HMEC

Highway Materials Engineering Course

PARTICIPANT WORKBOOK

Steel, Welding, and Coatings

MODULE

C

U.S.Department of Transportation
Federal Highway Administration

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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 C: Steel, Welding, and Coatings is the third module in the FHWA HMEC.

The newly revised Module C is designed to include detailed technical content and provide numerous opportunities to apply the content. Experiences such as laboratory testing, analysis, and other identified opportunities are included.

This module includes the newest information available for steel. Many of the processes associated with steel are particularly appropriate for visual representations. Besides hands-on experiences, this module includes a variety of graphics, animated process flows, photographs, and videos.

Module C Overview

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

Instructor-led Training (ILT)

1 Introduction and History	2 Physical Properties of Structural Steel	3 High Strength Bolts and Fasteners	4 Welding Process	5 Weld Inspection
6 Fabrication	**Laboratory Experience: Welding**	16 Hot Topics (Steel and Welding)	**Review Part 1**	7 Corrosion and Its Control
8 Surface Preparation	9 Removing Lead-based Paints	**Final Assessment Part 1**	10 Coating Materials	11 Coating Application
Laboratory Experience: Coatings	12 Common Coating Failures	13 Maintaining the Coating System	14 Certification Programs	15 Coating Specifications
16 Hot Topics (Coatings)	**Review and Final Assessment Part 2**			

Module Goals

The goals for this module are as follows:

- Apply the basics of steel metallurgy to the selection of materials and their structural performance
- Explain basic welding procedures and the ways they affect the performance of the structure
- Apply fundamental principles of high-strength bolts and fasteners to the selection, application, inspection, and testing of those materials
- Describe typical steel fabrication practices and the need for inspection to ensure quality
- Identify procedures to support proper steel installation
- Identify factors used to assess the in-service condition of structural steel
- Describe guidelines for use of un-coated weathering steels
- Describe the components of a paint coating system
- Describe a variety of coating materials, surface preparation requirements, application methods, and appropriate inspection techniques
- Describe galvanizing and zinc thermal spray coating systems
- Describe common regulations applied to health, safety, and environmental concerns related to paint and other coatings
- Apply written and pictorial standards and references for coatings
- Perform, analyze, and review results of typical failure analyses for steel, fasteners, and coatings

Learning Outcomes

Lesson 1: Introduction and History

- LO 1.1: Identify the various types of steel products and the history of their development
- LO 1.2: Describe various applications of structural steel in transportation applications
- LO 1.3: Describe the challenges of working with non-standard components in existing structures

Lesson 2: Physical Properties of Structural Steel

- LO 2.1: Explain the properties of steel that are significant to its performance in transportation applications
- LO 2.2: Explain the fracture toughness of steel and the testing procedures
- LO 2.3: Explain how the hardness of steel relates to strength and toughness properties
- LO 2.4: Explain the relationship of chemical composition and alloying elements to steel properties
- LO 2.5: Explain how the manufacturing process and heat treatment affects the properties of steels

- LO 2.6: Explain the industry standards and mill certification procedures for steel products
- LO 2.7: Describe fabrication practices that can change steel properties
- LO 2.8: Give examples of failure analysis case studies

Lesson 3: High Strength Bolts and Fasteners

- LO 3.1: Identify the major types of bolts and fasteners, their properties and limitations, and their applications
- LO 3.2: Describe the performance requirements of structural connections and how bolt properties affect that performance
- LO 3.3: Describe best practices in installation procedures for bolts and fasteners
- LO 3.4: Define the special concerns for using corrosion-resistant fasteners
- LO 3.5: Define the special provisions and concerns that apply to anchor bolts
- LO 3.6: Using given criteria, perform a forensics analysis to identify the failure mechanism and potential causes of bolts, fasteners, and connections

Lesson 4: Welding Process

- LO 4.1: Describe how welding is used in highway structures
- LO 4.2: Identify welding codes used to ensure sound practices in structural welding, particularly with respect to use of AASHTO/AWS D1.5 in steel bridges
- LO 4.3: Calculate carbon equivalency and explain its effects on the weldability of metals
- LO 4.4: Recognize the types of welding processes used for structural steel welding
- LO 4.5: Explain the effects of member distortion
- LO 4.6: Describe situations requiring special welding provisions
- LO 4.7: Describe key aspects of achieving weld quality

Lesson 5: Weld Inspection

- LO 5.1: Explain the fundamentals of weld inspection and the process to certify welding inspectors

Lesson 6: Fabrication

- LO 6.1: Identify the processes involved in bridge fabrication and describe the work flow through the shop
- LO 6.2: Identify certification programs available for fabrication shops based upon the specified code
- LO 6.3: Compare State specifications to the AASHTO/NSBA "Steel Bridge Fabrication Guide Specification"
- LO 6.4: Relate fabrication shop assembly to proper fit in the field
- LO 6.5: Identify documentation procedures for the fabrication process

Laboratory Experience: Welding

- LO 5.2: Perform various welding operations in the laboratory
- LO 5.3: Ensure that a weld meets the geometric standards specified in D1.5
- LO 5.4: Ensure that a weld meets the standards of the AWS D1.5 Bridge Welding Code
- LO 5.5: Analyze weld failures

Lesson 7: Corrosion and Its Control

- LO 7.1: Describe the economic consequences of steel corrosion
- LO 7.2: Explain the four components of the corrosion cell
- LO 7.3: Relate environmental factors, such as the presence of chlorides, to the corrosion of structural steel
- LO 7.4: Explain the basic mechanism by which corrosion is arrested or mitigated
- LO 7.5: Compare and contrast the elements and uses of barrier, inhibitive, and sacrificial coatings for steel
- LO 7.6: Explain proper usage of uncoated weathering steels

Lesson 8: Surface Preparation

- LO 8.1: Compare various methods of surface preparation for metal surfaces
- LO 8.2: Relate national and international standards on surface preparation to best construction practices in the field
- LO 8.3: Describe best practices for surface preparation and abrasive selection
- LO 8.4: Identify special challenges of working with recycled abrasive materials
- LO 8.5: Evaluate cleaning based upon written, pictorial, and sample blast standards

Lesson 9: Removing Lead-Based Paints

- LO 9.1: Identify State and Federal resources that apply to major areas of environmental and worker health and safety regulations for lead paint removal
- LO 9.2: Describe surface preparation methods that affect land, air, and water quality.

Lesson 10: Coating Materials

- LO 10.1: Explain the basic components of a coating
- LO 10.2: Given a specific coating, identify the appropriate curing mechanism
- LO 10.3: Explain the necessary elements of quality assurance as applied to common paint manufacturing methods
- LO 10.4: Interpret test results for common physical properties of a coating

Lesson 11: Coating Application

- LO 11.1: Explain the mixing procedures for one component and multi-component paints
- LO 11.2: Explain the effects of thinners on paint performance
- LO 11.3: Select the most appropriate paint application method given the benefits and challenges of each
- LO 11.4: Identify the impact of ambient conditions, paint mixing, application, and proper cure on a successful paint application
- LO 11.5: Point out important and relevant information on a Material Safety Data Sheet (MSDS)
- LO 11.6: Apply contractor quality control requirements to an acceptable finished product
- LO 11.7: Explain the requirements for the acceptance of paint work

Laboratory Experience: Coatings

- LO 11.8: Calculate humidity and dew point using both psychometric and U.S. Weather Bureau tables
- LO 11.9: Evaluate the cleanliness of panels cleaned to different grades
- LO 11.10: Measure the anchor profile on panels using both profilometer and replica tape methods
- LO 11.11: Measure coating thickness in accordance with procedures in SSPC PA 2
- LO 11.12: Use ASTM D 3359 Method A-x cut to perform tests
- LO 11.13: Measure coating thickness of individual layers on multi-coated panels

Lesson 12: Common Coating Failures

- LO 12.1: Identify and explain common coating failures, their causes, and cures
- LO 12.2: Identify structural steel design details or specification language that can lead to early coating failure
- LO 12.3: Discuss the main goals of a coating failure investigation

Lesson 13: Maintaining the Coating System

- LO 13.1: State the importance of maintaining the coating system
- LO 13.2: List factors and conditions that affect the longevity of maintenance paint jobs
- LO 13.3: Identify common strategies used to plan and execute maintenance paint work
- LO 13.4: Identify coating technologies used for maintenance paint work
- LO 13.5: Identify hazardous coatings prior to their removal

Lesson 14: Certification Programs

- LO 14.1: Explain the advantages and limitations of certification programs
- LO 14.2: Identify conditions that could result in a facility owner requesting an audit or filing a complaint
- LO 14.3: Explain the benefits of a qualified coating inspector

Lesson 15: Coating Specifications

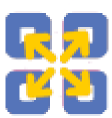
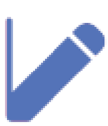
- LO 15.1: Describe the purpose and content of a coating specification
- LO 15.2: Evaluate your State coating specification for currency with standard industry practices and quality procedures

Lesson 16: Hot Topics

- LO 16.1: Explore current and emerging technology and trends that affect steel and coating systems

ILT Instruction Icons

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

Icon	Icon Name	Typical Use
	Timer	▪ Call out the estimated time for the lesson
	Important Information	▪ Call out important information.
	Q & A	▪ Check for understanding or agreement. ▪ Survey participants. ▪ Solicit feedback.
	Breakout/Small Group Exercise	▪ Break participants into groups. ▪ Provide directions for exercise.
	Video/Sound	▪ Show a video.
	Reference	▪ Reference another document or resource.
	Links	▪ Share a Web link for additional resources.
	Whiteboard	▪ Draw or document something on a whiteboard or easel pad.

Icon	Icon Name	Typical Use
	Safety	▪ Call out important safety information.
	Common Error	▪ Call out a system or process that is often misused.

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Lesson 1: Introduction and History
Steel, Welding, and Coatings
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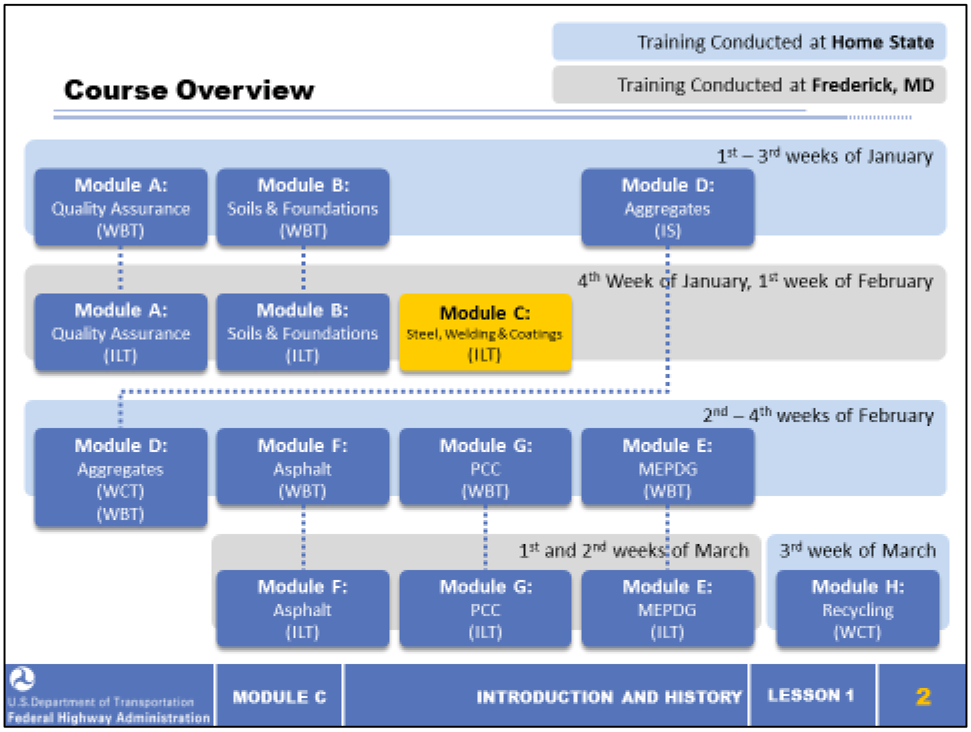
Training Conducted at Home State
Training Conducted at Frederick, MD
Course Overview
1st – 3rd weeks of January
Module A: Quality Assurance (WBT)
Module B: Soils & Foundations (WBT)
Module D: Aggregates (IS)
4th Week of January, 1st week of February
Module A: Quality Assurance (ILT)
Module B: Soils & Foundations (ILT)
Module C: Steel, Welding & Coatings (ILT)
2nd – 4th weeks of February
Module D: Aggregates (WCT) (WBT)
Module F: Asphalt (WBT)
Module G: PCC (WBT)
Module E: MEPDG (WBT)
1st and 2nd weeks of March
3rd week of March
Module F: Asphalt (ILT)
Module G: PCC (ILT)
Module E: MEPDG (ILT)
Module H: Recycling (WCT)
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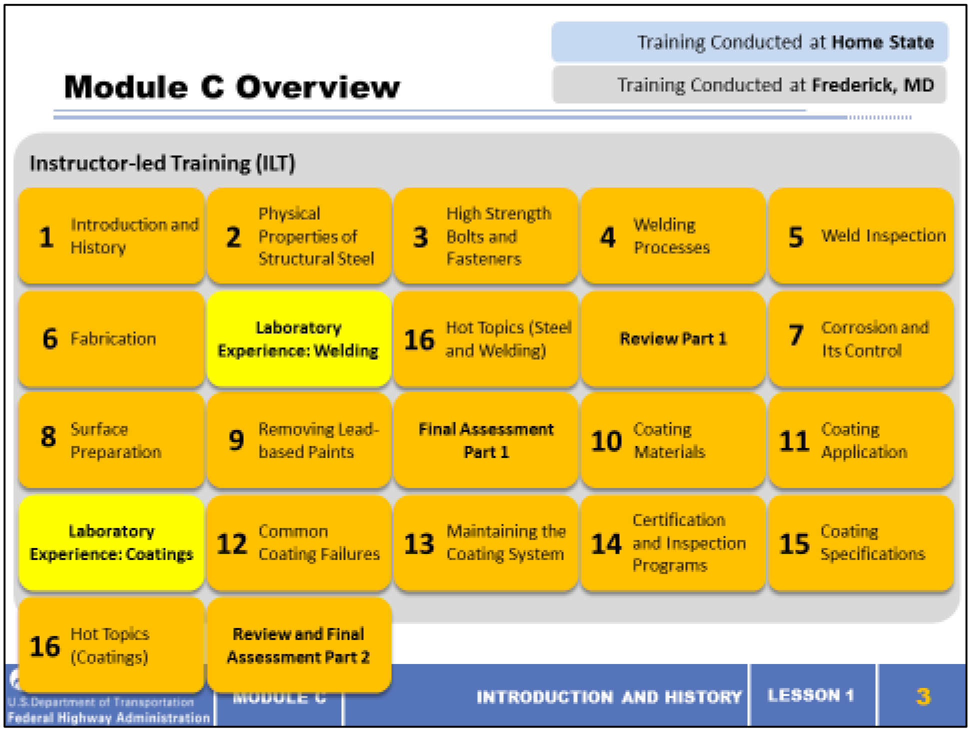
Training Conducted at Home State
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Module C Overview
Instructor-led Training (ILT)
1 Introduction and History
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Review and Final Assessment Part 2
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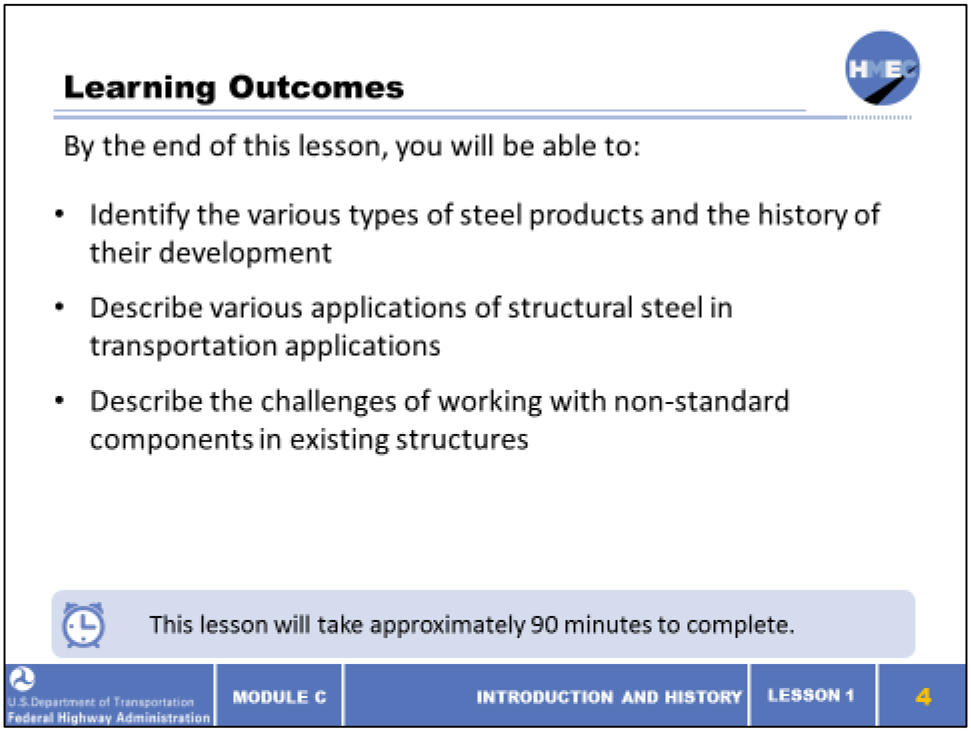
Learning Outcomes
HMEC
By the end of this lesson, you will be able to:
• Identify the various types of steel products and the history of their development
• Describe various applications of structural steel in transportation applications
• Describe the challenges of working with non-standard components in existing structures
This lesson will take approximately 90 minutes to complete.
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Aspects of Steel Production Influencing Structural Performance

- Over the next several lessons, you will discover how these aspects influence performance:
  - Steel chemistry and alloying elements
  - Rolling
  - Microstructure of the unfabricated steel
  - Inherent discontinuities
  - Residual stresses

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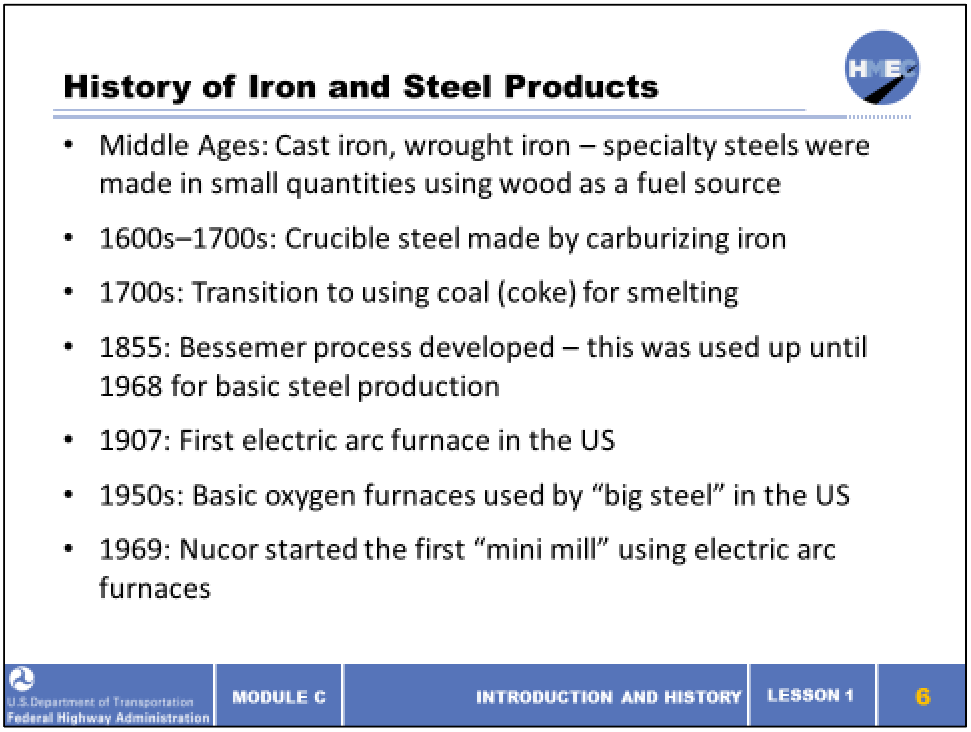

The origins of steelmaking are somewhat convoluted in the Middle Ages. Cast iron and wrought iron were being produced and steel was being made in small regional operations, primarily for weapons.

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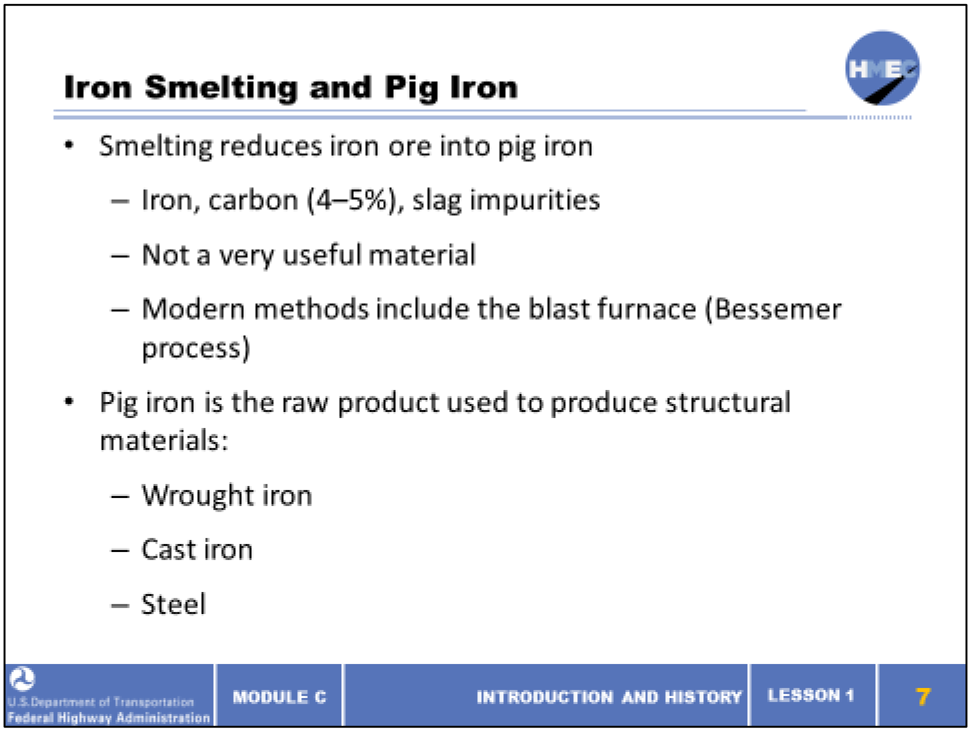
Iron Smelting and Pig Iron
• Smelting reduces iron ore into pig iron
– Iron, carbon (4–5%), slag impurities
– Not a very useful material
– Modern methods include the blast furnace (Bessemer process)
• Pig iron is the raw product used to produce structural materials:
– Wrought iron
– Cast iron
– Steel
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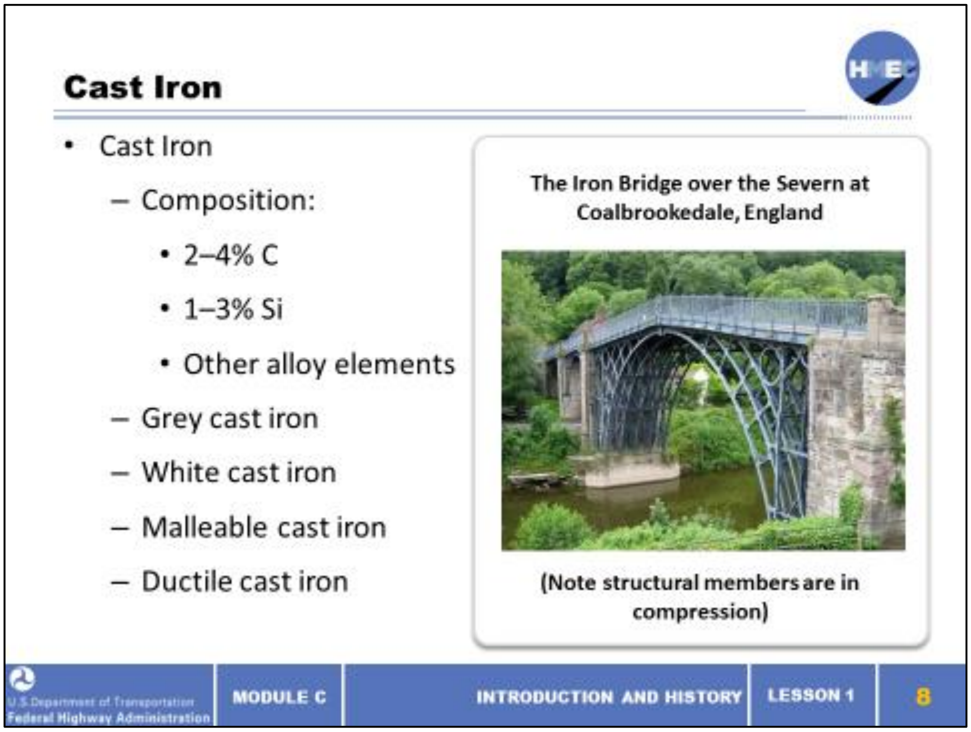

Cast iron has different forms, depending on alloying and processing. It is suitable for pouring into a mold (usually sand) to form cast parts. It is generally a brittle material but lower carbon formulations are possible (malleable and ductile iron). Its uses are limited in modern bridges, but can be useful for bearings and other specialty parts.

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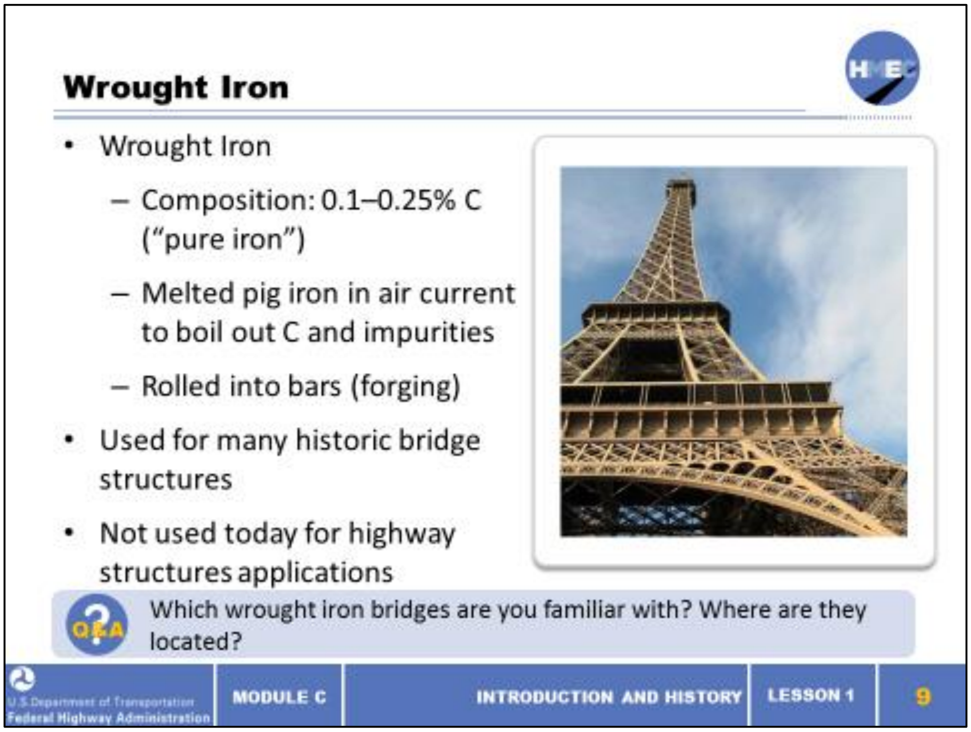

This is often called "pure iron" since there are almost no alloy elements. The processing involves heating pig iron in an air current that allows the carbon to combine with oxygen. The resulting low carbon iron is then hammered or forged to further remove impurities. Wrought iron is a malleable, ductile material and can be produced for structural applications. A number of bridges were built from this material prior to the 20th century, and some still exist today.

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The advantages of wrought iron are that it is historically significant, attractive, and has a good service history. The problems are unknown material properties, unsure of how to determine load rate, functional obsolescence, and upgrade/repair procedures.

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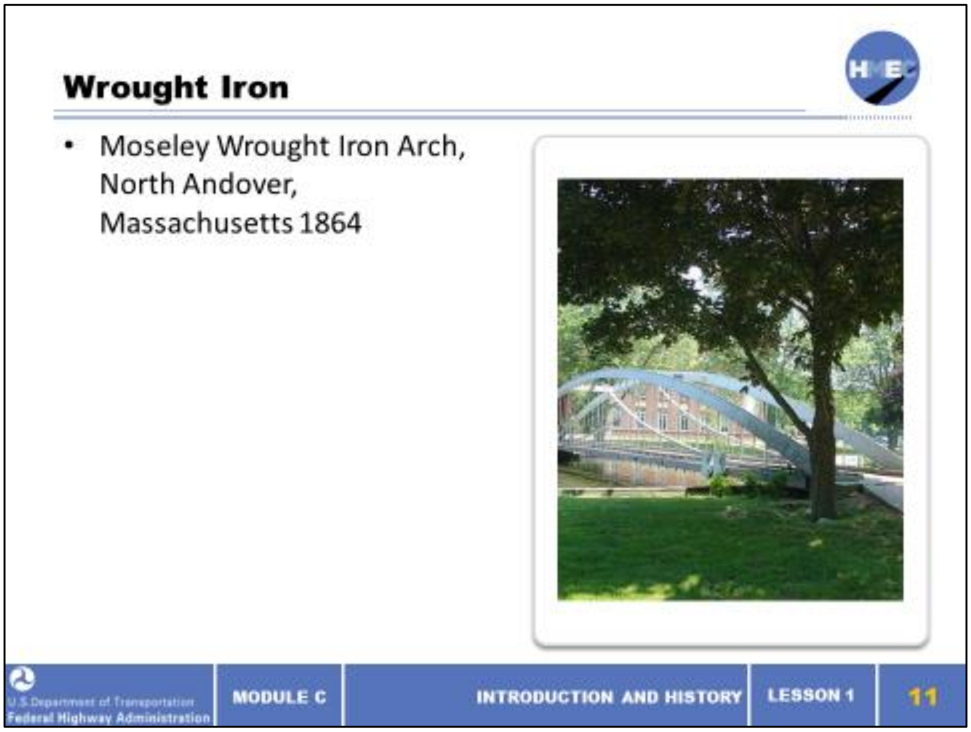

The Moseley Wrought Iron Arch Bridge, also known as the Upper Pacific Mills Bridge, is a historic, riveted, wrought iron bridge now located in North Andover, Massachusetts. It is a National Historical Civil Engineering Landmark now listed on the National Register of Historic Places as the oldest iron bridge in Massachusetts, and one of the oldest bridges in the US. The bridge was completed in 1864 as Moseley Truss Bridge built by the Moseley Iron Building Works of Boston, to connect the Pacific Mills with Canal Street in Lawrence, Massachusetts by spanning the North Canal. It partially collapsed in the late 1980s, but was saved by removal to the Merrimack College campus, where it was renovated in the early 1990s for placement over a campus pond. It was rededicated in this new location on October 23, 1995.

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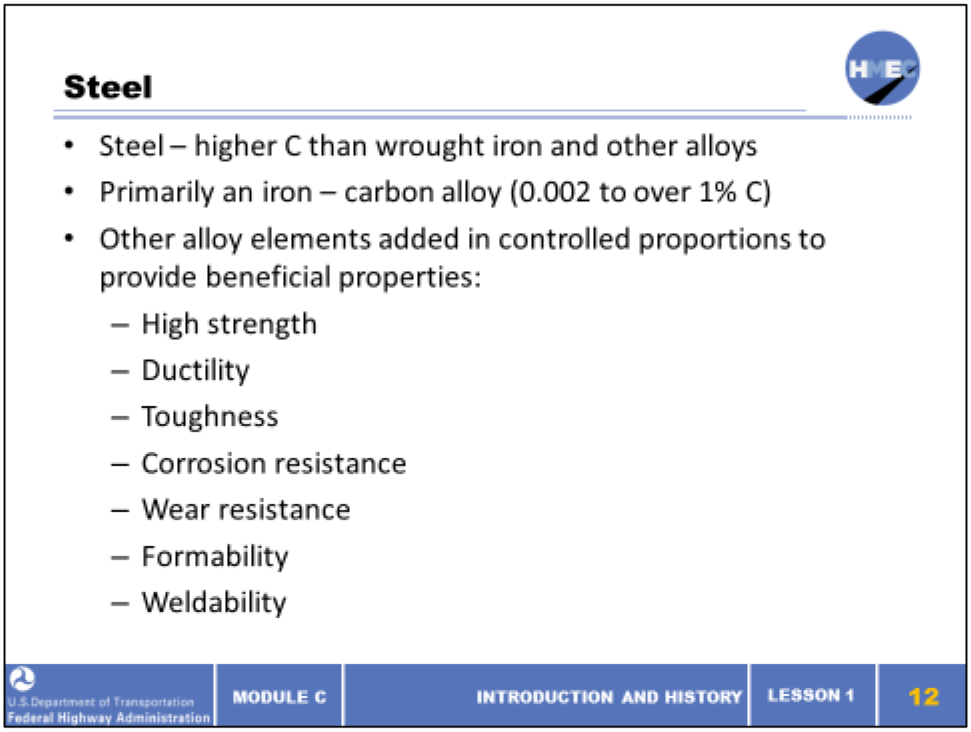

Steel provides a combination of properties that make it well suited for structural applications. Steel is also processed from pig iron but has higher carbon than wrought iron and additional alloy elements to improve its properties. The properties of steel include: high strength, ductility, toughness, corrosion resistance, wear resistance, formability, and weldability. Alloying allows the customization of steel for various applications.

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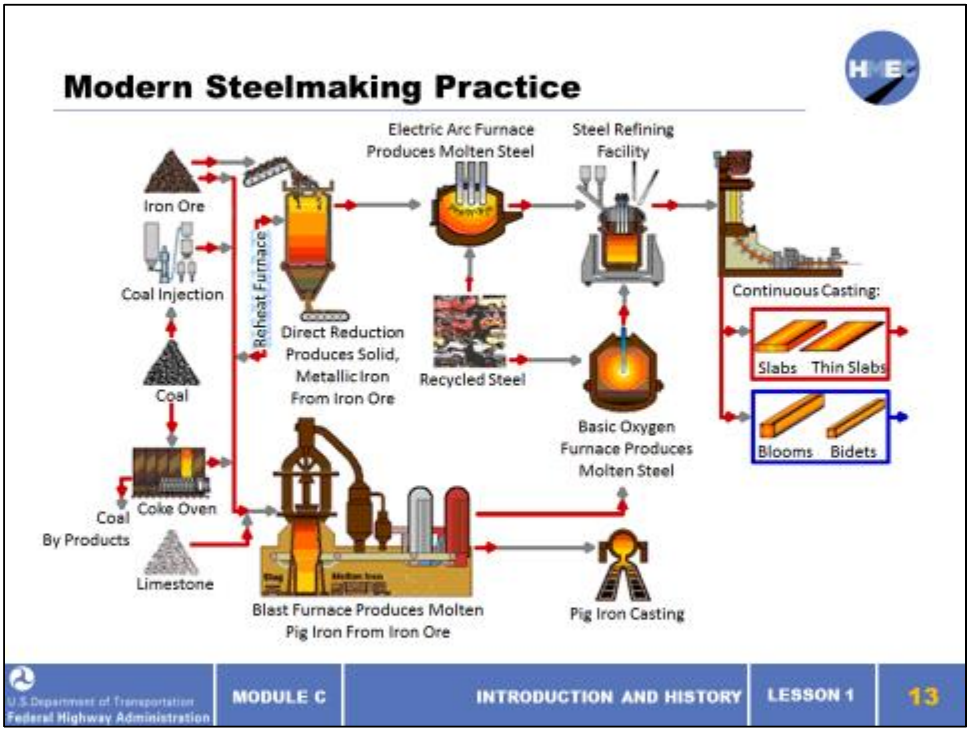
Modern Steelmaking Practice
Electric Arc Furnace Produces Molten Steel
Steel Refining Facility
Iron Ore
Coal Injection
Reheat Furnace
Direct Reduction Produces Solid, Metallic Iron From Iron Ore
Recycled Steel
Continuous Casting:
Slabs
Thin Slabs
Blooms
Bidets
Coal
Basic Oxygen Furnace Produces Molten Steel
Coal By Products
Coke Oven
Limestone
Blast Furnace Produces Molten Pig Iron From Iron Ore
Pig Iron Casting
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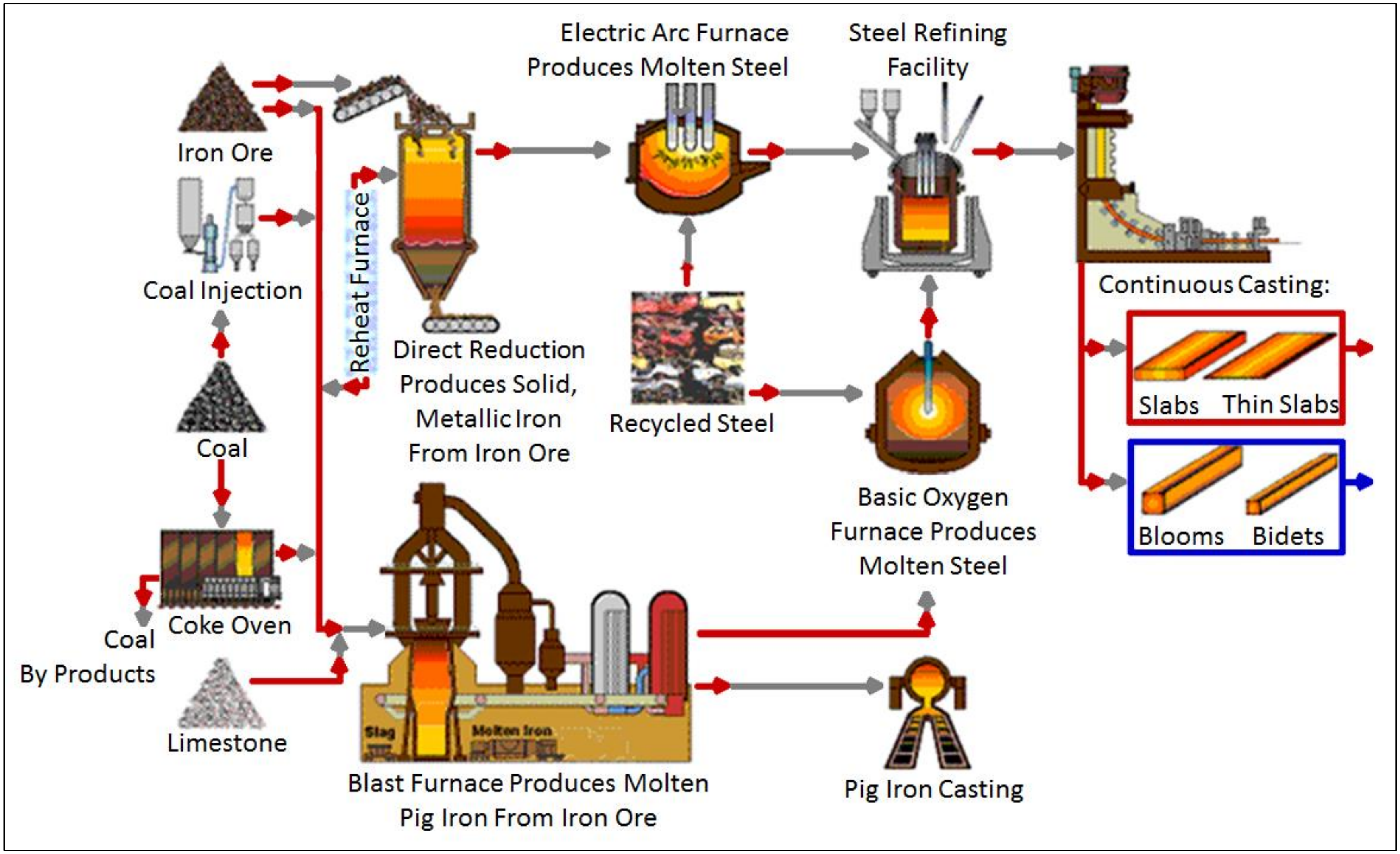
Electric Arc Furnace Produces Molten Steel
Steel Refining Facility
Iron Ore
Coal Injection
Reheat Furnace
Direct Reduction Produces Solid, Metallic Iron From Iron Ore
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Basic Oxygen Furnace Produces Molten Steel
Coke Oven
Coal By Products
Limestone
Slag
Molten Iron
Blast Furnace Produces Molten Pig Iron From Iron Ore
Pig Iron Casting

The first step in steel production involves the production of pig iron from iron ore. The traditional blast furnace (Bessemer process) heats ore along with coke, limestone, and oxygen. Coke is basically pure carbon and is produced by baking coal in a coke oven. This is a high air pollution process and was responsible for much of the air pollution in traditional steelmaking towns like Pittsburgh and Bethlehem, PA. The initial product is a cleaner variant and blooms are closer to the final product shape. It also reduces the energy required to reheat ingots. The direct reduction process uses natural gas instead of coke. For both methods, the furnaces are tapped at the bottom to remove the molten iron. Slag and other impurities tend to float to the top of the molten mixture.

The second step is to produce steel from the pig iron. In the traditional basic oxygen furnace (BOF), a large ladle is charged with some recycled steel. The molten iron is added and an oxygen lance is inserted to heat and melt the scrap. The alternate process is the electric arc furnace (EAF) where scrap and pig iron are melted by electric arcs between electrodes lowered into the furnace. The EAF process does not require molten iron and the steel can be produced from up to 100% scrap. The EAF process has enabled many “mini-mill” steel makers to arise and compete with the big steel companies (Nucor, Chaparrel, etc.). The result is cheaper, cleaner steel production.

The raw steel produced from either the BOF or EAF processes is then refined to achieve the proper alloy composition. Alloy elements are added or removed as required to meet the desired chemical composition goals. The steel is also “killed” to remove oxygen and degassed to control hydrogen and nitrogen.

One of the biggest modern advances in steelmaking is the continuous casting process. The old methods cast ingots that solidified in a mold. These were then reheated to red hot and rolled into product shapes. Today, the molten steel is poured into the top of the continuous caster and solidifies into slabs or blooms continuously. The red hot slabs or blooms can be immediately rolled into products.

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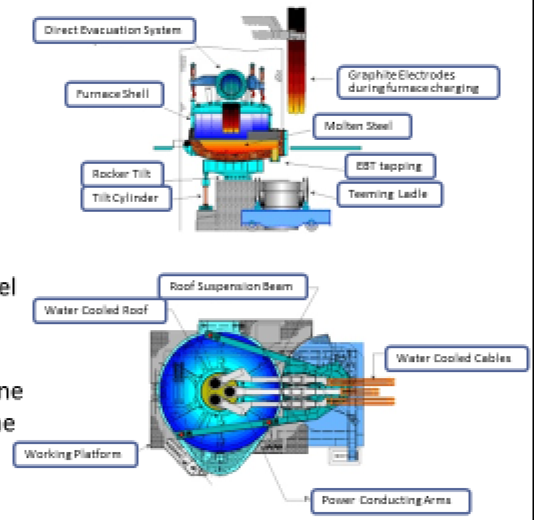
Modern Steelmaking – Electric Arc Furnace

- Scrap steel is charged into the ladle
- Graphite electrodes are placed through the top
- Electric arc melts the scrap charge
- The process repeats until the ladle is full
- The composition of molten steel is sampled
- Oxygen is injected and deslagging is performed to refine the chemical composition of the steel



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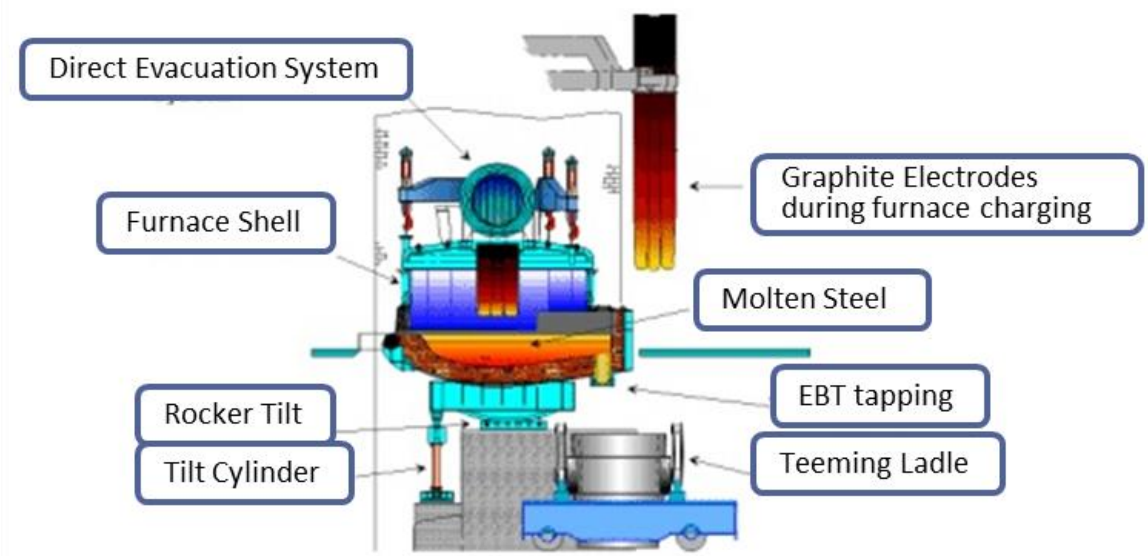
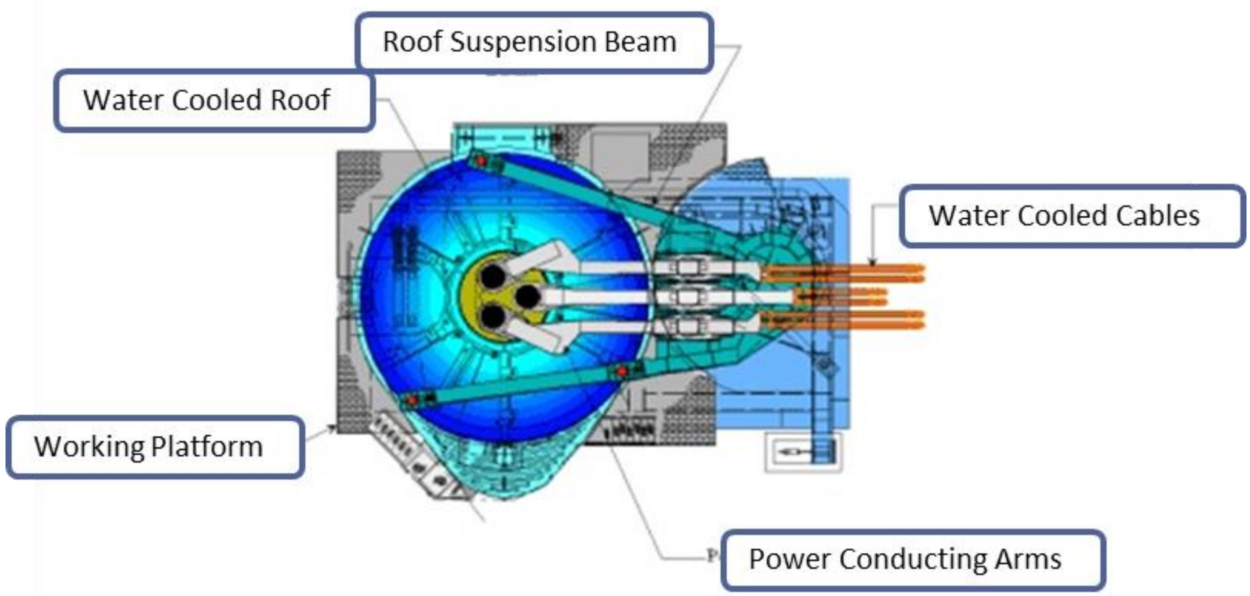

Direct Evacuation System
Furnace Shell
Graphite Electrodes during furnace charging
Molten Steel
EBT tapping
Rocker Tilt
Tilt Cylinder
Teeming Ladle


Roof Suspension Beam
Water Cooled Roof
Water Cooled Cables
Working Platform
Power Conducting Arms

This process takes a considerable amount of electrical energy. However, this furnace does not require liquid metal to start and is therefore suitable for producing steel from 100% scrap. This process is suitable for small operations that do not have a blast furnace or other source of molten metal. This process is responsible for the “mini-mills” that have increased competition and reduced cost for steel products.

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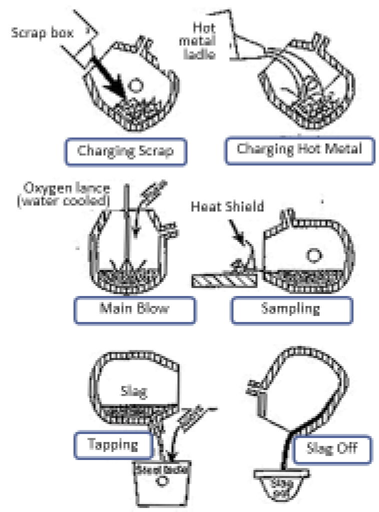
Modern Steelmaking – Basic Oxygen Furnace

- Scrap steel is charged into the ladle
- Liquid metal added from blast furnace
- Oxygen lance melts the steel
- Steel is tapped into a large ladle and slag is removed



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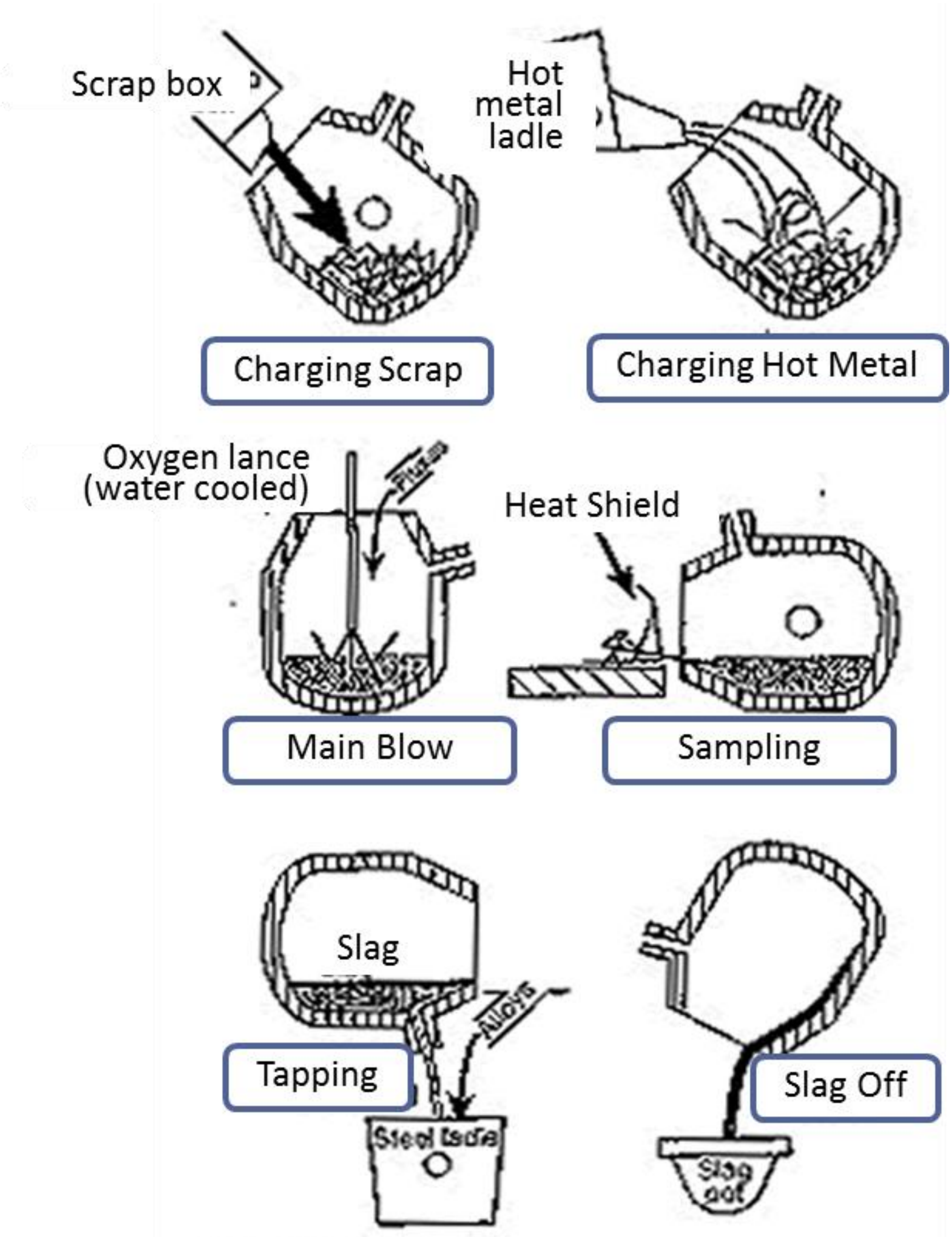
Scrap box
Hot metal ladle
Charging Scrap
Charging Hot Metal
Oxygen lance (water cooled)
Fluxes
Heat Shield
Main Blow
Sampling
Slag
Alloys
Tapping
Steel ladle
Slag Off
Slag pot

The process begins with a scrap charge of metal that is added to the furnace. Hot iron is poured in. An oxygen lance is lowered into the furnace and blown to melt the scrap and remove carbon from the steel. The steel is sampled for chemical composition and alloy elements are added as needed. The furnace is then “tapped” at the bottom to drain off the molten steel. Slag floats to the top and is removed along with impurities. This process is energy self-sufficient, the oxygen produces the heat and melts the steel. However, it requires liquid metal as a starting point. This is therefore not suitable for 100% scrap production.

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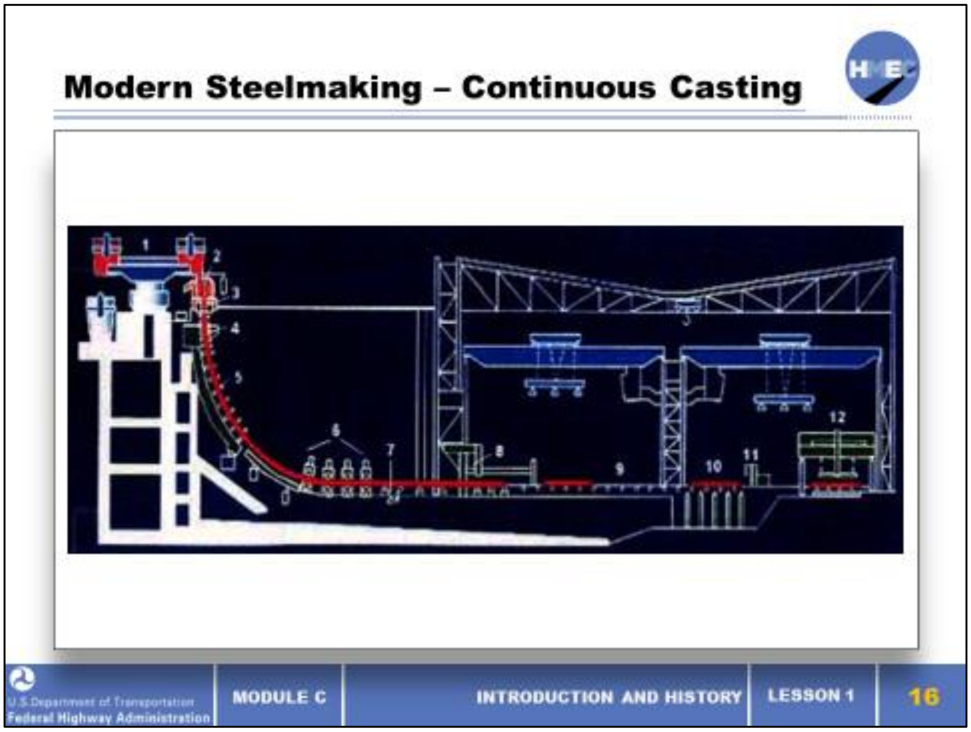

Prior to the introduction of continuous casting in the 1950s, steel was poured into stationary molds to form "ingots." Since then, continuous casting has evolved to achieve improved yield, quality, productivity, and cost efficiency. A continuous red-hot slab emerges from the bottom of the machine. Thermal cutting equipment cuts off the desired length of slab and cranes and rollers are used to move the material. This process was a major advance in the economics of steelmaking.

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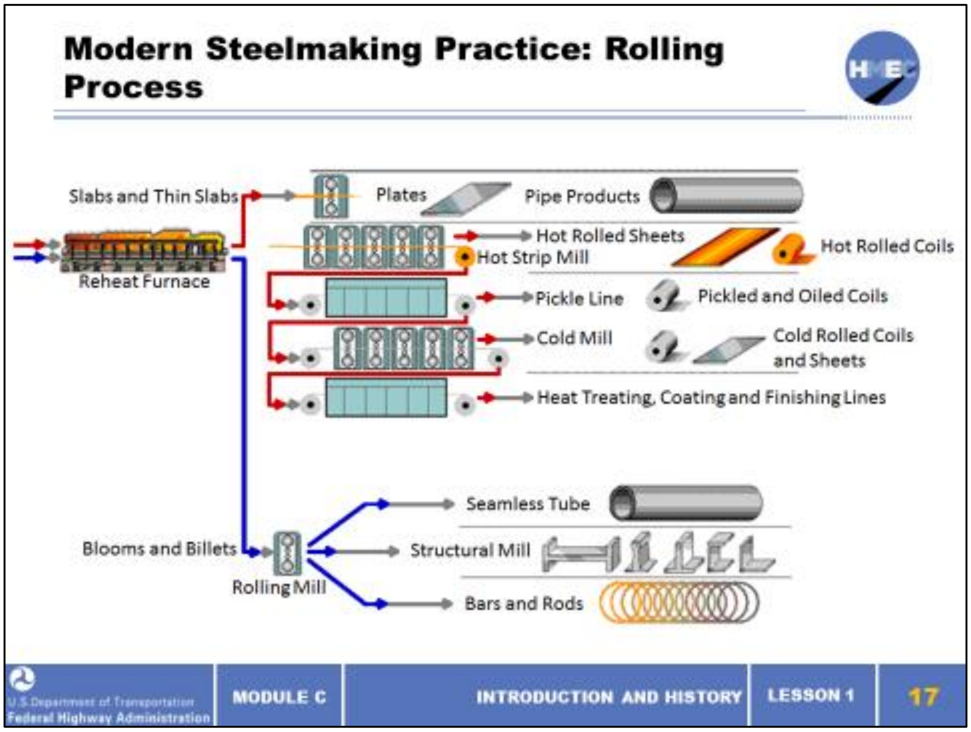
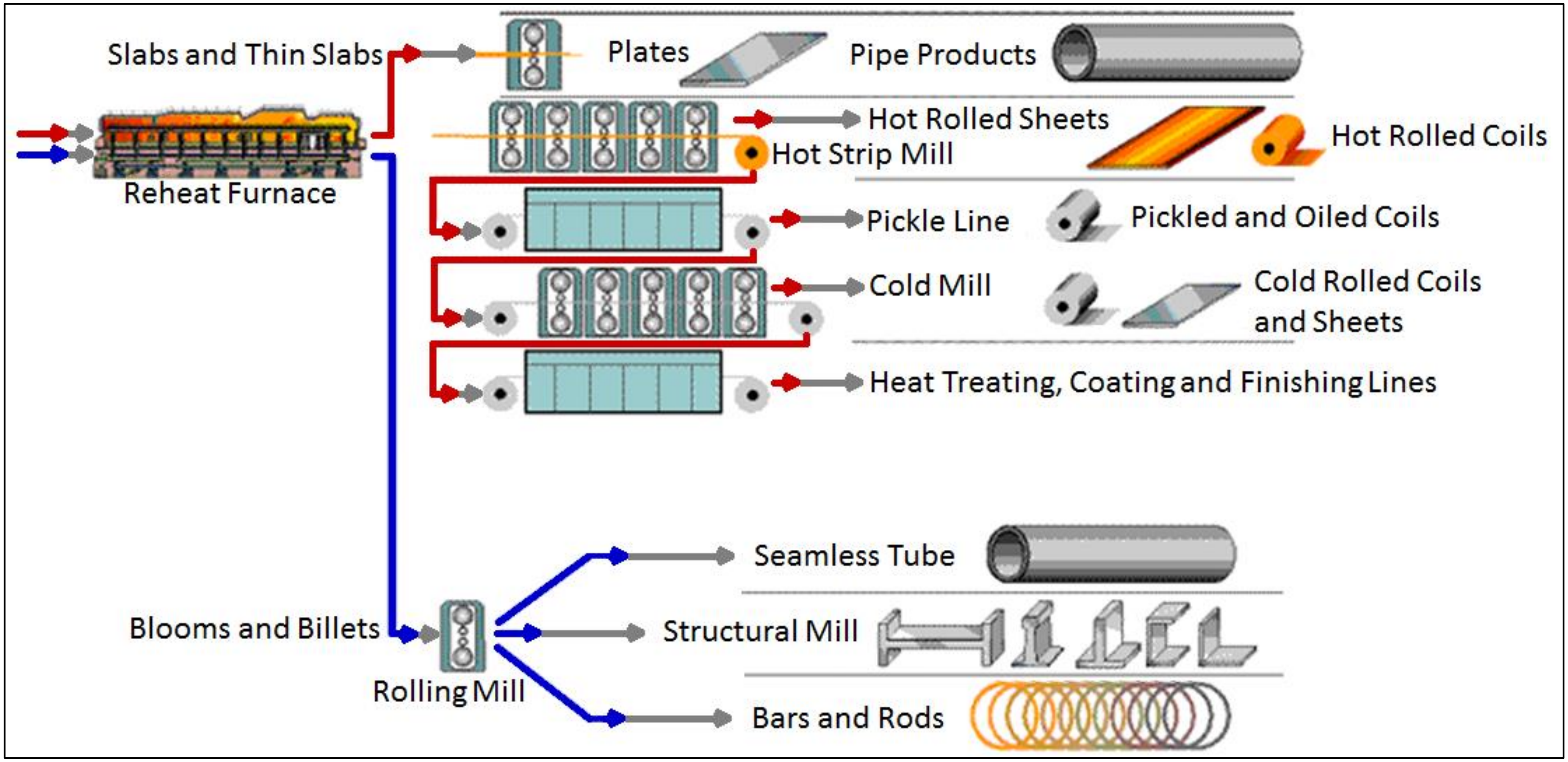

Modern Steelmaking Practice: Rolling Process
Slabs and Thin Slabs
Plates
Pipe Products
Hot Rolled Sheets
Hot Strip Mill
Hot Rolled Coils
Reheat Furnace
Pickle Line
Pickled and Oiled Coils
Cold Mill
Cold Rolled Coils and Sheets
Heat Treating, Coating and Finishing Lines
Seamless Tube
Blooms and Billets
Structural Mill
Rolling Mill
Bars and Rods
U.S. Department of Transportation
Federal Highway Administration
MODULE C
INTRODUCTION AND HISTORY
LESSON 1
17


Slabs and Thin Slabs
Plates
Pipe Products
Reheat Furnace
Hot Rolled Sheets
Hot Strip Mill
Hot Rolled Coils
Pickle Line
Pickled and Oiled Coils
Cold Mill
Cold Rolled Coils and Sheets
Heat Treating, Coating and Finishing Lines
Seamless Tube
Blooms and Billets
Structural Mill
Rolling Mill
Bars and Rods

The slabs are first reheated to the starting temperature for rolling. Many mills transfer the hot slabs directly to the rolling mill to reduce the energy required for reheating. The slabs are passed back and forth between high-pressure rollers to mechanically work the steel into shape. Obviously separate rolling lines are required for plates and structural shapes. Modern high-tech rolling mills utilize thermo-mechanical controlled processing (TMCP) to provide refined temperature and reduction control to improve properties.

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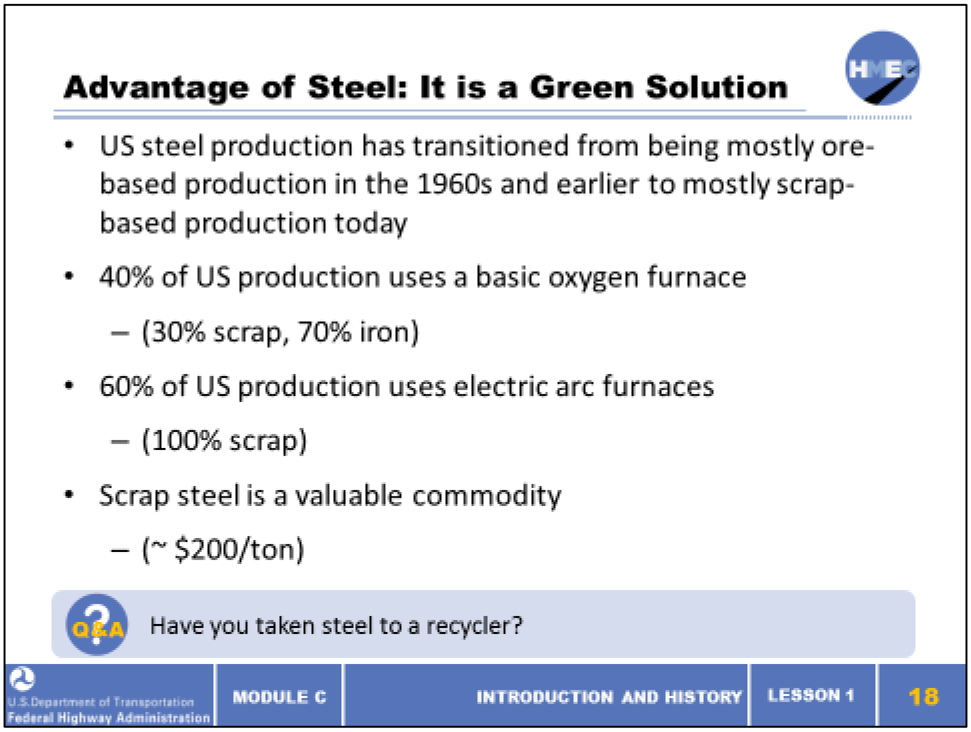
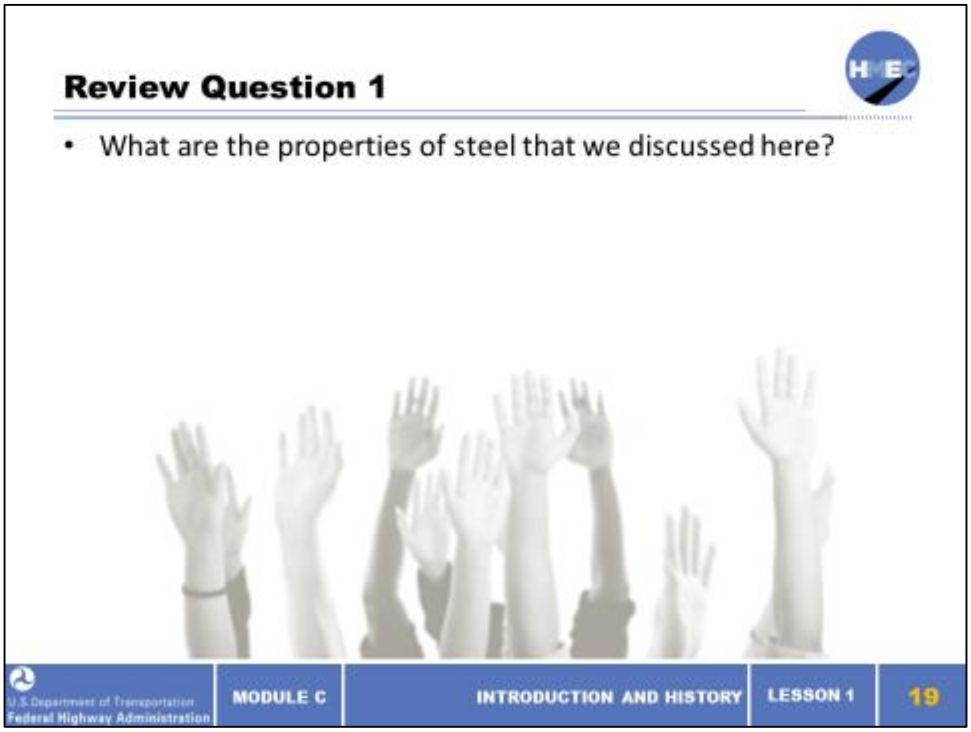
Slide 18



Scrap dealers pay well for scrap steel. This has led people to clean up many dump sites to make money. Almost all automobiles, ships, and other steel products are now recycled.

Slide 19


Review Question 1
• What are the properties of steel that we discussed here?
U.S. Department of Transportation
Federal Highway Administration
MODULE C
INTRODUCTION AND HISTORY
LESSON 1
19

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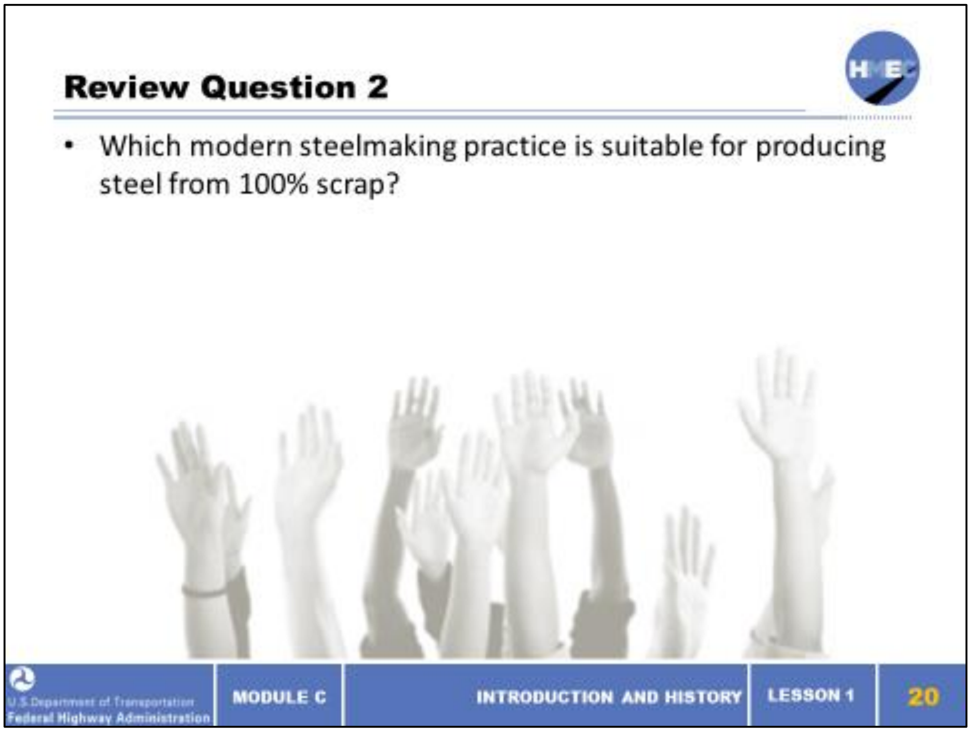
Slide 20


Review Question 2
• Which modern steelmaking practice is suitable for producing steel from 100% scrap?
U.S. Department of Transportation
Federal Highway Administration
MODULE C
INTRODUCTION AND HISTORY
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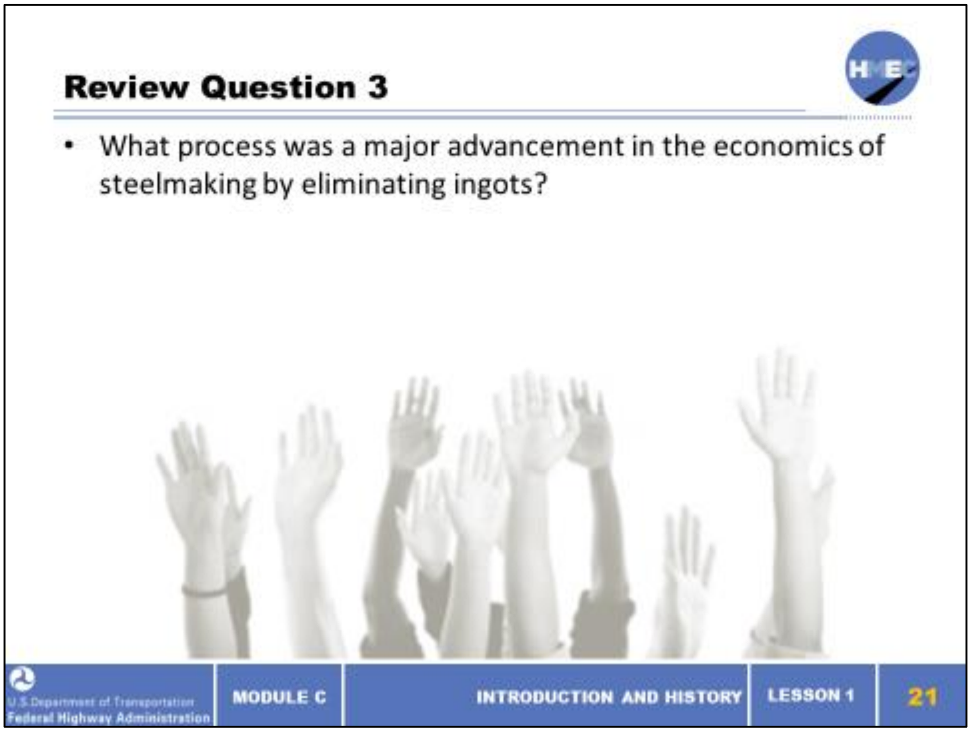
Slide 21


Review Question 3
What process was a major advancement in the economics of steelmaking by eliminating ingots?
U.S. Department of Transportation
Federal Highway Administration
MODULE C
INTRODUCTION AND HISTORY
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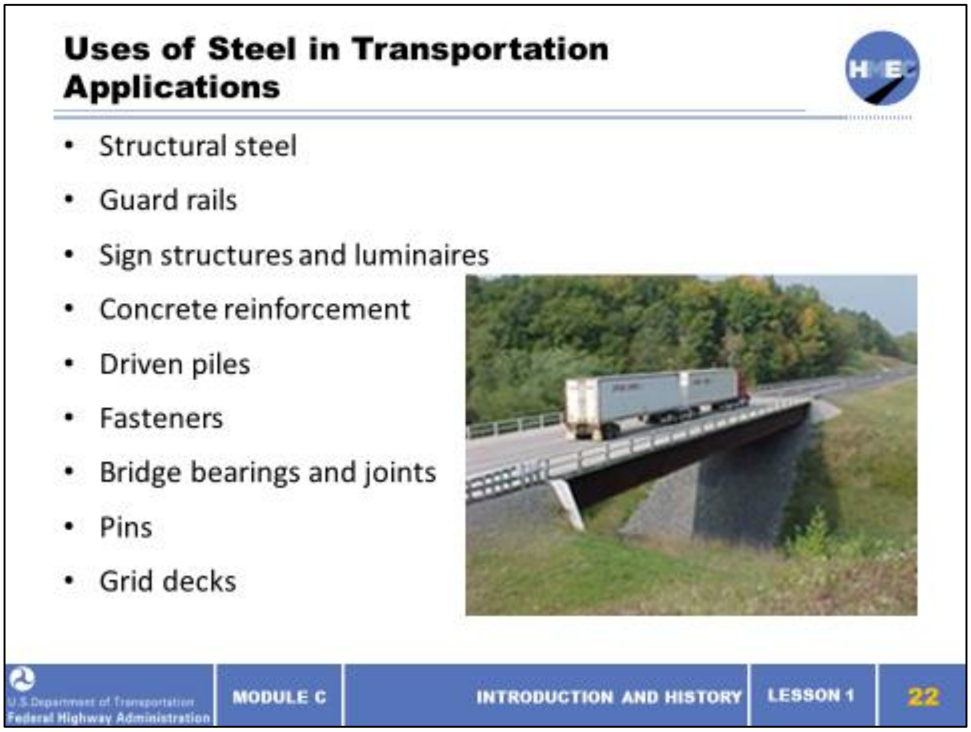
Slide 22



Steel is a very versatile material for bridge fabrication. Welded plate girders are the most common type of steel superstructure element. Welded plate girders can be produced efficiently in a fully optimized shape for the intended use. Many short-span bridges have been constructed of rolled W shapes. Some mills now produce extra deep shapes for this purpose (W36 through W44s, in other words, wide-flange shapes from 36 to 44 in. deep). Rolled shapes, however, currently are not cost-competitive with prestressed concrete girders in parts of the country and steel's market share has declined. Horizontally curved girders are almost entirely made of steel since steel can be fabricated to any desired curvature or shape. Steel can also be adapted to any vertical curved profile.

Slide 23

Steel is a very versatile material for bridge fabrication. Welded plate girders are the most common type of steel superstructure element. Welded plate girders can be produced efficiently in a fully optimized shape for the intended use. Many short-span bridges have been constructed of rolled W shapes. Some mills now produce extra deep shapes for this purpose (W36 through W44s, in other words, wide-flange shapes from 36 to 44 in. deep). Prestressed concrete girders, however, are very competitive with rolled shapes and steel's market share is declining in this portion of the market. Horizontally curved girders are almost entirely made of steel since steel can be fabricated to any desired curvature or shape. Steel can also be adapted to any vertical curved profile.

Diaphragms, crossframes, lateral bracing, and other members are commonly fabricated from steel-rolled shapes.

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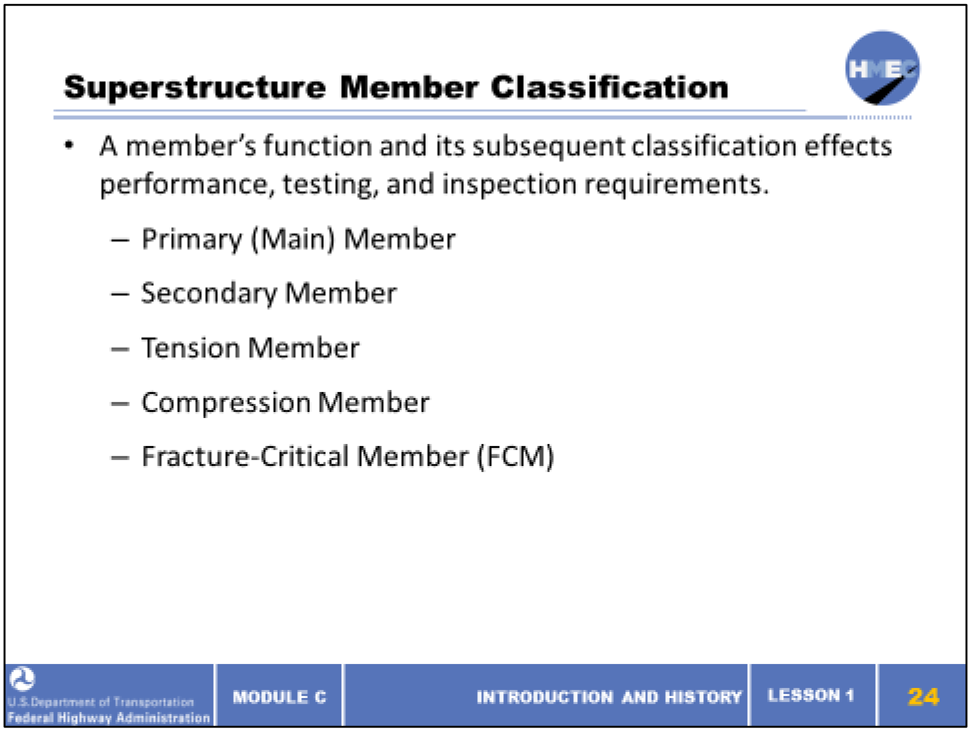
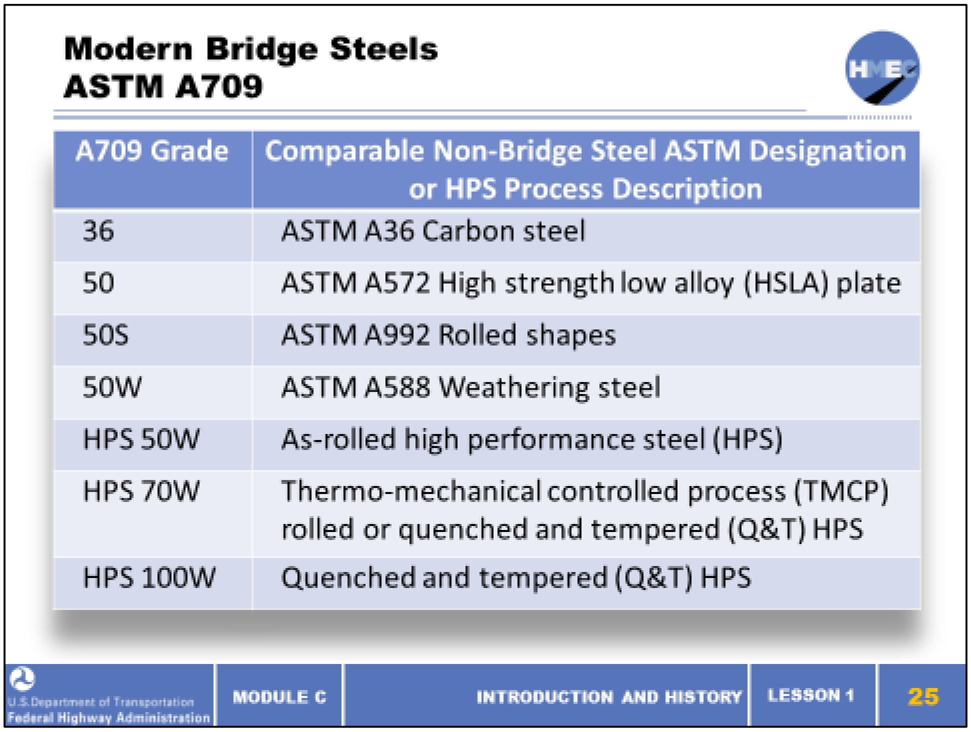


The AASHTO LRFD Bridge Design Specifications defines a primary member as a member designed to carry the loads applied to the structure as determined from an analysis. Further, it defines a secondary member as a member in which stress is not normally evaluated in the analysis.

Slide 25



A709 Grade	Comparable Non-Bridge Steel ASTM Designation or HPS Process Description
36	ASTM A36 Carbon steel
50	ASTM A572 High strength low alloy (HSLA) plate
50S	ASTM A992 Rolled shapes
50W	ASTM A588 Weathering steel
HPS 50W	As-rolled high performance steel (HPS)
HPS 70W	Thermo-mechanical controlled process (TMCP) rolled or quenched and tempered (Q&T) HPS
HPS 100W	Quenched and tempered (Q&T) HPS

The AASHTO Subcommittee on Bridges and Structures must approve all provisions in the A709 specification. The number in the grade indicates the yield strength. The W suffix indicates the grade has enhanced corrosion resistance and is suitable for unpainted use in some applications.

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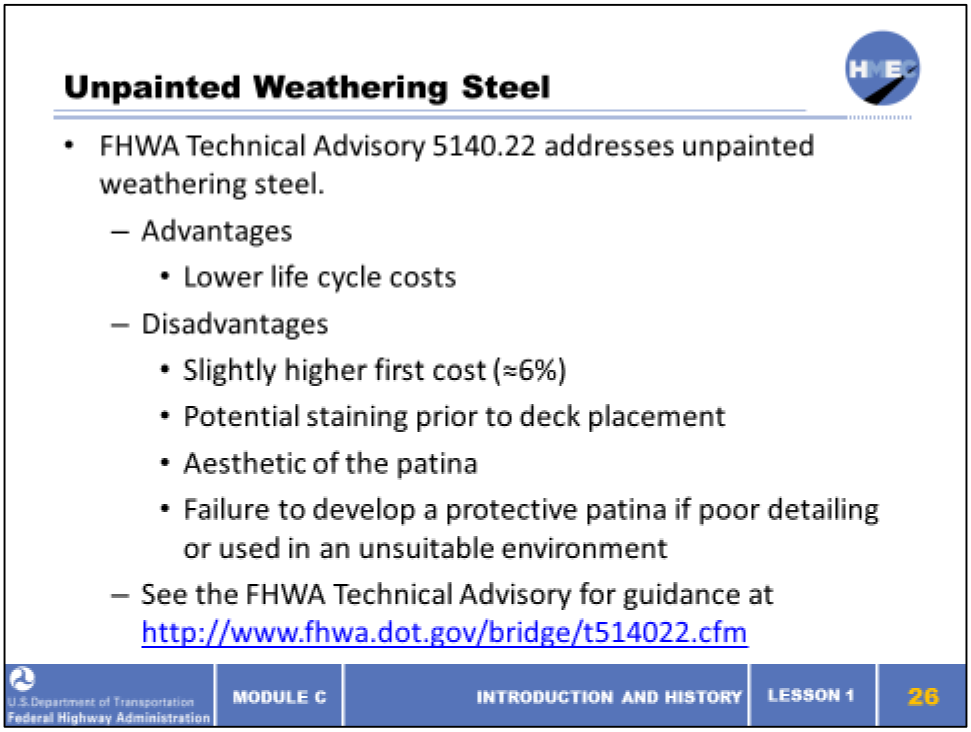
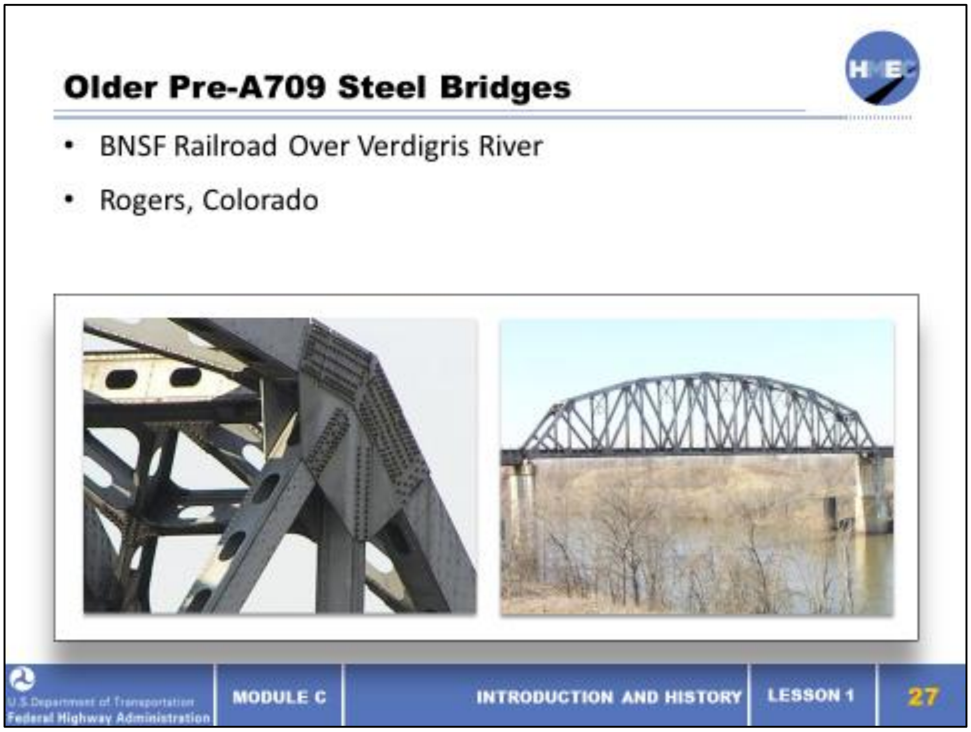


Unpainted weathering steel while slightly more expensive than traditional steel does not require initial painting or subsequent repainting with time. If the concrete abutment and piers are not protected, staining of the concrete can occur from corrosion product from the steel before it is protected from rain by the deck. This potential staining and the final steel color and texture are not attractive to all of the public. To the contrary, some owners actually specify unpainted weathering steel for rural sites as they find it blends well with nature. Finally, the proper location and detailing of unpainted weathering steel bridges are essential to good performance.

See the FHWA Technical Advisory for guidance at http://www.fhwa.dot.gov/bridge/t514022.cfm

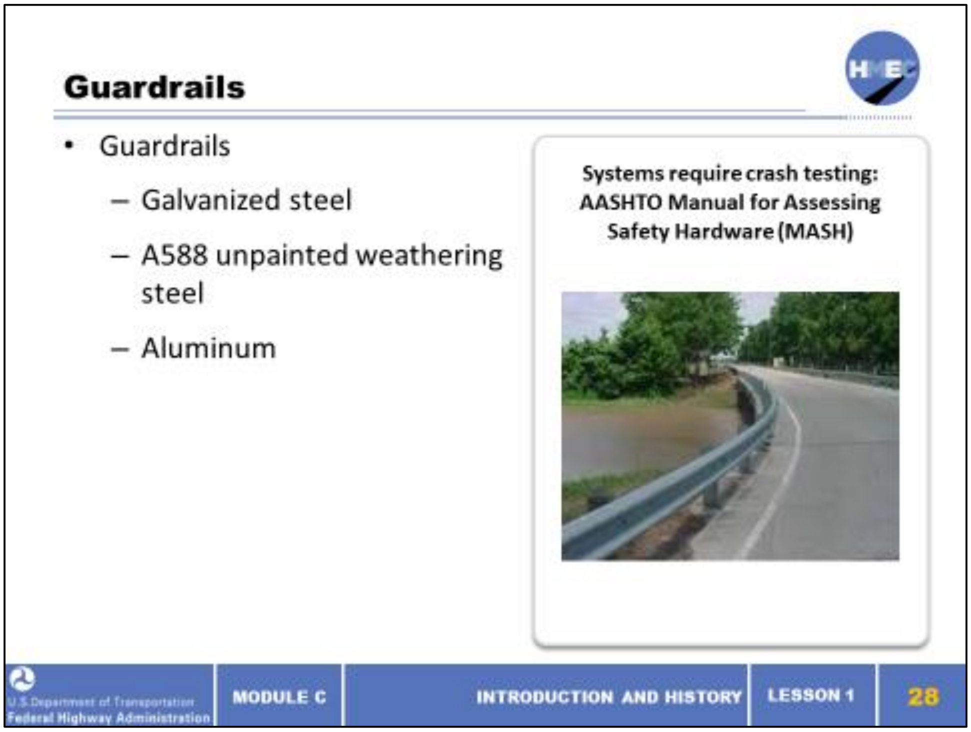
Slide 27



BNSF-Railroad Verdigris River Bridge, Rogers Colorado was built in the late 1950s. Although the field connections appear to have been bolted, all members are of the built-up riveted type. Basically, it is the Warren truss equivalent of the Parker truss. Compression members are built up of plates and angles into a box section, while tension members, depending on loading are built-up H-section or box section, and also entirely of plates and angles.

Potential problems include: unknown steel properties, unknown toughness, unknown rivet strength, section loss due to corrosion, and fatigue details including tack welds, weldability, and fracture-critical.

Slide 28



Some additional advantages of using steel for guardrails is that it is lightweight, easy to transport, and can be installed rapidly. The ductility of steel absorbs energy in impacts and can protect the vehicle occupants. This application requires low maintenance corrosion protection. Galvanized steel is the most common. When weathering steel is used, guardrail periodic inspections need to be performed to insure the integrity of the guardrail.

Unpainted weathering steel has been used but care must be taken in detailing to make sure the steel does not have a high time of wetness. Aluminum has been used but it is generally more expensive. Stainless steel is typically cost prohibitive. Painted steel is seldom used since it requires periodic maintenance.

The systems require crash testing in accord with The AASHTO Manual for Assessing Safety Hardware (MASH).

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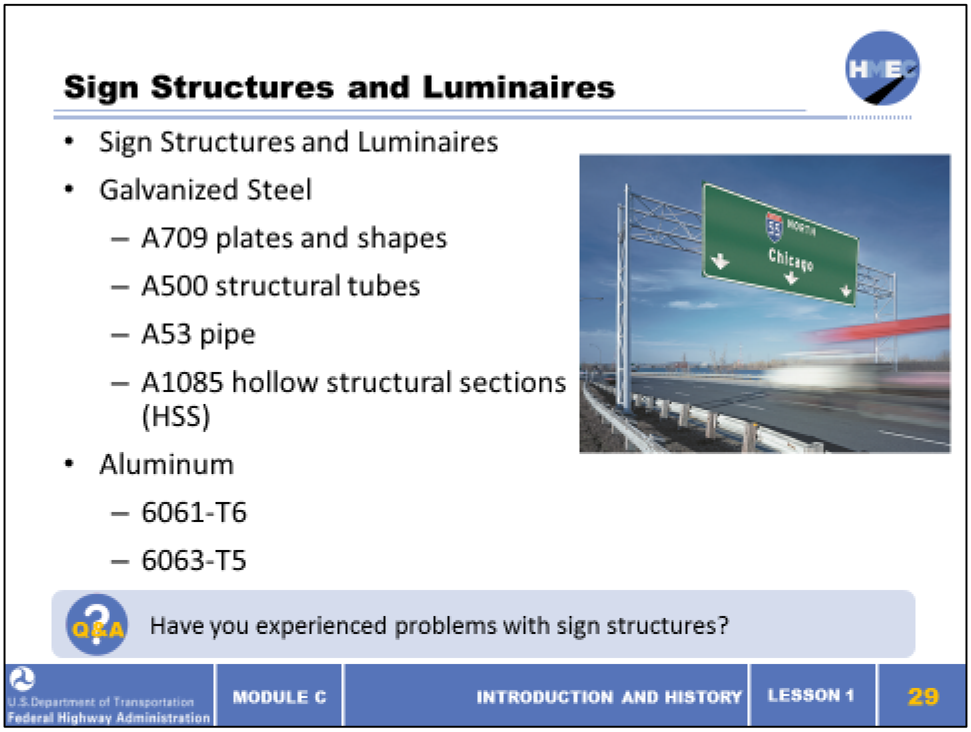
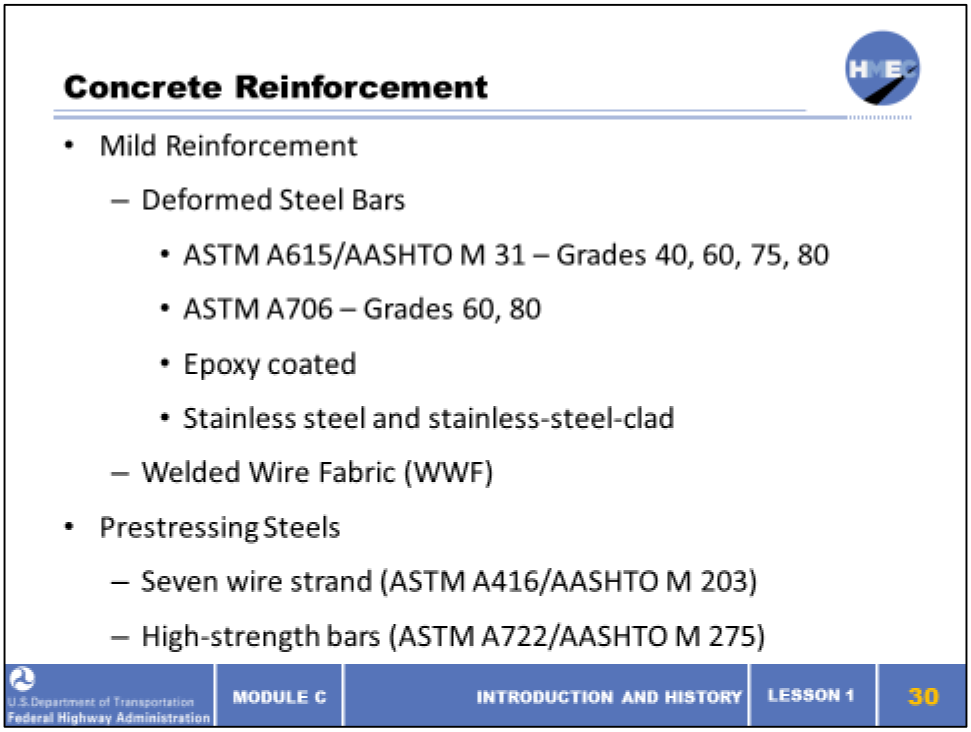
Slide 29



Sign structures represent the main application of pipes and tubes in transportation structures. The most common material for sign structure is galvanized steel. Uncoated weathering steel has been used in some applications but there have been some detailing and appearance problems. For example, high mast luminaires fabricated with tapered slip joints have developed severe rust pack-out problems splitting the tube walls. Aluminum is also used sometimes for sign structures.

Slide 30

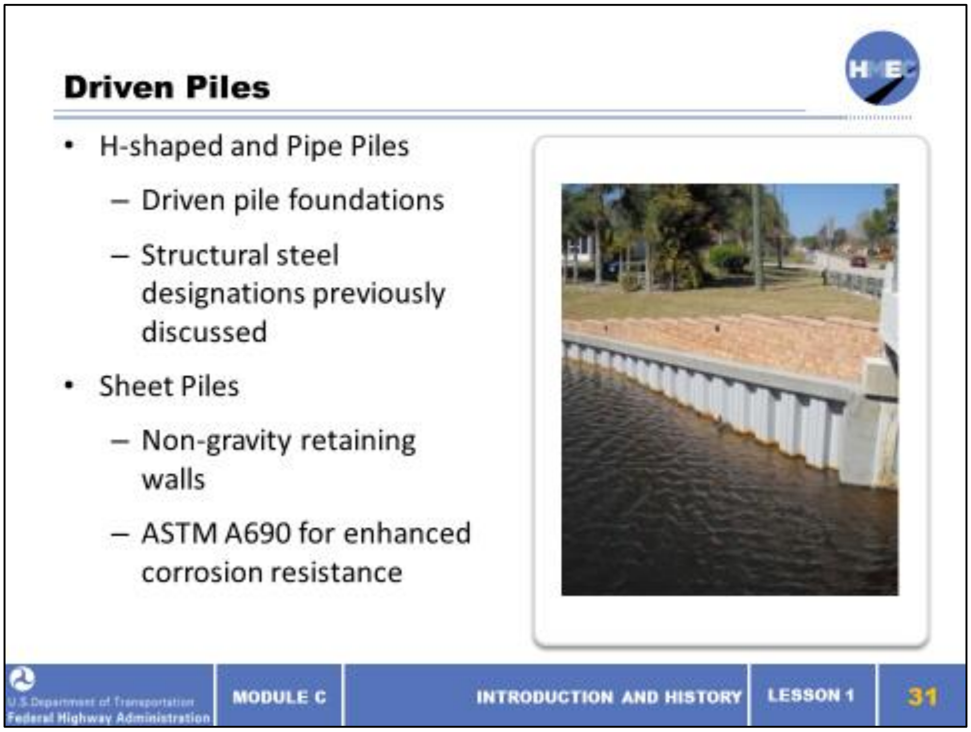


There are two basic classes of reinforcement: mild and prestressing. Mild reinforcement typically consists of round bars with deformed ribs on the surface to engage concrete. The most common grades are 40 and 60 corresponding to the material yield strength. ASTM A706 represents an enhancement of A615 as the weldability is increased and the yield strength is more tightly controlled with an upper limit. These are low alloy steel products similar in composition to A36 and A572 structural steels. It is important to provide corrosion protection, usually epoxy coatings, for many bridge applications. Welded wire fabric (WWF) is another mild reinforcing option for some applications.

AASHTO's National Transportation Product Evaluation Program (NTEP) audits reinforcing-bar and WWF manufacturers and maintains a database of the audits for the States.

Prestressing strands are composed of high strength wires (270 ksi tensile strength). Strands are designed to operate at about 85% of their strength and are required to have "low relaxation" properties. The strength is produced by combinations of alloying, heat treating, and cold drawing of the wires. High-strength bars (150 ksi tensile strength) are another option (commonly called the trademarked name, DYWIDAG bars, representing the German-based manufacturer, Dyckerhoff & Widmann AG). These are heat-treated products.

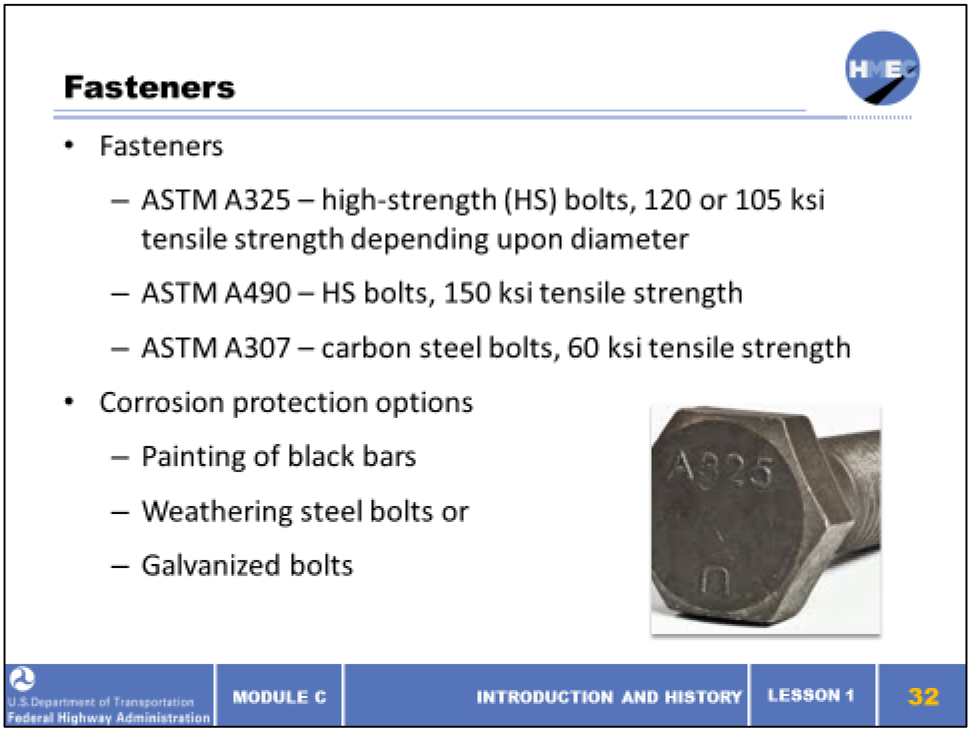
Slide 31



H-shaped and pipe piles are used as driven foundation components for bridges and other structures. The piles are driven into the ground and the structure is built upon them. They are specified in the structural steel designations discussed previously.

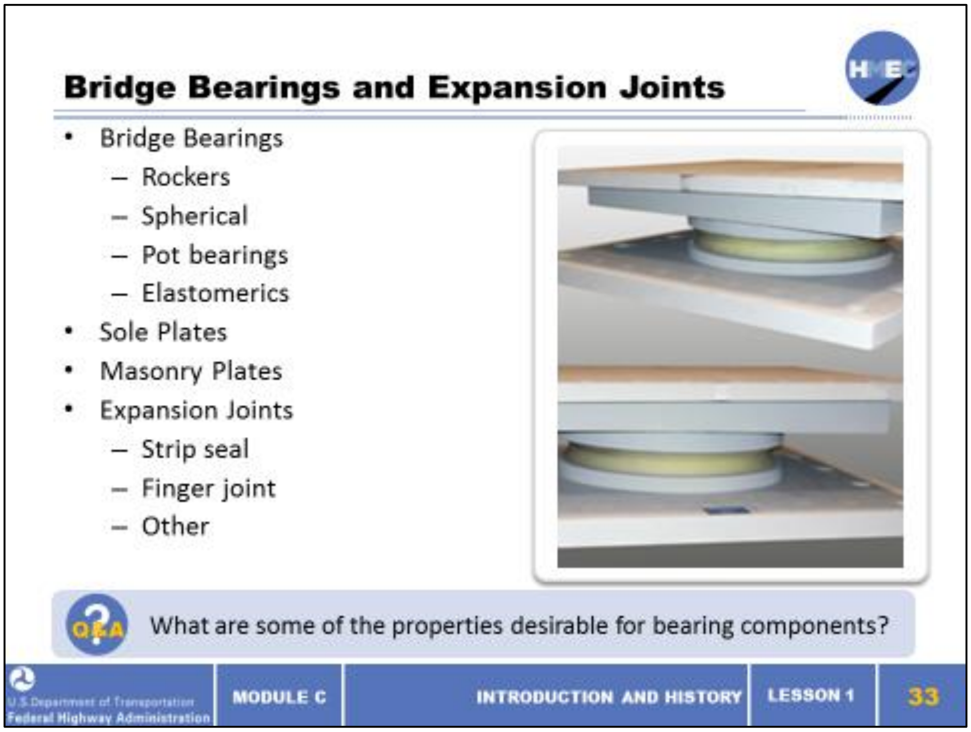
Sheet piles consist of rolled shapes that have interlocking joints. The piles can be driven and locked together for high-strength retaining wall structures. The biggest advantage is rapid construction as compared to concrete alternatives. Sheet piling can be used for abutment walls, but the most common use is for temporary retaining walls during phases of substructure construction. Sheet piles tend to have corrosion issues in long-term usage situations.

Slide 32



Prior to World War II, rivets were the most common type of steel fastener. Hot rivets were inserted into holes and hammered to fill the hole and form a head on both sides. Bolts have now replaced rivets due to reduced installation costs, however there technically still are some using rivets. In general, bolts are used to connect parts in the field and welding is used to connect parts in the fabrication shop. Either provide adequate performance but economics favor this difference.

Slide 33



Bearings are required to provide support points and accommodate thermal expansion in structures. There are a wide range of bearing types depending on design requirements. Some are all steel (rockers), some are a combination of steel, rubber, polytetrafluoroethylene (PTFE) (commonly known by its trademarked name, Teflon), bronze, etc. Steel is used to spread loads where structures bear on concrete and to support and contain other materials.

Sole plates are steel plates attached to the bottom of the superstructure through which the loads are applied to the bearings. Masonry plates are steel plates attached to the bearing seat on abutments or piers through which the loads from the bearing are applied to the substructure.

Expansion joints are used to accommodate thermal movements. They are high-maintenance bridge components. Modern bridges are designed to minimize the number of joints.

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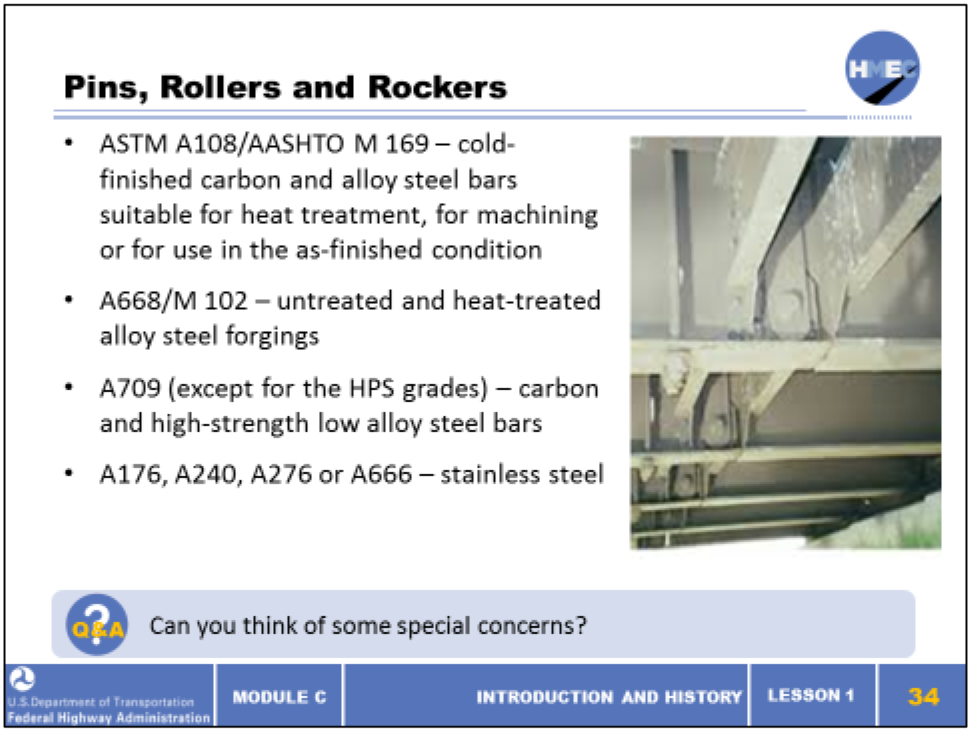
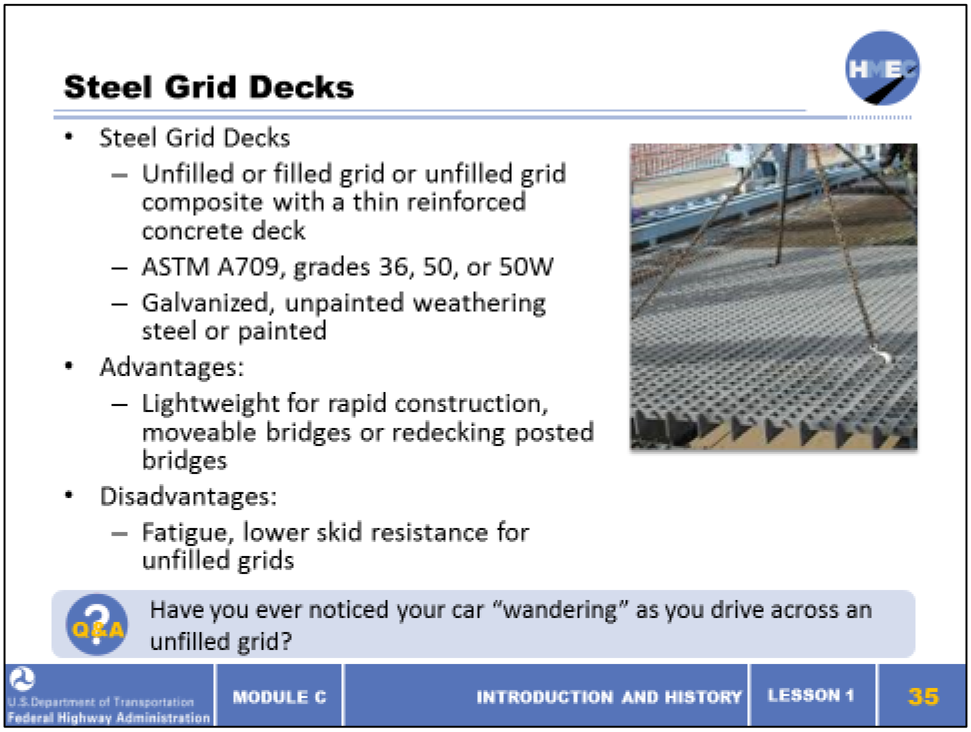
Slide 34



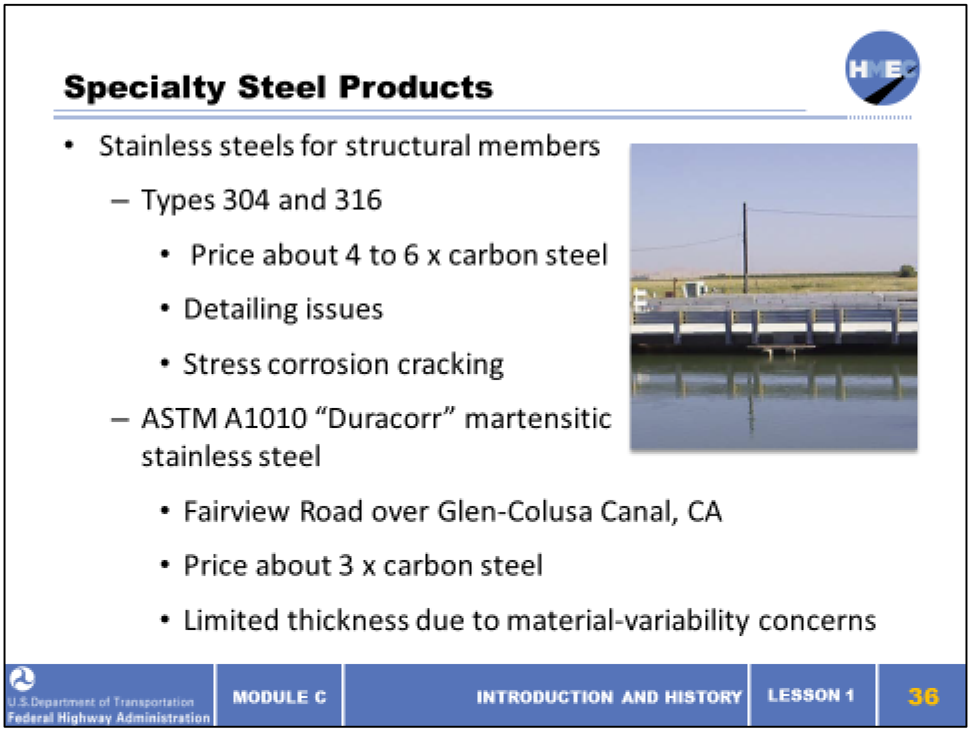
Pin and hanger links were historically used to accommodate expansion and contraction in structures. In the past they were sometimes used to simplify structural analysis and eliminate the indeterminacy in structures. Some of the disadvantages include: they are subject to corrosion, they are difficult to inspect, they have reduced structural redundancy, and they are high maintenance items. Pin and hangers are not used in modern bridges due to these difficulties.

Slide 35



Steel grid decks can be open unfilled grids, grids fully or partially filled with concrete (an overfill is used to get a concrete ride surface), or unfilled grids topped with a thin composite concrete slab. Advantages of steel grid decks include that they are lightweight, can be rapidly constructed, can increase the live-load capacity of posted bridges, and reduce the lifting capacity of a moveable bridge. The disadvantages include fatigue and open unfilled grids have lower skid resistance.

Slide 36



Traditional stainless steels (SS) are much more expensive compared to carbon-based steels. Two special issues: 1. SS must not be in contact with carbon steel or corrosion will occur, and 2. Some SS are vulnerable to stress corrosion cracking. As an example, SS rods suspending tunnel ceilings have been known to fail since they are under sustained tension and can have chloride exposure.

ASTM A1010 Duracorr is a new steel. Arcelor-Mittal developed an improved grade of corrosion-resistant steel. This is a difficult performance objective to achieve. Duracorr is one candidate that provides about 10 times the corrosion resistance compared to carbon steels. It was developed for lining coal cars to reduce corrosion. Several experimental bridges have now been built in California and Oregon. Current practice normally limits the maximum thickness of plates furnished under this specification to 2 in.

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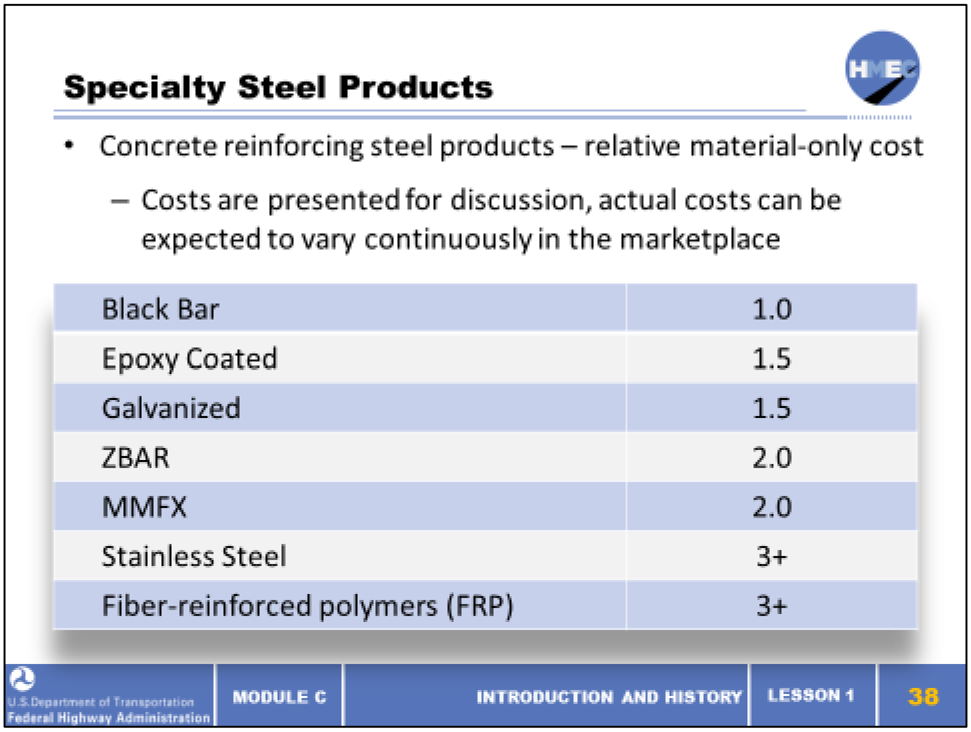
Slide 37

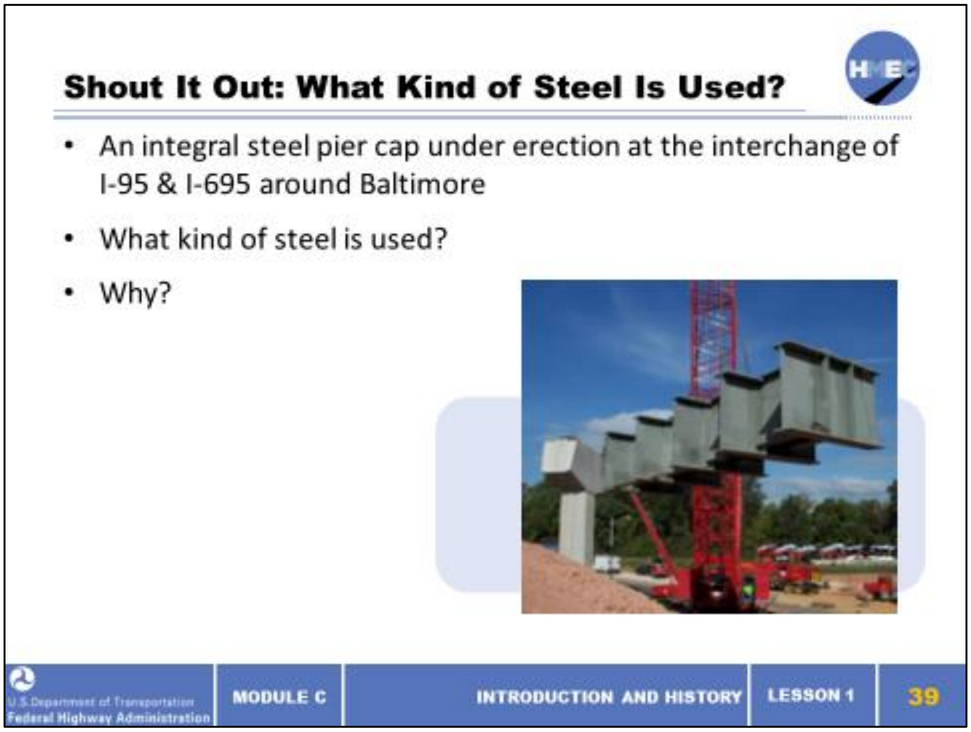
Coated bars can fail if the integrity of the coating is impaired. There are several alternative products that enhance the corrosion resistance of the bars themselves.

Slide 38



In decks the mechanical properties of rebar are of secondary importance compared to the corrosion resistance. Strength often does not govern in deck applications. Experimental concrete decks in Canada without any reinforcing steel report good performance. Wheel loads tend to be carried by arching action, not flexure of the deck.

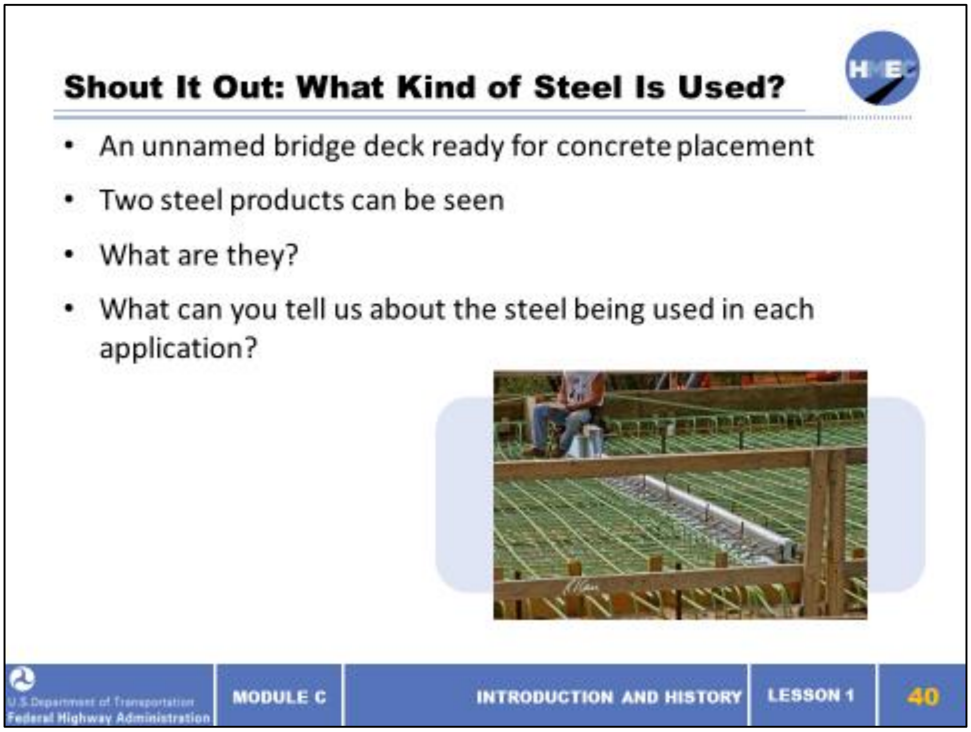
Slide 39



The I-95/I-695 interchange is very new construction. As a new steel superstructure, it must be a grade of ASTM A709. The plate girder has no coating final or a shop-applied primer, so it is grade 50W, HPS 50W, HPS 70W, or HPS 100W. It is not HPS 100W, as this is not economical for plate girders. It could be any of the others.

Speculating, such a deep girder is probably comprised of HPS 70W flanges for extra capacity but 50W webs for economy.

Slide 40

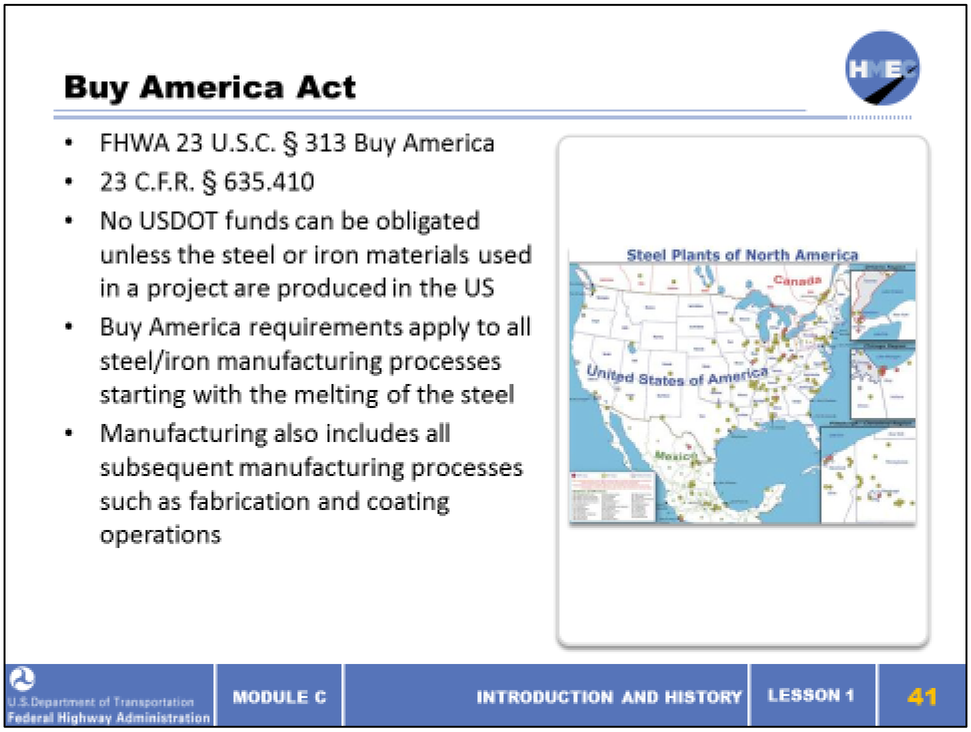


Two steel products are evident in this photograph of an unknown project.

Epoxy-coated steel reinforcement bars (see the green color?). Either ASTM A615 or A706. Probably ASTM A615, which is much more common except for seismic zones or field welding of bars is required.

Steel expansion joint. Unpainted but to be encased in concrete. Probably ASTM A709 grades 36 or 50, the most common and cheapest. Grades 36 and 50 have equal prices. Grade 36 is no longer cheaper and not even widely available because of this; grade 50 also satisfies grade 36.

Slide 41

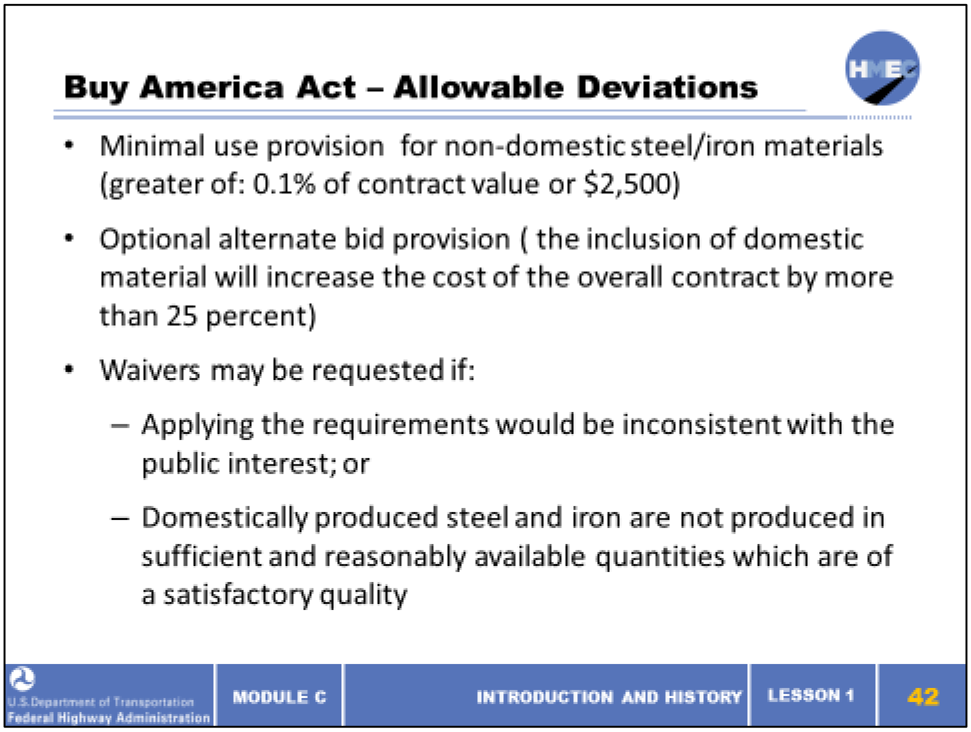


Global competition often makes foreign steels cheaper than domestic producers. Many foreign producers have lower labor costs and relaxed environmental provisions. There have been product quality concerns with the cheaper steels in some cases.

Buy America has two main beneficial impacts: It provides jobs and industry in America and it protects American companies from unfair foreign competition.

Federal Aid funds are used for most of the highway bridge projects in the US and Buy America applies. Bridges that use all private or State funds are not governed by this policy.

Slide 42



Waivers are somewhat difficult to obtain and requires approval at the FHWA headquarters level.

Slide 43

Does Buy America Apply?

- Scenario 1: Billets are produced in Italy and then shipped to the US for rolling and shaping.
- Scenario 2: A steel beam is produced in the US and shipped to Canada for further fabrication (drilling of holes and welding).

Q&A Does Buy America apply? When can it be waived?

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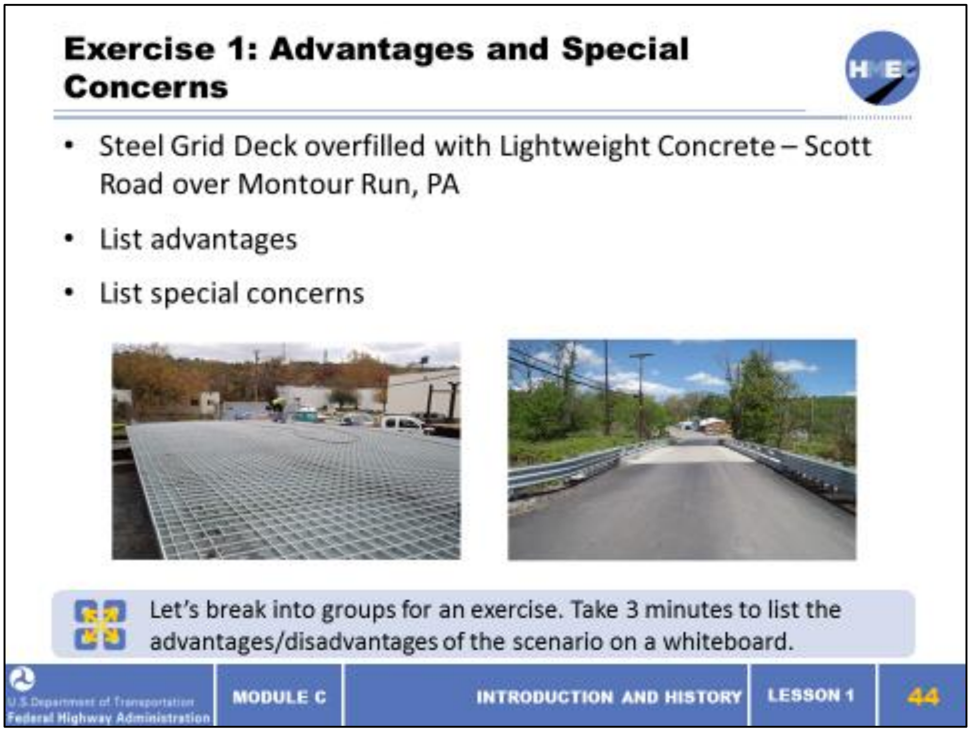
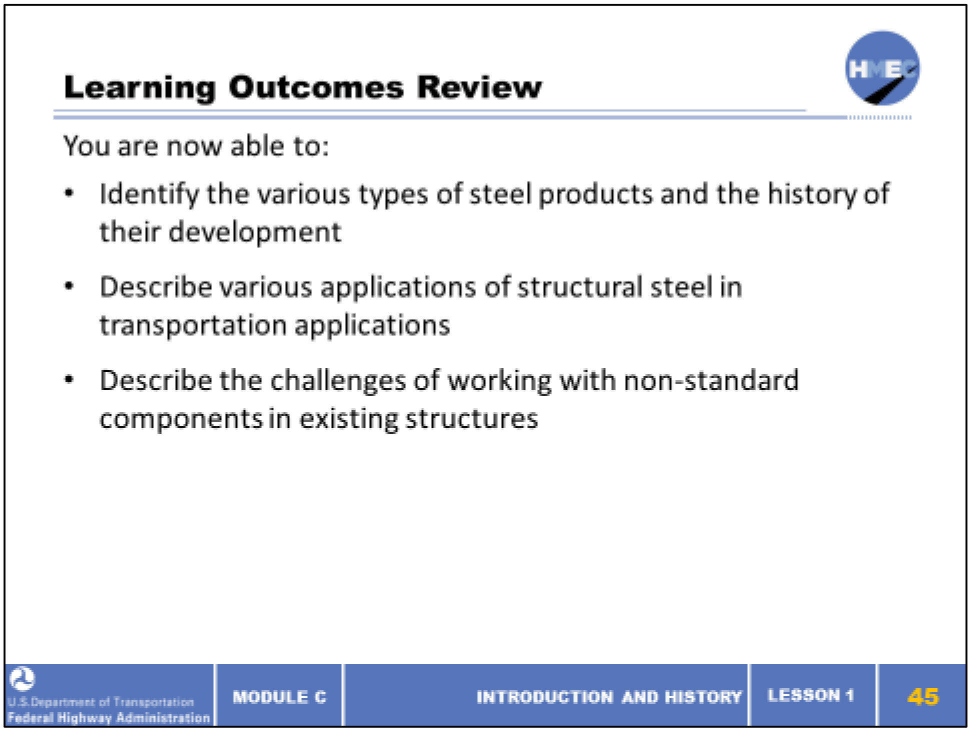


Prefabricated grid-deck panels are placed on steel girders for rapid construction. The panels are made composite to studs welded to the girders by filling the deck.

Slide 45


HMEC
Learning Outcomes Review
You are now able to:
• Identify the various types of steel products and the history of their development
• Describe various applications of structural steel in transportation applications
• Describe the challenges of working with non-standard components in existing structures
U.S. Department of Transportation
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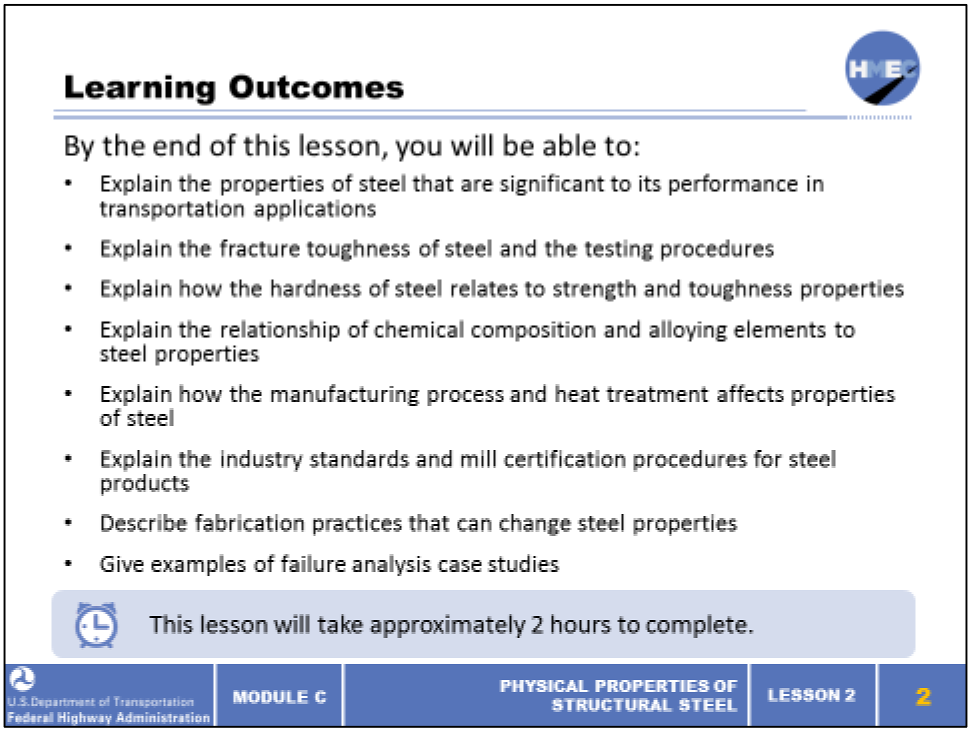
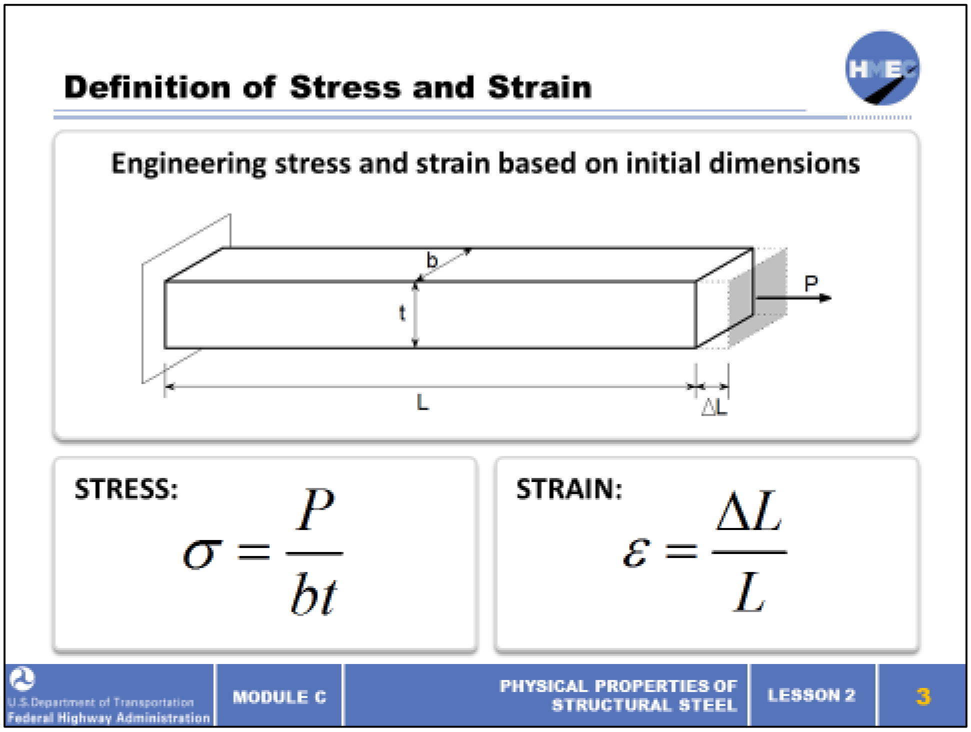
Slide 1


ILT
HMEC
Highway Materials Engineering Course
Lesson 2: Physical Properties of Structural Steel
Steel, Welding, and Coatings
U.S.Department of Transportation
Federal Highway Administration
MODULE
C

Slide 2

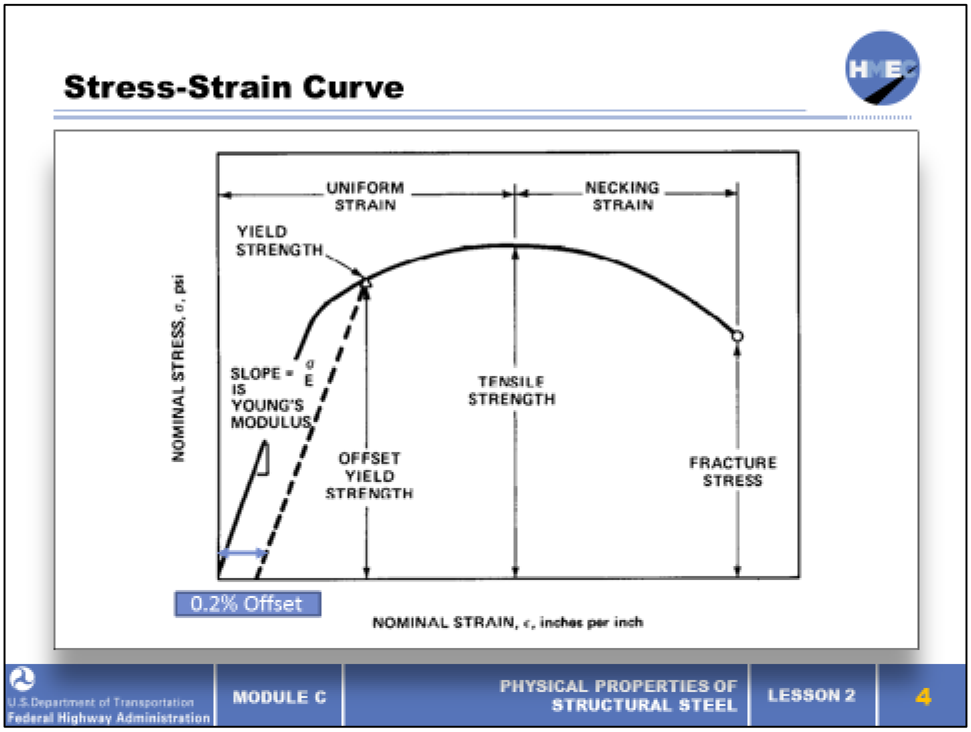

Learning Outcomes
HMEC
By the end of this lesson, you will be able to:
• Explain the properties of steel that are significant to its performance in transportation applications
• Explain the fracture toughness of steel and the testing procedures
• Explain how the hardness of steel relates to strength and toughness properties
• Explain the relationship of chemical composition and alloying elements to steel properties
• Explain how the manufacturing process and heat treatment affects properties of steel
• Explain the industry standards and mill certification procedures for steel products
• Describe fabrication practices that can change steel properties
• Give examples of failure analysis case studies
This lesson will take approximately 2 hours to complete.
U.S. Department of Transportation
Federal Highway Administration
MODULE C
PHYSICAL PROPERTIES OF STRUCTURAL STEEL
LESSON 2
2

Slide 3



When you apply an axial load to a steel bar, it elongates. Based on the load and amount of elongation, we define stress and strain. The most common definition is engineering stress and strain that is based on the initial dimensions of the unloaded, undeformed bar.

Slide 4



The stress-strain curve determines how a material responds to load. The state of steel under stress always lies somewhere along this curve. The curve determines when permanent deformation occurs (yielding), and when the ultimate tensile strength is reached. Note that a non-redundant member in tension fails when the tensile strength is reached.

This curve shows a steel without a defined yield plateau. This is typical for high-strength steels, A709 grades high-performance steel (HPS), 70W, HPS 100W, high-strength reinforcing steel, and high-strength bolts. The yield strength is determined by constructing a line parallel to the initial elastic loading line at 0.2% strain. This is called the 0.2% offset method.

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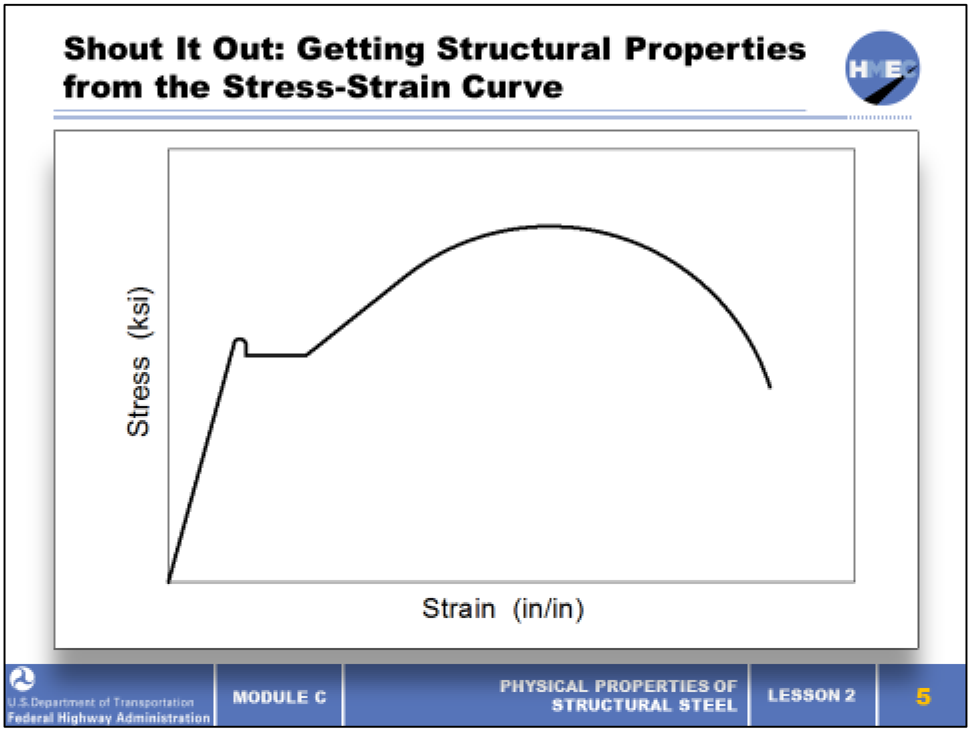
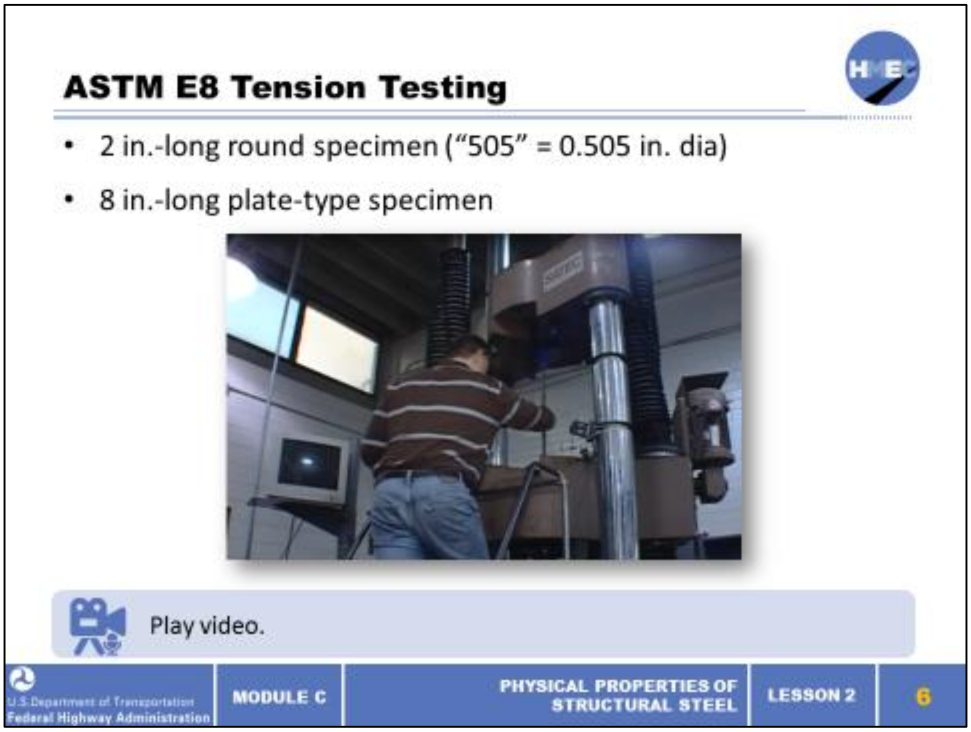
Slide 5


Shout It Out: Getting Structural Properties from the Stress-Strain Curve
Stress (ksi)
Strain (in/in)
U.S.Department of Transportation
Federal Highway Administration
MODULE C
PHYSICAL PROPERTIES OF STRUCTURAL STEEL
LESSON 2
5

Slide 6



The basic tension test does not directly measure strain. The testing machine measures load and crosshead movement or displacement. Stress and strain are calculated values as discussed on slide 3. Grade 36 and 50 structural steels have a yield plateau. Yield is defined as a pause in the increase in load. Tensile strength is defined based on the maximum load achieved. Percent elongation is physically measured.

Slide 7

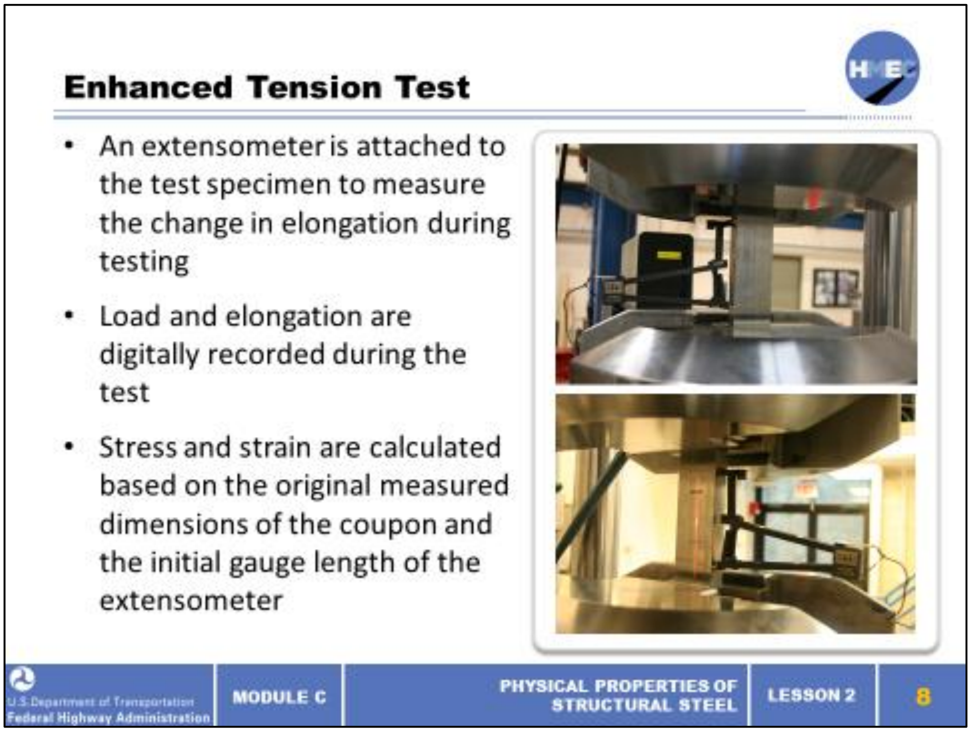
ASTM E8 Tension Testing

- Sample Test Report for ASTM A709 Grade 50

standard used	material and sample ID	specimen type	yield strength		yield point elongation	tensile strength (ksi)	elongation (%)
			value (ksi)	method			
E8	1	plate	52.2	2% offset	na	67.9	23
E8	2	plate	56.7	2% offset	na	73.7	21
E8	3	plate	61	2% offset	na	79.3	24
E8	4	plate	63.2	2% offset	na	82.2	25
E8	5	plate	54.7	2% offset	na	71.1	23
E8	6	plate	62.5	2% offset	na	81.3	22

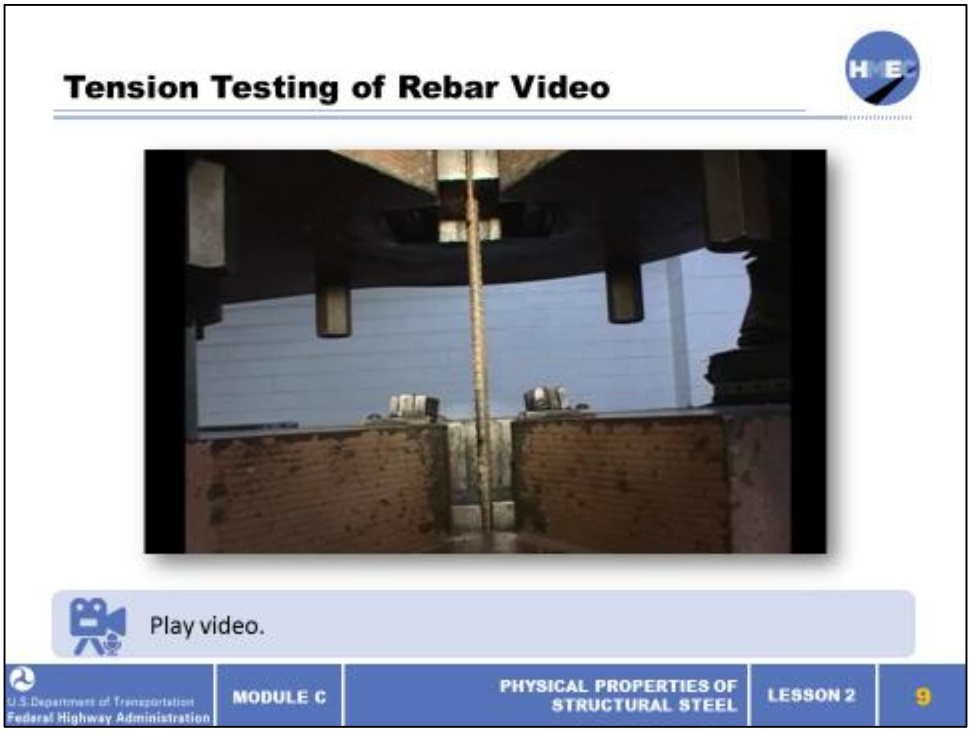
ASTM E8 does not include a standard test report form. It does include the information that should be included in the test report. The sample test report shown includes the requirements of E8. Note that ASTM A709 does not specify a yield point elongation.

Slide 8



The extensometer used to measure elongation must be very accurate (0.0001 in resolution or better). It is attached with clips or pins to the steel to start at the desired initial gauge length (2 in. or 8 in.). Elongation is directly measured and strain can then be calculated. Results have traditionally been recorded on an x-y pen plotter along with the load. Modern systems record the data digitally.

Slide 9


Tension Testing of Rebar Video
Play video.
U.S. Department of Transportation
Federal Highway Administration
MODULE C
PHYSICAL PROPERTIES OF STRUCTURAL STEEL
LESSON 2
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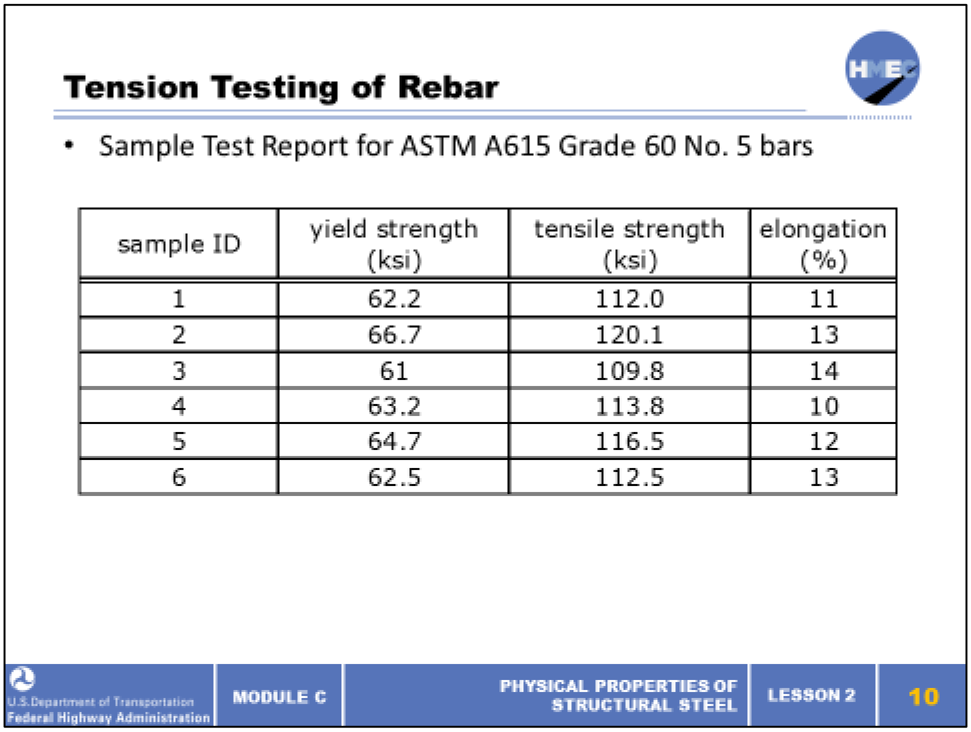
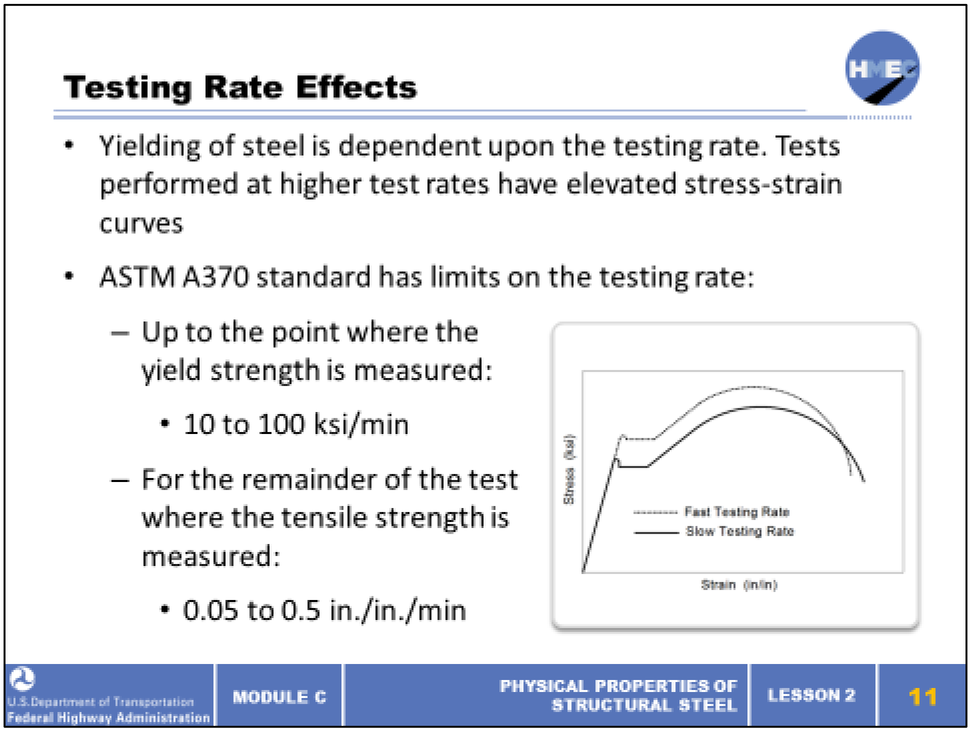
Slide 10



sample ID	yield strength (ksi)	tensile strength (ksi)	elongation (%)
1	62.2	112.0	11
2	66.7	120.1	13
3	61	109.8	14
4	63.2	113.8	10
5	64.7	116.5	12
6	62.5	112.5	13

Like ASTM E8, ASTM A370 does not include a standard reporting form. Unlike ASTM E8, ASTM A370 does not include reporting requirements. However, it is clear that the specified parameters for ASTM A615 must be reported in the sample case.

Slide 11



Steel mills typically test at the higher rate limits to minimize testing time. This also gives an upper bound on strengths. There have been many cases where supplemental testing performed in DOT labs has shown lower strengths than those reported on the mill certificates. Testing at different rates may partially explain some of the differences.

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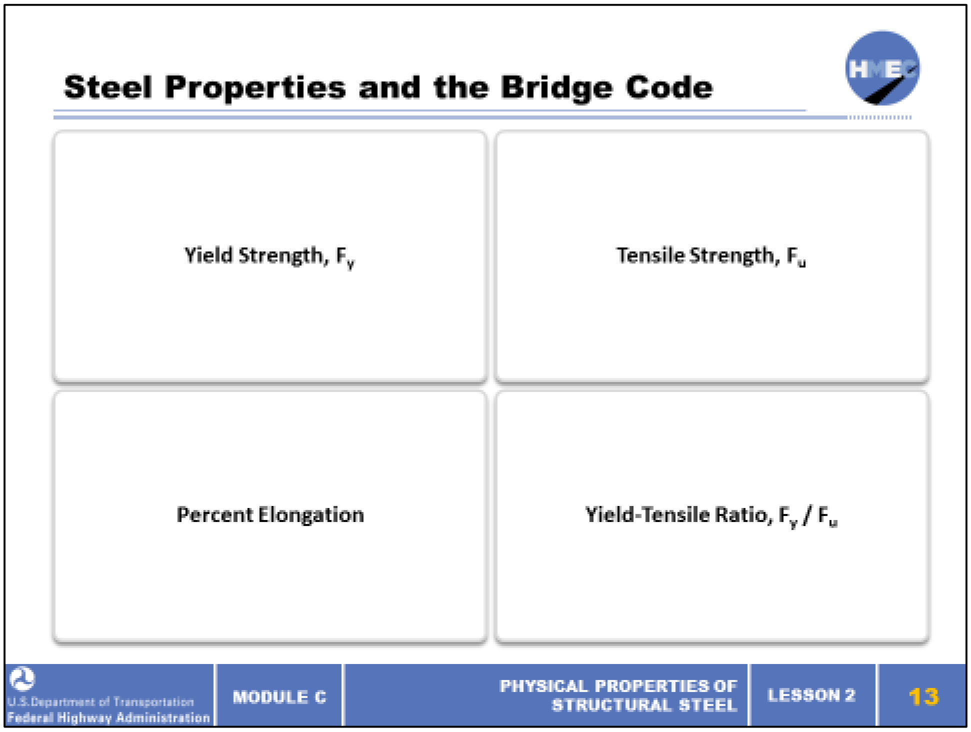
The details of the tension testing procedure is defined in ASTM E8. This standard allows for testing of a wide range of products. The ASTM A370 standard defines specific requirements for testing of steel products. The ASTM A709 specification provides the required test values for each steel grade.

Slide 13


Steel Properties and the Bridge Code
HMEC
Yield Strength, F_y
Tensile Strength, F_u
Percent Elongation
Yield-Tensile Ratio, F_y / F_u
U.S. Department of Transportation
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ASTM A709 Strength Requirements

Grade	Yield Strength (ksi)	Tensile Strength (ksi)	Elongation (%)
36	36 min	58 min, 80 max	23 @ 2 in.
50	50 min	65 min	21 @ 2 in.
50W	50 min	70 min	21 @ 2 in.
50S	50 min	65 min	21 @ 2 in.
HPS 50W	50 min	70 min	21 @ 2 in.
HPS 70W	70 min	85 min, 110 max	19 @ 2 in.
HPS 100W	100 min	110 min, 130 max	18 @ 2 in.

Q&A: Would you expect the percent elongation requirement to be higher or lower if an 8 in. gauge length is used in testing?

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All grades have specified minimums for F_y, F_u, and percent elongation. No limits are placed on the F_y/F_u ratio. The mill reports for steel products typically show strengths that exceed the required minimum. Steel strength has an inherent statistical variability. Mills typically design compositions to minimize rejections in the manufacturing process. The mean delivered yield strength is typically about 6% to 8% higher than the specification minimums.

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ASTM A709 Chemistry Requirements

Element	36	50	50W	HPS 70W	HPS 100W
C	0.27 max	0.023 max	0.19 max	0.11 max	0.08 max
Mn	0.85–1.2	1.35 max	0.80-1.25	1.10–1.35	0.95–1.5
P	0.04 max	0.04 max	0.04 max	0.02 max	0.015 max
S	0.05 max	0.05 max	0.05 max	0.006 max	0.006 max
Si	0.15–0.40	0.15–0.40	0.30-0.65	0.03–0.05	0.15–0.35
Cu	---	---	0.25-0.40	0.25–0.40	0.90–1.2
Ni	---	0.005–0.05	0.40 max	0.25–0.40	0.65–1.0
Cr	---	---	0.40-0.65	0.45–0.70	0.40–0.65
Mo	---	---	---	0.02–0.08	0.40–0.65
V	---	0.01–0.15	0.02-0.10	0.04–0.08	0.04–0.08
Al	---	---	---	0.01–0.04	0.02–0.05
N	---	---	---	0.05 max	0.015 max
Nb	---	0.005–0.05	---	---	0.01–0.03

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Limits are set on the chemical composition of steels conforming to each grade. Many elements are expressed as minimums. Some are expressed as maximums and some indicate a range between upper and lower limits. Some elements are limited since they may have deleterious effects on steel properties.

