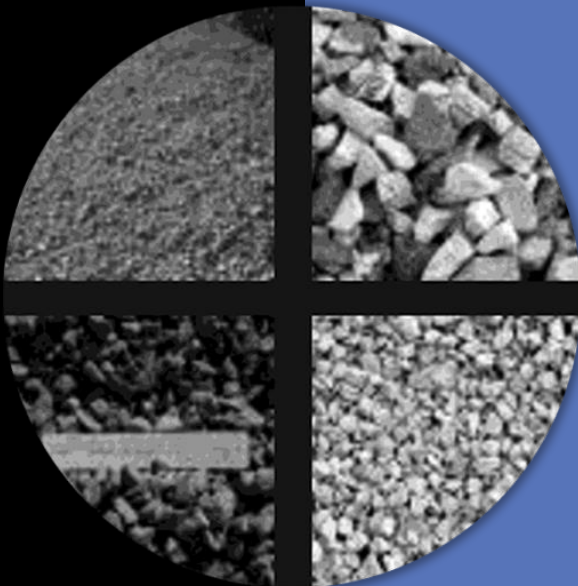




# HMEC

**Highway Materials Engineering Course**

**PARTICIPANT WORKBOOK**



## **Aggregates for Transportation Construction Projects**



U.S. Department of Transportation  
**Federal Highway Administration**

**MODULE**

# **D**



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## **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:

### Independent Study (IS)

- 1** Introduction to Aggregates
- 2** Aggregates Background
- 3** Lab Experience: Physical Properties of Aggregates

### Web-conference Training (WCT)

- 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)

- 9** Aggregates for Hot-Mix Asphalt
- 10** Aggregates for Portland Cement Concrete

### Web-conference Training (WCT)

- 11** Introduction to WCT Session #2
- 12** Hot Topics
- Review and Final Assessment

## 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:

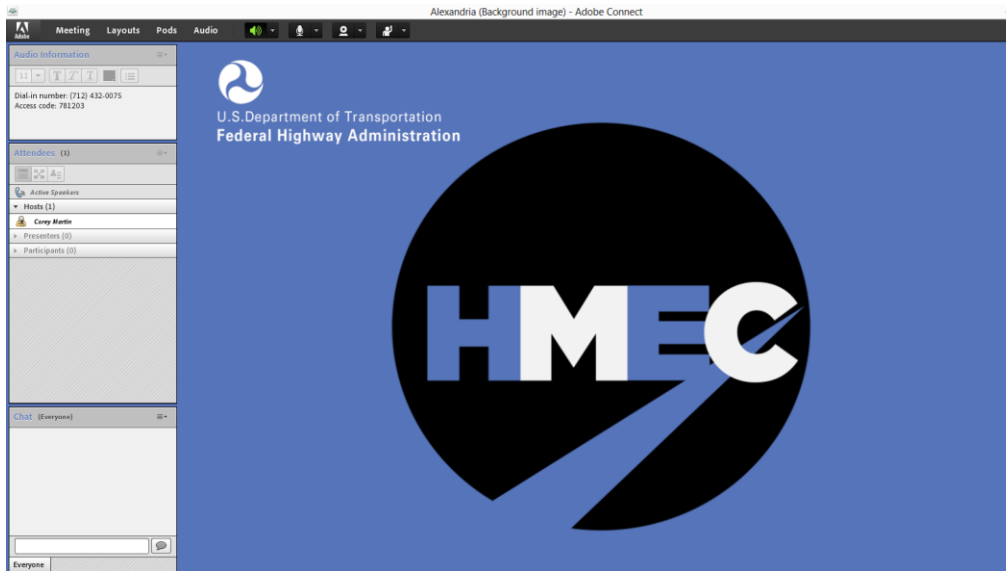


Figure 1: Welcome Layout Screen Shot with Various Pods

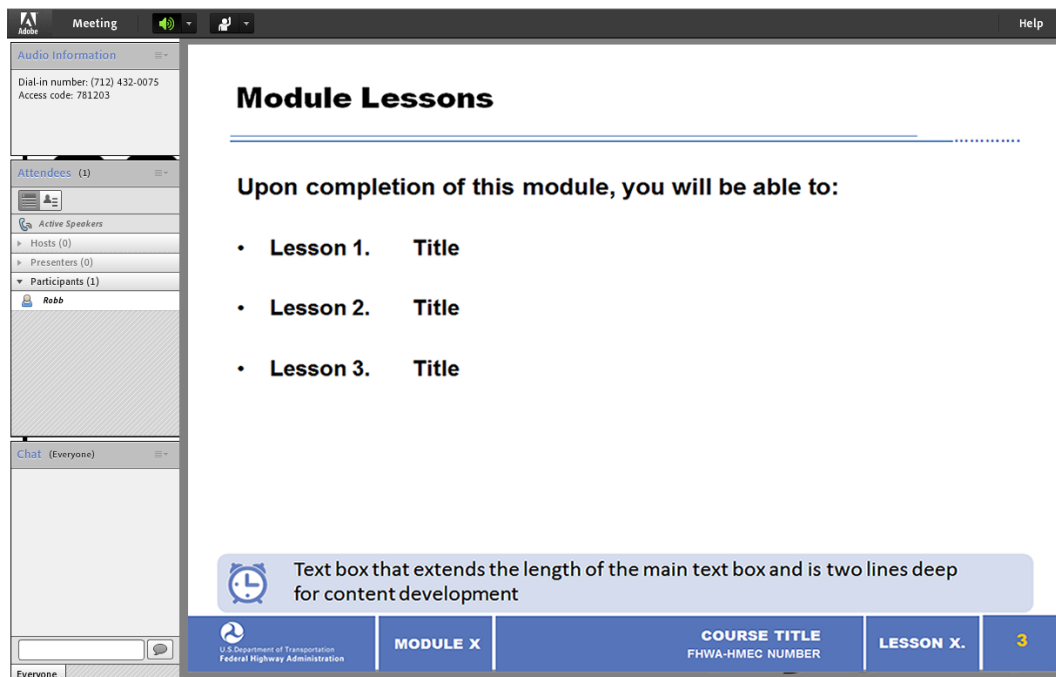












Figure 2: Adobe Connect Presentation Layout

## 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	<ul style="list-style-type: none"> <li>Call out the estimated time for the lesson</li> </ul>
	Chat Pod	<ul style="list-style-type: none"> <li>Ask and answer open-ended question(s).</li> <li>Post hyperlinks to Web sites.</li> <li>Provide further information to select attendees.</li> <li>Encourage attendees to share ideas with each other.</li> <li>Email contents of the pod.</li> </ul>
	Note Pod	<ul style="list-style-type: none"> <li>Capture discussion points.</li> <li>Provide a way for small groups to document their results.</li> <li>Email contents of the pod.</li> </ul>
	Whiteboard Tool	<ul style="list-style-type: none"> <li>Edit illustrations, such as diagrams, charts, documents, maps, and photographs.</li> <li>Record participant responses.</li> <li>Create visual examples.</li> </ul>
	Poll Pod	<ul style="list-style-type: none"> <li>Ask multiple-choice questions with one or more correct answers.</li> <li>Gather opinions, i.e., conduct a survey.</li> <li>Prioritize a list of text items.</li> </ul>
	Web Share Pod	<ul style="list-style-type: none"> <li>Share new content or resources.</li> <li>Instruct participants to search for information.</li> </ul>



Icon	Icon Name	Typical Use
	Phone Discussion	<ul style="list-style-type: none"> <li>Facilitate introductions.</li> <li>Ask and answer verbal questions.</li> <li>Explain new ideas, concepts, or methods.</li> <li>Encourage learners to answer each other's questions.</li> </ul>
	Breakout Rooms	<ul style="list-style-type: none"> <li>Assign small-group activities.</li> <li>Create a customized workspace for each breakout group to differentiate assignments for each group.</li> <li>Monitor breakout room discussions using chat pod and provide feedback.</li> </ul>
	Important Information	<ul style="list-style-type: none"> <li>Call out important information.</li> </ul>
	Q & A	<ul style="list-style-type: none"> <li>Check for understanding or agreement.</li> <li>Survey participants.</li> <li>Solicit feedback.</li> </ul>

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WCT

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

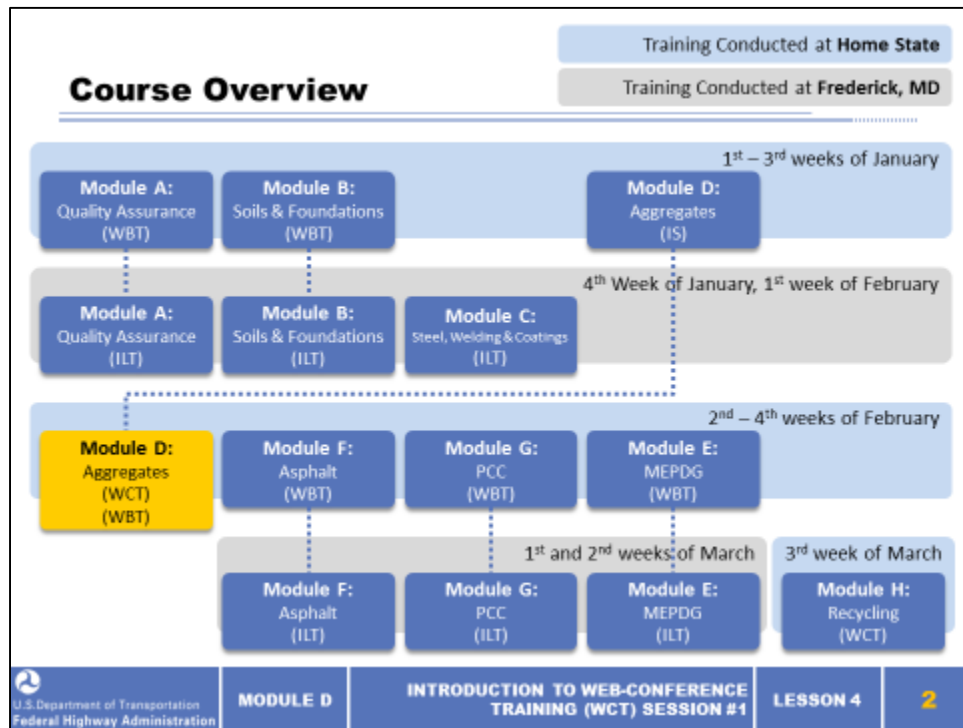
**Aggregates for Transportation Construction Projects**

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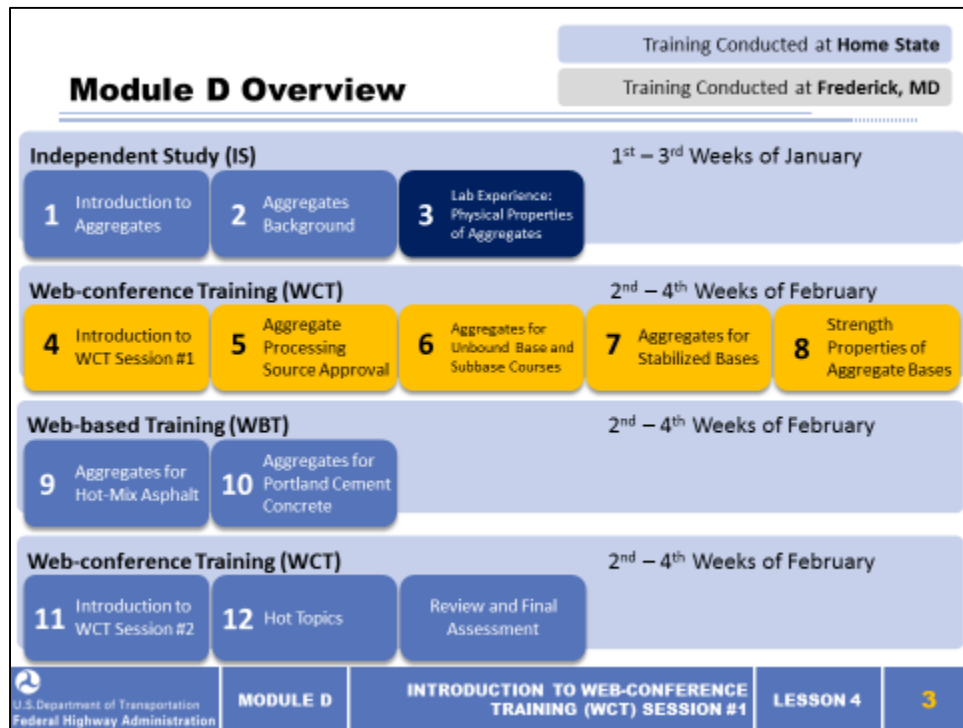
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## Slide 2



## Slide 3



# 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.


Slide 5



# Introductions


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- Host (what they do and why)
- Instructor (background information)

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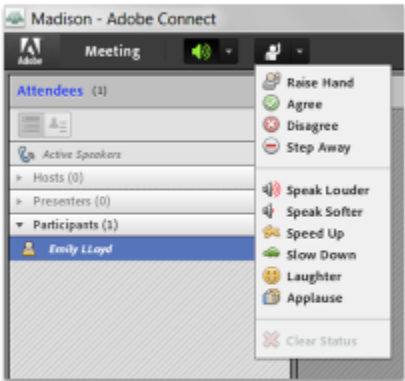
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## Slide 6



## Using the Attendee List Pod

- Use the attendee list pod to indicate your status
- If you have to step away for a minute, use the “Step Away” status
- Remember to clear the status when you return to your desk
- The host will monitor the attendee list pod during the lesson



During Lesson 3, you visited your State or district laboratory. Had you already observed or participated in these labs at some point in your career?

  
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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



## Web Conference Protocol

- The WCT lessons are meant to be highly interactive
- These sessions are mostly open microphone, meaning you can ask questions, offer an opinion or just make a comment
- Keep in mind there are NO BAD QUESTIONS and we encourage you to ask questions at all times
- If you have a question on some particular topic, rest assured, you are probably not alone
- We are going to cover a lot of material in a relatively short time
  - You are encouraged to read supplemental information
  - An incredible amount of information is available in the internet
  - For example, a Google search on “sieve analysis of coarse aggregates,” returns over 19,000 articles
- And the main thing to remember...PARTICIPATE!

 Let's take a poll. How would you rate your level of experience with aggregate-related issues (laboratory and field applications)?

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

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## Slide 8

## Lesson 1 Review

- In Lesson 1, you reviewed aggregate-related specifications based on your agency's standards
- These specifications were likely based on AASHTO/ASTM standards but may have been altered to suit regional/local conditions



Let's discuss the similarities and differences between agency specifications.

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

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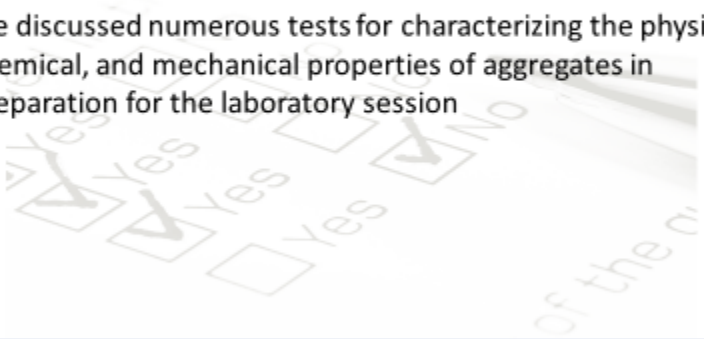
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## Slide 9




## Lesson 2 Review

- In Lesson 2, you looked up a number of AASHTO and ASTM standards and compared them against your agency's standards
- We discussed numerous tests for characterizing the physical, chemical, and mechanical properties of aggregates in preparation for the laboratory session



 Let's review Lesson 2 with a series of knowledge checks.

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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



- 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
  - Abrasion, wear, and degradation tests
  - Cleanliness tests
  - Shape characteristic tests
  - Strength and deformation-related tests
  - Pore property tests
  - Hardness and abrasion tests
  - Volumetric stability tests

## Slide 11

<b>Gradation-Related Tests</b>			
Sieve Analysis	T 27	C 136	Sieve Analysis of Fine and Coarse Aggregates
Wash Loss	T 11	C 117	Materials Finer than 75- $\mu$ m (#200) Sieve in Mineral Aggregates by Washing
Hydrometer Test	T 88		Particle Size Analysis of Soils: Hydrometer Test

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Slide 12




## 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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Slide 13

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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Slide 14




## Aggregate Cleanliness

- 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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Slide 15


Strength and Deformation-Related Tests			
Resilient Modulus	T 307		Determining the Resilient Modulus of Soils and Aggregate Minerals

[illegible]


Slide 16

## Strength and Deformation-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 strength and deformation tests.



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## Slide 17

Hardness and Abrasion Tests		
-	-	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

- 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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## Slide 19

<b>Abrasion, Wear and Degradation Tests</b>		
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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## Slide 21

<b>Particle Shape and Surface Characteristic Tests</b>			
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)

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## Particle Shape Characteristic 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 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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Slide 24

## 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.

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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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## Volumetric Stability 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 volumetric stability tests.



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## Slide 27

### Laboratory Experience Review Questions

- Three questions were posed at the end of Lesson 3 to begin the process of linking laboratory testing and aggregate properties to practical applications
  - What is your agency's process for accepting unbound base and subbase materials?
  - What is your agency's process for accepting stabilized base materials?
  - How does your agency determine the appropriate stabilizer?

Think back to the questions posed at the end of Lesson 3.

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

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## Slide 28



## Learning Outcomes Review

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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**HMEC**  
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Lesson 5: Aggregate Processing Source Approval



**Aggregates for Transportation Construction Projects**




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Slide 2




## Learning Outcomes


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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.



**MODULE D**

**AGGREGATE PROCESSING SOURCE  
APPROVAL**


**LESSON 5**

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## Slide 3



## Aggregate Properties

- Physical properties
  - Particle grading, shape, angularity, texture
  - Density, pore properties
- Chemical properties
  - Affinity for asphalt, bond with PC paste
  - Reactivity in service (ASR, ACR)
- Mechanical properties
  - Resistance to applied loads

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AGGREGATE PROCESSING SOURCE  
APPROVAL

LESSON 5

3

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

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## Slide 4


## Aggregate Usage



- Aggregate usage varies widely based on location
  - The physical, chemical, and mechanical properties of aggregates are the deciding factors in their use
  - Availability and economics also play a major role in determining suitability
- The majority of aggregates are from natural sources
- In order to keep up with the demand for aggregates, new sources of high-quality materials are necessary:
  - Locating new sources requires knowledge of local geology
  - Assessing aggregate quality requires knowledge of rocks and minerals



How could you use the Mohs Hardness test kit as a quick field check when evaluating aggregate sources?

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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.

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## Slide 5

### Sources of Natural Aggregates

- Types of Rock – Bedrock Sources
  - Igneous
  - Sedimentary
  - Metamorphic
- Types of “Soil” – Sedimentary Deposits
  - Boulders, cobbles
  - Gravel and sand
  - Silts and clays
- The types of rock (aggregates) that are in common use vary substantially throughout the US

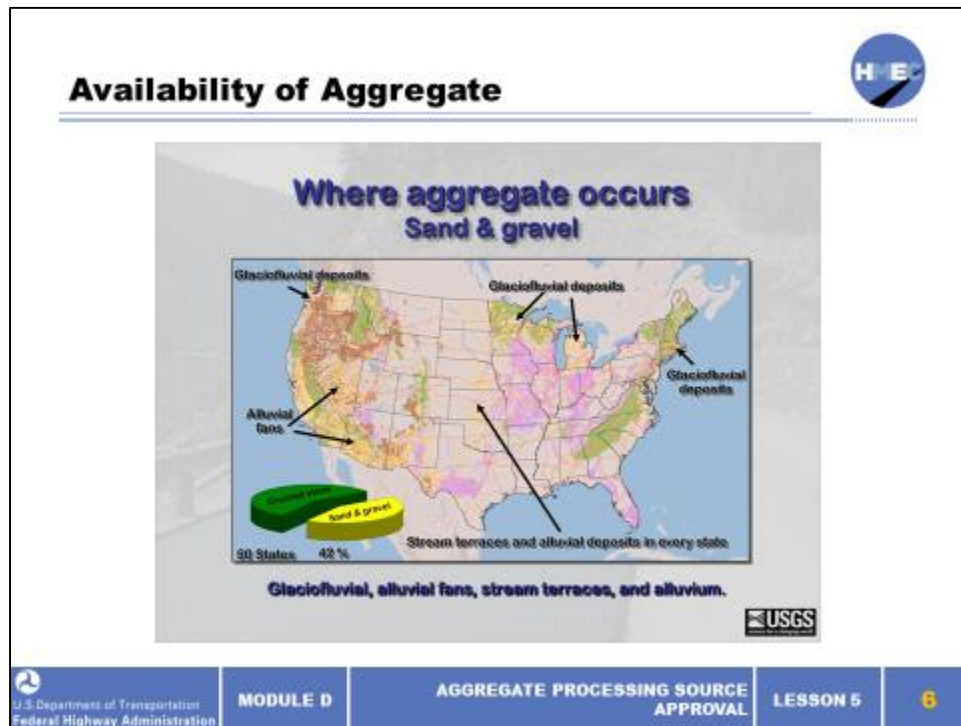


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High-quality aggregates can be obtained from any of the three types of rock:

- 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
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## 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](http://pubs.usgs.gov/of/2011/1119/pdf/OF11-1119_report_508.pdf)

