and a set of layers moduli is identified that generates a calculated deflection basin that is close to the deflection basin produced during the FWD test.

It should be noted that the final set of the back calculated moduli is not a unique one but they represent the best estimates for the given pavement structure.

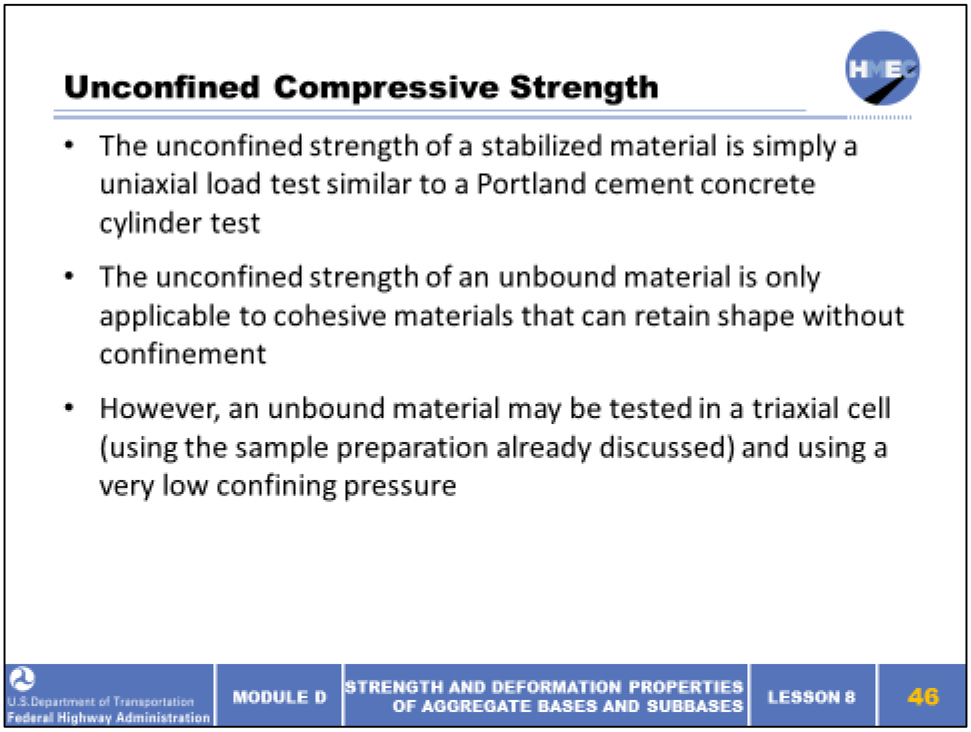
In addition, the use of the multi-layer elastic theory leads to a constant modulus for each layer. Therefore, a special attention should be paid to ensure that the FWD load is close to the design load.

Slide 45



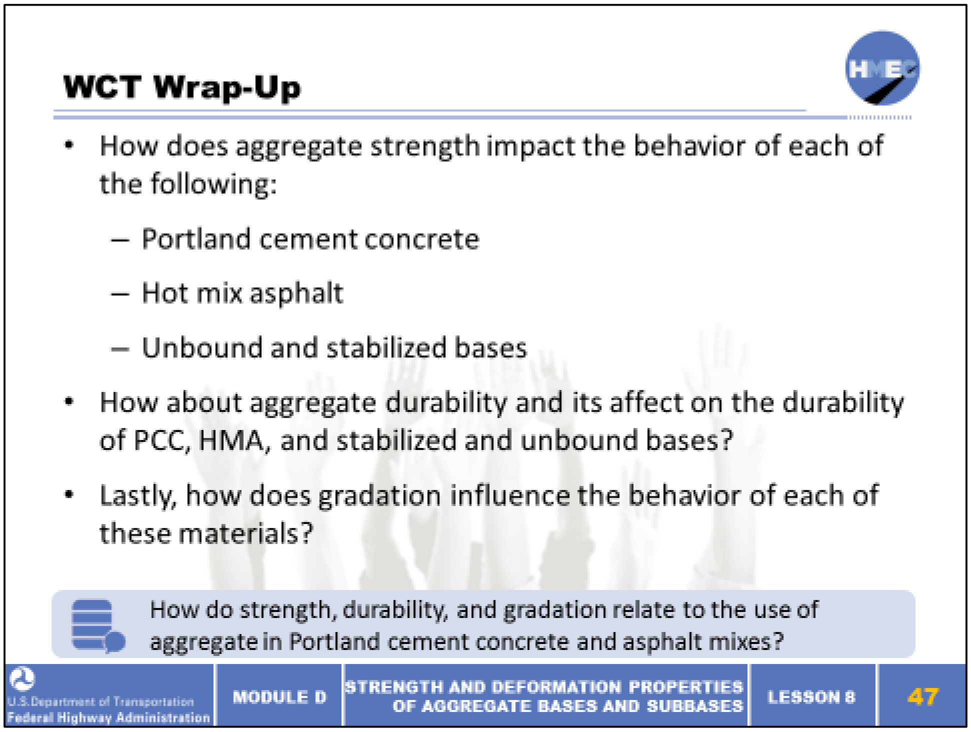
This test procedure is used to provide input to a Texas pavement design procedure.