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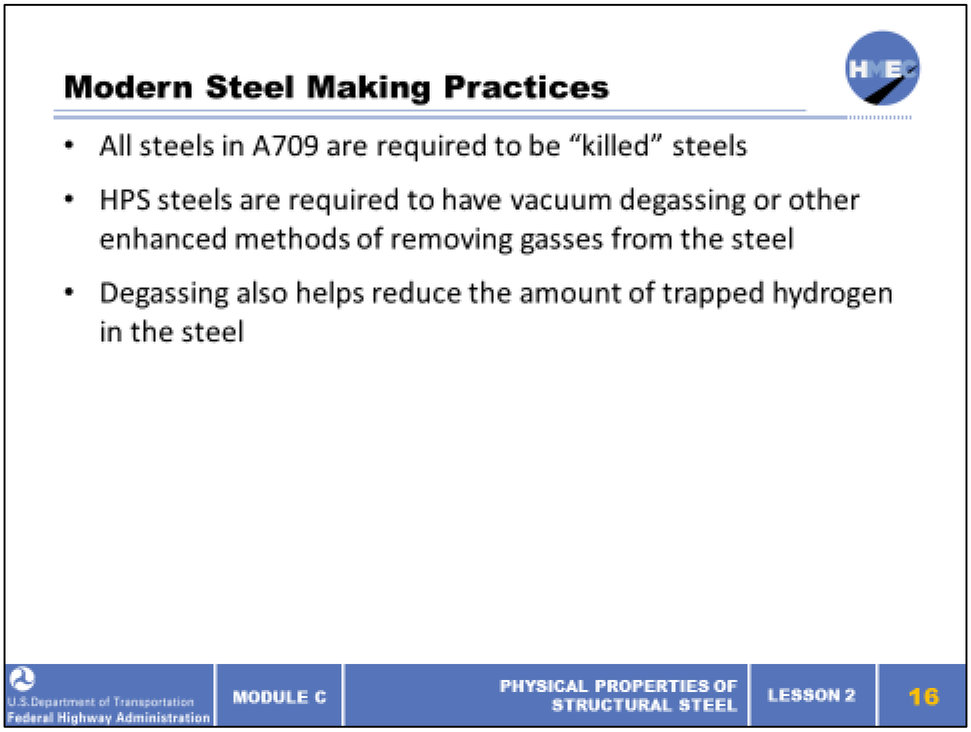

After oxygen is blown through the molten steel in the blast furnace, the steel contains dissolved gasses and acts very agitated. Steel in this state will cause defects when it solidifies. The A709 specification requires steel to be "killed." There are various additions and/or degassing practices that can be used to calm down the molten steel and remove gasses.

Hydrogen control, provided by degassing or other means, is important for the higher strength steels. Hydrogen is a very reactive element and any that is trapped in the steel when it solidifies tends to migrate out and break the bonds between grains. The result is lower toughness and possible fatigue concerns. Hydrogen control is mandatory for the HPS steel grades.

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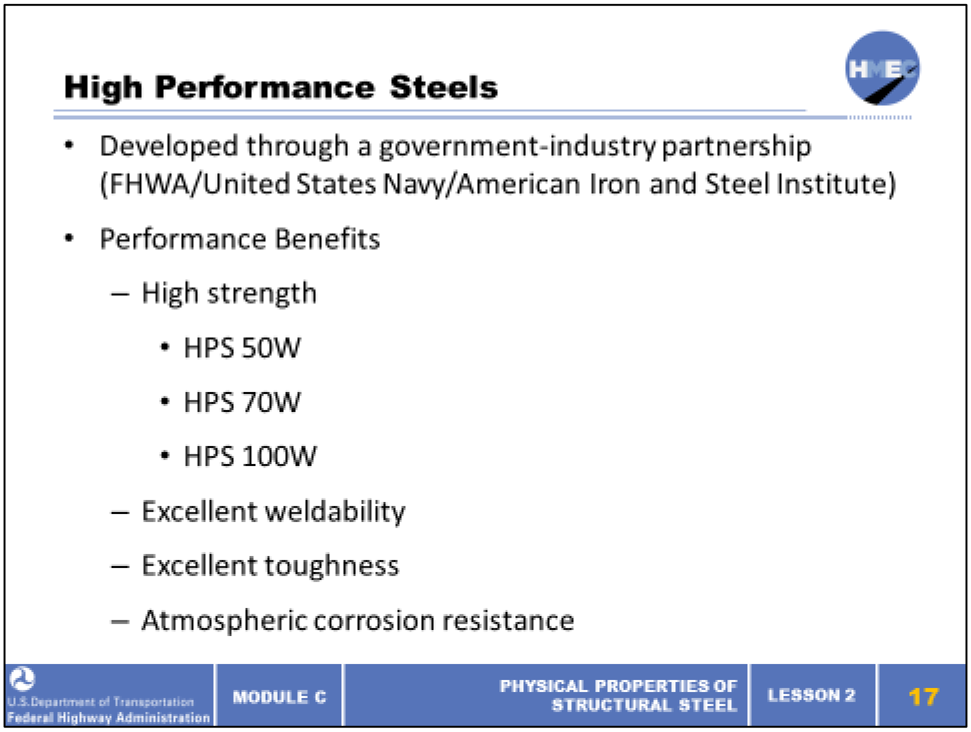

HPS steels were developed specially for use in bridge structures to overcome deficiencies in conventional quenched and tempered steels. The old grades A852 and A514 had demonstrated a susceptibility for cracking in fabrication and have caused problems in some bridge applications. Grades HPS 70W and HPS 100W have now replaced the old grades in A709. HPS 50W is a non-heat treated version of the HPS 70W grade that has enhanced toughness. Research is underway to better utilize this advance to make fracture-critical members more cost effective.

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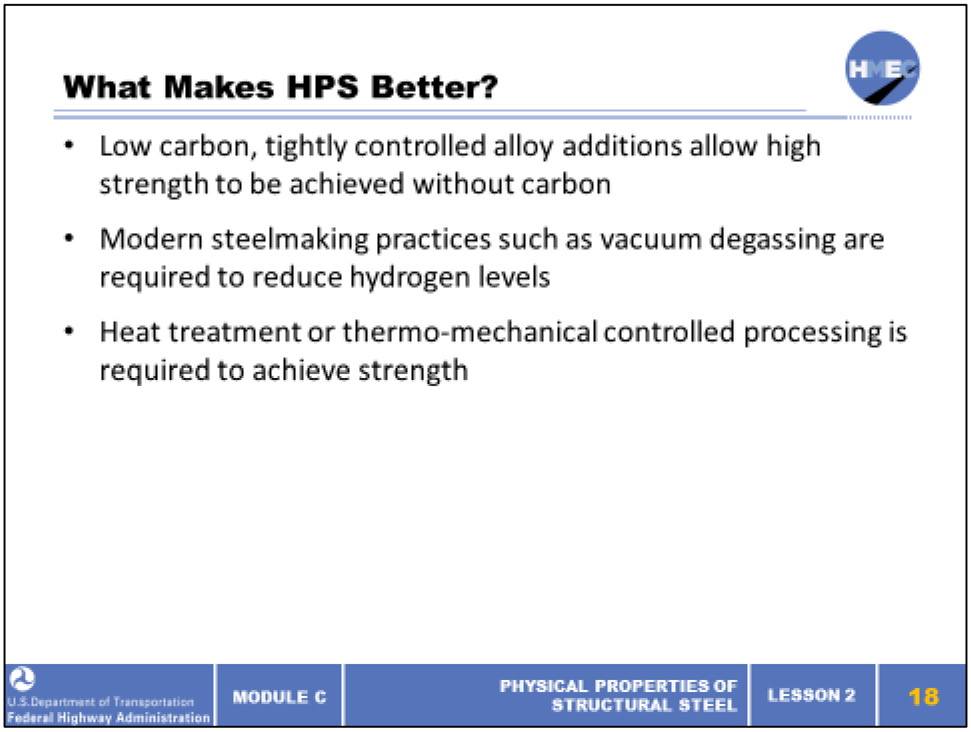

HPS grades take advantage of the best of modern steelmaking practice. The main advantage is reducing the amount of carbon required to achieve steel strength. A refined alloy composition is required to compensate for the carbon reduction. The chemical composition limits for HPS are much more controlled compared to conventional steel grades. In addition, degassing processing is required to reduce hydrogen levels and reduce the potential for weld cracking. This also has the advantage of increasing the fracture toughness.

All HPS grades meet the minimum chemical composition requirements for “weathering steels.” Some grades are projected to have enhanced weathering characteristics compared to grade 50W.

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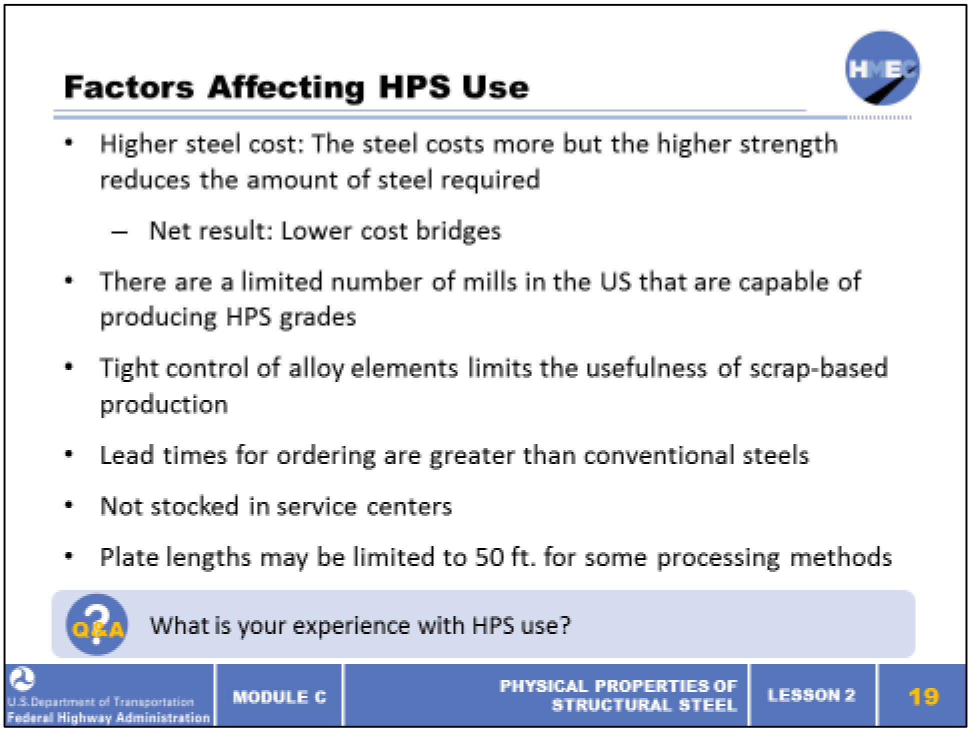

Steel costs more but the higher strength reduces the amount of steel required. The net result is a lower cost bridge. There are a limited number of mills in the US that are capable of producing HPS grades. The tight control of alloy elements limits the usefulness of scrap-based production. Lead times for ordering are greater than conventional steels.

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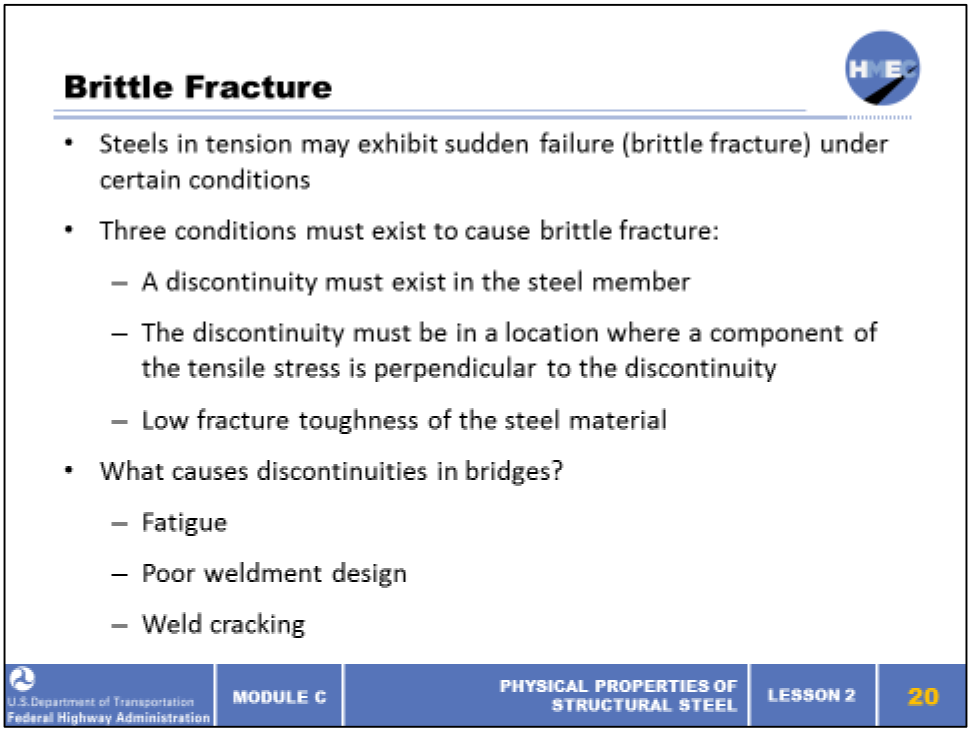

This is a simple overview of the concept of fracture mechanics. Under certain conditions, normally ductile steel can fail in a sudden brittle manner (fracture). The science of fracture mechanics was developed following an incident where a Liberty ship fractured in half while being loaded at the dock. There have been several dozen examples of brittle fracture that resulted in failure of bridge members.

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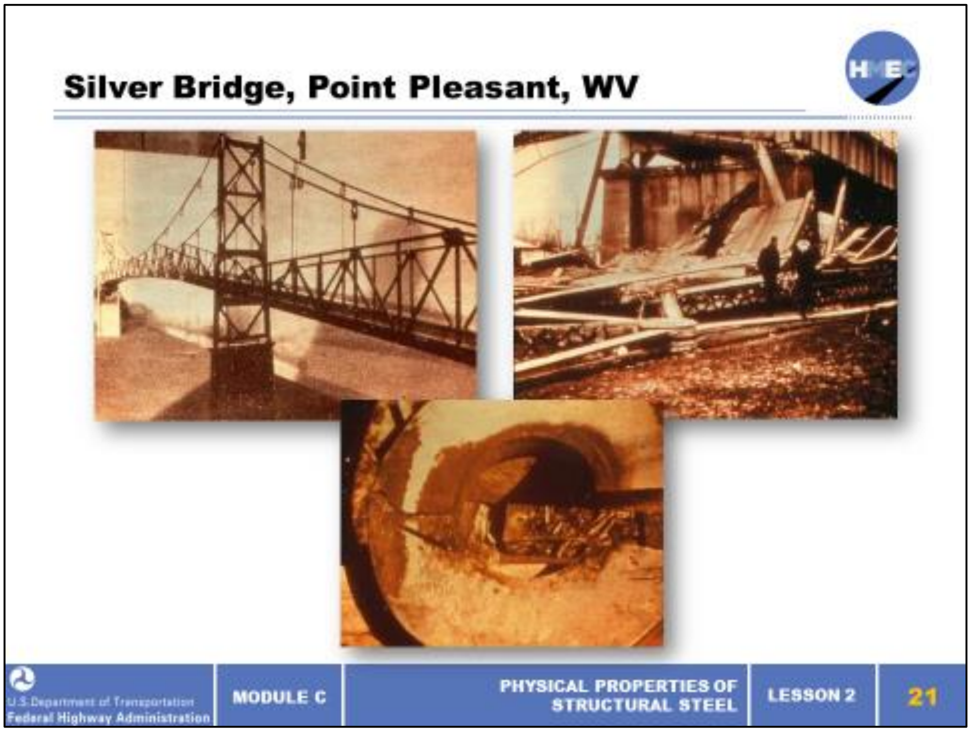

In 1967, the Silver Bridge in Point Pleasant, WV failed due to brittle fracture. The bridge failed during rush hour while traffic was stopped on the bridge. There were 78 casualties, making this the worst bridge failure on record. The cause was failure of the eye of one of the eye bars forming the suspension system for the span. This is classified as a non-redundant member since its failure caused collapse. This type of member was subsequently defined as fracture-critical.

The FHWA and AASHTO developed the concept of fracture-critical member fabrication and inspection to prevent future recurrences of this type of failure. The concept of fracture-critical members is currently well established, but it was developed considering the limitations of older generation steels. Modern HPS steels are much more resistant to this type of failure. Revisions are needed to fracture-critical inspection requirements to reflect this change.

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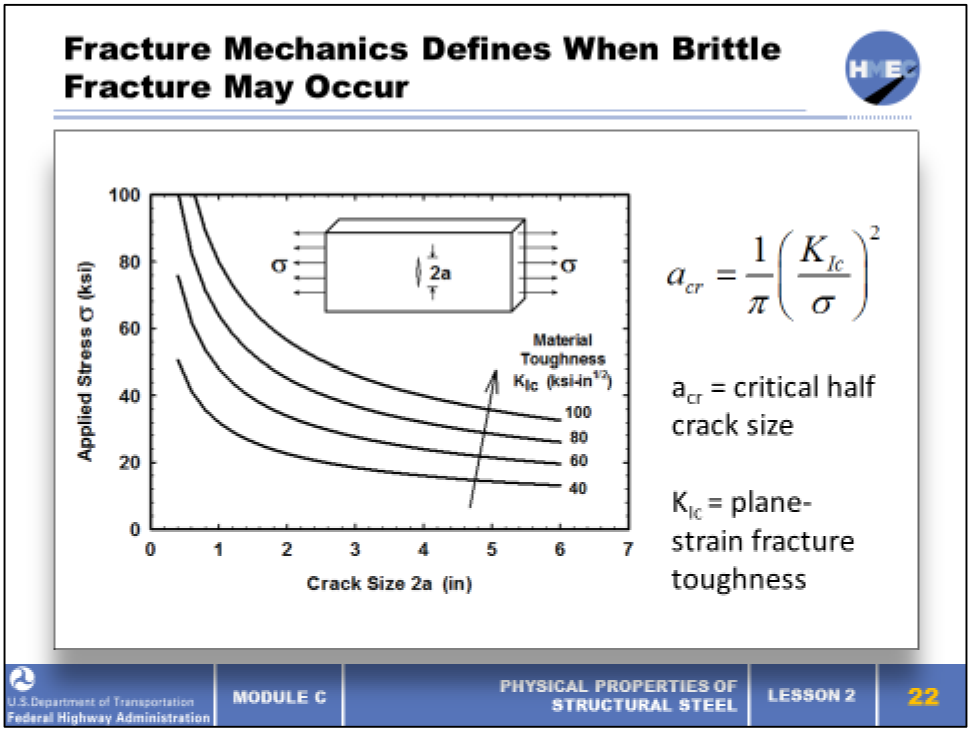

The material's resistance to brittle fracture is defined as the plane strain fracture toughness K_{Ic}. In its simplest form, the crack size required to cause fracture can be calculated based on the fracture toughness and the applied stress level. The equations become much more complicated when more complicated geometries and residual stresses must be considered to apply fracture mechanics to real situations.

The three factors that determine fracture are 1. material toughness, 2. stress level, and 3. discontinuity size. The AASHTO fracture-control plan was developed to control all three aspects of fracture. The most common cause of discontinuities is fatigue, and design and inspection rules have been developed for its prevention. Toughness requirements have been established for bridge steels.

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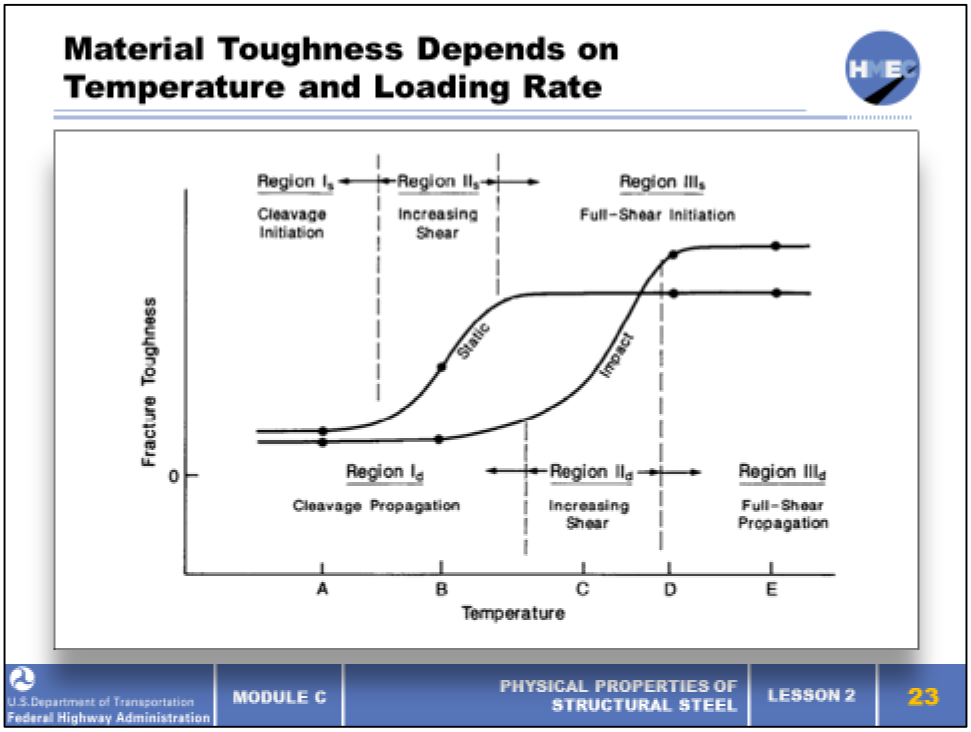

Steel toughness undergoes a brittle to ductile transition as a function of temperature. Steel is a brittle material at very low temperatures and is vulnerable to brittle behavior—this is called the lower shelf. At higher temperatures, the steel has very high fracture toughness—this is called the upper shelf. A transition region exists between the two extremes.

Under slow or static loading rates, the fracture resistance can be defined based on static rate testing. At higher loading rates, there is a temperature shift and the fracture resistance curve is shifted to the right. At a given service temperature (say point B) a steel may have sufficient toughness to resist fracture under slow loading rates. However, if the loading rate is increased, the toughness is much lower on the impact curve.

We set out material toughness requirements to provide mid-transition toughness at bridge loading rates. The Charpy V-Notch (CVN) test used to measure toughness is performed at impact loading rates. This is the basis for the temperature shift that will be discussed next.

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Measuring Steel Fracture Toughness

- K_{Ic} can be measured directly with fracture mechanics tests but the testing is very expensive and not suited for product testing (ASTM E1820)
- Charpy V-Notch (CVN) test is much simpler and less costly
  - It is the standard test for steel products (ASTM E23)

Play video.

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Measuring Steel Fracture Toughness

- Sample Test Report for ASTM A709 Grade 50, non-Fracture-Critical, under 2 inches thick

specimen ID	specimen type	test temperature (°F)	absorbed energy (ft.-lbs.)
1	CVN type A	70	20
2	CVN type A	70	18
3	CVN type A	70	22
4	CVN type A	70	19
5	CVN type A	70	25
6	CVN type A	70	23

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ASTM E23 does not include a standard test report form. It does include the information that should be included in the test report. The sample test report shown includes the requirements of E23.

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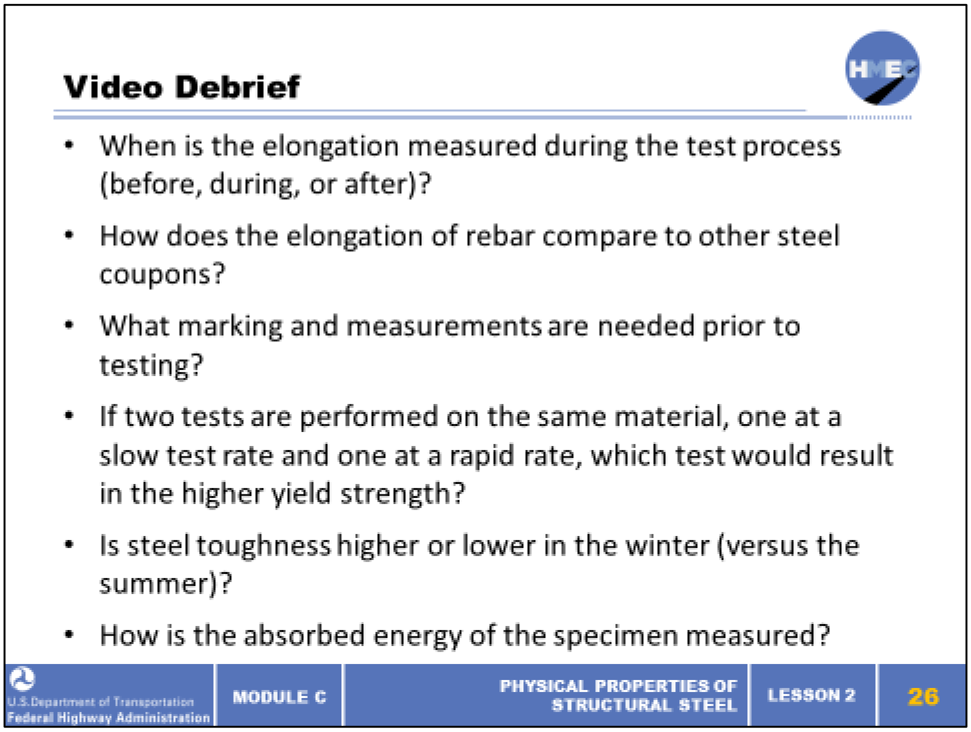
Video Debrief
HMEC
• When is the elongation measured during the test process (before, during, or after)?
• How does the elongation of rebar compare to other steel coupons?
• What marking and measurements are needed prior to testing?
• If two tests are performed on the same material, one at a slow test rate and one at a rapid rate, which test would result in the higher yield strength?
• Is steel toughness higher or lower in the winter (versus the summer)?
• How is the absorbed energy of the specimen measured?
U.S. Department of Transportation Federal Highway Administration
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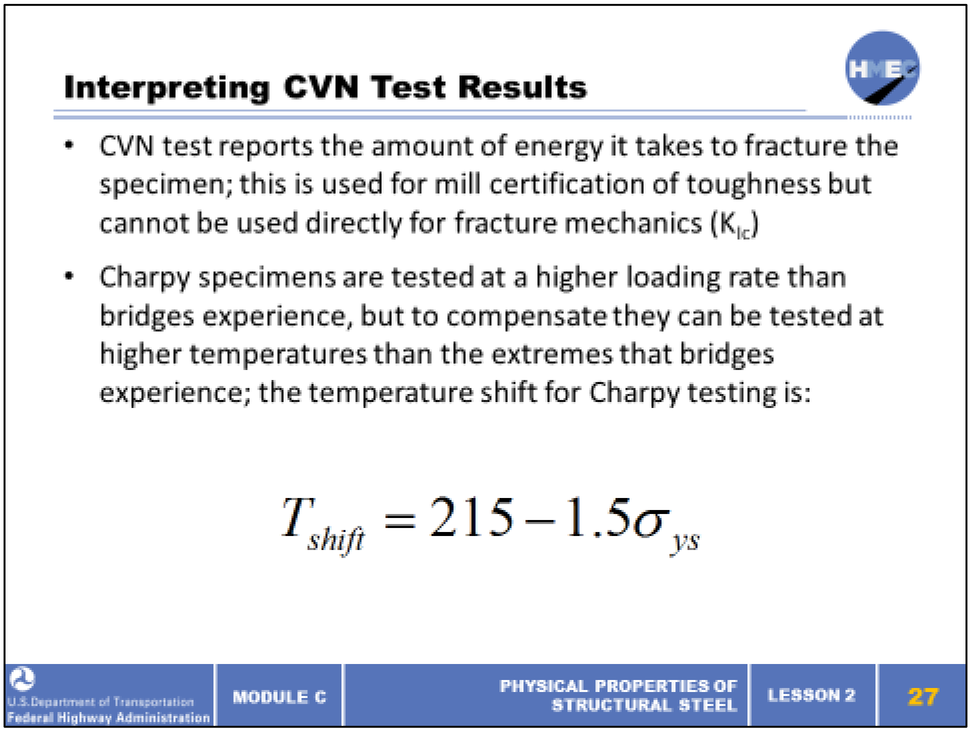
Interpreting CVN Test Results
HMEC
• CVN test reports the amount of energy it takes to fracture the specimen; this is used for mill certification of toughness but cannot be used directly for fracture mechanics (K_{Ic})
• Charpy specimens are tested at a higher loading rate than bridges experience, but to compensate they can be tested at higher temperatures than the extremes that bridges experience; the temperature shift for Charpy testing is:
$$T_{shift} = 215 - 1.5\sigma_{ys}$$
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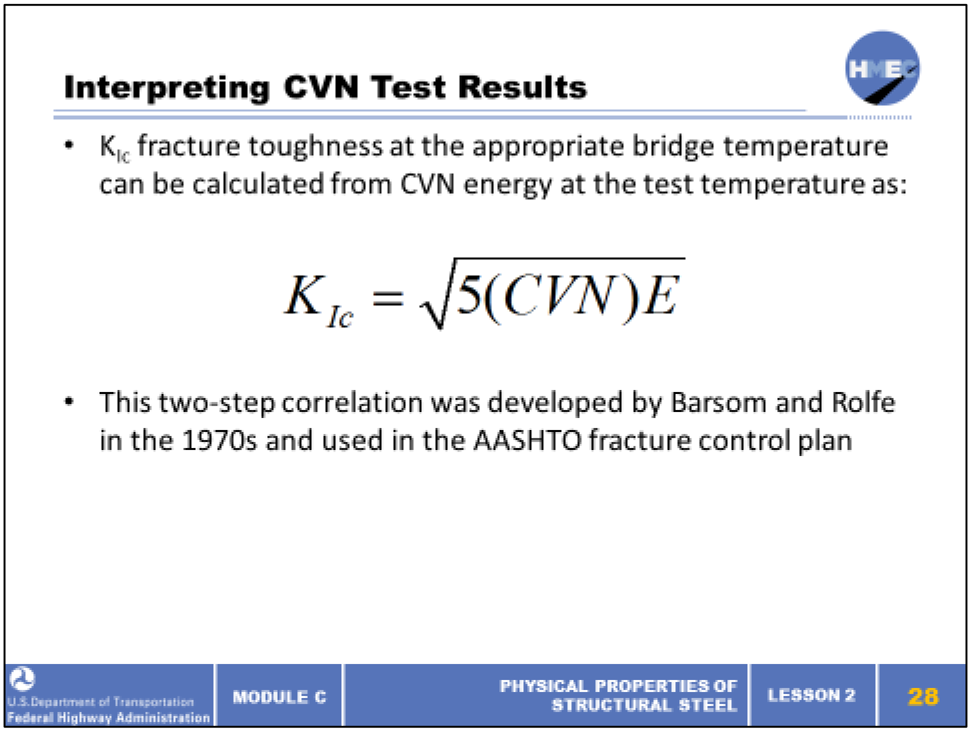

A simple equation converts the CVN energy into toughness that can be used for fracture mechanics (K_{Ic}). Barsom and Rolfe developed this two-step correlation procedure in the 1970s.

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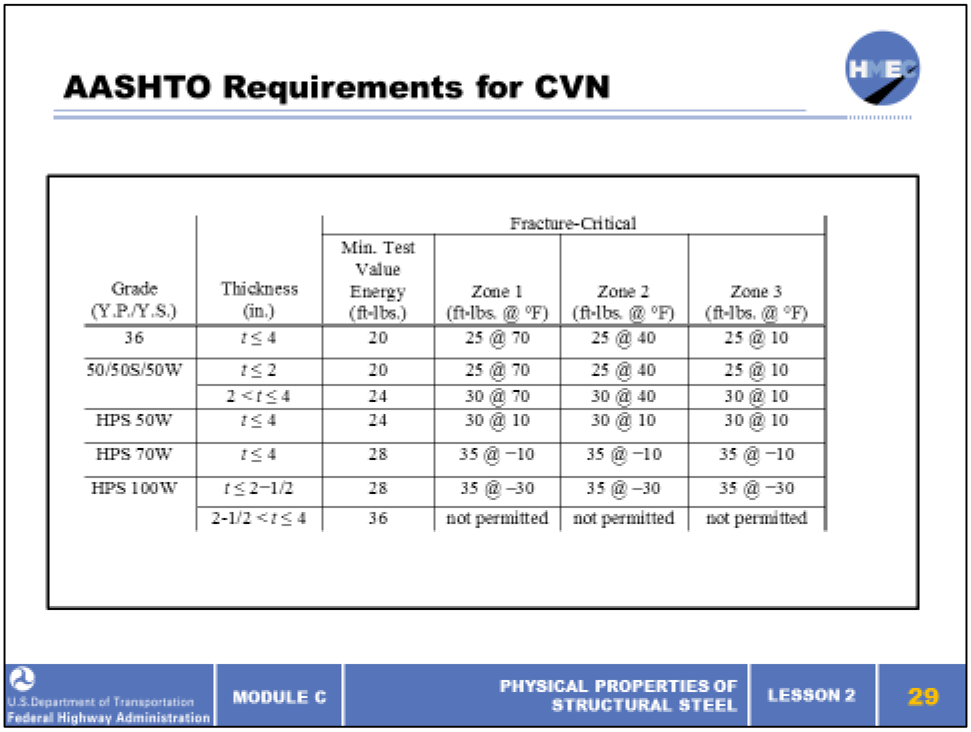

Grade (Y.P./Y.S.)	Thickness (in.)	Fracture-Critical			
		Min. Test Value Energy (ft-lbs.)	Zone 1 (ft-lbs. @ °F)	Zone 2 (ft-lbs. @ °F)	Zone 3 (ft-lbs. @ °F)
36	$t \leq 4$	20	25 @ 70	25 @ 40	25 @ 10
50/50S/50W	$t \leq 2$	20	25 @ 70	25 @ 40	25 @ 10
	$2 < t \leq 4$	24	30 @ 70	30 @ 40	30 @ 10
HPS 50W	$t \leq 4$	24	30 @ 10	30 @ 10	30 @ 10
HPS 70W	$t \leq 4$	28	35 @ −10	35 @ −10	35 @ −10
HPS 100W	$t \leq 2\text{-}1/2$	28	35 @ −30	35 @ −30	35 @ −30
	$2\text{-}1/2 < t \leq 4$	36	not permitted	not permitted	not permitted

AASHTO requires CVN testing for steel that will be used in primary members that are loaded in tension. The country is divided into three temperature zones where the lowest anticipated service temperatures are 0 °F, -30 °F, and -60 °F. Fracture-critical members are those that may cause collapse of the structure if they fail. Higher toughness is required for these members.

Note that the test temperatures do not match the lowest anticipated service temperature (LAST) due to the previously discussed temperature shift. Also note that higher strength steels require more toughness.

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AASHTO Requirements for CVN

Grade (Y.P./Y.S.)	Thickness (in.)	Nonfracture-Critical		
		Zone 1 (ft-lbs. @ °F)	Zone 2 (ft-lbs. @ °F)	Zone 3 (ft-lbs. @ °F)
36	$t \le 4$	15 @ 70	15 @ 40	15 @ 10
50/50S/50W	$t \le 2$	15 @ 70	15 @ 40	15 @ 10
	$2 < t \le 4$	20 @ 70	20 @ 40	20 @ 10
HPS 50W	$t \le 4$	20 @ 10	20 @ 10	20 @ 10
HPS 70W	$t \le 4$	25 @ −10	25 @ −10	25 @ −10
HPS 100W	$t \le 2\text{-}1/2$	25 @ −30	25 @ −30	25 @ −30
	$2\text{-}1/2 < t \le 4$	35 @ −30	35 @ −30	35 @ −30

Q&A Why do higher strength steels require more toughness?

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All other members are nonfracture-critical. The test temperatures are warmer than the service temperatures due to the temperature-shift effect.

Note again that higher strength steels require more toughness.

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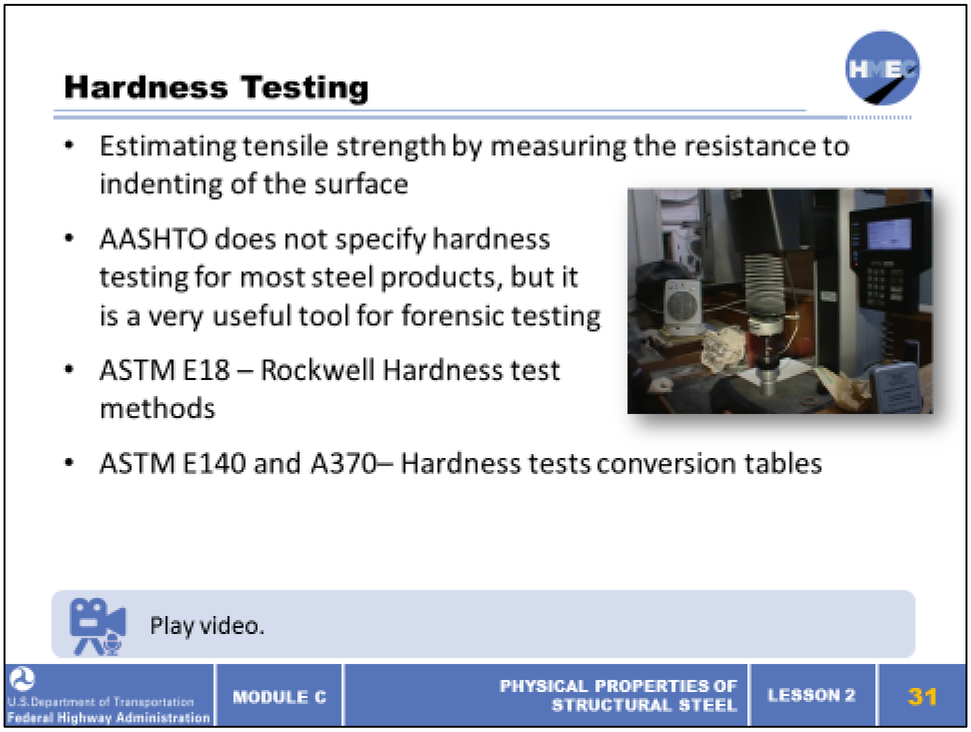

Hardness testing is a method of estimating tensile strength by measuring the resistance to the indenting of the surface. AASHTO does not specify hardness testing for most steel products, but it is a very useful tool for forensic testing. The following video shows the laboratory testing procedure for small samples but portable equipment is available for field testing on large members.

ASTM E18 provides the standards for Rockwell Hardness testing. ASTM E140 and A370 provide tables to convert between the various hardness-test methods.

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Hardness Testing

Sample Test Report for ASTM A709 Grade 50

specimen ID	hardness (HRB)
1	65
2	72
3	71
4	75
5	80
6	67
average	72

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ASTM E18 does not include a standard test report form. It does include the information that should be included in the test report. The sample test report shown includes the requirements of E18. The units "HRB" indicate that the Rockwell B scale was used.

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Portable hardness testers are available for use in the field. A hand-held indenter (snap punch) is pressed on the surface and the diameter of the resulting dent is measured with a scope. The depth of indentation is calculated from the diameter knowing the indenter point geometry. The tests are quick and essentially non-destructive but they require careful surface grinding preparation for accuracy.

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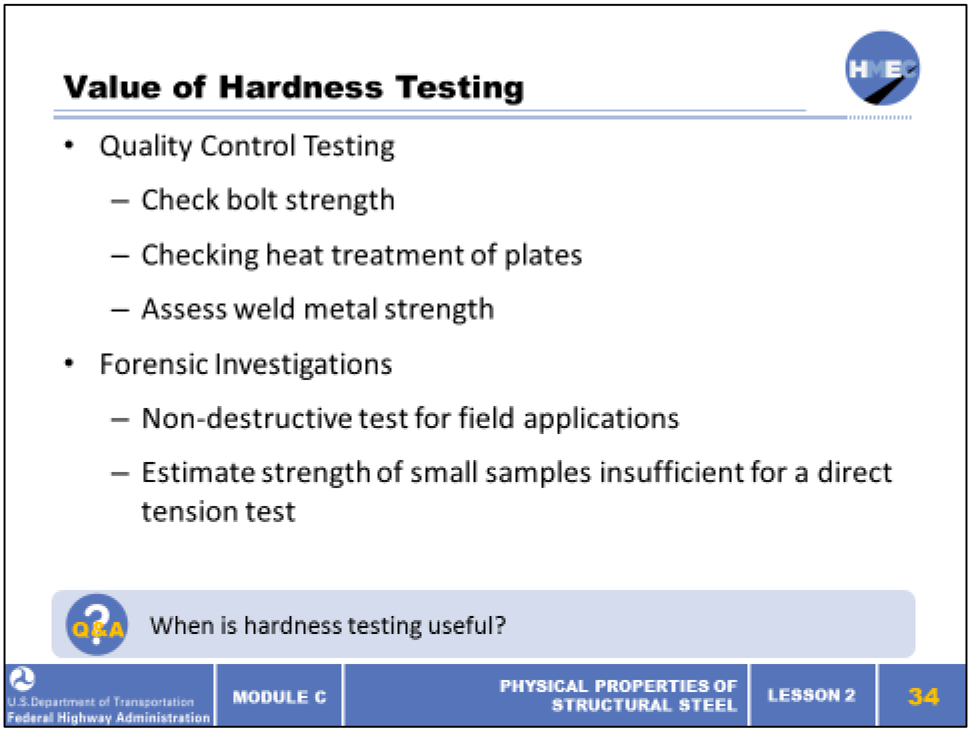
Value of Hardness Testing
• Quality Control Testing
– Check bolt strength
– Checking heat treatment of plates
– Assess weld metal strength
• Forensic Investigations
– Non-destructive test for field applications
– Estimate strength of small samples insufficient for a direct tension test
Q&A
When is hardness testing useful?
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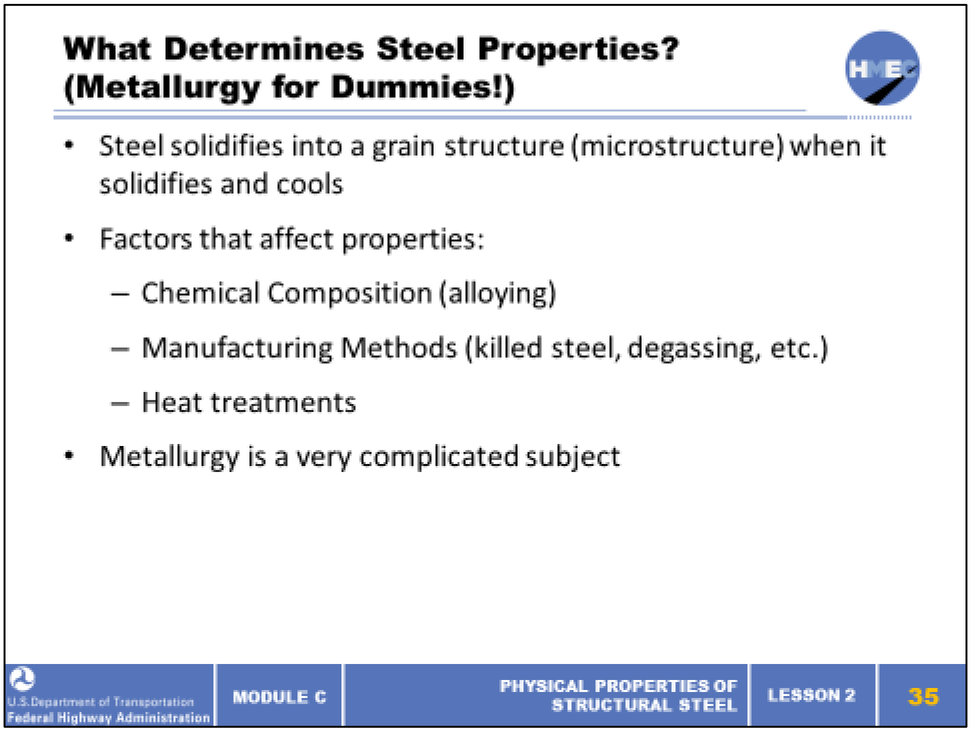

This is a general overview of the concepts. Evaluation of microstructure requires services of a specially trained metallurgist.

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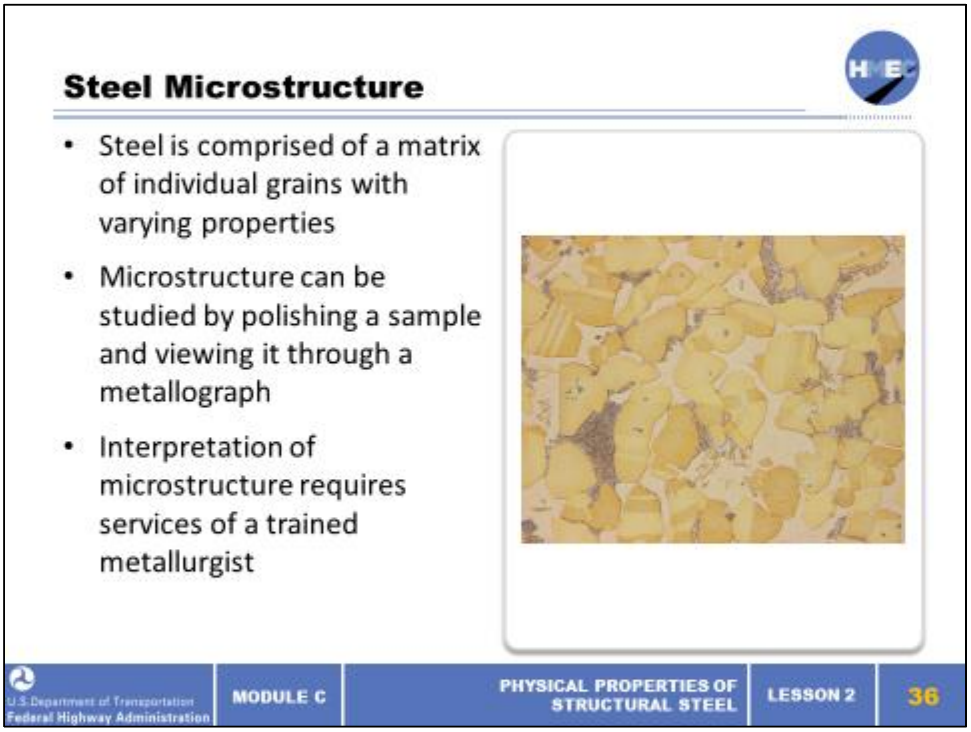

The grain structure can be viewed by polishing a sample to a high level and viewing it under a specialized microscope called a metallograph. Interpretation of microstructure requires a trained metallurgist. This is not an exact science. In many cases, different metallurgists will interpret the same metallograph photo differently. Microstructure evaluation is very useful to assess effects of chemistry and processing in steelmaking. Microstructure is less useful to evaluate the suitability of steel products for bridge service. Many different microstructures can provide adequate physical properties.

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Element	Symbol	Advantages	Disadvantages
Carbon	C	Increases strength and hardness Low cost	Decreases ductility and toughness; Decreases weldability; Moderate tendency to segregate
Manganese	Mn	Increases strength Controls harmful effects of sulfur	
Phosphorous	P	Increases strength and hardness; Can increase atmospheric corrosion resistance	Decreases ductility and toughness; Can be considered an impurity; Strong tendency to segregate
Sulfur	S	Increases machinability	Generally considered undesirable; Decreases ductility and toughness; Decreases weldability; Strong tendency to segregate
Silicon	Si	Used to deoxidize (kill) molten steel	
Aluminum	Al	Used to deoxidize (kill) molten steel Refines grain size, thereby increasing strength and toughness	
Vanadium	V	Small additions increase strength	
Columbium	Nb	Small additions increase strength	
Nickel	Ni	Increases strength and toughness	
Chromium	Cr	Increases strength Increases atmospheric corrosion resistance	
Copper	Cu	Increases atmospheric corrosion resistance	
Nitrogen	N	Increases strength and hardness	Decreases ductility and toughness
Boron	B	Small amounts increase hardenability in low carbon, heat treated steels	
Zirconium			
Titanium			

This section presents a very elementary introduction into the art of metallurgy. Understanding this subject requires extensive training beyond the abilities of most DOT materials engineers. Some alloy elements are essential to provide adequate mechanical properties and corrosion resistance. The concentration of some elements must be limited since they have adverse effects on steel properties. Some elements must be controlled within limits to ensure the proper microstructure forms.

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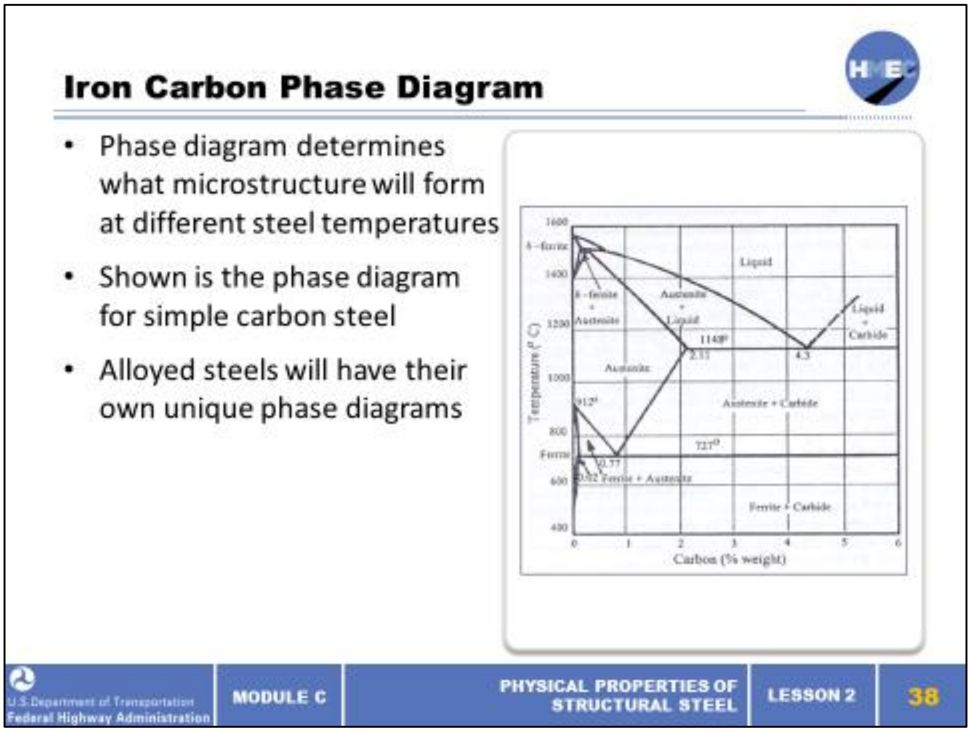
Iron Carbon Phase Diagram
Phase diagram determines what microstructure will form at different steel temperatures
Shown is the phase diagram for simple carbon steel
Alloyed steels will have their own unique phase diagrams
U.S. Department of Transportation Federal Highway Administration
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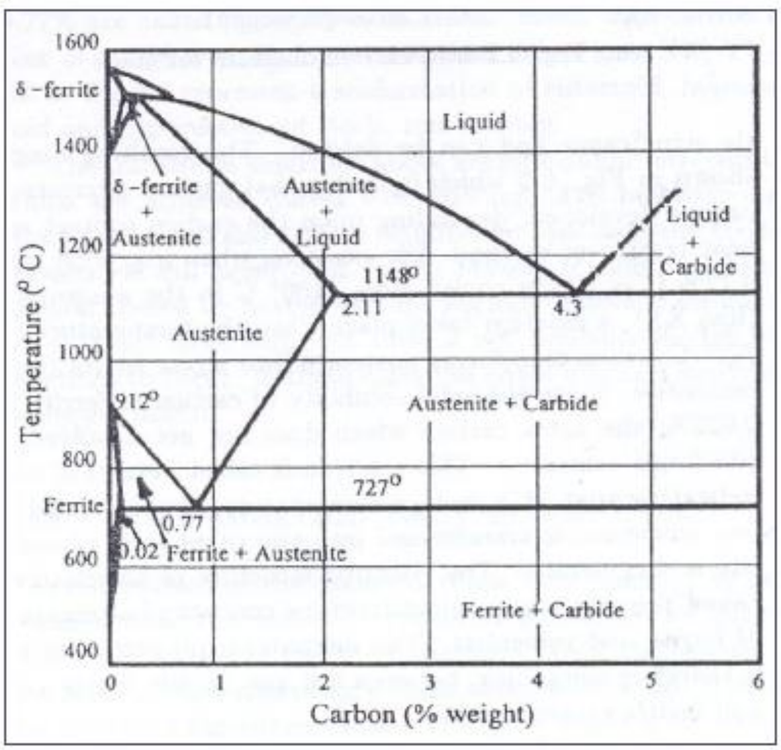
1600
δ –ferrite
1400
1200
1000
800
600
400
Temperature (° C)
Liquid
δ –ferrite + Austenite
Austenite + Liquid
Liquid + Carbide
1148°
2.11
4.3
Austenite
912°
Austenite + Carbide
727°
Ferrite
0.77
0.02
Ferrite + Austenite
Ferrite + Carbide
0
1
2
3
4
5
6
Carbon (% weight)

Steels with the same chemical composition will develop different microstructures depending on temperature. Each composition with alloying elements will have a unique phase diagram. As an example, the phase diagram for a basic carbon steel is shown. For example, let's look at a composition with 2% carbon. The melting temperature of the steel is the upper line at 1400 °C. At reduced temperatures between 1400 and about 1150 °C, the steel begins to solidify into austenite. At temperatures between 1150 and 727 °C, the microstructure is a mixture of austenite and carbide. At lower temperatures, the microstructure changes to a mixture of ferrite and austenite and finally ferrite and carbide.

This diagram is used for steels where the temperature change is slow and the steel is held at a relatively constant temperature.

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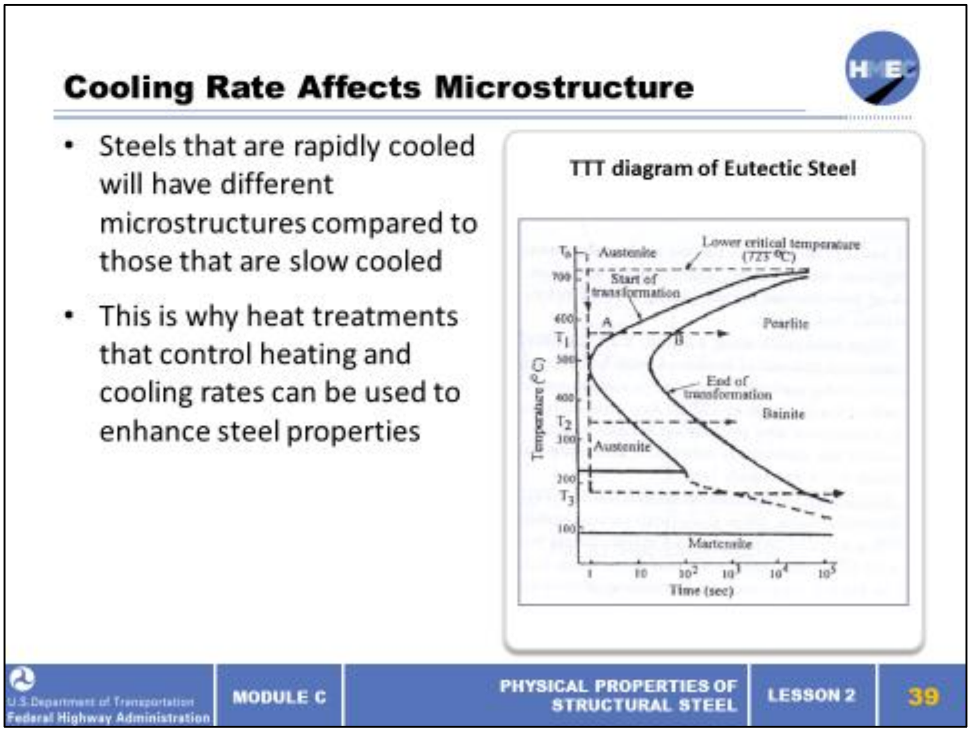

Steels heated to the lower critical temperature (723 °C) and cooled at different rates will develop different microstructures. Rapid quenching results in a microstructure called martensite. This has high strength but relatively low ductility and toughness. This process is typically followed by tempering where the steel is reheated to a sub-critical temperature and allowed to cool at a slower rate. This reduces strength somewhat but restores ductility and toughness.

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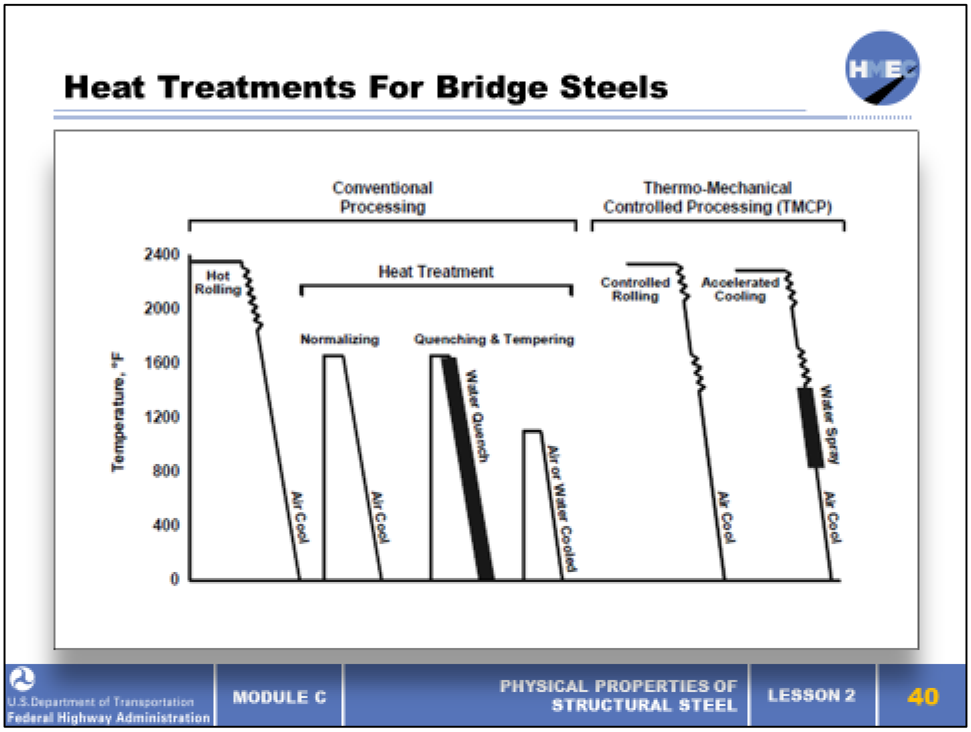

Traditional hot rolling heats the steel red hot to about 2400 °F and runs it back and forth under the rollers as the plate slowly cools. After the required thickness and size is achieved, the plate is allowed to slow cool. This procedure can be used for all grades but steel with F_y > 50 ksi must have additional heat treatments.

Normalizing is a heat treatment where the plate is reheated, held at temperature, and allowed to slow cool. This is sometimes used to improve the microstructure, particularly when high CVN toughness and uniformity are required.

Quenching is a process where the plate is reheated and rapidly cooled with water. This increases strength but results in brittle steel. Quenching is followed by tempering where the steel is again reheated to a lower temperature and allowed to cool at a slower rate. The quenching and tempering (Q&T) process is used for steels with F_y = 70 and 100 ksi. The net result is a steel with high strength and good toughness. These processes are traditionally performed in a separate heating oven.

Modern steel mills have the capability of refined temperature control during the rolling process, which is called TMCP processing. The rolling process can be paused to allow plates to cool or water sprays can be applied for higher cooling rates. This provides some of the advantages of the Q&T process without the need to reheat the plates. However, the time on the rolling mill may be increased. The net result is lower cost steel. Not all steel producers have the capability of performing TMCP rolling operations.

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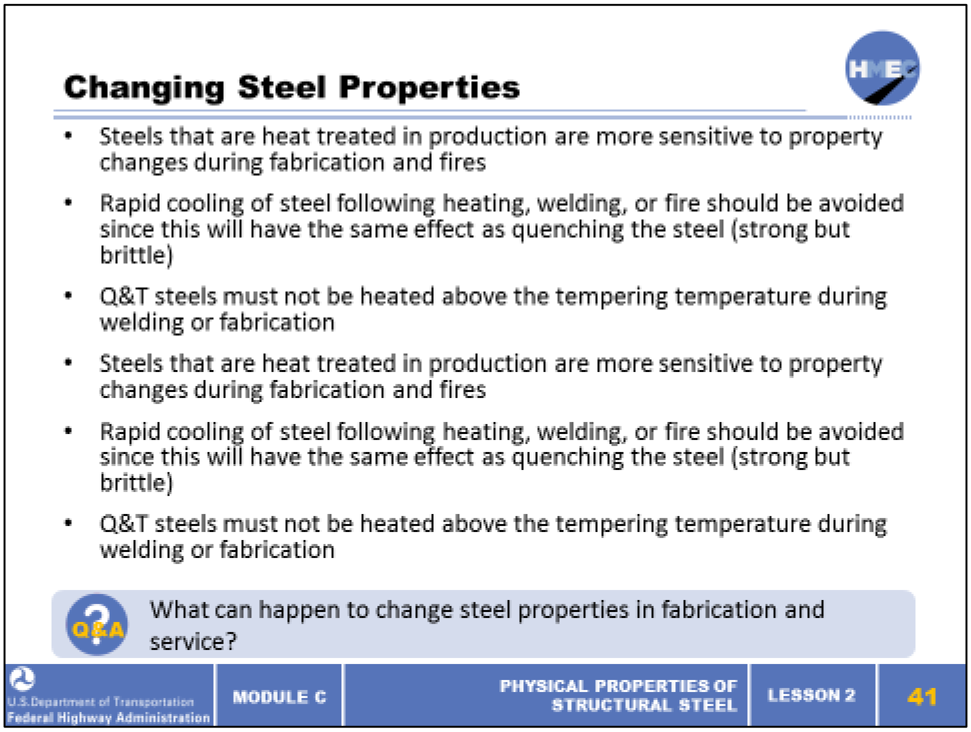
Changing Steel Properties
HMEC
Steels that are heat treated in production are more sensitive to property changes during fabrication and fires
Rapid cooling of steel following heating, welding, or fire should be avoided since this will have the same effect as quenching the steel (strong but brittle)
Q&T steels must not be heated above the tempering temperature during welding or fabrication
Steels that are heat treated in production are more sensitive to property changes during fabrication and fires
Rapid cooling of steel following heating, welding, or fire should be avoided since this will have the same effect as quenching the steel (strong but brittle)
Q&T steels must not be heated above the tempering temperature during welding or fabrication
Q&A
What can happen to change steel properties in fabrication and service?
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Federal Highway Administration
MODULE C
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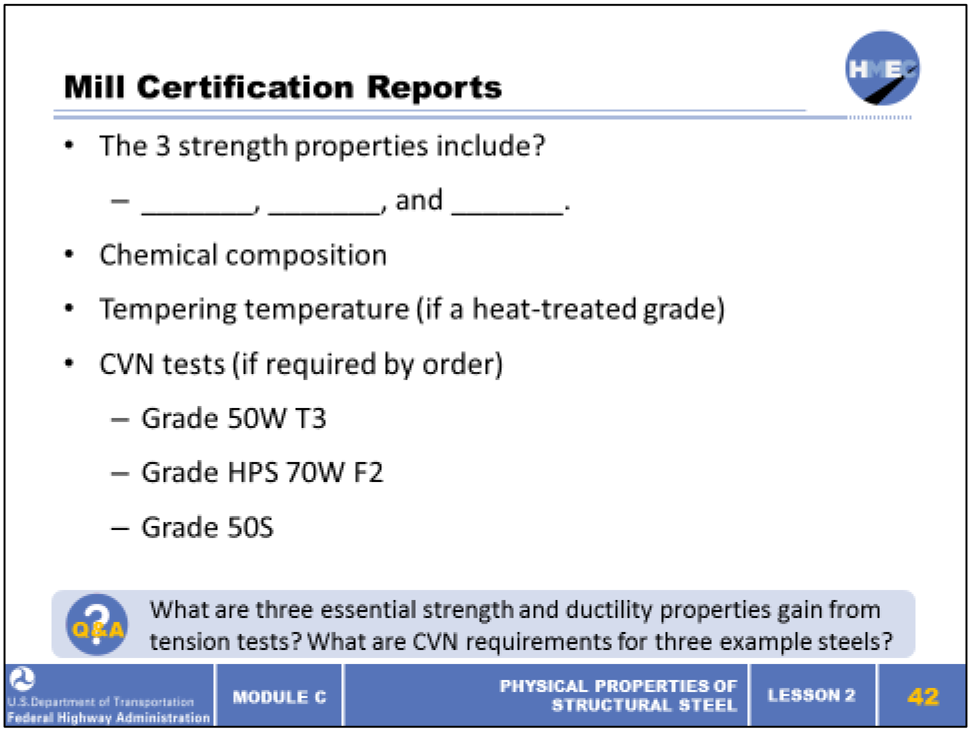

The chemistry composition is measured and reported for each heat of steel. The heat number is reported on the mill certification report. Each heat must comply with the applicable specification.

The tempering temperature, if any, must be reported for each heat-treated plate. This temperature cannot be exceeded in fabrication or the steel properties will be adversely changed.

CVN testing is a supplemental requirement that is specified for primary tension members. A T suffix is added to the grade if CVNs are required and the steel is to be used in nonfracture-critical applications. An F suffix is added for fracture-critical applications. A number following the suffix indicates the service temperature zone

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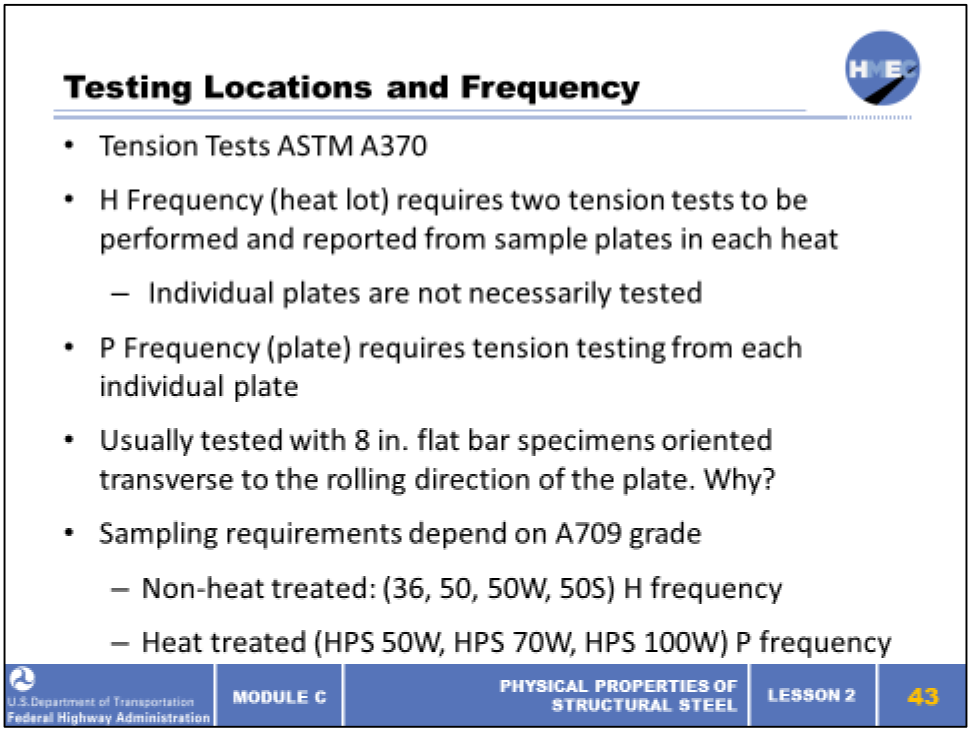
Testing Locations and Frequency
HMEC
• Tension Tests ASTM A370
• H Frequency (heat lot) requires two tension tests to be performed and reported from sample plates in each heat
– Individual plates are not necessarily tested
• P Frequency (plate) requires tension testing from each individual plate
• Usually tested with 8 in. flat bar specimens oriented transverse to the rolling direction of the plate. Why?
• Sampling requirements depend on A709 grade
– Non-heat treated: (36, 50, 50W, 50S) H frequency
– Heat treated (HPS 50W, HPS 70W, HPS 100W) P frequency
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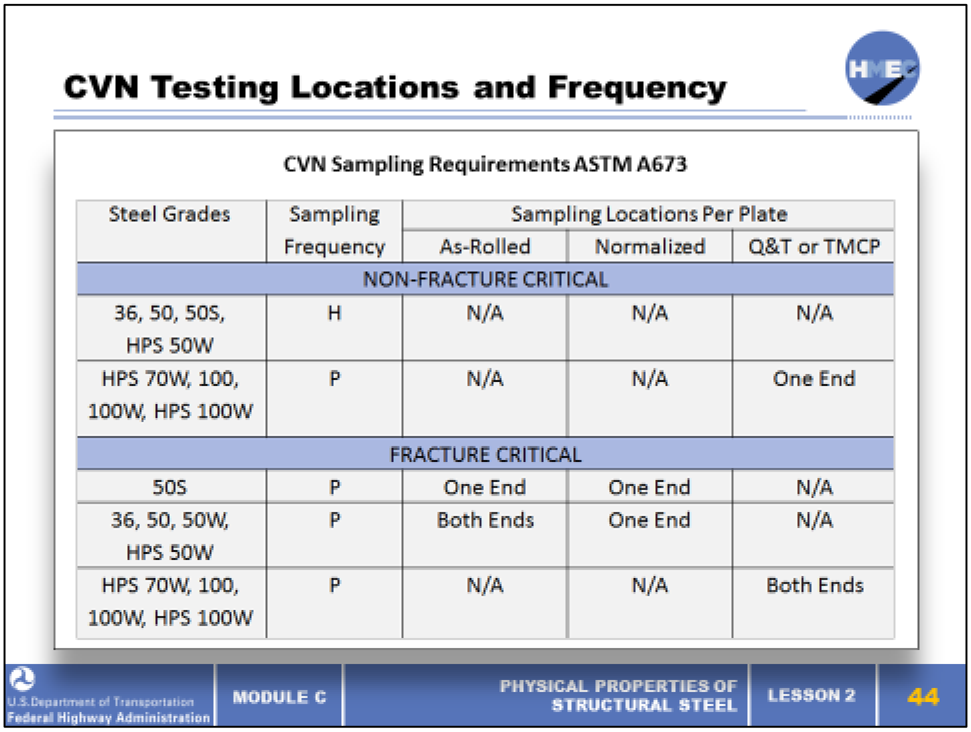

CVN Sampling Requirements ASTM A673

Steel Grades	Sampling Frequency	Sampling Locations Per Plate		
		As-Rolled	Normalized	Q&T or TMCP
NON-FRACTURE CRITICAL				
36, 50, 50S, HPS 50W	H	N/A	N/A	N/A
HPS 70W, 100, 100W, HPS 100W	P	N/A	N/A	One End
FRACTURE CRITICAL				
50S	P	One End	One End	N/A
36, 50, 50W, HPS 50W	P	Both Ends	One End	N/A
HPS 70W, 100, 100W, HPS 100W	P	N/A	N/A	Both Ends

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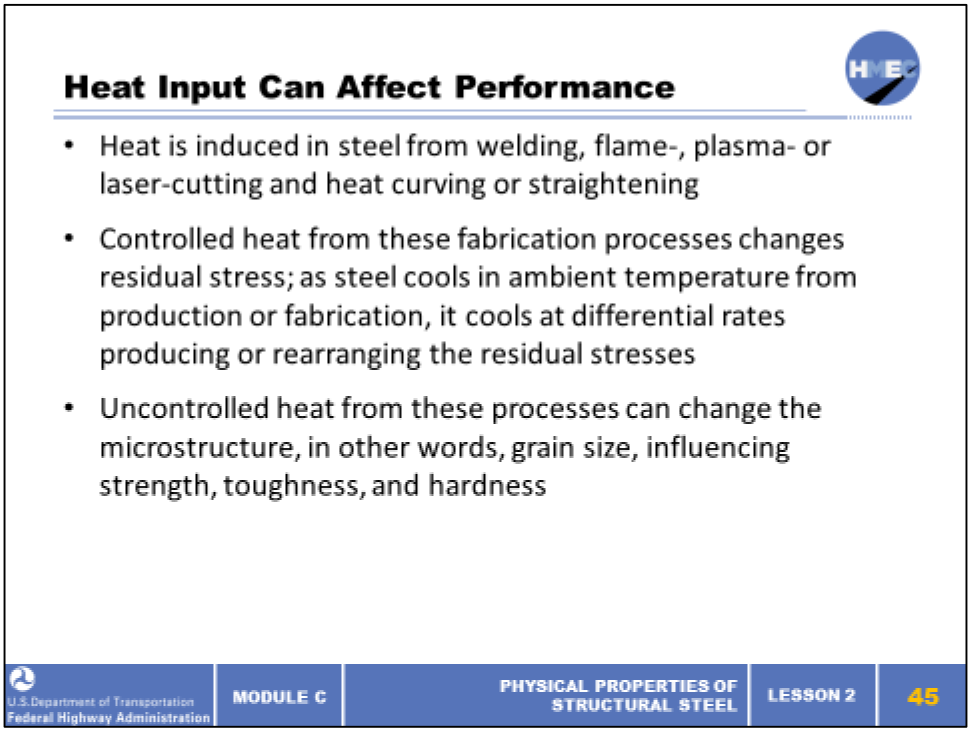

As an aside, the last portion of a piece of steel to cool goes into tension. For example, a flame-cut edge will take longer to cool than the other side of the plate which saw less heat. As the flame-cut edge cools it tries to shrink but the other side, already cool resists the shrinkage. This, the flame-cut edge has tension induced while the other side of the plate has an equalizing compression induced.

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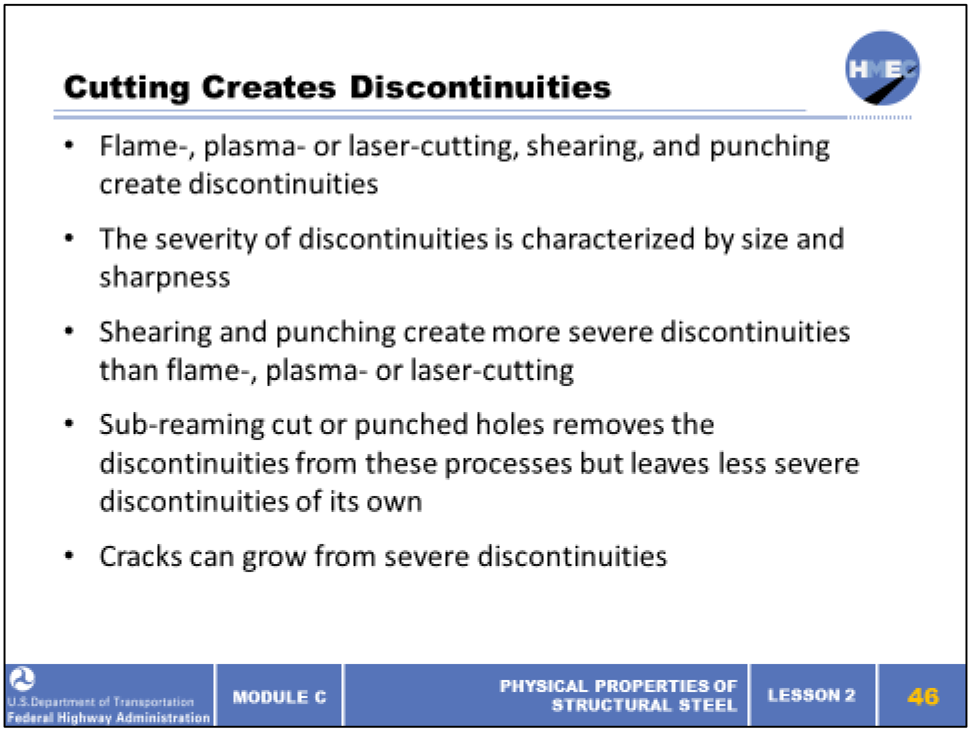

Steel must be cut in the fabrication process, either to length or width or to produce bolt holes. As the cuts are made, discontinuities are created. Each process creates its own severity of discontinuity. Fatigue cracks and fractures can grow from severe discontinuities.

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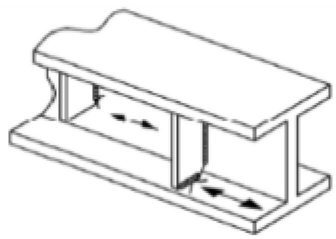
Welding Reduces Fatigue Resistance

- Fatigue cracks grow from discontinuities
- Stress concentrations accelerate crack growth
- Inherent discontinuities in rolled steel are inconsequential
- Inherent discontinuities from welding at the stress concentration represented by the weld toe are the primary initiation sites for fatigue cracks
- Weld-profile and discontinuity-size control are all important



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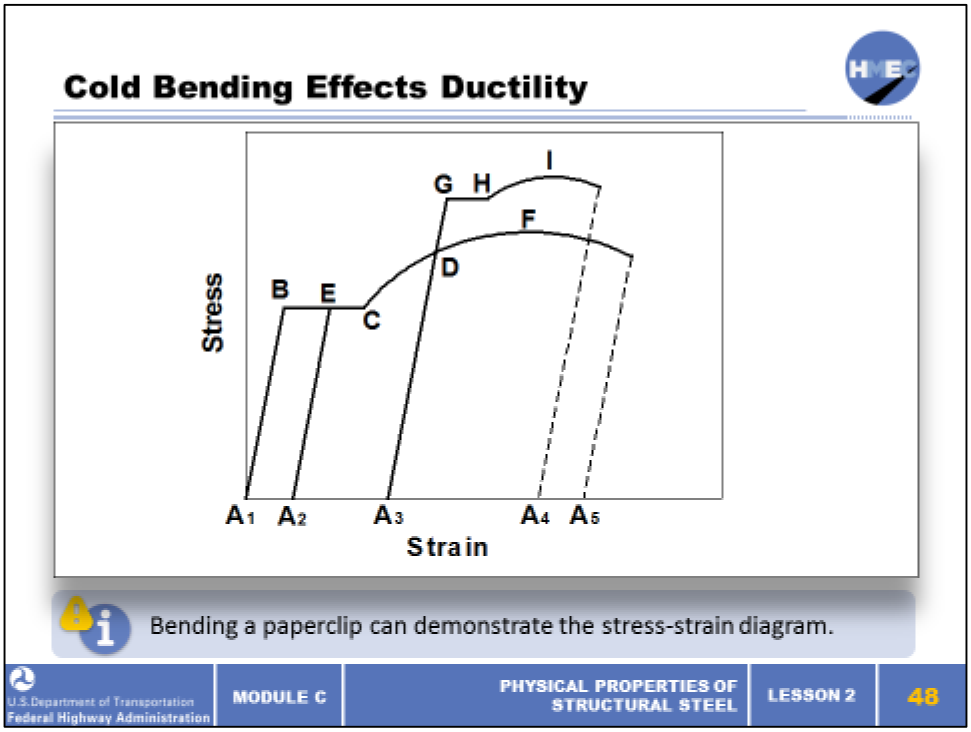

For low levels of plastic deformation below the onset of strain hardening, steel is loaded from A1 to B and elongates at yield to point E. If the steel is unloaded it returns to point A2. There is some permanent plastic deformation of the steel

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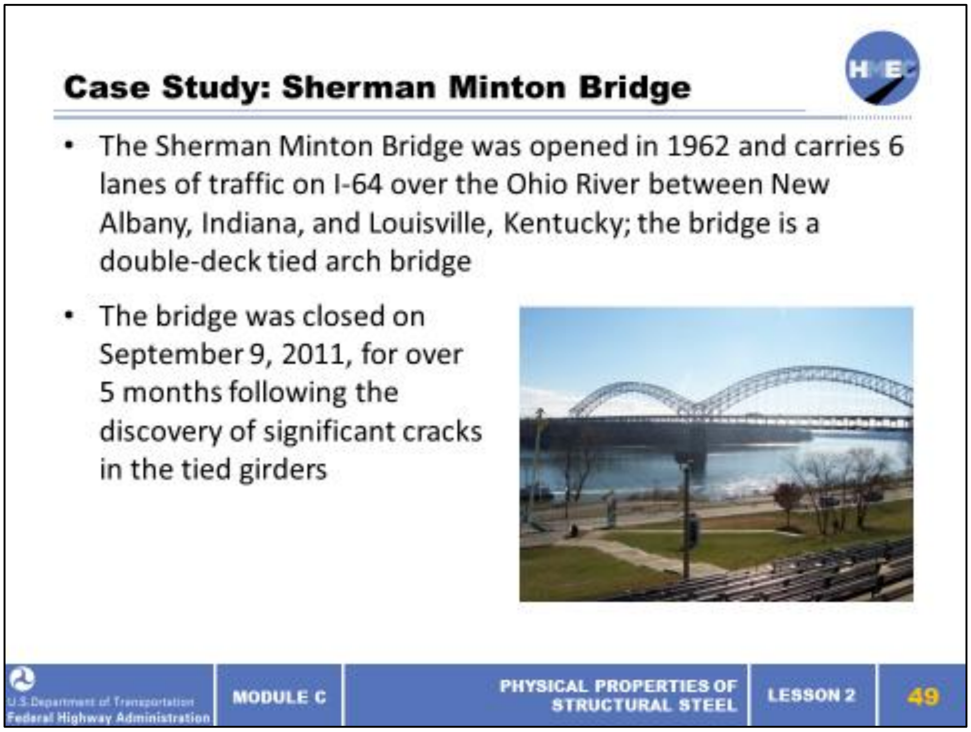
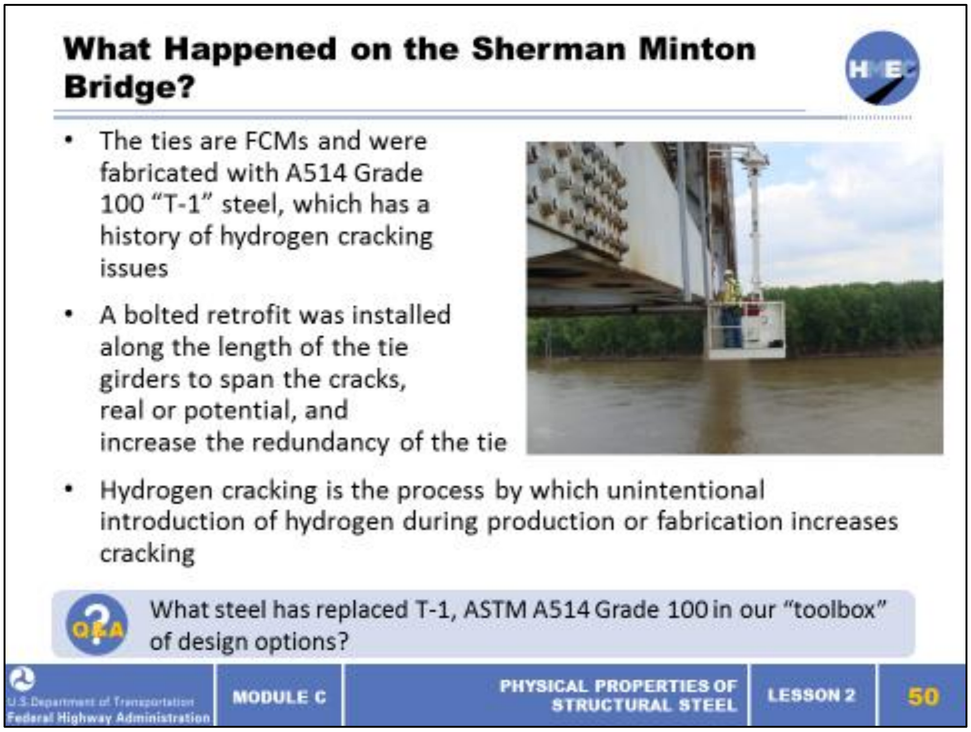


The Sherman Minton Bridge is a tied-arch bridge. Previous inspections had found cracking on the bridge in the tie girders, but inconsistencies in reporting allowed these cracks to remain without further remediation. In September of 2011, the significance of the cracks was recognized.

Slide 50



The tie girders are FCMs, critical elements to a tied arch. T-1 steel is no longer used for bridges. High-strength steel, such as T-1, can be susceptible to hydrogen cracking. Hydrogen can be introduced during production or welding. Production and weld control mitigate the susceptibility.

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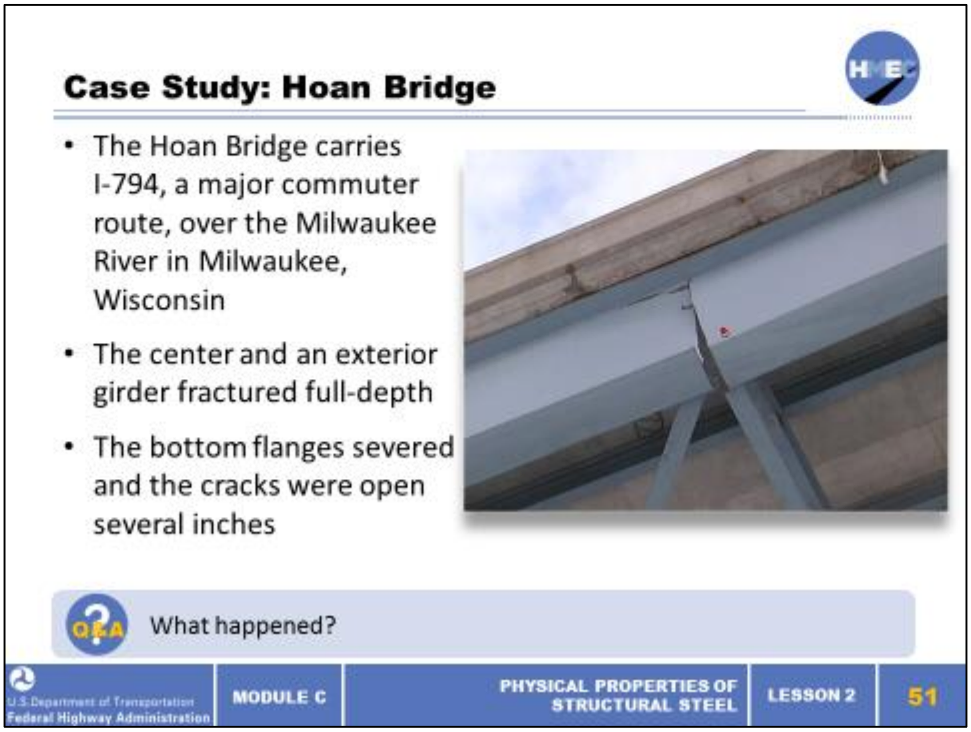

Conditions: 4:00 am, temperature about -11 °F, a motorist noticed a 3-ft. dip in the roadway, alerted authorities, and the bridge was immediately closed.

There was a full-depth fracture in the center girder. The bottom flange is severed and the crack is open several inches. The fracture propagated up the web and into the top flange. The buckling at the top of the web occurred after the fracture. The exterior girder had the same full depth fracture as in the center girder.

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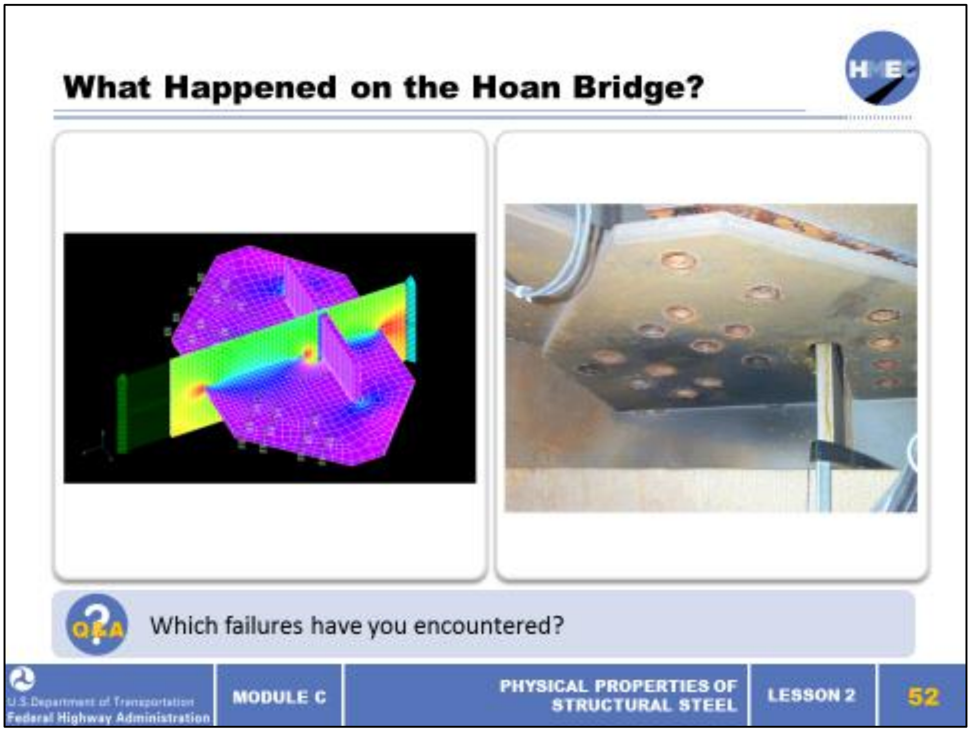

An inspection performed weeks before the fracture did not find any discontinuities.

The gusset plate detail has a slot that was cut to cleat the transverse stiffener plate as shown in the right photo. Finite element stress analysis, shown in the left photo, was performed to understand the effects of the gusset plate attachment. Results showed the web plate was subjected to high stress concentrations and triaxial constraint at the fracture initiation site. This created conditions that are similar to the conditions at the crack tip in a fatigue crack. Under high constraint, the material cannot yield and relieve stress concentrations.

The AASHTO LRFD Bridge Design Specifications now prohibit details with intersecting welds that cause high constraint conditions.

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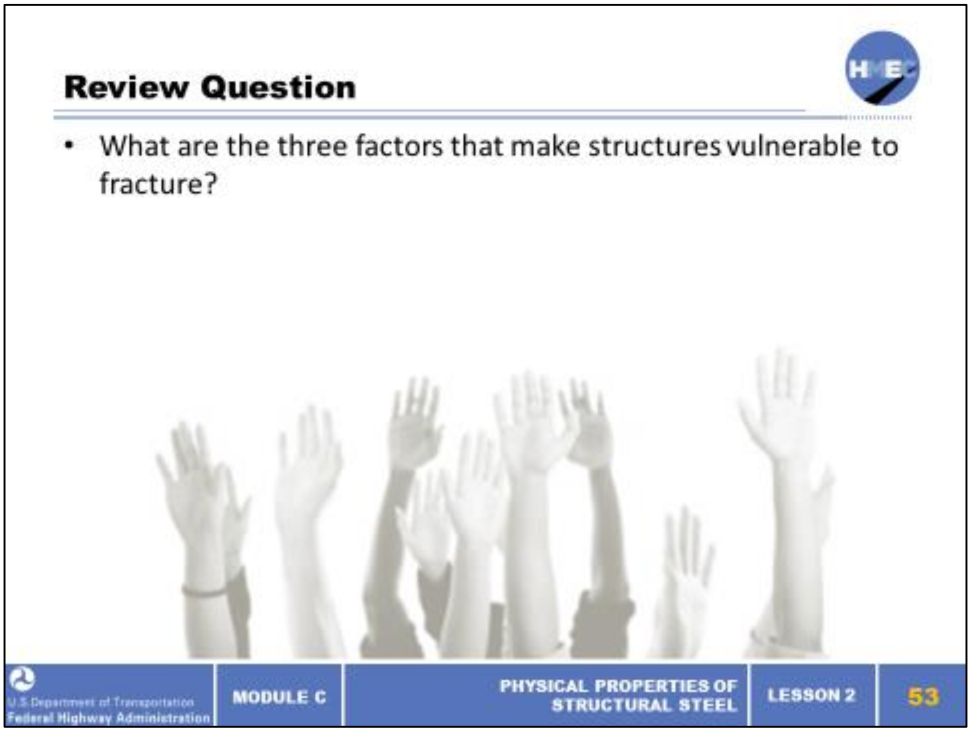
Review Question
What are the three factors that make structures vulnerable to fracture?
U.S. Department of Transportation
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MODULE C
PHYSICAL PROPERTIES OF STRUCTURAL STEEL
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Learning Outcomes Review
HMEC
You are now able to:
• Explain the properties of steel that are significant to its performance in transportation applications
• Explain the fracture toughness of steel and the testing procedures
• Explain how the hardness of steel relates to strength and toughness properties
• Explain the relationship of chemical composition and alloying elements to steel properties
• Explain how the manufacturing process and heat treatment affects properties of steel
• Explain the industry standards and mill certification procedures for steel products
• Describe fabrication practices that can change steel properties
• Give examples of failure analysis case studies
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PHYSICAL PROPERTIES OF STRUCTURAL STEEL
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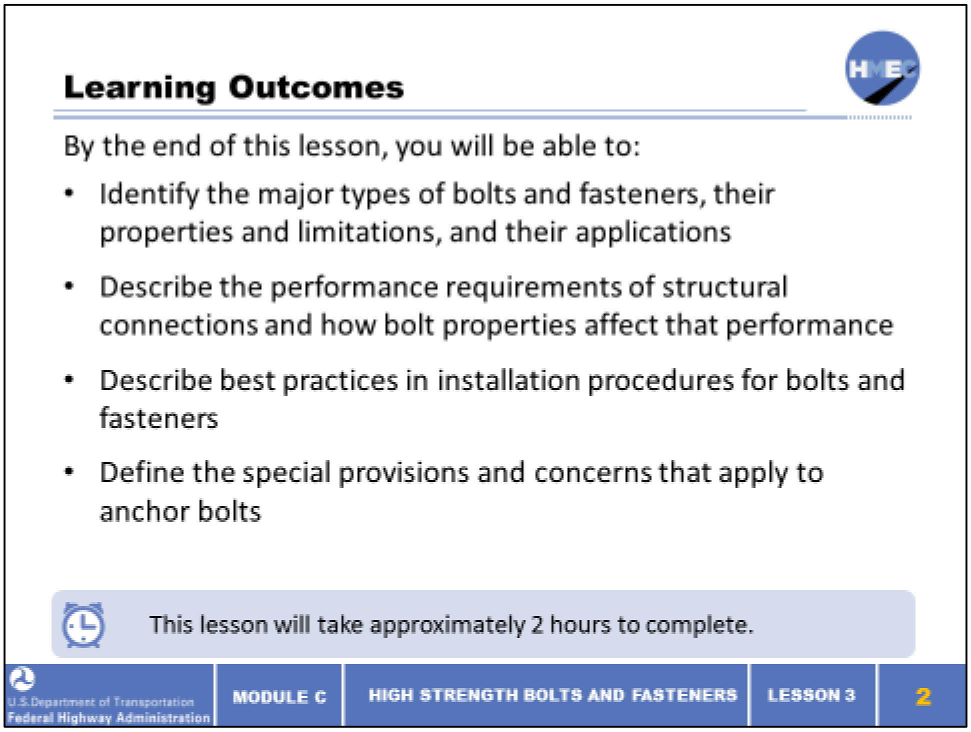
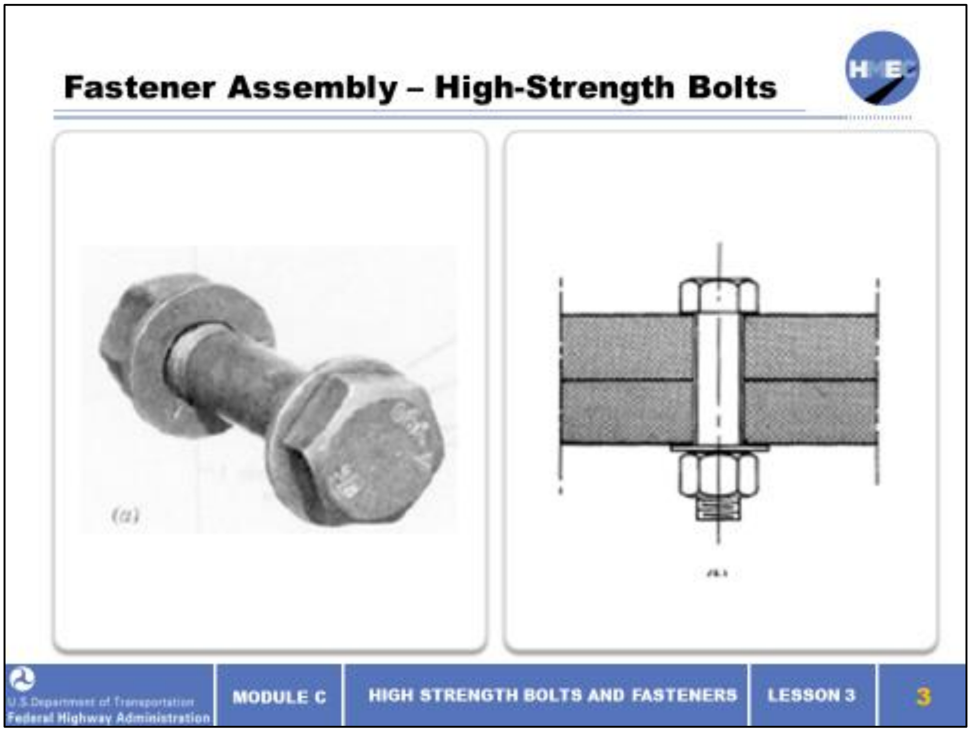
Slide 1


HMEC
Highway Materials Engineering Course
Lesson 3: High Strength Bolts and Fasteners
Steel, Welding,
and Coatings
U.S.Department of Transportation
Federal Highway Administration
MODULE
C

Slide 2

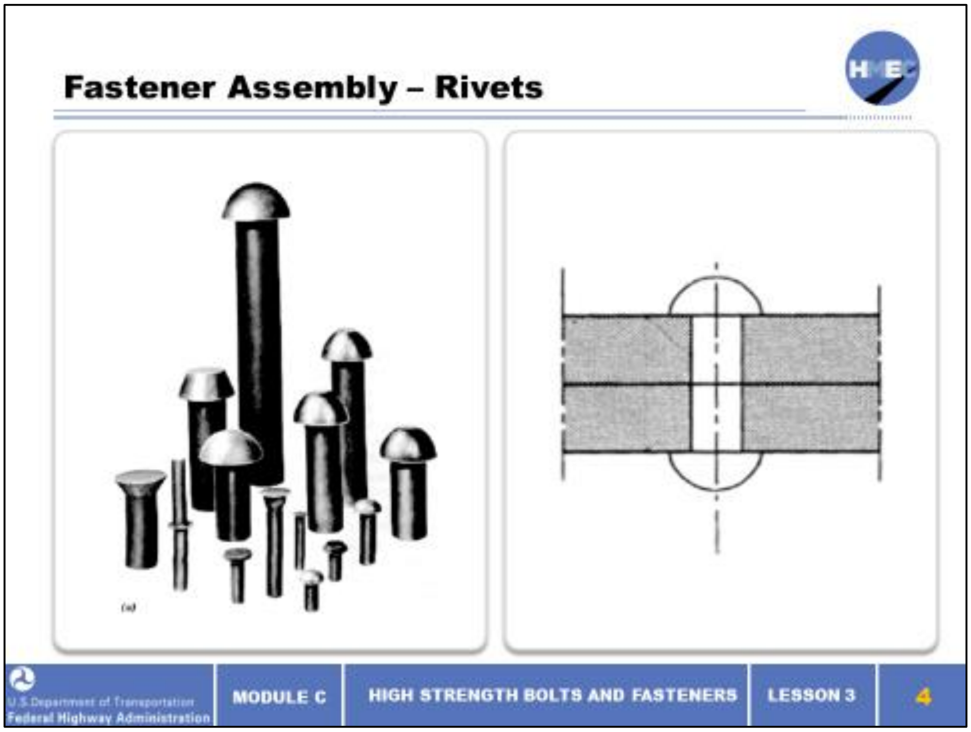

Learning Outcomes
By the end of this lesson, you will be able to:
• Identify the major types of bolts and fasteners, their properties and limitations, and their applications
• Describe the performance requirements of structural connections and how bolt properties affect that performance
• Describe best practices in installation procedures for bolts and fasteners
• Define the special provisions and concerns that apply to anchor bolts
This lesson will take approximately 2 hours to complete.
U.S. Department of Transportation
Federal Highway Administration
MODULE C
HIGH STRENGTH BOLTS AND FASTENERS
LESSON 3
2

Slide 3



A fastener is the assembly of a bolt, nut, and washer that is installed to connect two or more parts together. The components are matched according to the grade of fastener. The design strength of the connection depends primarily on the properties of the bolt. The nut and washer are required to install and pretension the bolt so that the design capacity is reached.

Slide 4



Rivets are a type of fastener that were used exclusively up until the 1960s. They have since been replaced by high-strength bolts and welding. However, many older structures exist and are still in service that have riveted construction. Rivets are also used for historic preservation of these existing structures. The rivets start as a round rod with a conical head formed on one end. They are inserted in a hole and hammered to fill the hole and forge a head on the opposite end.

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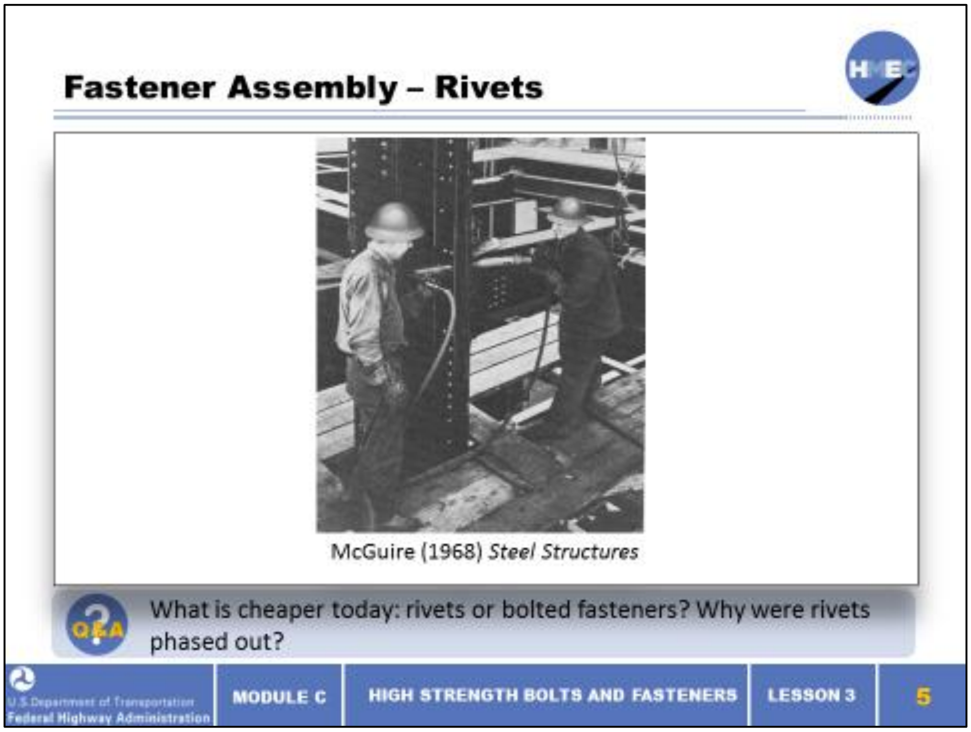
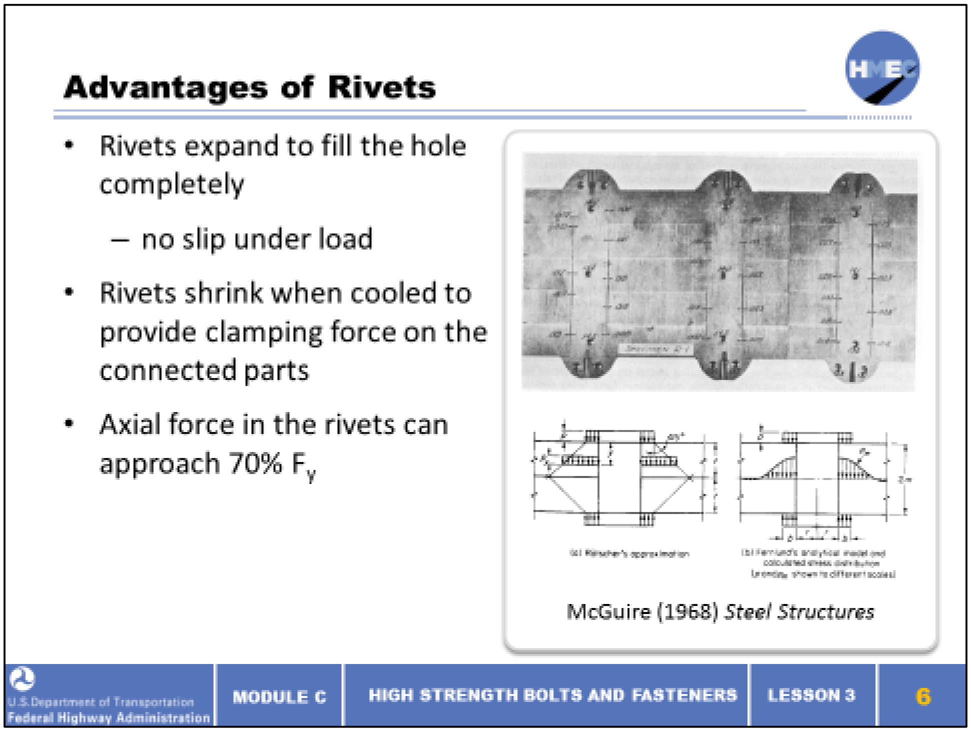


The rivet installation procedure includes the follow steps:

1. Heat rivet to about 1800 °F (red hot).
2. Place in hole (diameter 1/16 larger than rivet shank) using tongs.
3. Place a pneumatic backing bar.
4. Hammer forge the head on the opposite end.

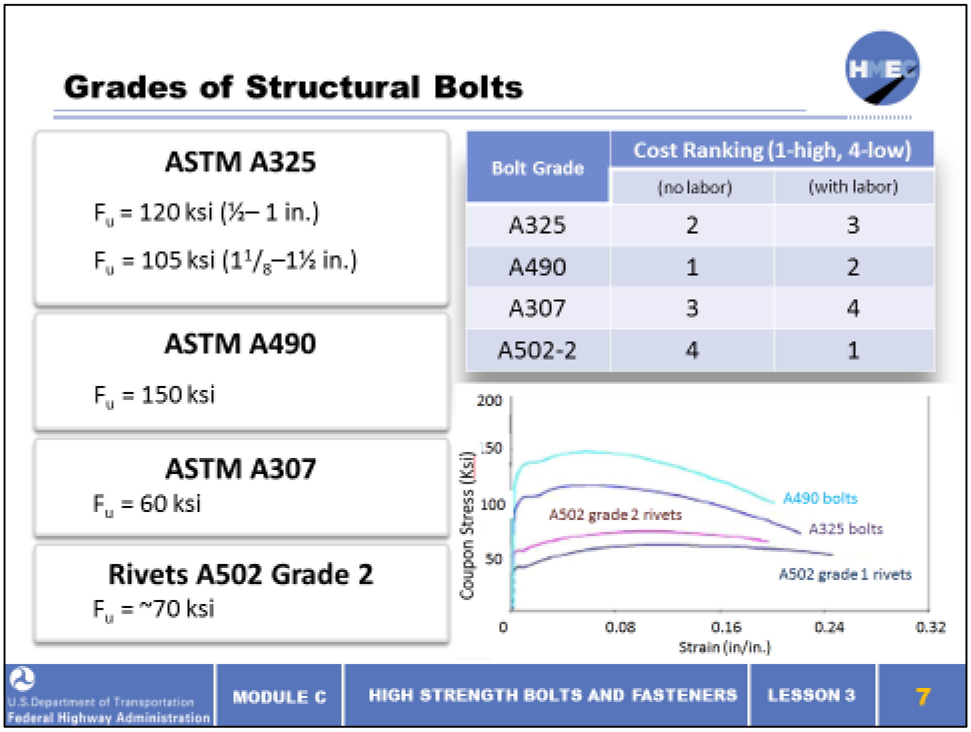
The rivet contracts as it cools, thereby developing clamping pressure on the joint.

Slide 6



Rivets fill the holes, thereby preventing slip of the connection under the load. In contrast, a high-strength bolted connection will slip into bearing before failure. Rivets also provide clamping force on the connection when they contract as they cool.

Slide 7



The ASTM A325 fasteners are the most common for use in structural connections. The stress-strain curve is similar to that for quenched and tempered (Q&T) structural steel. Like Q&T steel, bolts must be heat treated during manufacturing to attain the desired properties. Heating bolts above their tempering temperature will degrade properties. Rivets are shown for comparison. A490 structural bolts are a high-strength option for certain special uses. Bolt strength is specified in terms of the tensile strength instead of the yield strength.

The figure shows the typical stress-strain curves for A502 grade 1 and 2 rivets. Clearly, high-strength bolts are stronger. ASTM A307 bolts are used for applications where strength is not critical and for non-slip critical applications. They have a similar stress-strain curve as A502 grade 1 rivets. Splices and connections in bridge superstructures always use A325 or A490 bolts. These grades can develop the clamping force necessary for slip-critical connections.

Slide 8

Rivet Hardness

- Hardness is used to specify rivet strength in ASTM A502

	Grade 1		Grade 2		Grade 3	
	Min.	Max.	Min.	Max.	Min.	Max.
Rockwell B	55	72	76	85	76	93
Brinell, 500-kgf load, 10-mm ball	103	126	137	163	137	197

Remember, hardness can be used to estimate tensile strength.

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The ASTM A502 specification lists hardness requirements for the three different rivet grades. This is for un-driven rivets. Forging the rivet into the hole can be expected to alter hardness.

Hardness tests are possible on installed fasteners. A small area of the head can be ground smooth and tested with a portable hardness tester. Portable hardness measurements typically have more variability compared to laboratory equipment. The surface hardness of the bolt or rivet head does not necessarily represent the fastener shank upon which the connection strength depends. Therefore, field hardness measurements should be interpreted with caution. They can be useful if substandard or counterfeit fasteners are suspected.

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Slide 9

Bolt Hardness

Grade	Diameter (in.)	Length	Rockwell C Hardness (HRC)	
			Minimum	Maximum
A325	½–1	< 3D	25	34
		> = 3D	---	34
	1⅛–1½	< 3D	19	30
		> = 3D	---	30
A490	½–1½	< 3D	33	38
		> = 3D	---	38

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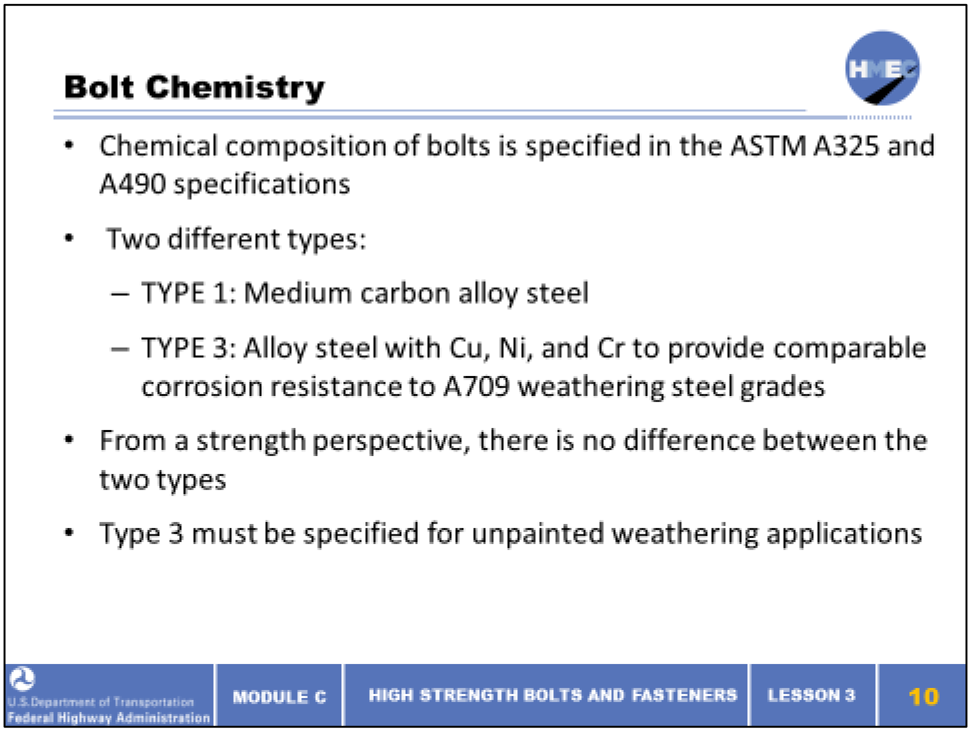
Bolts must be heat treated to obtain their strength. Recall that Q&T processing must be followed by tempering to ensure adequate ductility and toughness. The check on maximum hardness ensures tempering has been performed adequately and protects against brittle bolts.

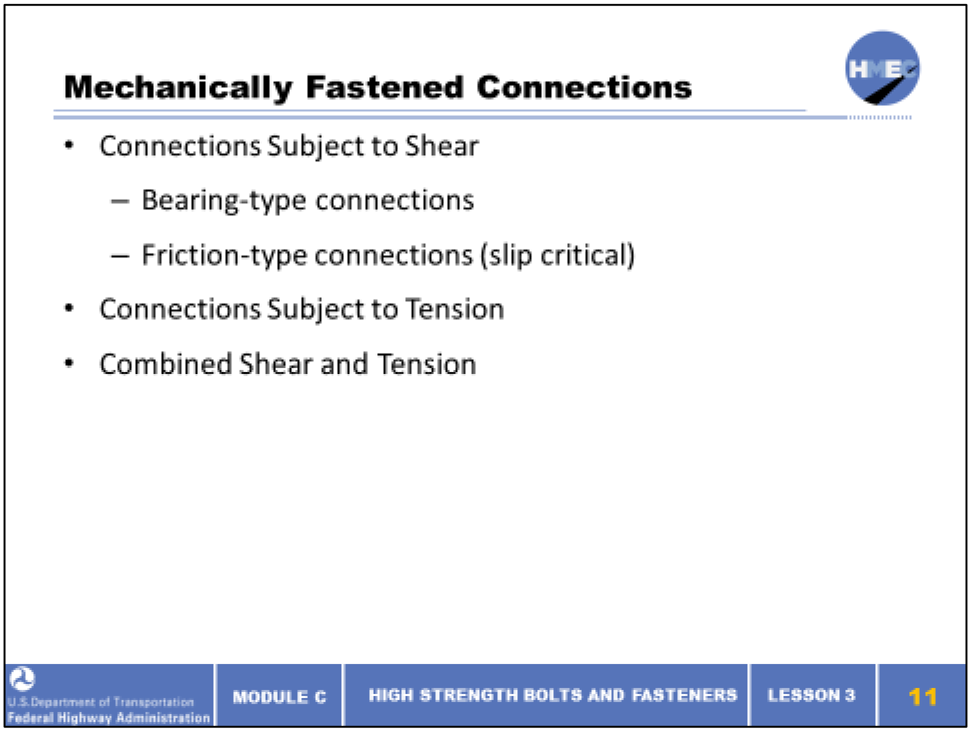
Hardness tests are possible on installed fasteners. A small area of the head can be ground smooth and tested with a portable hardness tester. Portable hardness measurements typically have more variability compared to laboratory equipment. The surface hardness of the bolt or rivet head does not necessarily represent the fastener shank upon which the connection strength depends. Therefore, field hardness measurements should be interpreted with caution. They can be useful if substandard or counterfeit fasteners are suspected.

Slide 10



From a performance perspective, both types meet the required strength and ductility for structural applications. Type 3 is required to provide adequate corrosion performance when used in unpainted weathering steel connections. Type 3 can also be used in painted connections but the cost is somewhat higher.

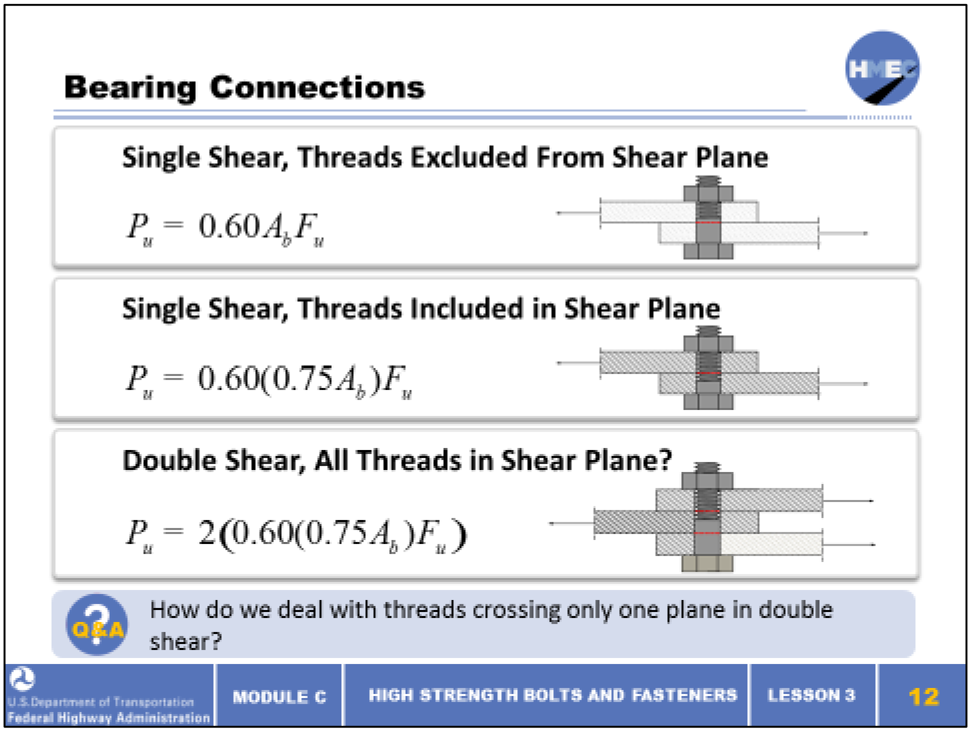
Slide 11



The most common type of connection is a shear-type connection where one connected part wants to slip relative to the other. This causes shear stress in the fastener at the interface plane between the two parts. Bearing-type connections assume the force is transferred to the bolt by the sides of the hole. Friction-type connections require the bolt to be tightened to provide substantial clamping force between the two parts. The shear force is transferred by friction between the two parts.

Tension connections are less common. These are created when attached parts, such as hanger brackets, are loaded to provide tension on the bolt. Many connections fall between the two extremes and introduce a combination of tension and shear in the bolt. The interaction of the two types of loading must be considered in design.

Slide 12



The fastener strength is determined by the shear strength of the bolt shank. The ultimate shear stress $F_{uv} = 0.6\ F_u$. Connections in single shear have one shear plane across the bolt shank. The strength depends on whether the threads are located in or outside of the shear plane.

Connections in double shear have two shear planes crossing the bolt shank. The fastener has twice the single shear capacity.

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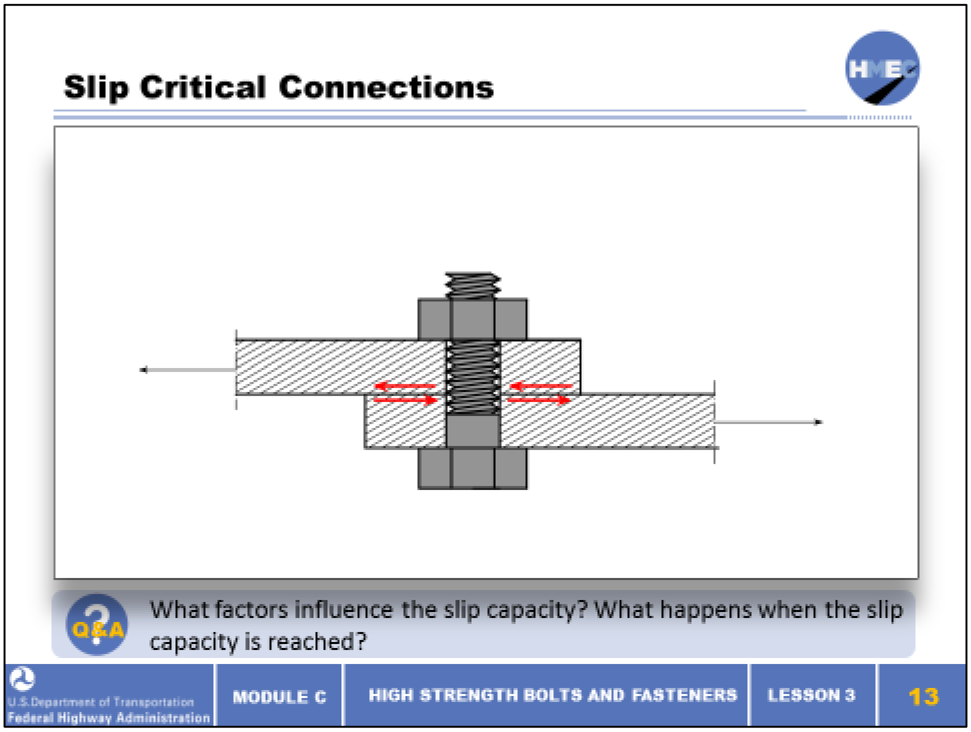
Slide 13



It is critical that bolts be installed to adequate tightness to provide the necessary clamping pressure to the connection. It is also critical that the contact surfaces of the connected parts called the faying surfaces are prepared to provide an adequate coefficient of friction.

When the connection slips into bearing, it has the ultimate capacity of a bearing connection. We design bridge connections to resist slip under service loads. The ultimate strength of the connection is based on the bearing capacity.

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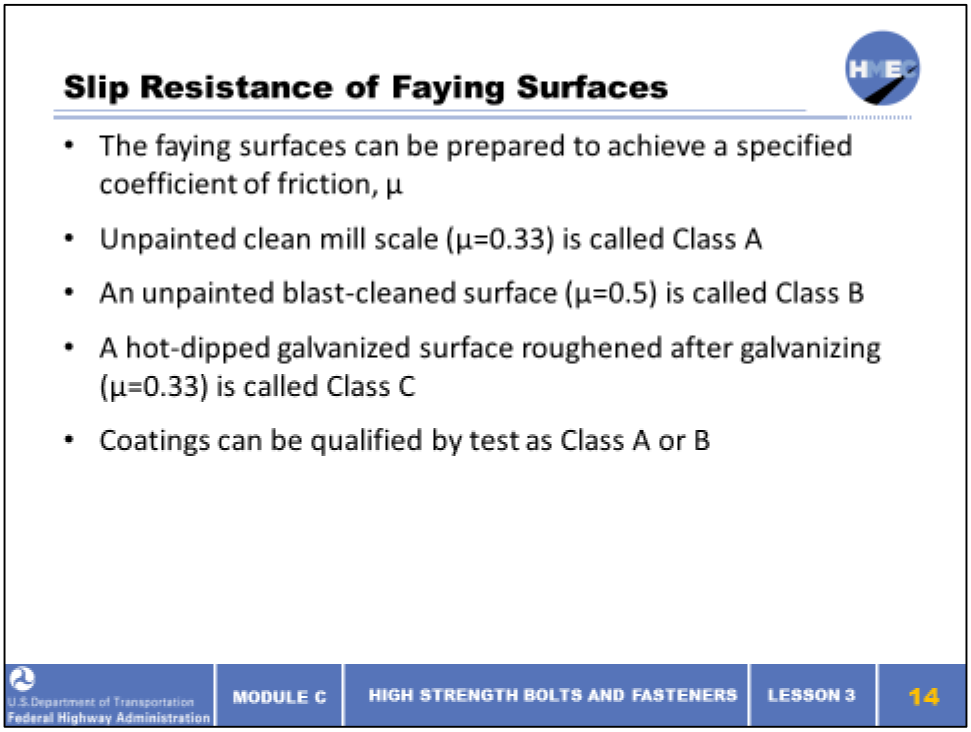
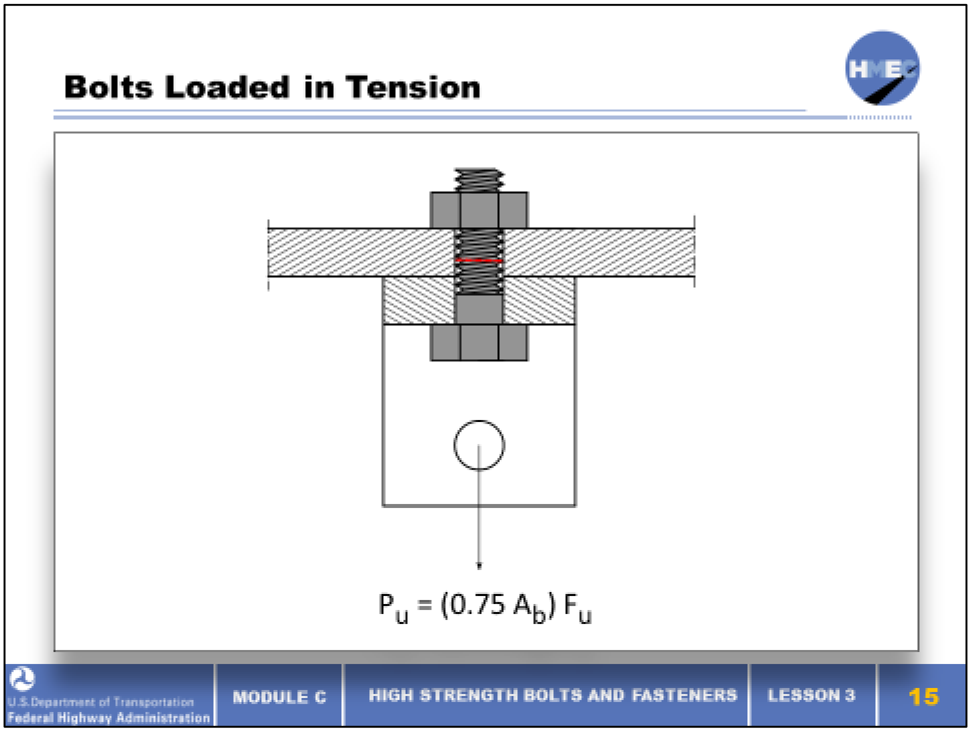
Slide 14



Different surface treatments are classified based on their coefficient of friction. Paints can be qualified based on their measured coefficients of friction in these classes as well.

Slide 15



Under tension the failure will always occur at the weakest portion of the bolt (through the root notch of the threads). The capacity is the tensile strength of the bolt times 75% of the nominal bolt area. Seventy five percent is a conservative approximation made so we do not have to know the root diameter of the threads that will be different for each bolt diameter.

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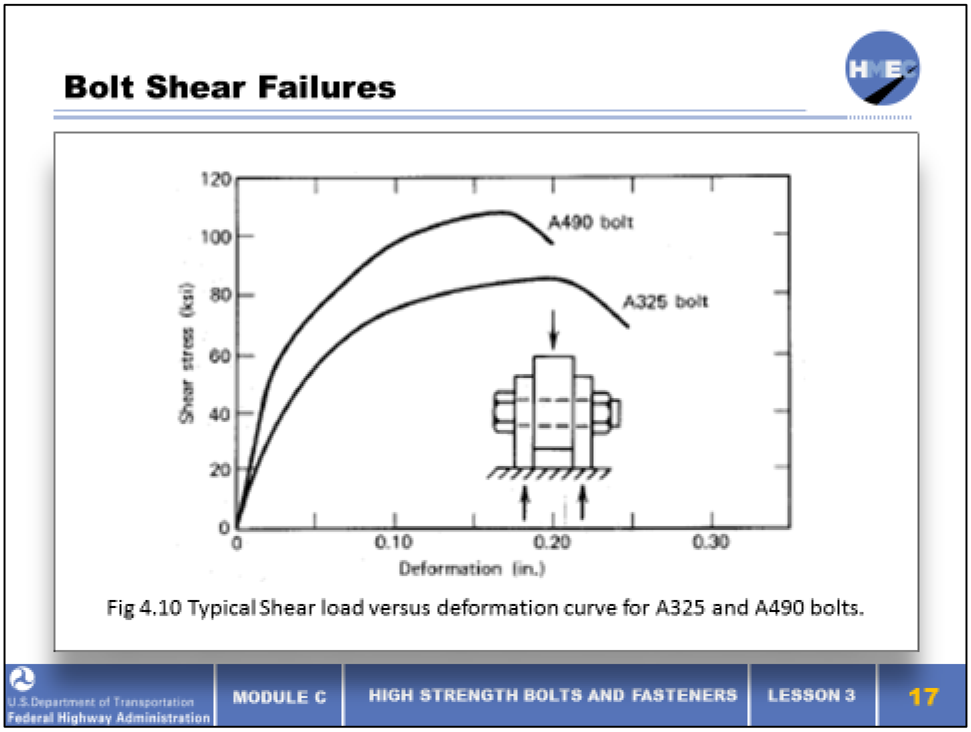
It is impossible to have friction-free threads, and when a nut is tightened it applies some torque to the bolt shank. The failure mode is therefore a combination of tension and shear due to torsion. The tension capacity is weaker when the tension is due to tightening of the nut. The most common bolt failure is due to over-tightening during installation (left bolt photo). There is a limited amount of necking in the threaded area and the failure plane is perpendicular to the bolt shank. A direct tension failure (right photo) has more necking of the bolt diameter and an angled failure plane.

Slide 17

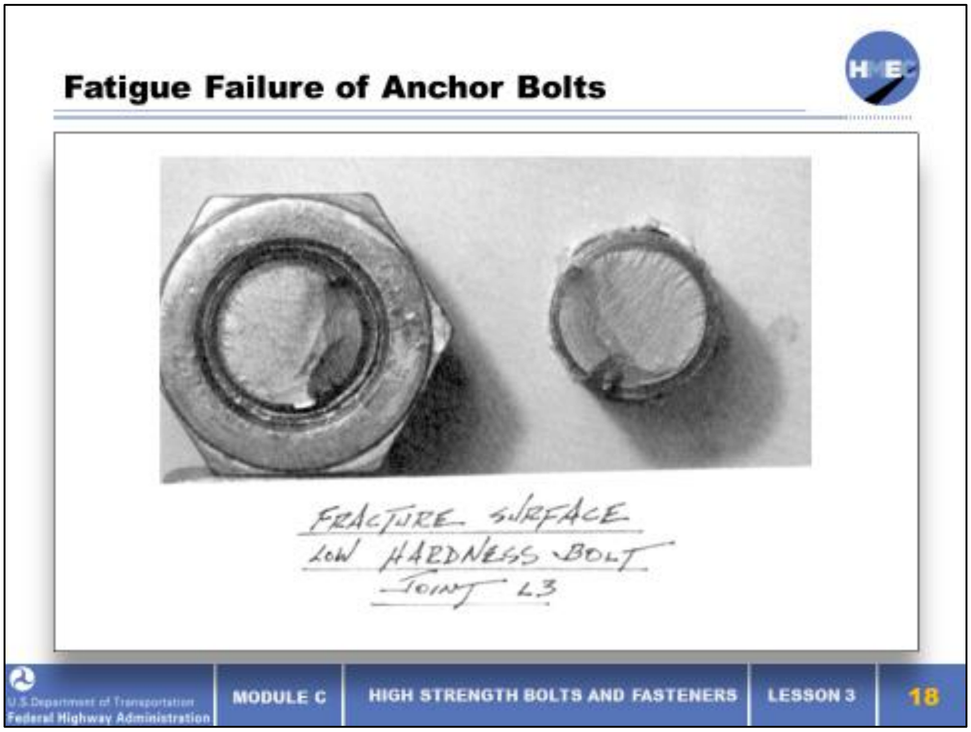


The strength of the bolts usually exceeds the strength of the connected parts. Special hardened fixtures are required to cause a shear failure in the laboratory. A490 bolts have higher strength but lower ductility.

For reference:

- The shear capacity of A325 is 0.6 (120) = 72 ksi; and
- The shear capacity of A490 is 0.6 (150) = 90 ksi.

Slide 18



This type of failure affects bolts loaded in tension that have a variable (cyclic) load applied. An example are bolts that connect cantilever sign structures. Fatigue starts in the root notch of the thread at the point of highest cyclic tension. The crack continues to grow slowly in proportion to the cyclic loading. The bolt fails when there is not enough section left to resist the loads.

Factors to discuss include:

• Proper bolt tightening;
• Cyclic loads due to wind and resonance of the structure; and
• Improper galvanizing (this is a current research issue).

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There are many limit states that are considered in connection design in addition to bolt strength. For the connected parts:

- Bearing strength;
- Tearout strength;
- Gross section yielding;
- Net section rupture; and
- Block shear.

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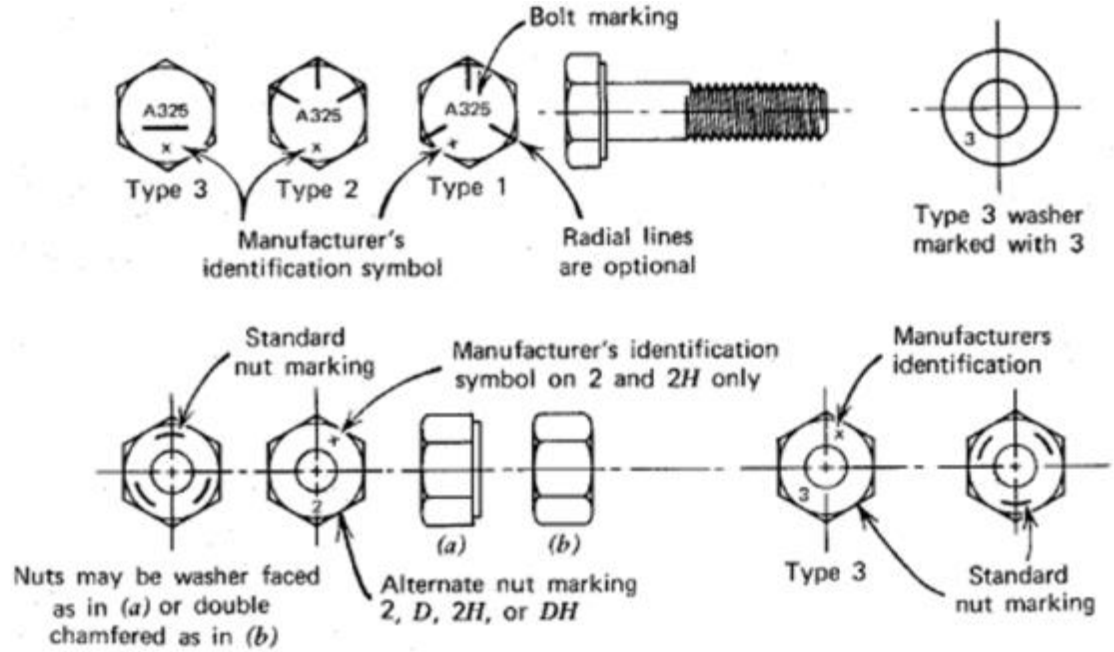
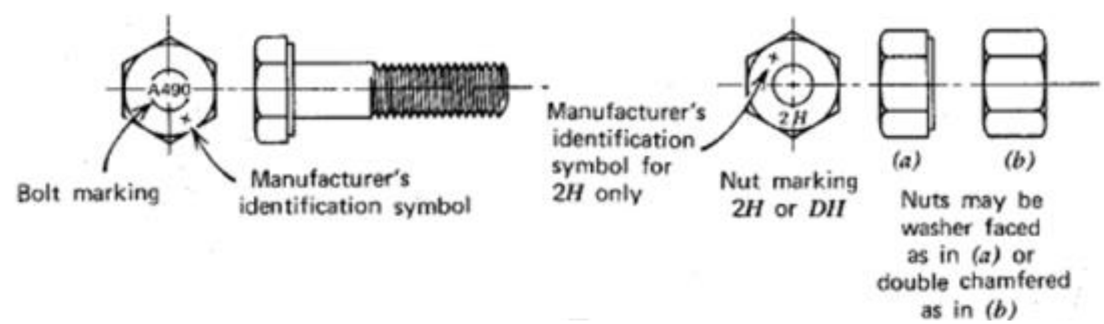
Slide 20

A325 bolts

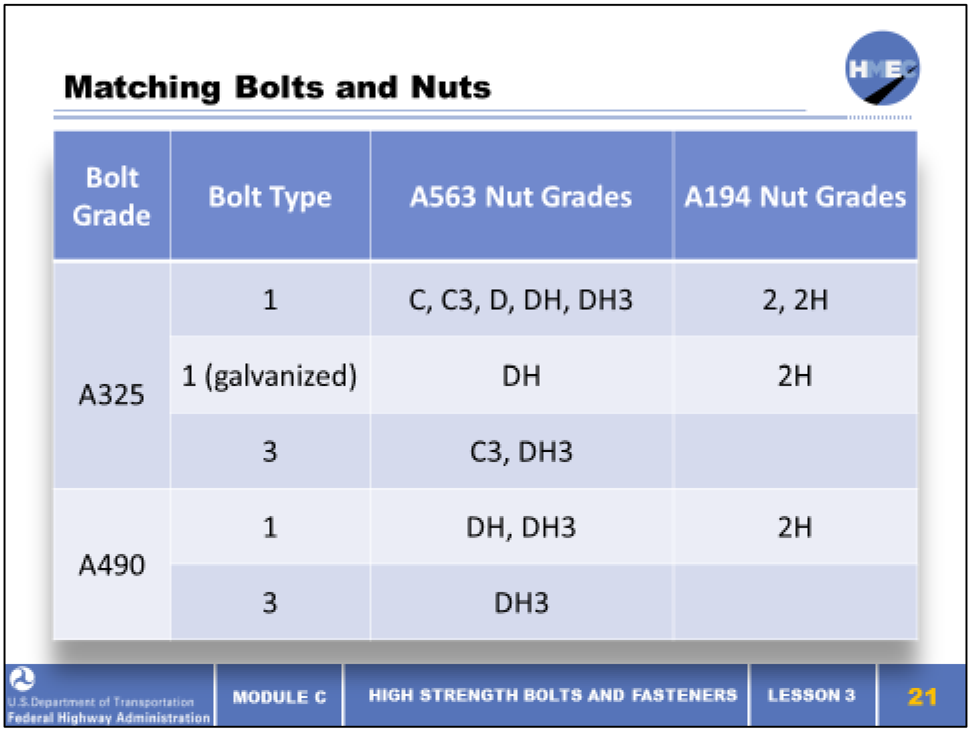


A490 bolts



The bolt grade is required to be clearly marked on the bolt head. This facilitates inspection and verification that the proper fasteners have been installed in a given connection. The bolt manufacturer's symbol is also required on the bolt head. Radial lines indicating bolt type are optional, except the underline is required for Type 3 to identify weathering. Nuts are also required to have grade markings to ensure a compatible fastener assembly.

Slide 21



Bolt Grade	Bolt Type	A563 Nut Grades	A194 Nut Grades
A325	1	C, C3, D, DH, DH3	2, 2H
	1 (galvanized)	DH	2H
	3	C3, DH3	
A490	1	DH, DH3	2H
	3	DH3	

The nuts are "heavy hex nuts" that have a sufficient thread length to prevent stripping. This ensures that the fasteners will fail by reaching the tensile strength of the bolt. Note that the same nut grades may be used for both A325 and A490 bolts in some cases. Why? The nut threads can develop the capacity of either bolt). Weathering nuts are required for Type 3 bolts. Note that weathering nuts can also be used on Type 1 bolts that are painted.

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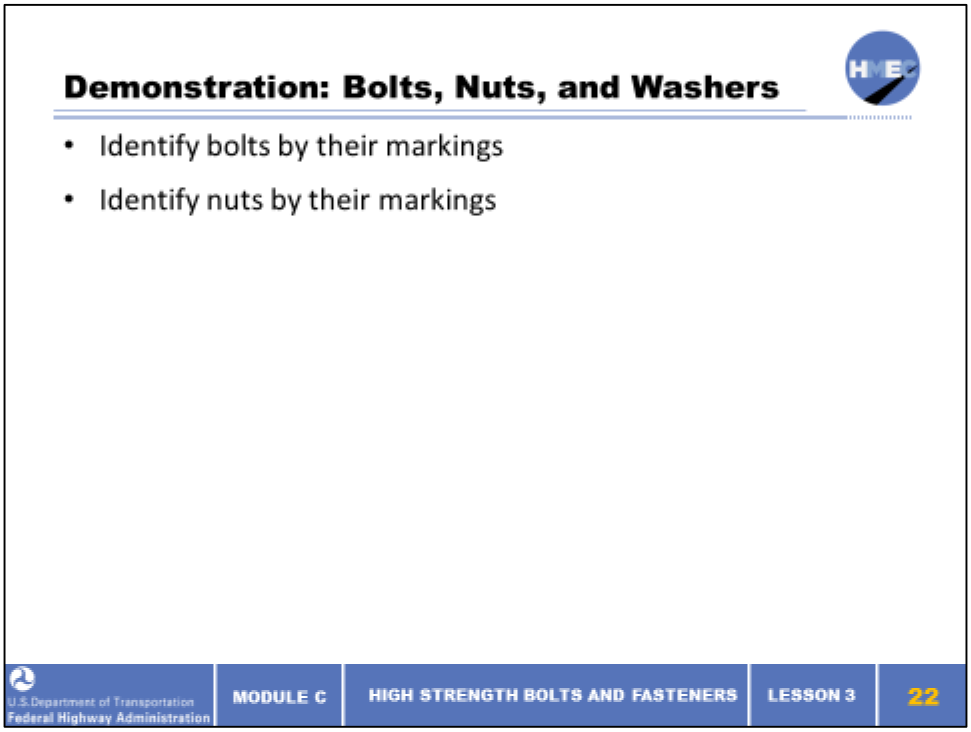
Slide 22



The bolt grade is clearly marked on the bolt head. Nuts also have grade markings to ensure a compatible fastener assembly.

Slide 23

Nut Hardness

Nut Grade	Minimum Hardness	Maximum Hardness
C, C3	HRB 78	HRC 38
D	HRB 84	HRC 38
2	HRB 84	---
Recommended	HRB 89	HRC 38

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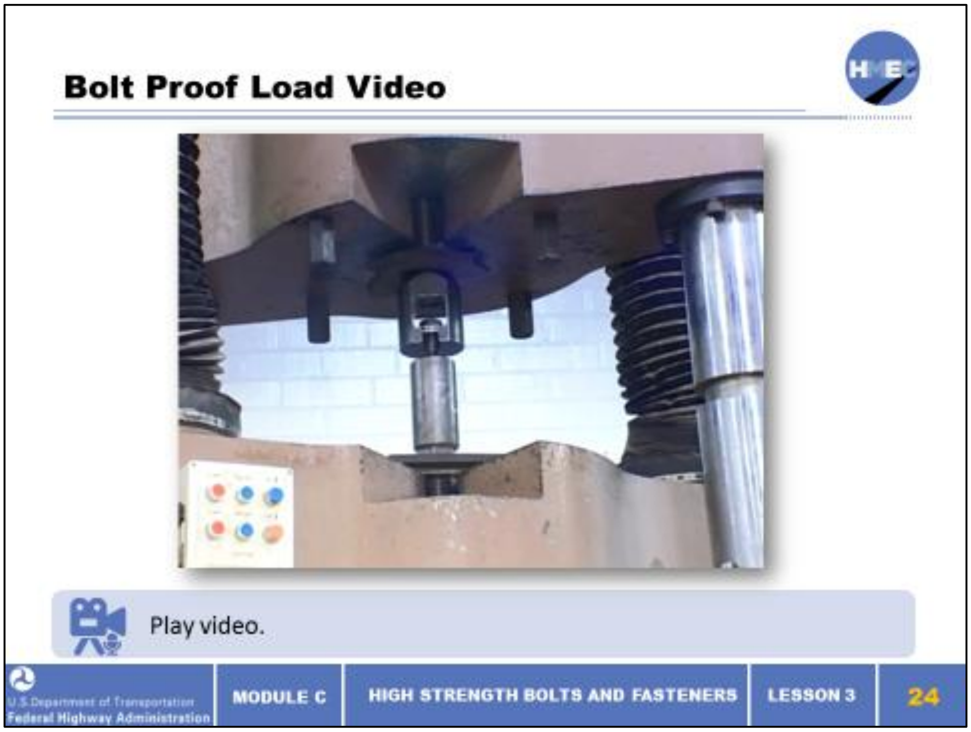
The Rockwell "B" scale is used to specify the minimum hardness since nuts are generally lower strength compared to bolts. Similar to bolts, the maximum hardness is checking to ensure the nuts have been tempered properly and are not brittle. The minimum hardness is specified for some grades along with a recommended hardness. The nut hardness is not a critical measure of performance. Nuts must have sufficient capacity to pass the rotational capacity tests discussed next. Weak nuts will strip before the required bolt capacity is reached.

Slide 24



This test pulls a bolt in a similar way that a bolt would be loaded in a tension connection. The load in the bolt is pure tension. Similar to a plate tension test, the before and after length of the bolt is measured to determine the elongation. Note that the bolt will always fail in the threaded region and that the failure plane is angled.

Test steps:

1. Center-punch each end of the bolt to determine gauge length.
2. Measure gauge length.
3. Mount in testing machine.
4. Apply proof load.
5. Remove from testing machine.
6. Measure elongation. There should be **none**.
7. Remount in testing machine.
8. Reapply load until fracture.

The reported results are proof strength (ksi), elongation, and tensile strength (ksi).

Slide 25

Bolt Proof Load

Sample Test Report for ¾-inch ASTM A325 bolt

sample ID	proof load (kips)	elongation	tensile load (kips)	failure location
1	28.4	none	40.5	in threads
2	28.4	none	41	in threads
3	28.4	none	42.1	in threads
4	28.4	none	41.8	in body
5	28.4	none	42.5	in threads
6	28.4	none	40.9	in threads

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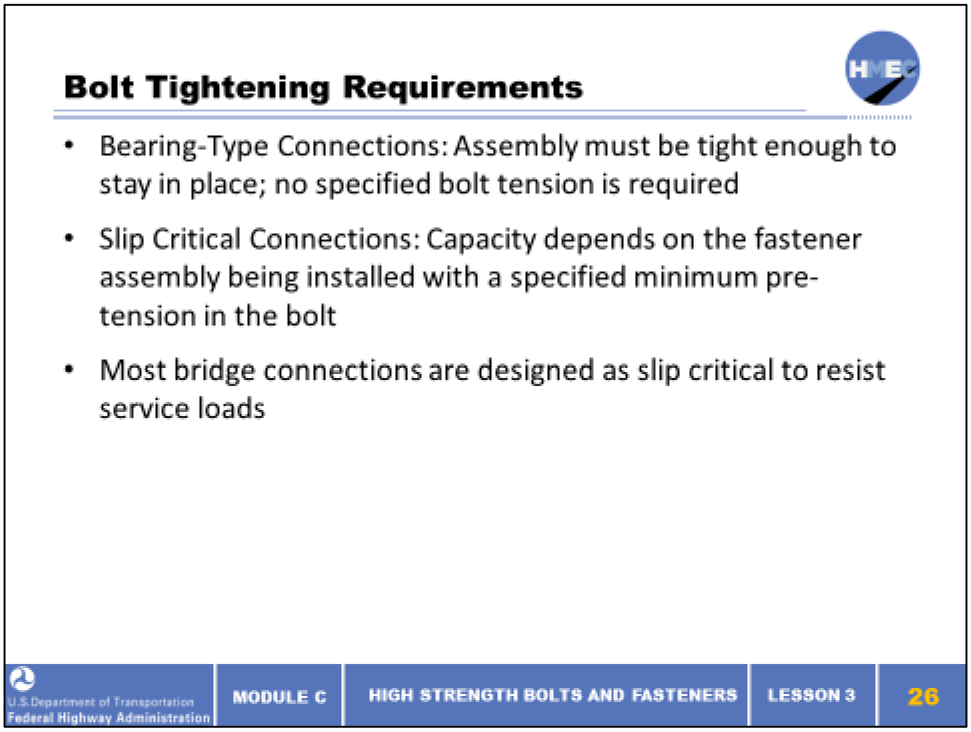
ASTM A370 does not include a standard test report form. It does include the information that should be included in a test report for bolts. The sample test report shown includes the data typically gathered during a proof test. An acceptable test shows no elongation under the proof load and does not fail at the juncture of the bolt and the head.

Slide 26



The strength of bearing-type connections does not depend on the pretension in the fastener. Installation is not critical for this type of connection, the fasteners must be sufficiently tightened to prevent loosening.

The capacity of slip critical connections depends on having a specified amount of tension on the bolt after installation to ensure adequate clamping force on the connection. The tension is created by tightening the fastener assembly. Therefore, proper tightening procedures are essential. Bolts are usually tightened by an air or hydraulic impact wrench. The tightening method must be calibrated to ensure it reliably introduces the proper tension.

All connections in bridges that are subject to cyclic loading are designed as slip critical to resist the maximum load that is expected in service. After slip failure, the connection has an additional factor of safety with respect to total connection failure. Therefore, if a slip critical connection fails, it does not cause failure of the structure. It creates serviceability problems, such as fretting of the faying surfaces from repeated reversal of loads or simple misalignment of the joint causing a kink in the member.

Slide 27

A Skidmore-Wilhelm bolt tension calibrator is a load cell that measures the amount of torque to be applied to the bolts of a fastener assembly to achieve the appropriate torque. The tension calibrator is used to perform the rotational capacity test.

Slide 28

Test steps:

1. Measure the bolt length, the distance from the end of the bolt to the washer face at the bolt head to shank interface.

2. Install the bolt in the tension calibrator with the required spacers or washers so that the bolt stick-out is flush with the nut to a maximum of three threads. This will typically provide three to five threads within the grip, the distance between the bolt head and the inside face of the nut. This same stick-out requirement applies during installation.

3. Tighten the fastener assembly using a spud wrench to the specified initial tension.

4. Match mark the bolt, nut and face plate of the calibrator.

5. Using the calibrated torque wrench, tighten the fastener assembly to at least the minimum installation tension and record both the tension and torque. Torque shall be read with the nut rotating. The torque value from the test shall not exceed T= 0.25 PD. P= tension in pounds. D = bolt diameter in feet.

6. Further tighten the bolt the specified fraction of a turn. The rotation is measured from the initial marking in step 4.

7. Record the tension at the completion of the rotation in step 6. The tension shall equal or exceed 1.15 x the minimum installation tension. The minimum required values are listed in the table below.

8. Loosen and remove the nut. There shall be no signs of thread shear failure, stripping or torsional failure. The nut shall turn, with your fingers, on the bolt threads to the position it was in during the test. The nut does not need to run the full length of the threads. If you cannot turn the nut with your fingers it is considered thread failure.

The following constitute a failure of the rotational capacity test.

- Exceeding the maximum allowable torque in the torque/tension comparison.
- Failure to achieve the required rotation.
- Failure to achieve the required tension at the required rotation.
- Thread failure.

Note: http://www.fhwa.dot.gov/bridge/rotational.cfm and the AASHTO/NSBA Steel Bridge Collaboration S10.1 – 2007, Steel Bridge Erection Guide Specification

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Slide 29

Rotational Capacity Test

Sample Test Report for ¾-inch ASTM A325 bolt

sample ID	initial				after twice* the installation rotation			thread condition OK?
	measured tension (kips)	measured torque (ft-lb)	permitted max torque (ft-lb)	OK?	measured tension (kips)	minimum tension (kips)	OK?	
1	28	403	437	✓	34	32	✓	✓
2	28	414	437	✓	36	32	✓	✓

* For long bolts, less than twice is the specified rotation.

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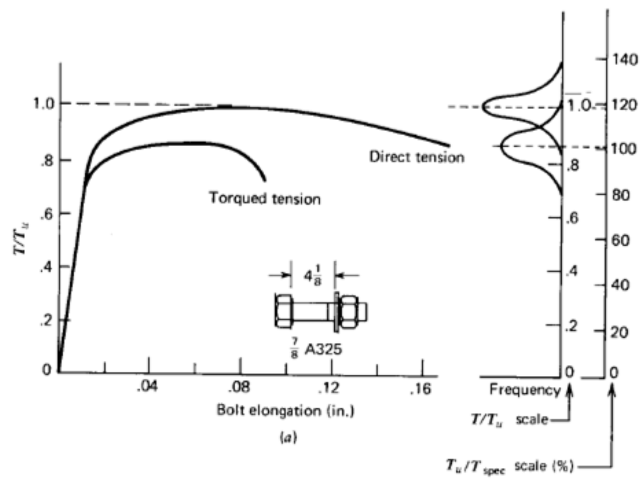
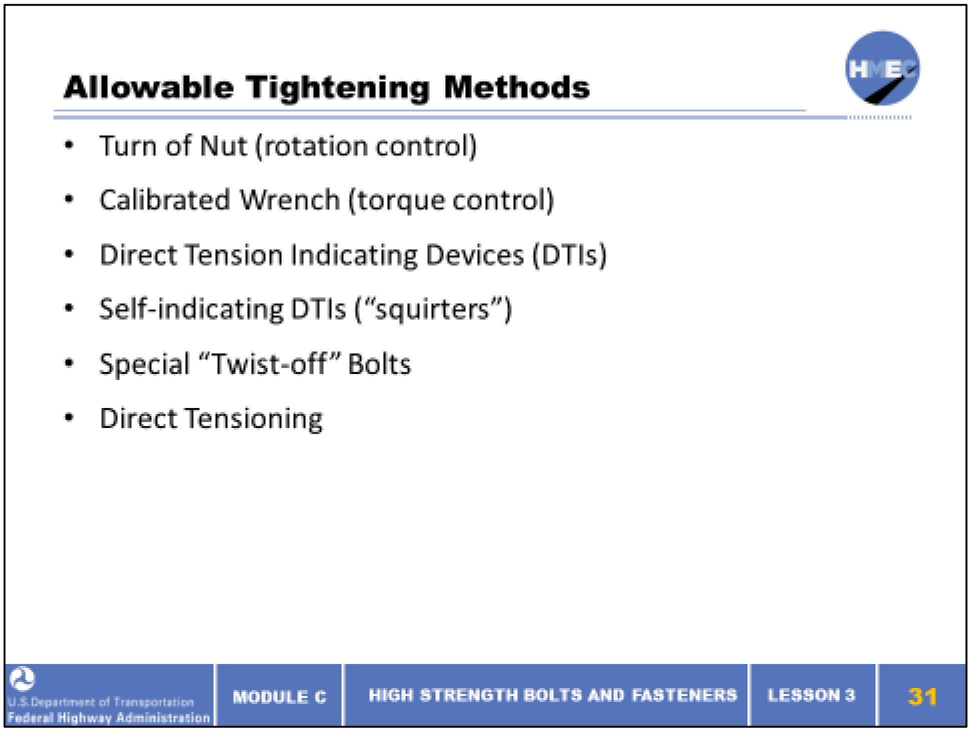
No ASTM standard exists for the rotational capacity test report. The sample test report shown includes all of the pertinent data to be recorded.

Slide 30


1.0
.8
.6
.4
.2
0
T/T_u
.04
.08
.12
.16
Bolt elongation (in.)
(a)
Direct tension
Torqued tension
$4\frac{1}{8}$
$\frac{7}{8}$ A325
140
120
100
80
60
40
20
0
Frequency
T/T_u scale
T_u/T_{spec} scale (%)

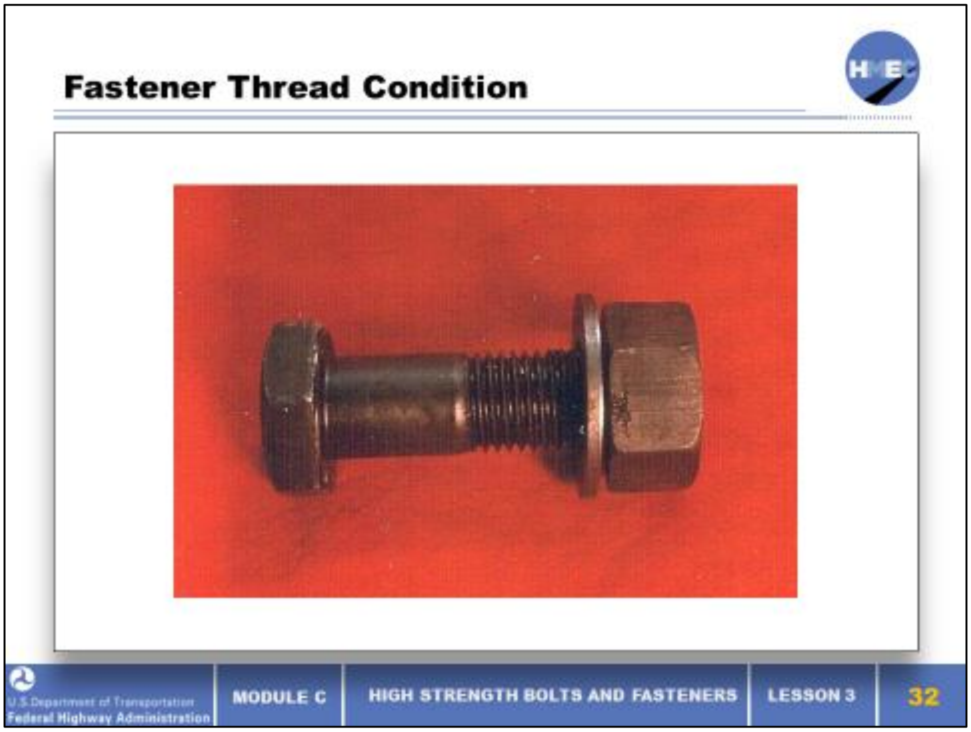
This slide shows the results from two bolt tests, one that was pulled in direct tension and one where the nut was torqued to provide tension.

Slide 31



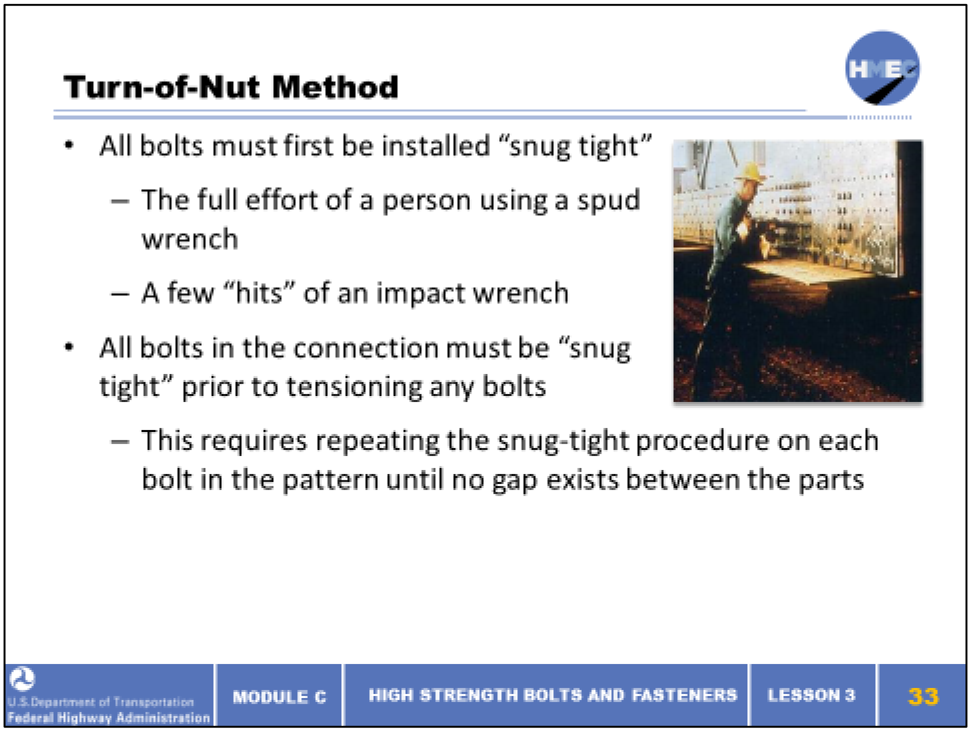
The Skidmore device is used to calibrate each of these tightening methods. Torque and rotation can be applied either by hand or using powered equipment. For the turn-of-nut method, the required rotation is applied to the assembly and the resulting tension is measured. The calibrated wrench method measures the required torque to reach the specified minimum tension. DTIs are simply washers with dimples that get crushed with the proper bolt load. Feeler gauges are used to quantify the crushing. Self-indicating DTIs "squirt" a dye when the dimples are properly crushed. Finally, twist-off bolts are bolts with an attachment that breaks off in twisting when the proper torque is applied. There are special hydraulic jacks that can be used to direct tension the fasteners. This is relevant to tightening anchor bolts.

Slide 32



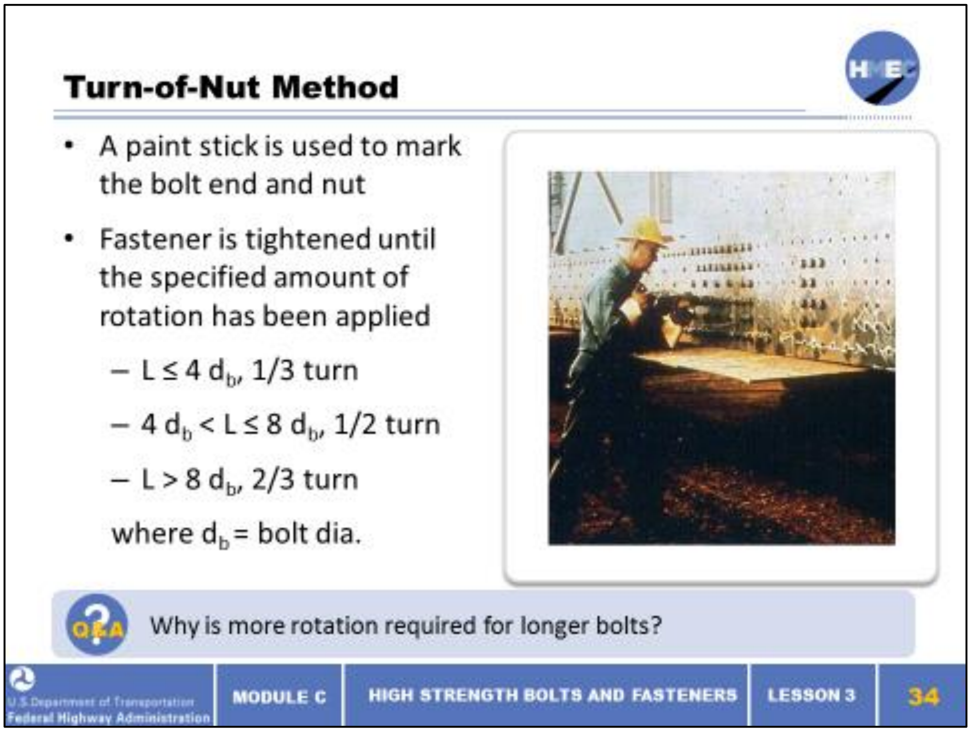
Fasteners must be tested as assemblies using the actual nuts, bolts, and washers to be installed. The condition of the threads is critical. Fasteners must be protected from wetness, which will develop corrosion on the threads. The bolts and nuts must have an adequate lubrication coating to prevent galling of the threads, often referred to as a cold-welding process, when the surfaces of male and female threads are placed under heavy load such as during fastening. The condition of the lubrication also has a significant effect on the rotational capacity.

Slide 33



It is common that the connected parts are not perfectly flat. If there is any gap, the first fasteners tightened will loosen as more fasteners are tightened. Therefore the "snug-tight" procedure must be repeated over the entire pattern until no more bolt loosening occurs.