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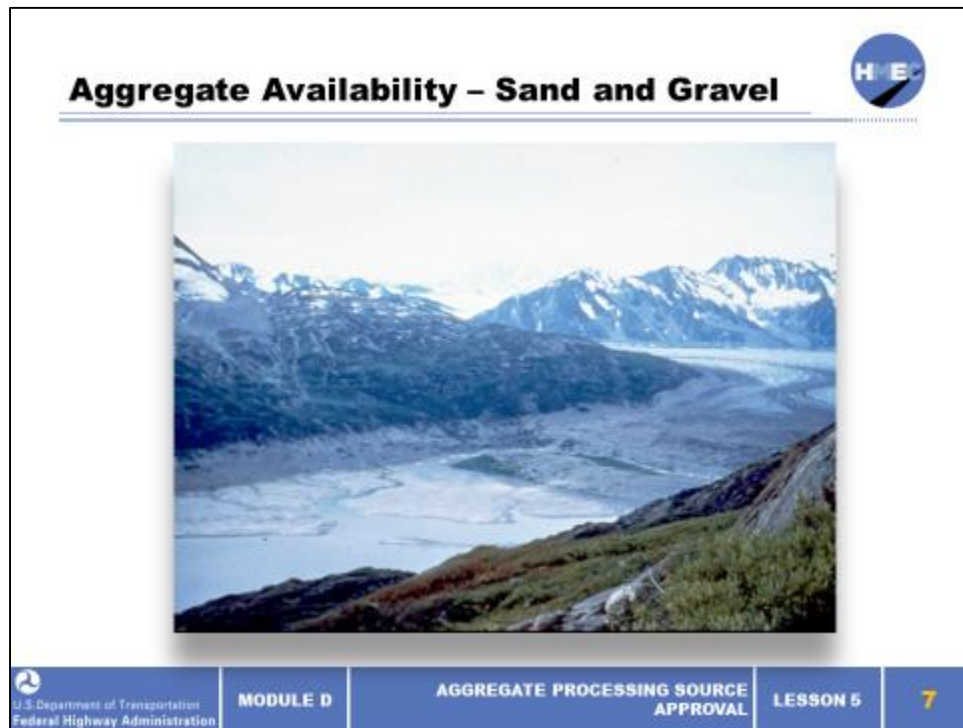
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## Slide 7



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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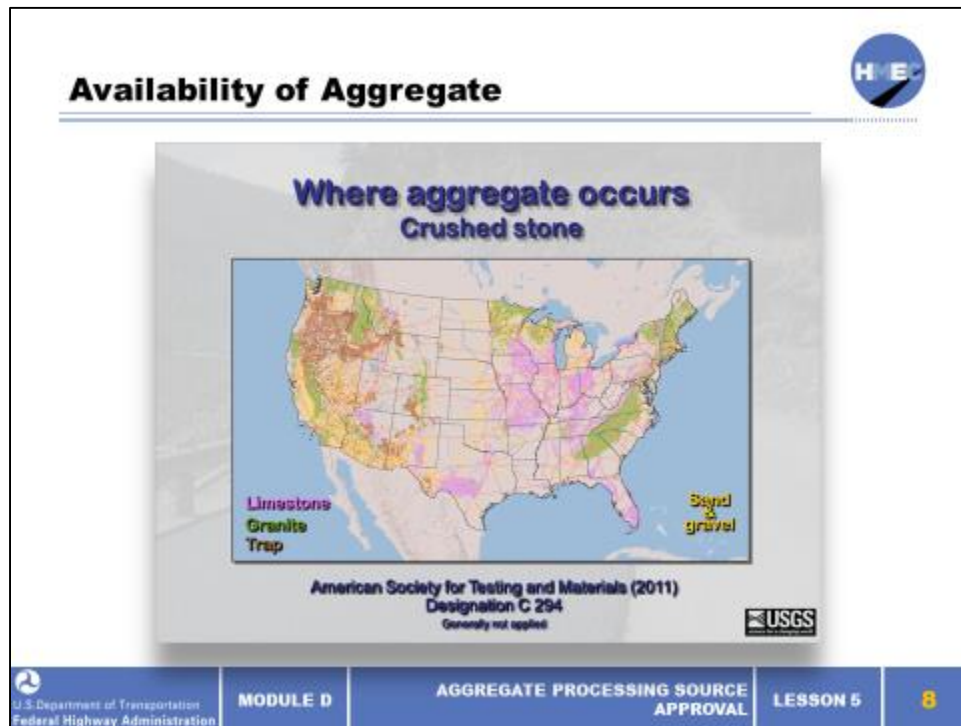
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## Slide 8



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](http://pubs.usgs.gov/of/2011/1119/pdf/OF11-1119_report_508.pdf)

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## Slide 9

### Aggregate Availability – Crushed Stone

- Crushed stone is quarried from areas where hard, strong bedrock is near the surface
  - Surface quarries
  - Underground mines



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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.

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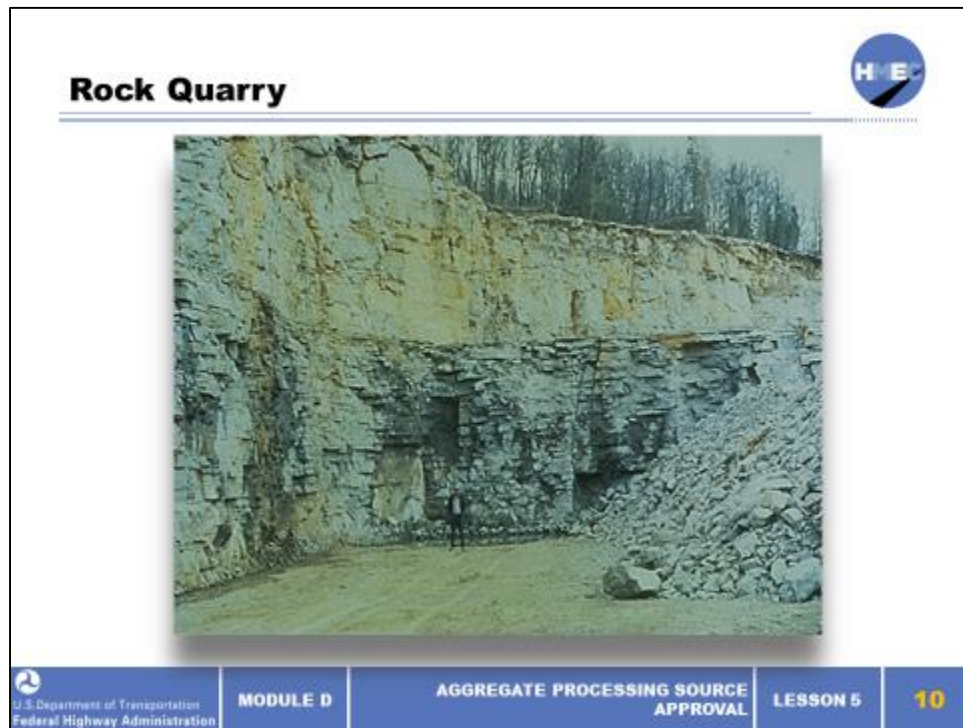
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## Slide 10



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

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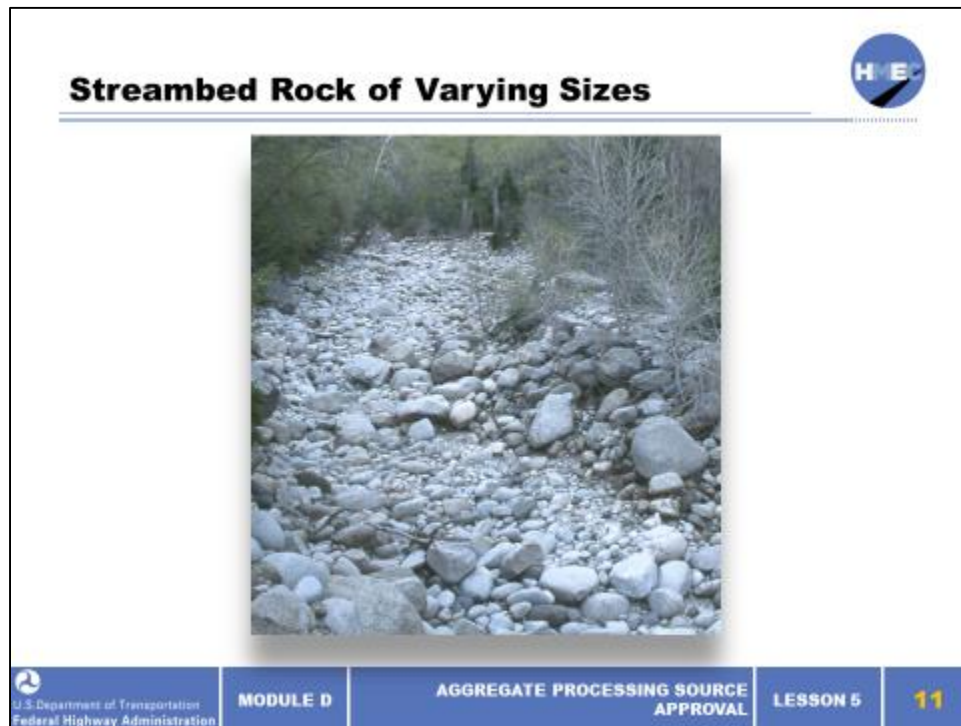
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## Slide 11



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.

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## Slide 12

<b>Igneous Rocks</b> 		
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.

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## 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.

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## 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)

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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.

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Slide 15




## Exercise 1: Applications Analysis

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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			



What are the ideal characteristics for each use? What trade-offs might be required? How might these trade-offs affect performance and economy for each use?

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


[illegible]

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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[illegible]

## Slide 17

### Aggregate Mining and Processing



- Aggregate mining and processing varies substantially based on the type of material
- Most established hard rock mining or quarrying operations consist of blasting an exposed rock face within the quarry, transporting the large rock fragments to a series of crushers, and screening the particles into various sizes depending on intended use
- Sand and gravel pits are generally much shallower and less expansive than hard rock quarries
  - The pits may be operated either dry or flooded (with excavation taking place under water)
  - The excavated material is washed to remove unwanted clay and silt material and then separated into sand and gravel
  - The gravel is then screened into different size fractions

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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.

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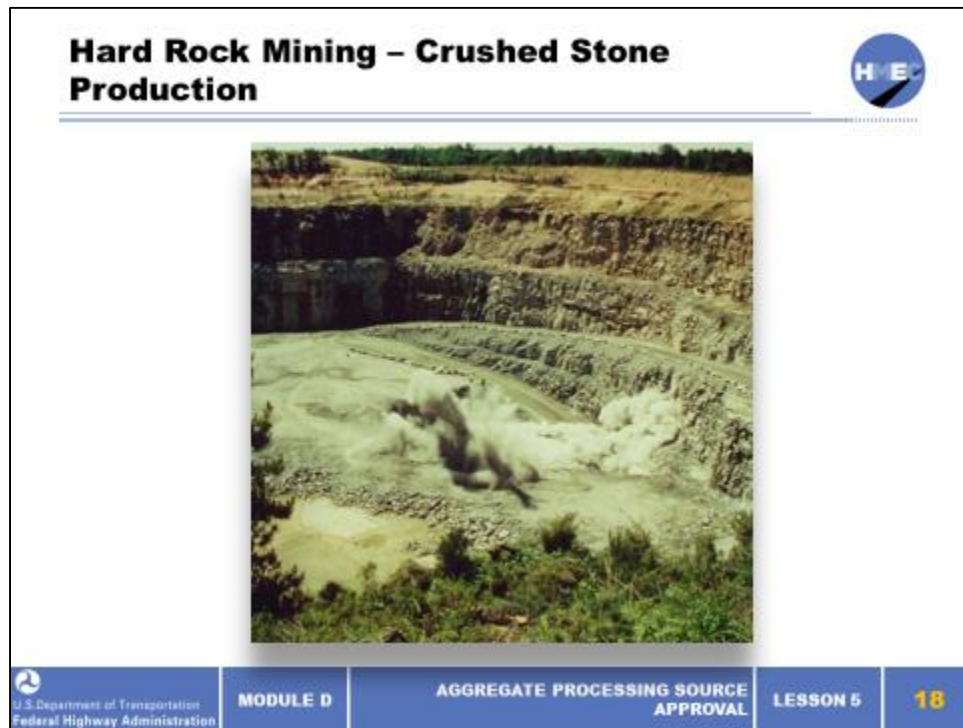
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## Slide 18



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

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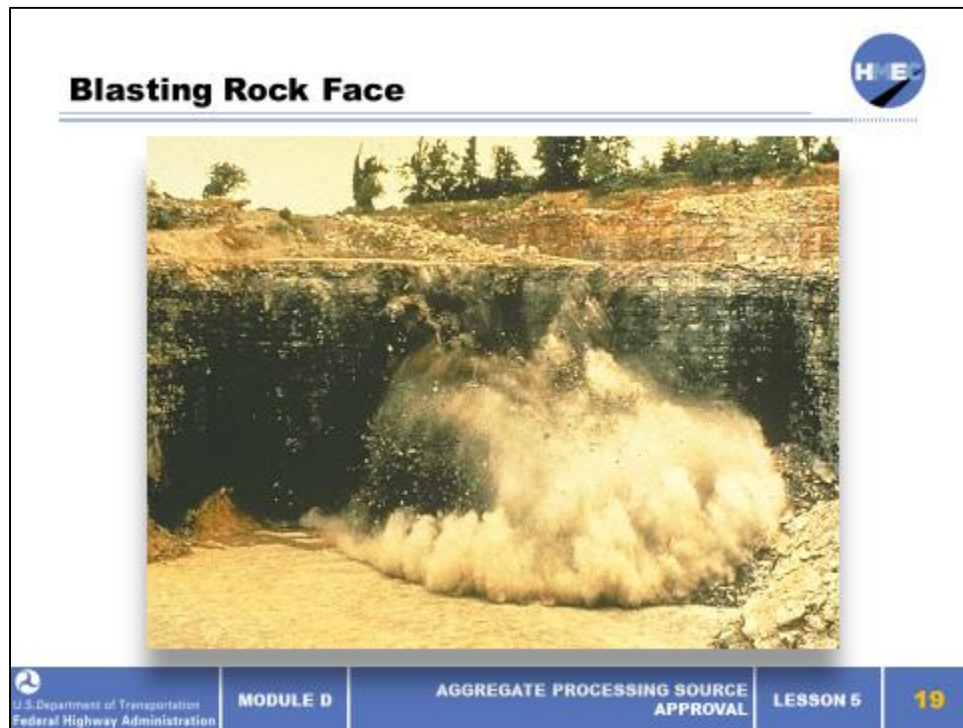
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## Slide 19



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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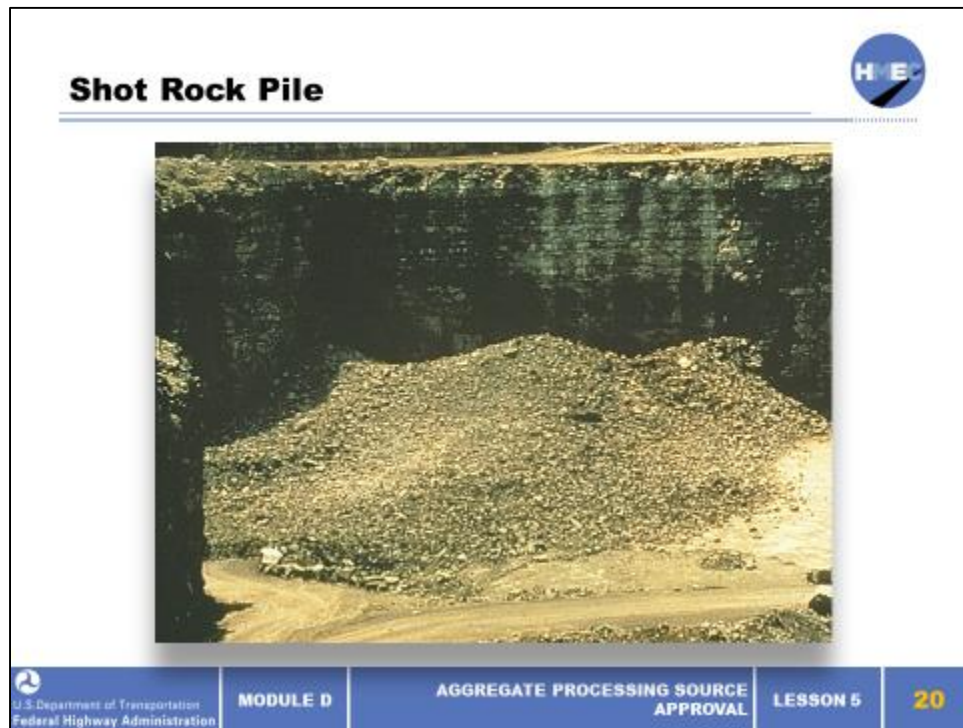
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## Slide 20



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

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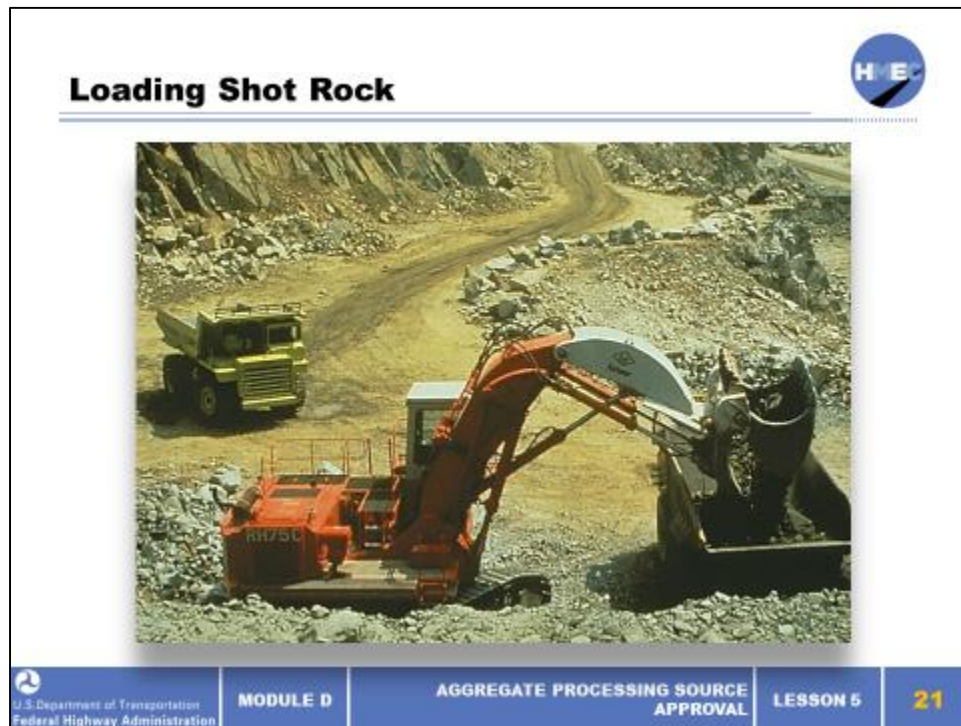
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## Slide 21



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.

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## Slide 22

## Primary Crusher



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

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## 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.

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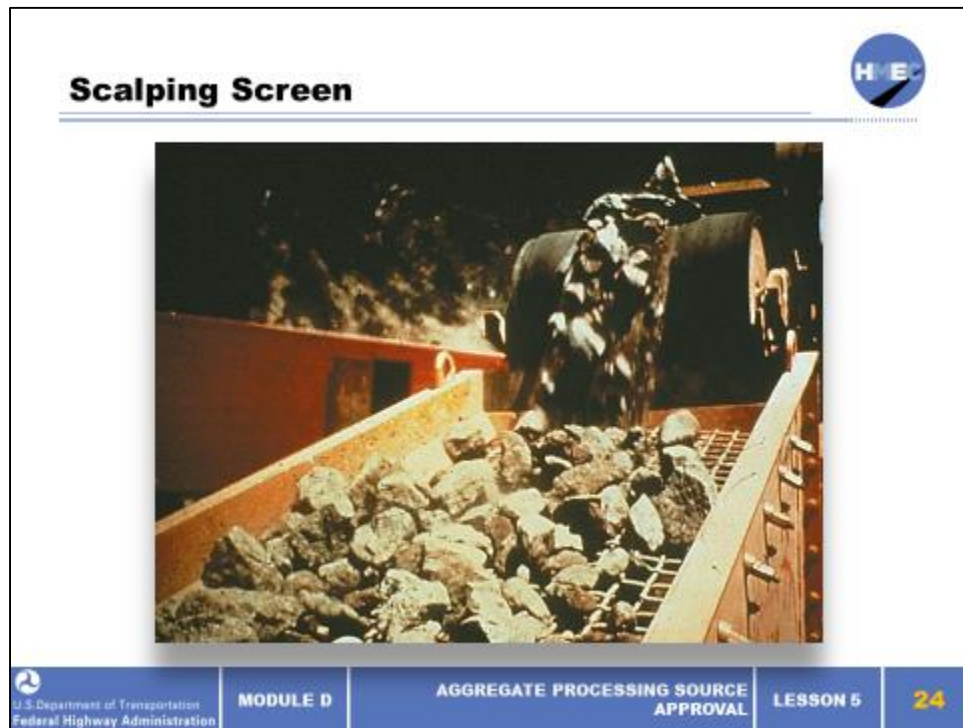
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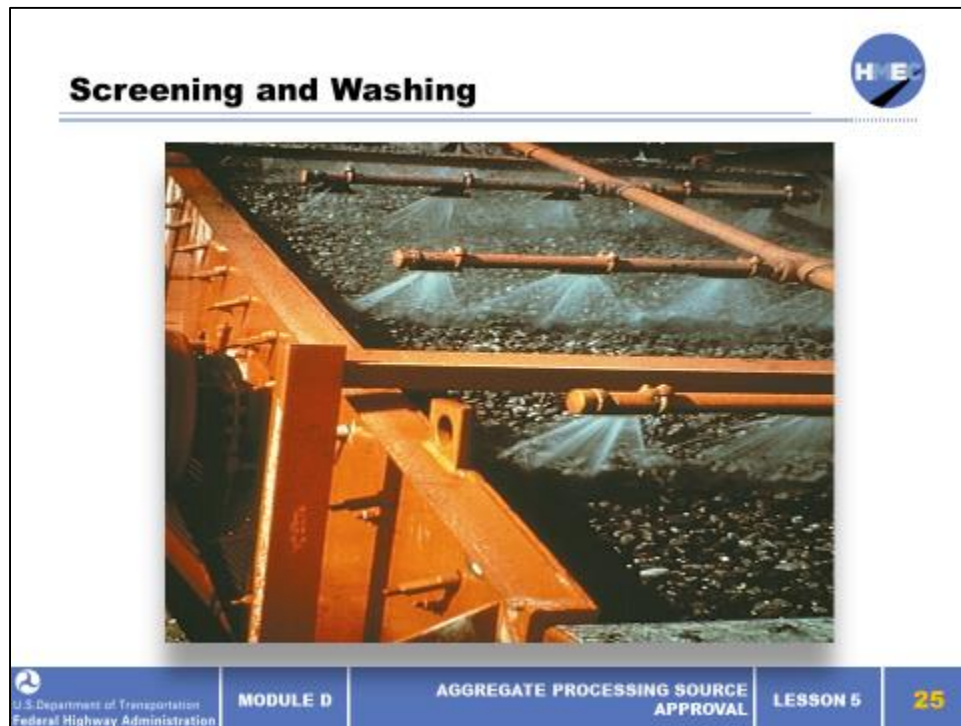
Slide 24



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

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## 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.

