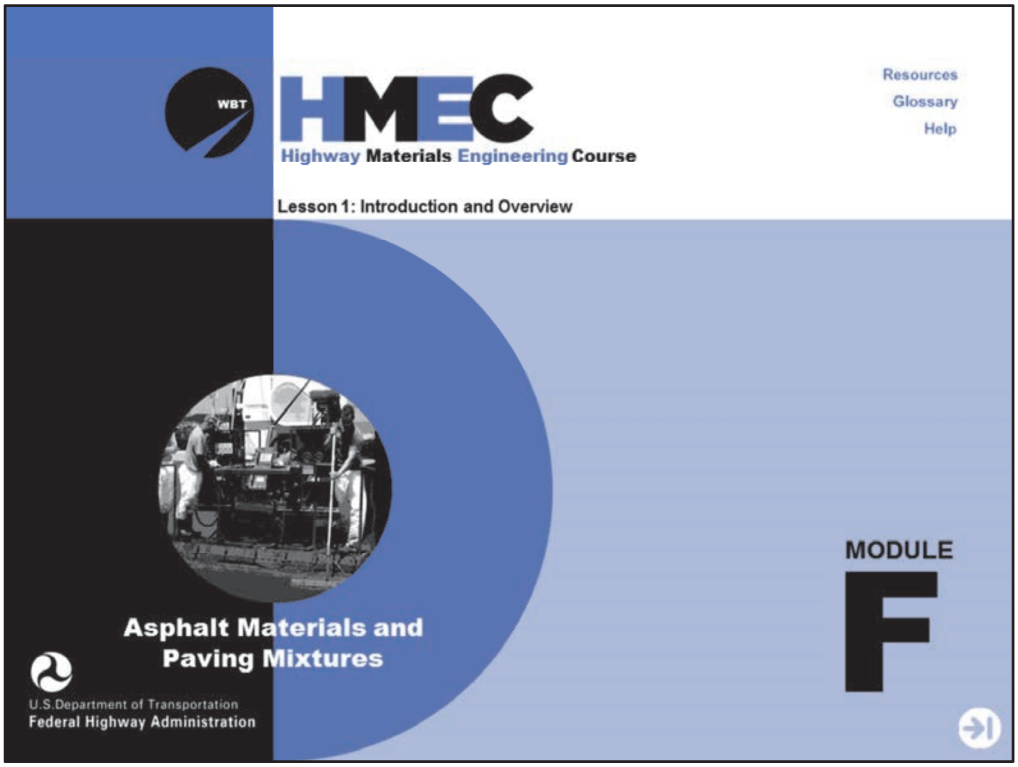
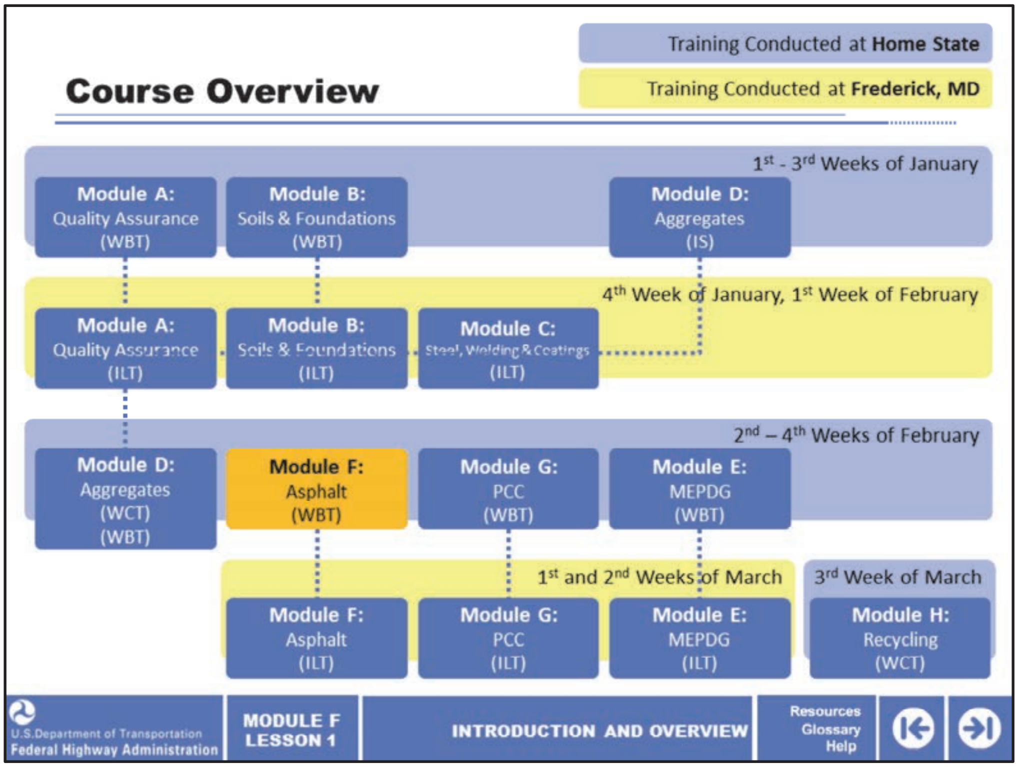


Welcome to the Highway Materials Engineering Course Module F, Lesson 1: Introduction and Overview. This lesson begins with an evolution of asphalt binders, mixtures, production/construction equipment, and specifications that have had a major impact on asphalt pavements.

A printer-friendly version of the lesson materials can be downloaded by selecting the paperclip icon. A copy of the slides and narration are provided for download.

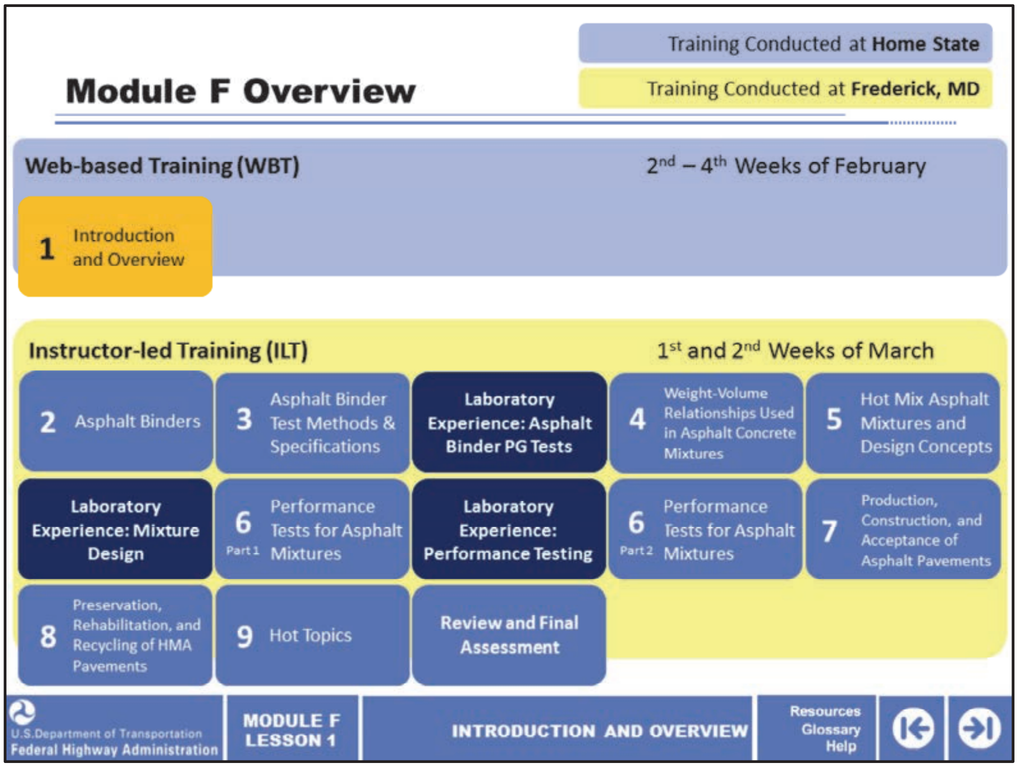
If you need technical assistance during the training, please select the Help link in the upper right-hand corner of the screen.



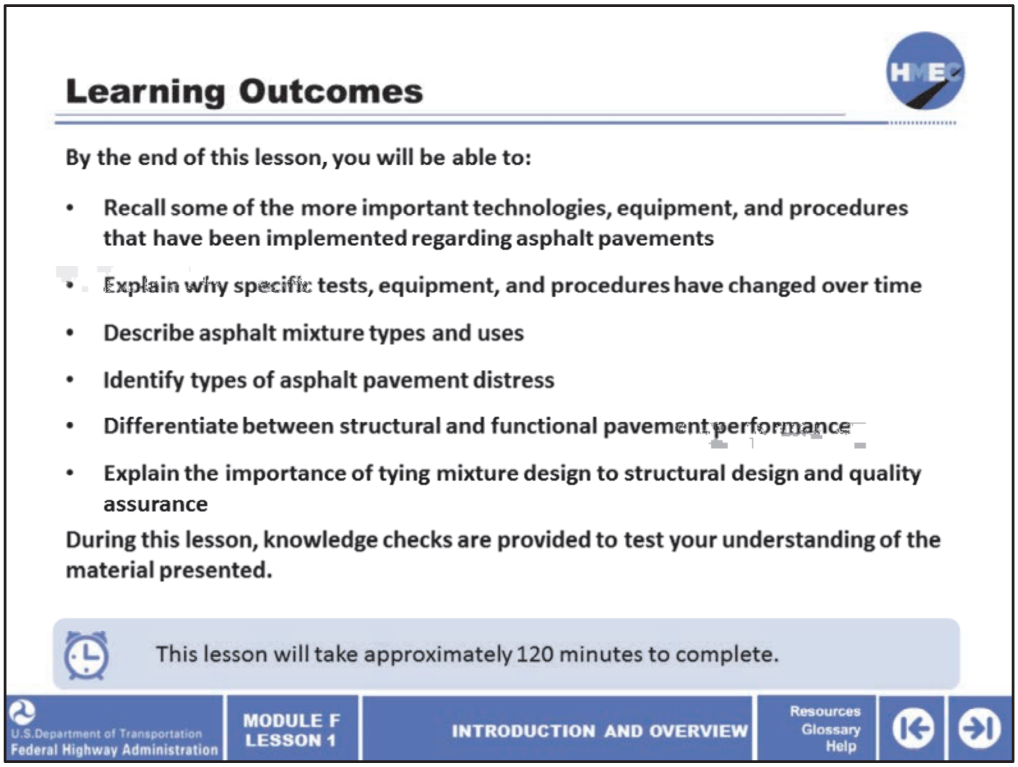
The Highway Materials Engineering Course was previously presented in a traditional instructor-led course over a 6-week period. The course is now being presented in a blended format over an 11-week period.

Module F: Asphalt Materials and Paving Mixtures is the sixth module in the FHWA Highway Materials Engineering Course (HMEC).

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



Module F consists of 9 lessons. Lesson 1 is completed in the Web-based training (WBT) portion of the course. Lesson 2 is the first instructor-led training (ILT) lesson. Lessons 3–6 are completed as ILT lessons, and lessons 3, 5, and 6 each has a related lab experience. Then, lessons 7–9 are completed as ILTs before the review and final assessment.

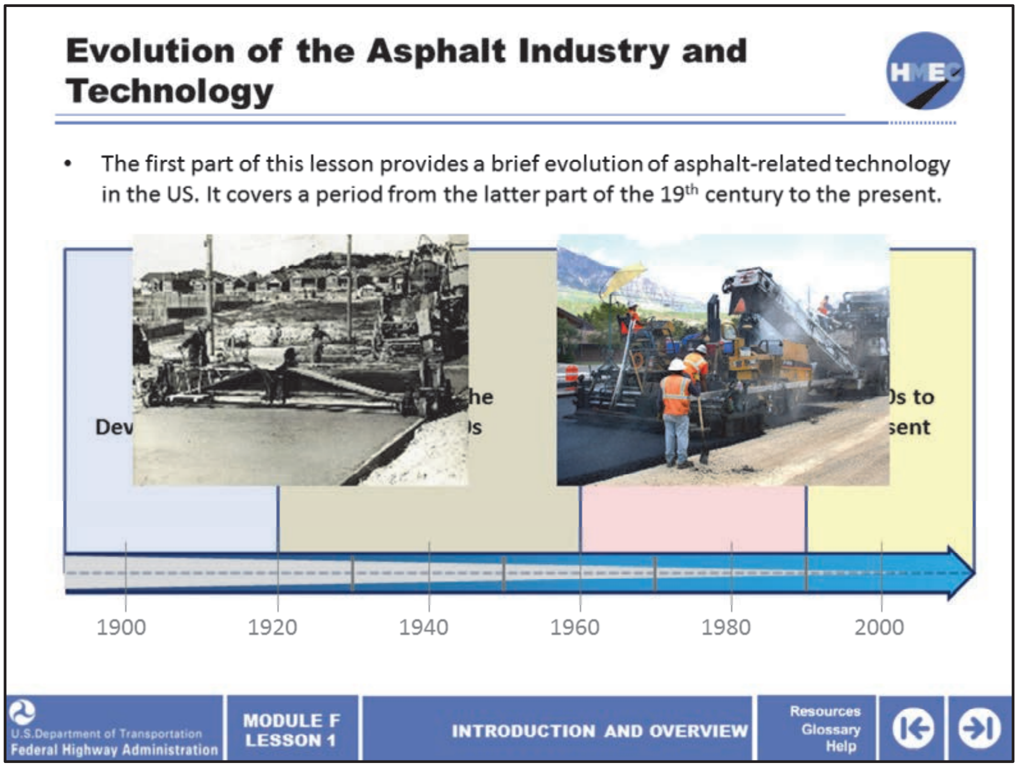


By the end of this lesson, you will be able to:

- Recall some of the more important technologies, equipment, and procedures that have been implemented regarding asphalt pavements;
- Explain why specific tests, equipment, and procedures have changed over time;
- Describe asphalt mixture types and uses;
- Identify types of asphalt pavement distress;
- Differentiate between structural and functional pavement performance; and
- Explain the importance of tying mixture design to structural design and quality assurance.

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

This lesson will take approximately 120 minutes to complete.



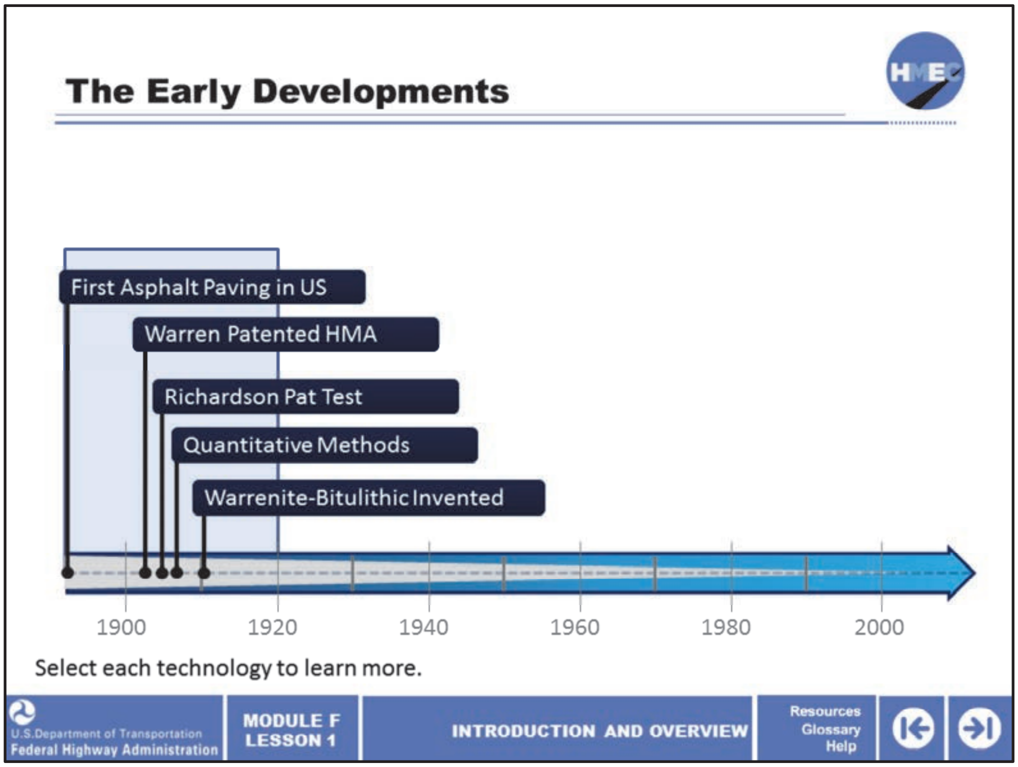
The first part of this lesson provides a brief evolution of asphalt-related technology in the US. It covers a period from the latter part of the 19th century to the present. Specifically, it identifies when key or critical technology was implemented in the US and discusses what impact each has had on asphalt pavement performance.

In order to provide this information in a clear chronological manner, we are dividing the timeline into four sections. They are:

- Early developments;
- 1920s to the late 1950s;
- 1960s to the late 1980s; and
- 1990s to present.

Image description: Photo of early 19th century paving.

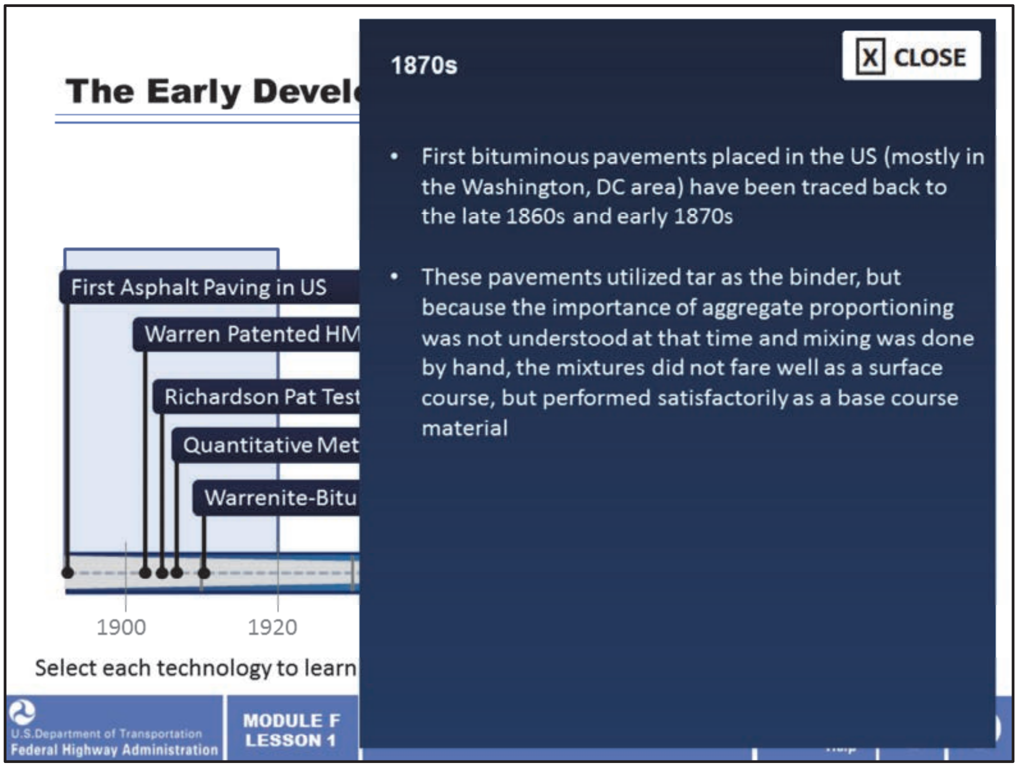
Image description: Photo of a modern paving machine.



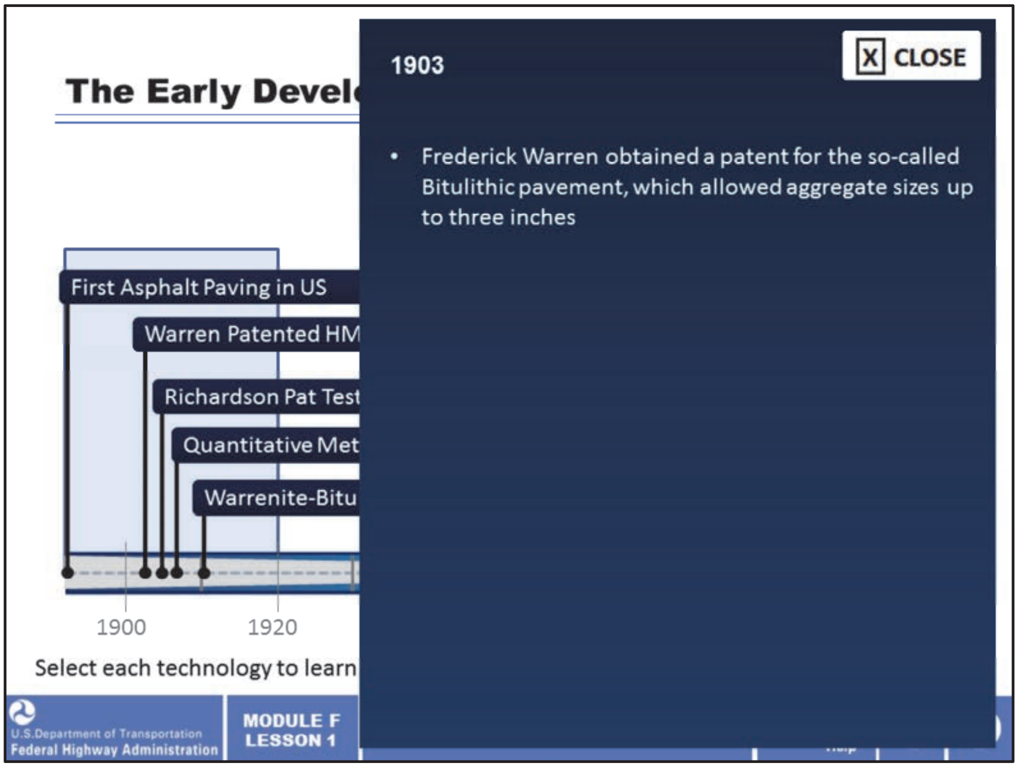
Let's start with the evolution of asphalt-related technology in the US. This timeline will cover the early developments from the latter part of the 19th century to 1920. The highlights here are:

- First asphalt paving in US about 1870—mostly in Washington, DC;
- Warren patented hot mix asphalt (HMA) in 1903;
- Richardson pat test, ca. 1905;
- Quantitative methods for obtaining dense-graded mixtures (Texas A&M); and
- Warrenite-Bitulithic was invented by a retired Warren employee in 1910.

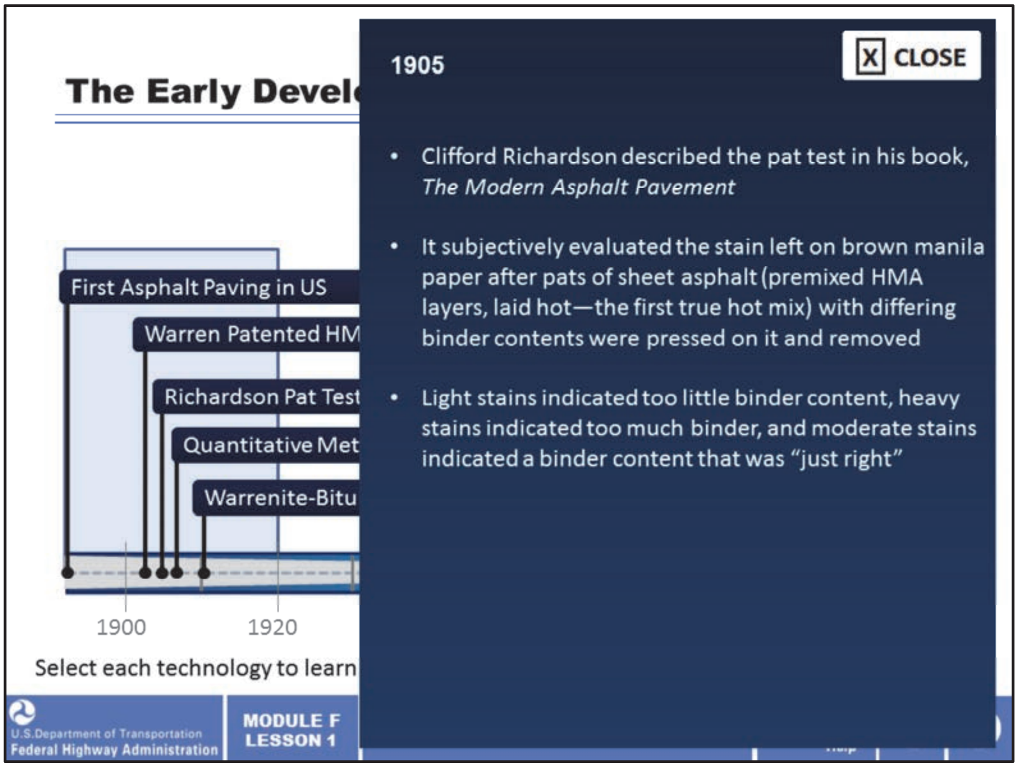
Select each technology to learn more.



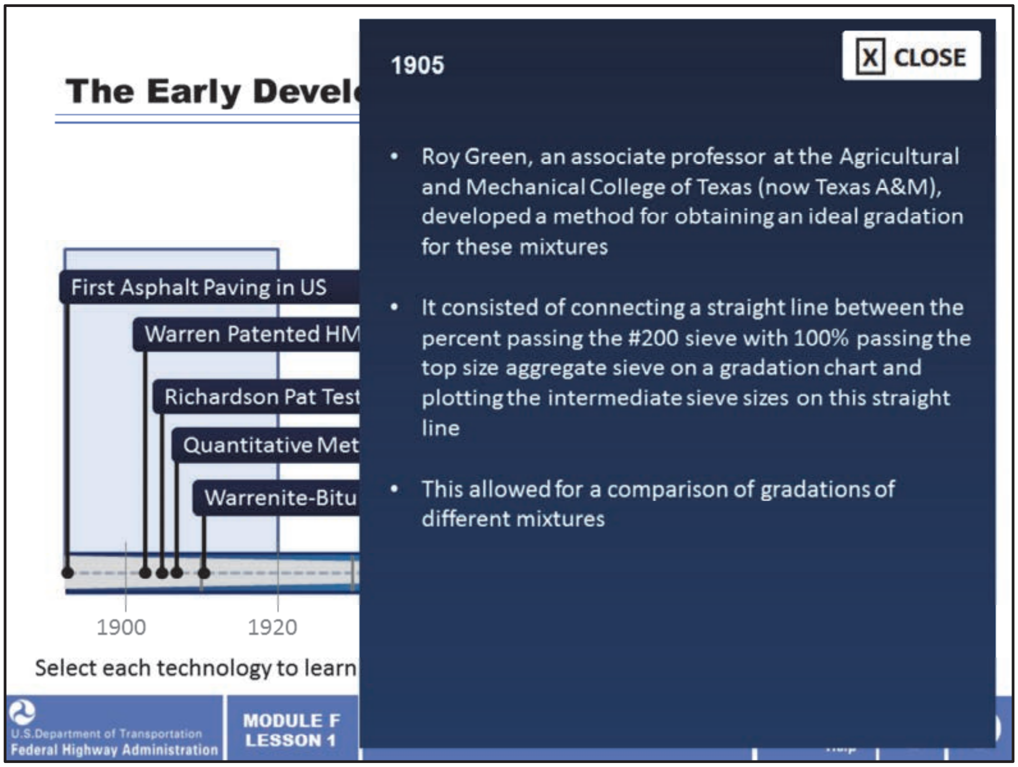
The first bituminous pavements placed in the US (mostly in the Washington, DC area) have been traced back to the late 1860s and early 1870s. These pavements utilized tar as the binder, but because the importance of aggregate proportioning was not understood at that time and mixing was done by hand, the mixtures did not fare well as a surface course, but performed satisfactorily as a base course material.



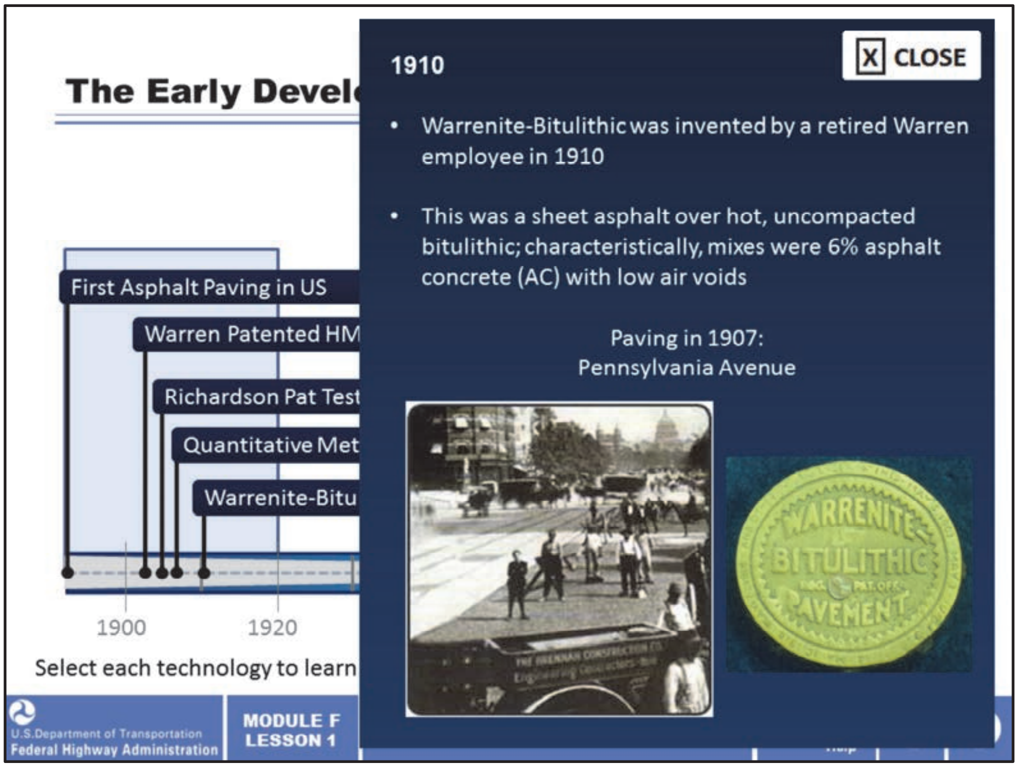
In 1903, Frederick Warren obtained a patent for the so-called Bitulithic pavement, which allowed aggregate sizes up to three inches.



At about the same time, Clifford Richardson (1905) described the pat test in his book, *The Modern Asphalt Pavement*. It subjectively evaluated the stain left on brown manila paper after pats of sheet asphalt (premixed HMA layers, laid hot—the first true hot mix) with differing binder contents were pressed on it and removed. Light stains indicated too little binder content, heavy stains indicated too much binder, and moderate stains indicated a binder content that was "just right."



Roy Green, an associate professor at the Agricultural and Mechanical College of Texas (now Texas A&M), developed a method for obtaining an ideal gradation for these mixtures. It consisted of connecting a straight line between the percent passing the #200 sieve with 100% passing the top size aggregate sieve on a gradation chart and plotting the intermediate sieve sizes on this straight line. This allowed for a comparison of gradations of different mixtures.

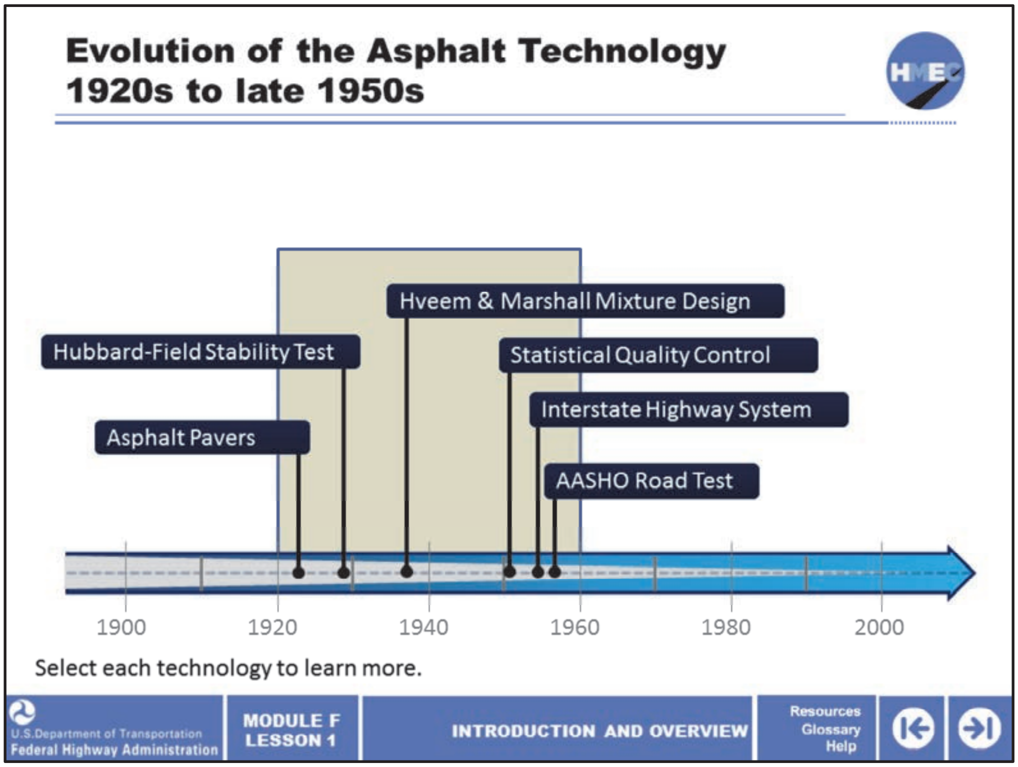


Warrenite-Bitulithic was invented by a retired Warren employee in 1910. This was a sheet asphalt over hot, uncompacted bitulithic. Characteristically, mixes were 6% asphalt concrete (AC) with low air voids.

The Warrenite-Bitulithic medallion is in the pavement in Washington, DC.

Image description: Photo of Pennsylvania Ave 1907.

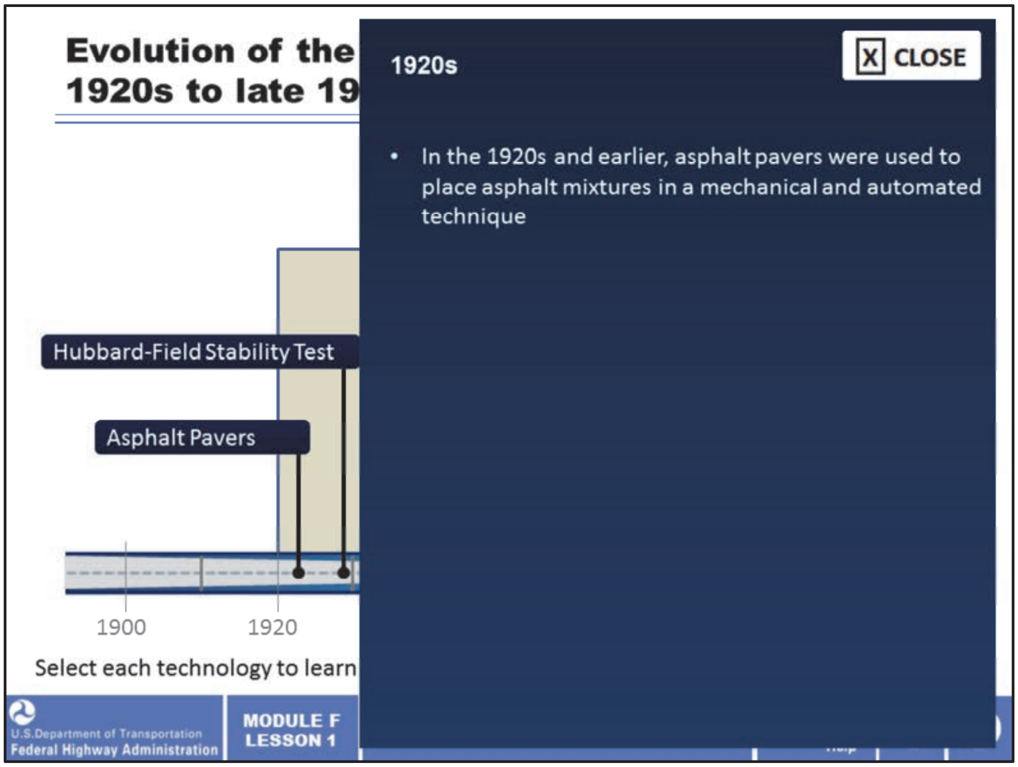
Image description: Photo of Warrenite-Bitulithic medallion.