Slide 46



The unconfined compressive strength of stabilized base materials, primarily Portland cement and lime-fly ash-stabilized bases is a commonly specified quality assurance parameter. The target strengths are dependent on the pavement design assumptions.

Slide 47


WCT Wrap-Up
HMEC
• How does aggregate strength impact the behavior of each of the following:
– Portland cement concrete
– Hot mix asphalt
– Unbound and stabilized bases
• How about aggregate durability and its affect on the durability of PCC, HMA, and stabilized and unbound bases?
• Lastly, how does gradation influence the behavior of each of these materials?
How do strength, durability, and gradation relate to the use of aggregate in Portland cement concrete and asphalt mixes?
U.S. Department of Transportation
Federal Highway Administration
MODULE D
STRENGTH AND DEFORMATION PROPERTIES OF AGGREGATE BASES AND SUBBASES
LESSON 8
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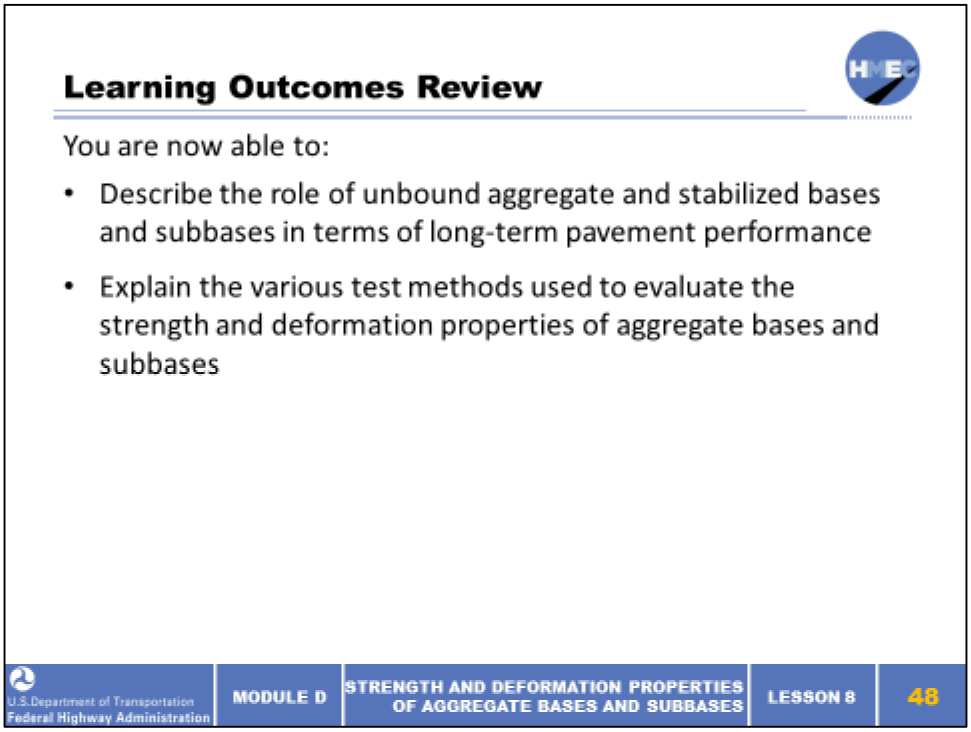
Slide 48