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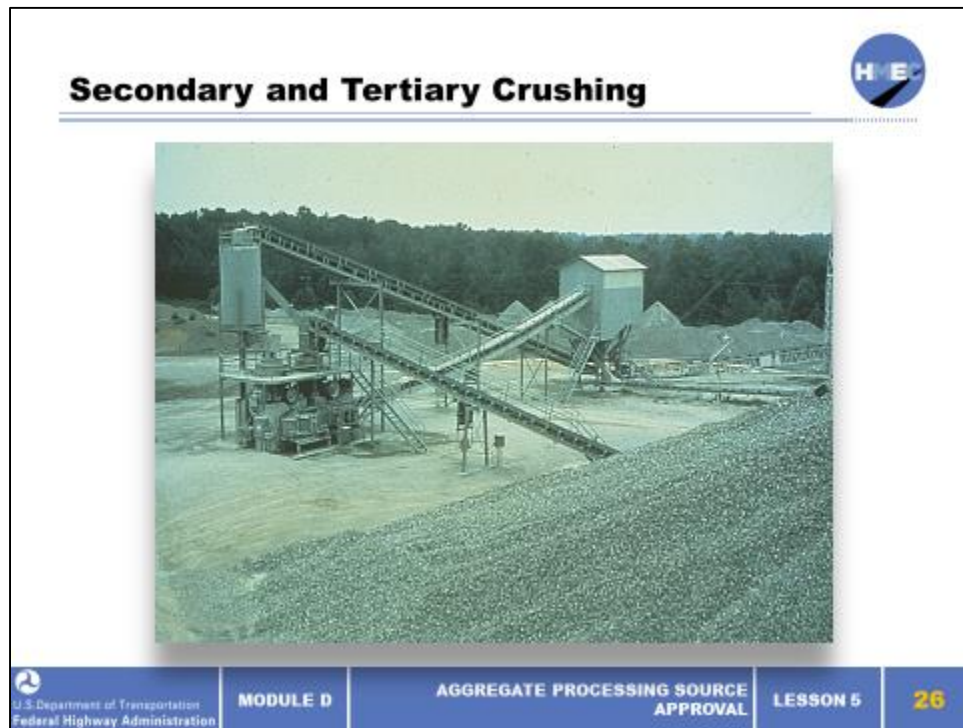
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## Slide 26



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

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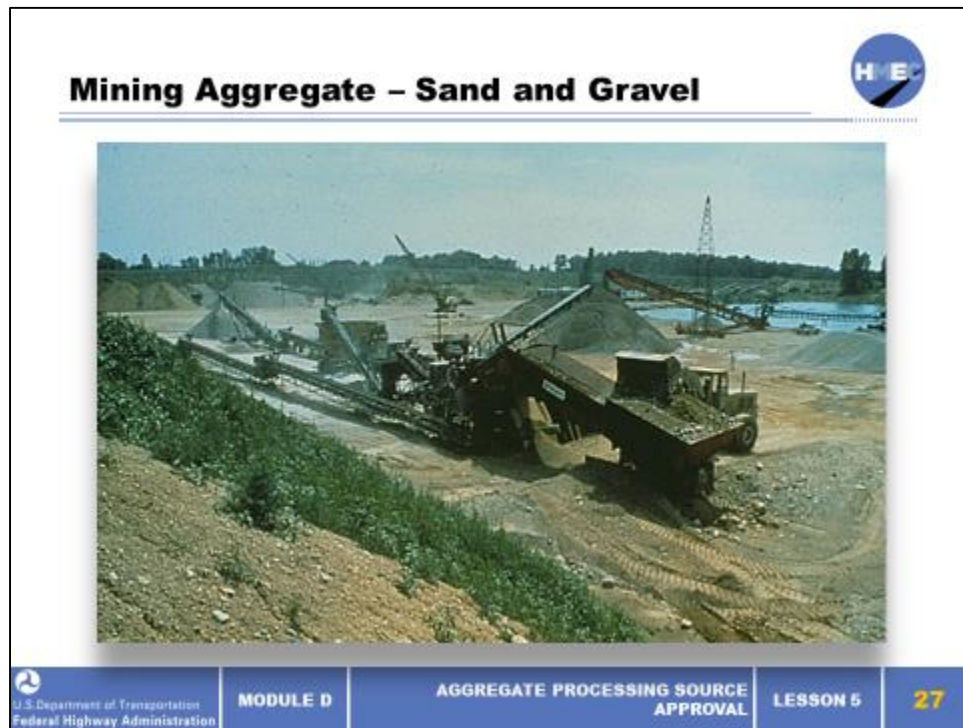
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## Slide 27



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

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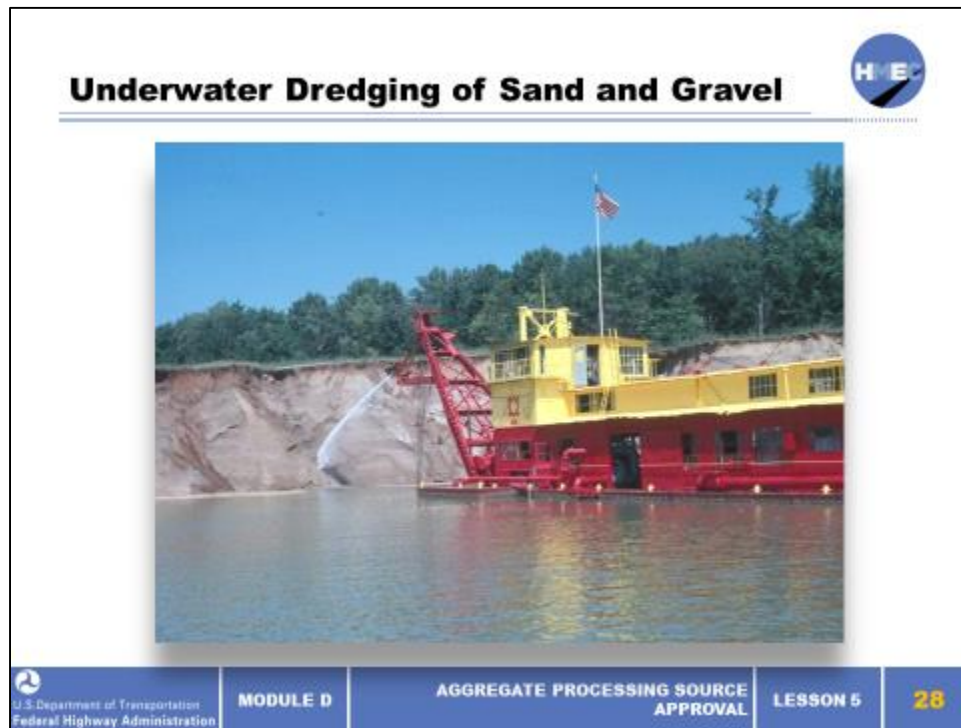
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## Slide 28



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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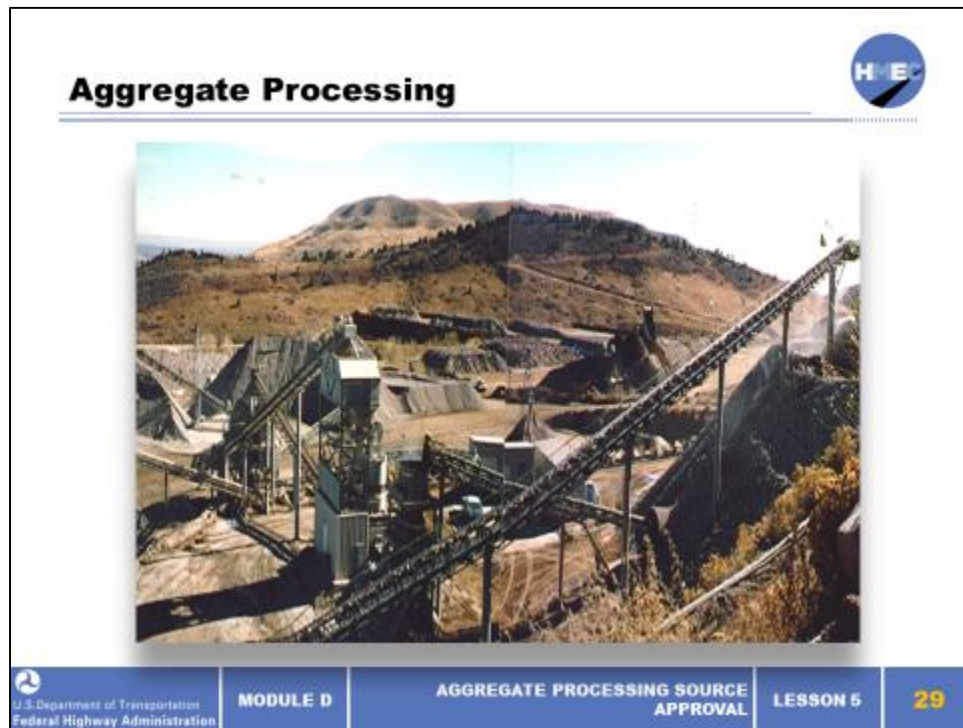
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## Slide 29



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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## Slide 30



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.

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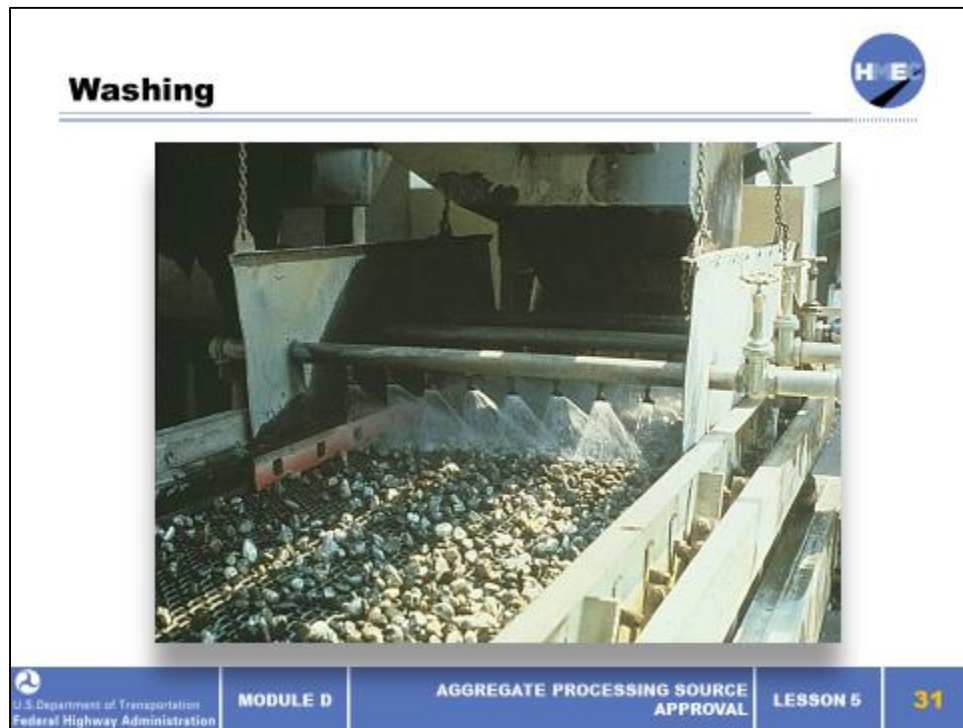
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## Slide 31



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

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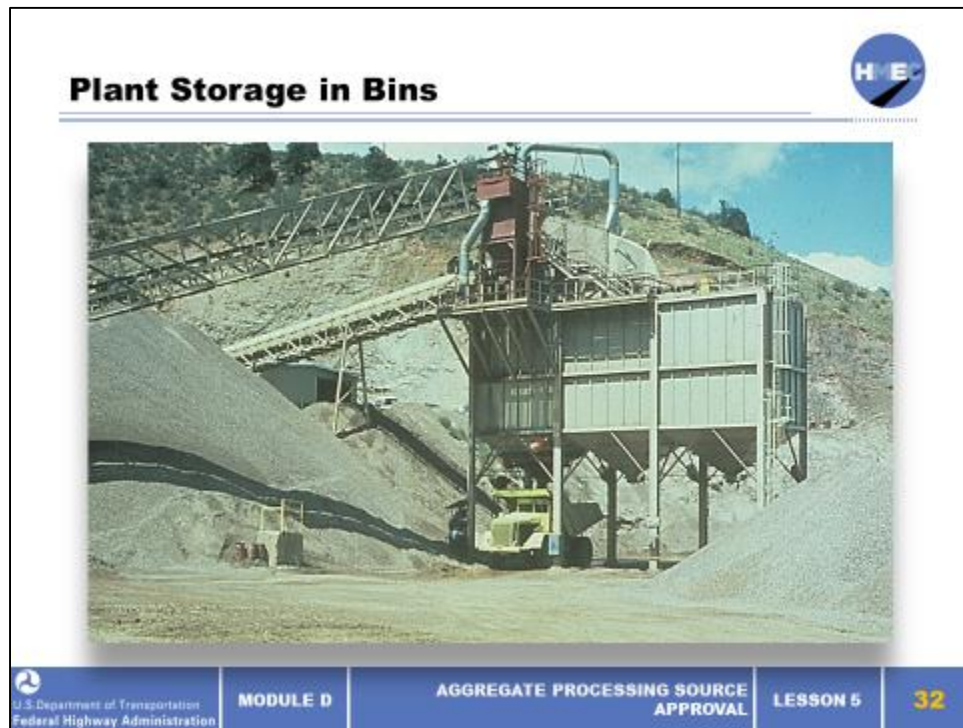
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## Slide 32



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

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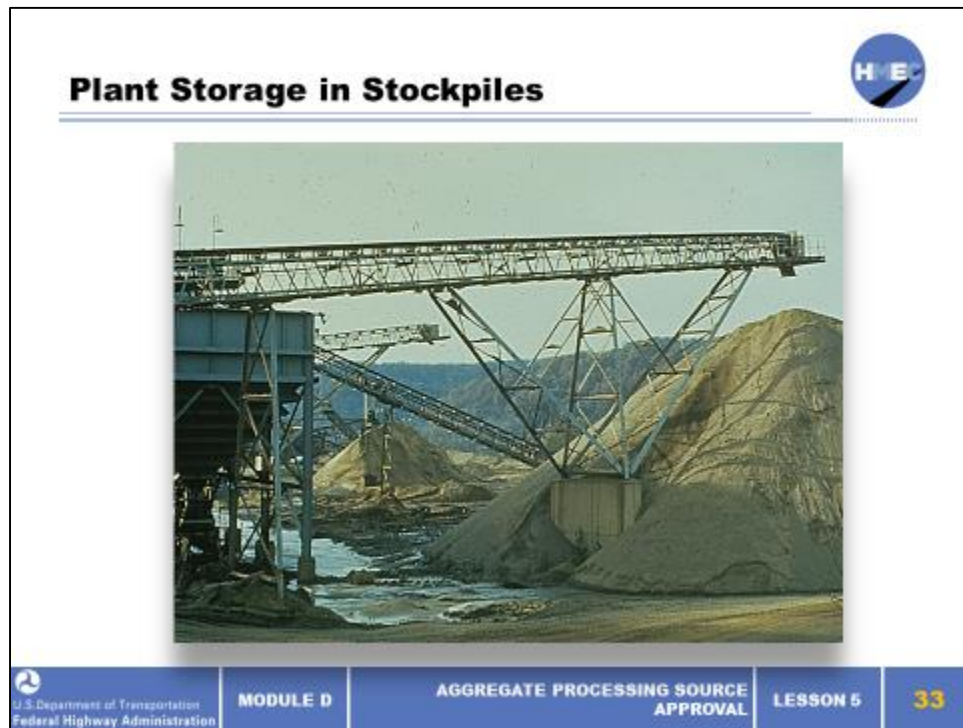
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## Slide 33



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.

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## Slide 34

### Aggregate Stockpiling

- Aggregates are stockpiled both at the manufacturing/processing facility and subsequently at the material supply facility (PCC or AC production plants, aggregate supplier, etc.)
- The stockpiles are typically divided based on a specific size range of aggregates (fine, intermediate, large)
- A best-practices video on stockpiling was produced by the Ohio Aggregates and Industrial Minerals Association and FHWA which will be shown in a later lesson

 Do you have experience going to a rock quarry or sand/gravel operations to validate the state of operations?

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APPROVAL

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

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## Slide 35

### Processing Effects on Aggregate Properties



- Crushed coarse aggregate shape (crushing operations)
- Crushed fine aggregate shape (crushing operations for processed rock)
- Aggregate grading and amount of fines (crushing operations)
- Deleterious materials (all phases of production)
- Coatings and cleanliness (screening and washing operations)
- Variability (screening and handling operations)

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Aggregate production methods can affect a number of aggregate properties.

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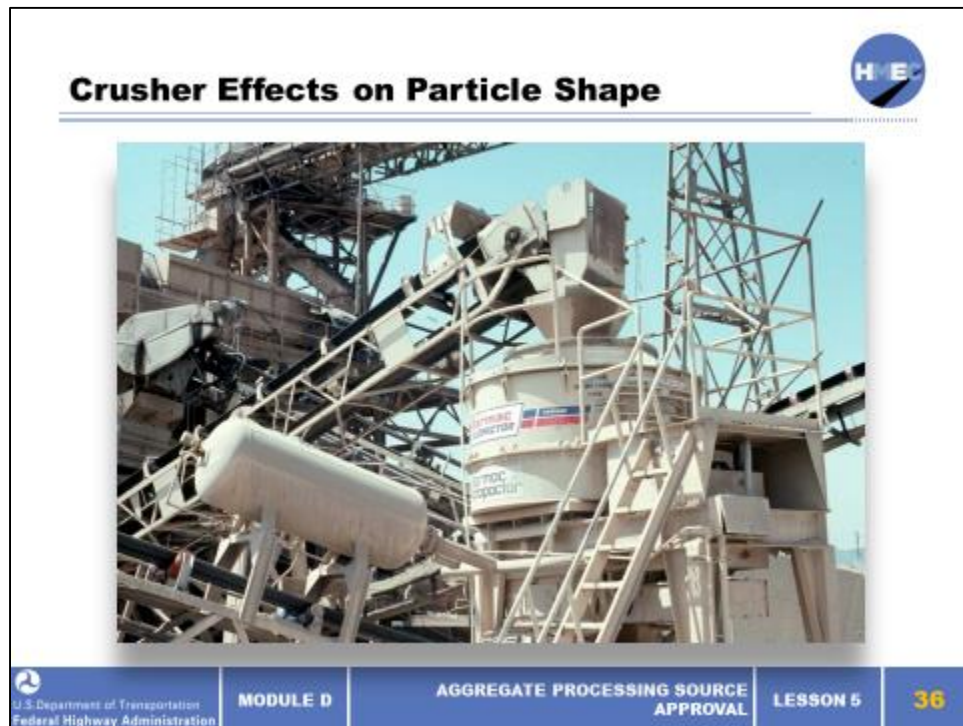
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## Slide 36



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.

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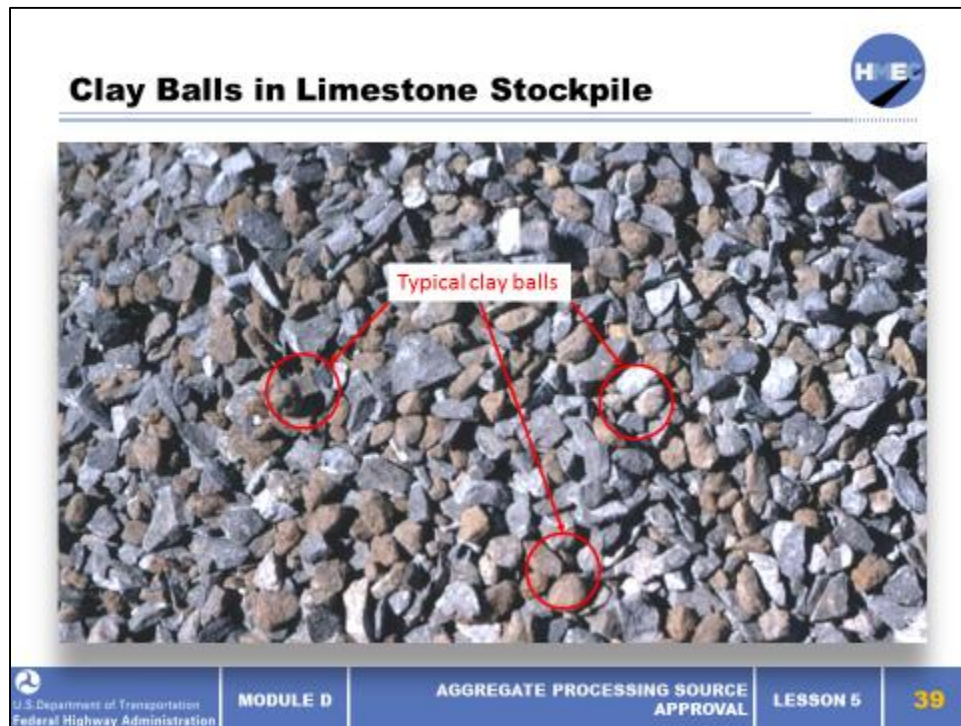
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## Slide 38



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

### Evaluating Potential Aggregate Sources

- Locating – geological and topographic maps
- State mining and surveys, DOT records
- Site investigation – auger drills, pits, cores
- Characterize each layer and estimate quantities
- Grading and quality of sand and gravel
- Rock material density and quality, trial blast
- Coarse pieces – quality and how it will crush
- Fines – quality and character (clay vs. silt)

How do you evaluate potential aggregate sources in your area?