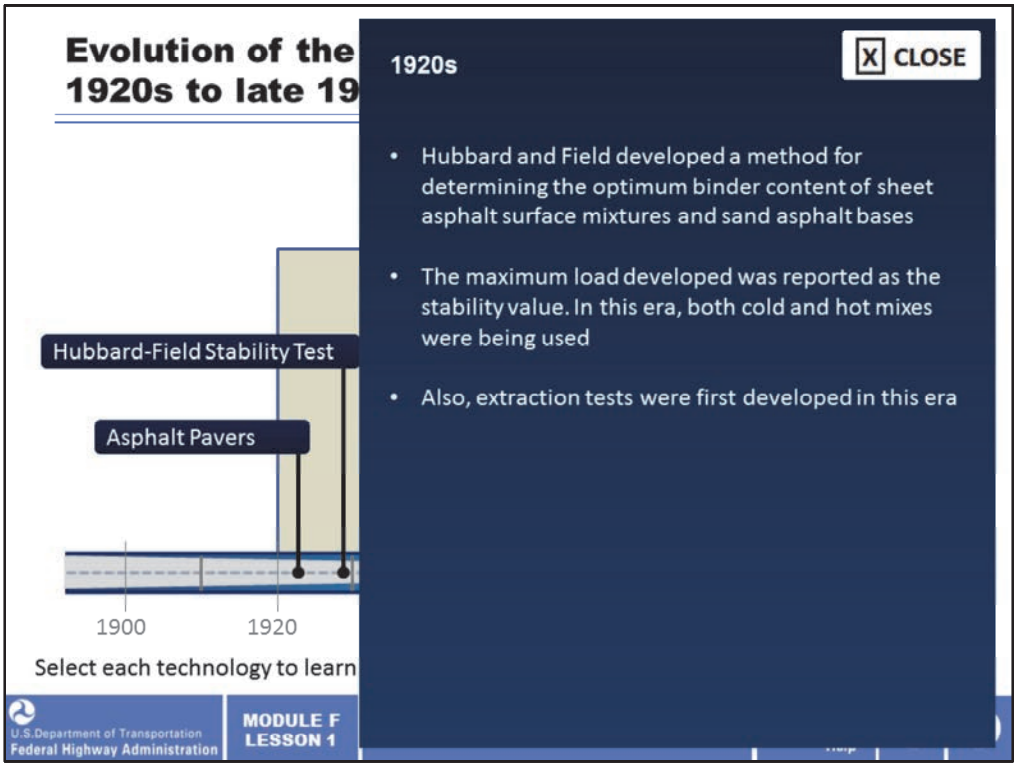
This screen and the next screens follow a timeline of the contemporary history of asphalt technology, and identifies some of the more important technology deployments that have had a significant impact on asphalt mixtures and pavements. Let's talk about the 1920s through the late 1950s. The highlights here are:

- Asphalt pavers were used to place asphalt mixtures;
- Development of the Hubbard-Field stability test;
- The Hveem and Marshall mix design procedures were deployed in the 1930s;
- Introduction of statistical quality control measures;
- The interstate system was also initiated; and
- The American Association of State Highway Officials (AASHO) Road Test.

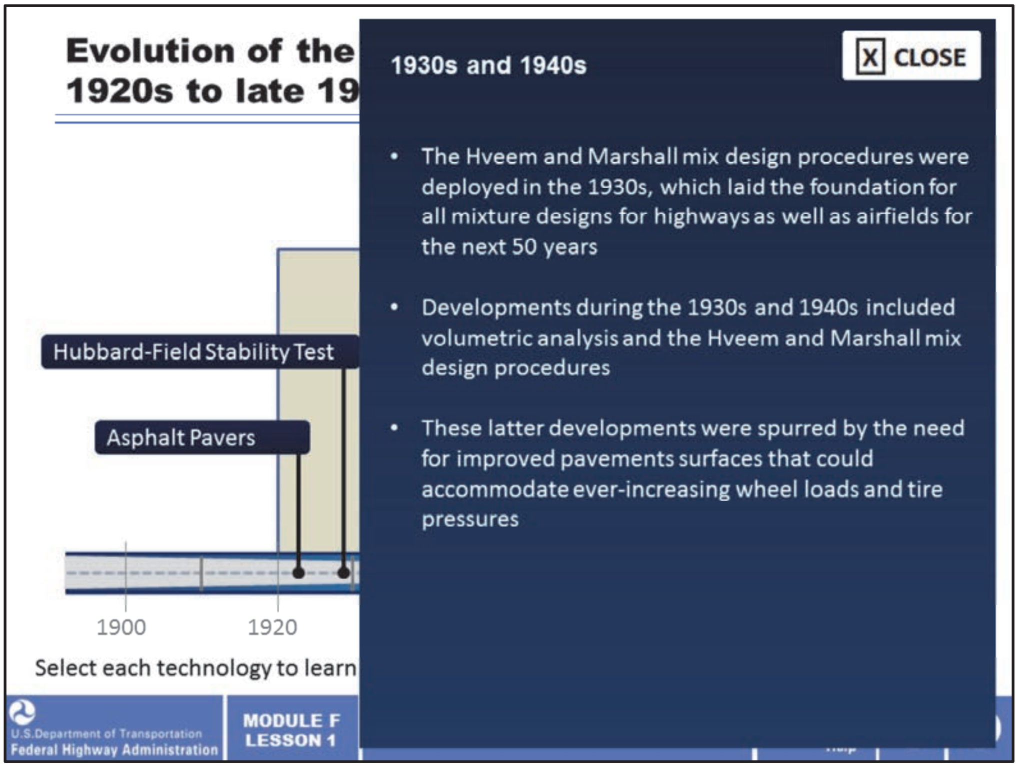
Select each technology to learn more.



In the 1920s and earlier, asphalt pavers were used to place asphalt mixtures in a mechanical and automated technique.



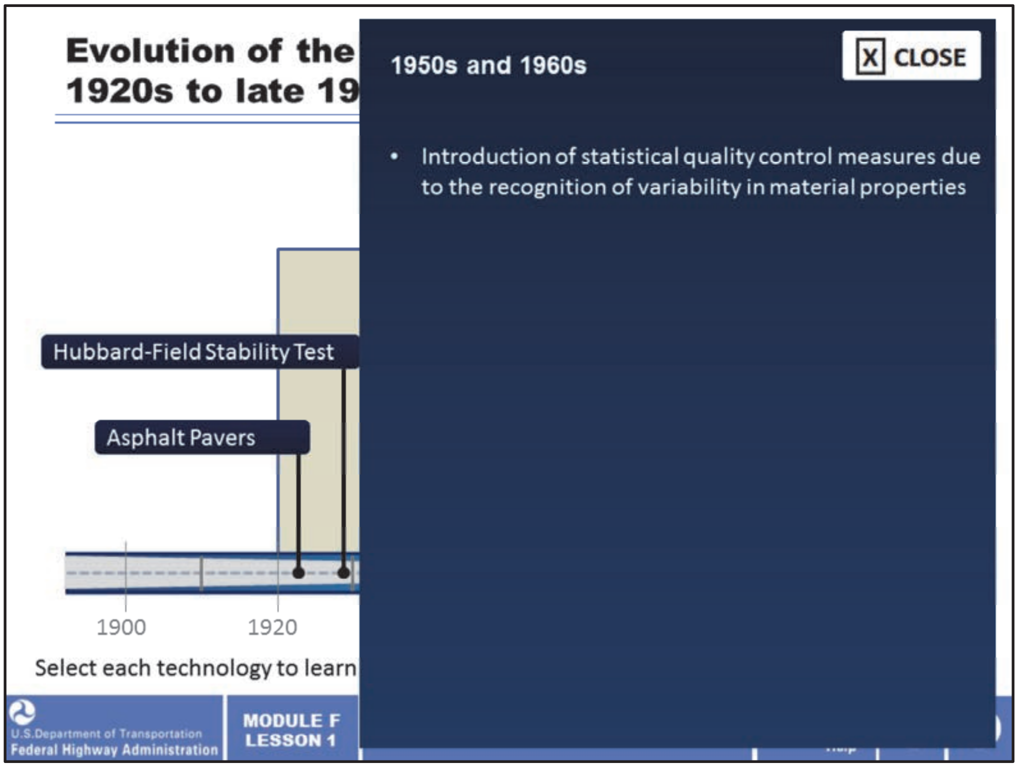
Other important developments included the development of the Hubbard-Field stability test.



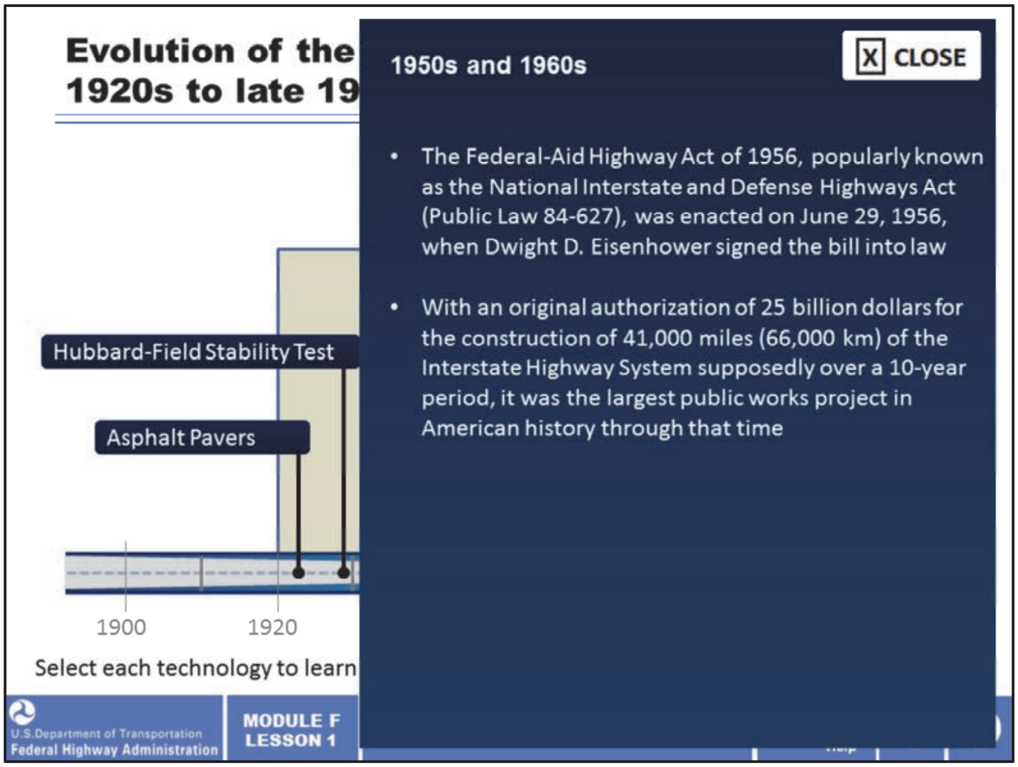
The Hveem and Marshall mix design procedures were deployed in the 1930s, which laid the foundation for all mixture designs for highways as well as airfields for the next 50 years. The more important technical advancements or deployments during this time period was the Hveem and Marshall mixture design methods and AASHO Road Test. The Hveem mixture design method was adopted by the majority of States west of the Mississippi River, while the Marshall mixture design method was primarily adopted by those agencies east of the Mississippi River.

Developments during the 1930s and 1940s included volumetric analysis and the Hveem and Marshall mix design procedures. These latter developments were spurred by the need for improved pavements surfaces that could accommodate ever-increasing wheel loads and tire pressures.

The Corps of Engineers Waterways Experiment Station (WES) did extensive studies utilizing the Marshall mix design method to develop criteria for designing mixtures for airfield pavements. Researchers at WES selected the Marshall method because they wanted a sample preparation procedure that would involve minimum effort and time but would provide a rational basis for selecting the proper binder content. It could also be taken to the field for quality control purposes.

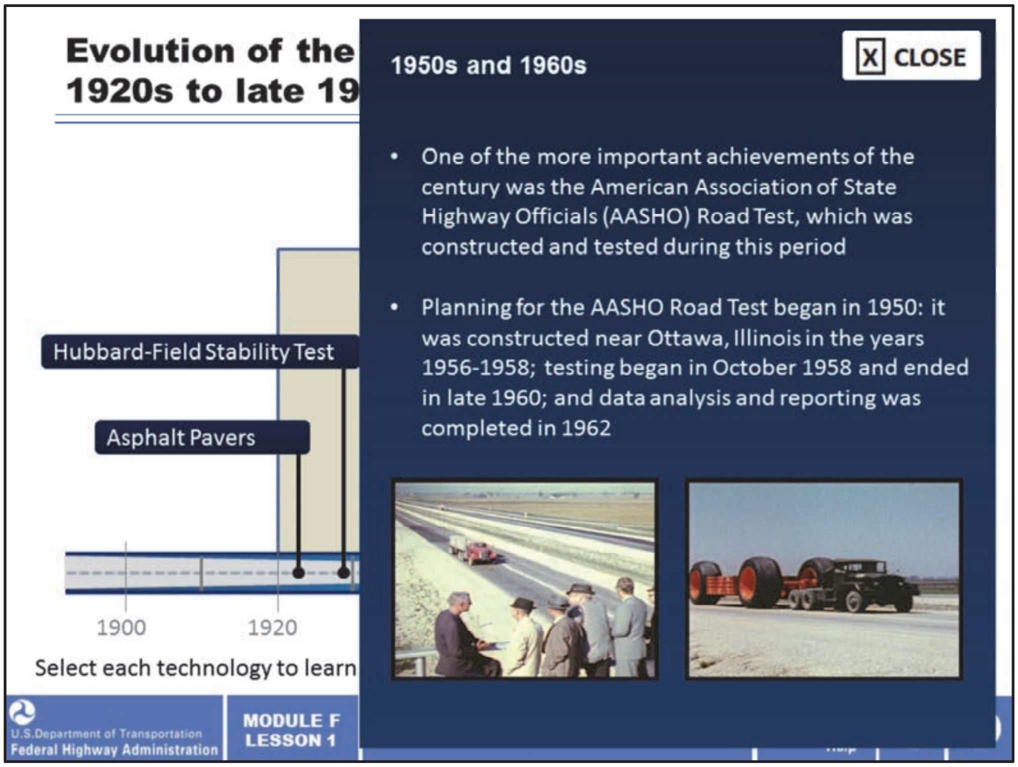


This period also saw the introduction of statistical quality control measures due to the recognition of variability in material properties.



The Federal-Aid Highway Act of 1956, popularly known as the National Interstate and Defense Highways Act (Public Law 84-627), was enacted on June 29, 1956, when Dwight D. Eisenhower signed the bill into law.

With an original authorization of $25 billion for the construction of 41,000 miles (66,000 km) of the Interstate Highway System supposedly over a 10-year period, it was the largest public works project in American history through that time.



One of the more important achievements of the century was the American Association of State Highway Officials (AASHO) Road Test, which was constructed and tested during that period. The structural design procedure derived from the AASHO Road Test was adopted by just about all agencies in the US and is still in use today by multiple agencies. The AASHO design procedure was based on the serviceability criteria that was developed from the road test. However, it is an empirical-based procedure that is now being replaced across North America.

Planning for the AASHO Test Road began in 1950: it was constructed near Ottawa, Illinois in the years 1956-1958; testing began, October 1958 and ended in late 1960; the data analysis and reporting was completed in 1962.

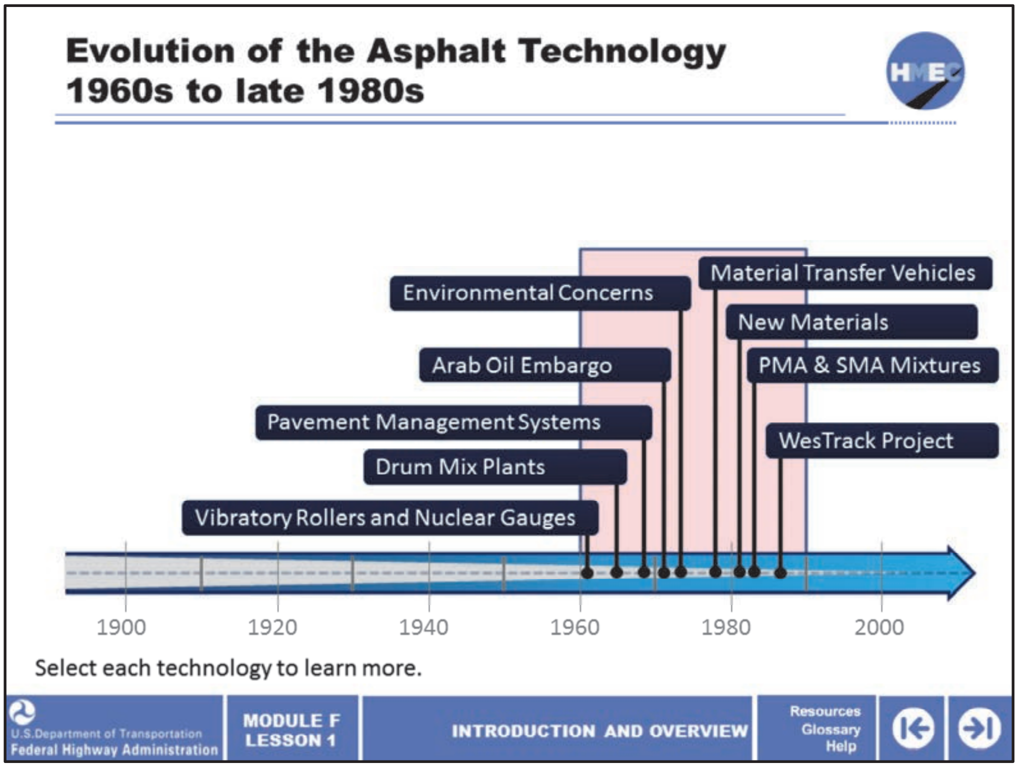
The test site in Ottawa, Illinois was seven miles of one-half asphalt, one-half concrete roadway built with a variety of surface, base, and subbase thicknesses. This provided the foundation for evaluating stresses from moving vehicles.

The design of pavements and bridges on the interstate system mostly followed the results of the AASHO Road Test. The AASHO Road Test is acclaimed as “a landmark in highway and bridge design that has never been equaled.”

Road Test engineers developed the concept of serviceability ratings. These were subjective ratings—on a scale ranging from 0 (impassable) to 5 (perfect road)—by a panel of highway users based on smoothness and rideability. Correlations of distress indicators with these ratings were made using multiple linear regression analyses to develop the present serviceability index (PSI). Newly constructed HMA pavements typically have a PSI greater than 4 and over time this value decreases due to traffic loading and environmental factors. The change in PSI during the Road Test was correlated to the number of axle loads and pavement thickness to develop the basic thickness design equation for both flexible and rigid (concrete) pavements. The design equation has been used for most pavement thickness designs in the US since its development.

Image description: Photo of men circa 1950’s, wearing suits and observing a highway with a truck coming down the road.

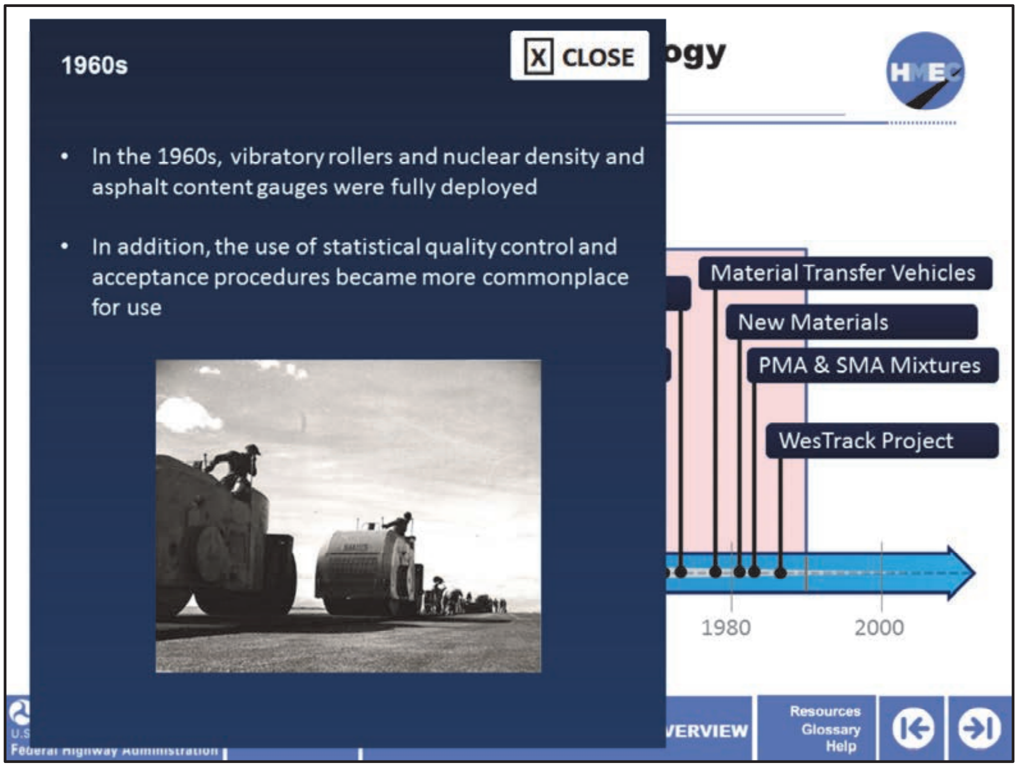
Image description: Photo of testing on AASHO track 1950's.



This screen lists and summarizes a timeline of the contemporary history of asphalt technology, and identifies some of the more important technology deployments that have had a significant impact on asphalt mixtures and pavements. The most important deployments during this time period were the advent of vibratory rollers, the use of drum mix plants, and the construction of WesTrack to answer performance-related specification issues. The highlights are:

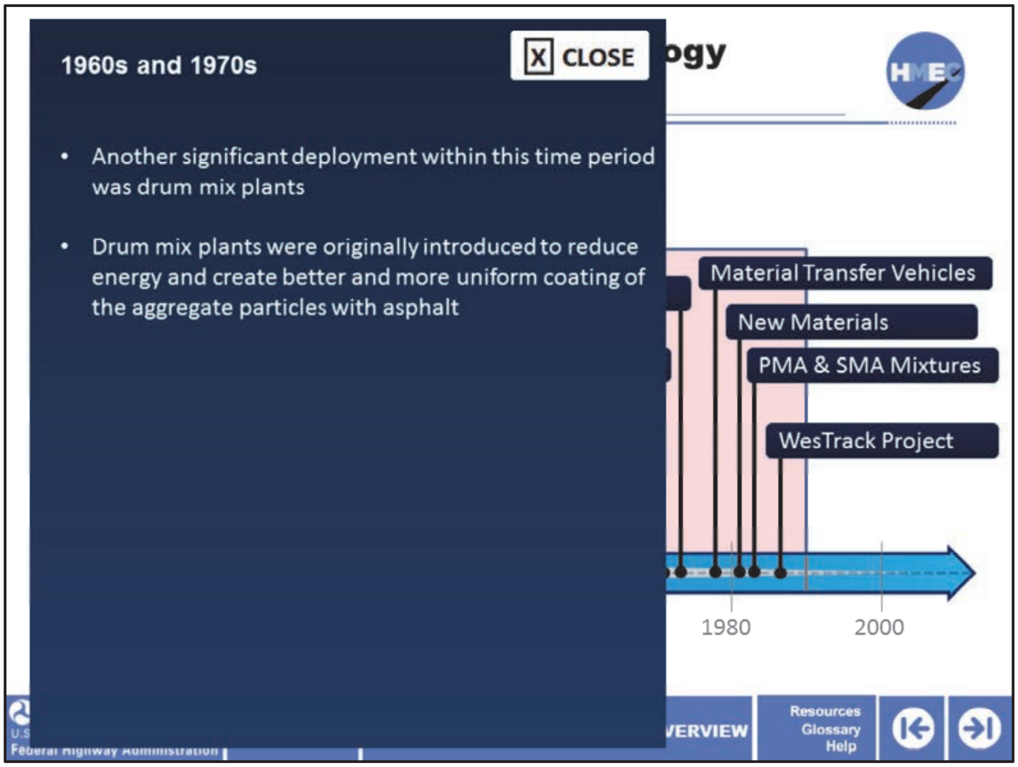
- Vibratory rollers and nuclear density and asphalt content gauges;
- Drum mix plants;
- Pavement management systems (PMS);
- Arab oil embargo;
- Environmental concerns;
- Material transfer vehicles;
- New materials;
- Polymer-modified asphalt (PMA) mixtures and stone matrix asphalt (SMA) mixtures; and
- WesTrack project.

Select each technology to learn more.

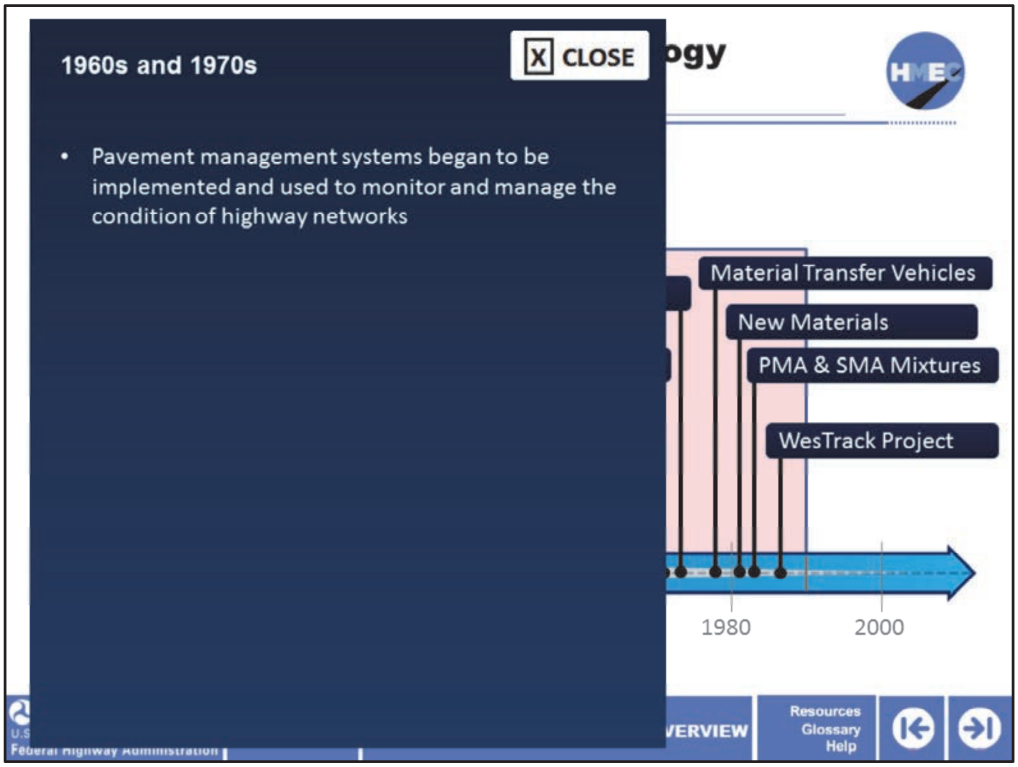


In the 1960s, vibratory rollers and nuclear density and asphalt content gauges were fully deployed. In addition, the use of statistical quality control and acceptance procedures became more commonplace for use.

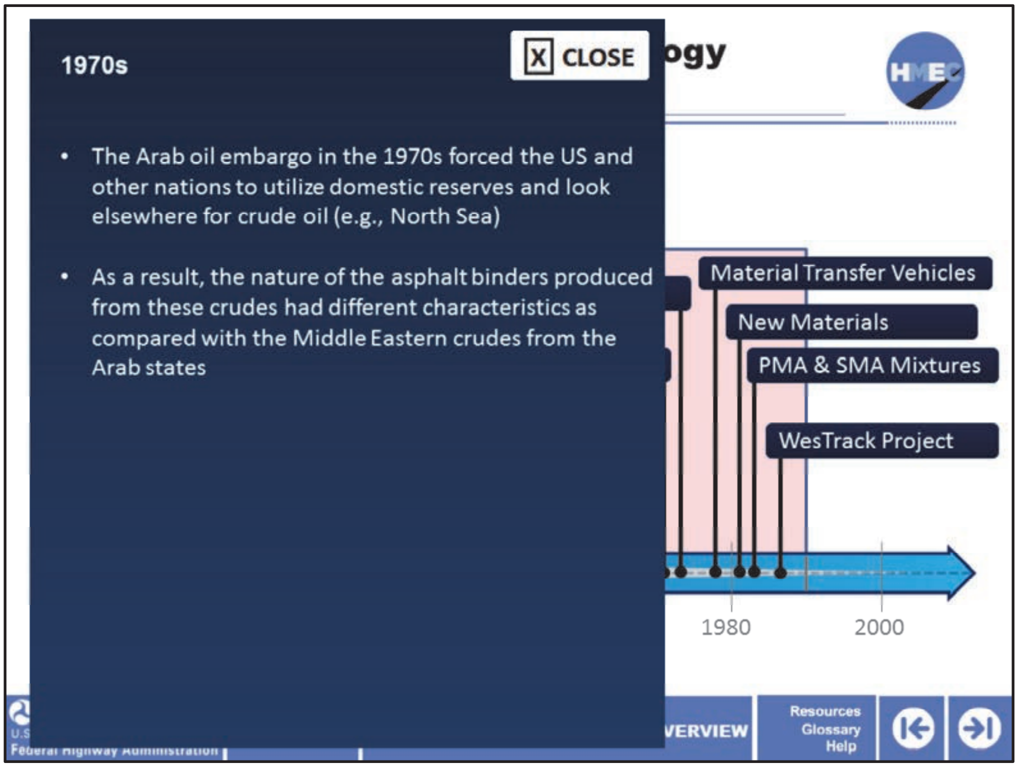
Image description: Photo of vibratory rollers from 1960's.



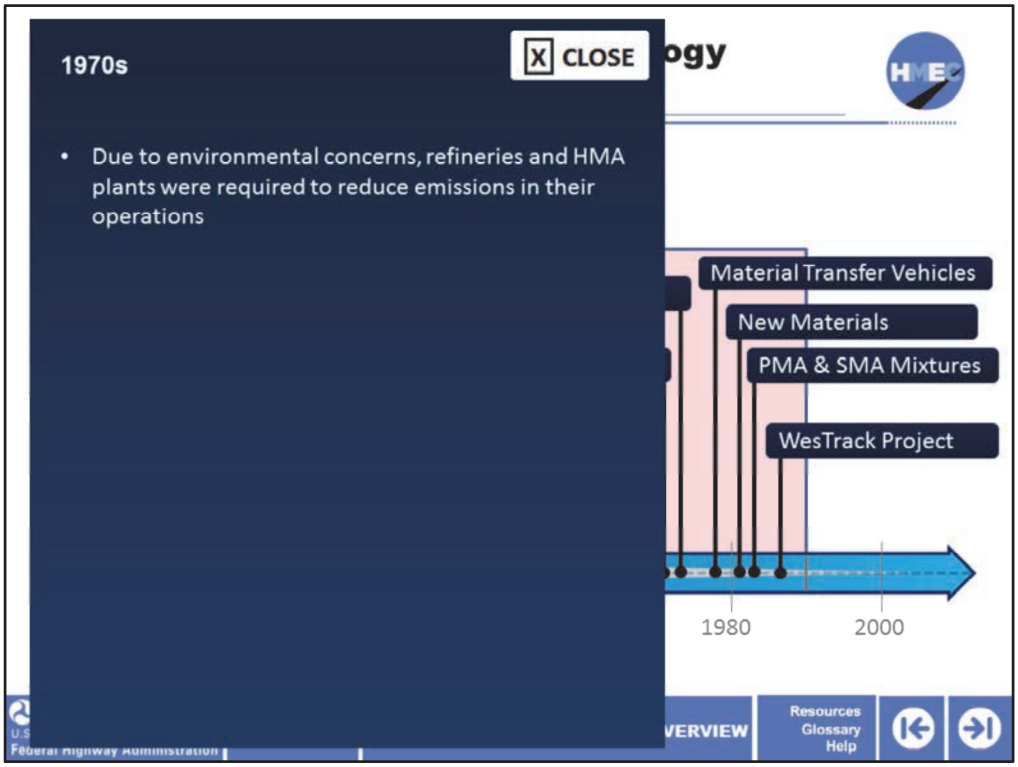
Another significant deployment within this time period was drum mix plants. Drum mix plants were originally introduced to reduce energy and create better and more uniform coating of the aggregate particles with asphalt.



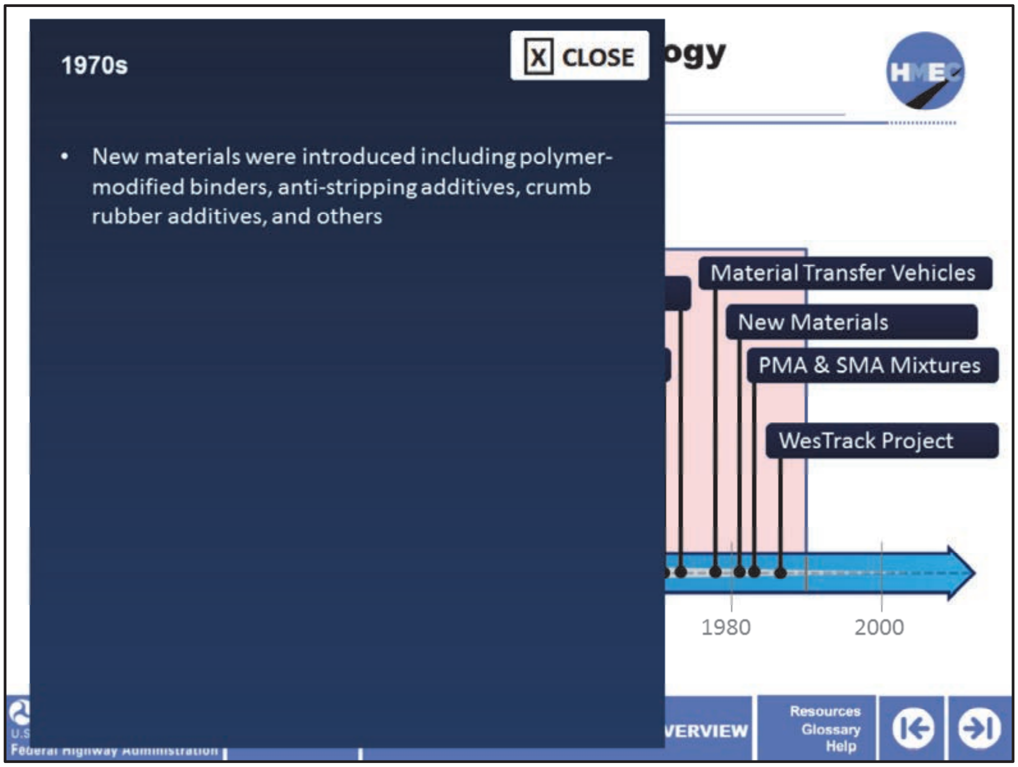
Pavement management systems began to be implemented and used to monitor and manage the condition of highway networks.



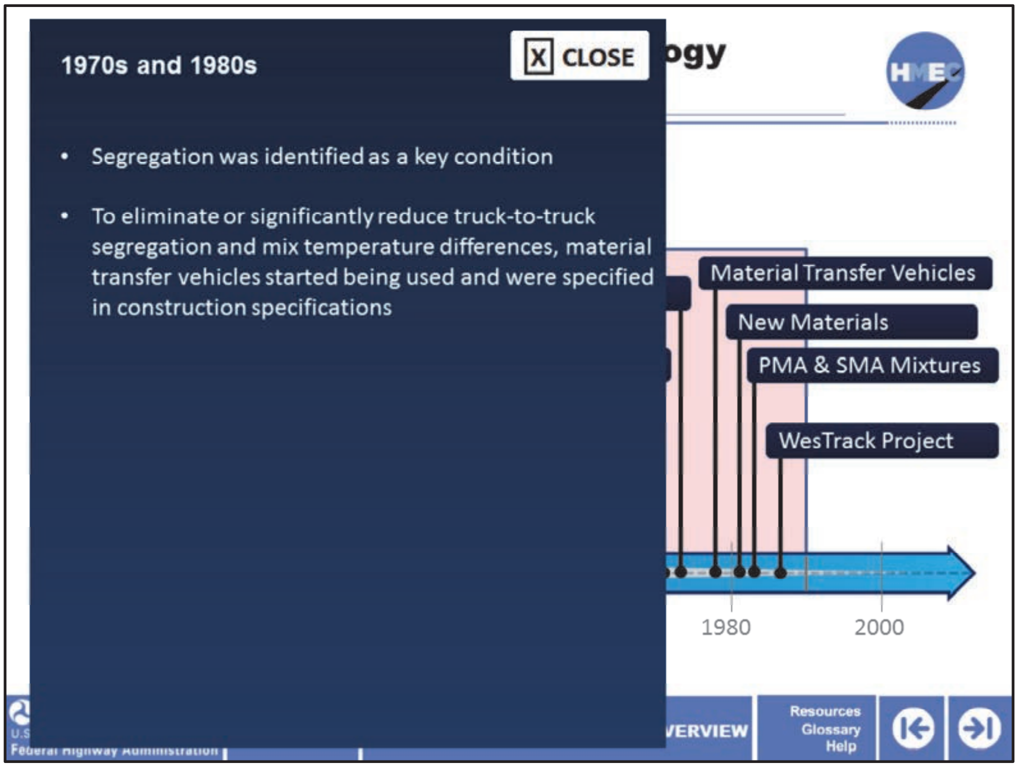
The Arab oil embargo in the 1970s forced the US and other nations to utilize domestic reserves and look elsewhere for crude oil (e.g., the North Sea). As a result, the nature of the asphalt binders produced from these crudes had different characteristics as compared with the Middle Eastern crudes from the Arab states.