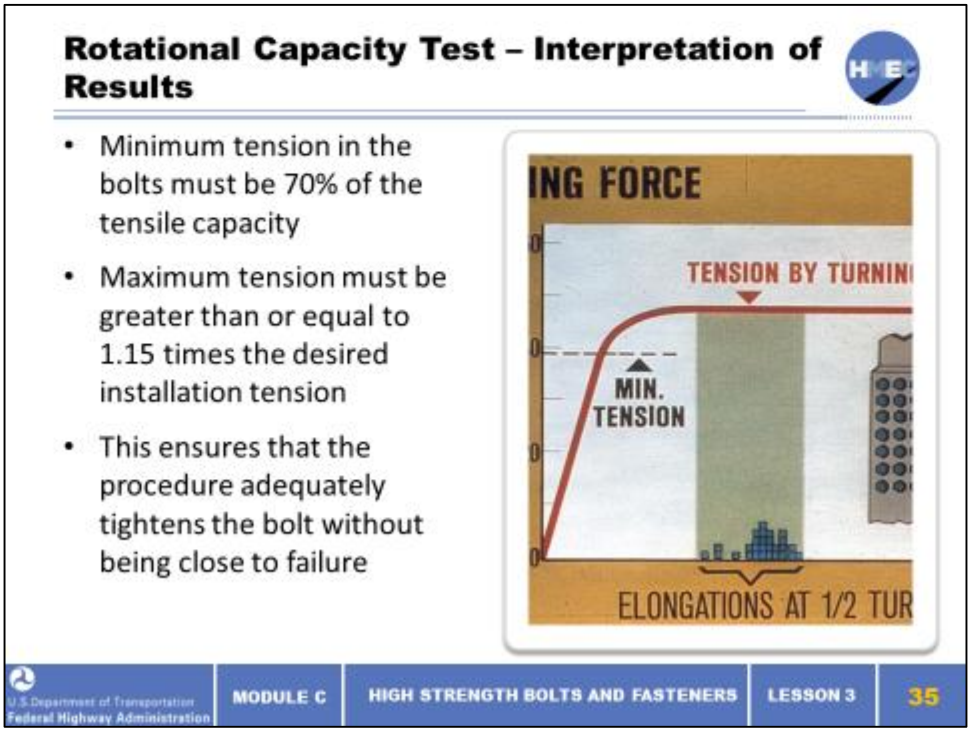
Slide 34



When all bolts are snug tight, a paint stick mark is made on the bolt end and nut. The nuts or bolts are then turned until the desired rotation is reached. The paint stick markings serve as inspection evidence that the required rotation has been applied.

For required nut rotations of 1/2 turn and less, the tolerance is plus or minus 30 degrees; for required nut rotations of 2//3 turn and more, the tolerance is plus or minus 45 degrees.

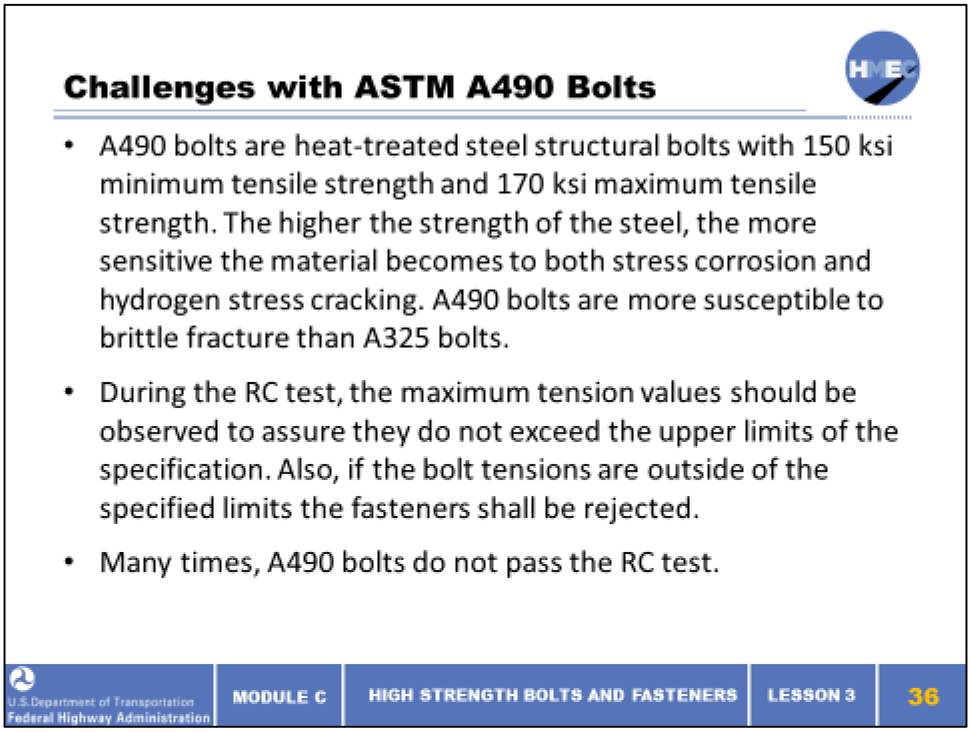
Slide 35



Note that the load versus deformation curve becomes relatively flat at the desired condition for the installed fastener. There is a fairly wide tolerance of the amount of rotation required to achieve this tension. Torque methods are more sensitive to calibration.

The turn-of-nut method is usually preferred since it is less sensitive to procedure and does not require calibration as often.

Slide 36



Their higher strength makes A490 more susceptible to brittle fracture. The rotational capacity (RC) test is a challenge for A490 bolts. A325 bolts are preferred wherever possible.

Slide 37

Alternate Bolting Methods – Calibrated Wrench

- An impact wrench is used to install bolts in the Skidmore device on the jobsite
- Wrench is adjusted to apply the necessary torque to create the proper tension in the bolt
- Wrenches must be calibrated daily on the diameter, length, and thread condition of bolts to be used that day
- Care must be taken to ensure the wrench stays in adjustment
  - Same hose length
  - Same air pressure
  - No wrench setting changes
- Proper installation depends on having a calibrated wrench
- This requires much more care than turn-of-nut and is more difficult to inspect

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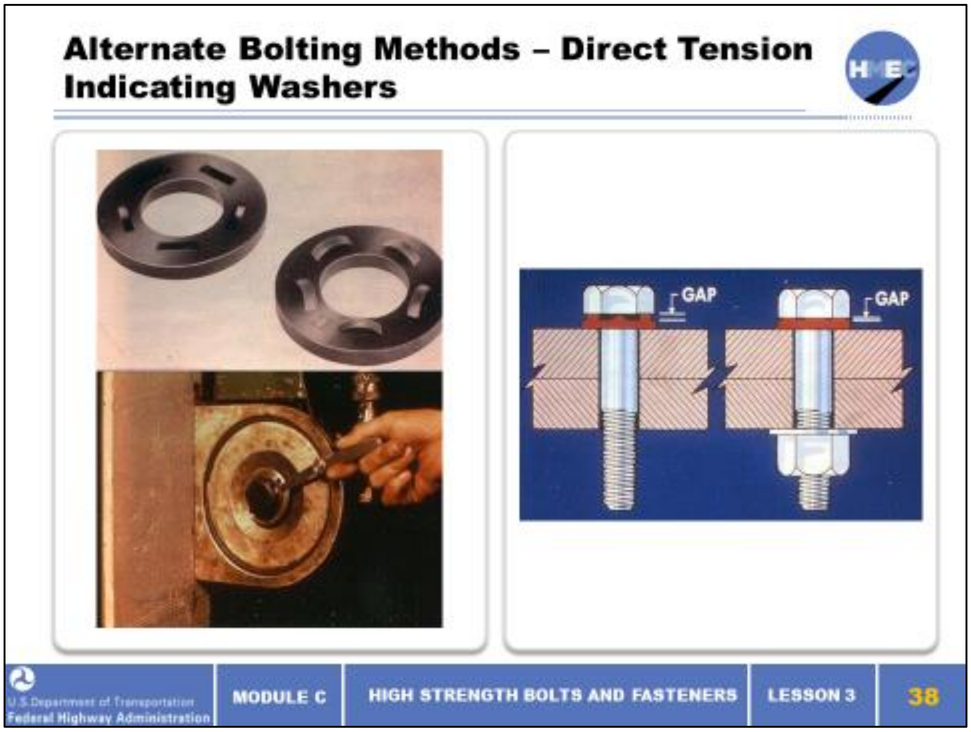
Slide 38

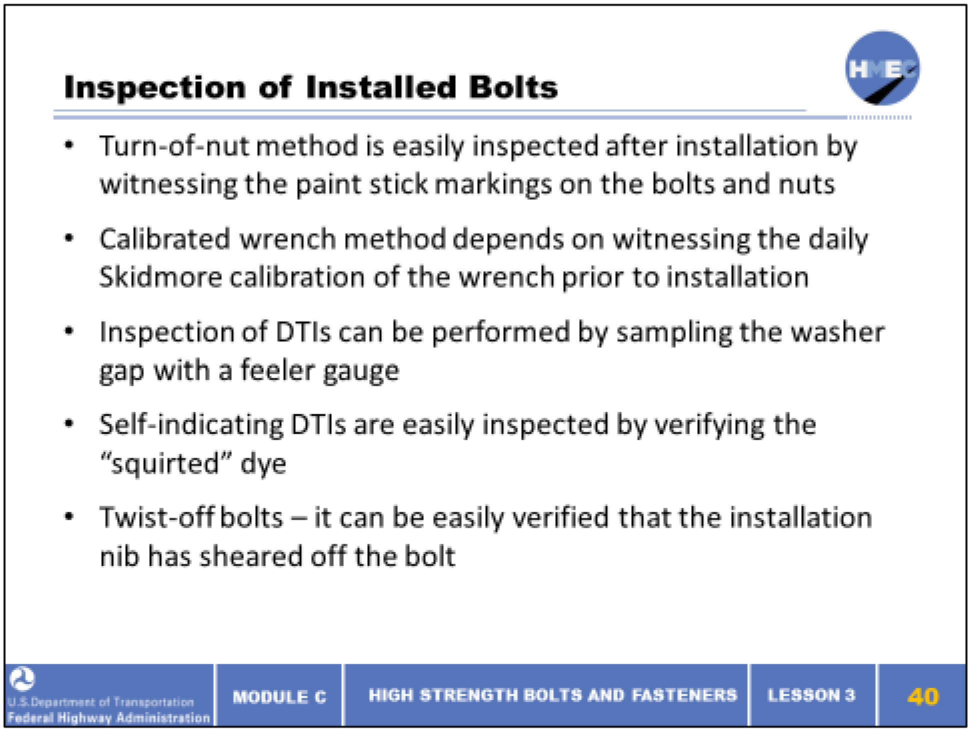


DTIs are an alternative method that allows the tension of an installed bolt to be measured directly. Washers are fabricated with deformations that create a space between the bolt head and the washer. These are typically installed under the part that does not turn during tightening. Tightening the assembly crushes the deformations and reduces the gap. Adequate tension is verified by inserting a feeler gauge into the gap. The gap will be too large for under-tightened bolts and too small for over-tightened bolts. DTIs are allowed under the turned element provided there is a hardened washer, plus an assembly of a captive DTI nut is available.

Slide 39

There are typically no provisions for attaching a wrench to the bolt head—it looks like the domed head of a rivet. This is a one-sided fastening system that does not require holding the bolt head with a wrench. If desired, a twist-off bolt with a hex head is available. The end of the bolt has a splined nib with a reduced diameter than the bolt threads. A special powered wrench is used for tightening. The wrench engages the nib and prevents rotation of the bolt shank while turning the nut. The nib is designed to shear off when the required tension is reached.

Slide 40


Inspection of Installed Bolts
Turn-of-nut method is easily inspected after installation by witnessing the paint stick markings on the bolts and nuts
Calibrated wrench method depends on witnessing the daily Skidmore calibration of the wrench prior to installation
Inspection of DTIs can be performed by sampling the washer gap with a feeler gauge
Self-indicating DTIs are easily inspected by verifying the "squirted" dye
Twist-off bolts – it can be easily verified that the installation nib has sheared off the bolt
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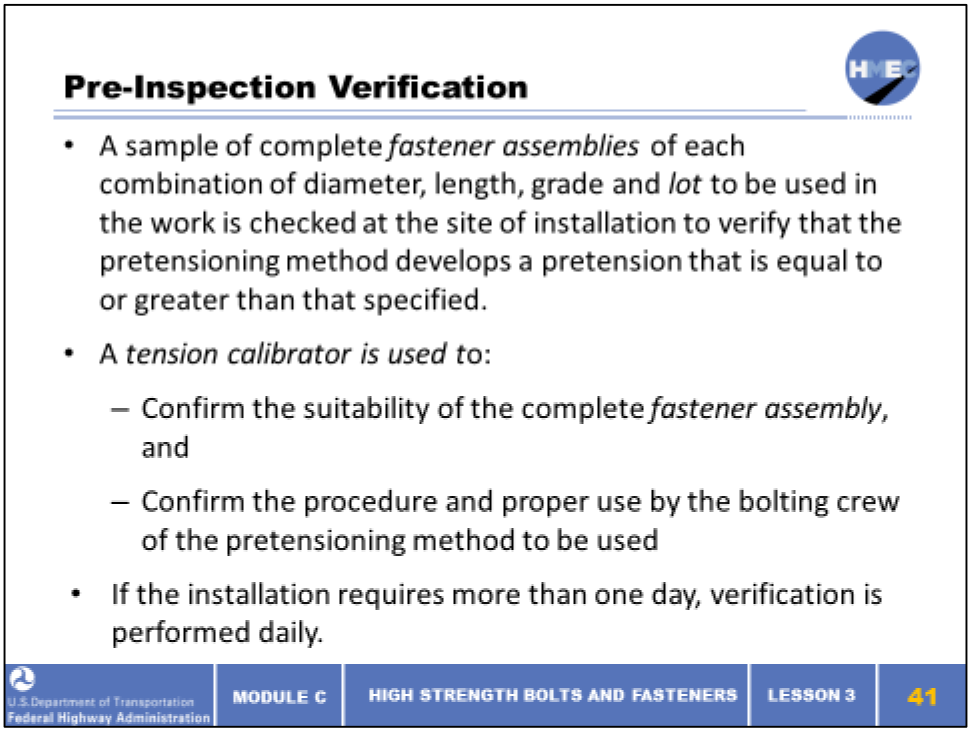
Slide 41



A representative sample of not fewer than three complete *fastener assemblies* of each combination of diameter, length, grade and *lot* to be used in the work shall be checked at the site of installation in a *tension calibrator* to verify that the pretensioning method develops a pretension that is equal to or greater than that specified. Washers shall be used in the pre-installation verification assemblies as required in the work

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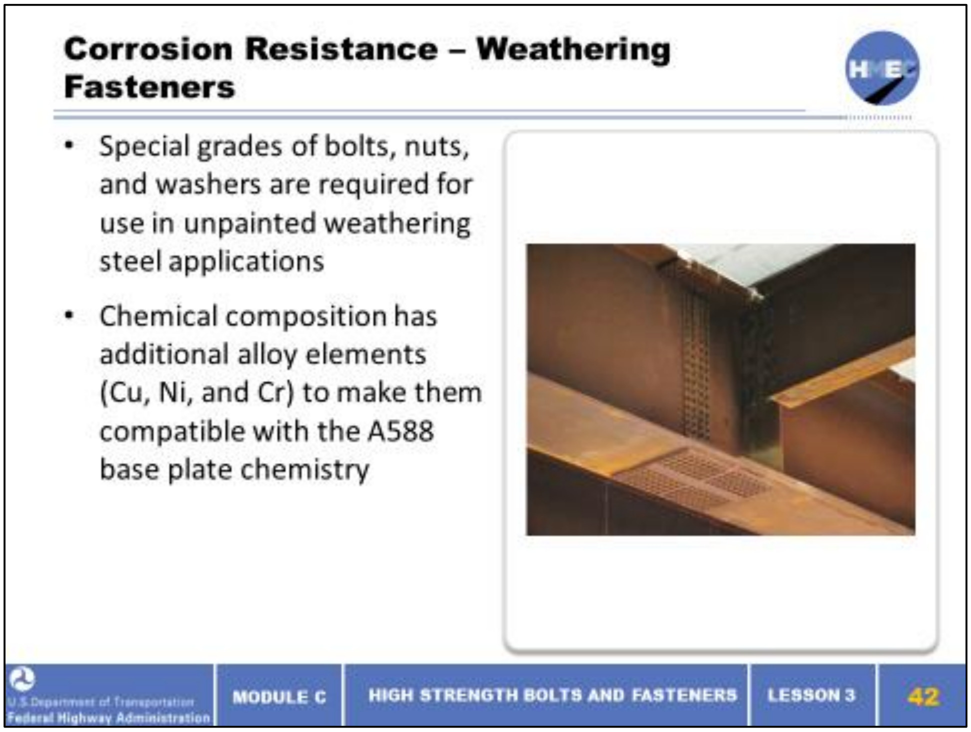
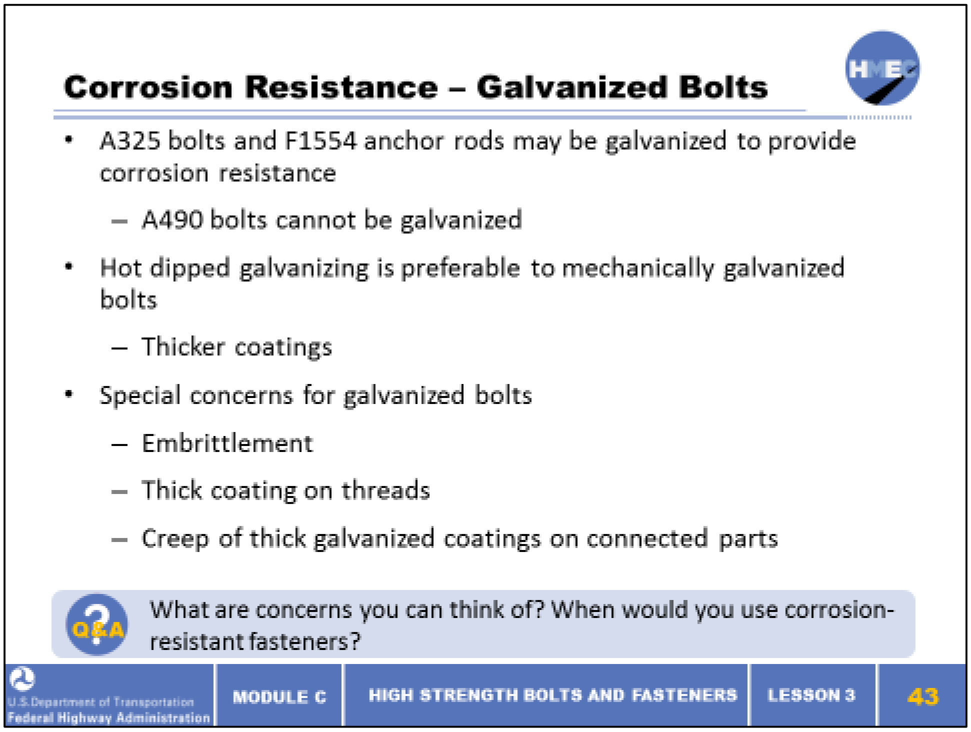
Slide 42



Special grades of bolts, nuts, and washers are required for use in unpainted weathering steel applications. The chemical composition has additional alloy elements (Cu, Ni, and Cr) to make them compatible with the A588 base plate chemistry. Type 3 bolts are required to provide the "weathering" chemical composition to match steel grade 50W plates.

Slide 43

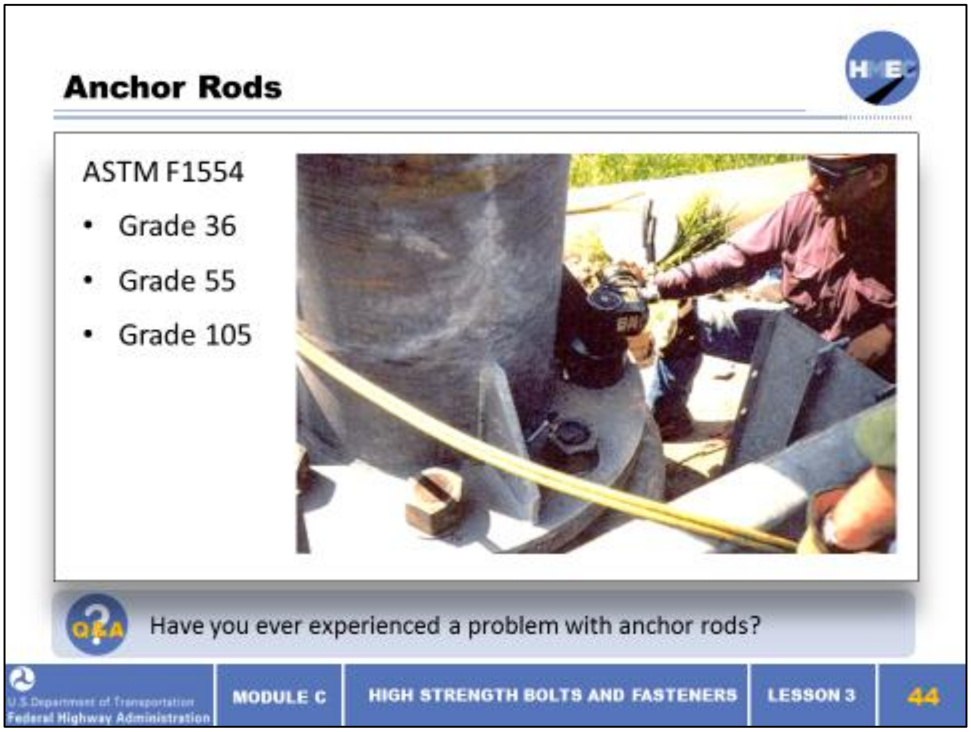


High strength (A490) bolts are sometimes susceptible to embrittlement when galvanized. The ductility of the bolts is therefore reduced. There is also a possible reduction in fatigue resistance. For this reason, galvanizing is limited to A325 bolts.

Thick coatings can affect thread tolerances and lead to wrench stalling.

The friction coefficient of slip critical connections depends on the coefficient of friction between the connected parts. Thick galvanized coatings can cause time dependent creep that allows the connections to slowly slip. This can lead to the slow development of deflections in some types of structures.

Slide 44

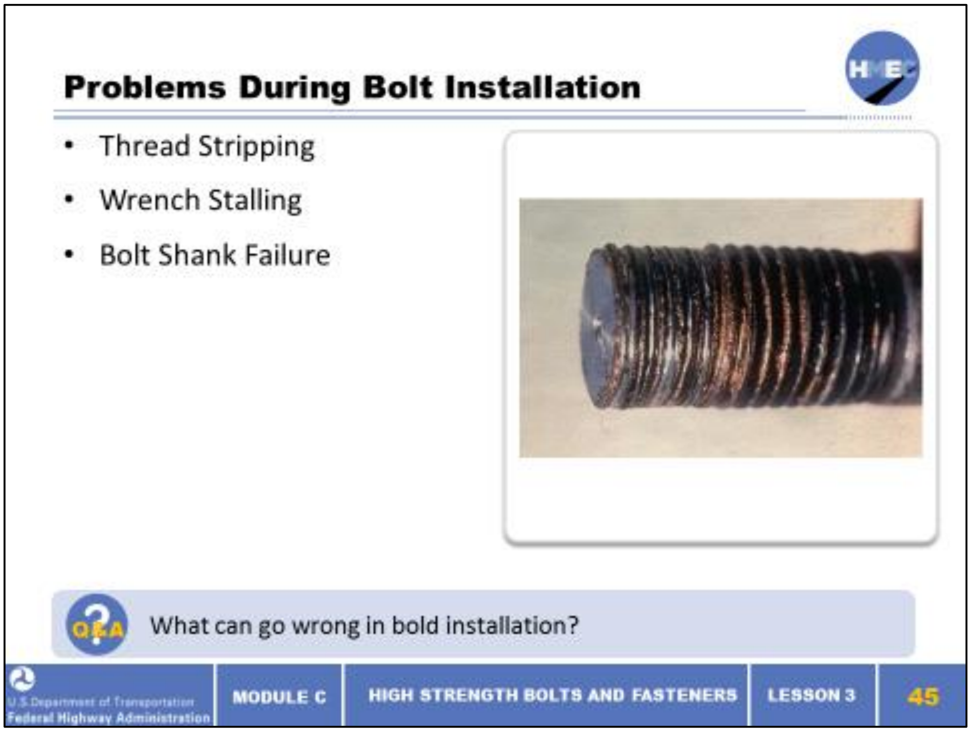


The grade indicates the yield strength of the rod. Anchor rods are often galvanized to resist corrosion.

Nuts are used to attach structural parts to a foundation. Installation is usually performed by the turn-of-nut method. Because of the large diameter, high-powered wrenches are required. Installation and proper tightening is critical for anchor rods that are loaded in tension. For sign structures, top and bottom nuts are often used to provide adjustment capability. The nuts must be properly snugged and the bottom nuts properly adjusted prior to starting the tightening procedure.

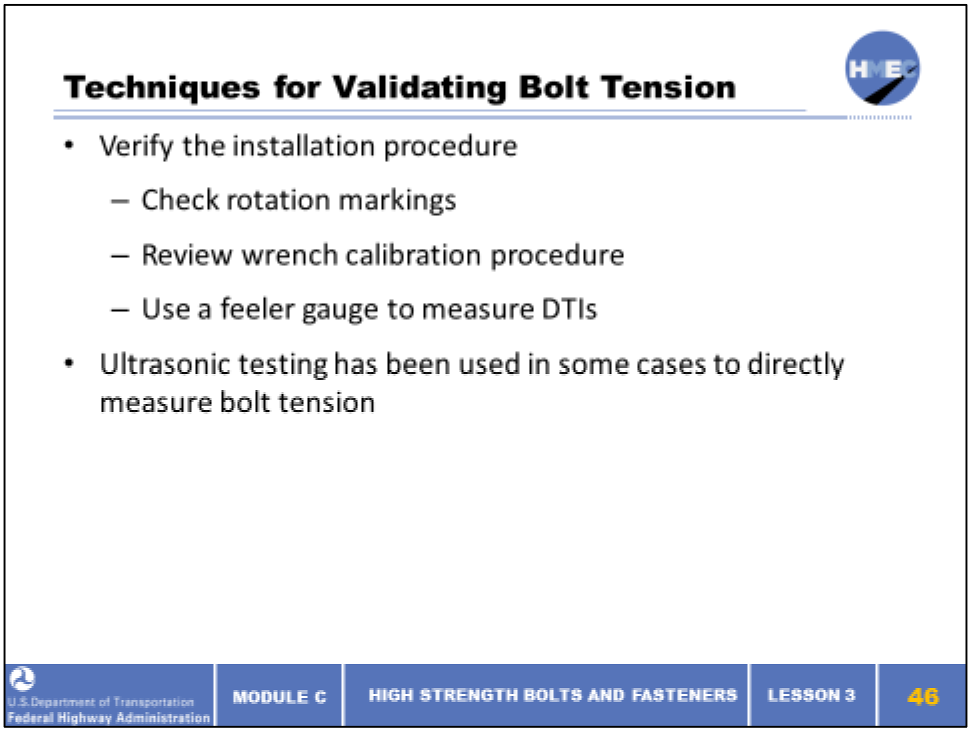
The stress range in the rods due to cyclic loading is calculated assuming each rod carries its proportional share of the load. Improper installation or loose nuts changes this assumption and overloads some rods in the pattern. There have been many cases of fatigue failure attributable to improper tightening.

Slide 45



Structural bolts cannot be reused. If they have a problem during installation, the bolt and nut must be removed and discarded. Once the problem is identified, a new bolt and nut must be installed.

Slide 46



The usual procedure is to inspect and validate that the proper installation techniques have been followed. Witness marks are present when the turn-of-nut method is used. The inspector can witness the final position of the marks. The calibrated wrench method is more difficult to inspect as the results depend on the integrity of the calibration procedures. DTIs can be directly measured using a feeler gauge.

Ultrasonic testing has also been used to directly measure bolt tension. The bolt head has to be ground smooth to allow attachment of an ultrasonic transducer. The velocity of sound waves traveling through steel changes when the steel is in a state of stress and the bolt will be slightly longer when it is in tension. The bolt head can be interrogated with an ultrasonic pulse that travels down and back along the length of the bolt. Changes in the return time can be calibrated to indicate tension. The UT device requires calibration on the actual bolts used in a Skidmore prior to use.

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Slide 47

Learning Outcomes Review

You are now able to:

- Identify the major types of bolts and fasteners, their properties and limitations, and their applications
- Describe the performance requirements of structural connections and how bolt properties affect that performance
- Describe best practices in installation procedures for bolts and fasteners
- Define the special provisions and concerns that apply to anchor bolts

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Slide 1


HMEC
Highway Materials Engineering Course
Lesson 4: Welding Process
MODULE
C
Steel, Welding, and Coatings
U.S.Department of Transportation
Federal Highway Administration

Slide 2

Learning Outcomes

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

- Describe how welding is used in highway structures
- Identify welding codes used to ensure sound practices in structural welding, particularly with respect to use of AASHTO/AWS D1.5 in steel bridges
- Calculate carbon equivalency and explain its effects on the weldability of metals
- Recognize the types of welding processes used for structural steel welding
- Explain the effects of member distortion
- Describe situations requiring special welding provisions
- Describe key aspects of achieving weld quality

This lesson will take approximately 3 hours, 30 minutes to complete.

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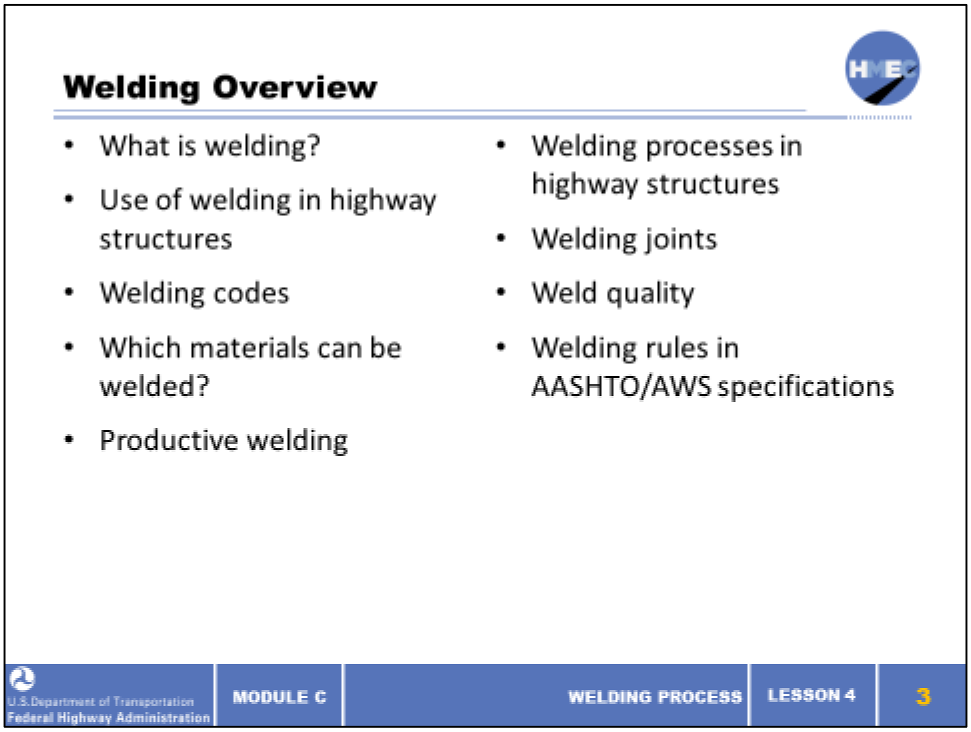
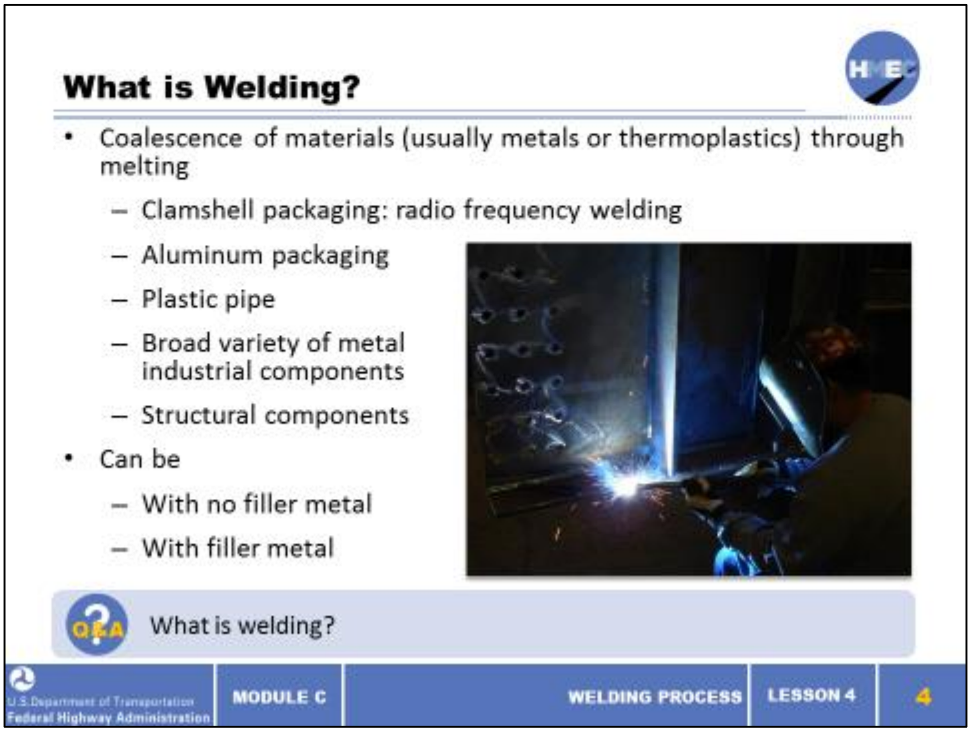
Slide 3



We will discuss what welding is as well as the use of welding in highway structures. We will also cover welding codes and which materials can be welded. We will discuss productive welding, welding processes in highway structures, welding joints, weld quality, and finally, the welding rules in AASHTO/American Welding Society (AWS) D1.5.

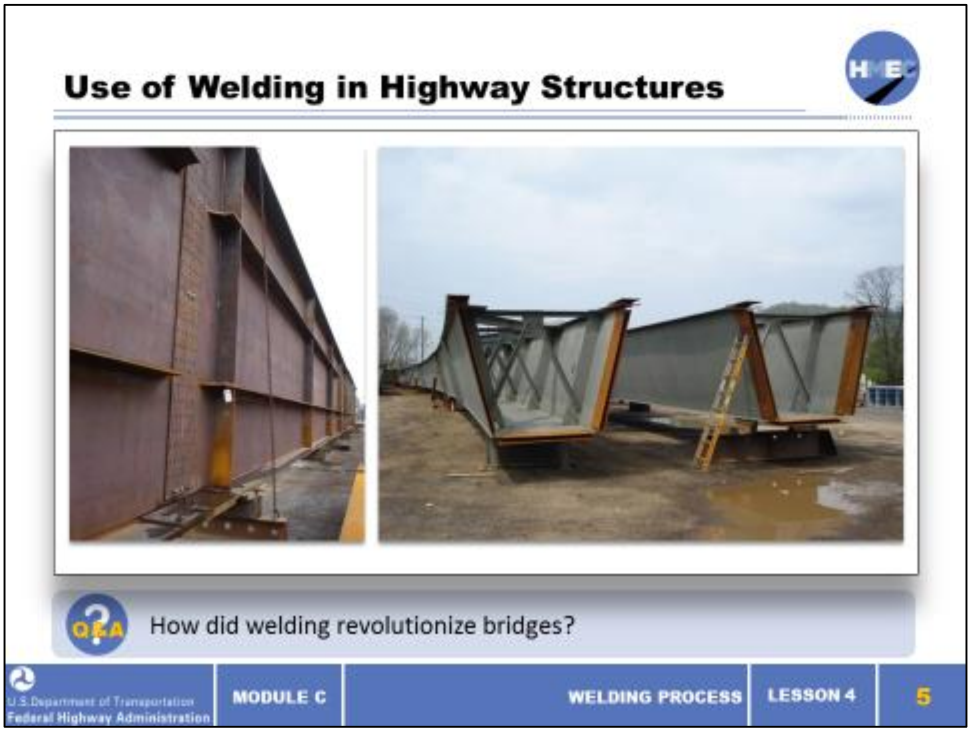
Slide 4



Welding is a manufacturing process that is highly useful for joining materials. You can weld just about any material that can be melted and re-solidified without destroying the material.

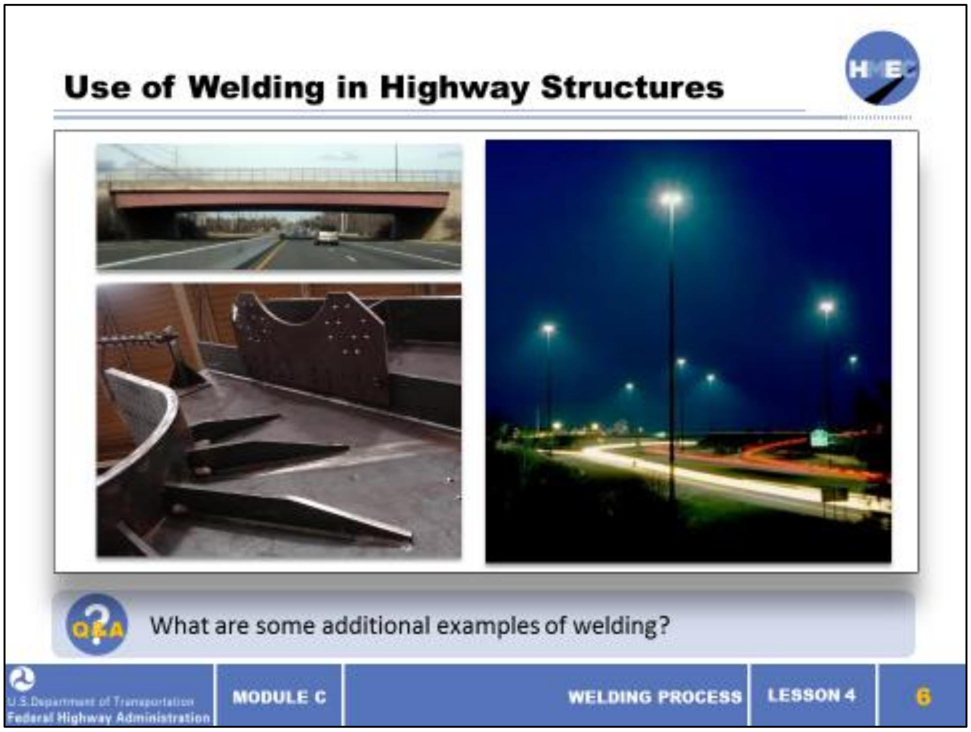
Examples include clam-shell packages (have fun with this—clam shell packing is very annoying), air-tight aluminum food packages, and many metal structures, such as bicycles, automobile frames, and, of course, steel structures. Welding can be done with no filler metal by simply melting the edges of the components to be joined and pressing them together. It can also be done with a filler metal by melting the two components to be joined plus additional metal.

Slide 5



Consider steel (or iron) bridges before welding. Early steel bridges were made of simple joined sections. Later, sections were built-up by combining multiple piles of plates, or making built-up I-shapes with riveted angles. This worked but it required a lot of effort. Welding readily allows I-shapes in a variety of shapes and sizes.

Slide 6



Here are some more examples of welding. As shown in the image on the screen, welding allows ready use of curved bridge shapes. Welding also allows for sophisticated stiffening design. For example, consider trying to make the stiffeners shown on the bottom left using bolted connections. Field welding allows for ready connections in the field, which can be especially important in accelerated bridge construction. Even concrete elements are sometimes joined in the field by embedded steel plates into the parts to facilitate field welding. Welding facilitates sign, light, and signal support structures. Consider the high mast pole shown on the right. These structures reach 150 ft. in height, and welding facilitates this.

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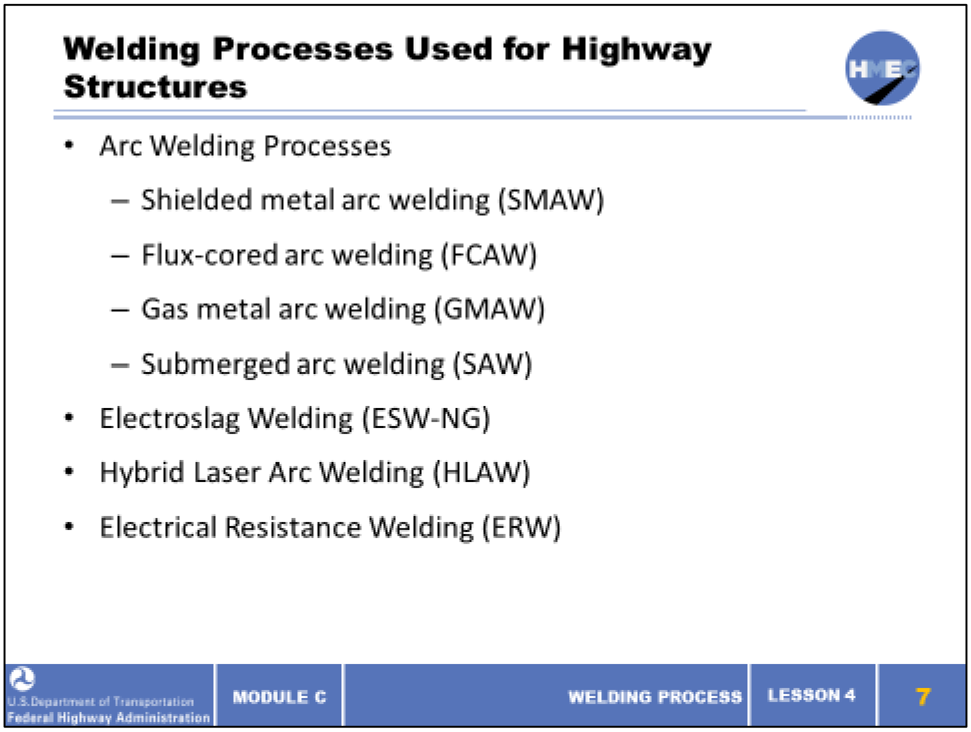
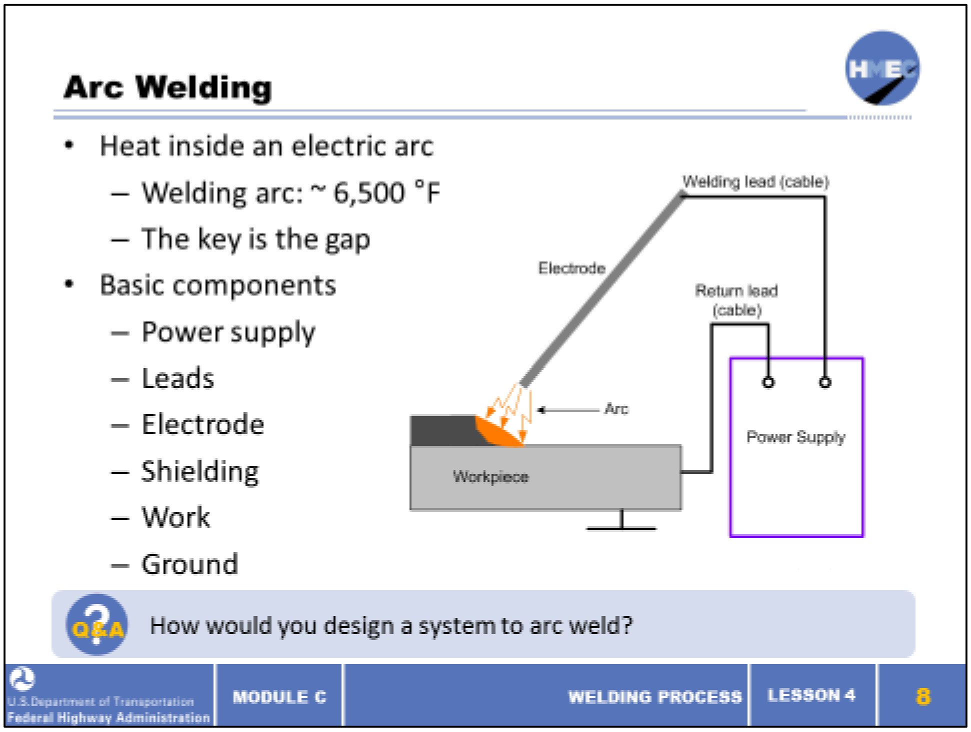
Slide 7



Traditionally, welding has been accomplished with arc welding processes, including those listed on this slide. Recently, however, narrow-gap electroslag welding (ESW-NG) has been making a comeback. Hybrid laser arc welding (HLAW) is currently used by one pole manufacturer, but it has potential for the future. As we discuss the processes, be mindful of the productivity preferences discussed on the previous slide.

Slide 8



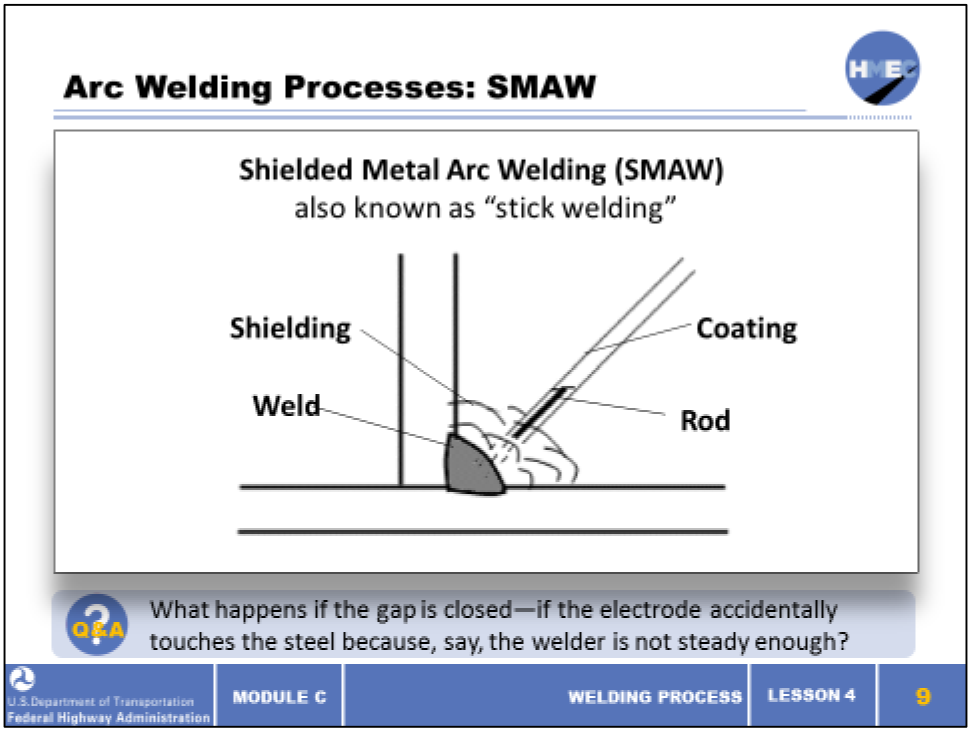
Arc welding takes advantage of an amazing electrical phenomenon: the electric arc. When electricity jumps across a gap, an intense heat (and light) results. The arc combines the temperature in a bolt of lightning (55,000 °F), the heat (sting) of a static shock, and the temperature of the welding arc (about 6,500 °F), which is plenty for melting steel.

The gap is crucial. Touch the electrode to the steel, closing the gap and the circuit, and the electricity will still flow, but it won't be very hot.

Basically, the power supply generates the current at the prescribed amperage and voltage. The leads then carry the current to the electrode (note that the length of the leads has an effect on the electric properties due to losses), and the electrode brings the current to the work, where it contributes to the weld. For example, when a weld metal fills the weld joint.

The grounds close the loop, and it's important to note that even the position of the grounds on the work can effect the welding arc. The shielding also plays an important role as it protects the arc from hydrogen and other contaminants. Later when we look at various processes, the source of shielding will be a key distinction.

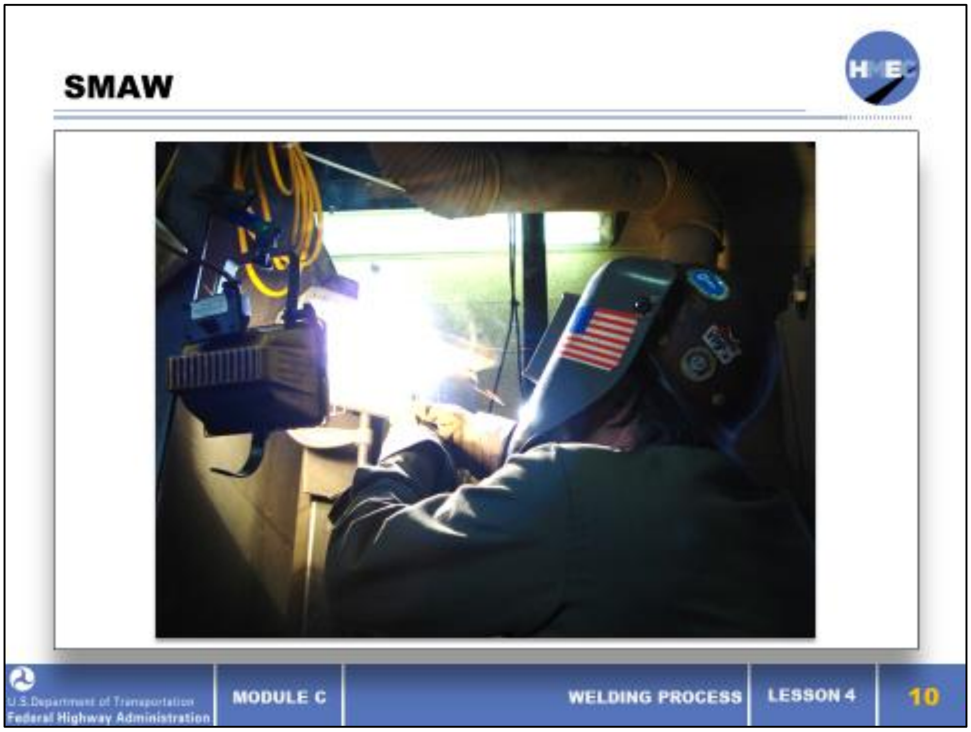
Slide 9



Shielded metal arc welding, or "stick" welding, is the oldest of the common arc welding processes used in highway structures. Note the gap in the figure. Weld metal flows from the rod to the base metal. During welding, the coating burns, forming the shielding.

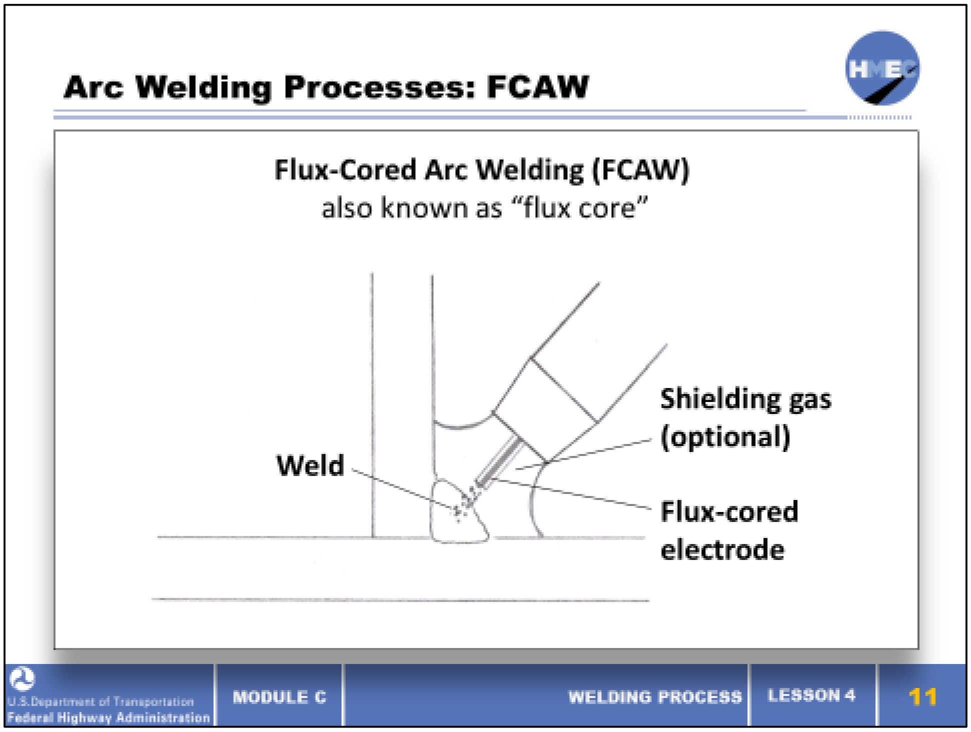
These days it is only popular for shorter welds because it is always hand-held, and sticks allow only short weld passes.

Slide 10



Note the shielding provided by the coating of the rod burning off. SMAW is useful in all positions, including as shown in the picture on the slide. Note the steady hand of the welder.

Slide 11



The electrode comes in wire spools and is fed to the work though the hand-held or mechanized welding gun. Inside the gun, the contact tube delivers current to the electrode as it is fed.

The electrode has flux within its core, hence its name "flux core." The flux burns during welding from shielding gas. Welding can be accomplished with just this shielding or in combination with shielding gas.

Wire-feeding from spools means that long welds can be accomplished without interruption. Note that there is no slag produced during the process; nonetheless, FCAW is not as clean a process as GMAW as it still requires some cleaning other than slag removal.

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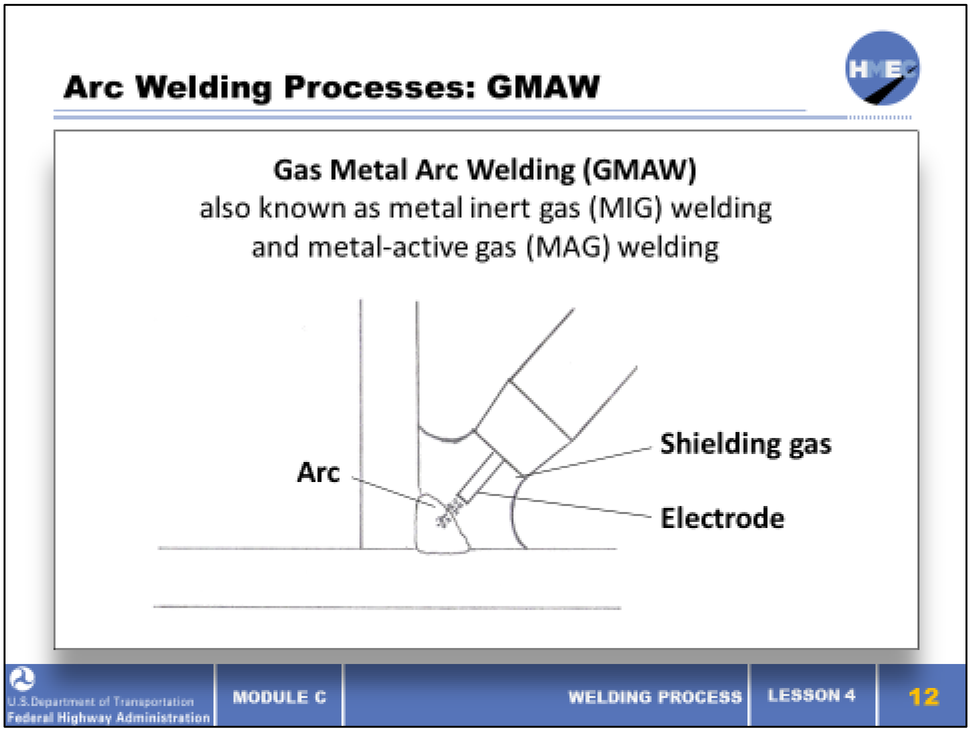
Slide 12



The electrode comes in wire spools and is fed to the work though the hand-held or mechanized welding gun. Inside the gun, the contact tube delivers current to the electrode as it is fed. Shielding gas is also delivered through the gun.

Wire-feeding from spools means that long welds can be accomplished without interruption. Note that there is no slag and therefore very little clean-up is usually required when using GMAW. GMAW can also be used with metal-cored wires, which are cored wires with alloying metals inside (instead of flux) that influence welding and final weld metal properties.

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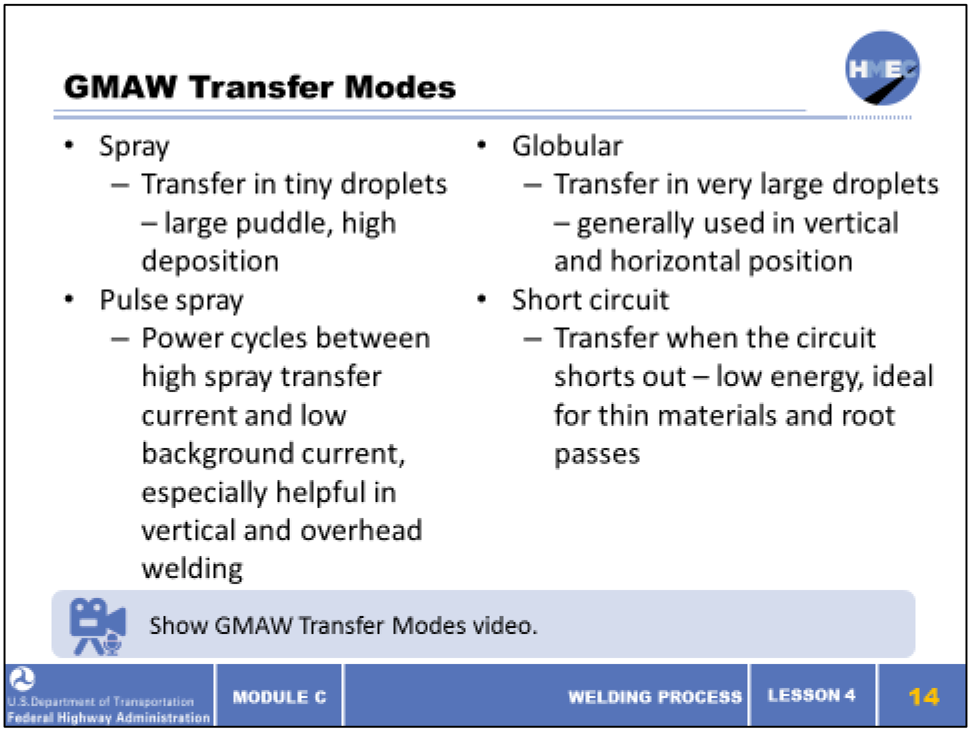
Slide 13

Note that the welder has positioned himself in such a way that he can keep his arm as steady as possible. The electrode is delivered by spool and continuously fed to the equipment. Final GMAW welds are very clean, usually with bits of silicon (i.e. glass), which are easily brushed away. The picture on the top left reflects a view of GMAW from inside of the welding hood.

Slide 14



The choice of which of the four modes to use is based on what is being welded. In steel structures, spray is the most common. High deposition makes it useful for filling smaller groove welds that may be in awkward positions (where SAW may not be suitable). It's also useful for fillet welding.

Pulse spray, a newer technology, is also growing in popularity for its versatility. Pulse spray, or just pulse, is like spray but its current cycles allow for faster cooling in the background current, and therefore its especially helpful for out-of-position welding.

Globular is not as common in steel structural welding.

In short-circuit transfer, the electrode actually touches the work, causing a short, and the short causes metal transfer. The touch is quick at 20 to 200 touches per second. This is good for joining thin materials. Consider how more robust welding would burn through thin steel, but it is poor for thicker steels. It isn't hot enough to melt thick steel, so there is a high probability of a lack of fusion with this process if it is used on most structural steels (given their thickness).

The misconceptions about short circuiting have led to some fears of GMAW entirely. Such fear is irrational because short-circuit transfer can simply and readily be avoided, and especially because GMAW (in other transfer modes) is very useful in the shop.

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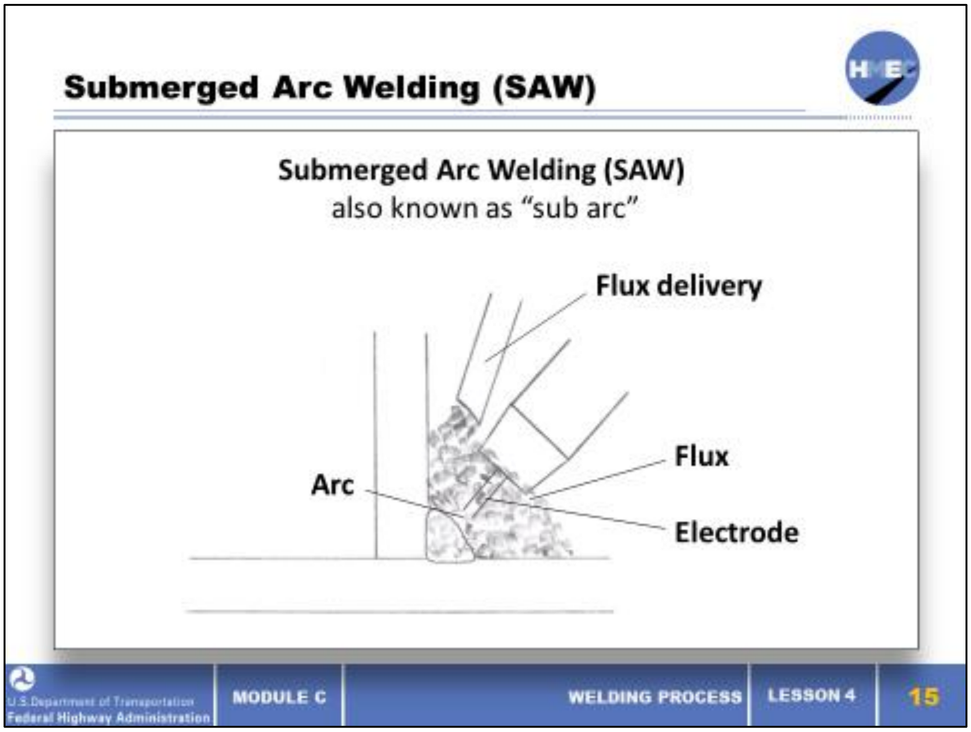
Slide 15



Sub arc is very popular for larger weld. It generally runs two to three times hotter than FCAW or GMAW, with wires that are larger, and so it has higher deposition.

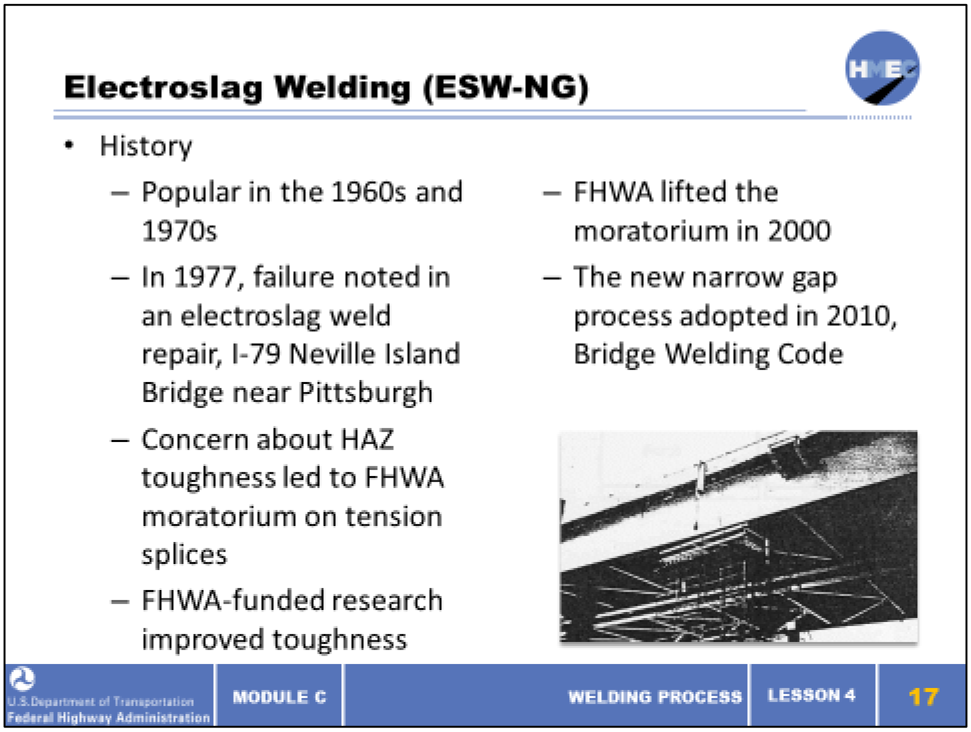
It is generally preferred for any situation that requires a lot of weld metal and that can be mechanized. It can be used hand-held as well, but starts to lose its advantages when done that way.

Flux is gravity-fed via a simple tube and there is a hopper above the operation. The flux completely covers the arc; the arc is "submerged" in the flux, hence its name. Not only does this offer protection from contaminants, but also it completely shields the arc from view. This means that welding can comfortably proceed without welding shield. The flux tube will travel with the wire feeder, and slightly ahead of it, so that the arc is always covered with flux. A small amount of slag with fused flux will form on top of the weld. As the slag cools, it shrinks and simply peels off of the weld. The remaining flux, which is still powder, will be vacuumed up and, after filtering, it will be reused.

Slide 16

As shown on left and bottom right, hand-held SAW is also used. It takes special skill to use this technique since the arc cannot be observed, unlike other arc welding processes. A considerable amount of flux is used, typically delivered and stored in bags, as shown in the center picture. Note that the used flux that isn't fused is vacuumed up and reused.

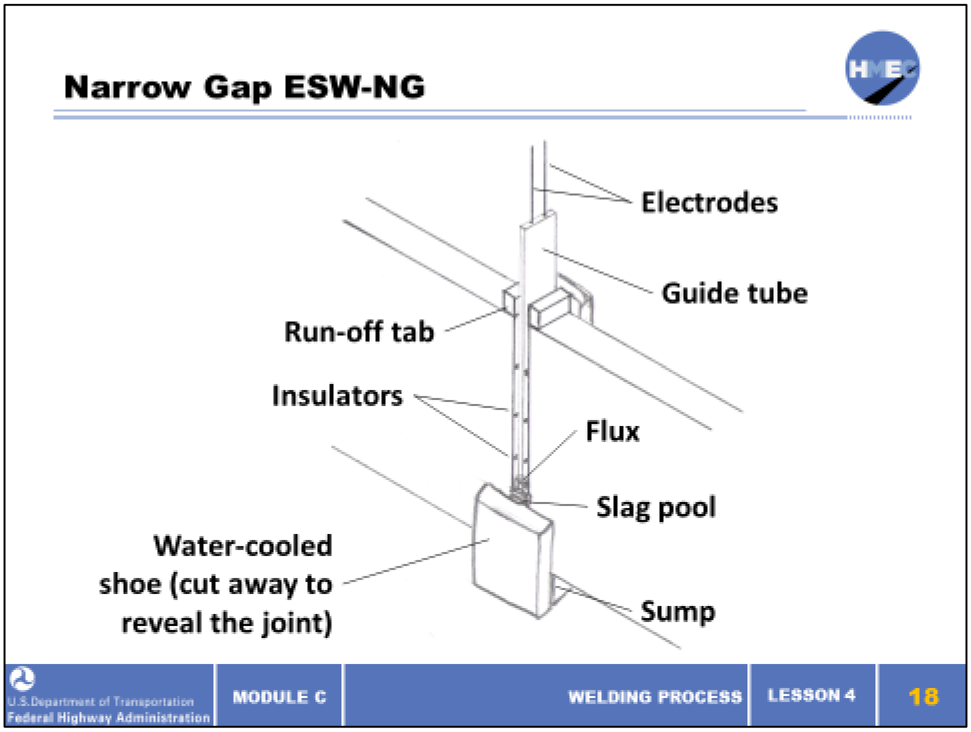
Slide 17



ESW-NG used to be popular until there was a failure. A tug boat captain looked up and saw a crack completely through the bottom flange and through the web up to the top flange. The crack initiated in a poorly executed weld repair. This is an important distinction: there wasn't anything wrong with the actual weld. However, forensic investigation found that toughness in ESW-NG heat-affected zones (HAZs) was not uniform.

Research sponsored by the FHWA found that making the welding gap narrower and not oscillating resulted in improved and more uniform HAZ properties, and they established a new process known as "narrow gap" ESW-NG. The new process was adopted into the Bridge Welding Code and is now gaining popularity in bridge shops.

Slide 18

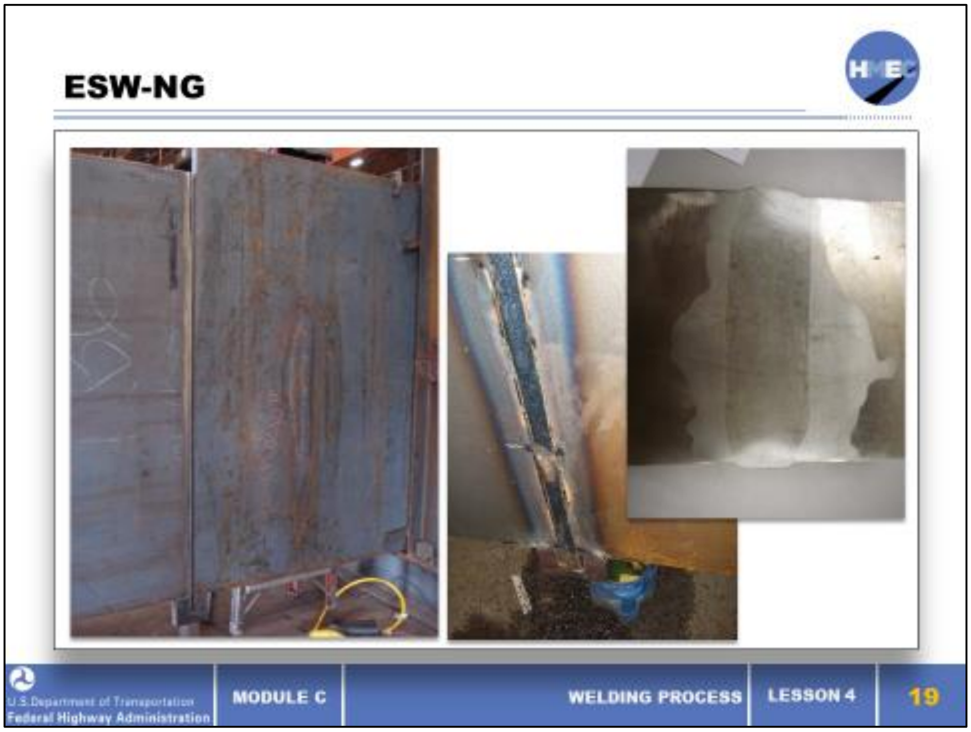


The two plates that are to be joined are carefully set next to each other to the right gap. Note that an advantage of ESW-NG is that the edge of the plate only needs to be square. It does not need a bevel of special geometry (if it isn't square, it might need to be trimmed so that it is indeed square). A sump is established at the base of the joint—this can simply be some extra metal equal to the thickness of the plate and covered by the shoe. The guide tube is placed in the joint. Note that insulators keep the guide tube in place and from touching the base plates. If the guide tube touches the base plate during welding, the process will short out and stop. Copper shoes are put on to close and cool the joint. Water lines are not shown, but the shoes are water-cooled. Here the shoe on front is cut away to reveal the weld pool and guide tube. In practice, the fabricator could pre-place shoes along the entire length of the weld, or leap-frog the shoes i.e., after the weld progresses up, remove a lower shoe and use it higher.

Run-off tabs are used at the top so that the weld metal will progress beyond the edge of the plates being welded. Note that the shoes will cover the run-off tabs to facilitate this run-off. Wires are fed through the guide tube. During welding, they will be consumed and therefore continuously fed—two are shown here. There isn't a particular limit on the number of wires. One wire might be used up to about 1½ in., two wires up to perhaps 3 or 3½ in., three wires might be efficient over that, up to 5 or 6 in., but these are rough numbers. When all is ready, one of the wires is fed completely down into the sump and arc welding starts. As the arc starts, wire continues to feed, and a pool of weld metal builds and heats up. Flux is gravity-fed from the top (simply dropped in, usually by an automatic feeder), and the wire continues to feed into it, forming a slag pool. With the tips of the wire buried in the pool, the process reverts to quiet resistance welding. The second wire is turned on and starts to feed the pool as well.

This initial process should be stable by the time the weld pool reaches the base metals. The wires will continue to be fed into the pool through the guide tubes and be consumed. The guide tube (and insulators) will also be consumed; a slight of amount of flux will continually be dropped (not a lot flux as used with SAW). The molten pool with a layer of slag and flux on top will rise in the cavity at about 2 in. per minute. When the pool passes the top of the plates and is in the run-tab area, the process will be stopped, and the weld is done. The amount of energy needed will be the amount of energy to just melt the edge of the plates on either side. This will cause the base metal to melt and then solidify with the contributed consumable metal to form the weld. If the amount of energy is too high for the thicknesses being welded, an overlarge weld (with potentially poor properties) will form. If the process is too cool for the plates being welded, the base metal will not melt or will partially melt, resulting in a lack of fusion. The two plates shown here are the same thickness; however, plates of different thickness can also be joined by simply using a beveled transition shoe.

Slide 19



On the left, two plates are being prepared for ESW. The gap is set, and the sump is in place. A run-off tab will be added at the top to match the wider plate.

In the middle, you see a completed ESW-NG weld. Again, note the sump where, behind the cooling shoes, the welding was begun. First, arc welding is used to initiate the process and establish the weld pool, and then resistance welding is used as the process reverts within the sump before reaching the actual plates to be welded. ESW-NGs are typically accomplished at about 2 in. per minute, so ESW-NG is a good way to accomplish a weld quickly.

On the right is an etched cross-section from an ESW-NG. Note that the narrow, elongated shape of the weld pass indicates minimal base metal contribution to the weld. Note that the whiter portion is not the HAZ, it's just an area where person making doing the etching inadvertently pooled the acid.

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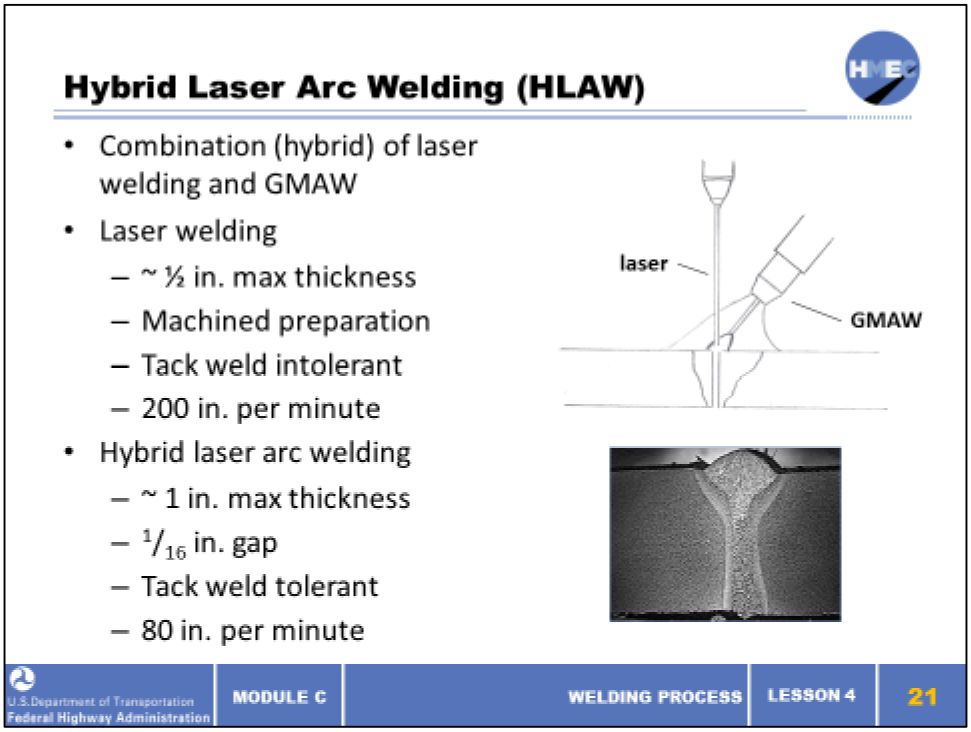
Slide 20


ESW-NG
Advantages of ESW-NG
• High quality
• High productivity
• Minimal distortion
MODULE C
WELDING PROCESS
LESSON 4
20

Slide 21



This process is new and not yet in the D1 welding codes; however, it is being used on highway structures by Valmont, a high mast pole fabricator.

AASHTO also discusses the process in their light structure code.

Laser welding is hyper fast—about 10 times faster than the traditional arc welding processes discussed today. But in laser welding, the laser works by melting both sides of the joint, therefore the joint must be narrower than the laser beam itself, and the joint must be machined.

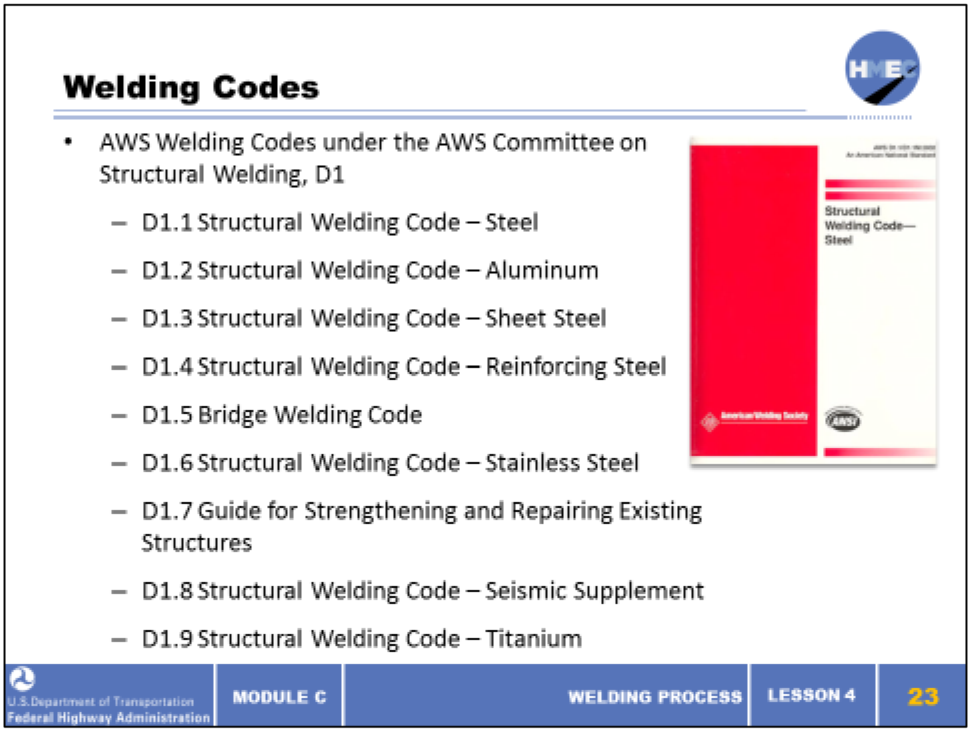
Also, the laser can't go over tack welds, so to use it, you must find some other way of holding the work together. The thickness limit is based on practical power limitations—½-inch thick is a practical limit of autogenous (laser only) laser welding; combining it with GMAW allows for thicker joints.

Slide 22

Note the fixtures being used to support the structural component being welded. As we have seen with all processes, parts must be brought and held together to facilitate welding. Usually this is done with tack welds; however, HLAW is not very tolerant of tack welds, so these fixtures are used to draw the plate being used for the pole segment into the proper final shape and to hold the edges to be welded close together to allow for welding.

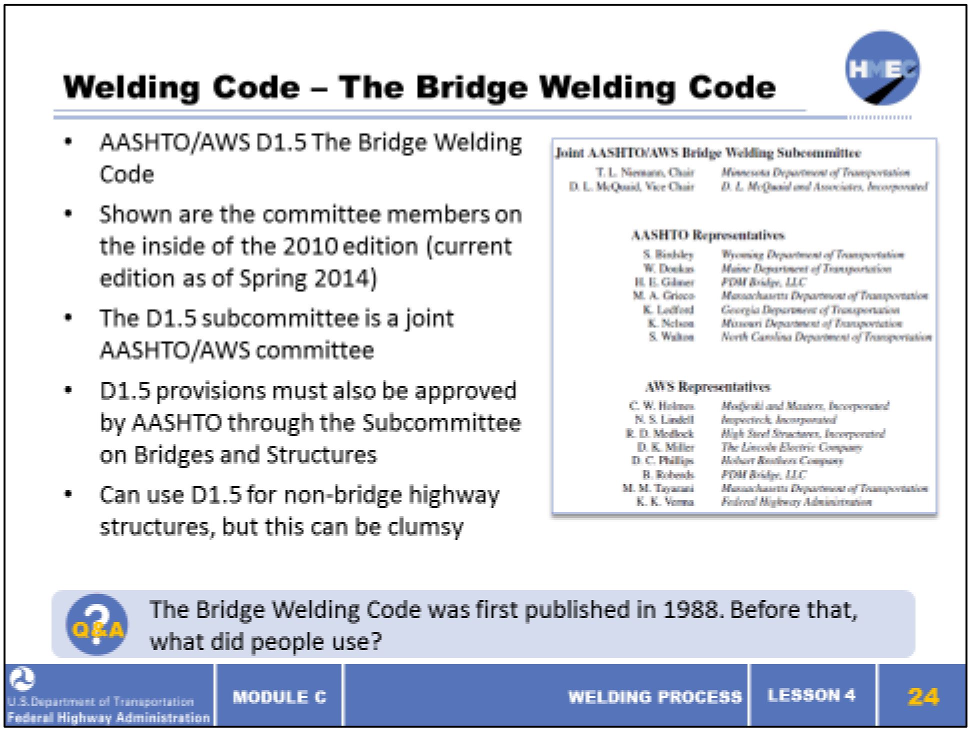
HLAW is fast and produces a very good full penetration weld on a thinner plate, but it does require extraordinary fixturing to accomplish. In the case of high mast poles, where the same long parts are being made over and over again and the same fixtures can be used repeatedly, HLAW is ideal.

Slide 23



AWS addresses several types of welding, including structural welding. Their biggest seller worldwide is notably D1.1 Structural Welding Code for Steel.

Slide 24



Unique among the D1 codes, the oversight committee for D1.5 is a joint committee—AASHTO has joint oversight on D1.5 and, like AWS (via the D1 committee), must approve code provisions.

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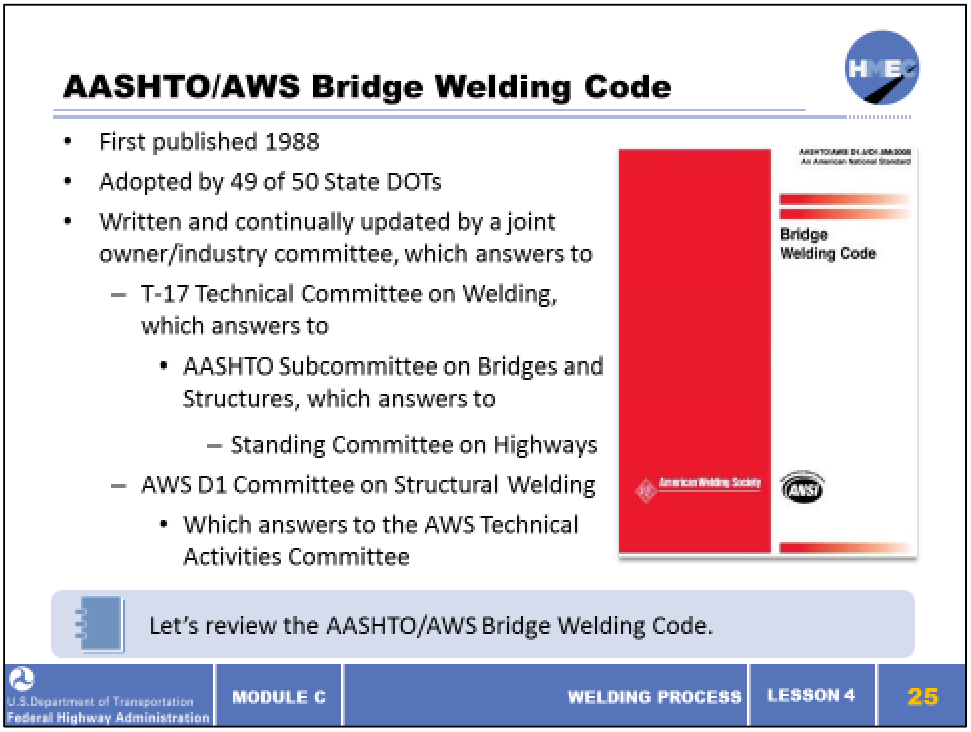
Slide 25

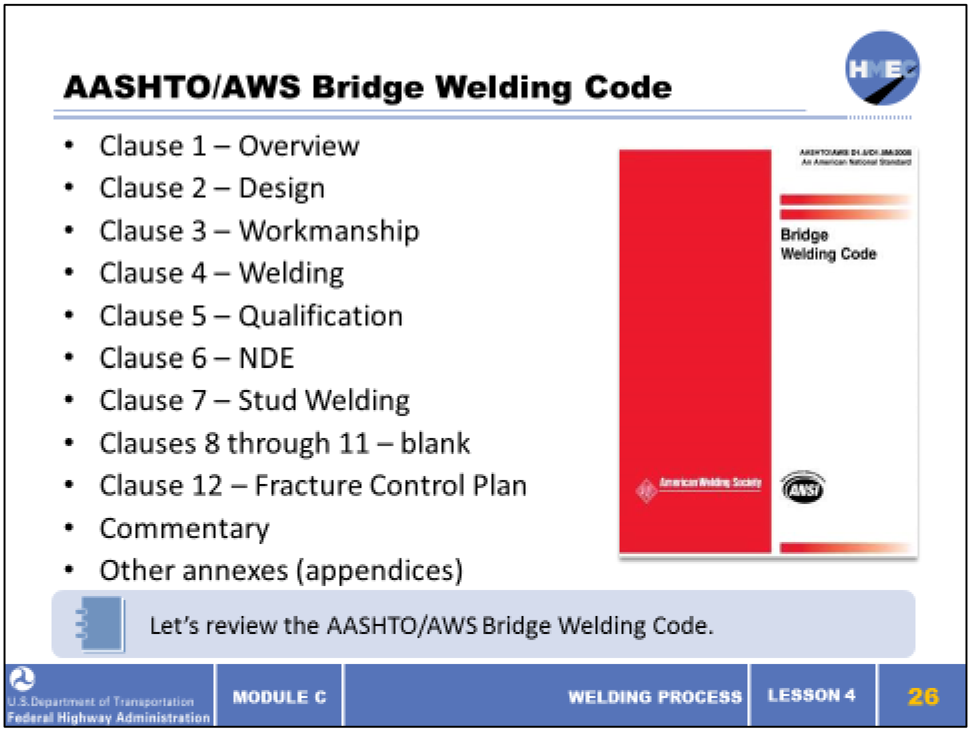


This code governs welding when referenced by owner contract documents—49 of 50 State DOTs do this by reference in their standard specifications. The exception is New York State DOT.

A joint owner/industry committee oversees the code—the instructor should point out the names and organizations of the committee members (found in the book). Once the joint committee has developed language, the code provisions from the owner side gets passed along to T-17, then to the Subcommittee on Bridges and Structures, and finally to the Highway Committee. From the industry side, it gets passed along to the AWS D1 Committee on Structural Welding and then the AWS Technical Activities Committee (TAC).

New editions are published about every five years. AWS does not publish interim specifications, however, AASHTO does do so, and these are available from the AASHTO bookstore.

Slide 26


AASHTO/AWS Bridge Welding Code
HMEC
• Clause 1 – Overview
• Clause 2 – Design
• Clause 3 – Workmanship
• Clause 4 – Welding
• Clause 5 – Qualification
• Clause 6 – NDE
• Clause 7 – Stud Welding
• Clauses 8 through 11 – blank
• Clause 12 – Fracture Control Plan
• Commentary
• Other annexes (appendices)
Bridge
Welding Code
ANSI
Let's review the AASHTO/AWS Bridge Welding Code.
U.S. Department of Transportation
Federal Highway Administration
MODULE C
WELDING PROCESS
LESSON 4
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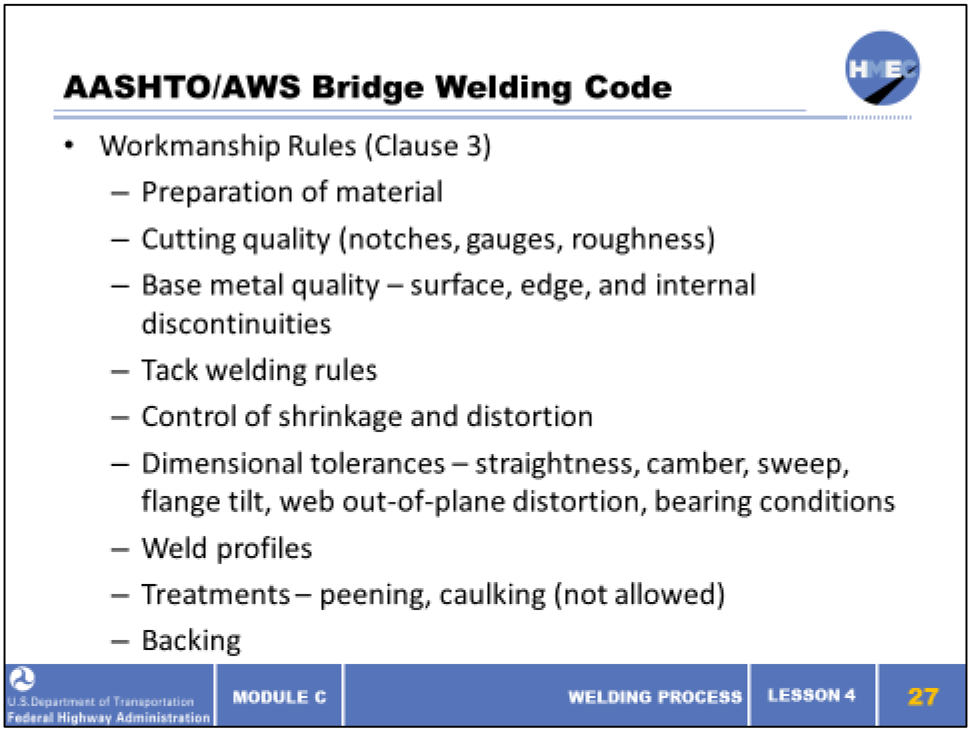
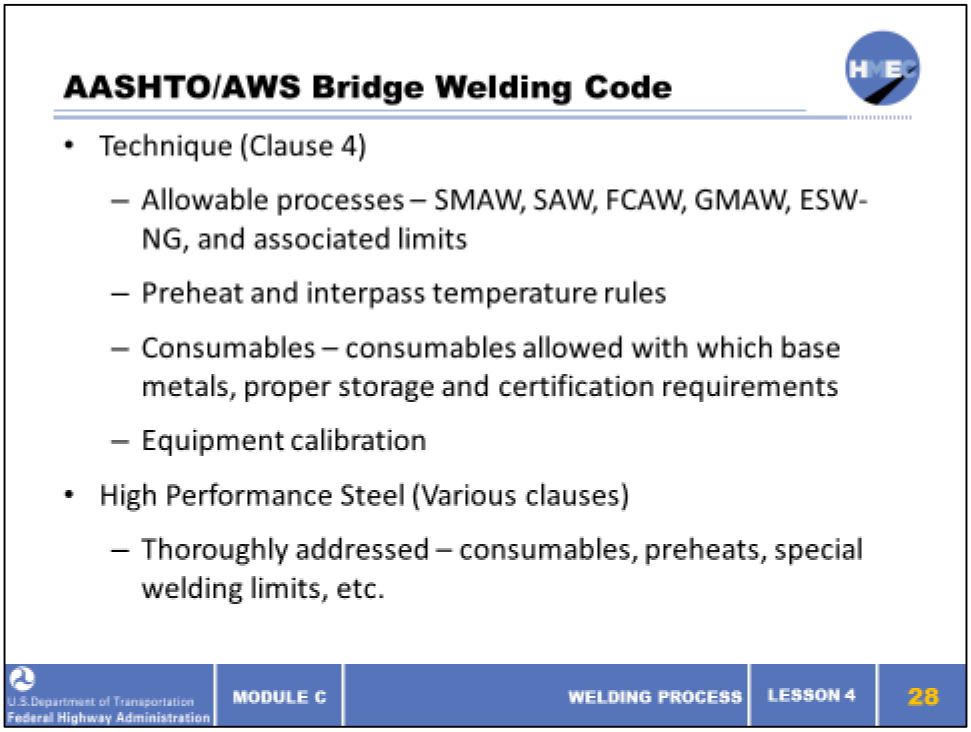
Slide 27



The workmanship rules of Clause 3 address more than just welds—they also address a wide variety of macro and micro tolerances for bridge girders. Note the emphasis on girders: D1.5 addressed I-girders very well but other steel bridge types not quite as well. It is okay for tub girders and other box elements, like pier caps. It is virtually silent on orthotropic deck. There will be more discussion on these points in the Lesson 6 on fabrication.

Slide 28

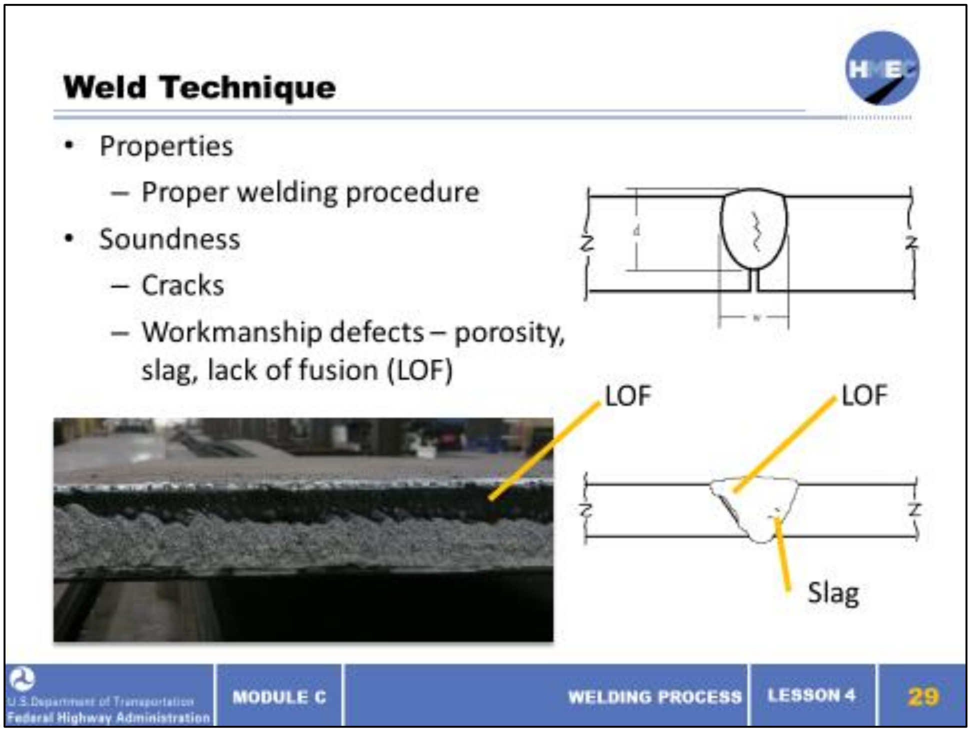


The processes allowed under D1.5 are the ones discussed earlier (except for HLAW).

Preheat and interpass temperature are important considerations for most welding procedures. Changing the temperature of the base metal before welding offers many improvements: increased crack resistance, improved metallurgical structures (generally because preheating the base metal improves ductility), and lower shrinkage stresses. Preheat reduces the quenching effects in the weld, and at times gets the base metal temperature hot enough so water can't condense. The interpass also has these quenching effects.

For each process, certain consumables are allowed. These are selected to ensure good material properties—like strength, ductility, and toughness—at the right service temperature. The consumables must be properly stored to assure weld quality.

Slide 29



The picture on the bottom left shows lack of fusion. The light gray was sound metal that is now broken away, and the top shows the edge of the plate which was intended to be melted by the weld metal (like the light gray) but was not. This joint is broken away and shows the lack of fusion (LOF). In practice, such LOF would be picked up by NDE (which will be discussed later).

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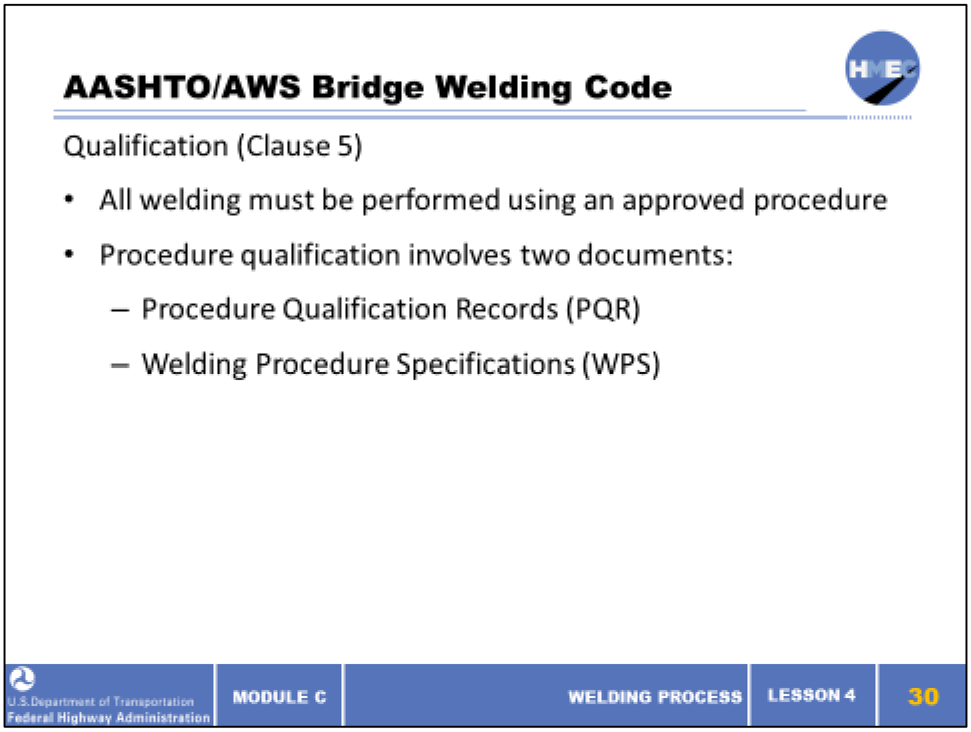
Slide 30



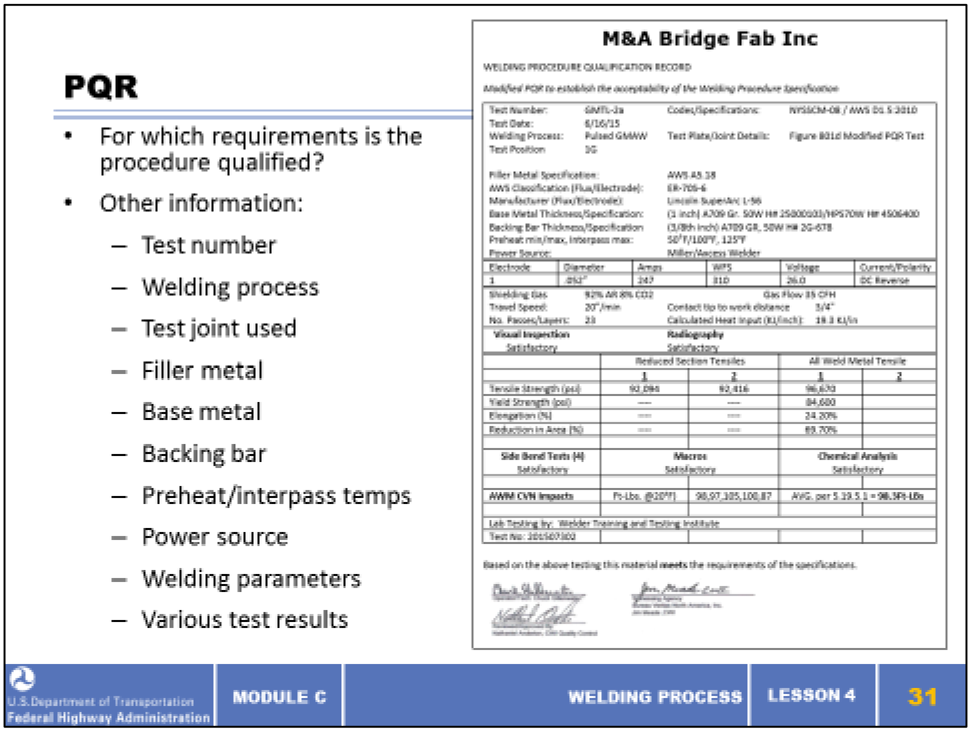
Under D1.5, all welding must be performed using an approved procedure. In addition, joints and welders must also be qualified. The code, D1.5 discusses procedure qualification in terms of two documents: the welding procedure specification (WPS), which is the part of the welding procedure that directs the technique of the welder, and the procedure qualification record (PQR).

The PQR is the procedure qualification record - as its name suggests, it is the record of all of the work done to qualify the procedure. The WPS is the welding procedure specification - this is the welding procedure that is actually used on the shop floor. The PQR, then, represents the testing that is done to qualify the WPS. One PQR can be used to qualify many WPSs.

All procedures must be approved. The fabricator sends the test results, which are recorded in a PQR, and the procedures to be used, known as welding procedure specifications (WPS), for approval.

Pre-qualified joints are discussed later in a few slides.

Slide 31


PQR
For which requirements is the procedure qualified?
Other information:
Test number
Welding process
Test joint used
Filler metal
Base metal
Backing bar
Preheat/interpass temps
Power source
Welding parameters
Various test results
M&A Bridge Fab Inc
WELDING PROCEDURE QUALIFICATION RECORD
Test Number:
Test Date:
Welding Process: Pulsed GMAW
Test Position
Filler Metal Specification:
Power Source:
Electrode
Diameter
Amps
WFS
Voltage
Current/Polarity
DC Reverse
Shielding Gas
Travel Speed:
Visual Inspection
Satisfactory
Radiography
Satisfactory
Reduced Section Tensiles
All Weld Metal Tensile
Tensile Strength (psi)
Yield Strength (psi)
Elongation (%)
Reduction in Area (%)
Side Bend Tests (4)
Satisfactory
Macros
Satisfactory
Chemical Analysis
Satisfactory
AWM CVN Impacts
Based on the above testing this material meets the requirements of the specifications.
U.S. Department of Transportation
Federal Highway Administration
MODULE C
WELDING PROCESS
LESSON 4
31

M&A Bridge Fab Inc

WELDING PROCEDURE QUALIFICATION RECORD

Modified PQR to establish the acceptability of the Welding Procedure Specification

Test Number:	GMTL-2a	Codes/Specifications:	NYSSCM-08 / AWS D1.5:2010
Test Date:	6/16/15		
Welding Process:	Pulsed GMAW	Test Plate/Joint Details:	Figure 801d Modified PQR Test
Test Position	1G		

Filler Metal Specification:	AWS A5.18
AWS Classification (Flux/Electrode):	ER-70S-6
Manufacturer (Flux/Electrode):	Lincoln SuperArc L-56
Base Metal Thickness/Specification:	(1 inch) A709 Gr. 50W H# 25000103/HPS70W H# 4506400
Backing Bar Thickness/Specification	(3/8th inch) A709 GR, 50W H# 2G-678
Preheat min/max, Interpass max:	50°F/100°F, 125°F
Power Source:	Miller/Axcess Welder

Electrode	Diameter	Amps	WFS	Voltage	Current/Polarity
1	.052”	247	310	26.0	DC Reverse

Shielding Gas	92% AR 8% CO2	Gas Flow 35 CFH	
Travel Speed:	20”/min	Contact tip to work distance	3/4"
No. Passes/Layers:	23	Calculated Heat Input (KJ/inch):	19.3 KJ/in

Visual Inspection	**Radiography**
Satisfactory	Satisfactory

	Reduced Section Tensiles		All Weld Metal Tensile	
	1	2	1	2
Tensile Strength (psi)	92,094	92,416	96,670	
Yield Strength (psi)	----	----	84,600	
Elongation (%)	----	----	24.20%	
Reduction in Area (%)	----	----	69.70%	
Side Bend Tests (4) Satisfactory	**Macros** Satisfactory		**Chemical Analysis** Satisfactory	
AWM CVN Impacts	Ft-Lbs. @20°F)	98,97,105,100,87	AVG. per 5.19.5.1 = **98.3Ft-LBs**	
Lab Testing by: Welder Training and Testing Institute				
Test No: 201507302				

Based on the above testing this material **meets** the requirements of the specifications.

Operator/Tech: Chuck Gillenwater

Reviewed/Approved By:
Nathaniel Anderton, CWI Quality Control

Witnessing Agency
Bureau Veritas North America, Inc.
Jim Meade ,CWI

The first point to know about the PQR is to which requirements is the procedure qualified? In this particular case the procedure is qualified to two specifications (it is dual certified) - the New York State Construction Manual and AWS D1.5.

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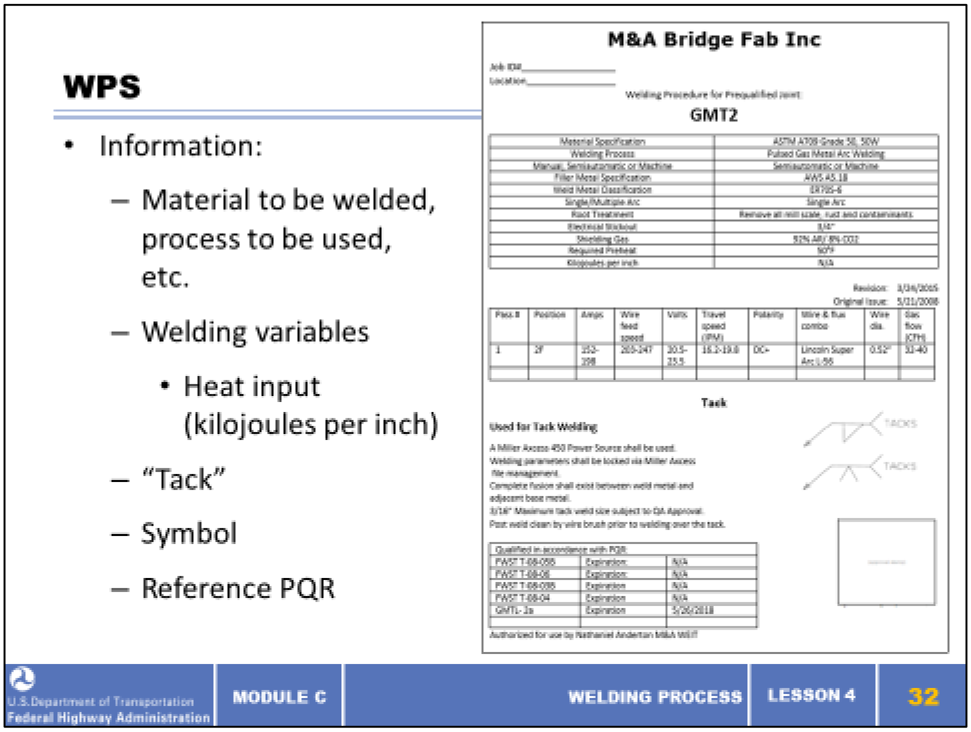
Slide 32


WPS
Information:
Material to be welded, process to be used, etc.
Welding variables
Heat input (kilojoules per inch)
"Tack"
Symbol
Reference PQR
M&A Bridge Fab Inc
GMT2
Tack
U.S. Department of Transportation
Federal Highway Administration
MODULE C
WELDING PROCESS
LESSON 4
32

M&A Bridge Fab Inc

Job ID#__________________
Location_________________

Welding Procedure for Prequalified Joint:

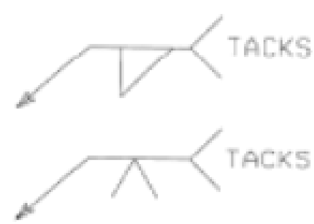
GMT2

Material Specification	ASTM A709 Grade 50, 50W
Welding Process	Pulsed Gas Metal Arc Welding
Manual, Semiautomatic or Machine	Semiautomatic or Machine
Filler Metal Specification	AWS A5.18
Weld Metal Classification	ER70S-6
Single/Multiple Arc	Single Arc
Root Treatment	Remove all mill scale, rust and contaminants
Electrical Stickout	3/4"
Shielding Gas	92% AR/ 8% CO2
Required Preheat	50°F
Kilojoules per inch	N/A

Revision: 3/24/2015
Original Issue: 5/21/2008

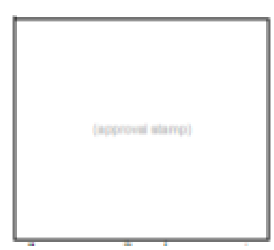
Pass #	Position	Amps	Wire feed speed	Volts	Travel speed (IPM)	Polarity	Wire & flux combo	Wire dia.	Gas flow (CFH)
1	2F	152-198	203-247	20.5-23.5	16.2-19.8	DC+	Lincoln Super Arc L-56	0.52"	32-40

Tack



Used for Tack Welding

A Miller Axcess 450 Power Source shall be used.
Welding parameters shall be locked via Miller Axcess file management.
Complete fusion shall exist between weld metal and adjacent base metal.
3/16" Maximum tack weld size subject to QA Approval.
Post weld clean by wire brush prior to welding over the tack.

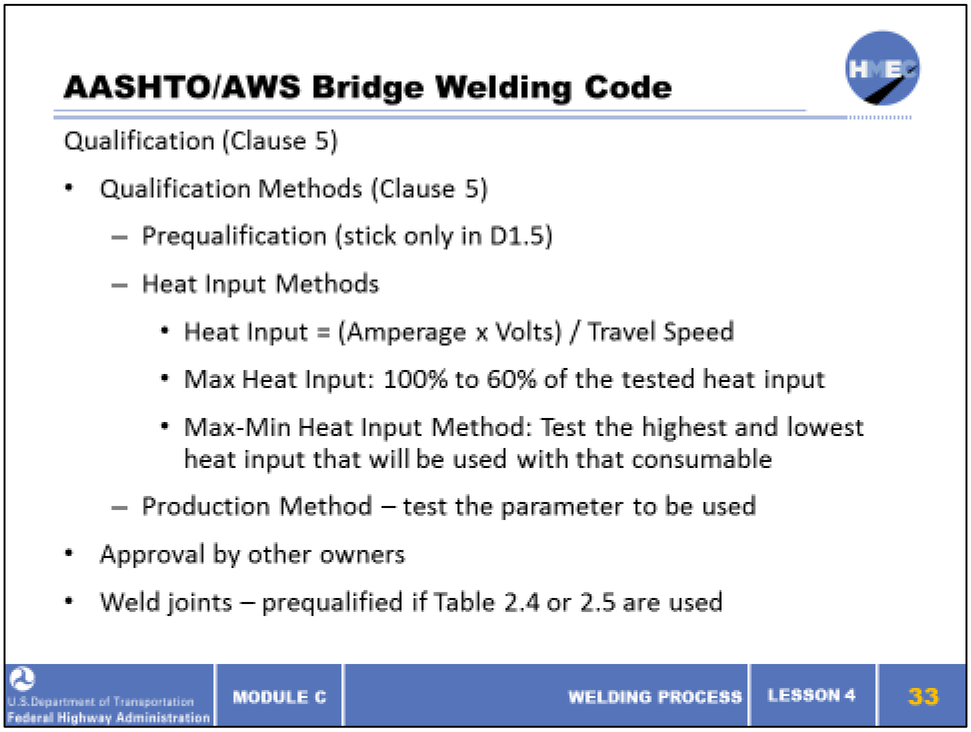


Qualified in accordance with PQR:		
FWST T-08-05B	Expiration:	N/A
FWST T-08-06	Expiration:	N/A
FWST T-08-03B	Expiration	N/A
FWST T-08-04	Expiration	N/A
GMTL- 2a	Expiration	5/26/2018

Authorized for use by Nathaniel Anderton M&A WEIT

The WPS has its own set of details. The intent of the WPS is that the welder will actually welding within the limits of the WPS on the shop floor. The welder is provided the WPS but typically doesn't see / need the PQR.

Slide 33

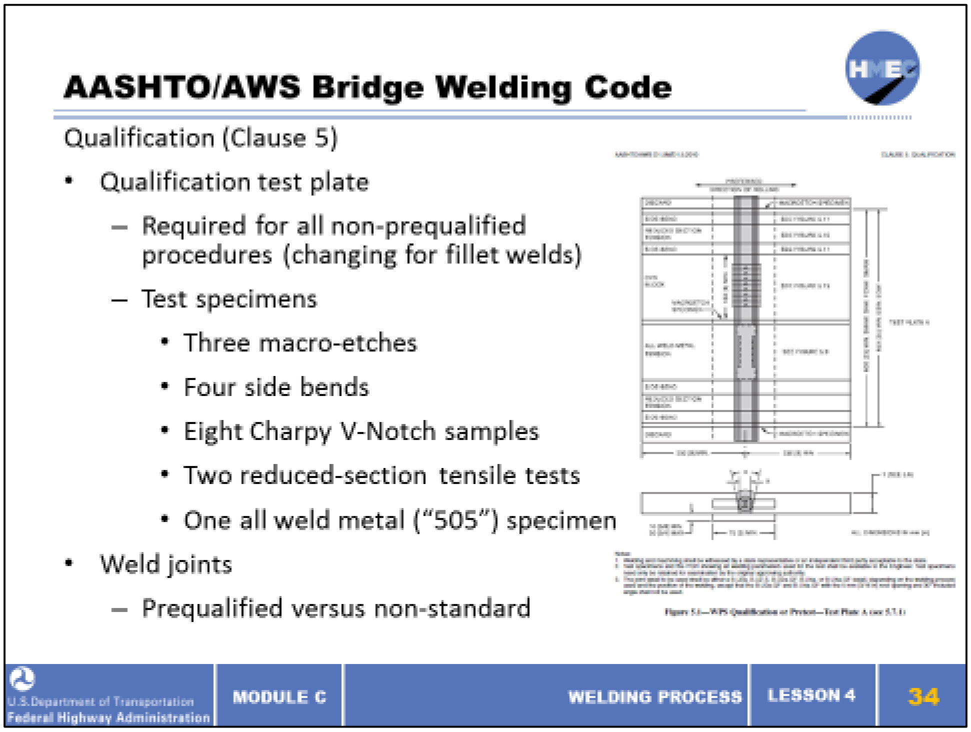


Stick procedures must be approved, but they are prequalified (i.e., no testing is required, but the fabricator must submit the procedure for approval). Procedures for all other processes must be qualified by test. Methods include the heat input methods. Under the maximum method, the fabricator creates a heat input window using one test under the max-min method, and the fabricator creates a window bounded by these limits.

Production method: This method offers an alternative to creating a heat input window. Instead of creating the heat input window, the actual parameters that will be used are tested, then the code allows some variance on each parameter, such as ± 10% of the volts tested, ± 10% of the amperage testing.

Most owners accept procedures approved by other owners without additional testing.

Slide 34



All welding procedures require a groove weld test. There are some choices, but almost always the plate shown is used. Note that the code is changing and in the future most fillet weld procedures will not need a groove test. This is a nice improvement because some welding consumables are designed for use in fillet welds and these consumables do not perform well in groove welds, which makes it hard to qualify a procedure with the change.

The macro-etches provide a good look at the welding cross-section. You can see the shape of each pass and how it lays in the joint, and also how much grain refinement results from the procedure.

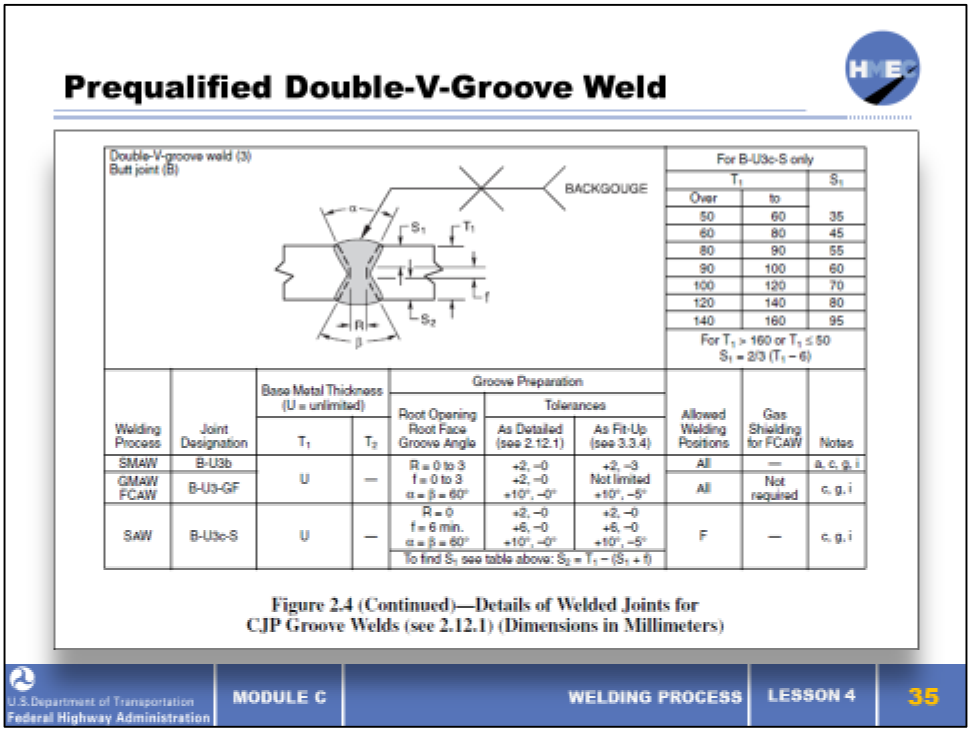
The reduced section tensile test only tests for ultimate tensile strength. The nice thing about it is that is encompasses both base metal and weld metal, and therefore gives you an idea of how the materials will work together.

The side bends test for ductility, and there may not be discontinuities over ⅛ in.

The Charpy test for toughness: note that with the way the Charpy V-notch (CVN) is in the weld throat, the test is basically of all weld metal. The all weld metal test provides a more comprehensive look at tensile properties: elongation, yield strength, and ultimate strength. Note again, though, that only the weld metal is actually being tested here. This specimen is known as a “505” specimen because the cross-sectional area of the necked-down part of the specimens is 0.505 in. in diameter.

This plate is used if the joint to be used in that actual welding (and addressed in the WPS) is prequalified. Otherwise, a plate must be used that represents the joint. This can lead to some confusion: usually the procedure is not prequalified, but the joint is. So, qualification is based on using a prequalified joint. If the fabricator wants to use a unique joint, he may do so, but he must conduct additional testing to show that the joint (and its associated welding) is sound.

Slide 35



Even though the joint is prequalified, the welding procedure itself may or may not be. Most welding procedures under D1.5 are not prequalified; however, many procedures under other structural welding codes are indeed prequalified.

The code provides tolerances for use of the joint; however, it's important to note that the tolerances vary among welding procedure. Tolerances apply to bevel angle (shown as alpha for the bevels on top and beta for the bevels on the bottom), root opening, "R", depths of bevels, "S", in association with the thickness of the plates being welded, and the size of the root face, "F."

Non-prequalified joints may also be used, but these must be tested and are subject to approval by the engineer.

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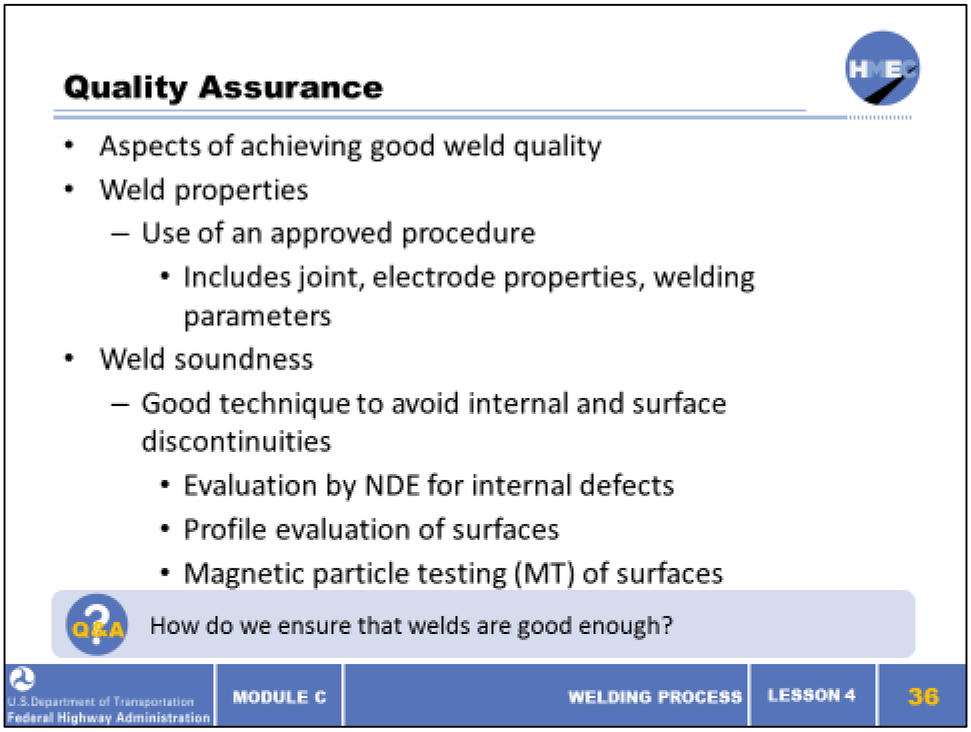
Slide 36



Quality assurance gets to the key reason that welding codes exist: to help ensure that the accomplished welds are good, i.e., to help ensure quality is achieved.

Welding codes establish requirements for welding procedures and technique. D1.5 goes further than most by requiring testing for most welding procedures (note that most procedures used under D1.1 are prequalified).

NDE will be discussed in the next lesson; a discussion of profiles is coming up.

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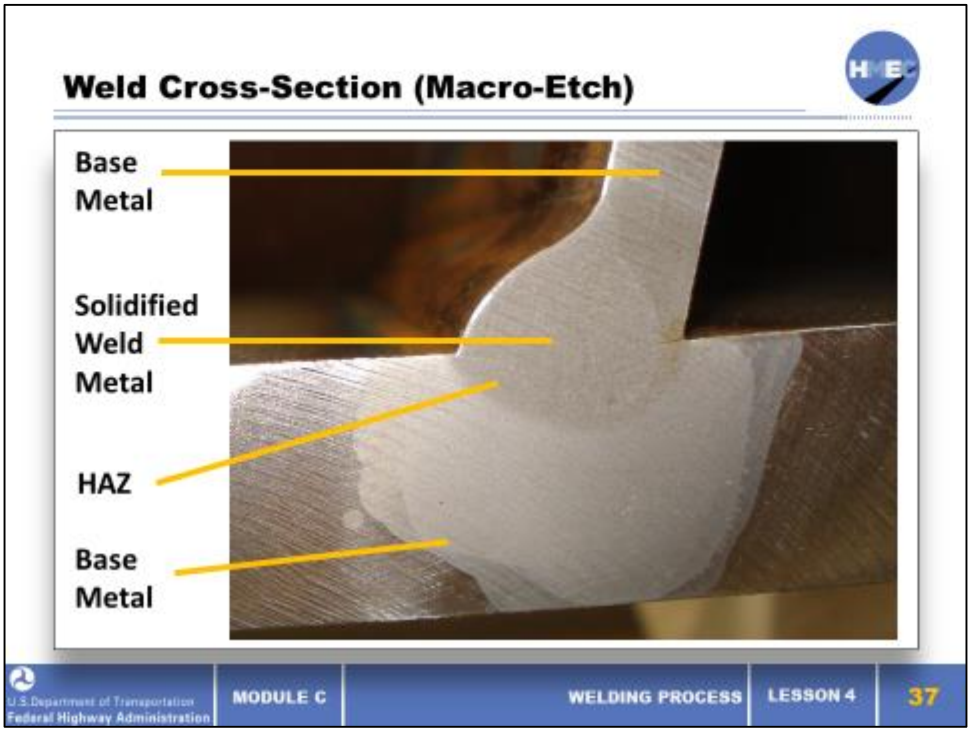
Slide 37



There are three basic parts of a weld:

1. The two base metals being joined;
2. The solidified weld metal, which is a mixture of the deposited consumables and base metal; and
3. The heat-affected zone, which is the part of the base metal that has been heated enough during welding to alter the base metal but not melt it or mix it with consumables.

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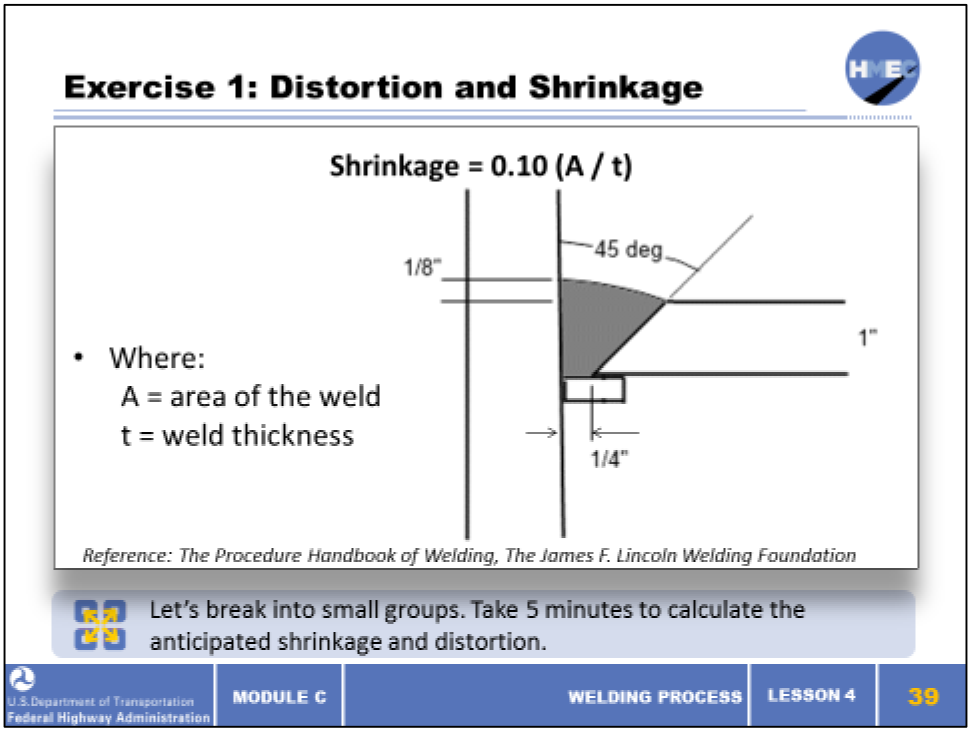
Slide 38

Once weld metal has solidified, it shrinks as it cools to ambient temperature. The sketch on the top left reflects this in exaggeration. Each pass of a multiple-pass weld will shrink a joint further.

In the joint on the right, the flange is pre-rotated at fit-up in anticipation of welding shrinkage. This joint will be filled from the top, then rotated, back-gouged, and welded to completion. Shrinkage can be calculated; often shop personnel use experience for presetting.

On the bottom left, final distortion is checked. This sub-assembly has four full penetration welds. The fabricator will have to present the stiffeners to base plate to anticipate the actual shrinkage. If need be, distortion can be corrected with heat.

Slide 39



Anticipated shrinkage and distortion can be calculated. In the example shown, the horizontal plate will shrink towards the vertical plate. How much will it shrink?

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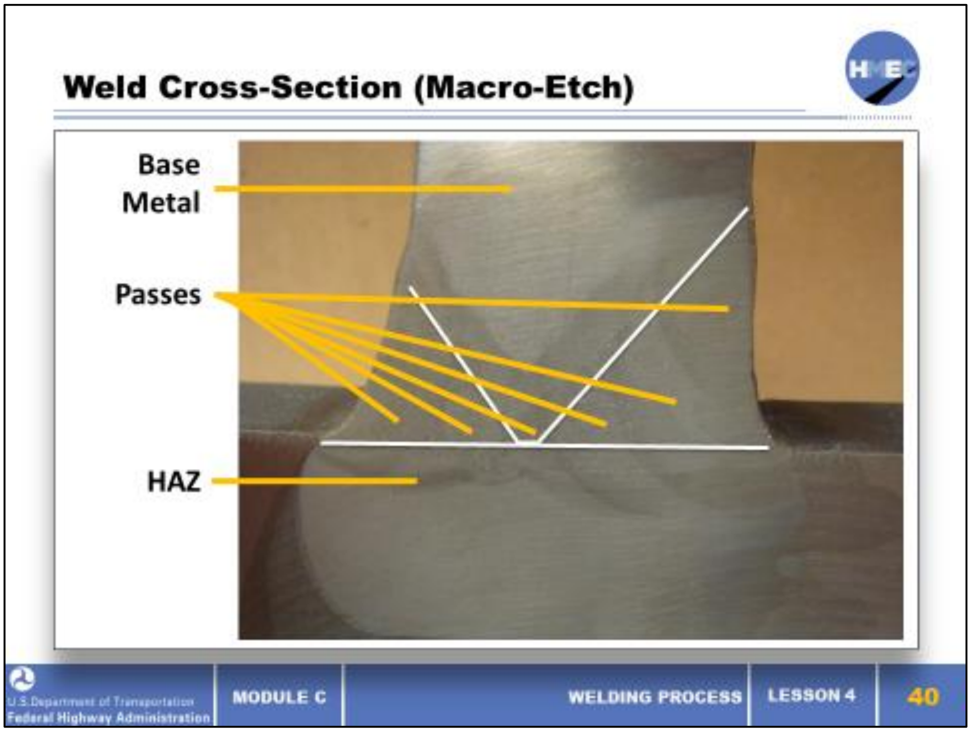
Slide 40



The passes are apparent; note also grain refinement. When one pass is put on top of another pass, the second pass refines the grain of the first pass. This leads to finer grains and tougher welds.

The likely sequence of this joint was: passes on the right, with the joint rotated 90 degrees counter-clockwise from what is shown, so that welding was done in the flat position. Then, the work was rotated 180 degrees so the joint was rotated 90 degrees clockwise from shown. Finally, back-gouging was used to sound metal and fill.

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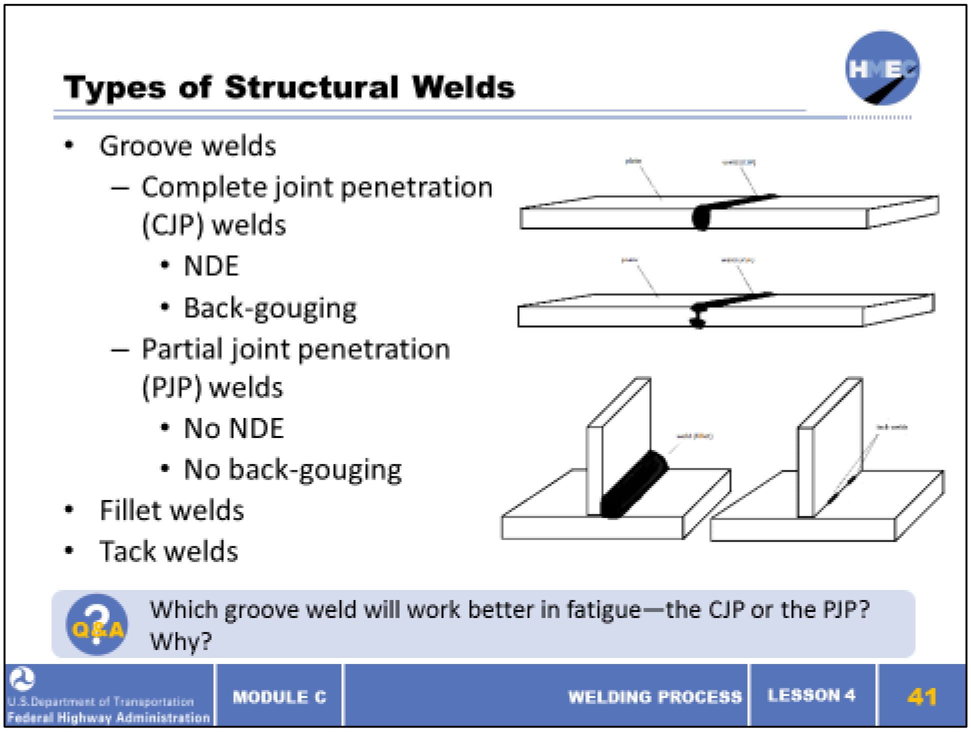
Slide 41



Groove welds basically join the entire cross-section of the components being joined like these plates, which are like girder welds and flanges. Complete joint penetrations (CJPs) are the most common. Partial joint penetrations (PJPs) are sometimes used when it is not necessary to provide an entire cross-section of weld metal; however, they are not common in bridges due to fatigue concerns. Imagine the potential for trouble if your girder flange has a PJP. The workmanship (quality) of CJPs is often verified by nondestructive testing, like radiography testing (RT) or ultrasonic testing (UT)—such workmanship is not verified with PJPs. Consider how the radiograph of the second weld shown here would look. CJP also implies (but not necessarily requires) back-gouging to help ensure complete fusion at the root.

Tack welds are usually temporary welds. They are used to hold the work together until the proper weld can be accomplished. They are very useful. Consider how the fabricator would hold the work together if he could not use tack welds to do it. That would probably result in some large fixtures. The code requires tack welds to be of good quality; however, the code does allow tack welds to be applied with preheat if the final weld will completely melt the tack welds. Hot processes like SAW will melt most small tacks; it is a good idea to do a mockup and macro-etch to verify this remelt.

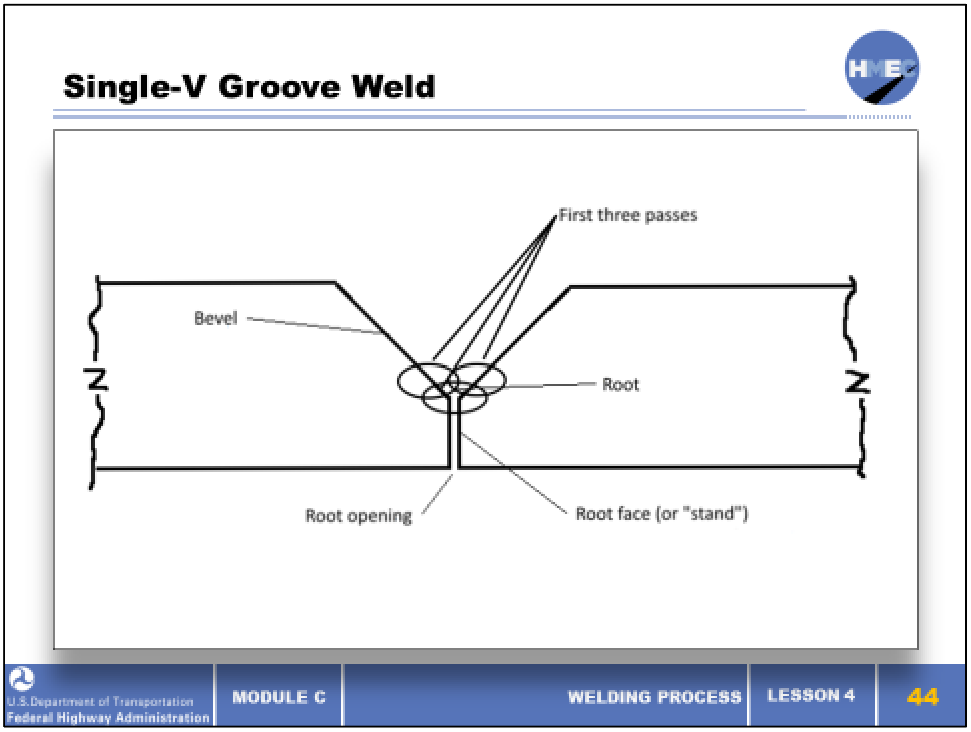
Slide 42

Here the fabricator bevels the plate to prepare it for groove welding. Bevels must be accomplished well to help ensure productivity and quality. Note that the fabricator has first trimmed back the edge of the plate to ensure a clean cut. The cutting operation has been mechanized to achieve uniformity.

Slide 43

Note the run-off tab allows welding to start off of the work. The run-off needs to be the same bevel geometry as the actual plate and fit tightly to the side of the plate to help ensure quality.

Slide 44



These two plates have been prepared with a single v joint—you can see the v.

The sequence of welding for this joint will be: fill the top, flip the work over and back-gouge to sound weld metal, and fill the back side.

The fabricator will fill with the weld with stringer passes, the first three passes are shown. To achieve good quality, the welder will accomplish each pass with care. After each pass, he will inspect the weld to ensure it is clean and ready to properly take the next pass. If the welder is not careful, defects trapped slag, porosity, or lack of fusion can result.

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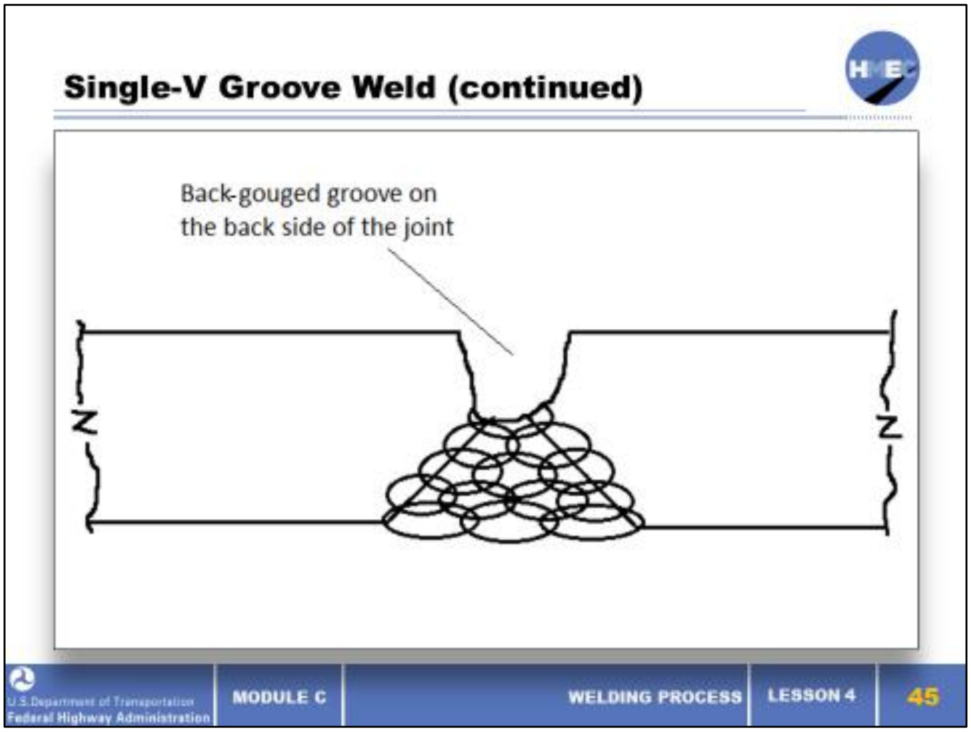
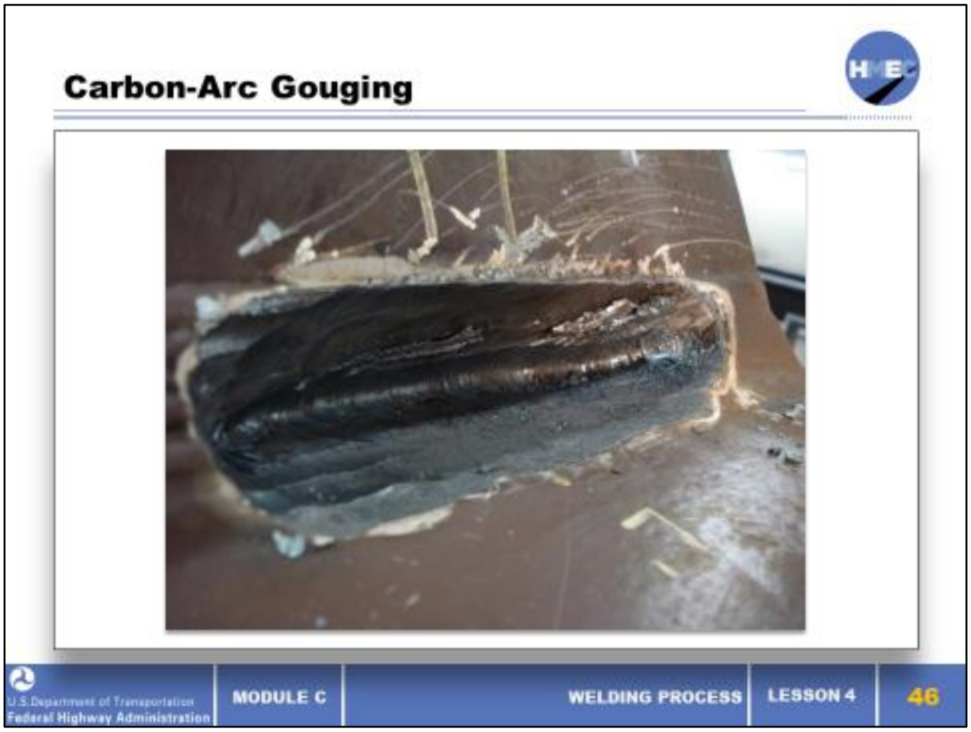
Slide 45



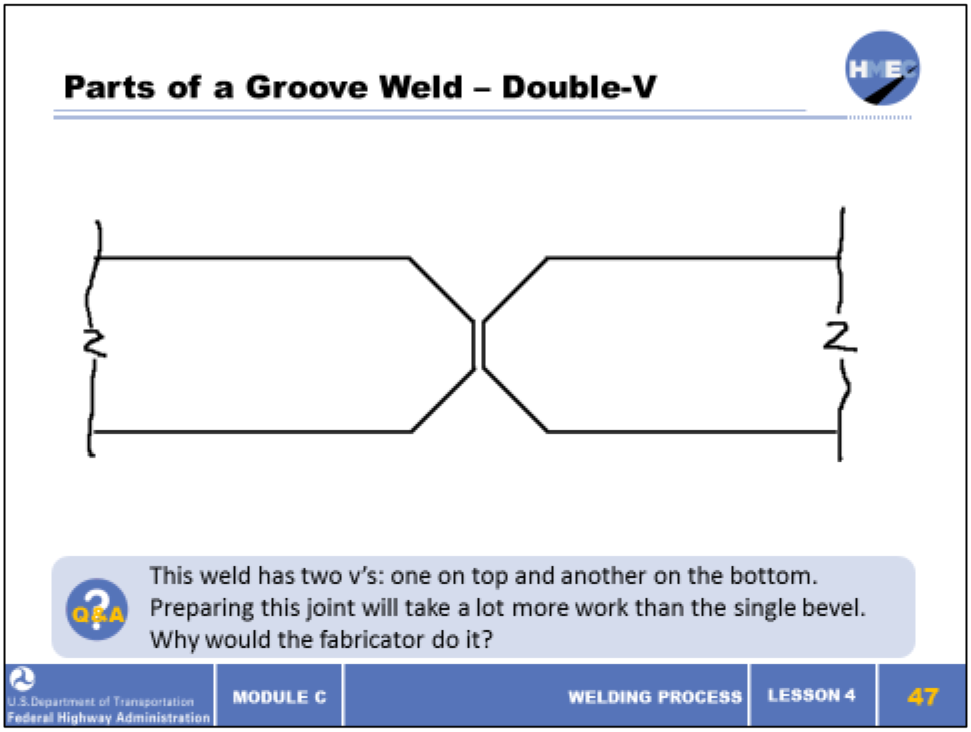
Back-gouging must be accomplished carefully to provide a suitable preparation for the reverse side passes. Remember that the weld must be accomplished with good workmanship; if this is a bridge butt splice, it may be tested by NDE.

Slide 46



Both applications require the same technique: back-gouge to a condition that will facilitate replacement by stringer passes. Note the boat-shape nature of the excavation, which will facilitate clean pass-by-pass filling of the joint.

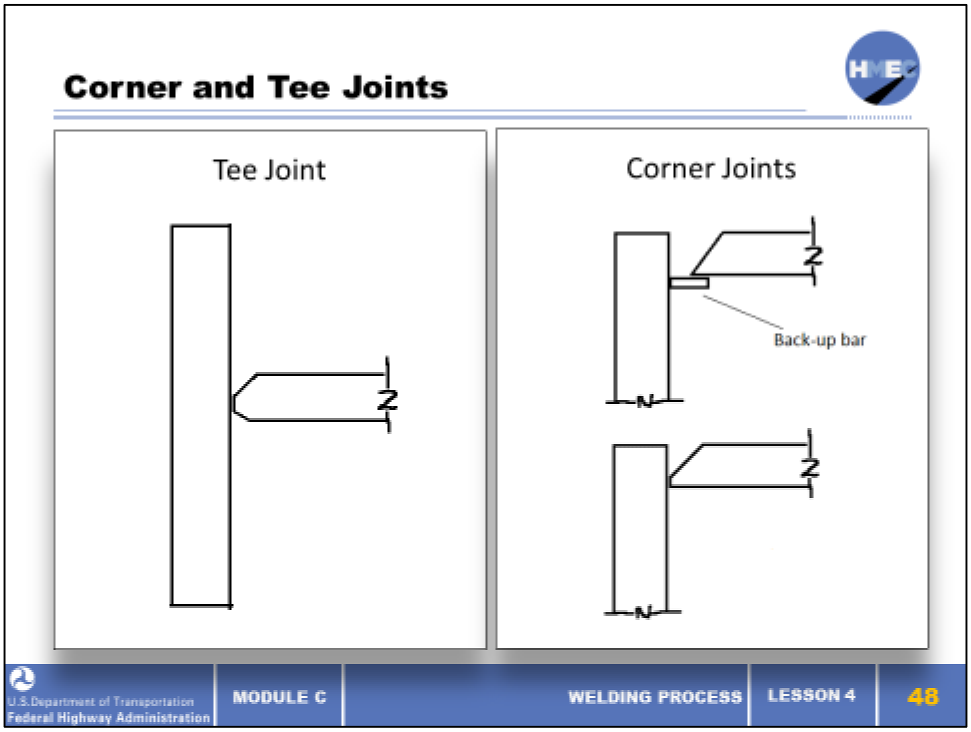
Slide 47



This distinction between this joint and the previous joint is that this one would be used for thicker material.

Note the two opposing v's. On thicker plates, a back-gouged preparation would be too deep and narrow, and removing material by back-gouging takes time. On thicker joints, the fabricator gets a head start preparing the back side of the weld by beveling first.

Slide 48



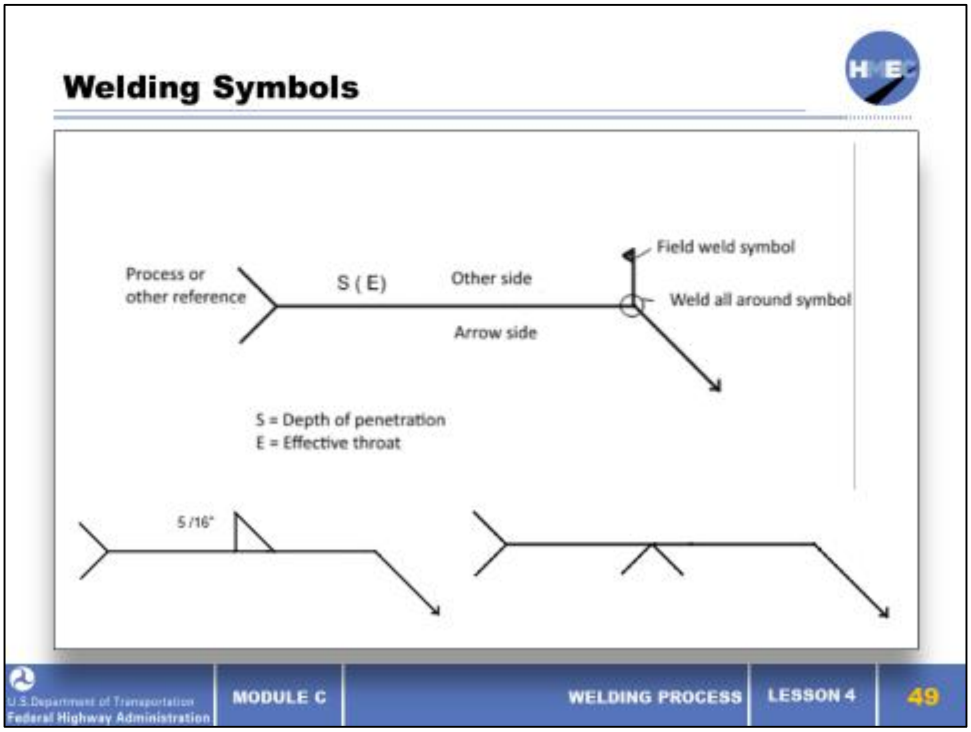
The tee joint on the left represents a typical approach for accomplishing a full penetration tee. It has been prepared for welding first on the top side, then turning the work over and back-gouging to sound metal, and then filling the back side.

The joint on the right represents a typical approach for accomplishing full penetration corner welds. Note the back-up bar on the top joint. Such a bar would be used for corners where it will only be possible to access the weld from one side. Box sections with full penetration corner welds represent a good example of such applications. In corner joints, back-up bars are usually left in place (due to restricted access).

By contrast, the corner joint on the bottom right does not have a back-up bar and has been detailed for back gouging. For the tee and for the corner joint on the bottom right, note the close fit-up at the root joint. A close (though not necessarily "tight") gap helps achieve good workmanship.

Similarly, in the joint on the top right, close fit-up between the back-up bar and the beveled plate is also important for quality; usually "tight fit" is preferred in this condition, otherwise slap could get trapped at the root of the joint.

Slide 49



If you are going to do any weld design, it is highly recommended that you obtain a reference copy of AWS A2.4, Standard Symbols for Welding, Brazing, and Nondestructive Examination. As we'll see, there are a few basic elements in the weld symbol that are easily understood but there are many more elements for special instruction, and the best place to find them is A2.4.

The horizontal line in the symbol is the reference line. To the right of the reference line in these three cases (they can be right to left as well) is the arrow: the arrow must clearly point to the two components being joined. The proper protocol is for the tip of the arrow to touch the two components right at the joint where they will be joined.

In the top symbols, the "S" and the "E" designate a weld as a partial joint penetration weld. The "E" value is the effective through, and the "S" is the joint preparation depth. If these letters are missing, it will be assumed that the weld is full penetration. The field weld symbol and the weld all around symbol are handy. Note especially the "far side" and "other side" clarification—it is important not to mix this up.

On the bottom left is the fillet weld symbol. It is very simple: be sure to show the size. In this case, we are calling for a $^{5}/_{16}$-in. weld.

On the bottom right is the groove weld symbol. Note that it has no dimensions. If a full penetration weld is needed, this is all that is needed, and no dimensions are necessary.

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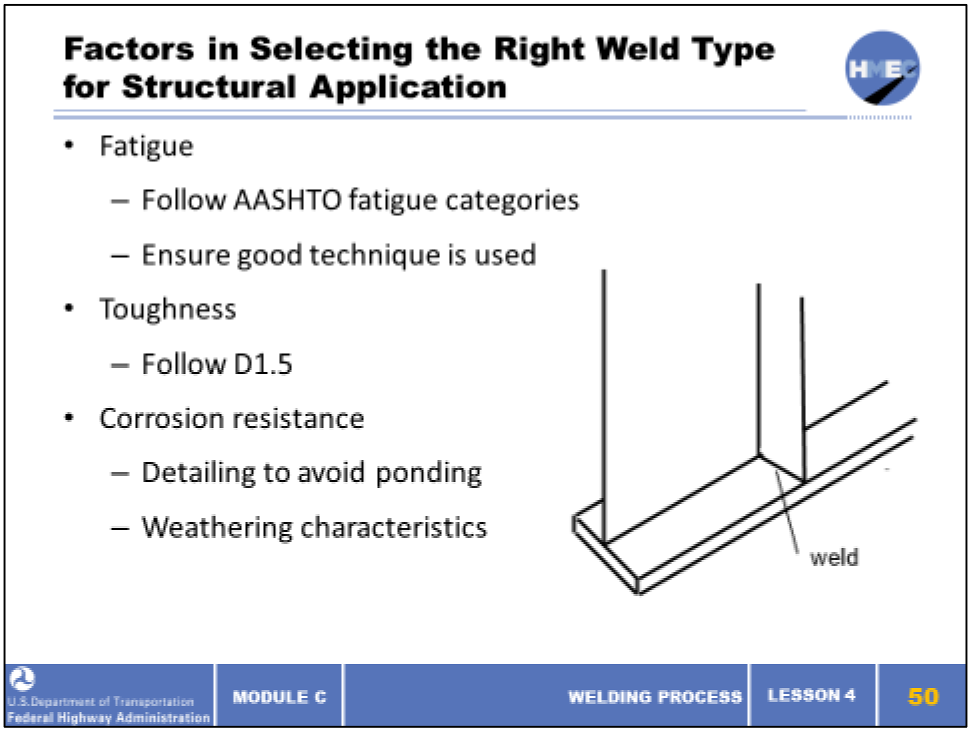
Slide 50



Proper fatigue design is crucial to the long-term durability of the bridge. Welds are known to fail in fatigue; however, practices to avoid fatigue problems with welds are also well known now, and by using them, problems can be avoided.

In terms of design, use the right fatigue category for the right situation. The AASHTO design specifications provide a stress range that will result in infinite life for any detail provided the connection is designed for the right stress range. For example, consider the weld on the right. Assuming that the flange is location in a tension zone, the weld will have a fatigue impact on the plate. Should the weld be avoided? No. The best economy is the design the flange to accommodate the stress range that the flange needs for infinite life.

On the shop floor, then, good fatigue performance (matching the category used in design) can readily be accomplished by following good shop practice, especially including the profile requirement described above.

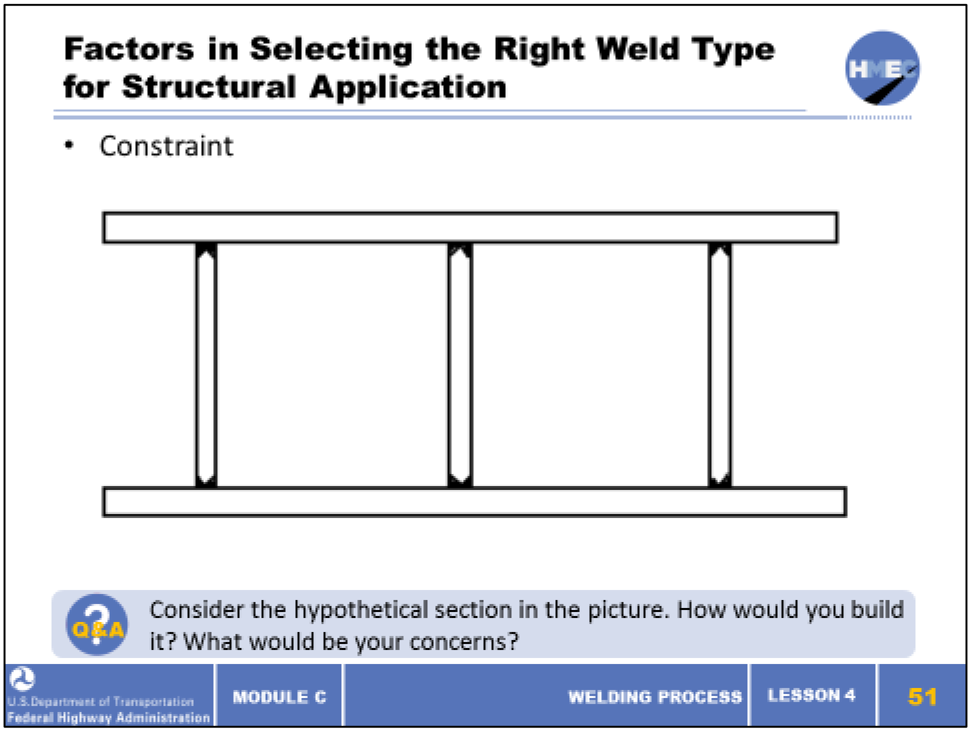
Toughness refers to the crack resistance of the weld metal; good toughness is desired to help resist crack growth should one ever occur. Fundamentally, the best way to ensure that there is sufficient toughness in the weld is to follow the practices in D1.5. Code provisions are written to achieve good toughness, including:

- Only allowing welding processes that will provide good toughness;
- Combining consumables with base metals, which will provide good toughness; and
- Requiring practices to ensure proper toughness, such as the use of properly qualified welding procedures and associated preheat controls.

The primary concern for achieving good corrosion resistance in a welded steel structures is to avoid details that will collect water and allow it to pond. This typically doesn't have very much to do with welding practices in terms of the welding procedures chosen as much as with detailing – i.e., the arrangements of the plate and other elements that make up the structural components.

With respect to weathering steel, special consumables are used so that welds will also have weathering properties—this is required by D1.5. Since weathering is a surface effect, it is possible to achieve good weathering performance from full penetration welds by simply using consumables with weathering properties in the passes that will be at the surface of the weld. However, in practice, the fabricators do not switch out consumable in this way because it is not worth the cost savings.

Slide 51



As reflected earlier, weld metal shrinks when it cools. Therefore, welds draw components closer together as the weld metal solidifies and then cools. This is a normal phenomenon in day-to-day fabrication practice that fabricators deal with readily when building components that they are familiar with. However, when designs involve components that are framed together and will pull against each other, constraint can be a problem.

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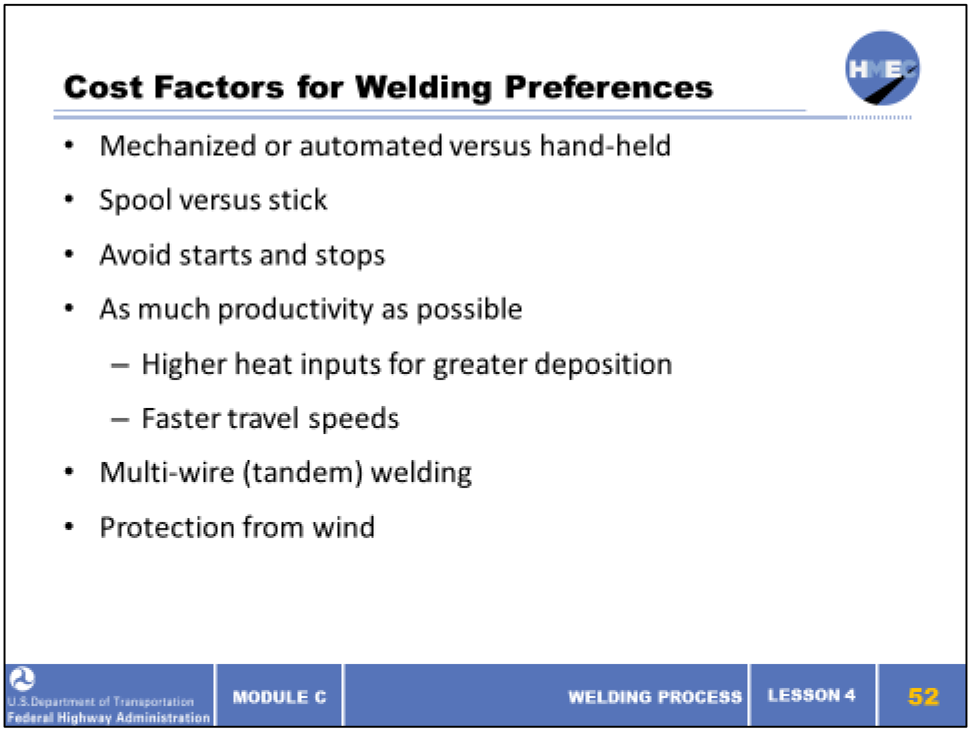
Slide 52



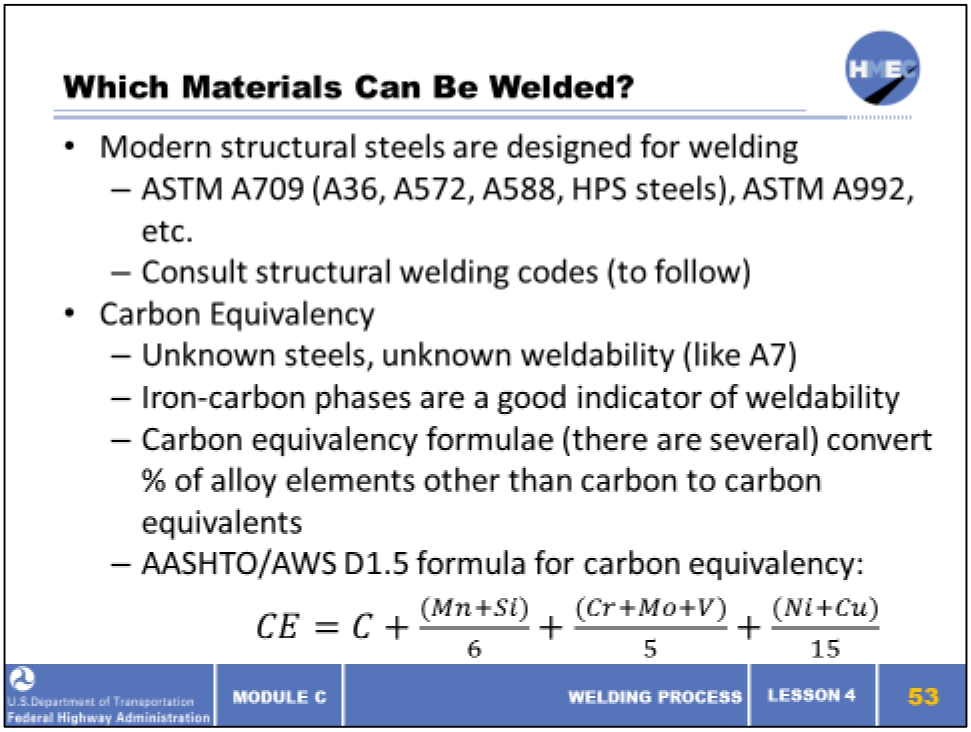
To the extent possible, the fabricator will seek to mechanize or automate welding—doing so improves efficiency and weld uniformity. Fabricators prefer processes that facilitate wire-feeding to keep production going. Avoiding stops and starts will not only improve productivity, but it will also facilitate quality.

When filling groove welds, fabricators would like put down as much weld metal per pass as possible to help accomplish the weld as efficiently as possible. Larger wires and more heat input are desired for large welds.

Tandem welding is a good way to increase deposition. Tandem means welding with multiple wires in the same puddle. It can be as many as four or five wires, although the use of two wires is more common.

Proper shielding to keep contaminants out of the weld puddle is important; therefore, wind can make welding difficult by blowing away shielding gas. Field welding can be challenging in adverse weather. Note, though, that field welding is very useful—one must simply take care to ensure that shielding is not compromised.