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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.

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## Slide 41

### Evaluation When Expanding Existing Aggregate Pit or Quarry



- Step 1: Look at previous uses and service records
- Step 2: Site investigation – auger drills, holes, cores
- Step 3: Identify and characterize each layer
- Step 4: Relate to geology maps – beds and layers
- Step 5: Other known aggregates from the formation
- Step 6: Coarse pieces – quality, porosity, soundness
- Step 7: Fines – quality and character (clay vs. silt)
- Step 8: May set limits on allowed mine layers

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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.

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## Slide 42

### **Service Record for Aggregates**



- Age of structure or pavement
  - 10–20 years to indicate good performance
  - Consider environment
- Condition assessment, effect of aggregates
  - Petrographic examination of cores
  - Compare aggregates to current sources
- Characterize asphalt binder and cement paste

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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

### **Evaluation of an Existing Rock Quarry**



- Drill cores and/or sample exposed layers
- Trial blast and crush material in the lab
- Petrography of rock material for aggregate
  - General quality (strength, porosity)
  - Deleterious materials in seams and nodules
  - Description related to potential uses
  - Rock formation—relate to known performance
  - Can processing improve quality?
- Durability tests of the crushed material

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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

### Evaluation of an Existing Sand and Gravel Source



- Sample with auger or dig holes
- Field sieve analysis and minus #200
- Petrography of cobbles, gravel, and sand
  - Deleterious particles, seams, or layers
  - Description related to potential uses
  - Deposit type—relate to known performance
- Processing? – crusher size, washing
- Durability tests of the gravel and sand

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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.

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## Slide 45

### **Representative Sampling and Testing of Processed Aggregate**



- There are a number of laboratory tests that are used in conjunction with the evaluation methods just discussed
- Depending on the intended use of the aggregates, the following tests may be required:
  - Sulfate soundness test (freeze/thaw)
  - LA abrasion (abrasion resistance and toughness)
  - Aggregate shape characteristics (fractured faces and texture)
  - Petrographic examination
  - Others to be discussed

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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.

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
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Slide 46

## Representative Sampling and Testing of Processed Aggregate



- 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.



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MODULE 3


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## Slide 47



### Petrographic Analysis

- ASTM C 295 “Standard Guide for Petrographic Examination of Aggregates for Concrete,” commonly known as petrographic analysis, is another tool for detailed aggregate examination
- Petrographic analysis can be used for a variety of purposes including:
  - Comparison between a known rock or aggregate sample with validated performance and a new material source
  - Determination of soluble or reactive minerals in a rock or aggregate sample (alkali-silica reaction, ASR, and alkali-carbonate reaction, ACR)
  - Estimation of particle shapes (cubical, spherical, elongated, etc.)
  - And a variety of other uses as identified in the ASTM standard

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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.

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## Slide 48

### Additional Characterization Testing

- Additional tests may be warranted based on intended use:
  - Deleterious materials
  - Alkali aggregate reactivity (AAR) potential
  - Frictional characteristics
  - Others specific to use in PCC and AC (to be addressed in those modules)
- You may have performed laboratory tests in Lesson 3 that determined some of these parameters

Are there additional tests, other than those already discussed, that you feel might be appropriate?

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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).

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## Slide 49

### Agency Approaches to Aggregate Source Approval



- There are many methods used to qualify aggregate sources at the State level
- The key elements include the following:
  - Sampling procedures
  - Testing procedures
  - Frequency of testing
  - Qualification standards for different end uses
  - AASHTO, ASTM, or agency-specific standards

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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.

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## Slide 50

## Agency Approaches to Aggregate Source Approval

Pit/Quarry Approval	Project Sample Approval
<ul style="list-style-type: none"> <li>Do you perform yearly quality checks? (yes, no; if no, how often?)</li> <li>How often do you visit pits and quarries?</li> <li>Do you maintain approved source lists? (yes, no)</li> <li>Do you perform QA testing on random samples? (yes, no; if yes, how often?)</li> </ul>	<ul style="list-style-type: none"> <li>Do you sample on a lot basis? (if not, how?)</li> <li>Do you check durability of proposed aggregates? (yes, no; if yes, how often?)</li> <li>Do you perform QA testing on random samples? (yes, no; if yes, how often?)</li> <li>Do you pre-qualify sources on a project basis? (yes, no)</li> </ul>

⋮ Please answer the following questions based on your experience with aggregate source approval in your area.

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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.

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## Slide 51

### Agency Approaches to Acceptance



- What tests do you typically perform for aggregate use in PCC?
- What tests do you typically perform for aggregate use in AC?
- What tests do you typically perform for aggregate use in bases?
- Do you routinely perform tests for other uses of aggregate? (subbases and borrow material)
- Do you sample from the stockpile, conveyor or other location?
- How often do you perform these tests? (lot, daily, weekly?)
- What criteria do you use for acceptance and rejection?

 The following questions pertain to common practices in your area regarding the aggregate acceptance program.

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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.

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## Slide 52

### **Aggregate Producers' Approach to Quality Control**

- Experiences with aggregate producers
- 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

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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.

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## Slide 53



## Learning Outcomes Review

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

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## Slide 54



## Learning Outcomes Review

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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# HMEC

Highway Materials Engineering Course

Lesson 6: Aggregates for Unbound Base and Subbase Courses




## Aggregates for Transportation Construction Projects

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# 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.



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MODULE D

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AND SUBBASE COURSES

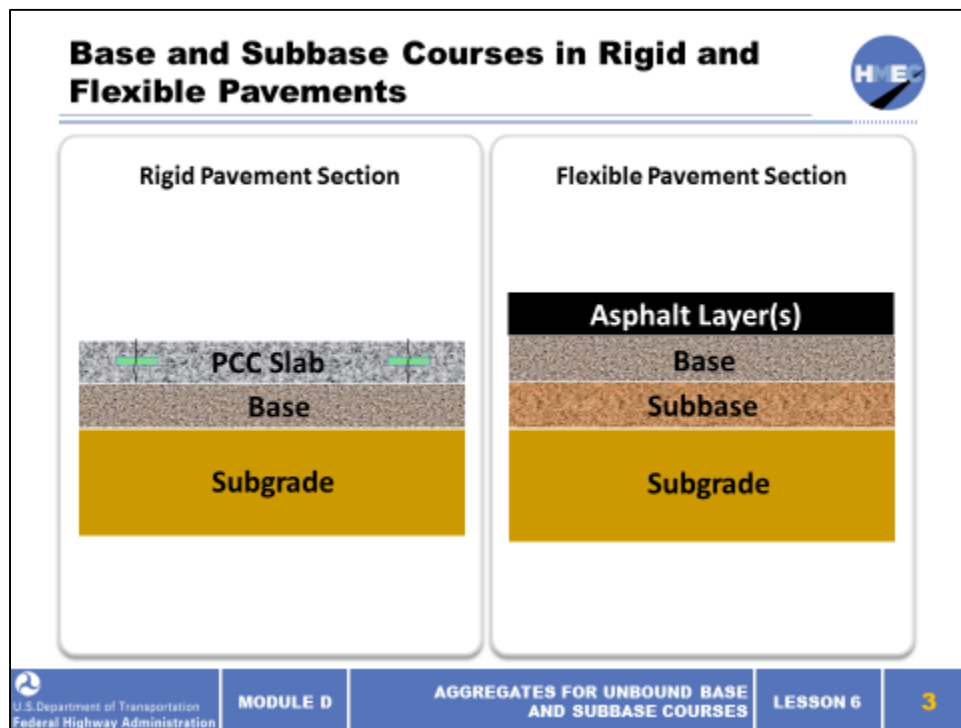
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## Slide 3



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



## Base and Subbase Definitions

- Standard definitions of base and subbase courses
  - Base course: The layer immediately beneath the surface asphalt layers or PCC slab
    - May be bound or unbound granular material
    - Can be either dense graded or open graded depending on the pavement design and specification requirements
  - Subbase course: The layer immediately beneath the base course and on top of the subgrade in a flexible pavement system

 What terminology is used in your State related to bases and subbases?

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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.

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## Slide 5



## Function of Bases and Subbases

- Function of a base course in a rigid pavement system
  - Used as a working platform during construction
  - Provides long-term, uniform pavement support
  - Dissipates stresses within the pavement
  - Reduces the potential for pumping, faulting, and environmentally induced distresses
- Function of a base and subbase in a flexible pavement system
  - Dissipates stress as a function of layer thickness and material properties; i.e., each layer dissipates stress to a different degree
  - Used as a working platform during construction
  - Provides long-term, uniform pavement support

 Refer to NCHRP Report 453 for additional information:  
[http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp\\_rpt\\_453.pdf](http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp_rpt_453.pdf)

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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.

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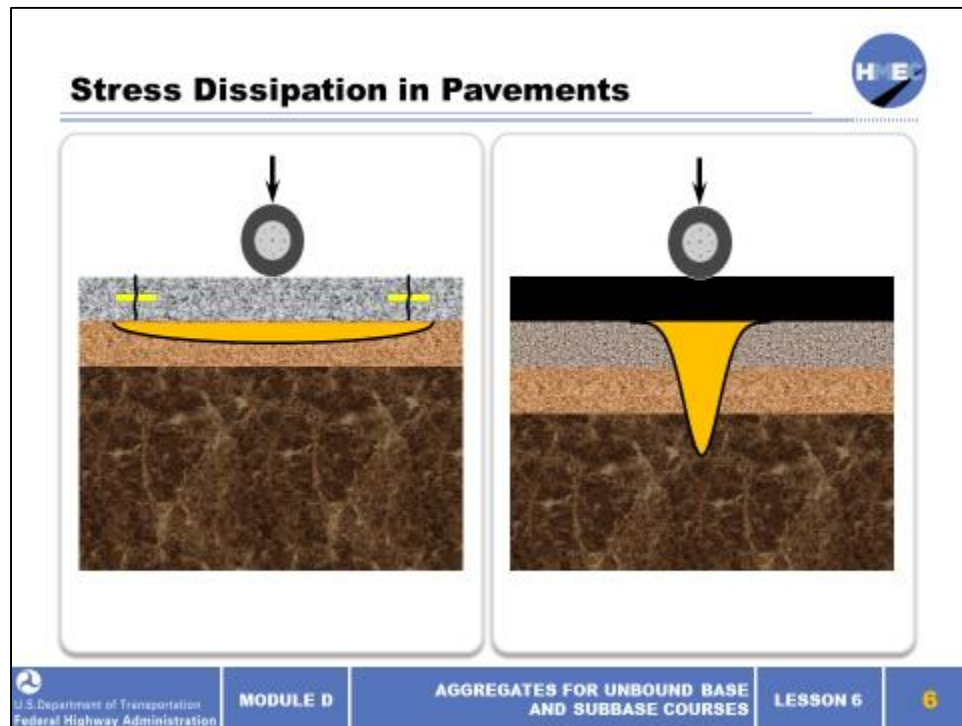
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## Slide 6



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

### Agency Use and Selection of Unbound Base Materials




- Based on your experience, are unbound base materials used in flexible pavements?
- Based on your experience, are unbound base materials in used rigid pavements?
- What is the basis for selecting the base/subbase materials?





What are your experiences with the use of unbound base materials in flexible and rigid pavements?



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AND SUBBASE COURSES

LESSON 6

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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


### Coarse Aggregate Properties for Unbound Bases and Subbases

- Shape
- Angularity
- Surface texture
- Strength
- Abrasion resistance
- Soundness



Coarse Aggregate

This list does not include combined aggregate properties such as gradation, resilient modulus, California Bearing Ratio (CBR), and others.

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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.

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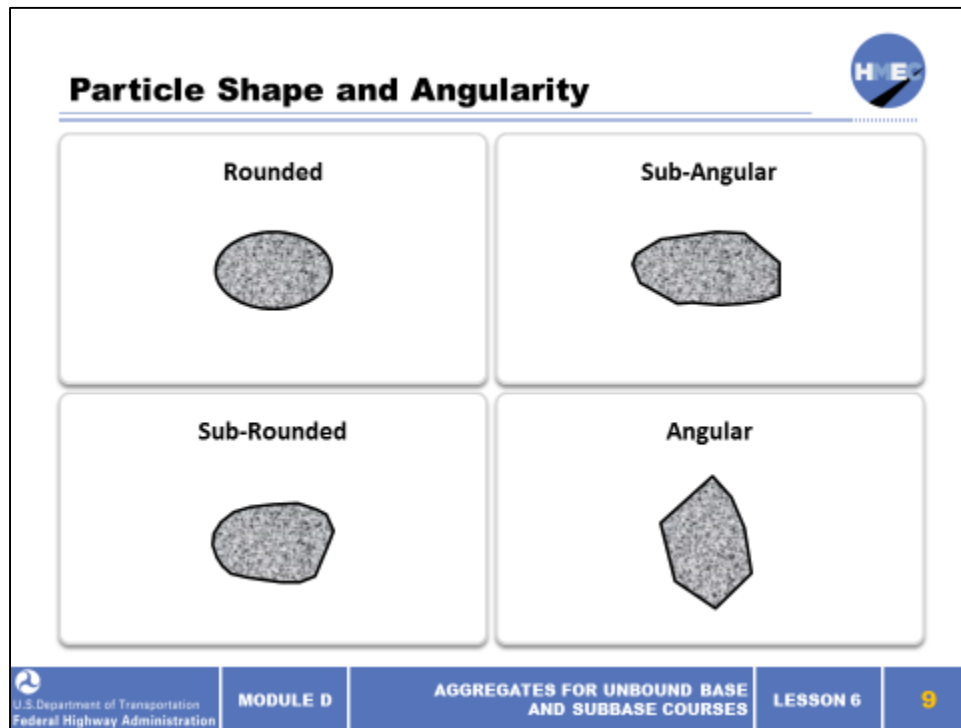
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## Slide 9



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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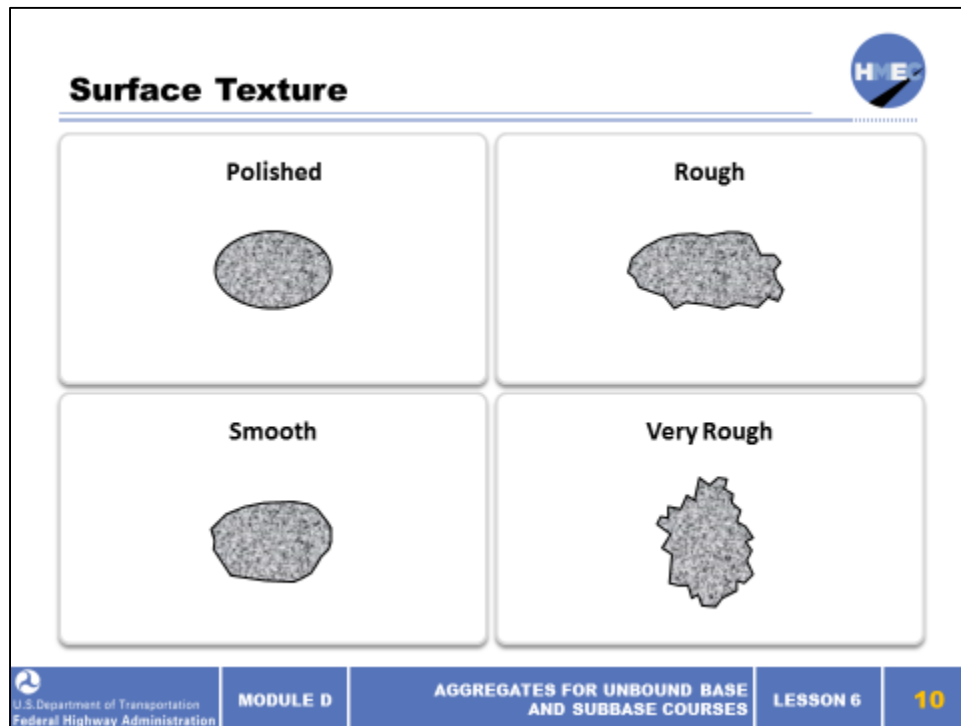
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## Slide 10



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

## Strength

- Aggregate strength is rarely a consideration for “normal” aggregates
- The primary issue regarding aggregate strength is during placement and compaction where low strength aggregates may break and alter the gradation



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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.

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## Slide 12

### Abrasion Resistance

- The abrasion resistance of aggregates is important for unbound aggregate bases and, to a lesser extent, subbases
- Abrasion can occur during placement and compaction as well as in service under repetitive traffic loadings
- Abrasion resistance is particularly important in flexible pavement bases where the stress levels can be high enough to cause wear



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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

- Soundness is the resistance of aggregate particles to disintegration under the actions of wetting/drying or freezing/thawing
- Soundness is a property of the aggregate, while the required level of resistance to this type of degradation is dependent on the environment where the aggregate will be used





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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.

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## Slide 14



### Key Aggregate Properties

- For each of the aggregate shapes and textures shown, note the following:
  - Particle shape
  - Angularity
  - Gradation
- Discuss the effects on particle interaction
  - Placement
  - Densification
  - Stability

 Consider different aggregate blends with a variety of different aggregate properties. What are the effects on particle interaction?

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AGGREGATES FOR UNBOUND BASE  
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The properties of the aggregate impact particle interaction.

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## Slide 15

### Fine Aggregate Properties for Unbound Bases and Subbases

- Cleanliness
- Atterberg limits
  - Particularly the plasticity index



Fine Aggregate

Fines (minus #200 material)

This list does not include combined aggregate properties such as gradation, resilient modulus, California Bearing Ratio (CBR) and others.

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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



### Cleanliness and Plasticity

- Cleanliness refers to the amount and characteristics of the minus #200 content (fines)
- These materials have a significant impact on the stability of the coarser aggregates when present in appreciable quantities
- The plasticity of the fines is equally important as high plasticity materials lead to greater moisture sensitivity (loss of stability when wet)

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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.

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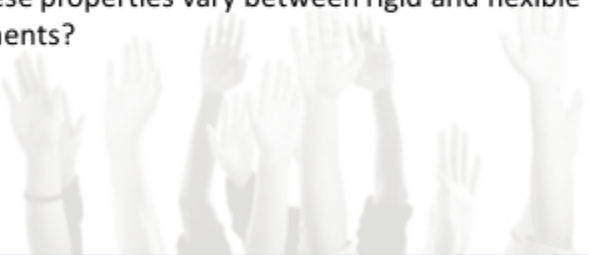
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## Slide 17

### Aggregate Properties in an Unbound Aggregate Base and Subbase




- What do you consider the most important coarse aggregate properties for use in a base and subbase?
- What do you consider the most important fine aggregate properties for use in a base and subbase?
- Do these properties vary between rigid and flexible pavements?





What are the desirable quality characteristics of aggregates in an unbound aggregate base and subbase?



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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.

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## Slide 18

### Aggregate Gradation

- Gradation plays a major role in the performance of both aggregate bases and subbases
- The key gradation parameters include:
  - Maximum aggregate size
  - Overall combined gradation
  - Percent passing #200 sieve

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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.

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## Slide 19

<b>AASHTO Grading Requirements</b>						
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 from AASHTO M 147, Materials for Aggregate and Soil Aggregate Subbase, Base and Surface Courses.

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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.

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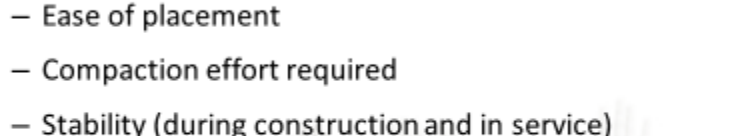
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Slide 20

## Effects of Deviations to the Specified Gradations




- 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?

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[illegible]

## Slide 21



### Percent Fines

- The quality and percentage of fines are a primary consideration in evaluating aggregates for unbound bases and subbases
- These materials range from high plasticity clays to rock flour (from aggregate crushing), each with distinct properties
- The moisture susceptibility and drainability of the base or subbase are the key effects to consider

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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.

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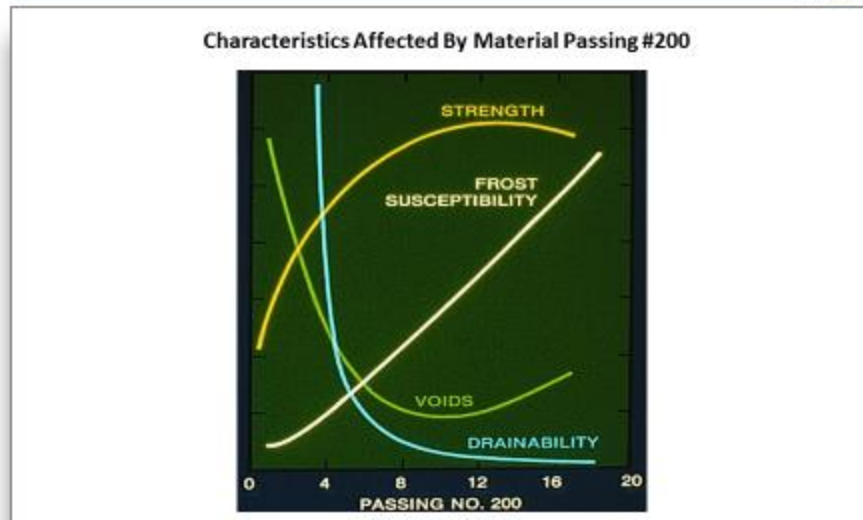
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Slide 22

### Effects of Fines

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## MODULE D

### AGGREGATES FOR UNBOUND BASE AND SUBBASE COURSES

## LESSON 6

22

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

[illegible]




## Slide 23

### Desirable Aggregate Gradation Characteristics

- 100% crushed particles
- Largest maximum size without segregation
- Minimum percent fines necessary for placement and stability
- Hard, tough, and sound aggregate





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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.

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## Slide 24

### Desirable Aggregate Gradation Characteristics

- In order for aggregates to have sufficient in-service stability and to facilitate compaction, a well-graded material is frequently specified
- We have discussed 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

 What are the negative aspects of a high fines content?

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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.