Learning Outcomes Review
You are now able to:
• Describe the role of unbound aggregate and stabilized bases and subbases in terms of long-term pavement performance
• Explain the various test methods used to evaluate the strength and deformation properties of aggregate bases and subbases
U.S. Department of Transportation
Federal Highway Administration
MODULE D
STRENGTH AND DEFORMATION PROPERTIES OF AGGREGATE BASES AND SUBBASES
LESSON 8
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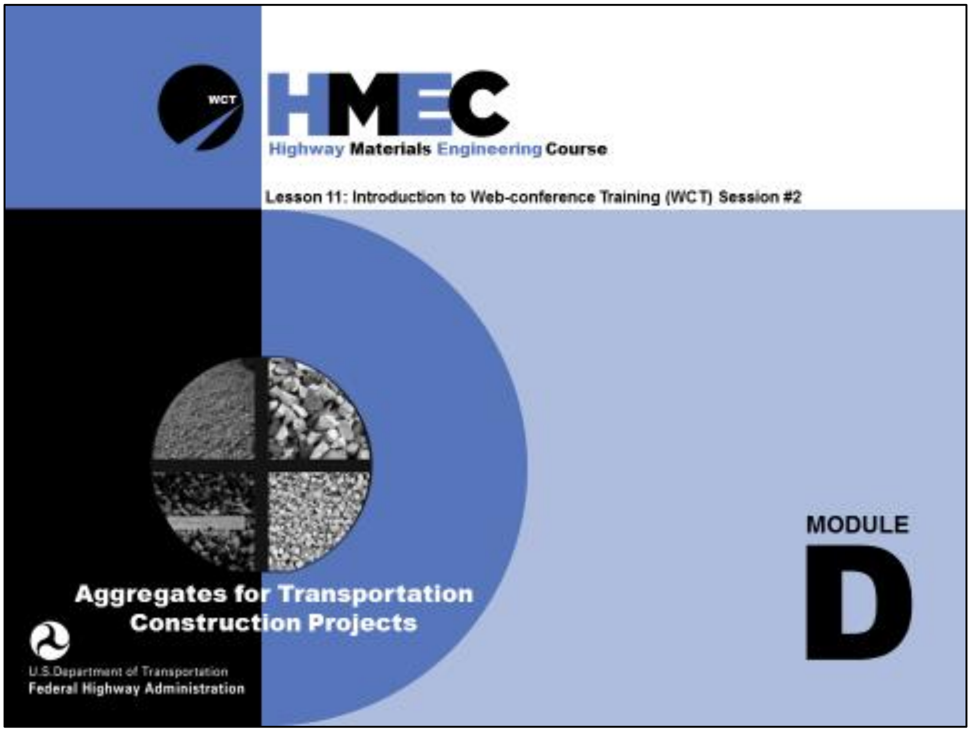
WCT
HMEC
Highway Materials Engineering Course
Lesson 11: Introduction to Web-conference Training (WCT) Session #2
Aggregates for Transportation Construction Projects
U.S.Department of Transportation
Federal Highway Administration
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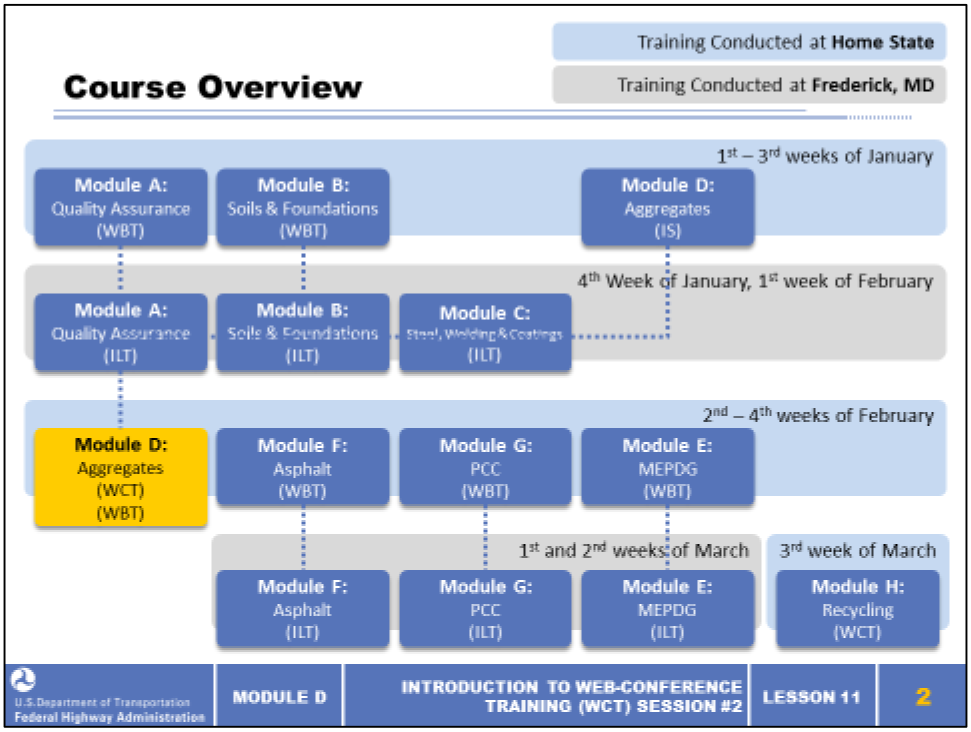
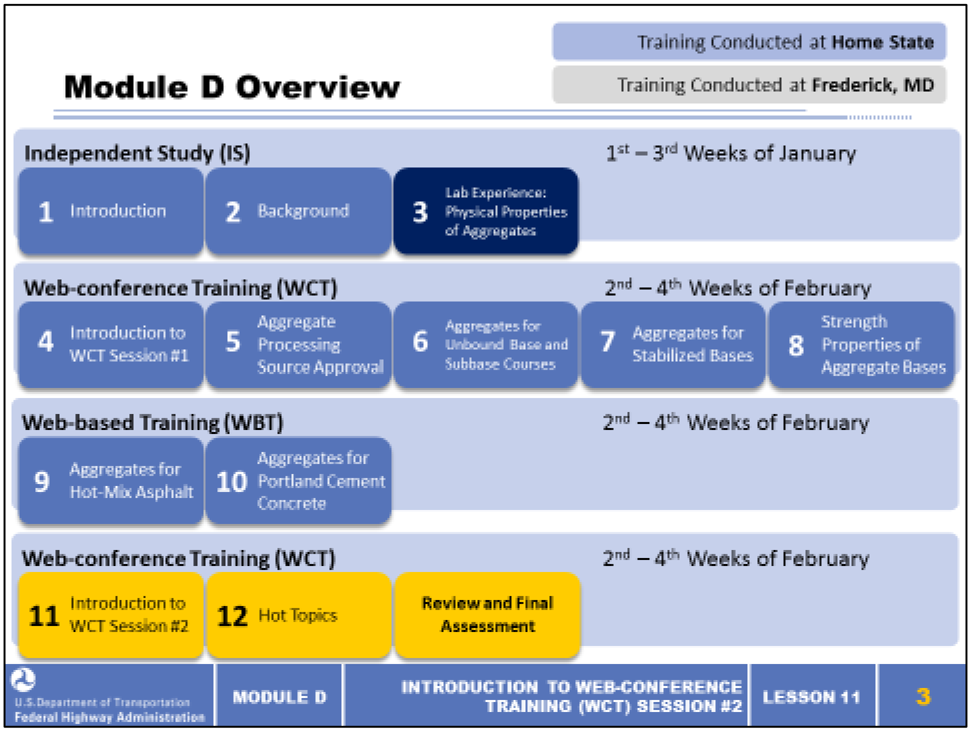
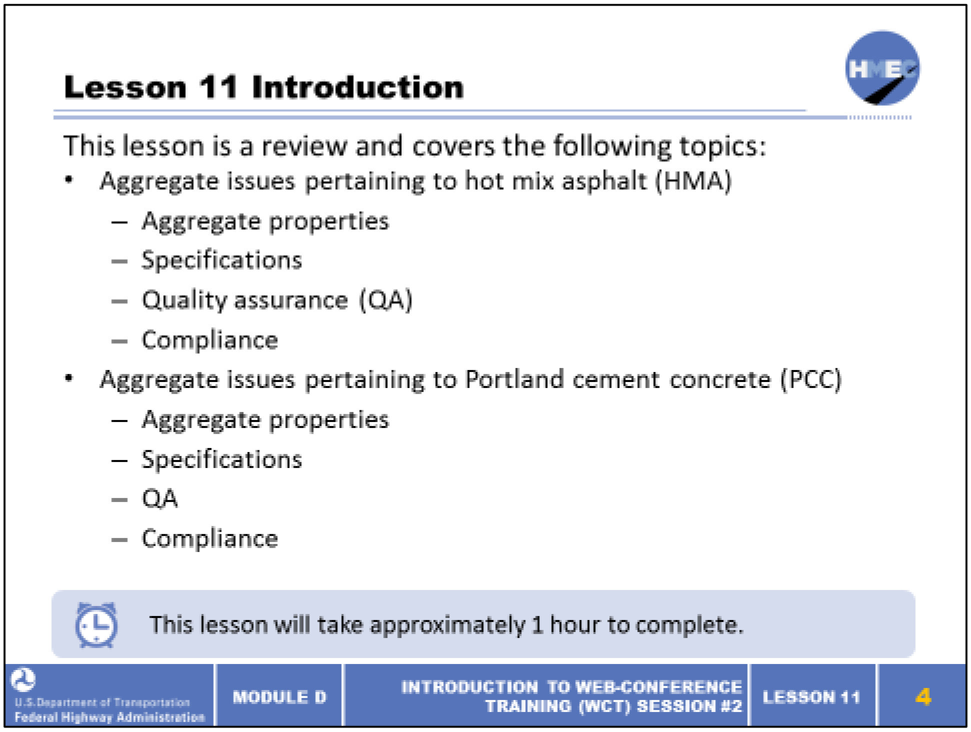