Slide 53



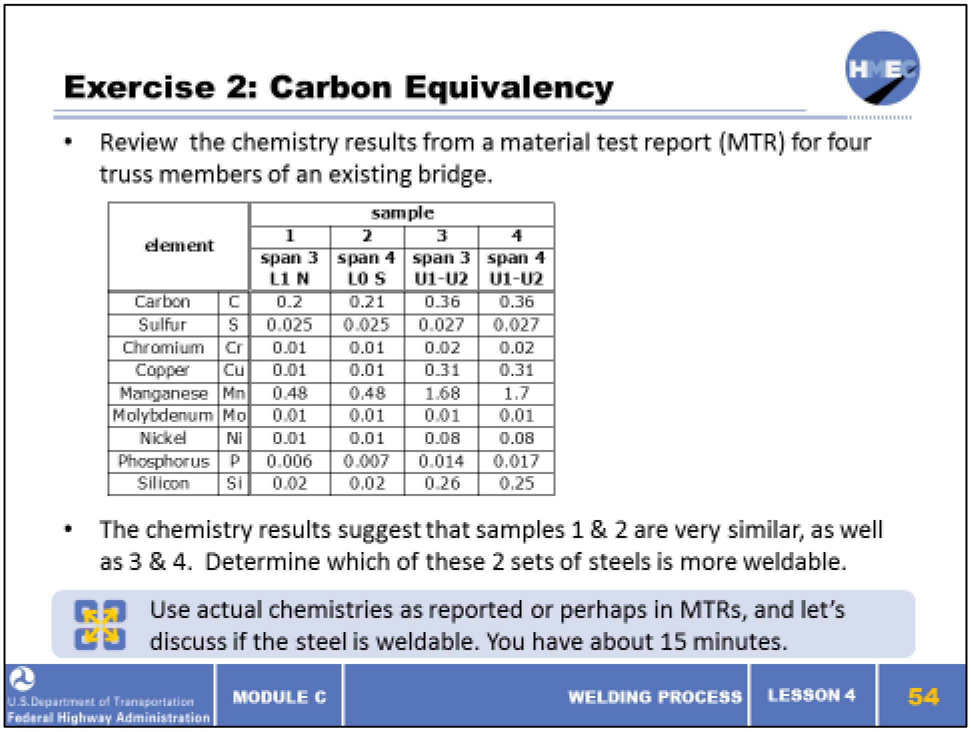
Not all types of iron on steel can be welded. Most modern structural steel can be welded: this simply facilitates construction of structures. A709 steels certainly are weldable; there are many others for weldable structural shapes, tubes, and other types of plates. The respective ASTM specification should speak to the weldability of the steel.

Another good way to see if a steel is weldable is to see if it is listed in one of the AWS welding codes: if it is there, it is weldable, as discussed previously.

Use a “carbon equivalency” (CE) as a good way to establish weldability of a steel that is unknown or is a known grade of unknown weldability. For example, many older structures were made using ASTM A7 steel; this steel was not designed for welding and had a broad chemistry, so its weldability varies.

There are many CE formulae; the one listed here is found in the Bridge Welding Code. If the weldability of a steel is unknown, you can establish weldability by taking a sample, running its chemistry, and then using its actual chemistry to establish weldability using a CE formula.

Slide 54



Exercise 2: Carbon Equivalency

- Review the chemistry results from a material test report (MTR) for four truss members of an existing bridge.

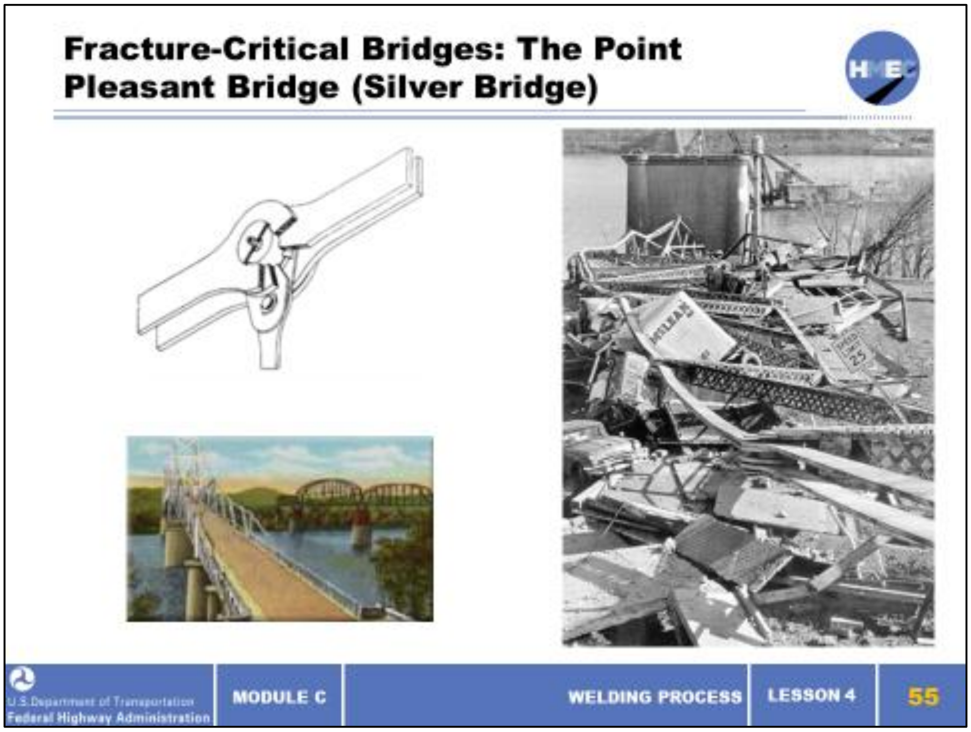
element		sample			
		1	2	3	4
		span 3 L1 N	span 4 L0 S	span 3 U1-U2	span 4 U1-U2
Carbon	C	0.2	0.21	0.36	0.36
Sulfur	S	0.025	0.025	0.027	0.027
Chromium	Cr	0.01	0.01	0.02	0.02
Copper	Cu	0.01	0.01	0.31	0.31
Manganese	Mn	0.48	0.48	1.68	1.7
Molybdenum	Mo	0.01	0.01	0.01	0.01
Nickel	Ni	0.01	0.01	0.08	0.08
Phosphorus	P	0.006	0.007	0.014	0.017
Silicon	Si	0.02	0.02	0.26	0.25

- The chemistry results suggest that samples 1 & 2 are very similar, as well as 3 & 4. Determine which of these 2 sets of steels is more weldable.

Use actual chemistries as reported or perhaps in MTRs, and let's discuss if the steel is weldable. You have about 15 minutes.

The chemistry results suggest that samples 1 & 2 are very similar, as well as 3 & 4. Determine which of these 2 sets of steels is more weldable.

Slide 55



The failure of the Point Pleasant Bridge (or "Silver Bridge") in 1967 awoke the bridge community to the potential hazards of non-redundant bridges.

The Silver Bridge was an eyebar suspension bridge—a typical suspension bridge whose suspenders were comprised of eye bars. This was not such an uncommon practice, but the problem in the Silver Bridge was that each link was only comprised of two eyebars (by contrast, the eyebar suspension bridges across the Allegheny River in Pittsburgh have six or seven eye bars per link). The bridge was opened in 1928 and had been in service for 39 years when it collapsed. One eyebar had a small crack (0.1 in., or 2.5 mm, long) developed from fretting wear. When the crack grew to enough to reduce the cross-section beyond its ability to carry the applied load, the eyebar broke; instantly the entire load shifted to the remaining eyebar in the link and the other eyebar also failed. Hence, one of the two bridge suspenders failed, and the entire bridge collapsed. The bridge was fully loaded with rush hour traffic; there were 46 fatalities.

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Slide 56

The Silver Bridge raised awareness of the potential dangers of non-redundant structures: if a structure has an area of load where this is only one load path available to carry the load, then the structure is non-redundant. And, if the load path of a non-redundant bridge fails, then the structure will fail. Consider the bridge shown; if one of the girders were to fail (presuming the deck is in place and the bridge is in service), would failure of one girder cause bridge to collapse? No – not in and of itself. Hence, the bridge is redundant.

The I35W Bridge in Minneapolis provides a more recent example: like many truss bridges, the I35W Bridge had load areas where only one load path was present. Like the Silver Bridge, the I35W Bridge was in service for decades before it collapsed. Unfortunately, the original design featured a handful of gusset plates that, by mistake, were under-designed. Due to factors of safety, the gusset plates performed fine in service for many years until, at the time of the collapse, the bridge loads were higher due to the presence of construction materials; these construction materials combined with live loads to overload the under designed gusset plate; the gusset plate failed, and the bridge collapsed.

Following the Silver Bridge collapse, practices were put in place to help protect the public from similar failures. A key step was to designate non-redundant bridges as fracture-critical, which

FHWA defines as follows: "Fracture-critical members or member components are steel tension members or steel components of members whose failure would be expected to result in collapse of the bridge."

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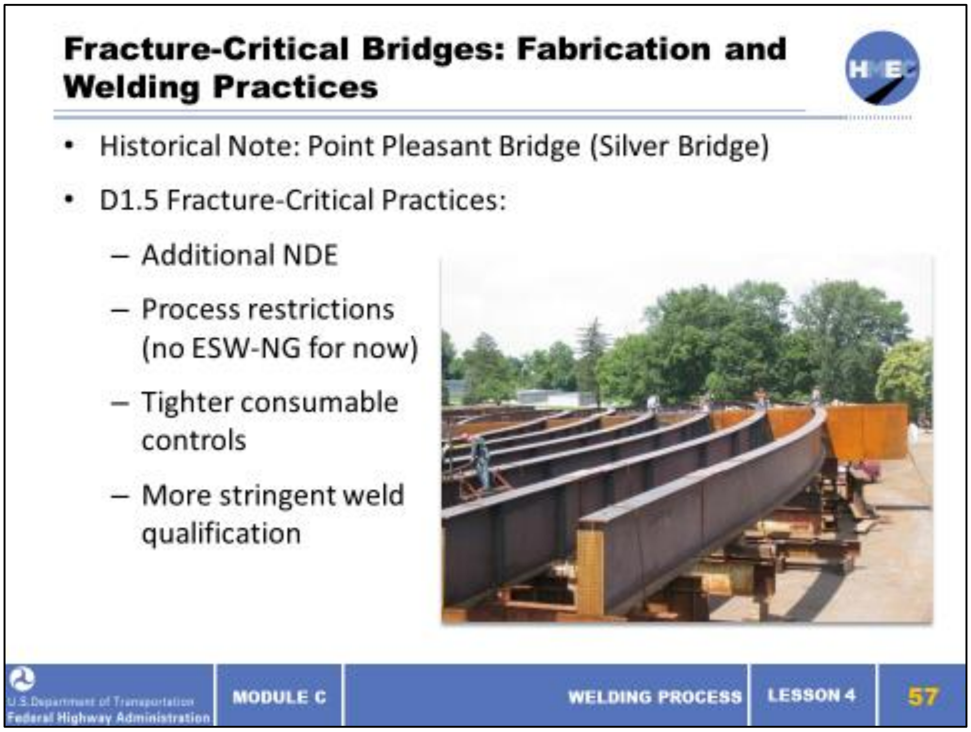
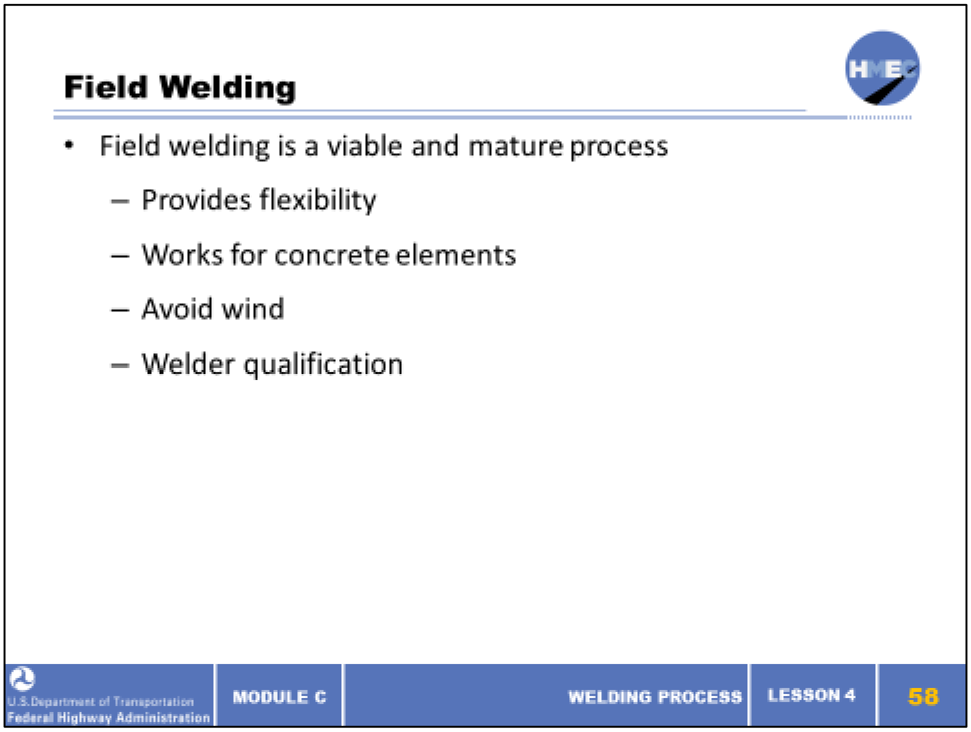
Slide 57



The Silver Bridge failure was precipitated by a crack that grew from fretting wear; in addition to raising awareness about the potential hazard of non-redundant structures, the Silver Bridge also demonstrated that such a failure could result from a small crack. Hence, practices were established for close inspection of fracture-critical bridges (for cracks), and fabrication practices were put into place for such members. Originally, State DOTs adopted these requirements in their own specification or contract plans; later they were adopted as Clause 12 of D1.5. Therefore, special fabrication practices will be applied when a steel structural member is designated as fracture-critical and the member is built under AASHTO/AWS D1.5. These are summarized as listed on the slide.

Slide 58



People are often leery of field welding, but it is both straightforward and very effective. Field welding offers flexibility in design because it can be so easy to join members in the field using it.

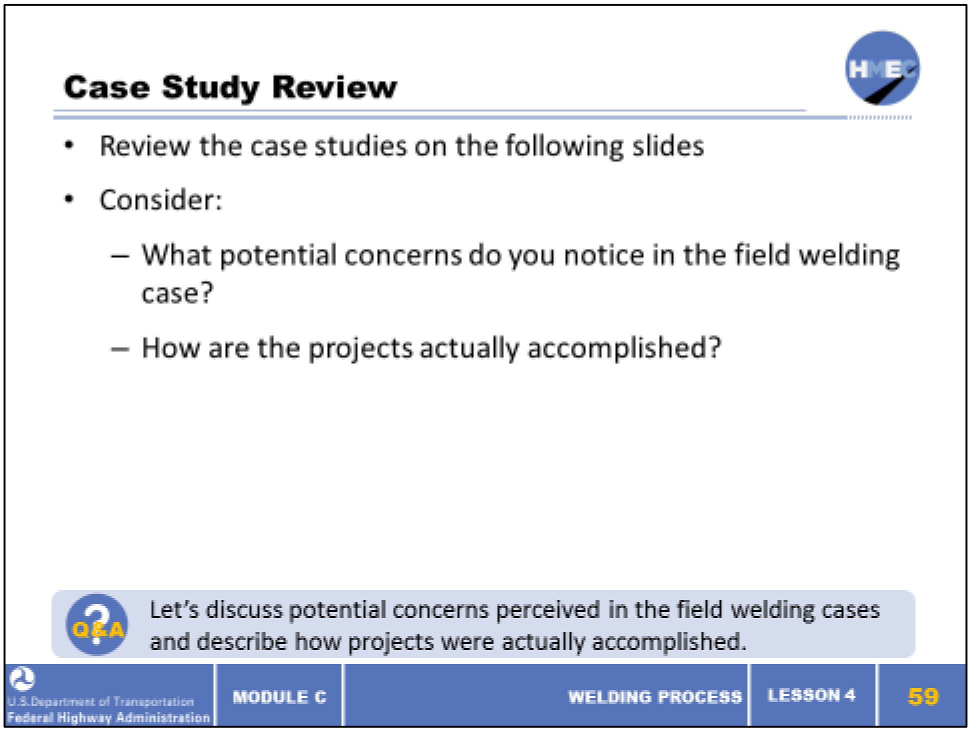
Over the years, some States have field welded their main member's connections—notably Texas, Virginia, and Georgia.

It is counter-intuitive, but field welding works for concrete elements as well. Some engineers have embedded steel plates into their prestressed components for subsequent welding in the field, particularly on accelerated bridge construction (ABC) projects.

Welding in the field is really about the same as welding in the shop, except for the wind effects—winds can blow away shielding gas and seriously compromise weld quality.

Welder qualification is straightforward and not very different from shop work. Field welders do typically need to be good welders because in the field it is much more likely that out-of-position welding will be needed.

Slide 59


Case Study Review
HMEC
Review the case studies on the following slides
Consider:
What potential concerns do you notice in the field welding case?
How are the projects actually accomplished?
Q&A
Let's discuss potential concerns perceived in the field welding cases and describe how projects were actually accomplished.
U.S. Department of Transportation Federal Highway Administration
MODULE C
WELDING PROCESS
LESSON 4
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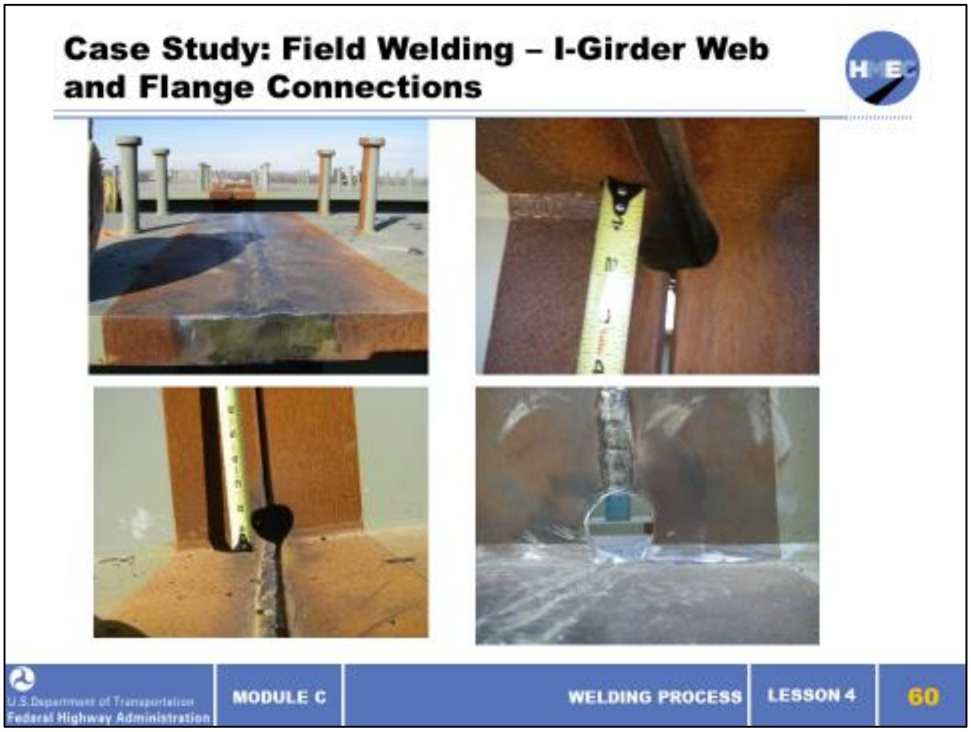
Slide 60



The picture on the top left shows a completed top flange weld in the foreground; the connection in the background is prepped for welding. The picture on the top right shows the top flange and the top of the web prepped for welding. Why is there a hole here? The access hole, known commonly as a “rat” hole or “apple” hole, facilitates 100% welding of the flange with no connection at the corner to the web. This practice is used because if the web weld was carried right to the corner it would be very difficult to achieve a clean weld in that corner. The pictures on the bottom reflect bottom flange and lower web welds; welding has started on the bottom left and is complete on the bottom right.

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Slide 61

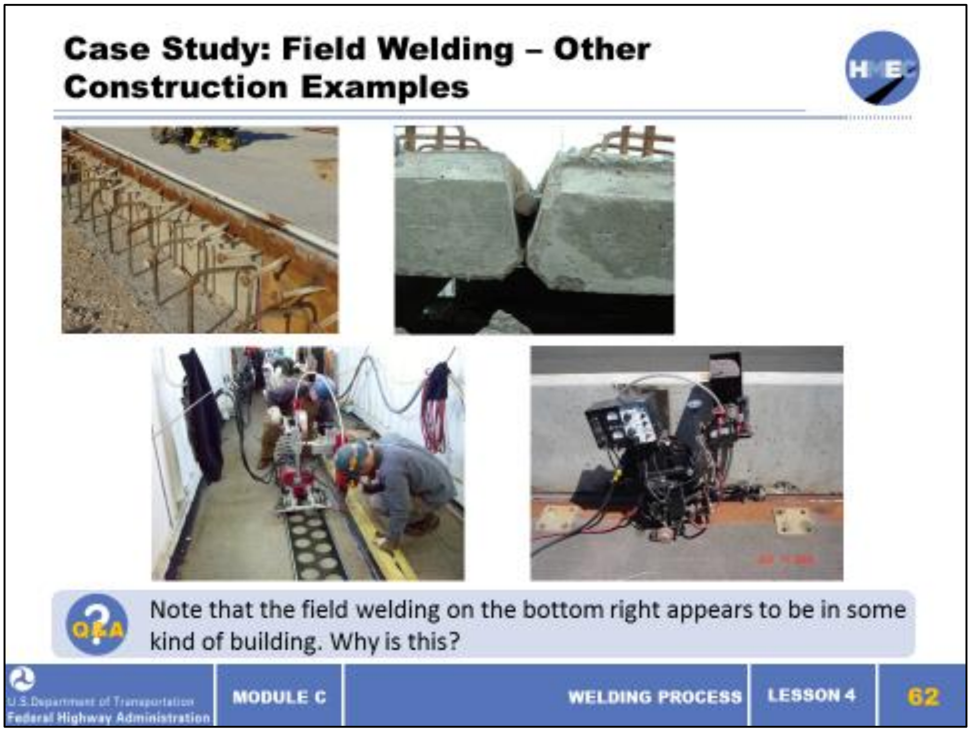
The top left picture shows the typical standard TxDOT I-girder cross frame connection, which is a field welded detail. This cross frame is also shown on the bottom right. There is one bolt in each corner used for erection—to pull the members together and hold them together. Once the steel is in place, the connections are welded. TxDOT has used this detail for decades and built thousands of bridges this way. Similarly, diaphragms are installed this way (top right and bottom left).

Of interest, note the half-tube stiffener used in the bottom right photo (as well as the field welded cross frame). What is the purpose of this tube? Discuss. Detailing framing members on sharp skews is challenging: the tube allows attachment of the connection plate with ease at any angle.

Note that to facilitate field welding, the girders, cross frames, and diaphragm were masked in the shop during painting.

The pictures two pictures show sole plates and girder bottom flanges prepped for field welding. This is a common practice around the country and provide great flexibility in establishing these connections.

Slide 62



The top left photo shows a field weld on an expansion joint rail. Field welding offers flexibility for accomplishing a broad variety of such attachments.

On the top right, field welding is used to connect the top flanges of concrete tee beams. Note the flexibility that the use of field welding offers. As long as the rod rests on the plates which are embedded in the concrete flange, the weld can be accomplished. Hence, this welded joint offer field tolerance for beam elevation and camber.

In the two photos on the bottom, field welding is being used to join the deck plates on orthotropic deck bridges. Consider such use of a steel plate as a deck. Joining the plates with a full penetration weld more readily provides a ride quality surface that a bolted connection because bolts would protrude into the space above the deck plate. Such bolted connections on orthotropic deck bridges have indeed been used but only on an exception basis; field welded joints are much more common among the thousands of square feet of deck in use on orthotropic deck bridges around the world.

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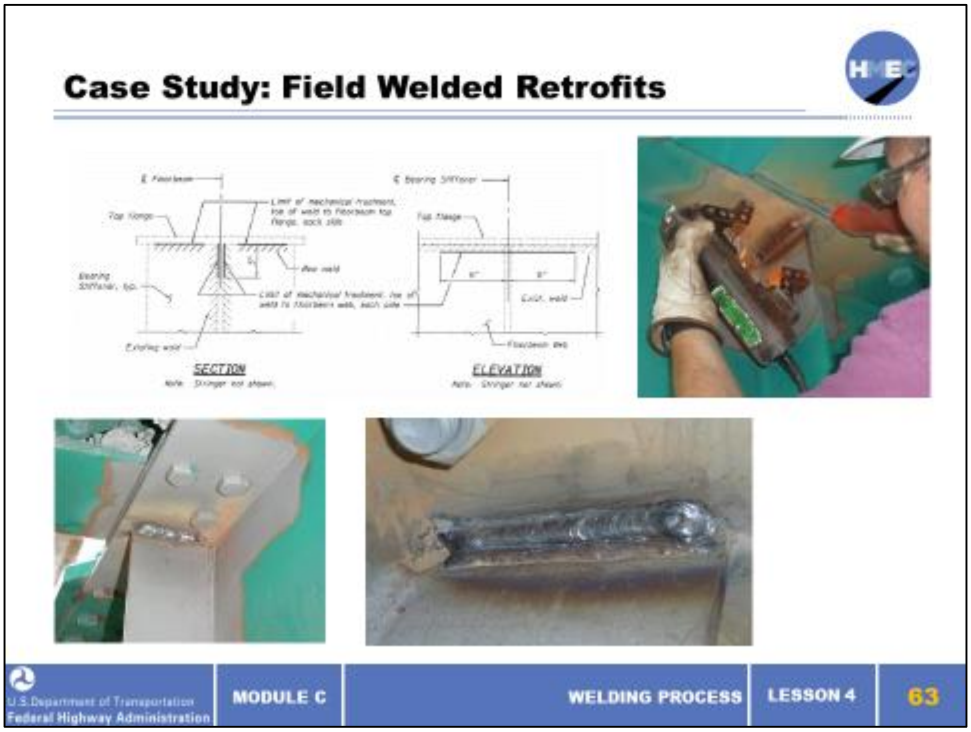
Slide 63



The pictures shown reflect a common and very useful example of field welding retrofits: joining of connection plates to flanges. This older bridge was built before fatigue performance issues from out-of-plane bending was understood. We didn't always know that if connection plates are not joined to flanges, cyclic loads from framing can caused webs to tear at the end of the stiffeners if they are not attached to flanges. Such joints are always welded in modern bridges, but not so in older bridges. Field welding offers a useful and effective retrofit.

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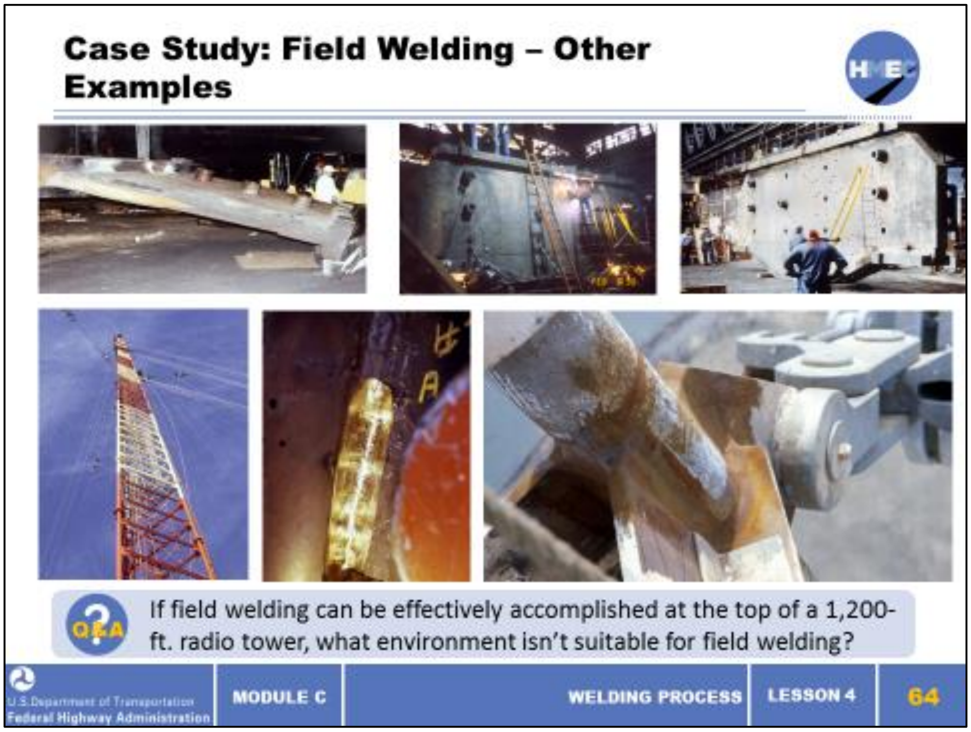
Slide 64



The pictures on the top row reflect a weld repair made to a 50,000 ton forge press girder which had fractured; the fracture face is visible in the picture on the top left. The girder is 13 ft. deep, 36 ft. long, and has webs and flanges that are 12 in. thick. The middle picture on the top shows the welds being accomplished, and the finished work in shown on the top right.

The bottom row shows repairs made at the top of a 1,200-ft. radio tower. Here, guy pull-offs needed to be repaired; such is shown in the second picture, and the completed repair is shown on the bottom right.

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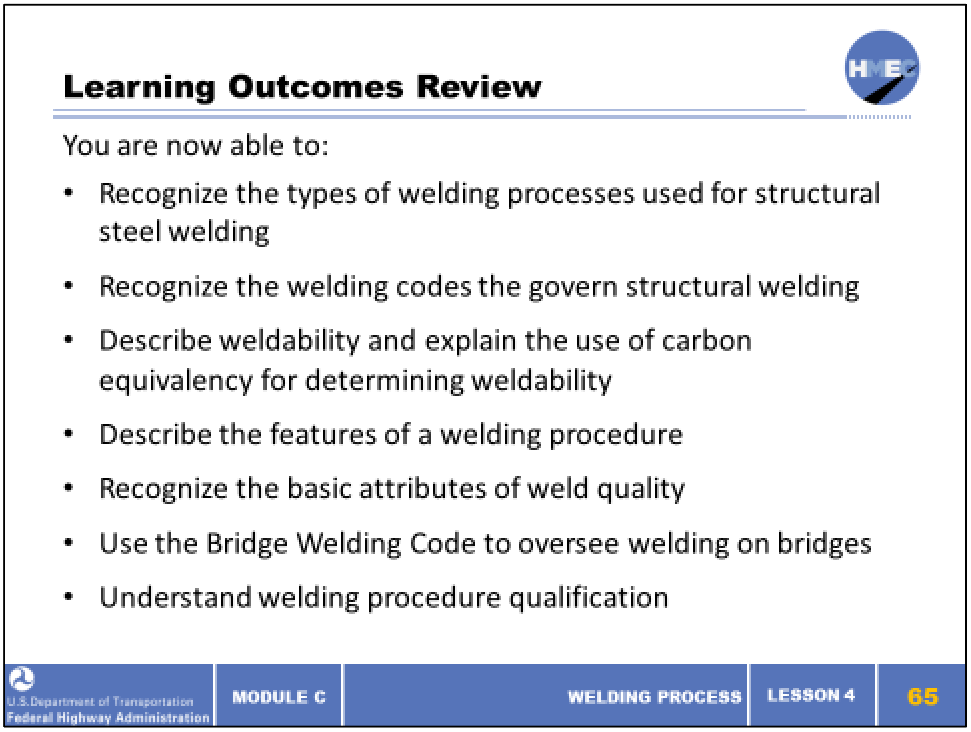
Slide 65


Learning Outcomes Review
You are now able to:
• Recognize the types of welding processes used for structural steel welding
• Recognize the welding codes the govern structural welding
• Describe weldability and explain the use of carbon equivalency for determining weldability
• Describe the features of a welding procedure
• Recognize the basic attributes of weld quality
• Use the Bridge Welding Code to oversee welding on bridges
• Understand welding procedure qualification
U.S. Department of Transportation
Federal Highway Administration
MODULE C
WELDING PROCESS
LESSON 4
65

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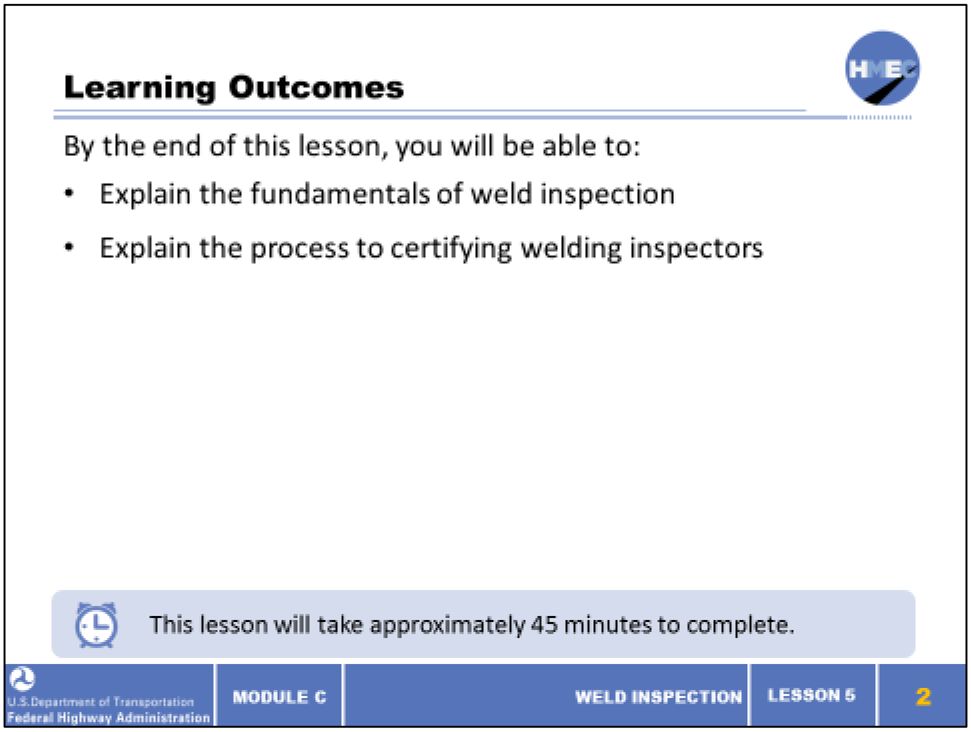
Slide 1


ILT
HMEC
Highway Materials Engineering Course
Lesson 5: Weld Inspection
Steel, Welding, and Coatings
U.S.Department of Transportation
Federal Highway Administration
MODULE
C

Slide 2


Learning Outcomes
HMEC
By the end of this lesson, you will be able to:
• Explain the fundamentals of weld inspection
• Explain the process to certifying welding inspectors
This lesson will take approximately 45 minutes to complete.
U.S.Department of Transportation
Federal Highway Administration
MODULE C
WELD INSPECTION
LESSON 5
2

Slide 3

The inspector must ensure that the work satisfies specification requirements. They should not accept less, as satisfying the specifications is the best way to ensure good performance of the bridge. On the other hand, they should not demand more because doing so is a breach of contract. Satisfying the specifications is key to good long-term performance of the structure. In a steel structure, this is especially true of cleaning and painting.

Documentation provides a record of how the project was executed in case it's needed in the future. It also protects the owner in case of claims or legal action.

The inspector is the eyes and ears of the engineer in the shop. He/she should keep the engineer up to speed with the progress of the job. It is a good idea to relay anything that is out of the ordinary or that seems out of place. The inspector should work in such a manner as to facilitate the project schedule. The fabricator will have committed to a schedule. Hold points should be avoided but if they are necessary, the inspector should be ready to take care of them with the fabricator. It is important to be sure steel is properly cleaned before painting, but making the fabricator wait a long time for a cleaning inspection can impede project progress and compromise the cleaning condition. Additionally, when the work is complete, assembly verification should be conducted expeditiously. The inspector needs thorough knowledge of the work, and, where applicable, must have proper certifications.

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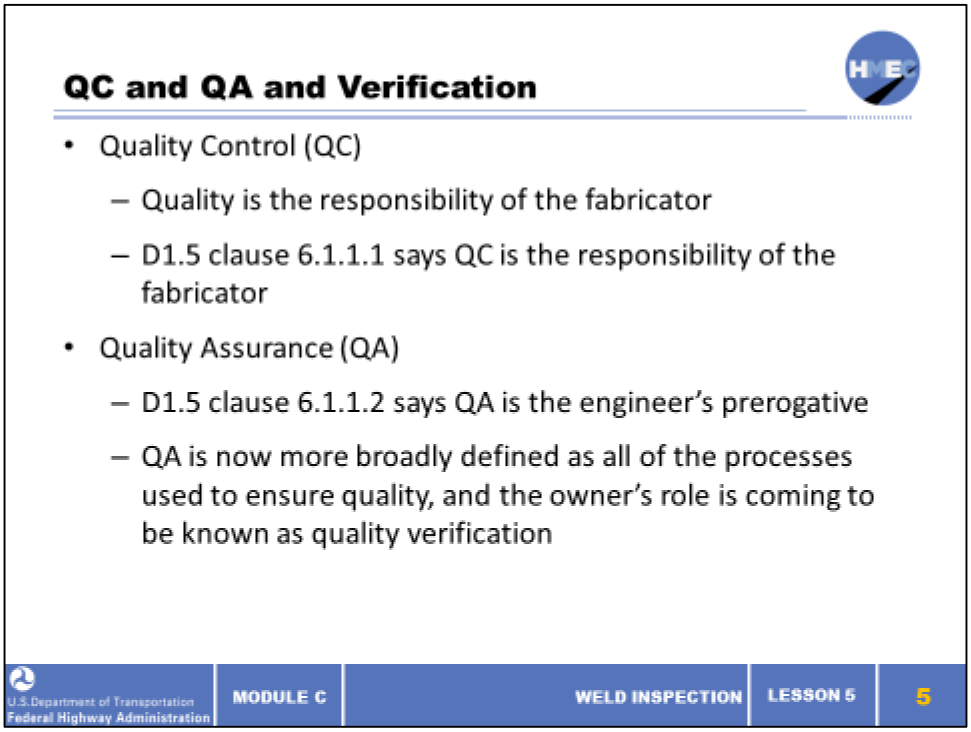
Slide 4

Gray areas do come up often. Specs are written with the idea that everything is covered and that every eventuality is anticipated, but this is often not the case. In gray-area situations, the inspector should rely on the engineer, and the engineer should work with the fabricator on how to proceed. In the best case, the engineer and fabricator readily come to an agreement on how to move forward. More formal steps may be necessary if the parties can't reach an agreement.

Slide 5



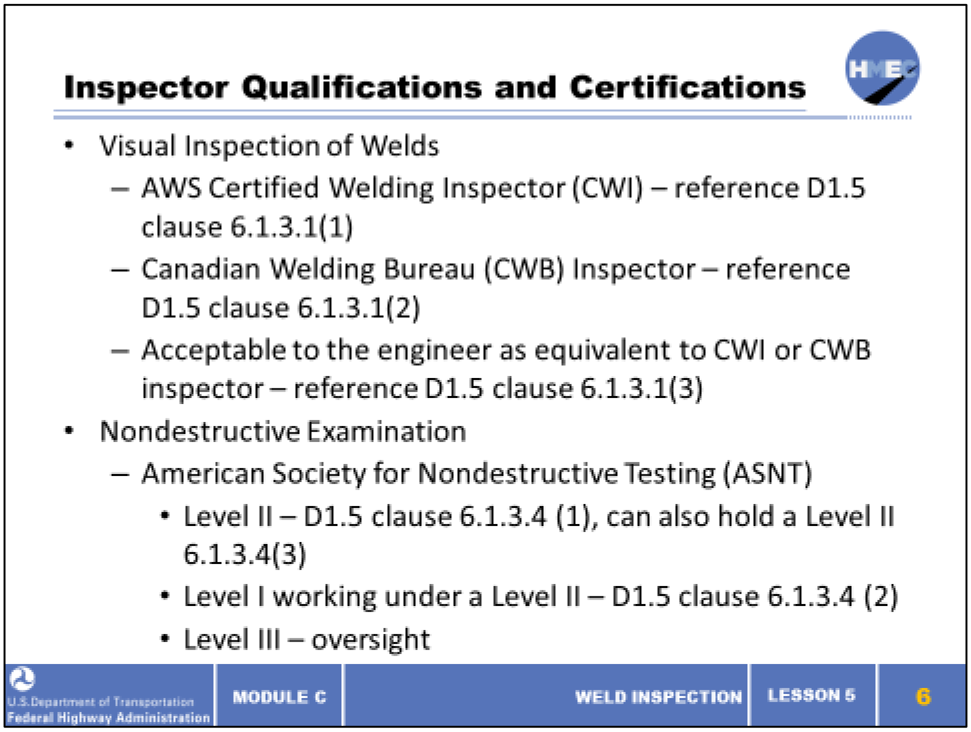
The fabricator is responsible for quality. The fabricator has a contract that defines the requirements of the job, and he must satisfy that contract. The American Welding Society (AWS) D1.5 clause 6.1.1.1 defines quality control (QC) as the responsibility of the fabricator.

Clause 6.1.1.2 of D1.5 makes a distinction between requirement and prerogative, stating that the owner does not have to inspect the work.

D1.5 uses "quality assurance" to describe what the owner does. This use is customary in highway fabrication; however, it is inconsistent with other industries and, in particular, with the International Organization for Standardization (ISO).

ISO assigns the company responsibility for quality management and quality assurance. Based on this, there is movement in the industry to describe the owner's checking as quality verification.

Slide 6



The presence of certified welding inspectors (CWIs) is quite universal in steel structure fabrication. The AWS Bridge welding codes requires the weld inspectors have a CWI or equivalent "acceptable to the engineer," or be a Canadian Welding Bureau (CWB) inspector. Most owner inspectors are also CWI. CWI is administered by the American Welding Society (AWS); CWB is administered by the Canadian Welding Bureau (CWB). Nondestructive inspection certification technicians must be certified under the American Society for Nondestructive Testing (ASNT) recommended practice SNT-TC-1A.

Level II technicians carry full responsibility for conducting nondestructive inspection and interpreting results. Level III technicians (or professionals) certify the Level II technicians. This is different from CWI and CWB because in both of those inspectors are directly certified by AWS and CWB, respectively. With NDE, the Level II techs are certified by the Level III, but the Level III does not work for ASNT. Rather, the Level III can work for the company that the inspector works for (including if this is the fabricator) or can be contracted by the Level II's company.

The Level III technicians take rigorous tests conducted by ASNT in each method that the Level III status is sought; once the tests are passed, ASNT will declare him as a Level III. The Level III technician oversees the inspection plan used by the company and the testing, experience verification, and qualifications of the Level II.

The Level I technician is a Level II technician in training; he can only conduct tests under the supervision of a Level II. The Level III may act as a Level II and actually conduct NDE.

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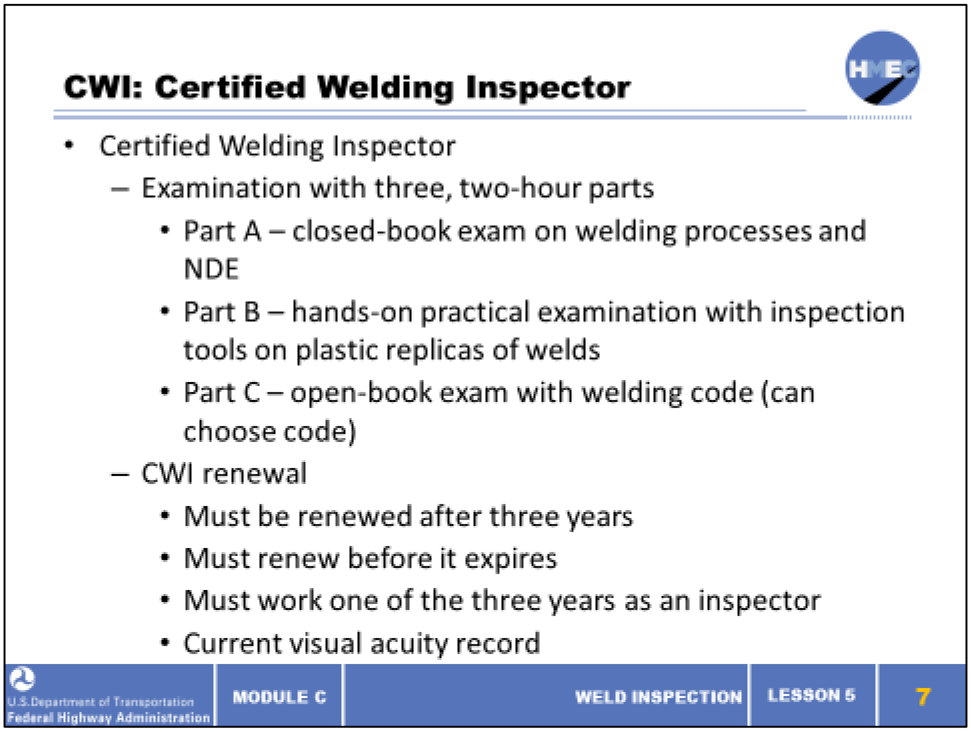
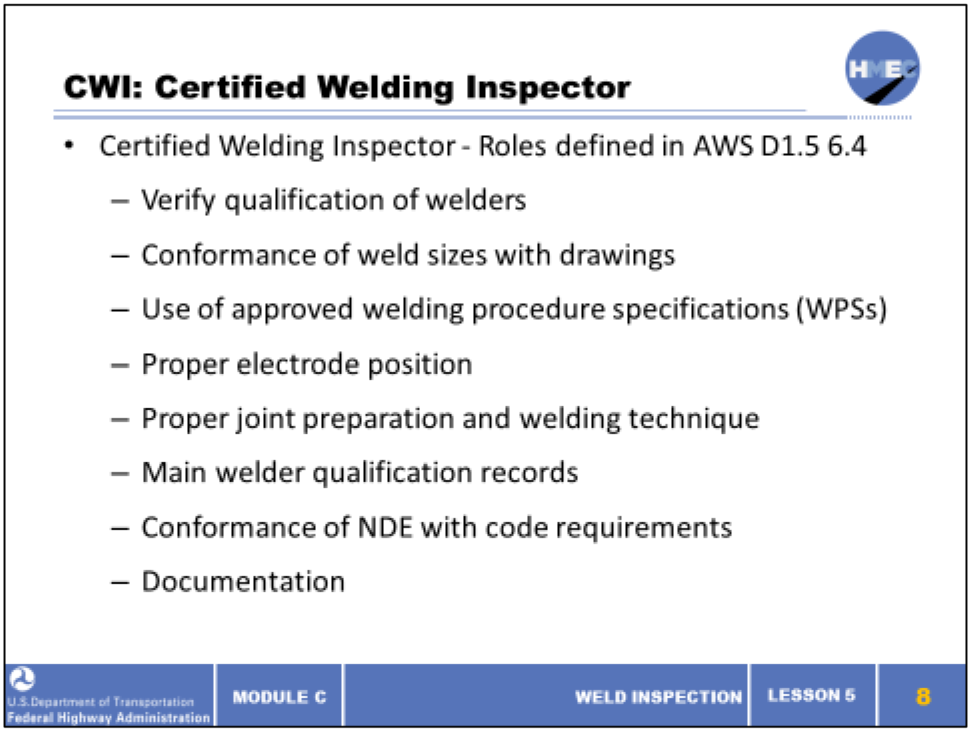
Slide 7



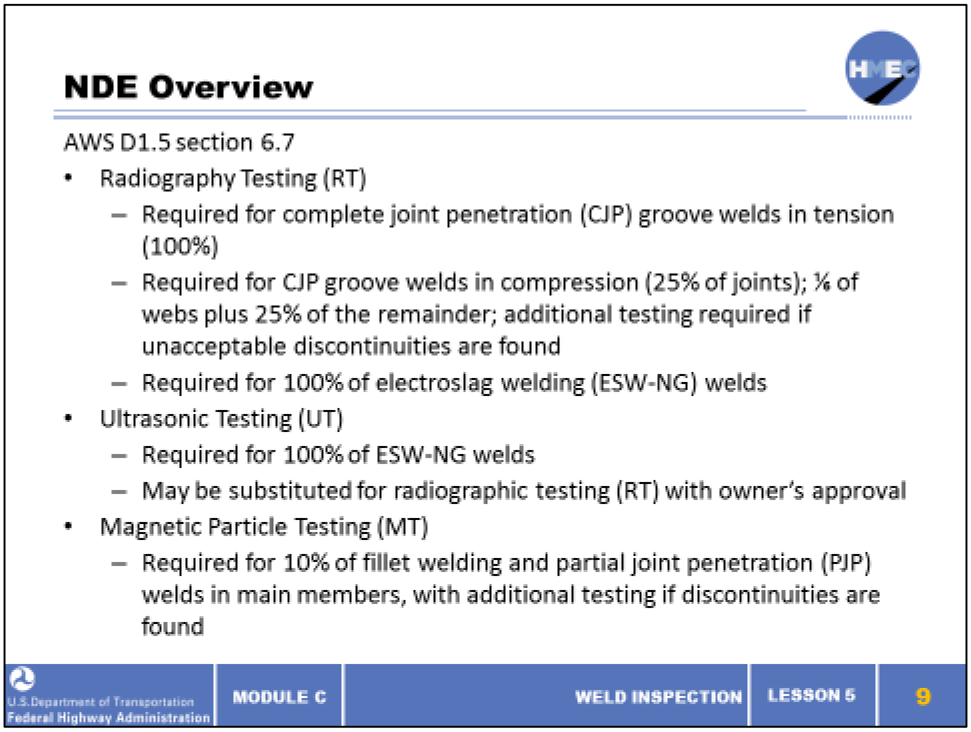
The CWI program is geared towards visual welding.

Slide 8



The CWI program is geared towards visual welding.

Slide 9



Some owners allow ultrasonic testing (UT) in lieu of radiographic testing (RT). Fabricators generally prefer UT because it is more portable and does not have the safety implications of radiation from X-ray tubes or sources. Many owners prefer RT over UT because RT more readily provides the owner with a permanent test record. RT is well suited to finding workmanship defects like slag, porosity, and lack of fusion, but it's not so well suited to finding cracks. UT is excellent at finding planar defects like cracks.

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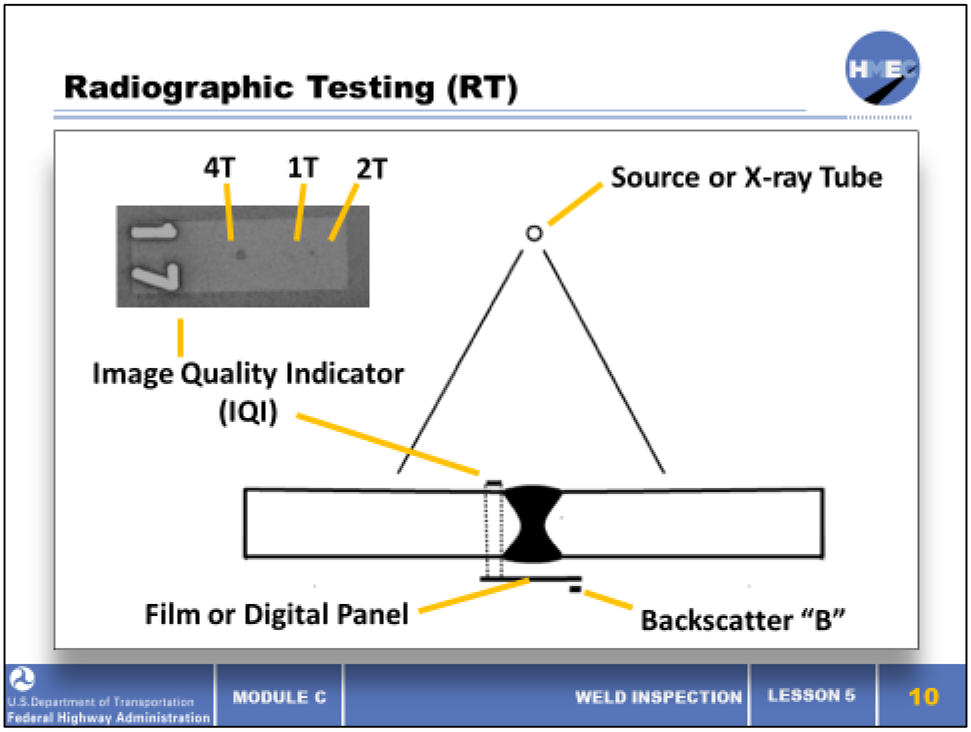
Slide 10



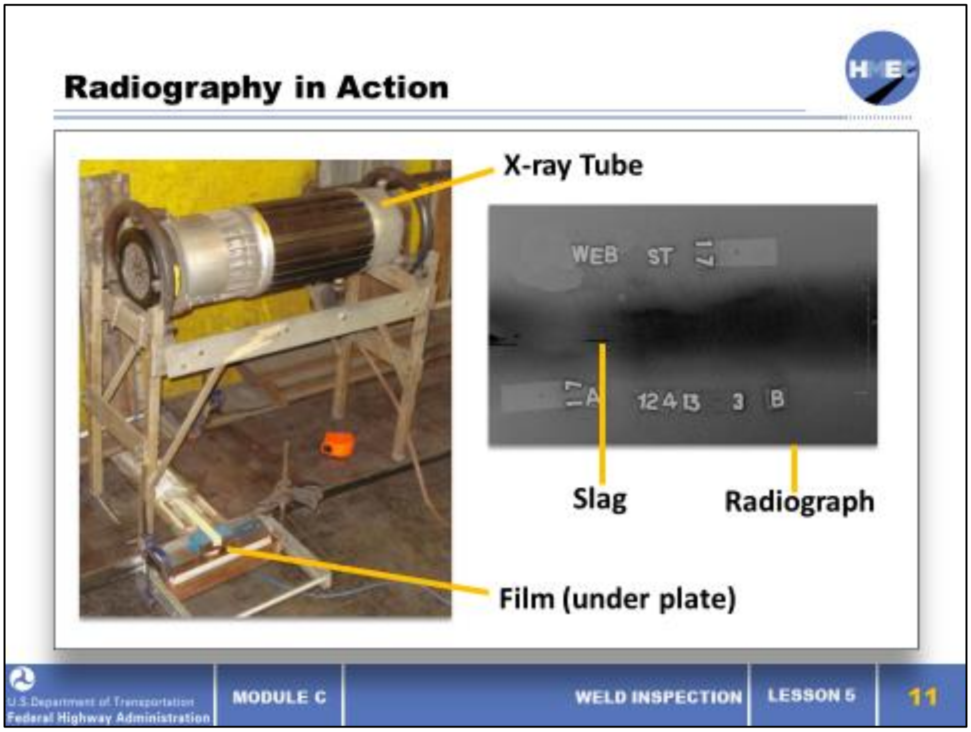
Radiography (or RT for radiographic testing) of welds is very similar to medical radiography. X-rays are generated by an X-ray tube or by using a radioactive source. Radioactive sources are powerful but require special control, subject to State environmental regulations. Tubes are easier to manage because they only emit radiation when turned on, and this radiation is less than that of a source. Note, though, that this means exposure times will be longer. Fabricators conduct testing away from workers. Sometimes this means moving the parts to be tested to a remote part of the shop or waiting until an off shift to shoot the X-rays. This waiting can be an unfortunate, but necessary, disruption to work flow.

X-rays flow from the source or tube through the plate to the film or digital panel. Note the presence of the image quality indicator (IQI). The IQI is placed near the weld on the opposite of the plate as the film. X-rays pass through the IQI, and the IQI shows up on the radiograph; when the radiograph is examined, the IQI must show up to demonstrate that the X-ray has been properly taken. Note that it is possible to over-expose the shot, in which case, no indications will be visible.

In the example shown, a number 17 penetrometer (or "penny") is shown, which, if the 4T hole is being used, is the right thickness for plates ⅝ in. to ⅗ in. thick. Basically, seeing the 4T hole on the required penny tells you that you would be able to see a 4T-sized defect on the radiograph if indeed there was such a defect in the weld.

Another popular type of IQI is the wire type. The wire-type IQI has different diameters of wire, and when using it you have to be able to see the required diameter wire on the radiograph. Another requirement is for a “B” beneath the joint to indicate if too much backscatter has occurred. Usually, X-rays are shot with plates near the shop floor, and it is possible for radiation to bounce off of the floor and expose the film. You don’t want the film you’re looking at to have been exposed via backscatter instead of the proper X-rays coming through the weld. In other words, if you can see the “B”, the X-ray has failed.

Slide 11



On the left, you see an X-ray tube in place with film (could be a digital panel) under the plate, ready for the shot.

On right, you see a radiograph (not the same plate shown on left). Note the penny. Also note “A” and “B”—this is not a backscatter B; rather, it is common to use A to B to indicate the area of interest. In this image, the area to the left of the A and the right of the B is not being tested. Finally, note the line of slag—this X-ray doesn’t pass!

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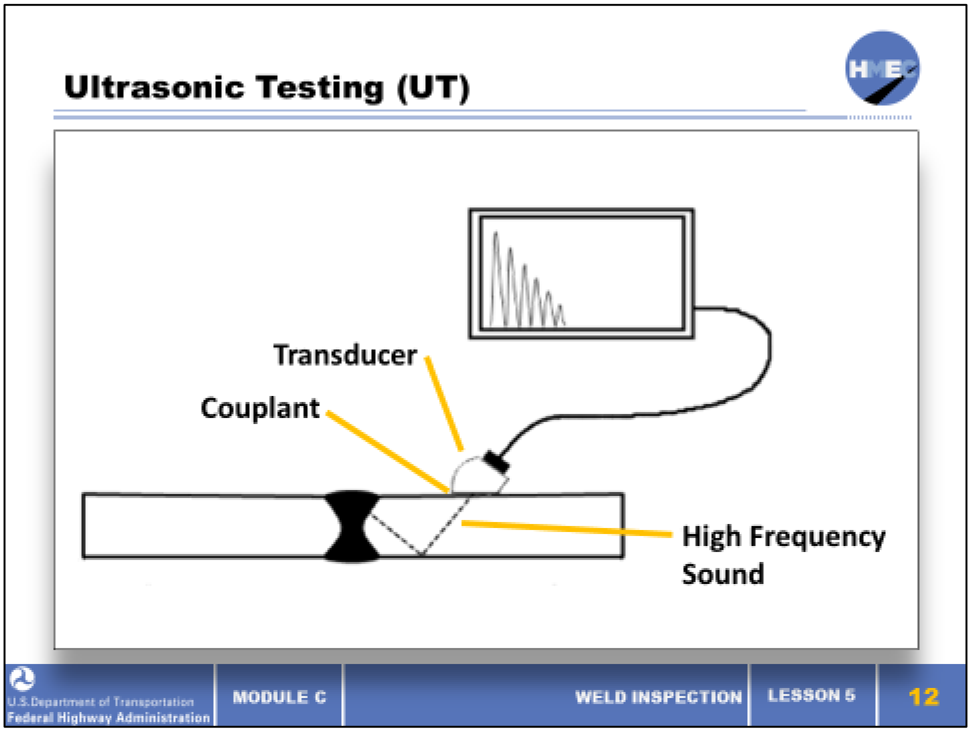
Slide 12



Ultrasonic testing, or UT, operates by sending high frequency sound through the weld. As the sound strikes the various surfaces of the plate, some of it bounces back, and the transducer receives the signal. If the material is uniform, as steel plate and associated welds are expected to be, then non-disrupted sound will return to the transducer. If a defect is present, a disrupted signal will reach the transducer in the form of an unusual drop in decibel. Trigonometry and the length of the sound path tell the technician where the defect is located.

The Level II technician knows how to interpret the sound loss to characterize the defect. The technician scans back and forth to ensure the sound is sent through the entire weld. Considering that the amount of signal loss will depend upon how squarely the sound hits the defect, a thorough exam probes at different angles—45 degrees, 60 degrees, and 70 degrees.

Also, when a defect is encountered, the transducer is turned at several angles (or “rastered”) to, once again, hit the defect at the most direct angle to best characterize it. The UT test record is a written report documented by the technician who conducts the test. Consider that UT can provide the depth of a defect, unlike an X-ray, which only provides a top-down view of the weld. Fabricators often take advantage of this fact: If a rejectable defect is found by X-ray, the fabricator will evaluate the defect again by UT to determine the depth of the defect and to facilitate repair.

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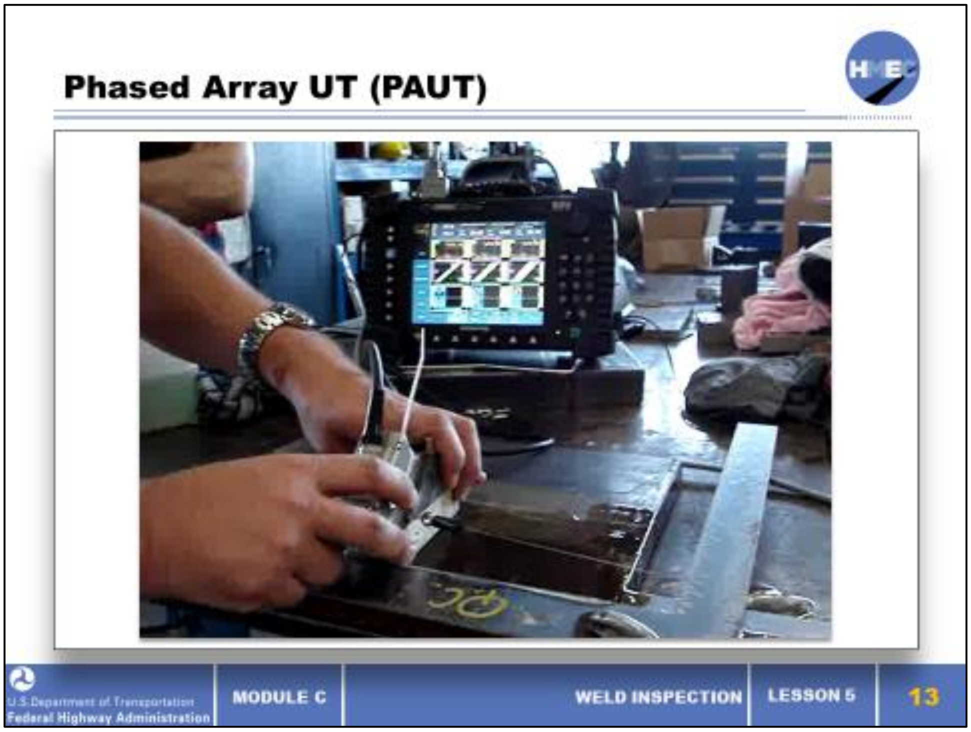
Slide 13

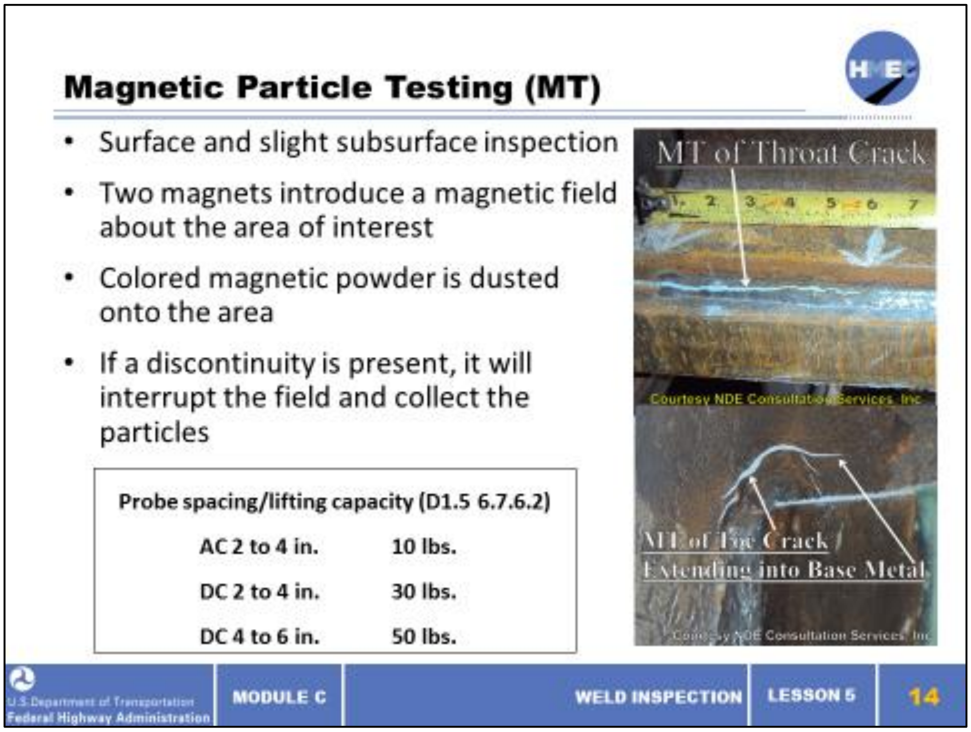


With phased array UT, a group (or an array) of crystals send multiple sound signals at one time, as opposed to just one sound signal as is used in traditional UT. The signals can all be sent at the same angle (linear scan) or at a variety of angles (sector scan), therefore it is not necessary to scrub (provided the weld fits within the scanning pattern). For example, if you were going to scan first with a 45-degree angle, then a 60-degree angle, and then a 70-degree angle, you could instead set the transducer to scan all angles from 45 to 70. With this setting, one transducer would send sound at 45 degrees, the next at 46 degrees, the next at 47 degrees, and so on until it reached 70 degrees.

The PAUT transducer, as shown here, has multiple crystals—note how large it is. Because PAUT is sending sound at multiple angles, it can create "views" from multiple directions, which means this technique provides a better picture of any particular problem. Perhaps most importantly, PAUT can be encoded. A wire encoder is shown here. The end position (off screen) of the wire is fixed, so as the probe is moved parallel to the weld (along the square shown). The encoder knows where it is at any given time, and the "pictures" of the weld are precisely associated with the position along the weld. This allows you to go back to the data file at any time and know the condition at every point in the weld that was tested.

Encoded PAUT provides a permanent digital record of the test, and also allows interpretation of the results at any time. In essence, PAUT is less operator sensitive.

Slide 14



Magnetic particle testing is an excellent surface inspection technique that will readily find surface discontinuities, including those that you cannot see. If good practices are followed, however, there is no reason to expect a significant amount of findings. In other words, MT ensures that shop practices and welds are sound. The principle behind MT is simple: introduce a magnetic field into the work and then use iron filings to identify any discontinuities. Amperage is passed between the two probes and a magnetic flux is produced at right angles to the current. If a discontinuity interrupts these lines of force, they are diverted to the surface and draw the particles to them.

Only discontinuities angled against the field will show, so the probes must be placed on the steel twice, at positions 90 degrees to each other. You can see this placement on the figure on the screen—the probes are placed first at the red dots, and then at the green dots. To ensure the magnetic field is strong, a minimum amount of weight must be lifted with the magnets (or yoke). In this process, MT can be used to check between weld passes or to check that a surface is sound before beginning welding.

How strong to the magnets need to be? Magnets need to be of sufficient strength to introduce enough of a magnetic field to guide particles and collect the particles at discontinuities. D1.5

provides lifting requirements for magnets that are effective and simple to use—note the weight lifting requirements in the box on the slide.

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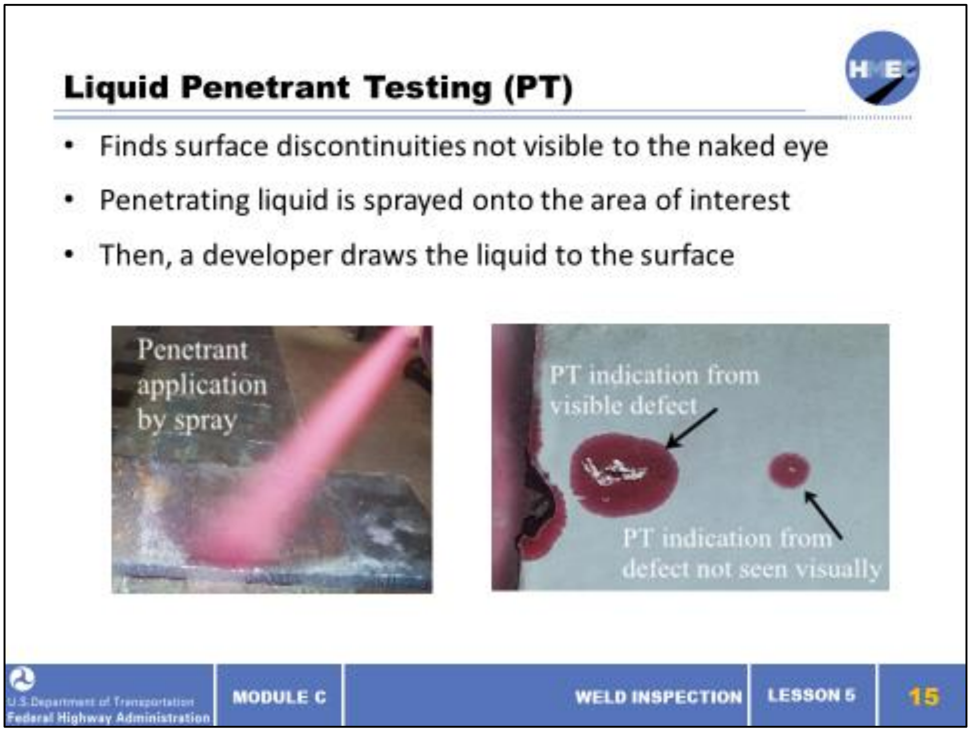
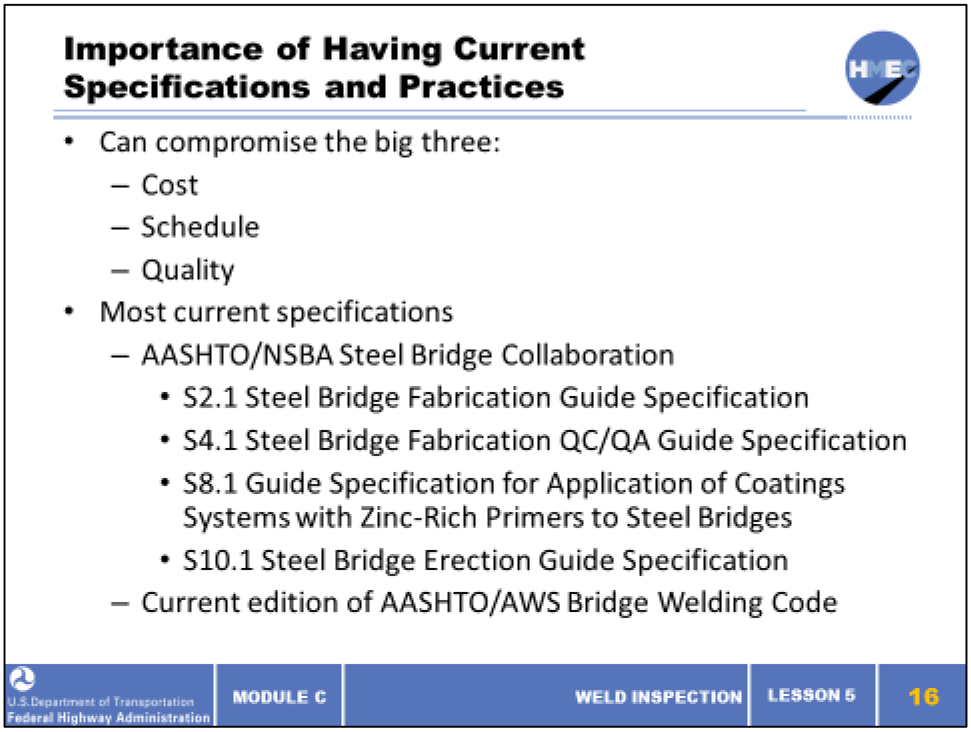
Slide 15



Unlike RT, UT, and MT, there are not prescribed PT tests in D1.5. Instead, it is used to examine areas of concern. The process begins with cleaning the surface of interest. Next, a dye is sprayed onto the surface, followed by a dye with a white developer. Indications will show up as red in the white field. Like MT, PT is good for surface investigations, but it takes much longer because the surface must be cleaned, then the dyes and penetrants used, and then all must be cleaned later.

Slide 16



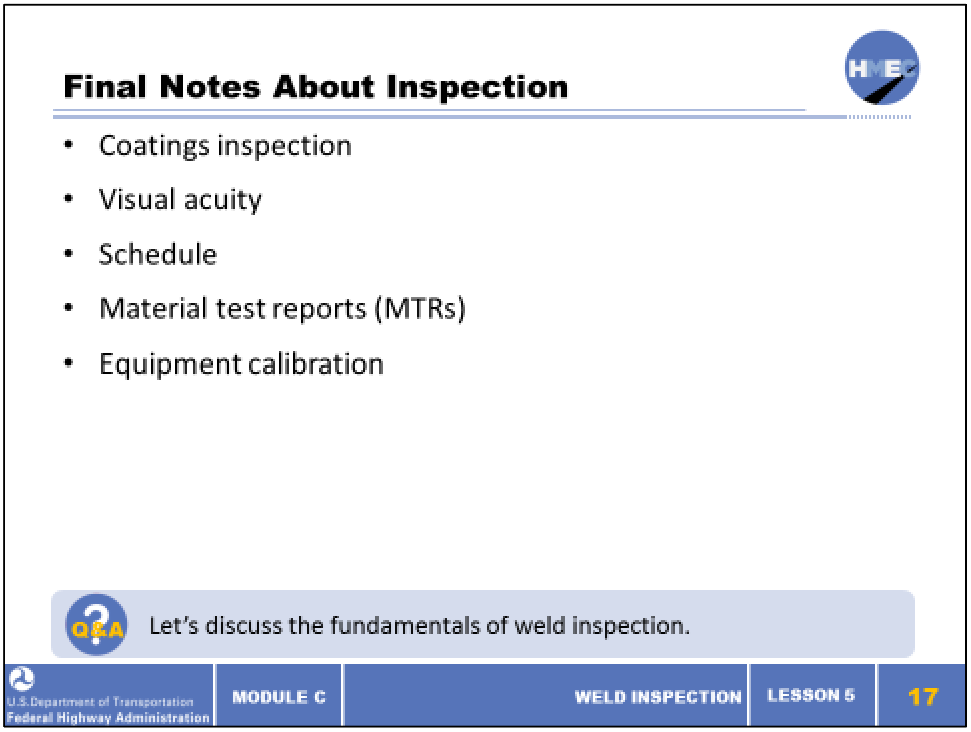
Like other aspects of construction, fabrication is very competitive. Most fabricators are constantly working to improve so they can stay competitive.

Use of the latest codes and practices help to facilitate the use of the latest shop practices, which in turn becomes the best cost, quality, and schedule.

Example:
• Historic welding practice: shielded metal arc welding (SMAW)
• Improved welding practice: gas metal arc welding (GMAW)

GMAW provides better penetration and faster welding. It also facilitates mechanization and automation. However, some owners restrict its use and insist upon SMAW. Not only is SMAW slower and harder to use (generally), but fabricators also tend to have more welders proficient in the newer, better process. So, insisting on SMAW might be insisting on welders who aren’t as good.

Slide 17



An important area of inspection is coatings inspection. Proper cleaning and proper application of the structural coating are essential to the long life of a structure. Coatings inspection will be discussed in greater depth later.

Visual acuity: The inspector needs to have good eyesight (corrected is fine) in order to perform inspection duties—D1.5 has requirements for this.

Schedule: To the extent possible, try to minimize disruptions to the fabrication process when inspecting. Fabricators apply manufacturing principles in order to achieve success. They need to keep the work moving without disruption; facilitating them creates a better product for you.

Material test report (MTR): Inspectors review the MTR for each plate used on the bridge.

Equipment calibration: Both the fabricator's equipment and the inspector's equipment need to be within calibration to ensure proper execution and evaluation of the work.

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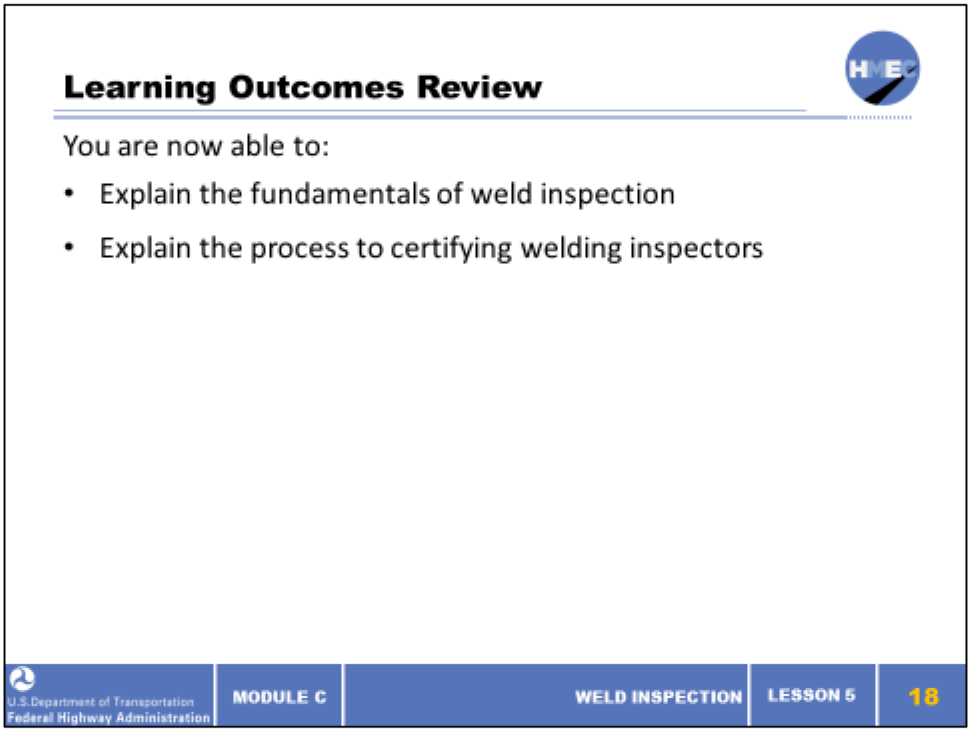
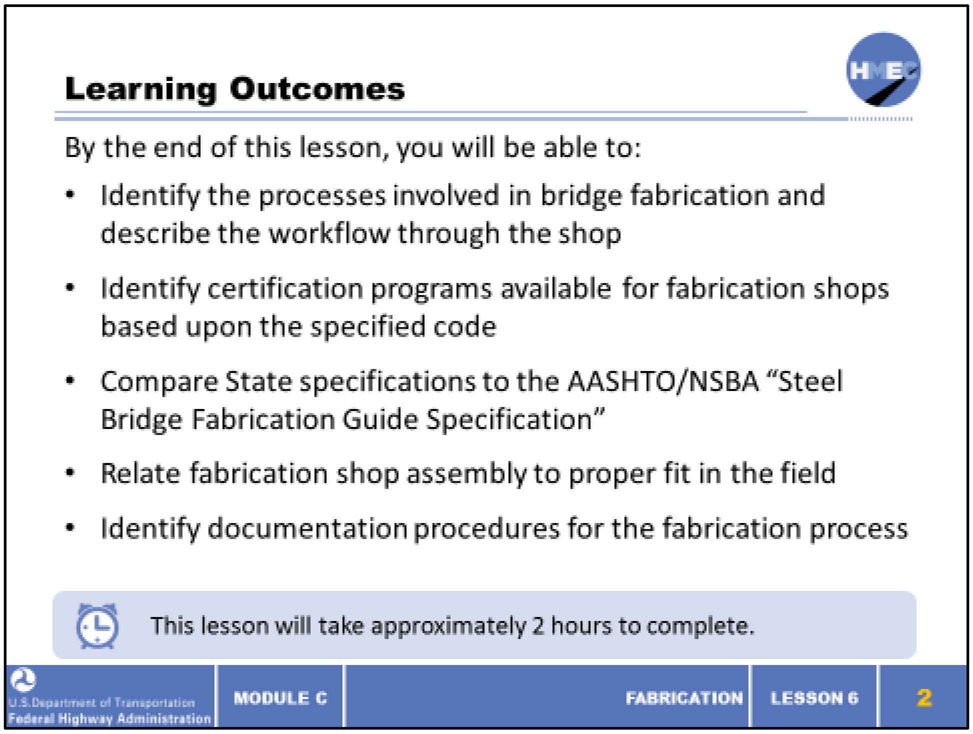
Slide 18


Learning Outcomes Review
You are now able to:
• Explain the fundamentals of weld inspection
• Explain the process to certifying welding inspectors
U.S.Department of Transportation
Federal Highway Administration
MODULE C
WELD INSPECTION
LESSON 5
18

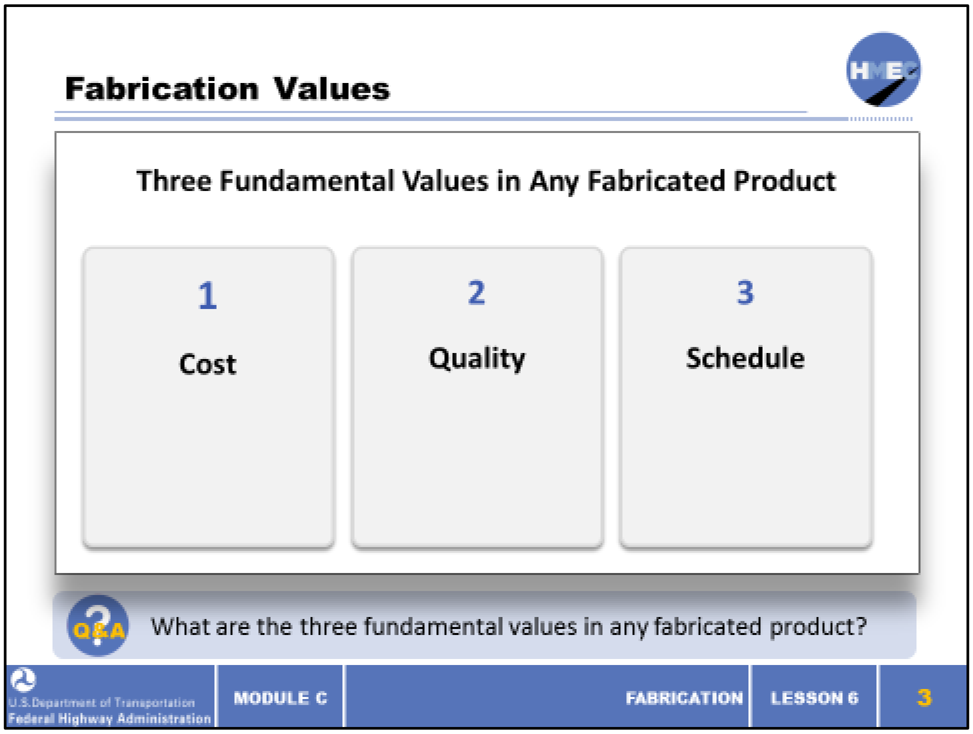
Slide 1


ILT
HMEC
Highway Materials Engineering Course
Lesson 6: Fabrication
Steel, Welding, and Coatings
U.S.Department of Transportation
Federal Highway Administration
MODULE
C

Slide 2


Learning Outcomes
By the end of this lesson, you will be able to:
• Identify the processes involved in bridge fabrication and describe the workflow through the shop
• Identify certification programs available for fabrication shops based upon the specified code
• Compare State specifications to the AASHTO/NSBA "Steel Bridge Fabrication Guide Specification"
• Relate fabrication shop assembly to proper fit in the field
• Identify documentation procedures for the fabrication process
This lesson will take approximately 2 hours to complete.
U.S. Department of Transportation
Federal Highway Administration
MODULE C
FABRICATION
LESSON 6
2

Slide 3



Fabrication fundamentals are cost, quality, and schedule. These fundamentals are introduced first because they represent the key fabrication values and drive fabrication projects overall, including choices associated with fabrication processes. It is said that you cannot have all three: For example, if you want it cheap, you can't go fast and can't achieve good quality. But the fact is that all three values can indeed be pursued. True, there is tension among them but they are not mutually exclusive. It's important to note that one thing that helps a project achieve all of these values is cooperation.

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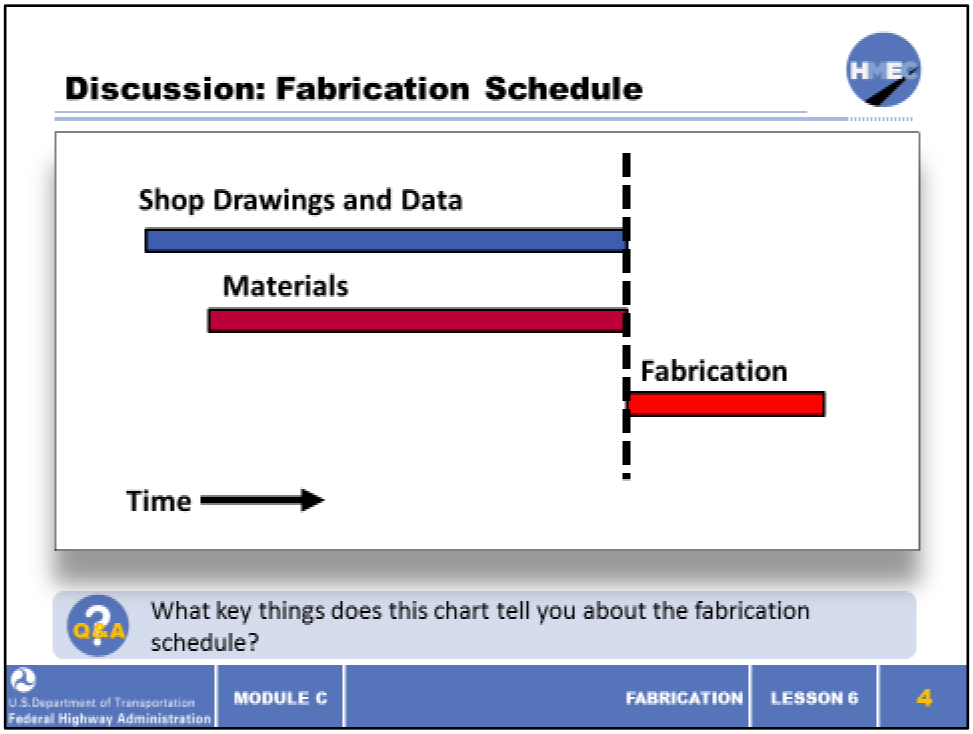
Slide 4


Discussion: Fabrication Schedule
HMEC
Shop Drawings and Data
Materials
Fabrication
Time
Q&A
What key things does this chart tell you about the fabrication schedule?
U.S. Department of Transportation
Federal Highway Administration
MODULE C
FABRICATION
LESSON 6
4

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Slide 5

Fabrication Schedule – Material Delivery

- Stock materials
- Service center versus mill order
- Plate lead times and lengths

	Lead Time	Max Lengths
Grade 50, 50W	8 to 10 weeks	varies; practical: 89 ft.
Grade HPS70W, < 2 in.	10 to 12 weeks	varies; practical: 89 ft.
Grade HPS70W, > 2 in.	12 to 16 weeks	50 ft.

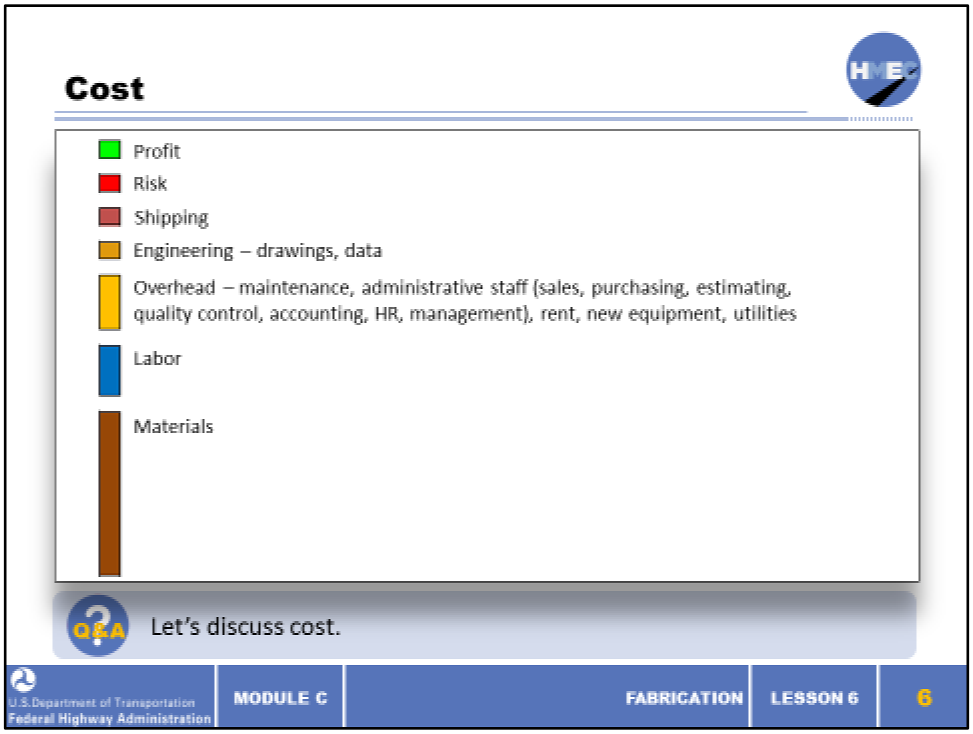
- Production of deeper rolled beams is typically limited to 2-to 3 times per year due to low demand

Q&A Let's have a discussion about fabrication.

U.S. Department of Transportation Federal Highway Administration | MODULE C | FABRICATION | LESSON 6 | 5

The material source of supply is a big factor in how much impact material delivery can have on a project schedule.

Slide 6



Here is a rough representation of fabrication cost. We all want to be cost cautious. Owners want the best value for the dollar and fabricators want to be competitive, and like so many things in construction, the fabricated structures market is very competitive. Note the influence of material cost. Depending upon market forces, material can be half of the cost of fabricated product, or more. This makes it a significant cost item: saving material can save cost. But remember, labor counts too, so be mindful of practices that reduce material cost while increasing labor.

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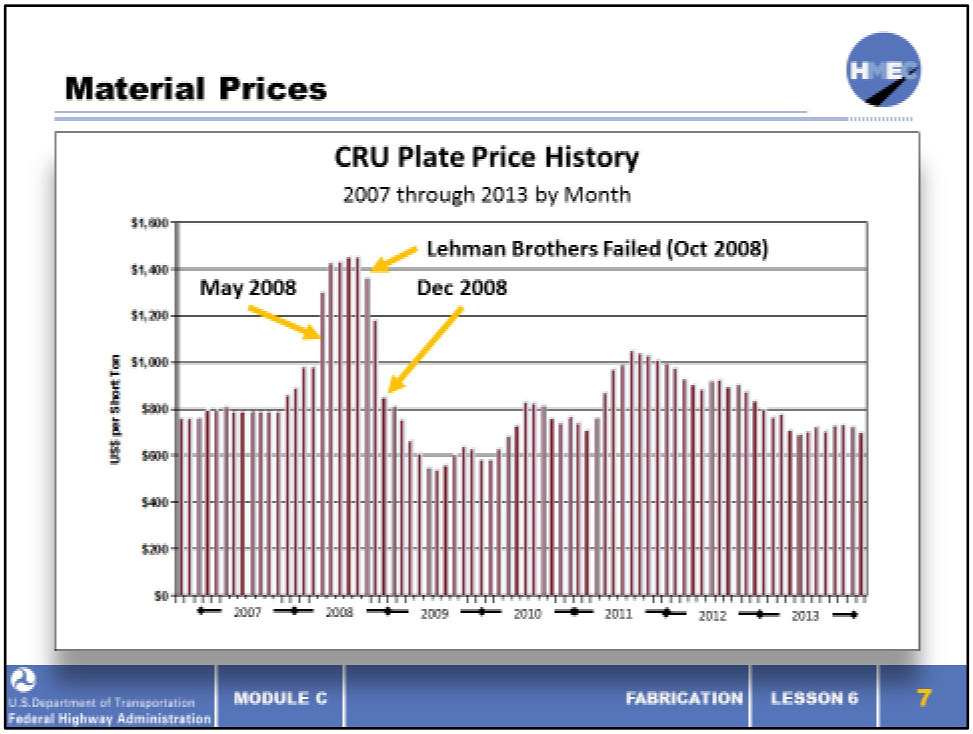

CRU, originally named Commodities Research Unit, is a private, independently owned company that analyzes, assesses, and projects prices for steel among other commodities. In May 2008, CRU shows that steel prices shot up due to demand spikes for scrap steel (about half of new steel is made from recycled scrap). If you were a fabricator who bid a job (or in the terminology of the trade, sold a job) in early 2008 and took delivery of the steel that summer, you may have been sunk. Ouch. However, the opposite is true if you bid a job that summer and took deliveries at the end of the year.

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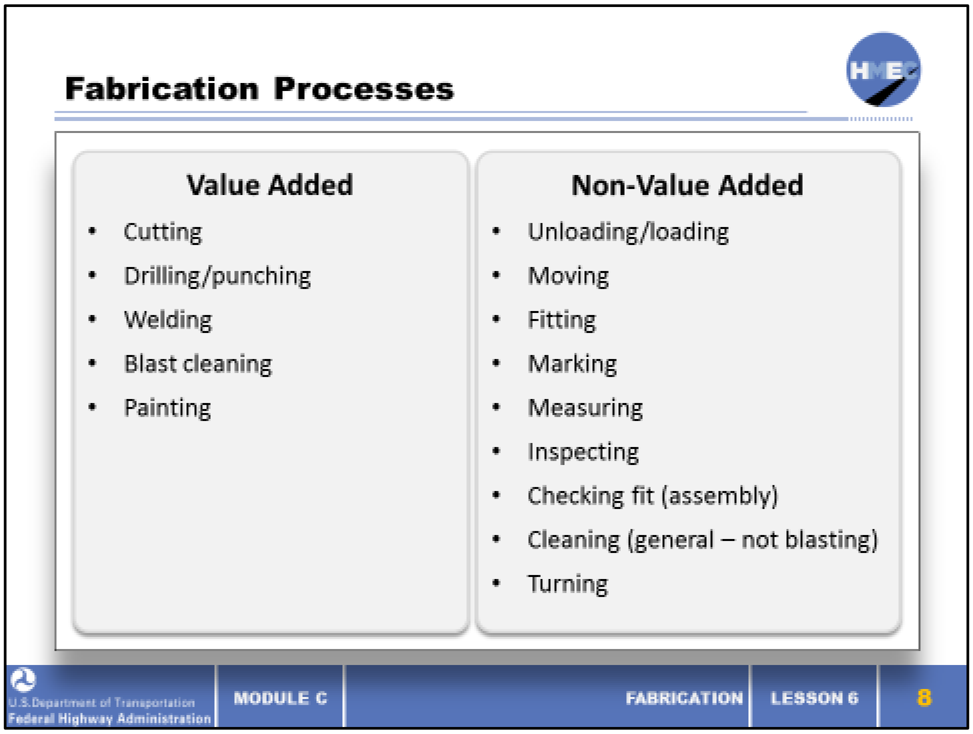
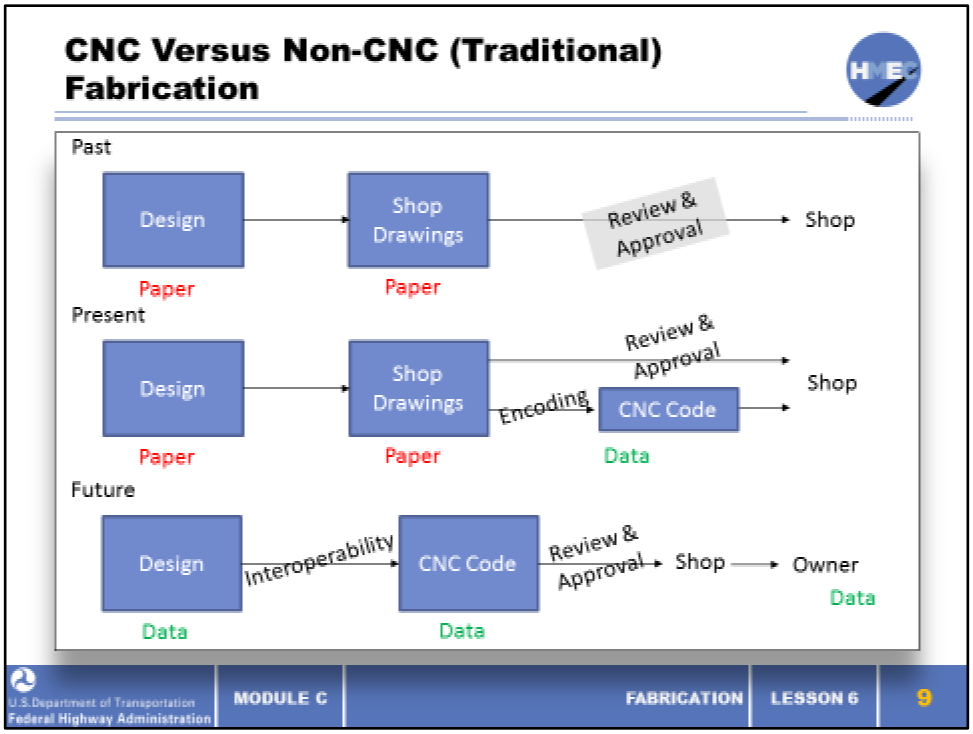
Slide 8



Fabrication processes are divided into value-added and non-value added. Both of these are important—people tend to forget the non-value added processes, such as moving, turning, etc. Recognize the difference between value-added and non-value processes. All require effort, so all represent time spent in the fabricator's estimate (i.e., just because a process, like moving, doesn't add value does not mean that a fabricator need not account for it). In fact, the opposite is true, and we tend to forget about the non-value added processes when we think about our impact on cost.

Slide 9



As computers have become readily available, we turn to CNC programing for numerous advantages:

- Accuracy – usually 0.001 in. accuracy;
- Speed; and
- Mechanization/automation – less hands on.

Different fabricators use different levels of CNC equipment depending upon their preferences and speed of equipment, but certainly CNC represents the future.

We're also in a project flow transition from paper for data. The shop flow has driven the need for data as CNC has become the better, faster, cheaper way of accomplishing work. Where before the fabricator put only drawings into the shop, he now puts drawings and data into the shop. In the future, only data will go to the shop with very few drawings (and these will be electronic). Further, that data will be available for the owner to help build complete bridge information models.

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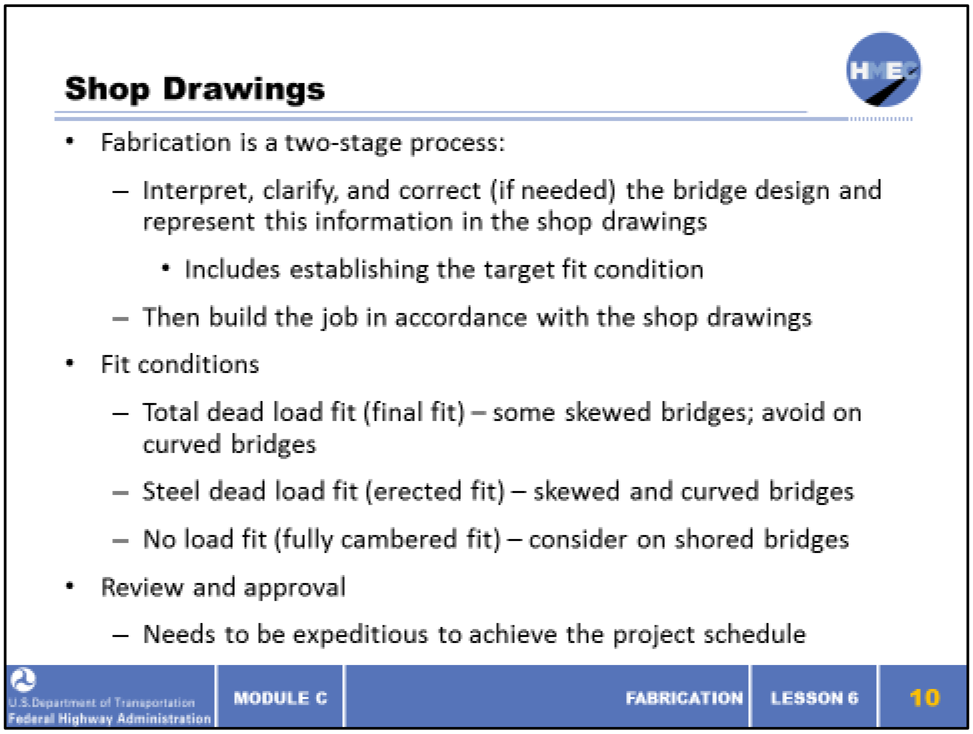
Slide 10



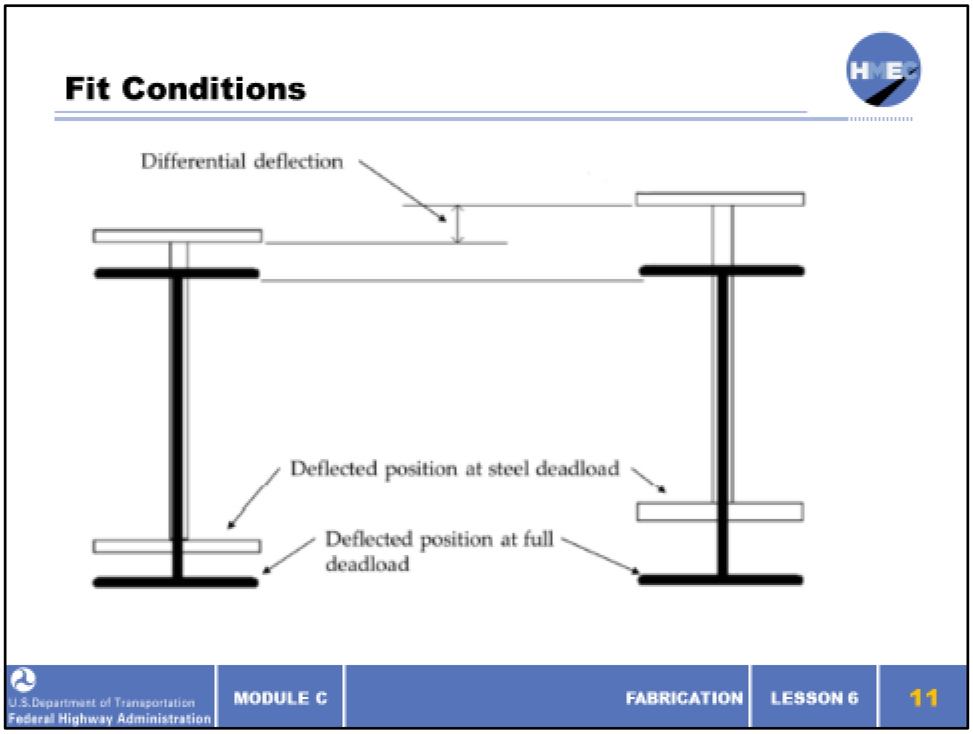
Though bridge designs are complete when fabricators get their jobs, the shop needs far greater detail to actually execute the project.

Some fabricators have in-house detailing capability; others only procure drawings by subcontract. Creating bridge shop drawings is highly specialized and detailers must understand bridge deck geometry, how this geometry relates to the steel, how camber relates to the deck, and how the bridge components will fit as the bridge deflects during the construction cycle. Bridge detailing software is not available off the shelf, so detailers use their own in-house software.

Bridge fitting is important but not well understood. Unless a bridge is straight and square, the girders and cross-frames will not fit in the same way at no-load, at steel dead load, and at final dead load. This is because girders deflect under their own weight and under the weight of the deck and other features, but on skewed and curved bridges the girders do not deflect the same amount at either side of the cross-frame. Put another way, each cross-frame is attached to two girders—one girder on either side. At that location where the cross-frame is attached to the girder, the girder will deflect first under its own weight and then later under full dead load weight. On skewed and curved I girder bridges, the amount of this deflection in the girder on one side of the cross-frame is not the same as it is in the girder on the other side of the cross-frame. This is a simple matter of physics. The implication, then, is that the cross-frames will only truly “fit” in one condition. In detailing, the cross-frames will be detailed to fit at total dead load, steel dead load, or no load, and this will effect constructability and final bridge geometry. The designer will probably designate the fit condition to be used, but it will actually be reflected in the shop drawings, which is why this is an important part of the shop drawing process.

In the United States bridge world (note that a scanning tour of international bridge fabrication in 1999 found no other country that followed this practice), it is customary (and usually required) for shop drawings to be submitted to the owner/engineer for review and approval. Owner specifications also require that work not begin until the drawings are approved. On the one hand, this is prudent—review of the shop drawings by the engineer helps ensure that the fabricator is going to build the job in a way that is consistent with the design. But on the other hand, this puts the reviewer on the fabricator’s critical path. If the reviewer takes longer than that fabricator budgeted in his schedule, then waiting on the drawings will make the fabricator late. This also puts a burden on the fabricator to get drawings done in a timely manner to help give the reviewer a reasonable amount of time for the review.

Slide 11



Reference: Skewed and Curved Steel I-Girder Bridge Fit, National Steel Bridge Alliance (NSBA) White Paper (http://www.aisc.org/WorkArea/showcontent.aspx?id=38766)

Slide 12

Fit Conditions

Loading Condition Fit	Construction Stage Fit	Description	Practice
No-Load Fit (NLF)	Fully Cambered Fit	Cross-frames detailed to fit to the girders in their fabricated, plumb, fully-cambered position under zero load.	Drops set using the no-load el evations of the girders (i.e., the fully cambered girder profiles).
Steel Dead Load Fit (SDLF)	Erected Fit	Cross-frames detailed to fit to the girders in their ideally plumb as-deflected positions under the self-weight of the steel after erection.	Drops set using the steel dead load elevations, calculated as the fully cambered girder profiles minus the steel dead load deflections.
Total Dead Load Fit (TDLF)	Final Fit	Cross-frames detailed to fit to the girders in their ideally plumb as-deflected positions under the total dead load.	Drops set using the total dead load girder profiles, equal to the fully cambered profiles minus the total dead load deflections.

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Reference: Skewed and Curved Steel I-Girder Bridge Fit, National Steel Bridge Alliance (NSBA) White Paper (http://www.aisc.org/WorkArea/showcontent.aspx?id=38766)

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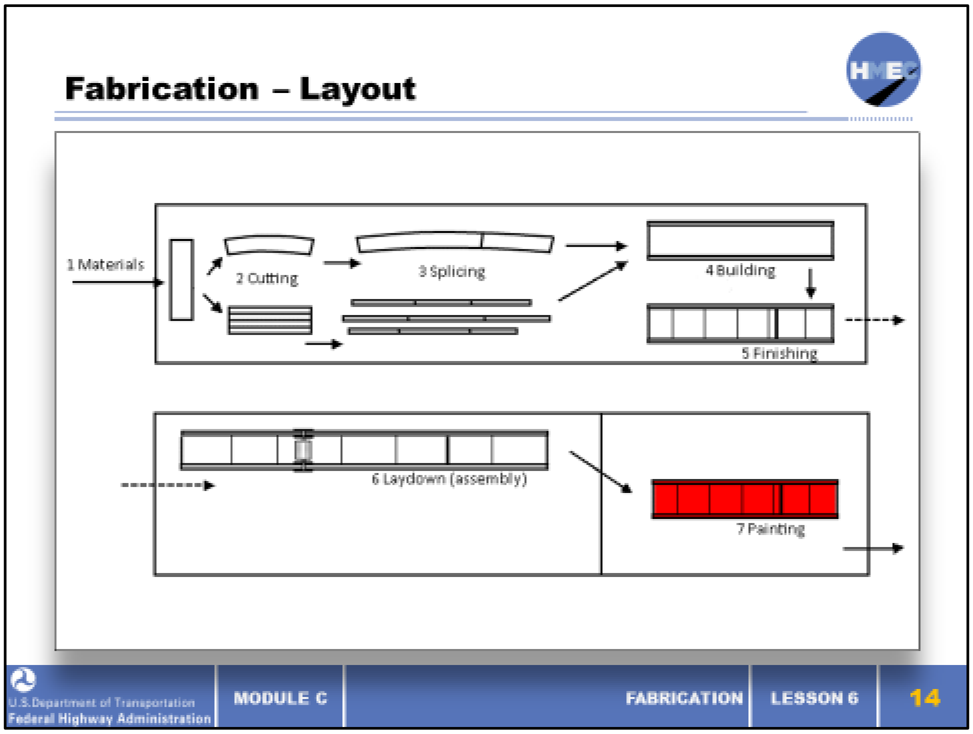
Slide 13

Consider this completed, ready-to-ship component from a transportation structure. How would you build it? Where would you start? Where would you finish? How would you lay out your shop to build it?

Slide 14



This graphic represents the typical flow of girders through the shop: plate goes in one end, and girder comes out the other end.

Slide 15

Considerations for moving material include:

• Safety, including attentive practices for ensure everyone is clear and stays clear of the moving material.
• Crane capacity, ensuring that the moving equipment. Typically cranes in the shop are rated for the load being lifted.
• Ensuring that the material is not damaged by the way it is picked up. Note in the picture that the hooks will not dig into the material. For very large pieces, it is sometimes necessary to add temporary lifting lugs; these require engineer's approval.
• Ensuring stability in how the load is balanced between the two pick points. For typical lifts, like moving plate, shop workers know how to move material based on their own knowledge and experience; for moving or turning large pieces, an engineer may need to be consulted, and the move or turn may need to be designed.

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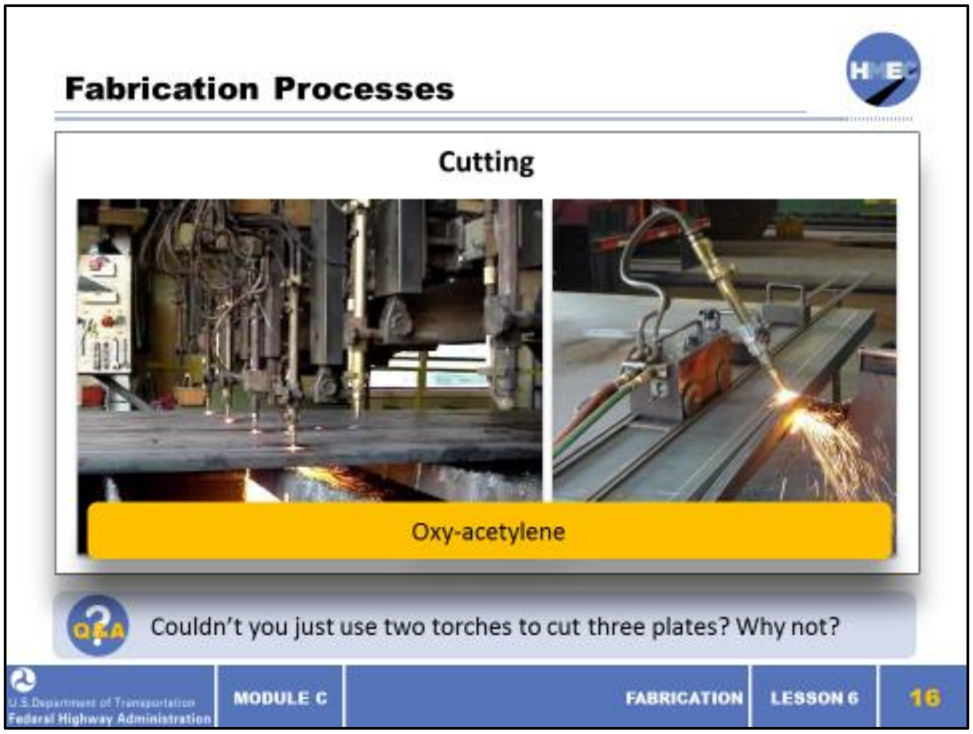
Slide 16



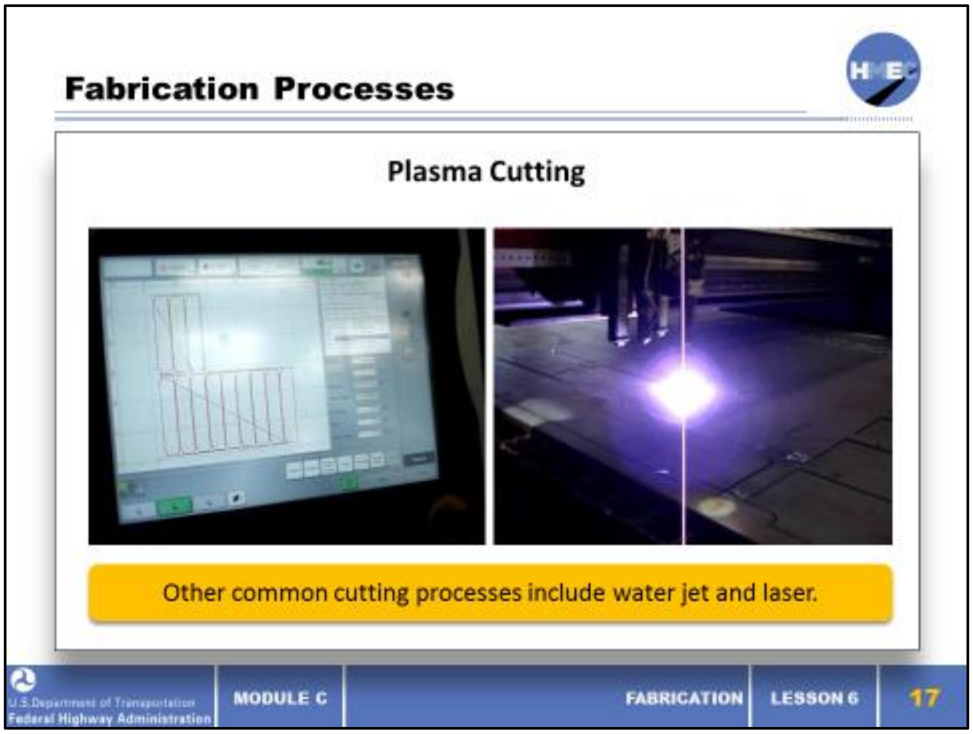
This is a very common and efficient means of cutting steel that has been used for 100 plus years.

Combining oxygen with a burning fuel increases the flame temperature; combining oxygen with propane will increase flame temperature from 3,600 °F to 4,500 °F; acetylene combined with oxygen burns at 6,300 °F. It can also be used for welding, though not very efficiently, so this isn't common in shops that fabricate transportation structures.

Oxy-acetylene can cut steel over a foot thick, so it can handle any typical transportation structure. It works much better when mechanized (as shown); mechanizing helps achieve straight, even, smooth cuts.

Note that in the picture on the left, three flanges are being cut from one plate—this reflects a practice that helps achieve the best cost. These flanges are going to girders that have the same flange thickness; if each girder had a different thickness, then only one flange could be cut at a time, and there would be considerable material wasted.

Slide 17



Plasma is a newer process. For fabricators who have both plasma and oxy-acetylene capabilities, plasma is generally preferred for better speed as well as accuracy. However, at thicknesses above two inches, it slows down considerably, so two inches maximum is generally regarded as the practical limit for plasma cutting. Plasma is also much smokier and noisier than oxy-acetylene cutting, so it must be used over water or a down-draft system.

Note the use of CNC cutting in this picture; both oxy-acetylene and plasma cutting can be readily driven by CNC programming.

Two other processes are listed that can cut steel: water jet and laser. Neither is common in transportation structure fabrication shops.

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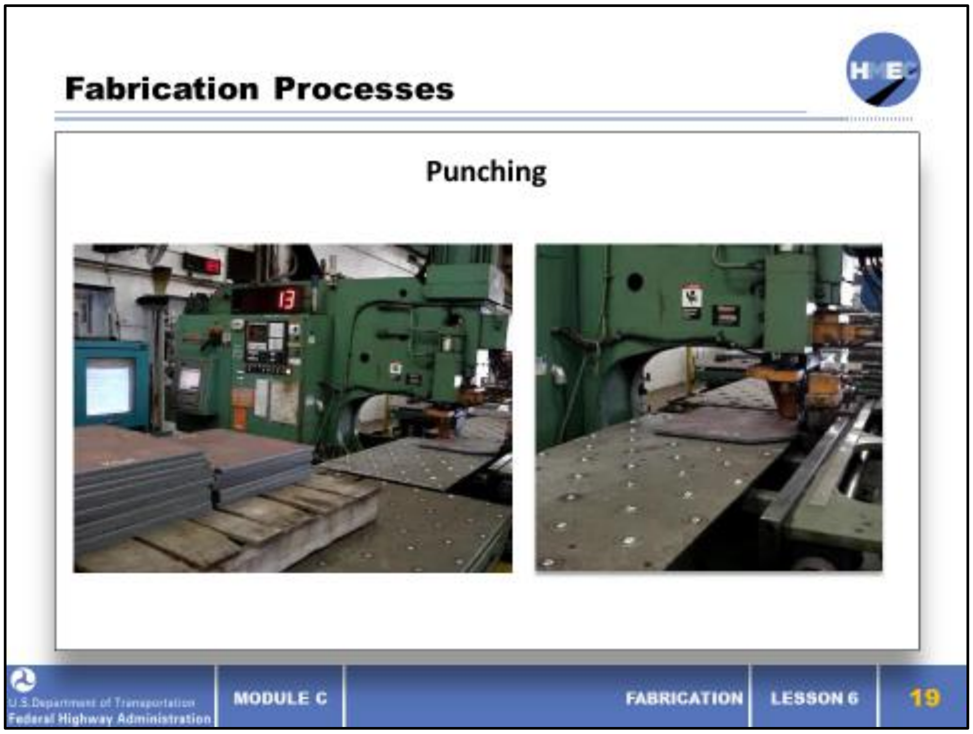
For fabricators who have CNC drilling and punching equipment, CNC equipment is much preferred over hand drilling or reaming. However, not all pieces lend themselves to CNC processes. In such cases, the fabricator might drill through a template or use reaming. In reaming, the fabricator makes subsize holes in the components and splice plates, puts the pieces together, and then reams the holes to full size. A reaming bit is tapered from the tip, which can fit through the subsize holes, up to the desired size of the hole.

Slide 19



The picture on the left reflects CNC punching—at the monitor, the operator pulls in files to run the equipment and sketches to see the part being made, then he will load the blank gusset plates into the equipment and then the punch operates. A close-up of the operation is on the right. The table moves the part to the punch tool. Holes can be punched without CNC processing as well.

The fabricator's thickness limit on punching depends upon his equipment: bigger, more powerful equipment is needed to punch holes in thicker plates. Punching up to ¾ in. is common. Research has shown that connections with punched holes do not have quite the ductility that connections with drilled holes have, so punching is not allowed for bridge girder flange or web splices. However, it is allowed for cross-frame connections, including when the cross-frames are considered to be main members.

Therefore, depending upon equipment availability, fabricators will choose to punch holes when they can.

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Slide 20

Here are six welding processes discussed earlier today.

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Slide 21

Steel is readily bendable, and fabricators use a number of approaches to accomplish bending.

The most common type of bending is cold bending of plates. Using brake press forming, the plate is bent about a die of a given radius intended to result in the final desired radius on the product. There are minimum bending radius limits in specifications (usually 5t) because bending the plate at too tight of a radius could tear the plate or compromise the plate properties. For plates that are too thick for simple cold bending, heat is added to assist in the bending.

Cold methods are also used for cambering and sweeping sections. Usually this is limited to rolled shape because plate girders tend to be too big for bending fixtures.

Plate girders, then, are cambered and swept using heat. As shown in the photo on the right, heat is being used to adjust the camber of this member. Camber is usually cut into the member by cutting of the web to the right profile, but sometimes adjustment is needed. Note in the picture that in addition to heating the flange, a vee heat has been introduced into the web. Hence both the web and flange will shrink after cooling and introduce additional camber.

Introducing sweep by heat, or heat curving, is very common. Heat curving helps save flange material by allowing flanges to be cut straight and then curved later, when they are in the girder.

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Slide 22

Modern paint systems last much longer than the systems used decades ago, and a key reason for this is cleaning. In older days, steel was painted without proper cleaning and it didn't last; present systems have been known to last 50+ years and this a tremendous benefit to owners. Before painting, steel is blast-cleaned using shot to the finish specified to be used with the coating system; for zinc primer systems this is an SSPC SP 10, or near-white blast. Bridge fabricators use cabinets like the one shown to readily clean big bridge girders; they may have smaller cabinets for smaller parts; the steel can also be hand blasted. Blast cleaning removes mill scale and introduces an anchor pattern that facilitates adhesion of the zinc primer. Different blast media are used; steel shot is the most common.

Metallizing is gaining popularity—this is spraying-on of molten zinc. The cleaning required for metallizing is distinctly different than for paint: a great anchor pattern is needed, and this requires special media other than shot, typically grit. A bridge fabricator who has both metallizing projects and painted projects in the same shop might choose to hand-blast the steel that gets metallized rather than use the same cabinet and media on both painted and metalized pieces because the deeper anchor pattern would require significantly more paint. Also, the media used for metallizing tears up the inside of the cabinet more quickly than just shot.

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Painter starts with the primer, either the organic or inorganic, depending upon what is specified on the job. Then the second or second and third coats are applied, either in the field or in the shop. When they are applied in the shop, as is shown here, the fabricator must first wait for the primer to cure. Organic zinc primers typically cure quickly, so when this system is used, the fabricator can usually start applying the second coat almost immediately after primer application is finished. Conversely, inorganic zinc takes about 18 hours to cure, so in when it is used, the fabricator must wait before applying the next coat. This can have big impact on shop through-put as it may be necessary to move girders away from a painting station for this waiting while another girder is painted.

Slide 24

Truck shipping offers the most flexibility. Trucks can handle very large pieces and provide the flexibility to load right at the plant and deliver right to the job site. While plate is generally delivered to shops by rail, it is hard to take advantage of rail shipping for bridge members because they are too long to fit on one car. That means that they would take three cars. Also, most bridge sites don't have rail access, so even if a fabricator were to deliver bridge pieces near the bridge site by rail, he will probably have to truck it a bit to get to the actual bridge. Therefore, the trucking cost would be incurred anyway. Therefore, rail tends to make send when sending relatively short pieces long distances.

Shipping by barge can make sense for many pieces delivered over a long distance to bridge site if there is water access at the bridge. So barge shipping can be helpful for long water crossings over navigable water. Barges can also be useful for shipping very large pieces that won't otherwise fit on a truck on train. Note, however, that only a limited number of fabricators have water access, so building a bridge that requires water access for shipping to the job site would limit the number of fabricators who can bid a job.

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Slide 25

Curved girder summary: There are two ways of accomplishing the curve in curved girders: heat-curving and cut curving.

Heat-curving is just as it sounds: girders are built straight and then curved with heat. To do this, girders are laid on their side and supported at either end. Then heat is applied along the top edges of the flanges (as indicated in the picture on the left), starting at one end of the girder and progressing to the other end. The amount of heat applied and the speed of travel vary with the size of the girders and the amount of curve desired. The weight of the girder works with the heat to introduce curve. Girders that have very thick flanges and tight radii cannot be heat curved, and specifications have associated limits, including the AASHTO Bridge Construction Specifications (consult project specifications on your project), but most girders can be made by heat curving straight I-girders. Note that doing so helps optimize material.

Cut curving is a second option for creating curved girders. In this method flanges are cut to the final desired radius; then the girder is built by attaching the web to the curved flanges. Note that webs, being relatively thin plates, readily conform the radius on the flanges.

A hybrid can also be used – i.e., girders can be built by cutting the flanges to a radius near the final desired radius and the accomplishing the remainder of the curving using heat. A fabricator might desire to do this if a number of girders have flanges that have the same in section slightly different radii: the plates can be cut to the same radius, helping to optimize plate usage, and then given a final adjustment.

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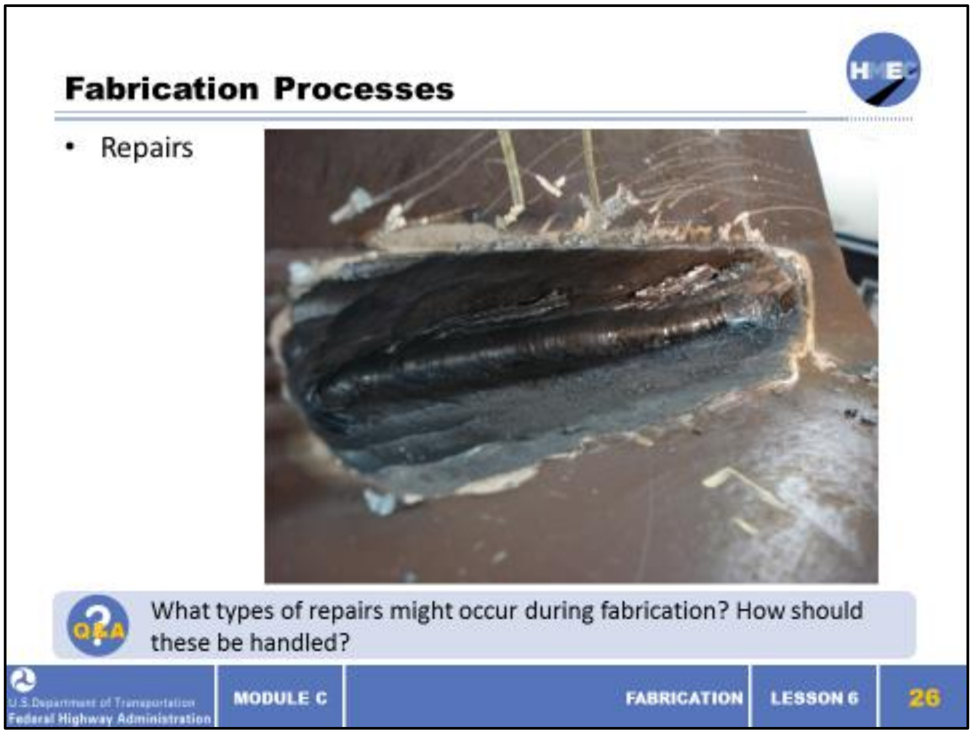

Fabricators try to avoid them, but some repairs are indeed necessary. Some good examples:

• Removing discontinuities from full penetration welds – in the picture shown, weld metal has been removed to clear this weld of defects; since this appears to be a tee joint, the discontinuities were probably found by UT. Now the weld will be filled – and retested with UT.
• Repairing weld profiles (undercut, porosity, undersize welds, etc.)
• Replacing mis-cut flanges
• Replacing stiffeners or connection plates that were put onto girders in the wrong location
• Correction camber or sweep
• Repairing base metal defects – note, for example, the some based metal defects show up with plate is cut or when plate is welded

Specifications allow fabricators to make some repairs on their own, without consulting the engineer; other repairs require the engineer's approval. For example, undercut is noted on a weld, the fabricator will simply remediate this (probably just be adding weld metal). On the other hand, a fabricator may have mis-located a stiffener and wish to see if it can remain in place (perhaps instead of moving it over a few inches); this will require approval of the engineer. A good practice is for the fabricator to establish standard, pre-approved procedures that can be ready to use if needed with the inspector's approval.

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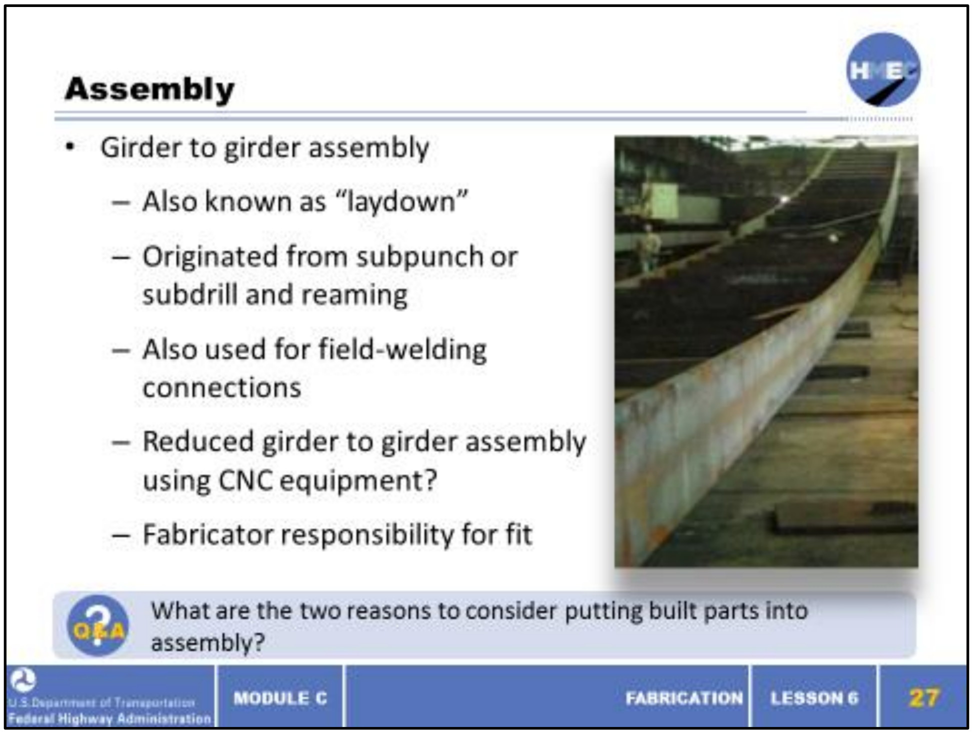

Before CNC equipment came into use, girders were assembled to complete holes is a way that assured fit. Holes would be drilled or punched "subsize" as accurately as possible, and then the parts would be brought together, set into place in the proper orientation, and then reamed to full size with the parts together, or assembled. This is commonly (but not always) done with the girders laying down. Hence, this process is also known as "laydown." Girders shown here are in laydown. The fabricator has oriented the two girders to each other in the same way that the parts would be together in the field.

This process is also used when the girders are welded in the field instead of bolted. The ends of the girders are prepared for field welding (the ends of the webs and flanges are beveled), and then the ends of the girders are brought very close together to ensure the joint will be in tolerance in the field for welding.

With CNC drilling, holes can be drilled full-size without putting the girders together. In such cases then, the girders might be brought together just to ensure fit. However, even this can be unnecessary when CNC equipment is used. The fabricator may put a sampling of girders together to demonstrate the effectiveness of his processes for achieving accuracy, but just a sample not all girders.

However, not all owners are comfortable with a reduction in girder-to-girder assembly. The AASHTO construction specifications have language that allows reduced assembly, and most State specifications have the same or similar language, but some owners mandate the assembly as a check regardless. Most specifications say that reduced assembly is only allowed with approval of the engineer. In such cases, it is beneficial for the engineer to allow reduced assembly based on demonstrating proficiency because assembly takes considerable effort, thereby adding time and cost to the project. As a counter, some engineers feel that it is always prudent or necessary to put girders into assembly.

An important thing to remember: the fabricator remains responsible for fit in the field whether or not the girders are assembled in the shop.

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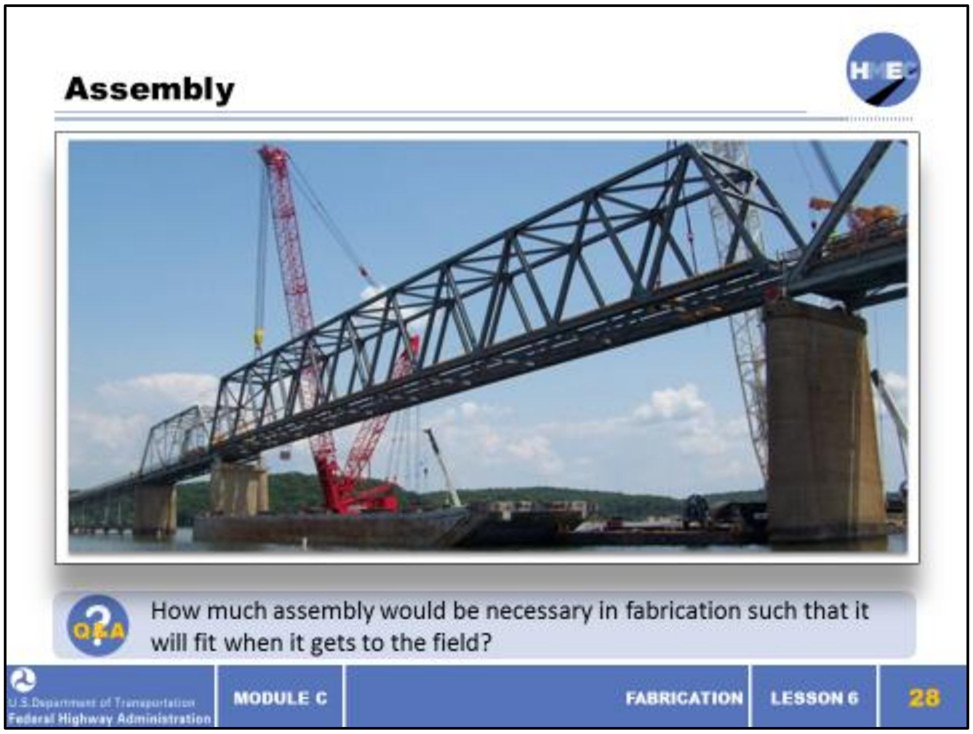
Assembly
How much assembly would be necessary in fabrication such that it will fit when it gets to the field?
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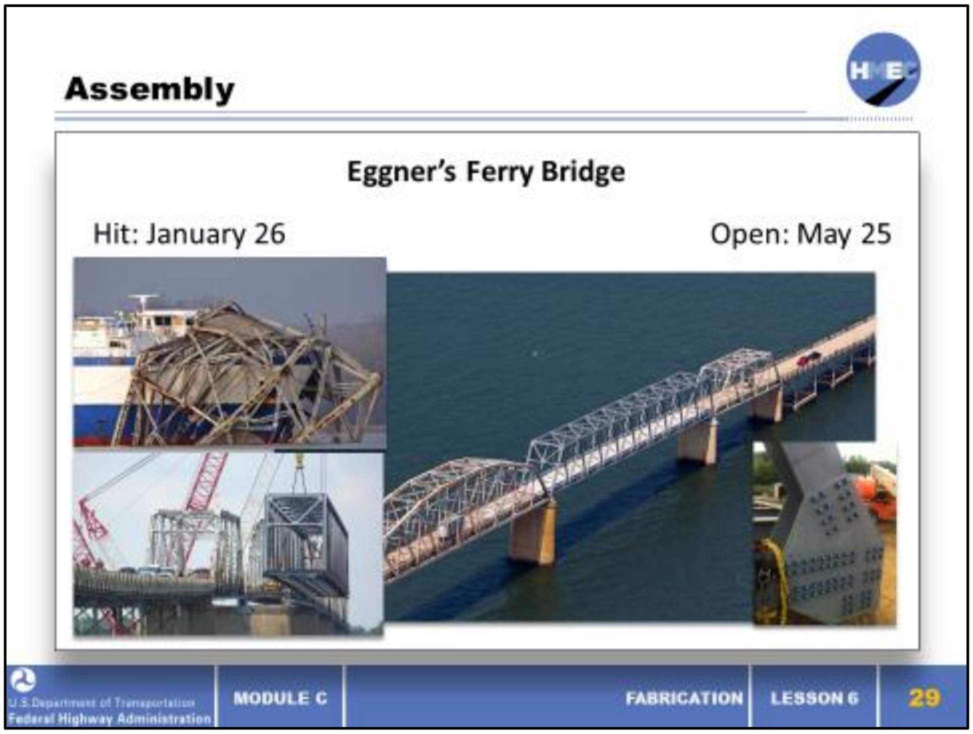
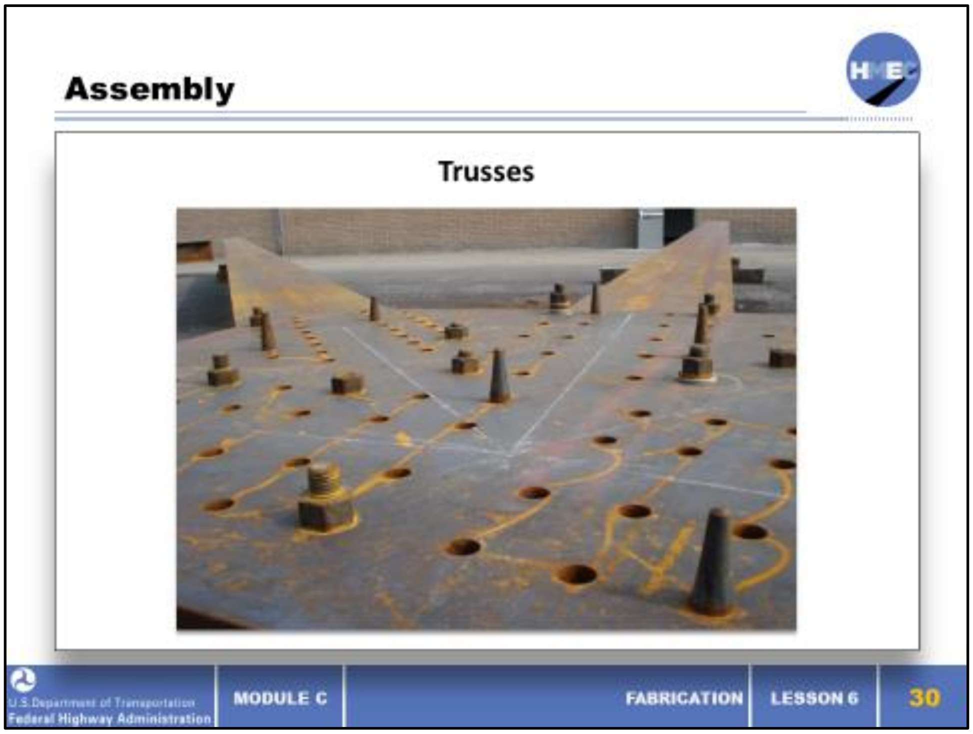


On January 26, 2012 an 8,200-ton cargo ship took out a 322 ft. truss span in the Eggner's Ferry Bridge, which carries US 68/KY 80 over Kentucky Lake. This created an emergency situation for replacing the span. In March and April, the detailer developed shop drawings for the contractor of the replacement span. One fabricator drilled the main members and another fabricator made the gusset plates. Both drilled holes full-size using CNC equipment, and the parts were brought together in the field for the first time: no shop assembly, and all 13,000 holes fit. Not only was the time and cost of assembly saved, but also avoiding assembly helped achieve an 11-week replacement of the span. The bridge opened May 25, 2012.

Slide 30



The need for assembly depends on the complexity of the truss, especially the connections. Some trusses, like Egger's Ferry, need little or no assembly; others may need assembly to help accomplish complex connections. The fabricator may choose to use subsize holes and reaming in assembly to accomplish the connections. As a simple example, a truss with box chords, with four planes at each node, is more likely to need assembly than a truss with I sections, and therefore only three planes per node.

A further complication with trusses is that some of them are details for force-fitting—remember the fit discussion of I-girders earlier? Like I-girder bridges, trusses fit differently at different loading conditions. Some truss are designed to fit in the final condition; hence, they only truly fit with all loads (or weight) present. To assemble them in the field, then, before all weight is on the steel, the members must be forced together. Similarly in the shop, the steel will not readily fit; if fit verification is required on such projects, this can be accomplished in stages. For example, as shown, first assemble top chords with diagonals; then break this apart and assembly bottom chords with diagonals.

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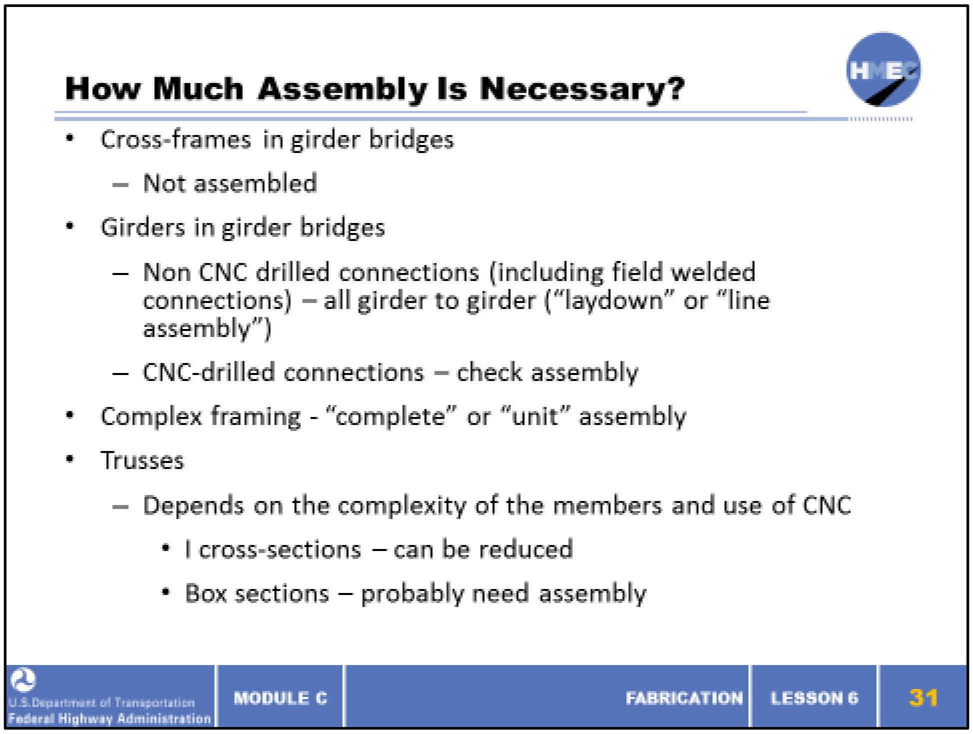

Assembly requires time and effort and therefore adds cost. From an owner's standpoint, it is not good practice to require more assembly than necessary because doing so adds unnecessary cost. Conversely, the risk of requiring too little is risking that members will not fit in the field. If this happens, the fabricator is still responsible for fit; however, as an owner you may be concerned that lack of fit will result in time delays.

Cross-frames are rarely included in assembly unless mandated by the owner.

Girders made by traditional processing subpunched and reamed will require assembly for both fabrication (they must be assembled to be reamed) and checking fit. If CNC equipment is used, then such assembly isn't necessary to accomplish the holes. Rather, a check-assembly of, perhaps, one girder line can be used to demonstrate that the processes used by the fabricator will indeed ensure fit. The fabricator may use some form of "virtual assembly," possibly to include lasers, to ensure fit.

For complex girder bridges, "complete" or "unit" assembly may be necessary. An example if framing elements (cross-frames or diaphragms) are of a variety of lengths and are close together. Such systems are stiff and do not have the flexibility to accommodate even small variations in length.

As discussed, the amount of assembly needed for trusses varies. As the Eggner's Ferry Bridge shows, even zero assembly is possible using CNC drilling.

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Assembly
Curved Plate Girder Bridge
What assembly (shop fit verification) is needed for this bridge?
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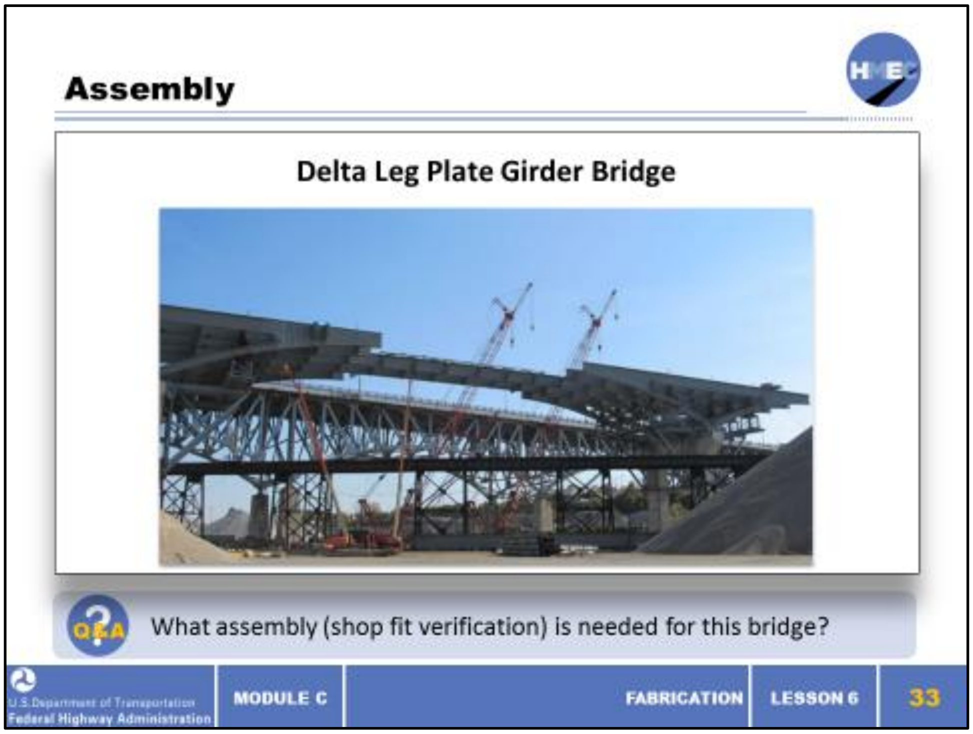
Assembly
Delta Leg Plate Girder Bridge
What assembly (shop fit verification) is needed for this bridge?
U.S. Department of Transportation
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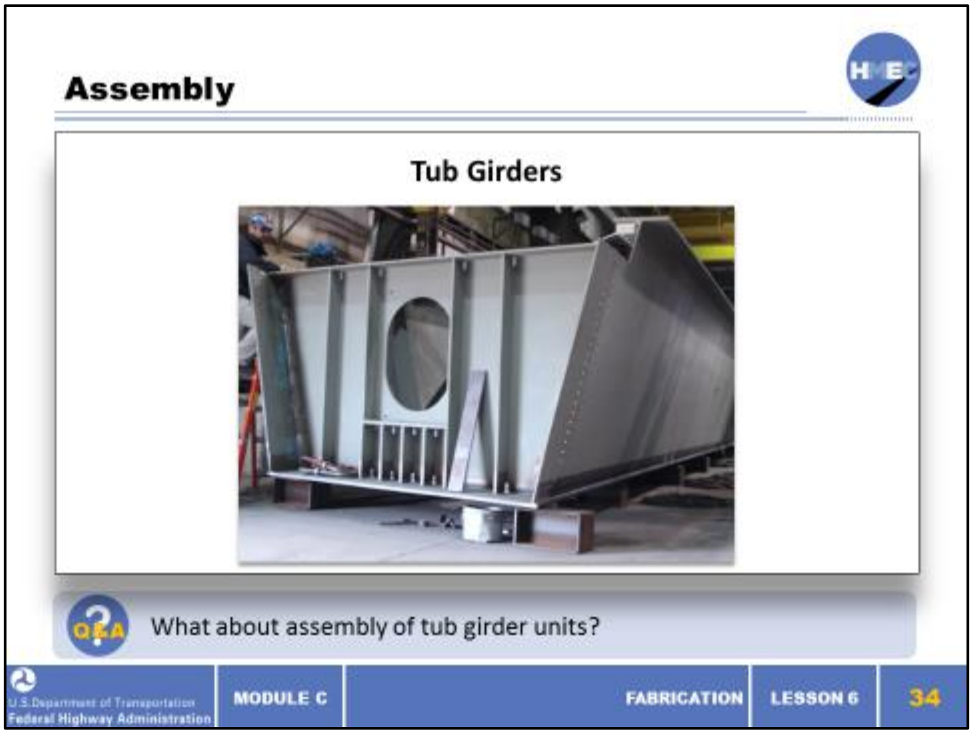
Assembly
Tub Girders
What about assembly of tub girder units?
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Assembly
Rural, Simple Span Plate Girder Creek Crossing
What about the assembly of a simple span bridge?
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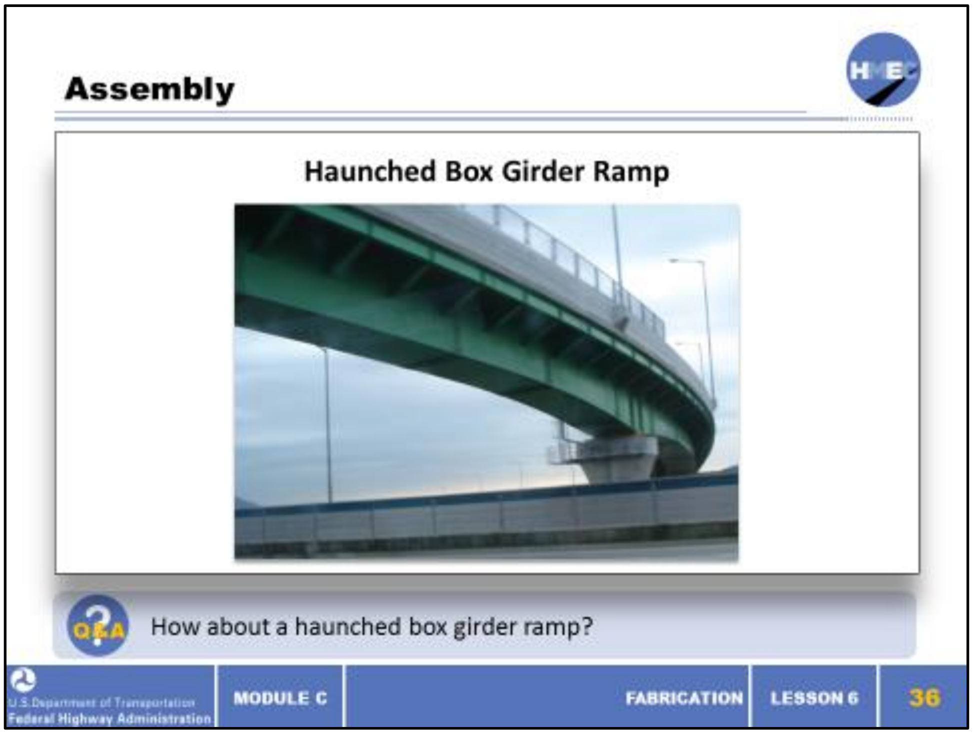
Assembly
Haunched Box Girder Ramp
How about a haunched box girder ramp?
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When you select a supplier to perform work for you, you want to make sure that the supplier is good at what they do. Think about your new car (consider finding someone in class who has a car that they love). It's time for maintenance. Are you going to take your precious vehicle to a guy who has only been a mechanic for a week? Or perhaps have never worked on your car? Well, no. You want to be sure the mechanic knows what he is doing.

You must ensure that your bridge fabricator knows what he/she is doing. The problem: How do you do this in our low-bid transportation world? The answer (in part) is certification. Requiring certification establishes that the fabricator who gets the job has a minimum ability to accomplish the project. Unfortunately, there is no certainly that because the fabricator has a certification means that the fabricator will do a superb job. That's true for any number of reasons, but at least certification sets a minimum proficiency level.

The fabricator certification program is sponsored by AISC, the American Institute of Steel Construction, which is the fabricator trade association. Fabricators sponsor this because, as an industry, they have a vested interested in seeing their members produce good work. And the fabricators who make quality a priority and strive to do a good job want to compete with other fabricators who are doing the same.

Recently AISC went to a quality management system (QMS) approach: they replaced a checklist program with a program focused on quality proactivity. For example, they are looking for error prevention rather than correction, and they are looking for a holistic plan-do-check-act cycle and quality goals.

As shown, AISC has different programs depending upon the type of work the fabricator does. The bridge component certification is intended for the broad variety of steel transportation structures that are not bridges. Example are listed—some, like cross-frames, are actually bridge components; others, like light supports, are not, so the title is a misnomer.

Within the bridge program there are also three categories. The key difference between a simple bridge and an intermediate bridge is whether or not the bridge has splices. Intermediate covers most girder bridge and smaller trusses; advanced addresses more complex bridges. Examples of bridge types are shown, but these are just examples; a complete list can be found in the AISC standard.

The coatings certification is independent, so a fabricator who intends to supply painted product will need both the certification for that product and the coatings certification. The program is divided into two types: open and enclosed shop.

The erector certification certainly has applicability to transportation structures based on its scope; however, it is not used by bridge erectors with great frequency. This is primarily because most owners do not require it.

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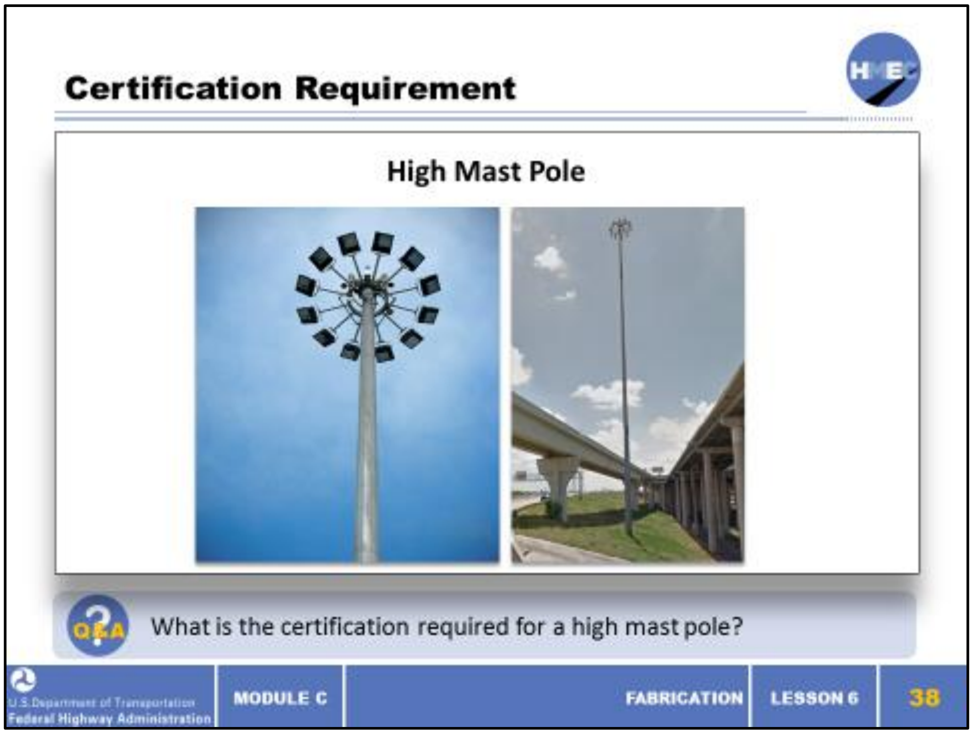
Certification Requirement
High Mast Pole
What is the certification required for a high mast pole?
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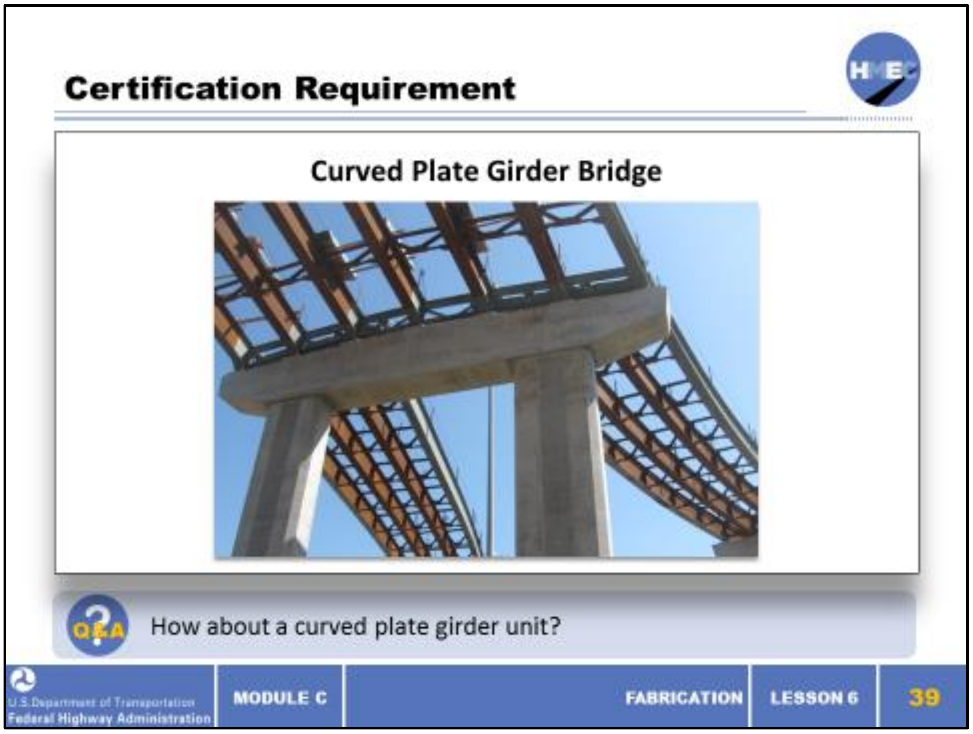
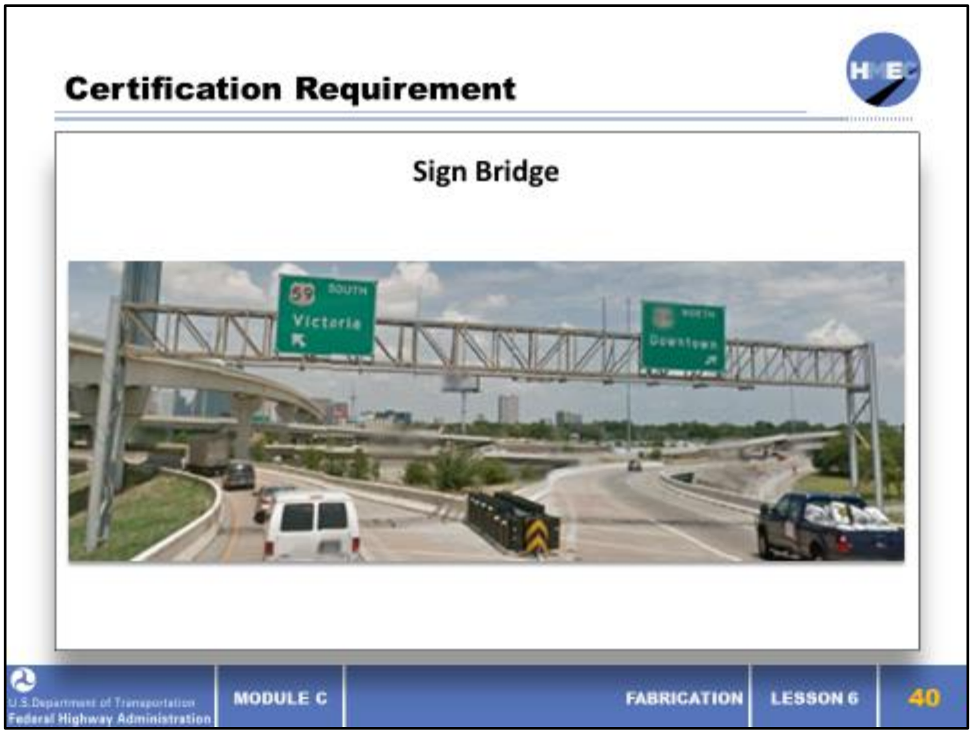


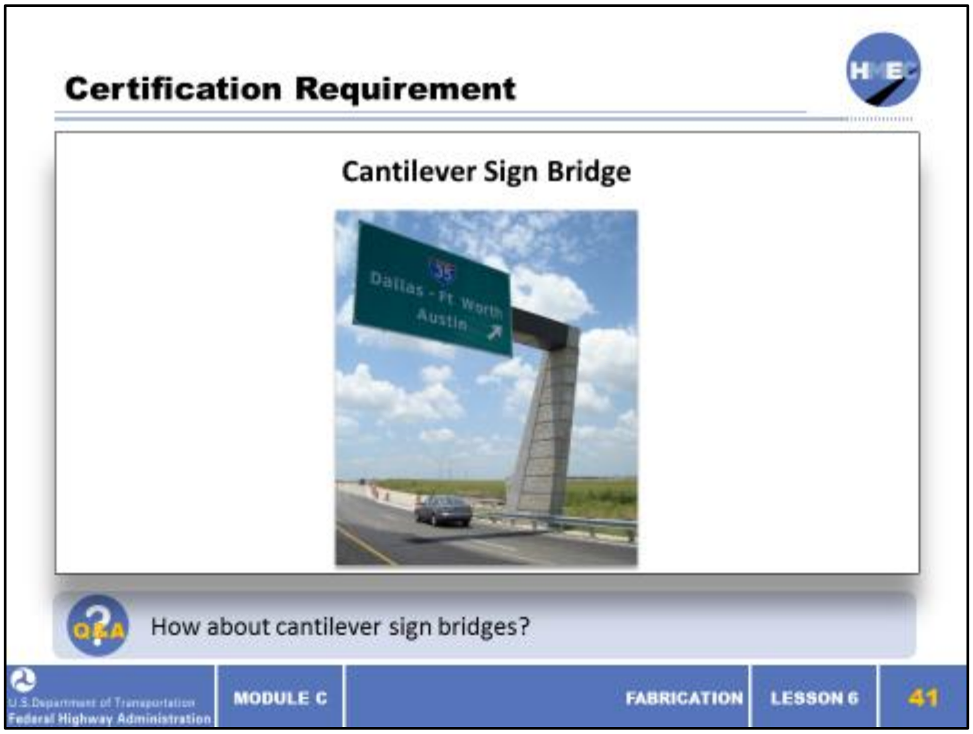
Regarding welding, there is full penetration welding and fillet welding. Cutting webs and building girders for continuous bridges achieves the proper camber along their entire length. Thus achieving proper girder sweep. This accomplishes girder to girder and girder to cross-frame connections that fit.

Slide 40



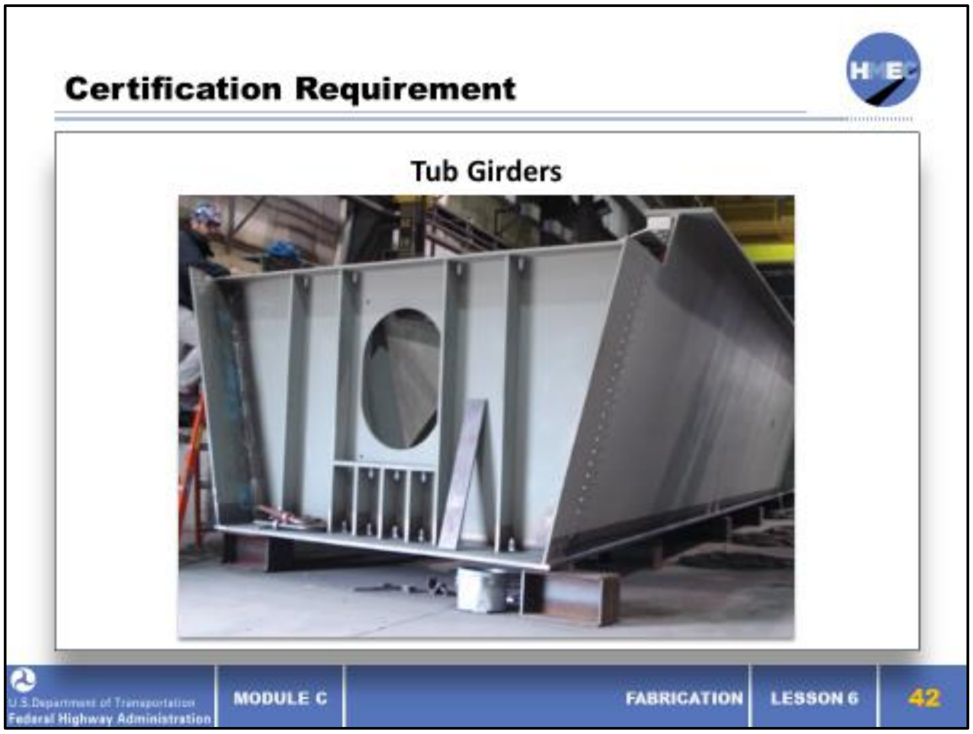
This structure is built from bolted angle truss. The key skill is to establish the correct geometry for each piece so that each can be cut and punched (or drilled).