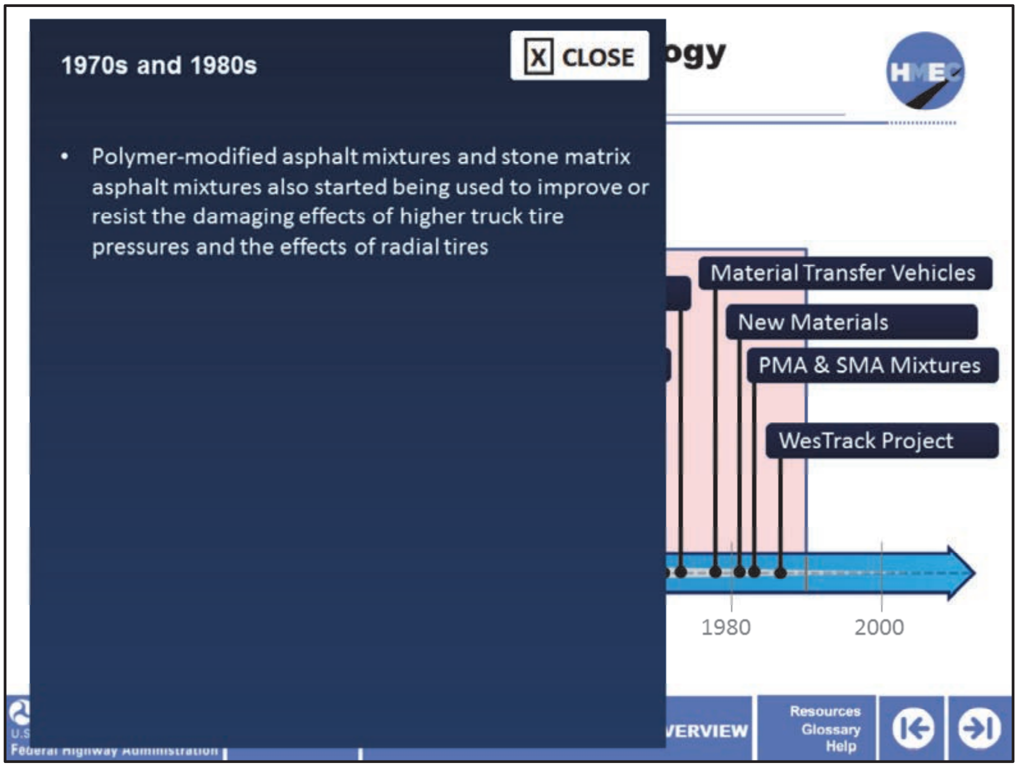
Also, due to environmental concerns, refineries and HMA plants were required to reduce emissions in their operations.



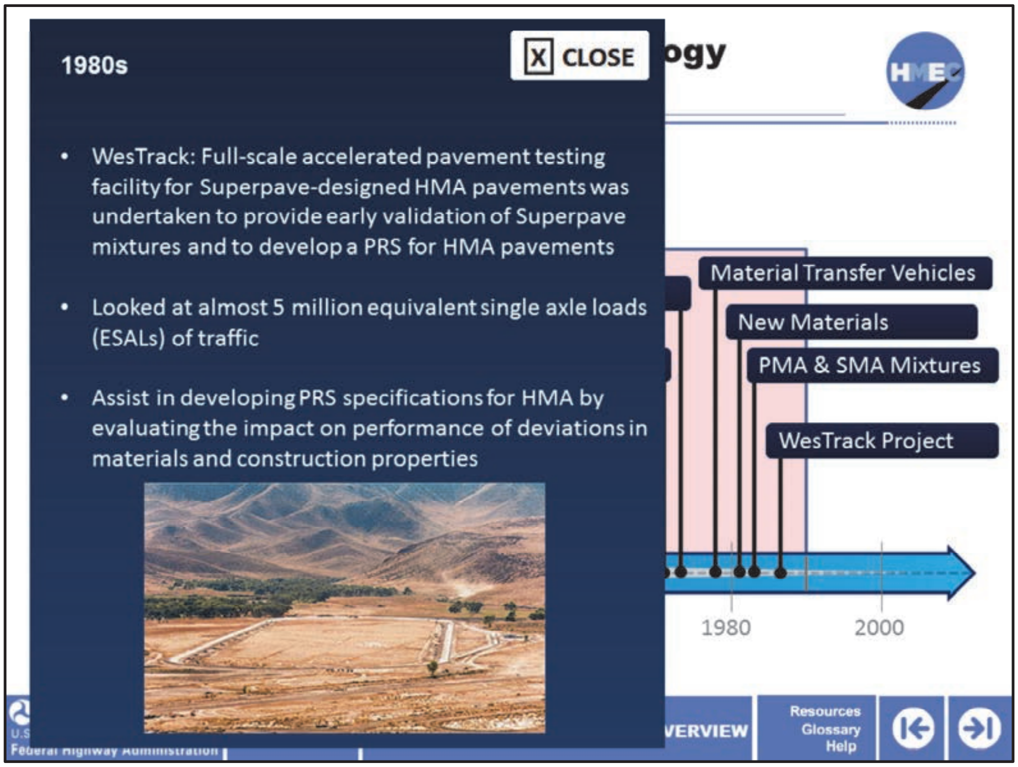
New materials were introduced including polymer-modified binders, anti-stripping additives, crumb rubber additives, and others.



Segregation was identified as a key condition. To eliminate or significantly reduce truck-to-truck segregation and mix temperature differences, material transfer vehicles started being used and were specified in construction specifications.



Polymer-modified asphalt mixtures and stone matrix asphalt mixtures also started being used to improve or resist the damaging effects of higher truck tire pressures and the effects of radial tires.

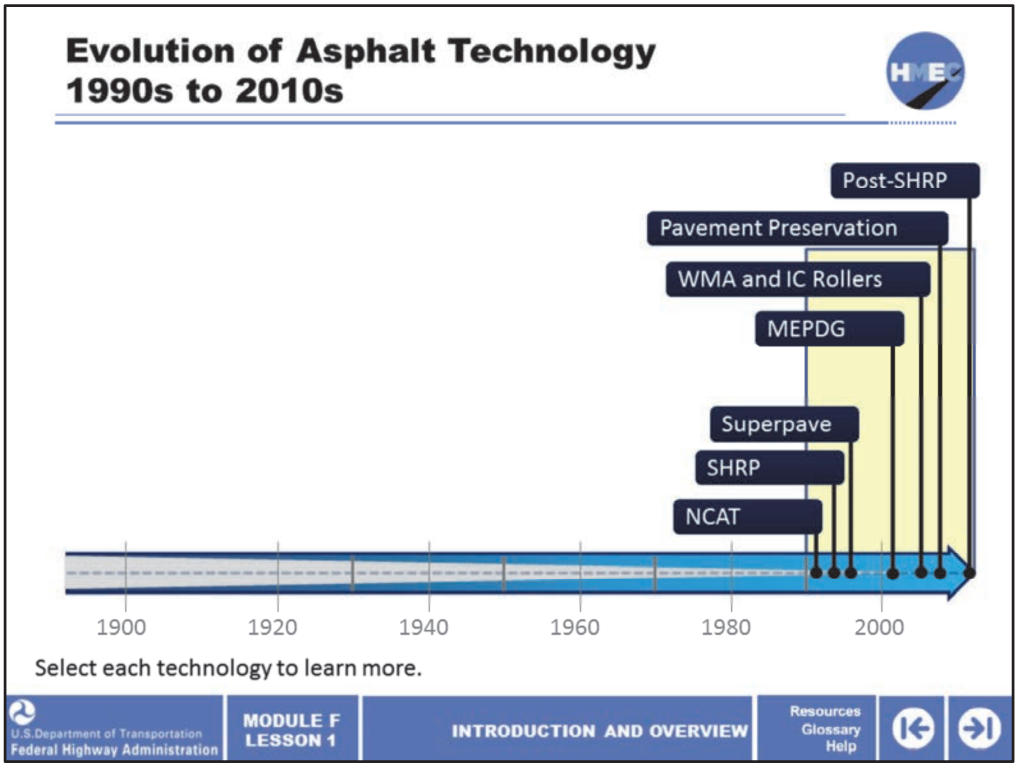


The other key research study that was implemented during the 1980s was WesTrack to assist in the development of performance-related specifications.

During the WesTrack project, a full-scale accelerated pavement testing facility for Superpave-designed HMA pavements was undertaken to provide early validation of Superpave mixtures and to develop a performance related specification (PRS) for HMA pavements. This 26-section, oval track looked at almost 5 million equivalent single axle loads (ESALs) of traffic.

WesTrack's goals were to assist in developing PRS specifications for HMA by evaluating the impact on performance of deviations in materials and construction properties from design values in a large scale and to provide early field verification of Superpave mix designs.

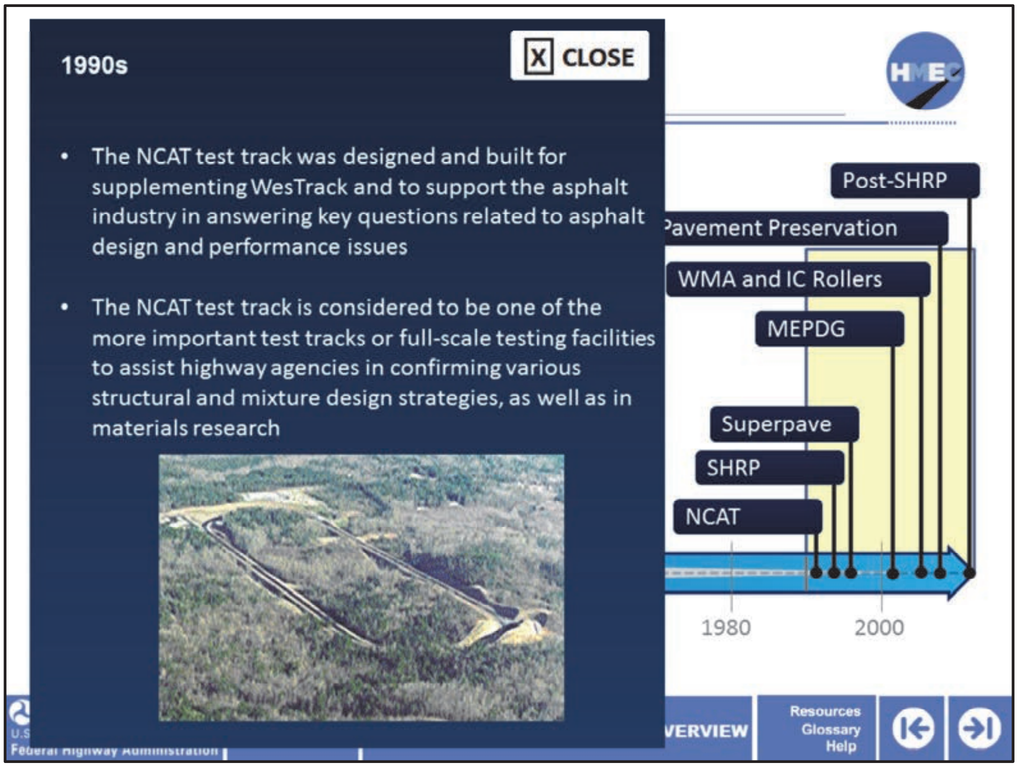
Image description: Photo of WesTrack project, a full-scale accelerated pavement testing facility for Superpave-designed HMA pavements.



This screen lists and summarizes a timeline of the contemporary history of asphalt technology, and identifies some of the more important technology deployments between the 1990s through 2010 that have had a significant impact on asphalt mixtures and pavements. The highlights here are:

- The National Center for Asphalt Technology (NCAT);
- Introduction of Strategic Highway Research Program (SHRP);
- Superpave Technology;
- Warm mix asphalt (WMA) and intelligent compaction (IC) rollers;
- The Mechanistic-Empirical Pavement Design Guide (MEPDG);
- Pavement preservation; and
- Post-Strategic Highway Research Program (SHRP) implementation activities.

Select each technology to learn more.

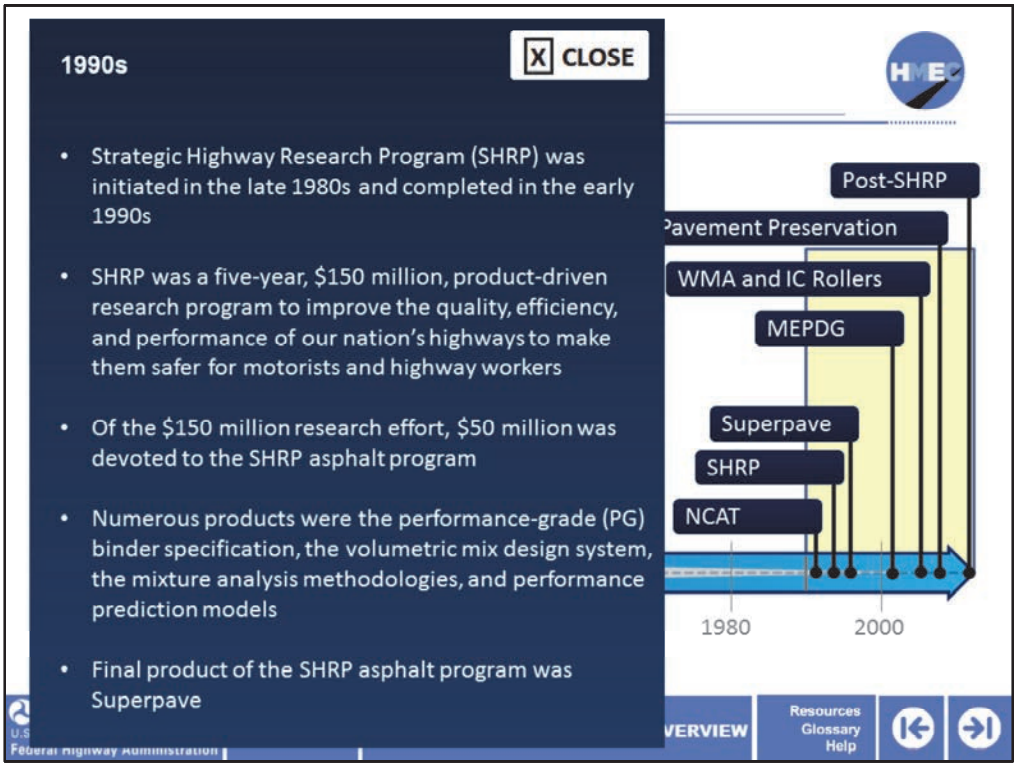


In the 1990s, the National Center for Asphalt Technology (NCAT) test track was built and put into service. This screen provides an overview of the NCAT test track. It was originally built and designed as a rutting experiment to confirm rut-resistant mixtures.

The NCAT test track was designed and built for supplementing WesTrack and to support the asphalt industry in answering key questions related to asphalt design and performance issues. New materials have been introduced including polymer-modified binders, anti-stripping additives, crumb rubber additives, and others that have been tested at the NCAT facility. In addition, various structural design strategies have also been tested and confirmed, such as the perpetual pavement concept and high binder content. Stiff mixtures and fatigue resistant mixtures have also been tested as an example.

The NCAT test track is considered to be one of the more important test tracks or full-scale testing facilities to assist highway agencies in confirming various structural and mixture design strategies, as well as in materials research.

Image description: Photo of the National Center for Asphalt Technology (NCAT) test track.



The Strategic Highway Research Program (SHRP) was initiated in the late 1980s and completed in the early 1990s. Results from SHRP represent the greatest impact on the asphalt technology since development of the asphalt paver.

The SHRP was a five-year, $150 million, product-driven research program to improve the quality, efficiency, and performance of our nation's highways to make them safer for motorists and highway workers.

The research was performed by independent contractors and was targeted in four areas:

1. Asphalt binders and mixtures – $50 million
2. Portland cement concrete and structures – $22 million
3. Maintenance – $28 million (pavement maintenance, work zone safety, and snow and ice control)
4. Long-Term Pavement Performance (LTPP) Program – $50 million

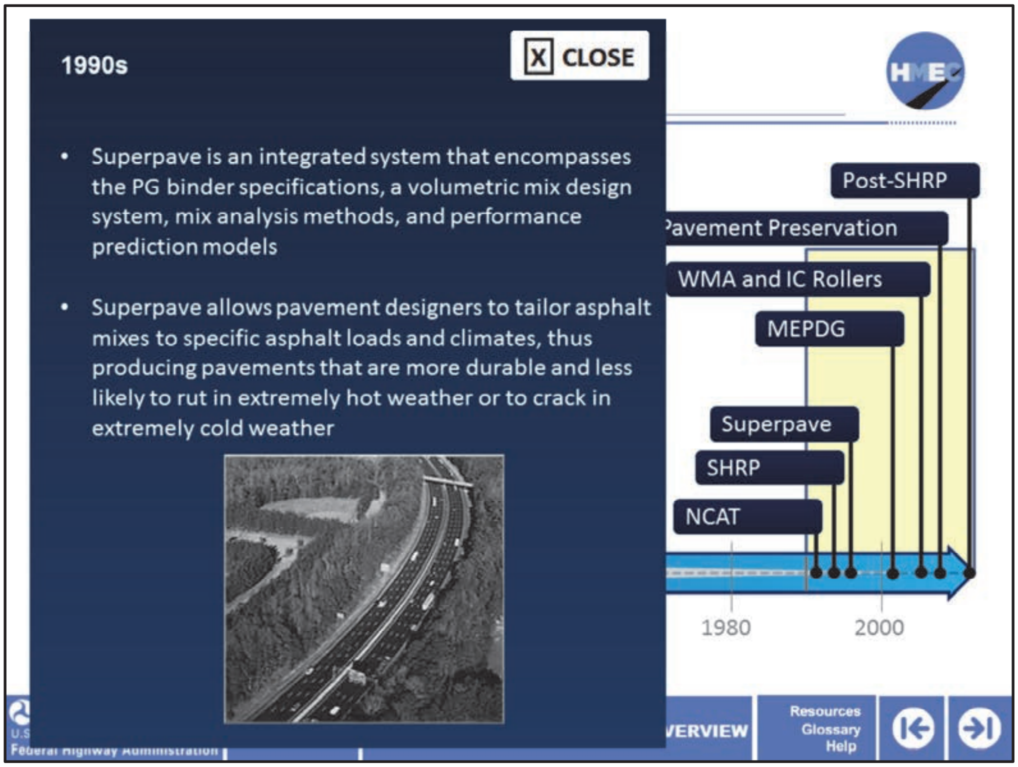
Of the $150 million research effort, $50 million was devoted to the SHRP asphalt program.

This element of the SHRP research effort focused on:

• The physical and chemical properties of asphalt binders;
• Development of improved testing systems to measure the performance-based properties

of asphalt binders and HMA mixtures;
• Development of improved models to predict pavement performance;
• Development of the performance-based specification for asphalt binders; and,
• Development of the HMA mixture design system.

Numerous products were developed from the SHRP research effort. However, the principal products include the performance-grade (PG) binder specification, the volumetric mix design system, the mixture analysis methodologies, and performance prediction models. Much of this module of the course will be devoted to these products. The final product of the SHRP asphalt program was Superpave.



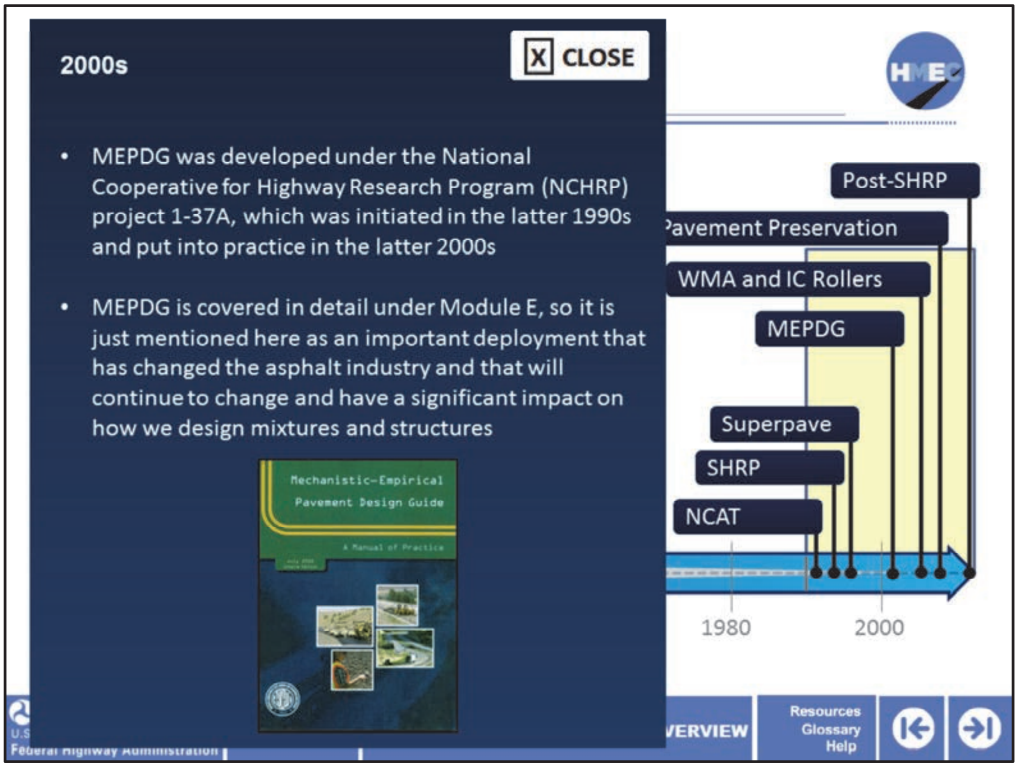
Several technology advancements were developed during SHRP, including the Superpave mix design system and the performance-grade binder specification. Superpave is an integrated system that encompasses the PG binder specifications, a volumetric mix design system, mix analysis methods, and performance prediction models.

Superpave allows pavement designers to tailor asphalt mixes to specific asphalt loads and climates, thus producing pavements that are more durable and less likely to rut in extremely hot weather or to crack in extremely cold weather. The Superpave system consists of three elements:

1. A process for selecting the most appropriate asphalt binder;
2. A lab procedure for optimizing the mix design; and
3. A prediction of how well the mix will perform in the real world.

"Superpave" is an abbreviation. What does it stand for? Superior Performing Asphalt Pavements.

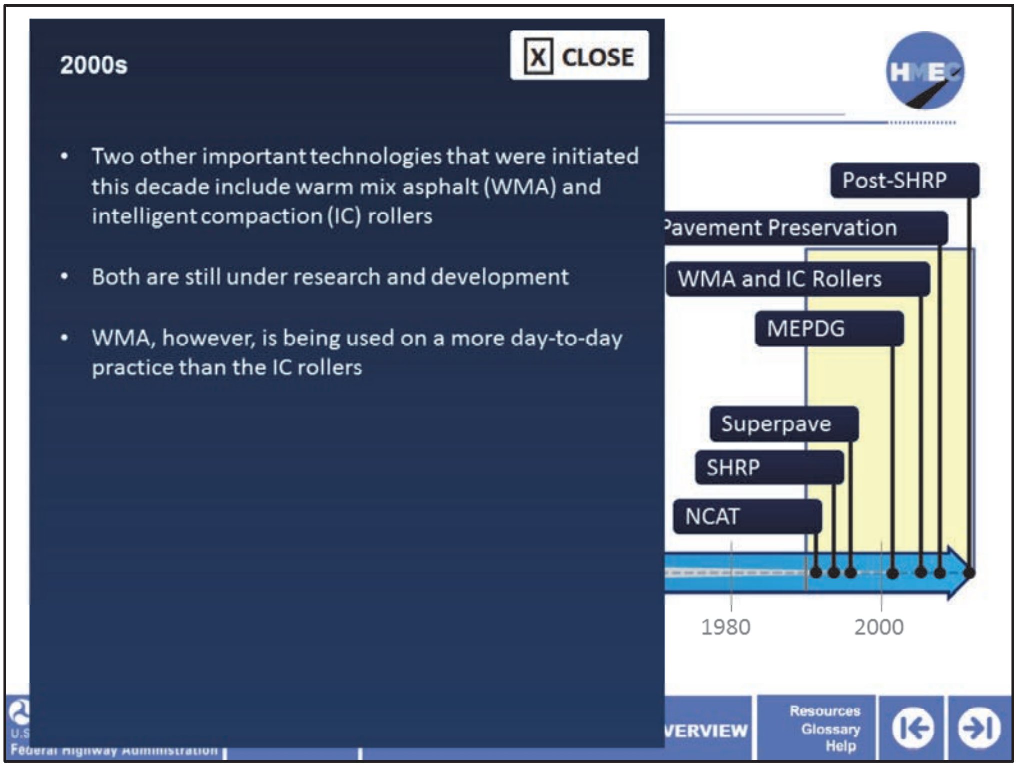
Image description: Photo of a highway overview.



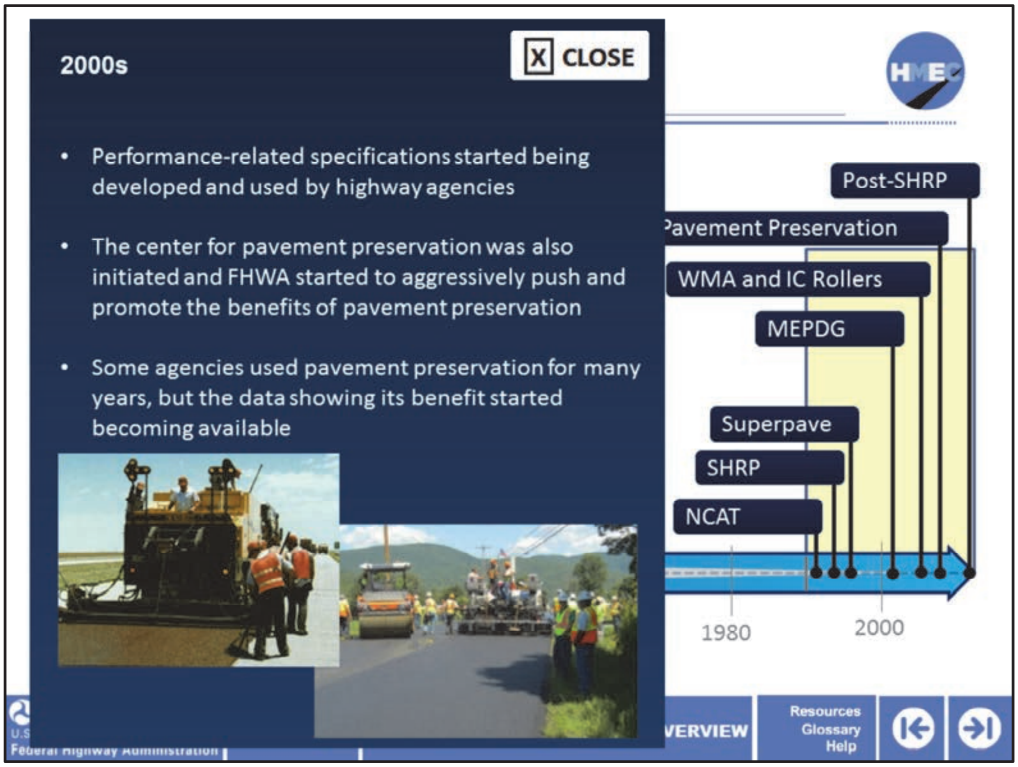
A major deployment since the AASHO Road Test regarding structural design was the Mechanistic-Empirical Pavement Design Guide (MEPDG). The MEPDG was developed under the National Cooperative for Highway Research Program (NCHRP) project 1-37A, which was initiated in the latter 1990s and put into practice in the latter 2000s.

The MEPDG is covered in detail under Module E, so it is just mentioned here as an important deployment that has changed the asphalt industry and that will continue to change and have a significant impact on how we design mixtures and structures.

Image description: Cover of MEPDG Manual.



Two other important technologies that were initiated this decade include warm mix asphalt (WMA) and intelligent compaction (IC)rollers. Both are still under research and development. WMA, however, is being used in more day-to-day practice than the intelligent rollers.

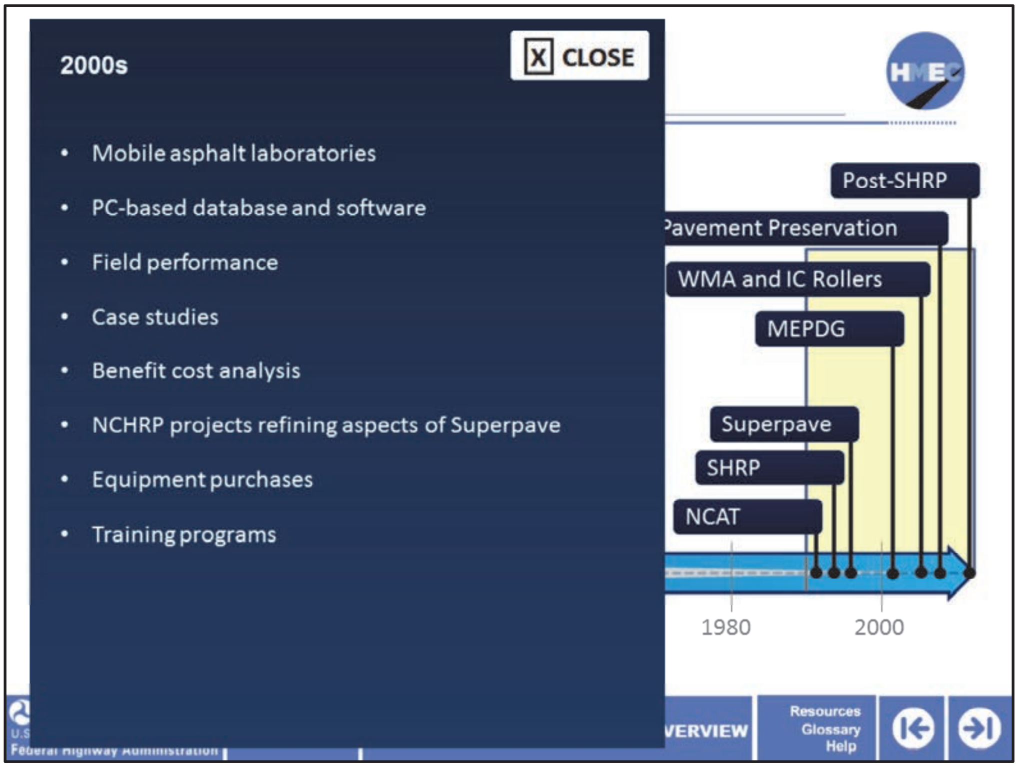


Continuing on the timeline, performance-related specifications (PRS) were being developed and used by multiple agencies after the WesTrack project. Although PRS had been used by different agencies prior to the 2000s, WesTrack provided a national perspective and focus on this type of specification.

The center for pavement preservation was also initiated and FHWA started to aggressively push and promote the benefits of pavement preservation. Some agencies used pavement preservation for many years, but the data showing its benefit started becoming available.

Image description: Photo of a micro surfacing paver.

Image description: Photo of warm mix asphalt paving.



Little funding for implementation was budgeted in the Strategic Highway Research Program (SHRP); funding for these activities required additional legislation. As a follow-up program to SHRP, Congress authorized $108 million over six years as part of the Intermodal Surface Transportation Efficiency Act (ISTEA) of 1991, to establish programs to implement SHRP products and to continue SHRP's Long-Term Pavement Performance (LTPP) program.

The FHWA was given the responsibility of directing the implementation efforts to facilitate the application of the research findings. Several concurrent efforts were undertaken, as indicated here.

- Mobile asphalt laboratories: The labs are still traveling around the US to ensure States learn to use the Superpave mix design system.
- PC-based software: The National Cooperative Highway Research Program (NCHRP) project 9-7 developed a database from field study information. This database is used by State highway agencies and contractors to track production data and by researchers in developing new software.
- Field performance: The mobile labs gathered and verified data critical to creating QC/QA test procedures.
- Equipment purchases: The Federal Highway Administration (FHWA) assisted in the initial purchase of new mixture and PG binder test equipment.
- Training programs: Training is available from the Superpave Resource Centers (see Web site), the Asphalt Institute, and NHI.

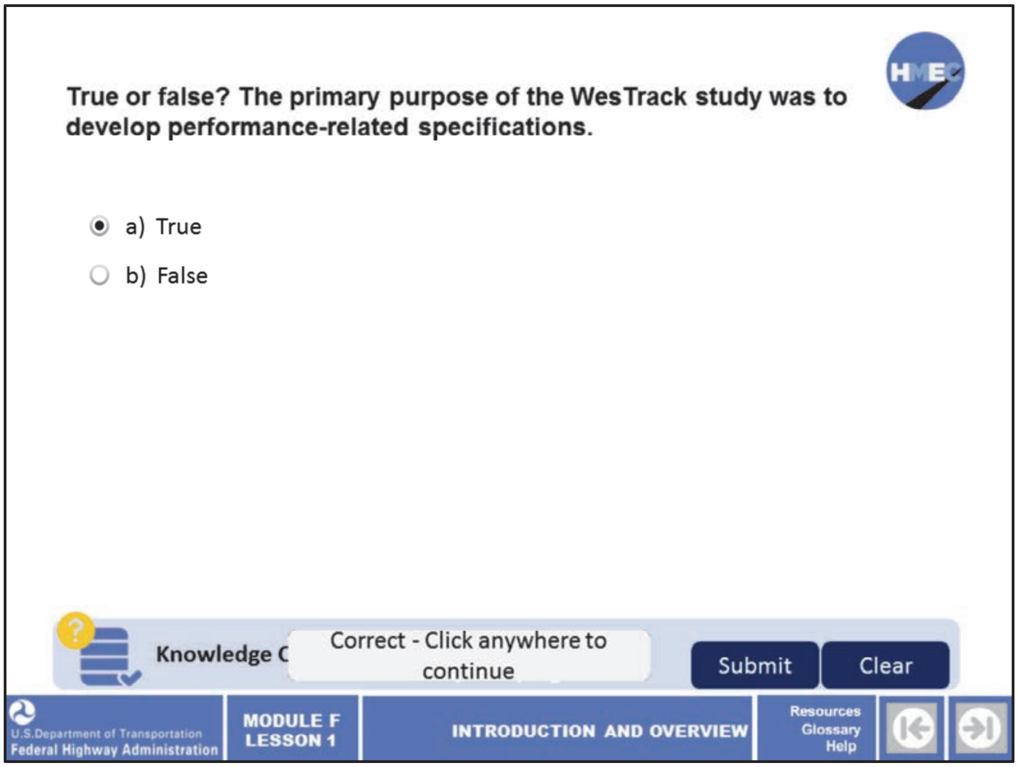
Also as a follow-up of the SHRP, the FHWA funded a study to assess the cost effectiveness of the SHRP. The costs for SHRP related-research, development, and implementation have been estimated to be $230 million over a 20-year period for binder alone. (LTPP is a 20-year program.)

In terms of benefits, it has been estimated that the research products could extend HMA pavement lives on the order of 4 years on a portion of the US network, resulting in savings of billions of dollars.

Given these estimates, benefit-to-cost ratios of 26 to 43 can be realized for public agencies and 72 to 116 for highways users. Together these amount to benefit-to-cost ratios of 98 to 159 for both agencies and users. This ratio illustrates that for every $1 spent on research, development, and implementation, public highway agencies/users can expect a rate of anywhere from $98 to $159, depending on the speed of implementation.

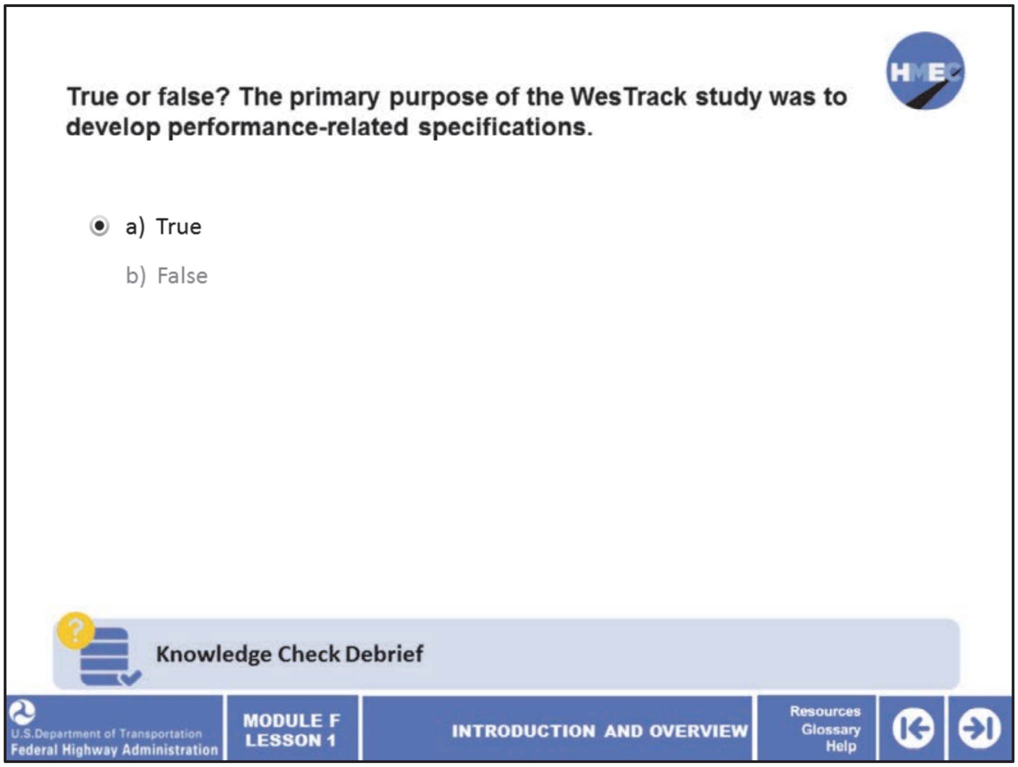
Reference:

Epps, John and Ardila-Coulson, Maria. (1997) "Summary of SHRP Research and Economic Benefits of Asphalt". Road Savers. FHWA Report FHWA-SA-98-012

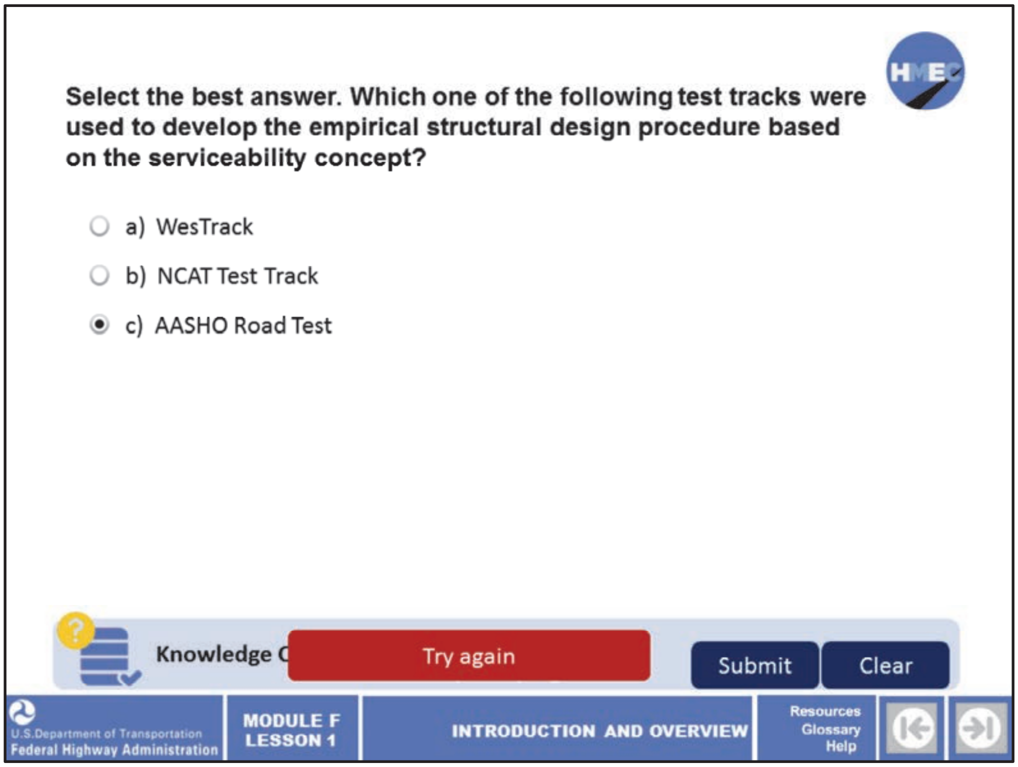


True or false? The primary purpose of the WesTrack study was to develop performance-related specifications.

a) True; or
b) False.