Training Conducted at Home State
Training Conducted at Frederick, MD
Course Overview
1st – 3rd weeks of January
Module A: Quality Assurance (WBT)
Module B: Soils & Foundations (WBT)
Module D: Aggregates (IS)
4th Week of January, 1st week of February
Module A: Quality Assurance (ILT)
Module B: Soils & Foundations (ILT)
Module C: Steel, Welding & Coatings (ILT)
2nd – 4th weeks of February
Module D: Aggregates (WCT) (WBT)
Module F: Asphalt (WBT)
Module G: PCC (WBT)
Module E: MEPDG (WBT)
1st and 2nd weeks of March
3rd week of March
Module F: Asphalt (ILT)
Module G: PCC (ILT)
Module E: MEPDG (ILT)
Module H: Recycling (WCT)
U.S. Department of Transportation Federal Highway Administration
MODULE D
INTRODUCTION TO WEB-CONFERENCE TRAINING (WCT) SESSION #2
LESSON 11
2

Slide 3


Training Conducted at Home State
Training Conducted at Frederick, MD
Module D Overview
Independent Study (IS)
1st – 3rd Weeks of January
1 Introduction
2 Background
3 Lab Experience: Physical Properties of Aggregates
Web-conference Training (WCT)
2nd – 4th Weeks of February
4 Introduction to WCT Session #1
5 Aggregate Processing Source Approval
6 Aggregates for Unbound Base and Subbase Courses
7 Aggregates for Stabilized Bases
8 Strength Properties of Aggregate Bases
Web-based Training (WBT)
2nd – 4th Weeks of February
9 Aggregates for Hot-Mix Asphalt
10 Aggregates for Portland Cement Concrete
Web-conference Training (WCT)
2nd – 4th Weeks of February
11 Introduction to WCT Session #2
12 Hot Topics
Review and Final Assessment
U.S. Department of Transportation
Federal Highway Administration
MODULE D
INTRODUCTION TO WEB-CONFERENCE TRAINING (WCT) SESSION #2
LESSON 11
3

Slide 4


Lesson 11 Introduction
HMEC
This lesson is a review and covers the following topics:
• Aggregate issues pertaining to hot mix asphalt (HMA)
– Aggregate properties
– Specifications
– Quality assurance (QA)
– Compliance
• Aggregate issues pertaining to Portland cement concrete (PCC)
– Aggregate properties
– Specifications
– QA
– Compliance
This lesson will take approximately 1 hour to complete.
U.S. Department of Transportation
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MODULE D
INTRODUCTION TO WEB-CONFERENCE TRAINING (WCT) SESSION #2
LESSON 11
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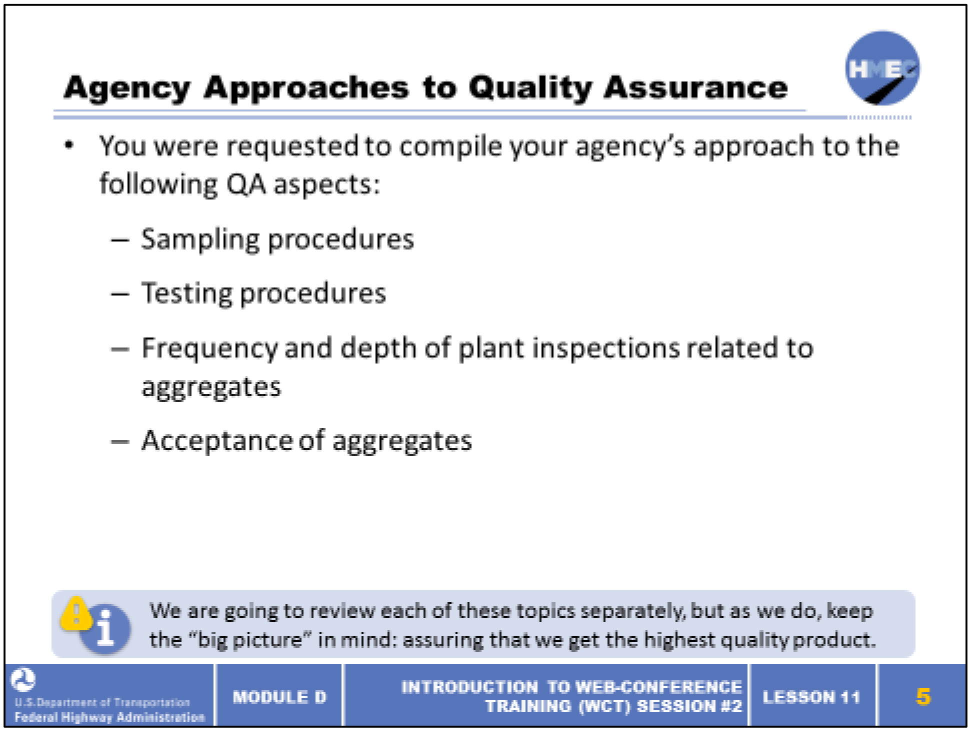
Slide 5