Slide 41



Certification Requirement
Cantilever Sign Bridge
Dallas - Ft. Worth
Austin
How about cantilever sign bridges?
U.S. Department of Transportation
Federal Highway Administration
MODULE C
FABRICATION
LESSON 6
41

Slide 42



Regarding welding, there is full penetration welding and fillet welding. Cutting webs and building girders for continuous bridges achieves the proper camber along their entire length. Thus achieving proper girder sweep. This accomplishes girder to girder and girder to cross-frame connections that fit.

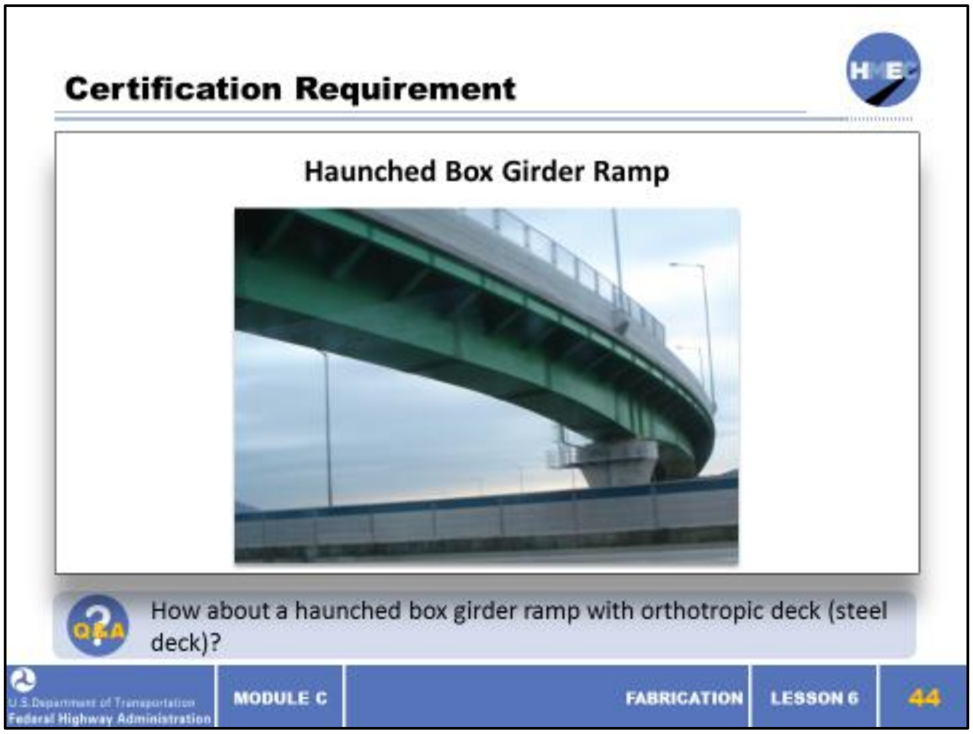
In addition to the above, which are the same for I-girder bridges, the fabricator must have the skill to assemble plates to the proper cross-section in five planes (two top flanges, two webs, and bottom flange) while also achieving proper camber and sweep in the rather stiff cross-section.

Slide 43

Let's look at rural creek crossing. This is a rather simple bridge, but the members are comprised of plate girders (or built-up sections) and not rolled beams, so an intermediate bridge certification would be required.

- Welding – fillet welding (probably no full penetration welds in these sections).
- Cutting webs and building girders to proper camber.
- Accomplishing cross-frame connections that fit.

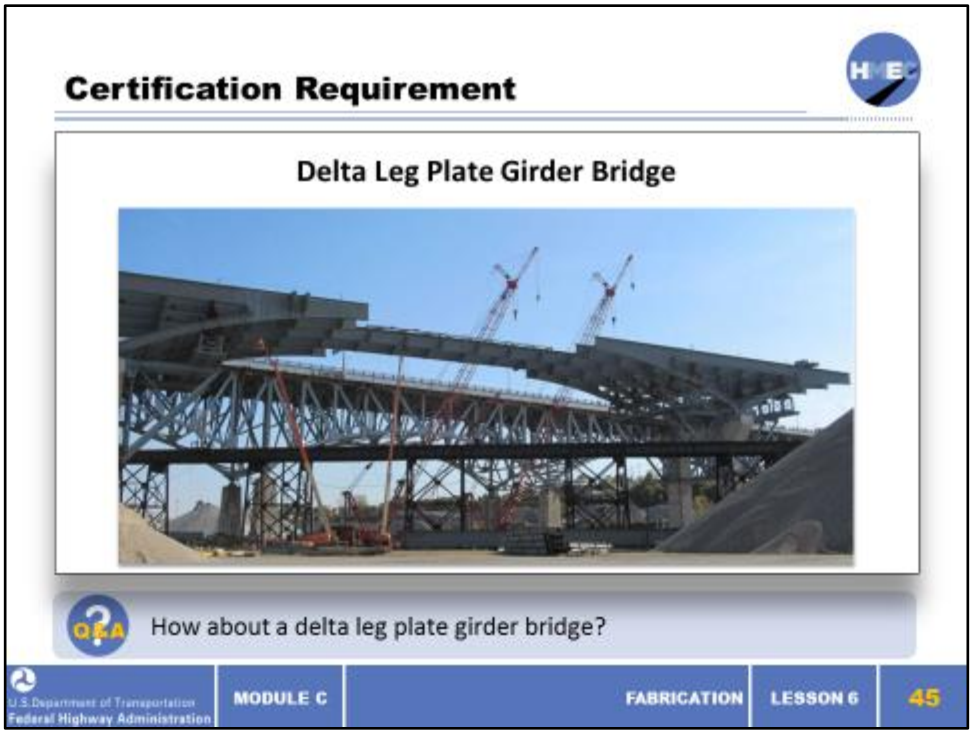
Slide 44



This requires Advance Bridge Certification. Note that the radius might also dictate Advanced Bridge – a variable depth web (haunched) bridge with radius under 1000 feet falls into the Advance Bridge Category. The skills needed to build these section are similar to those of the tub girder skills.

How about the light supports (light poles)? This is component.

Slide 45



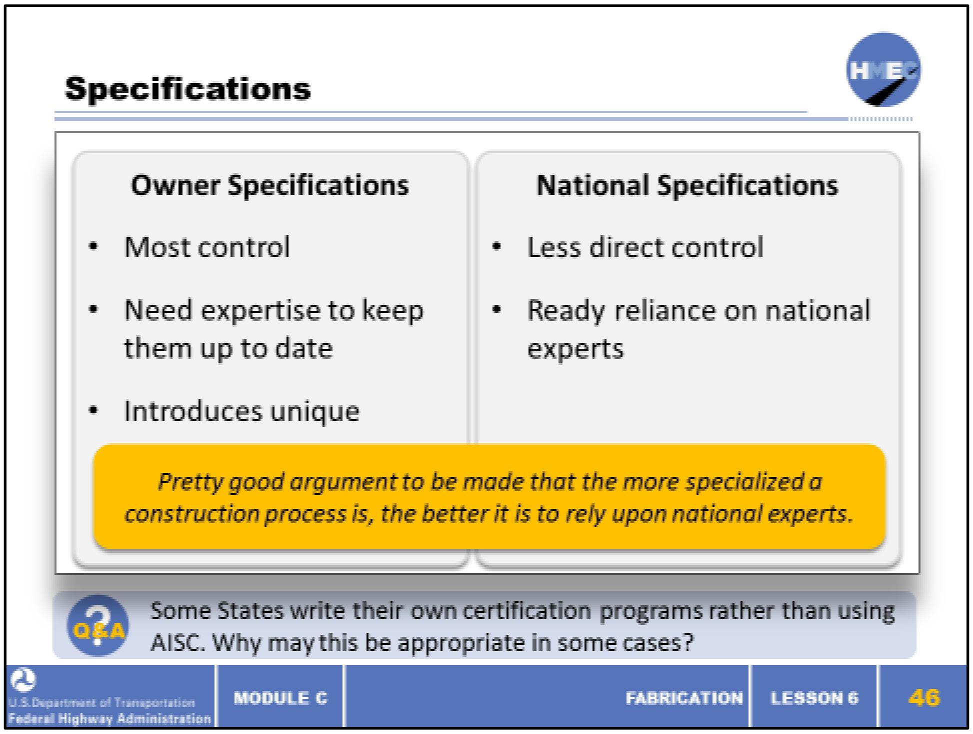
This is an advanced bridge. The AISC certifications do not include "delta leg" bridge in their descriptions, but there would be little argument that this bridge falls into the advanced bridge category. Further, it is unlikely, in practice, that a fabricator who only maintains an intermediate certification would pursue this work. However, if there is any concern or confusion about the required certification, it is a simple matter to specify advanced bridge in the plans.

Noted skills:

- Welding – full penetration welding and fillet welding.
- Cutting webs and building girders for continuous bridges which achieve the proper camber along their entire length.
- Achieving proper girder sweep.
- Accomplishing girder to girder and girder to cross-frame connections that fit.

In addition to these I girder skills, above, handling members with exceptionally large plates (webs over 1 in. for example), which are stiffer and heavier, and achieving the complex geometry of an unusual, closed section (the delta frame) with multiple pieces.

Slide 46



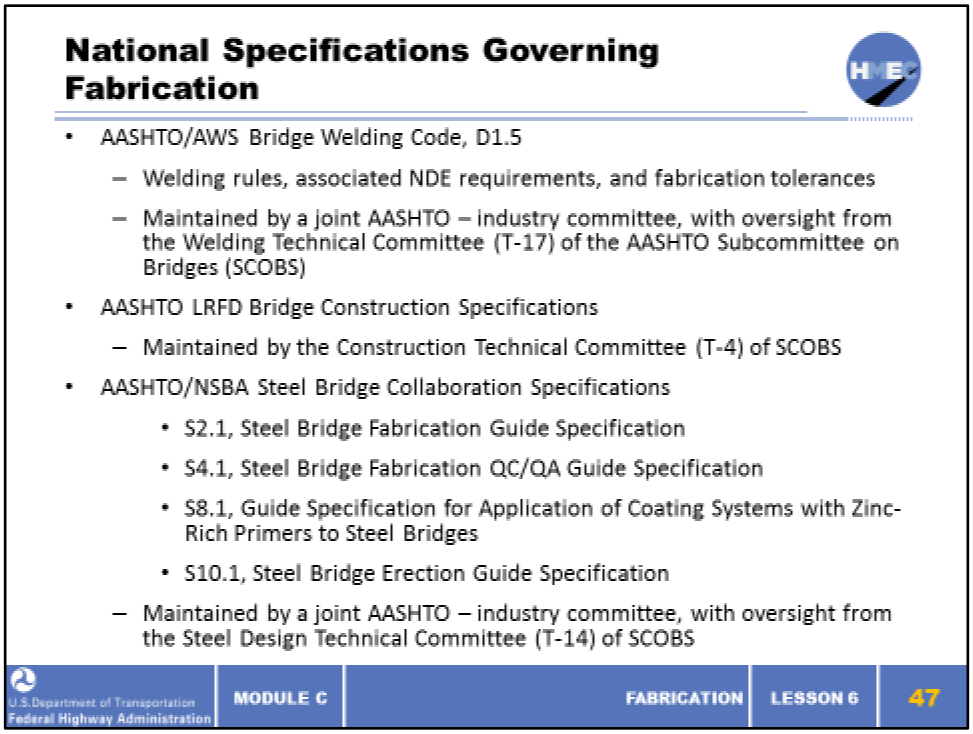
When considering which specifications to use for fabrication contracts, a first consideration is whether to use your own specifications or adopt national ones.

As an owner, using your own specification gives you the most direct control; you can write what you want into your specifications and then demand it. But this may not be very effective. You might specify something that doesn't represent the best value or perhaps isn't even attainable.

When you use national specifications, you sacrifice some control but you gain the benefit of the expertise from around the country and beyond. Further, you avoid the need to maintain in-house expertise for specification development.

Take welding for example: how many people at DOTs know a lot about welding science? Actually, several DOTs do have proficient welding experts on staff that they can rely upon; but not all of them. Before D1.5 was published in 1988, there were a broad array of welding rules in place and an unfortunate variety. Consider the inefficiency and cost that can be introduced when each owner has its own rules. For example, consider welding procedure testing. Tests cost $5,000 to $10,000; owners who have their own rules expect tests done to their rules; hence use of in-house specifications raised the prospect of a lot redundant testing.

Slide 47



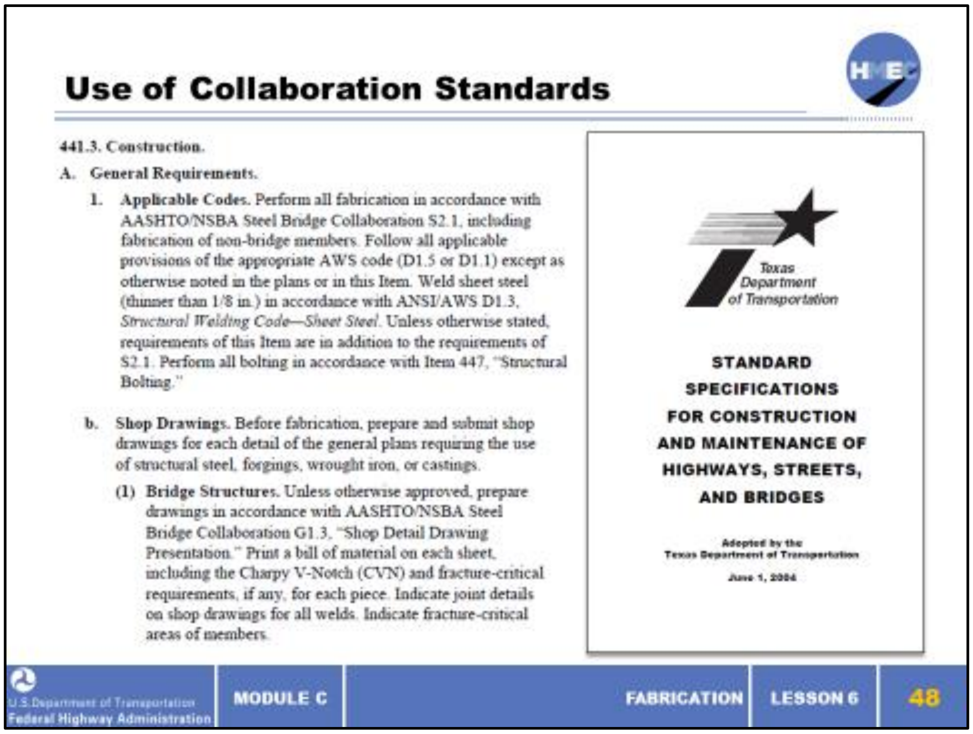
The Bridge Welding Code is a national specification. It is overseen by the AASHTO SCOBS via the SCOBS Technical Committee on Welding. All work developed by the D1.5 committee is submitted for approval via T-17 for SCOBS approval, and measures only go into the code if approved by SCOBS.

The AASHTO Construction Specification is also useful. A handful of States reference this document in their standards specifications in lieu of developing their own language.

The AASHTO/NSBA Steel Bridge Collaboration is a joint owner/industry committee, which develops standards for steel bridge design and construction, including the four specifications listed here. The collaboration was started in 1997 with the goal of standardizing practices to improve quality, lower costs, and improve steel bridge deliveries. The founders approached both the NSBA, representing industry, and the AASHTO SCOBS, representing owners and asked them to support the effort. The leadership of both groups supported the idea and facilitated formal approval such support. Now, all of the collaboration work is approved by the NSBA and the AASHTO SCOBS via Technical Committee 14, Steel Design, before it is published.

The idea with the Collaboration Guide Specifications is that owners adopt the guide specifications for their respective practices directly in lieu of having their own requirements in their standard specifications. A handful of owners have indeed done this.

Slide 48



TX DOT adopted collaboration specifications by reference in their standard specifications. For example, here they reference S2.1 for fabrication requirements and G1.3 for shop drawing presentation.

These documents are available for free download from the AISC Web site (https://www.aisc.org/Default.aspx) and from the AASHTO Bookstore; paper copies are also available from the AASHTO Bookstore.

Slide 49

Note that some are "Guide Specifications" and some are "Guidelines." The collaboration intends that owners adopt guide specifications directly, by reference, in their standard specifications; they are written in spec-type language which facilitates this. In this family of documents, the specification type documents carry an "S" designation.

AISC Web site: https://www.aisc.org/Default.aspx

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Slide 50

AASHTO/NSBA STEEL BRIDGE COLLABORATION

Task Group 2, Steel Bridge Fabrication
Heather Gilmer, Texas Department of Transportation, *Chair*

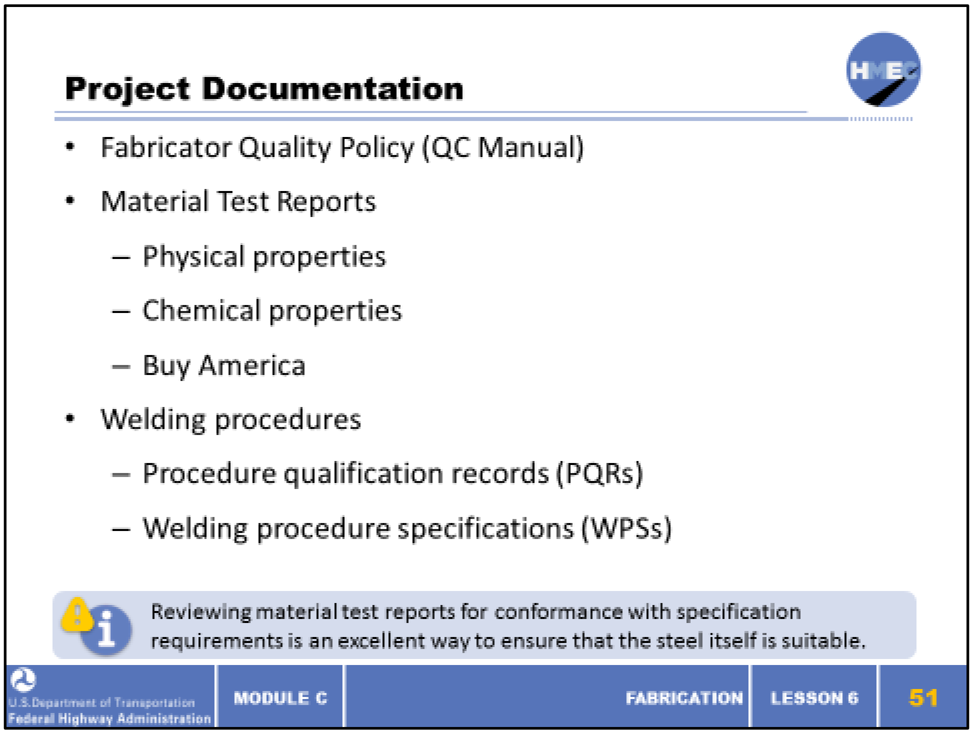
Fred Beckmann	Consultant
Jeff Bishop	Grand Junction Steel
Marv Blimline	Maryland State Highway Administration
Joe Bracken	Pennsylvania Department of Transportation
Tom Calzone	Carboline Company
Bob Cisneros	High Steel Structures
Chris Crosby	Industrial Steel Construction, Inc.
Alex DeHart	Trinity Industries
Lain Duan	California Department of Transportation
Denis Dubois	Maine Department of Transportation
Roger Eaton	HDR Engineering
Jon Edwards	Illinois Department of Transportation
Karl Frank	University of Texas
Andy Friel	Haydon Bolts
Walter Gatti	Tensor Engineering
Barry Glassman	Minnesota Department of Transportation
Dennis Golabeck	URS
Susan Hida	California Department of Transportation
Jamie Hilton	KTA-Tator

Dennis Golabeck	URS
Susan Hida	California Department of Transportation
Jamie Hilton	KTA-Tator
John Holt	Texas Department of Transportation
Bob Horwhat	Pennsylvania Department of Transportation
Ken Hurst	Kansas Department of Transportation
Bob Kase	High Steel Structures
Darrin Kelly	DeLong's, Inc.
Peter Kinney	Bureau Veritas
Eric Kline	KTA-Tator
Andy Kottenstette	U.S. Labs
Scott Krause	High Steel Structures
Ronnie Medlock	High Steel Structures
Ray Monson	Mactec
Sam Moussalli	Iowa Department of Transportation
Kent Nelson	Missouri Department of Transportation
Todd Niemann	Minnesota Department of Transportation
Russ Panico	High Steel Structures
Paul Rimmer	New York State Department of Transportaion
Kim Roddis	University of Kansas
Calvin Schrage	National Steel Bridge Alliance
Bob Stachel	R.W. Hunt Company
Maury Tayarani	Massachusetts Highway Department
Krishna Verma	Federal Highway Administration
Bill Wallhauser	KTA-Tator
Gary Wisch	DeLong's, Inc.
John Yadlosky	HDR Engineering

Here are the members of the task group the developed the 2008 (present) edition of S2.1. Consider that by adopting S2.1 directly, the owner gets the collective wisdom of a large list of steel bridge fabrication professionals, including representatives from DOTs, fabricators, academia, and consultants (inspectors).

Between this slide and the previous slide, peruse and discuss the standard with the class pointing out highlights of fabrication requirements, including the commentary. Remember to emphasize the owner/industry representation of the people who developed the standard, and the fact that the standard has owner approval.

Slide 51



To achieve certification in the AISC program, fabricators must have a policy that reflects the fabricator's commitment to quality and the fabricator's quality management system. The fabricator's manual will not become part of the project records, but it is available for review by the owner.

Material test reports (MTRs) provide quality assurance for the materials used in the bridge. For every steel component—plate, shape, bar, shear stud, etc., the producer of the components creates an MTR and certifies it to be correct. These MTRs are delivered to the fabricator with the material; traditionally they have been on paper, but this documentation often now electronic. The supplier will have checked the MTRs for correctness before supplying the material; the fabricator will also check them to ensure that the physical and chemical properties are correct. All material designated on a job will be supplied to a material specification (usually ASTM); the properties, therefore, will be verified against this specification. If Buy America is required (as is usually the case), this should be on the MTRs as well. The MTRs should be submitted with the fabricator's project documentation for payment.

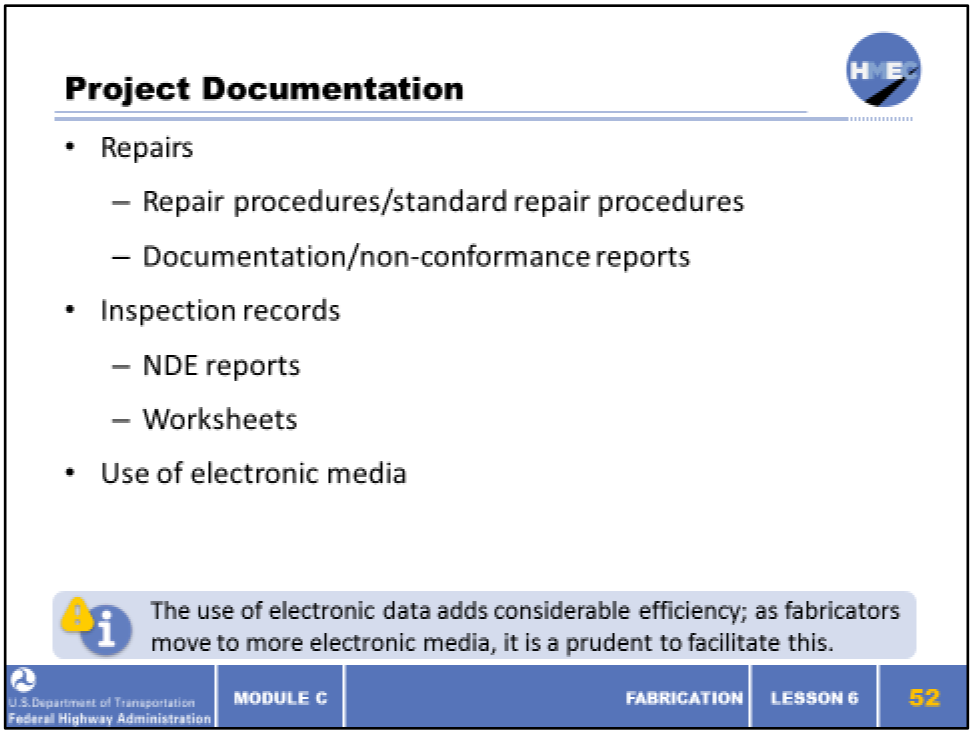
As discussed in Lesson 4, all welding is to be done in accordance with an approved welding procedure. In D1.5, this means that the welding must be done in accordance with an approved welding procedure specification (WPS). As discussed in Lesson 4, the WPS has all of the details that the welder needs to follow. If testing is required to qualify the WPS (as is usually the case in D1.5), then the test results should be documented on an associated PQR. Note that for work done under D1.1, more procedures are prequalified than those in D1.5.

Review of material test reports for conformance with specification requirements is an excellent way to ensure that the steel itself is suitable. Fabricators procure such an MTR for their plate and document the specific use of the plate using its heat number. Inspection records tie heat numbers to components, and the MTRs are convey to the owner when the project wraps up.

The fabricator's inspection records cover a broad variety of quality evaluation from NDE results to geometry checking. Of note, the industry is in a transition to digital media for x-ray evaluation, and, for owners who want to permanent copies of the x-ray, digital RT will greatly facilitate this.

The fabricator will also keep records of repairs that are made and will reflect any final fabrication of the work which varies from the original design in as-built shop drawings. If desired, they can be conveyed to the owner as permanent records.

Slide 52

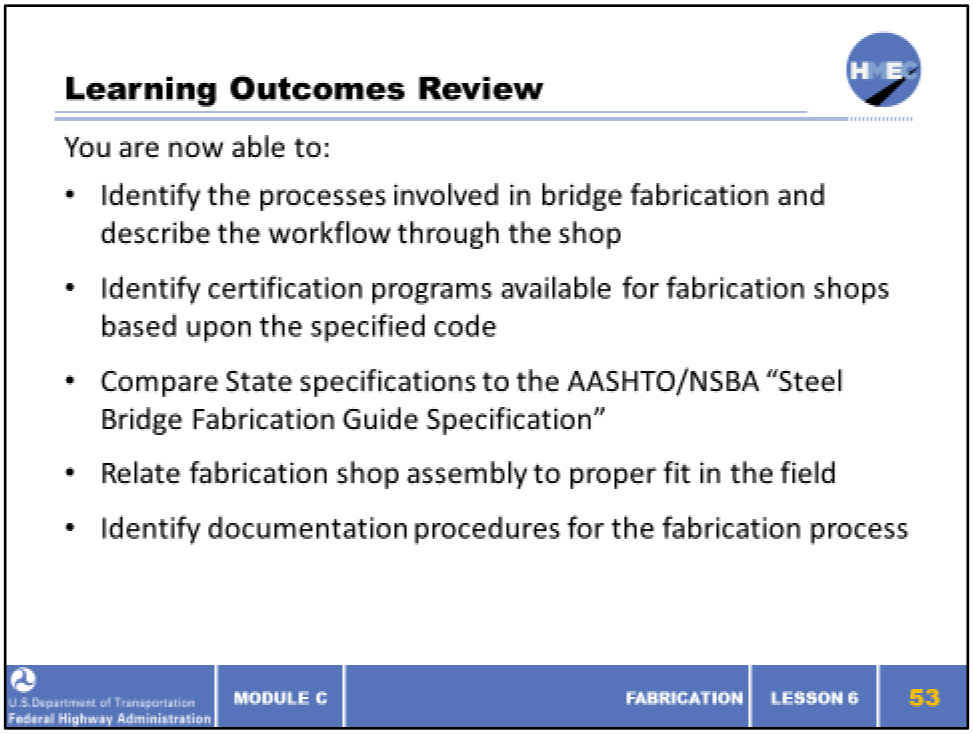


For most projects, it will be necessary to make repairs during the course of fabrication. These repairs can vary from small items, like repairing the occasional torch notch from cutting or slag inclusion from welding. Other repairs are more serious, like, for example, misallocating a stiffener. Specifications allow the fabricator to proceed with repairs for routine items, like the slag inclusion; other items require specific approval of the engineer. For such items, fabricators typically put standard repair procedures in place; these will still require the approval of the engineer, but because they are "standard" they may only require a verification by the inspection that the repair is within the scope of the procedure for the fabricator to proceed. If a standard repair procedure is not in place, then the fabricator will write to the owner for approval of his repair. Either way, such non-conformances will become a part of the fabrication record.

The fabricator's inspection records cover a broad variety of quality evaluation from NDE results to geometry checking which are documented on worksheets. Of note, the industry is in a transition to digital media for x-ray evaluation, and, for owners who want to permanent copies of the x-ray, digital RT will greatly facilitate this.

As reflected in the comments above, project records are becoming electronic—from shop drawings to radiographs to MTRs. Use of electronic data adds considerable efficiency; as fabricators move to more electronic media, it is a prudent to facilitate this.

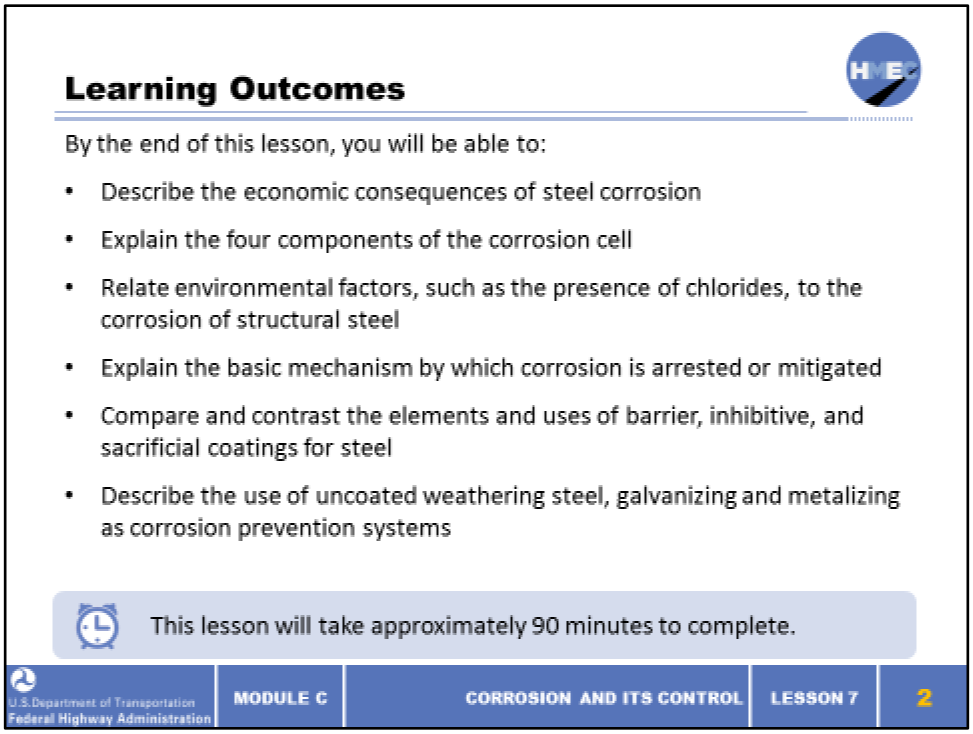
Slide 53


Learning Outcomes Review
HMEC
You are now able to:
• Identify the processes involved in bridge fabrication and describe the workflow through the shop
• Identify certification programs available for fabrication shops based upon the specified code
• Compare State specifications to the AASHTO/NSBA "Steel Bridge Fabrication Guide Specification"
• Relate fabrication shop assembly to proper fit in the field
• Identify documentation procedures for the fabrication process
U.S. Department of Transportation
Federal Highway Administration
MODULE C
FABRICATION
LESSON 6
53

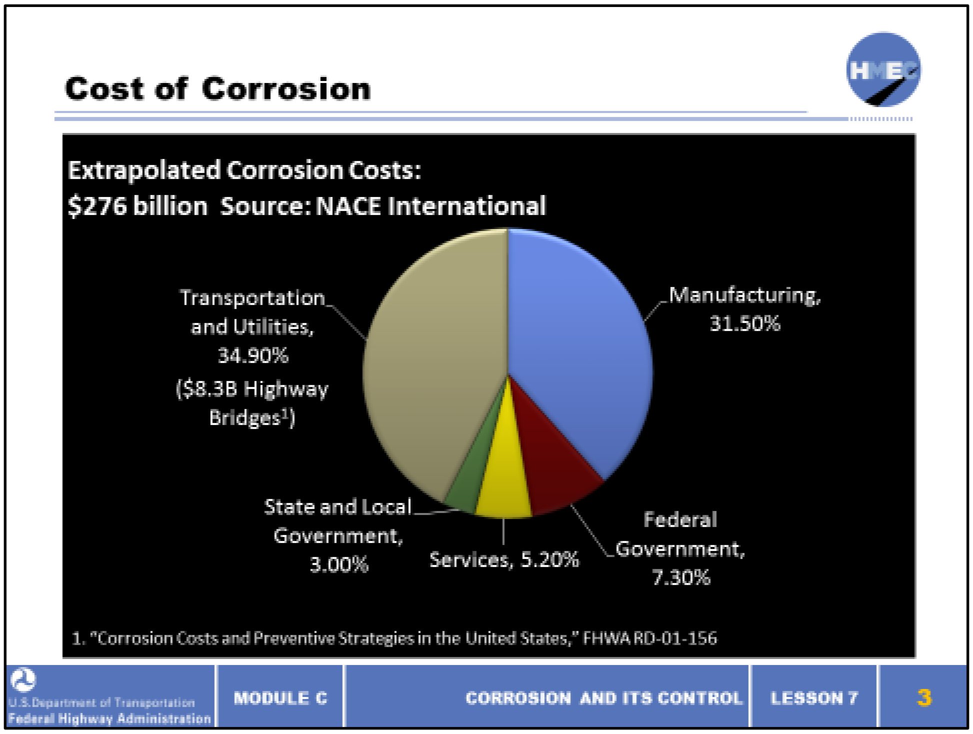
Slide 1


ILT
HMEC
Highway Materials Engineering Course
Lesson 7: Corrosion and Its Control
Steel, Welding, and Coatings
U.S. Department of Transportation
Federal Highway Administration
MODULE
C

Slide 2


Learning Outcomes
HMEC
By the end of this lesson, you will be able to:
• Describe the economic consequences of steel corrosion
• Explain the four components of the corrosion cell
• Relate environmental factors, such as the presence of chlorides, to the corrosion of structural steel
• Explain the basic mechanism by which corrosion is arrested or mitigated
• Compare and contrast the elements and uses of barrier, inhibitive, and sacrificial coatings for steel
• Describe the use of uncoated weathering steel, galvanizing and metalizing as corrosion prevention systems
This lesson will take approximately 90 minutes to complete.
U.S. Department of Transportation
Federal Highway Administration
MODULE C
CORROSION AND ITS CONTROL
LESSON 7
2

Slide 3



According to NACE International, the cost of corrosion in the United States alone is estimated at $276 billion per year, with approximately $8.3 billion attributed to highway bridges, based on a 2002 study released by FHWA.

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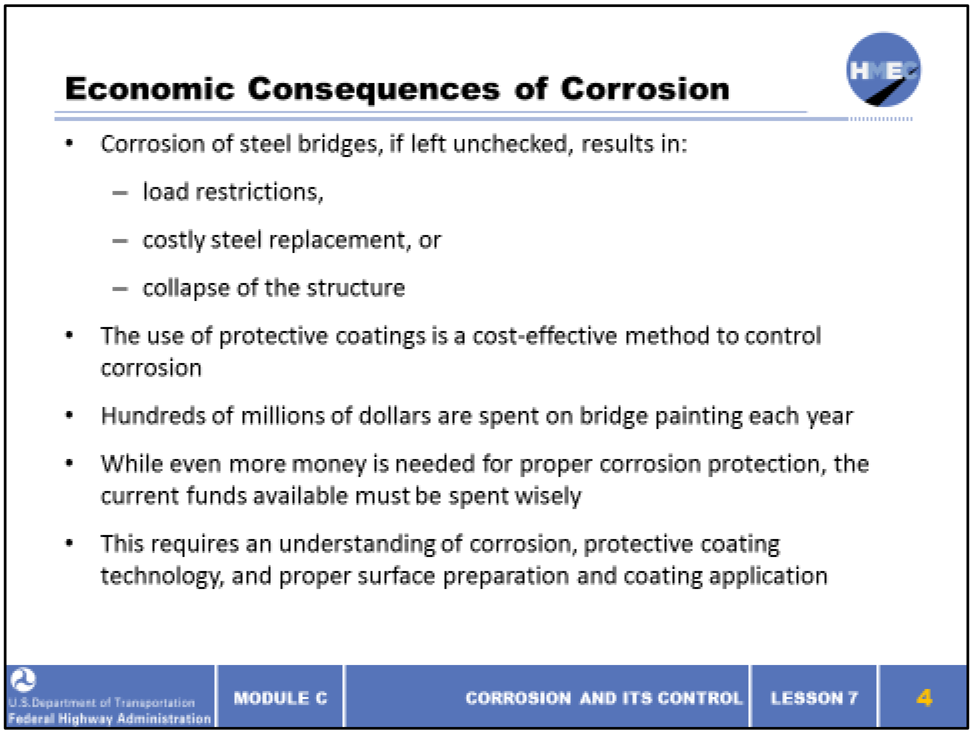
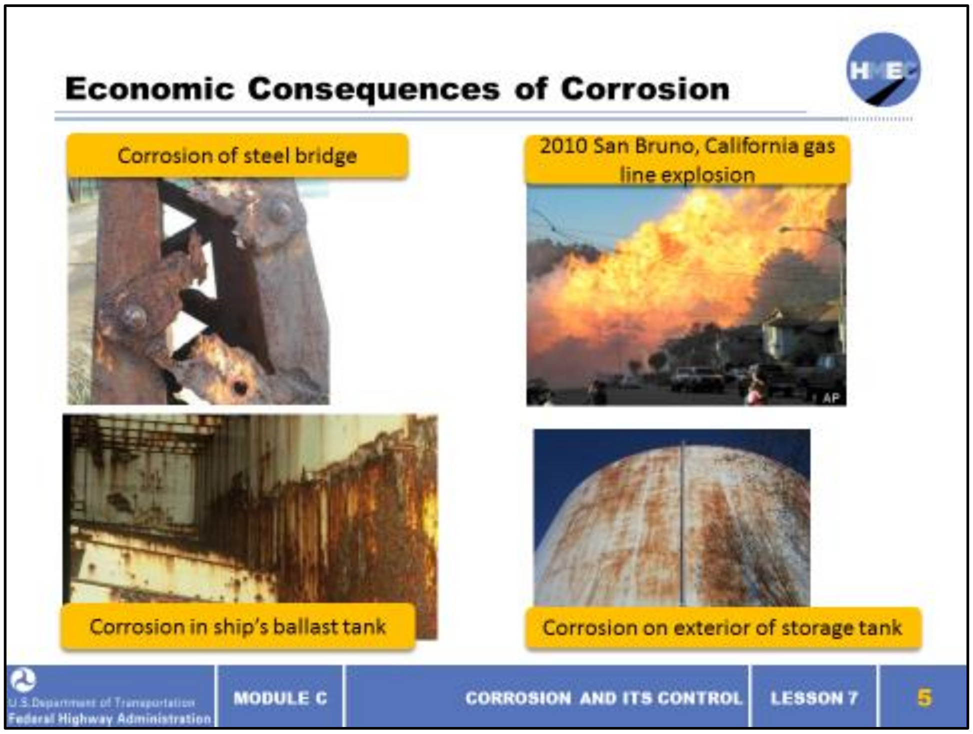
Slide 4



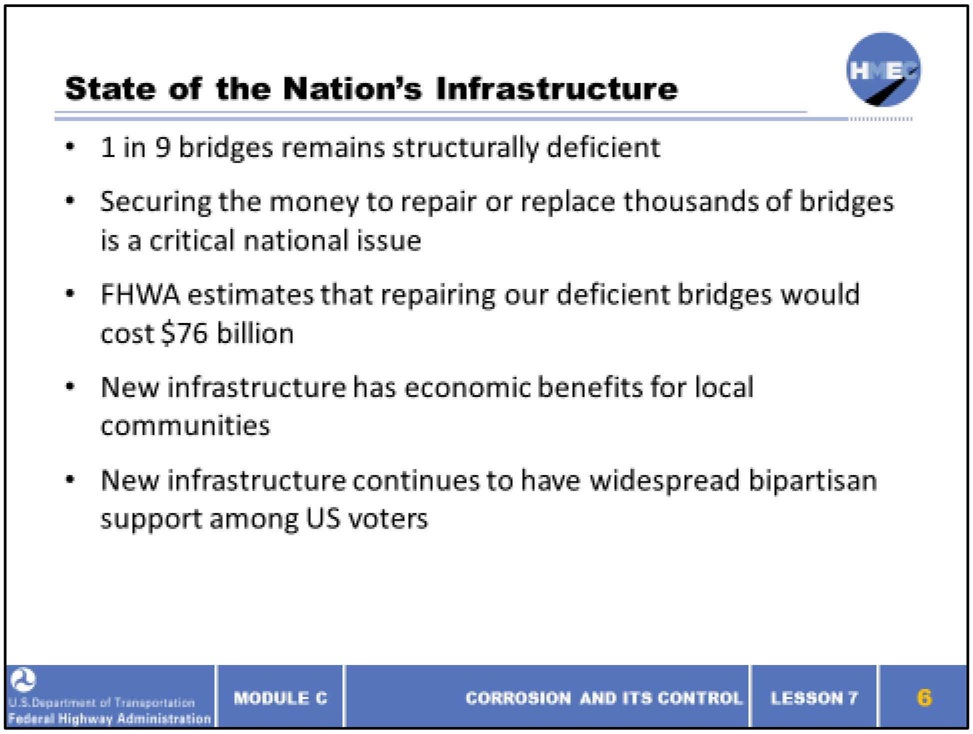
Corrosion of steel bridges, if left unchecked can result in load restrictions, costly steel replacement, or even collapse of the structure. The use of protective coatings is a cost-effective method to control corrosion. Hundreds of millions of dollars are spent on bridge painting each year. While even more money is needed for proper corrosion protection, the funds currently available must be spent wisely. This requires an understanding of corrosion and its control through protective coating technology, proper surface preparation and coating application.

Slide 5



These pictures depict some recent events in the United States that were directly the result of corrosion, such as the 2010 San Bruno gas pipeline explosion, which resulted in 38 homes being lost. A recent study estimates the US Navy spends up to $3.15 Billion combating corrosion. No sector of our nation's infrastructure is immune to corrosion - transportation (ship, road, rail, air), gas transmission, defense, municipal water, oil and gas storage, etc. all have to deal with corrosion.

Slide 6



One in nine bridges remains structurally deficient. Considering declining gas tax revenues for transportation and other budget woes, securing the money to repair or replace thousands of bridges is a critical national issue. The Federal Highway Administration (FHWA) estimates that repairing our deficient bridges would cost a staggering $76 billion. New infrastructure has economic benefits for local communities, which compete against each other for new business and new residents. New infrastructure continues to have widespread bipartisan support among US voters, even in the face of diminished support for increased State and Federal spending and the growing US Federal deficit.

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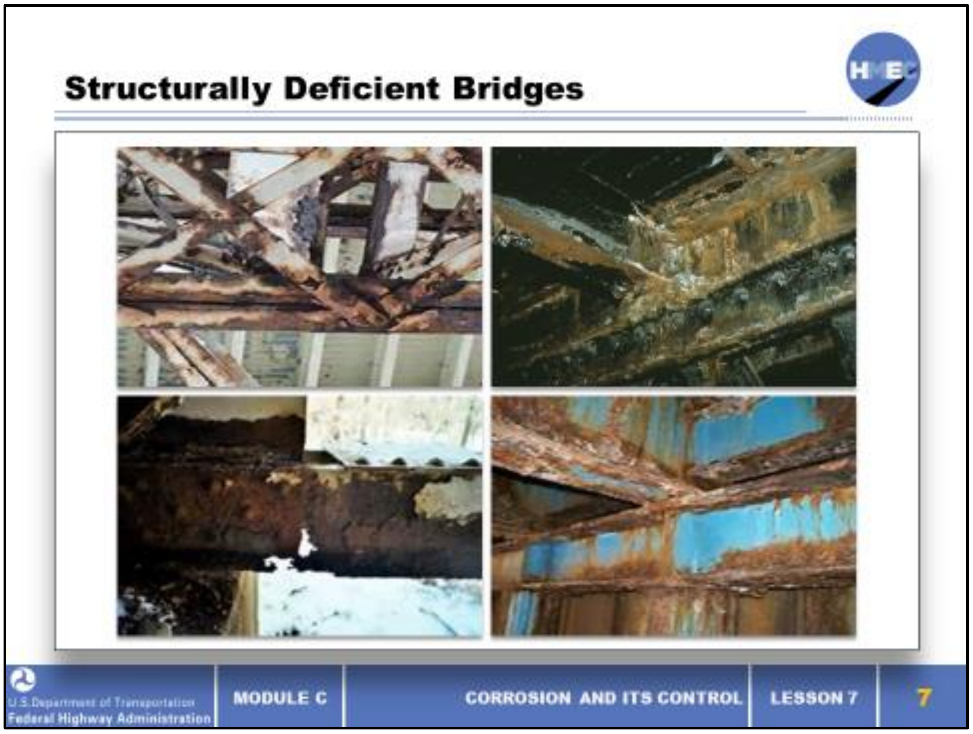
Slide 7


Structurally Deficient Bridges
U.S. Department of Transportation
Federal Highway Administration
MODULE C
CORROSION AND ITS CONTROL
LESSON 7
7

Slide 8

Definition of Corrosion

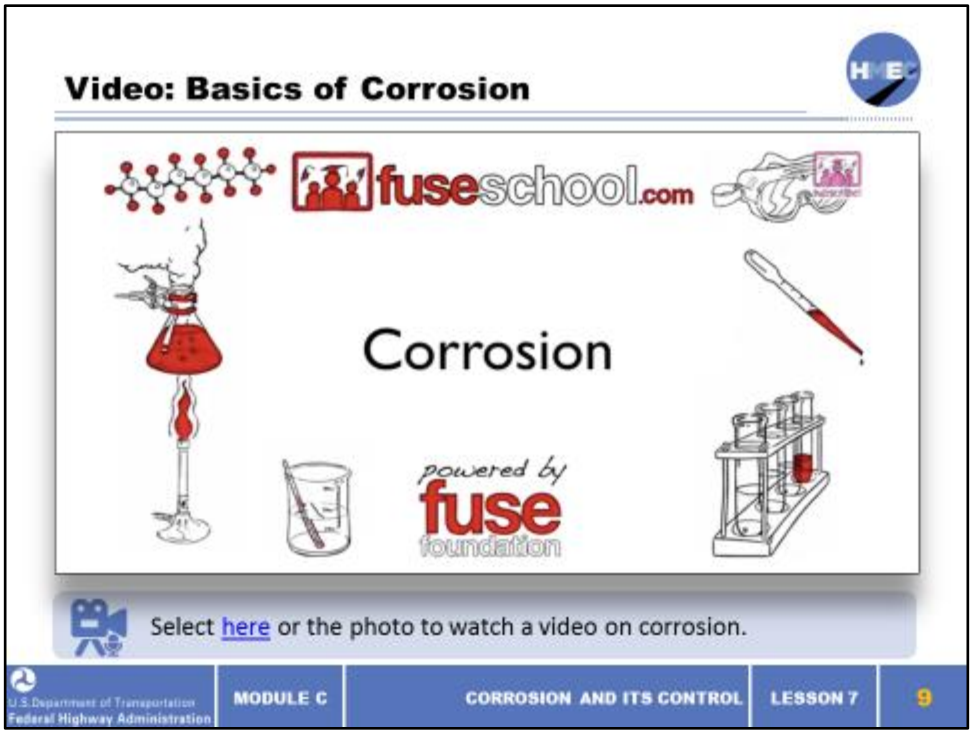
- "The destruction of a material by chemical or electrochemical reaction to its environment"
- The Society for Protective Coating's definition is "The deterioration of any material (usually a metal) due to reaction with the environment in contact with the material that results in loss of the material and its properties (e.g., loss of steel)"

For our purposes:

"The destruction of steel by its conversion to iron oxide (rust)"

U.S. Department of Transportation Federal Highway Administration | MODULE C | CORROSION AND ITS CONTROL | LESSON 7 | 8

Slide 9



https://www.youtube.com/watch?v=T4pSuflO9fk

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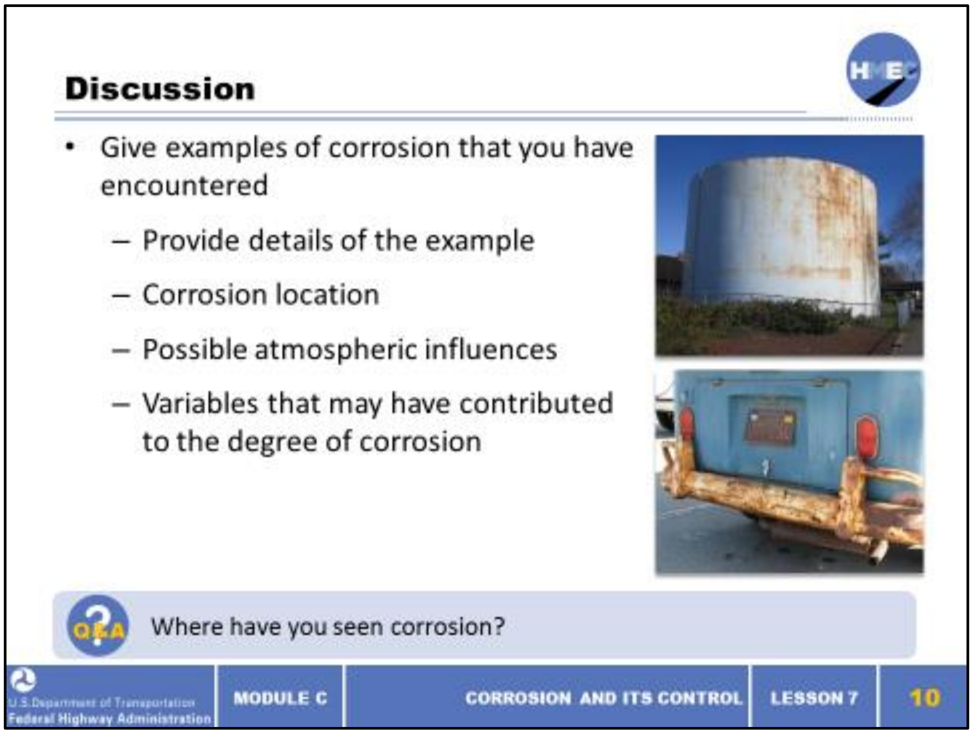
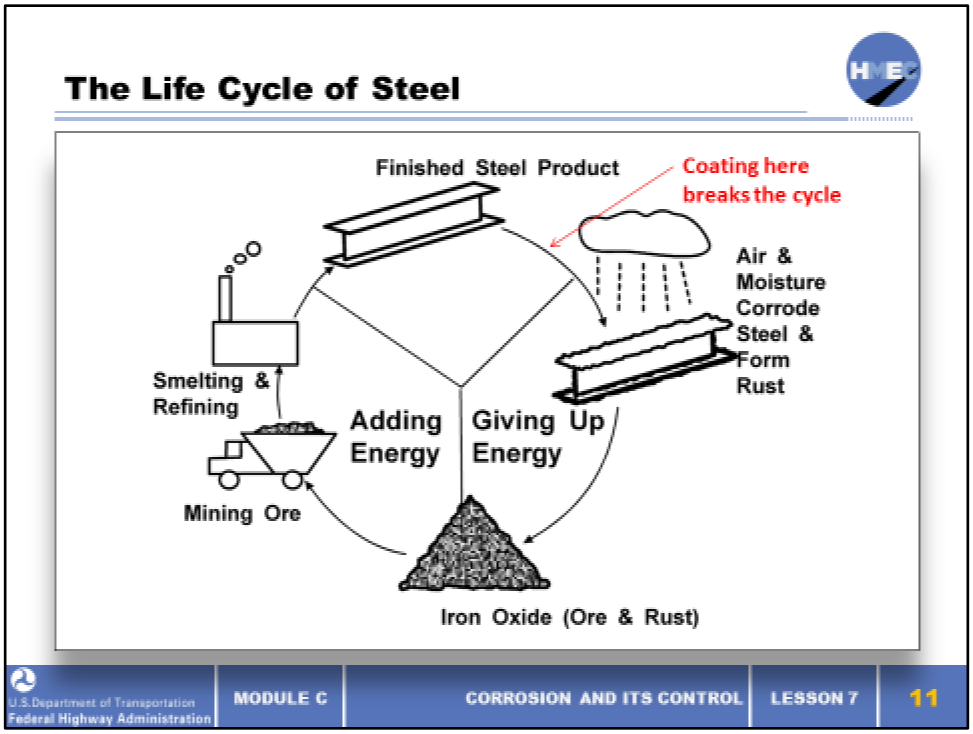
Slide 10



To understand how protective coatings (paints) protect a steel surface, the nature of corrosion must be understood, including why it occurs and how it can be prevented.

Slide 11



The resulting finished steel is unstable as refined, and has a natural tendency to release the energy that was added by the blast furnace and to return to its natural state: iron ore. This takes place in the presence of an electrolyte, such as moisture in the air. Protection of steel from corrosion involves methods that will slow or stop this natural release of energy. In the case of exposed structural steel, the most common method is the application of protective coatings, which isolate the metal from the destructive elements.

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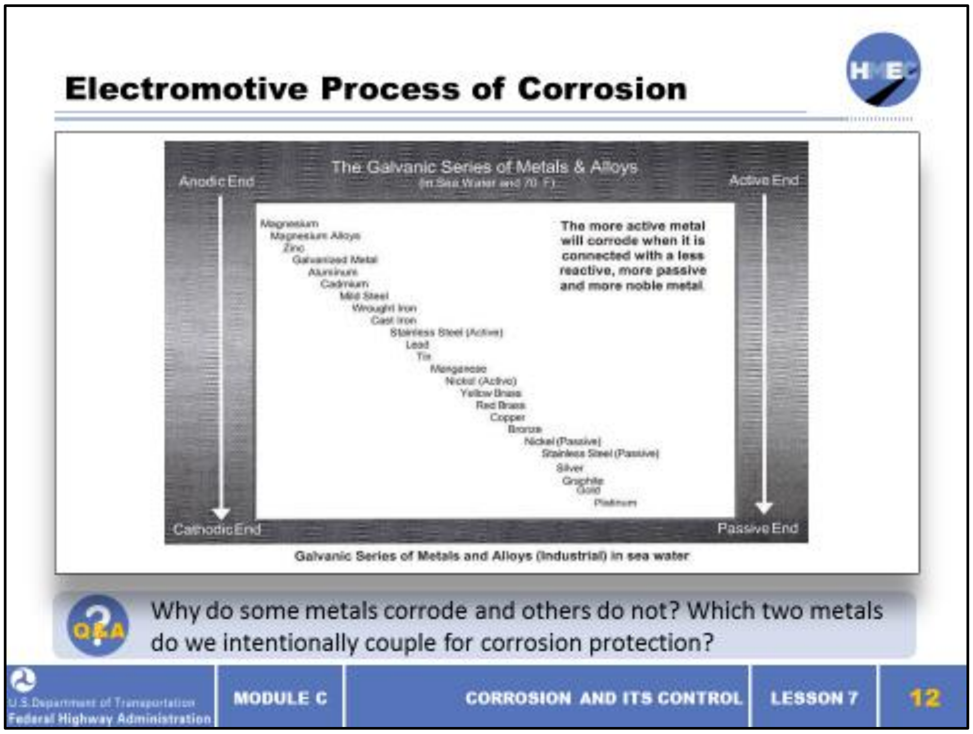
Slide 12



Why do some metals corrode and others do not? The electromotive force (EMF) series lists the various metals according to their comparative potentials. If two of them are coupled together, an oxidation-reduction reaction occurs, with the more active metal being the anode and the less active being the cathode. The more active metal will corrode preferentially to the more noble metal. This chart or ones similar to this is referred to as the "galvanic series of metals."

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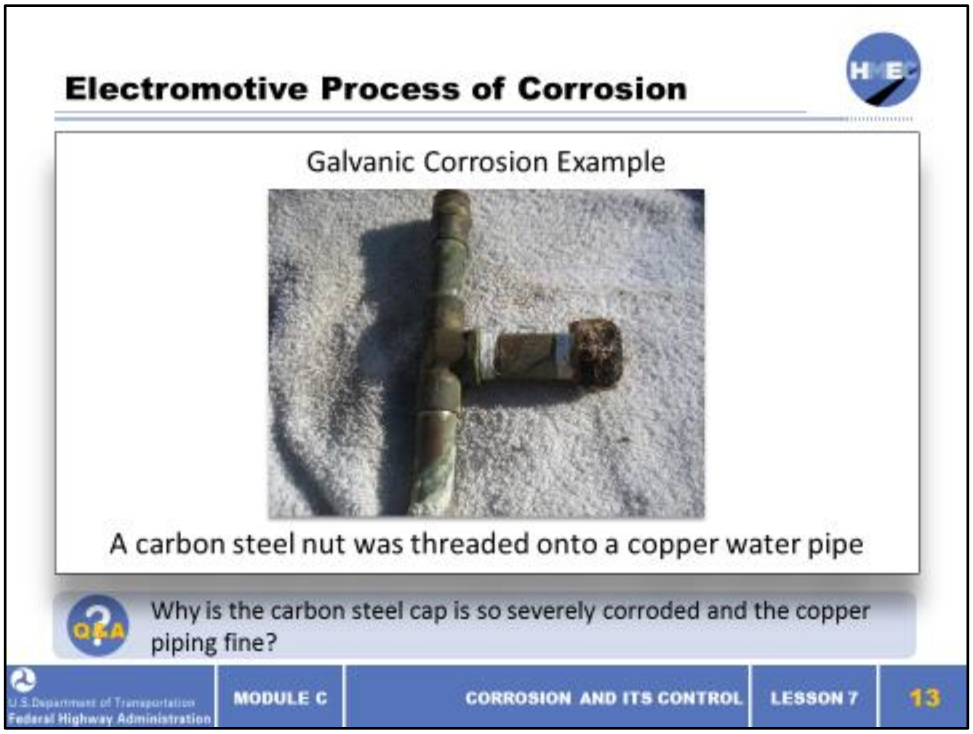
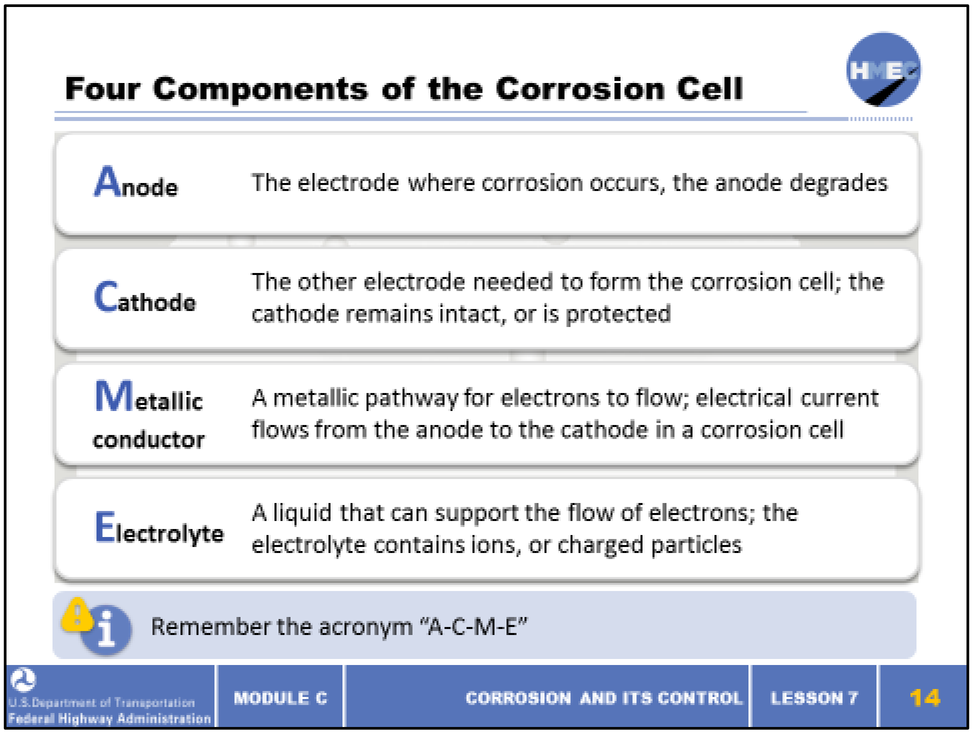
Slide 13



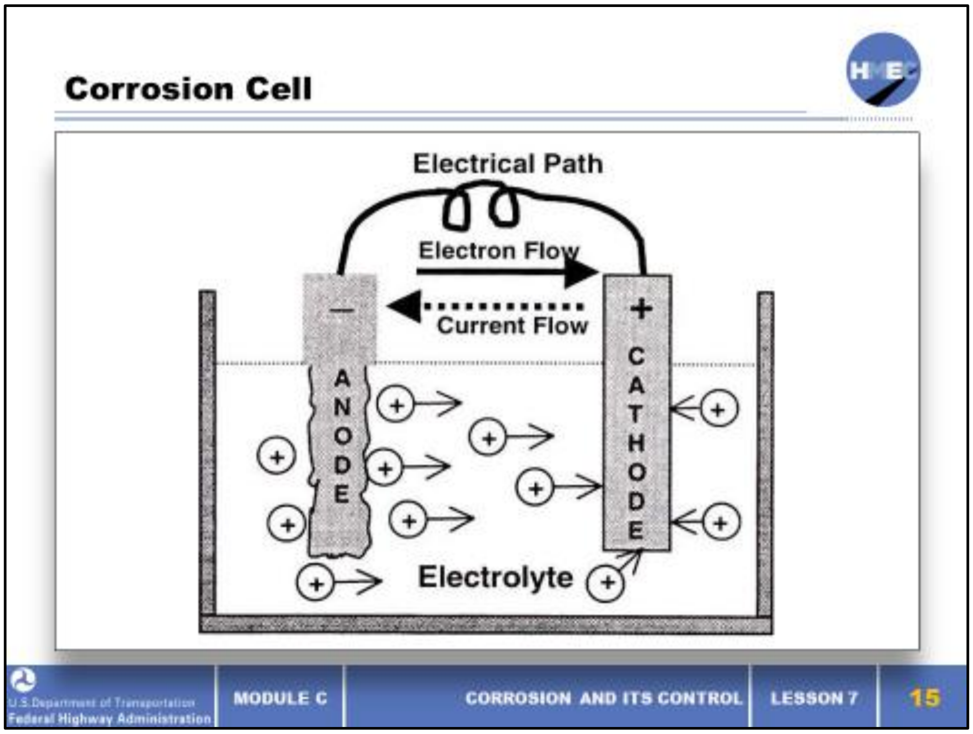
One common type is galvanic corrosion. This occurs when two dissimilar metals are in contact. The metal higher on the EMF series becomes the anode and corrodes.

Slide 14



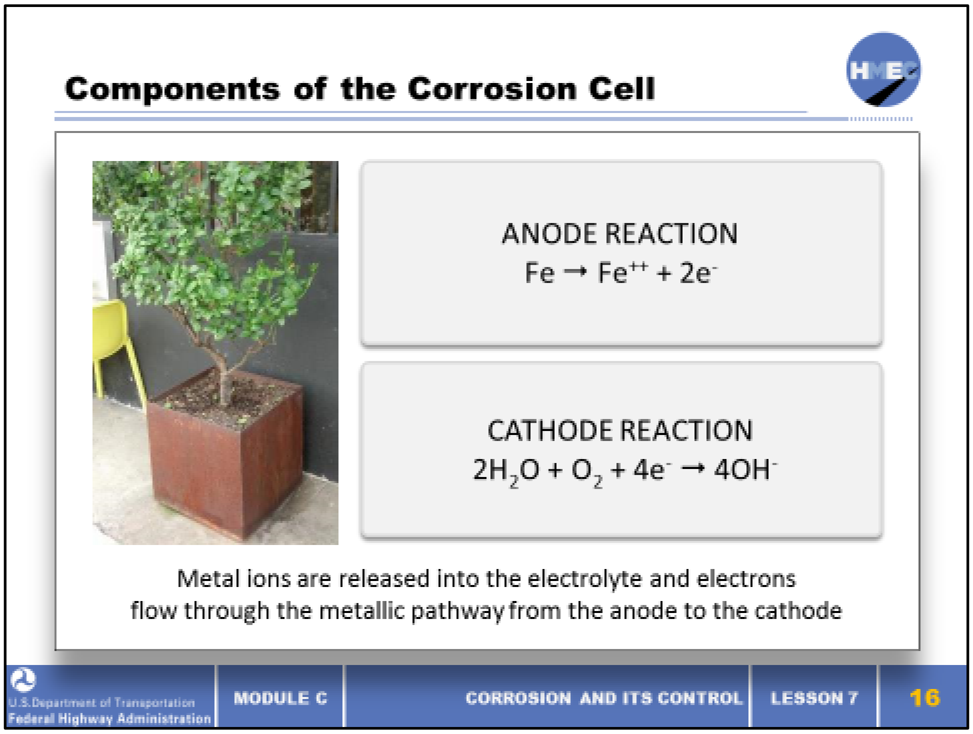
Unless all four of these elements are present, corrosion will not occur. The electrolyte is a solution of salts, minerals, acids, alkalis, or other chemical compounds in water or atmospheric moisture, which is capable of conducting electrical current.

Slide 15



Steel, being a heterogeneous material, contains millions of anodes and cathodes within its structure. Grain boundaries and inclusions of materials other than iron create in differences in electrochemical potential, which creates the anodes and cathodes. The anodic areas of the steel corrode and dissolve into the electrolyte and ions are consumed at the cathode. Electrical current flows through the metallic pathway from the anode to the cathode.

Slide 16



As steel contains anodes and cathodes, and is an electrical conductor, it already contains three of the four elements needed for corrosion. Protective coatings are used to isolate the steel from the environment, thereby preventing moisture (electrolyte) from wetting the surface. If the coating completely covers the surface and is thick enough to insulate the flow of electrons, current will not flow and corrosion will be stopped. The actual electrochemical reactions that occur when steel corrodes are quite complex. However, the basic reactions for atmospherically exposed steel in a chemically neutral environment are dissolution of the metal at the anode:

$Fe \text{ ----> } Fe^{++} + 2e^-$

and reduction of oxygen at the cathode:

$2H_2O + O_2 + 4e^- \text{ ---> } 4OH^-$

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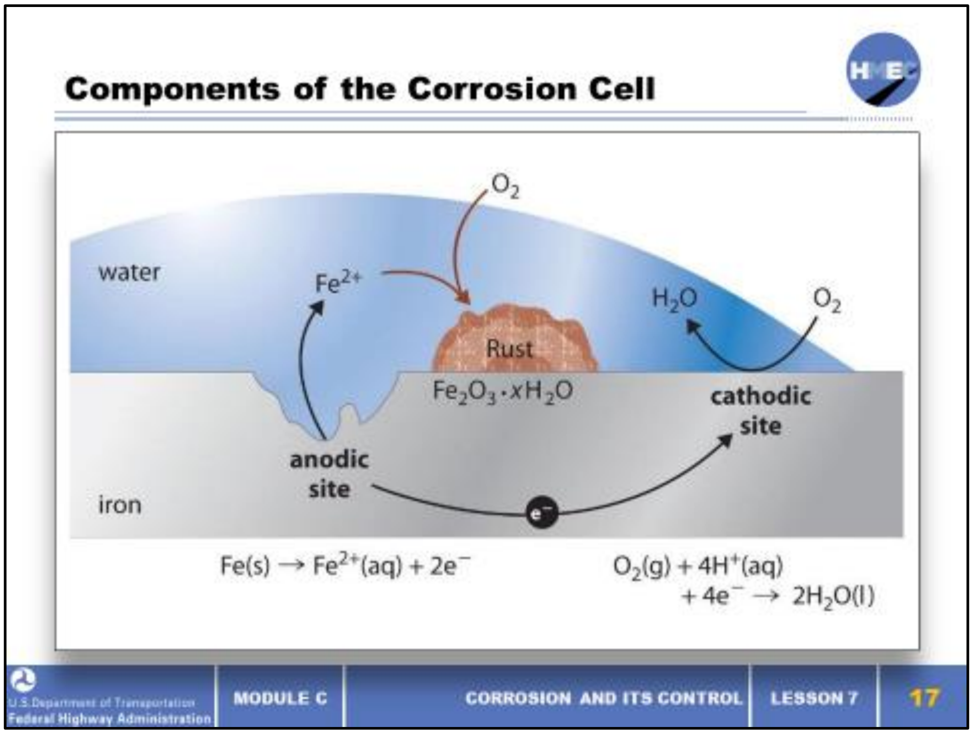
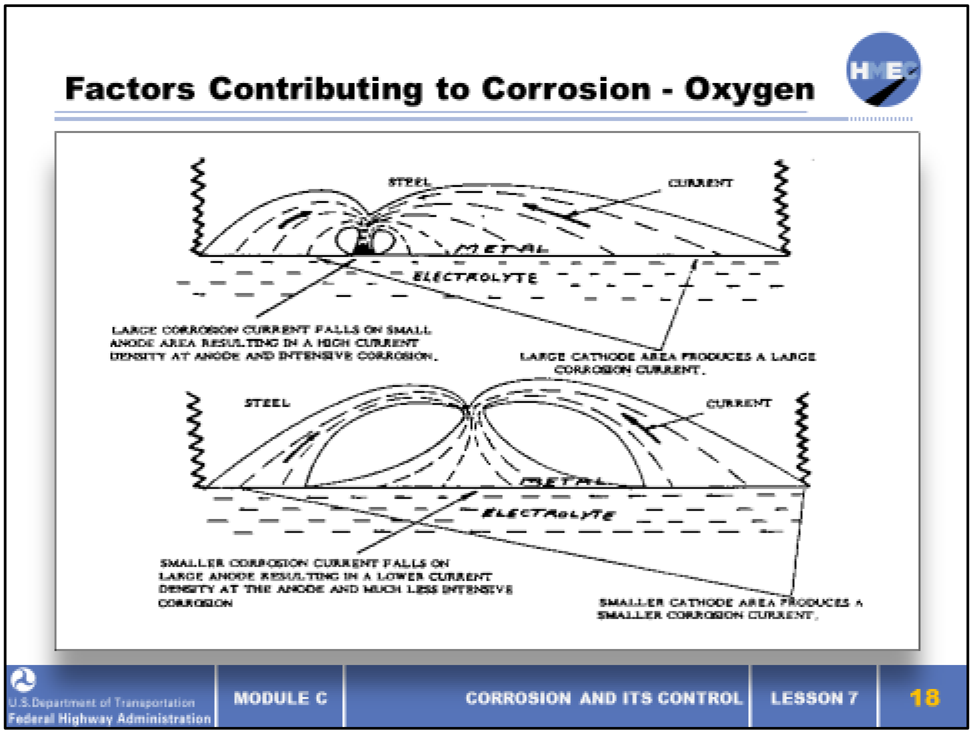
Slide 17



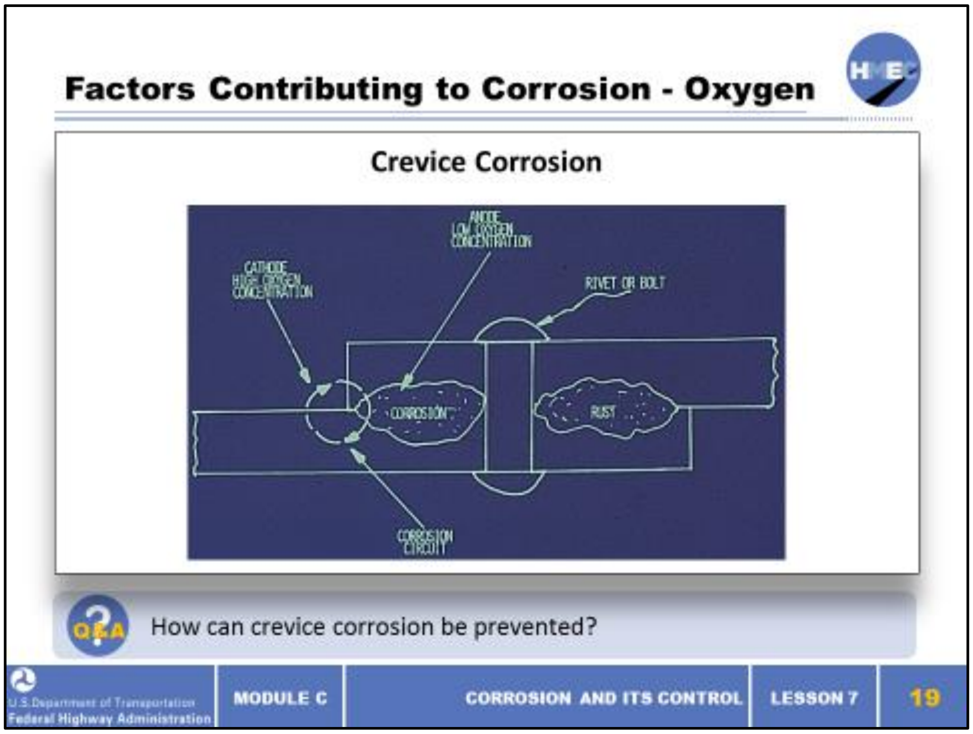
Here is a depiction of the components of the corrosion cell.

Slide 18



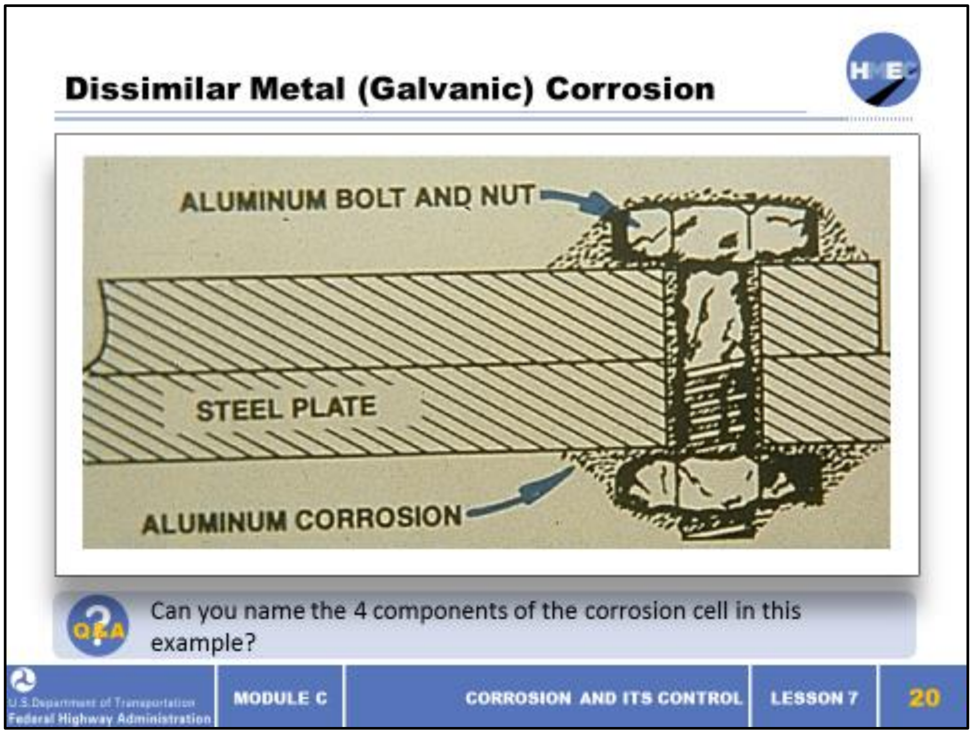
Oxygen is necessary for the cathode reaction. If differences in oxygen content occur, an oxygen concentration cell develops. An example of this is corrosion under a mound of dirt on a flange. The outer edge of the mound is high in oxygen, so this becomes the cathode in the reaction. The steel under the center of the mound is depleted in oxygen and thus becomes the anode.

Slide 19



A mound of dirt on a flange causes pitting corrosion as the oxygen concentration cell established has a small anode. In this example, a low oxygen concentration can act as an anode, and the higher oxygen concentration just outside the crevice can act as a cathode, creating pitting corrosion inside the crevice.

Slide 20



Take a look at the aluminum nut and bolt used to fasten two plates of steel. The aluminum will corrode, or sacrifice itself preferentially to the steel, due to its position on the galvanic chart. Area relationships are important in corrosion, too. The corrosion rate of most metals is controlled by the cathode reaction. The same amount of current reaching a one-square-inch anode will result in corrosion 10 times as intense as if the same current fell on a 10-square-inch anode. The practical implications of this are that small skips during coating application are serious defects, as are scratches in an existing coating.

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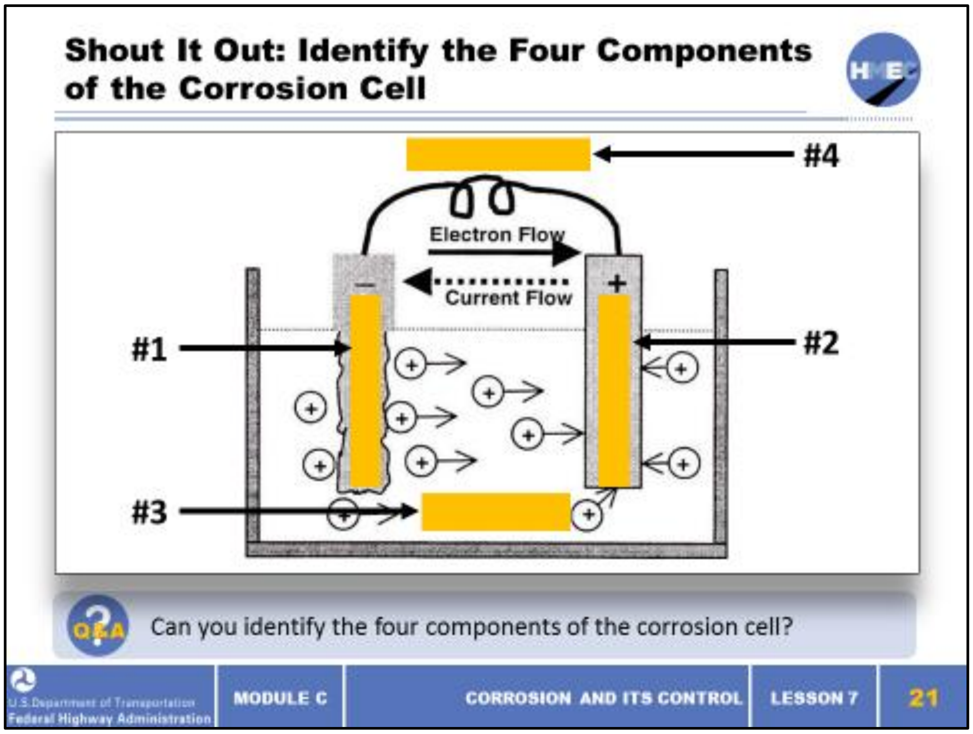
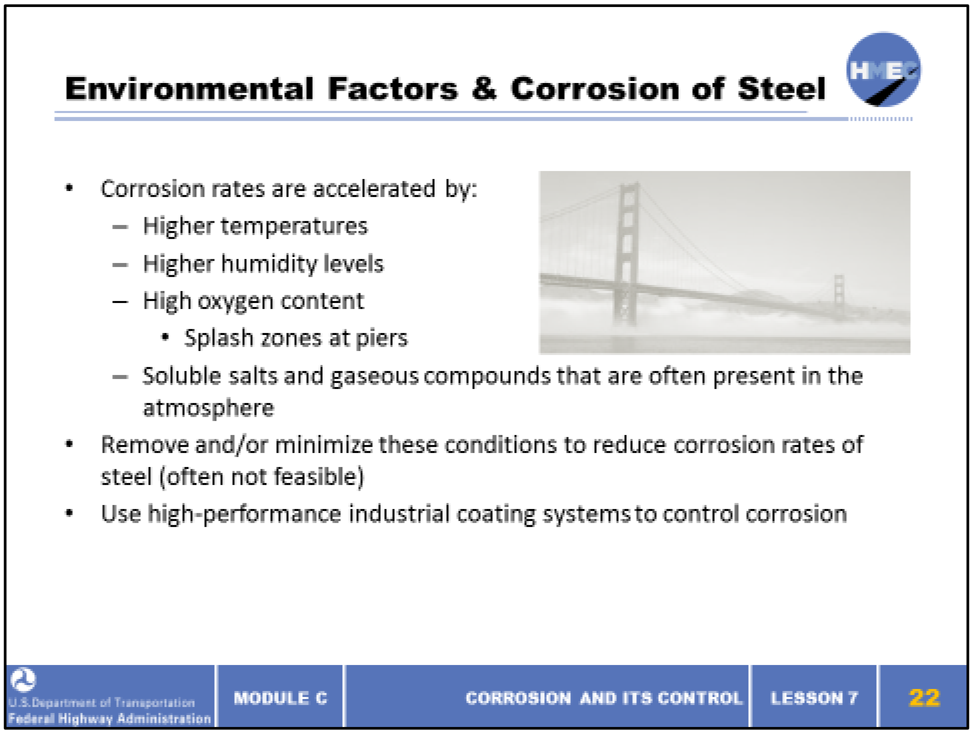
Slide 21



Steel, being a heterogeneous material, contains anodes and cathodes within its structure. Grain boundaries and inclusions of materials other than iron result in differences in electrochemical potential.

Slide 22

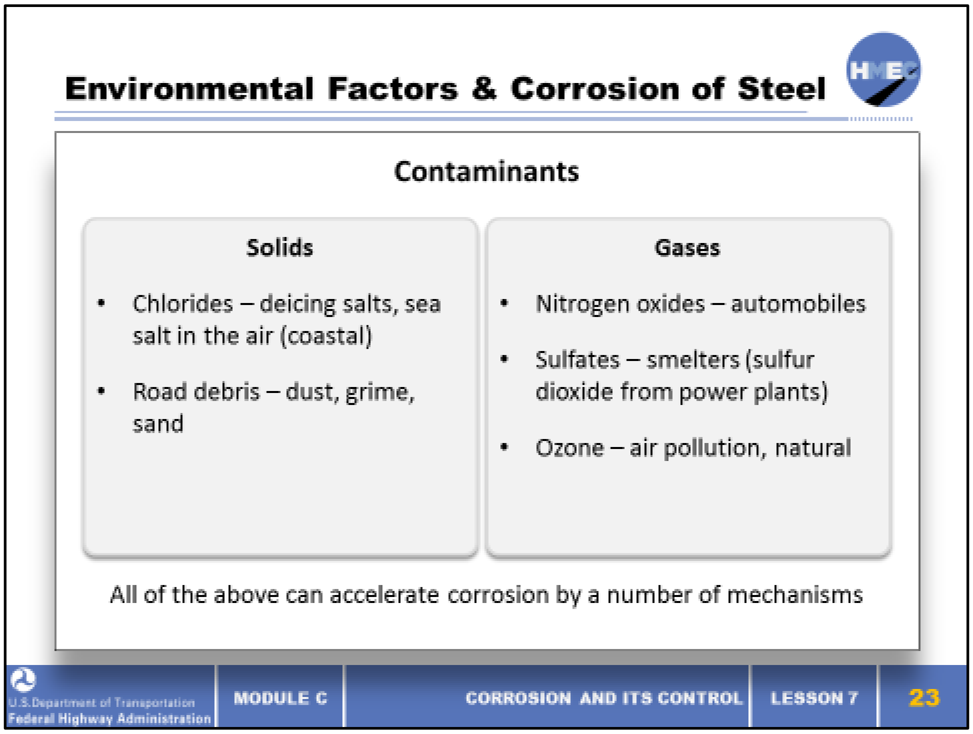


The environment plays an important role in determining corrosion rates. As an electrolyte is needed in the corrosion reaction, the time the steel stays wet will influence how fast it corrodes. Contaminants in the air or on a substrate, such as steel or aluminum will accelerate corrosion. In the case of oxides of sulfur, they are known to be involved in the corrosion reactions, therefore areas with acid rain or coal burning power plants will be a more corrosive environment. Other specific pollutants emitted into the air may even attack the protective coating.

Soluble salts may be present in the atmosphere or may be intentionally deposited on to the steel (e.g., deicing salts) and can include chlorides, sulfates, and nitrates. Gases can include chlorine, ammonia, sulphur dioxide, hydrogen sulfide, and oxides of nitrogen. Such species increase the conductivity of the electrolyte, thereby accelerating corrosion reactions.

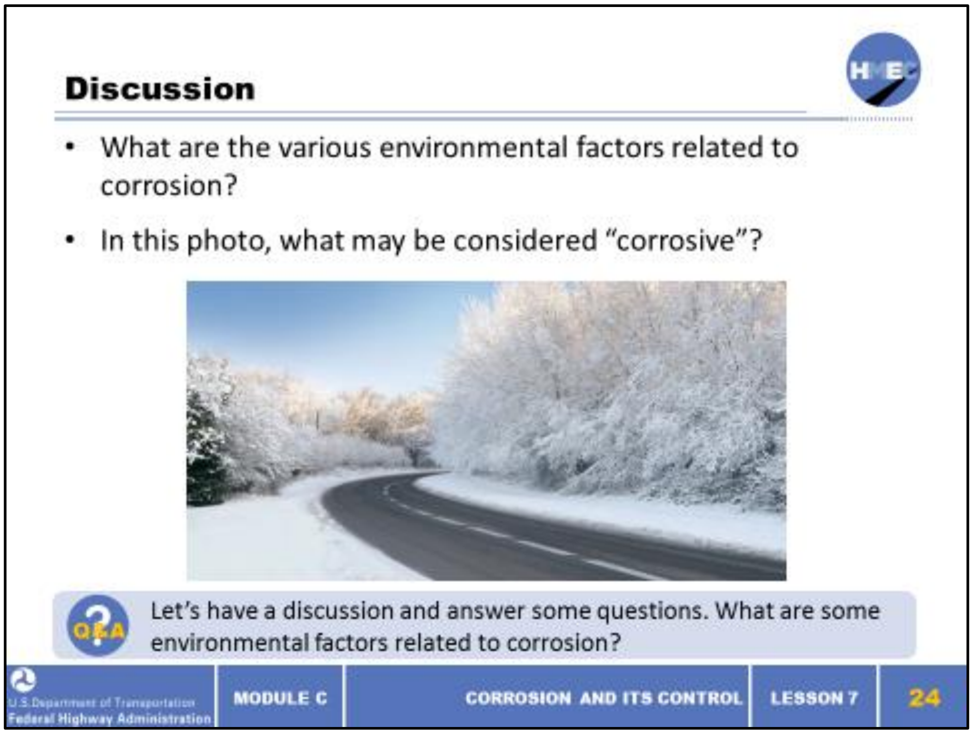
The rate of corrosion can be reduced by minimizing or eliminating these accelerators; however that is oftentimes not feasible. In these cases we use high performance industrial coating systems to reduce the effects of the environment, thereby reducing the rate of corrosion.

Slide 23



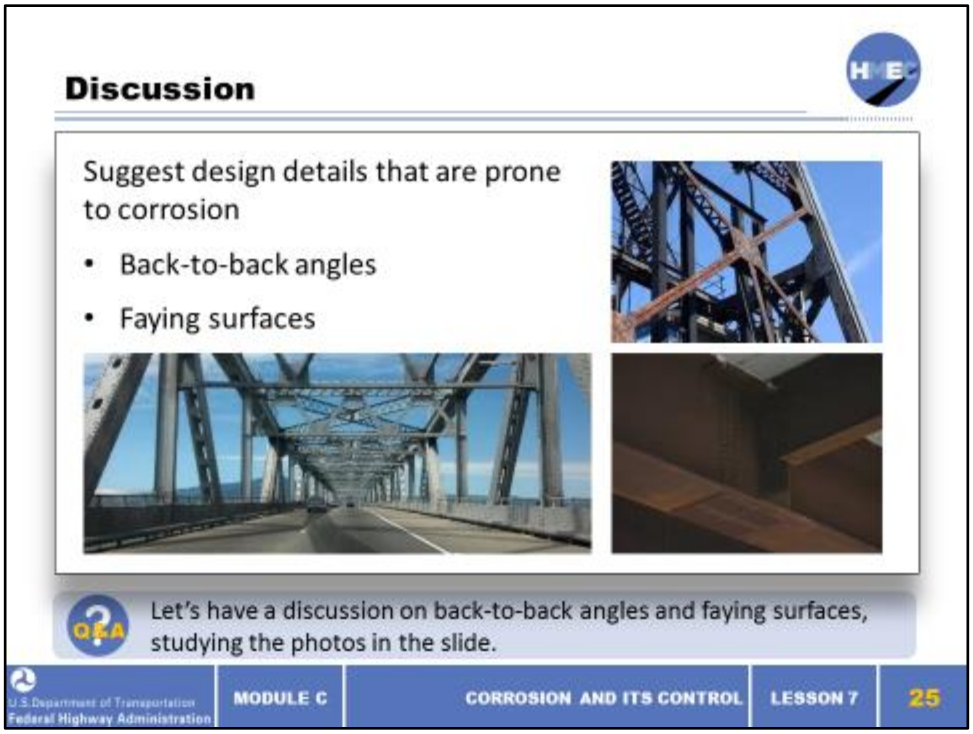
Contaminants can be solid or gas. Example of solids include chlorides (deicing salt, sea salt), sulfates (smelters/sulfur dioxide), or road debris (dust, grime, sand). Gases include nitrogen oxides from automobiles or ozone, including air pollution or natural. The presence of such contamination on a substrate can increase that substrates conductivity, thereby greatly speeding up the corrosion reactions.

Slide 24



The environment plays an important role in determining corrosion rates. Contaminants in the air or on a substrate can accelerate corrosion.

Slide 25


Discussion
Suggest design details that are prone to corrosion
• Back-to-back angles
• Faying surfaces
Let's have a discussion on back-to-back angles and faying surfaces, studying the photos in the slide.
U.S. Department of Transportation
Federal Highway Administration
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CORROSION AND ITS CONTROL
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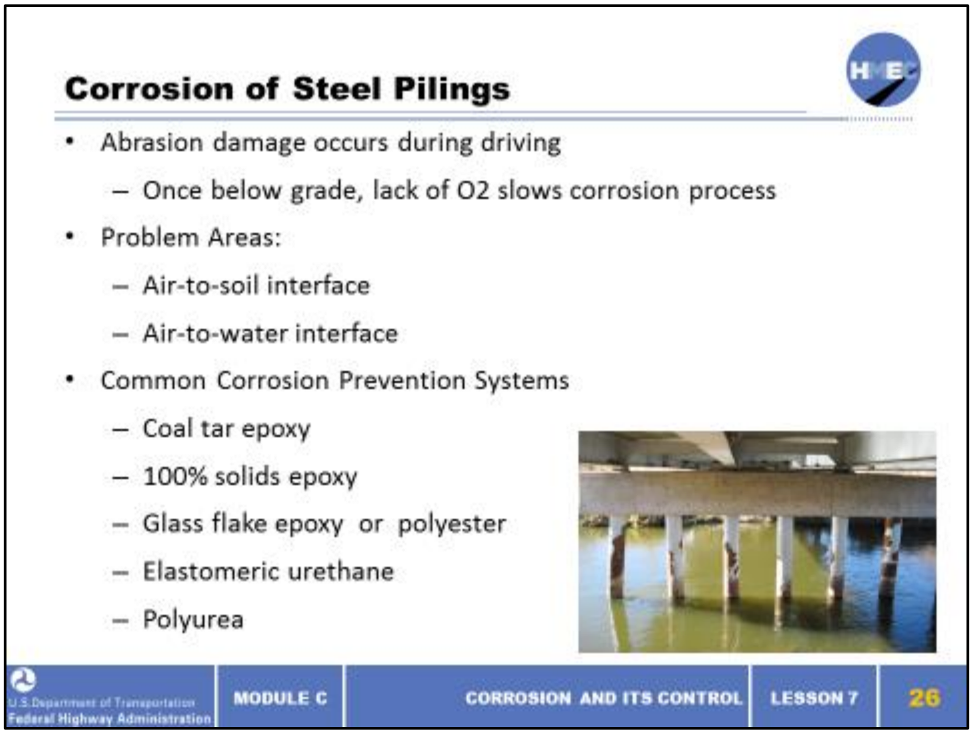
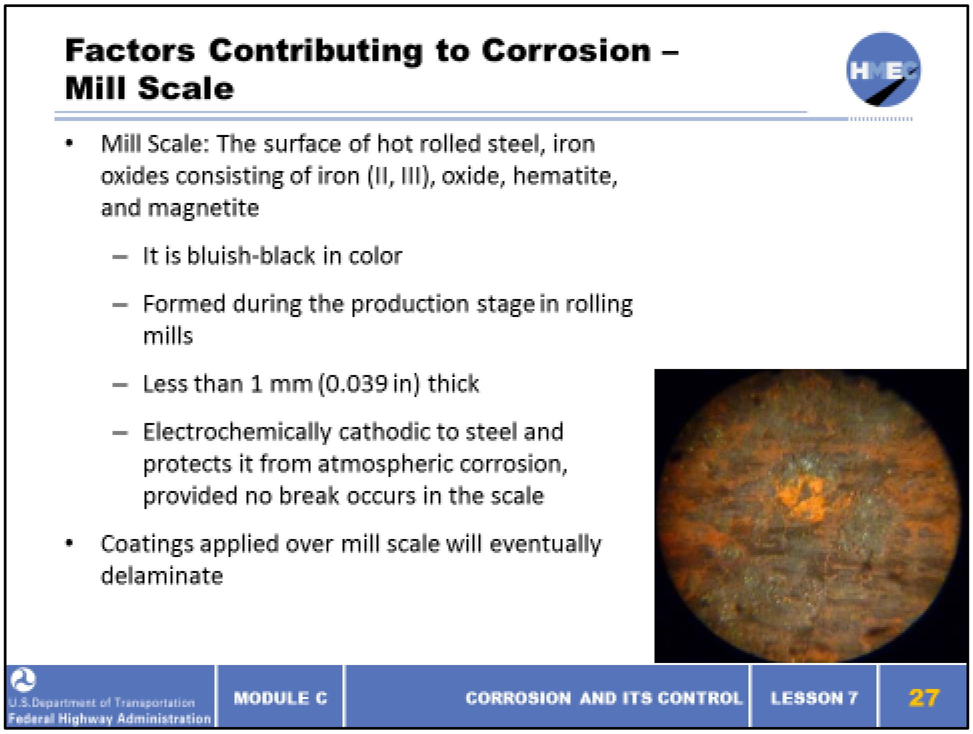
Slide 26



Abrasion damage to the installed coating systems often occurs during installation, but the good news is that the pilings, once underground are exposed to very little oxygen so the corrosion process is significantly slowed. The problem areas for the pilings are at the air-to-soil interface and the air-to-water interfaces, including splash zones. These environments are dynamics and corrosion and section loss are common at these interfaces. Several types of coatings can be used to help protect these pilings.

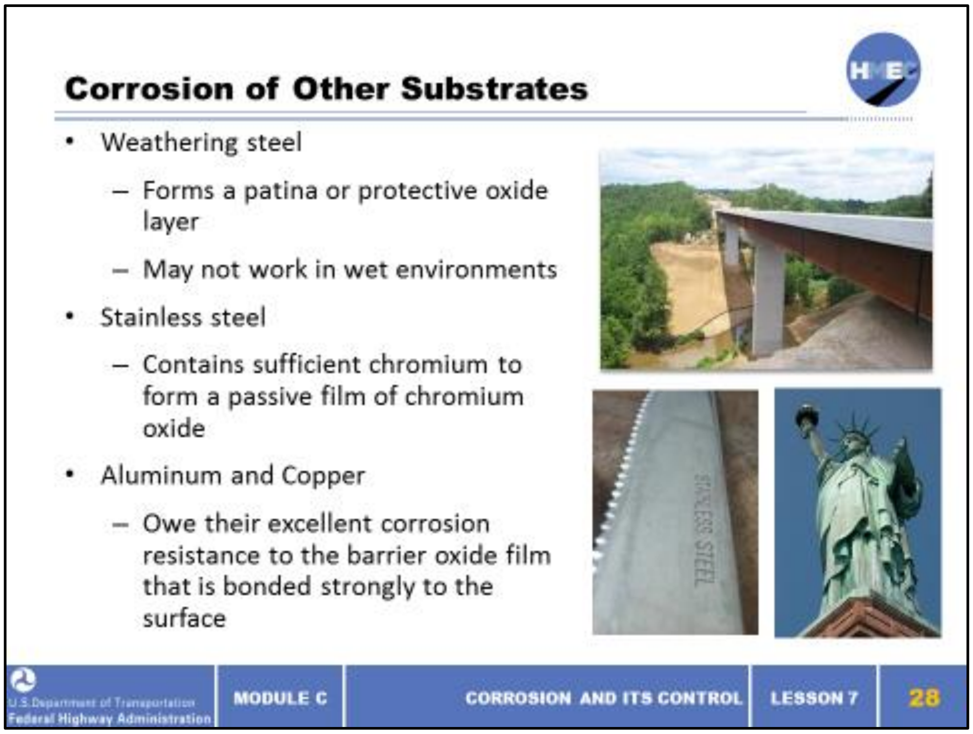
Coal tar epoxy has the longest history of performance in steel piling applications and can be expected to provide 20+ years of protection. Other coatings include 100% solids epoxy, epoxy or polyester coatings reinforced with glass flake, thick film elastomeric urethane and polyurea. Thermal spray coatings (metalizing) have also been considered.

Slide 27



Mill scale is the surface of hot rolled steel. It is iron oxides consisting of iron (II, III), oxide, hematite, and magnetite. It is bluish-black in color. Formed during the production stage in rolling mills, it is less than 1 mm (0.039 in) thick. It is electrochemically cathodic to steel and protects it from atmospheric corrosion, provided no break occurs in this scale. However the mill scale will expand and contract at a different rate than the base steel, which causes it to crack. Once moisture contacts the exposed steel it causes the steel to corrode, spalling the mill scale from the steel (taking the coating with it). Mill scale is frequently removed from steel surfaces by abrasive blast cleaning.

Slide 28



Weathering steel is not rust-proof in itself. If water is allowed to accumulate in pockets, those areas will experience higher corrosion rates. Weathering steel is sensitive to humid subtropical climates and it is possible that the protective patina may not stabilize but instead continue to corrode.

Stainless steel contains sufficient chromium to form a passive film of chromium oxide, which prevents further surface corrosion by blocking oxygen diffusion to the steel surface and blocks corrosion from spreading into the metal's internal structure.

Aluminum and copper owe their excellent corrosion resistance to the barrier oxide film that is bonded strongly to its surface and the fact that if it's damaged, it reforms immediately in most environments. On a surface freshly abraded and then exposed to air, the barrier oxide film is only 1 nm thick but is highly effective in protecting the aluminum from corrosion. Copper forms a greenish-blue layer (also called a patina) that forms a barrier to prevent corrosion.

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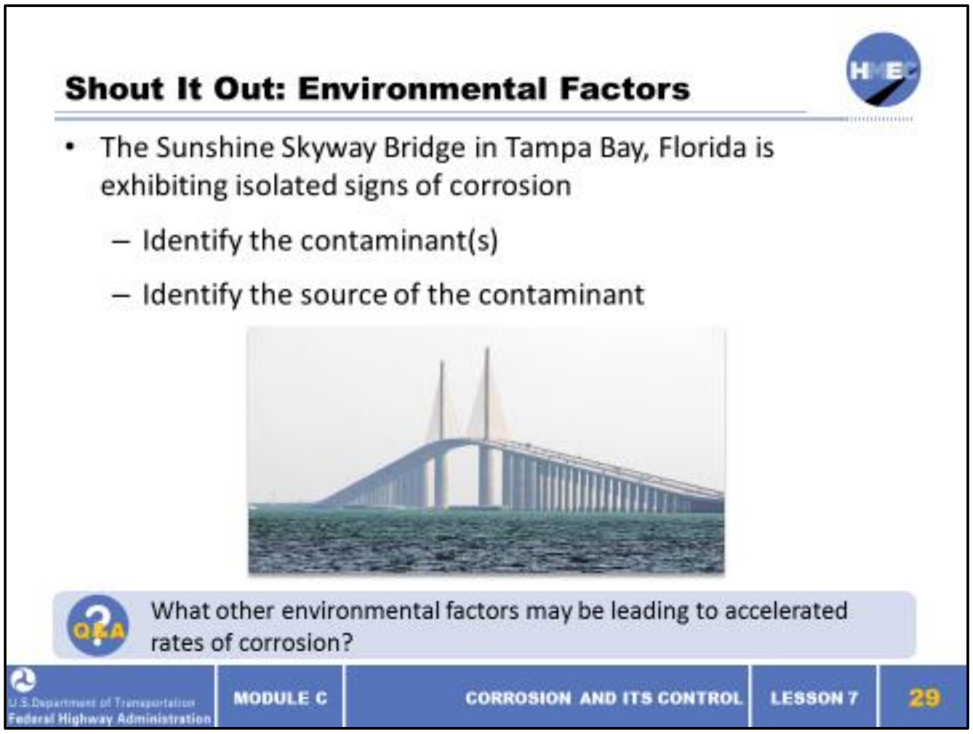
Slide 29


Shout It Out: Environmental Factors
The Sunshine Skyway Bridge in Tampa Bay, Florida is exhibiting isolated signs of corrosion
Identify the contaminant(s)
Identify the source of the contaminant
What other environmental factors may be leading to accelerated rates of corrosion?
Q&A
U.S. Department of Transportation
Federal Highway Administration
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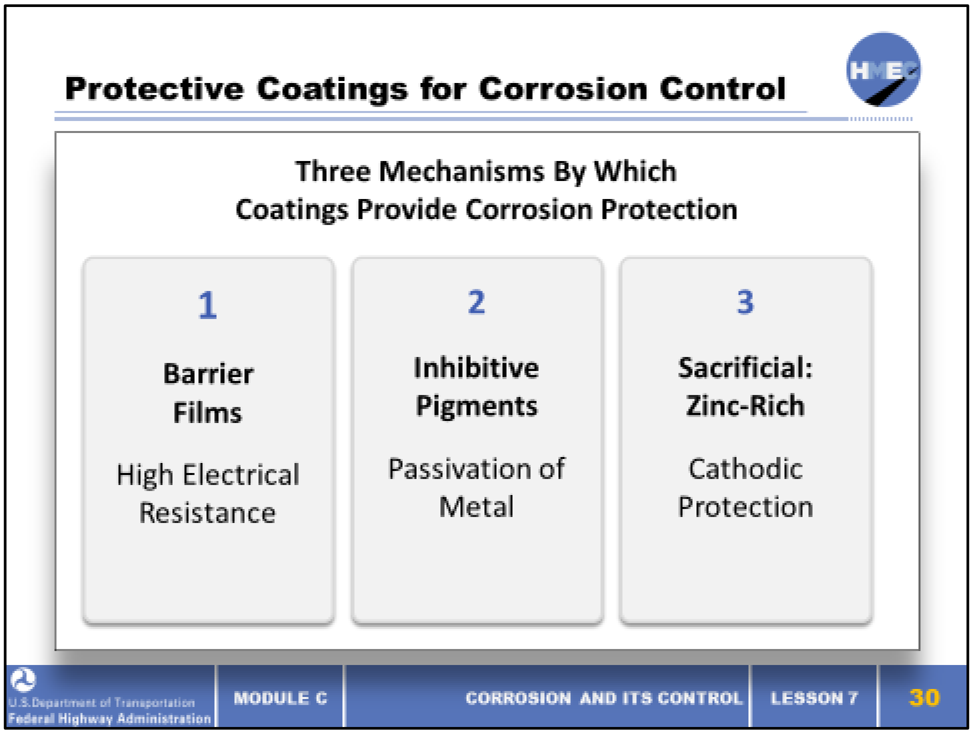
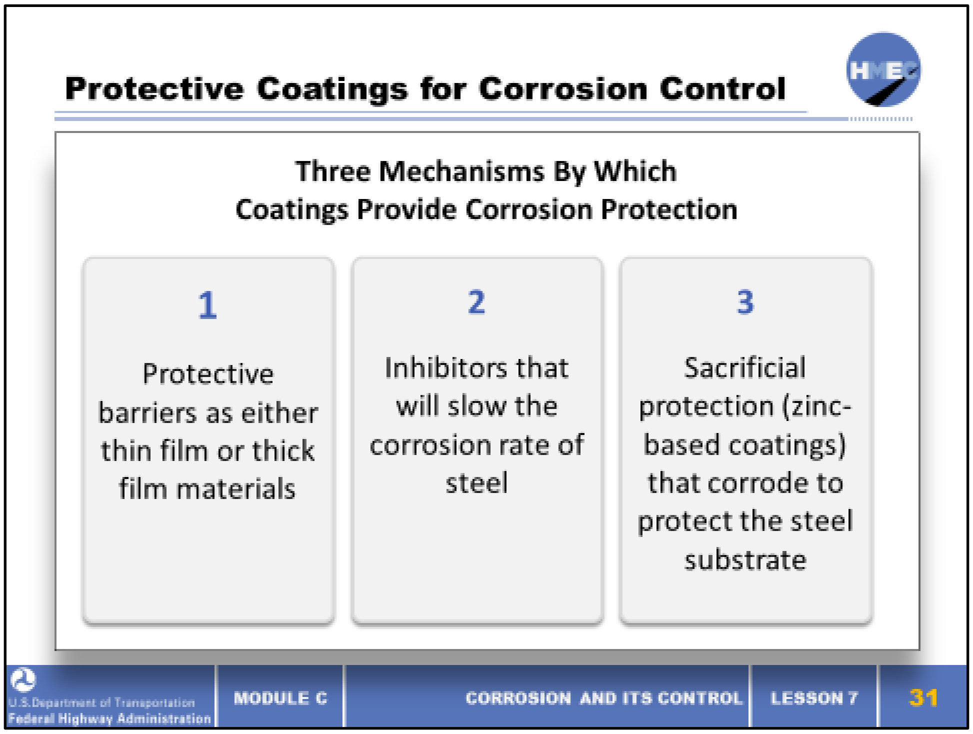
Slide 30



There are three types of coating types to provide corrosion protection. These are: barrier coatings (high electrical resistance), inhibitive coatings (passivation of metal), and sacrificial coatings (zinc-rich cathodic protection).

Slide 31

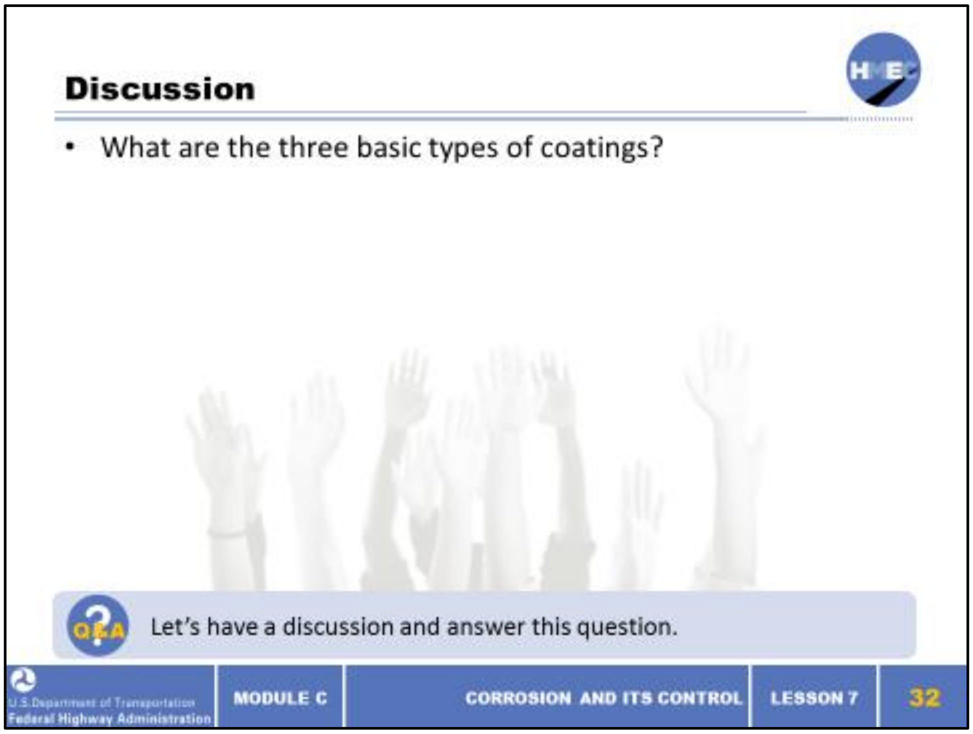


There are three mechanisms by which coatings provide corrosion protection. The first is protective barriers as either thin film or thick film materials. Barrier coatings work solely by isolating the steel from the moisture. They have low water and oxygen permeability.

The second is inhibitors that will slow the corrosion rate of steel. Inhibitive primer coatings contain passivating pigments. These are low solubility pigments that migrate to the steel surface when moisture passes through the film and passivate the steel surface. These include lead- and chromate-based primers.

Sacrificial protection (zinc-based coatings) that corrode to protect the steel substrate is the third mechanism. Sacrificial primers contain pigments such as elemental zinc. Since zinc is higher than iron in the EMF series, when corrosion conditions exist, the zinc is the anode and corrodes to protect the steel. Sacrificial primers require intimate contact between the steel surface and zinc particles in the primer.

Slide 32


Discussion
What are the three basic types of coatings?
Let's have a discussion and answer this question.
U.S. Department of Transportation
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CORROSION AND ITS CONTROL
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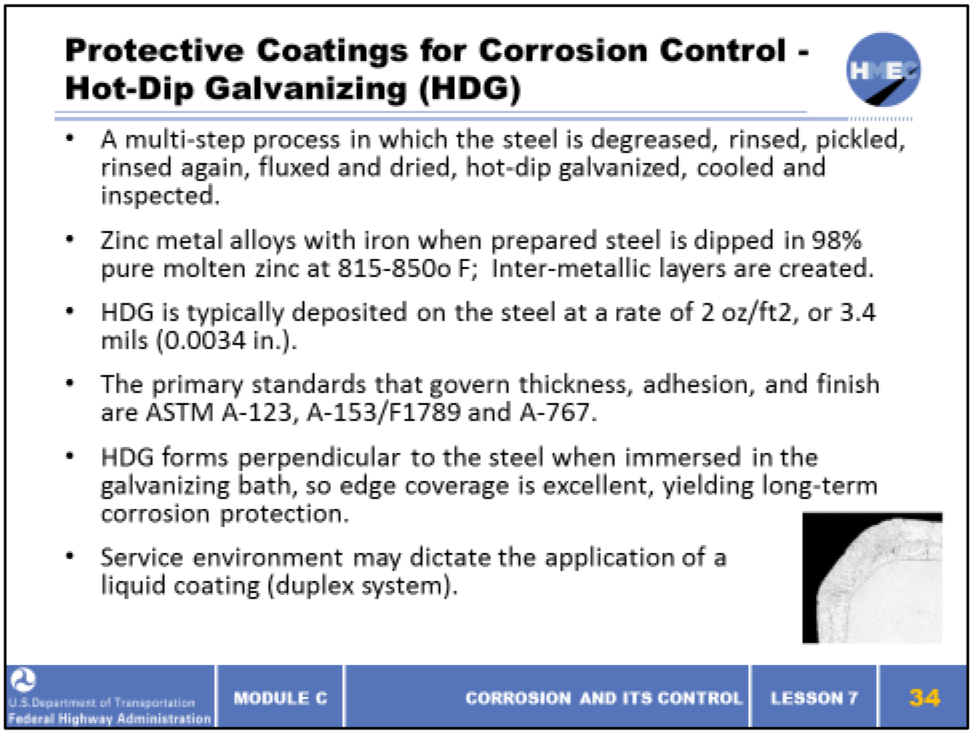
Slide 33

HDG is used extensively in the bridge and highway industry, as you can see by these photos here. They provide an impact resistant coating to steel guard rails, mostly all of our signage posts are galvanized steel, pre-fabricated bridge structures are galvanized, and several fasteners used on bridges are galvanized. They are considered to be both barrier and sacrificial due to the impenetrable solid zinc metal layer which alloys with iron –so you can think of it as a barrier to the elements attacking the steel. Due to the zinc nature, it also provides sacrificial protection to the metal, the same as an inorganic zinc primer offers when the steel is damaged. The more active zinc metal will sacrifice itself to protect the underlying steel.

Slide 34



HDG is a process where steel is immersed in a molten bath of pure zinc, and after a certain amount of time, is raised and drained. After a multi-step process the result is a 3-4 mil layer of zinc on the steel. The process produces an inter-metallic layer with lesser amounts of iron and greater amounts of zinc towards the top surface of the galvanizing. The primary standards that govern thickness, adhesion, and finish of HDG are ASTM A-123, A-153 and A-767. ASTM F1789 "Standard Terminology for F16 Mechanical Fasteners" is a referenced standard in A-153.

The galvanizing forms perpendicular to the steel when immersed in the bath, which produces excellent edge coverage and therefore corrosion protection on areas not covered well by traditional liquid applied coatings. However depending on the service environment HDG may be coated with a traditional liquid-applied coating, which is known as a duplex system.

More information on the process and specification thereof can be found on the American Galvanizers Association's (AGA's) website at www.galvanizeit.org

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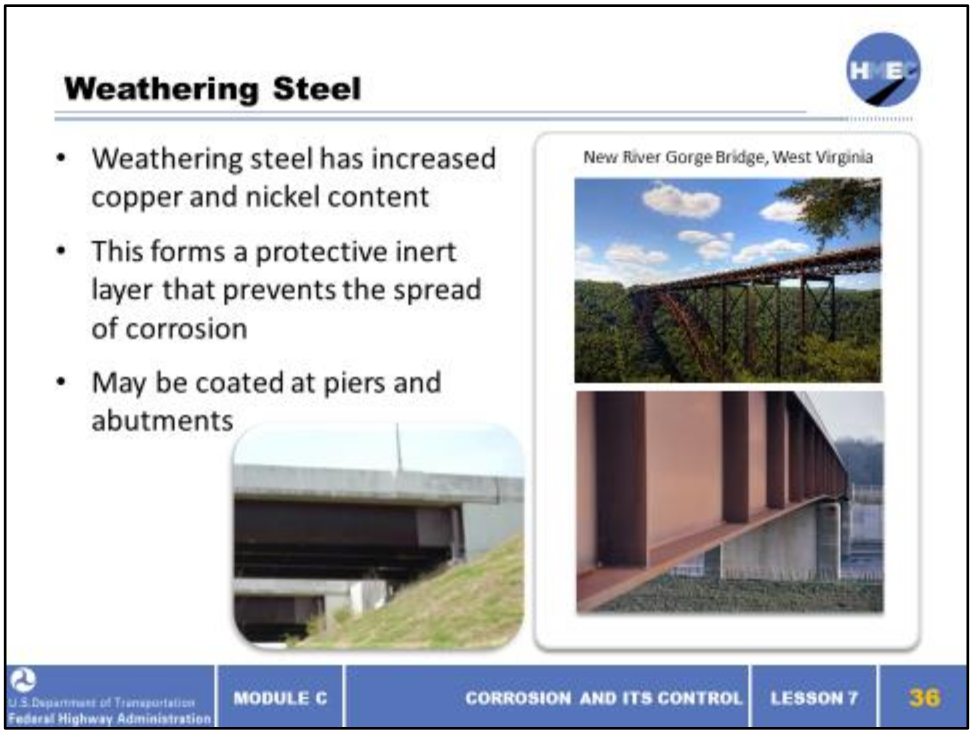
Slide 35

Metalizing has been used on bridges since the mid-1980's but has not been popular due to the high capital cost of the equipment, the high degree of surface cleanliness required, and the lack of specialized applicators. This has changed however in the past twenty years. Flame spray has been replaced by arc spray, which has resulted in increased productivity. Many feel the greatest return on investment and lower life cycle costs for bridge maintenance painting are found with metalizing.

Slide 36



Weathering steel has increased copper and nickel content. This forms a protective inert layer, often referred to as a patina that prevents corrosion of the base metal. Agencies may specify the application of a protective coating 6-8 feet from abutments and piers to prevent deterioration below leaking deck expansions.

Slide 37

Shout It Out: Is Uncoated Weathering Steel the Proper Material?

- Is uncoated weathering steel the proper material for:
  1. Marine coastal areas – yes or no?
  2. Low-level water crossings – yes or no?
  3. Design details that serve as water and debris traps – yes or no?
  4. Structures covered in vegetation – yes or no?

Q&A Let's have a discussion and answer these questions.

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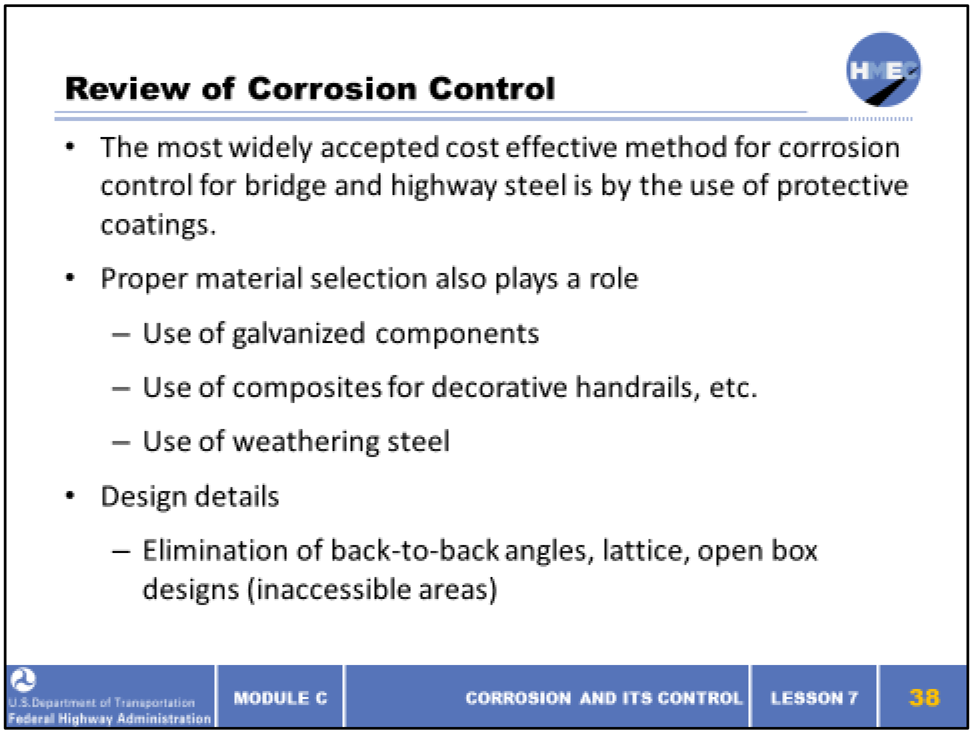
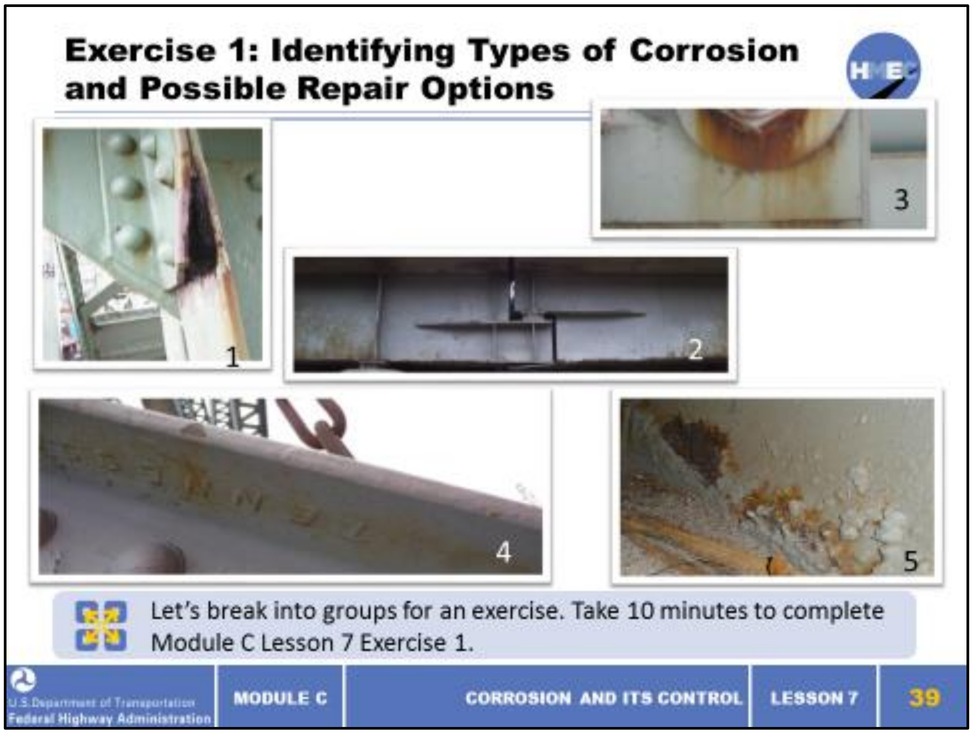
Slide 38



Mention again to reinforce that the most widely accepted means for corrosion control for bridge and highway overpass steel is by the use of protective coatings. Proper material selection in other design areas help such as the use of corrosion resistant alloys and galvanizing. Also mention elimination of back-to-back angles, lattice and inaccessible areas to paint help in the effort to combat corrosion.

Slide 39


Exercise 1: Identifying Types of Corrosion and Possible Repair Options
1
2
3
4
5
Let's break into groups for an exercise. Take 10 minutes to complete Module C Lesson 7 Exercise 1.
U.S. Department of Transportation Federal Highway Administration
MODULE C
CORROSION AND ITS CONTROL
LESSON 7
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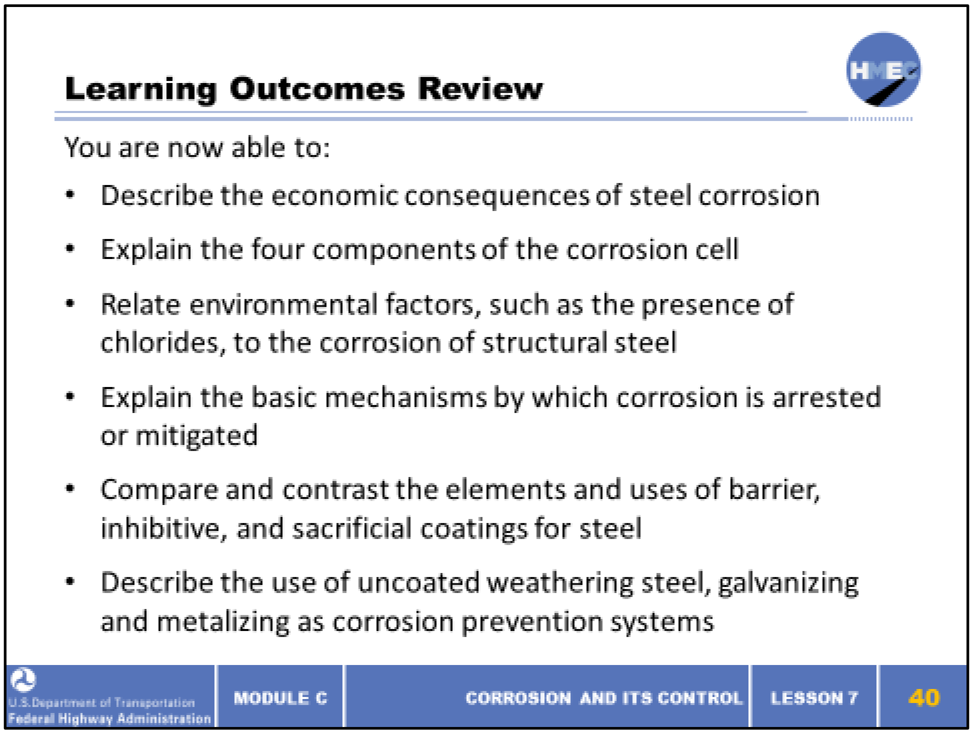
Slide 40


Learning Outcomes Review
HMEC
You are now able to:
• Describe the economic consequences of steel corrosion
• Explain the four components of the corrosion cell
• Relate environmental factors, such as the presence of chlorides, to the corrosion of structural steel
• Explain the basic mechanisms by which corrosion is arrested or mitigated
• Compare and contrast the elements and uses of barrier, inhibitive, and sacrificial coatings for steel
• Describe the use of uncoated weathering steel, galvanizing and metalizing as corrosion prevention systems
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LESSON 7
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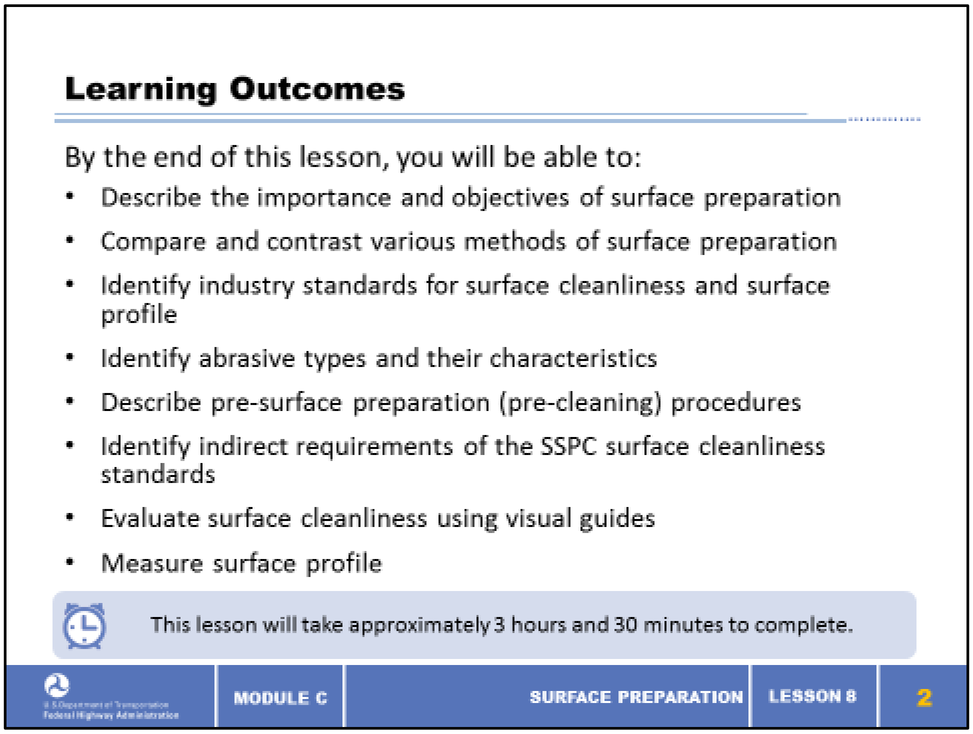
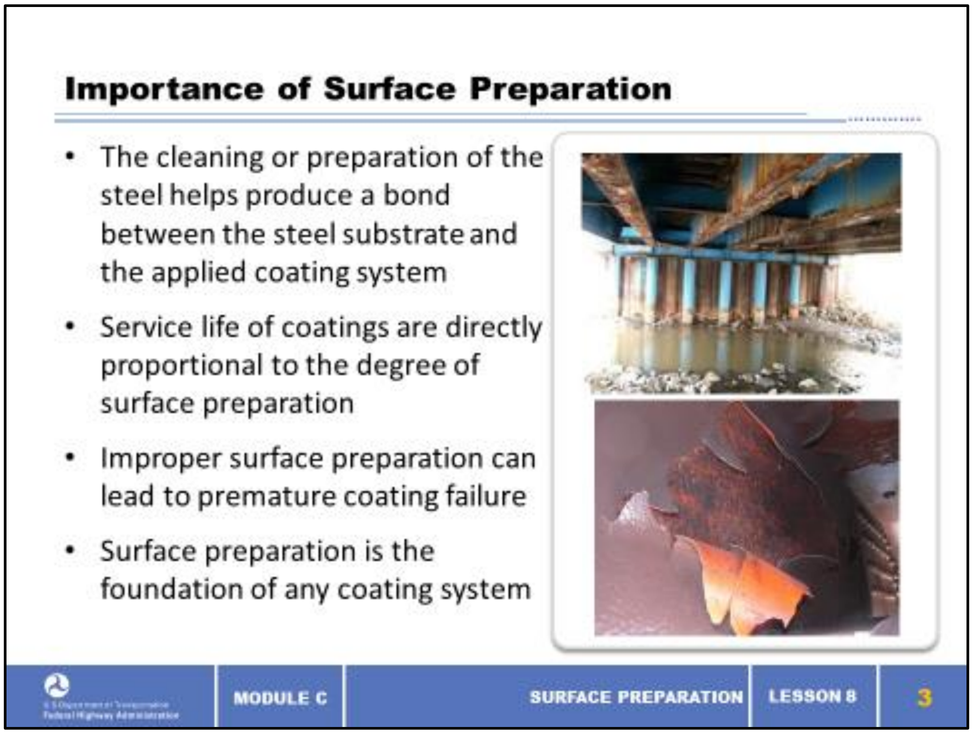
Slide 1


ILT
HMEC
Highway Materials Engineering Course
Lesson 8: Surface Preparation
Steel, Welding, and Coatings
U.S. Department of Transportation
Federal Highway Administration
MODULE
C

Slide 2


Learning Outcomes
By the end of this lesson, you will be able to:
• Describe the importance and objectives of surface preparation
• Compare and contrast various methods of surface preparation
• Identify industry standards for surface cleanliness and surface profile
• Identify abrasive types and their characteristics
• Describe pre-surface preparation (pre-cleaning) procedures
• Identify indirect requirements of the SSPC surface cleanliness standards
• Evaluate surface cleanliness using visual guides
• Measure surface profile
This lesson will take approximately 3 hours and 30 minutes to complete.
MODULE C
SURFACE PREPARATION
LESSON 8
2

Slide 3



The service life of a coating system is directly proportional to the degree of surface preparation. The better the preparation, the longer the coating service life. Improper surface preparation can lead to premature coating failure. Surface preparation is the foundation of any coating system. The most expensive, high performance coating can fail prematurely if the required degree of surface preparation is not achieved.

The images in the slide are examples of corrosion and coating delamination that may have resulted from improper surface preparation, or lack of surface preparation.

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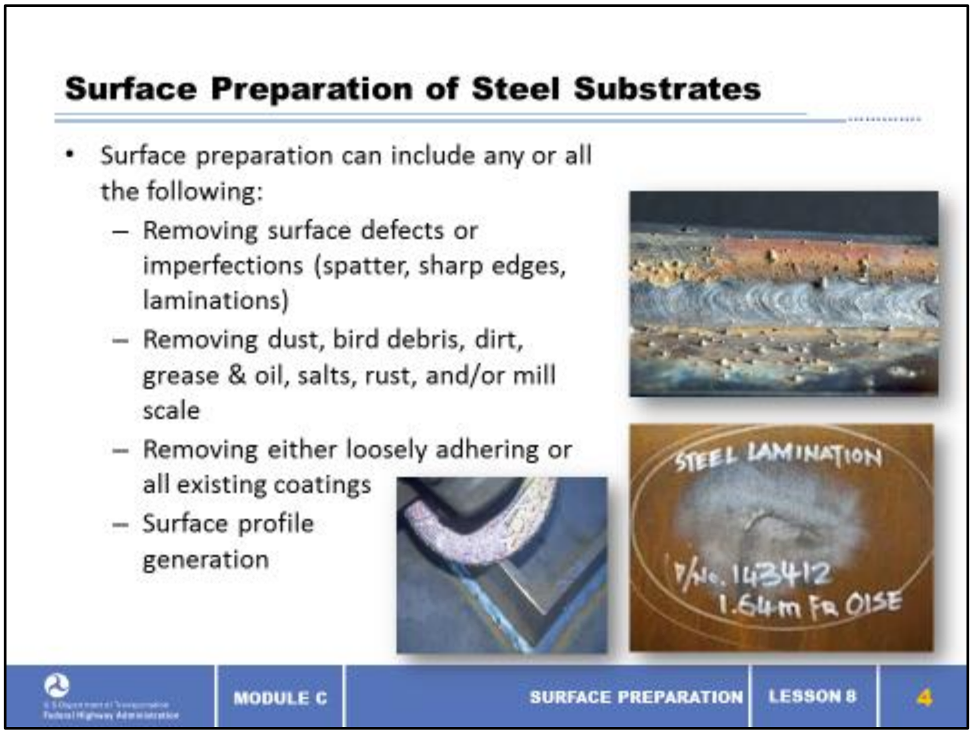
Slide 4



The procedures that may be invoked by the specification for correcting surface conditions that can affect coating performance include weld slag and spatter, burrs and laminations, sharp edges, and rough welds, which may need to be smoothed prior to surface preparation and coating application. Otherwise they act as potential sites for early onset of corrosion, since the rough topography of the steel is difficult to coat completely.

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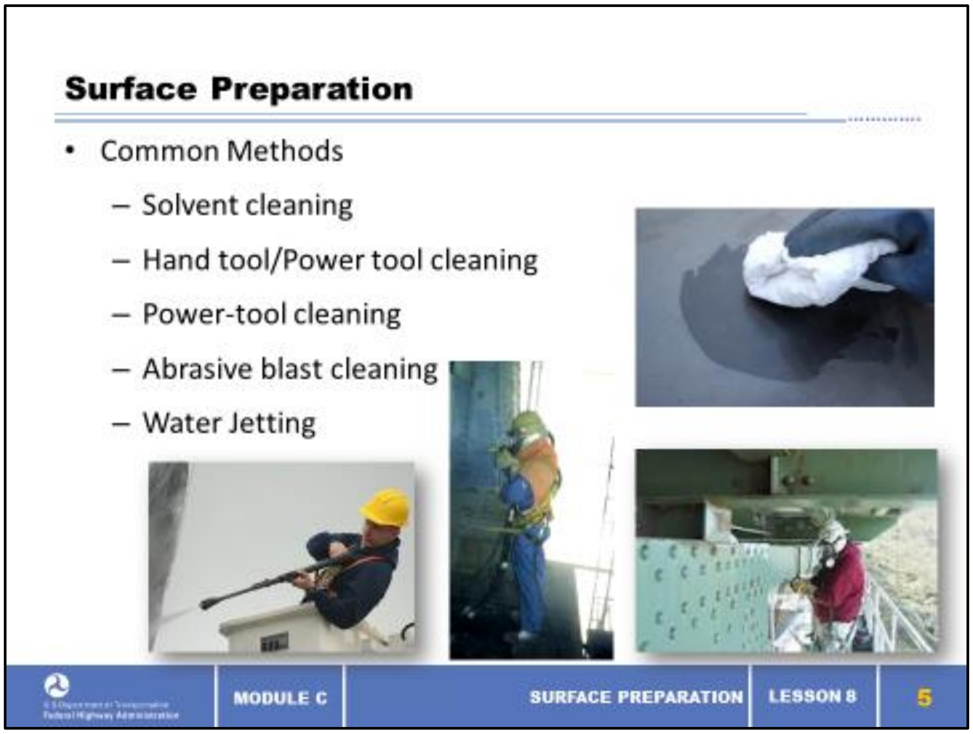
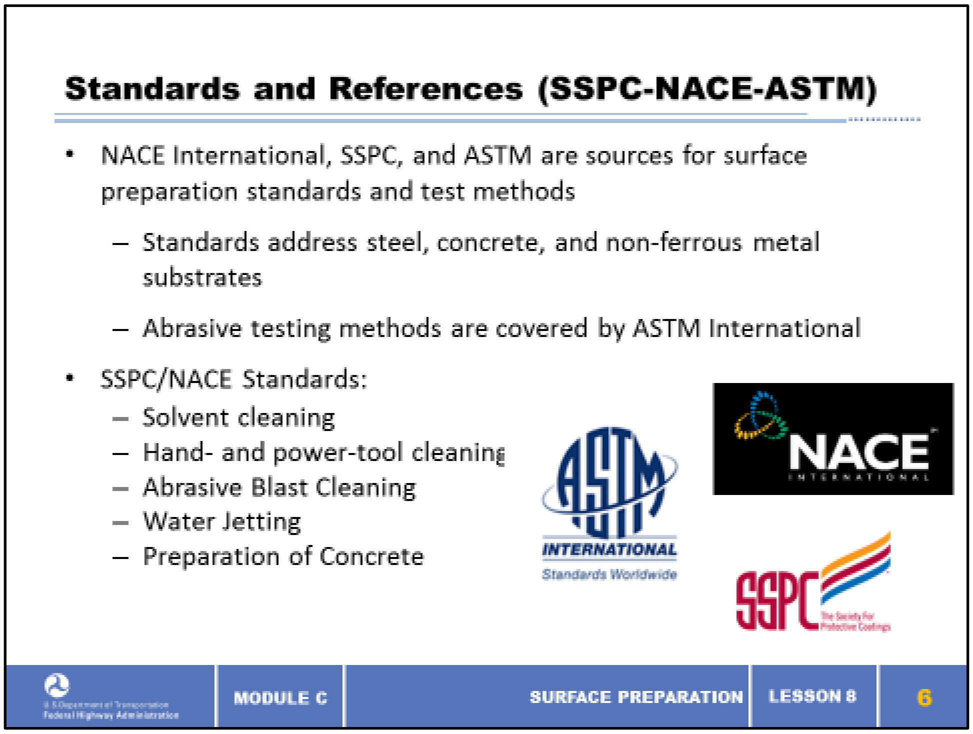
Slide 5



Surface irregularities like weld spatter, weld roughness, sharp edges and laminations are typically corrected by grinding prior to surface preparation. Note that torch cutting of steel can create hardening of the surface and may adversely affect surface profile generation during subsequent abrasive blast cleaning. This is particularly problematic for coatings that are highly susceptible to de-bonding without a sufficient surface profile, such as inorganic zinc-rich primers and thermal spray coatings (metalizing). Grinding of surfaces subjected to torch cutting removes the hardened surface layer and allows a surface profile (of the specified depth) to be imparted.

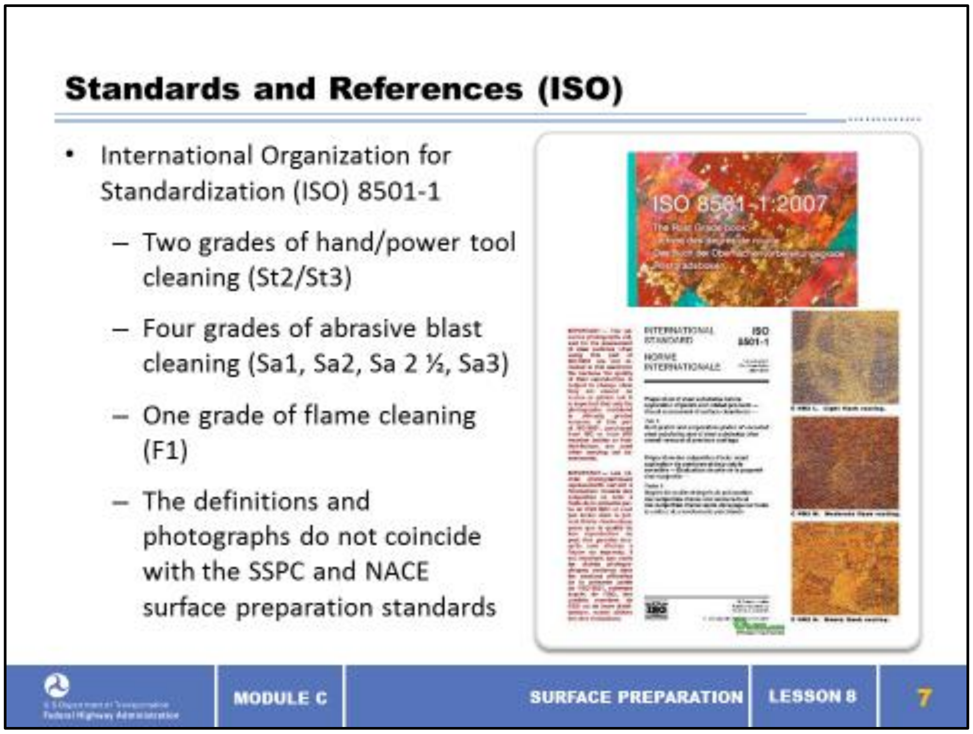
The most common methods of surface preparation on bridge structures include solvent cleaning, hand-tool and power-tool cleaning, abrasive blast cleaning and water jetting. We will be discussing these in more detail throughout this lesson.

Slide 6



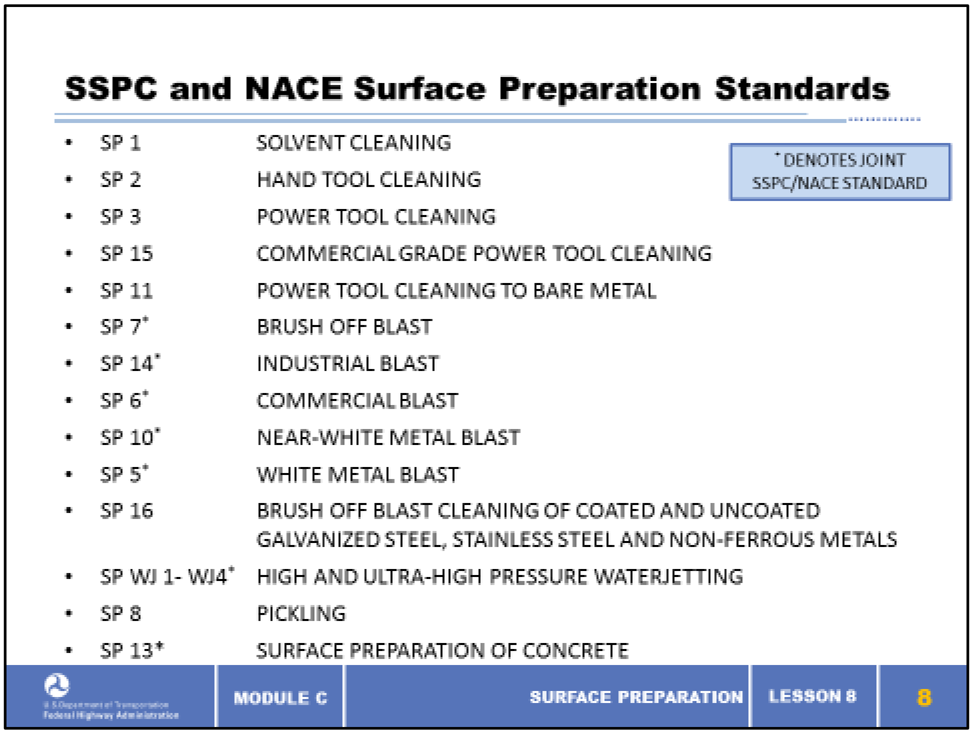
Surface preparation standards for the industry address steel, concrete, and non-ferrous metal substrates. SSPC/NACE standards discuss the processes of pre-cleaning, solvent cleaning, hand- and power-tool cleaning, abrasive blast cleaning (wet and dry), water-jetting, and preparation of concrete.

Slide 7



Two grades of hand and power tool cleaning (St2 and St3), four grades of abrasive blast cleaning (Sa1, Sa2, Sa 2 ½, Sa3) and one grade of flame cleaning (F1) are addressed by the ISO surface preparation standards. These standards are more widely recognized outside of the US, so for the purposes of this lesson, we will focus on the SSPC and NACE standards for surface preparation. Also, it is important to note that the definitions and photographic images in ISO 8501-1 do not coincide with the SSPC/NACE definitions and associated visual guides. While there are some similarities, they are not interchangeable.

Slide 8



There are 17 SSPC surface preparation standards; 10 are joint SSPC/NACE surface preparation standards, as noted with an asterisk. These are not regulations but rather consensus standards that can be referenced in bridge coating specifications. We will look at some of the more commonly used standards later in this lesson. ASTM, SSPC and NACE all have websites where you can purchase surface preparation standards. If you are a member of NACE or SSPC, the standards are available as free downloads. ASTM does not provide free downloads.

Notes: SSPC and NACE Standards are available at no charge to members (www.nace.org www.sspc.org)

ASTM standards must be purchased by members and non-members (www.astm.org)

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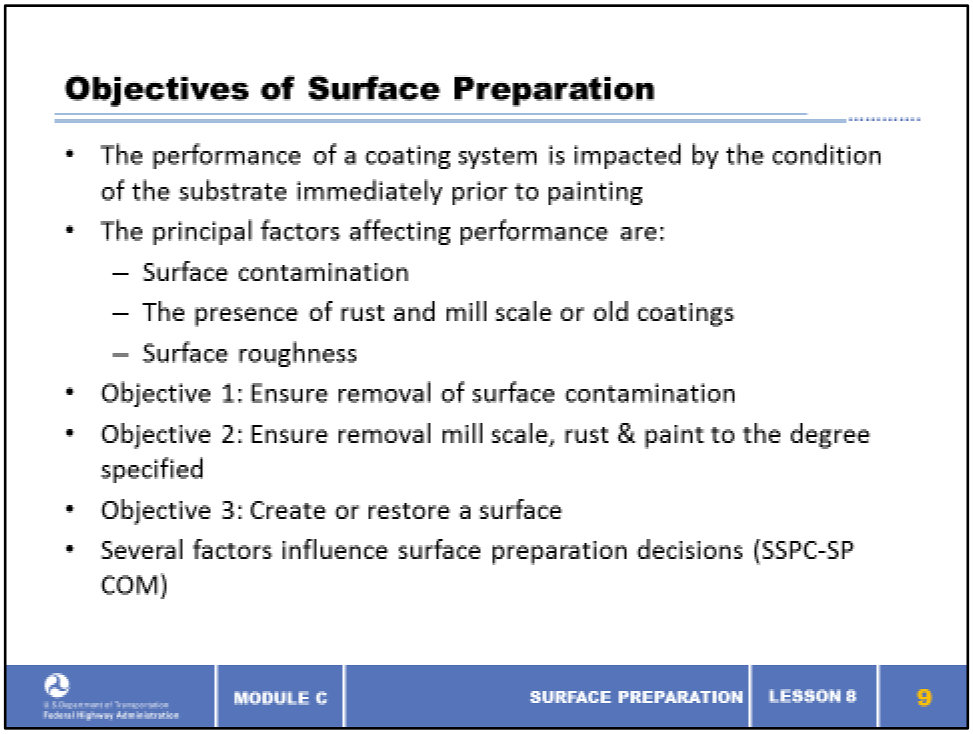
Slide 9



The performance of protective coatings applied to steel is significantly impacted by the condition of the substrate immediately prior to painting. The principal factors affecting performance are: surface contamination including salts, oils, grease, drilling and cutting compounds; the presence of rust and mill scale, or old coatings; and surface roughness or profile.

The three main objectives of surface preparation are to ensure that all contamination is removed, to remove existing rust, mill scale and old coatings to the degree specified and to create a surface profile that promotes adhesion of the coating system.

The method of surface preparation, the degree of surface cleanliness and the depth of the surface profile is dependent on a number of factors, including the size and scope of the project, the coating system selected, the service environment, the maintenance strategy on existing structures (e.g., spot preparation or complete removal & replacement of the system), the type and condition of the existing coating(s), the type of substrate material, and the economics of the project.

SSPC Surface Preparation Commentary for Metal Substrates (SSPC-SP COM) is a valuable resource that is intended to be an aid for the coating specifier in selecting methods, materials, and standards for specifying the proper surface preparation for steel, and other metals. The most current version is March 2015.

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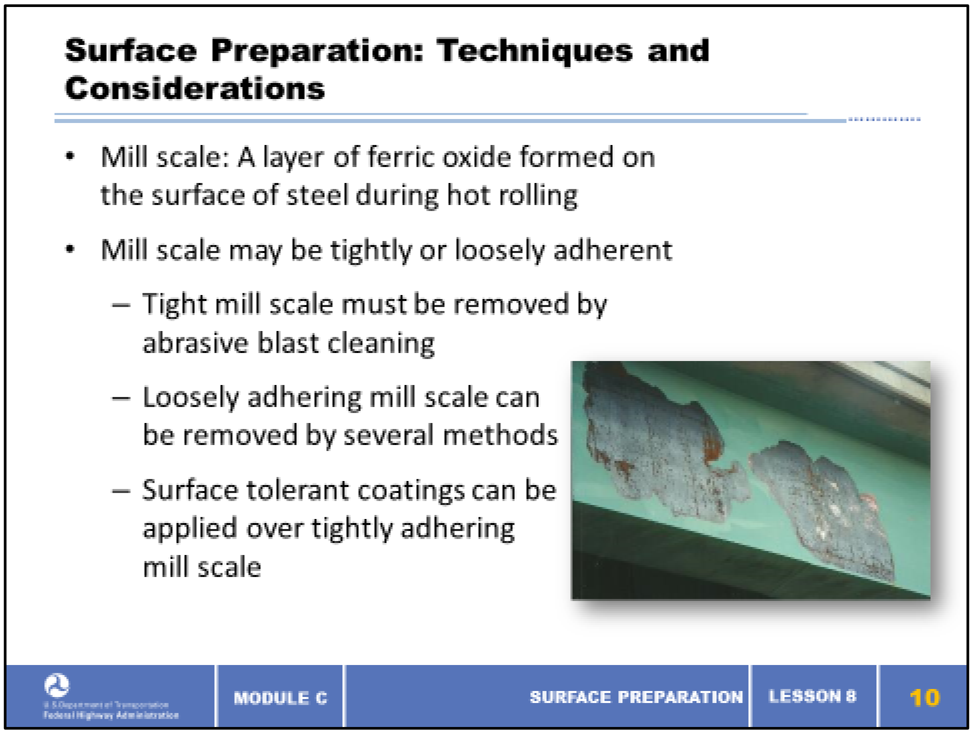
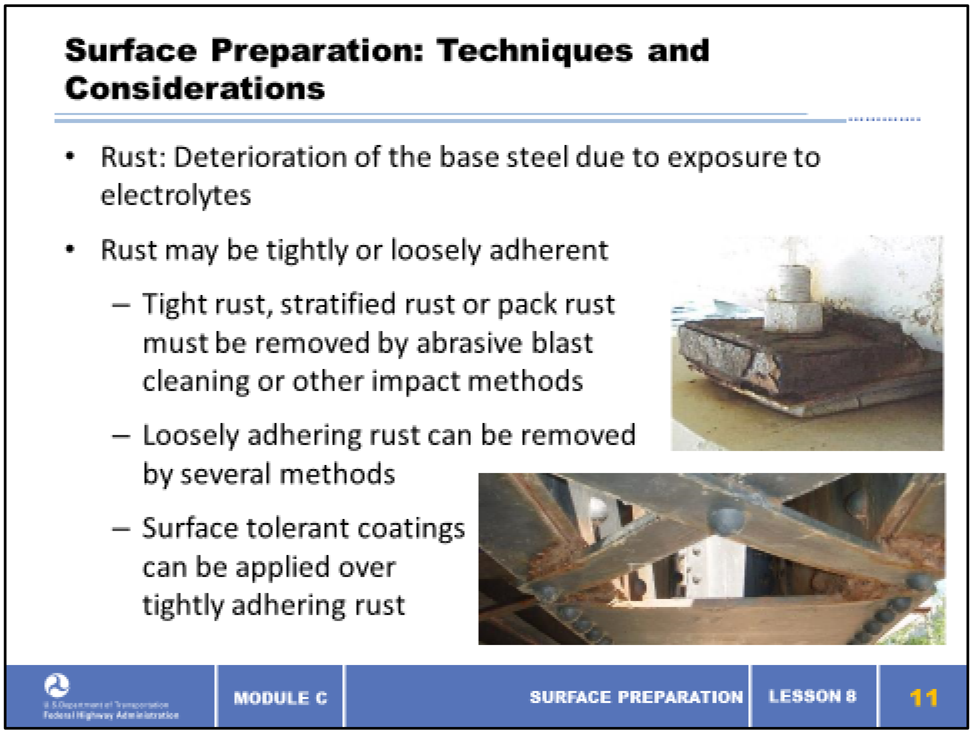
Slide 10



Mill scale is a layer of ferric oxide formed on the surface of steel during hot rolling. Adherent mill scale should be removed by abrasive blast cleaning, or power-tool cleaning (SSPC-SP 11, Power Tool Cleaning to Bare Metal or SSPC-SP 15, Commercial Grade Power Tool Cleaning). Hand- and power-tool methods (SSPC-SP 2/SP 3) can remove loosely adherent mill scale. Mill scale on older bridge structures can be thicker and may be very difficult to remove. Contractors that do not realize this will likely encounter labor and material cost overruns (they underbid the work).

Remember, mill scale is cathodic to the underlying steel. When it starts to break down as it is exposed to the elements, it can create corrosion of the base steel, and therefore it is best to remove it prior to coating.

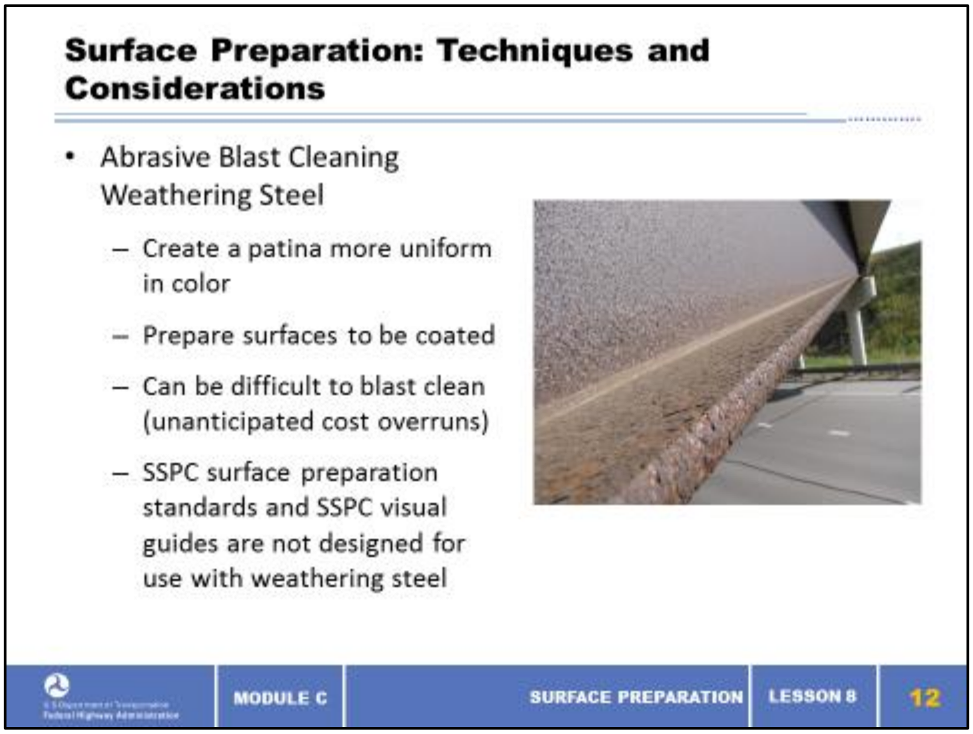
Slide 11



Rust and rust scale is most economically removed by abrasive blast cleaning. Stratified rust (top photo) and pack rust (bottom photo) may have to be removed by impact methods followed by abrasive blast cleaning.

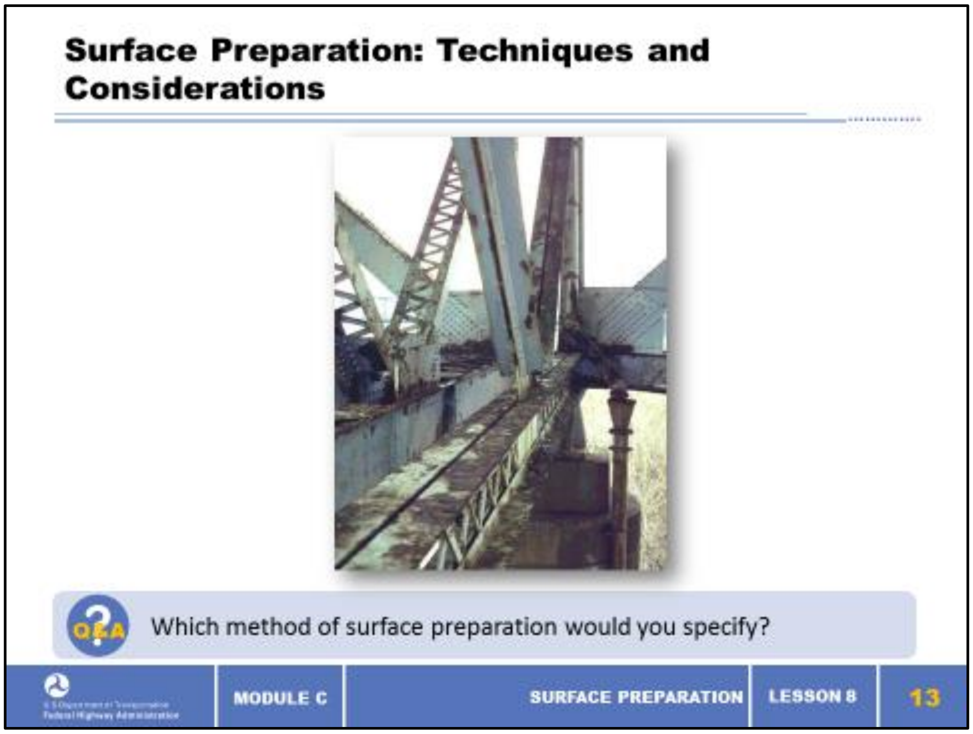
The degree of removal of rust will depend on the coating system to be applied and the prevailing service environment. Hand- and power-tool methods are also possible but are more labor intensive and best suited for small areas. Loosely adhering rust can cause delamination of the coating from the substrate if it is allowed to remain.

Slide 12



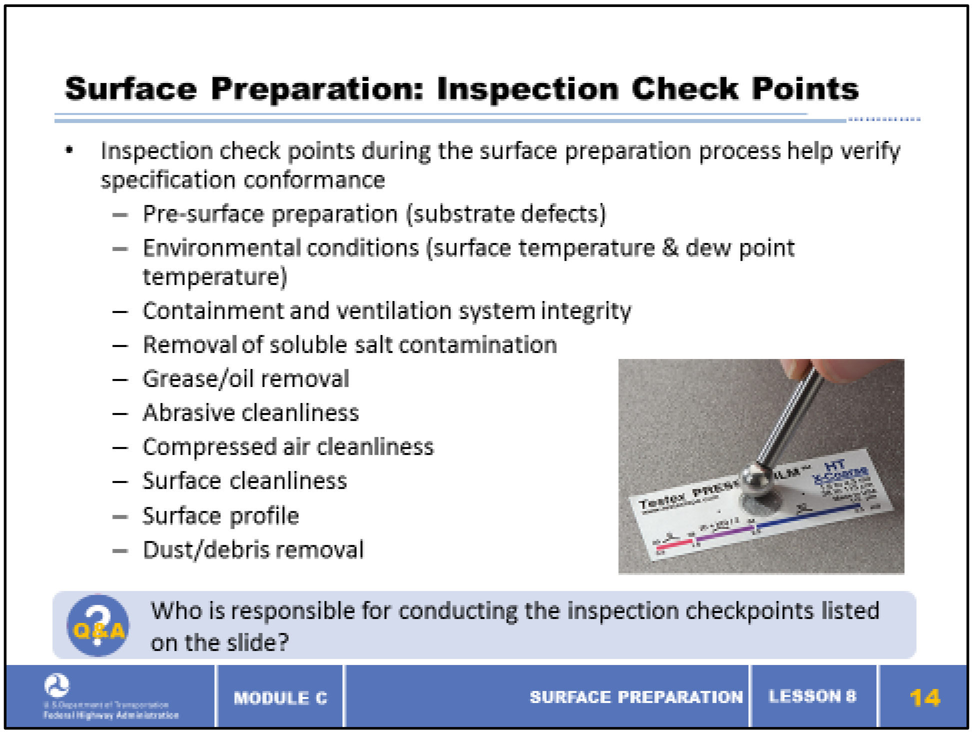
Some agencies may elect to abrasive blast clean weathering steel so that the patina that forms is more uniform in color. Other agencies elect to coat the weathering steel with a liquid-applied finish coat to preserve patina, particularly areas exposed to water and deicing materials, as we will discuss in Lesson 10. The scale layer on new weathering steel or the patina on exposed weathering steel may be very difficult to remove. Contractors that do not realize this will likely encounter labor and material cost overruns (they underbid the work). Also, the SSPC surface cleanliness standards and the SSPC Visual Guides (SSPC VIS 1) that we will learn about later in this lesson do not apply to weathering steel.

Slide 13



In this photo, what would be the most reasonable surface preparation method to specify given the current state of this bridge structure?

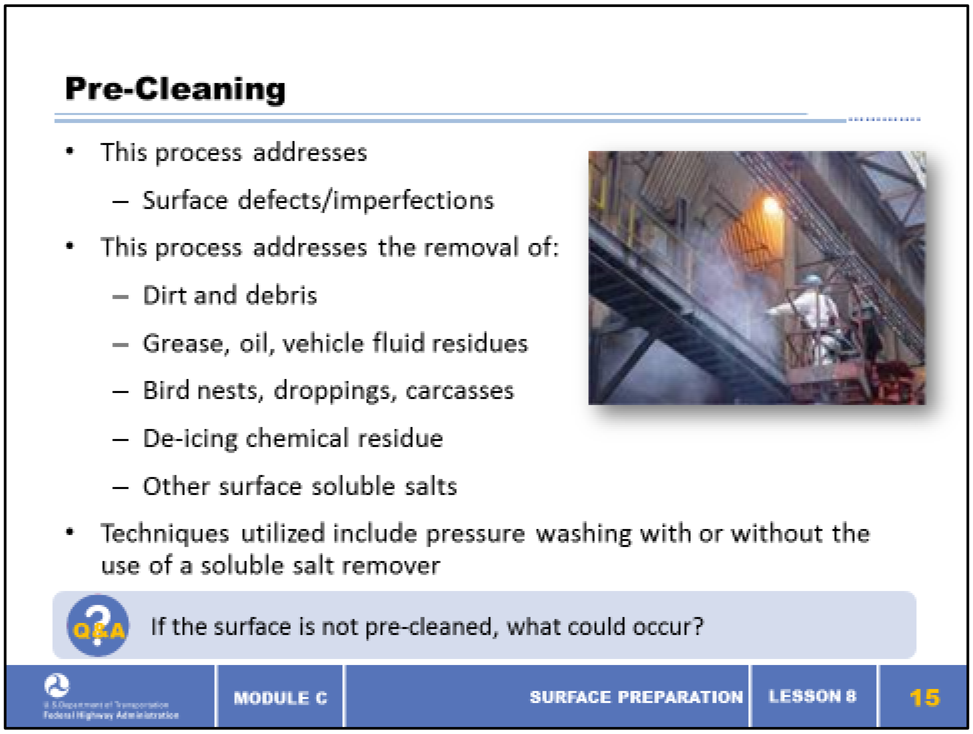
Slide 14



Inspection check points during the surface preparation process that can help to verify specification conformance include: pre-surface preparation (substrate defects); environmental conditions (surface temperature & dew point temperature); containment and ventilation system integrity to protect workers and prevent environmental pollution; removal of soluble salt contamination as appropriate; grease/oil removal; abrasive cleanliness (if abrasive blast cleaning is specified); compressed air cleanliness (if abrasive blast cleaning is specified, or for blow-down to remove surface dust/debris); surface cleanliness; surface profile as appropriate; and dust/debris removal prior to coating application.