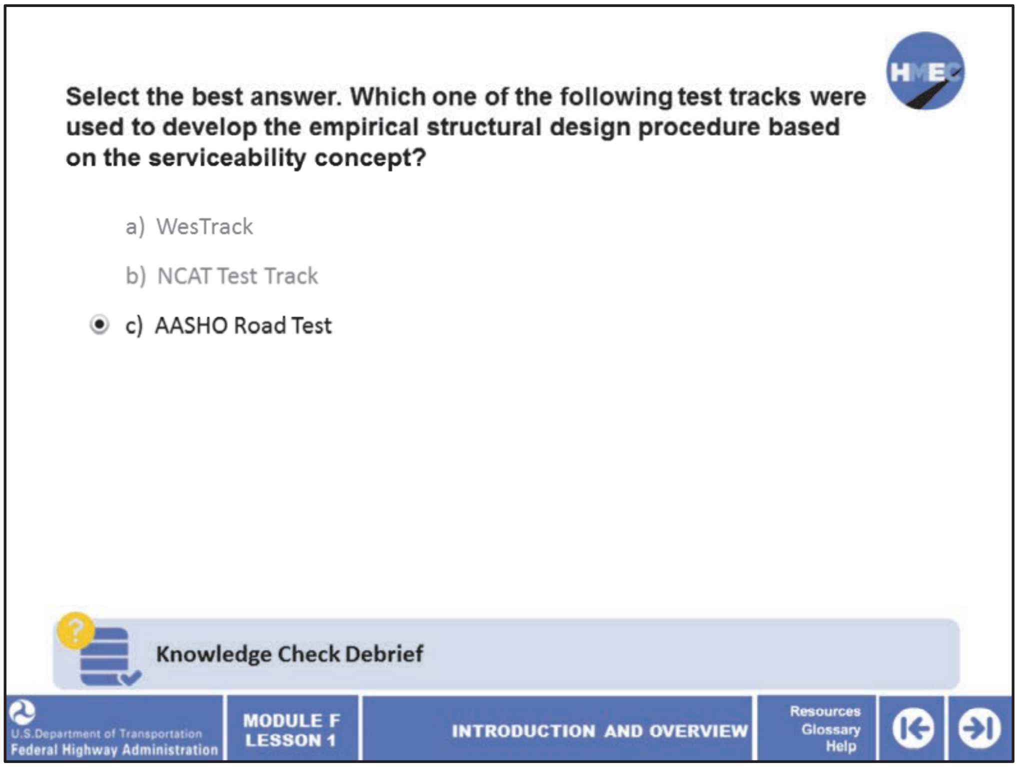


The correct answer is a) True. The primary purpose of the WesTrack study was to develop performance-related specifications.

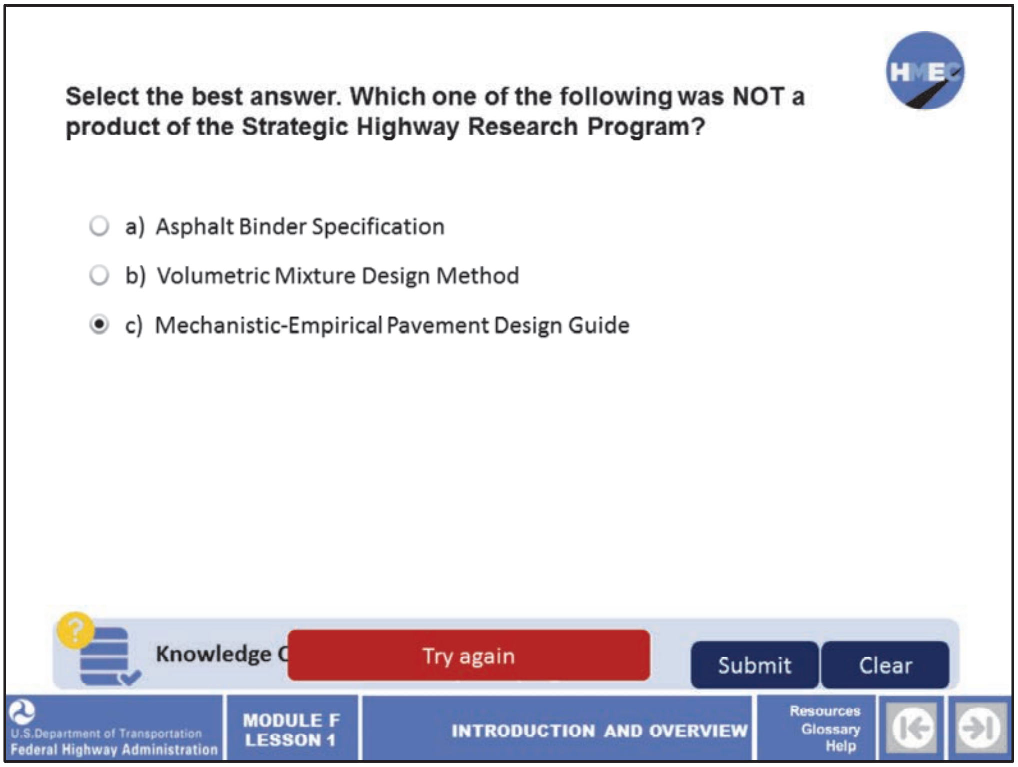


Select the best answer. Which one of the following test tracks were used to develop the empirical structural design procedure based on the serviceability concept?

a) WesTrack;
b) NCAT Test Track; or
c) AASHO Road Test.

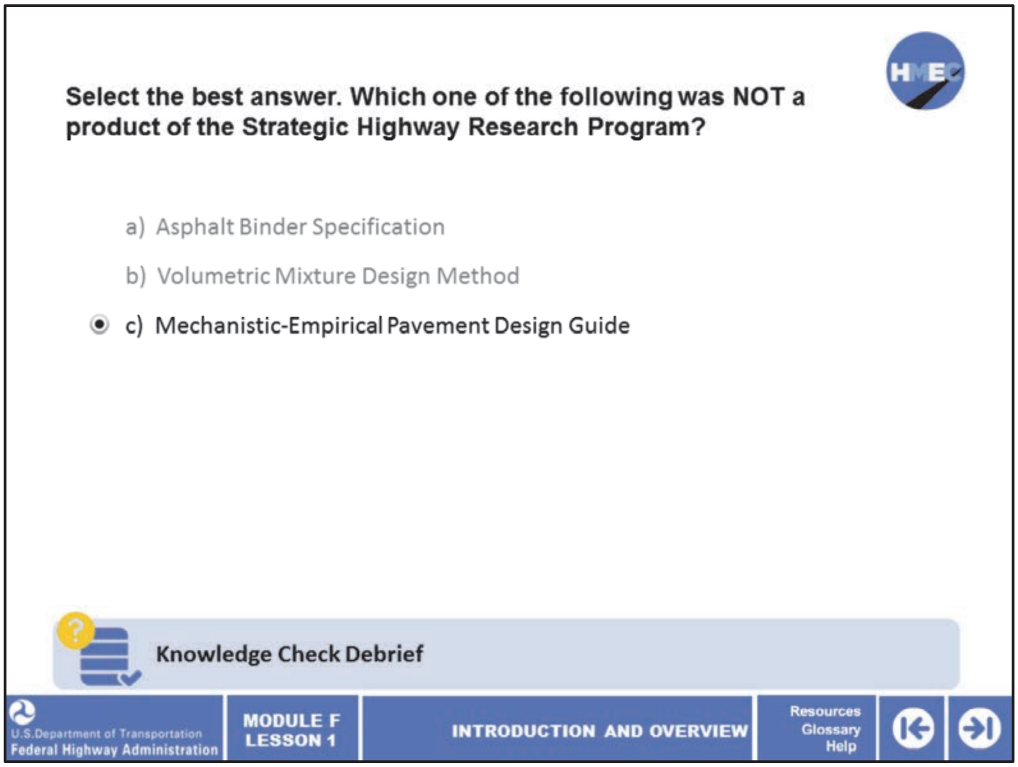


The correct answer is c) AASHO Road Test.

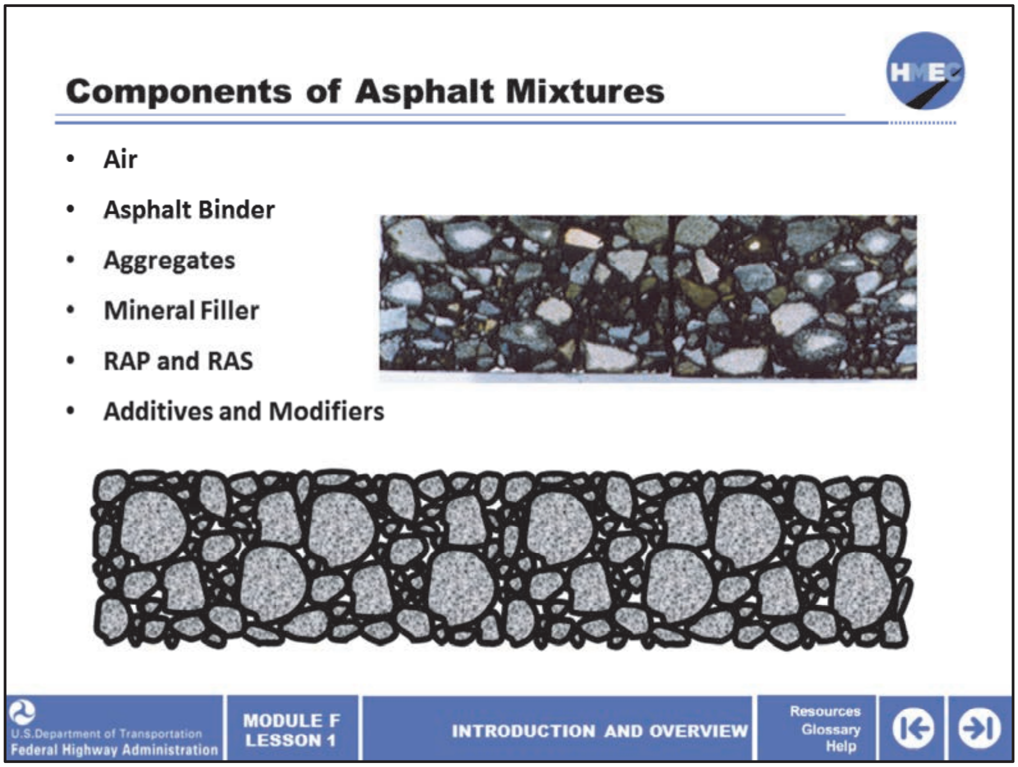


Select the best answer. Which one of the following was NOT a product of the Strategic Highway Research Program?

a) Asphalt Binder Specification;
b) Volumetric Mixture Design Method; or
c) Mechanistic-Empirical Pavement Design Guide.



The correct answer is c) Mechanistic-Empirical Pavement Design Guide.



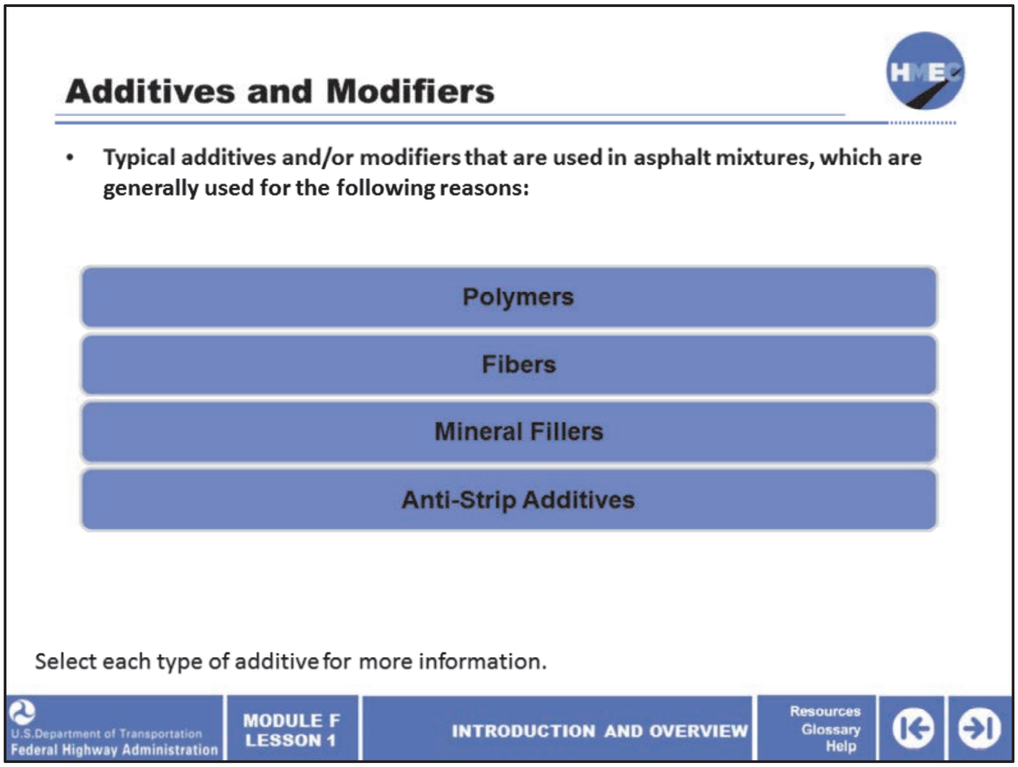
Asphalt mixtures consist of the following components:

- Air;
- Binder;
- Aggregates;
- Mineral Filler;
- Recycled asphalt pavement (RAP) and recycled asphalt shingles (RAS); and
- Additives and modifiers.

Some of these components were already discussed in some lessons from Module D. And, most of these components will be discussed again in more detail in later lessons of Module F. For now, it is important to identify the different components and how they fit together.

Image description: Photo of asphalt mixtures.

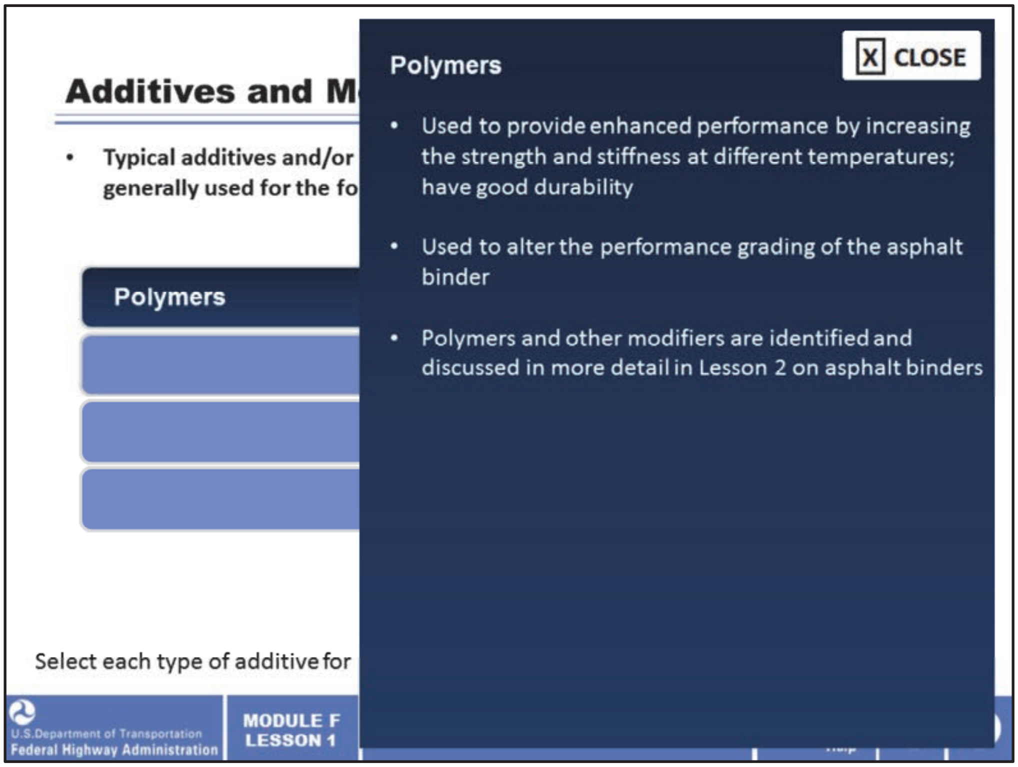
Image description: Illustration of asphalt mixtures.



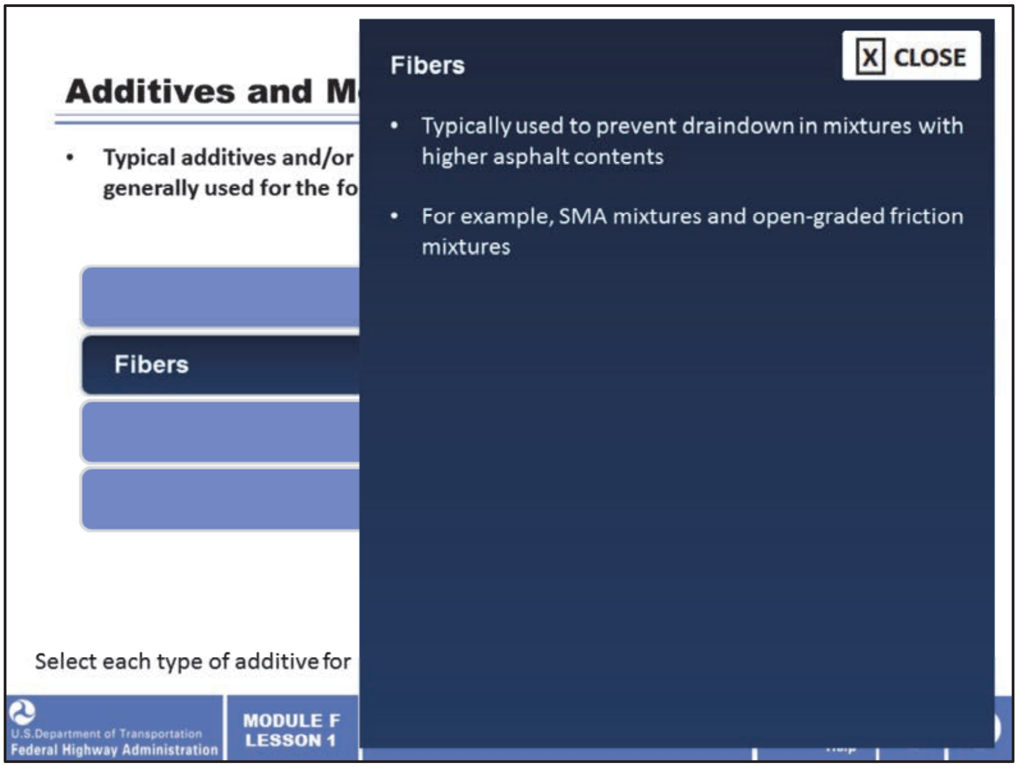
The next part of this lesson focuses on and introduces the different types of additives and modifiers that are used in asphalt mixtures. This screen summarizes and lists the different additives and/or modifiers that are used in asphalt mixtures, which are generally used for the following reasons:

- Polymers;
- Fibers;
- Mineral fillers; and
- Anti-strip additives.

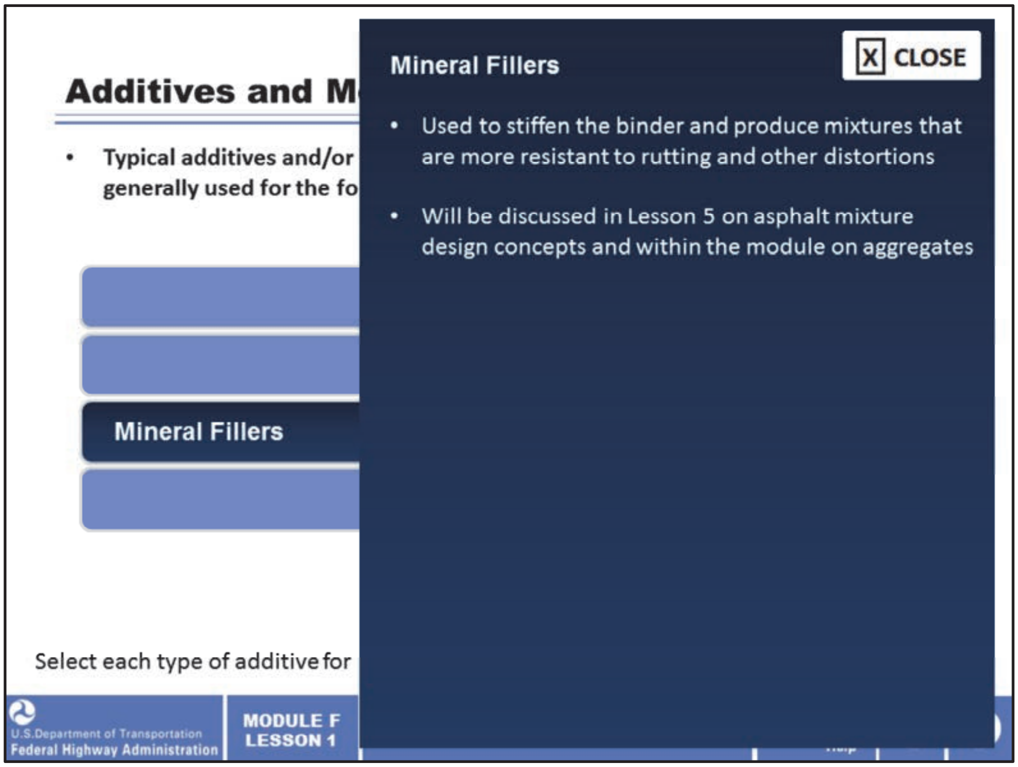
Select each type of additive for more information.



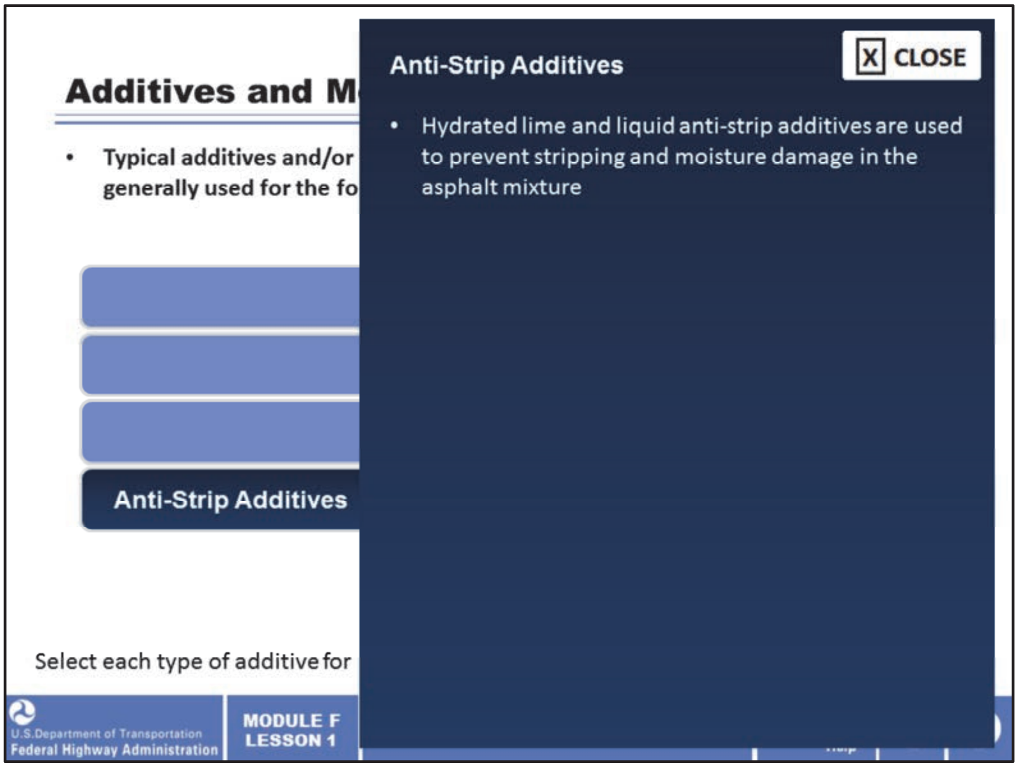
Polymers are used to provide enhanced performance by increasing the strength and stiffness at different temperatures, have good durability, and can be used to alter the performance grading of the asphalt binder. Polymers and other modifiers are identified and discussed in more detail in Lesson 2 on asphalt binders.



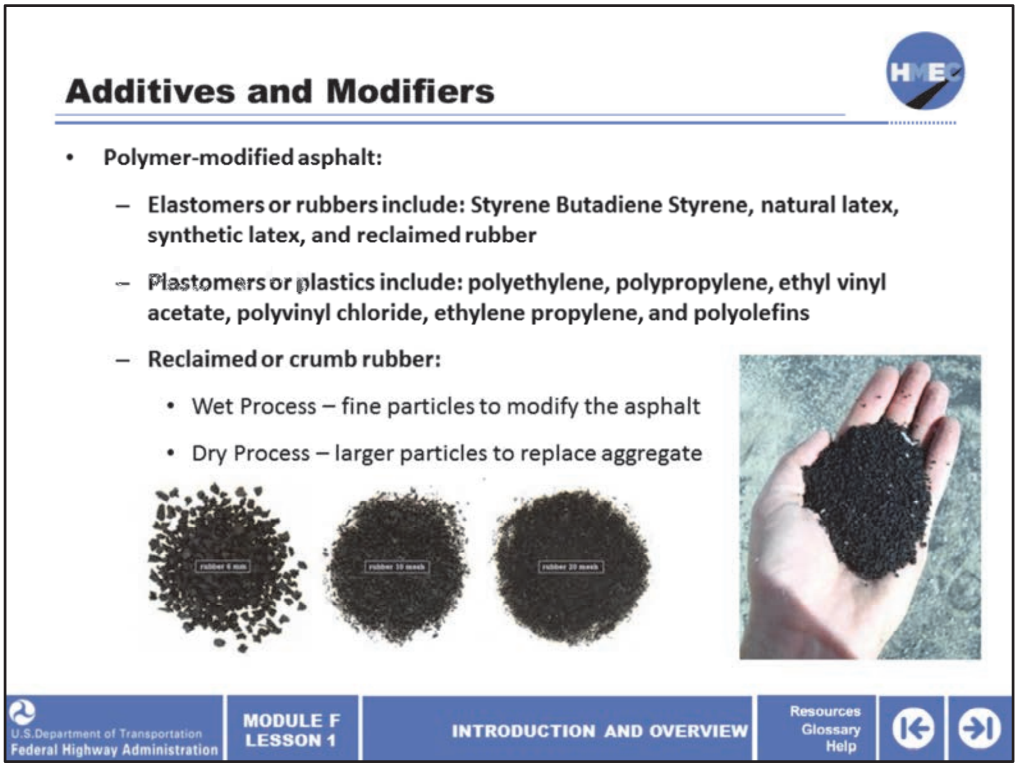
Fibers are typically used to prevent draindown in mixtures with higher asphalt contents—for example, stone mastic asphalt (SMA) mixtures and open-graded friction mixtures.



Mineral fillers are used to stiffen the binder and produce mixtures that are more resistant to rutting and other distortions. Mineral fillers will be discussed in Lesson 5 on asphalt mixture design concepts and within the module on aggregates.



Hydrated lime and liquid anti-strip additives are used to prevent stripping and moisture damage in the asphalt mixture.

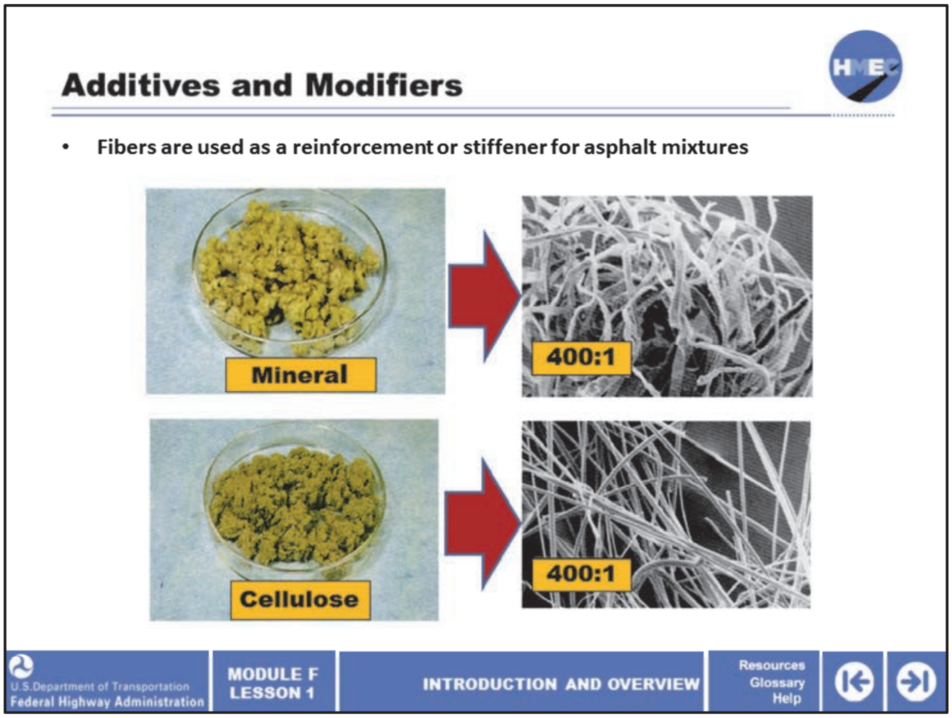


Polymer-modified asphalt has been used to enhance the performance of open-graded mixtures as a wearing surface of asphalt pavements. These mixtures have been found to be very resistant to cracking and rutting. Polymer-modified asphalts are typically used in high-stress or high-traffic areas. Polymer-modified asphalt can be categorized into two types: elastomers or rubber and plastomers or plastics.

Crumb rubber is used in asphalt mixtures. Crumb rubber can be added to the asphalt mixture through two processes: the wet process, which uses very fine rubber particles blended in with the asphalt itself prior to coating the aggregate, and the dry process, which basically uses larger rubber particles as a replacement for aggregate.

Image description: Photo of crumb rubber, various sizes.

Image description: Photo of a hand filled with crumb rubber.



Fibers are used as a reinforcement or stiffener for asphalt mixtures. They are used to increase the tensile strength and cohesion of asphalt mixtures. Fibers are also used to increase the amount of asphalt added to the aggregate blend without increasing the potential for draindown. The use of fibers are especially important for SMA and open-graded friction courses.

Fibers used in asphalt mixtures consist of natural fibers such as asbestos and synthetic fibers. Asbestos fibers, however, are no longer used because asbestos is a health hazard. Most of the fibers used in asphalt mixtures today are synthetic. Polypropylene and polyester fibers are typically used as reinforcement in the asphalt mixture. Cellulose fibers are used extensively in SMA mixtures for the purpose of increasing the amount of asphalt without any draindown. Mineral fibers are used in dense-graded, SMA, and open-graded mixtures. Typically, mineral fibers are manufactured from diabase as a raw material.

The screen shows two different fibers used in asphalt mixtures.

- Cellulose – 400:1;
- Mineral – 400:1.

Image description: Photo of mineral.

Image description: Photo of mineral magnified to 400:1.

Image description: Photo of cellulose.

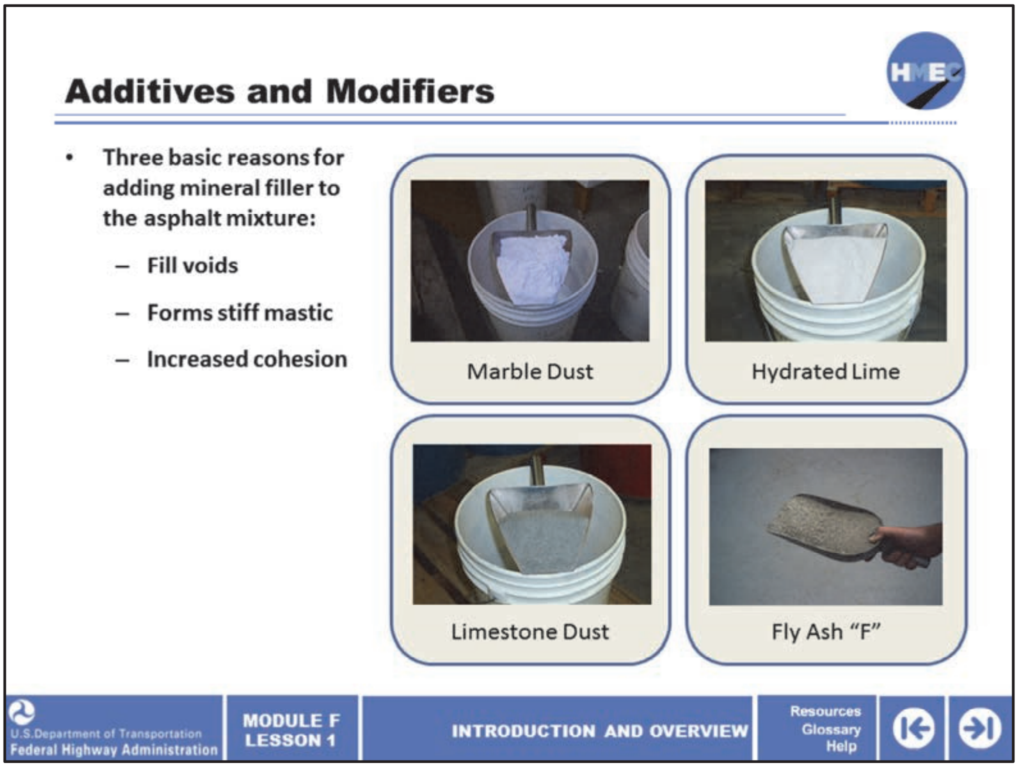
Image description: Photo of cellulose magnified to 400:1.

Pelletized fibers or fiber pellets are used so that more asphalt can be added to the aggregate blend without any draindown problem. The thick asphalt binder films increase the durability of the asphalt mixture—both dense-graded and open-graded mixtures.

Pelletized fibers are added to the mixture at the production plant. So some manufacturers deliver the pelletized fibers to the plant in plastic bags that melt when added to the mixture because some cannot be easily handled in bulk. Sometimes the pelletized fibers are air blown into the drum mixer. Different types of equipment are usually provided by the fiber manufacturers to handle and add specific fibers to the asphalt mixture during production.

Image description: Photo of hands holding fiber pellets.

Image description: Photo of pellet fluffer machine.



There are different types of mineral filler used in asphalt mixtures; most are mineral dust from the crushing and screening operations of the aggregates. There are three basic reasons for adding mineral filler to the asphalt mixture:

1. Fill voids to reduce the oxidation and permeability of surface mixtures, as well as to reduce the amount of asphalt required to meet the design air void level during mixture design process. Reduction in the target asphalt content, however, may not always be a

positive point toward long-term asphalt mixture performance.
2. Stiffen the mastic, which consists of the asphalt, filler, and fines to increase the rutting resistance of a mixture.
3. Increase cohesion of the asphalt mastic.

Hydrated lime is typically used in mixtures with aggregates that are susceptible to moisture damage and to improve the stiffness and strength of the mixture. Hydrated lime is the more common filler, which is an additive, used to increase the resistance to moisture damage.

Limestone dust, marble dust, and fly ash “F” are used to stiffen the mixture by stiffening the mastic. There are many other materials that are used as fillers, which include carbon black, sulfur, baghouse fines returned to the mixture during the production process, and Portland cement. Sulfur and carbon black are very fine and can modify the properties of the asphalt binder.