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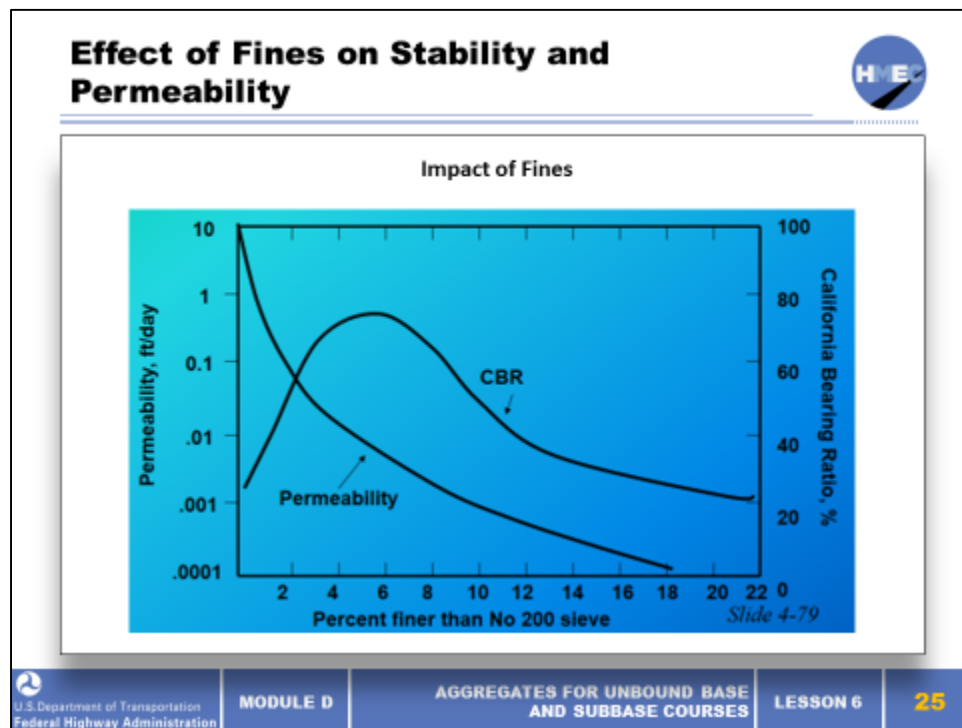
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## Slide 25



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.

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## Slide 26

### Blending for Consistent Gradation

- Base and subbase aggregates are blended to achieve target gradations as established by AASHTO and the agency
- 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)



Looking at the aggregate base in the photo, what properties would you expect to be influenced by the variable gradation shown?



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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.

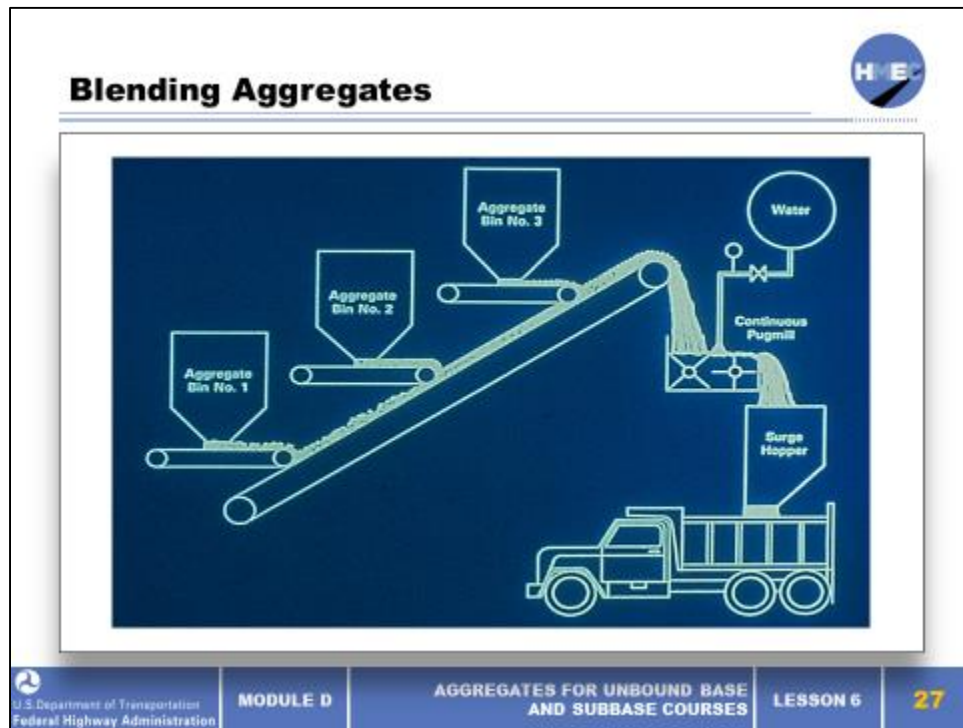
Base and subbase aggregates are blended to achieve target gradations as established by AASHTO and the agency. The AASHTO M 147 aggregate gradations are sufficiently broad to allow for significant deviations on most sieve sizes.

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

## Blending Aggregates

- 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
- 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



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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.

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## Slide 29

### Sources of Inconsistency in Gradation

- There are a number of possible causes for inconsistent aggregate gradation

	Segregation	Degradation	Contamination
Production	X		X
Storage (stockpiles, bunkers, and bins)	X		X
Hauling/loading/unloading	X	X	X
Placement	X	X	X
Compaction		X	
Construction traffic		X	





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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).

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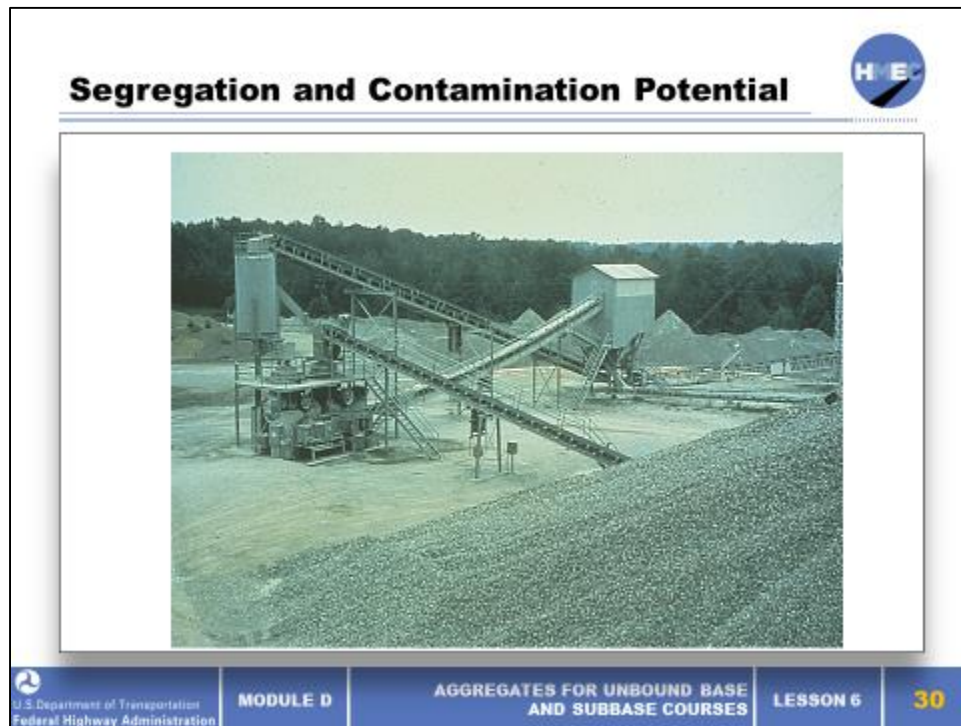
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## Slide 30



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

## Degradation Potential



The image shows a yellow Ingersoll Rand roller operating on a construction site. The roller is compacting a light-colored aggregate base. The background shows a clear sky and some distant trees.

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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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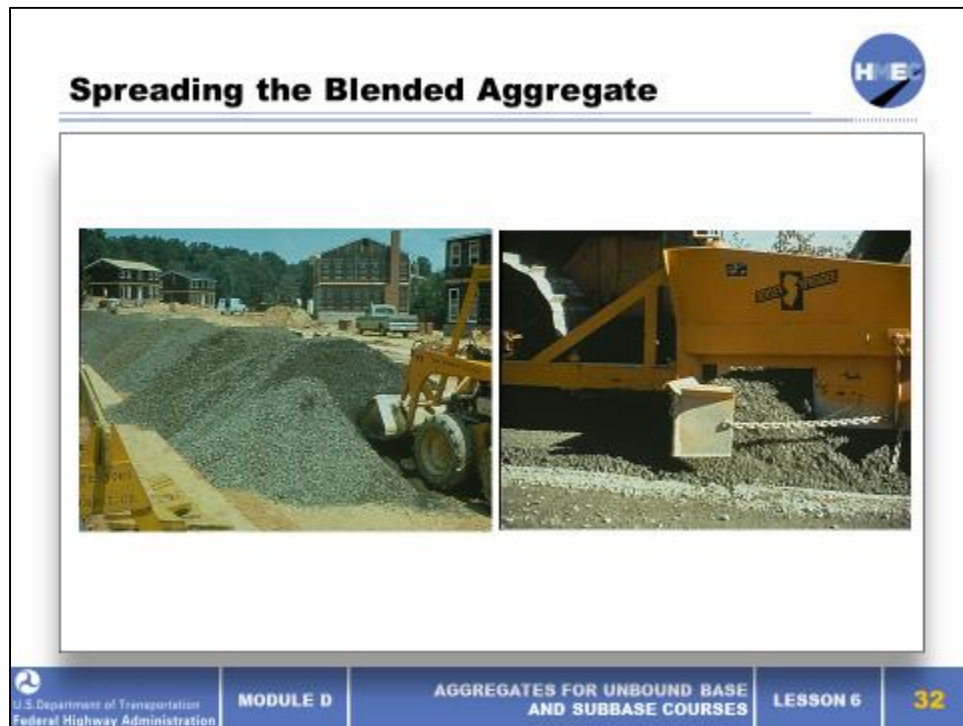
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## Slide 32



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.

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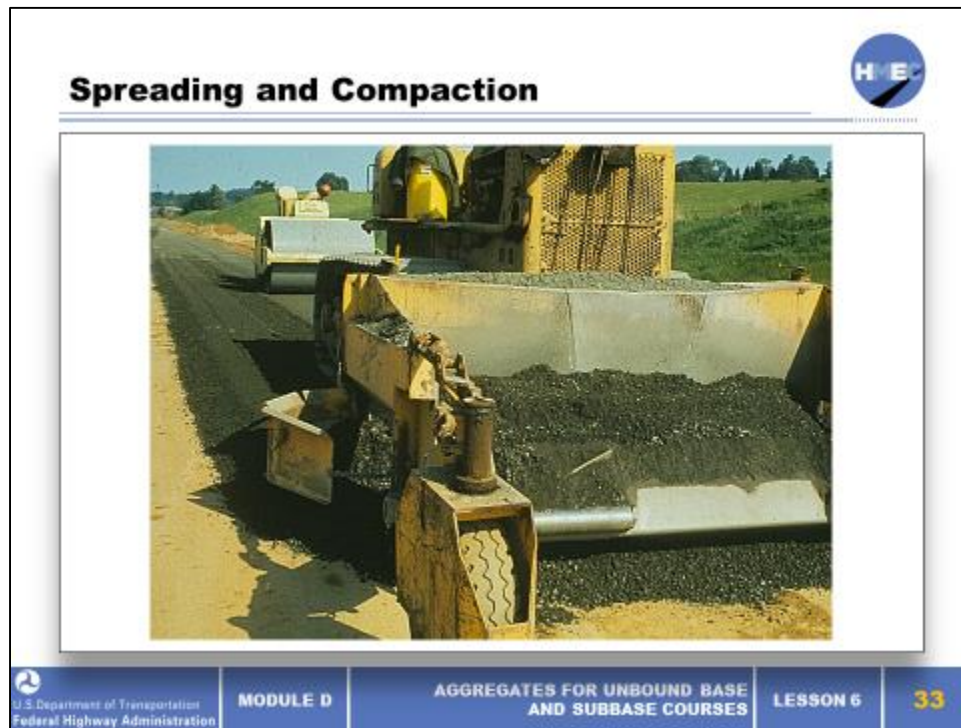
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## Slide 33



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?



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MODULE 3

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[illegible]

## Slide 35

### Constructing Single and Multiple Lift Base and Subbase Layers



- Unbound aggregate layers may be constructed in single or multiple lifts depending on a number of factors
  - Gradation, particle shape, surface texture
  - Underlying support conditions
  - Available equipment
- A study conducted by the International Center for Aggregate Research (ICAR) investigated thick, single lift layers

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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.

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## Slide 36

### ICAR Study: Measured Properties

- The basis for comparison of the test sections were density versus depth profiles
- The density measurements were made using nuclear density gauges



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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).

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## Slide 37



### ICAR Study: Test Sections

- A total of six test sections were constructed in three different States to assess the feasibility of constructing thick lifts for unbound aggregate base courses
- Texas: 12- and 21-in. lifts
- Georgia: 13-in. lift and 6- and 7-in. control lift
- Tennessee: 12- and 14.5-in. lifts

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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.

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## 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.

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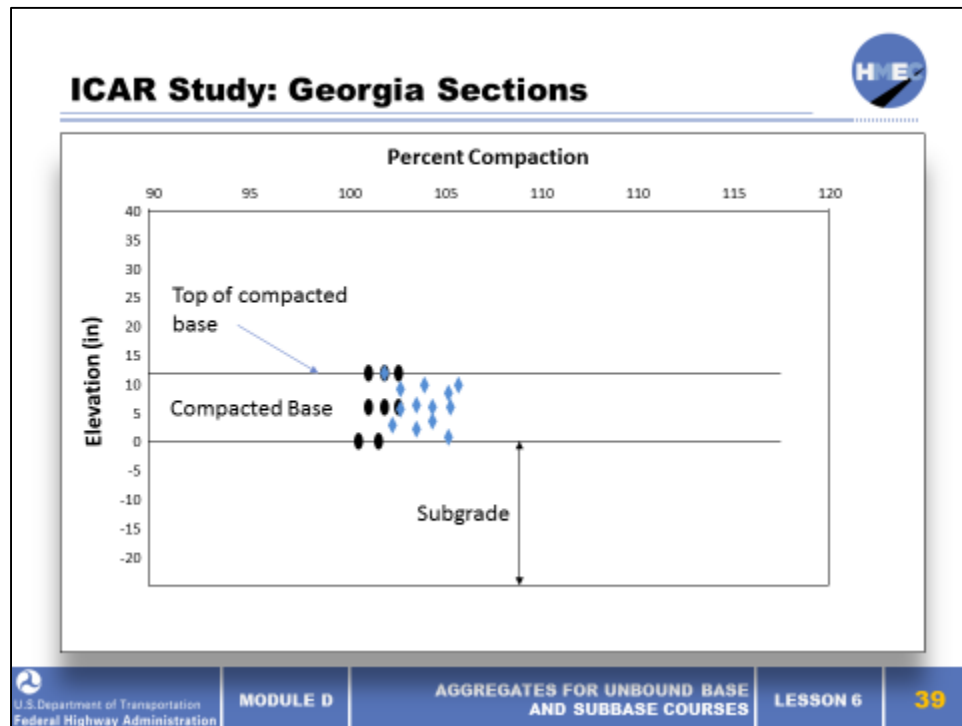


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## Slide 39



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.

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## Slide 40


### ICAR Study: Conclusions and Recommendations



- Density requirements can be met with thicker layer
- Vibratory smooth drum and vibratory sheepsfoot rollers provided similar results
- Recommend lift thickness: 4–13 in.



What has been your experience using locally available aggregates on workable lift thicknesses?



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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.

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## 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, daylighted system. Permeable bases should only be used if there is a commitment for long-term maintenance.

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## Slide 42

### Permeable Bases

- Unbound permeable bases are open-graded crushed angular aggregate with minimal fines
- The tradeoff with low fines is stability and potential problems with compaction



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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.

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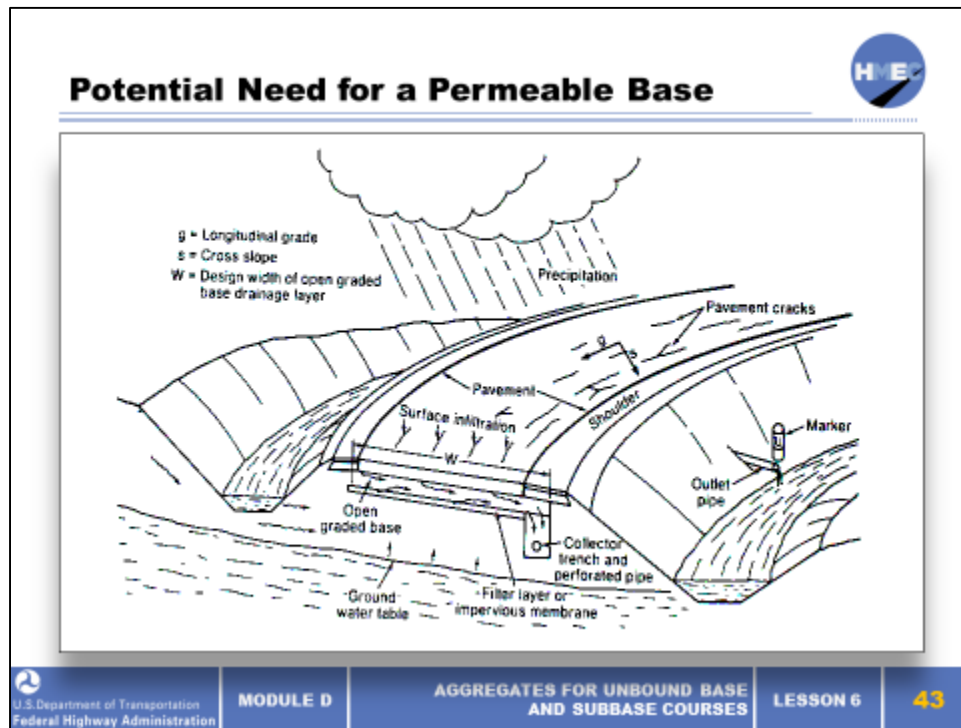
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## Slide 43



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.

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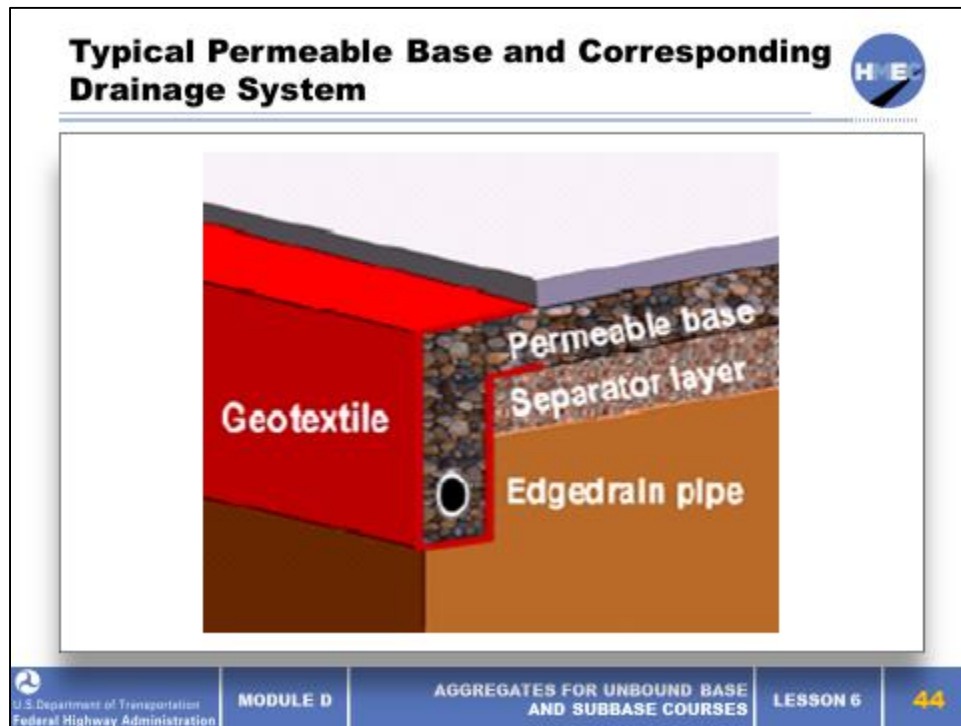
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## Slide 44



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




### Determining Permeability

- The permeability of the aggregate base can be characterized by the coefficient of permeability or “K”
- “K” is a vertical measure of permeability that is generally determined by one of the following standard test methods:
  - Falling head permeameter
  - Constant head permeameter



Note this is NOT the same as the modulus of subgrade reaction, also designated as “k.”

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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.

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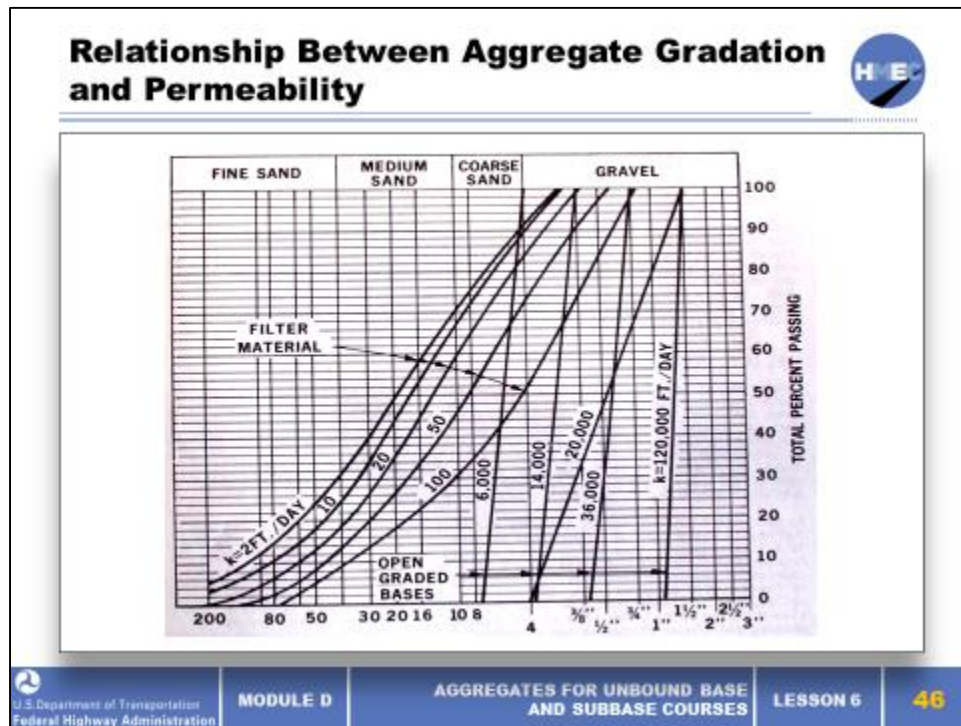
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## Slide 46




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.