Note that removal of grease/oil contamination is automatically invoked by all of the SSPC surface cleanliness standards (except SSPC-SP 13, Preparation of Concrete), and compressed air cleanliness and abrasive cleanliness are invoked by all of the SSPC surface cleanliness standards for abrasive blast cleaning.

Slide 15



The pre-cleaning process addresses surface defects and imperfections, and the removal of dirt and debris; grease, oil and vehicle fluid residues; bird nests, droppings and carcasses; as well as de-icing chemical residue and other soluble salts on the surface. Pressure washing, with or without a proprietary a soluble salt remover are among the techniques used. Note that some States do not allow pressure washing due to the potential to deposit lead paint into the soil or water beneath the structure.

Slide 16

SSPC-SP 1 addresses the removal all visible oil, grease, soil, drawing and cutting compounds, and other soluble contaminants. SSPC-SP 1 is a prerequisite to all other methods of surface preparation and it is automatically invoked. Grease and oil, if not removed properly, can be driven into the steel, spread to adjacent surface or contaminate the tool or abrasive media (if recyclable). Solvent cleaning is always performed prior to mechanical methods of surface preparation.

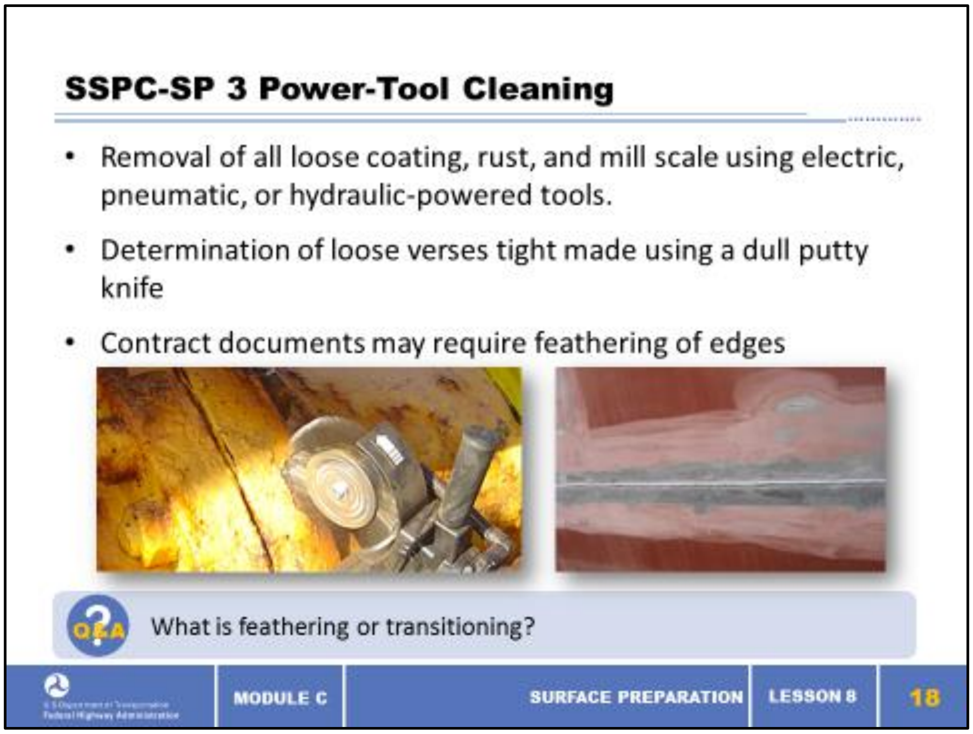
Specifications may also require neutralization (if using chemicals) as well as soluble salts testing and remediation to acceptable surface concentrations.

Slide 17

SSPC-SP 2 Hand-tool cleaning requires the removal of all loose coating, rust and mill scale. It is intended for spot maintenance work. Remember that SSPC-SP 1 Solvent Cleaning is automatically invoked by the SSPC hand tool cleaning standard. A dull putty knife is used to assess whether remaining materials are tightly adherent or not. The SSPC Glossary defines a dull putty knife as follows:

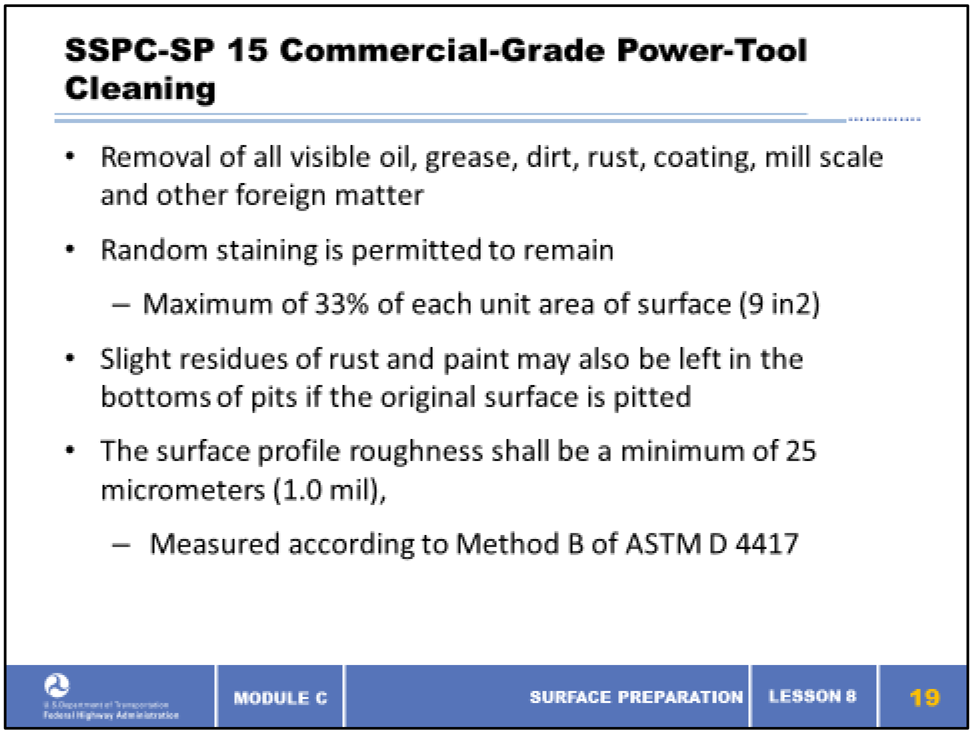
DULL PUTTY KNIFE (for use as an inspection tool): *"A commercially manufactured metal blade with these characteristics:*
Width – 1-1/2 to 3"; length– 3 to 5"; thickness – 30 to 50 mils. The putty knife is acceptable for use if the thickness at end of the blade is not less than 25 mils or 75% of its original thickness, whichever is greater. It shall not be used if the edge is nicked or gouged, or if dry paint or other material is present along the edge that would prevent the blade from making intimate contact with the surface. When used to test paint, mill scale, or rust remaining on the surface after cleaning, the blade shall be held flat against the surface and at a maximum of 45 degrees to the surface. The corners of the blade shall not be used to dig at the residues."

Slide 18



SSPC-SP 3 is intended for spot maintenance work. It requires the removal of all loose coating, rust and mill scale. Power tools include rotating flaps, needle scalers, non-woven fiber abrasive wheels, or rotating brush devices. Some can produce a surface profile although there is no requirement for this in SSPC-SP 3. A dull putty knife is used to assess whether remaining materials are tightly adherent or not. Remember that SSPC-SP 1 Solvent Cleaning is automatically invoked by the SSPC power tool cleaning standard.

Slide 19



SSPC-SP 15 Commercial-grade Power-tool Cleaning removes all rust, paint, oxides, mill scale, and other foreign matter to a more stringent degree than SSPC-SP 3. Random staining is limited to no more than 33% of each unit area. Slight residue of rust and coating are permitted to remain in the lower portions of the pits if the original surface is pitted. Inspection of the prepared surfaces is performed without the use of magnification. The tool selected must be able to produce a minimum 1-mil surface profile. Remember that SSPC-SP 1 Solvent Cleaning is automatically invoked by this standard.

Slide 20

SSPC-SP 11 Power-tool Cleaning to Bare Metal requires the removal of all rust, paint, mill scale and other foreign matter. No staining or residues are allowed to remain. This is more stringent than SSPC-SP 15. Slight residues are permitted to remain in the lower portions of pits if the original surface is pitted. Inspection of the prepared surfaces is performed without the use of magnification. Similar to SSPC-SP 15, the tool selected must be able to produce a minimum 1-mil surface profile. Remember that SSPC-SP 1 Solvent Cleaning is automatically invoked by this standard.

Slide 21


Surface Preparation Standards
Which of the three power tools shown would not be able to produce a steel surface conforming to SSPC-SP 15 or SSPC-SP 11?
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Review of Hand- and Power-Tool Surface Preparation Standards

TITLE	SSPC CODE	NACE CODE	ISO CODE
POWER-TOOL CLEANING TO BARE METAL	SSPC SP 11	None	None
COMMERCIAL-GRADE POWER-TOOL CLEANING	SSPC SP 15	None	None
POWER-TOOL CLEANING	SSPC SP 3	None	St 2/St 3*
HAND-TOOL CLEANING	SSPC SP 2	None	St 2/St 3*

* St 2: Thorough Hand- and Power-tool Cleaning
St 3: Very Thorough Hand- and Power-tool Cleaning

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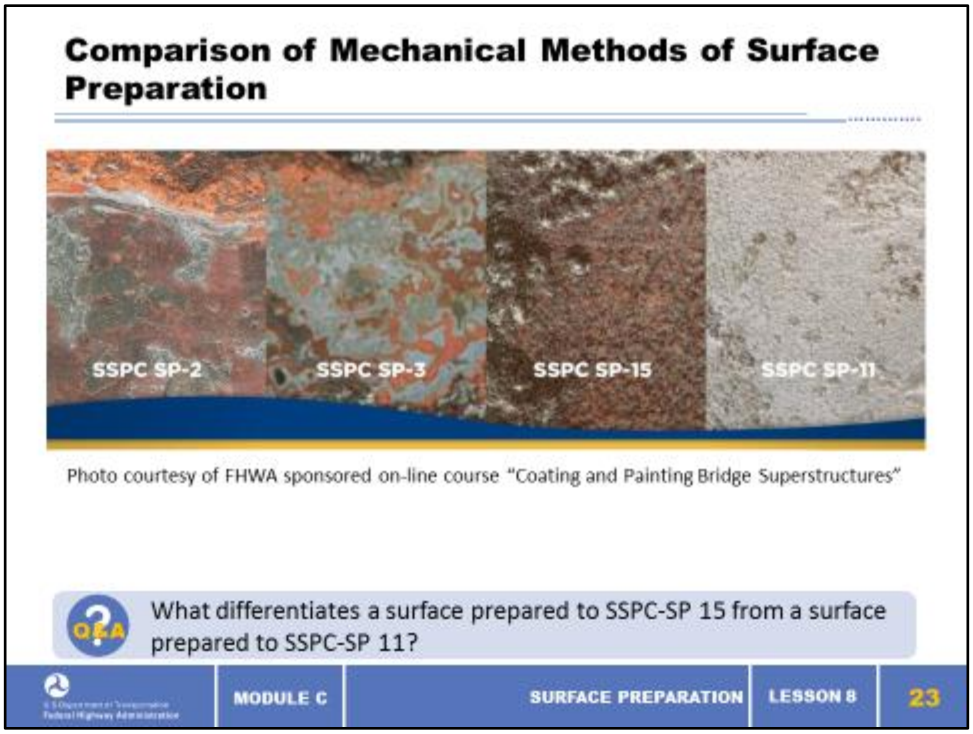
Cleaning methods are noted in the chart from least aggressive at the bottom to most aggressive at the top. Note that NACE does not address hand- and power-tool cleaning from a standards perspective, and the ISO and SSPC definitions are not equivalent.

Slide 23



Note how the surface progresses from a feathered surface with tight adhered coating on the left (SSPC-SP2) to a surface where all coating is removed by power tool cleaning (SSPC-SP 11).

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Slide 24


Abrasive Blast Cleaning
Q&A
What is unusual about the larger image shown on the slide?
MODULE C
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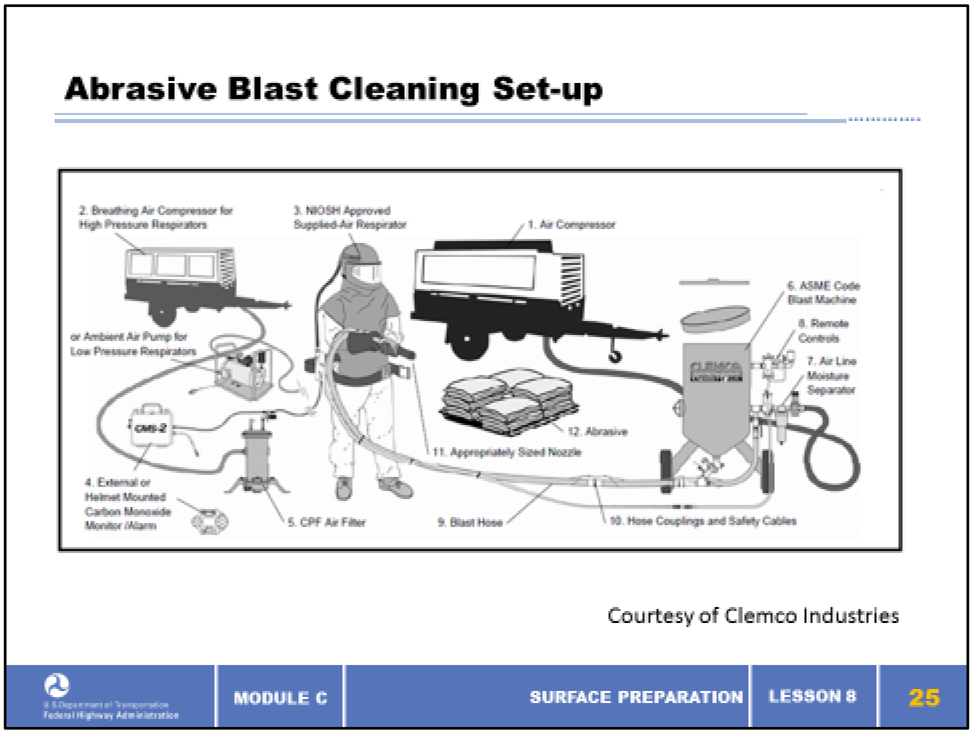

Abrasive blast cleaning involves the use of compressed air to propel hardened particles at speeds exceeding 500 mph towards a (steel) surface. The mass of the abrasive and the velocity of created by the compressed air produces kinetic energy, which in turn removes mill scale, rust, old coatings, etc. from the surface and simultaneously produces a surface texture or profile.

The equipment involved with abrasive blast cleaning is shown on the illustration. Containment and ventilation systems, grit recovery systems and hygiene facilities are not shown but are also considered components to an abrasive blast cleaning set-up.

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Slide 26

According to SSPC-SP 7, when viewed without magnification, all loosely adhering mill scale rust and paint must be removed; however tightly adherent mill scale, rust, and paint may remain on the surface. Mill scale rust and paint are considered tightly adherent if they cannot be removed with the blade of a dull putty knife. The depth of the surface profile must be specified separately.

There are three indirect or automatic requirements that are invoked when SSPC-SP 7 is specified. These include removal of grease and oil contamination per SSPC-SP 1 (described earlier), abrasive cleanliness (per ASTM D4940 and ASTM D7393) and compressed air cleanliness (per ASTM D4285). We'll be describing the abrasive cleanliness and compressed air cleanliness test later in this lesson.

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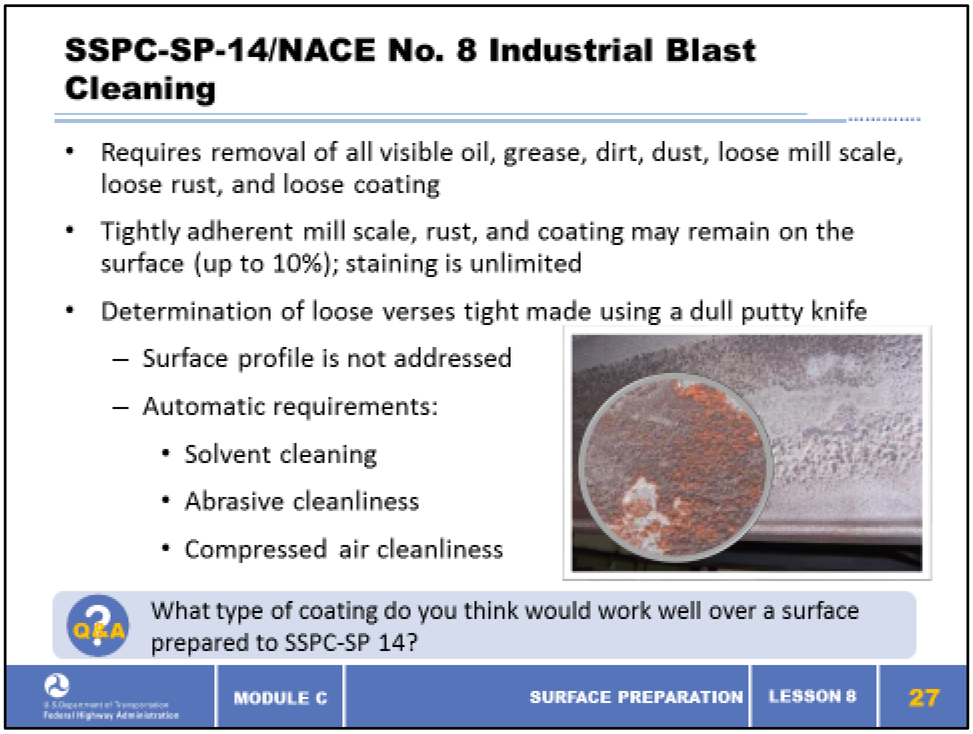
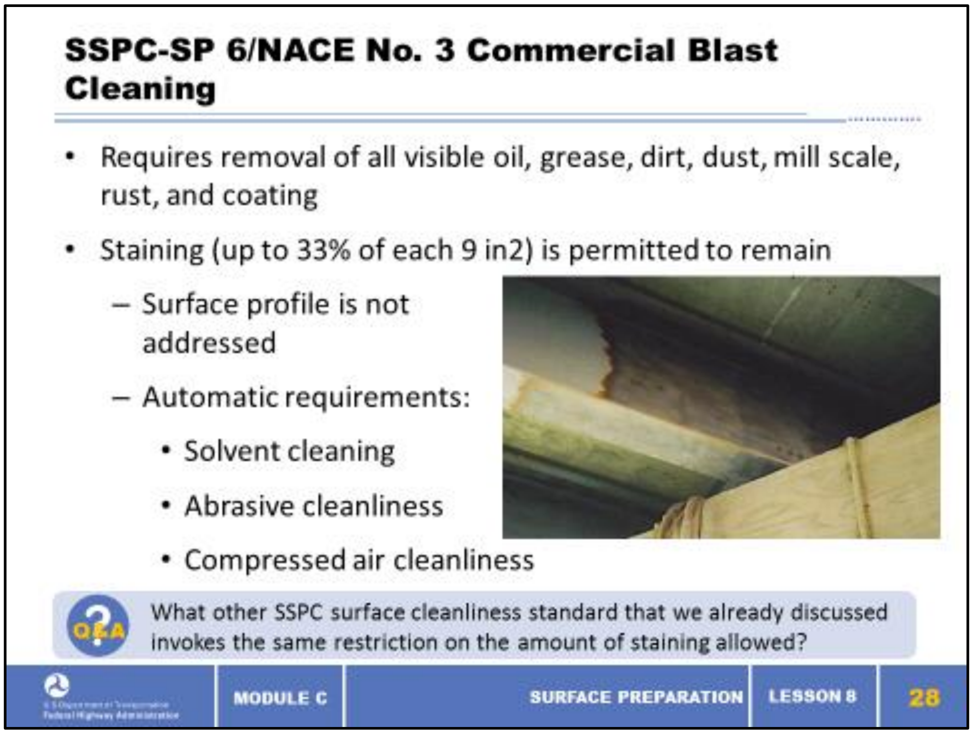
Slide 27



According to SSPC-SP 14, when viewed without magnification, all loosely adhering mill scale rust and paint must be removed; however tightly adherent mill scale, rust, and paint may remain on the surface as long as it is evenly distributed and does not exceed 10%. The amount of staining is unlimited. Mill scale rust and paint are considered tightly adherent if they cannot be removed with the blade of a dull putty knife. The depth of the surface profile must be specified separately.

There are three indirect or automatic requirements that are invoked when SSPC-SP 14 is specified. These include removal of grease and oil contamination per SSPC-SP 1 (described earlier), abrasive cleanliness (per ASTM D4940 and ASTM D7393) and compressed air cleanliness (per ASTM D4285).

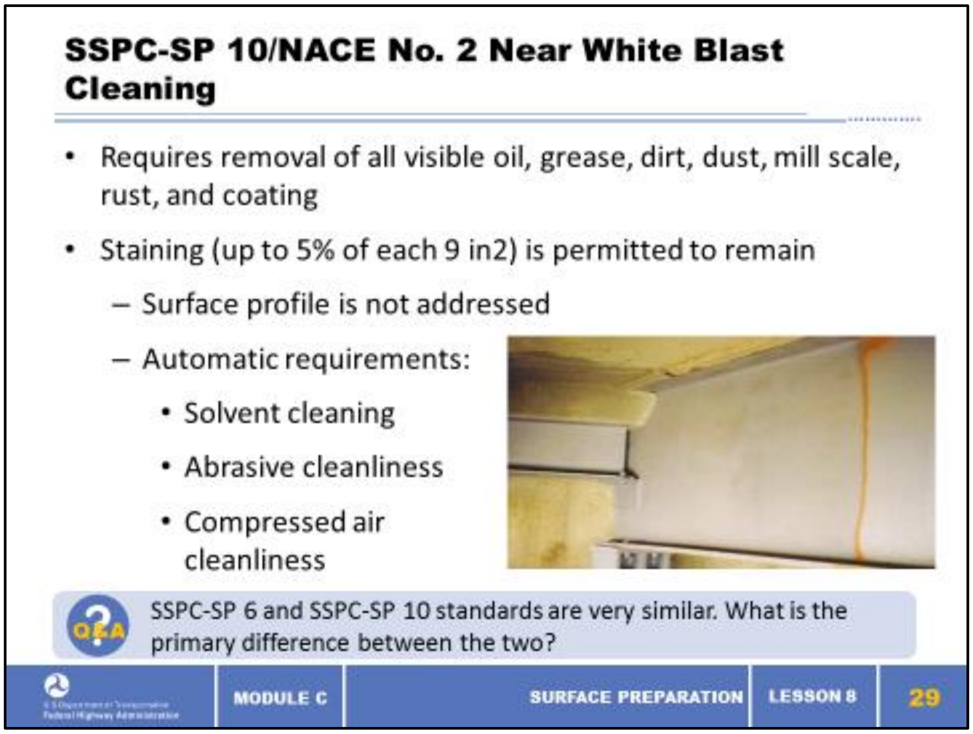
Slide 28



According to SSPC-SP 6, when viewed without magnification, all mill scale rust and paint must be removed. Staining from these materials may remain as long as it doesn't exceed 33% of each 9 square inches of prepared steel. The depth of the surface profile must be specified separately.

Three indirect or automatic requirements that are invoked when SSPC-SP 6 is specified. These include removal of grease and oil contamination per SSPC-SP 1 (described earlier), abrasive cleanliness (per ASTM D4940 and ASTM D7393) and compressed air cleanliness (per ASTM D4285).

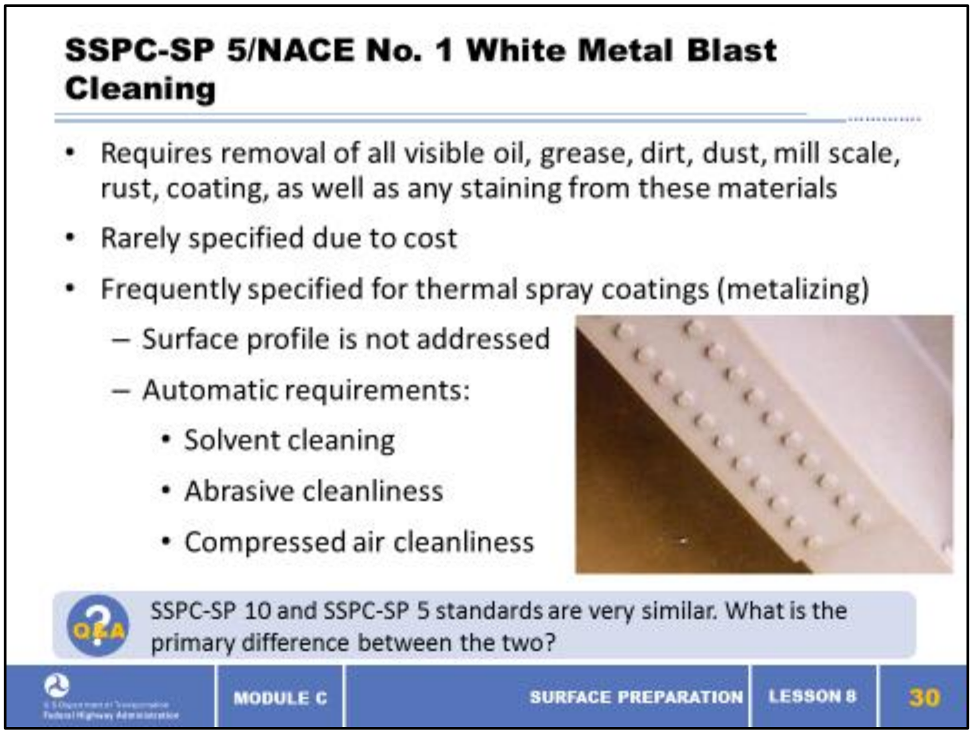
Slide 29



SSPC-SP 10, Near-white blast cleaning is the most common level of surface cleanliness specified by the bridge industry. According to SSPC-SP 10, when viewed without magnification, all mill scale rust and paint must be removed. Staining from these materials may remain as long as it doesn't exceed 5% of each 9 square inches of prepared steel. The depth of the surface profile must be specified separately. Acceptable variations in appearance that do not affect surface cleanliness include variations caused by type and thickness of steel, weld metal, mill or fabrication marks, heat treating, heat-affected zones, blast cleaning abrasive and differences in the blast cleaning pattern.

Three indirect or automatic requirements that are invoked when SSPC-SP 6 is specified. These include removal of grease and oil contamination per SSPC-SP 1 (described earlier), abrasive cleanliness (per ASTM D4940 and ASTM D7393) and compressed air cleanliness (per ASTM D4285).

Slide 30



SSPC-SP 5, White metal blast cleaning is rarely specified by the bridge industry due to the inherent costs. It is specified for thermal spray coatings (metalizing). According to SSPC-SP 5, when viewed without magnification, all mill scale, rust, paint and all staining from these materials must be removed. Nothing can be visible evident on the surface. The depth of the surface profile must be specified separately. Acceptable variations in appearance that do not affect surface cleanliness include variations caused by type and thickness of steel, weld metal, mill or fabrication marks, heat treating, heat-affected zones, blast cleaning abrasive and differences in the blast cleaning pattern.

Three indirect or automatic requirements that are invoked when SSPC-SP 6 is specified. These include removal of grease and oil contamination per SSPC-SP 1 (described earlier), abrasive cleanliness (per ASTM D4940 and ASTM D7393) and compressed air cleanliness (per ASTM D4285).

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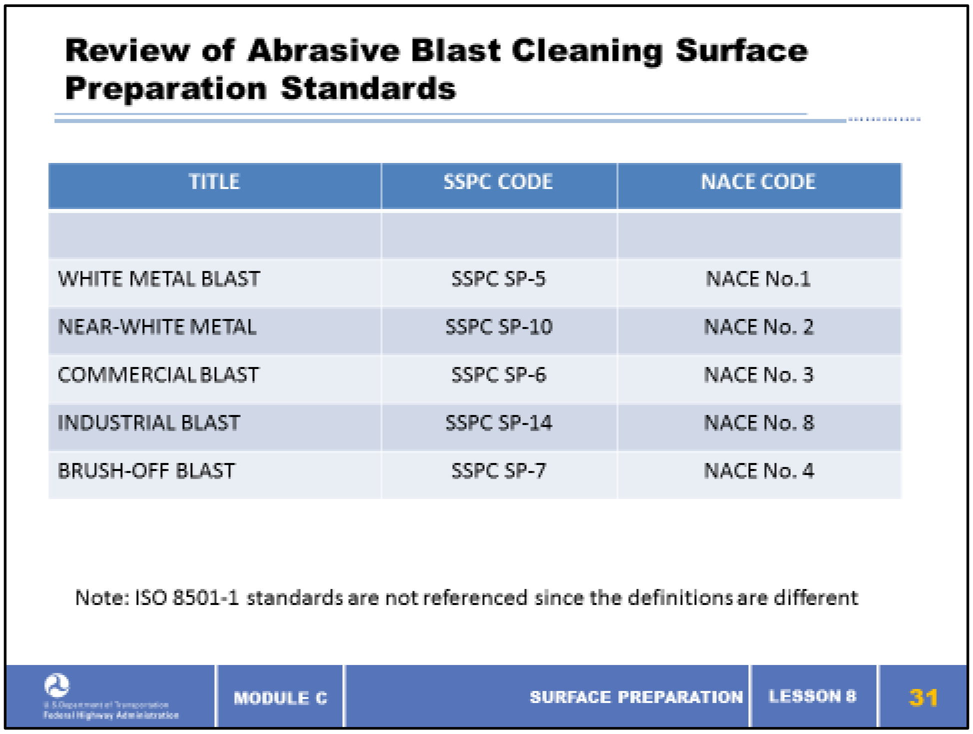

Review of Abrasive Blast Cleaning Surface Preparation Standards

TITLE	SSPC CODE	NACE CODE
WHITE METAL BLAST	SSPC SP-5	NACE No.1
NEAR-WHITE METAL	SSPC SP-10	NACE No. 2
COMMERCIAL BLAST	SSPC SP-6	NACE No. 3
INDUSTRIAL BLAST	SSPC SP-14	NACE No. 8
BRUSH-OFF BLAST	SSPC SP-7	NACE No. 4

Note: ISO 8501-1 standards are not referenced since the definitions are different

Cleaning methods are noted in the chart from least aggressive at the bottom to most aggressive at the top. The ISO standards are not listed since the ISO definitions and SSPC definitions are not equivalent.

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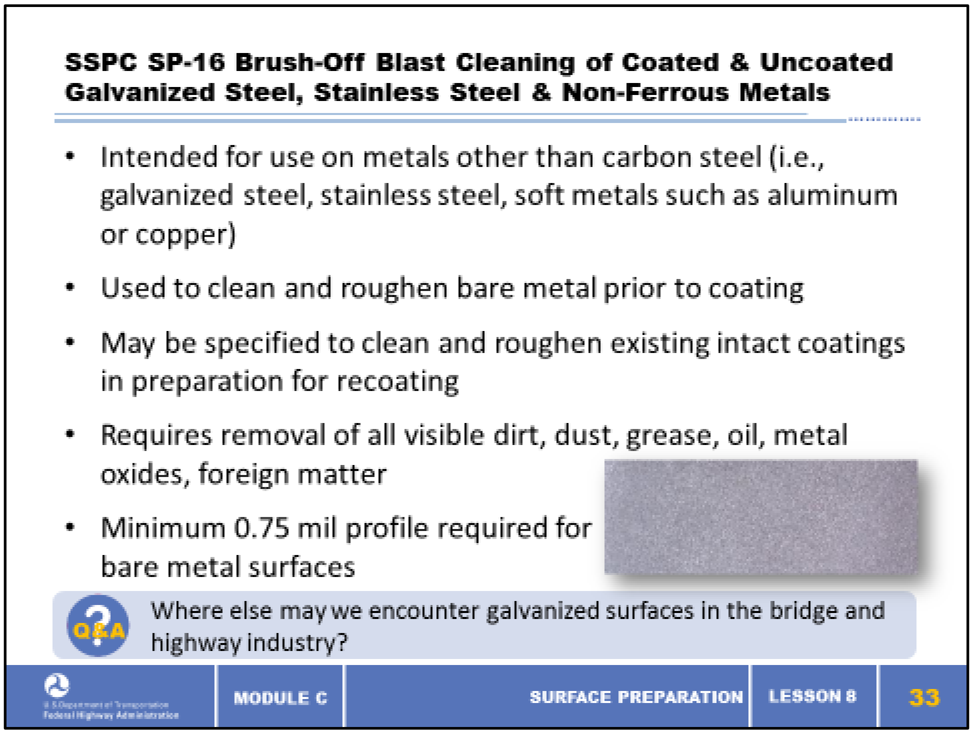
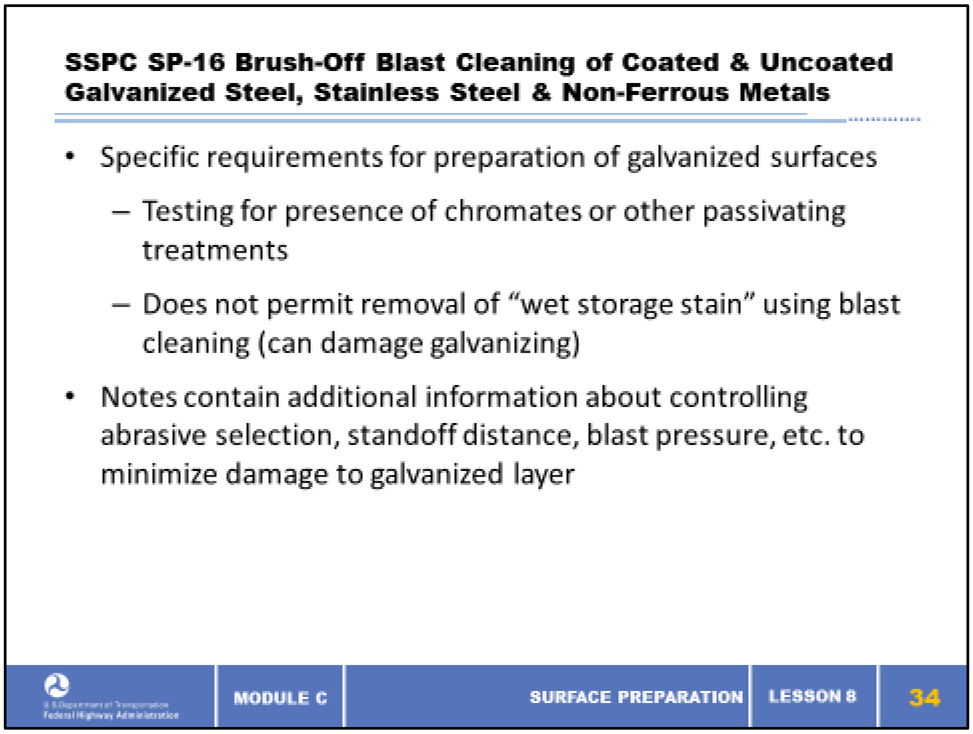
The photos progress from the least aggressive form of abrasive blast cleaning (SSPC-SP 7 Brush-off Blast) on the left to the most aggressive method (SSPC-SP 5 White Metal Blast) on the right.

Slide 33



SSPC-SP 16 addresses brush-off blast cleaning of coated and uncoated galvanized steel, stainless steel, and other non-ferrous metals. All of the previous surface cleanliness standards that were discussed were for steel surfaces. Some agencies that use galvanized bridges or coat galvanized handrail may invoke this standard for preparation of the galvanizing prior to painting. It may be specified when cleaning and roughening of bare metal is required prior to coating, or when roughening existing intact coatings is required in preparation for recoating. It requires removal of all visible dirt, dust, grease, oil, metal oxides, and foreign matter. A minimum 0.75 mil profile is invoked for bare metal surfaces.

Slide 34



SSPC-SP 16 addresses specific requirements for preparation of galvanized surfaces for the application of liquid applied coatings (known as a duplex system, which is discussed in more detail in Lesson 10). Chromates or other passivating treatments may interfere with coating adhesion, so the standard addresses methods for determining whether these are present on the galvanized surfaces. The standard does not permit removal of "wet storage stain" using blast cleaning abrasives due to the potential for significant damage to the galvanizing layer. There are notes which contain additional information about controlling abrasive selection, standoff distance, blast pressure, etc. to minimize damage to galvanized layer during the sweep blasting process.

SSPC-SP 16 provided specifiers with an option to successfully coat new galvanizing when the requirements listed in ASTM D6386 (coat within 48 hours of galvanizing or wait until it is fully weathered) are not feasible or desirable.

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Slide 35

Some agencies may elect to coat the galvanizing with a liquid-applied finish coat to preserve the galvanizing layer and/or improve the aesthetics. SSPC-SP 16 can be invoked by these specifications. The intent of SSPC-SP 16 is to remove any surface contamination (oxidation) and to roughen the surface for subsequent coating adhesion.

Slide 36


SSPC SP-16 Brush-Off Blast Cleaning of Coated & Uncoated Galvanized Steel, Stainless Steel & Non-Ferrous Metals
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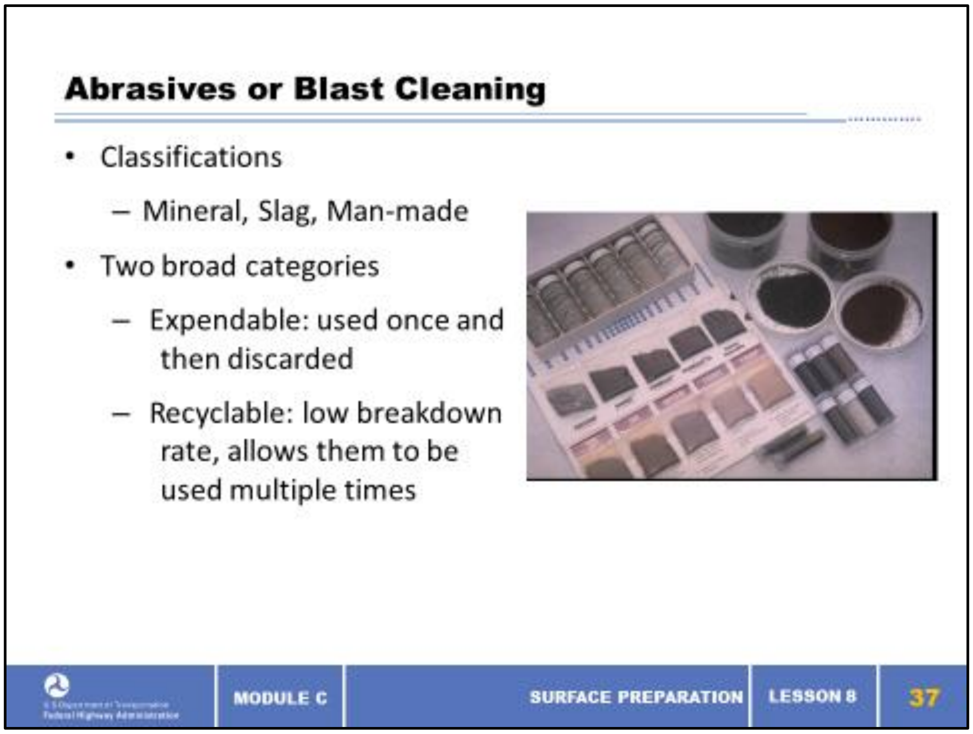
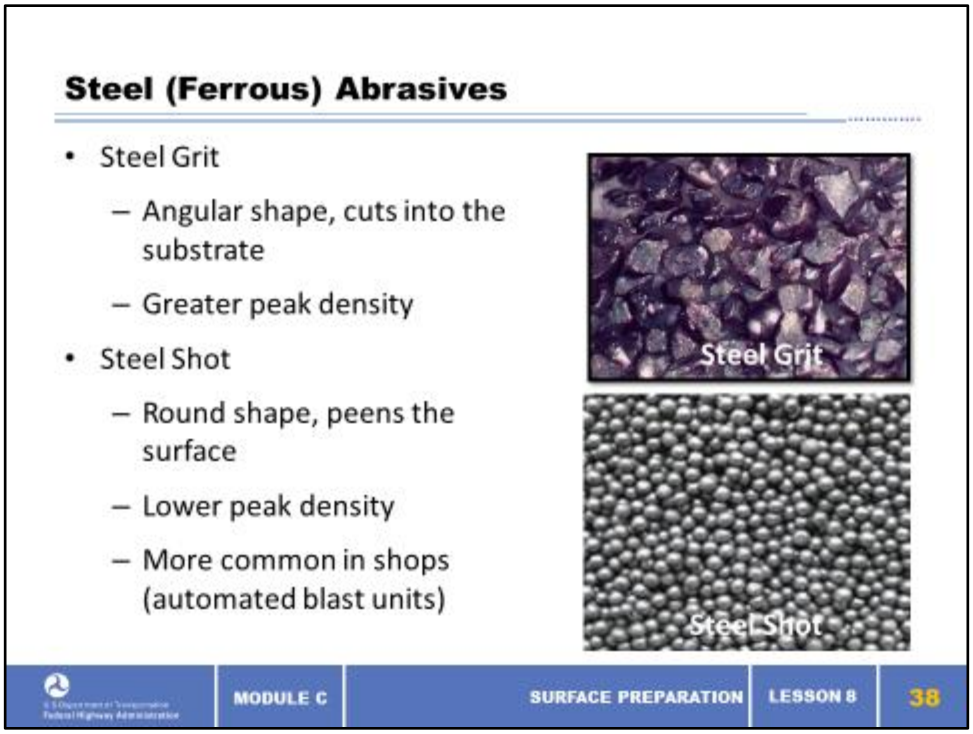


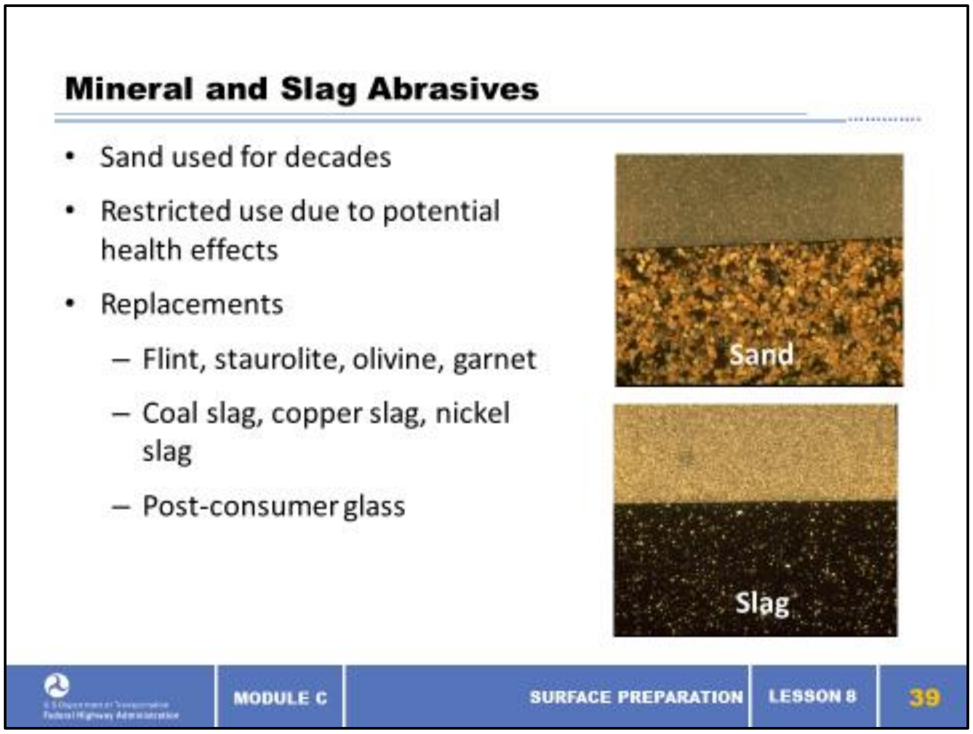
There are several types of abrasives available for use across the country. Some may only be regionally available due to the high cost of transporting them long distances. Some abrasives, even when categorized as the same generic type, can have different properties based upon the location they came from. Abrasives are classified as mineral, slag or man-made. They can be further categorized as expendable (one-time use) or recyclable (greater than one use prior to disposal).

Slide 38



Note that steel grit produces a different surface than steel shot. While both abrasive can produce a variety of different profile depths, the density of the peaks is comparatively greater with an angular abrasive than a rounded abrasive, yielding a greater surface area. Both types of steel abrasive can be recycled multiple times, provided the abrasive is kept dry. Steel shot is rarely used in the field; it is more commonly used to prepare new steel in a shop (in an automated blast unit).

Slide 39



Due to the potential adverse health effects of breathing dust from silica sand, it's use has declined significantly over the past decade or so. It has been replaced other mineral abrasives such as natural garnet, flint, olivine or Staurolite sand. Refractory slag (coal slag) and smelter slag (nickel and copper) are used as well, but are very friable and cannot be recycled. Garnet and aluminum oxide can be recycled to a degree, but typically no more than a once or twice before the abrasive breaks down to a size where it is no longer effective. Post-consumer glass (glass that we "recycle" weekly from our homes) is also manufactured into abrasive of various sizes. It too is expendable.

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Slide 40

Breakdown of abrasive inhibits productivity. Dust generated during blasting cleaning must be managed by proper air-flow inside the containment and dust collection. The surface also must be blown down and checked for imbedded grit. With non-recyclable abrasives, significant amounts of waste area is created—approximately 10-20 pounds of waste per square foot of prepared steel. For a 30,000 sq. ft. highway overpass, this can result in 300,000-600,000 pounds of spent grit and coating debris that must be handled, treated, and disposed of properly (more on the topic of waste disposal in Lesson 9).

Slide 41

SSPC Abrasive Standards

- SSPC-AB 1 – Mineral & Slag Abrasives
  - Categorizes by Type, Class and Grade
    - Type I: Natural mineral
    - Type II: Slag
    - Class A: <1% crystalline silica
    - Class B: <5% crystalline silica
    - Class C: Unrestricted crystalline silica
    - Grade 1-5: Surface profile yield

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SSPC-AB 1 addresses requirements for classification, evaluation, and performance of mineral and slag abrasives used for blast cleaning steel. It classifies an abrasive according to its type, class and grade. A specifier can require the use of an abrasive that conforms to SSPC-AB 1, or can be more specific (e.g., SSPC-AB 1, Type II, Class A, with a Grade 3 [2-3.5 mil] surface profile yield).

Slide 42

There are nine tests that must be performed before an abrasive manufacturer can claim that his abrasive conforms to SSPC-AB 1. Two of the nine tests must be confirmed in the shop or field prior to using the abrasive. They both pertain to abrasive cleanliness. One test is to determine whether there is oil contamination, and the other is to determine whether there is excessive water soluble contamination on the abrasive. We'll look at these two tests next since they are automatically invoked by all the SSPC Abrasive Standards as well as the SSPC surface cleanliness standards described earlier in this lesson.

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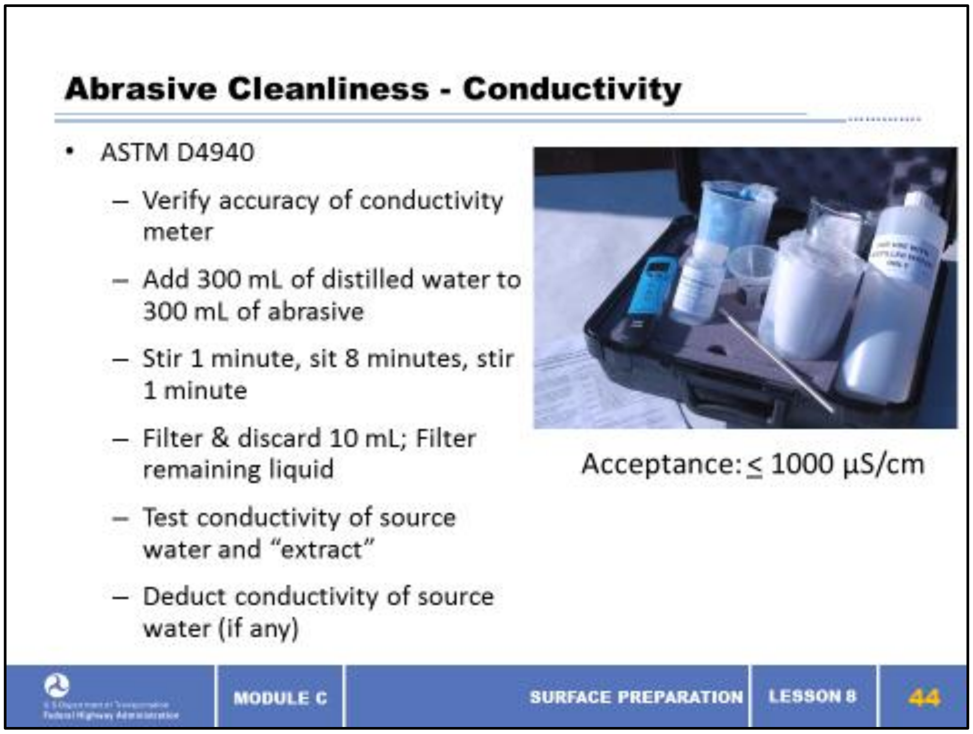
Place approximately 1" of abrasive in a clear container, followed by tap water 68-95F (≥ 1" above the abrasive).

Shake the abrasive/water slurry for 1 minute, then let the container sit idle for up to 5 minutes.

Visually assess surface of water for an oil sheen. No visible oil is allowed.

Slide 44



Verify the accuracy of the conductivity meter using a standard buffer solution. Add 300 mL of distilled water to 300 mL of the abrasive. Stir the abrasive/water slurry for 1 minute, then let it sit idle for 8 minutes, and stir the slurry again for 1 minute. Filter and discard 10 mL of the liquid, then filter the remaining liquid. Test the conductivity of source water and the "extract. Deduct the conductivity of source water (if any). The SSPC AB standards all cite the same acceptance criteria. The conductivity of the abrasive extract cannot exceed 1000 microsiemens per centimeter (µS/cm).

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Slide 45

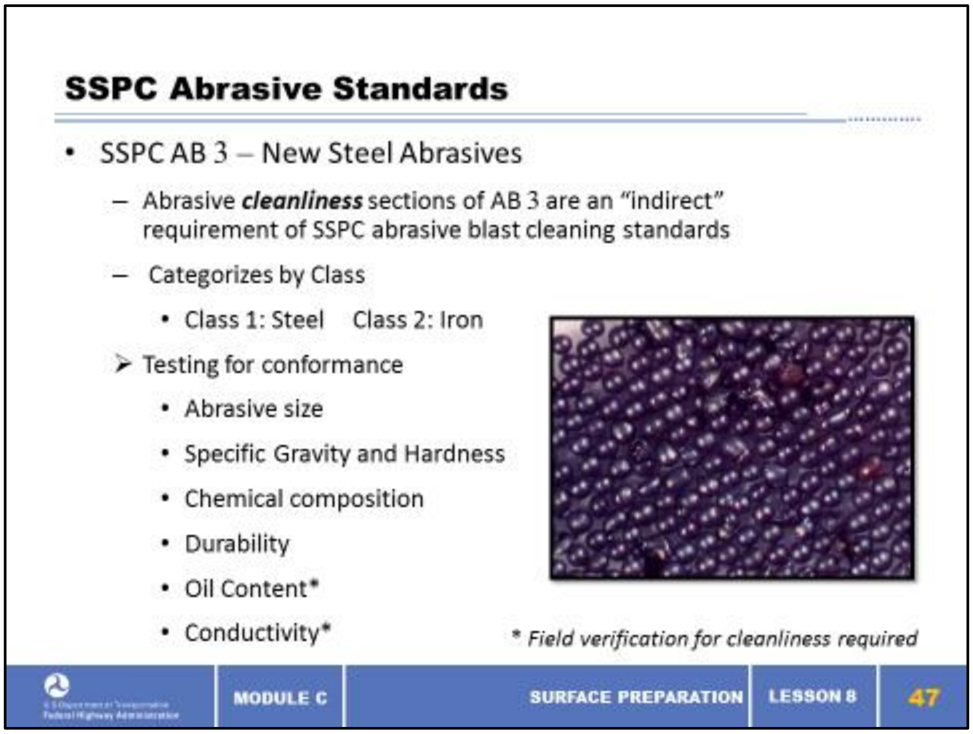
Any time compressed air is used in the surface preparation process, it must be tested for the presence of water and oil. While the compressor may be equipped with oil and moisture extractors or separators, it is important to verify this equipment is performing properly. ASTM D4285 describes a practice for conducting a compressed air cleanliness test or a blotter test. The compressed air is exhausted onto a collector (blotter paper, cotton cloth or plexiglass) for approximately one minute, downstream of any in-line extractors. The collector is examined for evidence of water and oil.

Slide 46

Requirements are given for laboratory and field testing of the recycled ferrous metallic abrasives work mix, including post-reclaim non-abrasive residue, lead content (between projects), water soluble contaminants and oil content.

Recycled ferrous metallic abrasives are intended for use in field or shop for abrasive blast cleaning of steel or other surfaces. Ferrous metallic abrasives must be kept dry or rusting and clumping can occur, seizing up the handling equipment and adversely impacting productivity.

Slide 47



SSPC-AB 3 addresses requirements for classification, evaluation, and performance of newly manufactured steel abrasives used for blast cleaning steel. It classifies an abrasive according to its class. Requirements are given for laboratory and field testing of the abrasive. Field testing includes analysis for water soluble contaminants and oil.

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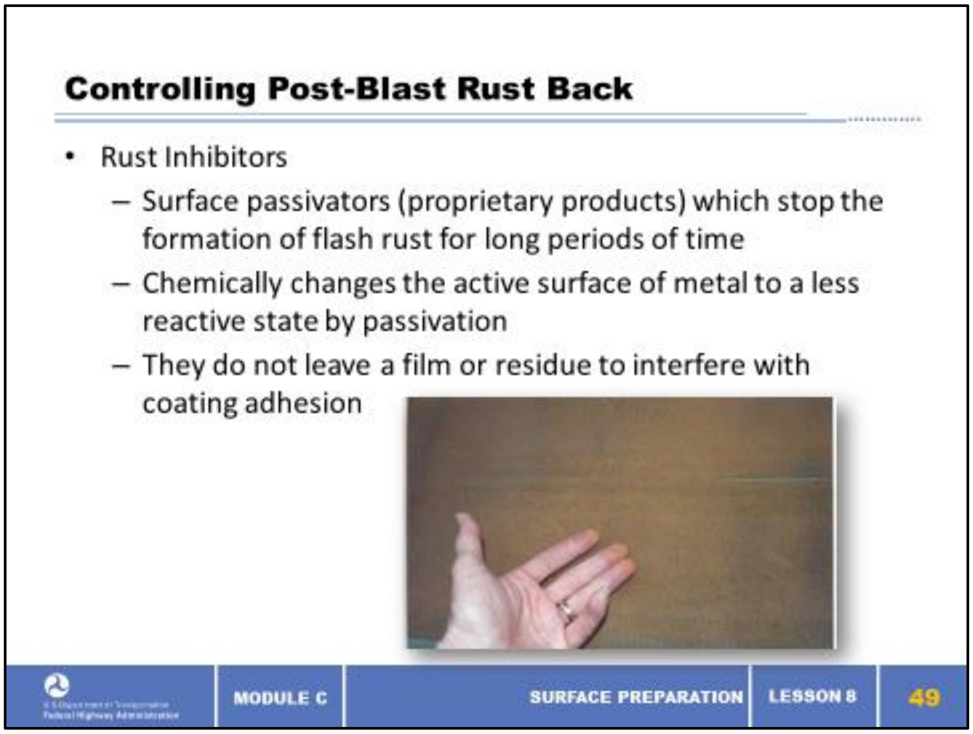
The standards listed on the slide address five different levels of wet abrasive blast (WAB) cleaning. The definitions are identical to the dry abrasive blast cleaning standards that we already covered in this lesson. In this case the abrasive is dampened to control airborne dust. A rust inhibitor that is compatible with the coating system must be added to the water; otherwise the steel will flash rust.

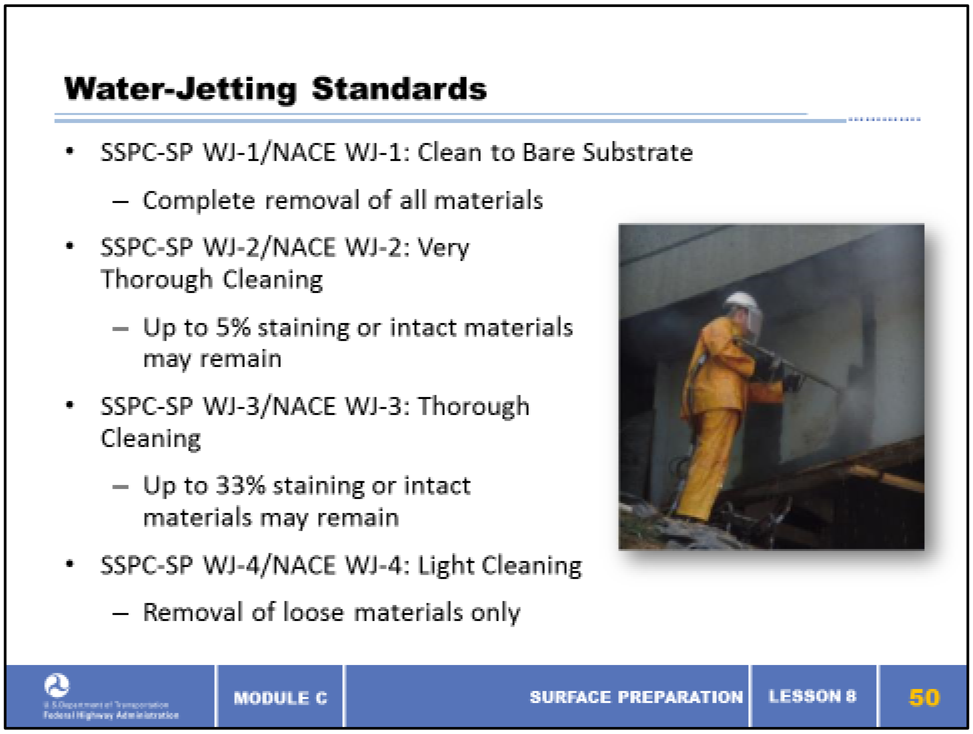
Slide 49



There are several commercially available rust inhibitors that can be applied to the surface to help retard rust-back. However surface passivation products of this type must be compatible with the applied coating. The coating manufacturer can provide this information to the specifier.

The period of time between final surface preparation and primer application is often specified. In no case should the surface be allowed to deteriorate prior to primer application, independent of the elapsed time. Additional surface preparation may be required to remove the surface rusting. The surfaces must meet the specified level of surface cleanliness immediately prior to coating.

Slide 50

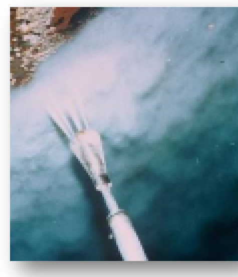


Water-jetting is a term used when water is pressurized to over 10,000 psi, typically over 30,000 psi, to remove coatings. The SSPC/NACE standards for water jetting are listed below. Similar to the SSPC surface cleanliness standards for abrasive blast cleaning, each of the four levels of water jetting represent different degrees of surface cleanliness; however the definitions are quite different from the dry abrasive blast cleaning.

Slide 51

Water-Jetting Precautions

- Water quality
  - pH of water should be neutral; potable water quality
  - Contaminated water
    - May leave residues on the surface
    - Affect the water pump operation
- Other Precautions
  - Flash rust will occur without a rust inhibitor in water
  - Containment of water can be challenging
  - Filtration of water prior to disposal by a POTW typically required



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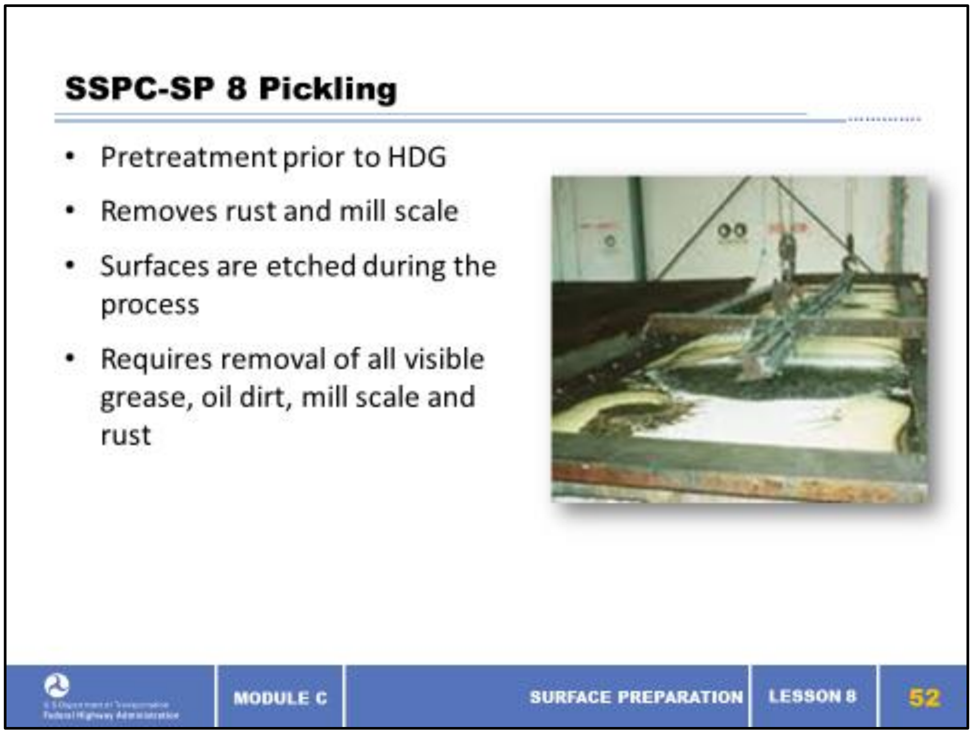
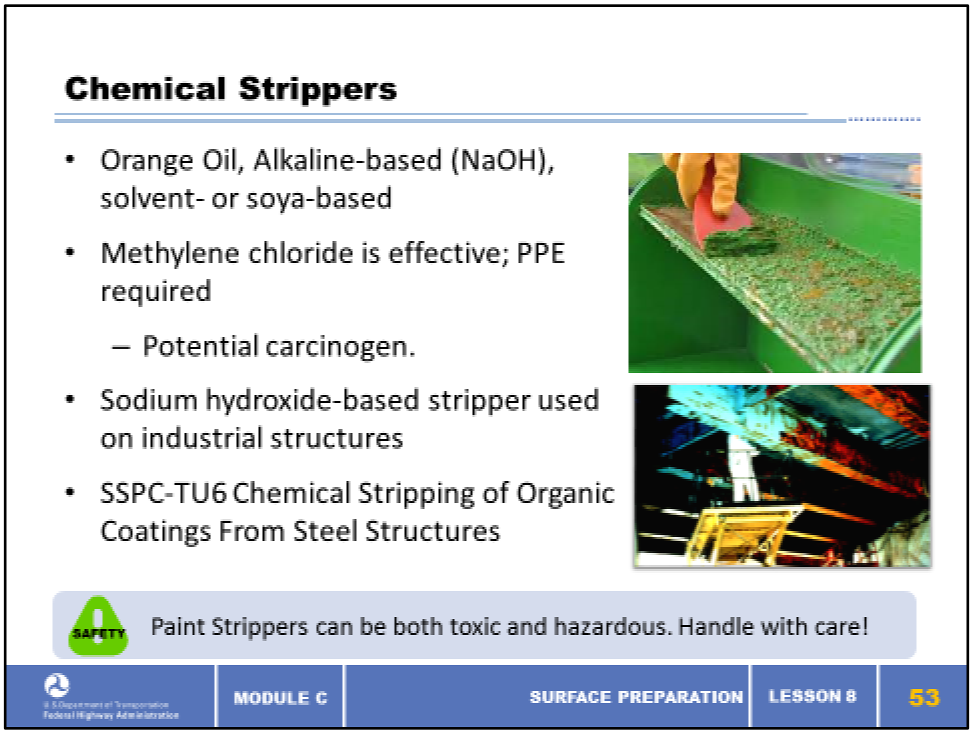
First, the pH of water should be neutral, and it should be potable water quality. Secondly, contaminated water may leave residues on the surface and can affect the long term functionality of the water pump. Thirdly, flash rust will occur unless a rust inhibitor is used in water. Fourth, containment of water can be very challenging. Finally, “gray water” cannot be disposed of in a landfill, so it must be collected, filtered and disposed of (with permission) in a publically owned treatment facility (POTW). It cannot be disposed of in a storm sewer.

Slide 52



Pickling in heated chemical baths typically require multiple steps, such as acid pickling, neutralization, and rinsing. Pickling is an effective method of removing rust and mill scale and etching the surface to be coated. It is a common pretreatment process prior to hot-dip galvanizing.

Slide 53



Chemical paint strippers attack the resin system in a coating and cause it to de-bond from the surface. They may consist of orange oil, or may be alkaline-based (such as sodium hydroxide), or may be solvent- or soya-based. Methylene chloride is a very aggressive paint stripper that was used for many years, however it has been identified as a potential carcinogen and is rarely used on large scale projects today. Sodium hydroxide-based stripper has been used to remove coatings from industrial structures, but they do require a dwell time of several hours on the surface and may require multiple applications.

SSPC-TU6 *Chemical Stripping of Organic Coatings from Steel Structures* defines chemical strippers and discusses their use for removing existing conventional organic coatings from steel structures.

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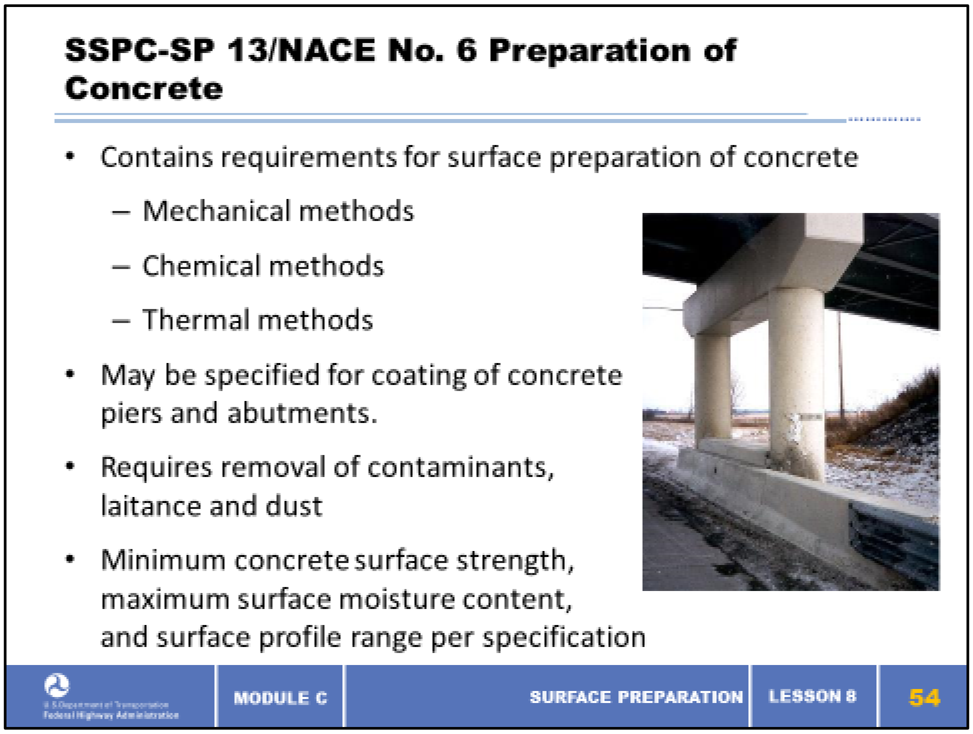
Slide 54



Surface preparation of concrete is contained in the SSPC SP13/NACE 6 standard. Concrete piers and abutments that are intended to be coated may be prepared according one of the methods described in the standard. As of 2015 this standard is under revision. An acceptable prepared concrete surface should be free of contaminants, laitance, loosely adhering concrete, and dust, and should provide a sound, uniform substrate suitable for the application of protective coating system. When required, a minimum concrete surface strength, maximum surface moisture content, and surface profile range should be specified in the procurement documents (project specifications).

Methods used to prepare concrete for coating include power washing, acid etching (for horizontal surfaces), water-jetting, abrasive blasting, shot blasting, scarifying, and grinding. The process typically involves treating cracks and filling pores prior to surface preparation and coating. The International Concrete Repair Institute (ICRI) publishes standards with corresponding visual references for evaluating the surface preparation of concrete. For more information log onto www.icri.org.

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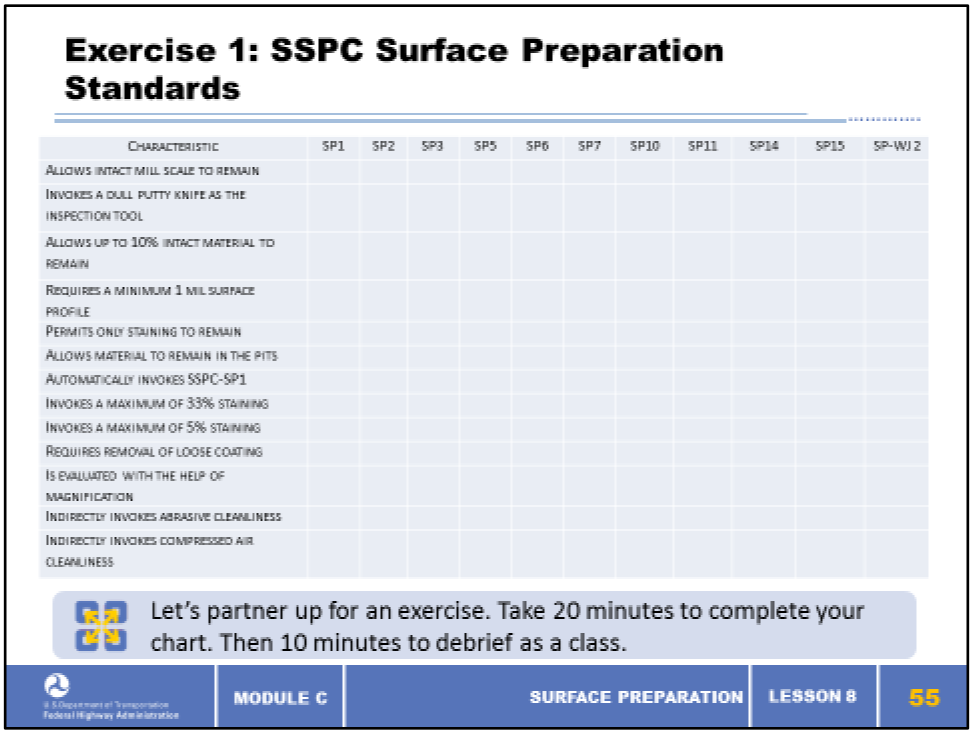
Slide 55



Focus on one "SP" column at a time. Read each characteristic in the left column. If the characteristic is true of the surface preparation standard, place a "✓" in the cell. If it is not true, leave the cell blank. Once you have challenged each characteristic against the surface preparation (SP) standard indicated at the top of the column, move right and repeat the process until you have challenged each characteristic against each of the 11 surface preparation standards. If you "✓" the cell, you are stating that the characteristic is true 100% of the time without exception. There are 143 cells (13 characteristics and 11 standards). When you are done you should have a total of 58 cells checked.

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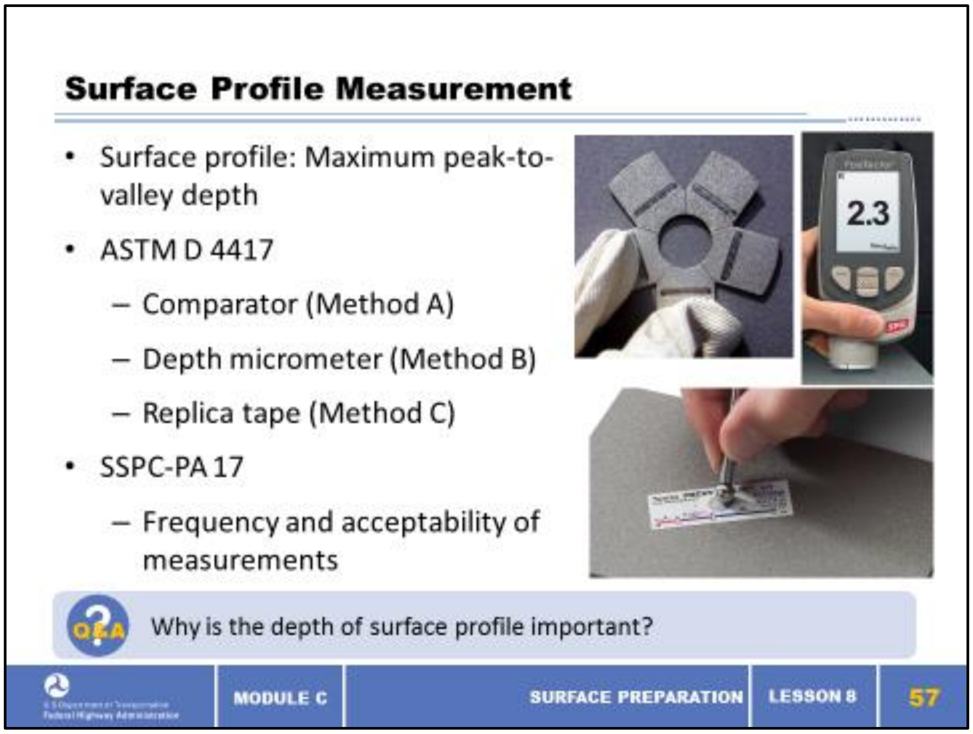
Slide 56

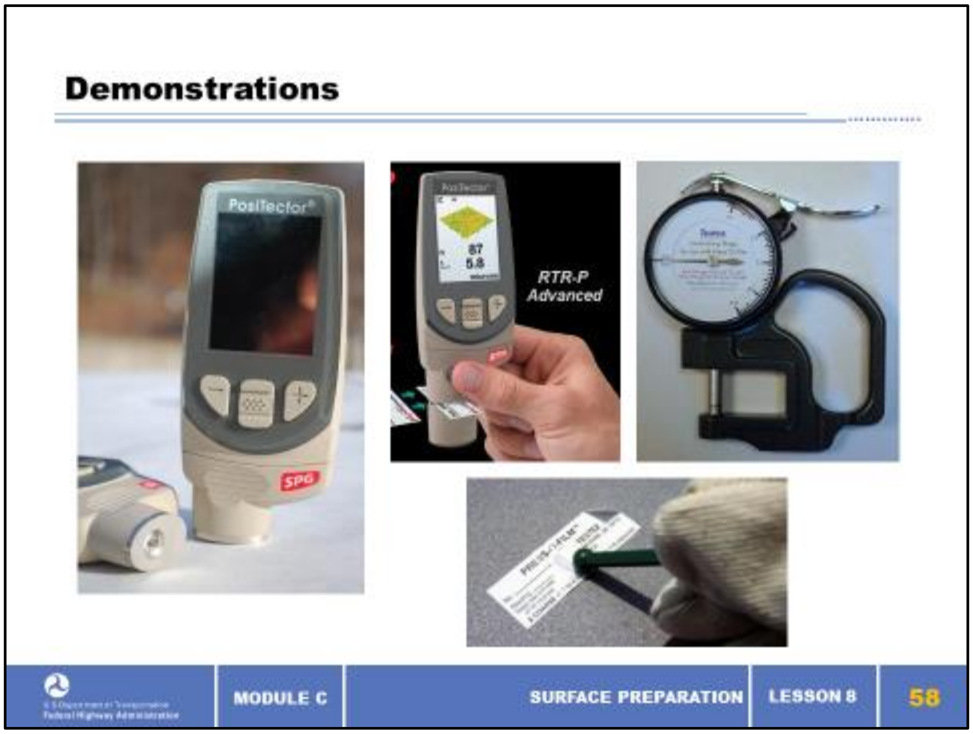
Quality assurance of surface preparation can include a visual assessment for cleanliness, measurement of the surface profile depth and testing for surface soluble salt contamination.

Slide 57



Surface profile is considered a measurement of the maximum peak-to-valley depth that is generated by abrasive blast cleaning and some power tools. ASTM D 4417 describes three methods of measuring the surface profile, including a visual comparator (Method A), a depth micrometer (Method B) and replica tape (Method C). The minimum number of readings per area is also provided in the standard, but the number of areas that are to be measured is not. SSPC-PA 17 provides the specifier with information on the number of areas to check per work shift of 12-hour period (whichever is shorter) and the acceptability of the measurements.

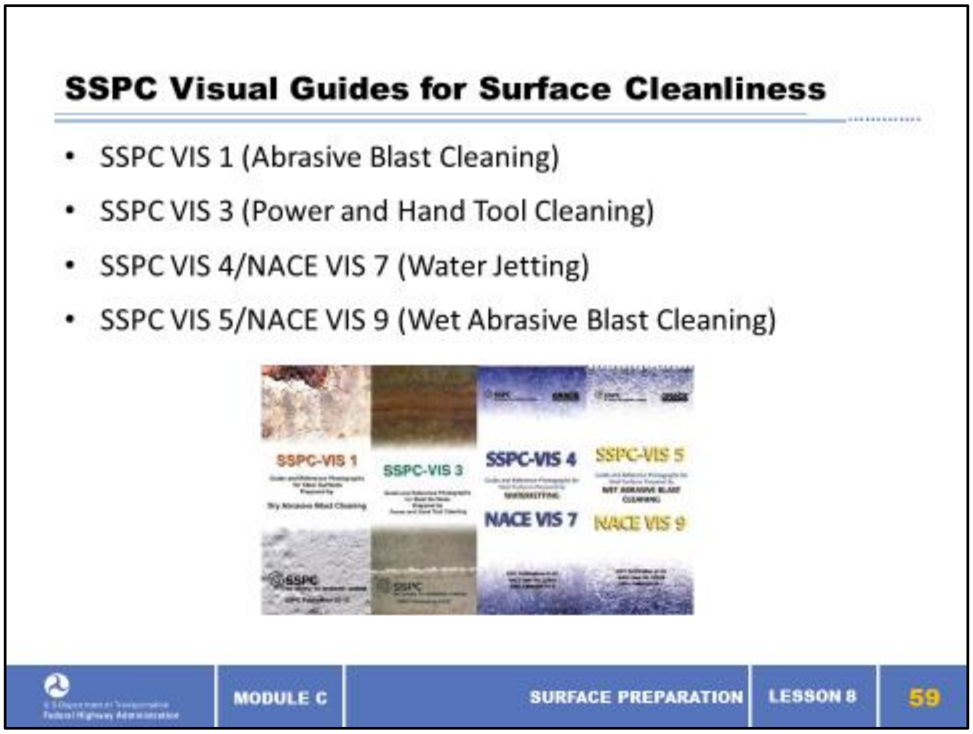
Slide 58



Method B (depth micrometer) – The surface profile is measured as the instrument foot sets on the peaks of the surface profile while a 60° conical-shaped pin projects into the valleys of the surface profile. First, verify "zero" on float glass plate, then obtain a minimum of 10 readings per "area." Record maximum profile reading (discard outliers). This method can be used for surface profile measurements in excess of 5 mils and is the only method allowed for surfaces prepared using power tools.

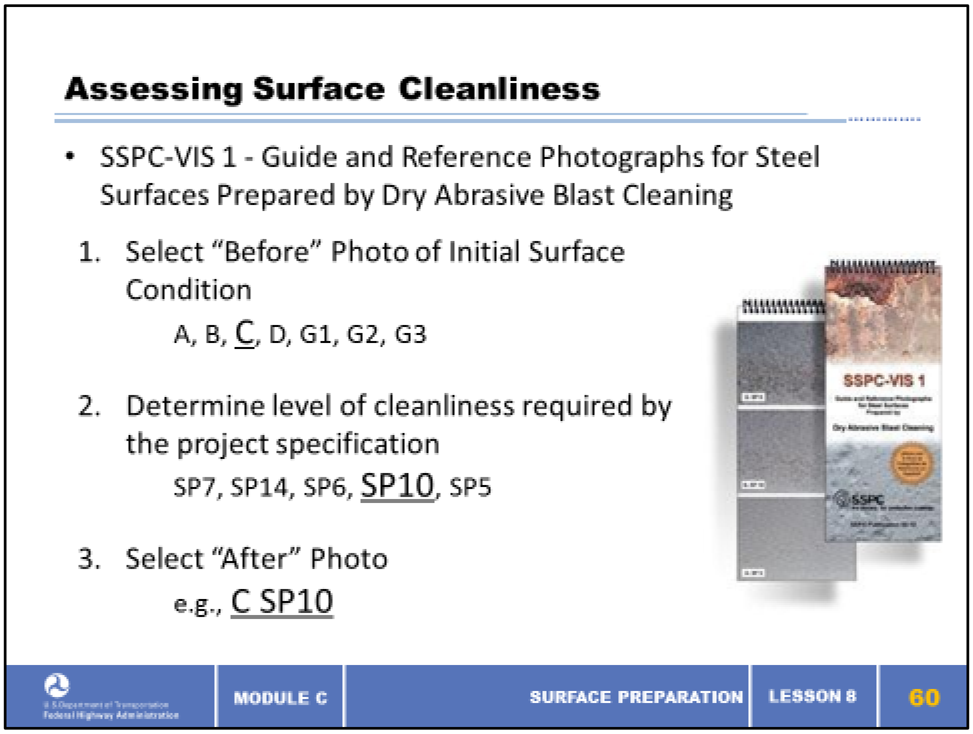
Method C (replica tape) - Remove any dust or debris from the surface. Select the range of replica tape that coincides with the anticipated surface profile depth (Coarse: 0.8-2.5 mils; X-Coarse: 1.5-4.5 mils; X-Coarse Plus: 4-5 mils). The tape is most accurate mid-range. Remove the paper backing from tape and attach the tape to the prepared surface. Use a burnishing tool and medium pressure to rub over the Mylar® surface until the test area is uniformly gray. Remove the tape and insert the burnished area between top and bottom anvils of the spring micrometer (or insert the tape into the replica tape reader [RTR]). Deduct 2 mils for the Mylar thickness and record the measurement. Obtain two readings per "area;" record the average measurement.

Slide 59



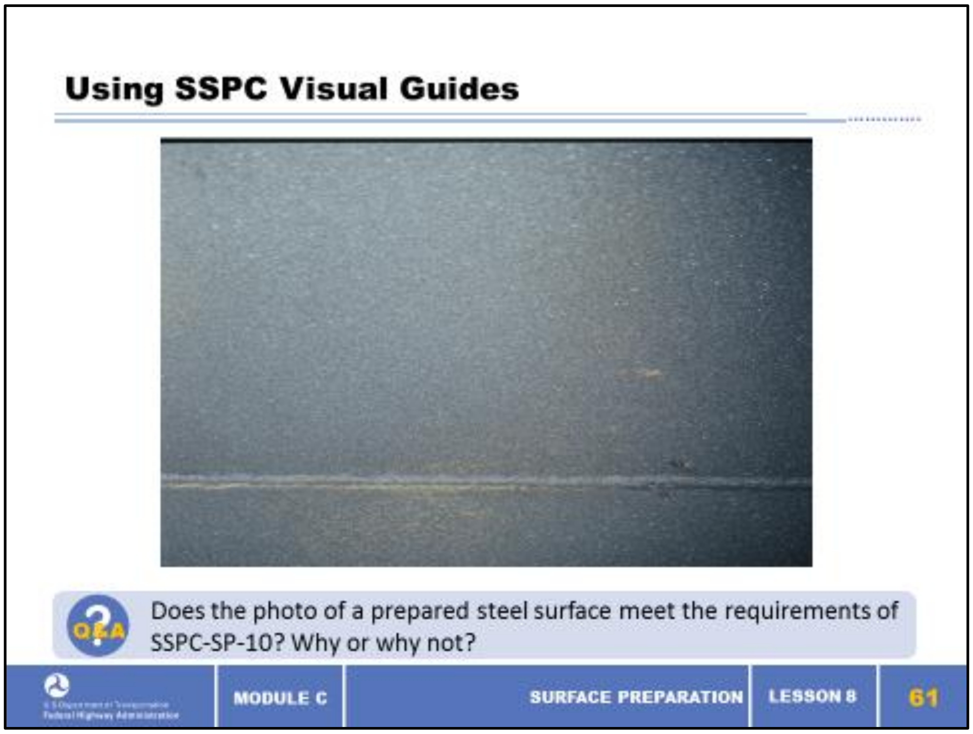
SSPC VIS 1 is used to evaluate the degree of surface cleanliness achieved after dry abrasive blast cleaning; SSPC VIS 3 is used to evaluate the degree of surface cleanliness achieved after power or hand tool cleaning; SSPC VIS 4/NACE VIS 7 is used to evaluate the degree of surface cleanliness achieved after water jetting; and SSPC VIS 5/NACE VIS 9 is used to evaluate the degree of surface cleanliness achieved after wet abrasive blast cleaning.

Slide 60

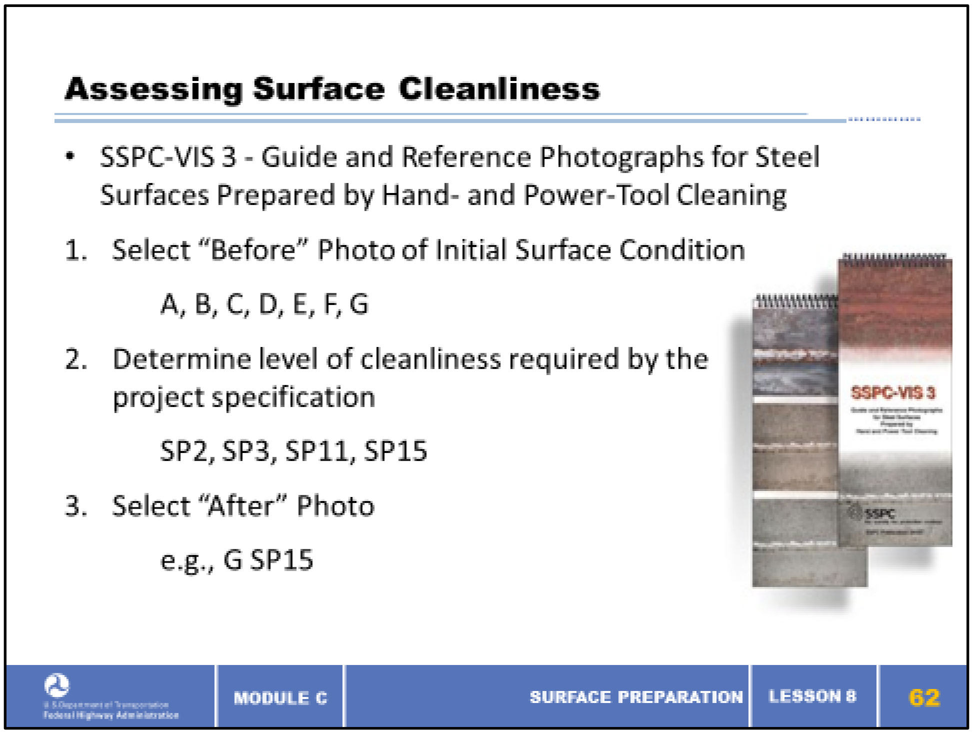


The visual reference guide features photos of previously coated and uncoated steel surfaces before and after dry abrasive blast cleaning. An appendix of photographs show variations in a white metal blast caused by abrasive type, profile depth, angle of view, and lighting. Note that this photographic reference is a guide and, in the event of a dispute, it is the written standard that governs and not the images depicted in the guide.

Slide 61


Using SSPC Visual Guides
Does the photo of a prepared steel surface meet the requirements of SSPC-SP-10? Why or why not?
MODULE C
SURFACE PREPARATION
LESSON 8
61

Slide 62



The visual reference guide features photos of previously coated and uncoated steel surfaces before and after hand and power tool cleaning. Note that this photographic reference is a guide and, in the event of a dispute, it is the written standard that governs and not the images depicted in the guide.

Slide 63


Using SSPC Visual Guides
Q&A
Does the photo of a prepared steel surface meet the requirements of SSPC-SP-11? Why or why not?
MODULE C
SURFACE PREPARATION
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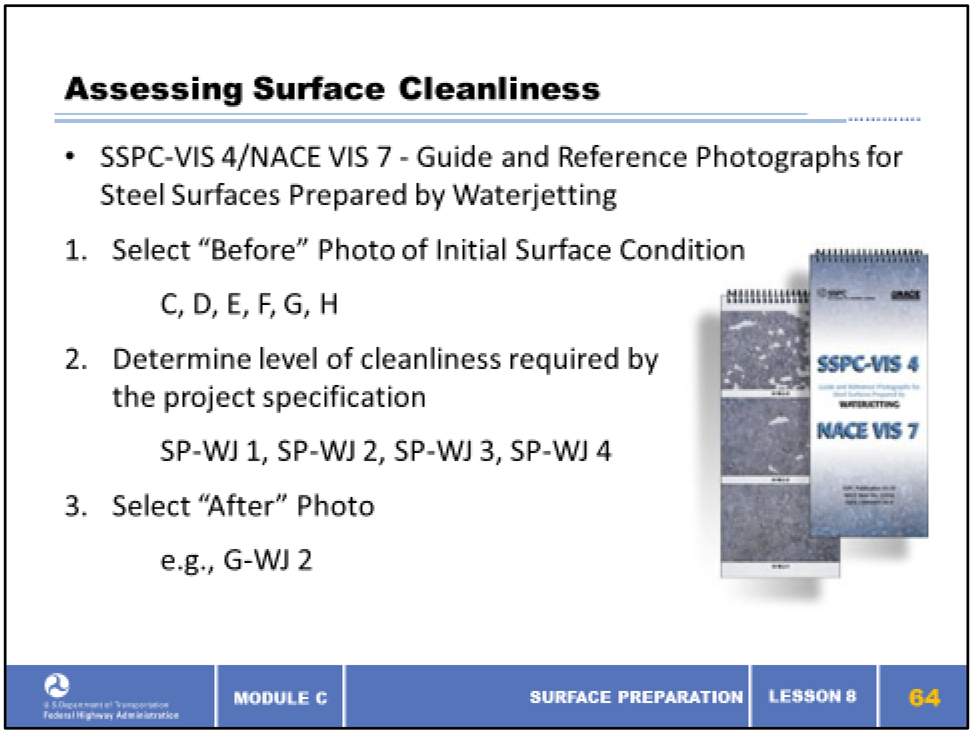
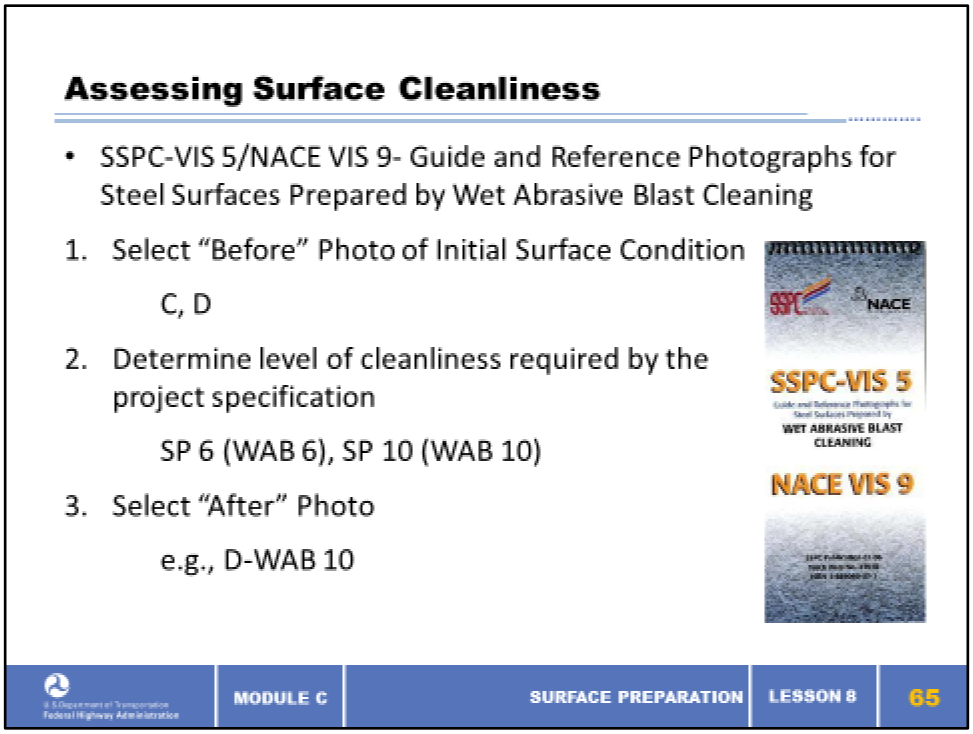
Slide 64



SSPC-VIS 4/NACE VIS 7 - Guide and Reference Photographs for Steel Surfaces Prepared by Waterjetting is a visual reference guide featuring photos of previously coated and uncoated, rusted steel surfaces before and after water jetting. A total of six different steel surfaces (two uncoated and four previously coated) before and after water-jetting are depicted.

Photographs illustrate four degrees of cleaning (WJ-1, WJ-2, WJ-3, and WJ-4) for each initial condition, with additional photos to illustrate light, moderate, and heavy flash rust after cleaning (provided a rust inhibitor is not used). Note that this photographic reference is a guide and, in the event of a dispute, it is the written standard that governs and not the images depicted in the guide.

Slide 65



SSPC-VIS 5/NACE VIS 9 - Guide and Reference Photographs for Steel Surfaces Prepared by Wet Abrasive Blast Cleaning is a visual reference guide featuring photos of previously rusted steel surfaces before and after wet abrasive blast cleaning. Two different steel surfaces (rusted; rusted and pitted) before and after wet abrasive blast cleaning are depicted.

Photographs illustrate two degrees of cleaning (SSPC-SP 6 and SSPC-SP10) for each initial condition, with additional photos to illustrate light, moderate, and heavy flash rust after cleaning (provided a rust inhibitor is not used). "WAB" indicates Wet Abrasive Blast. Note that this photographic reference is a guide and, in the event of a dispute, it is the written standard that governs and not the images depicted in the guide.

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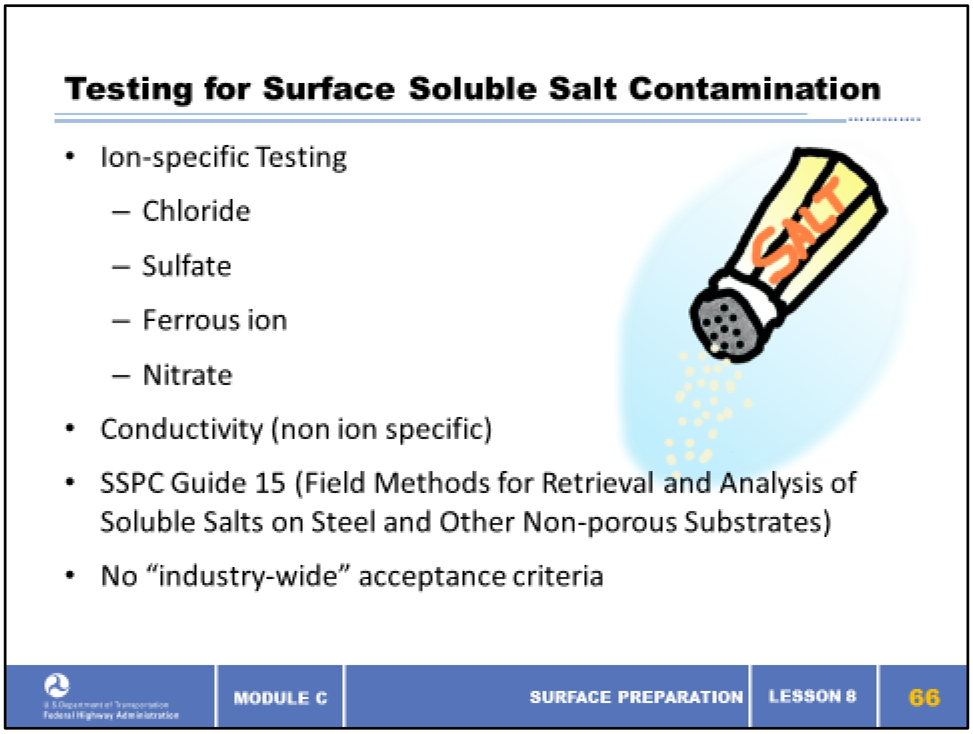
Slide 66



Soluble salts trapped beneath a coating film can draw moisture through the film by osmosis until the concentration of salt in water reaches equilibrium on both sides of the coating film. The result is a build-up of water beneath the coating film and blistering, also known as osmotic blistering. Naturally immersion environments are more prone to osmotic blistering than atmospheric exposure; however salts beneath a coating film are corrosion promoters.

Ion-specific testing of surface soluble salt contamination can include detection of chloride, sulfate, ferrous ion, and/or nitrate. Conductivity is non ion-specific but detects any soluble salt, which helps avoid performing multiple tests on the same sample. SSPC Guide 15 "Field Methods for Retrieval and Analysis of Soluble Salts on Steel and Other Non-porous Substrates" describes various methods of extraction and analysis that can be performed in the field. However the guide does not provide acceptance levels. The acceptable level of contamination must be specified in the contract documents.

Slide 67

Common retrieval methods include swabbing, the use of latex patches (top photo on slide) or latex sleeves. Common methods of analysis include the use of chloride indicator strips or tubes, drop titration for chloride detection, ferrous ion and nitrate test strips, the use of a conductivity meter (bottom photo on slide), which is non ion-specific, and the use of a special turbidity meter for sulfate detection.

Slide 68

Calculating Surface Concentrations (Example)

Entry	Result
PPM	124 PPM
Quantity of water used for extraction	2 mL
PPM x quantity of water used	124 x 2 = 248 µg
Area sampled	12.25 cm^2
Micrograms ÷ Area Sampled	248÷12.25=20.2 $µg/cm^2$

Q&A Calculate the surface concentration.

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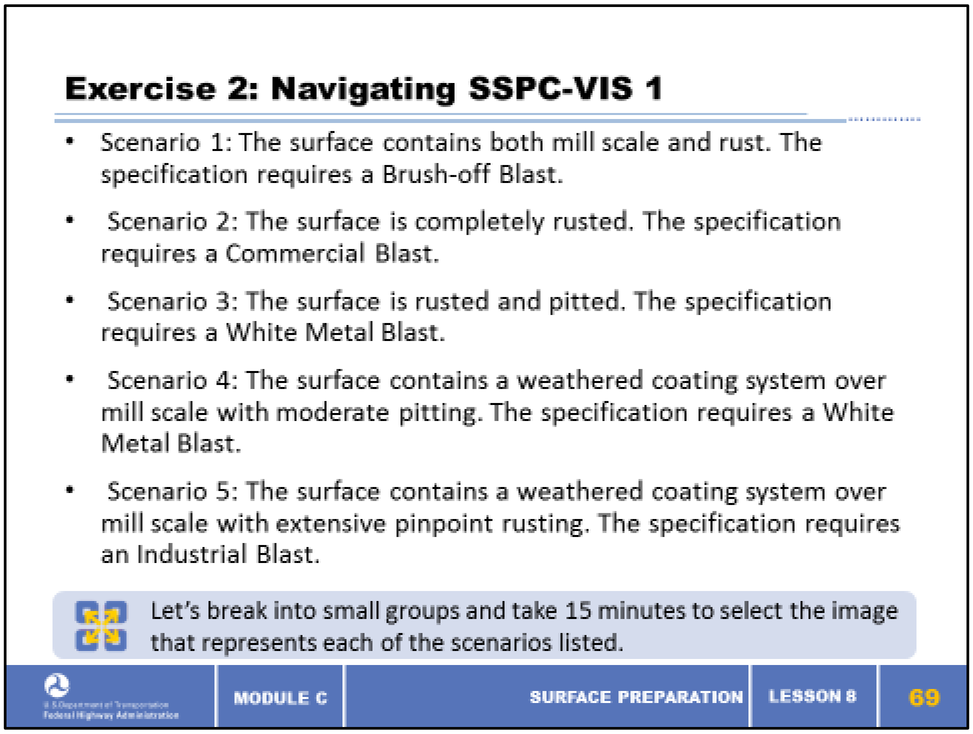
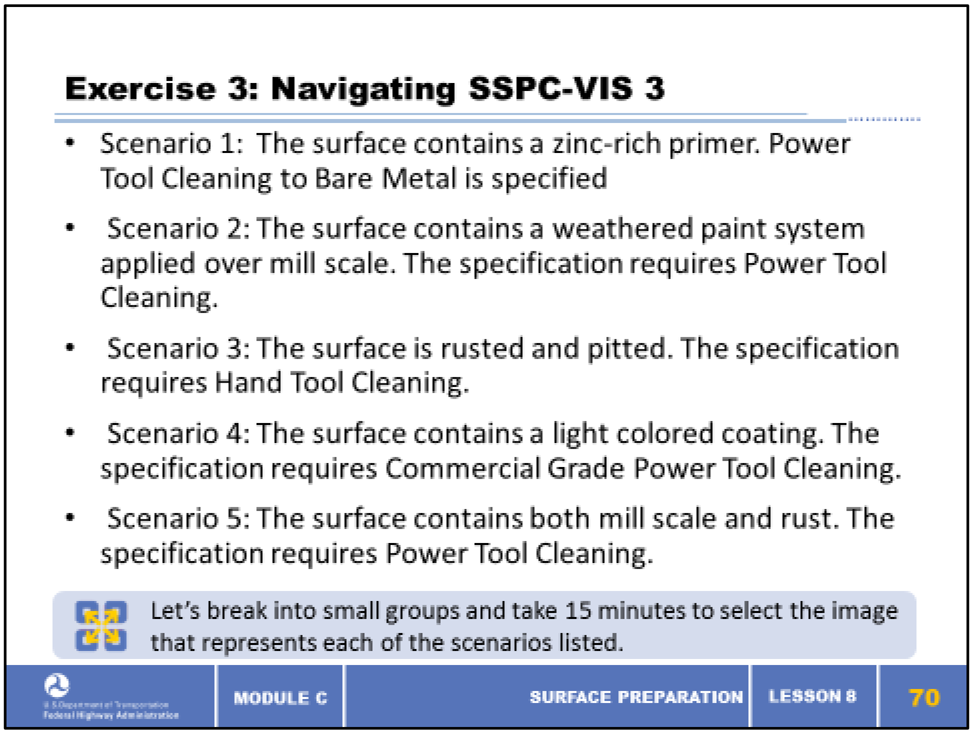
To calculate the surface concentration, multiply the PPM by the quantity of water used in the extraction, which will yield micrograms. Divide micrograms (µg) by the size of the test area (in cm^2) to yield the surface concentration in micrograms per square centimeter ($µg/cm^2$).

Slide 69



Identify and record the code for the photo you would use to inspect the surface based on each of the five descriptions (scenarios) listed on the slide and on the form. Identify the photo you would use to inspect the surface based on each of the five descriptions (scenarios) listed on the slide. The table in the front of the SSPC VIS 1 Guide may be helpful for this learning activity.

Slide 70



Identify and record the code for the photo you would use to inspect the surface based on each of the five descriptions (scenarios) listed on the slide and on the form. Identify the photo you would use to inspect the surface based on each of the five descriptions (scenarios) listed on the slide. The table in the front of the SSPC VIS 3 Guide may be helpful for this learning activity.

Slide 71

Exercise 4: Abrasive Characteristics

1. What type of abrasive is displayed?
2. How did your team determine the abrasive type?
3. Is the abrasive displayed expendable or re-usable?
4. What shape of surface profile would be generated by this abrasive (angular or peened)?
5. Which of the SSPC Abrasive (AB) Standards would apply to the abrasive displayed (AB 1, AB 2, AB 3 and/or AB 4)?
6. Indicate one advantage related to selecting this type of abrasive to prepare a bridge structure for coating.
7. Indicate one limitation or concern related to selecting this type of abrasive to prepare a bridge structure for coating.

In groups of 3-4, visit each station and answer the questions provided. You have about 45 minutes to complete this exercise.

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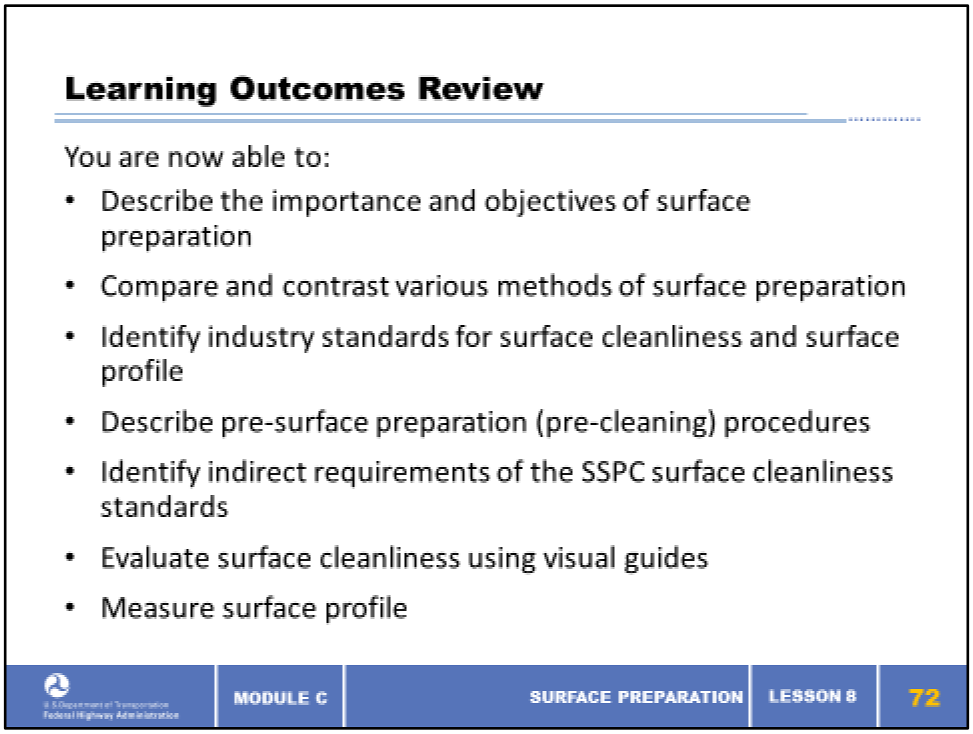
Slide 72


Learning Outcomes Review
You are now able to:
• Describe the importance and objectives of surface preparation
• Compare and contrast various methods of surface preparation
• Identify industry standards for surface cleanliness and surface profile
• Describe pre-surface preparation (pre-cleaning) procedures
• Identify indirect requirements of the SSPC surface cleanliness standards
• Evaluate surface cleanliness using visual guides
• Measure surface profile
MODULE C
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72

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Slide 1


HMEC
Highway Materials Engineering Course
Lesson 9: Removing Lead-Based Paints
Steel, Welding, and Coatings
U.S.Department of Transportation
Federal Highway Administration
MODULE
C

Slide 2

Learning Outcomes

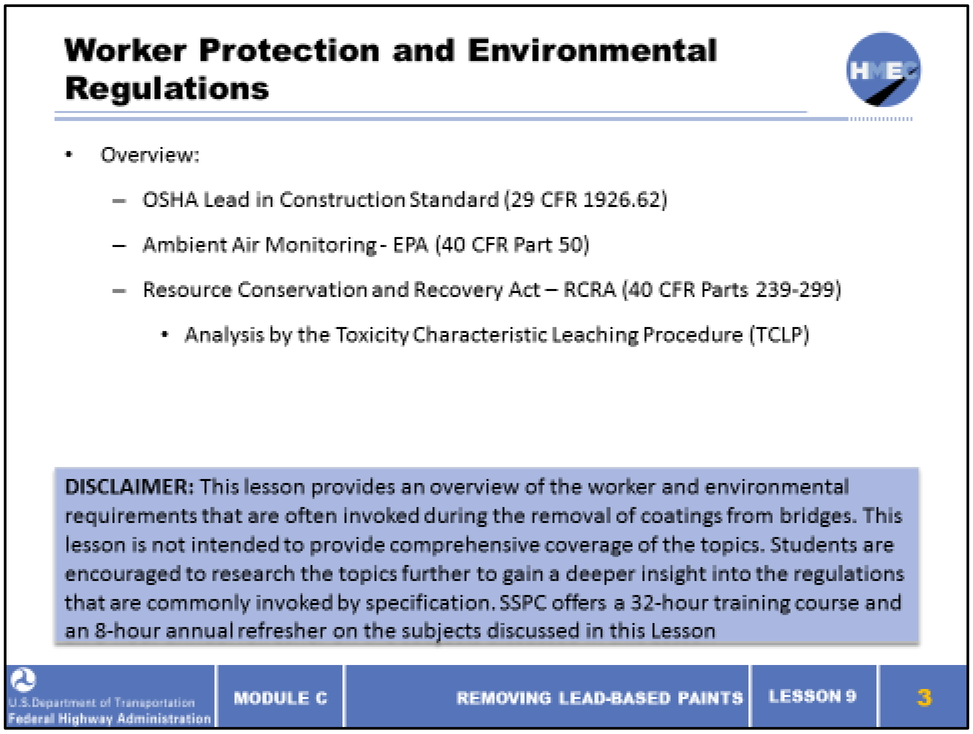
By the end of this lesson, you will be able to:

- Identify State and Federal resources that apply to major areas of environmental and worker health and safety regulations for lead paint removal
- Describe surface preparation methods that can potentially impact air, soil and water quality
- Conduct a simplified risk assessment

This lesson will take approximately 90 minutes to complete.

U.S. Department of Transportation Federal Highway Administration | MODULE C | REMOVING LEAD-BASED PAINTS | LESSON 9 | 2

Slide 3



Key regulations include the OSHA lead in construction standard and the Resource Conservation and Recovery Act (RCRA). If ambient air monitoring is invoked by project specification, it is performed according to 40 CFR Part 50. The Toxicity Characteristic Leaching Procedure (TCLP) is not a regulation but rather a test procedure to determine whether the waste is classified as hazardous or non-hazardous.

The following documents are referenced in this Lesson:

OSHA 29 CFR 1926.62 (lead)
EPA 40 CFR Subchapter D (Water Quality)
EPA 40 CFR Part 50 (Air Quality)
SSPC Guide 6, Containing Surface Preparation Debris Generated During Paint Removal Operations
SSPC Technology Update 7, Conducting Ambient Air, Soil, and Water Sampling
SSPC Guide 7, Disposal of Lead-Contaminated Surface Preparation Debris
Resource Conservation and Recovery Act – RCRA (40 CFR Parts 239-299)

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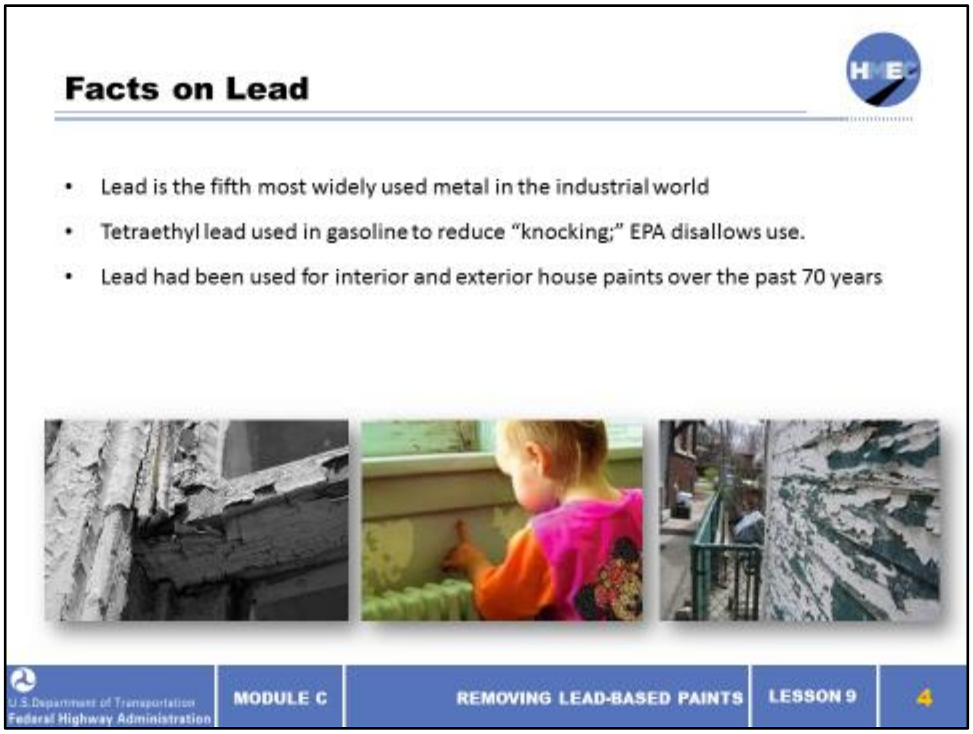
Slide 4



Lead is the fifth most widely used metal in the industrial world. Its principal use today is in storage batteries, but it is found in solder, old residential water piping, and (until recently) in gasoline additives to reduce "knocking." The use of tetraethyl lead in gasoline has diminished over the last 40 years due to EPA regulations. Lead had been used for interior and exterior house paints over the past 70 years. Lead acetate and lead carbonate pigments were used up until the 1940s and was banned in 1978. This long term use of lead in housing and child-occupied facilities created a national childhood lead poisoning crisis.

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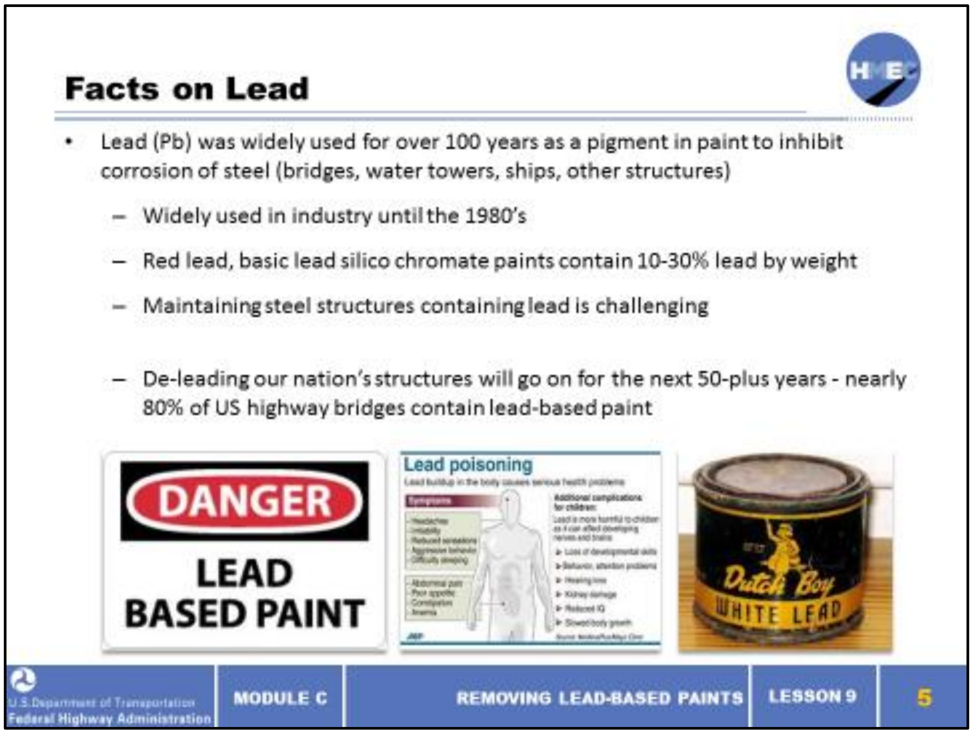
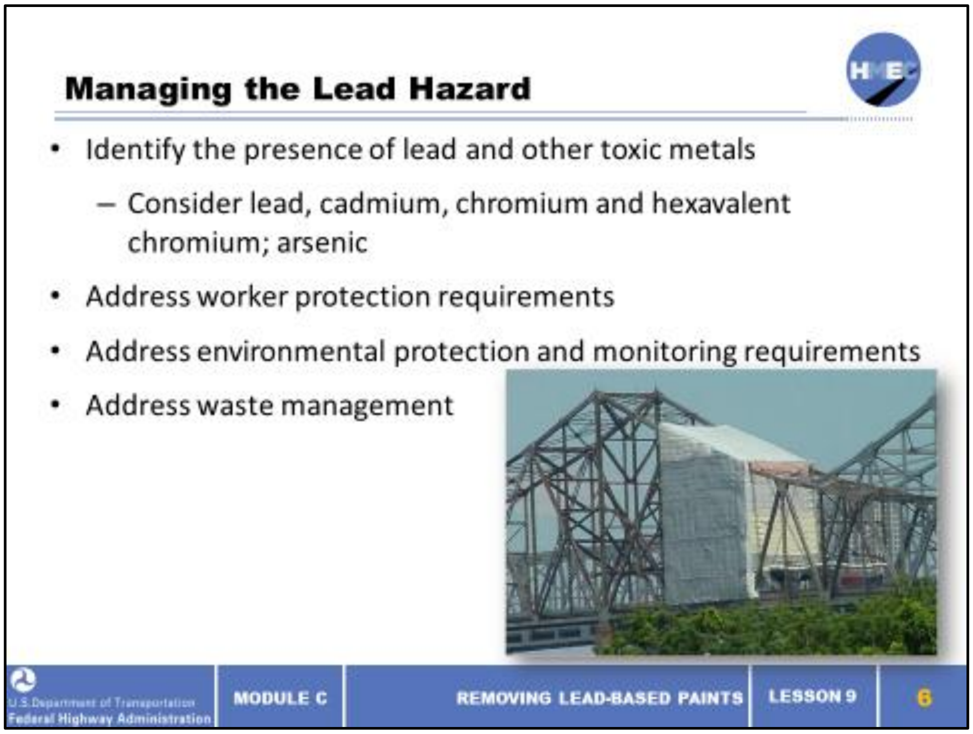
Slide 5



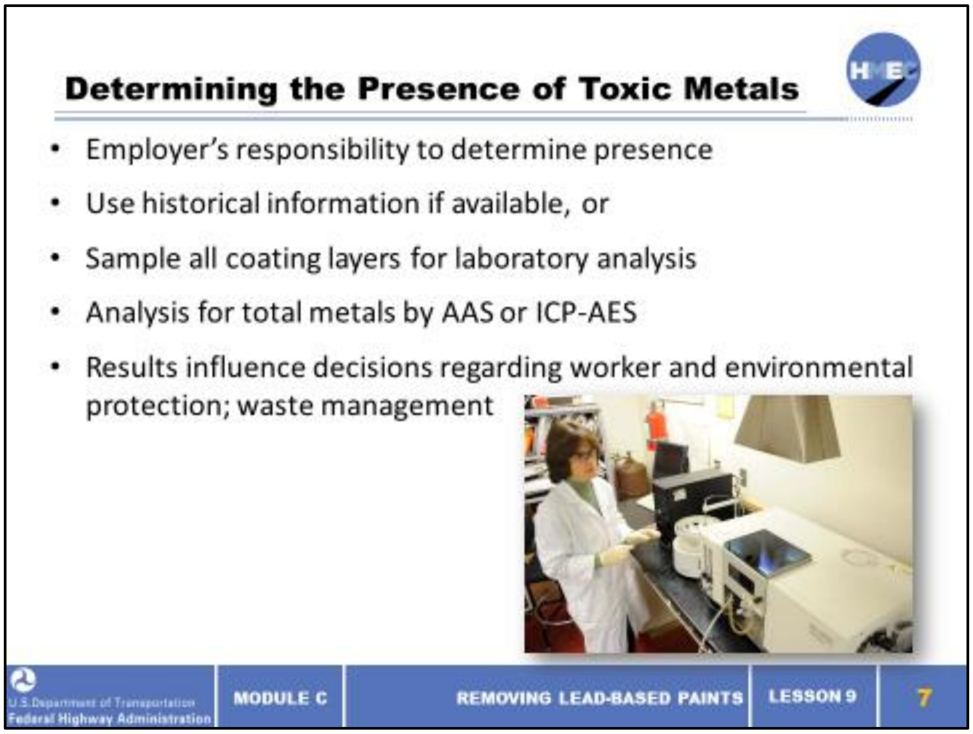
Lead was widely used for over 100 years as a pigment in paint to inhibit corrosion of steel (bridges, water towers, ships, other structures), up until the 1980's. Red lead, basic lead silico chromate paints contained 10-30% lead by weight. Most of the highway overpasses in this country were constructed between 1950–1980; all with several coats of lead- and chromate-based paints. These paints have all exhausted their useful lives and are being gradually abated. Maintaining the paint systems on these types of structures is challenging due to the inherent requirements for worker and environmental protection during any lead paint disturbing activities. De-leading our nation's structures will go on for the next 50-plus years, as nearly 80% of US highway bridges contain lead-based paint

Slide 6



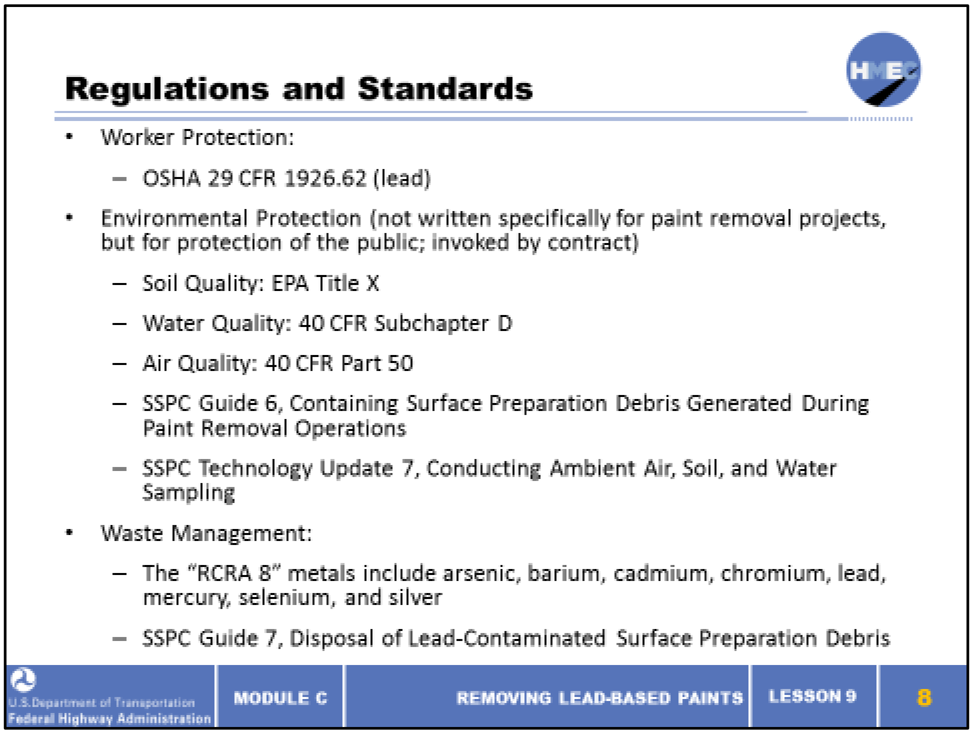
It is a good practice for Agency to identify the toxic metals in the coating, but it is the ultimate responsibility of the employer (contractor) to determine whether the existing coating system that requires maintenance contains lead or other toxic metals, including cadmium, chromium and hexavalent chromium. Arsenic may be present in coatings used to protect structures in a marine environment. If one or more of these toxic metals is present, then requirements for worker protection, environmental protection and hazardous waste management are invoked by specification.

Slide 7



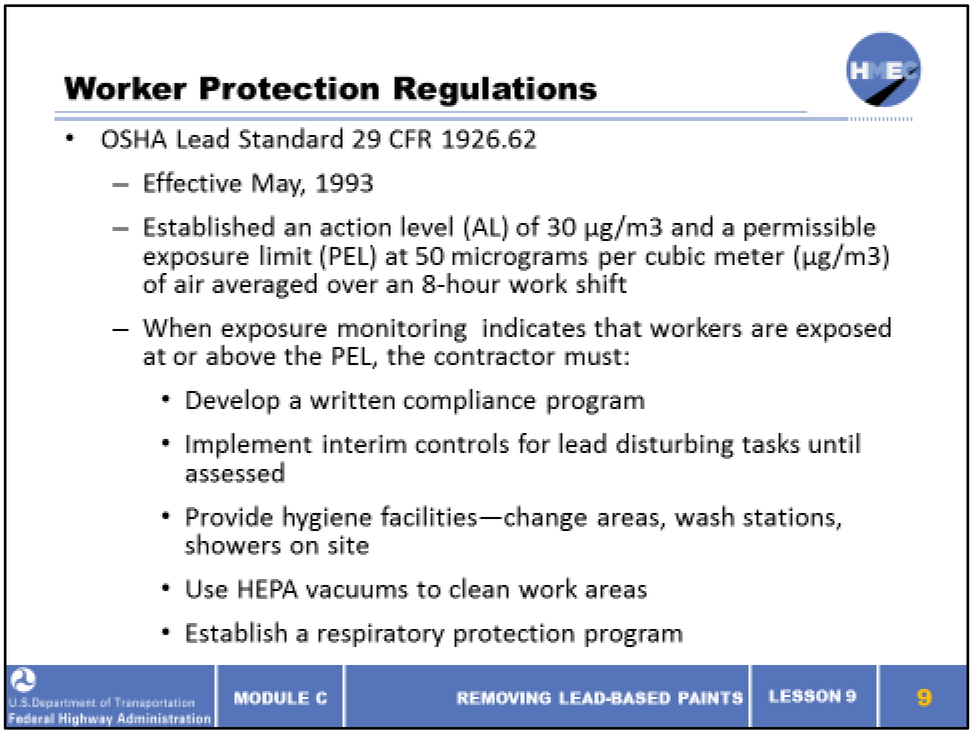
It is a good practice for Agency to identify the toxic metals in the coating, but it is the ultimate responsibility of the employer (contractor) to determine whether toxic metals are present in the existing coating. Some Agencies do not provide the toxic metal concentrations in the specification. If historical information regarding the type of coating is available it can be used; however oftentimes these records are unavailable or non-existent. So testing of the existing paint system is often required. While there are field methods like LeadCheck swabs that can be used to determine the presence of lead, they are not typically sensitive enough, and do not detect other toxic metals like cadmium and chromium. Laboratory analysis is often necessary. It is important to sample all coating layers, down to the steel surface, as toxic metals may be present in the primer layer or in multiple layers. Samples are transported with a Chain-of-Custody to a laboratory for analysis by atomic absorption spectroscopy (AAS) or inductively coupled plasma atomic emission spectroscopy (ICP-AES). The results of the analysis will influence decisions regarding worker and environmental protection, as well as management of the waste streams that are generated.

Slide 8



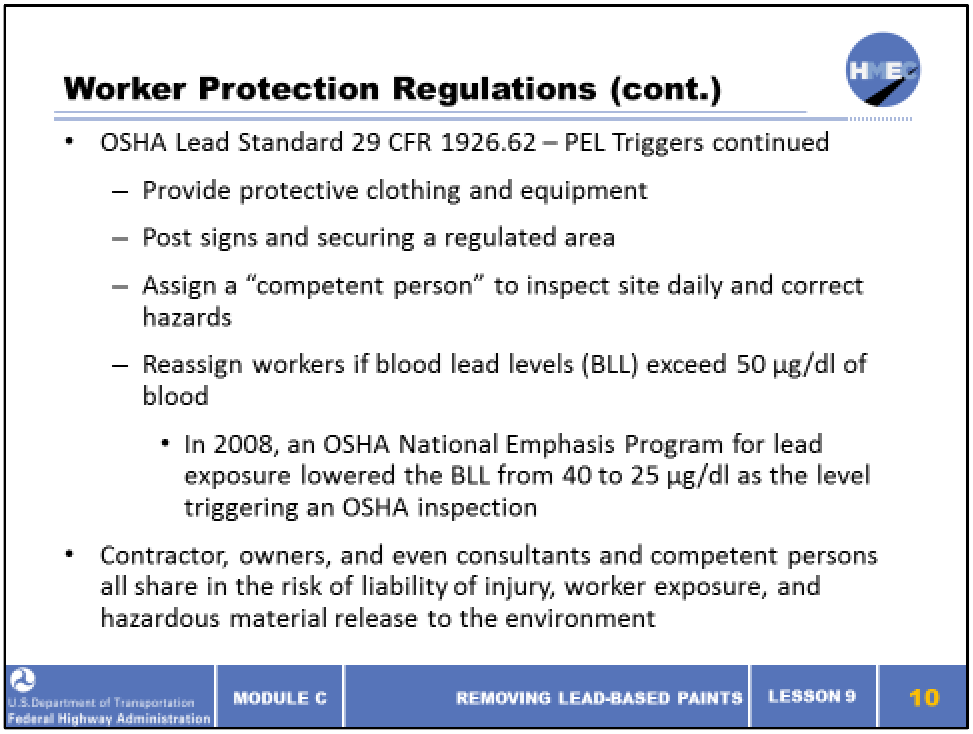
Bridge paints can contain lead, cadmium, chromium, and other toxic metals. When toxic metals are identified in any concentration, the Occupational Safety and Health Administration (OSHA) has requirements for worker protection, and the Resource Conservation and Recovery Act (RCRA) has requirements for disposal of hazardous materials. The Environmental Protection Agency (EPA) has regulations designed to protect the public health and welfare, so it is common to invoke these requirements (by contract) on bridge painting projects. This typically includes air, soil and water quality. SSPC Guide 6, "Guide for Containing Surface Preparation Debris Generated During Paint Removal Operations" describes various classes of containments for different paint removal methods, as well as methods for monitoring the effectiveness of the containment as they relate to maintaining air, soil and water quality. SSPC Technology Update 7 (TU 7) describes a variety of air, water and soil/sediment monitoring methods used for measuring emissions of lead, particulate matter, or dust emissions during surface preparation operations, construction or painting activities. SSPC Guide 7, "Guide to the Disposal of Lead-Contaminated Surface Preparation Debris" describes the procedures associated with classifying hazardous and non-hazardous waste streams and procedures for proper disposal.

Slide 9



Discuss that OSHA issued the Lead Exposure in Construction: Interim Final Rule in May, 1993, and set the permissible exposure limit (PEL) at 50 micrograms of lead per cubic meter of air (50 $\mu g/m^3$) averaged over an 8-hour work shift. OSHA requires employers to reduce exposure to lead below the PEL using engineering controls first, then work practices and personal protective equipment (PPE). The standard also sets an action level (AL) of 30 $\mu g/m^3$. Contractors must provide medical surveillance (blood testing), training, and exposure monitoring if workers are exposed at or above the action level.

Slide 10



The lead in construction standard invokes requirements for protective clothing and equipment, site-specific training on the lead hazards, posting of signs and securing a regulated area, assigning a "competent person" to inspect the jobsite daily and have the authority to take immediate corrective actions to correct any hazards, and for reassigning workers if blood lead levels (BLL) exceed 50 micrograms per deciliter (µg/dl) of blood.

Note that in 2008, OSHA developed a National Emphasis Program (NEP) on lead exposure and lowered the BLL that triggers an OSHA inspection from 40 to 25 µg/dl. Effective implementation of engineering controls, work practices and personal protective equipment can prevent an escalation in worker blood lead levels.

Contractors, bridge owners, consultants, and competent persons all share in the liability associated with worker injury and exposures, and hazardous material releases to the environment.

OSHA enforces the requirements of the lead standard and there are significant fines associated with violations. The presence of lead-based paint can significantly increase the scope and cost of a bridge painting project.

Slide 11

Common OSHA PPE Requirements for Bridge Painting Projects

Respirators:	Air purifying or supplied air
Protective Clothing:	Whole body coveralls (must be laundered or disposed of)
Eye Protection:	Required at all times
Head Protection:	Hard hats required for anyone on the bridge site
Foot and Hand Protection:	Work boot and gloves (must remain on-site)
Hearing Protection:	Required for any employee exposed to noise higher than 90 decibel (dBA).
Hygiene Facilities:	Hand wash facilities; shower facilities

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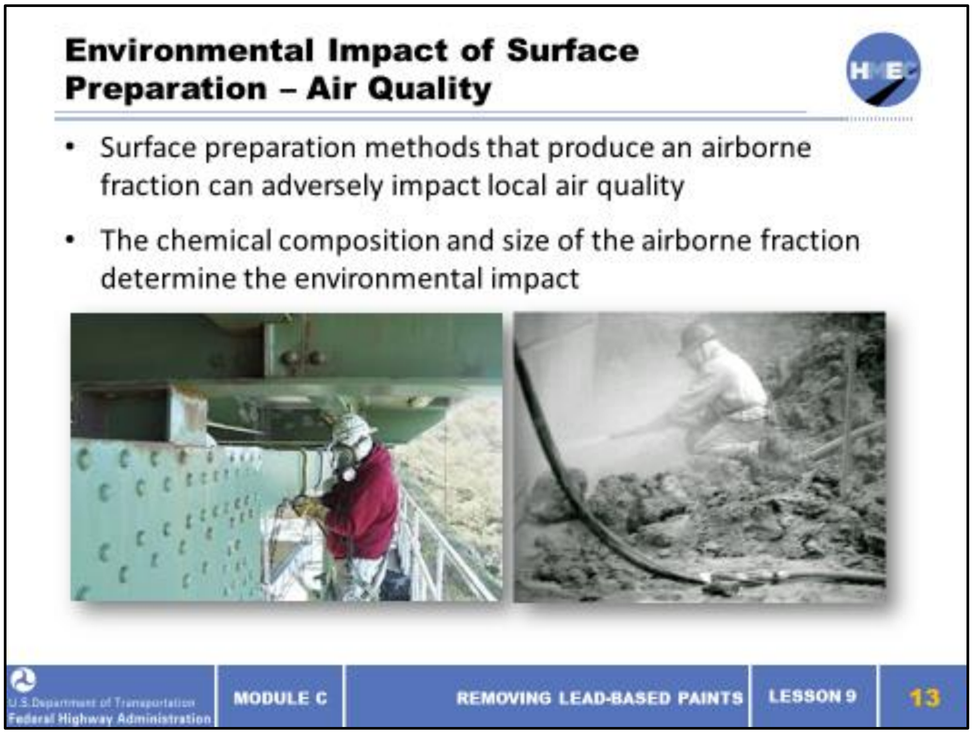
OSHA requires the use of respirators, protective clothing, and hygiene facilities to minimize/eliminate exposure to hazardous materials. In addition, protection for the hazardous environment includes use of eye and face protection, hard hats for head protection, work boots for foot protection, and hearing protection since the project sites almost always contain a noise hazard. The OSHA PEL listed in the Construction Industry Noise Standard (29 CFR 1926.52) is 90 decibel (dBA). Hearing protection is required for any employee exposed to noise rating higher than the PEL. Abrasive blasting cleaning produces noise levels that typically 100–110 dBA or higher. Employees should be enrolled in a hearing conservation program.

Slide 12

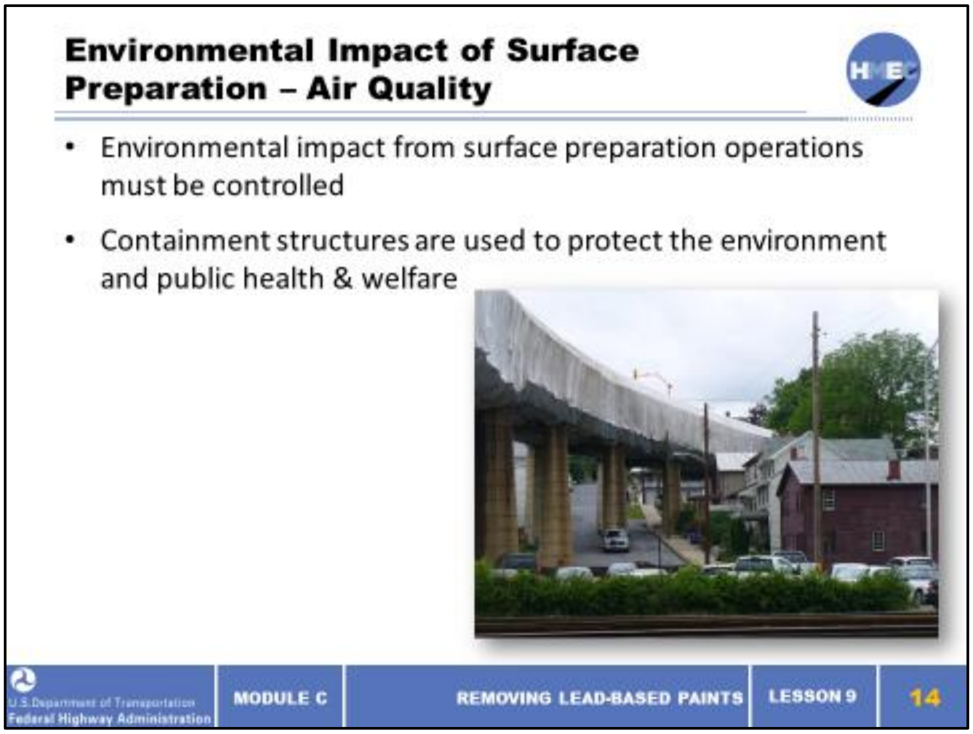
Surface preparation and all of the waste created obviously has environmental effects on the land, air, water, and soil quality. We rely on containment to prevent releases to the environment.

Slide 13



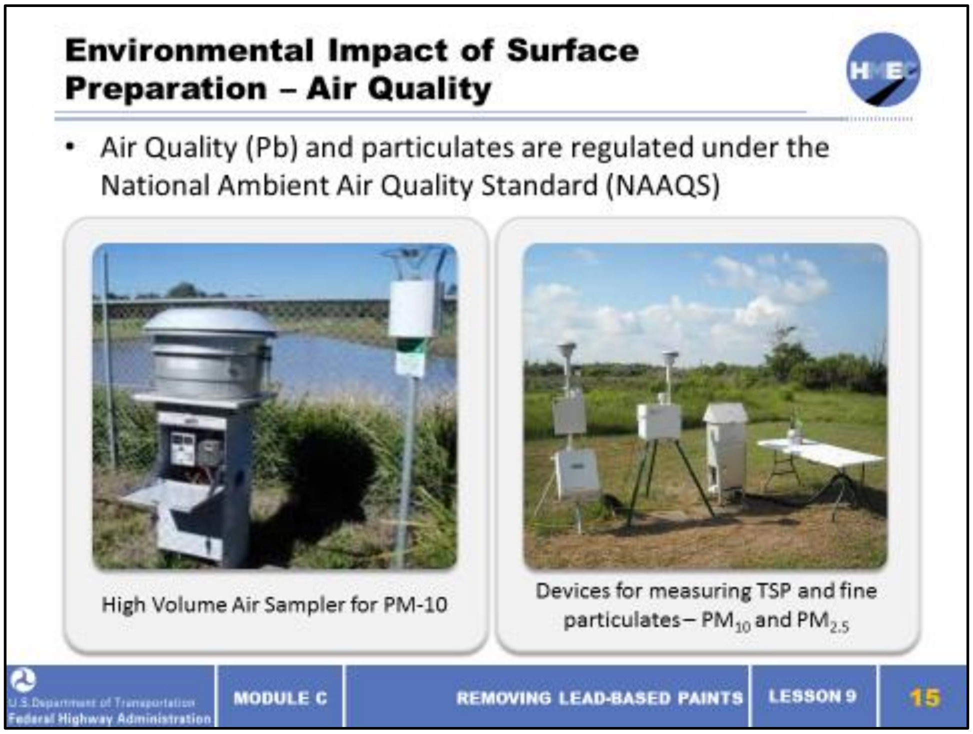
Surface preparation methods used on bridges can include mechanical hand or power tool cleaning, dry or wet abrasive blast cleaning, chemical stripping or water jetting. With the exception of chemical stripping, the particles will become airborne and may adversely impact air quality, whether by chemical composition and/or particle size.

Slide 14



A containment is designed, erected and maintained to protect the air and surrounding public from the effects of surface preparation operations, including nuisance dust. The contractor is responsible for designing, erecting and maintaining the integrity of the containment throughout the project, and for verifying that the load imparted by the containment does not adversely impact the structural integrity of the bridge.

Slide 15



Lead is measured in the form of total suspended particulate (TSP). TSP monitors allow all of the total suspended particulate in air to be collected through the sampling head (i.e., triangle top) and be deposited onto a filter. The filter is analyzed for lead.

The PM-10 monitor is designed to allow all size dust to enter into the sampling head (i.e., mushroom top). However, by forcing the air stream through a series of tubes and changing its direction, the sampling head discards the larger size dust and only finer particulate matter is deposited on a filter. The dust that travels the required pathway and is collected on the filter is generally less than 10 microns in diameter. That is, the dust that collects on a PM-10 filter is of a size small enough to be inhaled into the deep regions of the lung (respirable fraction). We have recently learned that PM-2.5 (particles smaller than 2.5 microns) can be trapped in the lungs and have adverse health effects. It doesn't matter what type of dust it is, only that it's small. The filter is weighed before installation and after removal to determine the weight of the PM-10 and PM-2.5 TSP and PM-10 monitors are identical except for the size of the selective heads and the filter media used.

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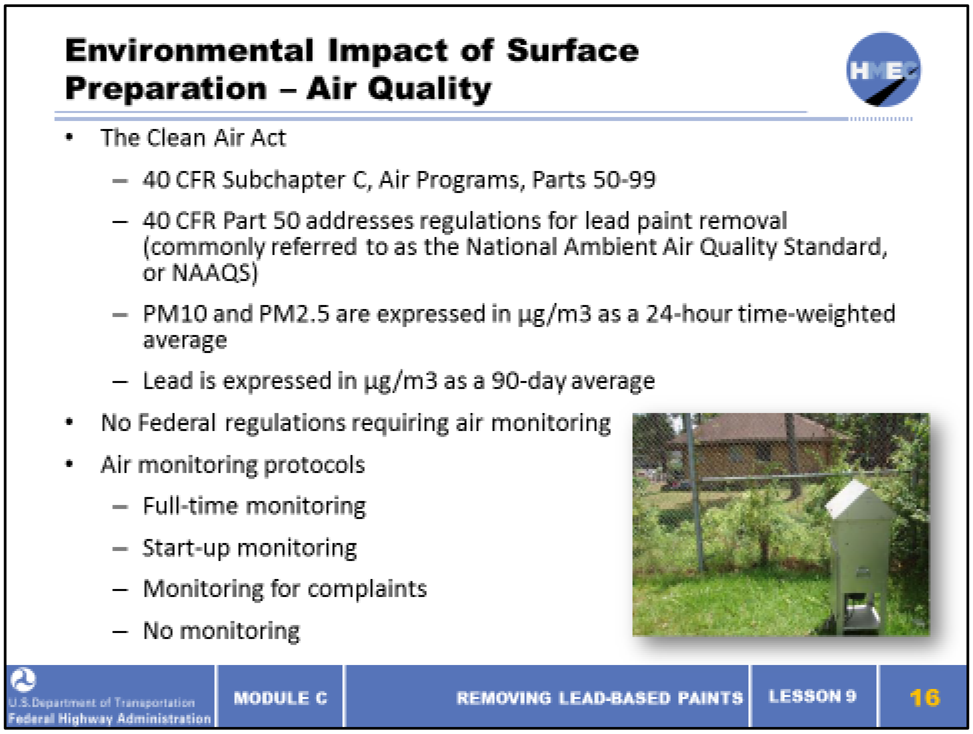
Slide 16

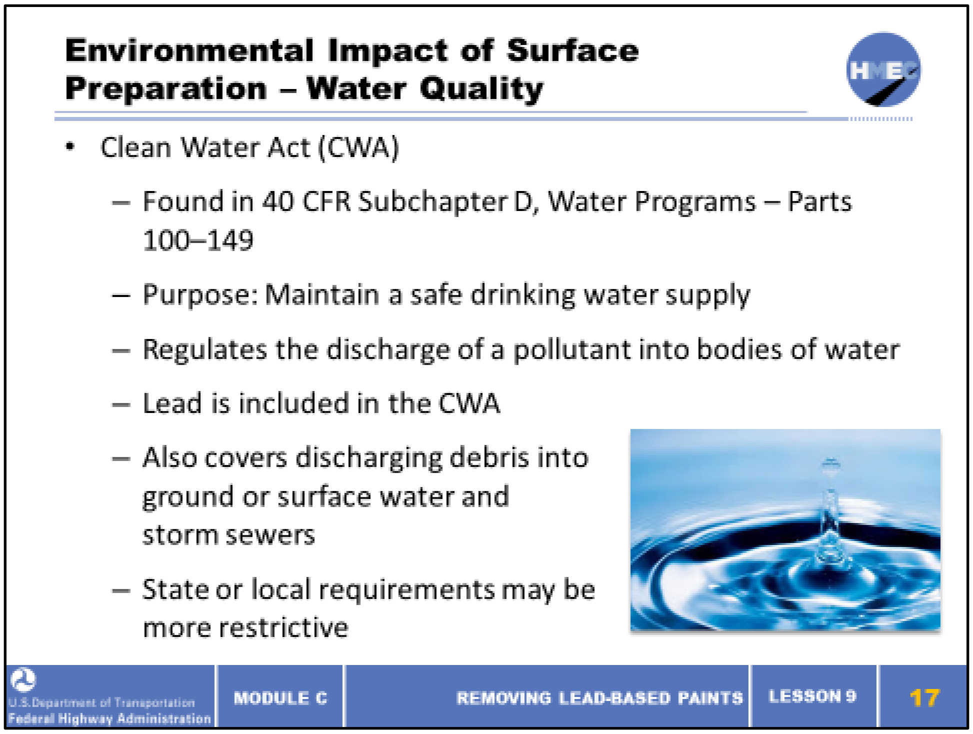


The Clean Air Act is found in 40 CFR Subchapter C, Air Programs, Parts 50-99 (40 CFR Part 50 addresses regulations for lead paint removal, and is commonly referred to as the National Ambient Air Quality Standard, or NAAQS). Allowable thresholds for PM_{10} and $PM_{2.5}$ are expressed in µg/m^3 as a 24-hour time-weighted average; the allowable threshold for lead is expressed in µg/m^3 as a 90-day average.

There are no Federal regulations that require ambient air monitoring on lead paint removal bridge projects. Some counties have requirements; but typically ambient air monitoring is invoked by contract.

Protocols for measuring air quality can vary from full-time, start-up, complaint, and/or no monitoring. Full-time monitoring is for properties with high visibility or when required by the contract. Start-up monitoring is used to establish suitability of the containment. Monitoring for complaints typically arises with visible emissions, and no monitoring is when public health not an issue, such as in a plant, where emissions will not carry beyond property lines, or there is no public access.

Slide 17



The Clean Water Act (CWA) was promulgated to ensure that the public has access to safe drinking water. The CWA regulates the discharge of a pollutant into bodies of water; onto the ground, which could potentially be carried into a water supply; or into storm sewers. Lead is one of the hazardous substances included in the CWA. It also addresses discharging debris into ground or surface water. Any state or local agency's water quality standards can be more restrictive than the Federal standard.

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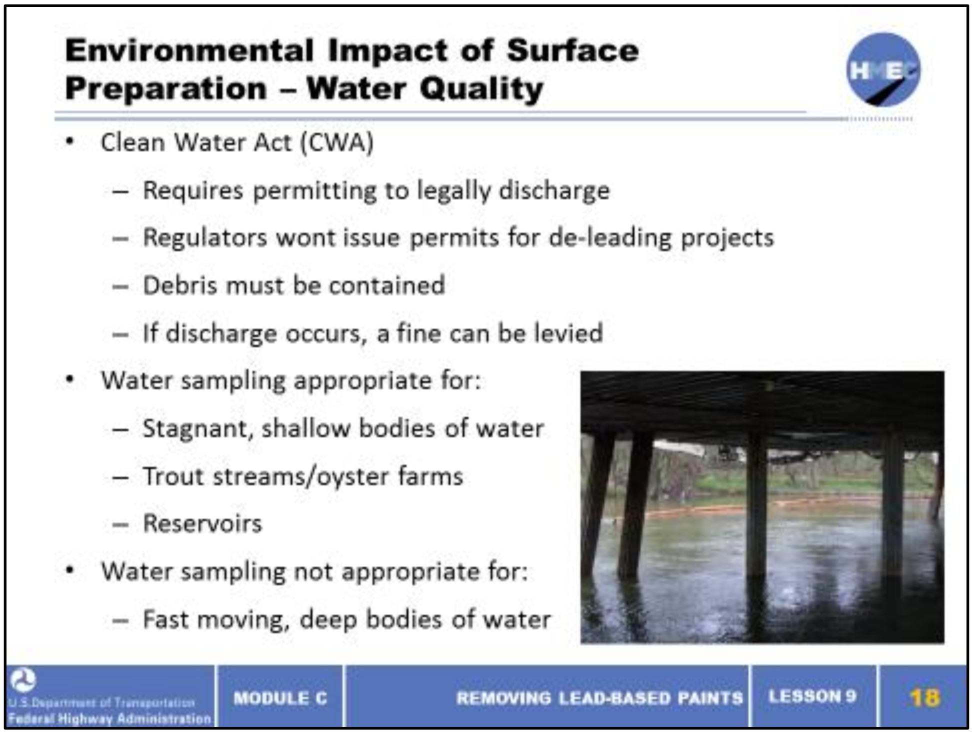
Slide 18



The CWA requires permitting to intentionally discharge into bodies of water. Regulators will not issue a permit for lead paint removal projects, therefore debris must be contained and not allowed to enter storm sewers or bodies of water. If a discharge occurs, a fine is levied for not securing a permit.

Water sampling may be appropriate for stagnant, shallow bodies of water, or sensitive sources such as trout streams and oyster farms. If a bridge is over a drinking water reservoir then water sampling may be appropriate. Water sampling is not appropriate for fast moving, deep bodies of water, and like soil (discussed next) can be highly variable making it difficult to compare pre- and post-project analyses.

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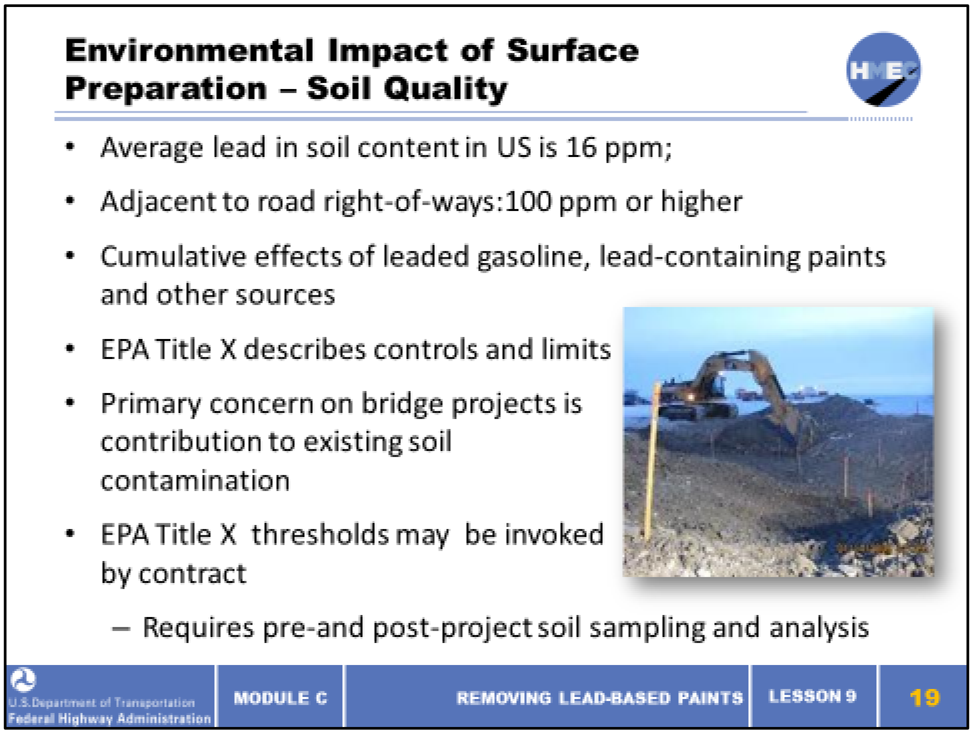
Slide 19

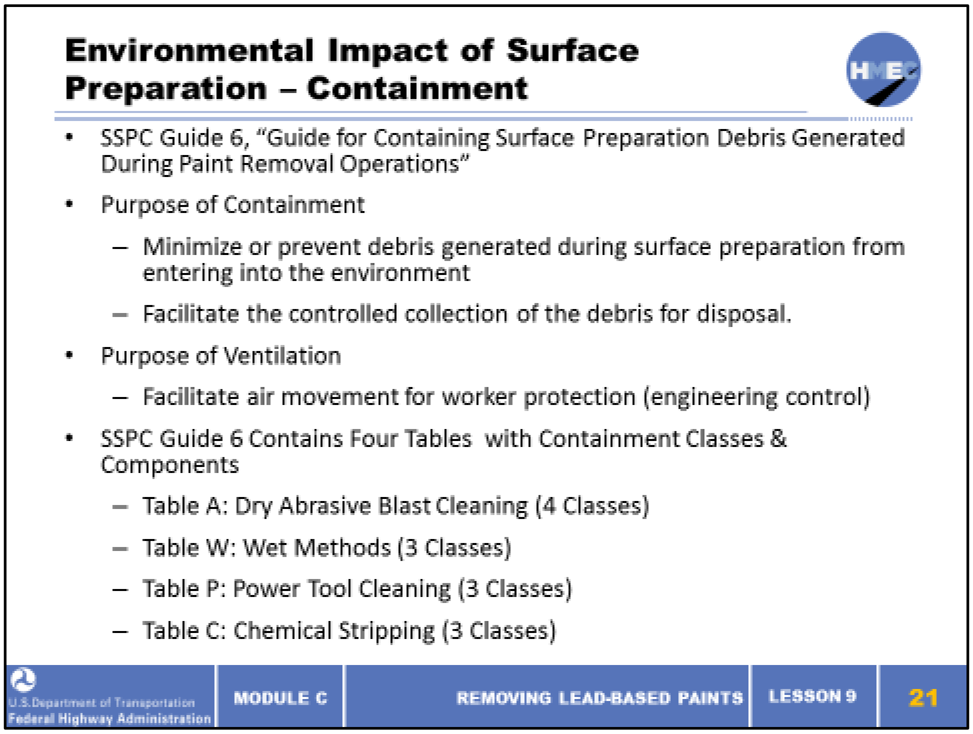


Due to cumulative effects of leaded gasoline, lead-containing paints and other sources, the average soil in the US has a lead content of 16 ppm; by road right-of-ways it is 100 ppm or higher. EPA Title 10 describes controls to prevent soil contamination, indicates the limits and provides thresholds when various isolation or remediation methods are required. However, the primary concern on bridge painting projects is whether the contractor contributed to existing lead levels in the soil by releases to the ground during paint removal operations. Pre-project soils samples may be obtained and analyzed only if there is visual evidence of deposits of paint chips and abrasive debris on the ground. In this case, post-project soil samples are collected at the identical locations as the pre-job samples and analyzed.

Slide 20

Once a location or locations are selected, a one-foot template is placed on the ground and one soil plug approximately ¾" diameter and ½" deep is taken from each of the four corners of the template and from the center of the template. The five plugs constitute a single soil sample. The pre-project samples are either analyzed for total lead content or stored for possible post-project analysis. After the project is completed, if there appears to be deposits on the soil, post-project samples are collected at the identical locations as the pre-project samples and analyzed. A statistical analysis of the data is performed to determine whether surface preparation operations contributed to background lead levels in the soil.

Slide 21



A Containment system includes the cover panels, screens, tarps, scaffolds, supports, and shrouds used to enclose an entire work area or a paint removal tool. The purpose is to minimize or prevent the debris generated during surface preparation from entering into the environment, and to facilitate the controlled collection of the debris for disposal. Containment systems may also employ the use of ground covers or water booms.

A Ventilation systems include both natural ventilation and mechanical ventilation (fans, hoods, and duct work), to provide air movement across the work area, and dust collectors to clean the discharged air.

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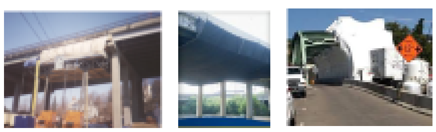
Slide 22

Environmental Effects of Surface Preparation – Containment

- Containment Components
  - Materials
  - Penetrability
  - Support structure
  - Joints
  - Entryway

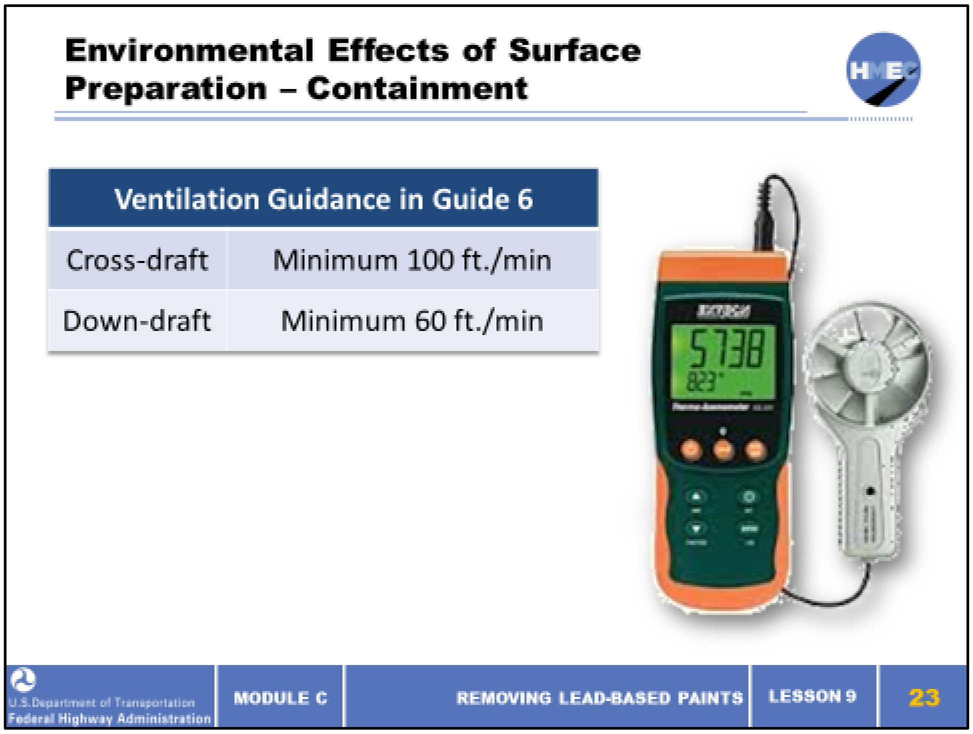


- Ventilation System Components
  - Air make-up
  - Input airflow
  - Air pressure
  - Air movement
  - Exhaust air filtration

Refer to the SSPC Guide 6 Tables A, W, P and C.

U.S. Department of Transportation Federal Highway Administration | MODULE C | REMOVING LEAD-BASED PAINTS | LESSON 9 | 22

Slide 23



A rotating vane anemometer like the one pictured can measure both cross-draft and down-draft air movement. SSPC Guide 6 references suggested minimum air movement from the Industrial Ventilation Guide, including 100 feet/minute cross draft ventilation and 60 feet/minute down draft ventilation.

Slide 24

There are several acts of Congress dealing with hazardous waste. By far the most significant is The Resource Conservation and Recovery Act (RCRA). Essentially this act banned open dumping of industrial wastes. It provided a comprehensive national program to encourage source reduction, recycling, and safe disposal of municipal wastes. What's more, RCRA mandated strict requirements for treatment, storage, and disposal of hazardous waste to minimize present and future risks. The RCRA has evolved significantly since its inception in 1976.

The Resource Conservation and Recovery Act (RCRA) of 1976, which amended the Solid Waste Disposal Act (40 CFR Parts 239-299), addresses solid (Subtitle D) and hazardous (Subtitle C) waste management activities. Subtitle C of RCRA (40 CFR Parts 260-299) establish a "cradle-to-grave" system governing hazardous waste from the point of generation to disposal. Currently, EPA has delegated its authority to implement various provisions of RCRA to 46 of the 50 States.

Slide 25

Identification of Solid and Hazardous Wastes - (40 CFR Part 261) lays out the procedure every generator should follow to determine whether the material created is considered a hazardous waste, solid waste, or is exempted from regulation. Standards for Generators of Hazardous Waste - (40 CFR Part 262) establishes the responsibilities of hazardous waste generators, including obtaining an identification number, preparing a manifest, ensuring proper packaging and labeling, meeting standards for waste accumulation units, and recordkeeping and reporting requirements. Each State is responsible for managing their hazardous waste program, and each State can interpret the Federal standard differently. In other words, some materials can be considered hazardous wastes in some States and not in others.

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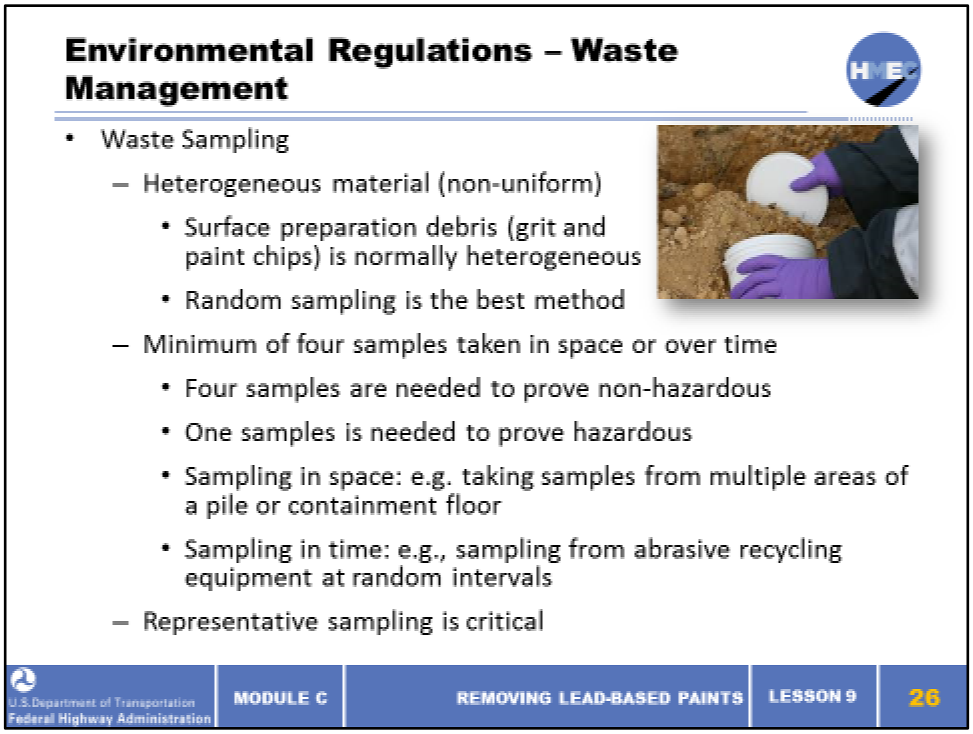
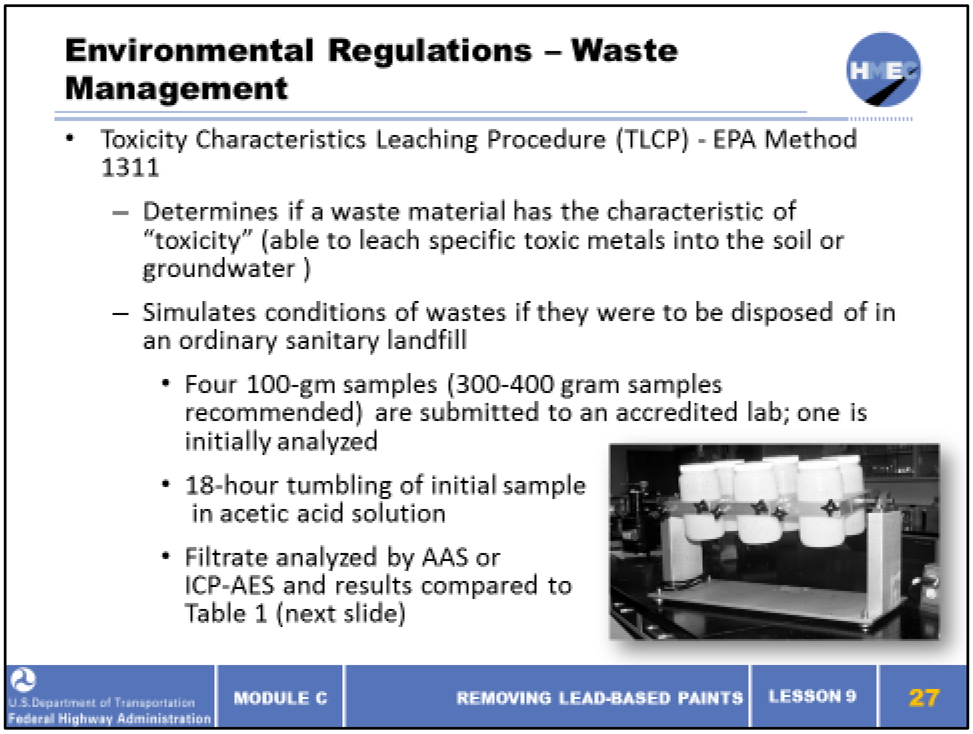
Slide 26



Waste sampling entails the use of a heterogeneous material, random sampling, and a minimum of four samples.