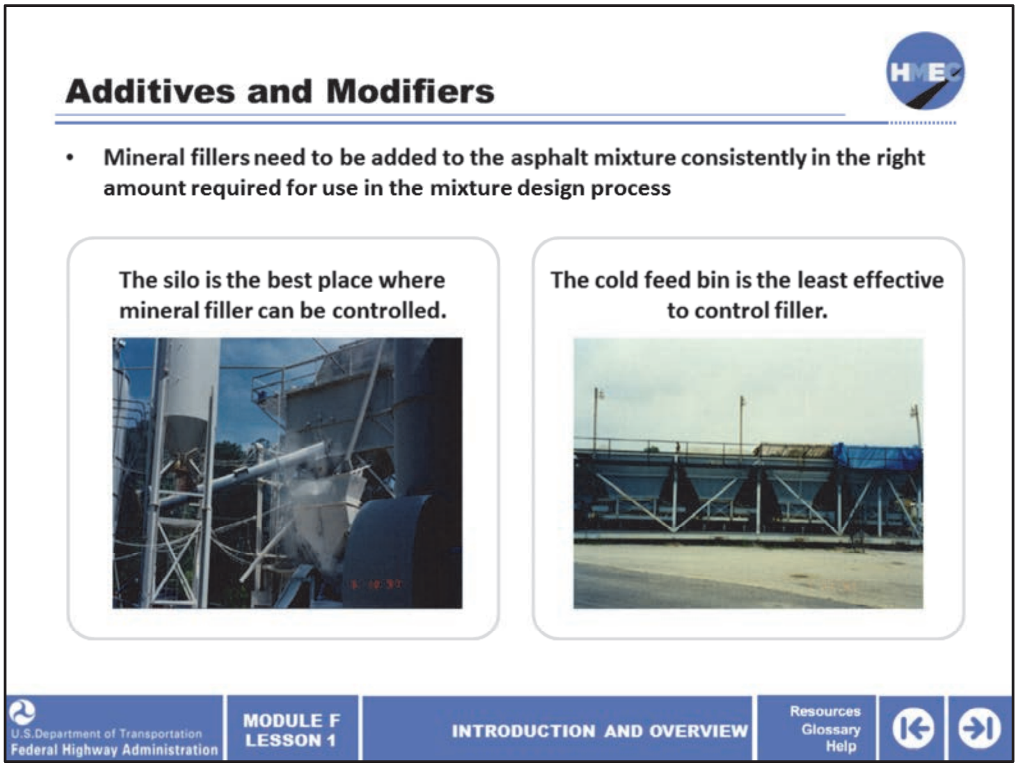
Baghouse fines and Portland cement, or dust from the aggregate crushing operation are the ones used more commonly. Most specifications place limits on the dust to asphalt binder ratio. A ratio of 0.6 to 1.2 by weight is common. The extent of the stiffening is generally dependent on the Rigden void content, which is the voids between the fine particles in a dry compacted state. The Rigden void content will be included in Lesson 5 on asphalt mixture design concepts.

Image description: Photo of marble dust.

Image description: Photo of hydrated lime.

Image description: Photo of limestone dust.

Image description: Photo of fly ash "F“.



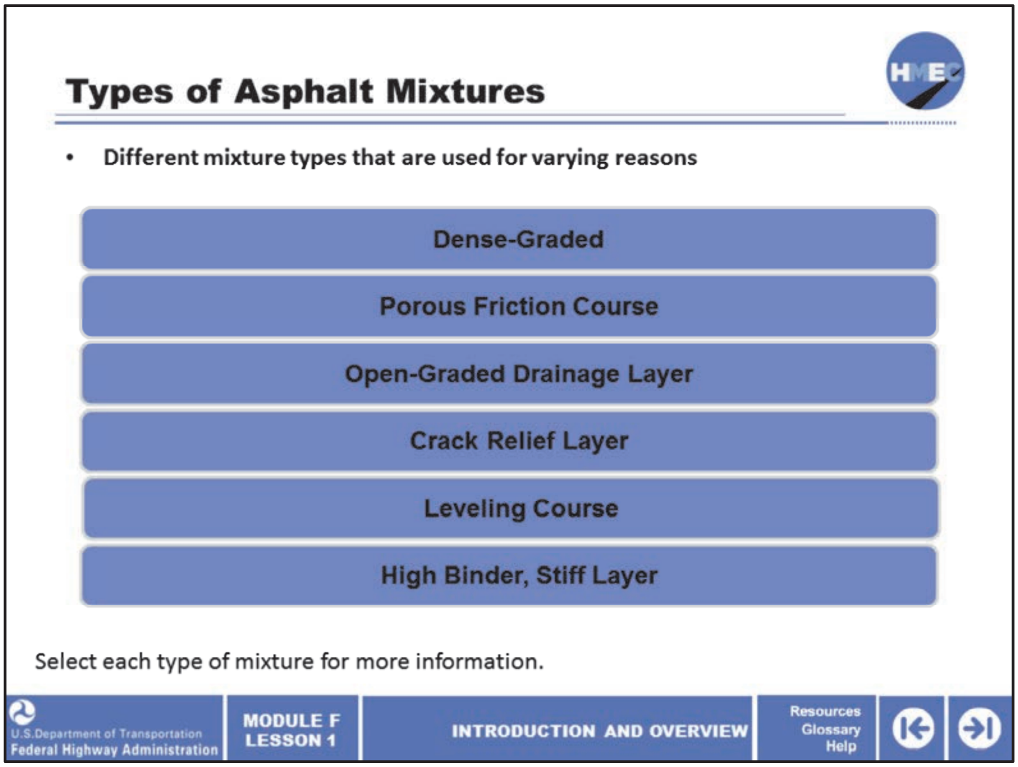
Mineral fillers need to be added to the asphalt mixture consistently and in the right amount required for use in the mixture design process.

The silo is probably the best place where mineral filler can be metered into production so that the amount can be easily controlled. The cold feed bin is probably the least effective location or means to add the mineral filler into the aggregate blend because the mineral filler needs to stay dry.

Any moisture tends to create clogs of mineral filler and the variability in the amount added increases significantly, resulting in increased variability in the asphalt mixture.

Image description: Photo of mineral filler silo.

Image description: Photo of cold feed bins.

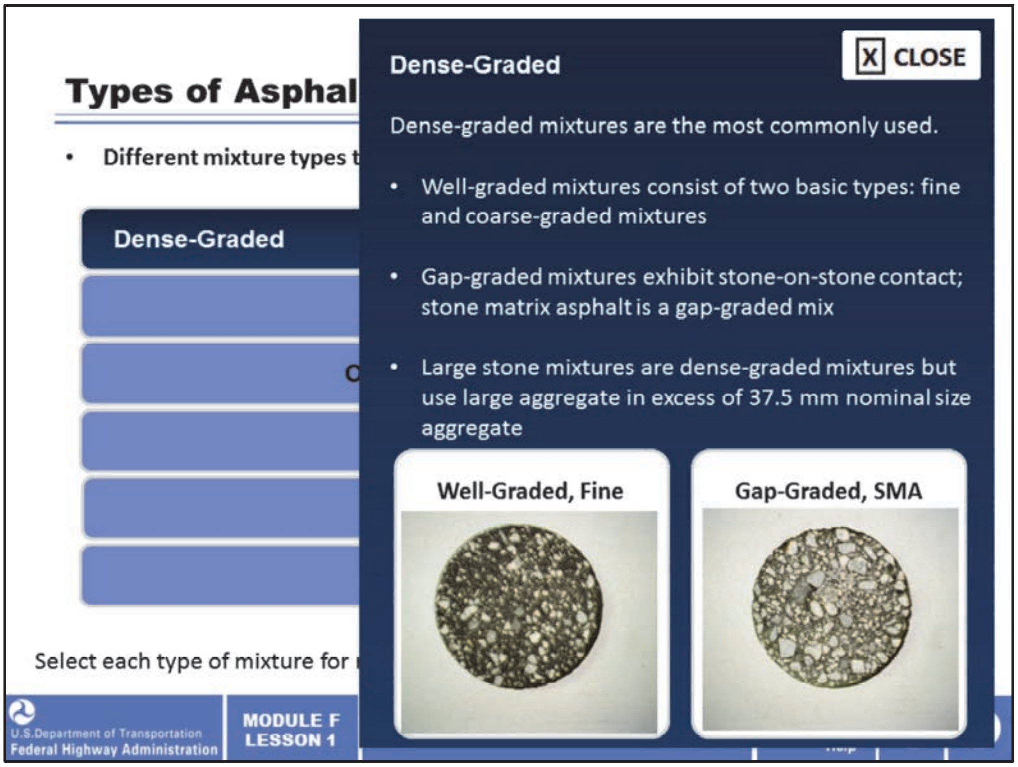


Now let’s focus on the types of asphalt mixtures that are typically used. This screen lists the different mixture types that are used for varying reasons.

They are:

• Dense-graded mixtures (well-graded and gap-graded mixtures);
• Porous friction or open-graded friction courses;
• Open-graded drainage layers;
• Crack relief layers;
• Leveling course mixtures; and
• High binder, stiff layer mixture.

Select each type of mixture for more information.

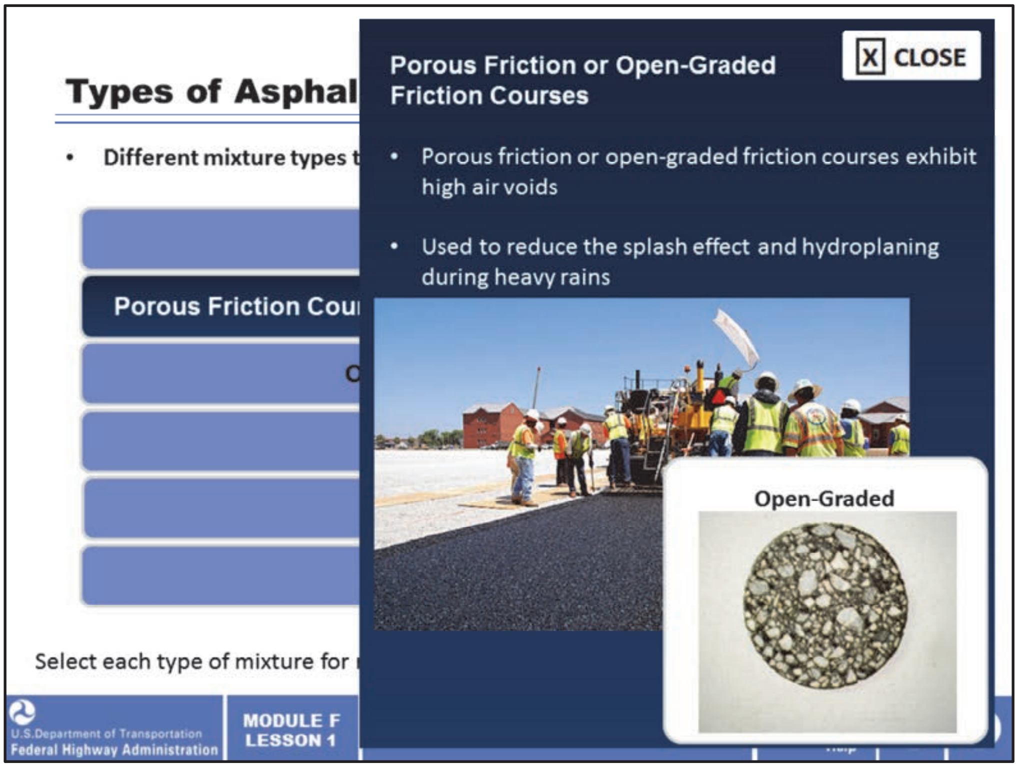


Dense-graded mixtures are the most commonly used. Examples of dense-graded mixtures include:

• Well-graded mixtures consist of two basic types: fine and coarse-graded mixtures. Both fine and coarse-graded mixtures generally follow or slightly deviate from the 0.45 power gradation line. Fine-graded mixtures typically fall above the 0.45 power gradation line (which will be discussed under Lesson 5), while coarse-graded mixtures fall below that line.
• Gap-graded mixtures exhibit stone-on-stone contact. Stone matrix asphalt is a gap-graded mix. These mixtures or aggregate gradation use fines to fill the voids between the coarse aggregate.
• Large stone mixtures are dense-graded mixtures but use large aggregate in excess of 37.5 mm nominal size aggregate. These mixtures are typically used as a base course because much thicker lifts can be placed and compacted. These mixtures also generally require less total asphalt because of the larger diameter aggregate with smaller surface area to be coated by the asphalt. Large stone mixtures can be classified as fine or coarse-graded mixtures, depending on where the actual gradation line falls relative to the 0.45 power gradation line.

Image description: Photo of well graded asphalt.

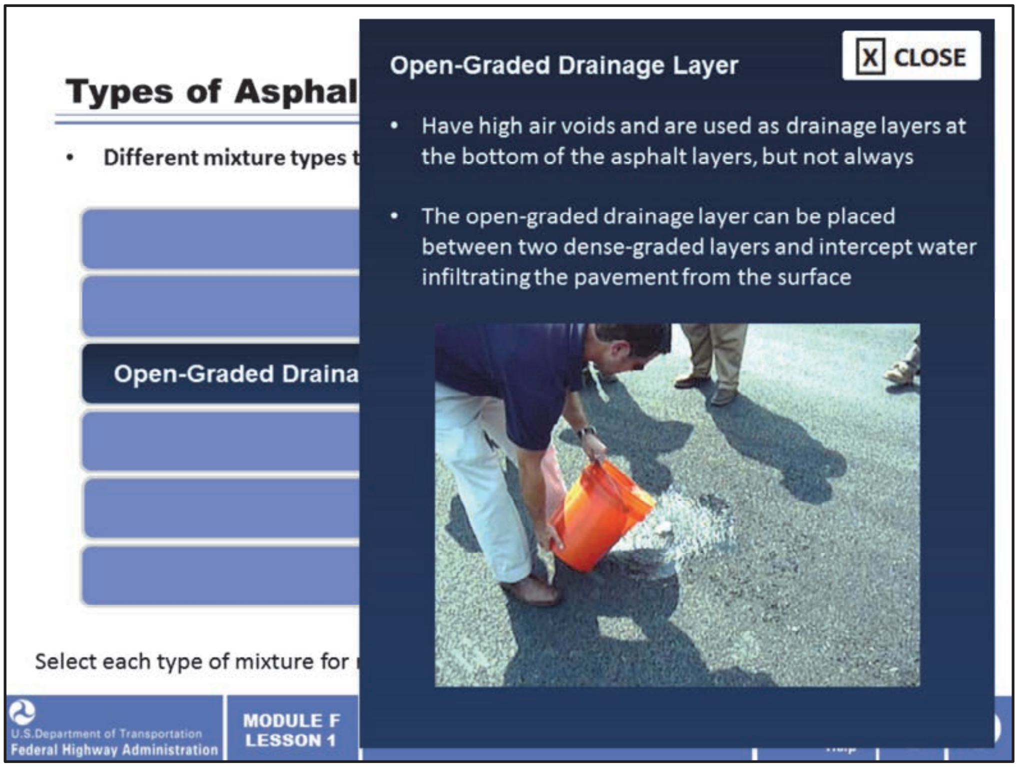
Image description: Photo of gap graded asphalt.



Porous friction or open-graded friction courses exhibit high air voids and are used to reduce the splash effect during heavy rains. They also reduce hydroplaning during wet weather because water can be retained in the air void structure of the open-graded mixture and removed more quickly laterally towards the edge of the pavement.

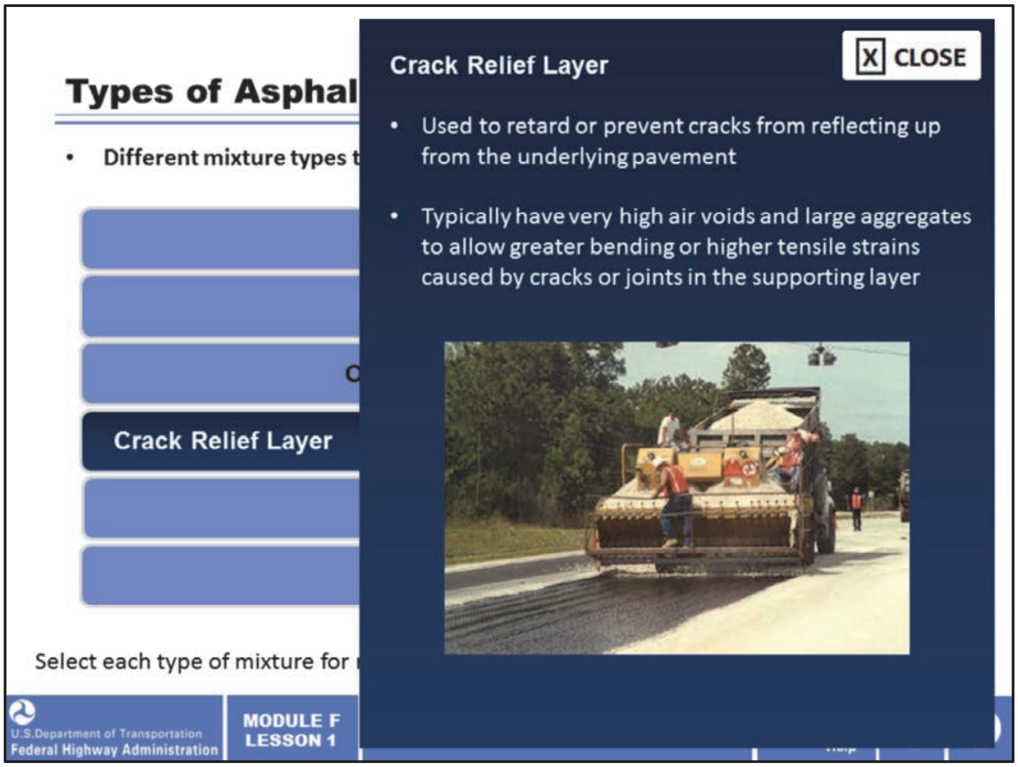
Image description: Photo of porous friction asphalt paving.

Image description: Photo of open graded asphalt.



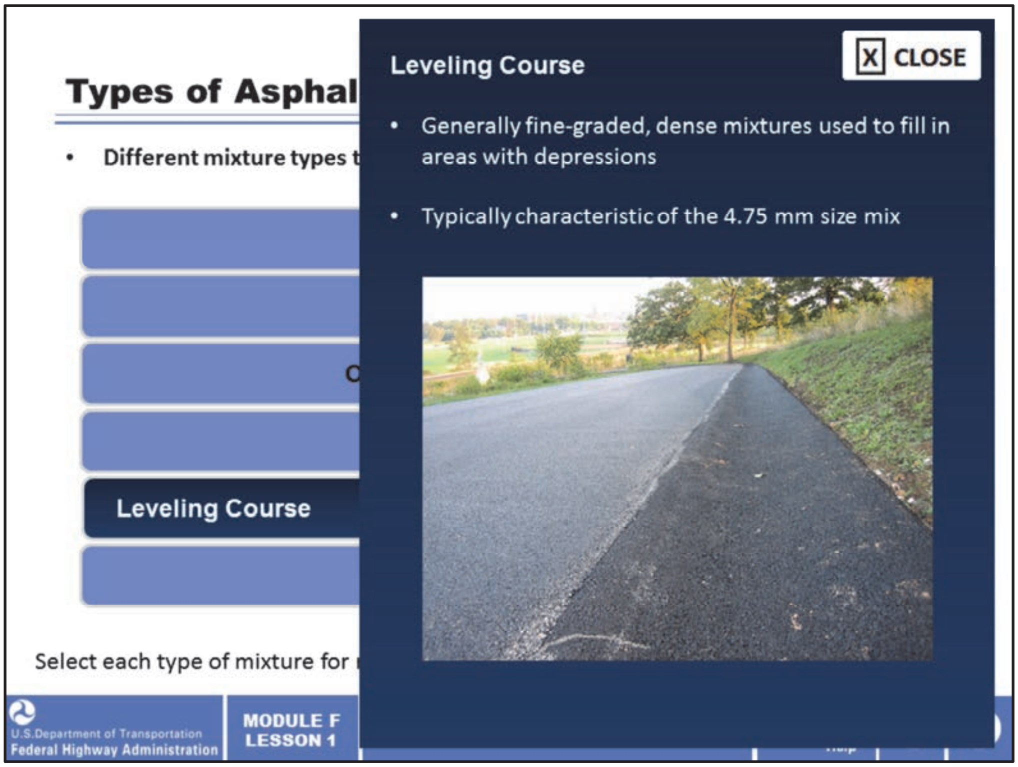
Open-graded drainage layers have high air voids and are typically used as drainage layers at the bottom of the asphalt layers, but not always. A few agencies place the open-graded drainage layer between two dense-graded layers to intercept water infiltrating the pavement from the surface.

Image description: Photo of open graded drainage asphalt



Cracks relief layers are used to retard or prevent cracks from reflecting up from the underlying pavement. These mixtures typically have very high air voids and large aggregates to allow greater bending or higher tensile strains caused by cracks or joints in the supporting layer.

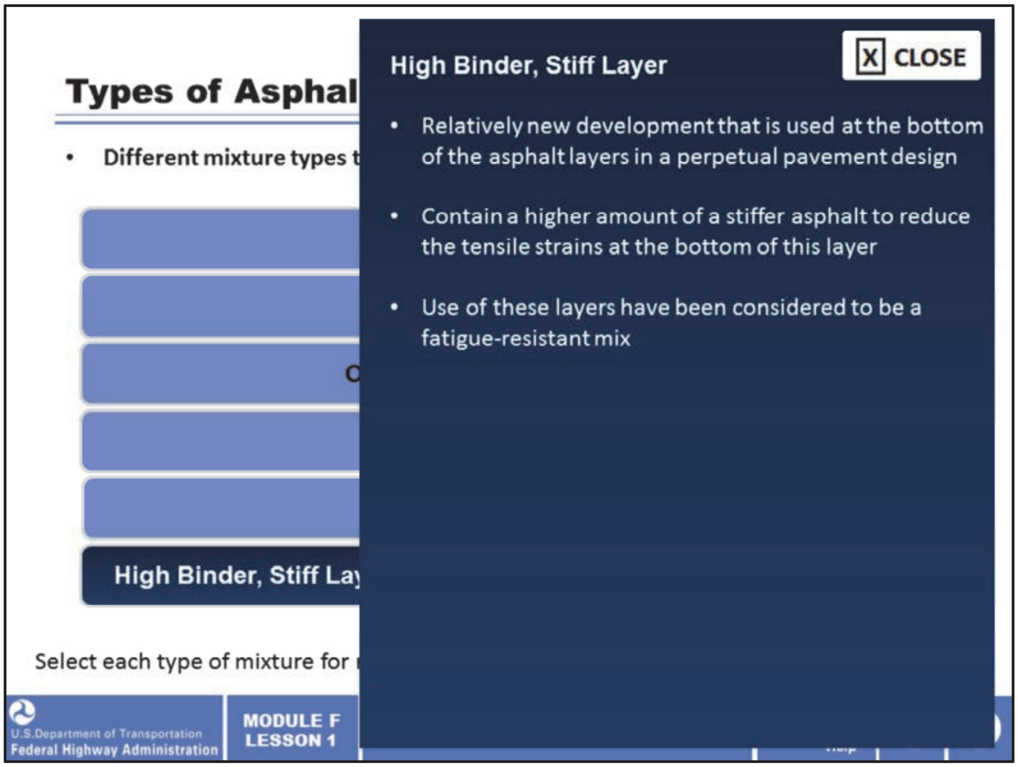
Image description: Photo of crack relief layer paving.



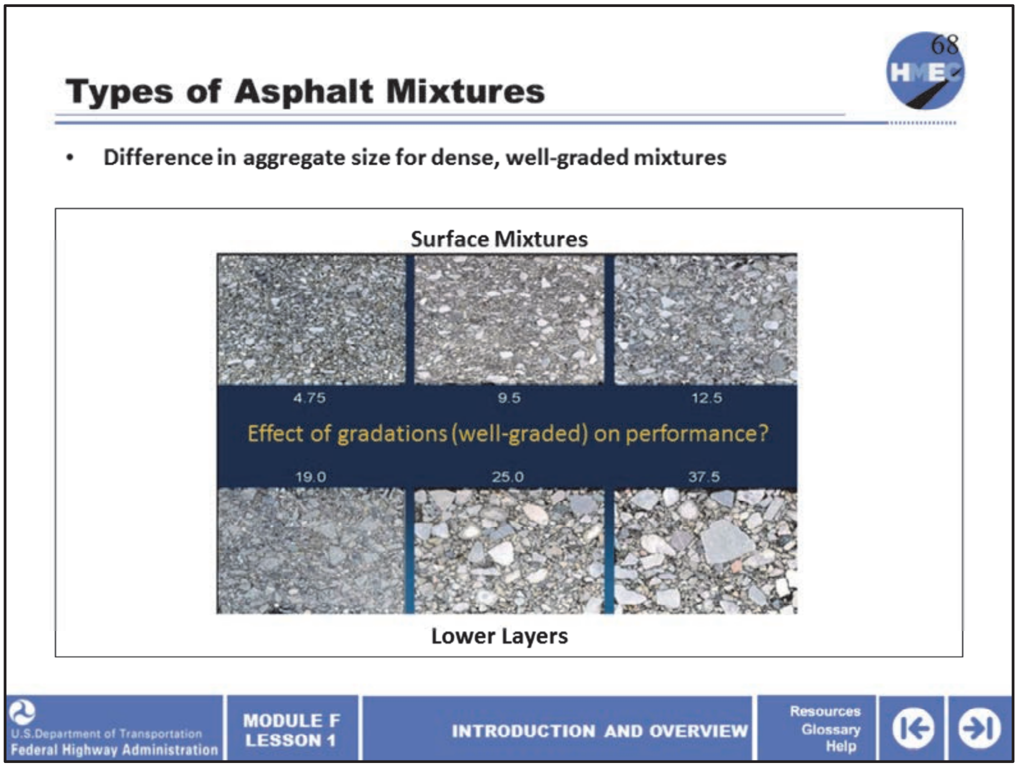
Leveling course mixtures are generally fine-graded, dense mixtures used to fill in areas with depressions. These layers are typically characteristic of the 4.75 mm size mix.

Thin lift overlays (typically 4.75 mm size mixes) are characteristic of leveling courses, but are placed on the surface so other properties become important—for example, the skid resistance of the mixture. Thin lift overlays are beginning to be used more extensively and can be used as a leveling course.

Image description: Photo of leveling Course on side or road.



The high binder, stiff layer mixture is a relatively new development that is used at the bottom of the asphalt layers in a perpetual pavement design. These mixtures contain a higher amount of a stiffer asphalt to reduce the tensile strains at the bottom of this layer. Use of these layers have been considered to be a fatigue-resistant mix.

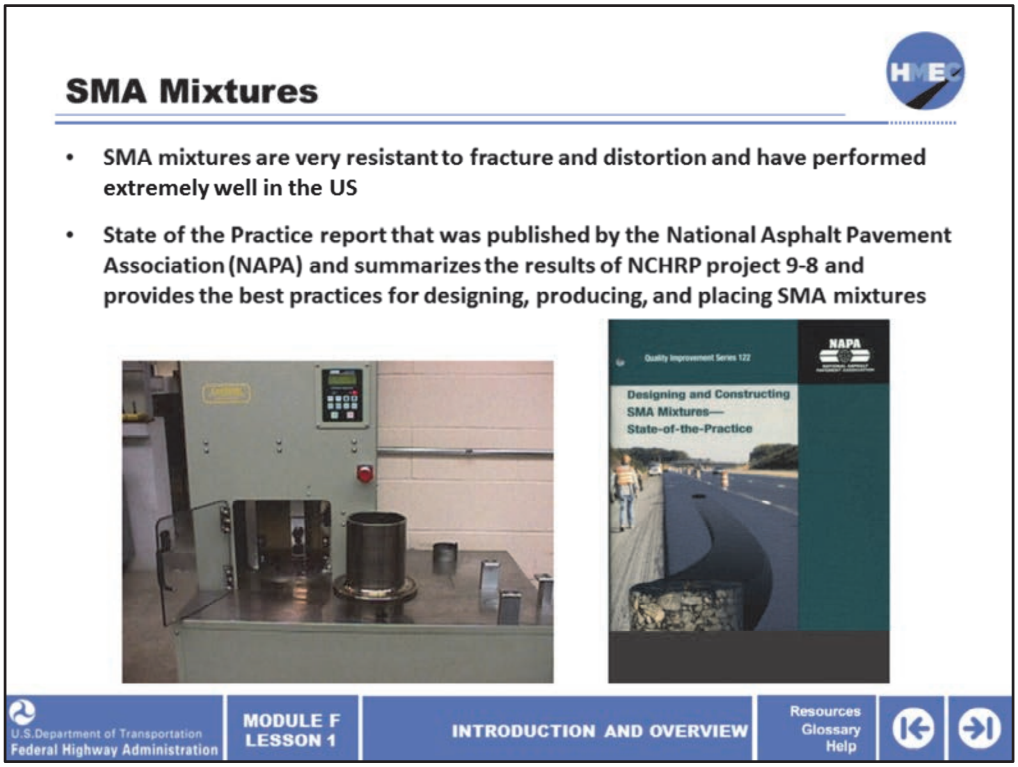


This screen illustrates the difference in aggregate size for dense, well-graded mixtures.

The smaller mixes (4.75 mm nominal maximum size aggregate) are used as surface mixes or leveling courses, while the larger mixes (37.5 mm nominal maximum size aggregate) are used in the lower layers.

Aggregate size and gradation has an important impact on the amount of asphalt derived from the mixture design process, but as long as the mixture design process is done properly, it has a smaller impact on the performance of the mixture. The larger the size of the aggregate, the less asphalt is derived. For example, the 37.5 mm nominal size aggregate blend typically requires less asphalt than for the 9.5 mm nominal size aggregate blend.

Image description: Photo showing the difference in aggregate size for dense, well-graded mixtures.



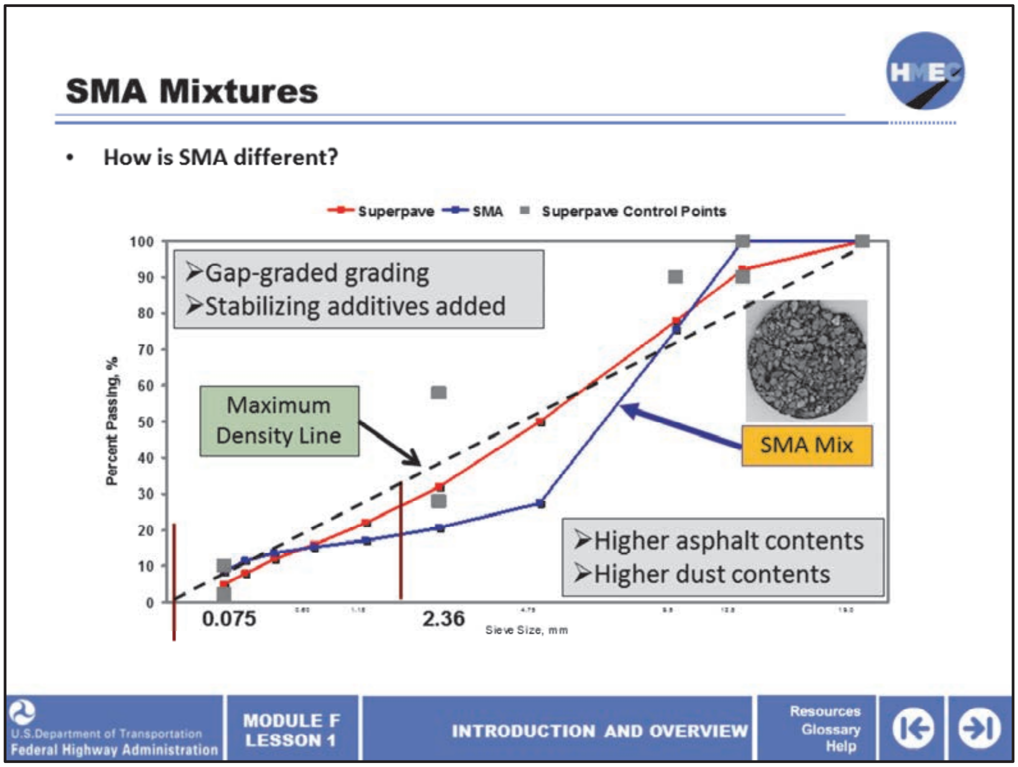
Another dense-graded mixture, is called stone matrix asphalt mixtures (SMA). SMA mixtures have a gap-graded gradation, which is illustrated on the next slide.

Stone matrix asphalt mixtures were introduced to the US from the European scan tour in the 1980s. Michigan was one of the first States to use SMA mixtures as a wearing course, but Maryland was one of the earlier States to use SMA on a large basis for rehabilitating their major highway routes. The performance of the SMA mixtures placed in Maryland has been considered a big success.

These mixtures are resistant to fracture and distortion (cracking and rutting). They have performed extremely well in the US. This screen shows the State of the Practice report that was published by the National Asphalt Pavement Association (NAPA) and summarizes the results of NCHRP project 9-8 and provides the best practices for designing, producing, and placing SMA mixtures.

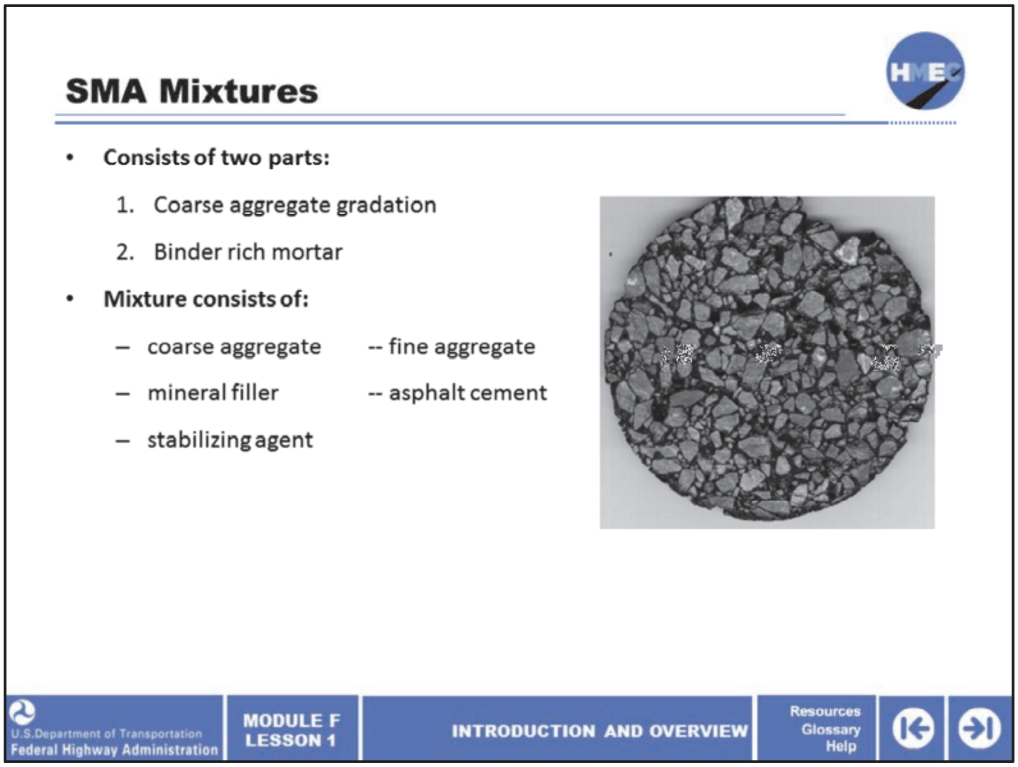
Image description: Photo of a lab.

Image description: SMA Mixtures - State of practice report.



This graph shows the difference between an SMA mix and a dense-graded Superpave mix. Notice that the amount of material passing the 2.36 mm (#8 sieve) for an SMA mix is about 20% and for the Superpave mix, is about 30% and that the 0.075 mm (#200 sieve) is about 10% for the SMA mix and about 6% for a Superpave mix.

Image description: Graph showing the difference between an SMA mix and a dense-graded Superpave mix.



The SMA mixture consists of a coarse-aggregate gradation and a high binder mortar that glues the mix together.