Agency Approaches to Quality Assurance
HMEC
You were requested to compile your agency's approach to the following QA aspects:
Sampling procedures
Testing procedures
Frequency and depth of plant inspections related to aggregates
Acceptance of aggregates
We are going to review each of these topics separately, but as we do, keep the "big picture" in mind: assuring that we get the highest quality product.
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INTRODUCTION TO WEB-CONFERENCE TRAINING (WCT) SESSION #2
LESSON 11
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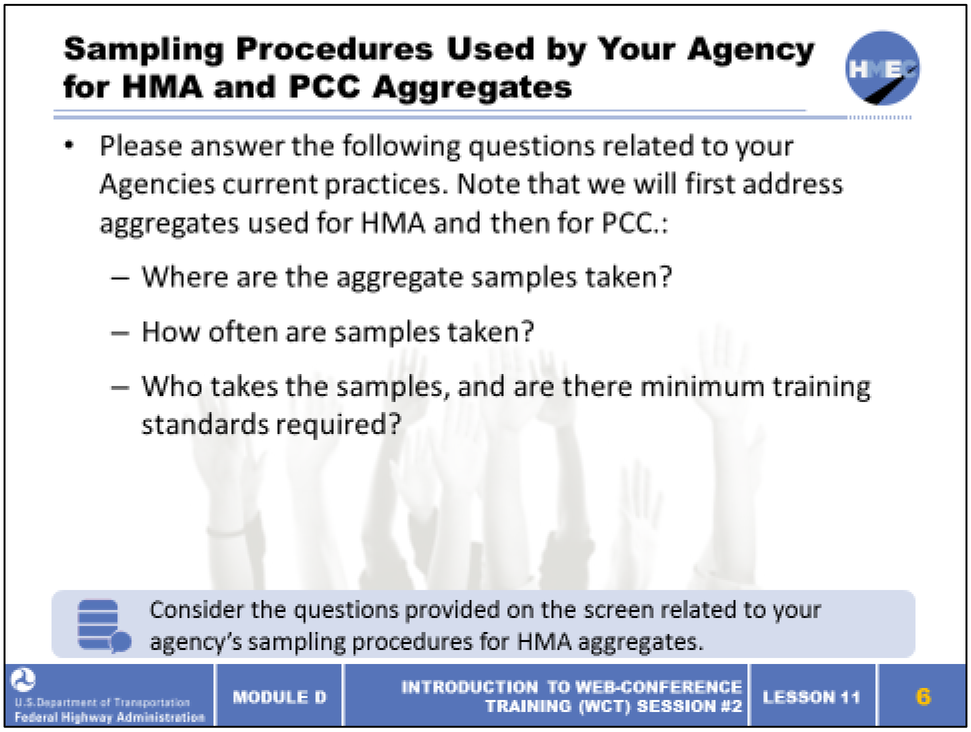
Slide 6


Sampling Procedures Used by Your Agency for HMA and PCC Aggregates
HMEC
• Please answer the following questions related to your Agencies current practices. Note that we will first address aggregates used for HMA and then for PCC.:
– Where are the aggregate samples taken?
– How often are samples taken?
– Who takes the samples, and are there minimum training standards required?
Consider the questions provided on the screen related to your agency's sampling procedures for HMA aggregates.
U.S.Department of Transportation
Federal Highway Administration
MODULE D
INTRODUCTION TO WEB-CONFERENCE TRAINING (WCT) SESSION #2
LESSON 11
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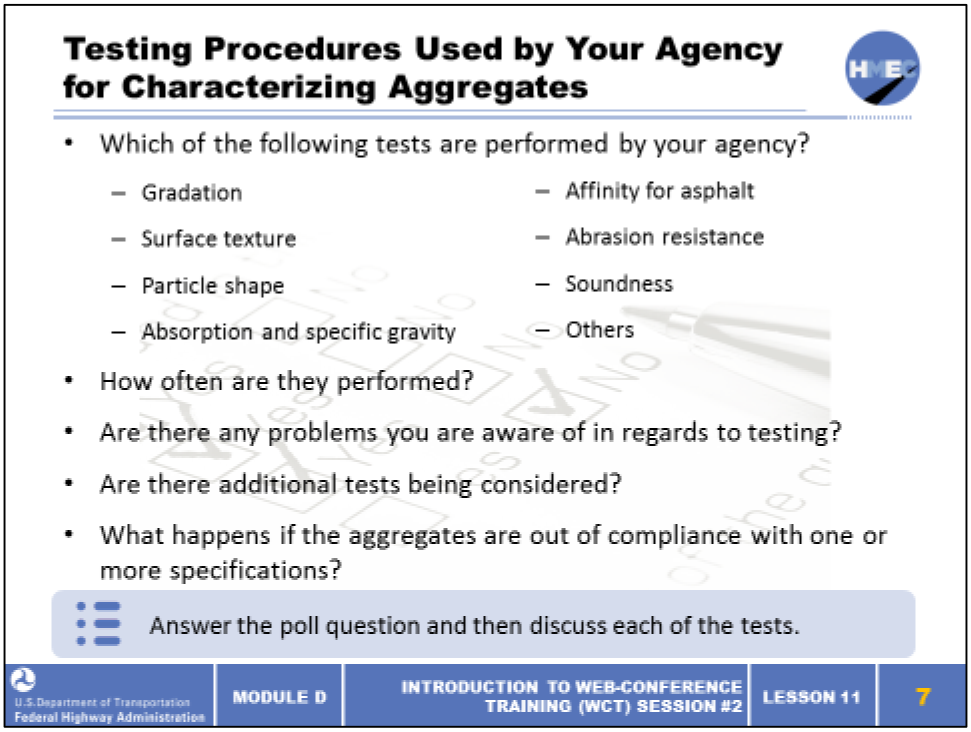
Slide 7