Slide 27



.The initial sample requires 18 hours of tumbling in an acetic acid solution under a controlled pH. Then you do the filtrate analysis by atomic absorption spectroscopy (AAS) or inductively coupled plasma-atomic emission spectroscopy (ICP-AES) and compare the result to Table 1 (shown on the next slide). The waste generator should use a laboratory that performs the analysis in accordance with test procedures and quality assurance requirements of the State or jurisdiction where the waste had been generated and in accordance with 40 CFR Part 268, Appendix 1

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Slide 28

Environmental Regulations – Waste Management

- Toxicity Leachate Threshold Levels (TCLP test result comparison):

Table 1
Toxicity Leachate Levels For Metals
(40 CFR 281 – as of November 1, 1993)

Element	Concentration mg/L (ppm)	EPA Hazardous Waste Number
Arsenic	5.0	D004
Barium	100.0	D005
Cadmium	1.0	D006
Chromium (total)	5.0	D007
Lead	5.0	D008
Mercury	0.2	D009
Selenium	1.0	D010
Silver	5.0	D011

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Impact of Toxic Metals– Costs (1980's)

1980's Painting Costs: Previous to OSHA Regulations on Lead Management	
Surface Preparation (SP-10)	$1.00/ft^2
Paint Application	0.90/ft^2
Materials – 3 Coats (IOZ, Epoxy, PU)	0.35/ft^2
Miscellaneous	0.25/ft^2
TOTAL	$2.50/ft^2

Referenced in *Journal of Protective Coatings and Linings*, Huffman, Socci, "Lead Paint Leaves its mark on Bridge Repainting Work", January 2000.

U.S. Department of Transportation Federal Highway Administration | MODULE C | REMOVING LEAD-BASED PAINTS | LESSON 9 | 29

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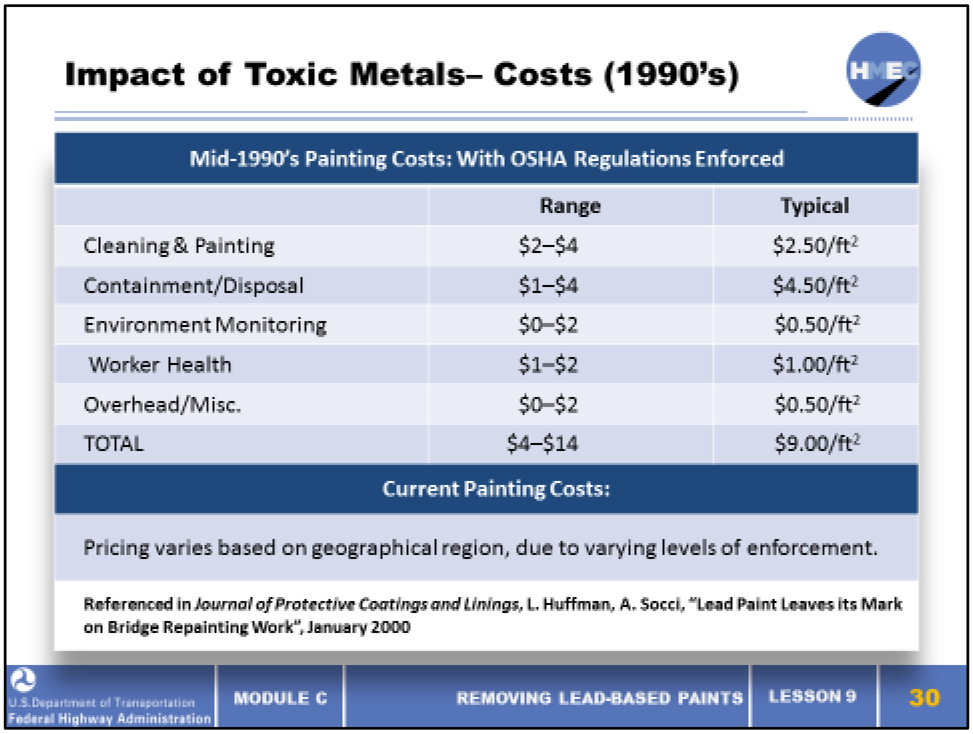


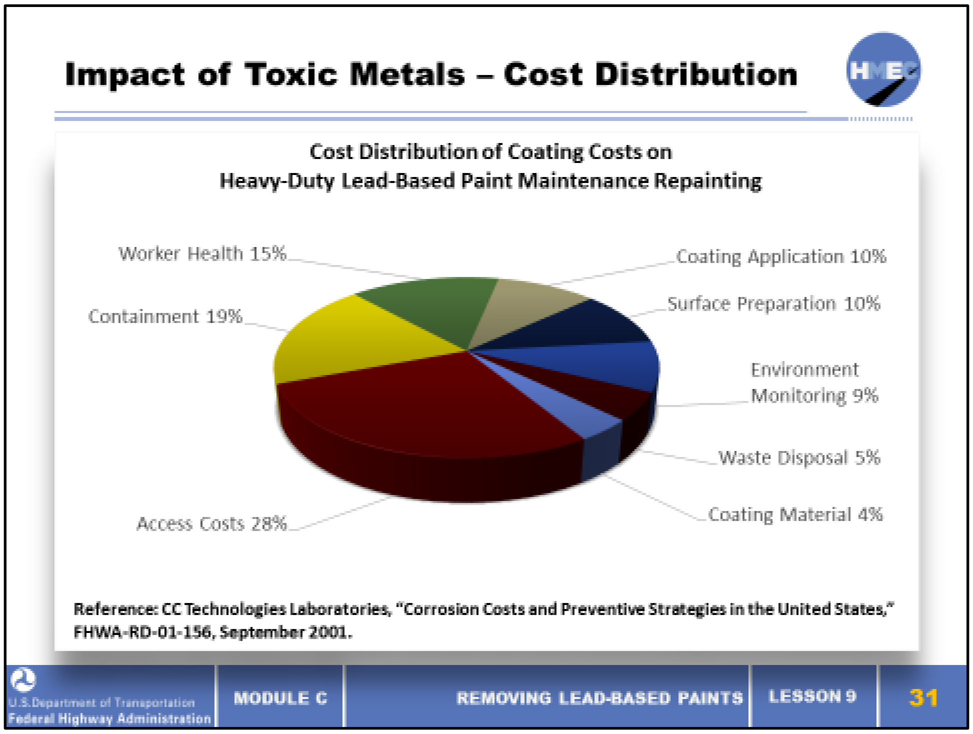
Impact of Toxic Metals– Costs (1990's)

Mid-1990's Painting Costs: With OSHA Regulations Enforced		
	Range	Typical
Cleaning & Painting	\$2–\$4	\$2.50/ft^2
Containment/Disposal	\$1–\$4	\$4.50/ft^2
Environment Monitoring	\$0–\$2	\$0.50/ft^2
Worker Health	\$1–\$2	\$1.00/ft^2
Overhead/Misc.	\$0–\$2	\$0.50/ft^2
TOTAL	\$4–\$14	\$9.00/ft^2
Current Painting Costs:		
Pricing varies based on geographical region, due to varying levels of enforcement.		

Referenced in *Journal of Protective Coatings and Linings*, L. Huffman, A. Socci, "Lead Paint Leaves its Mark on Bridge Repainting Work", January 2000

The costs of hazardous materials on bridges can triple the job cost. Typical in the US is \$7–14/ft^2, while some complex structures (major suspension bridges around metropolitan areas over bodies of water, for example) can be up to \$35–40/ft^2 due to containment and access issues.

Slide 31


Impact of Toxic Metals – Cost Distribution
HMEC
Cost Distribution of Coating Costs on
Heavy-Duty Lead-Based Paint Maintenance Repainting
Worker Health 15%
Coating Application 10%
Containment 19%
Surface Preparation 10%
Environment Monitoring 9%
Waste Disposal 5%
Coating Material 4%
Access Costs 28%
Reference: CC Technologies Laboratories, "Corrosion Costs and Preventive Strategies in the United States," FHWA-RD-01-156, September 2001.
U.S. Department of Transportation
Federal Highway Administration
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REMOVING LEAD-BASED PAINTS
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Group Discussion
How has the presence of lead in paint affected the industrial surface preparation and coating industry recently?
U.S. Department of Transportation
Federal Highway Administration
MODULE C
REMOVING LEAD-BASED PAINTS
LESSON 9
32

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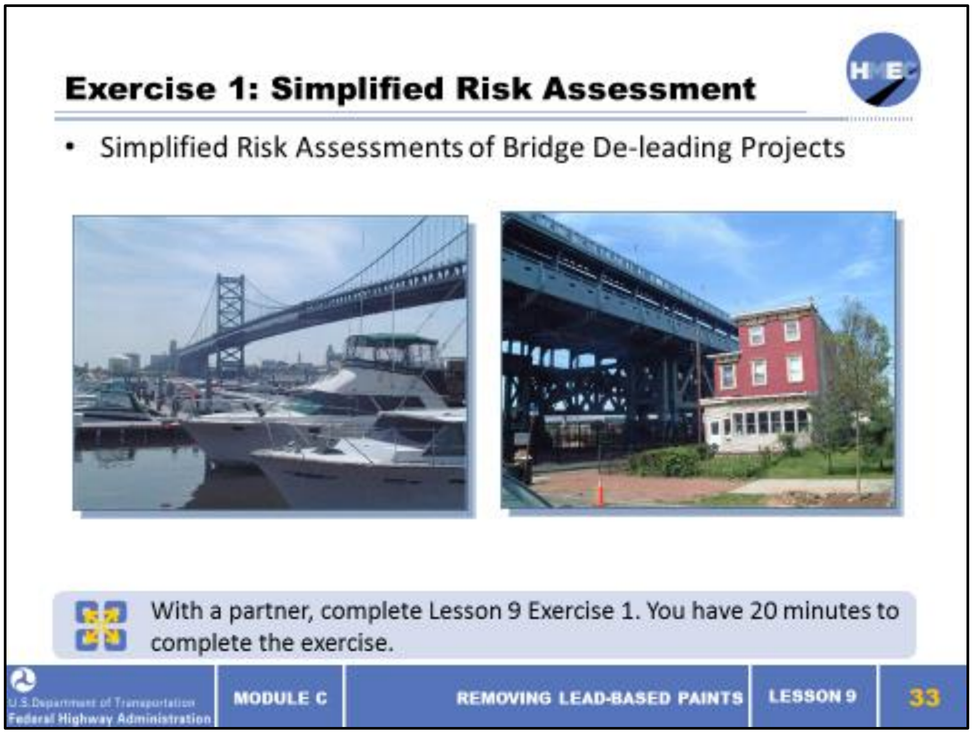
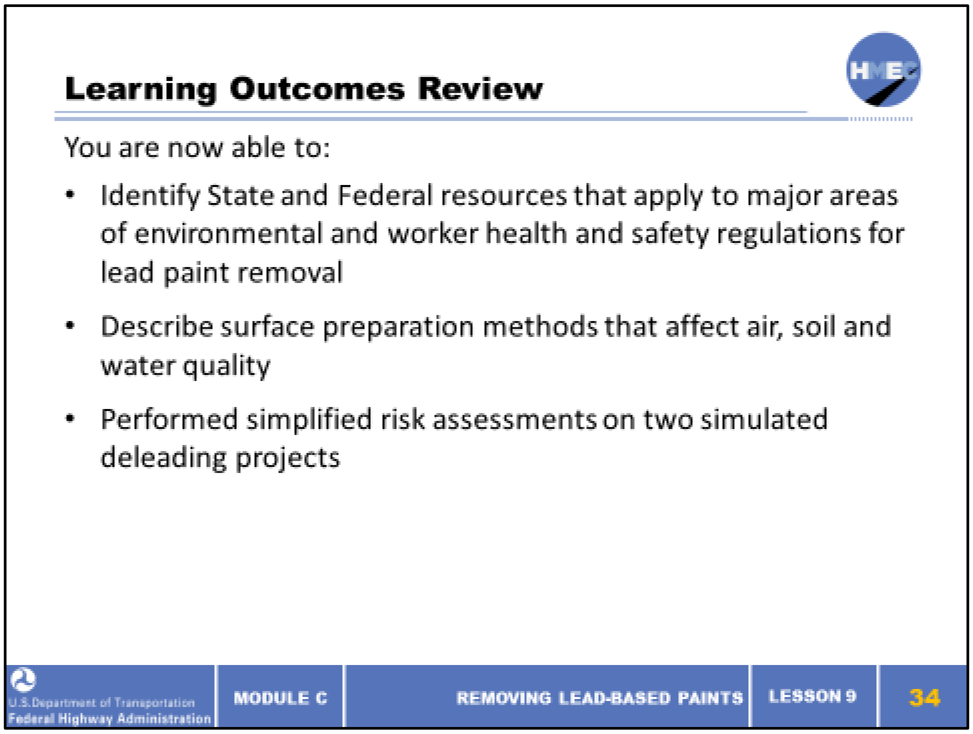
Slide 33


Exercise 1: Simplified Risk Assessment
• Simplified Risk Assessments of Bridge De-leading Projects
With a partner, complete Lesson 9 Exercise 1. You have 20 minutes to complete the exercise.
U.S. Department of Transportation
Federal Highway Administration
MODULE C
REMOVING LEAD-BASED PAINTS
LESSON 9
33

Slide 34


Learning Outcomes Review
You are now able to:
• Identify State and Federal resources that apply to major areas of environmental and worker health and safety regulations for lead paint removal
• Describe surface preparation methods that affect air, soil and water quality
• Performed simplified risk assessments on two simulated deleading projects
U.S. Department of Transportation Federal Highway Administration
MODULE C
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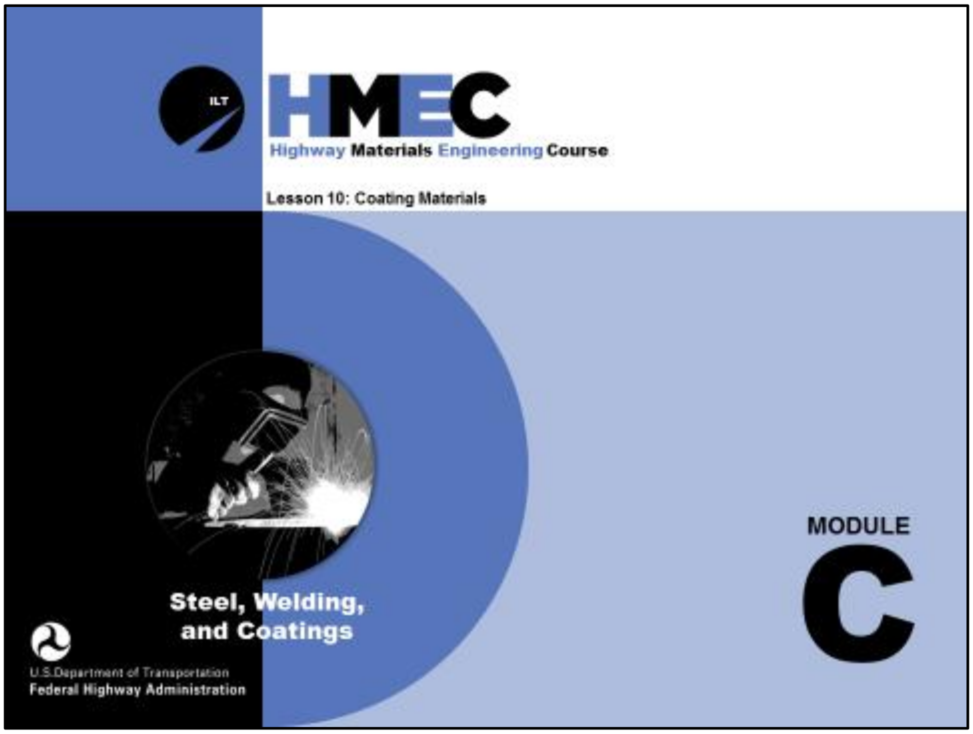
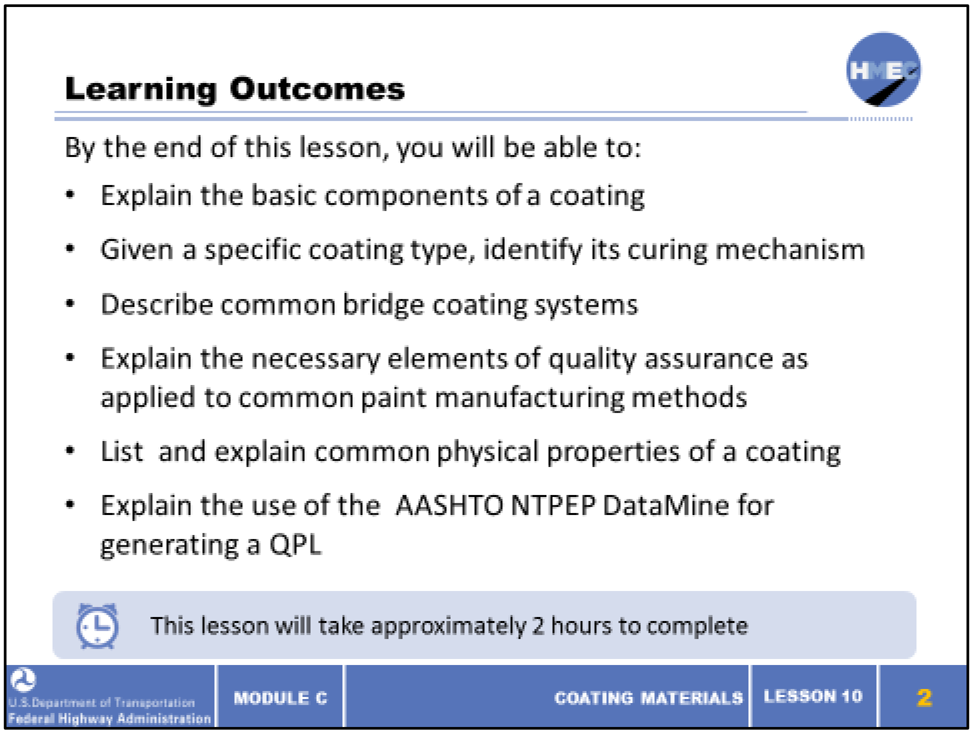
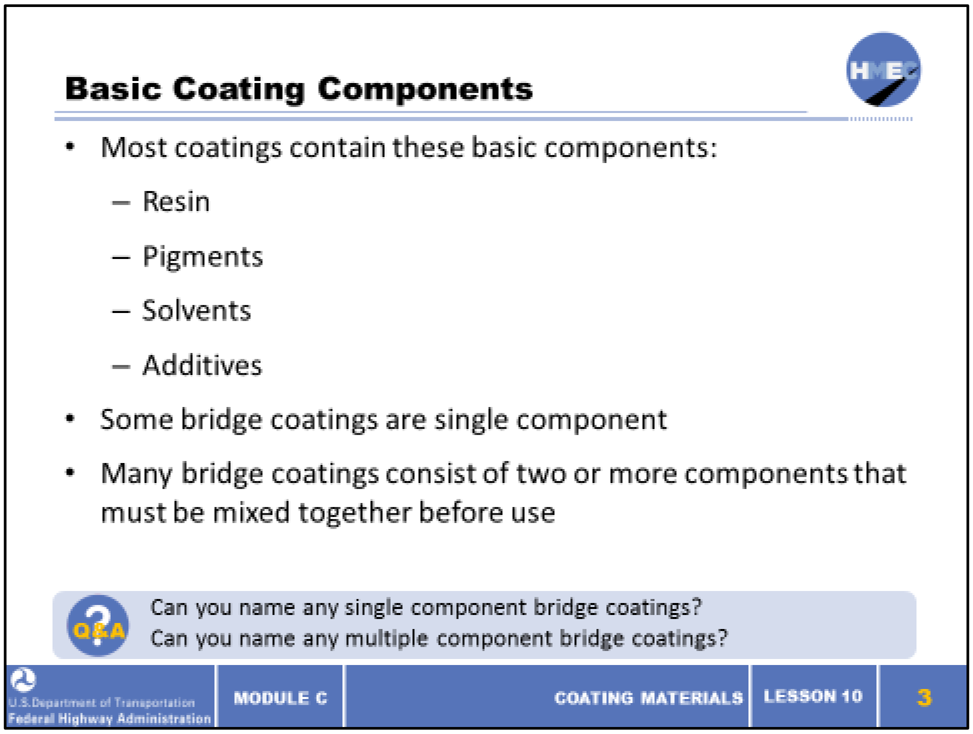
Slide 1


HMEC
Highway Materials Engineering Course
Lesson 10: Coating Materials
Steel, Welding, and Coatings
U.S.Department of Transportation
Federal Highway Administration
MODULE
C

Slide 2

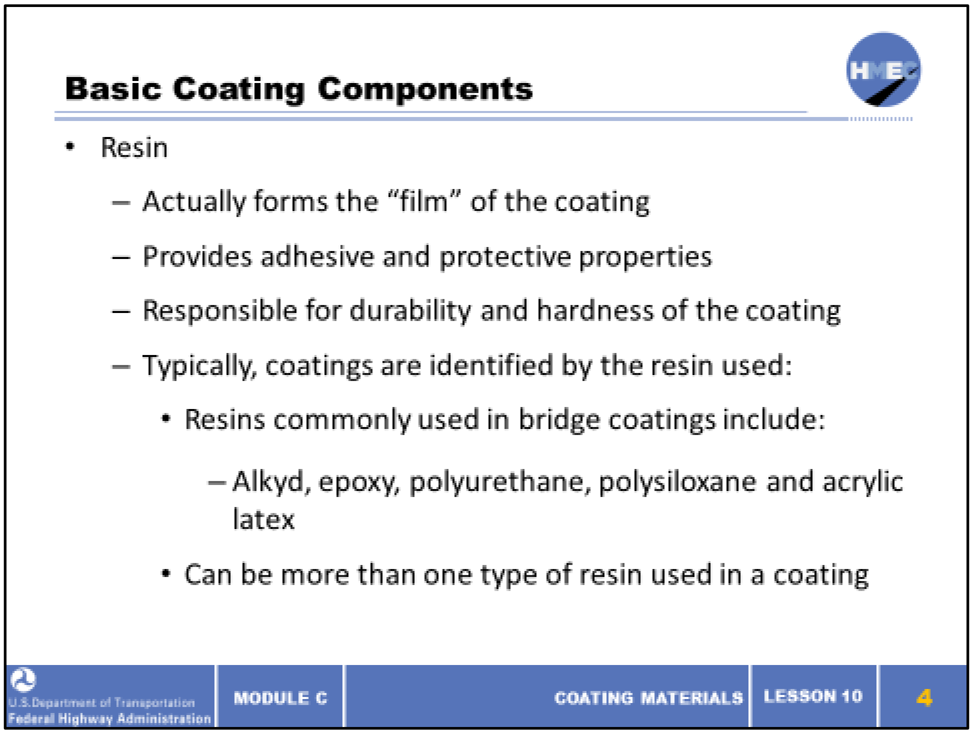

Learning Outcomes
By the end of this lesson, you will be able to:
• Explain the basic components of a coating
• Given a specific coating type, identify its curing mechanism
• Describe common bridge coating systems
• Explain the necessary elements of quality assurance as applied to common paint manufacturing methods
• List and explain common physical properties of a coating
• Explain the use of the AASHTO NTPEP DataMine for generating a QPL
This lesson will take approximately 2 hours to complete
U.S. Department of Transportation
Federal Highway Administration
MODULE C
COATING MATERIALS
LESSON 10
2

Slide 3



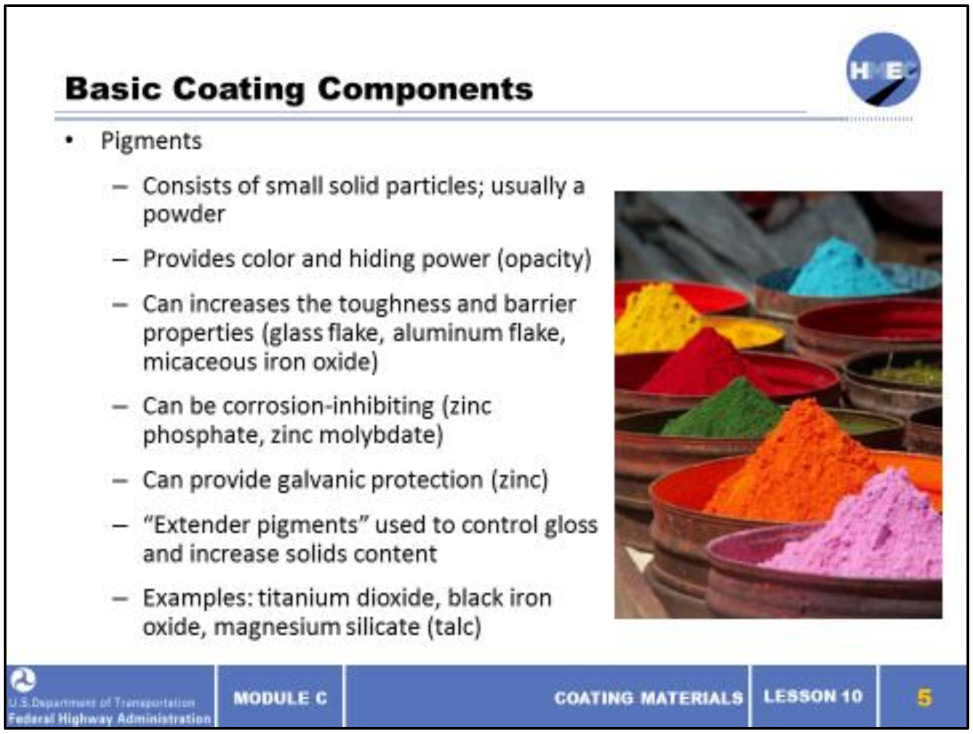
In general, industrial coatings have four main constituents: resin, pigment, solvent, and additives. Coatings can be single-component, or they can be multiple-component, which means that one component has to mix with one or two other components to get a chemical reaction in order to work.

Slide 4



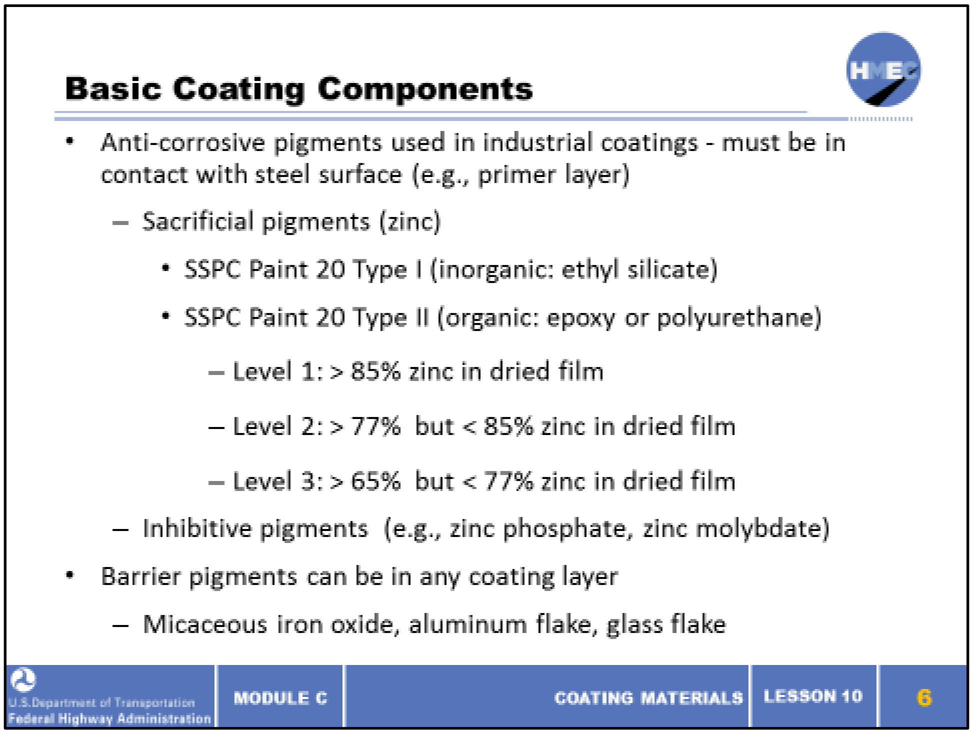
In general, the resin defines what type of coating it is; for example epoxy, alkyd, polyurethane, etc. The resin is the film forming component and provides the coating's adhesive and cohesive properties. The resin determines the coating's durability, hardness, flexibility, impact resistance, abrasion resistance and other performance properties.

Slide 5



Pigments are small particles, typically a powder but sometimes flake-like, that are added to the resin to impart features such as color, opacity, barrier properties, corrosion protection, and increased solids content.

Slide 6

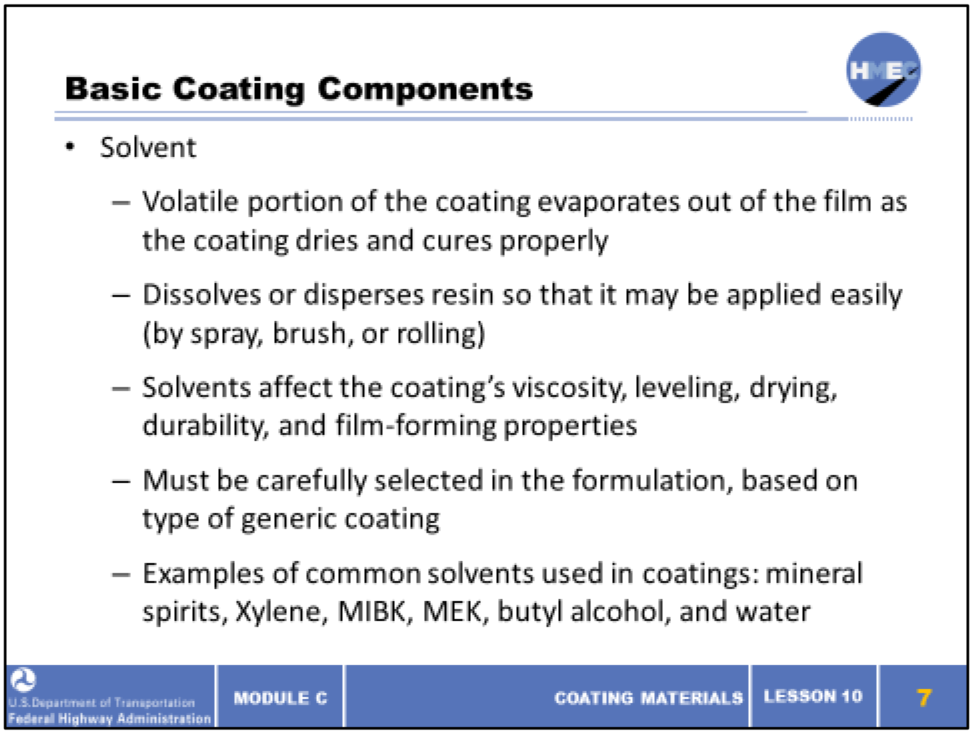


Pigments that impart corrosion protection must be in contact with the steel, so these are typically found in primers. Zinc acts as a sacrificial pigment since zinc is anodic to steel. SSPC Paint 20 lists two types of zinc-rich primers: Inorganic and organic. The type is not related to the zinc itself, but rather the resin system used with the zinc. Type 1 (inorganic) uses a solvent borne or waterborne ethyl silicate binder with up to three levels of zinc. Type II (organic) uses a solvent borne resin like epoxy or polyurethane with up to three levels of zinc. The galvanic properties of inorganic zinc (IOZ) primers are reportedly better than the organic zinc (OZ) primers since there is less insulating properties between the zinc particles and the zinc-to-steel interface; yielding better cathodic protection. However organic zinc-rich primers are easier to apply. Typically IOZ primers are applied to new steel in a shop, while OZ primers are used for maintenance of existing bridge structures, although OZ primers are used in the shop as well.

Examples of inhibitive pigments include zinc phosphate and zinc molybdate. Red lead and lead chromate primers were widely used as inhibitive pigments on bridges; however their inherent toxicity when “disturbed” during maintenance activities has all but eliminated their use.

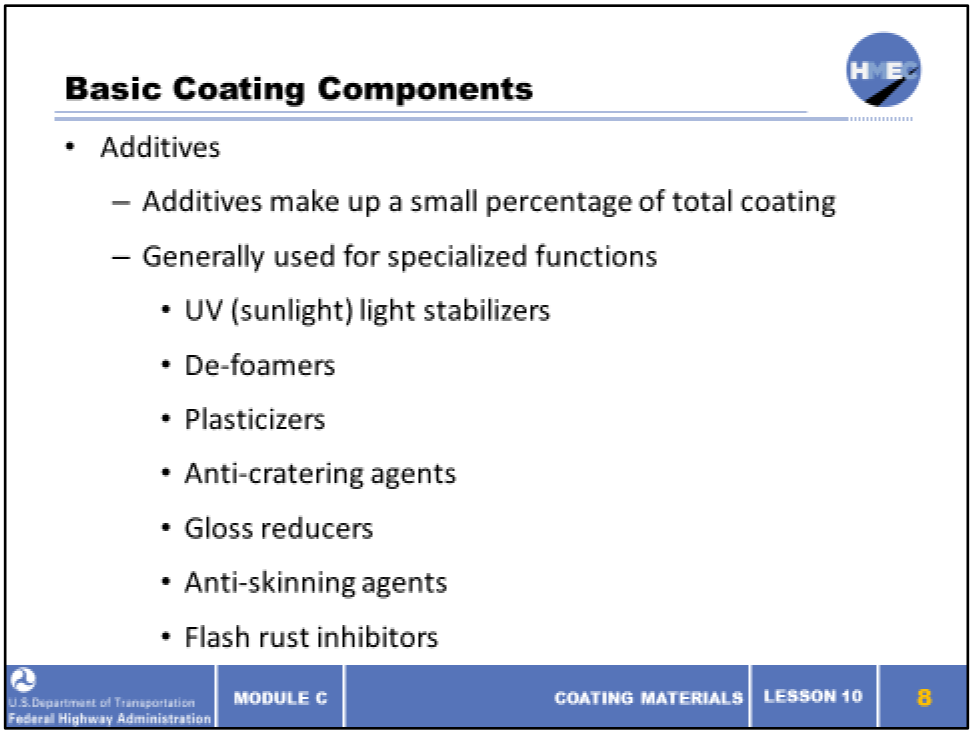
Barrier pigments like micaceous iron oxide, aluminum flake and glass flake can be used in any coating layer.

Slide 7



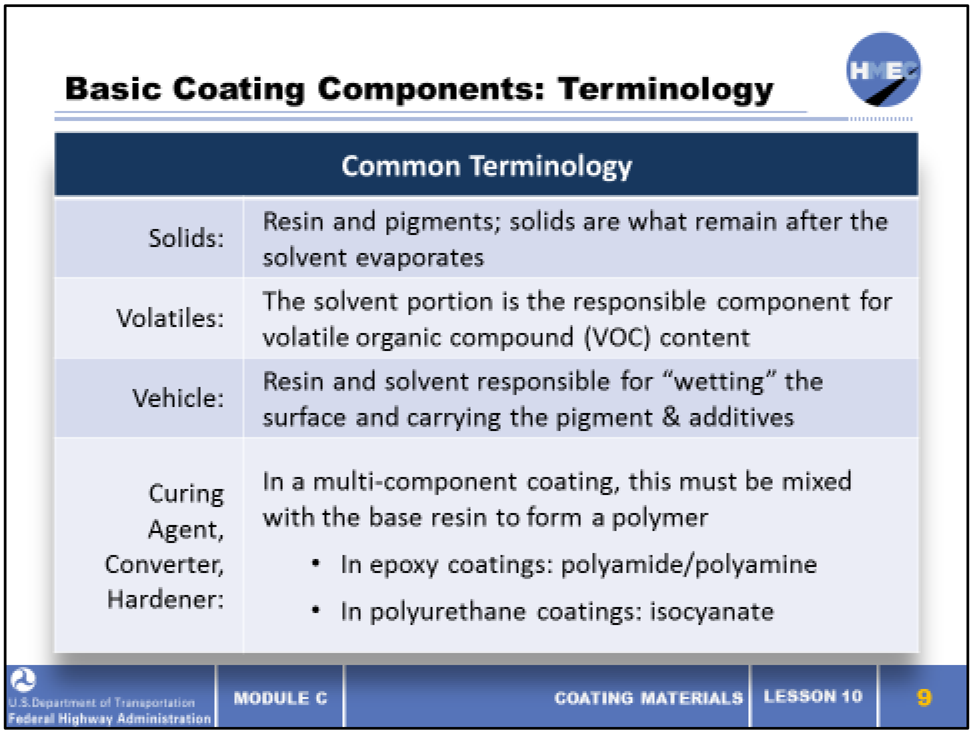
Solvents serve a number of functions. Without solvents in the coating, the resin/pigment blend is similar to molasses stored in a refrigerator. Primary solvents reduce the viscosity of the resin/pigment blend so that it can be applied by brush, roller or spray. Secondary solvents are somewhat slower to evaporate and help the coating knit and flow together once applied to the surface.

Slide 8



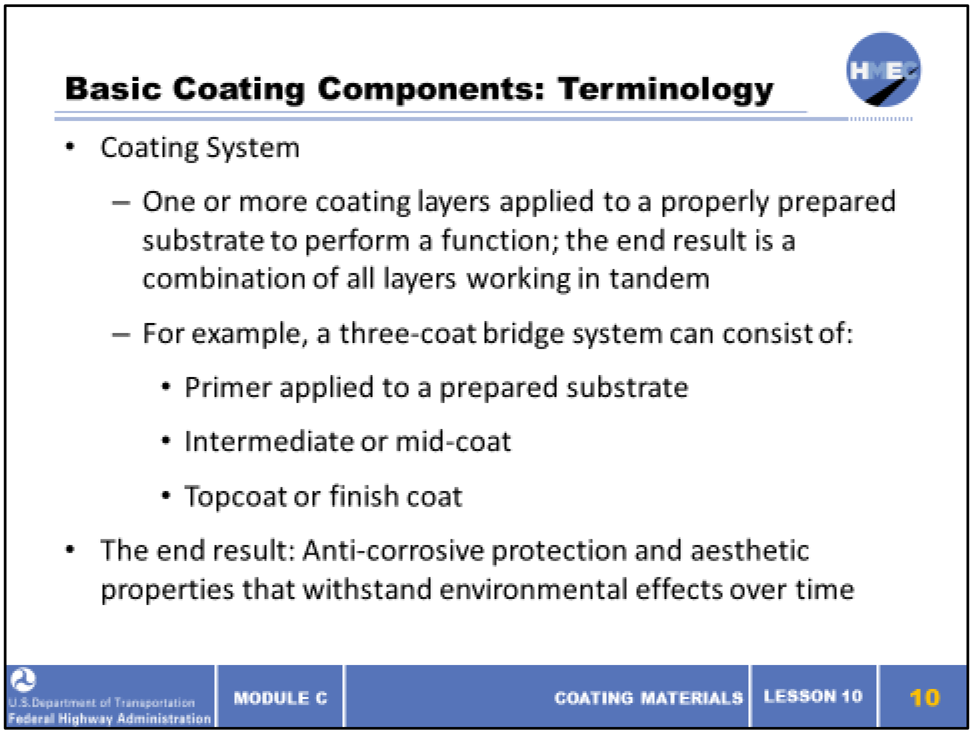
Additives are added to the formulation in very small quantities (typically <1% by weight) to impart a specific function, such as light stability or reducing gloss, as well as those listed here. Waterborne acrylic latex coatings have flash rust inhibitors formulated into the primer so the water in the paint does not cause rust bleed-through of the primer.

Slide 9



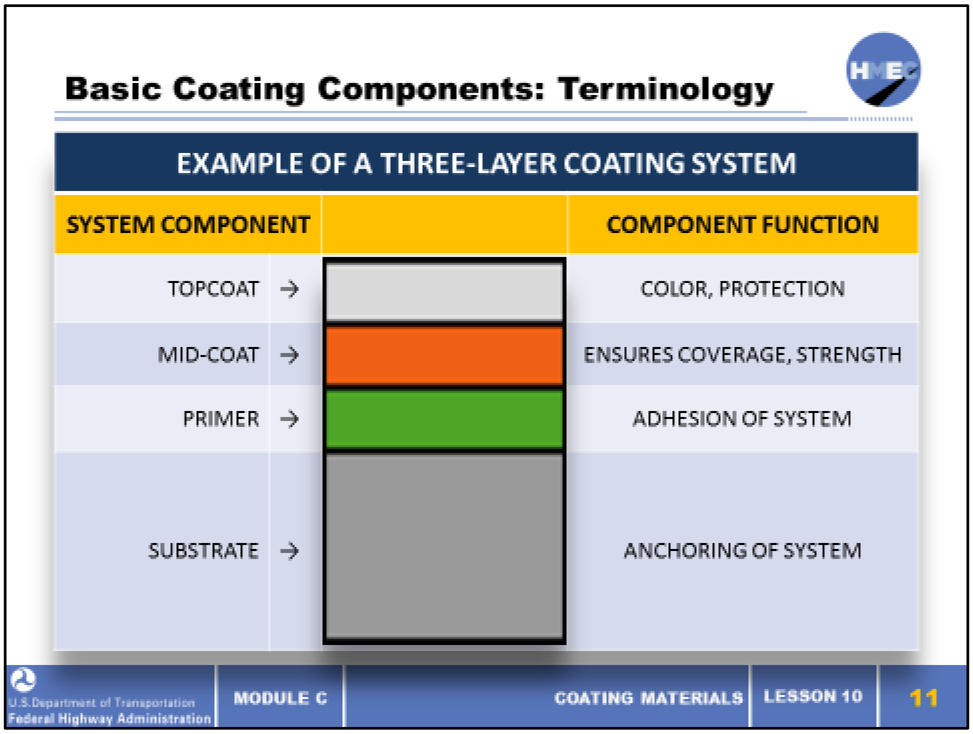
Solids, volatiles, and vehicle are all important terms. Note that there are many terms that mean the same thing, such as curing agent, converter, and hardener, which all refer to Part B (the curative) of a multi-component coating. Similarly, the resin or base refers to the other component. A catalyst or accelerator may also be added to accelerate the cure during cooler application conditions.

Slide 10



Coating systems consist of one or more coating layers applied to a properly prepared substrate to perform a function; the end result is a combination of all layers working in tandem. The surface preparation/substrate are considered part of the coating system. For example, a three-coat bridge system consists of a primer applied to a properly prepared substrate, an intermediate coat or mid-coat, and a topcoat or finish coat. The intended end result is a durable, corrosion-protective system that provides aesthetic properties for many years.

Slide 11



Read the system component layer (on the left) and discuss its specific function (listed on the right). Stress that the primer may also provide corrosion prevention when formulated with sacrificial or inhibitive pigments, the mid-coat provides barrier protection and the topcoat is the first line of defense, providing barrier properties as well as color and gloss retention for aesthetics.

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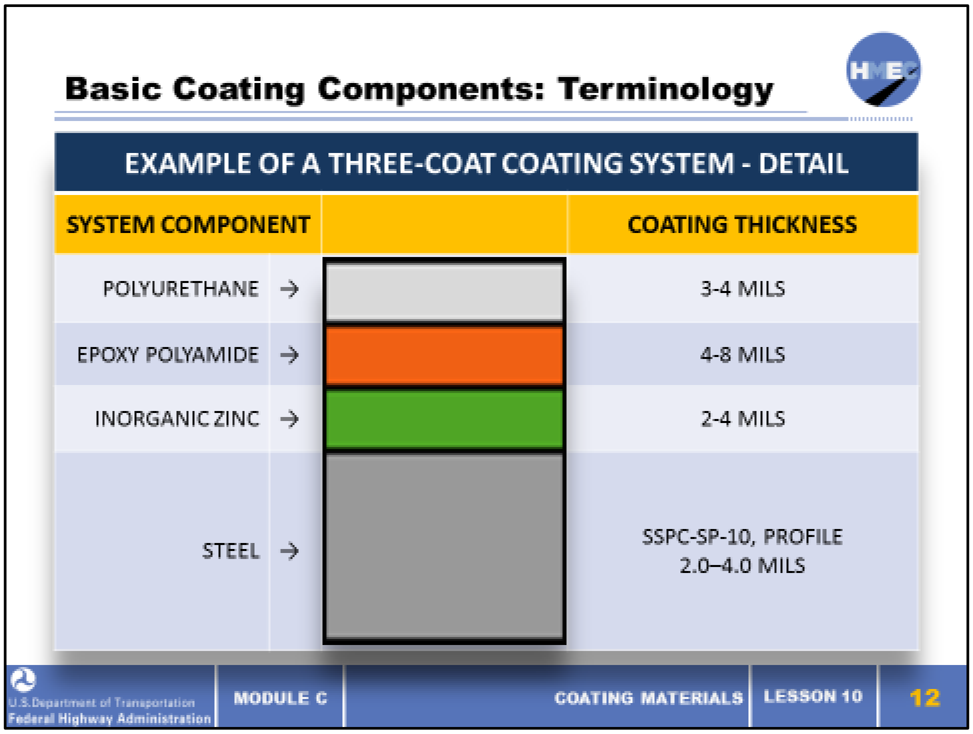
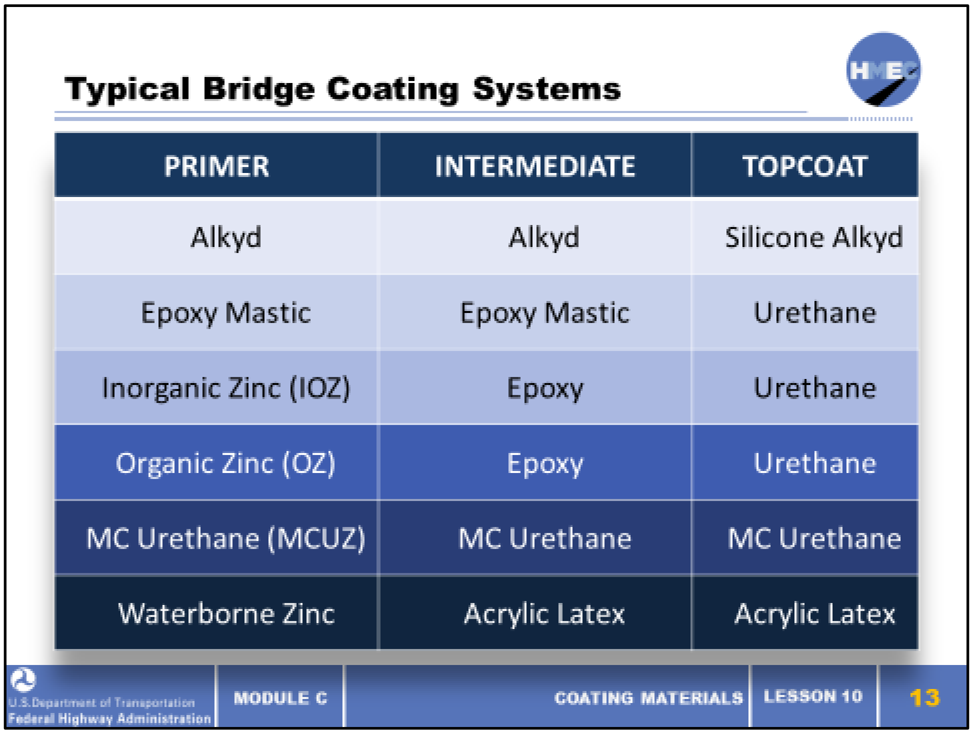
Slide 12



The most widely used system, regarded by many as the state-of-the-art is the zinc-epoxy-urethane system. When applied properly, this system can provide over 25 years of corrosion protection before it will need any significant maintenance. Look at the typical thickness of each layer. An organic zinc primer (e.g., zinc-rich epoxy) applied at 3-5 mils can replace the inorganic zinc primer at 2-4 mils.

Slide 13

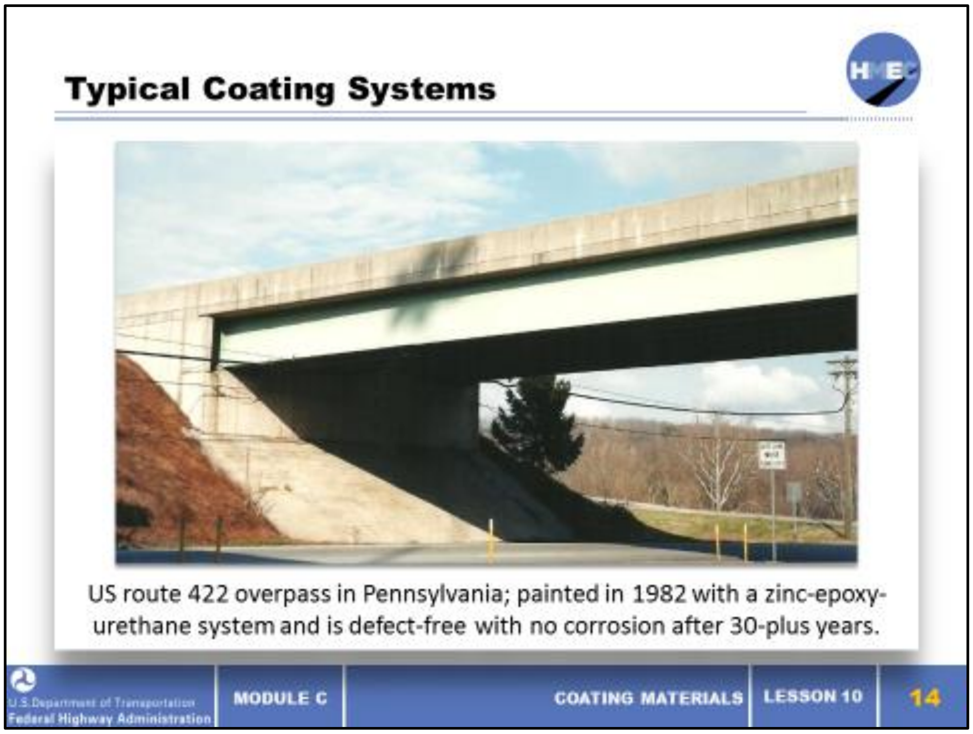


Typical Bridge Coating Systems

PRIMER	INTERMEDIATE	TOPCOAT
Alkyd	Alkyd	Silicone Alkyd
Epoxy Mastic	Epoxy Mastic	Urethane
Inorganic Zinc (IOZ)	Epoxy	Urethane
Organic Zinc (OZ)	Epoxy	Urethane
MC Urethane (MCUZ)	MC Urethane	MC Urethane
Waterborne Zinc	Acrylic Latex	Acrylic Latex

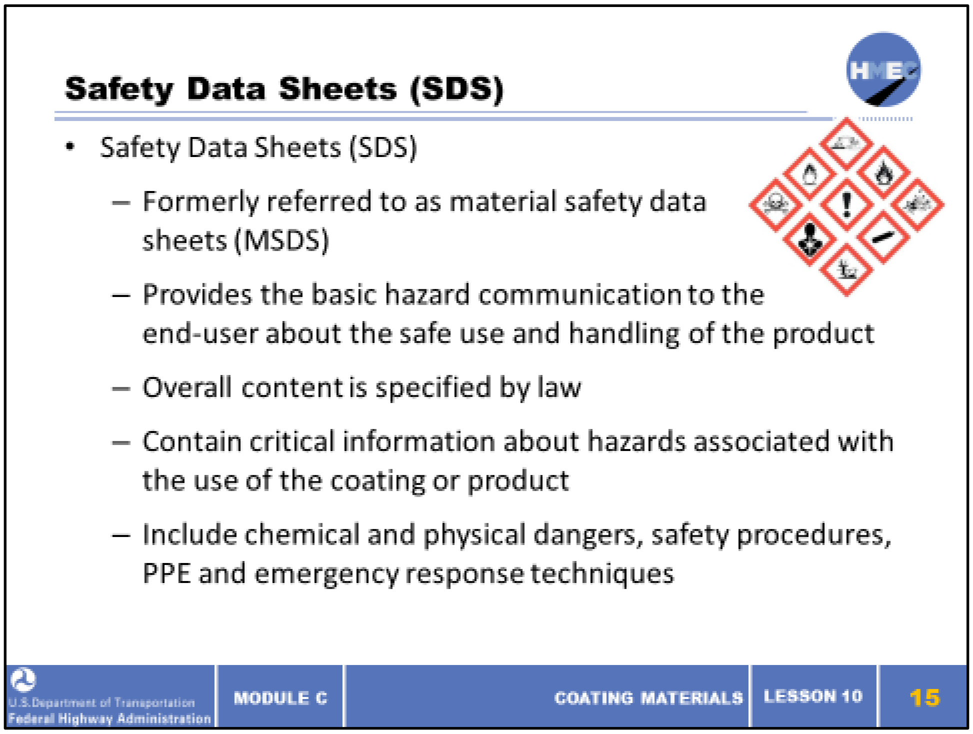
Coating systems are specified by owners for a number of reasons, such as the corrosiveness of the environment, environmental concerns (VOCs), and cost. This slide looks at systems commonly used on bridges. There are several manufacturers that offer these generic coating systems. Note that all coating materials for a given system should be selected from the same manufacturer. For example, an Agency should not allow the primer from manufacturer A and the mid-coat and/or finish coat from manufacturer B and/or C. Co-mixing manufacturer's products can result in a lot of finger pointing when coating defects or failure occurs. Using of multiple manufacturers can also create warranty issues. And co-mixing of components from different manufacturers should be prohibited.

Slide 14



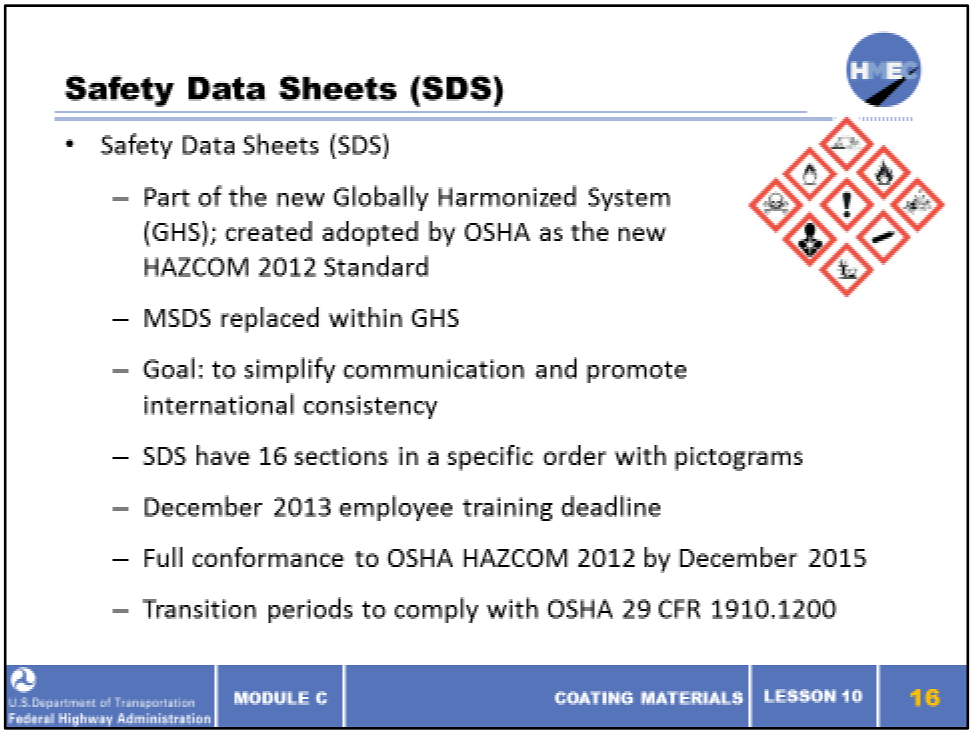
Other than some chalking of the finish coat on the fascia beam, this coating system is providing corrosion protection to the steel in a relatively harsh northeast environment.

Slide 15



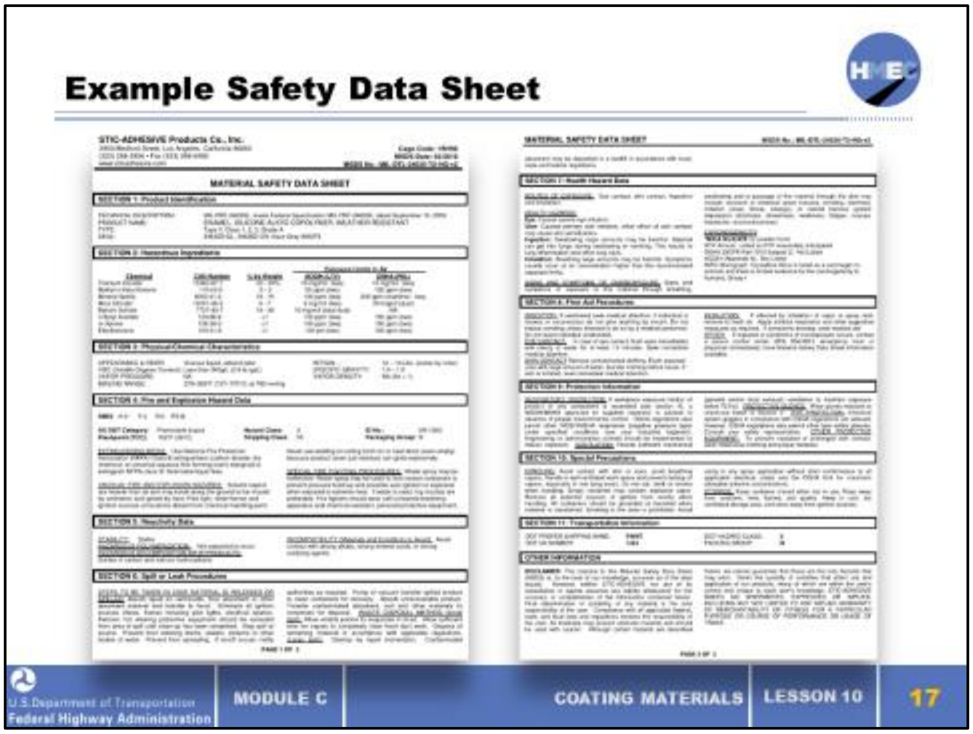
Safety data sheets (SDS) were formerly referred to as material safety data sheets (MSDS). They provide the basic hazard communication to the end-user about the safe use and handling of the product. The content is specified by law, the old MSDS content order may not always be the same among all manufacturers, and however, they essentially contained critical information about hazards associated with the use of the coating and properties associated with dangerous handling. Information contained in the SDS include chemical and physical dangers, safety procedures, personal protective equipment and emergency response techniques.

Slide 16



SDS are part of the new Globally Harmonized System (GHS), which was created by the United Nations and adopted by OSHA as the new HAZCOM 2012 Standard. MSDS were replaced within GHS. SDS were aligned; the goal is to simplify communication and promote international consistency. The new SDS are required to have 16 sections in a specific order with pictograms. All employees were required to be trained in the new format by December 2013. All shipments of HAZMAT, SDS, and labeling must comply with HAZCOM 2012 by December 2015.

Slide 17


Example Safety Data Sheet
U.S. Department of Transportation
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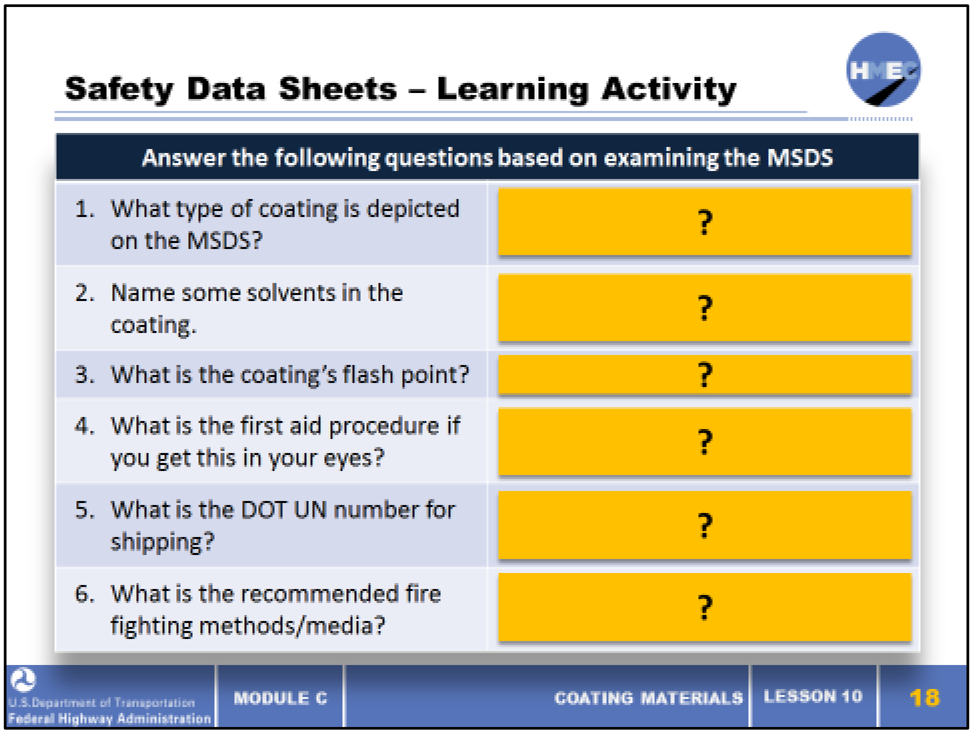
Slide 18


Safety Data Sheets – Learning Activity
HMEC
Answer the following questions based on examining the MSDS
1. What type of coating is depicted on the MSDS?
?
2. Name some solvents in the coating.
?
3. What is the coating's flash point?
?
4. What is the first aid procedure if you get this in your eyes?
?
5. What is the DOT UN number for shipping?
?
6. What is the recommended fire fighting methods/media?
?
U.S. Department of Transportation
Federal Highway Administration
MODULE C
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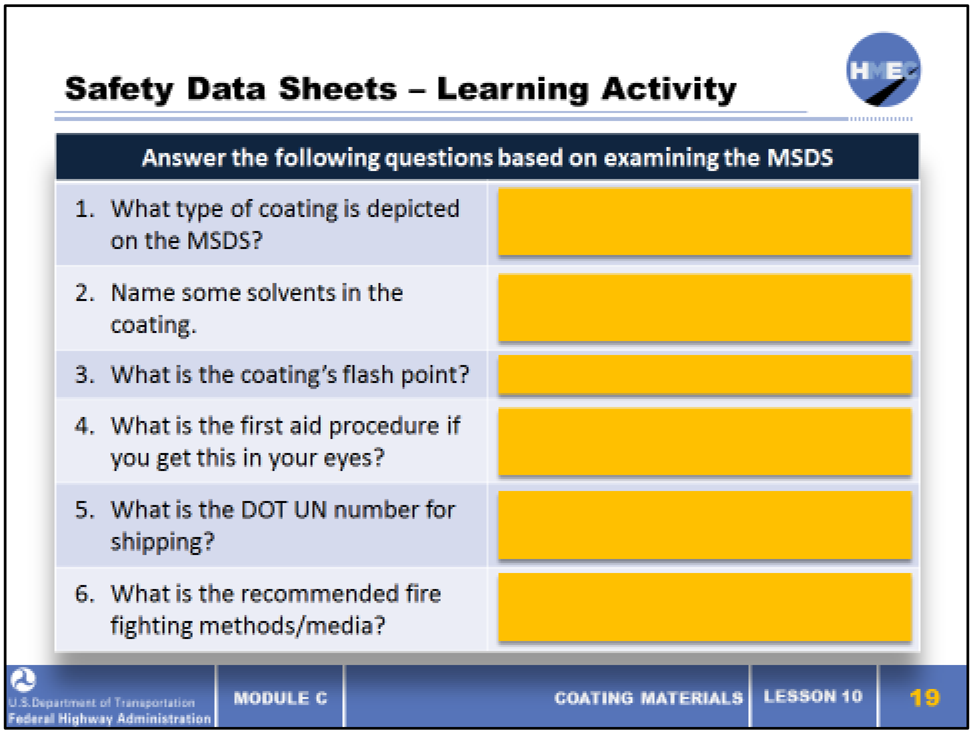
Slide 19


Safety Data Sheets – Learning Activity
HMEC
Answer the following questions based on examining the MSDS
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U.S. Department of Transportation
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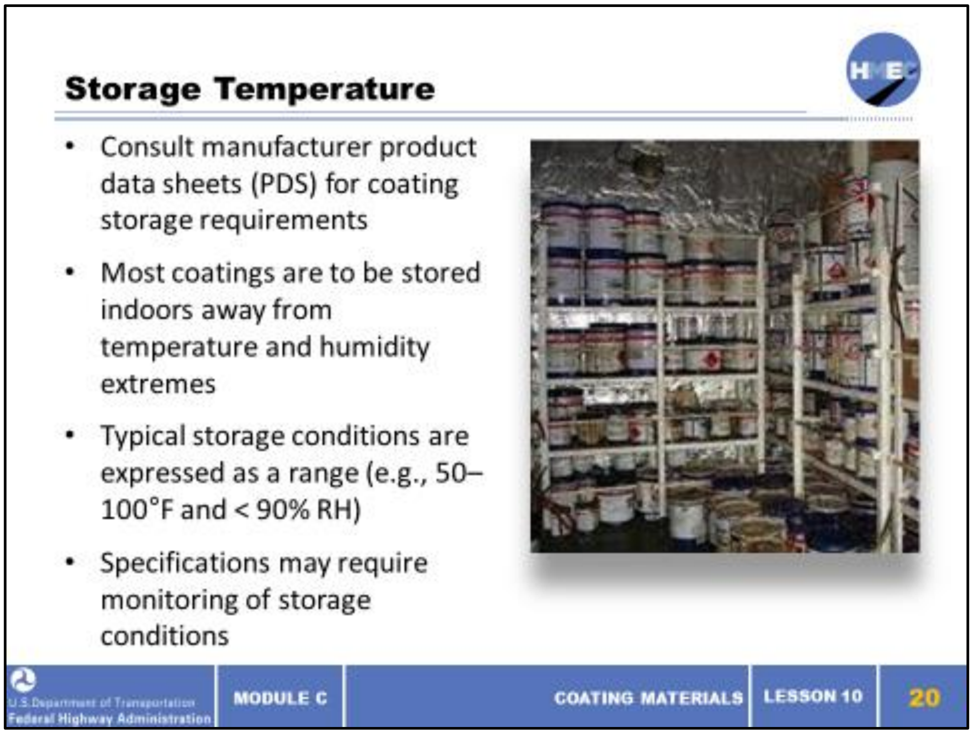
Slide 20

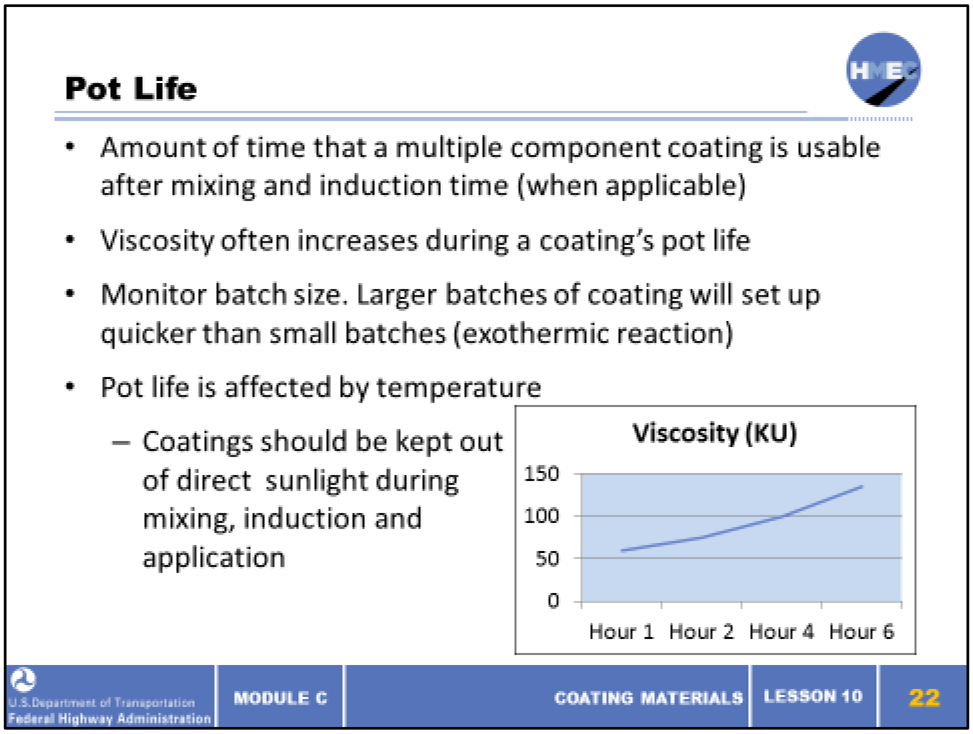


Stored in a storage shed or warehouse, coatings should be stored on pallets, up off the floor, as concrete flooring acts as a giant heat sink, causing coatings to become very cold, and therefore difficult to mix (coatings become more viscous with decreasing temperature). Storage conditions are often expressed as a range (e.g., 50– 100°F and < 90% RH) on the PDS. Specifications may require continuous monitoring of storage conditions for temperature and humidity.

Slide 21

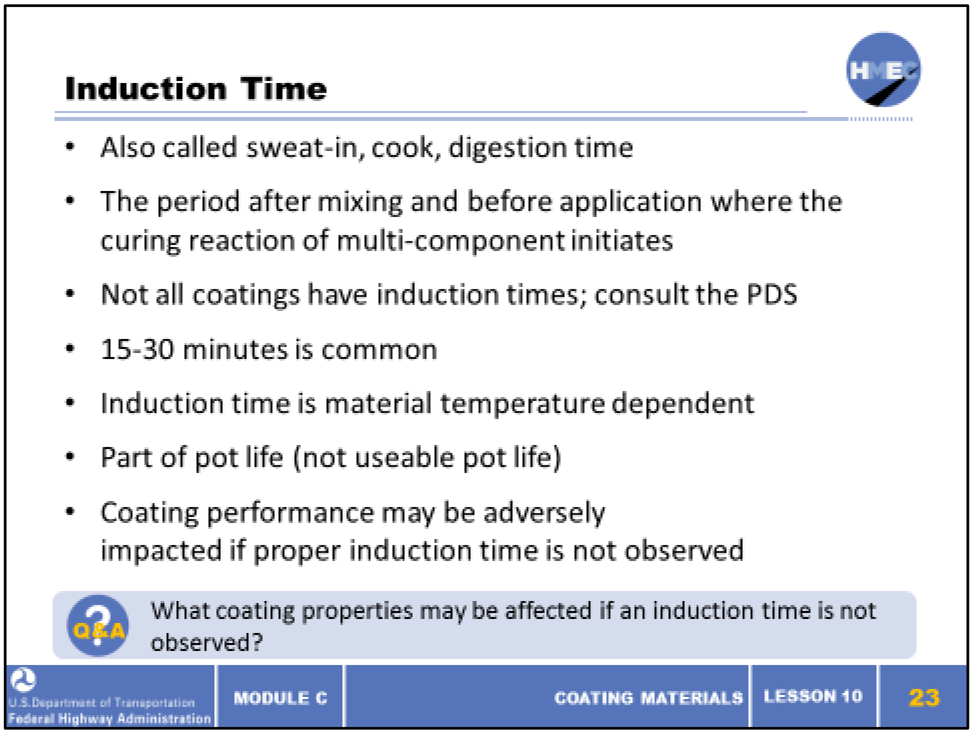
Shelf life is assigned by the manufacturer for liability. If a situation exists in the field where coating is discovered to be slightly outside of the shelf life, a paint manufacturer can test the product in their laboratory to extend the shelf life for a period of time after the expiration date. While a manufacturer may have batch retains that they can test, the retains will not be representative of on-site storage conditions.

Slide 22



Pot life is essentially the working life of the coating. When it can no longer be applied without visible defects, then the pot life is expired. Viscosity often increases during a coating's pot life (as illustrated by the graph), but not always. It is important to monitor batch size. Larger batches of mixed coating will set up quicker than small batches due to the volume of materials and an exothermic reaction. Pot life is affected by material temperature. To manage pot life, coatings should be kept out of direct sunlight during mixing, any induction and application.

Slide 23

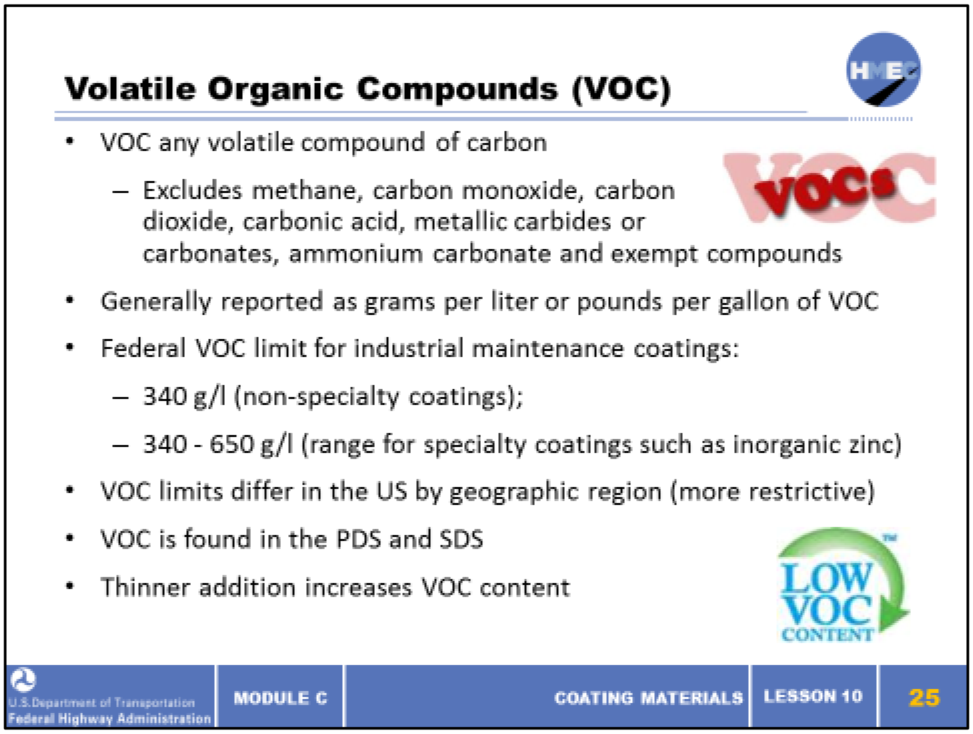


Also called sweat-in, cook or digestion time, an induction time is the time after mixing and before application where the curing reaction of multi-component coatings is initiated. Not all coatings have induction times; consult the PDS. Induction periods of 15 or 30 minutes is common. Induction time is based on the temperature of the coating material and begins when mixing is complete. Induction time is part of the pot life but it isn't part of the useable pot life. Coating performance may be adversely impacted if proper induction time is not observed.

Slide 24

Thinning may be permitted by the manufacturer but disallowed by the specification. If thinning is allowed it must be accomplished with the manufacturer's recommended compatible reducers and must not exceed the recommended amount. Note that thinning will increase the coating's VOC or volatile organic compound content, and could make a coating non-compliant with local and Federal air quality standards.

Slide 25


Volatile Organic Compounds (VOC)
HMEC
• VOC any volatile compound of carbon
– Excludes methane, carbon monoxide, carbon dioxide, carbonic acid, metallic carbides or carbonates, ammonium carbonate and exempt compounds
VOCs
• Generally reported as grams per liter or pounds per gallon of VOC
• Federal VOC limit for industrial maintenance coatings:
– 340 g/l (non-specialty coatings);
– 340 - 650 g/l (range for specialty coatings such as inorganic zinc)
• VOC limits differ in the US by geographic region (more restrictive)
• VOC is found in the PDS and SDS
• Thinner addition increases VOC content
LOW VOC CONTENT
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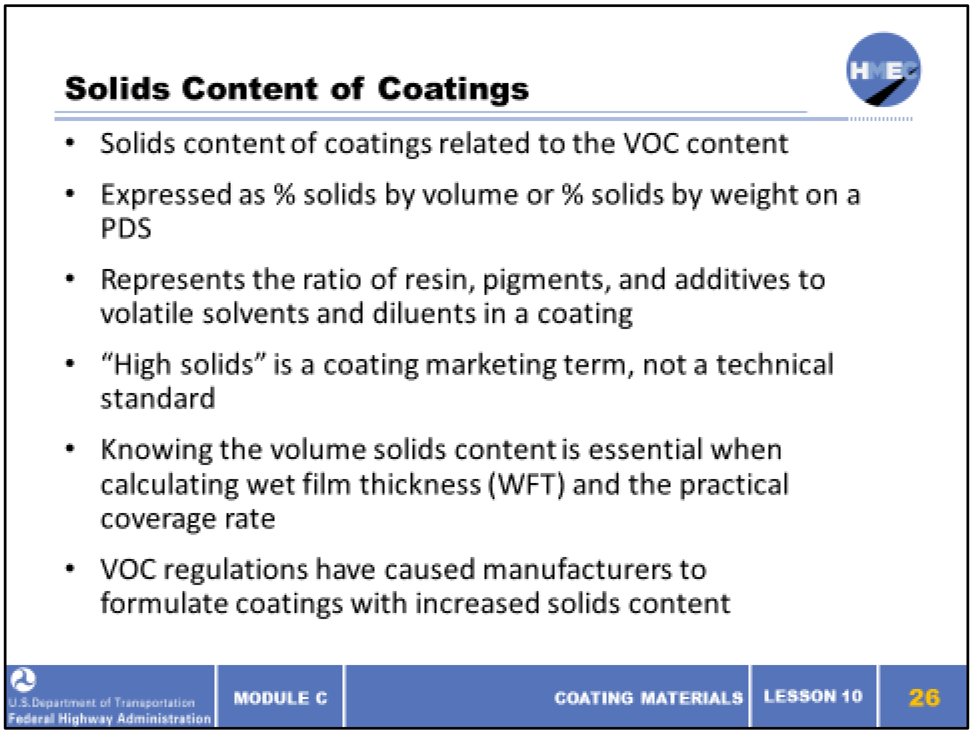
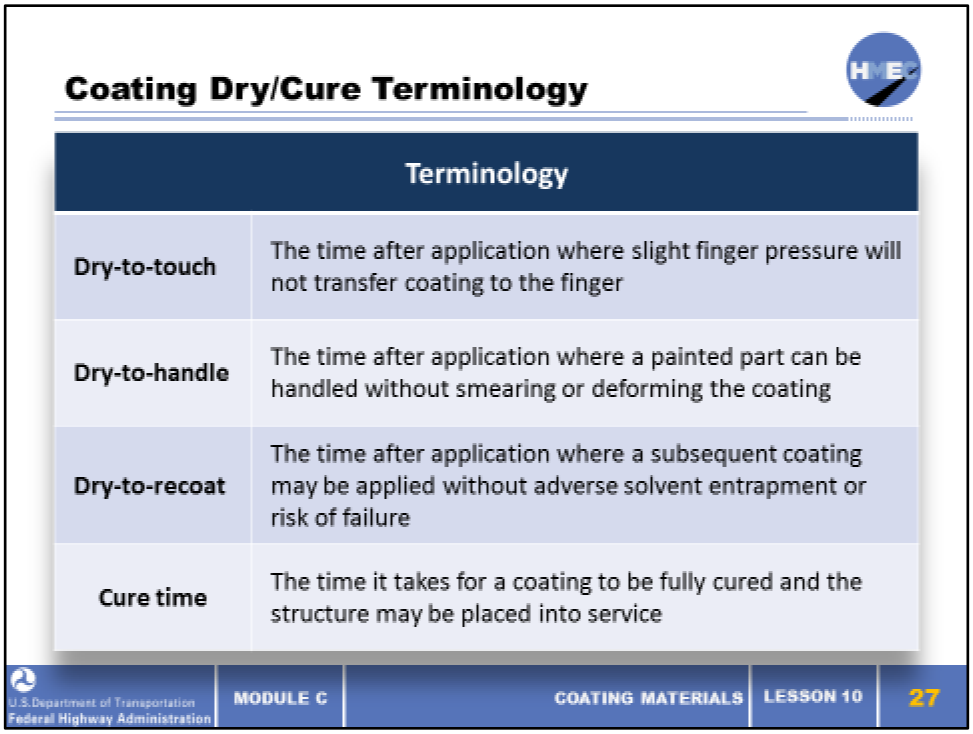


The solids content of coatings is related to the VOC content. It is expressed as % solids by volume or % solids by weight on a PDS and represents the ratio of resin, pigments, and additives to volatile solvents and diluents in a coating. "High solids" is a coating marketing term, not a technical standard. For example, a coating manufacturer may describe a coating containing 80% solids as a "high solids" material, while another manufacturer may make the same statement about a coating that only contains 60% solids.

Knowing the volume solids content is essential when calculating wet film thickness (WFT) and the practical coverage rate.

Slide 27



Coating Dry/Cure Terminology

Terminology	
Dry-to-touch	The time after application where slight finger pressure will not transfer coating to the finger
Dry-to-handle	The time after application where a painted part can be handled without smearing or deforming the coating
Dry-to-recoat	The time after application where a subsequent coating may be applied without adverse solvent entrapment or risk of failure
Cure time	The time it takes for a coating to be fully cured and the structure may be placed into service

Dry to touch, handle, recoat, and cure time all refer to properties of the coating when it is applied and before it is recoated. These are very important properties that coating applicators are concerned with, and all of these properties vary significantly with the prevailing temperature and relative humidity.

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Curing Mechanisms

- Air Oxidation
  - Oil-based alkyd coatings, including silicone alkyd co-polymers
  - Process continues for years until fully oxidized
  - Limitations on coating thickness, due to oxygen cure of the upper layers of the coating
    - Too thick applications result in soft under layers that will never cure
    - Skinning in the can

Q&A: What bridge coating was used for decades that cured by oxidation?

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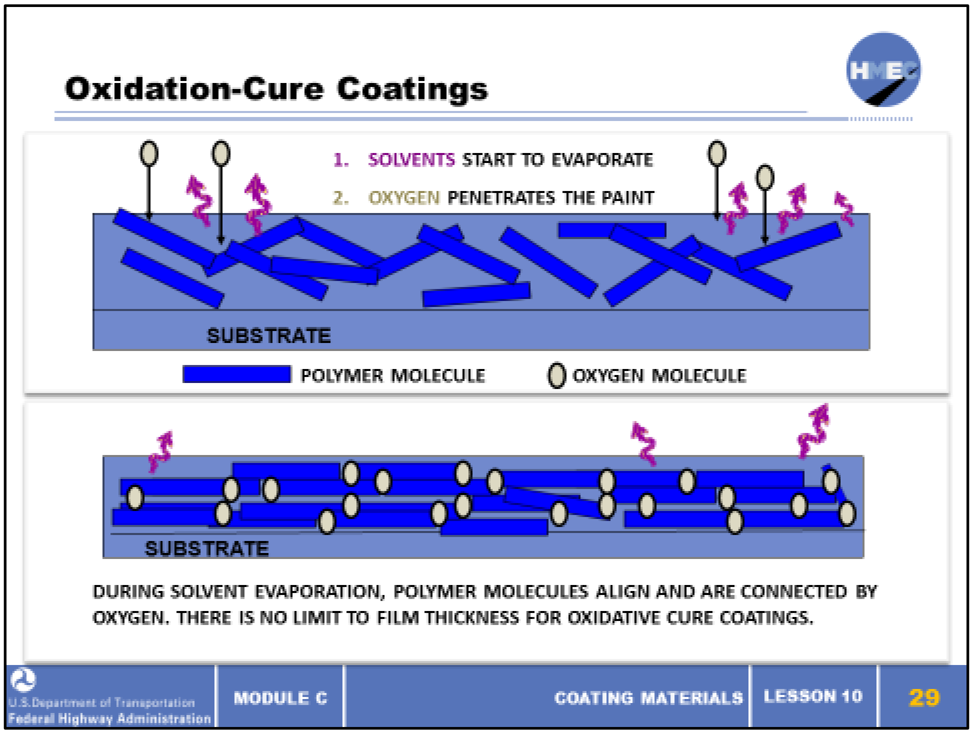

The brown ovals represent oxygen penetrating the wet paint layer as solvents (purple arrows) escape. The oxygen cross-links the resin causing the paint to gel, and eventually cure. If oxidative coatings are applied too thick, the top surface will cure blocking off oxygen migration to the body of the coating, resulting in soft/uncured paint.

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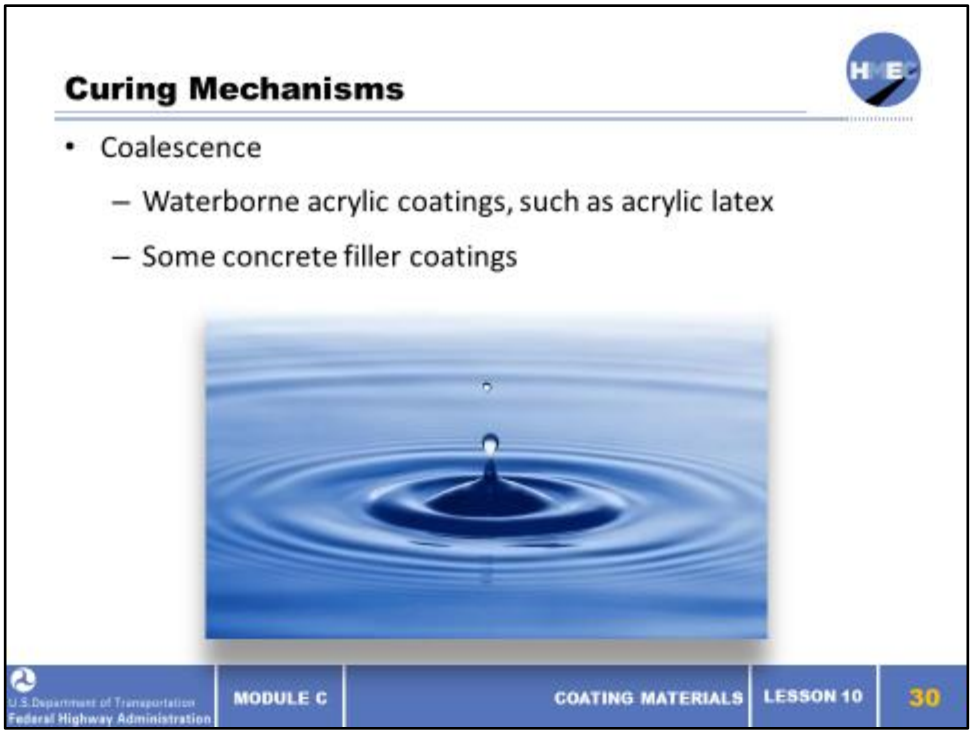
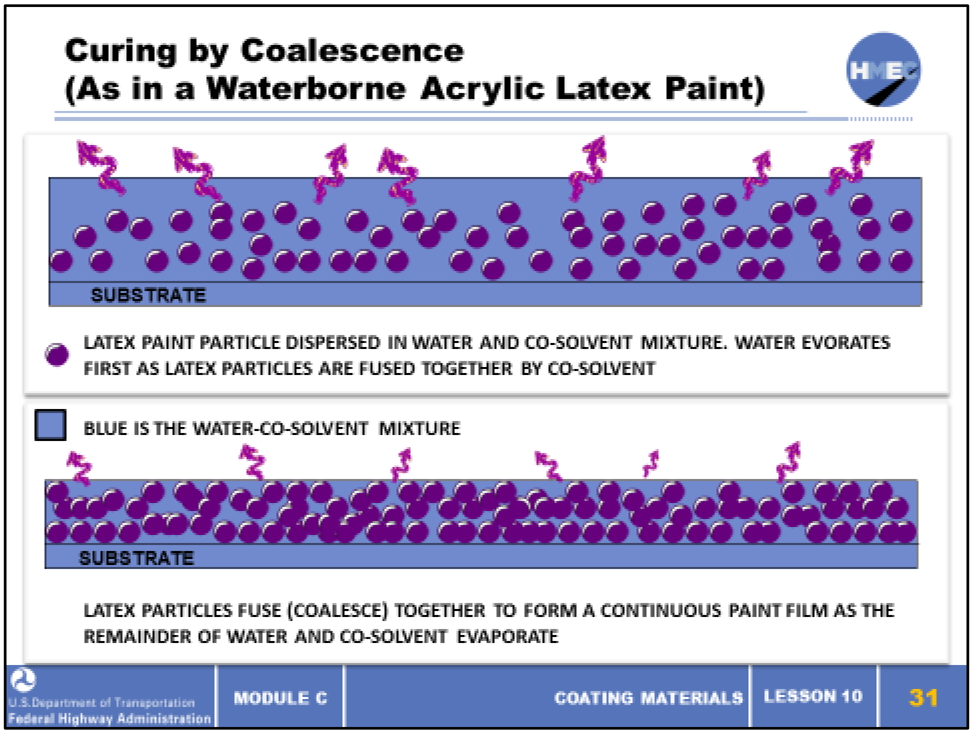
Slide 30



The term coalesce means "… to come together and form one mass or whole." We'll take a look at coalescence on the next slide. Basically, the waterborne acrylic latex coatings and some concrete filler coatings cure this way.

Slide 31



Here the latex particles (purple balls) fuse together (coalesce) by the co-solvent, as water (purple arrows) evaporates from the film. These coatings are not recommended to be applied under high humid conditions or at temperatures below 50°F, since water will not evaporate as readily from the paint film and the coalescing process can significantly slow or stop.

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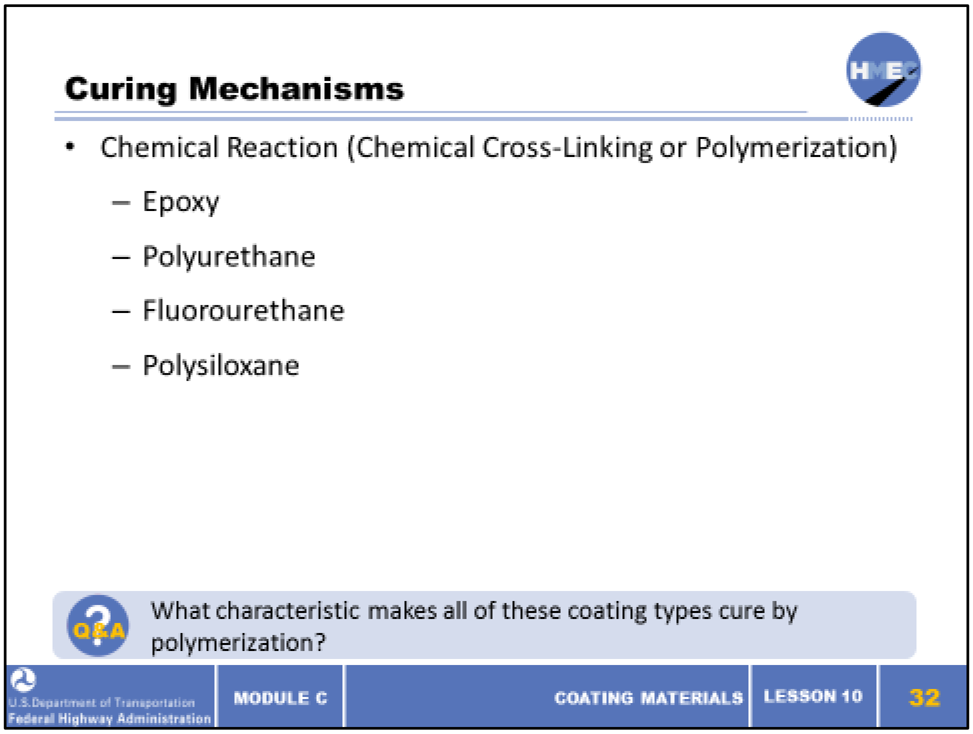
Slide 32



Bridge coatings that cure by polymerization include epoxy, polyurethane and polysiloxane and fluorourethane. If an organic zinc is epoxy or urethane-based, then it too cures by polymerization.

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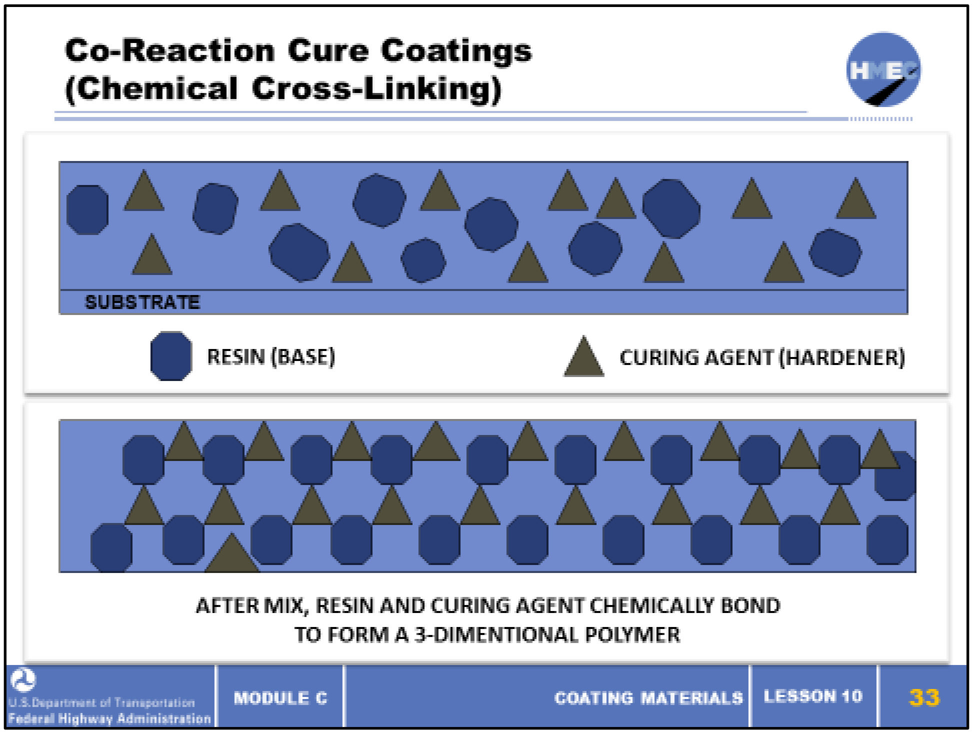
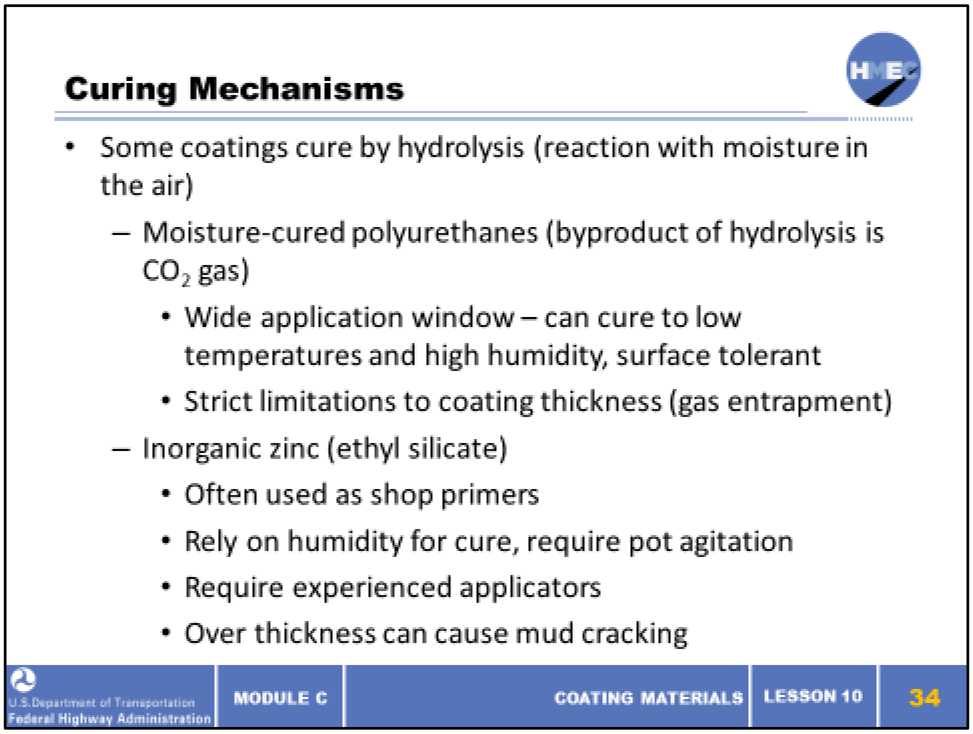


Coating will never cure if one neglects to add the Part B or hardener to a multi-component coating. This is a very simplified graphic of a two-part epoxy coating, where the top graphic shows a mixture of base resin (blue octagons) and curing agent (triangles) in the paint can. During the induction period (if applicable), the resin and base start to co-react, giving the coating strength and body to be able to be applied to a vertical surface without sagging.

Slide 34



Specifically we will be discussing inorganic zinc primers and moisture-cured urethanes. Emphasize that moisture-cure urethane is highly reactive with moisture and can outgas easily, which can produce pinholes or tiny gas-filled blisters in the applied film. Inorganic zinc coatings dry very quickly, but need moisture to cure and can be very finicky in their application, therefore only experienced applicators should apply inorganic zinc coatings.

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Typical Chemical Reactions of Coatings

Alkyd or Drying Oil + Oxygen	→	**Cured Alkyd Coating**
Epoxy + Curative (i.e., Amine, Polyamide, or Amidoamine)	→	**Epoxy Coating**
Polyol + Polyisocyanate	→	**Polyurethane Coating**
Silicate + Moisture	→	**Inorganic Silicate Binder** (commonly used with solvent-based zinc-rich primers, also known as IOZ)
Amine-Terminated Resin + Polyisocyanate	→	**Polyurea Coating**
Isocyanate-Terminated Resin + Moisture	→	**Cured MCU Coatings**

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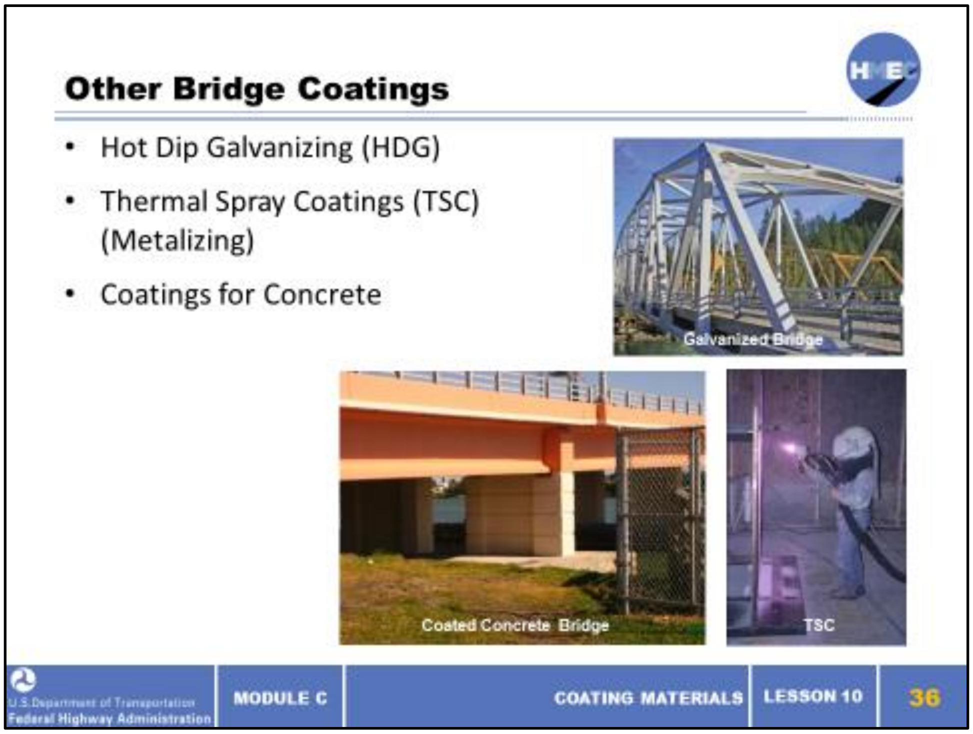

Other bridge coatings include hot-dip galvanizing, thermal spray or metalizing, and coatings, stains and sealers used on concrete elements of a bridge. Hot-dip galvanizing and thermal spray coatings were introduced as methods of corrosion prevention in Lesson 7; however we will describe some of the nuances associated with using these methods next. We'll conclude with a brief discussion on coatings used on concrete bridges

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Hot-dip galvanizing is used for corrosion protection of guard rail, signage poles, pre-fabricated bridges and cable bundles for suspension bridges. The only limit to what can be protected by galvanizing is the size of the bath in the galvanizing plant. Hot-dip galvanizing may be coated with liquid or powder coatings for barrier protection and aesthetics. These are known as duplex systems. According to an article published in the June 2015 issue of *The Journal of Protective Coatings and Linings* (Problems with Galvanizing), the service life of a duplex system may be 1.5-2.3 times the sum of the individual service lives for galvanizing or painting alone.

SSPC-Guide 19, *Selecting Coatings for Use Over Galvanized Substrates* assists owners and specifiers with the selection of an appropriate generic coating for protection of galvanized steel surfaces exposed to aggressive environments. Coating manufacturers can also be solicited for system recommendations.

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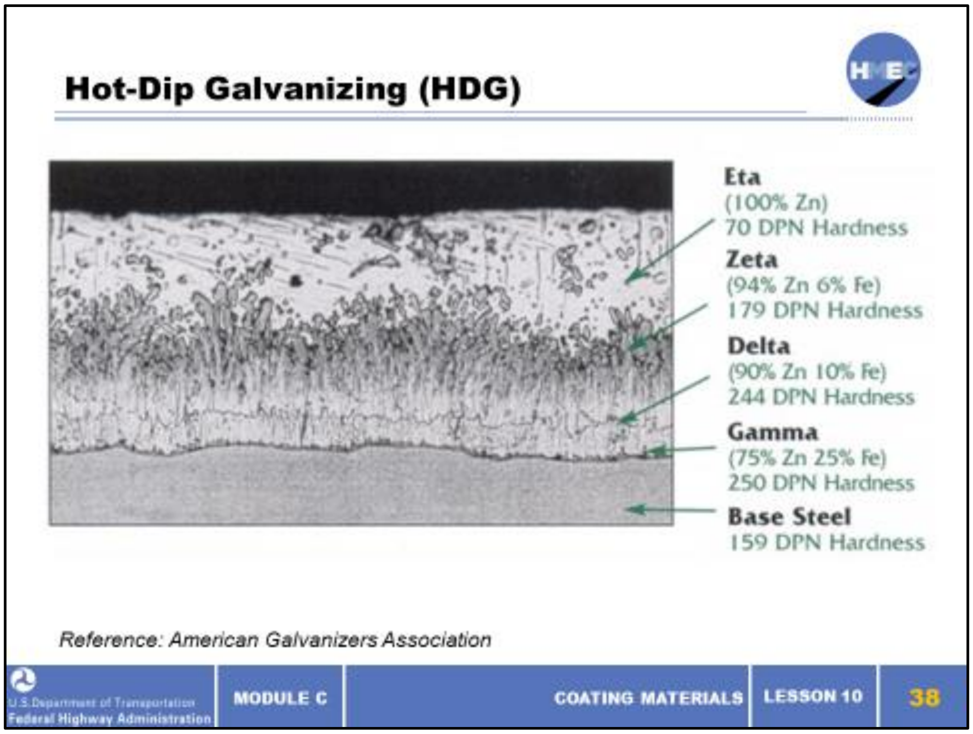

Hot-dip galvanizing forms an inter-metallic bond with the steel. Multiple layers of alloying are created by the galvanizing process. The Gamma layer contains approximately 75% zinc and 25% iron. The Delta layer contains approximately 90% zinc and 10% iron. The Zeta layers contains approximately 94% zinc and 6% iron, and the Eta or top layer contains 100% zinc.

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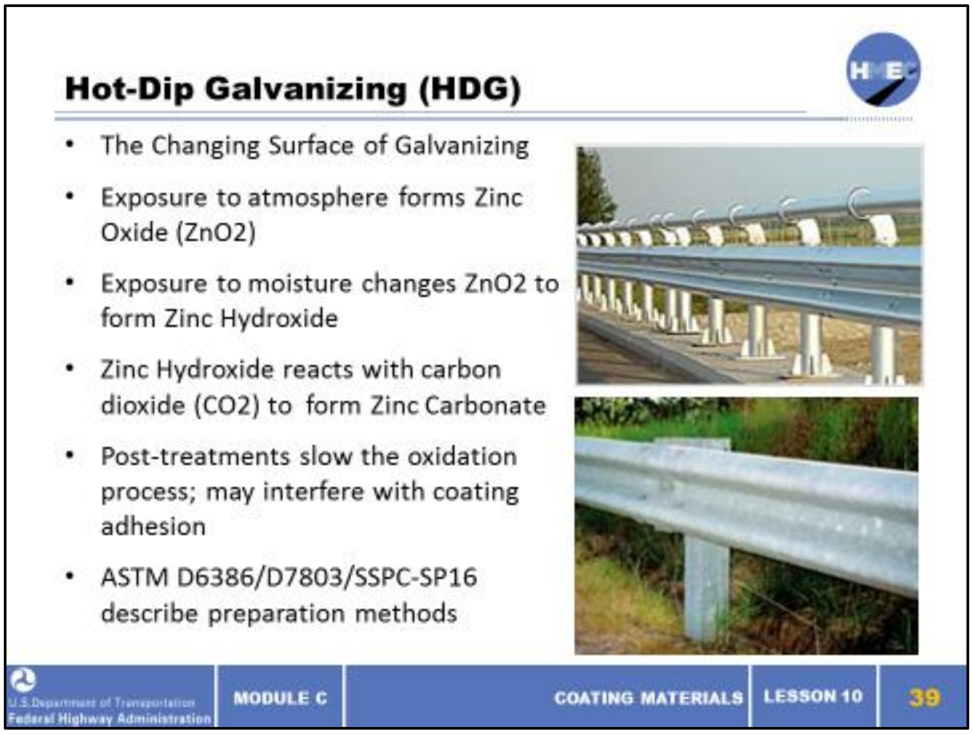

When hot-dip galvanizing is first exposed to the atmosphere it forms zinc oxide. Once moisture comes in contact with the surface it changes the zinc oxide to zinc hydroxide. The zinc hydroxide reacts with carbon dioxide in the air and forms zinc carbonate. Once this forms the galvanized surface is considered weathered, and is less difficult to coat.

Post treatments like water quenching and chromate quenching can interfere with coating adhesion. Phosphating of the galvanized steel however produces zinc phosphate, which prevents corrosion and promotes adhesion of an applied coating.

ASTM D6386, *Practice for Preparation of Zinc (Hot-Dip Galvanized) Coated Iron and Steel Product and Hardware Surfaces for Painting* ; ASTM D7803, *Practice for Preparation of Zinc (Hot-Dip Galvanized) Coated Iron and Steel Product and Hardware Surfaces for Powder Coating* ; and SSPC-SP 16, *Brush-off Blast Cleaning of Non-Ferrous Metals* can be very valuable references for specifying the preparation of galvanized surfaces for coating.

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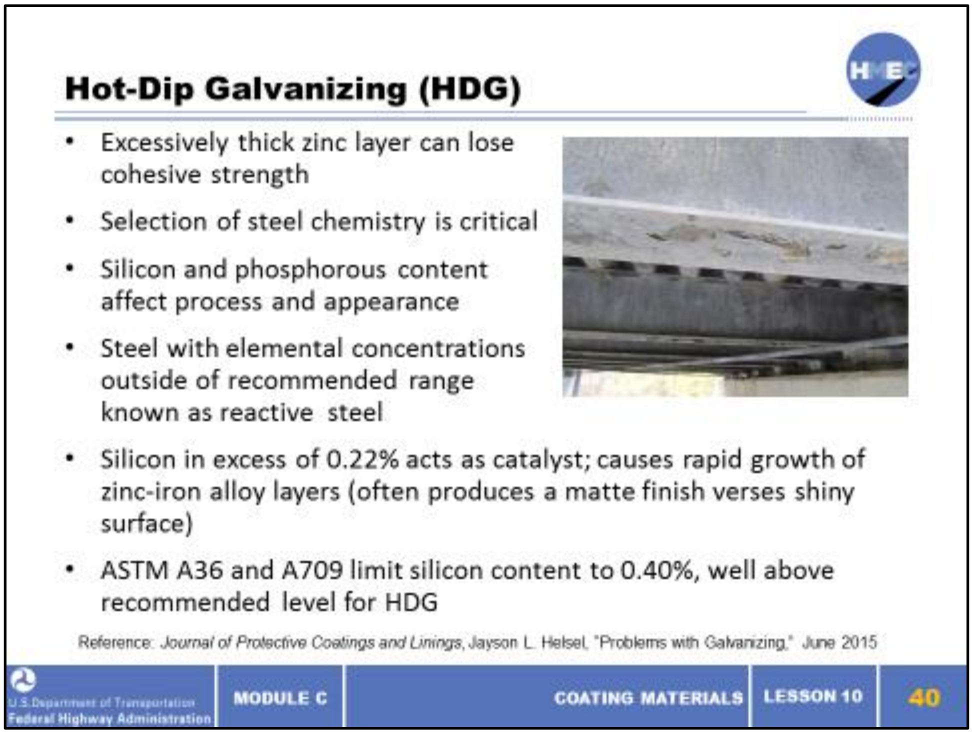

Even if galvanizing is not intended for painting, problems can develop with the zinc layer if the hot-dip process results in too thick of a layer. One key factor in avoiding an excessively thick zinc layer is proper steel selection. The chemistry of the steel influences appearance and other properties of the galvanizing. Trace elements in the steel such as silicon and phosphorus affect the galvanizing process as well as the structure and appearance of the galvanizing (coating). Steels with these elements outside of the recognized ranges are known as reactive steels. General guidance for steel selection recommends levels of carbon less than 0.25%; phosphorus less than 0.04 %, manganese less than 1.35%, and silicon levels less than 0.04% or between 0.15 and 0.22%.

Silicon may be present as an element in many steels commonly galvanized even though it is not a part of the steel's controlled composition, because silicon is used in the steel reduction process and is found in continuously cast steel. Both silicon and phosphorous act as catalysts during the galvanizing process, resulting in rapid growth of zinc-iron alloy layers. When the silicon content exceeds 0.22%, the steel is classified as reactive steel. An additional item of note with reactive steels is that the galvanizing often has a matte gray finish rather than the typical shiny surface.

A commonly specified standard for hot dip galvanizing structural steel, ASTM A123, “Standard Specification for Zinc (Hot-Dip Galvanized) Coatings on Iron and Steel Products,” specifies a minimum zinc thickness of 3.9 mils or 100 microns (for Coating Grade 100). Note that the Coating Grade is equivalent to the zinc thickness in microns as defined for specific thicknesses ranging from 35 to 100 microns (1.4 - 4 mils). Although it is not unusual to find zinc thickness on structural steel of several mils up to approximately 10 mils, widespread thicknesses far in excess of this range are a good indication that the steel may be reactive. An excessively thick zinc layer that is often produced when galvanizing reactive steel tends to be more brittle with a lower cohesive strength than would typically be expected. Depending on other factors, such as the exposure environment, these diminished properties can lead to the cohesive separation of the zinc layer as described for flaking zinc.

Unfortunately, industry standards for specifying steel do not limit the silicon content in steel for purposes of galvanizing. For example, ASTM A36, “Standard Specification for Carbon Structural Steel,” and ASTM A709, “Standard Specification for Structural Steel for Bridges,” both limit the silicon content to a maximum of 0.40%, which is well above the recommended level for galvanizing.

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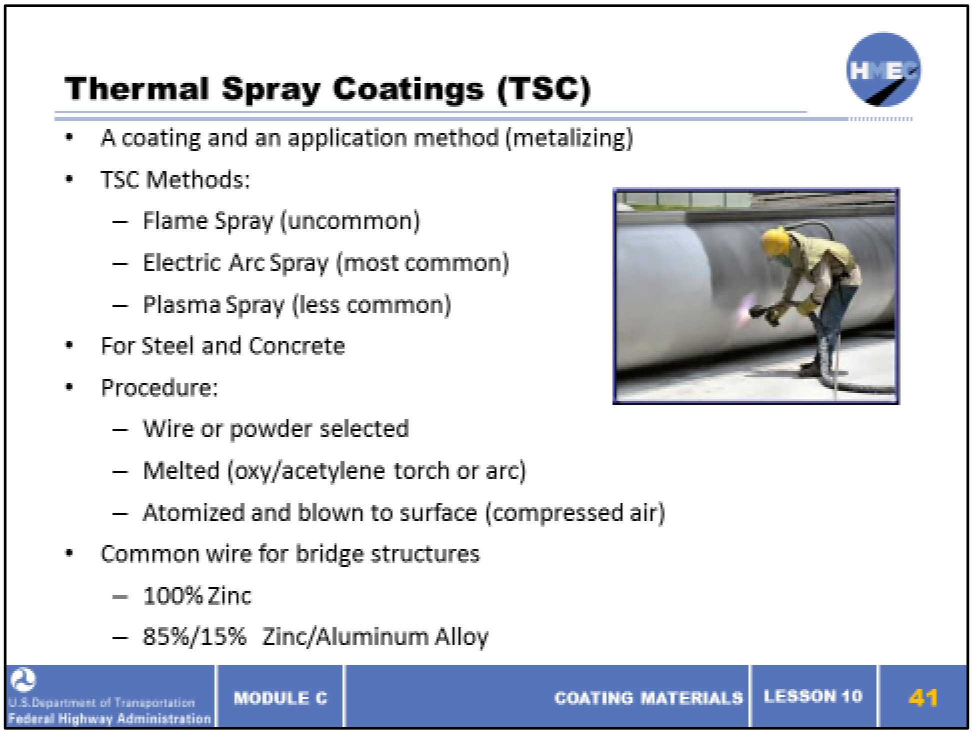

The terms thermal spray coating and metalizing describe a type of coating and an application method. There are three basic forms of metalized spray, including flame spray, electric arc spray and plasma spray. Plasma arc spray is not generally used for coating of structural steel or concrete. Arc spray is the most common (and most productive) of the three methods, and is typically the method employed in the shop or field for metalizing both new and existing bridge structures. TSC can be applied to both steel and concrete surfaces. In general, a metal wire or metal powder is fed into an application device (spray gun), melted, then atomized and blown to the surface of the structure using compressed air. The wire or powder can be made from a variety of metals and is selected based on the service environment and intended level of performance (the same way liquid-applied coatings are selected). The metals and alloys most commonly used on bridge structures include 100% zinc and an 85% zinc and 15% aluminum alloy.

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Electric arc spray metalizing uses relatively high electrical amperage to melt wire. Two wires are fed from individual spools into a spray gun. Each wire is given an opposing electrical charge between 375 and 400 amps. As the wires feed into the gun, they contact, arc and melt. Compressed air atomizes the molten metal wire and blows it onto the surface.

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SSPC, NACE and the American Welding Society (AWS) developed a "tri-society" guide (SSPC CS 23.00/AWS C 2.23M/NACE No. 12, "Specification for the Application of Thermal Spray Coatings (Metalizing) of Aluminum, Zinc, and Their Alloys and Composites for the Corrosion Protection of Steel"), which describes the requirements of metalizing and provides guidance on inspection procedures that are employed on projects incorporating metalized spray. Brief descriptions of the three metalizing processes are provided in this section.

The SSPC Painting Contractor Certification Program (PCCP) Qualification Procedure 6 (QP 6), "Standard Procedure for Evaluating the Qualifications of Contractors Who Apply Thermal Spray (Metalizing) for Corrosion Protection and Steel and Concrete Structures" qualifies contractors performing metalizing work.

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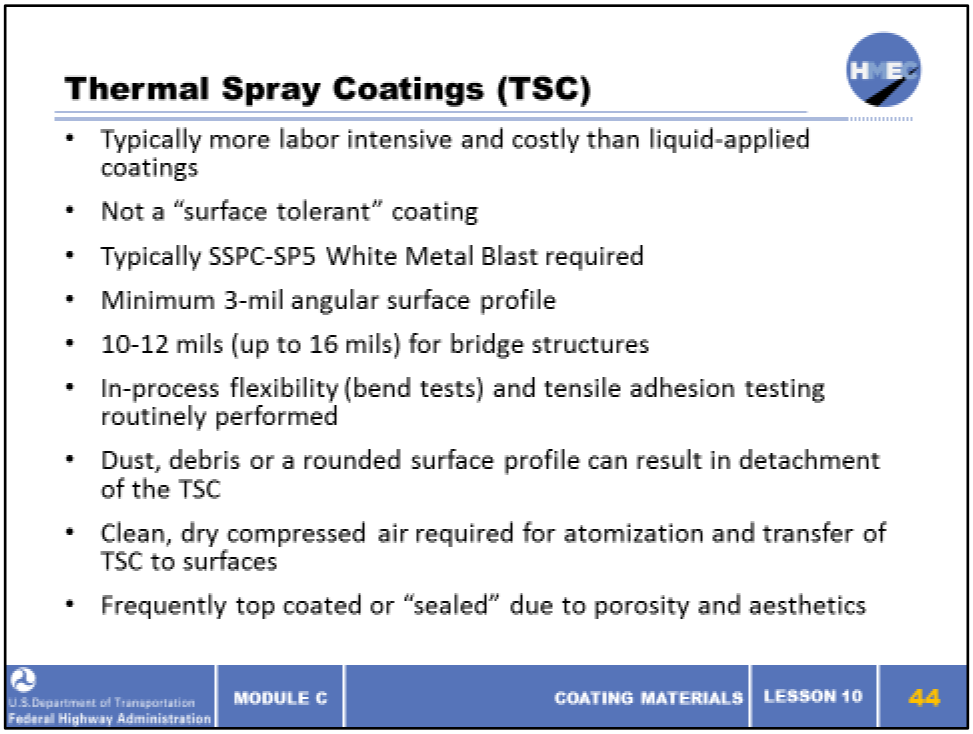

The application of metalizing can be more labor intensive and more costly than traditional liquid-applied coatings systems. Metalizing is not a surface tolerant coating and may fail catastrophically if the surface is not prepared properly (a "White Metal Blast" per SSPC SP 5/NACE No. 1 is often specified, along with a minimum 3-mil angular surface profile). A common thickness requirement for bridges is 10-12 mils, but can be up to 16 mils depending on the service environment. In-process flexibility (bend) testing and tensile (pull off) adhesion testing are routinely performed as part of the inspection process to help assess the quality of the application. Any residual dust or debris on the surface, an inadequate surface profile depth or a rounded surface texture, or poor quality compressed air can cause detachment of the TSC. It is frequently sealed with a penetrating sealer or a traditional polyurethane finish coat for added barrier protection (TSC can be porous) and aesthetics.

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Agencies will coat concrete to protect from chloride ion penetration and for aesthetics. Typical coating systems used include an epoxy primer/polyurethane finish, a multi-coat waterborne acrylic system, clear sealers, penetrating stains and occasionally thermal spray coatings with a sealer.

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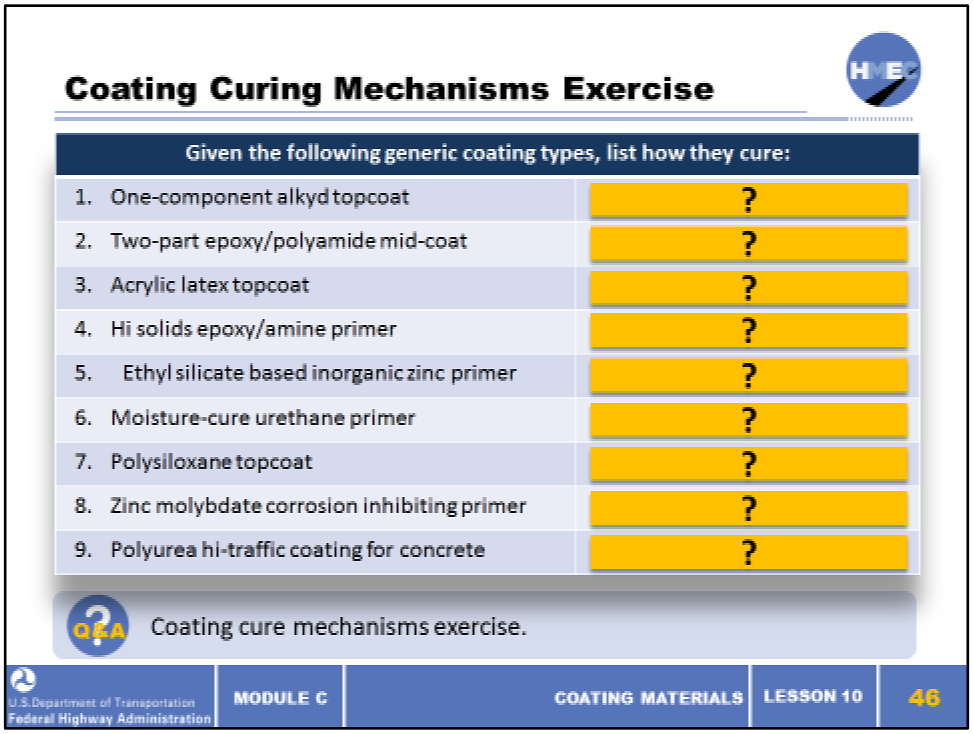
Coating Curing Mechanisms Exercise
HMEC
Given the following generic coating types, list how they cure:
1. One-component alkyd topcoat ?
2. Two-part epoxy/polyamide mid-coat ?
3. Acrylic latex topcoat ?
4. Hi solids epoxy/amine primer ?
5. Ethyl silicate based inorganic zinc primer ?
6. Moisture-cure urethane primer ?
7. Polysiloxane topcoat ?
8. Zinc molybdate corrosion inhibiting primer ?
9. Polyurea hi-traffic coating for concrete ?
Q&A
Coating cure mechanisms exercise.
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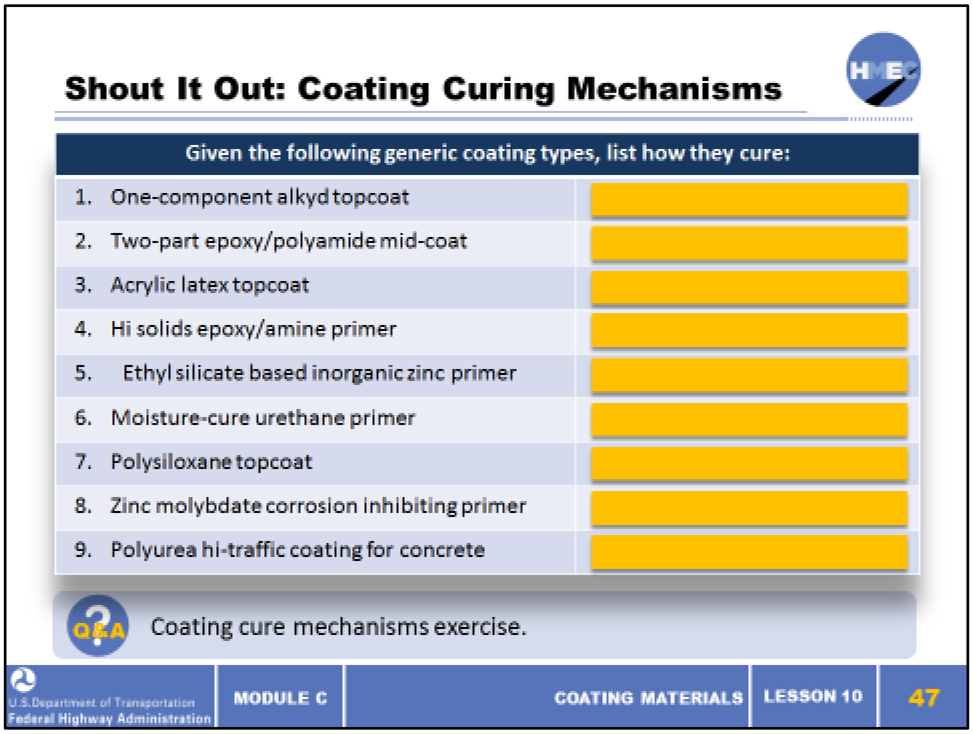
Shout It Out: Coating Curing Mechanisms
HMEC
Given the following generic coating types, list how they cure:
1. One-component alkyd topcoat
2. Two-part epoxy/polyamide mid-coat
3. Acrylic latex topcoat
4. Hi solids epoxy/amine primer
5. Ethyl silicate based inorganic zinc primer
6. Moisture-cure urethane primer
7. Polysiloxane topcoat
8. Zinc molybdate corrosion inhibiting primer
9. Polyurea hi-traffic coating for concrete
Q&A
Coating cure mechanisms exercise.
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There are several quality programs that a manufacturer can participate in. Many major coating manufacturers are ISO-certified, and some hold other industry-specific certifications like UL and NSF. The bridge industry focuses more on performance criteria than manufacturing. However an understanding of basic coating compositional properties will be helpful to the Highway Materials Engineer, especially if field batch sampling and testing is invoked by specification.

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That laboratories can perform receipt inspection tests on their raw materials, or review the raw material Certificate of Conformance (CoC). Batch retains are usually kept for the duration of the shelf life and may be used if there are observed differences in the field batches.

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Common Physical Property Tests

- Liquid Coating Properties Testing
  - Density, viscosity, fineness of grind, pigment content, VOC, solids content, etc.
- Application and Film Formation Tests
  - Pot life, resistance to sag, dry time
- Dried Film Tests
  - Adhesion to steel, color, gloss, abrasion resistance, and weathering resistance

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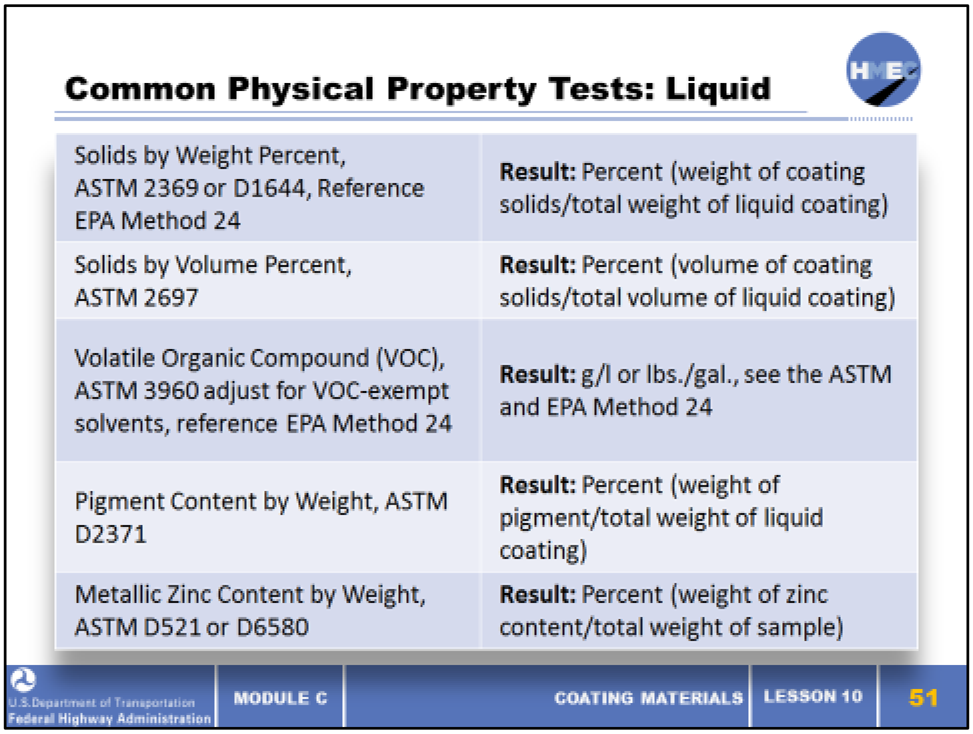

Common Physical Property Tests: Liquid

Solids by Weight Percent, ASTM 2369 or D1644, Reference EPA Method 24	**Result:** Percent (weight of coating solids/total weight of liquid coating)
Solids by Volume Percent, ASTM 2697	**Result:** Percent (volume of coating solids/total volume of liquid coating)
Volatile Organic Compound (VOC), ASTM 3960 adjust for VOC-exempt solvents, reference EPA Method 24	**Result:** g/l or lbs./gal., see the ASTM and EPA Method 24
Pigment Content by Weight, ASTM D2371	**Result:** Percent (weight of pigment/total weight of liquid coating)
Metallic Zinc Content by Weight, ASTM D521 or D6580	**Result:** Percent (weight of zinc content/total weight of sample)

ASTM test method usually applies to each test. For multi-component coatings, these tests are performed on one or both components, depending on the test.

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Common Physical Property Tests: Liquid

Test	ASTM Test Method
Weight per gallon	ASTM D1475
Viscosity, Brookfield (cps)	ASTM D2196
Viscosity, Stormer (KU)	ASTM D562
Fineness of Grind	ASTM D1260
FTIR spectroscopy	None

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All of these tests can be run in a coatings laboratory and the results may or may not appear on a PDS depending on manufacturer preference. FTIR spectroscopy produces a "fingerprint" of the coating for future reference.

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Physical Property Tests: Application

- Pot Life – measure viscosity after mixing for published pot life confirmation
  - No standard ASTM test method
  - Perform viscosity at 0, 25%, 50% and 100% of the stated pot life
  - Results: viscosity measurement value, such as cps or KU
- Sag Resistance, ASTM D4400
  - Results: mils (thousandth inch) or microns, matching sag bar gap
- Cure Time ASTM D1640 (set to touch, tack-free time, dry to touch and dry to handle)
  - Results: Minutes or hours

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Adhesion of the applied coating system can be assessed using any of three methods. ASTM D4541 is a tensile or pull-off test and requires the attachment of a loading fixture to the coated surface using an adhesive. Once the adhesive cures, a pull-off tester applies perpendicular force to the loading fixture (using mechanical, pneumatic or hydraulic mechanisms) to cause the coating system to break. A tensile value is recorded in psi or KPa and the location of break is recoded as cohesive, adhesive or glue. Tape adhesion and knife adhesion are performed by cutting an “X” into the coating system and evaluating the amount of disbondment after application and removal of tape (D3359) or subjective probing at the intersection of the “X” with the tip of the knife blade (D6677). The former is rated on a scale of 5A to 0A; the latter is rated on a scale of 10-0.

Gloss and color can be measured before and after weathering to assess the effect of solar radiation (sunlight) on color and gloss durability.

The degree of cure can be assessed using solvent rub tests performed according to ASTM D5402, or D4752 for inorganic zinc-rich primers

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The Research Council on Structural Connections (RCSC), an organization working under the American Institute of Steel Construction maintains the Specification for Structural Joints Using High-Strength Bolts. *APPENDIX A, TESTING METHOD TO DETERMINE THE SLIP COEFFICIENT FOR COATINGS USED IN BOLTED JOINTS* is used to determine whether coatings can be used on faying surfaces of slip-critical bolted connections that are determined to be Class A of Class B connections by the bridge design engineer.

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Class A includes surfaces containing unpainted clean mill scale and abrasive blast cleaned surfaces with coatings.

Class B includes surfaces containing unpainted abrasive blast cleaned steel and abrasive blast cleaned surfaces with coatings.

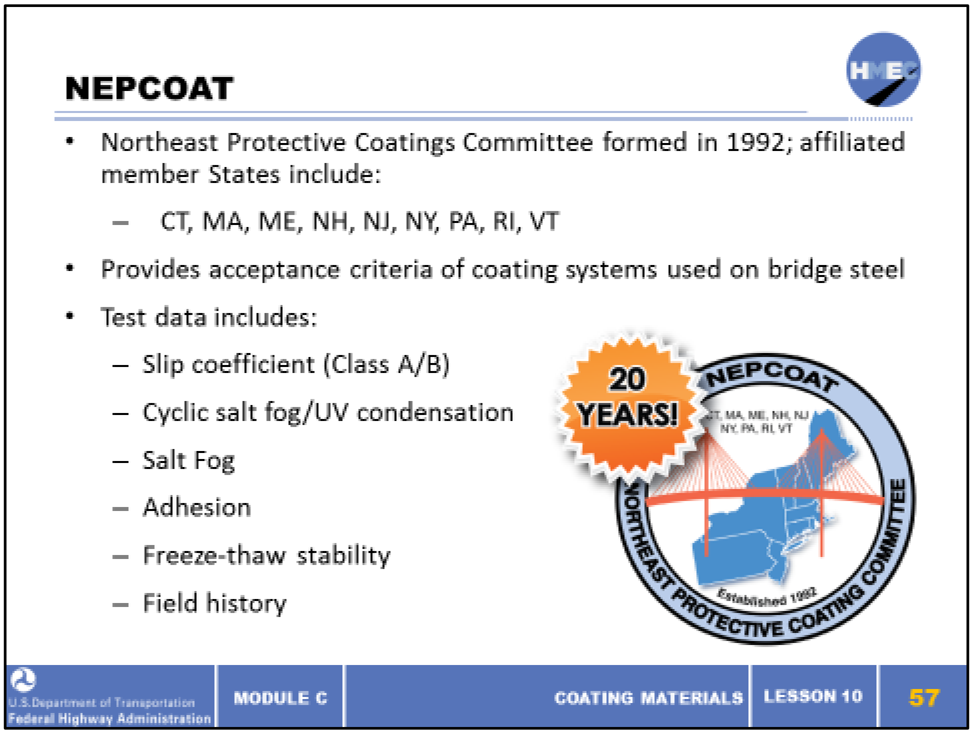
Class C is reserved for hot-dip galvanized surfaces that are prepared by wire brushing after galvanizing.

There is no requirement to use coatings on faying surfaces; however to prevent rust staining other potential corrosion problems, many bridge engineers will specify that a primer be applied to connection surfaces prior to bolt-up. On new steel, these connections are masked after primer application to prevent inadvertent application of additional coats.

Coatings are applied to specially prepared steel test plates adhering to the Essential Variables listed in Appendix A of the bolt standard. After the minimum cure time the coated panels are tested for slip coefficient and tension creep properties. Coatings are provided with either a Class

A or a Class B rating. Coatings not achieving either Class A or B are not permitted to be used on faying surfaces.

Slide 57



Northeast Protective Coatings Committee was originally formed in 1992; the current list of affiliated member States include: CT, MA, ME, NH, NJ, NY, PA, RI, and VT. NEPCOAT does not perform testing of coating systems. Rather, the member states use coating performance data generated by the AASHTO NTPEP Structural Steel Coatings (SSC) Work Plan. The committee applies their acceptance criteria to the data posted by NTPEP in DataMine. The data is generated by an independent testing laboratory approved by NTPEP. Coating systems are selected and submitted by coating manufacturers.

Test data includes: Slip coefficient (Class A/B/Fail); 5040 hours cyclic salt fog/UV condensation (includes color and gloss retention); 5000-hours Salt Fog; Pull-off (tensile) adhesion (primer only and full system); and Freeze-thaw stability (tensile adhesion after 30 thermal cycles). Field history is also reviewed for evidence of successful use on existing structures. A host of compositional properties tests are also conducted on the individual components and on the mixed components, however this data is used only for field batch verification by an agency; there is no pass/fail criteria other than VOC content.

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Slide 58

NEPCOAT works closely with FHWA, AASHTO, and NTPEP. Once the NEPCOAT committee reviews the available data (released from DataMine by the coating manufacturer) and applies the acceptance criteria, the "NEPCOAT approved" coating systems are posted to one of four potential lists (Lists A-D on the slide) depending on the generic type of primer and the number of coats. NEPCOAT, although an organization of northeastern States, has been looked at as a model for qualifying coating systems by other DOTs throughout the country.

Slide 59

AASHTO/NSBA Steel Bridge Collaboration S8.1-2014/SSPC-PA Guide 13, Guide Specification for Application of Coating Systems with Zinc-Rich Primers to Steel Bridges was updated and published in 2014. It represents a consensus on best industry practices for shop application of zinc-rich coating systems to previously uncoated bridge steel, including the proper preparation of the steel. A series of charts are included to simplify the application parameters for a system based on zinc-rich primers on new steel bridges. These charts detail requirements for surface preparation, environmental conditions, coating application, curing, verification testing, and prevention and remediation of non-conformances. The guide specification addresses a three-coat system consisting of primer, intermediate coat, and topcoat, but is also appropriate for application of a two-coat system or a primer only system.

The purpose of the Guide Specification is to establish and define the functions, operations, requirements, and activities needed to achieve consistent quality in steel bridge painting. It is based on a cooperative approach to quality, where the owner's and contractor's representatives work together to efficiently paint steel bridges and meet all contractual requirements.

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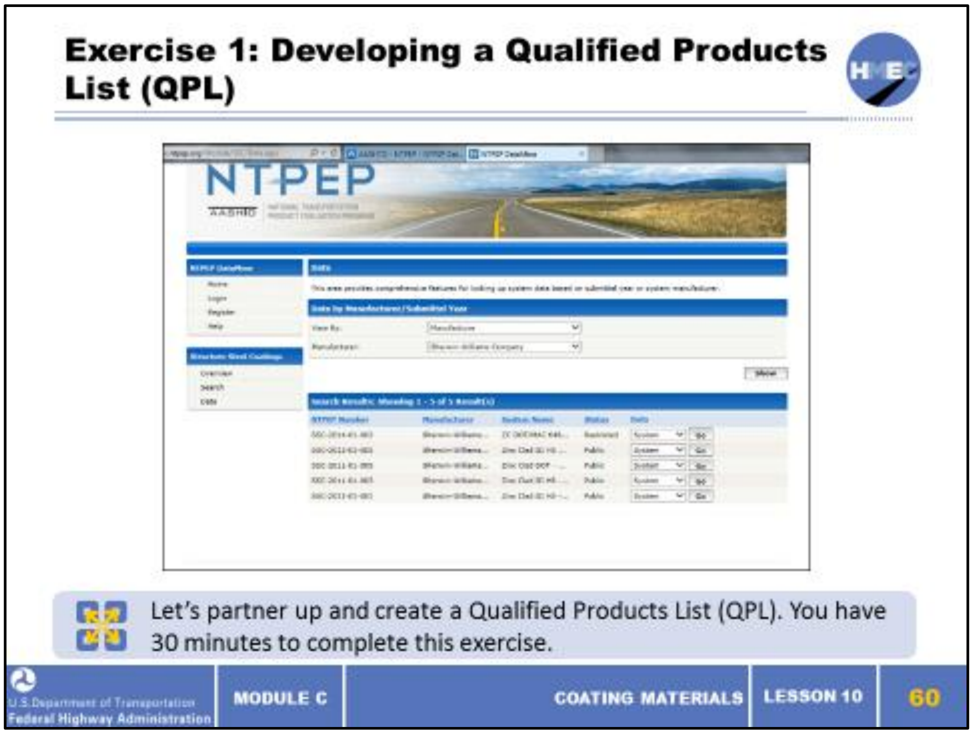
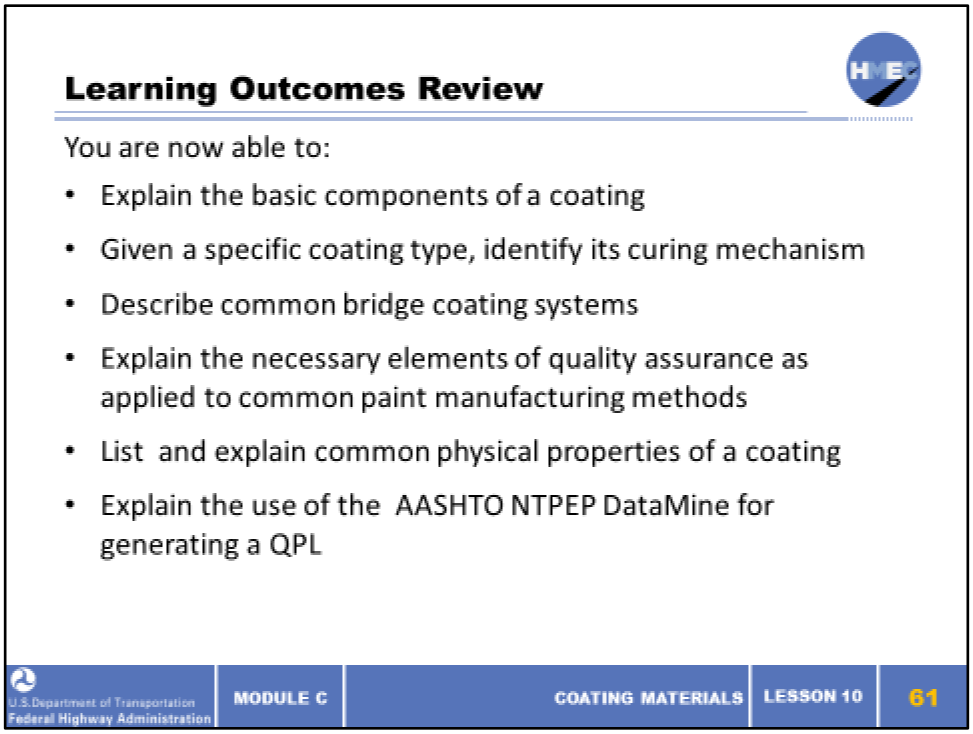
Slide 60


Exercise 1: Developing a Qualified Products List (QPL)
NTPEP
Let's partner up and create a Qualified Products List (QPL). You have 30 minutes to complete this exercise.
U.S. Department of Transportation
Federal Highway Administration
MODULE C
COATING MATERIALS
LESSON 10
60

Slide 61


Learning Outcomes Review
You are now able to:
• Explain the basic components of a coating
• Given a specific coating type, identify its curing mechanism
• Describe common bridge coating systems
• Explain the necessary elements of quality assurance as applied to common paint manufacturing methods
• List and explain common physical properties of a coating
• Explain the use of the AASHTO NTPEP DataMine for generating a QPL
U.S. Department of Transportation
Federal Highway Administration
MODULE C
COATING MATERIALS
LESSON 10
61

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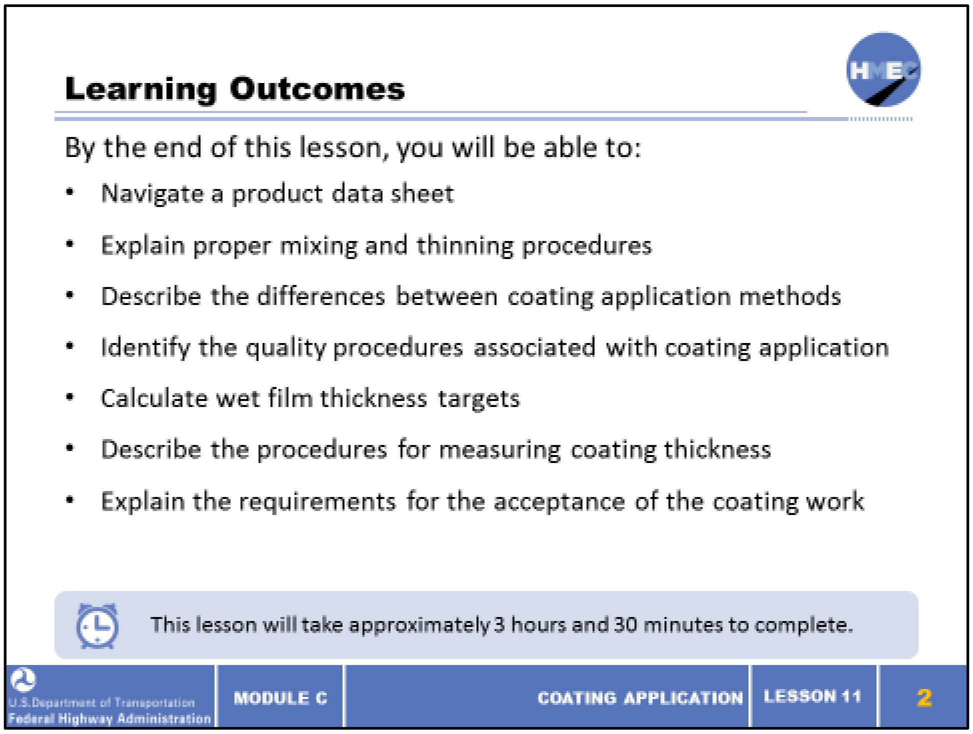
Slide 1


HMEC
Highway Materials Engineering Course
Lesson 11: Coating Application
Steel, Welding, and Coatings
U.S.Department of Transportation
Federal Highway Administration
MODULE
C

Slide 2


Learning Outcomes
HMEC
By the end of this lesson, you will be able to:
• Navigate a product data sheet
• Explain proper mixing and thinning procedures
• Describe the differences between coating application methods
• Identify the quality procedures associated with coating application
• Calculate wet film thickness targets
• Describe the procedures for measuring coating thickness
• Explain the requirements for the acceptance of the coating work
This lesson will take approximately 3 hours and 30 minutes to complete.
U.S. Department of Transportation
Federal Highway Administration
MODULE C
COATING APPLICATION
LESSON 11
2

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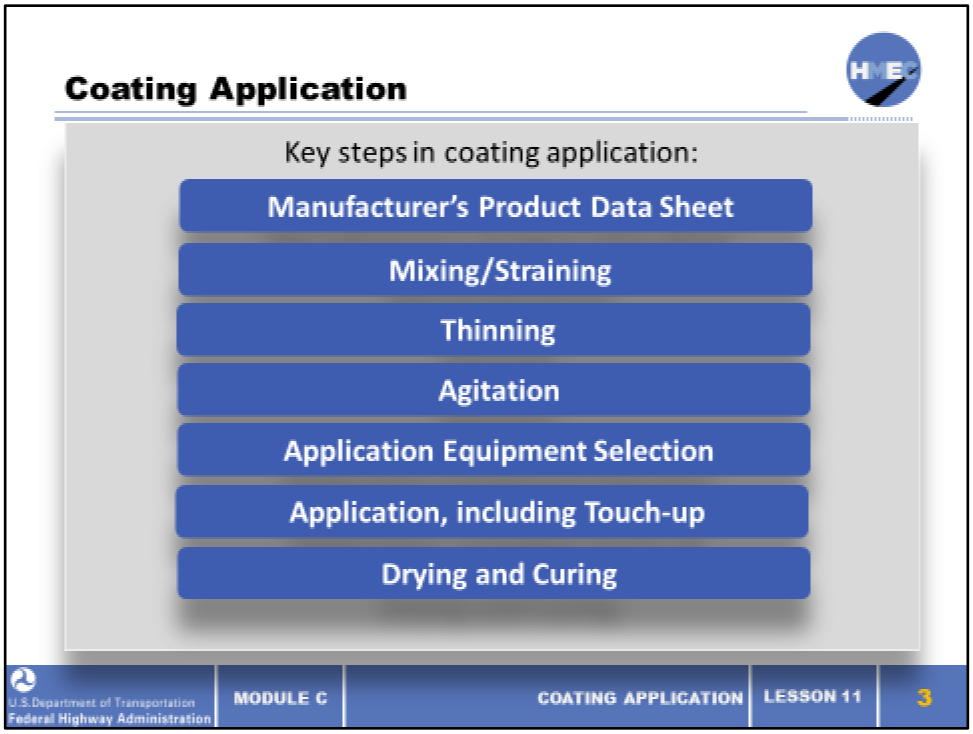
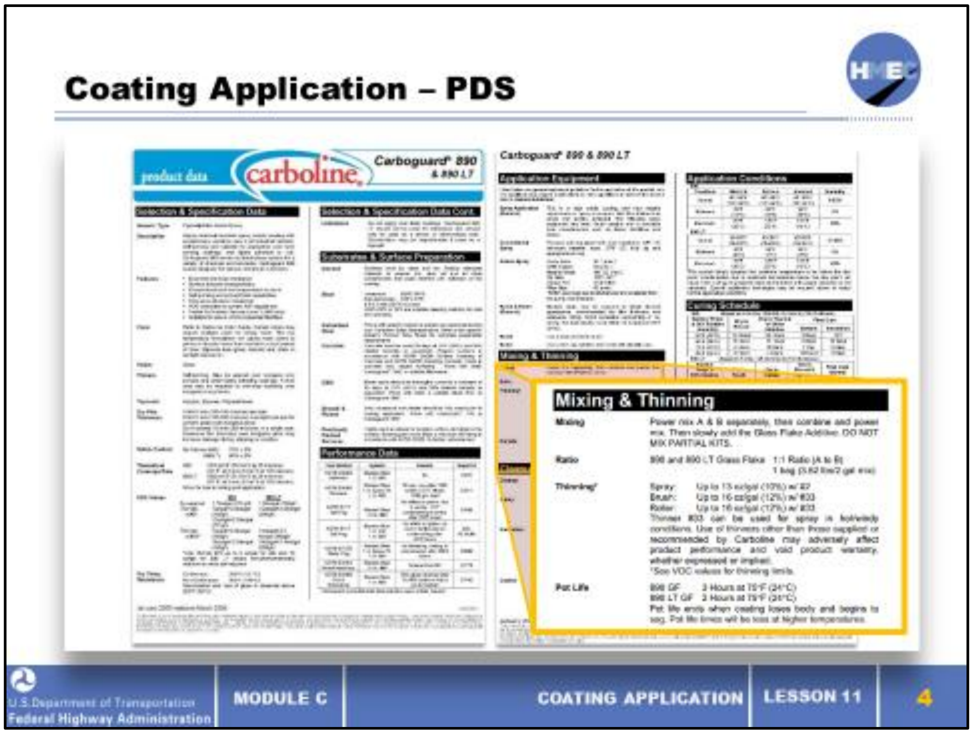
Slide 3



Proper coating application begins with reading and comprehending the instructions for proper use of the coating that are provided on the product data sheet (PDS). Reading and comprehending the information on a safety data sheet (SDS) is also very important. The subject of SDS was already covered in Lesson 10. Selection of the coating application method, mixing and thinning procedures, application and touch-up, and drying/curing all are part of the coating application sequence. Note that straining of the coating material and agitation of the spray pot during application are common with most zinc-rich primers, so they may be included in the sequence as well.

Slide 4



Unlike a SDS, which we discussed in Lesson 10, there are no regulations or standards governing the content and organization of a PDS. The information on a PDS can vary widely by manufacturer and product type. A PDS is designed to complement a project specification. If there are discrepancies between the two, the specification (contract) is the governing document. However the specifier should verify that the two do not conflict with each other. For example, the specification should not allow the application of a coating at 90% relative humidity (RH) if the PDS limits the application of the product to 85% RH. However, the reverse may occur, where the PDS allows application up to 90% RH but the specification limit is 85% RH (in this case, the specification is more restrictive). A PDS often contains both marketing and technical information. A PDS may also contain recommendations, where the project specification contains requirements.

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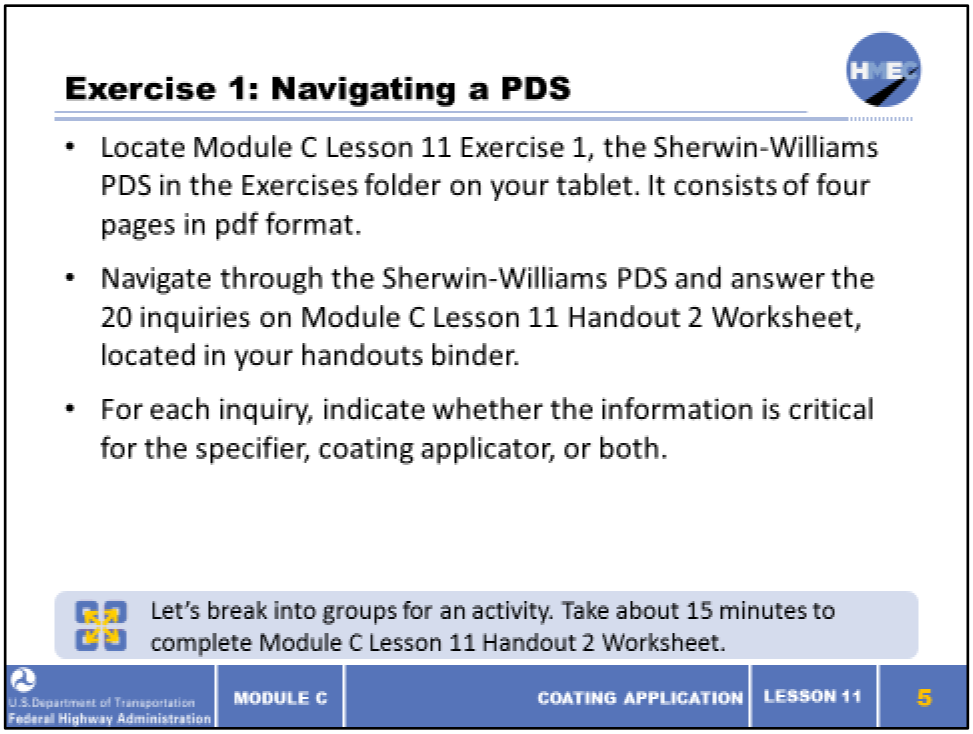
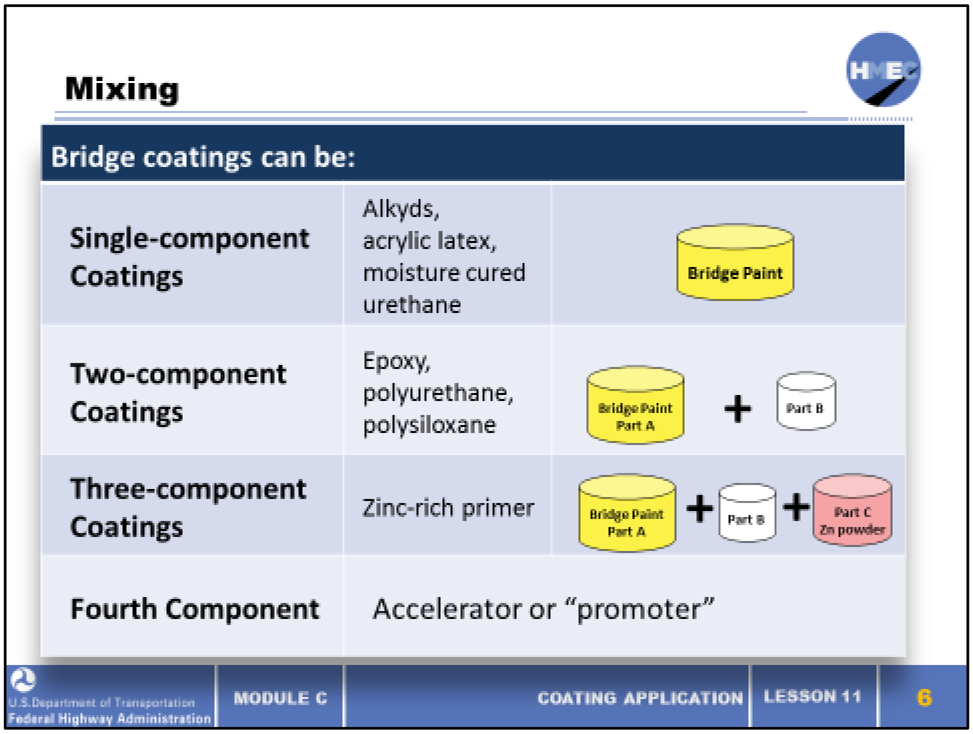
Slide 5


Exercise 1: Navigating a PDS
HMEC
Locate Module C Lesson 11 Exercise 1, the Sherwin-Williams PDS in the Exercises folder on your tablet. It consists of four pages in pdf format.
Navigate through the Sherwin-Williams PDS and answer the 20 inquiries on Module C Lesson 11 Handout 2 Worksheet, located in your handouts binder.
For each inquiry, indicate whether the information is critical for the specifier, coating applicator, or both.
Let's break into groups for an activity. Take about 15 minutes to complete Module C Lesson 11 Handout 2 Worksheet.
U.S. Department of Transportation
Federal Highway Administration
MODULE C
COATING APPLICATION
LESSON 11
5

Slide 6



Bridge coatings can be composed of one-, two-, three-, or even four-components. Multi-component coatings must be mixed properly and in the correct ratio of components to achieve the proper cure and performance properties. Two- and three-component materials are common for bridge structures. A fourth component is rare, but may be required when application is scheduled during cooler temperatures or when rapid recoat characteristics are desired.

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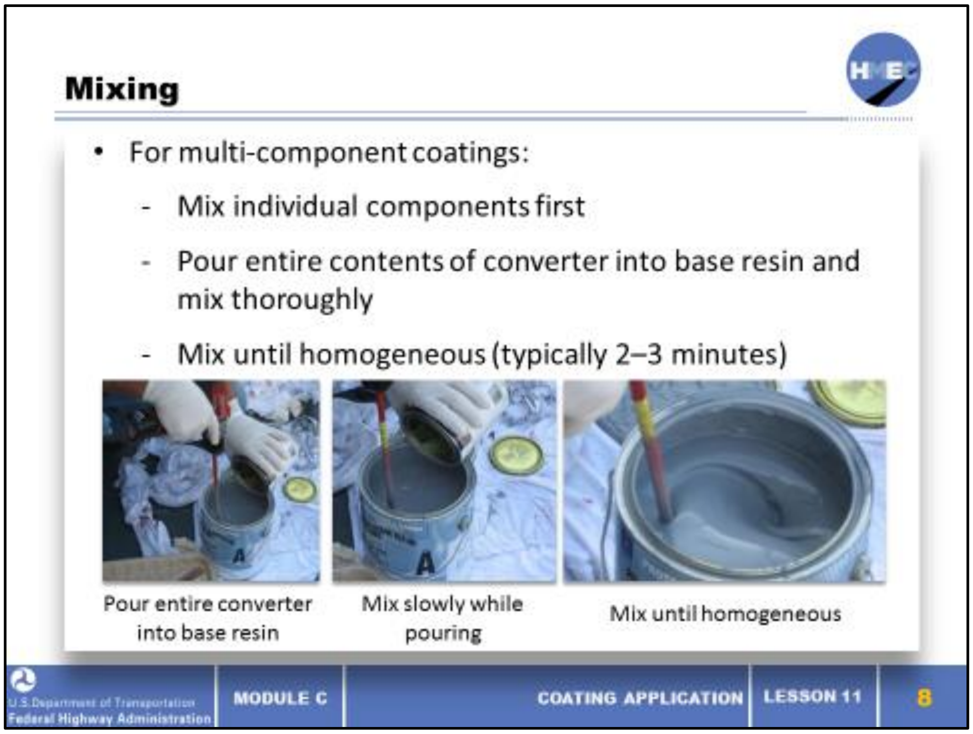
Slide 7

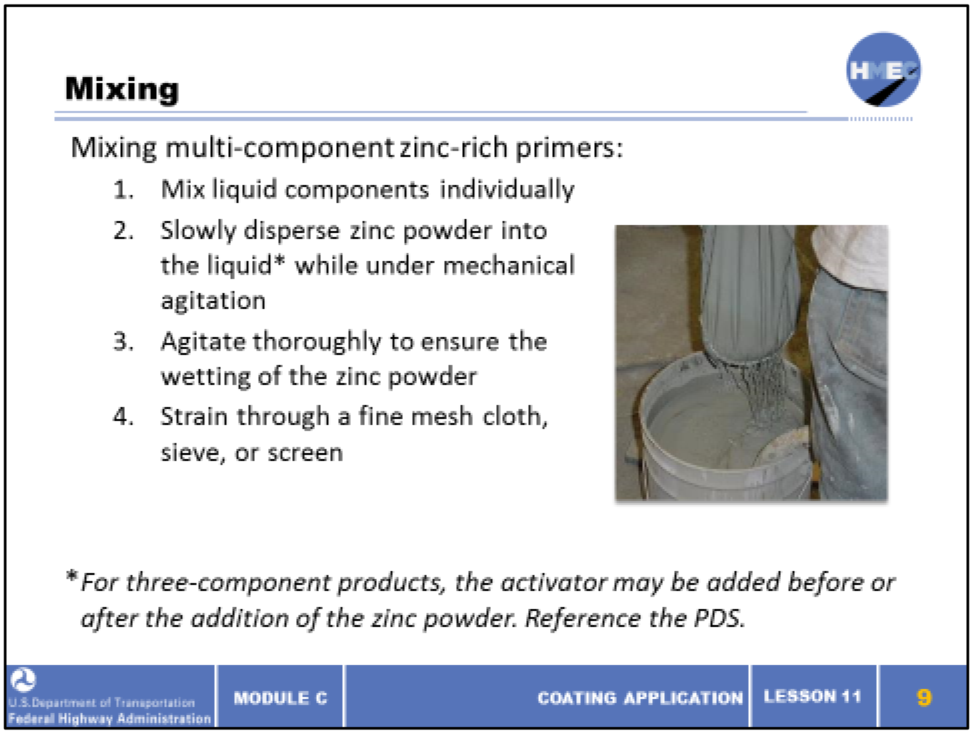
Low-speed mechanical mixers are essential for industrial coatings. The paint sticks we stir house paints with are not effective in mixing industrial coatings and should not be used except to scrape the sides of the cans. The mechanical mixing blades should be mounted in variable speed air-powered drills. High-speed mixers can whip air into the coating. Also, over-mixing coatings that cure using moisture may shorten the amount of available application time.