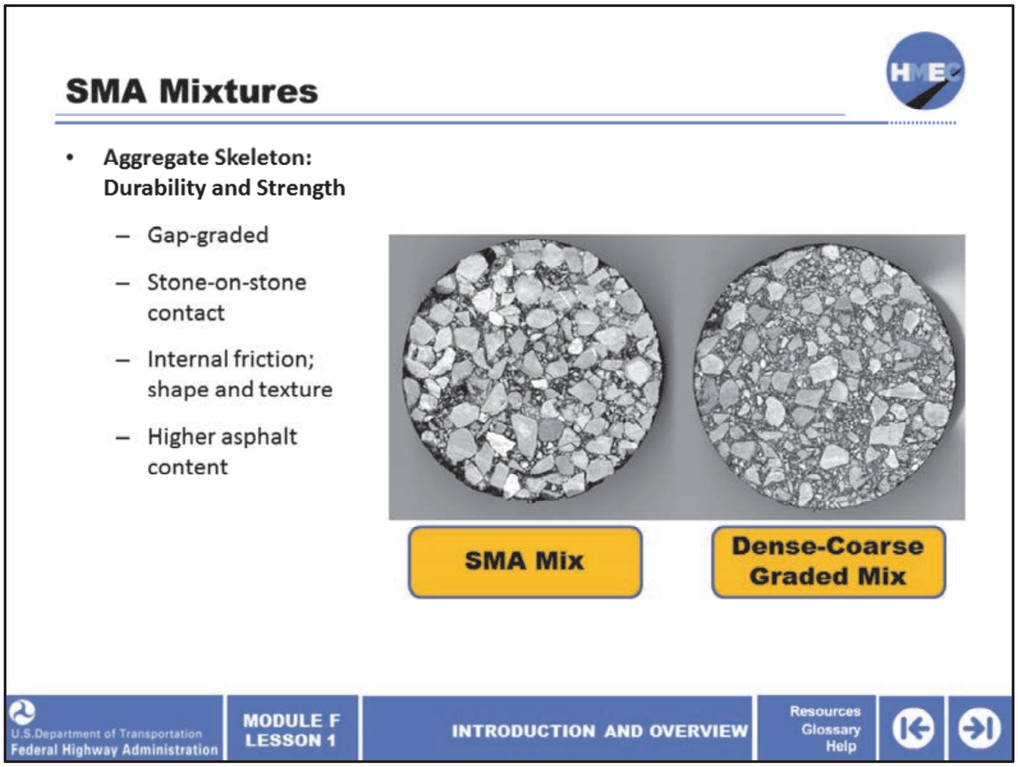
Its mix properties use a 50 blow Marshall or 100 gyration Superpave Gyratory Compactor (SGC). The asphalt content is selected at an air void of 4%. The mix properties for design and construction are covered in the NAPA manual referred to in an earlier slide.

It has a high VMA as compared to a dense-graded mix. The mixtures consist of crushed coarse aggregate, crushed fine aggregate, mineral filler, asphalt cement, and a stabilizing agent.

The stabilizing agent is used to prevent draindown of the asphalt and typically consists of fibers and/or polymers. The SMA mixture is typically designed to have a high coarse aggregate content (typically 70 to 80%), a high asphalt content (typically over 6% by weight), and high filler content (typically 10% by weight).

Although the Marshall hammer was initially used to design SMA mixtures, just about all agencies now use the gyratory compactor to design these mixtures.

Image description: Photo of an SMA mix core sample.



The goal of an SMA is a mix that has stone-on-stone contact. This screen shows a comparison of two cut cores or laboratory compacted specimens: one representing an SMA mix and the other a dense-coarse-graded mix.

As shown, the gap-graded or SMA mix has stone-on-stone contact while the dense-coarse-graded mix does not have or exhibit stone-on-stone contact. Some in the industry refer to the well or dense-graded aggregate blend for the core on the right in the photo as an aggregate blend where the coarse aggregate "are floating in a sea of fines."

SMA mixtures have exhibited excellent resistant to cracking and rutting and are reported to be very durable mixtures, as noted in a previous screen.

Image description: Photo showing an SMA mix and a dense-coarse graded mix.

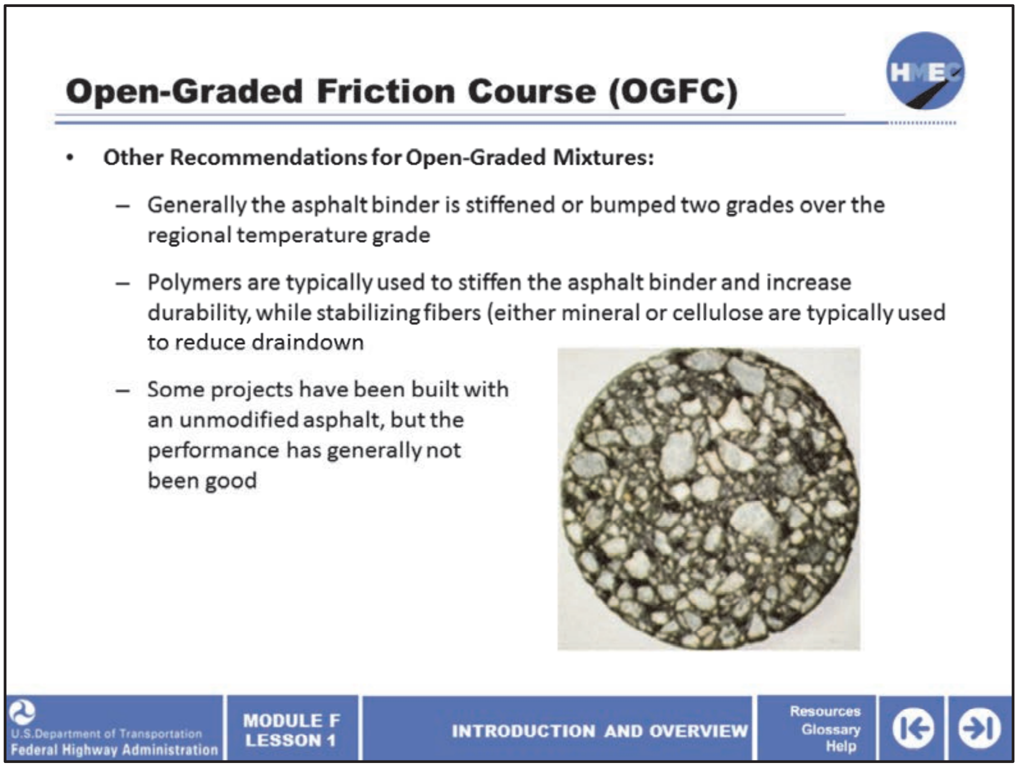
The next part of this section will cover open-graded friction courses or porous friction courses. An open-graded friction course (OGFC) consists of an asphalt mixture that is designed to have a large number of voids so that water can drain through and over the surface of this mixture. The large air void content is created by using a larger percentage of coarse aggregate.

Image description: Photo of OGFC paving.

Open-graded friction courses are used for five reasons:

1. Reduces hydroplaning because it quickly removes water during and shortly after heavy rains.
2. Improves and retains friction because of the aggregate requirements.
3. Reduces splash spray because water flows through the voids in the mix transversely over the pavement. This is shown on the screen. The left part of the screen has an OGFC surface while the right part of the screen does not—it has a dense-graded surface. The splash effect is significantly less with better visibility for the pavement with the OGFC.
4. Reduces noise because of the higher voids.
5. Improves visibility and reduces headlight glare because it moves the water quickly and has a macro-texture surface to reduce glare.

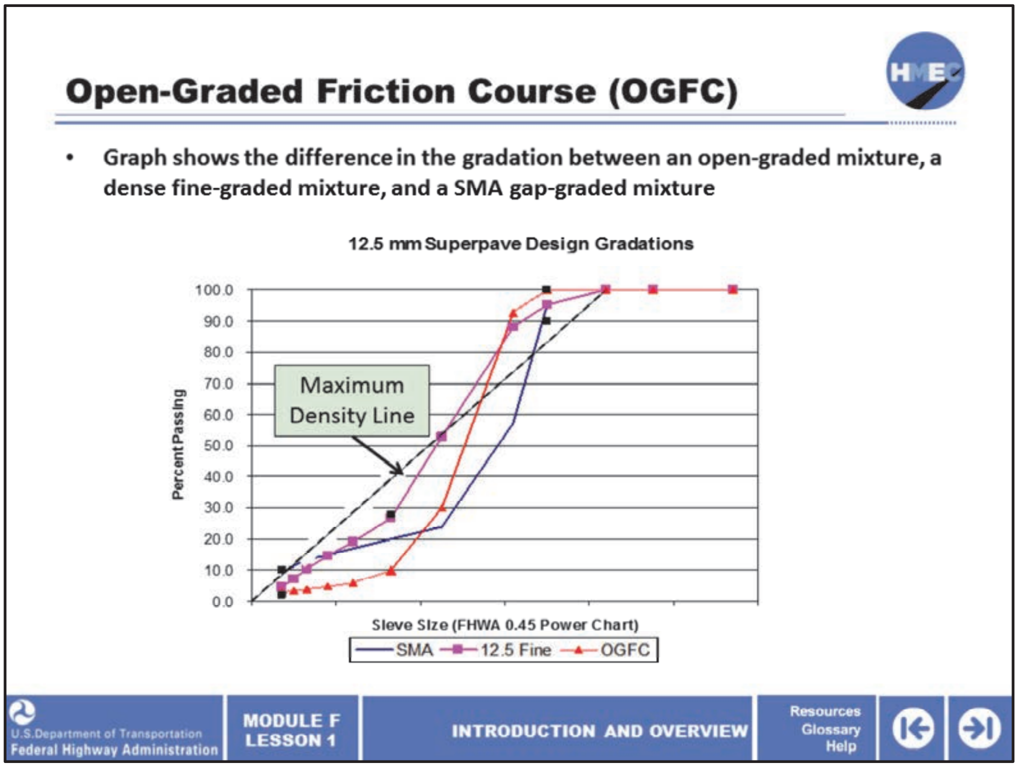
Image description: Photo showing OGFC with very little water on the pavement and conventional pavement covered with water.



For many open-graded surface mixtures, like porous friction courses, materials are used to stiffen the asphalt and prevent draindown of the higher amounts of asphalt used to coat the aggregate particles. Polymers are generally used to stiffen the asphalt and reduce draindown.

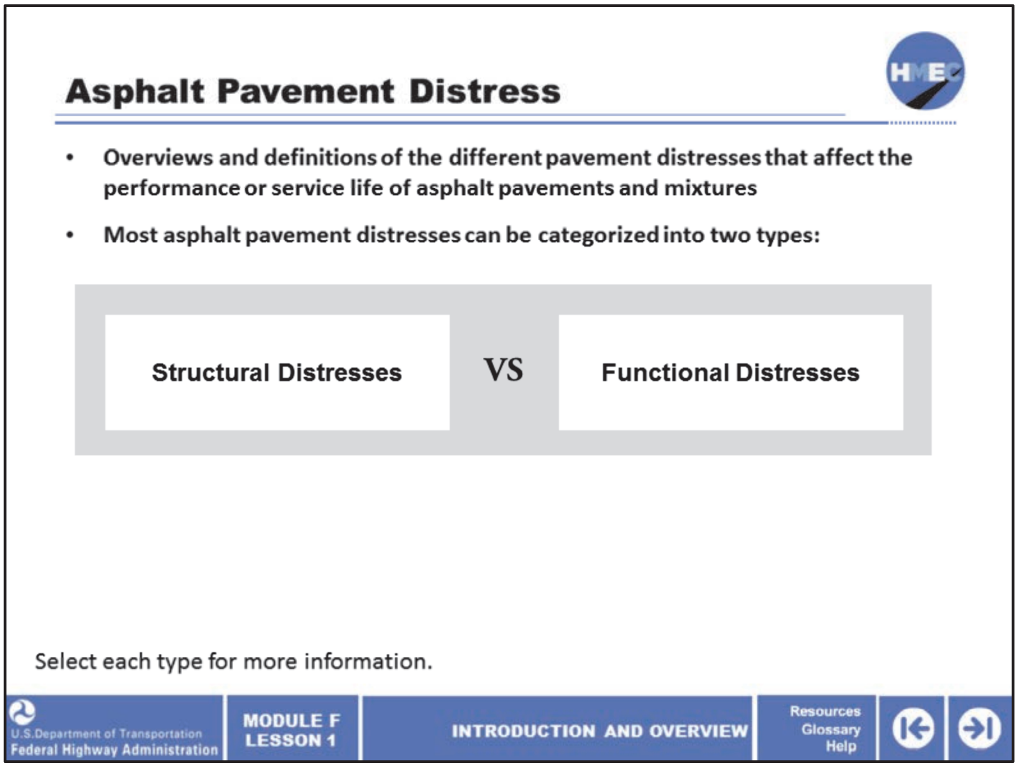
Fibers (either mineral or cellulose) can be used to prevent draindown in open-graded friction courses. In most cases when an asphalt binder is modified with a polymer, that polymer is an elastomer or rubber.

Image description: Photo of asphalt core sample.



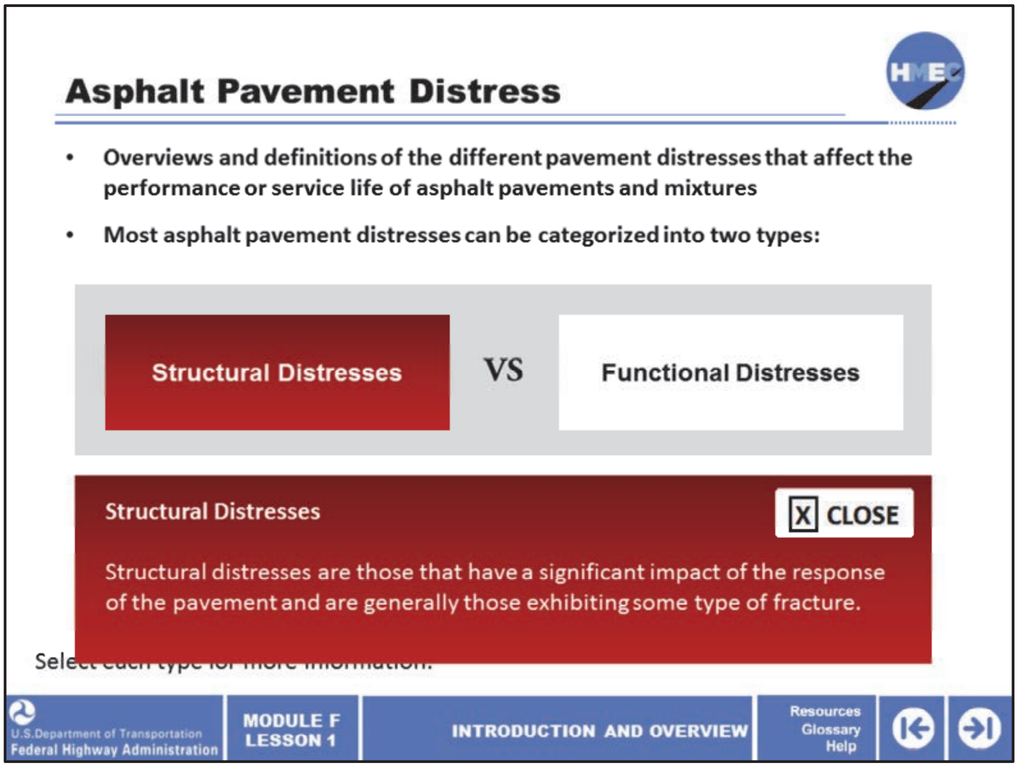
This graph shows the difference in the gradation between an open-graded mixture, a dense fine-graded mixture, and a SMA gap-graded mixture.

Image description: Graph showing the difference in the gradation between an open-graded mixture, a dense fine-graded mixture, and a SMA gap-graded mixture.

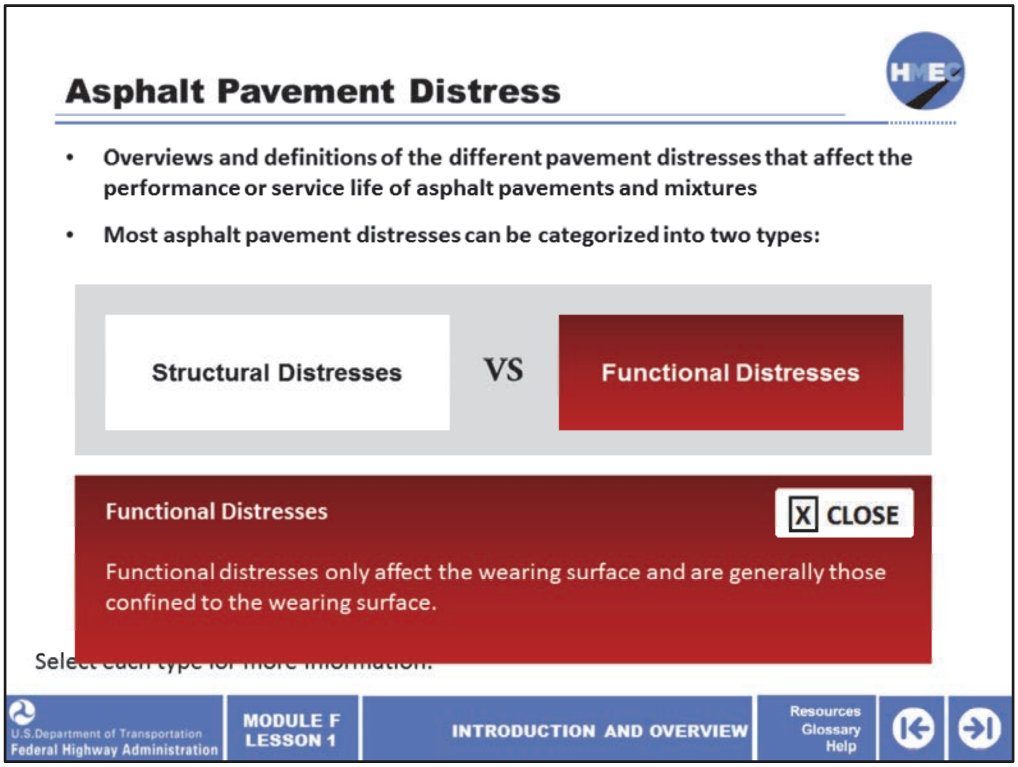


This section of the lesson will provide overviews and definitions for the different pavement distresses that affect the performance or service life of asphalt pavements and mixtures. Most asphalt pavement distresses can be categorized into two types: structural and functional distresses.

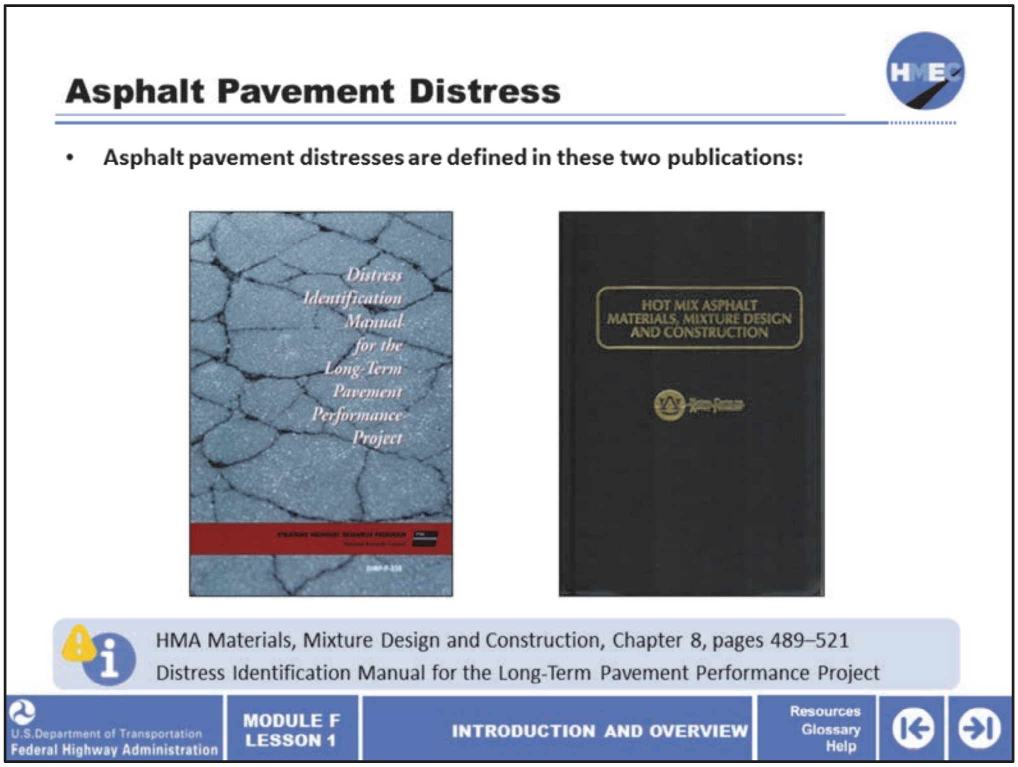
Select each type for more information.



Structural distresses are those that have a significant impact of the response of the pavement and are generally those exhibiting some type of fracture.



Functional distresses only affect the wearing surface and are generally those confined to the wearing surface.



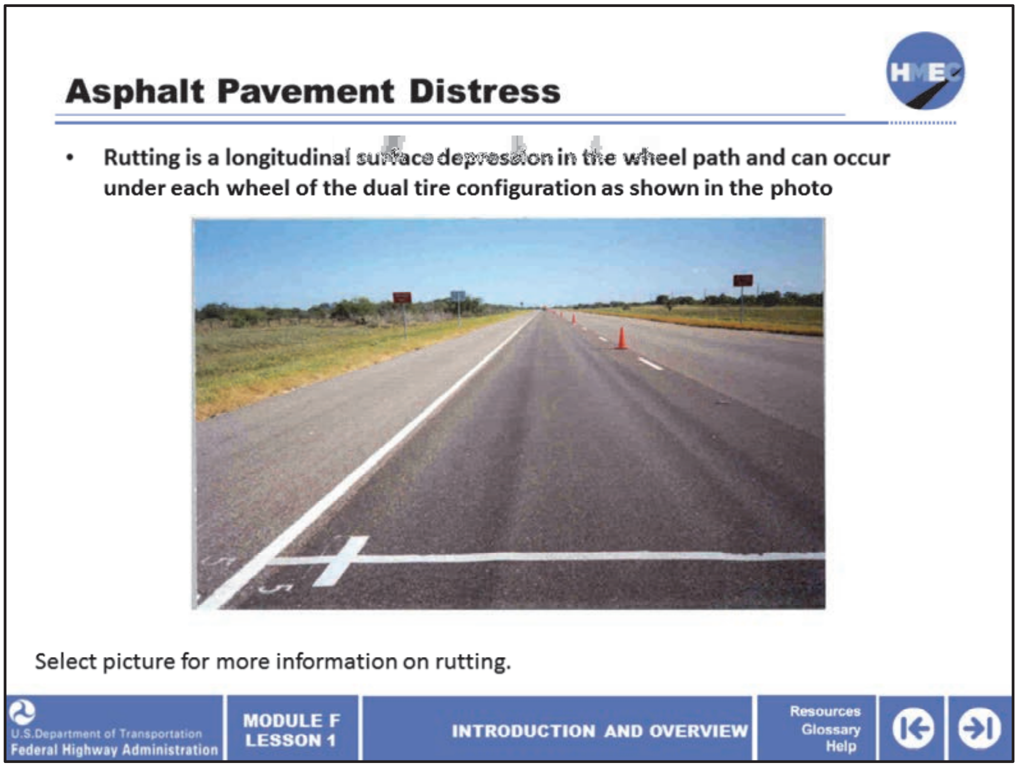
Asphalt pavement distresses are defined in these two publications: the *Distress Identification Manual for the Long-Term Pavement Performance Project* that is used to identify and measure the amount and severity of pavement distresses on all of the Long-Term Pavement Performance (LTPP) sections, and the NCAT textbook, *Hot Mix Asphalt Materials, Mixture Design and Construction*, which is the reference manual for this module.

For more information, refer to Chapter 8 (Performance/Distress of HMA), pages 489 to 521. The LTPP distress identification manual defines and describes how to measure each distress, while the NCAT textbook provides a more detailed explanation of the distress mechanism and the factors affecting each major distress.

Now let's look at types of asphalt pavement distress. We'll take a look at the mix design to alleviate these issues in subsequent lessons.

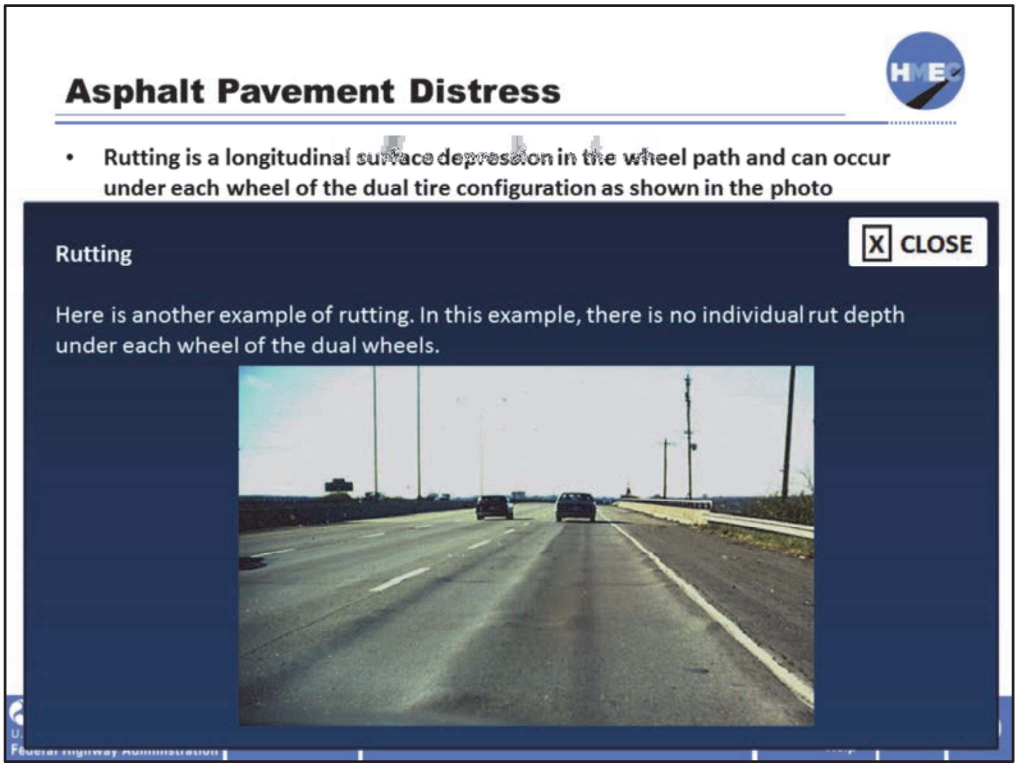
Image description: LTPP distress identification manual.

Image description: NCAT textbook, *Hot Mix Asphalt Materials, Mixture Design and Construction.*



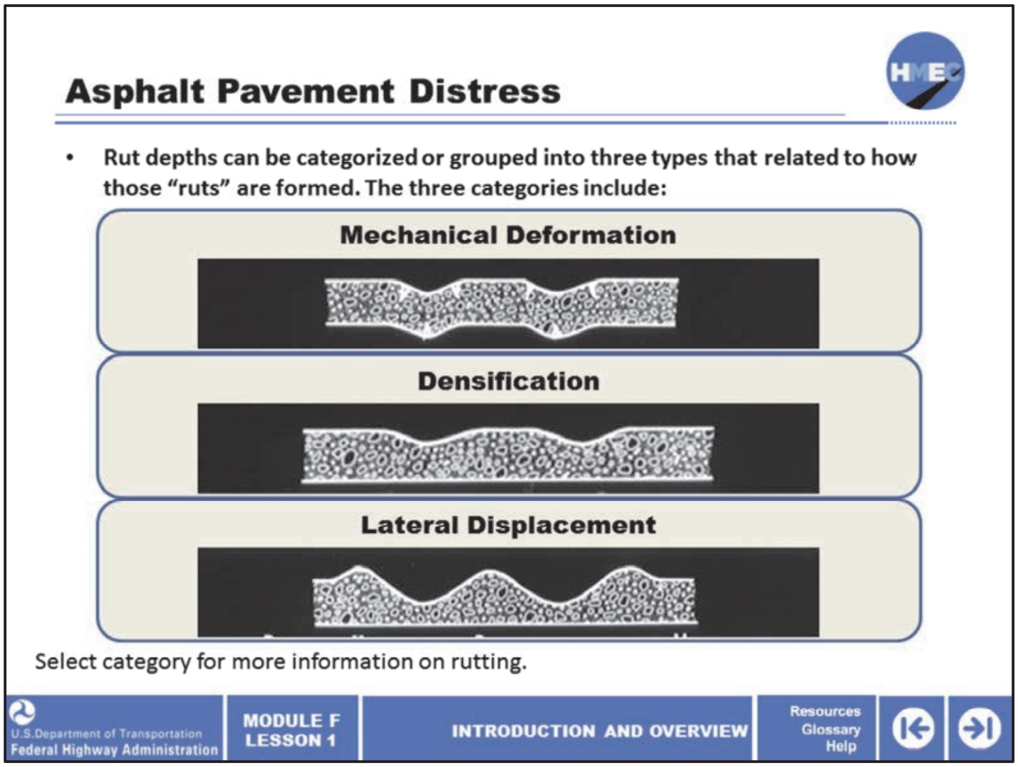
We will start with rutting. Rutting is a longitudinal surface depression in the wheel path. Rutting can occur under each wheel of the dual tire configuration as shown in the photo on the screen. Rutting within each wheel is usually a result of an improper mix design, high asphalt content, too soft asphalt (low viscosity) for the climate in which it is used, contaminated asphalt, or insufficient densification or rolling during construction.

Image description: Photo of Rutting on a highway.



Here is another example of rutting. In this example, there is no individual rut depth under each wheel of the dual wheels. This type of rutting is typically characteristic of rutting in the underlying aggregate base layer or embankment soils. It can also be characteristic of asphalt mixtures that exhibit moisture damage.

Image description: Photo of Rutting on a highway.



Rut depths can be categorized or grouped into three types that are related to how those ruts are formed. The three categories include:

1. Mechanical deformation;
2. Densification; and
3. Lateral displacement.

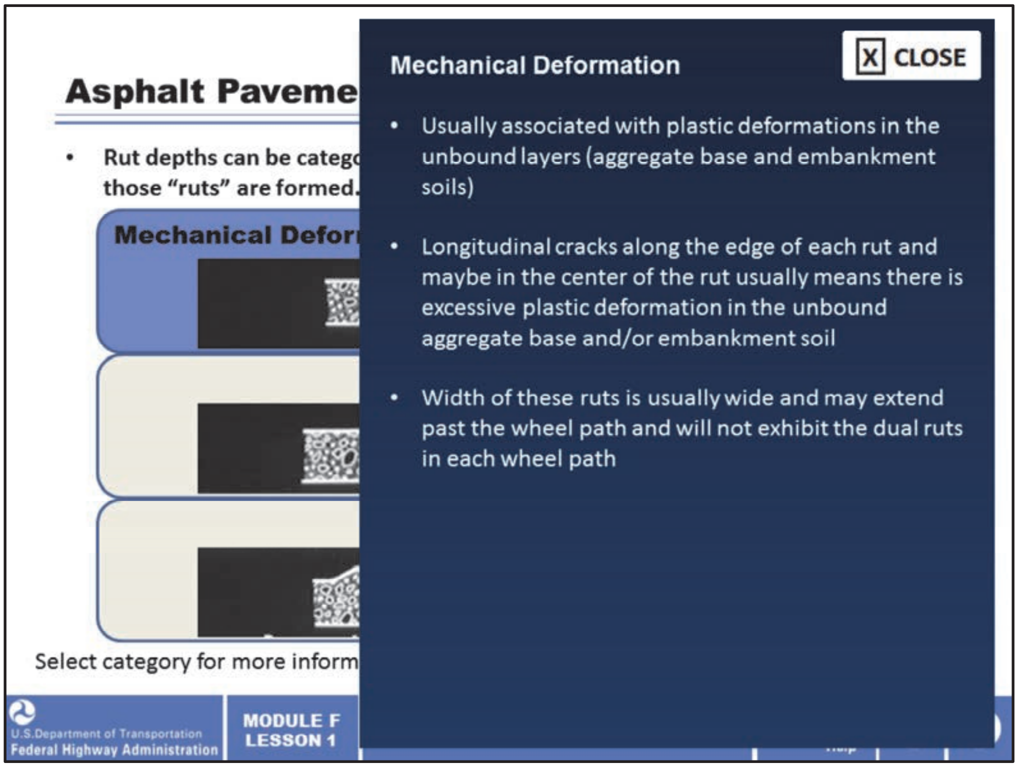
An important point related to the mixture and pavement design process is the assumption when using multi-layer elastic theory to calculate pavement responses to predict rut depths as discussed in Module E. The assumption is that all ruts form or occur in a one-dimension (vertical plastic strains), which is not reality. As noted in the screen, ruts can occur from the mixture moving in different directions. As an example, lateral flow (horizontal displacement of the asphalt mixture) is not predicted by the MEPDG rut depth transfer function. In addition, the cracking along the edge of the rut in mechanical deformation is not predicted by the MEPDG rut depth transfer function.

Select a category for more information on rutting.

Image description: Illustration of mechanical deformation.

Image description: Illustration of densification.

Image description: Illustration of lateral displacement.

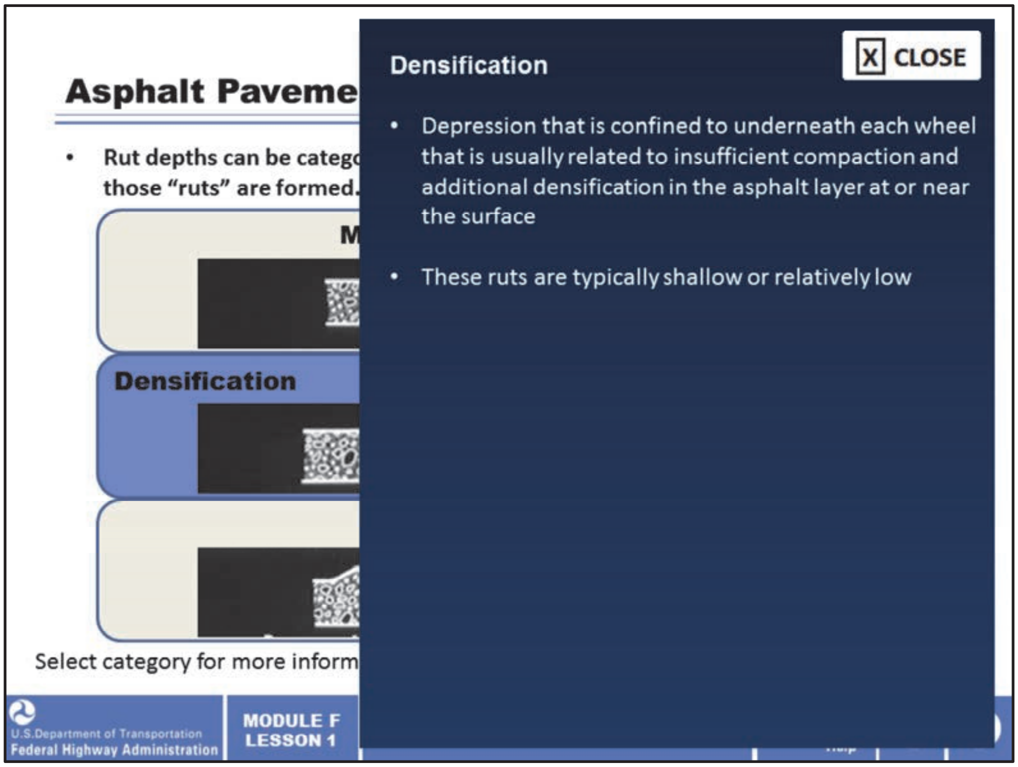


Mechanical deformation is usually associated with plastic deformations in the unbound layers (aggregate base and embankment soils). Longitudinal cracks along the edge of each rut and maybe in the center of the rut usually means there is excessive plastic deformation in the unbound aggregate base and/or embankment soil. The width of these ruts is usually wide and may extend past the wheel path and will not exhibit the dual ruts in each wheel path.

Image description: Illustration of mechanical deformation.

Image description: Illustration of densification.

Image description: Illustration of lateral displacement.

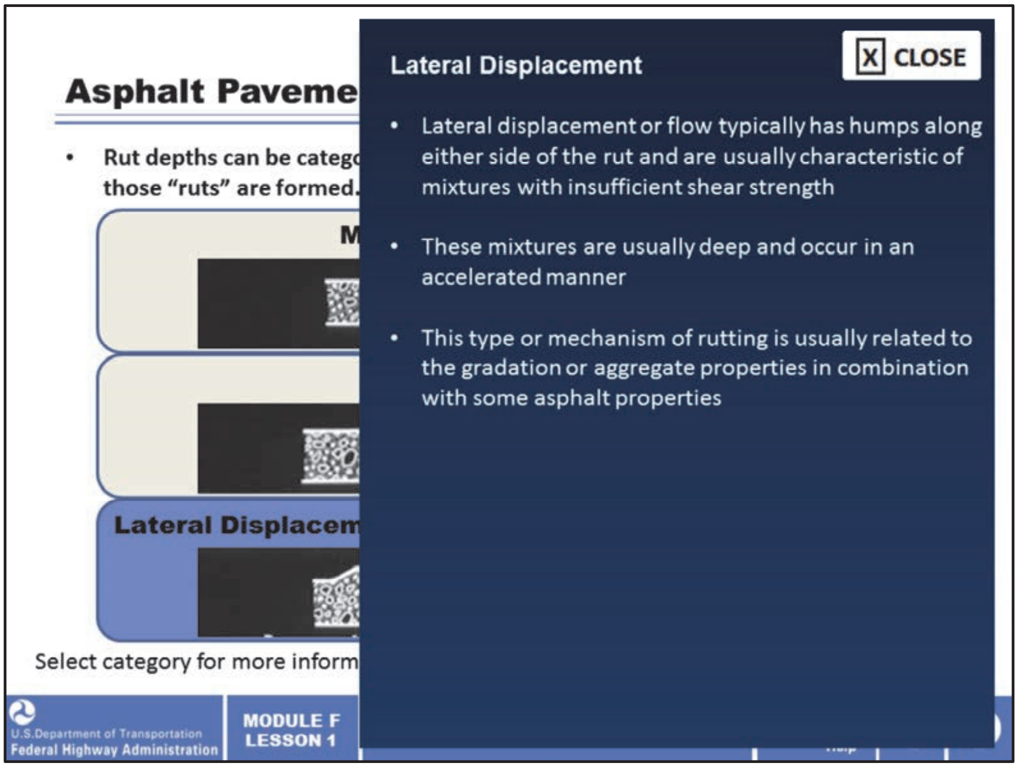


Densification is depression that is confined to underneath each wheel that is usually related to insufficient compaction and additional densification in the asphalt layer at or near the surface. These ruts are typically shallow or relatively low.