Testing Procedures Used by Your Agency for Characterizing Aggregates
HMEC
Which of the following tests are performed by your agency?
Gradation
Surface texture
Particle shape
Absorption and specific gravity
Affinity for asphalt
Abrasion resistance
Soundness
Others
How often are they performed?
Are there any problems you are aware of in regards to testing?
Are there additional tests being considered?
What happens if the aggregates are out of compliance with one or more specifications?
Answer the poll question and then discuss each of the tests.
U.S.Department of Transportation
Federal Highway Administration
MODULE D
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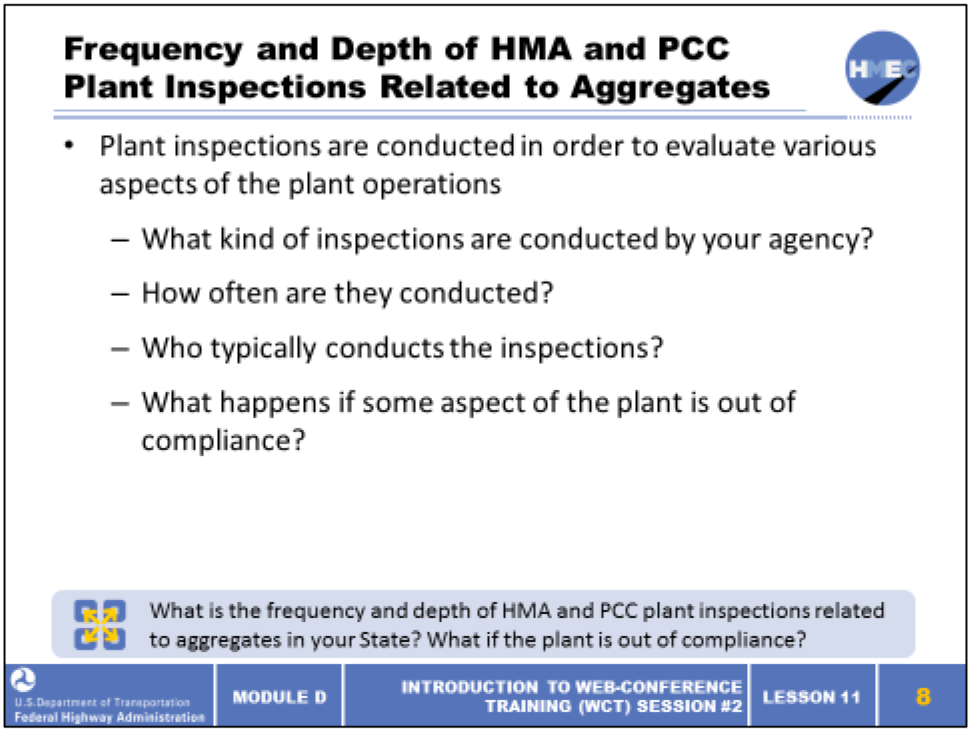
Frequency and Depth of HMA and PCC Plant Inspections Related to Aggregates
HMEC
• Plant inspections are conducted in order to evaluate various aspects of the plant operations
– What kind of inspections are conducted by your agency?
– How often are they conducted?
– Who typically conducts the inspections?
– What happens if some aspect of the plant is out of compliance?
What is the frequency and depth of HMA and PCC plant inspections related to aggregates in your State? What if the plant is out of compliance?
U.S. Department of Transportation Federal Highway Administration
MODULE D
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LESSON 11
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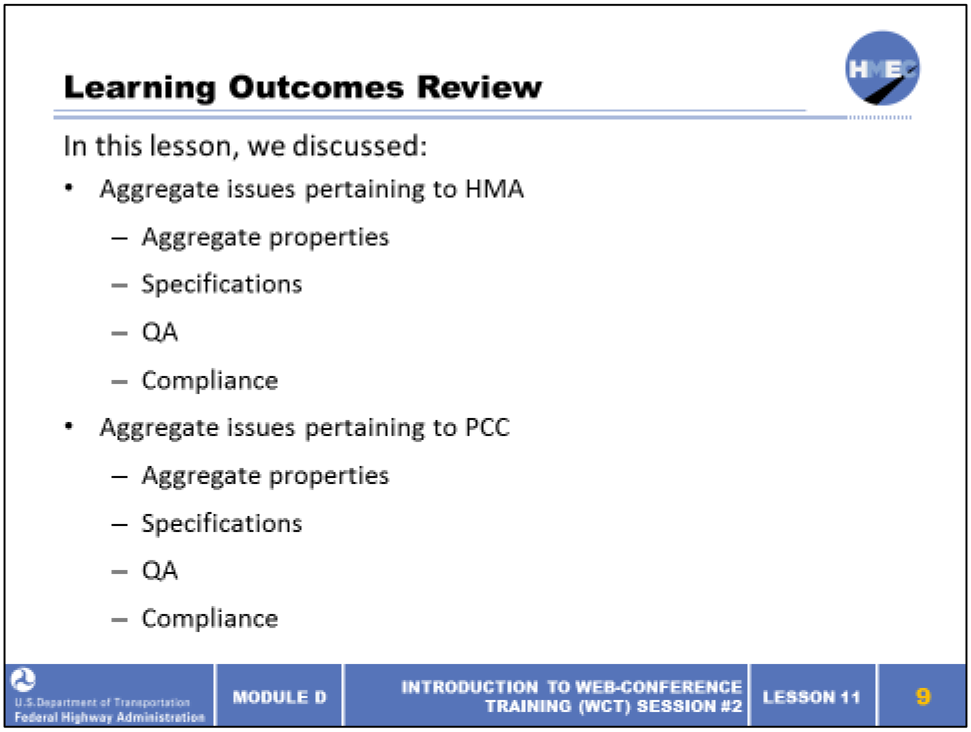
Slide 9