## Slide 47



### Density Specifications

- Density specifications conform to either AASHTO T 99 (Standard Proctor) or T 180 (Modified Proctor)
- The T 180 specification uses a much higher compactive effort and is suitable for most combined aggregate gradations used for unbound bases and subbases
- The moisture-density relationship is established in the laboratory and verified by one of the methods previously mentioned
- The majority of agency specifications call for 95–100% of the T 180 maximum density (or 101–105% T 99)

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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.

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## Slide 48



### **Determining In-place Density**

- The in-place density of unbound aggregate base and subbase materials is the primary quality assurance check performed in the field
- Deviations in density can be indicative of changes in gradation, soft spots in the subgrade, inconsistent compactive effort, and changes in thickness
- There are three methods typically used to determine in-place density:
  - Nuclear density test (AASHTO T 310)
  - Sand cone test (AASHTO T 191)
  - Water balloon test (ASTM D 2167)

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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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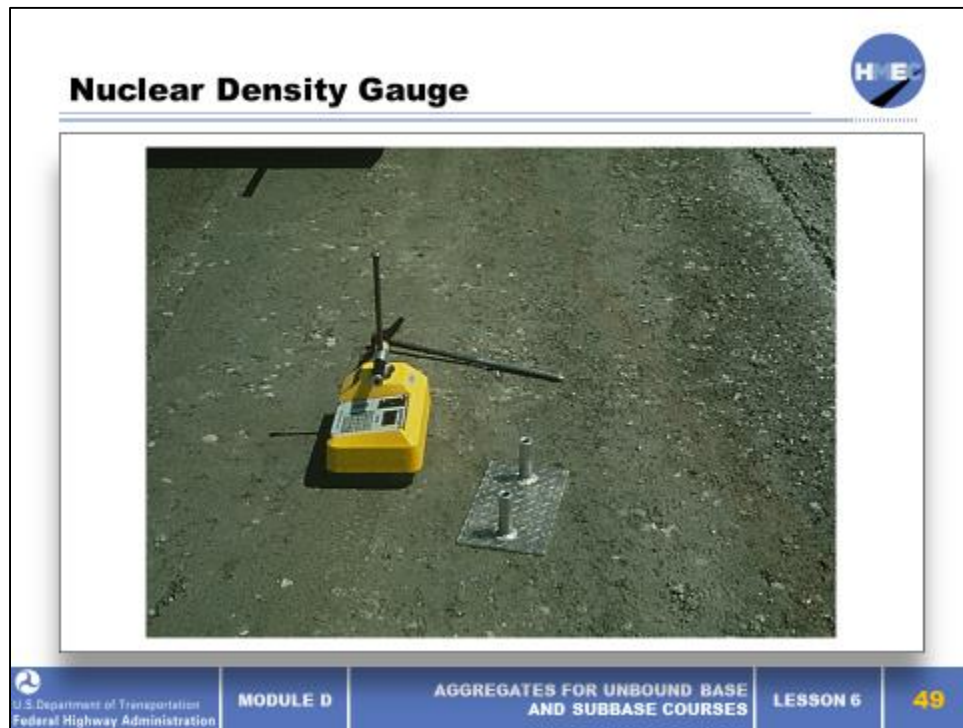
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## Slide 49



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.

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## Slide 50



## **Nuclear Density Test**

- 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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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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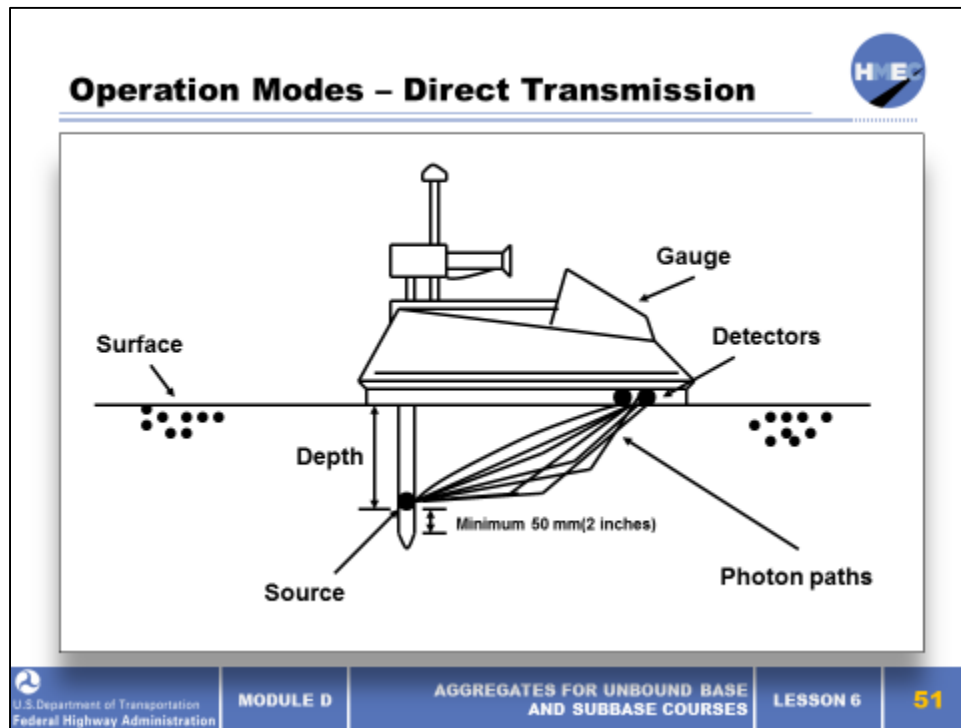
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## Slide 51



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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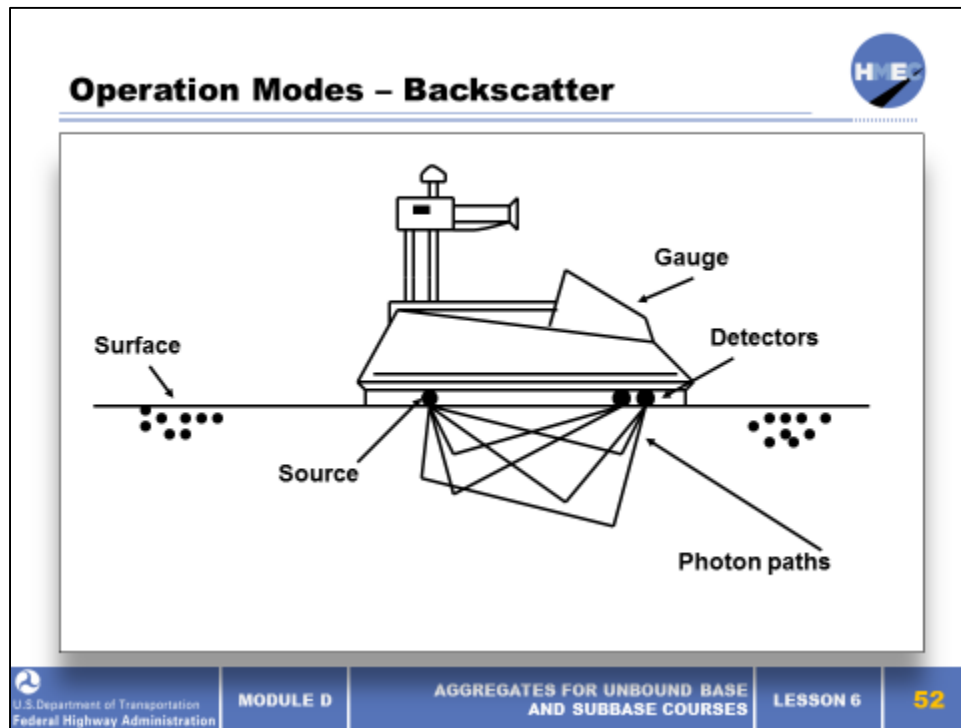
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## Slide 52



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.

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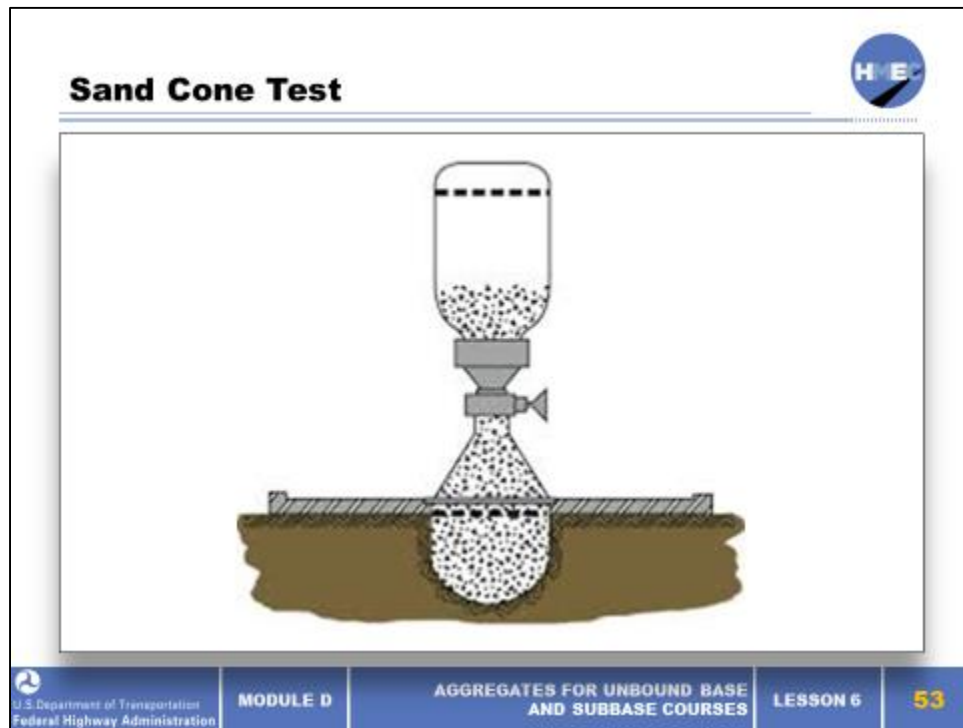
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## Slide 53



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

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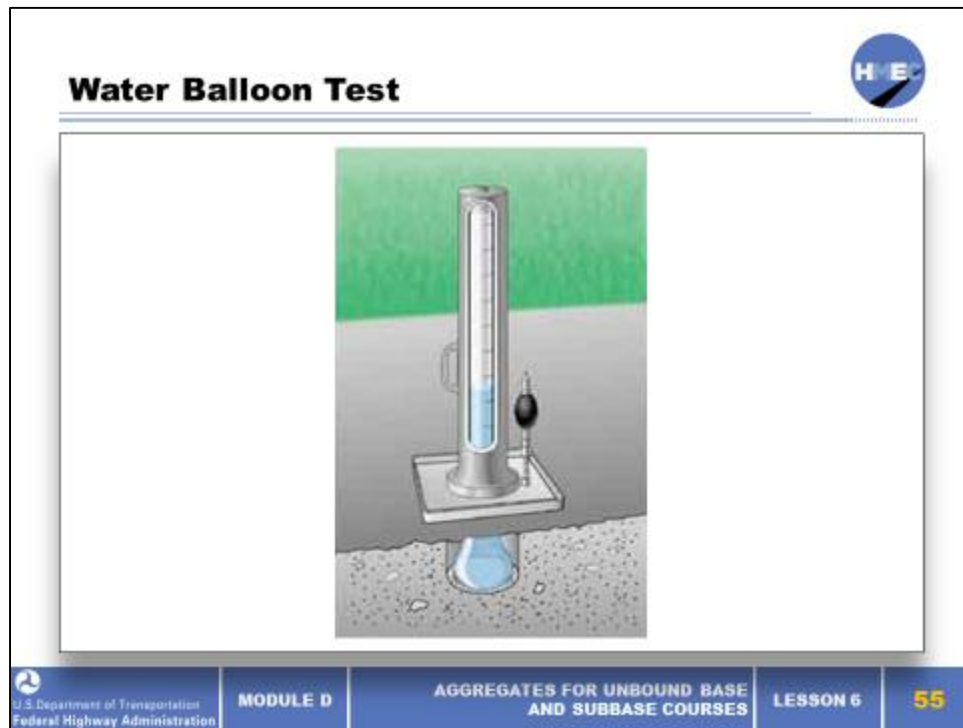
Slide 54

## Sand Cone Test



- 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

## Slide 55



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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## Slide 56


## Importance of Compaction and Proper Density



- Why is density important?
- What are the implications of not achieving target densities in unbound granular bases and subbases?
- What type of density testing is conducted by your agency?

 Why is density important? What are the implications of not achieving target densities in unbound granular bases and subbases?

 What type of density testing is conducted by your agency?

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MODULE D

AGGREGATES FOR UNBOUND BASE  
AND SUBBASE COURSES

LESSON 6

56

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.

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## Slide 57



### Unbound Base and Subbase Acceptance

- The process for accepting unbound base and subbase materials varies somewhat by agency
- Agencies may specify one of the following criteria for acceptance:
  - In-place density
  - Durability
  - Abrasion resistance
  - Gradation
  - Other

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AGGREGATES FOR UNBOUND BASE  
AND SUBBASE COURSES

LESSON 6

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.

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## Slide 58



### Common Acceptance Practices

- What acceptance standards do you routinely use at the production facility?
- Do you perform tests and have specific acceptance criteria when the aggregates are delivered to the job site?
- What do you do when a material or density is not in compliance?

 What are common acceptance criteria for unbound aggregate bases and subbases? How does it compare to other agencies?

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AGGREGATES FOR UNBOUND BASE  
AND SUBBASE COURSES

LESSON 6

58

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

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## Slide 59



## 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

 U.S. Department of Transportation Federal Highway Administration	MODULE D	AGGREGATES FOR UNBOUND BASE AND SUBBASE COURSES	LESSON 6	59
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# HMEC

Highway Materials Engineering Course

Lesson 7: Aggregates for Stabilized Bases



## Aggregates for Transportation Construction Projects

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MODULE

# D

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# 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.

## Slide 3

### Introduction and Function of Stabilized Bases



- Stabilized bases are used when it is necessary to improve locally available materials for use as a base course
- Stabilized bases are sometimes preferred over unbound aggregate bases for a variety of reasons:
  - 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
  - Pumping of the support layers in a rigid pavement is greatly reduced



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MODULE D

AGGREGATES FOR STABILIZED BASES

LESSON 7

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.

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## Slide 4

### Types of Stabilized Bases

- There are three types of stabilized bases in common use
  - Asphalt (asphalt-treated bases or ATB)
  - Portland cement (cement-treated bases or CTB)
  - Lime-fly ash
- Each of these types has application to a wide variety of conditions
- One of these options will likely prove to be the best-suited solution

What types of stabilized bases are you familiar with?

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MODULE D

AGGREGATES FOR STABILIZED BASES

LESSON 7

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.

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## Slide 5

### Benefits and Limitations of Stabilized Versus Unbound Aggregate Bases



- Structural thickness:
  - Stabilized bases are a design element and as such can potentially reduce the overall thickness of the pavement structure
  - Unbound bases have virtually no effect on slab thickness in rigid pavement design but have considerable influence on flexible pavement design thickness
- Material quality:
  - Stabilized bases may allow the use of marginal or poor quality materials under certain circumstances
  - Unbound materials must be of high quality, as discussed in Lesson 6

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AGGREGATES FOR STABILIZED BASES

LESSON 7

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.

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## Slide 6

### Benefits and Limitations of Stabilized Versus Unbound Aggregate Bases



- Pavement performance:
  - Stabilized bases generally improve long-term pavement performance if designed and constructed correctly
  - Unbound aggregate bases also generally improve pavement performance
- Cost:
  - Stabilized bases are constructed at an increased cost relative to unbound aggregate bases
  - Overall cost must be assessed on a project level

 Based on your experiences with unbound and stabilized bases, which have you found to be the most cost effective?

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LESSON 7

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.

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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?




## Slide 8

### **Selection of the Most Appropriate Stabilizer**



- The selection of the most appropriate stabilizer is based on two primary factors:
  - Amount of material passing the #200 sieve (fines)
  - The plasticity index (PI) of the fines
- Additional considerations may include:
  - Mineralogy (reactivity)
  - Cost
  - Available equipment
  - Expertise of the contractor

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MODULE D

AGGREGATES FOR STABILIZED BASES

LESSON 7

8

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

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## 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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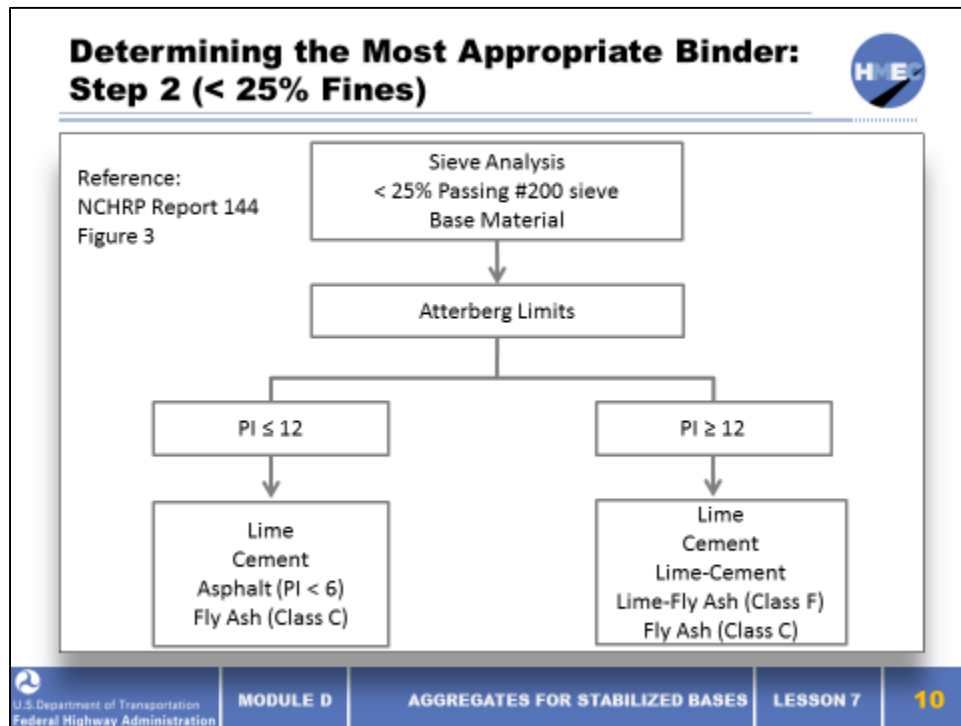
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## Slide 10



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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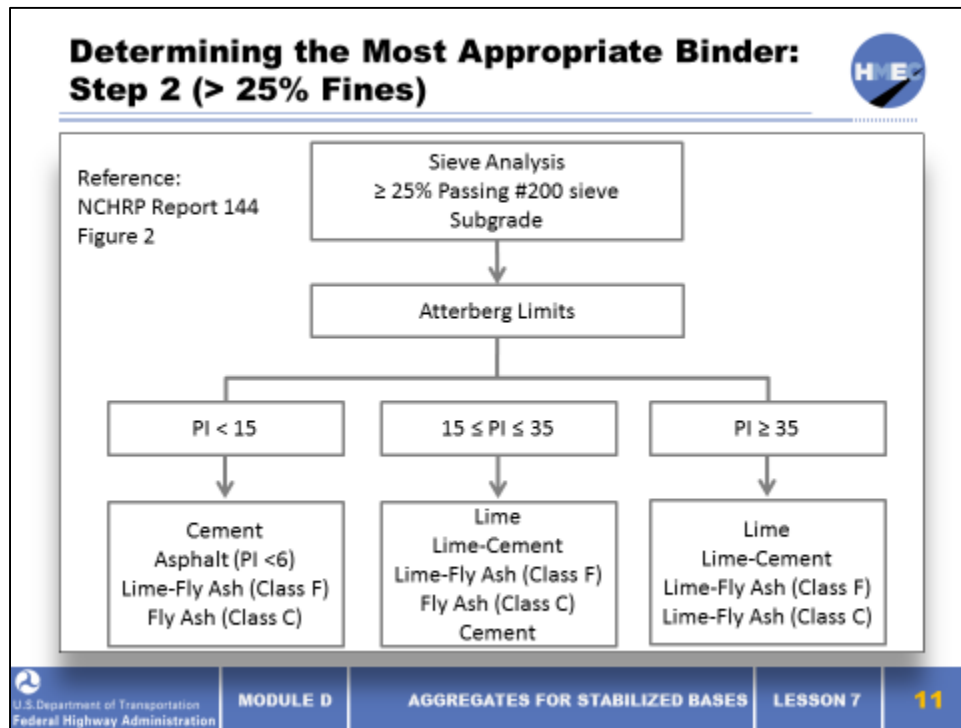


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## Slide 11



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

- 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?




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This image shows a blank sheet of white paper with horizontal ruling lines. The lines are evenly spaced and run across the width of the page. There are no margins, text, or other markings on the paper.

## Slide 13

### Stabilization Mechanism – Chemical

- Portland cement and lime-fly ash stabilization are predominantly chemical reactions
- Portland cement undergoes the same basic reaction as in PCC and forms similar hydration products (C-S-H and CH)
- Both hydrated and quick lime can be used as a binder



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LESSON 7

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

### Stabilization Mechanism – Mechanical

- Asphalt stabilization is a mechanical process in which the asphalt cement or emulsion/cutback causes the aggregate particles to adhere to one another
- Unlike Portland cement and lime-fly ash stabilization, fines are actually detrimental to performance
- Asphalt stabilization relies on adhesion and cohesion between the aggregate particles



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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.