Image description: Illustration of mechanical deformation.

Image description: Illustration of densification.

Image description: Illustration of lateral displacement.

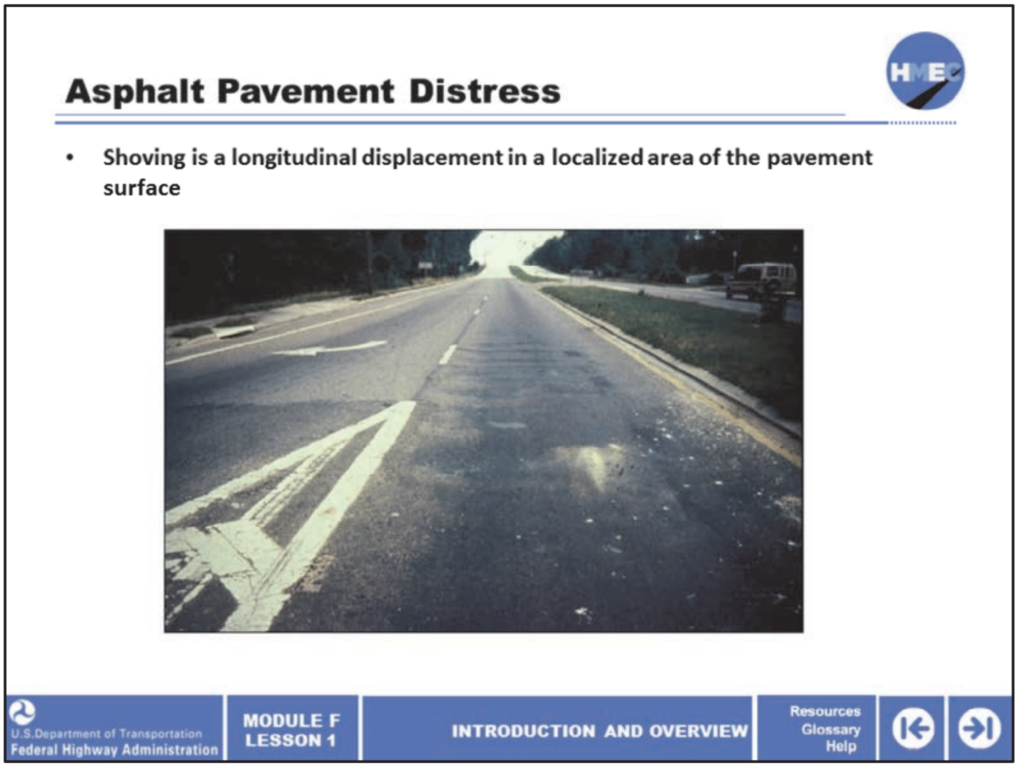


Lateral displacement or flow typically has humps along either side of the rut and are usually characteristic of mixtures with insufficient shear strength. These mixtures are usually deep and occur in an accelerated manner. This type or mechanism of rutting is usually related to the gradation or aggregate properties in combination with some asphalt properties.

Image description: Illustration of mechanical deformation.

Image description: Illustration of densification.

Image description: Illustration of lateral displacement.



Shoving is a longitudinal displacement in a localized area of the pavement surface. It is generally caused by braking or accelerating trucks and is normally located on hills, curves, or at intersections, as illustrated in this photo. Shoving normally has vertical displacements in the localized areas. Shoving is caused by shear flow of the mixture or slippage between two adjacent layers at or near the surface. Shear flow is caused by unstable mixtures with low shear strength.

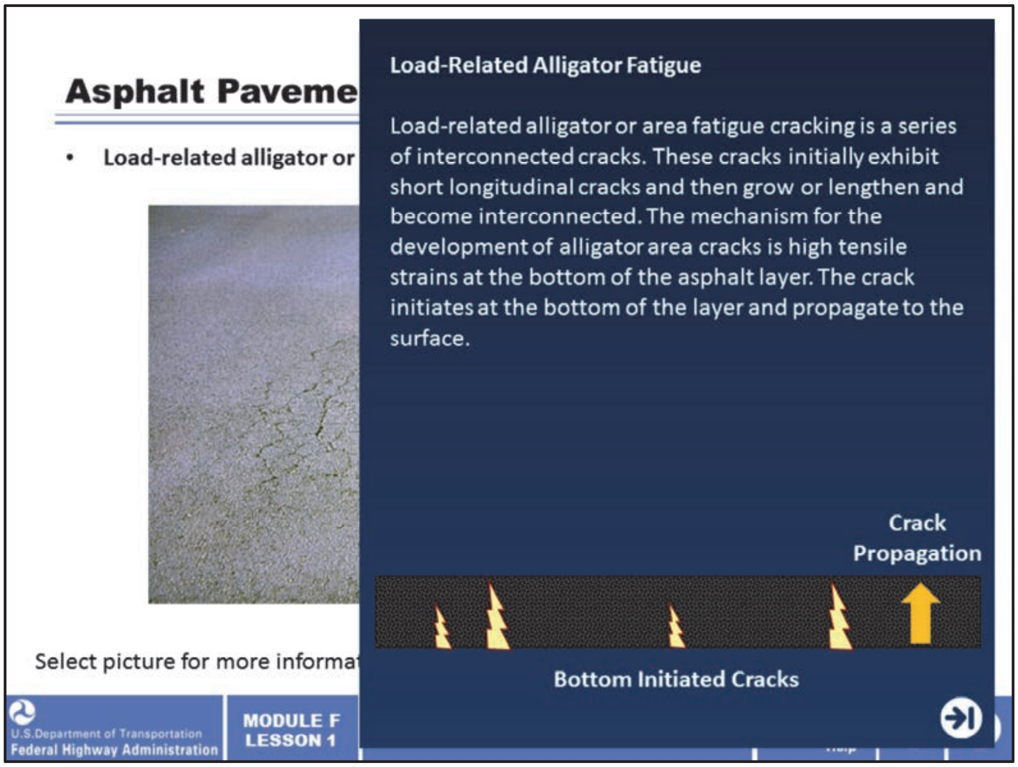
Image description: Photo of shoving problems on highway.

Shoving and cracking can also be caused by stripping in the asphalt layer. This photo exhibits localized shoving and cracking of the wearing surface. The shoving occurred in the asphalt layer below the wearing surface as a result of stripping and moisture damage in the lower layer.

Image description: Photo of shoving and cracking.

Load-related alligator or area fatigue cracking is a series of interconnected cracks and are an indication of significant damage to the asphalt mixture. This damage can be caused by high truck traffic for the layer thickness or inadequate structural support.

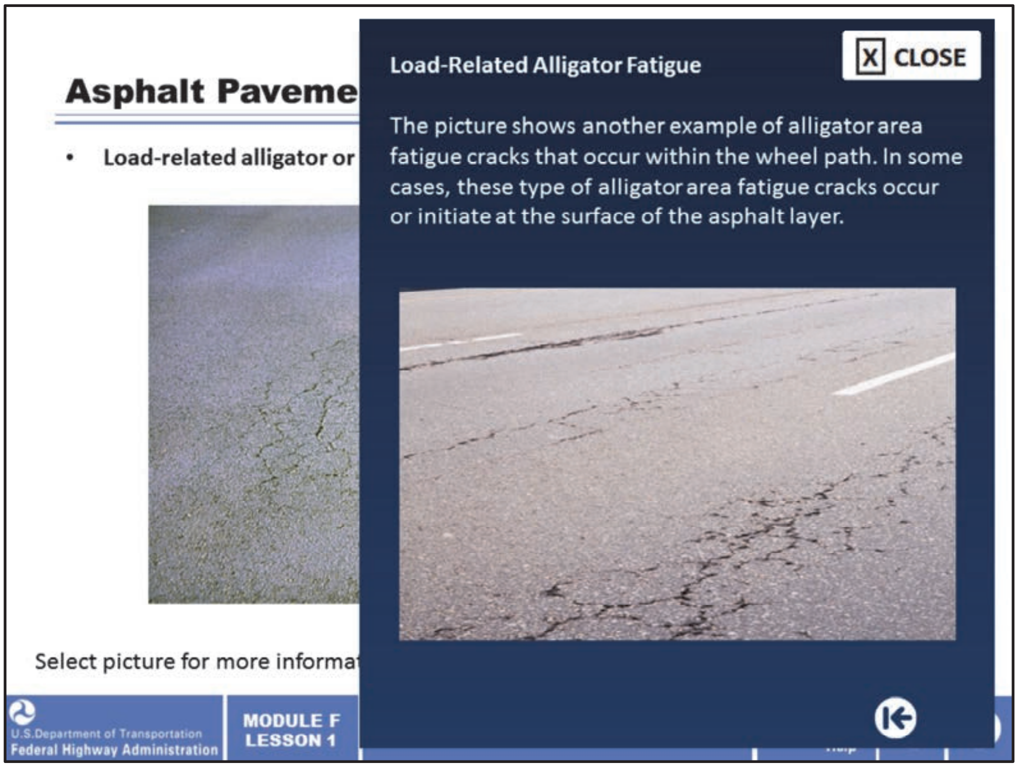
Image description: Photo of alligator cracking.



Load-related alligator or area fatigue cracking is a series of interconnected cracks, but they initially exhibit short longitudinal cracks and then grow or lengthen and become interconnected. The mechanism for the development of alligator area cracks is high tensile strains at the bottom of the asphalt layer. The cracks initiate at the bottom of the layer and propagate to the surface.

Image description: Photo of alligator cracking.

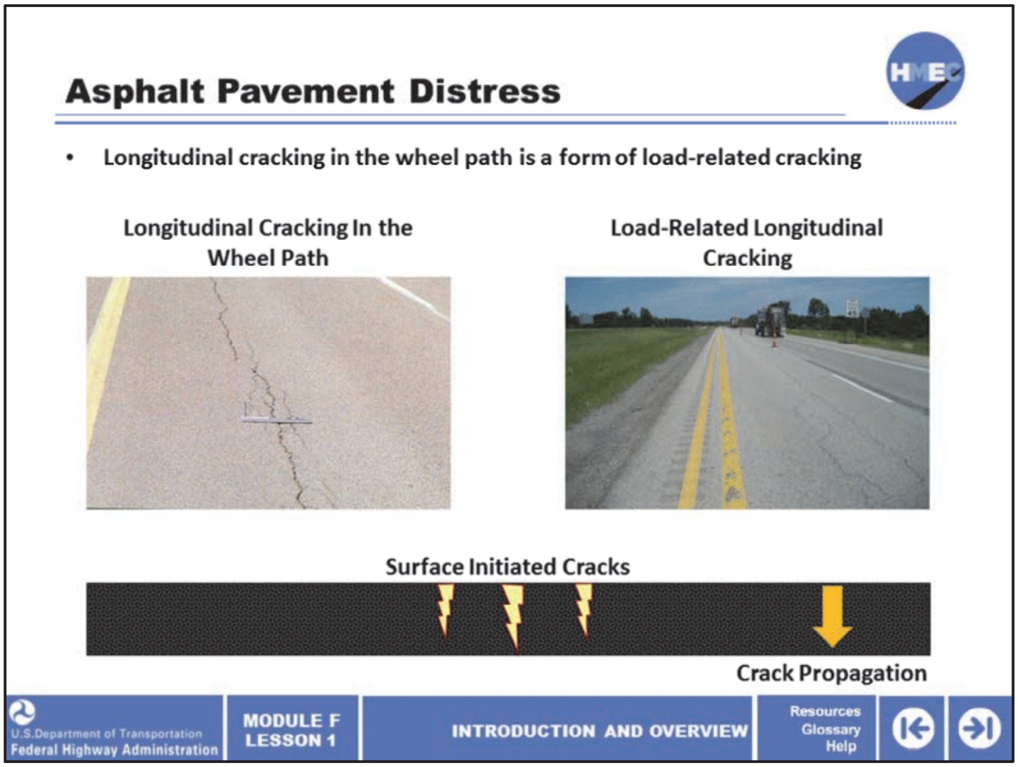
Image description: Illustration of bottom initiated cracking.



The picture shows another example of alligator area fatigue cracks that occur within the wheel path. In some cases, these type of alligator area fatigue cracks occur or initiate at the surface of the asphalt layer.

Image description: Photo of alligator cracking.

Image description: Photo of alligator cracking.



Longitudinal cracking in the wheel path is a form of load-related cracking. These longitudinal cracks sometimes start as short longitudinal cracks and then interconnect or form the alligator cracks, as previously defined. However, these longitudinal cracks sometimes continue to grow in the longitudinal direction and never form the classical alligator cracks.

These type of load-related cracks are believed to initiate at the surface and propagate downward through the HMA layer. These type of cracks can also be a result of construction or placement operations, which are created by weaknesses in the HMA mat through the paving operation.

Image description: Photo of longitudinal cracking in wheel path.

Image description: Photo of load related longitudinal cracking.

Image description: Illustration of surface initiated cracking.

Longitudinal cracking can also occur along and adjacent to the wheel path and longitudinal construction joint. Longitudinal cracking can also be the result of discontinuities and high air voids along the edge of the tapered or notched edge joint.

Image description: Photo of longitudinal cracking along wheel path and construction joint.

Slippage cracks can occur as a result of a poor bond between the asphalt wearing surface and underlying layer. These cracks are typically not related to a deficient mix property but poor or no bond between two layers.

Image description: Photo of slippage cracks due to poor bond.

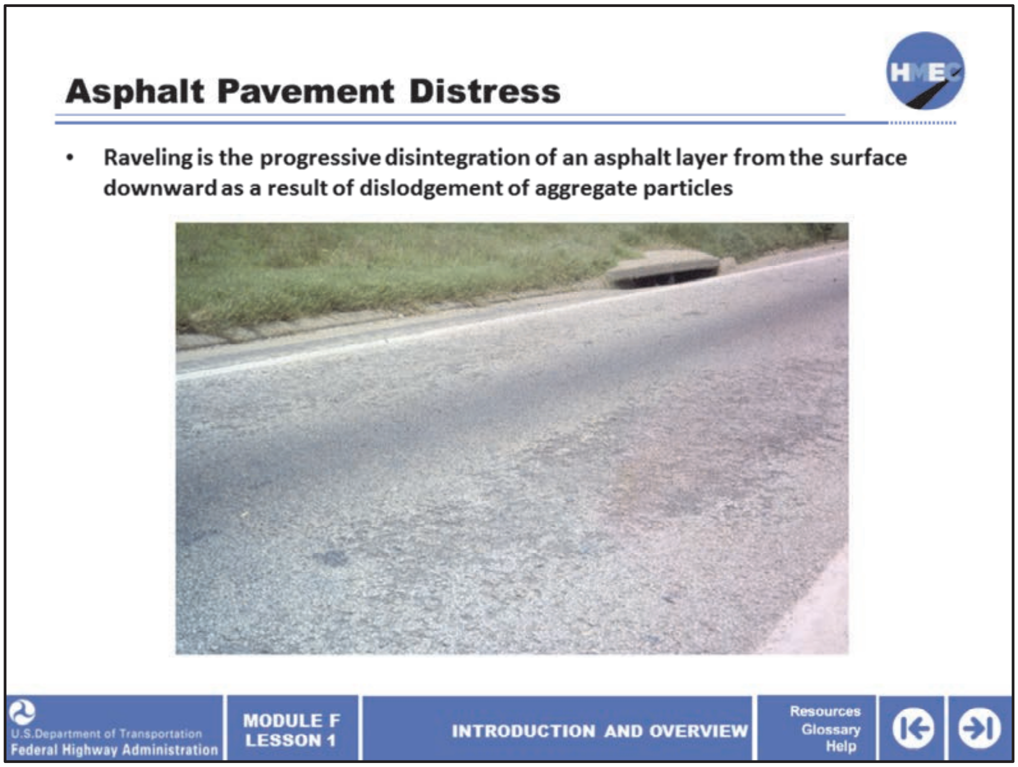
A common reason why asphalt pavements are rehabilitated is a result of poor longitudinal construction joints. The asphalt mixture along the longitudinal joint exhibits raveling as a result of high air voids along the joint.

Image description: Photo of poor longitudinal joints.

Image description: Photo of poor longitudinal joints.

Thermal cracks are non-load-related transverse cracks and are predominantly perpendicular to the pavement centerline. These cracks normally occur when the temperature at the surface drops sufficiently to produce a thermally induced shrinkage stress in the asphalt surface layer that exceeds the tensile strength of the asphalt mixture. These cracks initiate at the top and propagate downward.

Image description: transverse cracks on highway.



Raveling is the progressive disintegration of an asphalt layer from the surface downward as a result of dislodgement of aggregate particles. The dislodgement is caused by a loss of bond between the asphalt and aggregate particle. Raveling typically occurs in mixtures that are susceptible to moisture damage or stripping. Raveling can also be caused by aggregates with dust coating, unburned fuel, or in mixtures with low asphalt contents. Accelerated raveling usually occurs in areas with segregation at the surface.

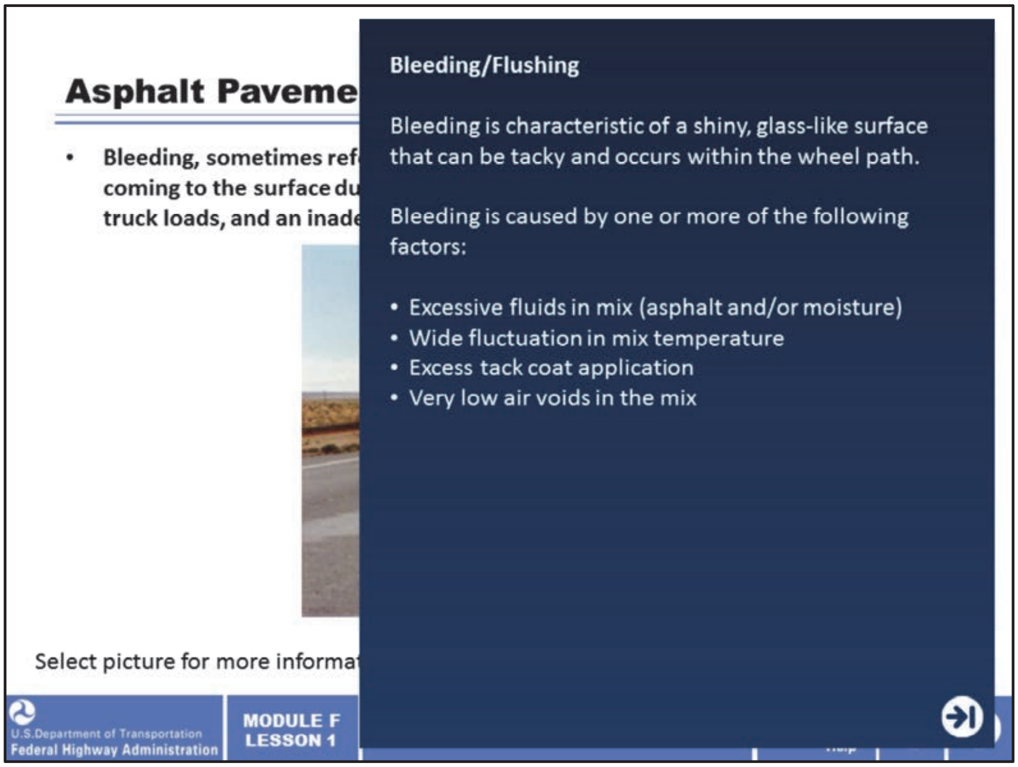
Image description: Photo of raveling in roadway.

This photo shows the effect of truck-to-truck segregation in terms of raveling and cracking.

Image description: Photo of truck to truck segregation.

Bleeding, sometimes referred to as flushing, is a result of excess asphalt binder coming to the surface due to elevated temperatures in combination with heavy truck loads, and an inadequate void structure.

Image description: Photo of bleeding flushing on highway.



Bleeding is characteristic of a shiny, glass-like surface that can be tacky and occurs within the wheel path.

Bleeding is caused by one or more of the following factors:

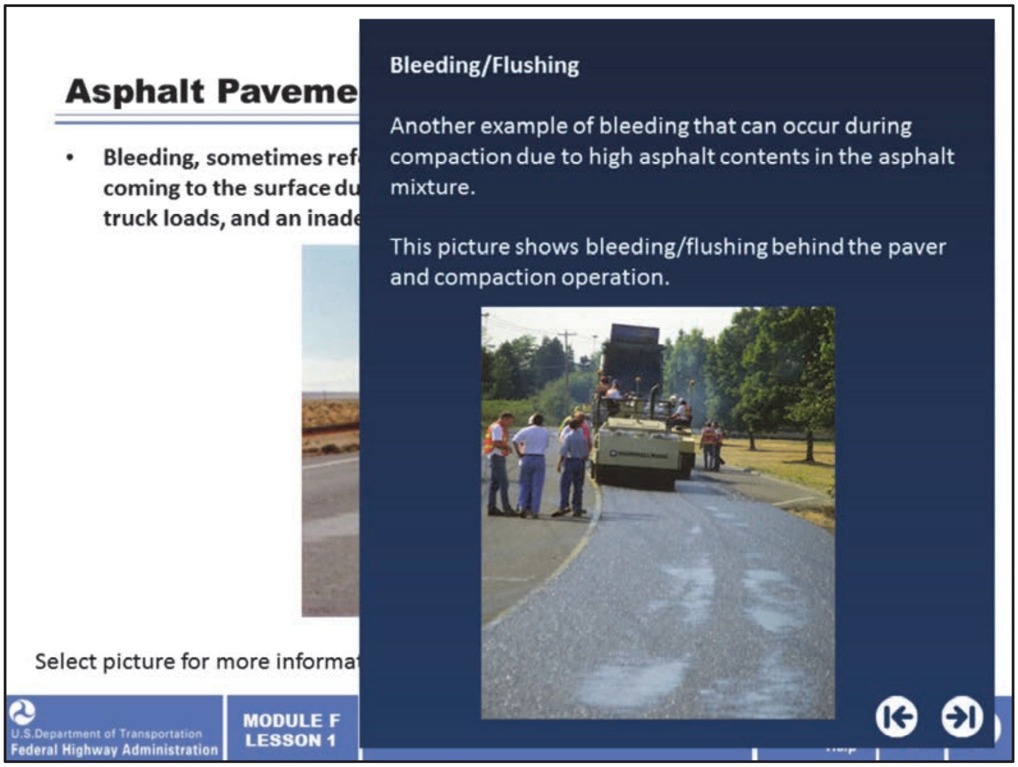
- Excessive fluids in mix (asphalt and/or moisture);
- Wide fluctuation in mix temperature;
- Excess tack coat application; or
- Very low air voids in the mix.

Image description: Photo of bleeding flushing on highway.

Bleeding defined as fat spots can occur during construction and be a result of excessive tack coats, or in some instances, binder draindown when placing open-graded mixes.

Image description: Photo of bleeding flushing on highway.

Image description: Photo of fat spot bleeding.

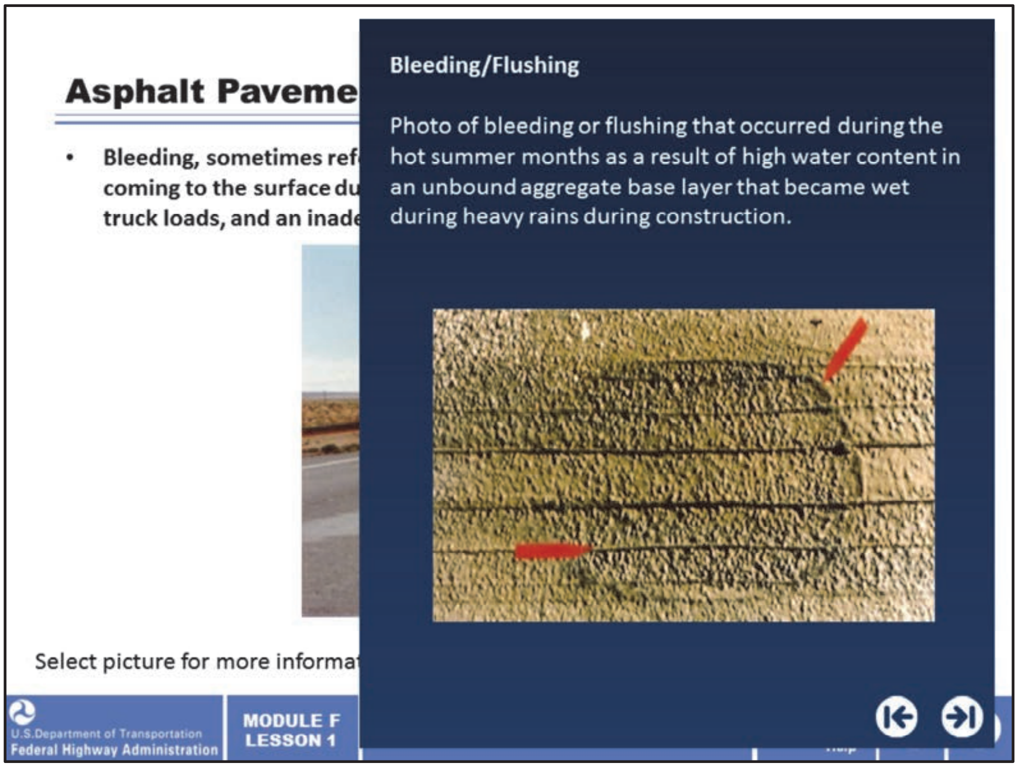


This is another example of bleeding that can occur during compaction due to high asphalt contents in the asphalt mixture.

This picture shows bleeding/flushing behind the paver and compaction operation.

Image description: Photo of bleeding flushing on highway.

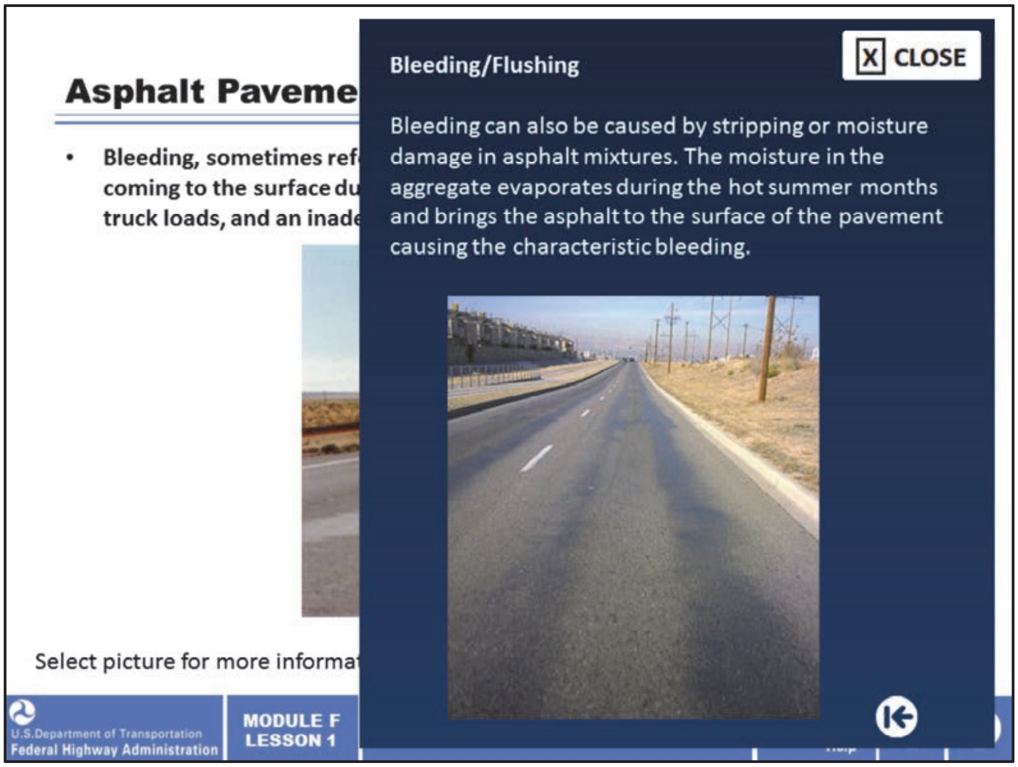
Image description: Photo of bleeding flushing behind paver compaction.



This photo is of bleeding or flushing that occurred during the hot summer months as a result of high water content in an unbound aggregate base layer that became wet during heavy rains during construction.

Image description: Photo of bleeding flushing on highway.

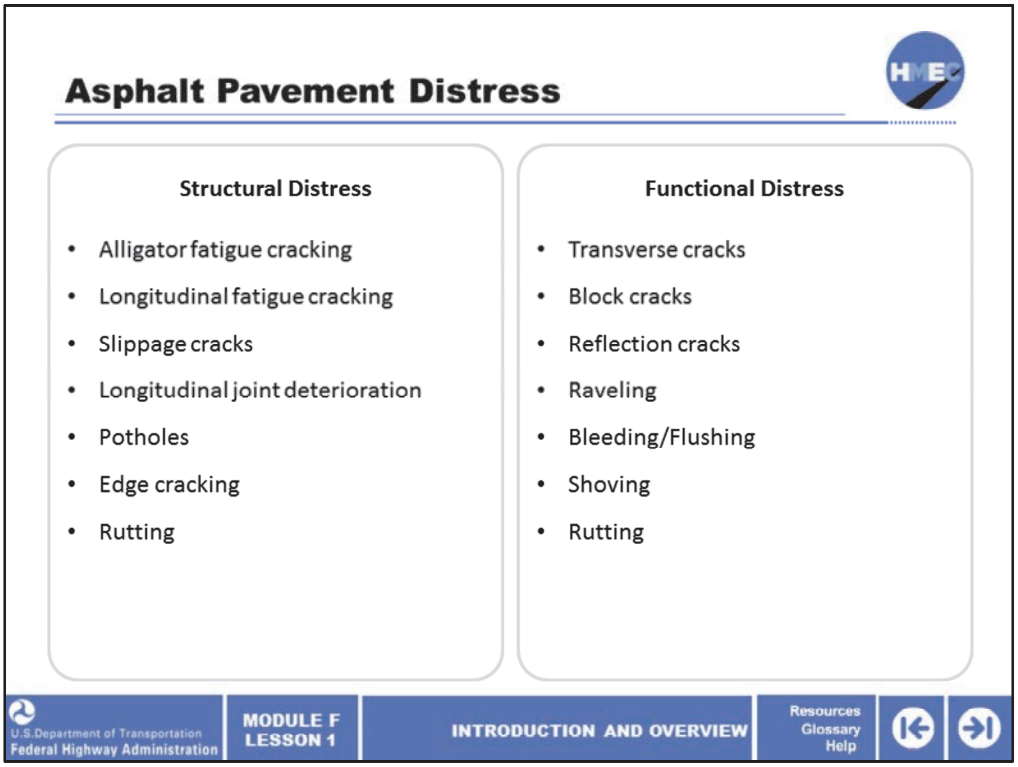
Image description: Photo of bleeding flushing because of high water content.



Bleeding can also be caused by stripping or moisture damage in asphalt mixtures. The moisture in the aggregate evaporates during the hot summer months and brings the asphalt to the surface of the pavement causing the characteristic bleeding.

Image description: Photo of bleeding flushing on highway.

Image description: Photo of bleeding due to moisture damage.



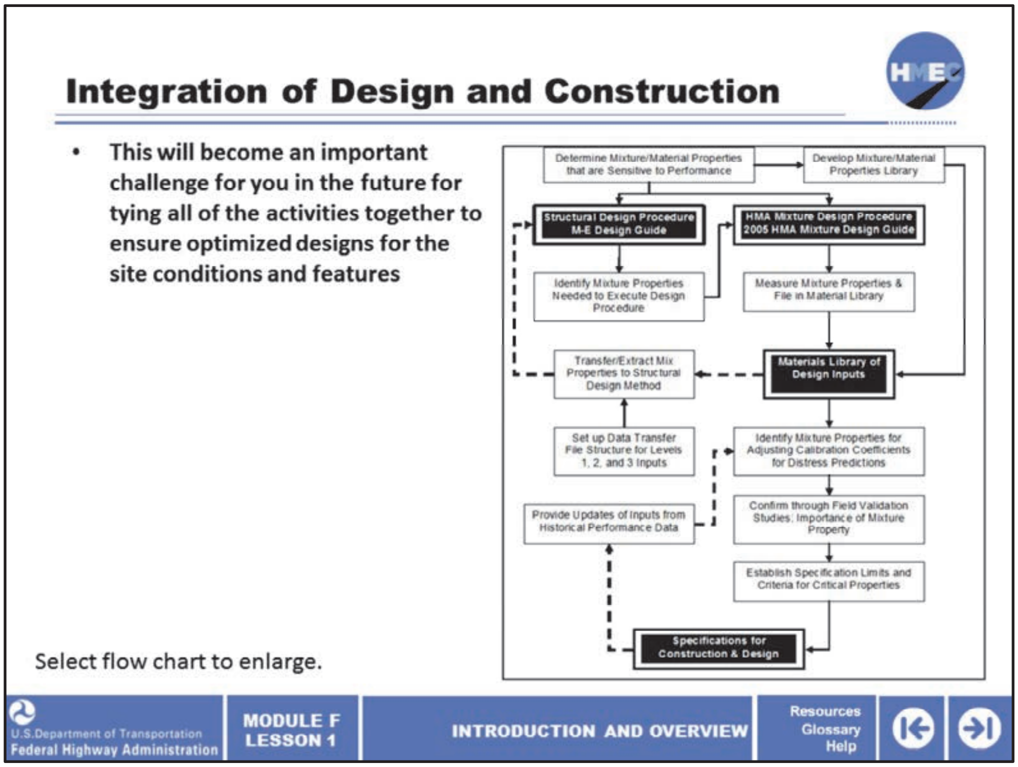
This screen summarizes the structural and functional related distresses.

As the volumetric properties change as part of the mixture design process, the probability of a structural or functional distress increase. The concept of mixture design is to minimize the occurrence of distress. The distresses that are typically used to design asphalt pavements using the MEPDG are also a part of integrating mixture design to structural design to construction.

The method of integrating the asphalt mix design process and the pavement design process most common in the US is to have the contractor responsible for the HMA mixture design, while the agency maintains responsibility for the pavement design and confirming the mixture design. Researchers and consultants have recommended for decades that HMA mixture and structural design be integrated into one system. Unfortunately, these two operations remain independent functions—even when both are the responsibility of the agency or same organization on a day-to-day basis.

The major reason for this independence is that most agencies use the 1993 AASHTO Design Guide for structural design and the Superpave-Gyratory volumetric method for mixture design. These design procedures are based on and use different material properties and design criteria. As a result, it is difficult to determine or know what impact HMA mixture volumetric properties have on the structural layer coefficients. Thus, some HMA mixtures placed have not performed as expected and the reliability of the structural design is unknown.

Image description: Photo of asphalt mixture being dumped.



This screen includes a simplified flow chart of the minimum steps needed to integrate a structural and HMA mixture design procedure. This will become an important challenge for you in the future for tying all of the activities together to ensure optimized designs for the site conditions and features. This overdue activity has become more probable for attaining this goal as a result of the implementation and adoption of the MEPDG by multiple agencies.

Select flow chart to enlarge.

Image description: Flow chart of the minimum steps needed to integrate a structural and HMA mixture design procedure.