Learning Outcomes Review
In this lesson, we discussed:
• Aggregate issues pertaining to HMA
– Aggregate properties
– Specifications
– QA
– Compliance
• Aggregate issues pertaining to PCC
– Aggregate properties
– Specifications
– QA
– Compliance
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INTRODUCTION TO WEB-CONFERENCE TRAINING (WCT) SESSION #2
LESSON 11
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WCT
HMEC
Highway Materials Engineering Course
Lesson 12: Hot Topics
Aggregates for Transportation Construction Projects
U.S.Department of Transportation
Federal Highway Administration
MODULE
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Appendix A: Acronyms

The following are acronyms referenced throughout the course that are important agencies or organizations:

Acronym	Proper Name
AASHTO	American Association of State Highway and Transportation
ACAA	American Coal Ash Association
ACI	American Concrete Institute
ACPA	American Concrete Paving Association
AI	Asphalt Institute
ASTM	American Society for Testing and Materials
AWS	American Welding Society
CFR	Code of Federal Regulations
DOT	U.S. Department of Transportation
EPA	Environmental Protection Agency
FHWA	Federal Highway Administration
NACE	National Association of Corrosion Engineers
NAPA	National Asphalt Pavement Association
NCAT	National Center for Asphalt Technology
NCHRP	National Cooperative Highway Research Program
NEPCOAT	North East Protective Coating
NHI	National Highway Institute
NRC	National Recycling Coalition
NRMCA	National Ready Mixed Concrete Association
NSA	National Slag Association
NSBA	National Steel Bridge Alliance

Acronym	Proper Name
NTPEP	National Transportation Product Evaluation Program
OSHA	Occupational Safety and Health Administration
RCSC	Research Council on Structural Connections
SSPC	Society for Protective Coatings
TRB	Transportation Research Board
USGS	U.S. Geological Survey

Appendix B: Resources

Additional information regarding Module D can be found in the following sources.

Rock and Mineral Identification for Engineers (FHWA publication)

https://www.fhwa.dot.gov/pavement/pccp/fhwahi91205.pdf

Aggregate Handbook, NSSGA (National Stone, Sand, and Gravel Association); available in a 2nd edition

http://www.nssga.org/

Ohio Aggregate and Industrial Minerals Association and FHWA joint publication – How to prevent stockpile segregation video

The proper stockpile management and loading procedures are one of the most critical parts of the overall highway construction process. Improper loading and sampling are the most common causes of segregated materials and are also the most easily corrected. http://www.fhwa.dot.gov/pavement/materials/video.cfm

Aggregate Imaging System

The Aggregate Imaging System combines hardware that captures real-time digital images of paving material samples, and software that analyzes shape, texture, and ratio characteristics of aggregates, such as hot mix asphalt and hydraulic cement concrete, to improve the speed and accuracy of testing. (Site contains reports, videos, presentations, and articles.) http://www.fhwa.dot.gov/hfl/partnerships/aims.cfm

NCHRP Report 453

http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp_rpt_453.pdf

NCHRP Report 539

http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp_rpt_539.pdf

NCHRP Report 557

http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp_rpt_557.pdf

NCHRP Report 555

http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp_rpt_555.pdf

NCHRP Report 405

http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp_rpt_405.pdf

AASHTO and ASTM Standards

ASTM D-2166

ASTM C-295 (Petrographic Analysis) ASTM C-294 (Definitions)