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Slide 15


## Types and Use of Stabilized Aggregate Bases




We have looked at a number of different options for stabilized bases. Based on your experiences;

- How widely are the various stabilized bases used in your state?
- Are they used predominantly in rigid or flexible pavements?





Consider experiences and agency policies related to the types and use of stabilized aggregate bases.

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AGGREGATES FOR STABILIZED BASES

LESSON 7

15

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

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## Slide 16

### Best Practices for Stabilized Bases

- Current practices regarding asphalt, Portland cement, and lime-fly ash stabilization
  - Overall stabilization process
  - Desirable engineering properties
  - Expected performance
  - Design criteria



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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.
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## Slide 17

### Asphalt – Process

- 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 are road mixed materials that are mixed and compacted on the roadway or plant mixed





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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 – Engineering Properties**



- The most important strength-deformation parameter for asphalt-stabilized bases is the resilient modulus
- Resilient modulus is a function of aggregate properties, asphalt properties, mix design, construction, and environmental conditions, particularly temperature
- Typical resilient modulus values range from approximately 200,000 pounds per square inch (psi) to over 1,000,000 psi
- Dense-graded asphalt treated bases provide a waterproofing membrane that can reduce moisture damage to both the subbase and subgrade
- Open-graded asphalt-stabilized bases allow for free draining of the water that infiltrates the surface of the pavement

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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.

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## Slide 19

### Asphalt – Performance

The performance of asphalt-stabilized bases has been very good when they are designed and constructed correctly

- Have you experienced any issues regarding the construction of asphalt-stabilized bases?



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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.

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## Slide 20



### Asphalt – Design Requirements

- Most base courses can be effectively stabilized by 2–3% asphalt binder by weight of aggregate
- The required aggregate properties include the following:
  - Works best with GW, GM, GC, SW, SP, SM, and SC materials
  - The most appropriate AASHTO materials include: A-1-a, A-1-b, A-2-4, A-2-5, A-2-6, A-2-7, and A-3
  - High percentage of fines is detrimental
- Stiffer asphalt grades are required for high traffic volumes and warmer climates while softer asphalt grades are recommended for colder climates
- Asphalt stabilized bases can make use of recycled asphalt pavement (RAP)

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LESSON 7

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

### Portland Cement – Process

- 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, and then thoroughly blending and compacting
  - In a pug mill or central batch plant and then hauling to the job site for placement and compaction



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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

## Portland Cement – Engineering Properties



- Target 500 psi for rigid and 750 psi for flexible pavement minimum strengths, unconfined compressive strength can be as high as 2,000 psi
- Typical elastic modulus: 1,000,000 psi
- Typical modulus of rupture: 200 psi
- The CTB provides both flexural and tensile strength as compared with unbound granular bases
- Drying shrinkage will occur to varying degrees
- Dense-graded, cement-treated bases provide a waterproofing membrane that can reduce moisture damage to the subgrade
- Open-graded, cement-stabilized bases allow for free draining of the water that infiltrates the surface of the pavement




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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

### Portland Cement – Performance

The performance of cement-stabilized bases has been very good when they are designed and constructed correctly

- Have you experienced any issues regarding the construction of Portland cement-stabilized bases?



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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.

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## Slide 24

### Portland Cement – Design Requirements

- Most base courses can be effectively stabilized by 3–5% Portland cement by weight of aggregate
- The required aggregate properties include the following:
  - It is necessary to have a minimum of 45% passing the #4 sieve
  - The PI < 30 (refer to the selection flow chart)
  - Less than 1% sulfate (to avoid adverse reactions with the cement)
  - Non-reactive aggregates (for long-term durability)
- Type II cement is normally used
- It has been successfully used in recycling old pavements

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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.

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## Slide 25

### Lime-Fly Ash – Process

- Lime-fly ash stabilized bases can be constructed:
  - On the grade by placing a uniform layer of properly mixed aggregate and adding the correct amount of lime, fly ash and water, and then thoroughly blending and compacting
  - In a pug mill and then hauling to the job site for placement and compaction



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AGGREGATES FOR STABILIZED BASES

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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.

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## Slide 26

### Lime-Fly Ash – Engineering Properties

- Seven-day compressive strength is generally in the range of 500 to 1,000 psi (note that strengths of approximately 1,700 psi are achievable)
- Flexural strength equal to approximately 20% of compressive strength and is generally about 150 psi
- Elastic modulus ranges from 1,000,000 to 2,500,000 psi but is typically assumed at 1,500,000 psi

 The durability of the material is highly dependent on the nature of the components, mix characteristics, and environment.



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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.

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## Slide 27

### Lime-Fly Ash – Performance

The performance of LFA-stabilized bases has been very good when they are designed and constructed correctly

- Does your agency use LFA-stabilized bases and if so, what issues have you encountered in construction?



Does your agency use LFA-stabilized bases and if so, what issues have you encountered in construction?

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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.

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## Slide 28

### **Lime-Fly Ash – Design Requirements**



- Most LFA base courses can be effectively stabilized by the following:
  - A lime content of 2.5–5% by weight of aggregates
  - A fly ash content of approximately 10–18% fly ash
- The design criteria is generally based on a minimum compressive strength (400 psi in many cases) and the maximum loss after freeze/thaw testing (10–14% typically)
- The durability of the aggregates is typically assessed by LA abrasion and sulfate soundness testing
- The use of recycled materials is acceptable and this technique is sometimes used with full-depth reclamation

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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.

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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?

  
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**29**

[illegible]

Slide 30

## Exercise 1 Solution: Best Practices for Selecting Stabilized Bases




Asphalt	Portland Cement	Lime-Fly Ash
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[illegible]

## Slide 31

### Desirable Aggregate Properties for Stabilized Bases

- The properties required for stabilized bases are very similar to unbound materials but have several differences, including this key difference:
  - The need for aggregates to “lock together” in unbound materials to provide strength
  - The binder in stabilized materials binds the aggregates together to provide strength



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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.

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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

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.

[illegible]

## Slide 33

<b>Guidelines for LFA Stabilization</b>				
<b>Mix Component</b>	<b>Mix Aggregate</b>			
	Crushed Stone	Gravel	Sand	Slag
<b>(a) Mix Proportions – Percent by Weight</b>				
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
<b>Sieve Size</b>	<b>(b) Aggregate Gradation – Percent Passing</b>			
	Crushed Stone	Gravel	Sand	Slag
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

### **Gradation, Percent Fines, and Compaction**



- As can be seen by examination of the materials passing the #200 sieve, there is not a clearly defined relationship in terms of fines content
- The primary differences in gradation are not so much a matter of unbound versus stabilized bases, but rather whether it is an open-graded, drainable base or a dense-graded base
- Fines are necessary in unbound bases to facilitate compaction and to achieve target density
  - Too high of a fines content can lead to instability
- In the case of stabilized bases, the fines are not as important for compaction and density since a portion of the void space is occupied by the binder

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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.

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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?

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LESSON 7

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Slide 36

## Exercise 2 Solution: Best Practices for Constructing Stabilized Bases



Asphalt


Portland Cement

Lime-Fly Ash


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Slide 37

## Agency Processes for Accepting Stabilized Base Items



- 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?

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AGGREGATES FOR STABILIZED BASES

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## Slide 38



## Learning Outcomes Review

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

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MODULE D

AGGREGATES FOR STABILIZED BASES

LESSON 7

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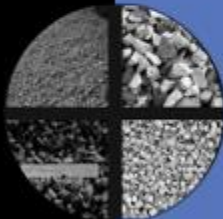
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# HMEC

Highway Materials Engineering Course

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



## Aggregates for Transportation Construction Projects



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MODULE  
**D**

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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.

Slide 3

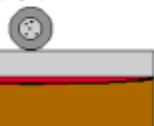
## Fundamentals of Bases and Subbases



**The base layer in a rigid pavement serves several functions:**

- Acts as a construction platform
- Minimizes pumping
- Can reduce moisture and temperature effects in the subgrade
- Helps to uniformly distribute load

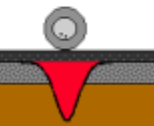
Concrete (Rigid) Pavement



**The base and subbase layers in a flexible pavement do the following:**

- Act as a structural element to dissipate stresses
- Can reduce moisture and temperature effects in the subgrade


Asphalt (Flexible) Pavement



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

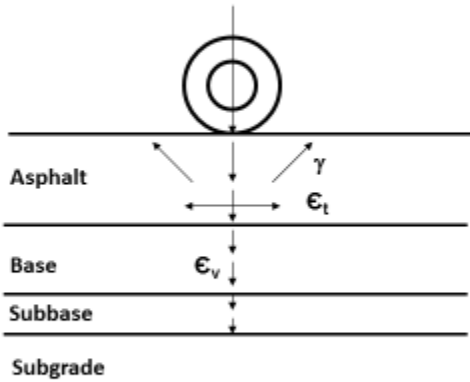
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## Slide 4




### Flexible Pavement Loading

- Are there any other critical stresses in this flexible pavement?




 Are there any other critical stresses in this flexible pavement?

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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.

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## Slide 5

### Rigid Pavement Loading

- Are there any other critical stresses in this rigid pavement?

The diagram shows a cross-section of a rigid pavement system. At the top, a circular load is applied to the surface. Below the surface is a layer labeled 'PCC' (Portland Cement Concrete). Underneath the PCC is a layer labeled 'Base', and at the bottom is a layer labeled 'Subgrade'. A series of downward arrows represent the load being distributed through the PCC slab. A horizontal double-headed arrow at the bottom of the PCC layer is labeled  $\epsilon_t$ , indicating tensile stress. The entire diagram is enclosed in a rounded rectangle.

Are there any other critical stresses in this rigid pavement?

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LESSON 8

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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.

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## Slide 6

### Comparison of Base and Subbase Types

- What are the benefits of unbound bases? The drawbacks?
- What are the benefits of stabilized bases? The drawbacks?



What are the benefits and drawbacks of unbound bases? What are the benefits and drawbacks of stabilized bases?

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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.

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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

## Slide 8


## Design Considerations for Flexible and Rigid Pavements



- Pavement design methodologies characterize bases and subbases by:
  - Strength and deformation
  - Erodibility (maintaining a level of support)
- Strength/deformation parameters differ for flexible and rigid pavements
- Objective of pavement structural design is:
  - To determine the required layer thickness
  - To provide a long-lasting pavement that can withstand imposed traffic loads and environmental conditions
  - Play a major role in controlling the magnitude of the pavement stresses, strains, and deformations



The common goal in both of these approaches is to minimize stress, strain, and deformations within each of the structural layers.

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LESSON 8

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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

### Design Considerations for Flexible and Rigid Pavements



- The base and subbase material properties considered for design generally include the following:
  - Resilient modulus for unbound materials
  - Elastic modulus for cement and lime-fly ash-stabilized materials
  - Dynamic modulus for asphalt-stabilized materials
  - Poisson's ratio for all materials
  - Modulus of subgrade reaction (k) for rigid pavements (composite k)

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**LESSON 8**

**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.

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## Slide 10

## Layer Coefficients for Unbound Bases and Subbases

- The layer coefficient is basically 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



 Based on your knowledge, what values does your agency typically assign to unbound aggregate bases—cement treated base, asphalt treated base, and lime-fly ash aggregate?

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Older versions of the AASHTO pavement design method (1972, 1986, and 1993) used the concept of structural layer coefficients ( $a_i$ ) 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.

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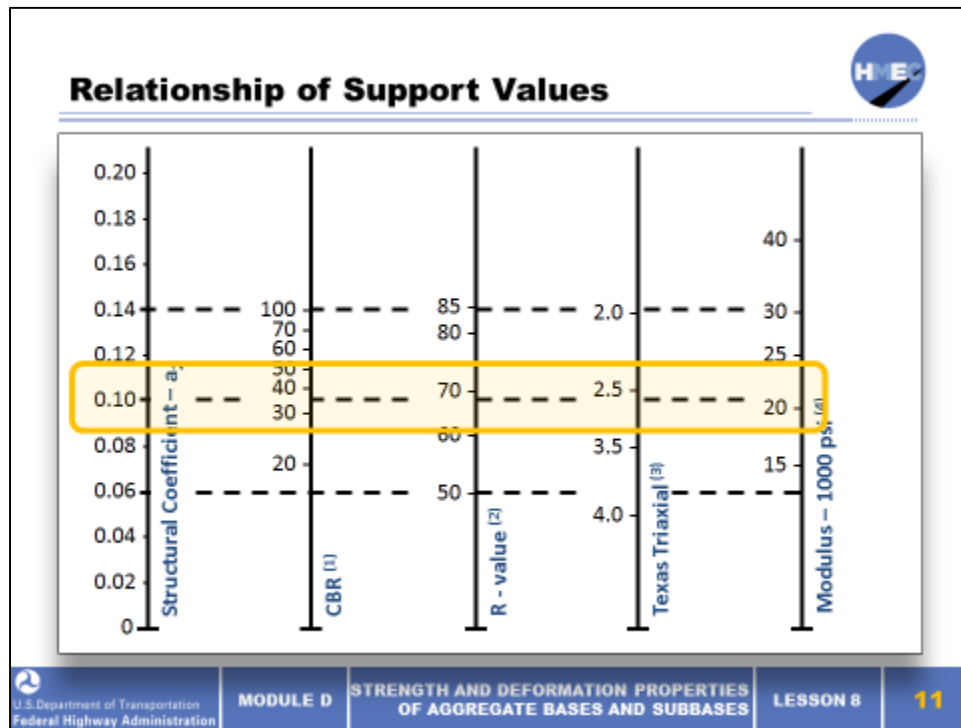
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## Slide 11







## Slide 12

### Layer Coefficients for Stabilized Bases

- Structural layer coefficients are used for all layers comprising the SN for a given design
- Typical layer coefficient values for stabilized bases are as follows:
  - Lime-fly ash-stabilized aggregate base: 0.14
  - Cement-treated aggregate base: 0.20
  - Bituminous-treated aggregate base: 0.20

 Substantial variation is possible based on the stabilized materials and mix design.

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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.

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Slide 13


## How Layer Coefficients are Used in Design

- 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?



MODULE D

STRENGTH AND DEFORMATION PROPERTIES OF AGGREGATE BASES AND SUBBASES


LESSON 8

13


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## Slide 14

### Strength and Deformation Characteristics of Bases and Subbases



- There are numerous methods to determine the strength and deformation characteristics of bases and subbases
  - Unbound or stabilized material
  - 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

 Which tests are performed by your agency?

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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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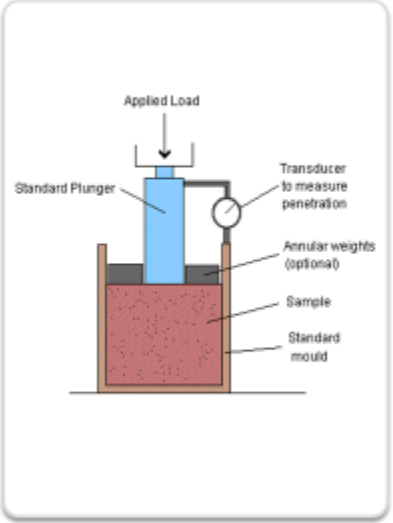
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## Slide 15

### California Bearing Ratio (CBR)

- An empirical test that relates the penetration of an unbound aggregate or soil sample relative to a crushed stone material
- The load is recorded at penetrations of 0.025, 0.05, 0.075, 0.100, 0.200, and 0.300 in
- The CBR is calculated as the ratio of the measured load at 0.10 in. penetration over the standard load of 1,000 pounds times 100



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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<sup>2</sup> 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  $[(600/1000) \times 100]$  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.


## Slide 16

### California Bearing Ratio (CBR)

- As is the case with many of the strength-deformation parameters, the CBR is related to other test methods as shown in this correlation to  $M_r$

$$M_r = 2555(\text{CBR})^{0.65}, \text{ psi}$$

 The CBR test is governed by the AASHTO T 193 test method.

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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.

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## 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.

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## Slide 18

**Field CBR**



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LESSON 8 18

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

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## 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.

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## 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.

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## Slide 21


## R Value Test



- The R value is calculated using the following formula:

$$R = 100 - [100 / ((2.5/D2)(P_v - 1)/P_h) + 1]$$

- Where:
  - $P_v$  = Vertical pressure = 160 psi
  - $P_h$  = Horizontal pressure corresponding to  $P_v$  = 160 psi
  - $D2$  = Displacement necessary to change pressure from 5 to 100 psi

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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




## R Value

- The R value has been used as a strength parameter in earlier versions of the AASHTO Pavement Design Guide
- Numerous relationships between M and the R value have been established

$$M_r = 1155 + 555(R), \text{ psi}$$

 The R value test is governed by the AASHTO T 190 test method.

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LESSON 8

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.

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## Slide 23

## Resilient Modulus of Unbound Base and Subbase Materials

- The resilient modulus test for unbound granular materials (bases and subbases) is the most representative laboratory characterization method for pavement support layers
- This procedure simulates varying levels of confinement and cyclic loading, thereby simulating the response of materials under traffic loading
- Many agency laboratories were equipped to perform resilient modulus testing on soils but not necessarily larger granular materials



The AASHTO T 307 test procedure is the prevailing standard for this procedure.

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MODULE D

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LESSON 8

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.

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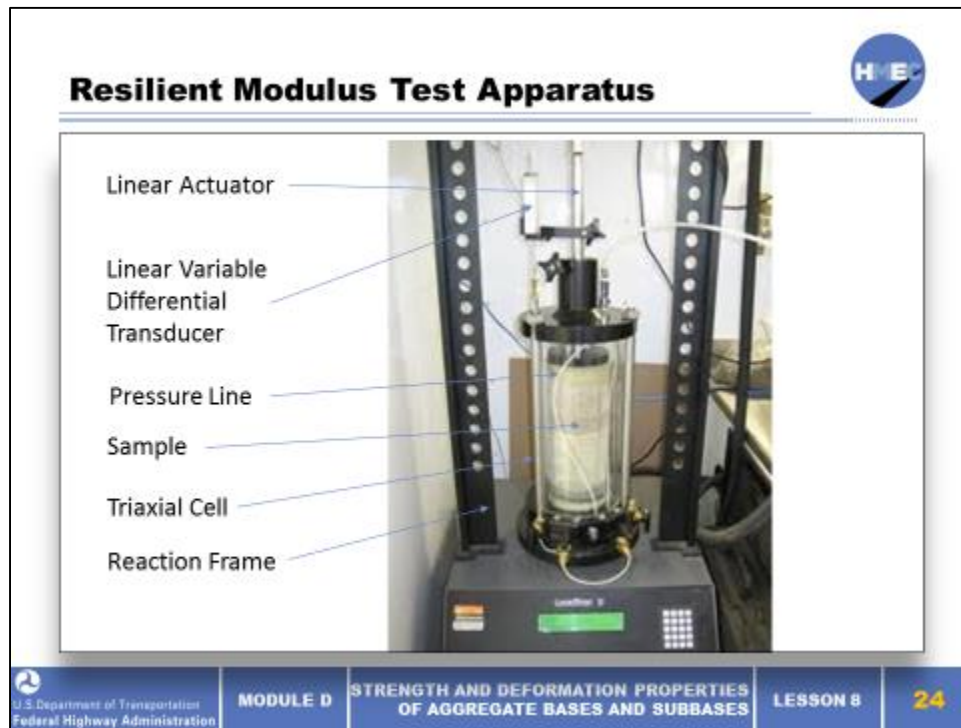
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## Slide 24



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.

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## Slide 25



### Resilient Modulus Test Sample

- The sample configuration is one of the issues with performing resilient modulus testing on large aggregate size materials
- The requirements for the sample are as follows:
  - Minimum diameter = 5 times maximum particle size
  - Minimum height = 2 times the diameter
  - Tested at the expected in-situ density and moisture content
  - Compacted with a vibratory compactor

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LESSON 8

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.

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## Slide 26

### **Resilient Modulus Sample Conditioning**



- Apply 500 conditioning cycles at:
  - Confining pressure: 15 psi
  - Cyclic stress: 13.5 psi
  - Constant stress: 1.5 psi
- If sample continues to decrease in height, continue until 1,000 cycles is reached

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**STRENGTH AND DEFORMATION PROPERTIES  
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**LESSON 8**

**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

### Resilient Modulus Sample Testing



- Apply 100 cycles for selected combinations of:
  - Confining pressures: 3, 5, 10, 15, 20 psi
  - Cyclic stress: 2.7, 4.5, 5.4, 8.1, 9.0, 13.5, 18.0, 27.0, and 36.0 psi
- Consult AASHTO T 307 for exact combinations

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**STRENGTH AND DEFORMATION PROPERTIES  
OF AGGREGATE BASES AND SUBBASES**

**LESSON 8**

**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.

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## Slide 28


### Calculating Resilient Modulus

- In its simplest form, the resilient modulus is calculated as:

$$M_r = \text{Repeated Stress} / \text{Recovered Strain}$$

- The term “resilient” indicates that the property of the material is measured under repeated constant stress that is significantly lower than the ultimate strength of the material

Based on your knowledge, is your agency able to perform resilient modulus testing on granular materials? If not, how is this value estimated for design?

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LESSON 8

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.

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## Slide 29

## Modulus of Stabilized Base Materials



- The modulus of stabilized materials is tested in a different manner than the resilient modulus of unbound granular materials
  - Asphalt-stabilized materials use the dynamic modulus
  - Portland cement-stabilized materials use the elastic modulus
  - Lime-fly ash-stabilized materials use the elastic modulus



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LESSON 8

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.

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Slide 30


## Dynamic Modulus of Asphalt-Stabilized Materials



- The dynamic modulus depends on temperature and rate of loading
- A modulus master curve is developed for these materials since the modulus is a function of both temperature and rate of loading



 Do you have familiarity with developing a master curve for the dynamic modulus of ATBs?

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LESSON 8

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).