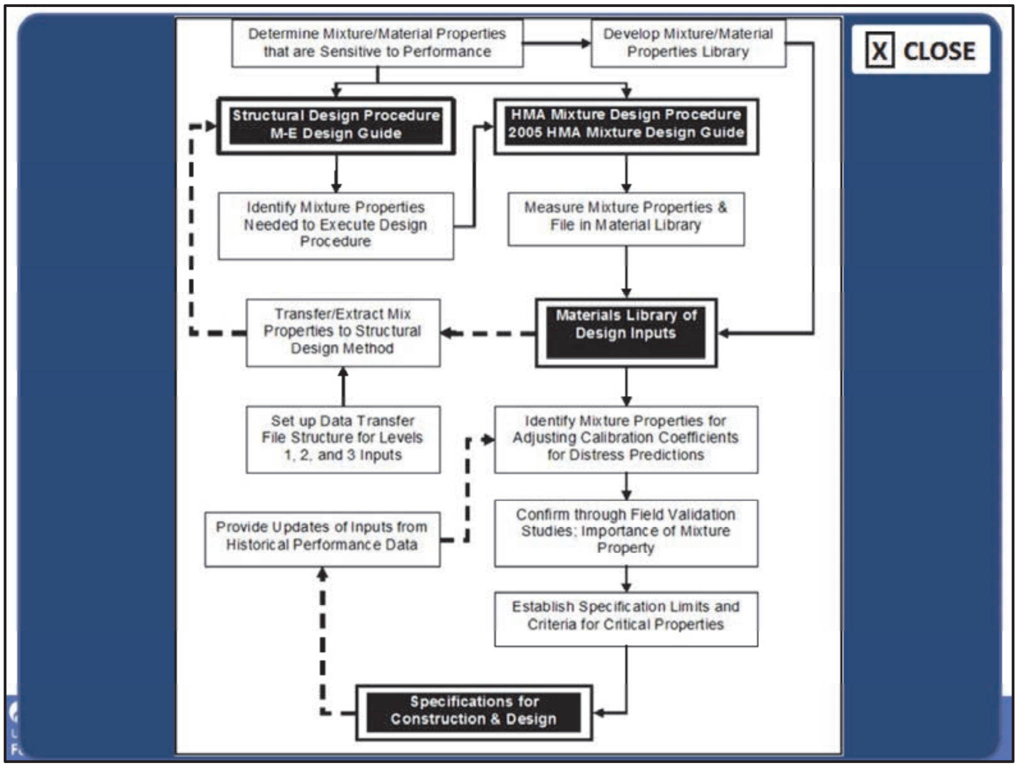
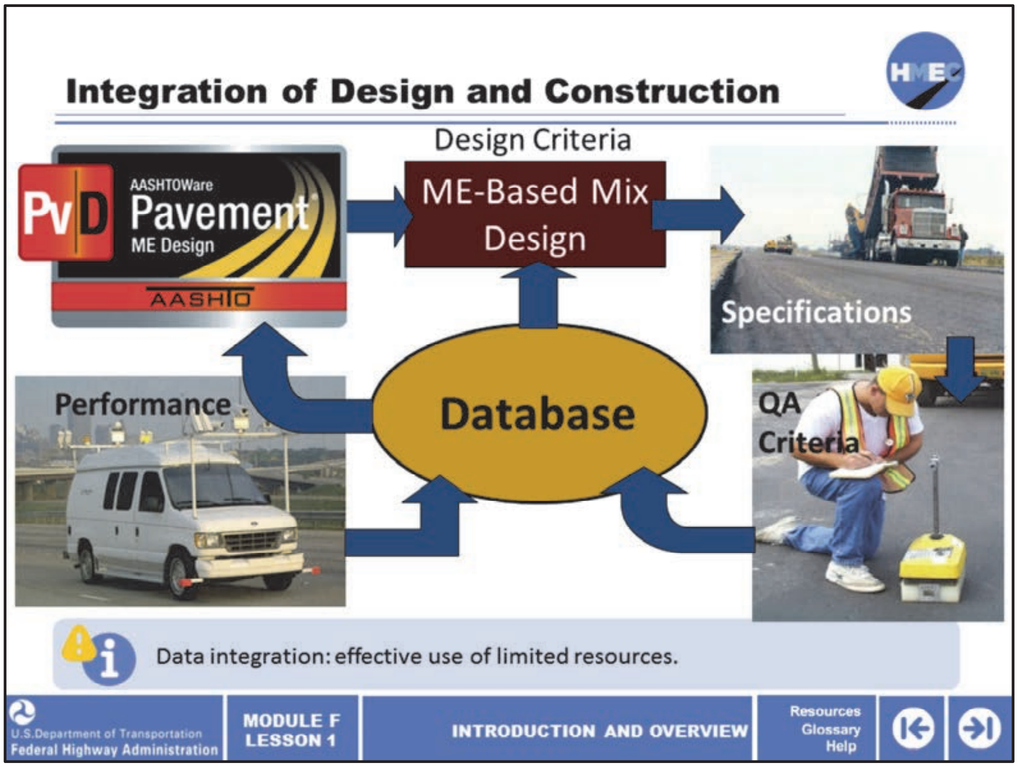


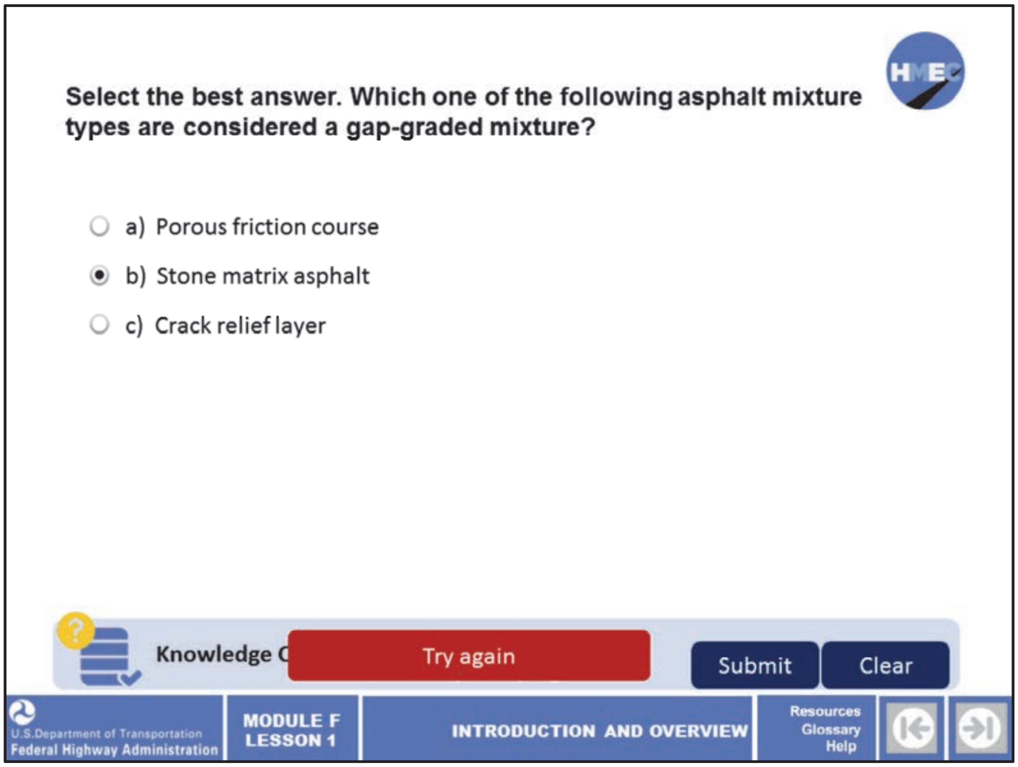
Image description: Flow chart of the minimum steps needed to integrate a structural and HMA mixture design procedure.



This shows a flow chart of the database and integration of structural design, mixtures design, construction and quality assurance, and performance of asphalt pavements.

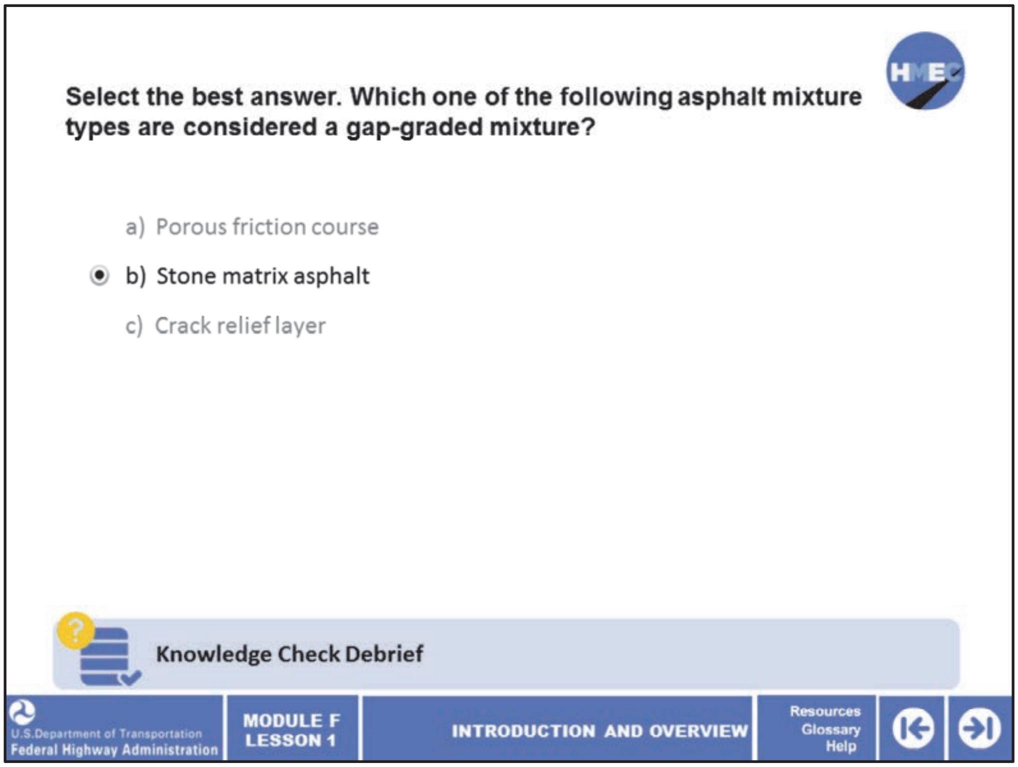
The integration of these activities have become a key issue since the MEPDG was developed because it provides the basics of tying the properties needed for structural and mixture design together, as well as those properties used in accepting or determining the quality of construction.

Image description: Flow chart of the database and integration of structural design, mixtures design, construction and quality assurance, and performance of asphalt pavements.

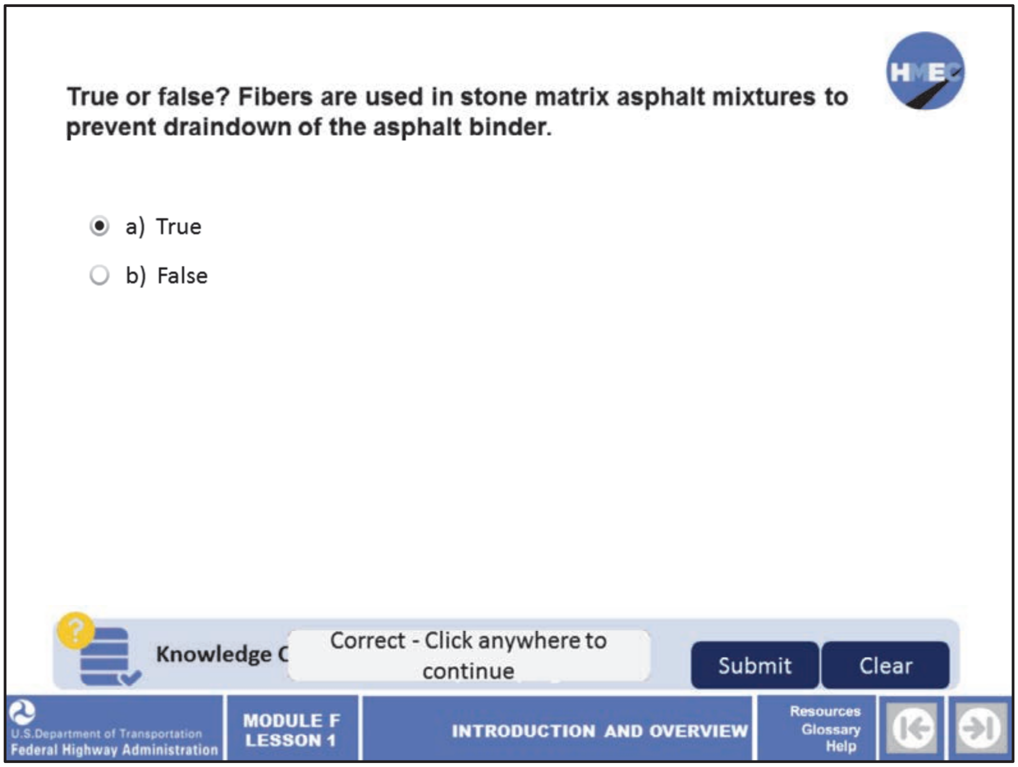


Select the best answer. Which one of the following asphalt mixture types are considered a gap-graded mixture?

a) Porous friction course;
b) Stone matrix asphalt; or
c) Crack relief layer.

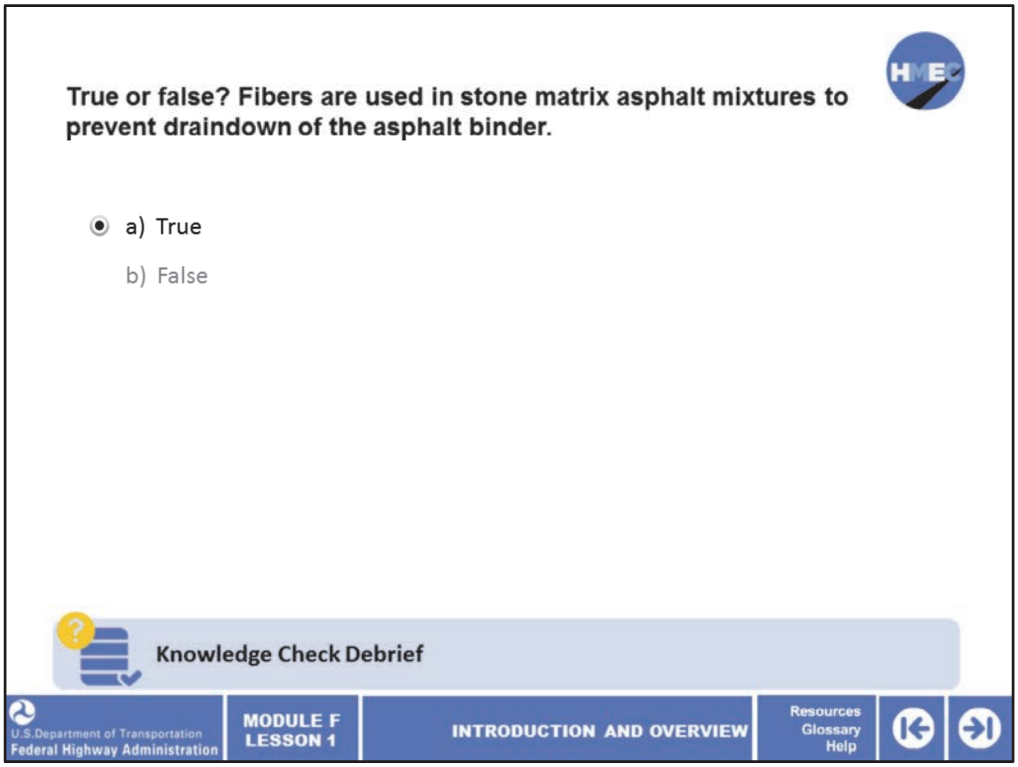


The correct answer is b) Stone matrix asphalt.

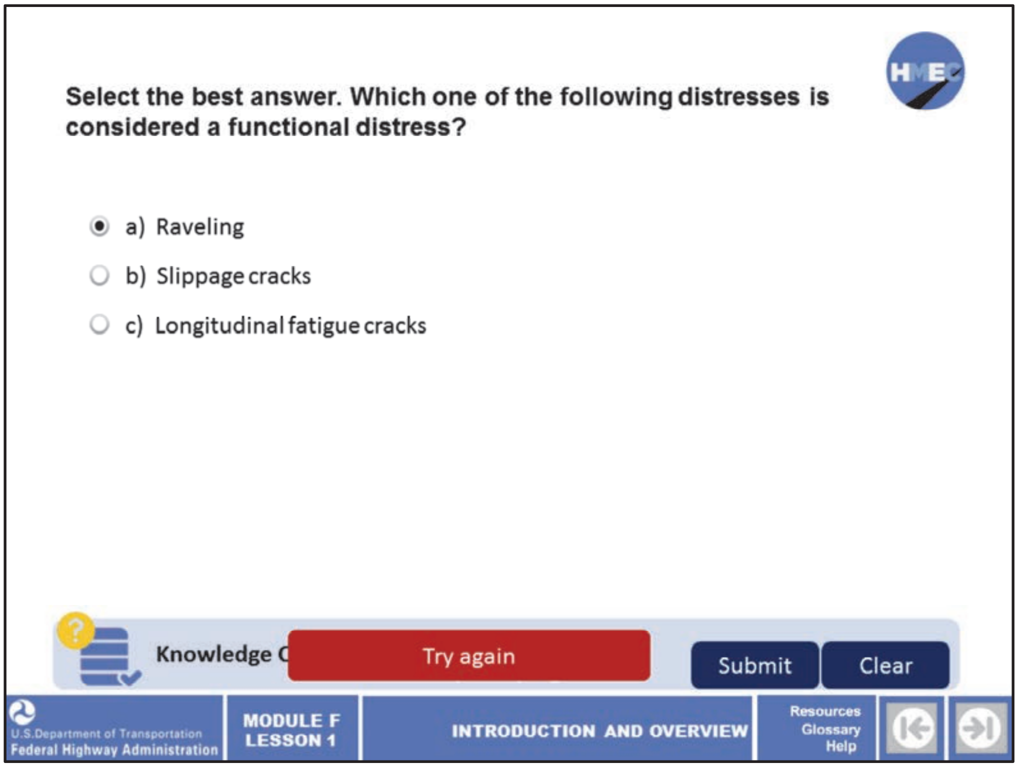


True or false? Fibers are used in stone matrix asphalt mixtures to prevent draindown of the asphalt binder.

a) True; or
b) False.

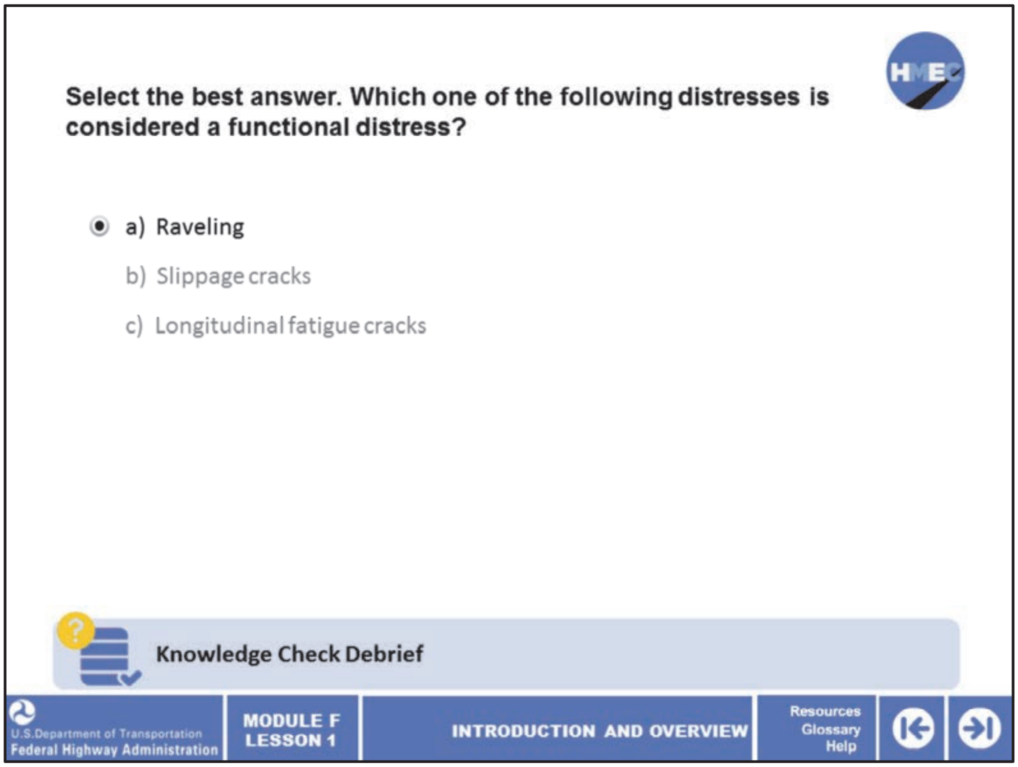


The correct answer is a) True. Fibers are used in stone matrix asphalt mixtures to prevent draindown of the asphalt binder.

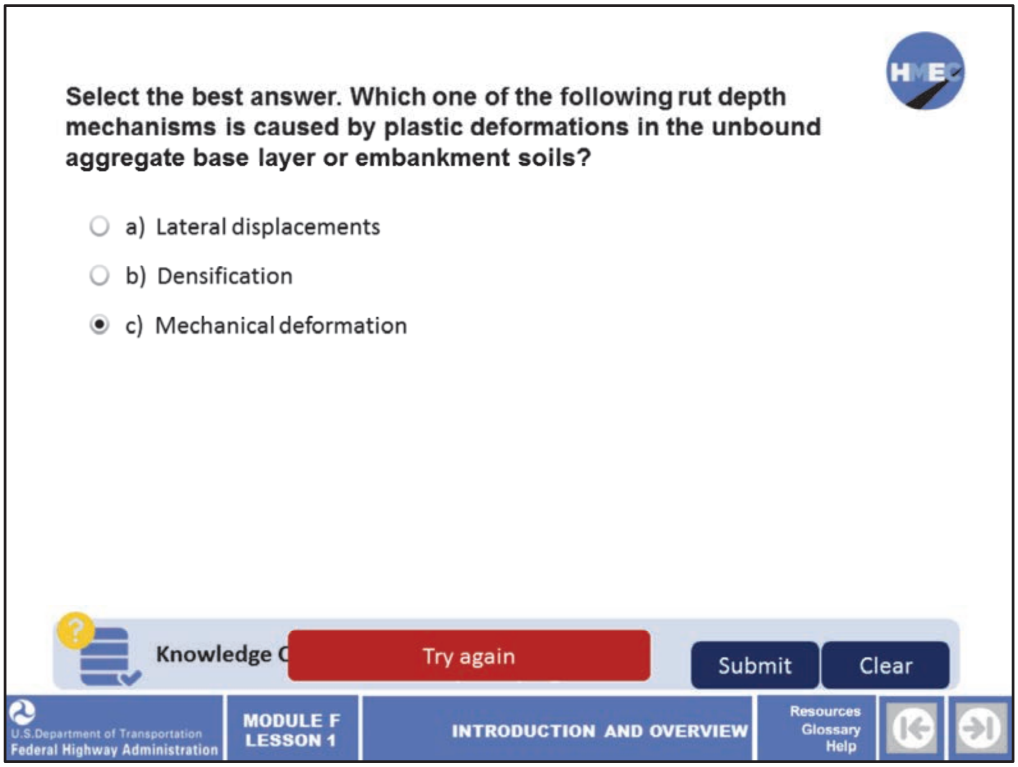


Select the best answer. Which one of the following distresses is considered a functional distress?

a) Raveling;
b) Slippage cracks; or
c) Longitudinal fatigue cracks.

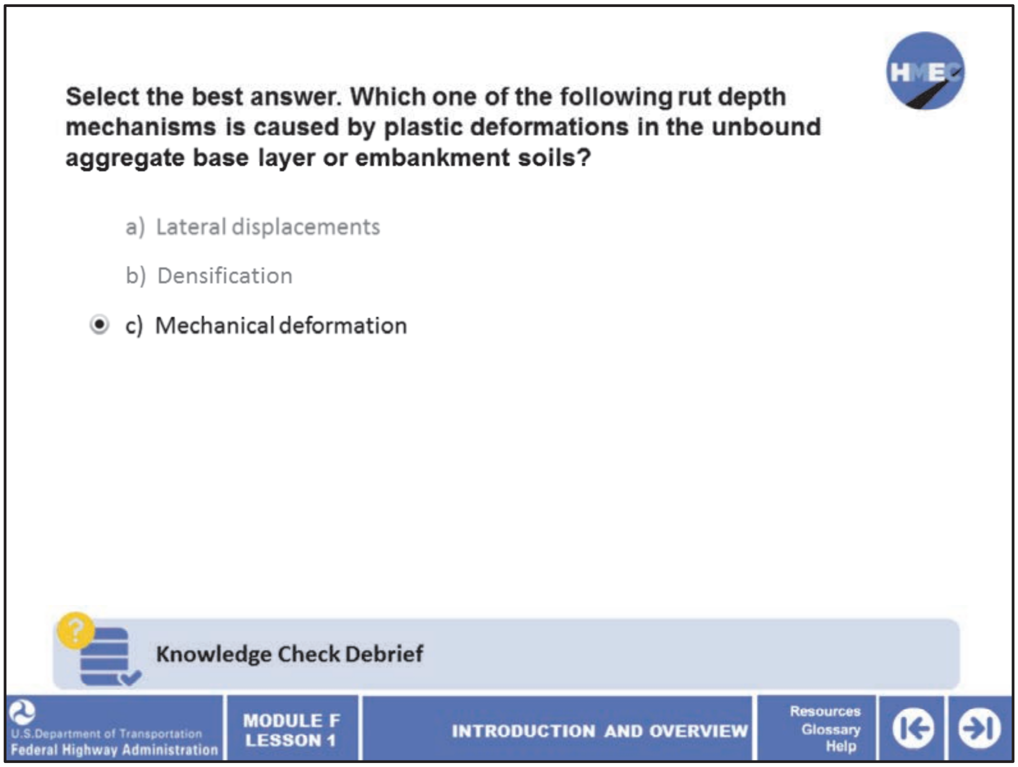


The correct answer is a) Raveling.

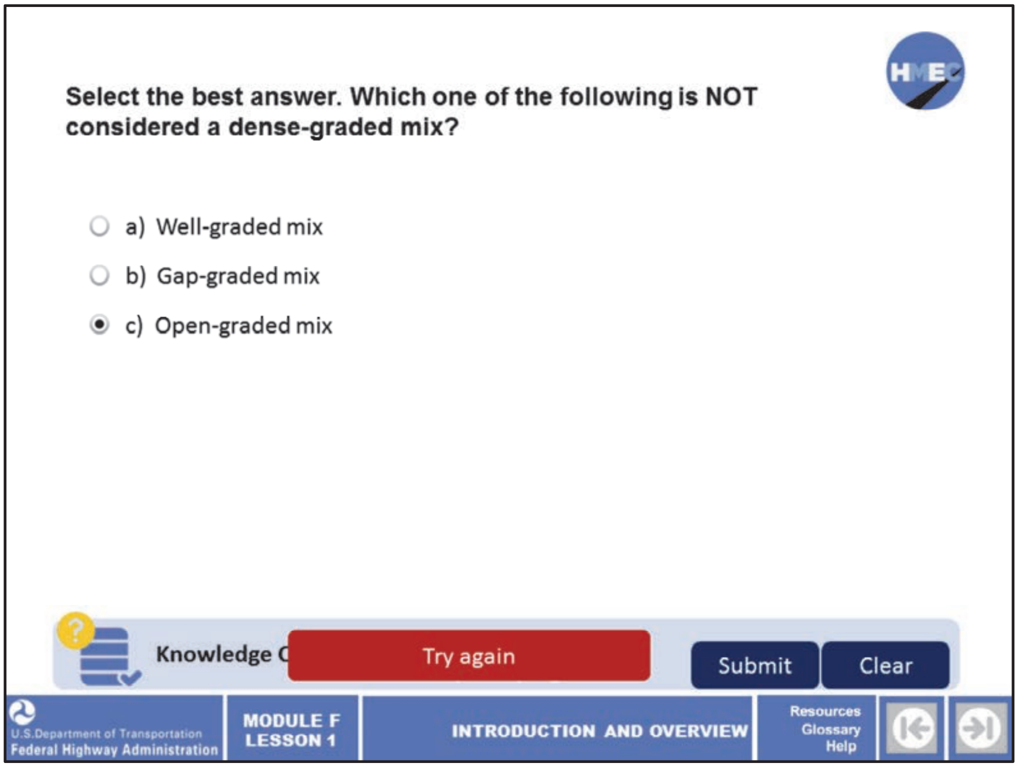


Select the best answer. Which one of the following rut depth mechanisms is caused by plastic deformations in the unbound aggregate base layer or embankment soils?

a) Lateral displacements;
b) Densification; or
c) Mechanical deformation.

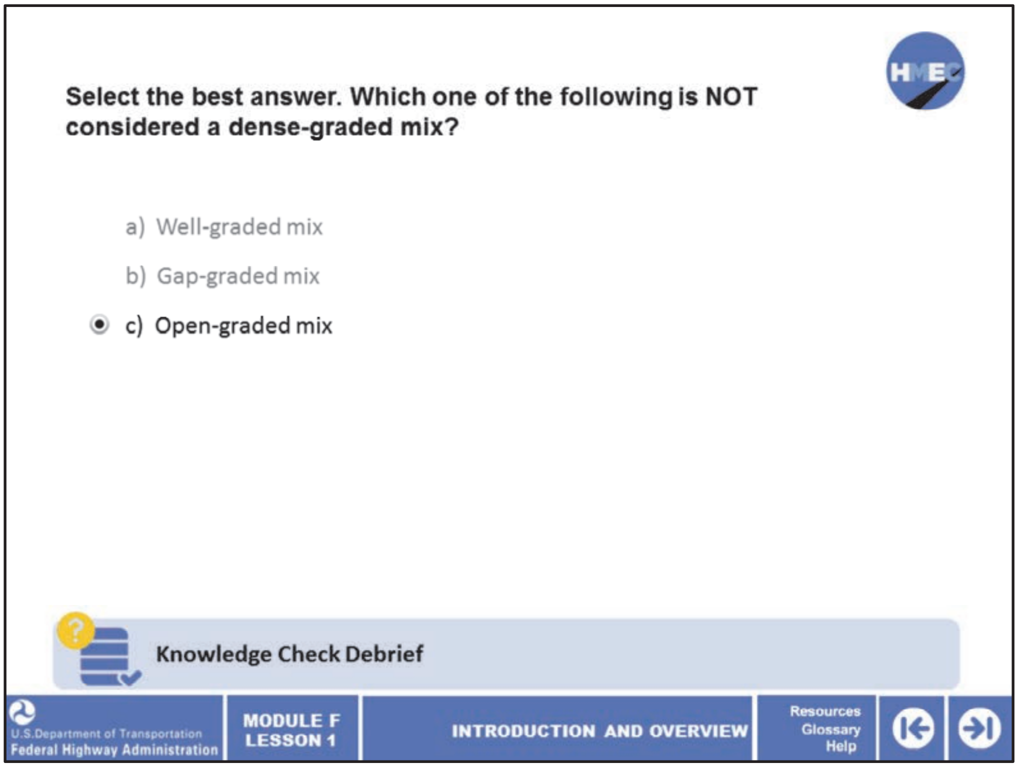


The correct answer is c) Mechanical deformation.

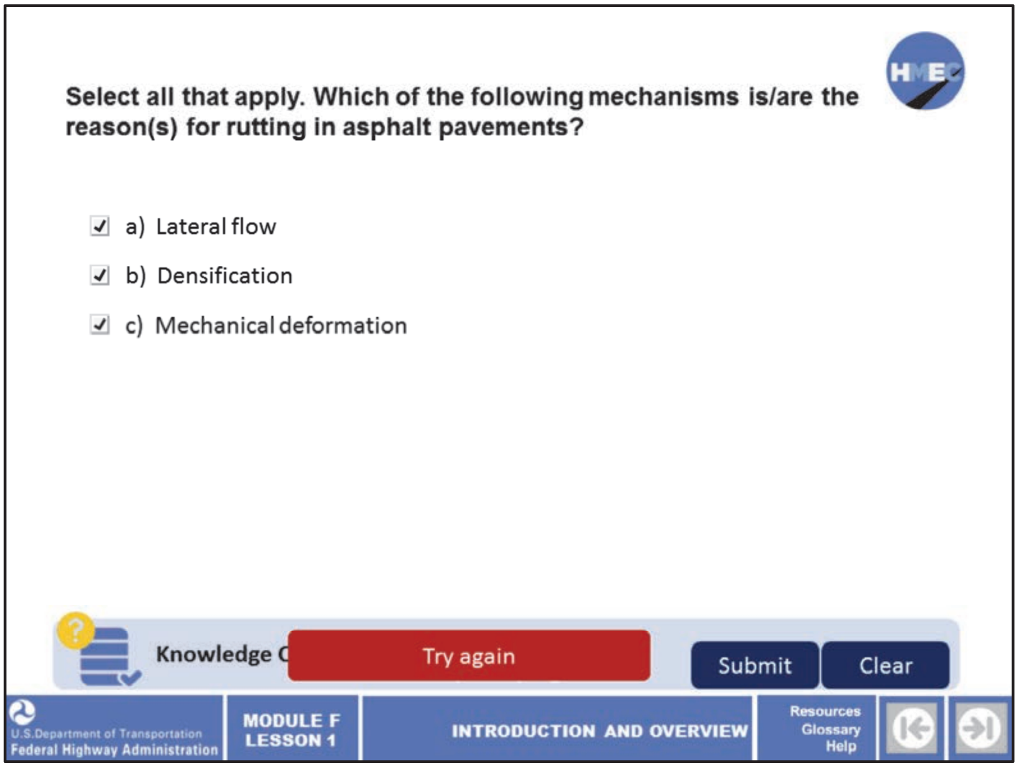


Select the best answer. Which one of the following is NOT considered a dense-graded mix?

a) Well-graded mix;
b) Gap-graded mix; or
c) Open-graded mix

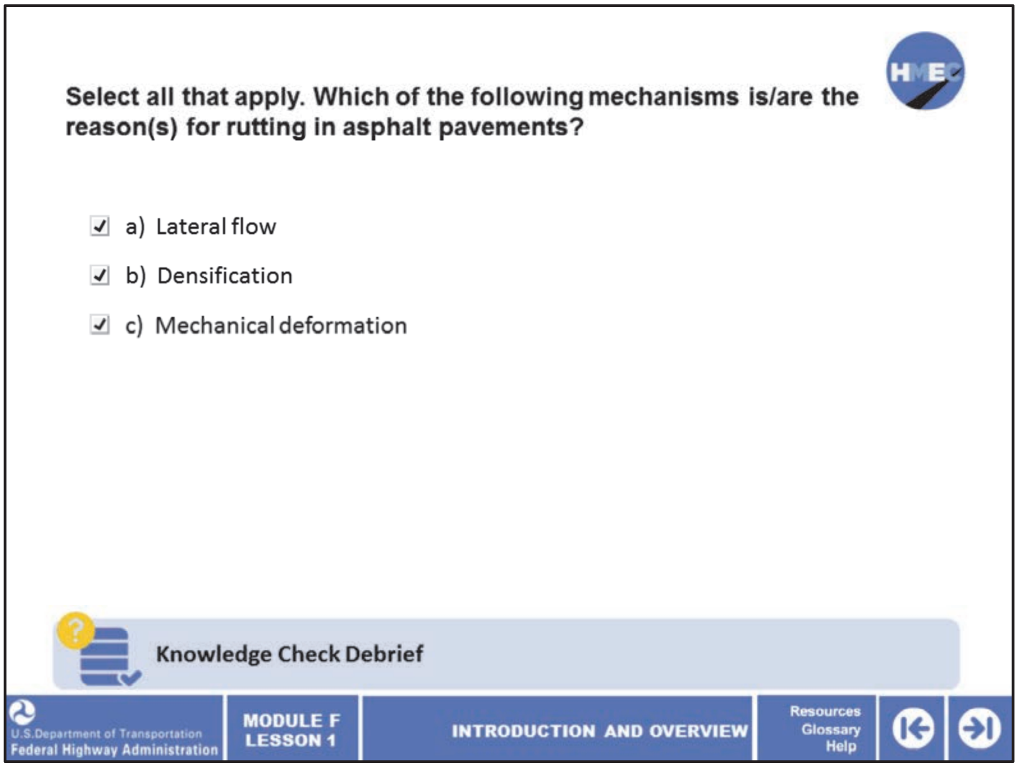


The correct answer is c) Open-graded mix.

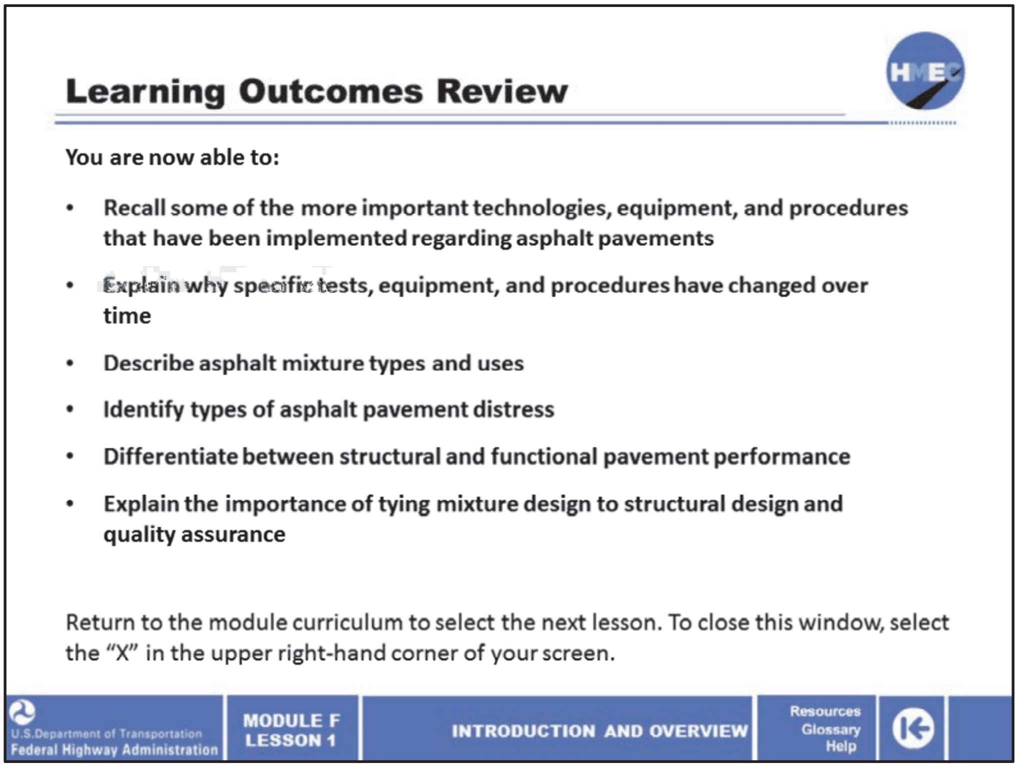


Select all that apply. Which of the following mechanisms is/are the reason(s) for rutting in asphalt pavements?

a) Lateral flow;
b) Densification; and/or
c) Mechanical deformation.



The correct answers are a) Lateral flow; b) Densification; and c) Mechanical deformation.



This concludes Lesson 1. You are know able to:

• Recall some of the more important technologies, equipment, and procedures that have been implemented regarding asphalt pavements;
• Explain why specific tests, equipment, and procedures have changed over time;
• Describe asphalt mixture types and uses;
• Identify types of asphalt pavement distress;
• Differentiate between structural and functional pavement performance; and
• Explain the importance of tying mixture design to structural design and quality assurance.

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