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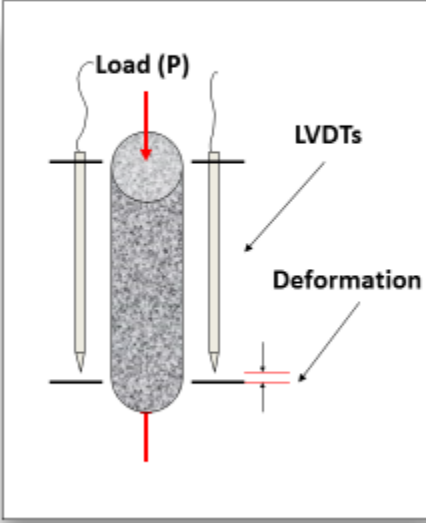
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## Slide 31

### Dynamic Modulus


$$E^* = \frac{\sigma_{\max}}{\epsilon_{\max}}$$

Where:

$\sigma$  = applied stress

$\epsilon$  = resultant strain

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LESSON 8

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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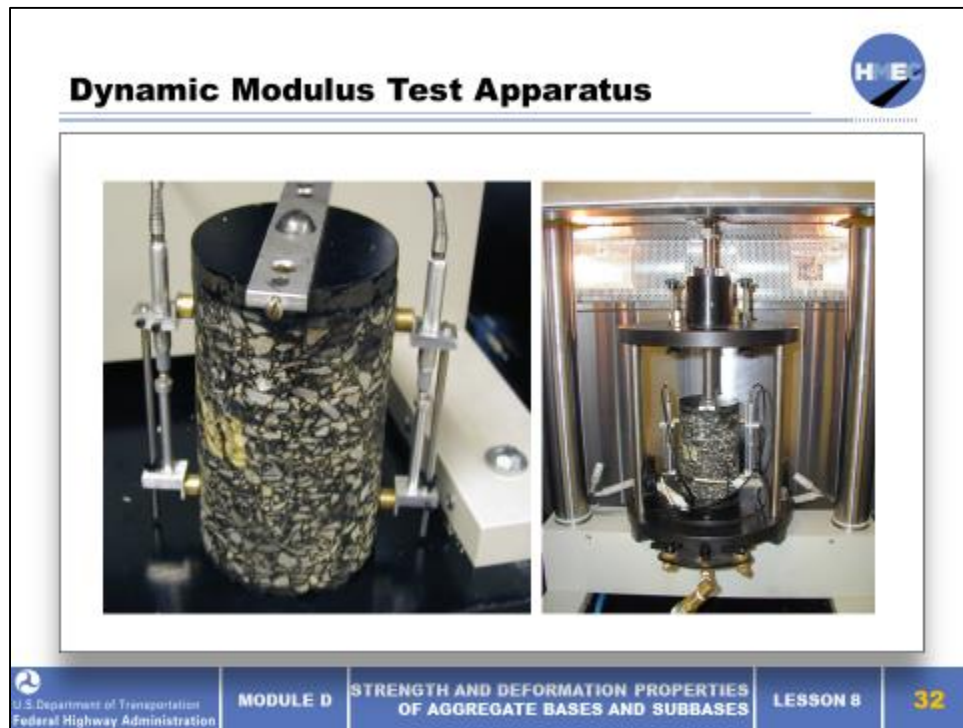
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## Slide 32



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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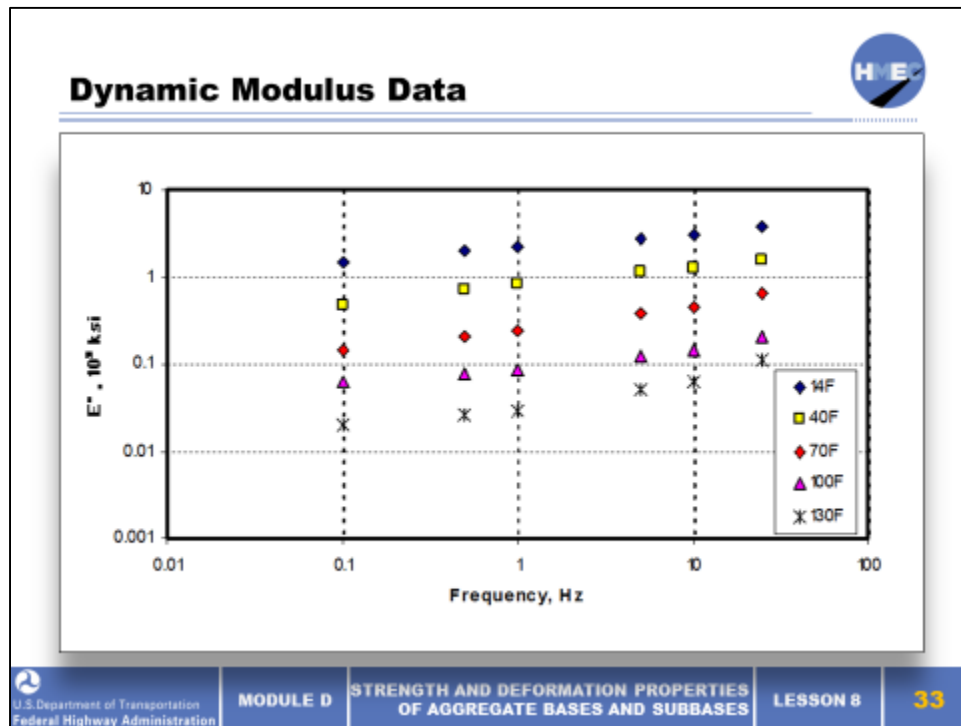
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## Slide 33



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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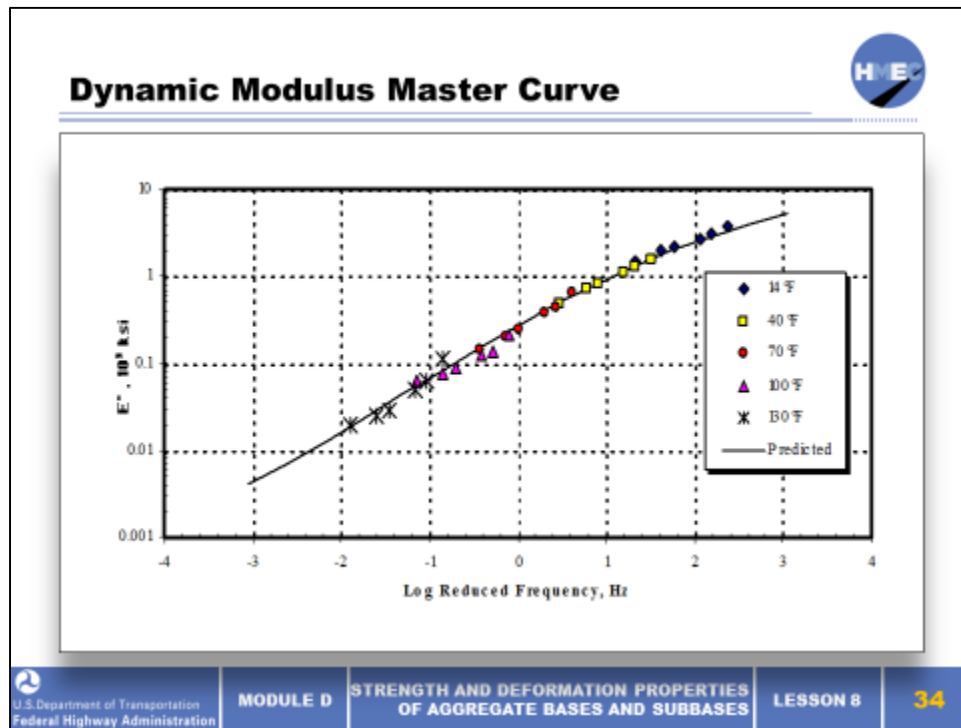
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## Slide 34



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


### Elastic Modulus – Portland Cement-Stabilized Materials




- The elastic modulus is not often determined in the laboratory
- The value is typically assumed based on the following correlation:

$$E = 57,000 (f'_c)^{0.5}, \text{ psi}$$

Where:  $f'_c$  = compressive strength, psi



The ASTM C 469 test procedure is the prevailing standard for this procedure.



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LESSON 8

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.

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## 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.

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## Slide 37


### Elastic Modulus Lime-Fly Ash-Stabilized Bases




- The elastic modulus is not often determined in the laboratory
- The value is typically assumed based on the following correlation:

$$E = 500 + q_u, \text{ psi}$$

Where:  $q_u$  = unconfined compressive strength, psi



The ASTM C 469 test procedure is the prevailing standard for this procedure.



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LESSON 8

37

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

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## Slide 38




### **In-Situ Resilient Modulus Determination**

- Resilient modulus can be determined in situ using:
  - A deflection testing device
  - One of several various back calculation techniques
- The most commonly used deflection device is the falling weight deflectometer (FWD)
- This is a non-destructive, rapid evaluation technique that is frequently used to assess the layer characteristics of existing pavements
- The FWD applies an impulse load to pavement surface and measures surface deflections at various radial distances



How does your agency determine in-situ modulus values for in-service pavements? Can you cite examples of where in-situ might be used?

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LESSON 8

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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.

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## 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

### **Falling Weight Deflectometer Testing**



- The FWD is designed to simulate the effects of moving traffic on the pavement and support layers
- Specific information regarding the FWD includes:
  - Impulse load to simulate traffic load: pulse width of 20–60 milliseconds
  - Circular load plate: 12-in. diameter
  - Load level 2,500–27,000 lbs.

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LESSON 8

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.

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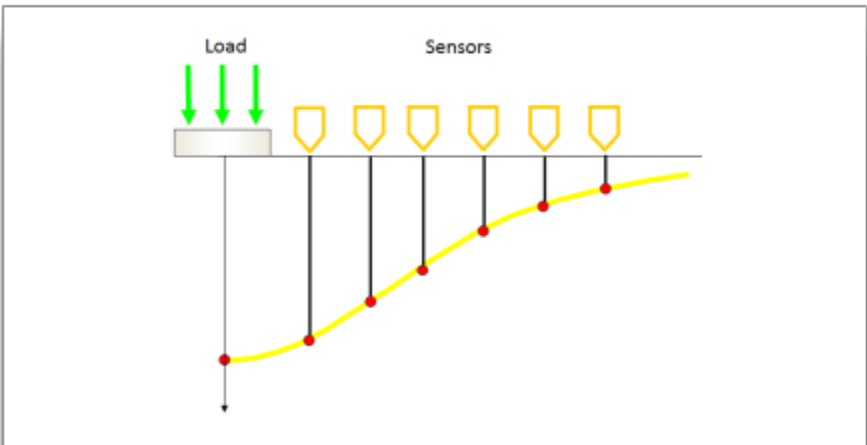
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## Slide 41

### Measurement of Surface Deflection



Load

Sensors

How do you think the stiffness of the pavement structure influences the surface deflections as shown on this slide?

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LESSON 8

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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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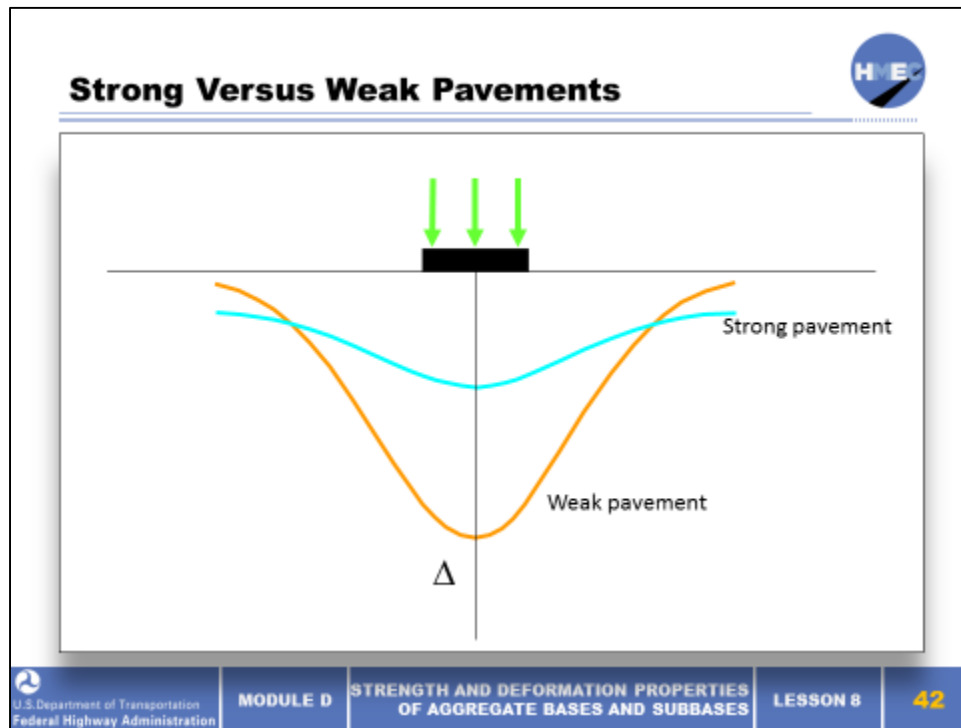
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## Slide 42



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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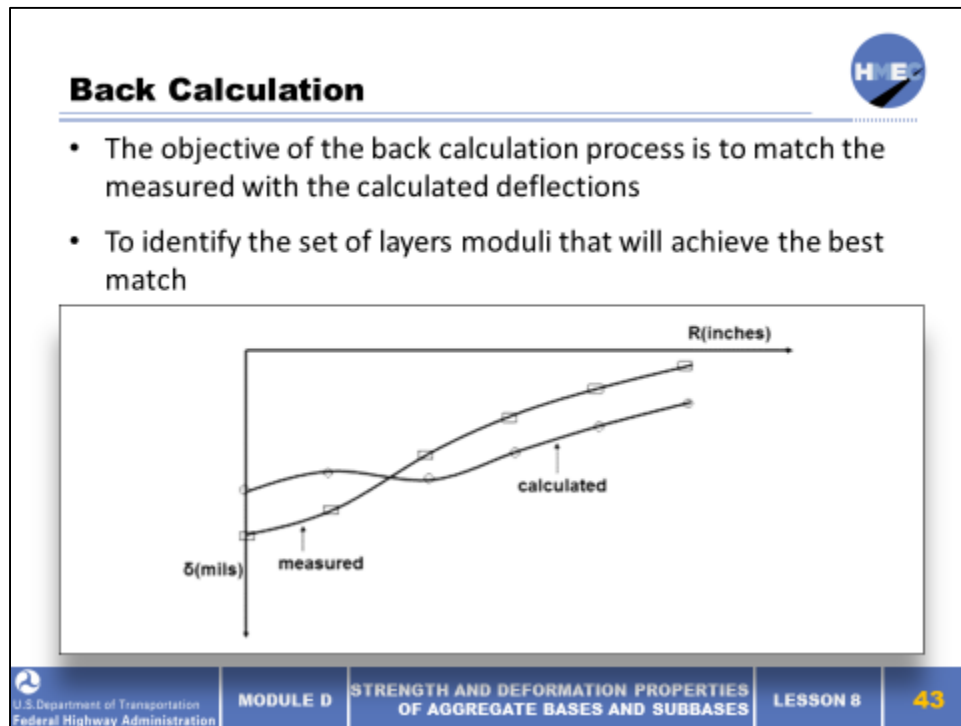
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## Slide 43



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




## Back Calculation

- Uses the multi-layer elastic theory
- The back calculated resilient modulus is appropriate for the stress conditions under the FWD test
- FWD load should be close to the anticipated traffic loading conditions



 What back calculation method does your agency use for analyzing FWD data?

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LESSON 8

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.

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## Slide 45



### Texas Triaxial Test

- The Texas triaxial test results are used for pavement design and are essentially a determination of the shear strength of unbound and stabilized bases
- This procedure has limited use and is not to be confused with the resilient modulus testing (triaxial tests) previously discussed

 For more details on this procedure, visit the Web site [www.txdot.gov](http://www.txdot.gov).

 U.S. Department of Transportation Federal Highway Administration	MODULE D	STRENGTH AND DEFORMATION PROPERTIES OF AGGREGATE BASES AND SUBBASES	LESSON 8	45
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This test procedure is used to provide input to a Texas pavement design procedure.

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## Slide 46



### Unconfined Compressive Strength

- The unconfined strength of a stabilized material is simply a uniaxial load test similar to a Portland cement concrete cylinder test
- The unconfined strength of an unbound material is only applicable to cohesive materials that can retain shape without confinement
- However, an unbound material may be tested in a triaxial cell (using the sample preparation already discussed) and using a very low confining pressure

 U.S. Department of Transportation Federal Highway Administration	MODULE D	STRENGTH AND DEFORMATION PROPERTIES OF AGGREGATE BASES AND SUBBASES	LESSON 8	46
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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.

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
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Slide 47




## WCT Wrap-Up

- 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?



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MODULE D


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OF AGGREGATE BASES AND SUBBASES

LESSON 8

47

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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	48
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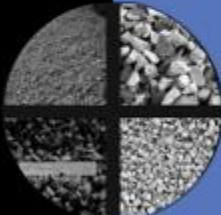
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# HMEC

Highway Materials Engineering Course

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



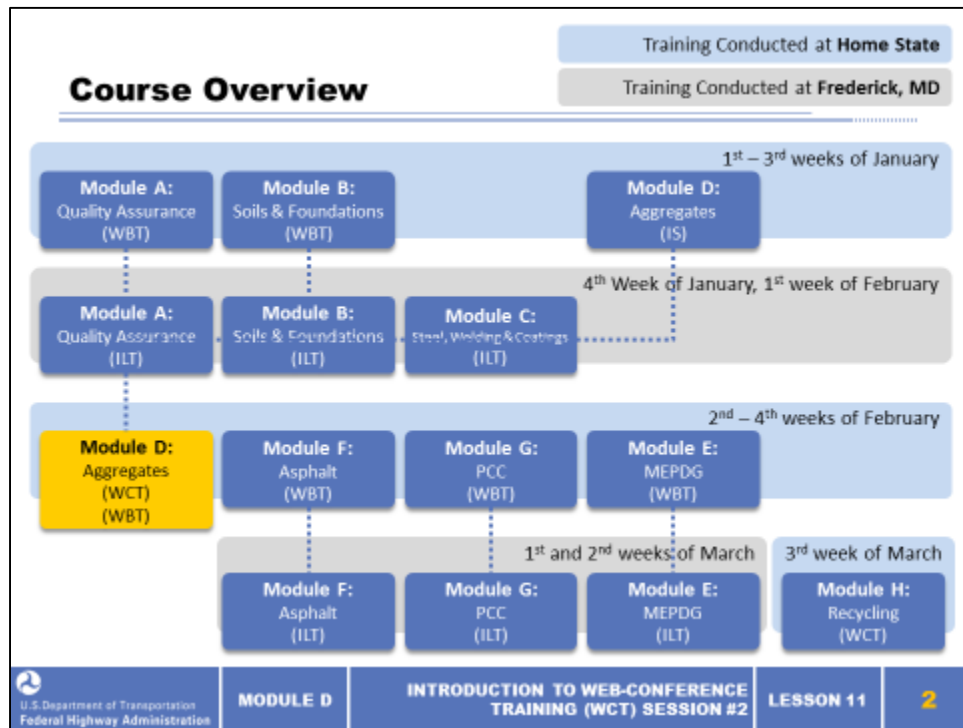
## Aggregates for Transportation Construction Projects

U.S. Department of Transportation  
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MODULE  
**D**

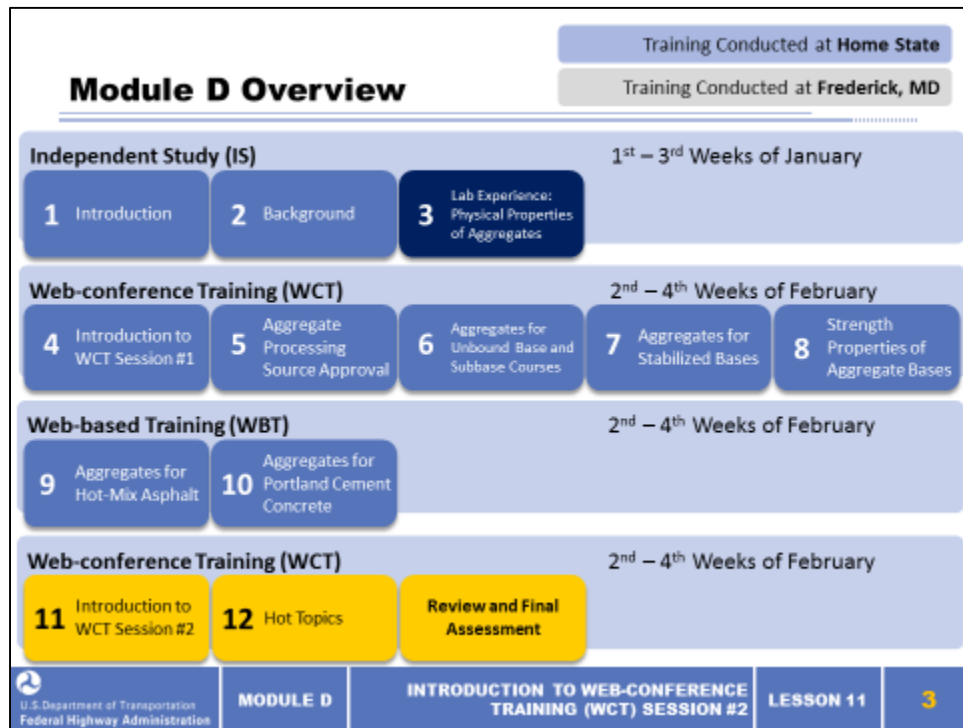
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## Slide 2





## Slide 3



Slide 4

## Lesson 11 Introduction



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.

Slide 5

## Agency Approaches to Quality Assurance



- 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.

Slide 6

## Sampling Procedures Used by Your Agency for HMA and PCC Aggregates

- 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.

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MODULE D

INTRODUCTION TO WEB-CONFERENCE  
TRAINING (WCT) SESSION #2


LESSON 11

6

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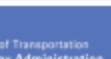
Slide 7

## Testing Procedures Used by Your Agency for Characterizing Aggregates



- 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.



**MODULE D**

**INTRODUCTION TO WEB-CONFERENCE TRAINING (WCT) SESSION #2**

**LESSON 11**

**7**

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Slide 8

### Frequency and Depth of HMA and PCC Plant Inspections Related to Aggregates



- 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?

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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Slide 1



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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](http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp_rpt_453.pdf)

### NCHRP Report 539

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**AASHTO and ASTM Standards**

ASTM D-2166

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