Slide 8



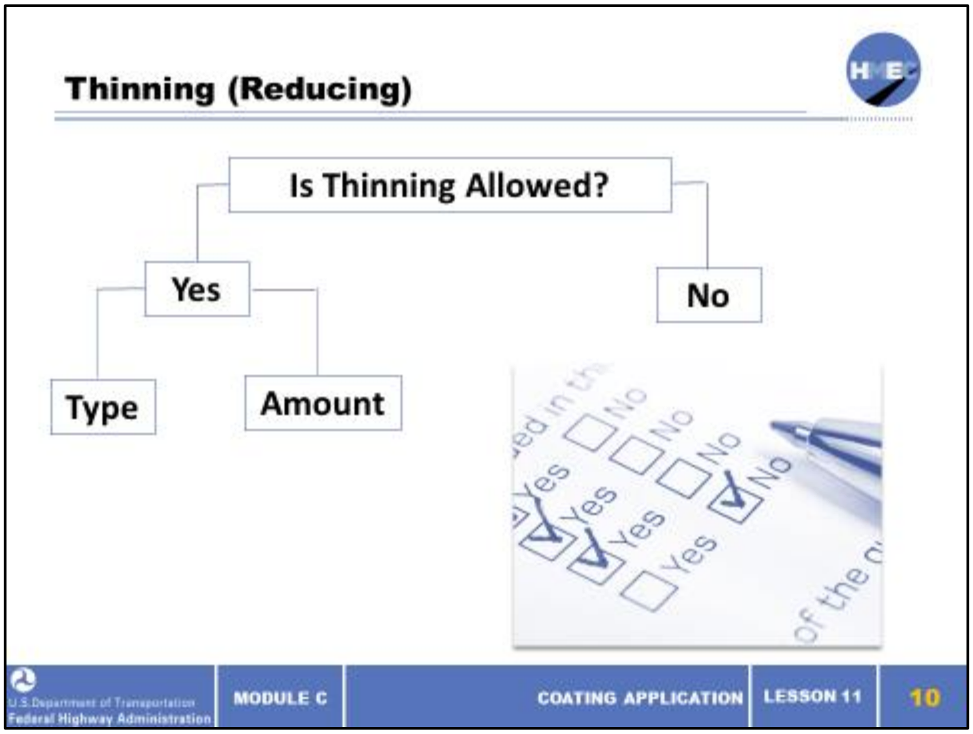
Notice how a mild vortex is created by the mechanical mixing blade in the blended coating on the right. This should be maintained until a homogenous mixture is attained, being cautious not to draw in too much air, as the air contains moisture than may react with the coating.

Slide 9



In order to properly mix a multi-component zinc-rich primer, first mix liquid components individually, then slowly disperse the zinc powder into the liquid while under mechanical agitation. This often requires working in pairs. Agitate the mix thoroughly to ensure that the zinc powder becomes thoroughly wetted. Strain the mix through a fine mesh cloth, sieve, or screen to remove any zinc particles that may have clumped during mixing. These particles can create spray gun tip clogs, or may end up in the coating film. Most non-zinc coatings do not require straining.

Slide 10



Before an applicator considers thinning, they need to consider several things beyond, "the coating needs to be thinned." Many applicators will automatically add thinner to a coating as though it is a required component. Thinners have benefits, but their use must be carefully weighed against the consequences. To do this, a series of three questions are considered.

1. Is thinning allowed? (Answer Yes or No.) Recognize that while a coating manufacturer may permit the use of compatible thinner, the specification may prohibit its use.

2. If thinning is allowed (answered "yes"), what type is required? Only the manufacturer's recommended thinners should be used. There is no universal thinner, nor is there a way to determine compatibility in the shop or field. The manufacturer's recommended thinner(s) is listed on the PDS. There may be several options, including those for hot/windy conditions or for locations where air quality regulations are more restrictive. Thinner should always be clean, new, and in its original container.

3. If thinning is allowed (answered "yes"), what amount is acceptable? The manufacturer will indicate the amount to add (typically by %) on the PDS. The addition of any non-exempt thinner will increase the VOC content of a coating. Most manufacturers publish the re-calculated VOC

content based on the type and amount of thinner added. Thinner should be measured into graduated containers; quantities added should never be estimated.

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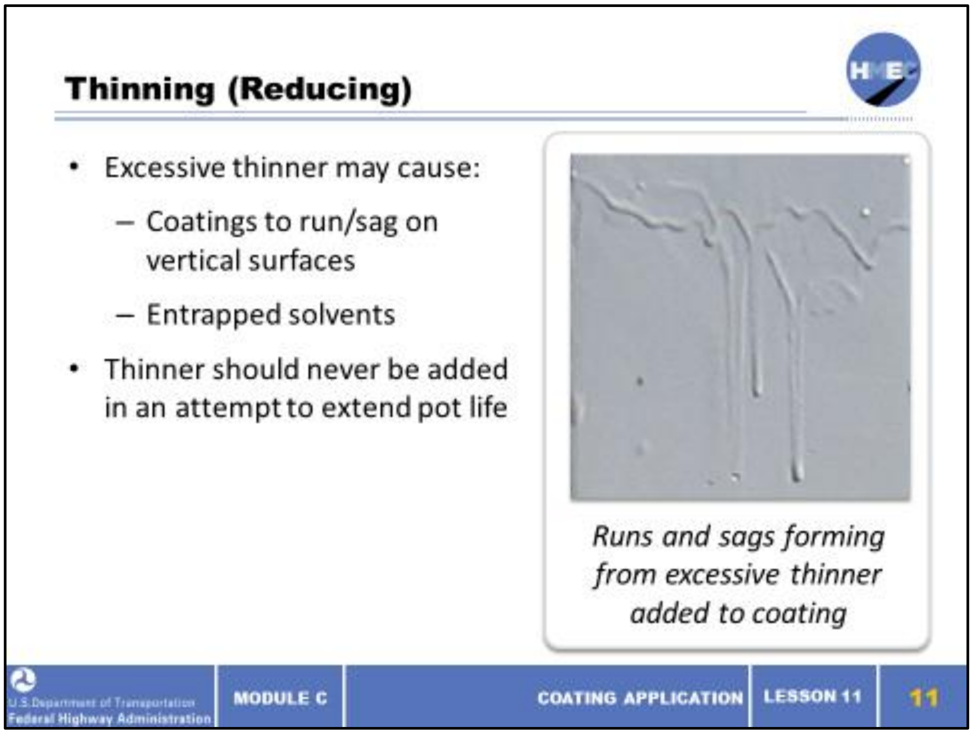
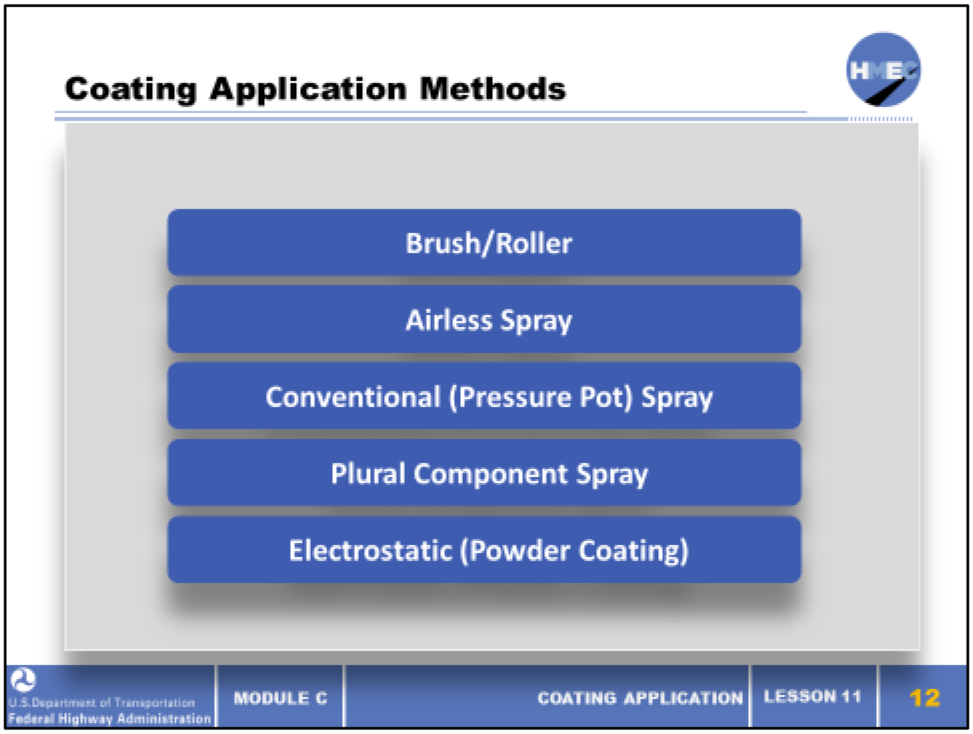
Slide 11



Excessive thinner addition can also cause the coating to "surface dry" before the solvents have an opportunity to escape from the film, which can result in a void-filled coating. If a sufficient amount of water is present on the outside of the coating, then there is a chance of osmotic blistering occurring once the coating is in service.

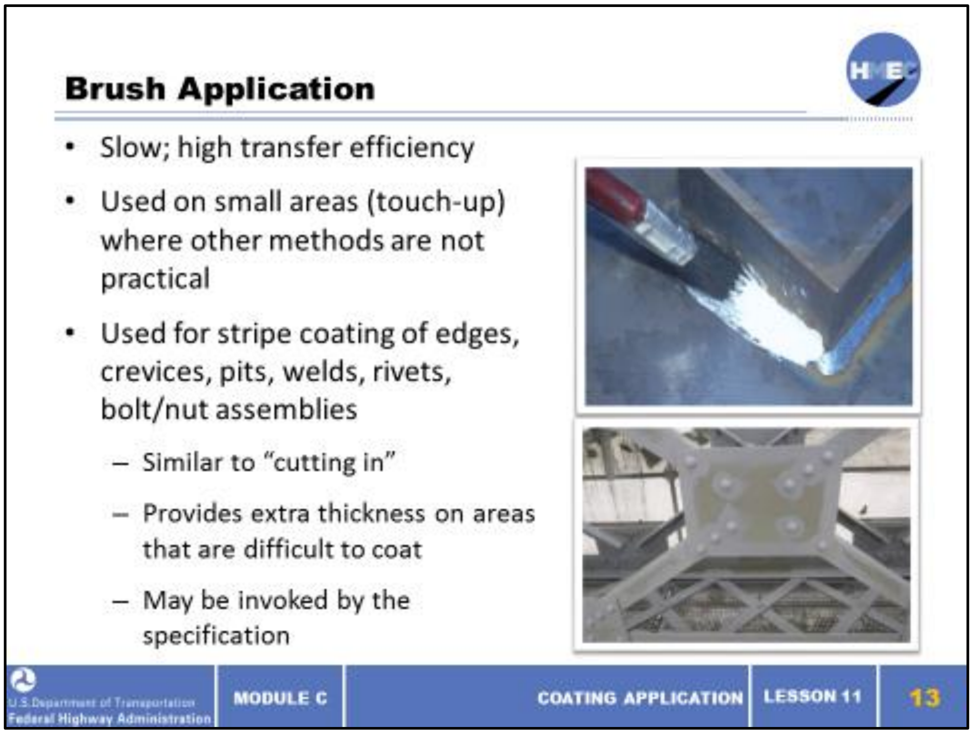
Many coatings become more viscous into their pot life. Thinner should never be added to a coating for the purpose of attempting to extend the pot life. Pot life can be controlled by reducing the material temperature.

Slide 12



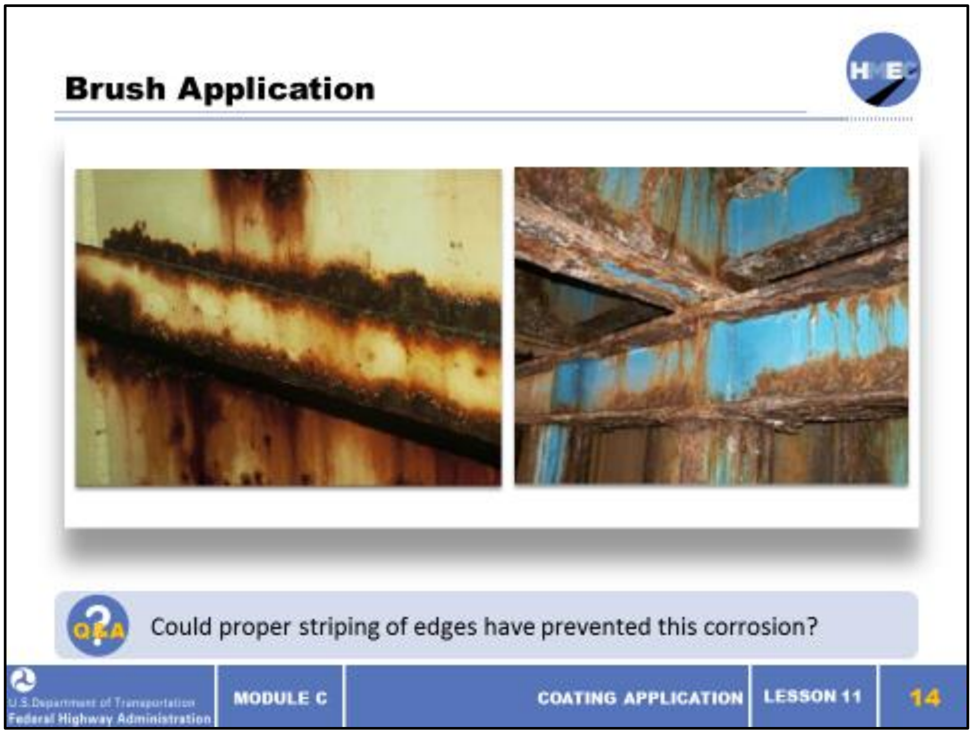
Bridge coatings may be applied by a brush and roller, airless and conventional or pressure pot spray, or plural component spray. Electrostatic spray is generally used for the application of powder coatings to hot-dip galvanized sign posts, light poles, or other structural components that are coated in the shop and erected in the field. We will briefly describe each. The intent of this section of the lesson is to familiarize you with the advantages and limitations of each of these methods. We will not be learning about application techniques.

Slide 13



Brush application is relatively slow and rarely used on large surfaces. However, it does possess a high transfer efficiency, which is the ratio of product loaded onto/into the application device to the amount of product that is transferred to the surface. On bridges, brushing is used on small areas where other methods of application like spray aren't practical. Brushes are often used for the application of stripe coats. A stripe coat is a coat of paint applied to inside corners, edges, welds, rivets, and bolt/nut assemblies. The intent of striping is to provide an added thickness on surfaces that are difficult to build coating onto. A significant amount of premature coating breakdown is often along edges where the specified coating thickness is difficult to achieve. The lower image on the slide illustrates thorough striping of surfaces that traditionally exhibit early failure. A specifier may require striping of each coat, or only on select coats. Striping of the finish coat is often excluded for aesthetics (provided the underlying layer(s) were stripe coated).

Slide 14


Brush Application
Could proper striping of edges have prevented this corrosion?
U.S. Department of Transportation
Federal Highway Administration
MODULE C
COATING APPLICATION
LESSON 11
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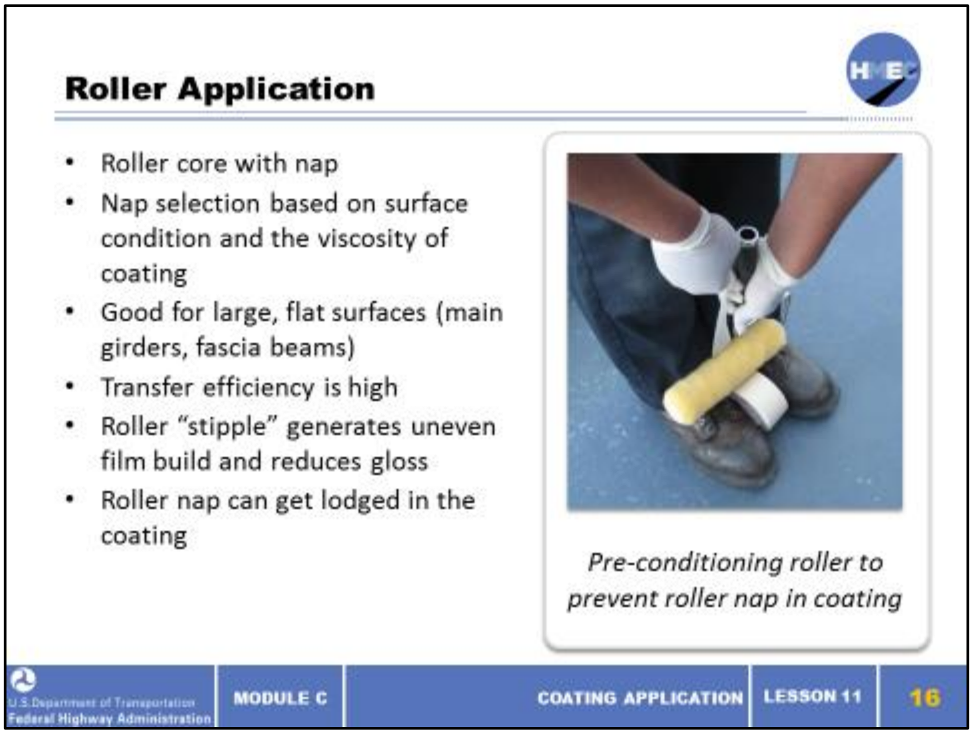
Slide 15

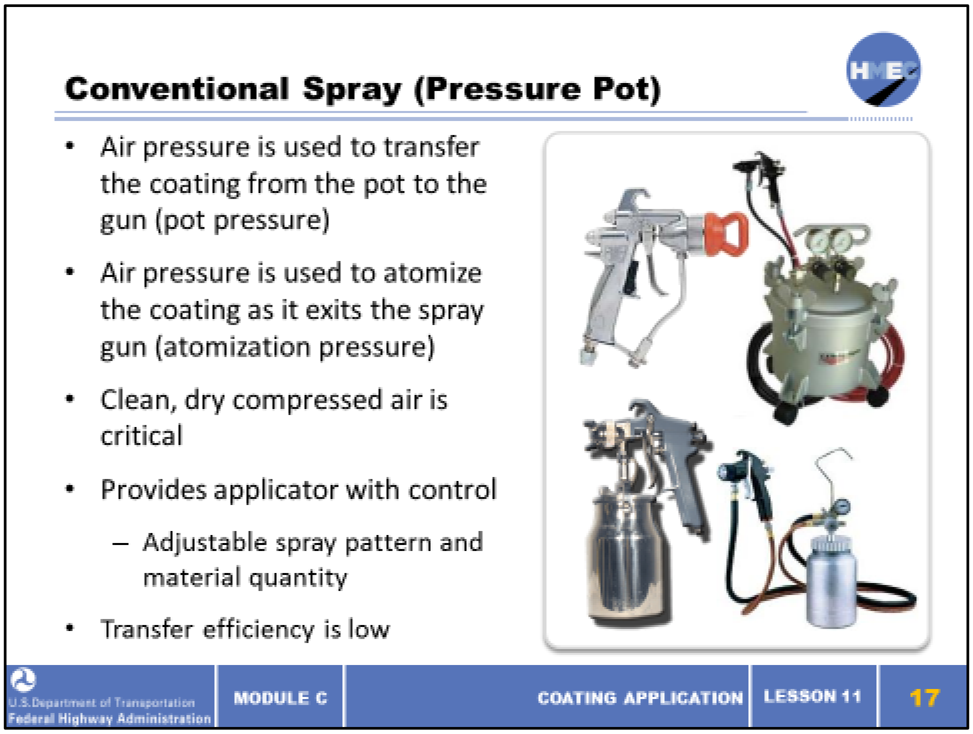
Brush application of maintenance coatings is a daily operation on this bridge located in San Francisco, California. Note that matching the color of the touch-up coating with the in-place coating is extremely difficult due to the effect of weather conditions, which causes the existing coating to fade over time. The primary purpose of the application of the touch-up coating by brush is for corrosion prevention, not aesthetics.

Slide 16



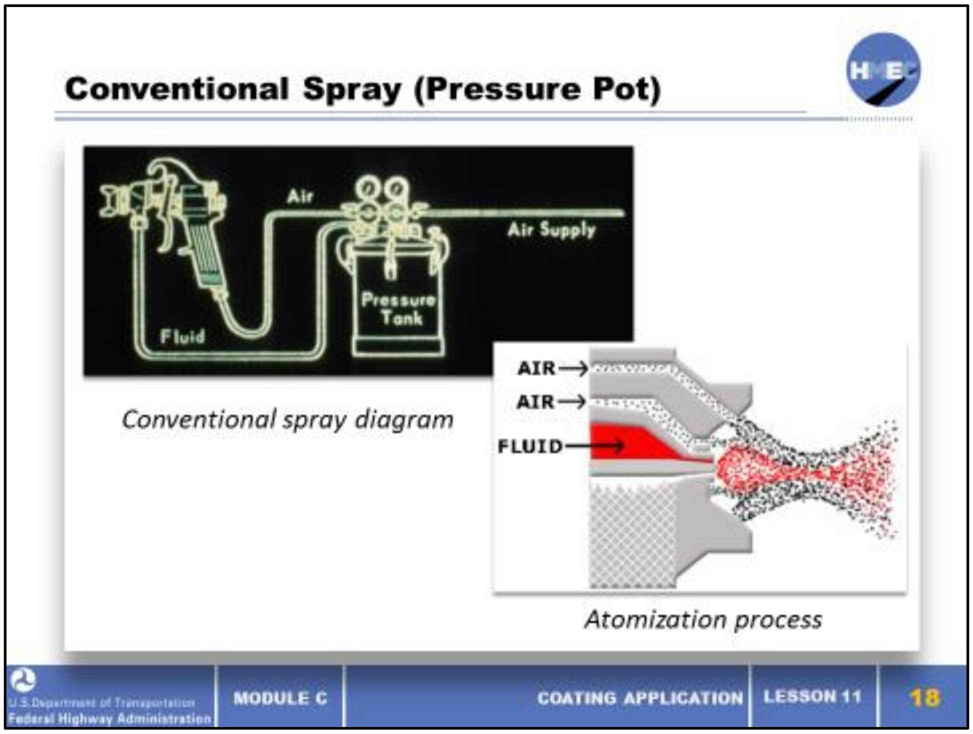
A roller consists of a core with nap and a handle. Various types of roller nap, nap length, and core diameters and lengths are available. Nap selection is based on surface condition and the viscosity of coating to be applied. Rollers are good for application of coatings to large, flat surfaces like main girders and fascia beams, but are difficult to use on intricate or irregular surfaces. The transfer efficiency is high. The specifier needs to recognize that the use of rollers creates roller "stipple," which results in uneven film build and reduced gloss. Also, roller nap can get pulled from the core and lodged in the coating. Pre-conditioning the roller core to remove the loose nap (using adhesive tape) can help to prevent this from occurring.

Slide 17



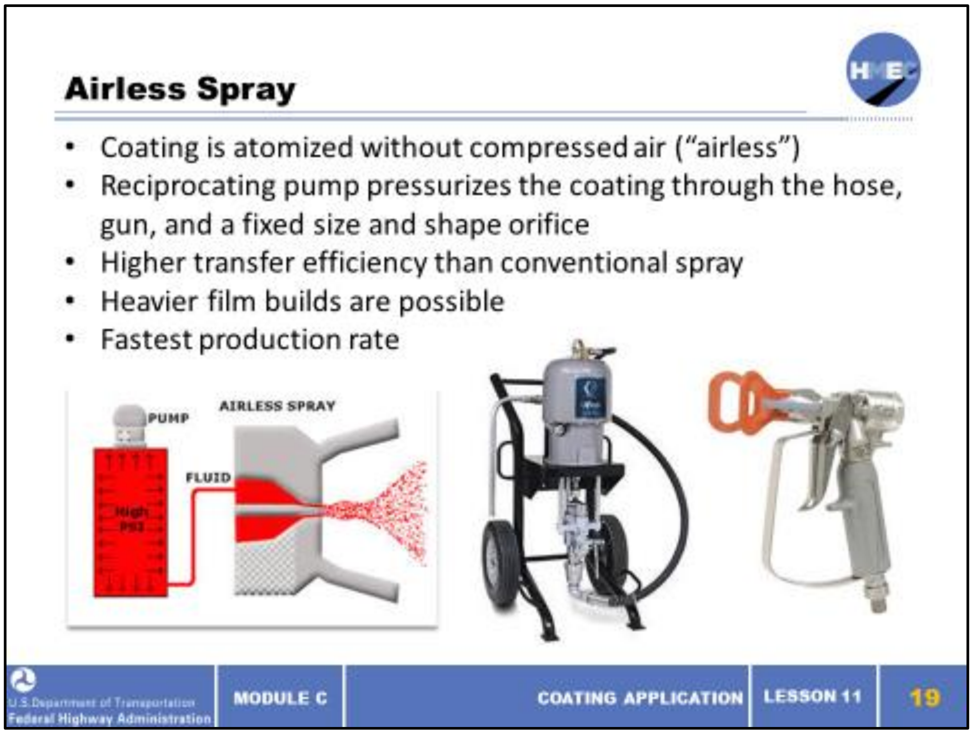
As the name infers, compressed air is an integral component to conventional (air) spray. Air pressure is used to transfer the coating from the pot to the gun (which is called pot pressure) and to atomize the coating as it exits the spray gun (known as atomization pressure). So the use of clean, dry compressed air is critical. A compressed air cleanliness test (ASTM D4285) that was described in Lesson 8 should also be performed prior to using conventional spray equipment. This type of application equipment provides the applicator with control over the amount of coating that enters the atomization chamber in the gun as well as the shape of the fan pattern as the coating is atomized. Since the ratio of compressed air-to-coating coming out of the spray gun is relatively high, the transfer efficiency of this method is low.

Slide 18



Compressed air enters the paint stream as it exits the nozzle (known as an air cap), which results in atomization.

Slide 19



With airless spray, the coating is drawn into a reciprocating pump through a siphon hose and placed under pressure (4,000–6,000 psi is common). The coating is atomized without compressed air (this system is "airless"). The coating enters the spray tip at several thousand psi pressure, then the pressure is released to atmospheric pressure as it exits the spray tip. This pressure differential causes the coating to atomize. The diameter of the hole in the spray tip (in thousandths of an inch) is fixed, as is the width of the spray fan. Airless spray tips are interchangeable. The transfer efficiency is higher (better) than conventional spray, and the application of more coating faster is possible. Other advantages of airless spray include:

• Reduced overspray and bounce back, which results in material savings and lower contribution of VOCs;
• Pressure pots are not required, so compressed air cleanliness is not as critical; and
•The coating is traveling towards the surface at a higher speed, so it can be "pushed" into crevices.

Slide 20

Although airless spray is very common for bridge painting, there are limitations including:

• The fan width of the spray tip is fixed without changing tips;
• Outside of the skill of the applicator there is little control over the quantity of the material being applied, which means that large volumes of paint are dispensed in short periods of time;
• It is difficult to coat small items due to lack of control over material quantity and fan shape exiting the gun; and
• The worker is prone to injection wounds if careless.

Slide 21

Plural component spray is often used for 100% solids coatings or products with very limited pot life (seconds or minutes). The liquid components are pumped through separate hoses to a manifold (similar to the process associated with airless spray), then blended in the correct ratio and sent through a short hose to the spray gun. Some pumps are external mix, which means the components are blended as they exit the spray nozzle. The components are heated in the hoppers to reduce the viscosity since thinners cannot be used with this system. The hoses are also heated for viscosity control and to maintain flow. A technician is often present to verify that the ratio, temperatures, and general operation of the pump are maintained during application, as off-ratio coatings must be removed and replaced. The transfer efficiency is similar to that of airless spray and the equipment is quite expensive to purchase and to repair.

Slide 22


Plural Component Spray
Various plural component spray rigs
U.S. Department of Transportation
Federal Highway Administration
MODULE C
COATING APPLICATION
LESSON 11
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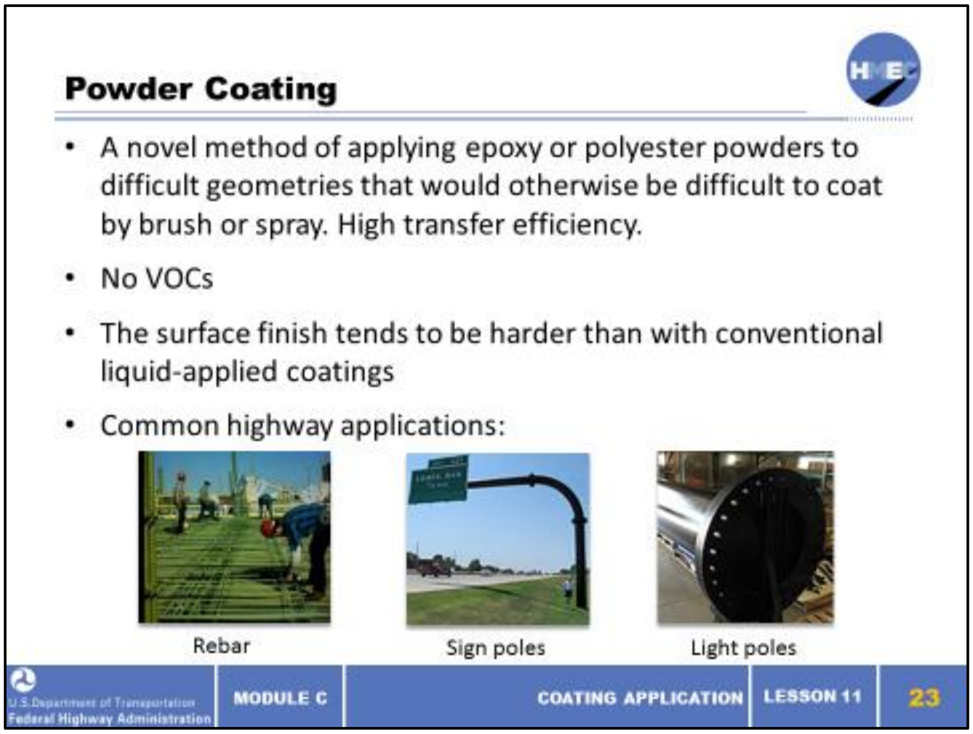
Slide 23



The application of powder coating takes place in specialized shops, not in the field. It boasts a high transfer efficiency and there are no VOCs emitted during cure (solvent-less). Parts such as sign poles, guide rails, and rebar are powder-coated items that are common highway applications. Galvanized surfaces are also sometimes powder coated to impart color and protect the galvanizing layer. The size of components that can be coated are limited by available ovens (for pre- and post-cure) or beds. Curing temperature must not affect the properties of the component material and precautions must also be taken when non-metallic or heat treatable alloys, such as aluminum 6061-T6, are used.

There have been some issues with powder coating hot-dip galvanizing (HDG) without first heating the HDG to drive off gases. If this occurs during the powder baking process, pinholing often occurs.

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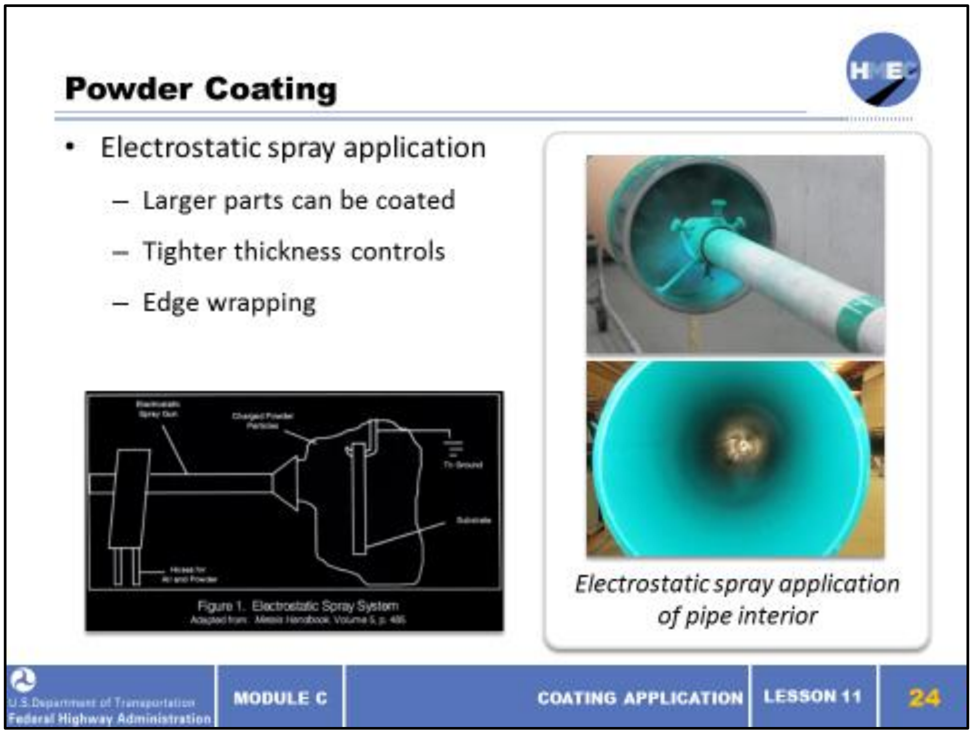
Slide 24



With electrostatic spray, the article is charged one way (e.g., grounded) and the powder particles are electrostatically charged opposite (+), thus the electrostatic “draws” the particles to the substrate.

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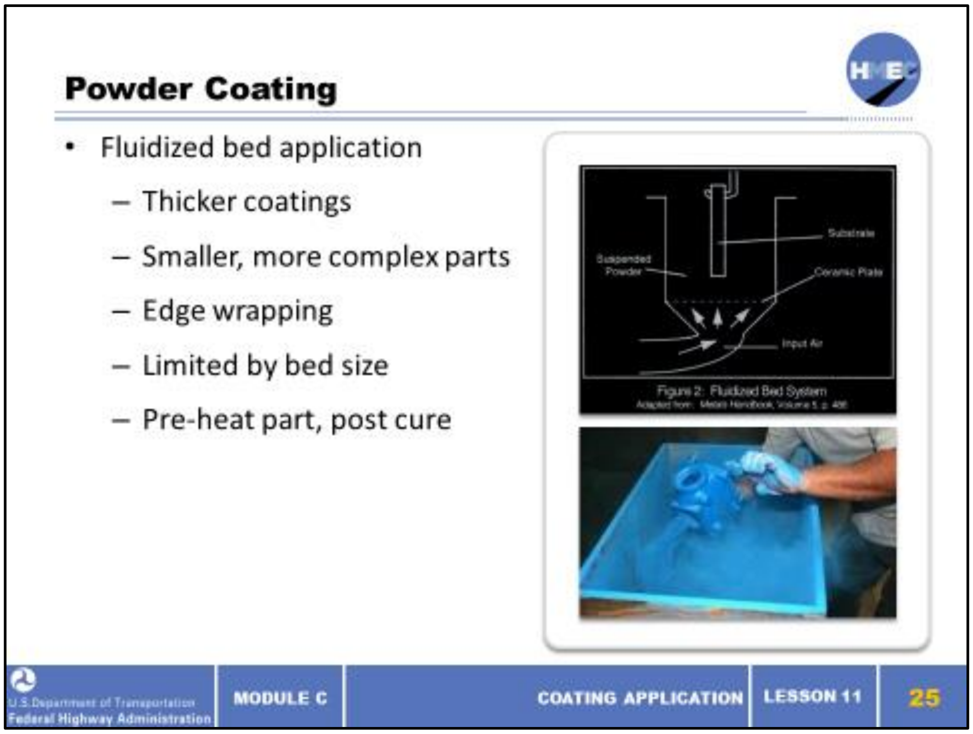
Slide 25



Shown here is a heated part, which is submerged in a fluidized bed of powder. The particles fuse to the prepared part, which is then placed into an oven for a specified post-cure period. During this phase, the powder melts, fuses, and cures to a continuous film.

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Slide 26

Selection Matrix – Application Methods

METHOD/APPLICATION	BRUSH	ROLLER	CONVENTIONAL	AIRLESS	PLURAL COMPONENT	POWDER
SPOT REPAIR MAINTENANCE	X					
SMALL AREA SPRAY			X			
LARGE APPLICATION AREA		X		X		
LOW COST APPLICATION		X				
HIGH BUILD EPOXY/FAST CURE					X	
SPECIALIZED PARTS						X
ZINC-RICH PRIMER			X	X		

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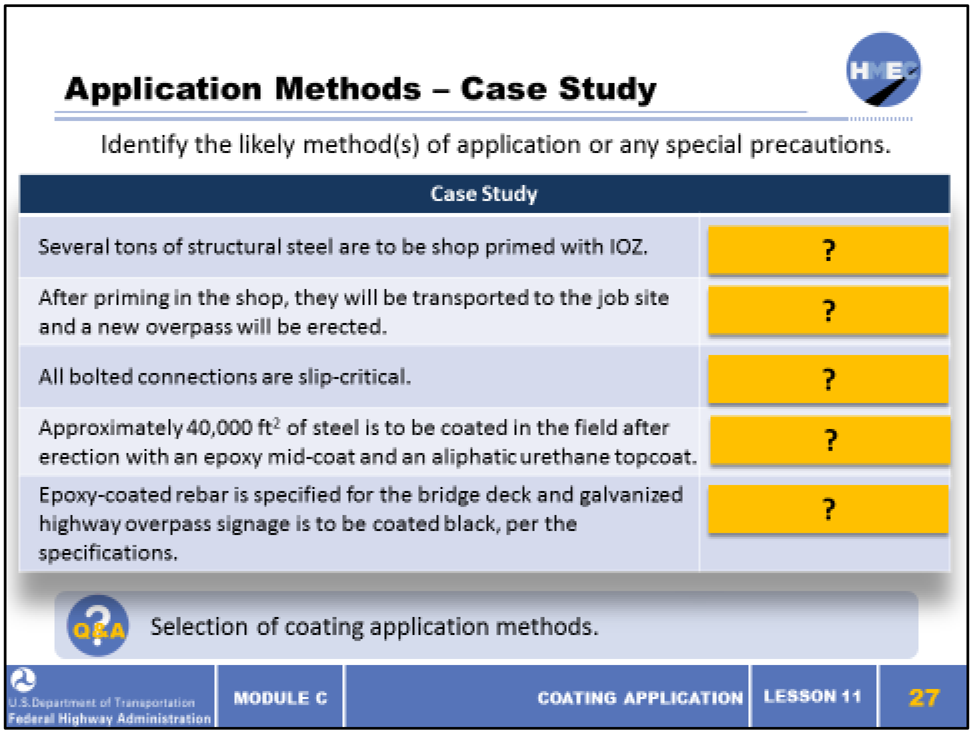
Application Methods – Case Study
Identify the likely method(s) of application or any special precautions.
Case Study
Several tons of structural steel are to be shop primed with IOZ.
?
After priming in the shop, they will be transported to the job site and a new overpass will be erected.
?
All bolted connections are slip-critical.
?
Approximately 40,000 ft² of steel is to be coated in the field after erection with an epoxy mid-coat and an aliphatic urethane topcoat.
?
Epoxy-coated rebar is specified for the bridge deck and galvanized highway overpass signage is to be coated black, per the specifications.
?
Q&A
Selection of coating application methods.
U.S. Department of Transportation
Federal Highway Administration
MODULE C
COATING APPLICATION
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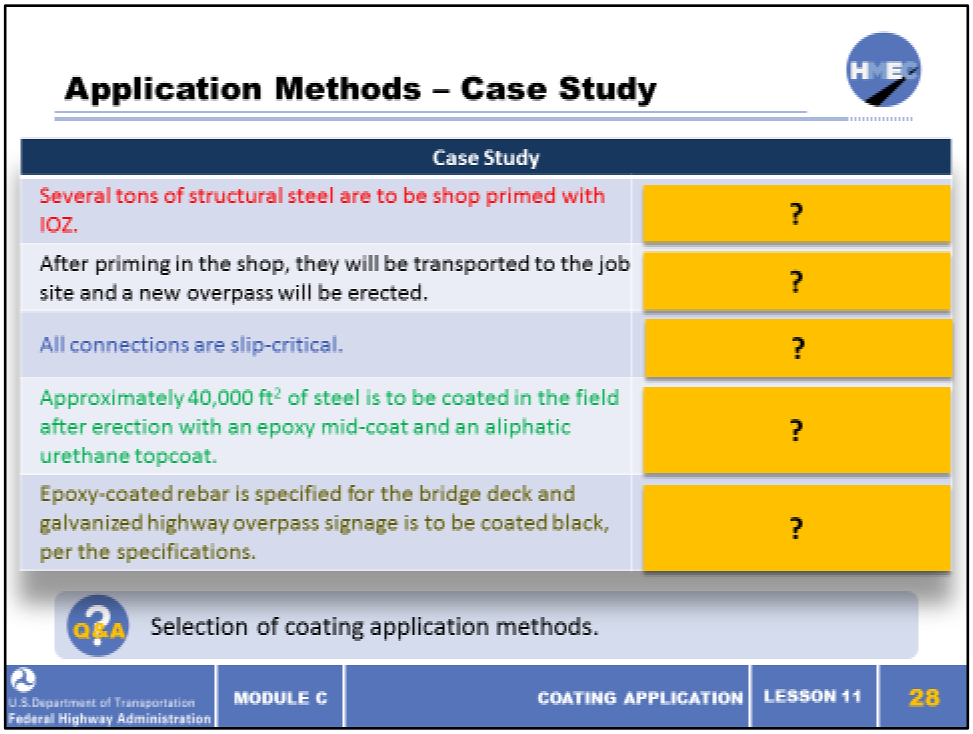
Application Methods – Case Study
HMEC
Case Study
Several tons of structural steel are to be shop primed with IOZ.
?
After priming in the shop, they will be transported to the job site and a new overpass will be erected.
?
All connections are slip-critical.
?
Approximately 40,000 ft^2 of steel is to be coated in the field after erection with an epoxy mid-coat and an aliphatic urethane topcoat.
?
Epoxy-coated rebar is specified for the bridge deck and galvanized highway overpass signage is to be coated black, per the specifications.
?
Q&A
Selection of coating application methods.
U.S. Department of Transportation
Federal Highway Administration
MODULE C
COATING APPLICATION
LESSON 11
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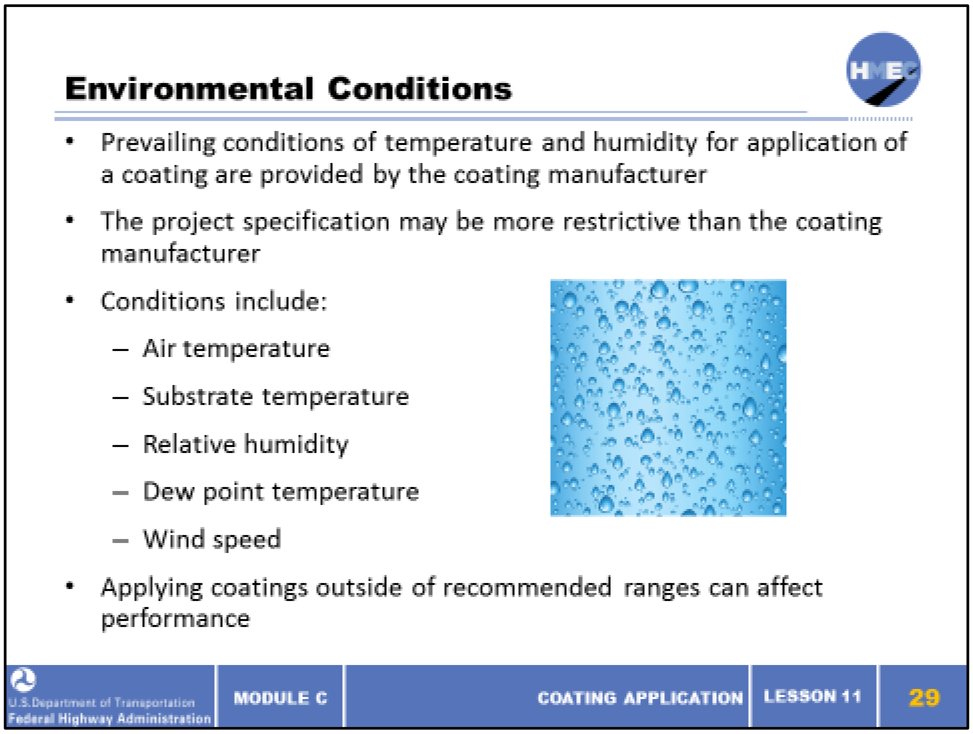
Slide 29



Prevailing conditions of temperature and humidity for application of a coating are provided by the coating manufacturer; however, the project specification may be more restrictive than the coating manufacturer. Environmental conditions that may impact coating application include air temperature, substrate temperature, the relative humidity, the dew point temperature, and the prevailing wind speed. Applying coatings outside of the recommended ranges can affect application properties, curing properties, and long-term performance.

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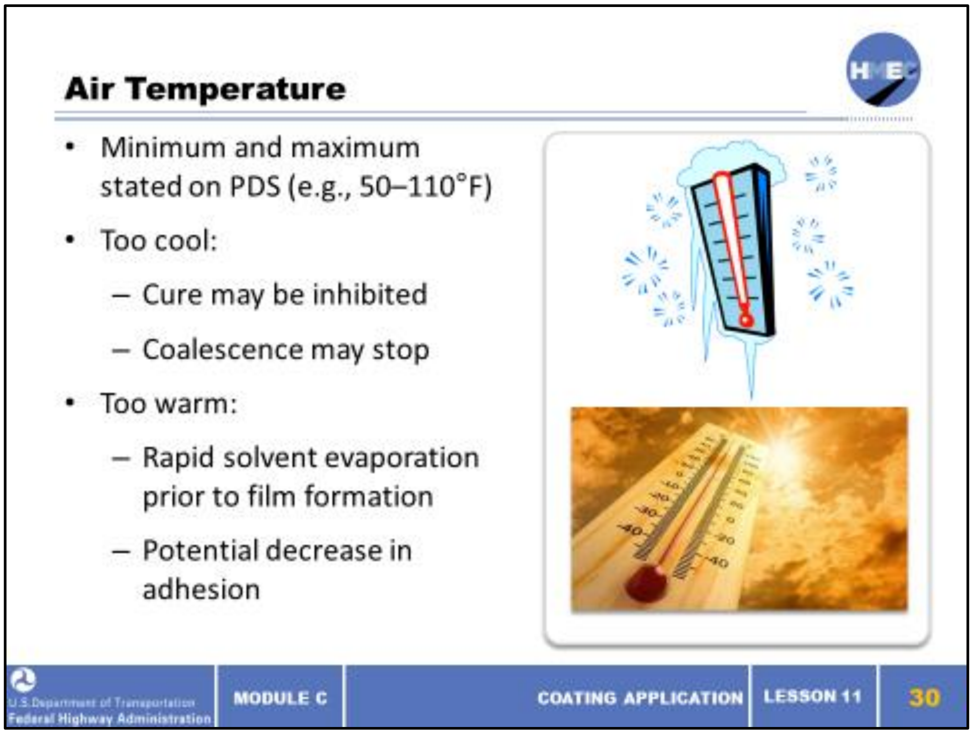
Slide 30



There is not a standard air temperature range that applies to all coatings. The minimum and maximum air temperatures for application and cure are listed on the manufacturer's PDS. For example, a common range for the application of epoxy coatings is 50–110°F; however, there are low temperature versions that may be applied down to 35°F. If the air temperature is too cool (below the manufacturer's minimum temperature), the drying and curing processes can be significantly retarded, and if the coating is a waterborne acrylic, the coalescing process may stop and the coating may never achieve its protective properties.

Conversely, if the air temperature is too warm, the solvents may evaporate from the film too quickly and the coating may not be able to flow/knit together and form a continuous film, revealing pinholes. Also, by curing too quickly, a coating may not be able to wet-out and bond to the underlying surface, resulting in decreased adhesion properties.

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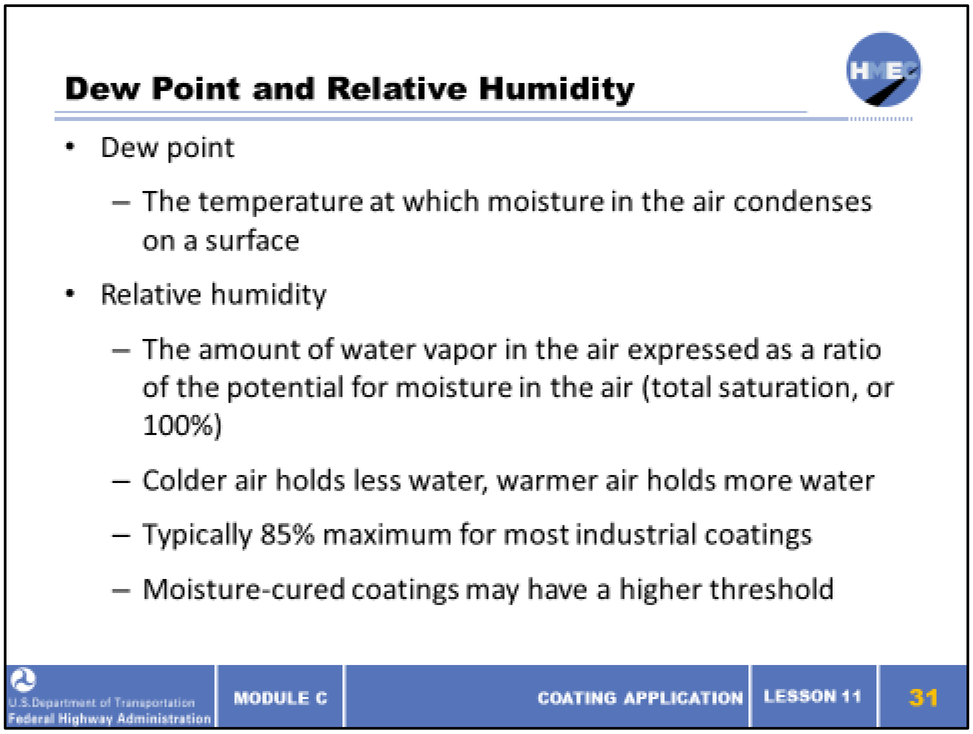
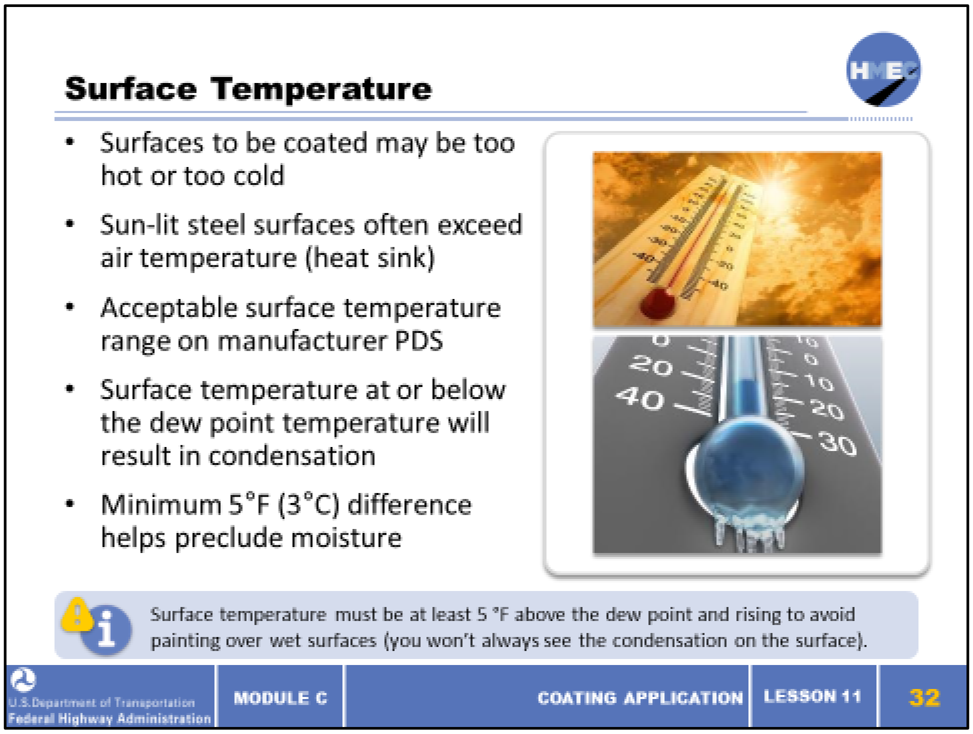
Slide 31



Dew point is the temperature at which the air has been cooled to become saturated with water vapor (i.e., 100% relative humidity) and causes condensation to form. At higher temperatures, air can hold more moisture so the dew point temperature decreases, but only at low relative humidity so we have to find the balance for optimal conditions.

Relative humidity (RH) is the amount of water vapor in a given amount of air versus the maximum amount of water vapor that the same volume of air can hold at the same temperature, expressed as a percentage of the maximum. Exterior surfaces can have large fluctuations in the RH during the course of a normal day. In the morning and evening during certain times of the year, the RH will be higher and lower during the course of the day. Warmer air can hold a greater amount of water vapor than cooler air. Most manufacturers and specifications require the RH to be less than 85%; although, moisture-cured products often have a higher threshold.

Slide 32

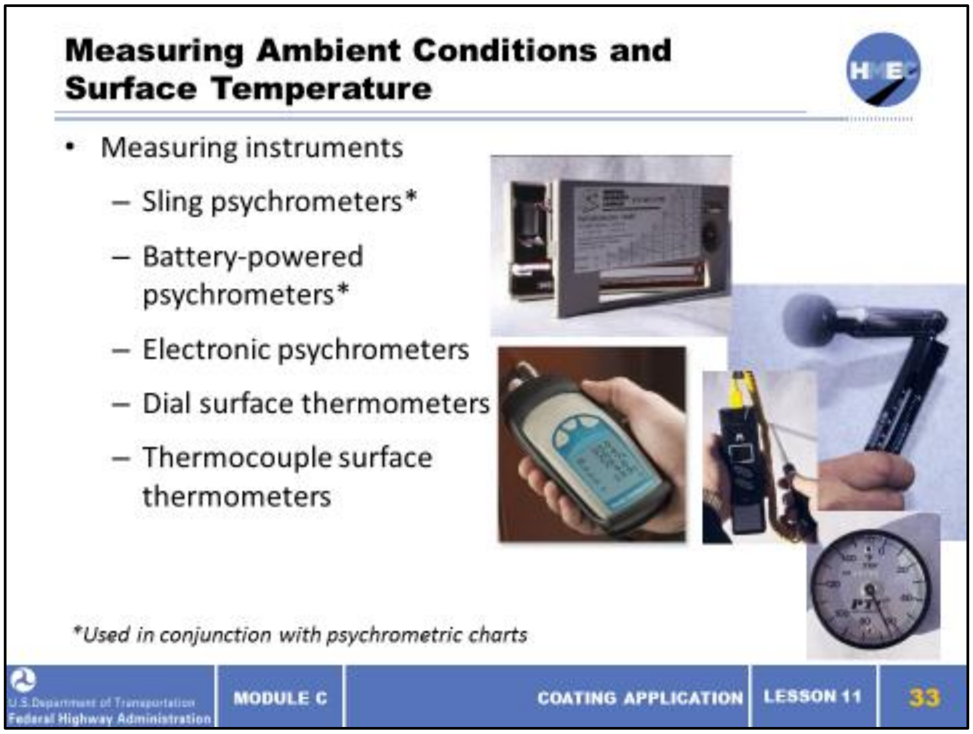


Similar to air temperature, the manufacturer will often list a minimum and maximum surface temperature on their PDS that may or may not mimic the air temperature range. Surfaces in direct sunlight may exceed the maximum surface temperature recommended by the manufacturer, even though the air temperature is within the acceptable range. At high temperatures, solvents can evaporate out of the paint too quickly and cause defects such as pinholes. If the surface temperature is too low, moisture from the air can condense on the cold surface. This condensation is not always visible to the unaided eye.

To prevent coating over moisture, the industry has adopted a general rule to verify the temperature of the surface is at least 5°F (3°C) higher than the dew point temperature to preclude condensation. This rule becomes a requirement when invoked by specification.

Theoretically, a slight increase in surface temperature over dew point temperature, even one degree, will prevent moisture in the air from condensing on a surface. The general rule (the surface temperature should be at least 5°F (3°C) above the dew point temperature, and rising) accounts for instrument tolerances as well as changing conditions and varying conditions across the surface. Specifications may deviate from this general rule and may require a greater difference for critical environments, while other specifications may allow a smaller difference. Most coating manufacturers will reference this same general rule on their PDS.

Slide 33



Instruments used to measure the prevailing environmental conditions and surface temperature include sling and battery-powered psychrometers, electronic psychrometers, and surface temperature thermometers, which can be analog, thermocouple, or even non-contact infrared type (not shown). Sling and battery-powered psychrometers that measure dry and wet bulb temperatures are used in conjunction with psychrometric charts to determine the relative humidity and dew point temperatures.

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The sling psychrometer consists of a plastic housing containing two bulb thermometers. The thermometers are identical, except that one contains a woven cotton filament or wick over one end. Since this wick will become saturated with water, we refer to this as the wet bulb thermometer. The other thermometer indicates the air temperature and is called the dry bulb thermometer. The thermometers are available in Fahrenheit or Celsius and are available from several manufacturers.

The sling psychrometer is ventilated by a whirling action. The standard governing the use of these types of instruments is ASTM E 337, which is the standard test method for measuring humidity with a psychrometer.

To use the sling psychrometer, verify that the wick is clean. If it is dirty, the pores may be clogged, preventing water contact with the bulb. An additional wick is provided in the capped reservoir on the end the device, and a replacement wick can be purchased.

Saturate the wick with distilled water, or fill the reservoir with the water. Verify the wick is thoroughly saturated, not just dampened. Whirl the instrument through the air, away from the body, at a rapid speed for 20 to 30 seconds, then stop and read the temperature of the wet bulb. Without rewetting the wick, whirl the instrument for an additional 20 to 30 seconds and take a second reading of the wet bulb thermometer. Repeat this process until two readings of the wet bulb thermometer are within one-half degree of one another, indicating that the wet bulb has stabilized at the lowest point. Read the temperature from the dry bulb thermometer last. Record the readings of the dry bulb and wet bulb thermometers.

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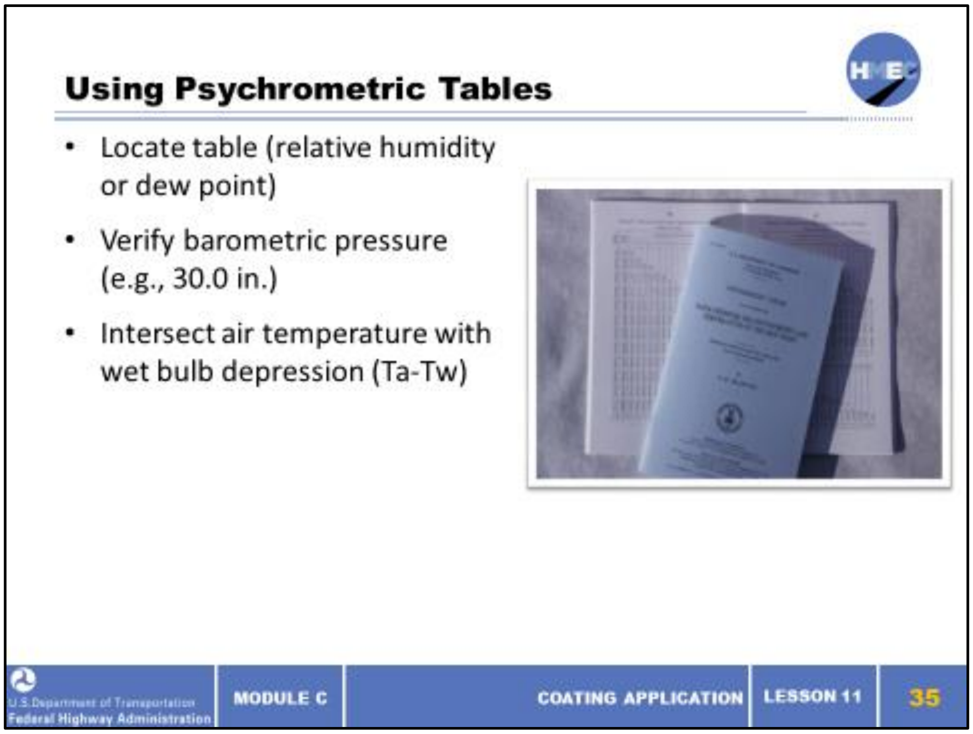
Slide 35



The US Weather Bureau published a book of relative humidity and dew point temperature look-up tables in the early 1900s. These are still used today. There are three steps to take when using these tables. First, locate the desired table, relative humidity or dew point temperature, by looking at the page heading. Most of the pages in the book look alike, so it is important to verify you are on the correct table. Second, select the table based on the prevailing barometric pressure. Tables are provided for 23, 25, 27, 29, and 30 inches pressure. If you do not know the barometric pressure, use the 30-inch pressure tables.

Intersect the dry bulb or air temperature with the difference between the dry and wet bulb temperatures, known as the depression of the wet bulb or Ta minus Tw, to determine the relative humidity or dew point temperature.

Slide 36

Electronic psychrometers do not use wet bulb science to determine relative humidity and dew point temperature, and therefore do not require water. Once powered-up and allowed to stabilize for several minutes, the air and surface temperatures, relative humidity, and dew point temperature are displayed. Most of these devices calculate the spread between the dew point and surface temperatures (remember, we are looking for the surface temperature to be a minimum of 5°F or 3°C higher than the dew point temperature). There are several manufacturers of these devices that offer similar features, even Bluetooth data output capabilities, as well as cloud-based data storage.

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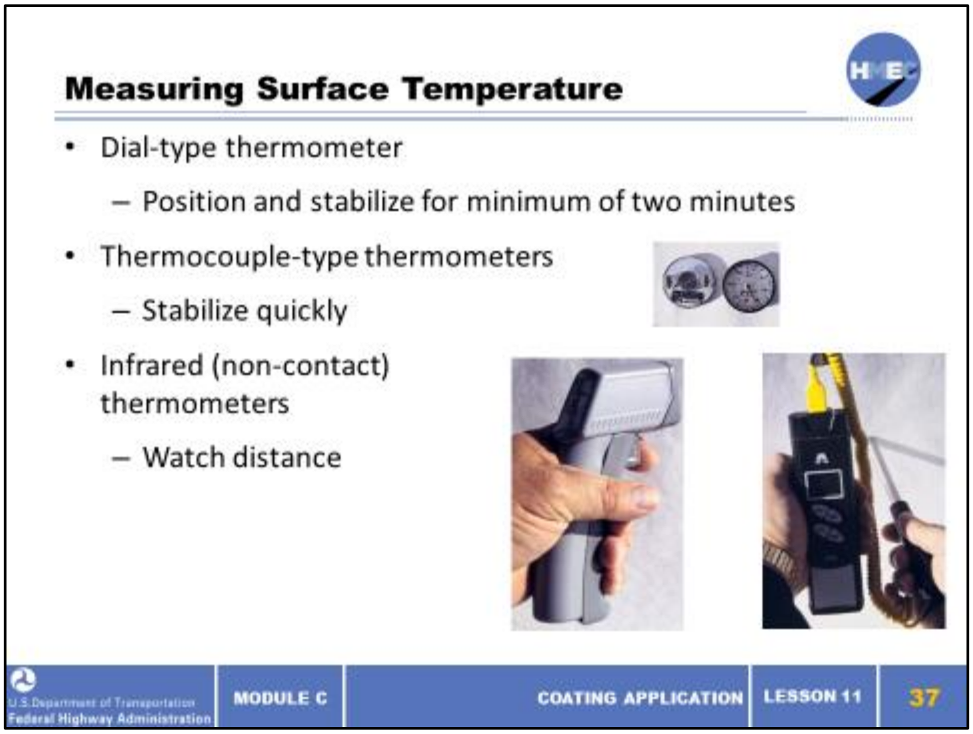
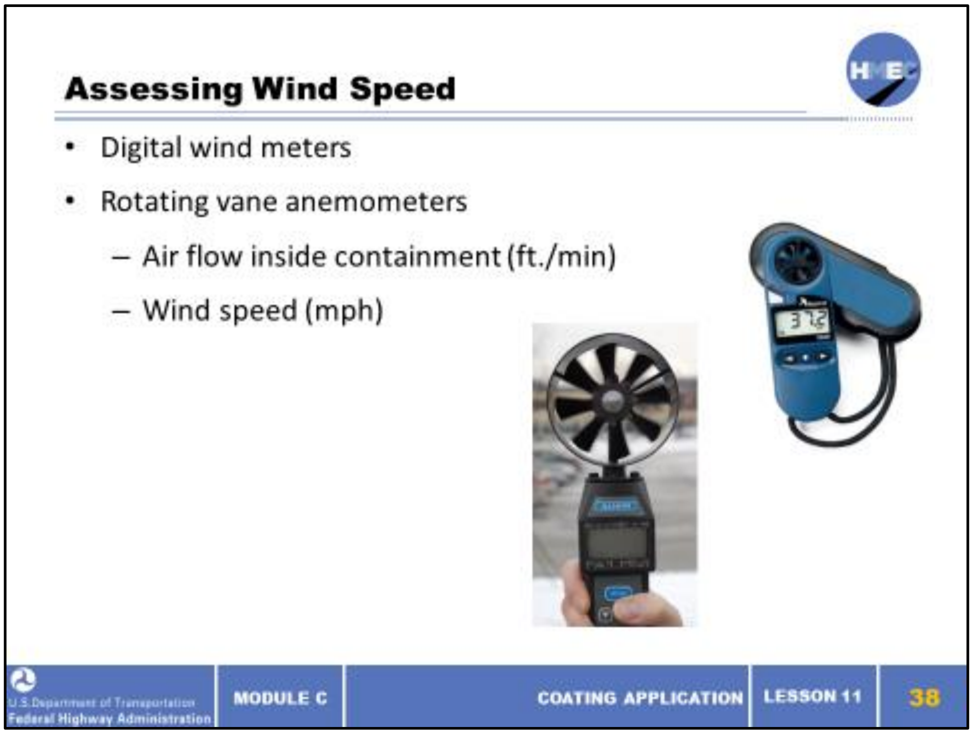
Slide 37



When sling or battery-powered psychrometers are used, the surface temperature must be measured using a separate thermometer. The surface temperature can be measured using dial-type thermometers shown in the top image, thermocouple type thermometers like the one shown in the left image, and non-contact infrared thermometers like the one shown in the bottom right image. Dial-type thermometers will need to stabilize for at least two minutes before they are read. The distance the non-contact thermometer is held from the surface should conform to the capability of the device.

Slide 38



Wind speed can be measured using digital wind meters or anemometers. Rotating vane anemometers are typically used to measure air flow inside containment but they can also be used to measure wind speed. While air flow inside containment is typically measured in terms of feet per minute, many anemometers can also display air movement in miles per hour or kilometers per hour, which are better units to use relating to measurement of wind speed.

Since most coating work on bridge structures is performed inside a containment, the significance of wind speed is more often associated with wind load on the bridge structure since bridges aren't designed to have containment tarps (and the associated wind load) on them. Occasionally, a project specification will require the contractor to drop the tarps within a certain period of time when winds exceed a certain speed.

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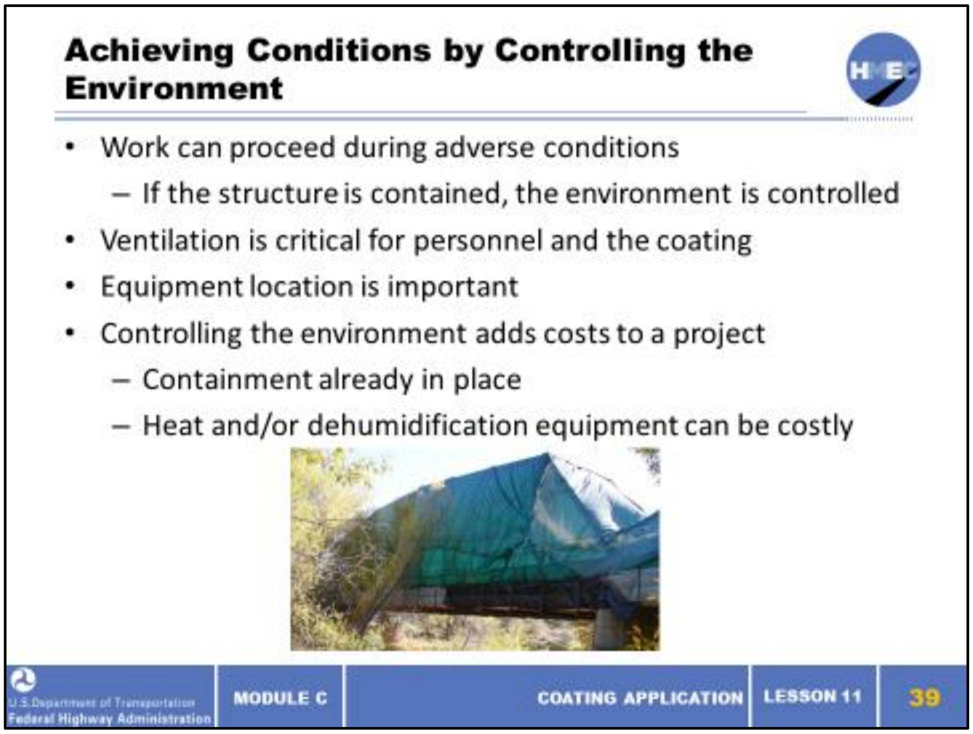
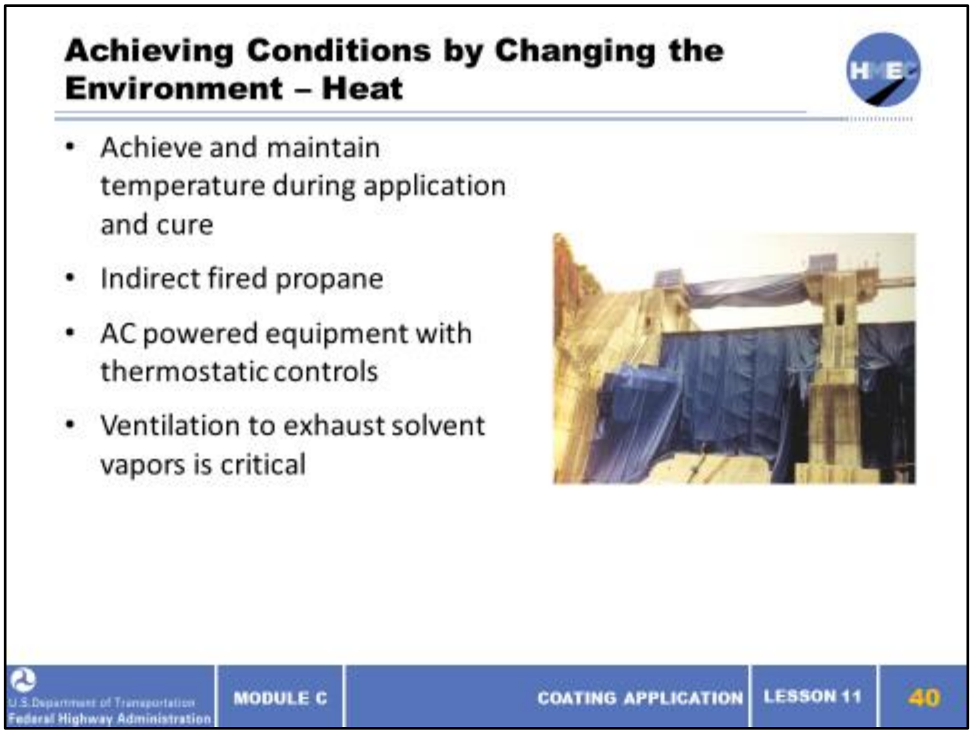
Slide 39



The containment structure on a bridge that remains in place during coating application is primarily to control overspray. However, if the enclosure is designed properly, the conditions inside can be controlled. When painting inside containment, you must have adequate ventilation for personnel safety (the vapors from coatings can be harmful if inhaled and the vapors may be flammable and present an explosion and/or fire hazard if the containment is not properly ventilated). While respiratory protection can help prevent the inhalation hazard, OSHA requires that engineering control be implemented, to the extent feasible, prior to relying on personal protective equipment. Ventilation is considered an engineering control.

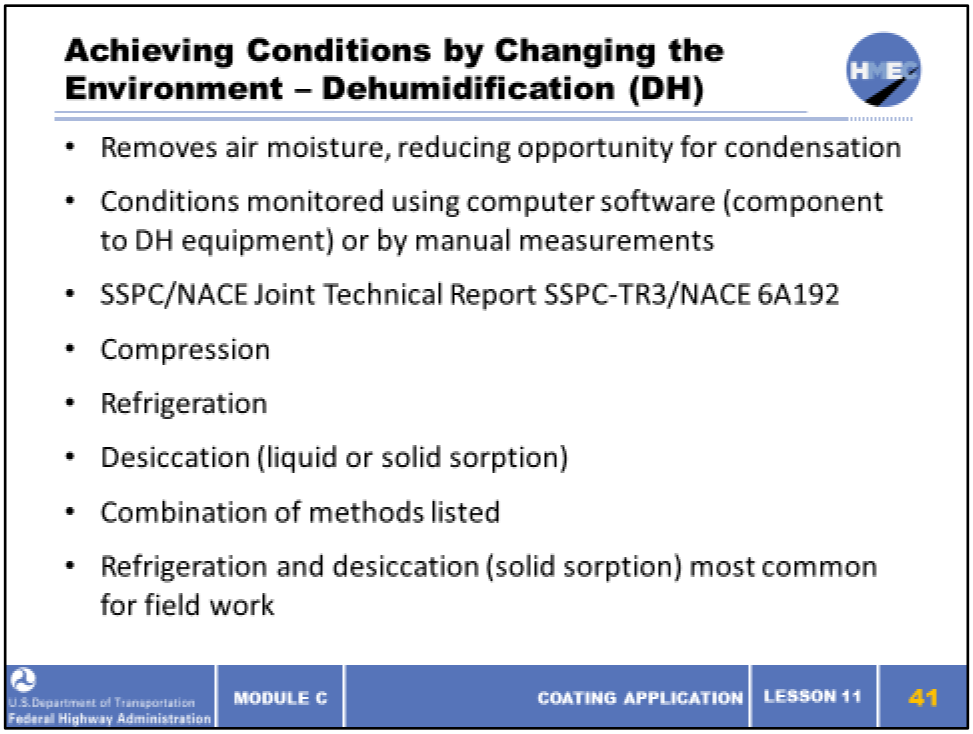
Heat and dehumidification equipment must be kept outside of the containment with the duct entering inside the containment. Propane heaters must be ducted to the outside air as exhaust contains hydrocarbons, and moisture that can contaminate surfaces. Naturally, controlling the conditions inside the containment adds to the cost of a project.

Slide 40



Heat can be used to increase the temperature in an enclosed area, in order to achieve minimum air temperatures during coating application and curing. Indirect fired propane heaters or thermostat-controlled AC powered heaters may be used. Since the infused heat will drive off solvent vapors, ventilation is critical.

Slide 41



Dehumidification (DH) equipment is quite common and is used to reduce moisture in the air, thereby reducing the opportunity for the moisture to condense on a surface. The conditions during DH operation can be monitored using computer software integral to the equipment, or by taking manual measurements of conditions. SSPC and NACE International produced a joint technical report on dehumidification and temperature control during surface preparation and painting, SSPC-TR3/NACE 6A192, *"Dehumidification and Temperature Control During Surface Preparation, Application and Curing for Coatings/Linings of Steel Tanks, Vessels and other Enclosed Spaces."*

Dehumidification can be a fairly complex topic. In a most simplistic look, DH can be accomplished by compression, refrigeration, desiccation, or a combination of these methods. Refrigeration and desiccation by solid sorption are the most common methods for control of the environment during field painting operations.

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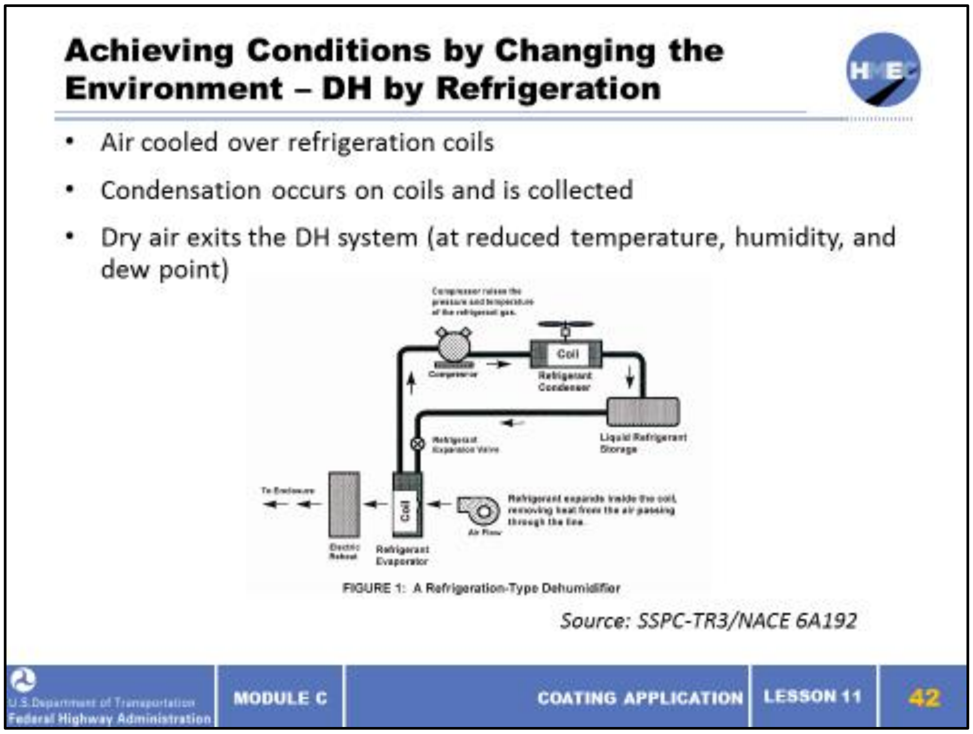
Slide 42



The image shown on the slide was extracted from the SSPC-NACE report. For refrigeration, air is drawn over refrigerated coils. The moisture in the air condenses on the cool coils and is collected. The dry air exits the dehumidification system at a reduced temperature, humidity, and dew point. This air is then introduced into the containment via duct work.

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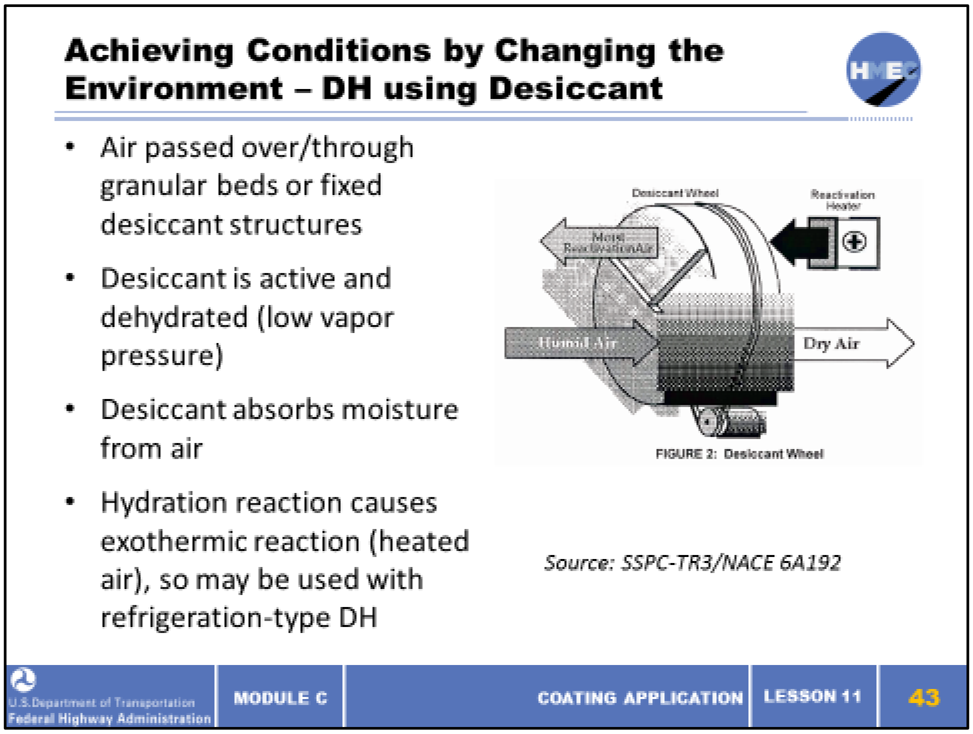
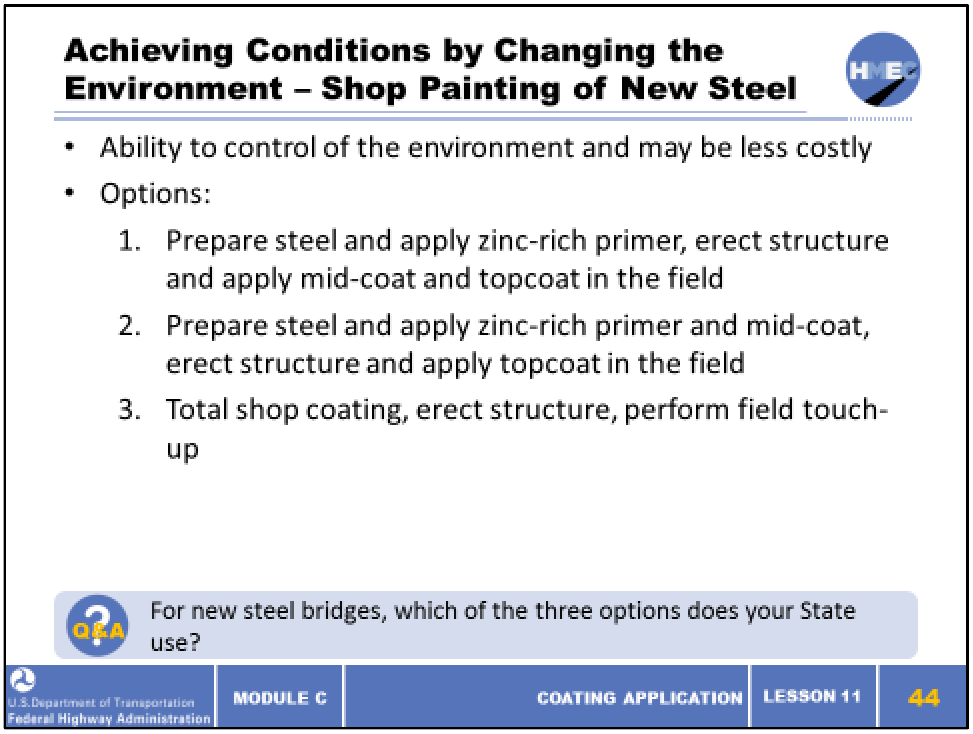
Slide 43



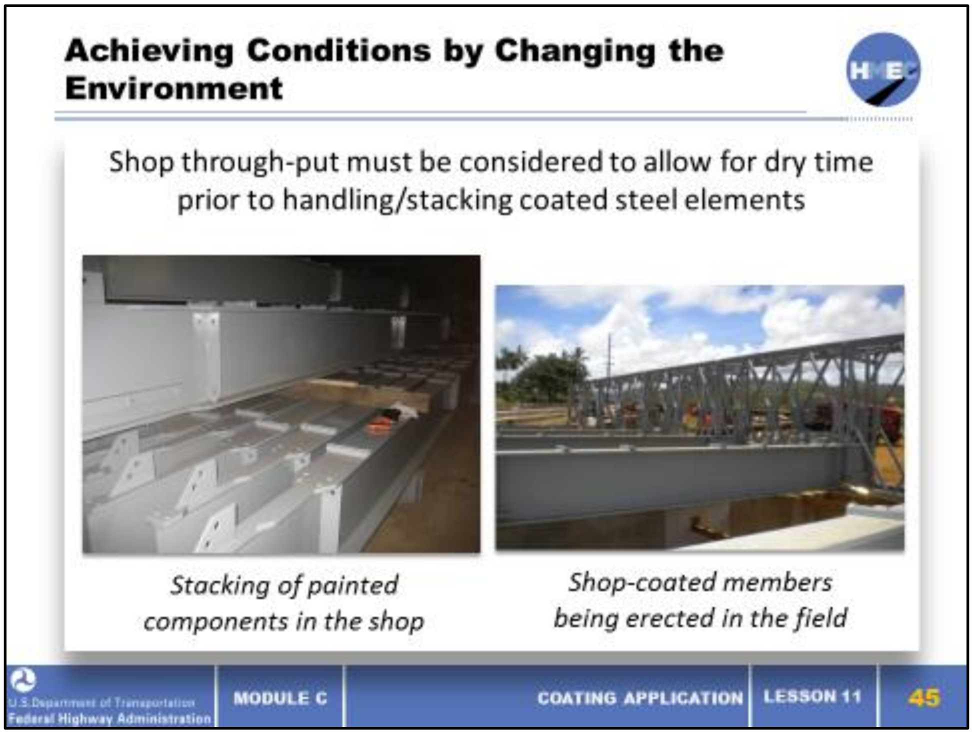
The image shown on the slide was extracted from the same SSPC-NACE report. In this case, the air is passed over or through granular beds or fixed desiccant structures. The desiccant, which can be silica gel or lithium chloride is active and dehydrated under a low vapor pressure. The desiccant absorbs the moisture from the air, which causes an exothermic or heated air reaction to occur. Post desiccant refrigeration may be used to further dry the air.

Slide 44



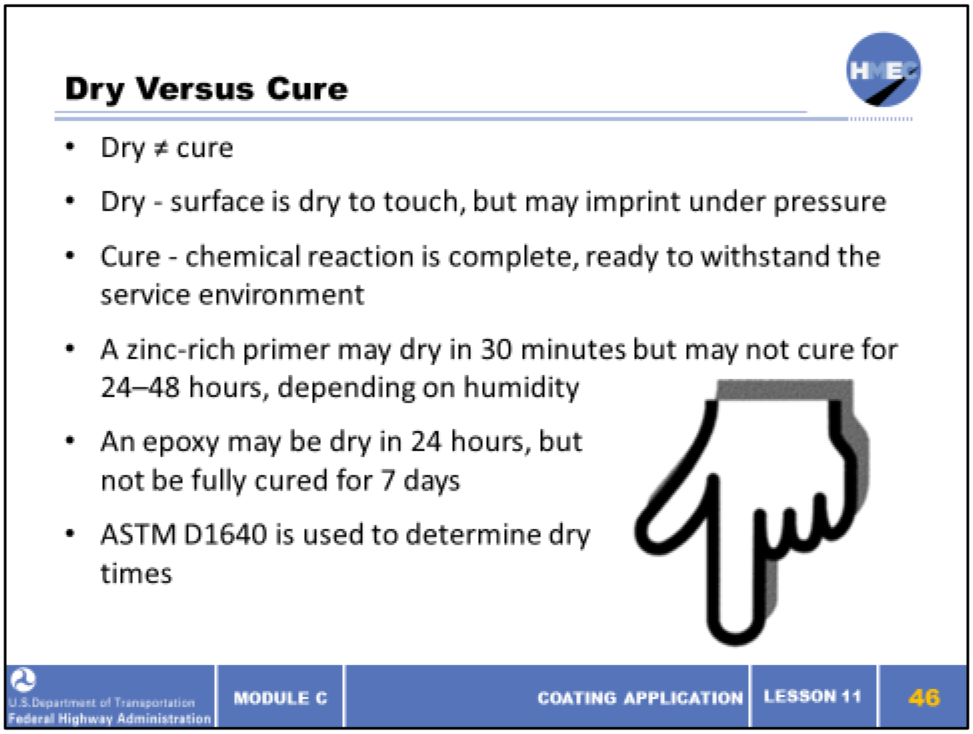
Shop painting of steel for new bridges or replacement steel for existing bridge structures is often done in a steel fabrication shop or a blast and paint shop. If the shop is enclosed, they have the ability to control of the environment and preparing and coating the steel may be less costly.

Slide 45



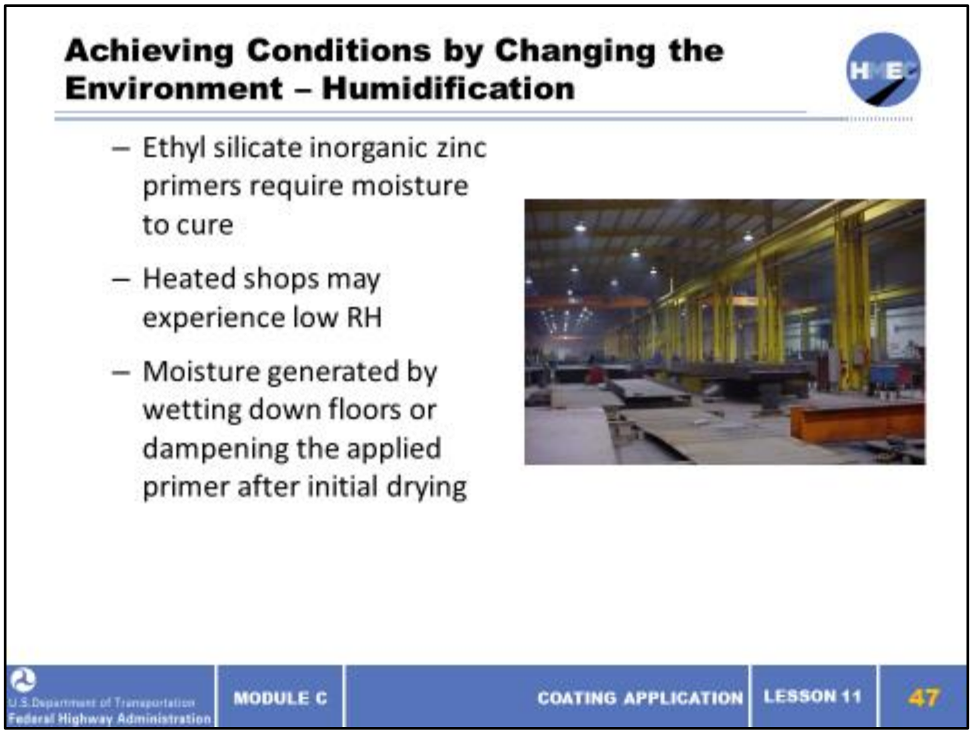
Application of multi-coat systems in a shop creates a bottleneck since freshly coated steel cannot be stacked, moved, or get dust and debris on it until it has sufficiently cured. Shop through-put must be considered to allow for dry time prior to handling/stacking coated steel elements; otherwise, significant damage to the coating system can occur.

Slide 46



Dry time is typically associated with handling time, such as set-to-touch, dry-to-touch, dry-through, dry-to-handle, and dry-to-recoat. Cure time is associated with the time required before the coating is resistant to the prevailing service environment. This is tricky with bridge coatings, since they are introduced into the service environment almost immediately. ASTM D1640, Standard Test Methods for Drying, Curing, or Film Formation of Organic Coatings, can be used to assess the drying and curing properties of coatings. Method D was added to the standard in 2014, which enables evaluation of drying/curing properties in the shop/field.

Slide 47



Use of heat in a shop environment during winter months may cause the humidity to be quite low. Ethyl silicate inorganic zinc-rich primers, a common primer used on new bridge steel, will dry very quickly in a heated environment, but will not cure without moisture. Those that mistake drying for curing can experience significant failure if the inorganic zinc is topcoated too soon. In these cases, humidification rather than dehumidification may be necessary. Because humidifying an entire paint bay can be costly, oftentimes it is done on a more localized basis, like wetting down the floor area or dampening the coating once the initial drying takes place. Oftentimes, multiple applications of water are required, since the water will evaporate fairly quickly in an arid environment. The shop should always consult the coating manufacturer's PDS before dampening coatings using water.

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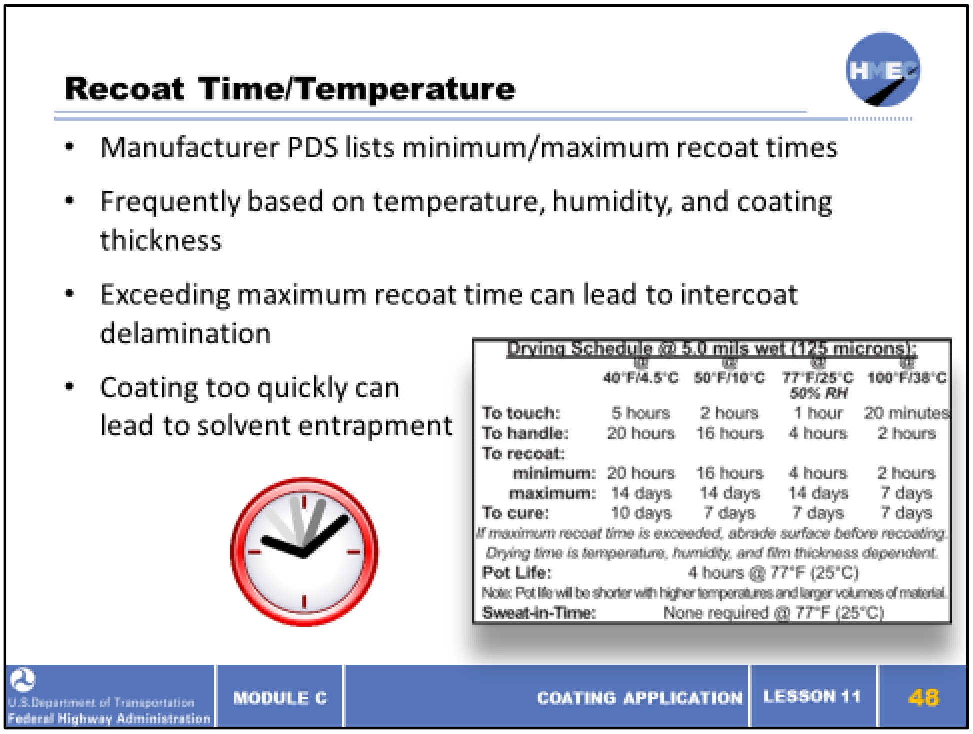
Slide 48



Minimum and maximum recoat times are indicated on the coating manufacturer PDS and are highly dependent on the air temperature, relative humidity, and coating thickness. Recoating outside of these intervals increases risk for failure due to intercoat delamination or solvent entrapment.

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Oftentimes, shops and field contractors will want to push the minimum recoat times to move the bridge painting project along. But maximum recoat times must also be considered, especially when coating work spans multiple painting seasons. If a coating has a maximum recoat time, it will be stated on the PDS. The maximum recoat time is dependent on the generic type of coating and the formulation, and is often dependent on the generic type of overcoat. For example, the maximum recoat time for an epoxy may be 90 days if another coat of epoxy will be applied, but only 30 days if a polyurethane is the next coat to be applied. When a recoat time is exceeded and preparation of the underlying surfaces isn't performed, there is great potential for intercoat delamination (as illustrated by the images on the slide). Many coating manufacturers will provide remedies for when a maximum recoat time is exceeded, including sanding or scuffing the surface to enhance the mechanical bond, or the use of surface conditioners that slightly soften the underlying layer. Naturally, dirt, dust, and chalking must be removed if present.

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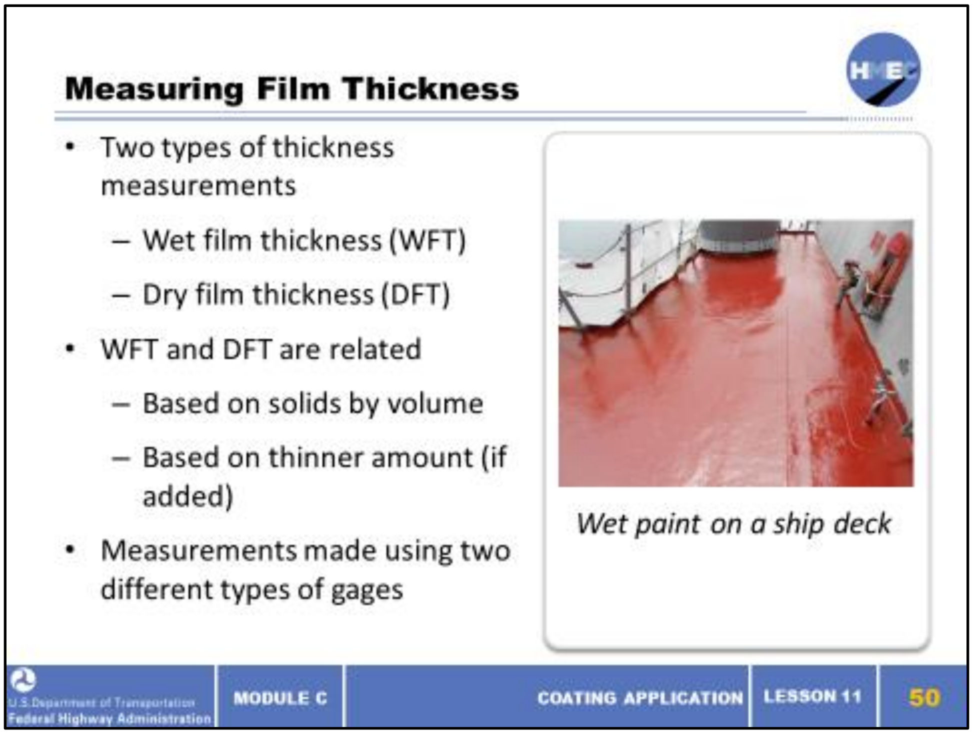
Slide 50


Measuring Film Thickness
• Two types of thickness measurements
– Wet film thickness (WFT)
– Dry film thickness (DFT)
• WFT and DFT are related
– Based on solids by volume
– Based on thinner amount (if added)
• Measurements made using two different types of gages
Wet paint on a ship deck
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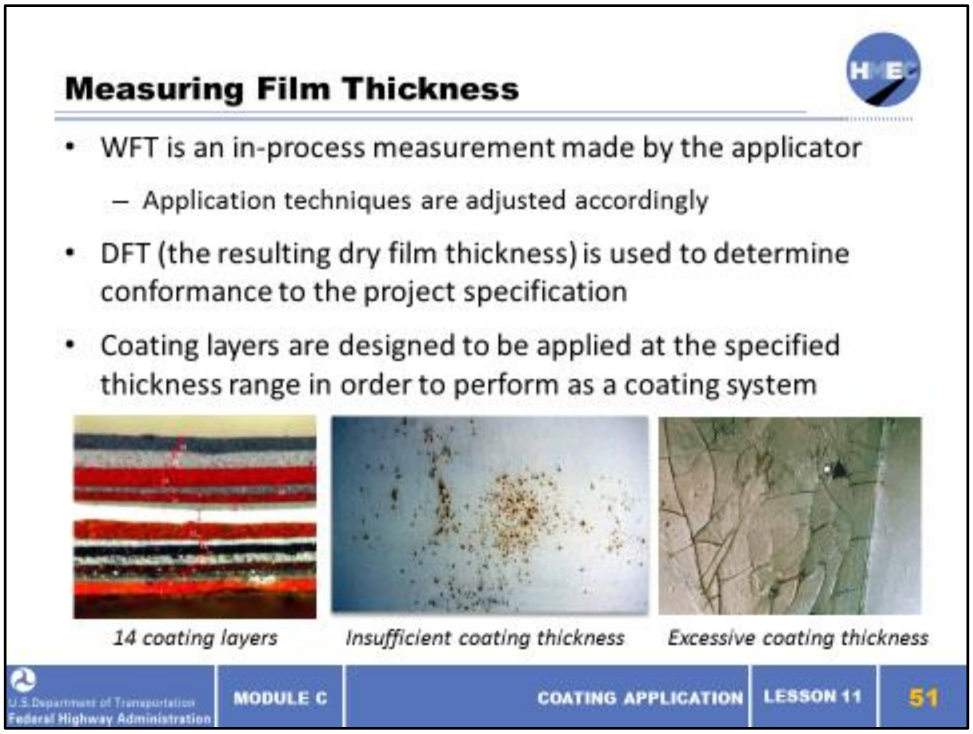

Measurement of the WFT is a means to an end. The applicator typically uses a WFT gage to monitor the film build as it is applied and adjusts the application technique and speed to achieve the desired WFT. Measurement of the DFT is used to determine specification compliance. Each coating layer has a recommended DFT that is often adopted by the specifier. Application of each coating layer at the specified thickness is paramount to coating system performance. That is, the application of an extra 2 mils (50 µm) of epoxy mid-coat cannot make-up for a zinc-rich primer that is applied 2 mils less than specified.

Coatings that are applied too thin provide a lack of barrier, inhibitive, and/or sacrificial (galvanic) protection. They may also expose bare metal, resulting in premature corrosion. Coatings applied too thick can result in solvent entrapment, cracking (mud cracking in the case of inorganic zinc primers), and build-up of internal (cohesive) and external (adhesive) stresses that can result in delamination. More isn't better. That is why each coating layer has both a minimum and a maximum coating thickness.

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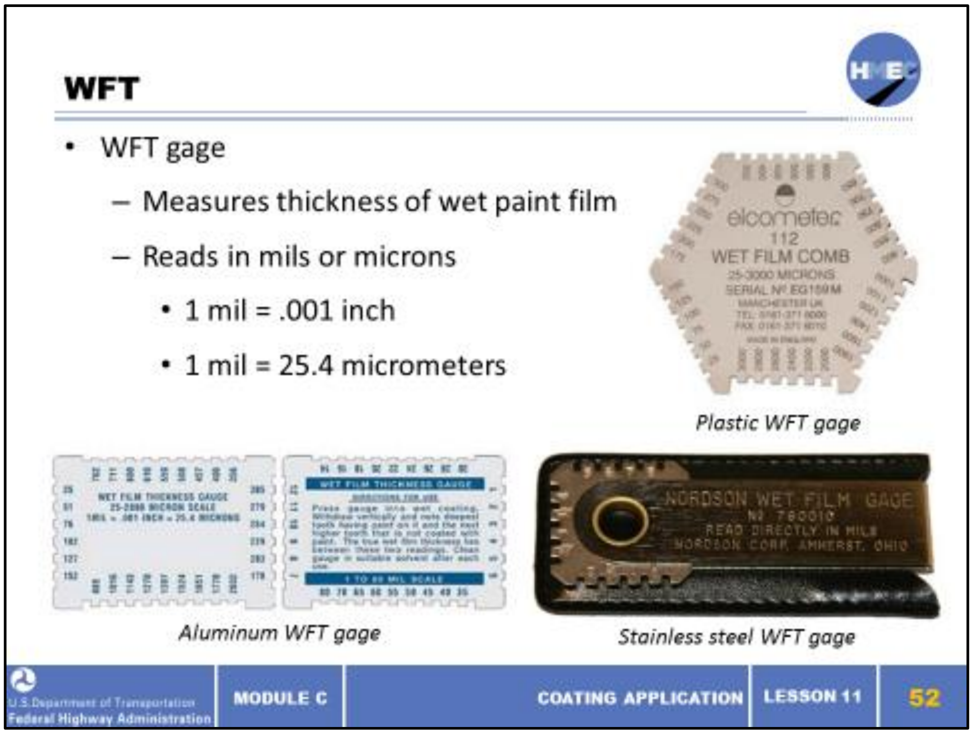
Slide 52



WFT gages or notch gages conform to ASTM D4414, Standard Practice for Measurement of Wet Film Thickness by Notch Gages. Various manufacturers of WFT gages are depicted on the slide. The stainless steel type are more durable, while the plastic and aluminum types are less expensive.

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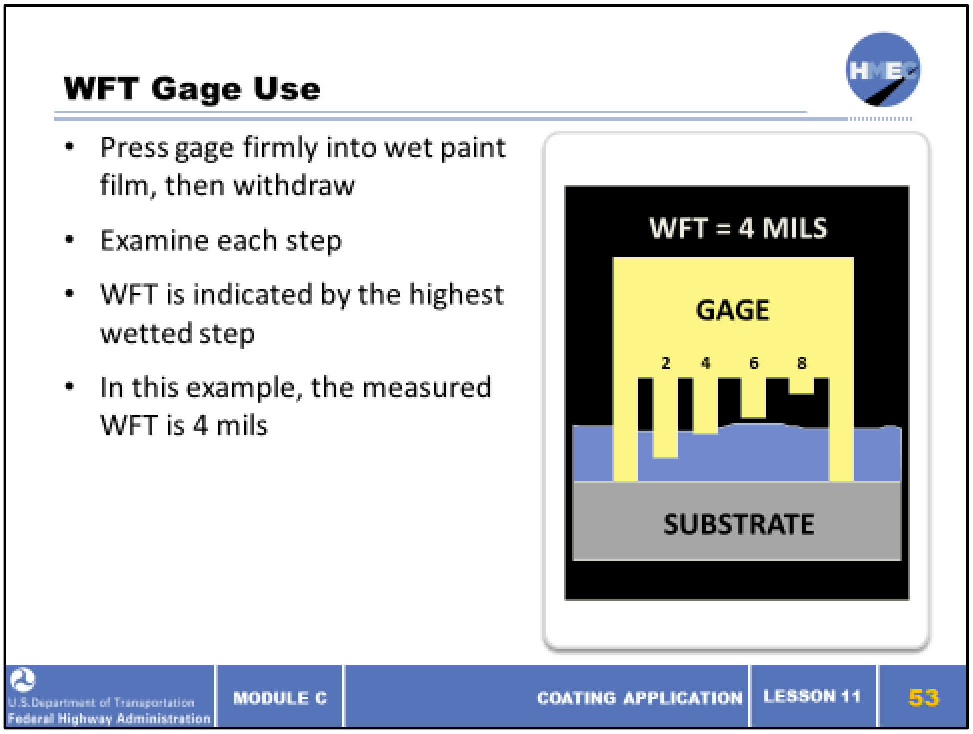
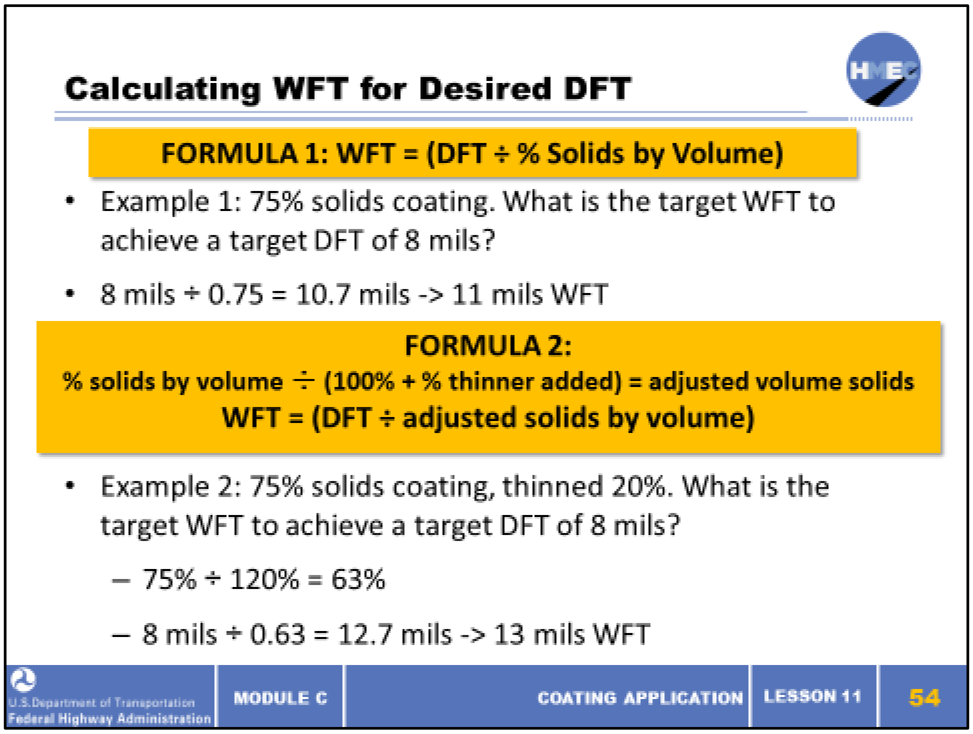


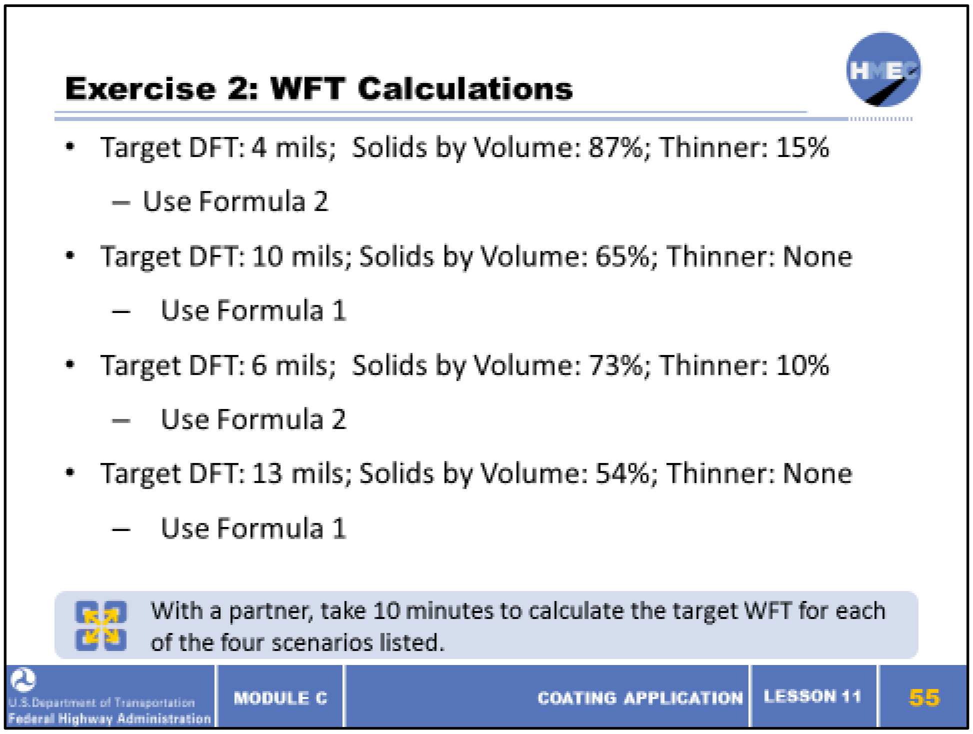
Immediately after the wet coating is applied, the applicator presses the gage firmly into the wet paint film, then withdraws it and examines each step. The WFT is indicated by the highest wetted step. The image shown on the slide represents a WFT of 4 mils. It may also indicate 5 mils, but the coating is not 6 mils thick since the 6-mil step does not have blue coating on it.

Slide 54



In some instances, the applicator may be able to obtain the required WFT directly from the manufacturer's PDS. However, if this does not match the specified DFT or if the coating is thinned, they will need to calculate the required WFT per coat. In order to do that, they will need to know the solids content of the coating by volume. This value is listed on the PDS. Simply divide the target DFT by the solids by volume (see the example below Formula 1 on the slide) to arrive at the target WFT. If the coating is thinned and the applicator knows how much thinner was added, then the target WFT can be calculated using Formula 2 on the slide. By adding thinner, the volume solids effectively decreases, so the corresponding WFT will increase to achieve the same DFT. Stated more simply, thinner is part of the wet film but not part of the dry film.

Slide 55



Using your calculator, determine the target WFT for each of the four scenarios on the slide. Direction is provided regarding which formula to use on the previous slide. Write your answers on the blank computer paper provided in your binder.

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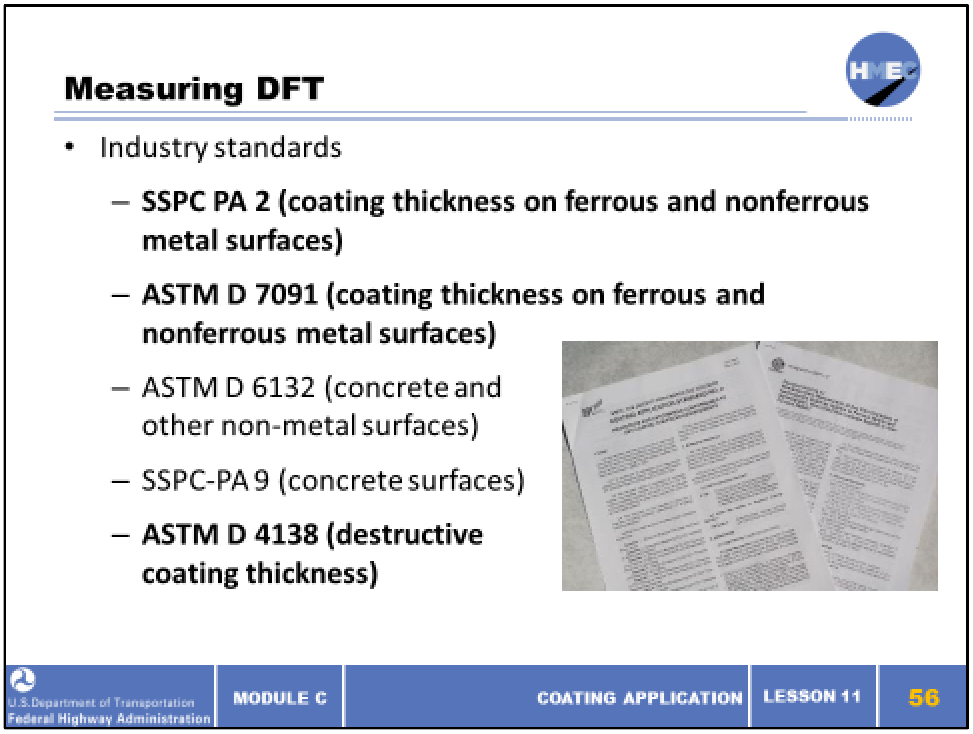

There are many standards in the industry for measuring the thickness of the applied coating once it has dried. The standards listed on the slide are the most common standards used in the bridge coatings industry. For this lesson, we will focus on SSPC-PA 2, ASTM D7091, and ASTM D4138.

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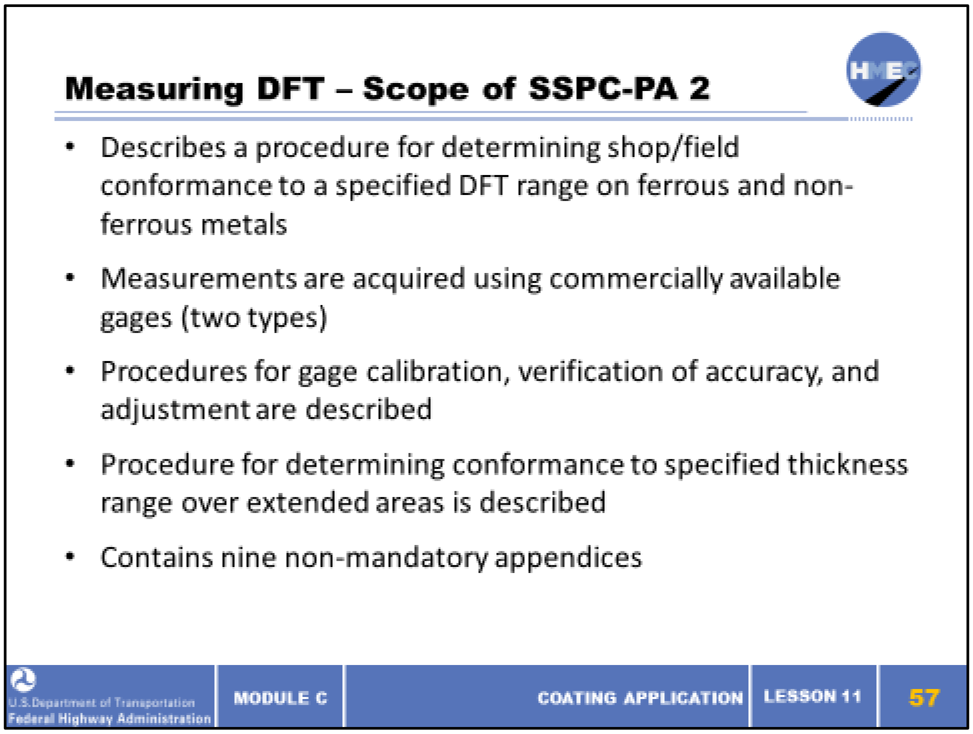

The standard describes procedures for measuring the thickness of non-magnetic coatings applied to ferrous and non-ferrous metal substrates. According to the standard, coating thickness measurements are obtained using two types of commercially-available gages produced by a variety of gage manufacturers across the US and even overseas.

SSPC PA 2 describes the procedures for gage calibration, verification of gage accuracy using traceable coated standards, gage adjustment, and measurement acquisition. Finally, the standard provides a procedure for determining whether a coating or coating system conforms to the specified thickness range over extended areas of a structure.

The standard contains nine appendices that are non-mandatory unless they are invoked by a contract document. Two of the nine appendices address coating work in a shop [Appendix 2 addresses Methods for Measuring DFT on Steel Beams (Girders) and Appendix 3 addresses Methods for Measuring DFT for a Laydown of Beams, Structural Steel & Misc. Parts after Shop Cleaning].

Note that PA 2 is not intended to be used for measuring the thickness of thermal spray coatings or metalizing. That procedure is described in SSPC-CS 23.

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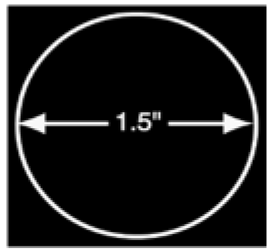
Measuring DFT Definitions in SSPC-PA 2

- Gage reading: A single instrument reading
- Spot measurement: The average of three, or at least three, gage readings made within a 1½ in. (4 cm) diameter circle
- Area measurement: The average of five spot measurements over each 100 ft^2 of coated surface
- Certified standards: Traceable coated/ plated plates



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A variety of Type 1 magnetic pull-off gages are shown to the left, while several manufacturers of Type 2 electronic gages are shown on the right. The gage type is determined by the specific magnetic properties used to measure the thickness of a coating and is not determined by the mode of data readout; for example, digital or analog. Since the use of Type 1 gages is nearly obsolete, we will focus on the use of Type 2 gages only.

The standard does not include gages that measure coating thickness on non-ferrous surfaces like concrete. Coating thickness measurement on these surfaces is described in SSPC-PA 9 and ASTM D 6132.

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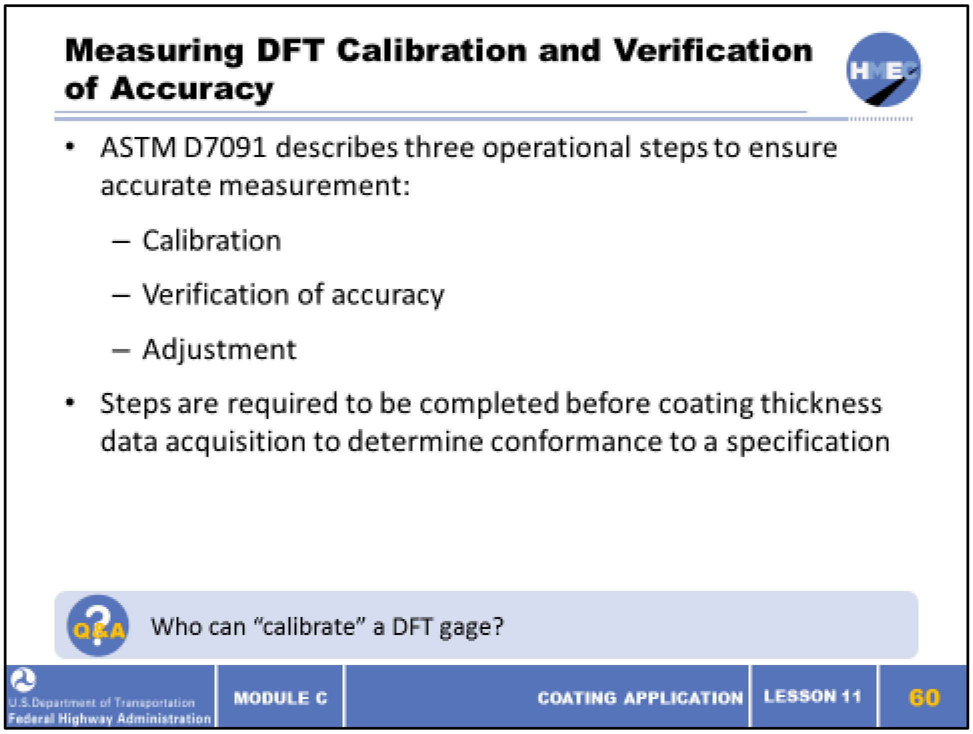
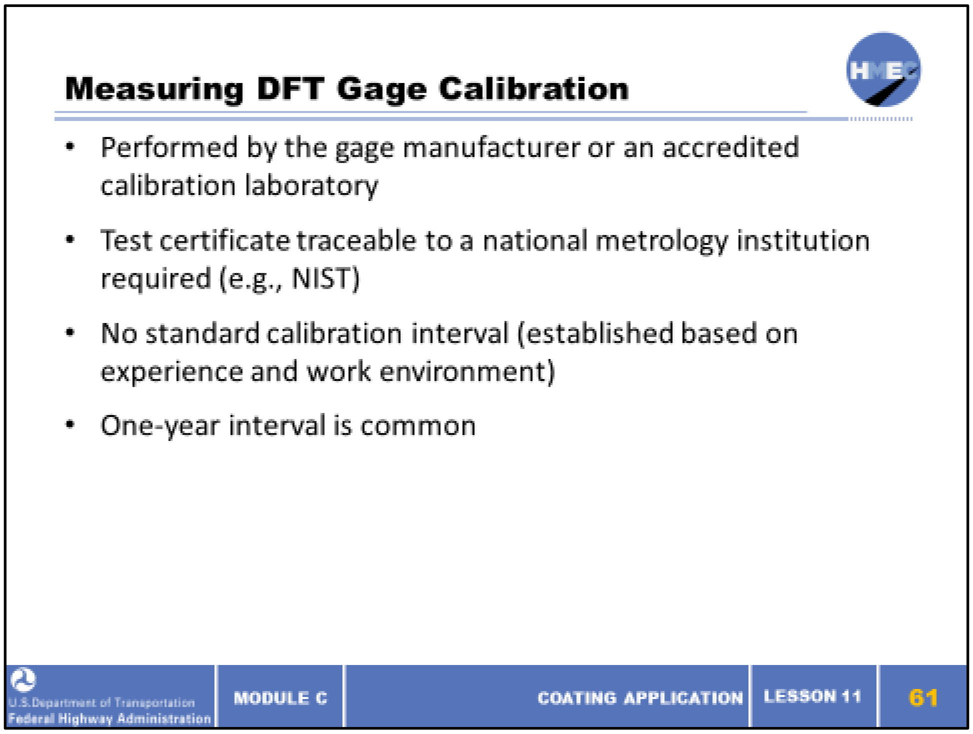


The ASTM D7091 standard practice describes three steps associated with assuring accurate measurement processes including gage calibration, verification of accuracy, and adjustment. Each of these steps must be completed before coating thickness measurements are acquired to determine conformance to a coating specification.

Slide 61


Measuring DFT Gage Calibration
• Performed by the gage manufacturer or an accredited calibration laboratory
• Test certificate traceable to a national metrology institution required (e.g., NIST)
• No standard calibration interval (established based on experience and work environment)
• One-year interval is common
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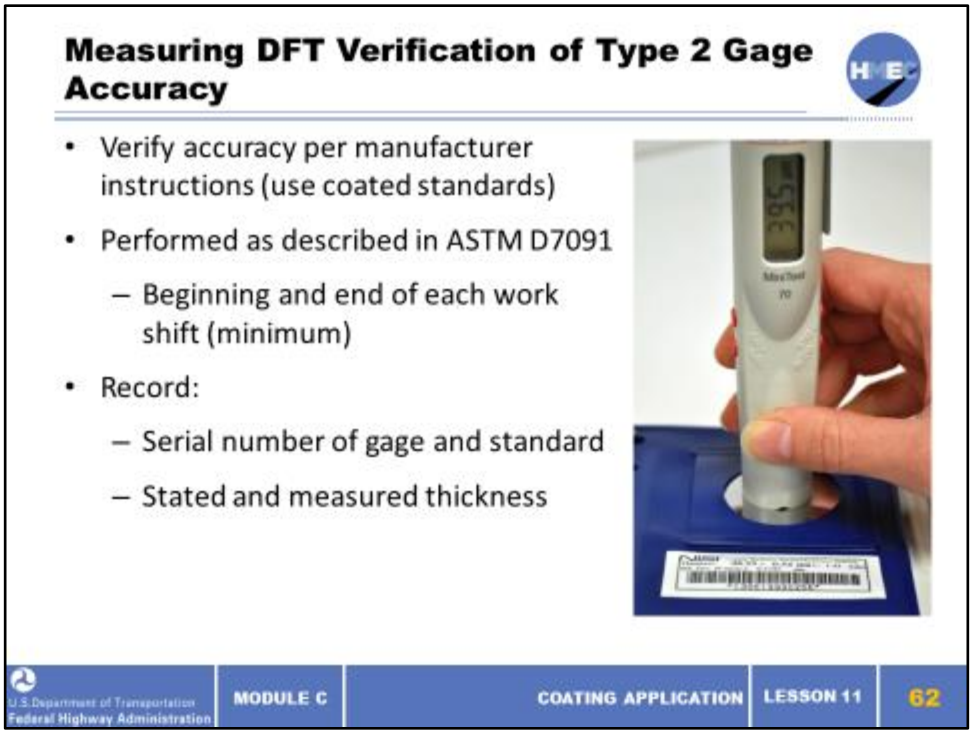
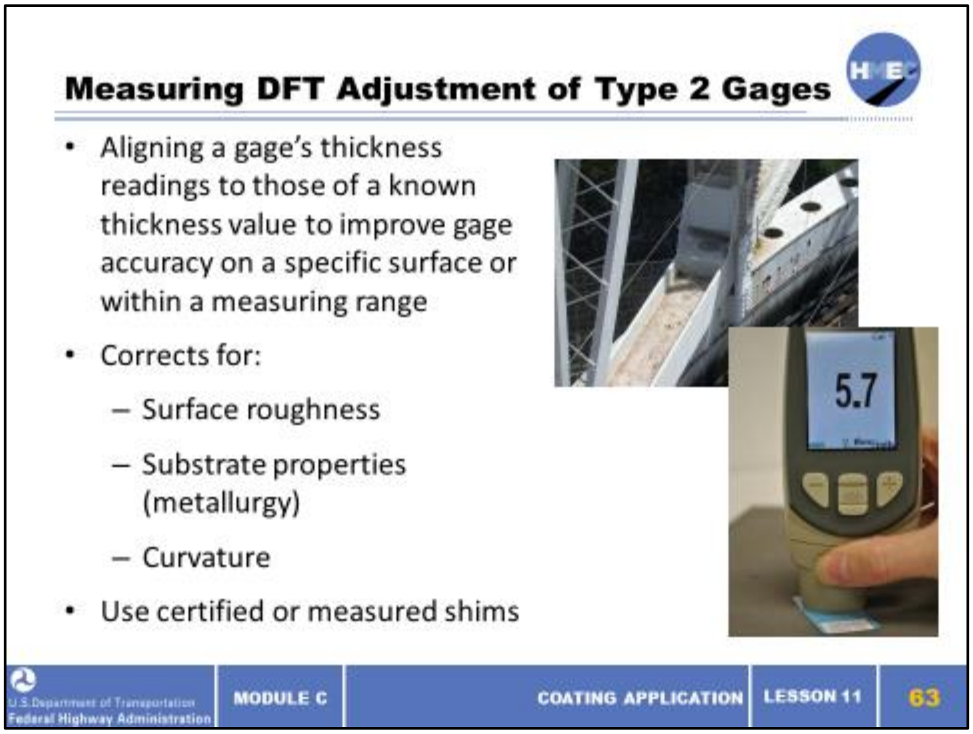


The operator should always verify the accuracy of the gage according to the manufacturer's instructions. To prevent acquiring measurements with an inaccurate gage, the gage is checked at least at the beginning and the end of each work shift with one or more coated reference standards. If the gage is dropped or suspected of giving erroneous readings during the work shift, its accuracy must be rechecked.

Slide 63



The last step prior to taking coating thickness measurements is to align the Type 2 gage to a known value to improve gage accuracy on the specific type and design of surface or within a specific measurement range. Some refer to this step as gage optimization. In this case, the gage is adjusted to match the measured shim thickness by placing a measured shim directly onto the prepared, uncoated structure. This compensates for roughness created by abrasive blast cleaning, curvature of the component or structure, the alloy of the steel, proximity to edges, or other surface conditions.

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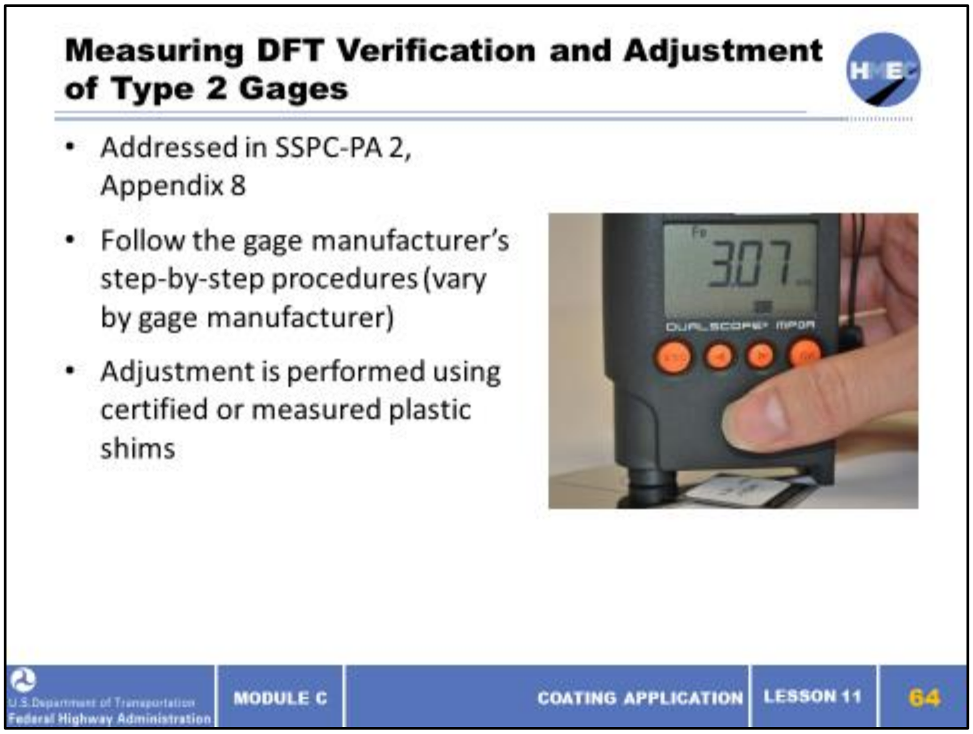
Slide 64



The step-by-step procedures for verifying gage accuracy vary widely between gage manufacturers. Type 2 gages are verified for accuracy using coated standards or certified shims. These gages can then be adjusted to correct for actual surface conditions and the shape and metallurgy of the substrate using certified or measured shims. Measured shims have the actual thickness value written on a label on the shim. Most gage manufacturers supply measured shims with their gages. Note that certified shims and measured shims are not the same.

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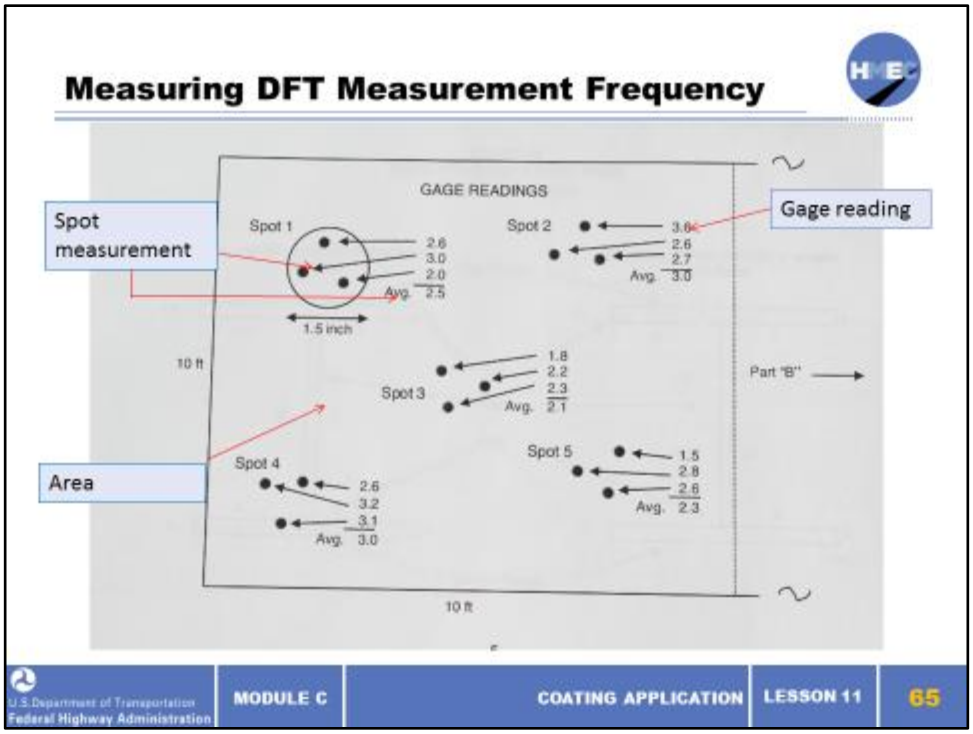
Slide 65



The figure shown on the slide was extracted from SSPC-PA 2. It illustrates three gage readings taken in five spots in an area of approximately 100 ft^2. The average of the three gage readings in each of the five spots has been calculated.

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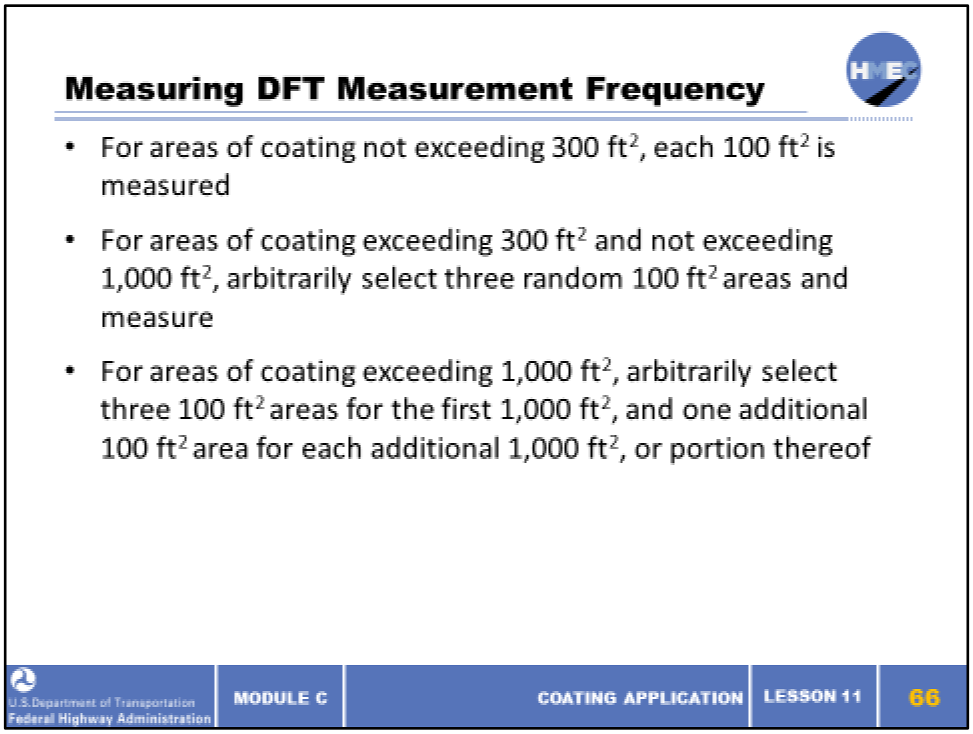
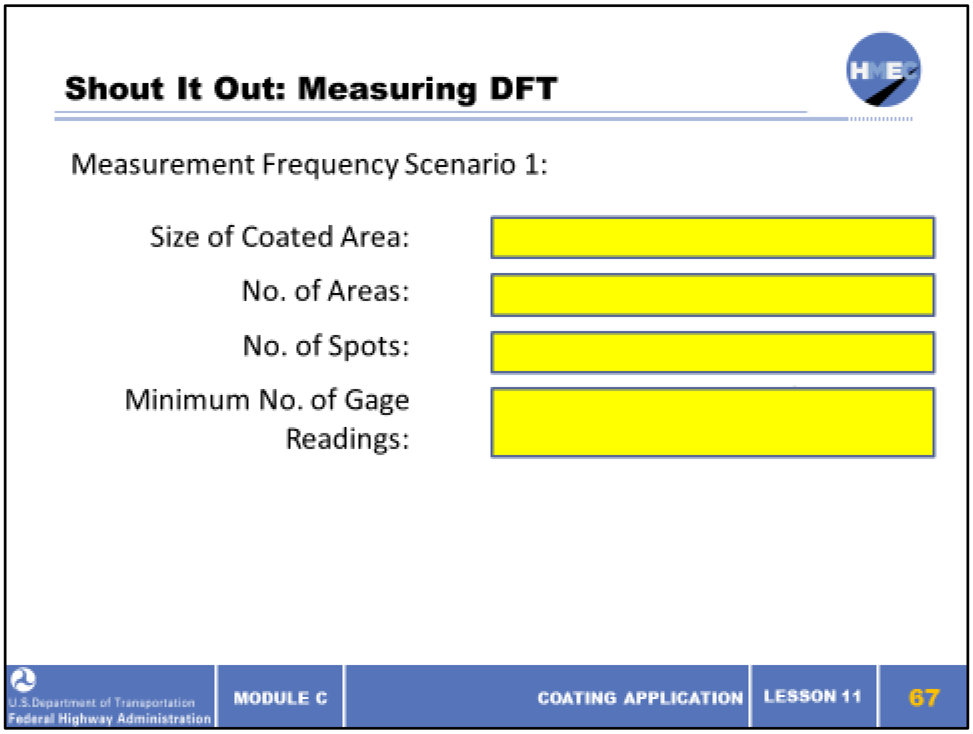
Slide 66



Other size areas or number of measurements may be specified by the owner in the job specifications.

Slide 67



Determine the number of gage readings, spot measurements, and areas based on 900 ft^2 of coated area.

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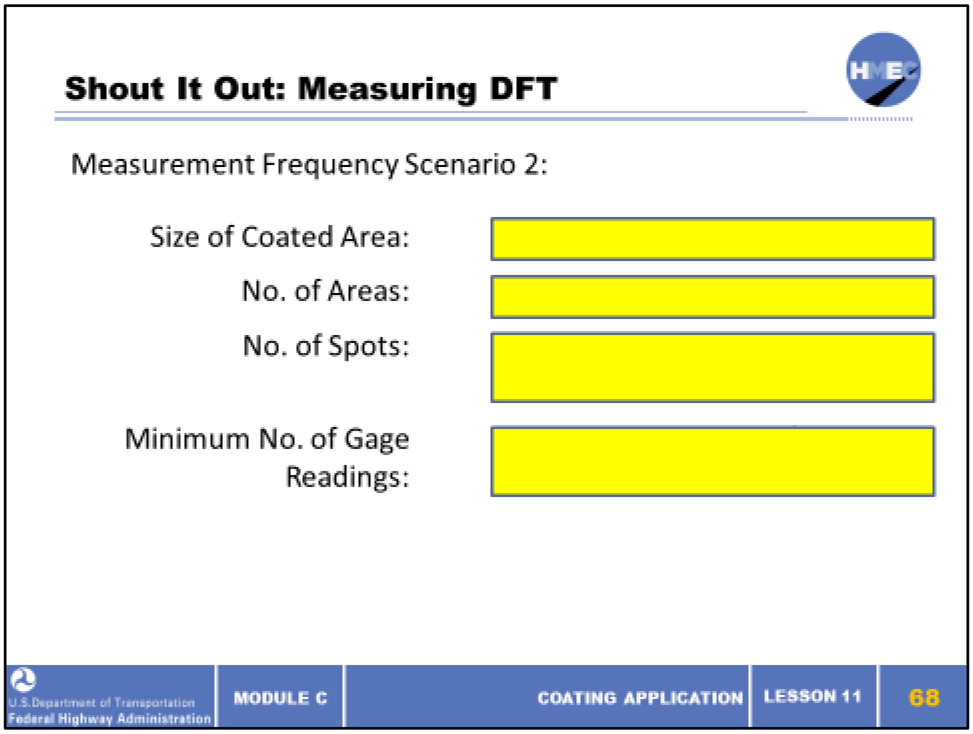
Slide 68



Determine the number of gage readings, spot measurements, and areas based on 12,500 ft^2 of coated area.

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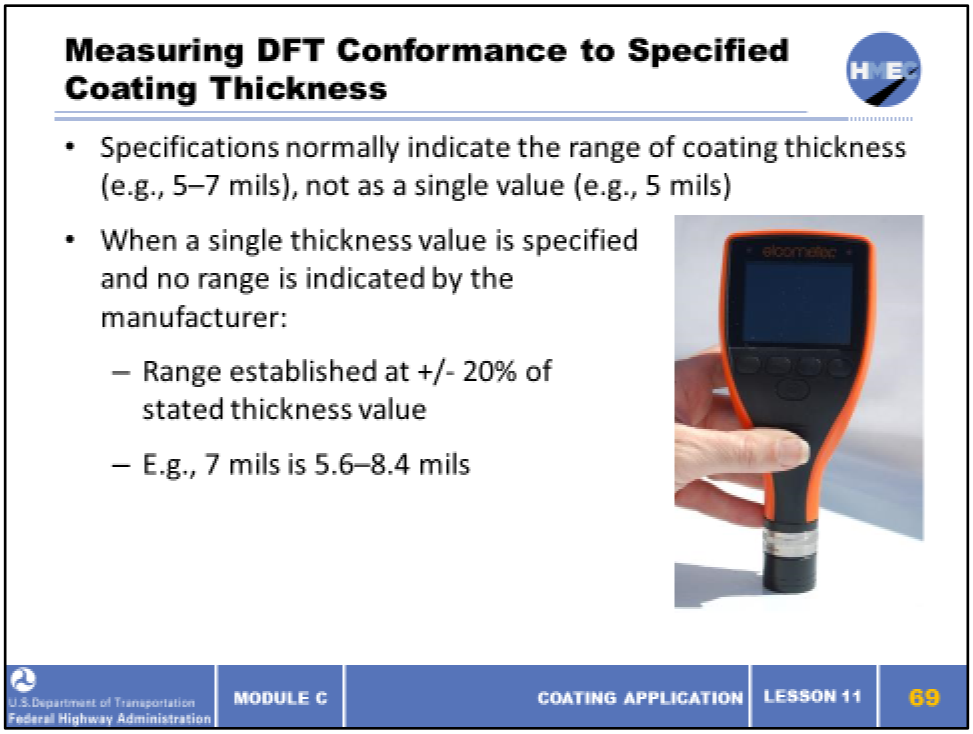
Slide 69



Properly prepared coating specifications will provide the contractor with a coating thickness range for each coating layer, since it is essentially impossible to apply a coating to achieve a single thickness value. That is, if 6 mils is the target thickness, the specifier should allow a range of 5 to 7 mils. If a coating thickness range is not specified and no range is indicated by the coating manufacturer, then SSPC-PA 2 establishes the range as plus-minus 20% of the stated value. For example, if the specifier and manufacturer require 7 mils thickness, 5.6 mils to 8.4 mils becomes the acceptable range for the coated area.

Slide 70

Measuring DFT Coating Thickness Restriction Levels

Thickness	Gage Reading	Spot Reading	Area Measurement
Level 1			
Minimum	Unrestricted	As specified	As specified
Maximum	Unrestricted	As specified	As specified
Level 2			
Minimum	Unrestricted	As specified	As specified
Maximum	Unrestricted	120% of maximum	As specified
Level 3			
Minimum	Unrestricted	80% of minimum	As specified
Maximum	Unrestricted	120% of maximum	As specified
Level 4			
Minimum	Unrestricted	80% of minimum	As specified
Maximum	Unrestricted	150% of maximum	As specified
Level 5			
Minimum	Unrestricted	80% of minimum	As specified
Maximum	Unrestricted	Unrestricted	Unrestricted

Note: If unspecified, Level 3 is the default

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Five levels are included, which gives the specifier some flexibility. Level 1 is the most restrictive and does not allow for any deviation of spot or area measurements from the specified minimum and maximum thickness, while Level 5 is the least restrictive, allowing unrestricted maximum thickness of the gage, spot, and area measurements. Depending on the coating type and the prevailing service environment, the specifier can select the DFT restriction level for a given project. For example, a maintenance coating project may invoke Level 4, which allows the coating to be 50% higher than the maximum specified thickness, provided the area measurement falls within specification. If no restriction level is specified, then Level 3 is the default. Note that Level 3 allows the spot measurements to be lighter or heavier than specified by 20%, and the average of the five spots, the area measurement, must be within specification.

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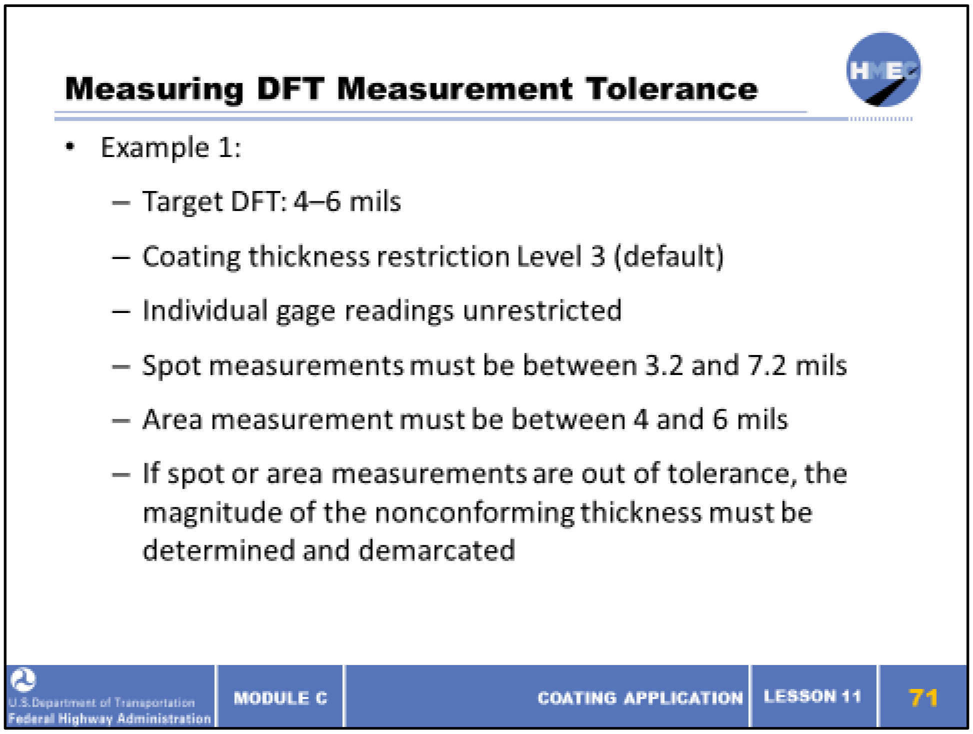
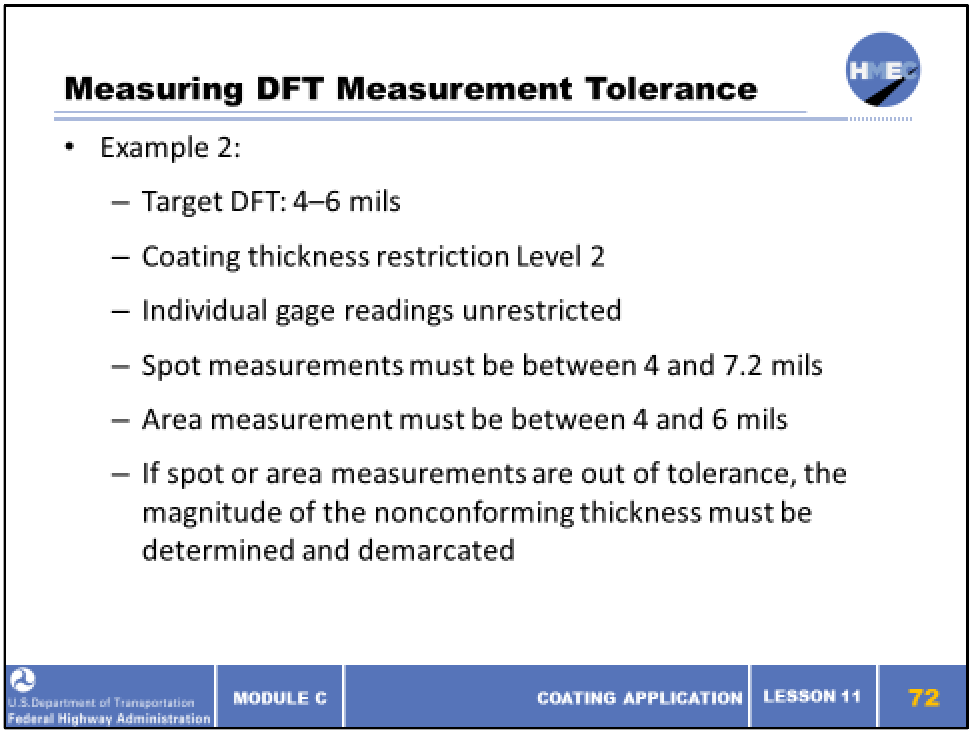
Slide 71



In this first example, the specified coating thickness is 4 to 6 mils. The individual gage readings that are obtained are unrestricted. The spot measurements can range between 3.2 and 7.2 mils, which is 80% of 4 mils and 120% of 6 mils. The area measurement must be between 4 and 6 mils.

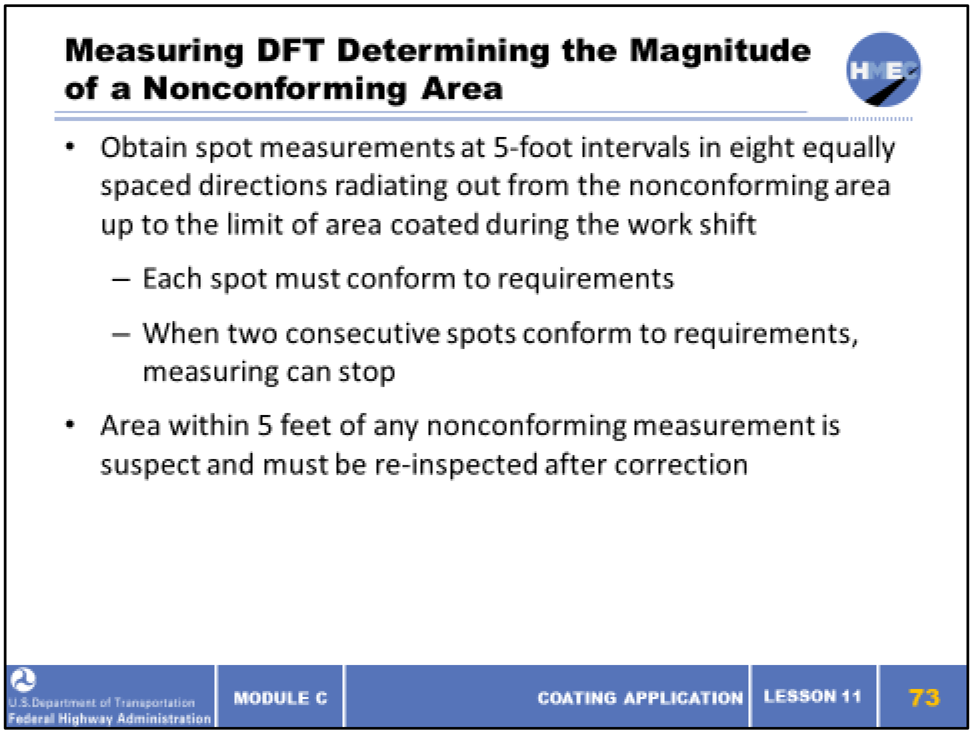
If spot or area measurements are outside of the allowable tolerance, the magnitude of the non-conforming area must be determined and the area demarcated.

Slide 72



In this second example, the specified coating thickness is 4 to 6 mils. The individual gage readings that are obtained are unrestricted. The spot measurements can range between 4 and 7.2 mils since Level 2 only allows 20% error on the maximum thickness and not the minimum. The area measurement must be between 4 and 6 mils.

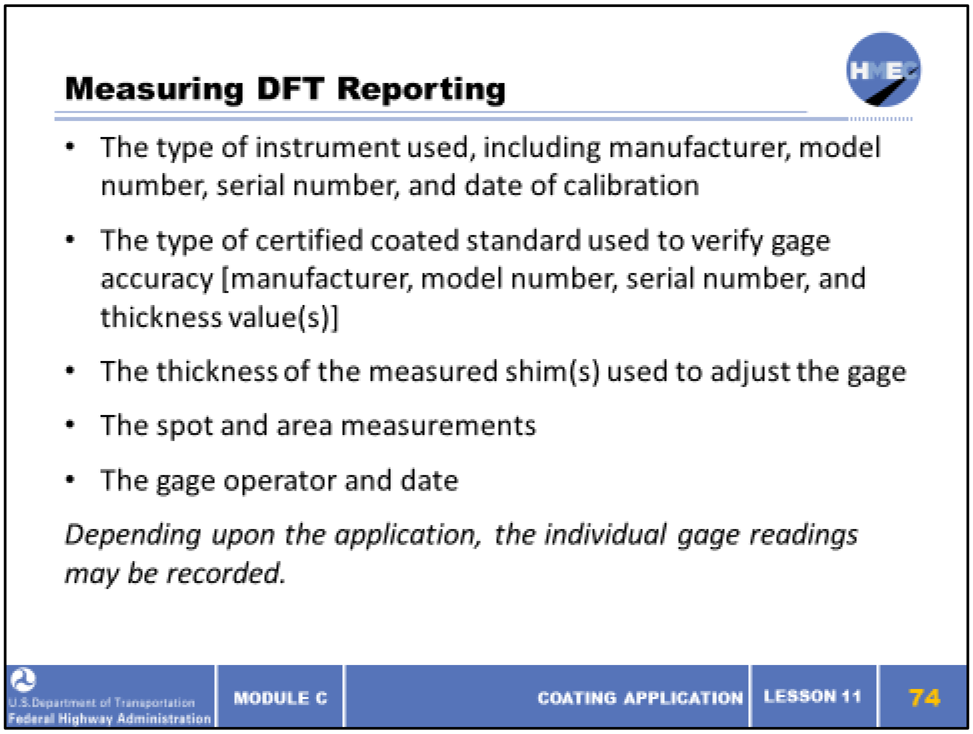
Slide 73



Up until 2012, when an area did not conform, the standard required that each 100 ft^2 area coated during the shift be measured to determine how bad the problem was. If 8,000 ft^2 were coated during a shift, then 80 areas, comprised of 400 spot measurements and 1,200 gage readings would have to be acquired, analyzed, and the defective areas demarcated for potential rework, which could severely impede production and the project schedule.

Recognizing this problem, SSPC put forth a considerable effort to create a better approach that would still properly address deficient or excessive film builds. When a defective area is discovered, additional spot measurements at 5-foot intervals are made in eight directions radiating outward from the nonconforming area, up to the limit of the area coated during the work shift. Each spot must conform the specified thickness, not the allowable spot tolerance. When two consecutive spots conform, measuring can stop in that direction. Any area within 5 feet of a nonconforming measurement is considered suspect and must be re-inspected after corrective measures have occurred.

Slide 74


Measuring DFT Reporting
HMEC
• The type of instrument used, including manufacturer, model number, serial number, and date of calibration
• The type of certified coated standard used to verify gage accuracy [manufacturer, model number, serial number, and thickness value(s)]
• The thickness of the measured shim(s) used to adjust the gage
• The spot and area measurements
• The gage operator and date
Depending upon the application, the individual gage readings may be recorded.
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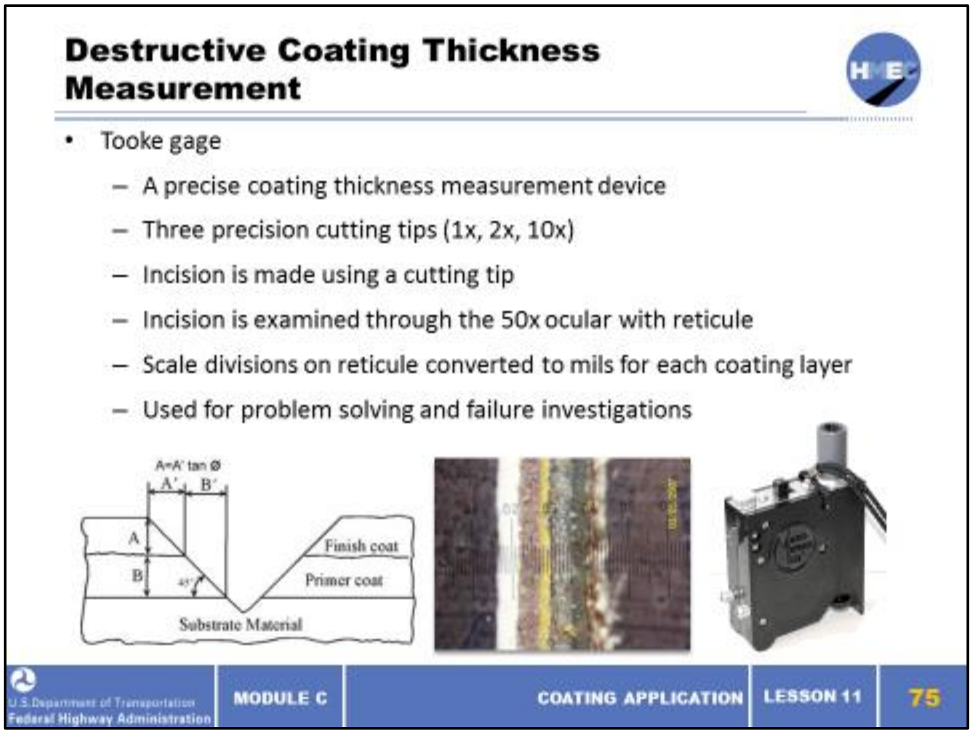
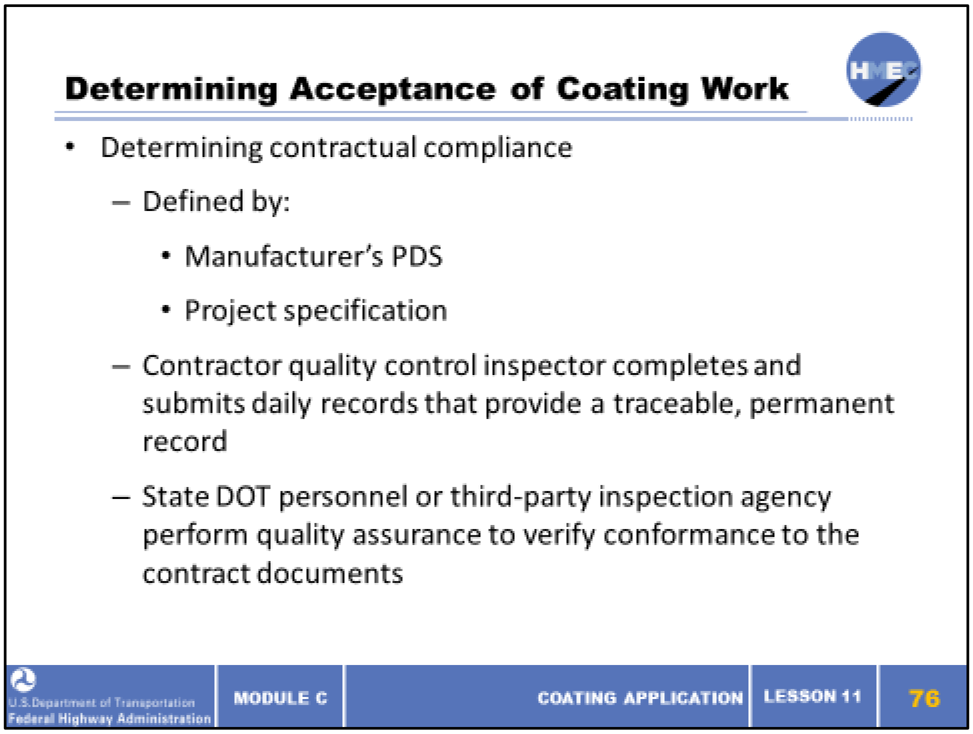


The Tooke gage conforms to ASTM D4138, Test Method for Measurement of Dry Film Thickness of Protective Coating Systems by Destructive Cross-Sectioning Means. It consists of a gage body and battery compartment, a 50 power illuminated microscope with a scale etched onto the lens, a focus adjustment for the microscope, and three tungsten carbide precision cutting tips. It is perhaps the most accurate field method of measuring coating thickness. There is no need to calibrate the Tooke gage, and it is unaffected by the type of substrate, the effect of the base metal, and its roughness. The Tooke gage is destructive, in that it makes an incision or groove (about the width of a line drawn with a pencil) through the coating film down to the substrate. In addition, the Tooke gage cannot be used to measure coating thickness beyond 50 mils.

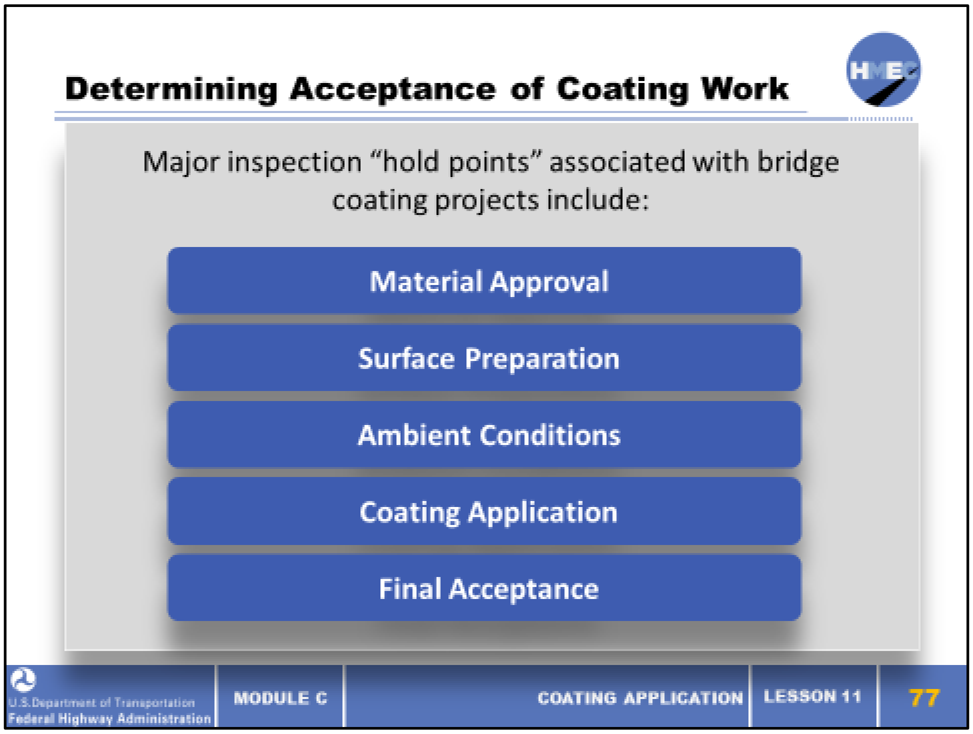
The Tooke gage measures coating thickness using basic trigonometry. That is, by cutting a precision "V" groove into the coating system using one of the tungsten carbide cutting tips, a right triangle is created. The angles of the right triangle are known. By measuring the length of one leg of the triangle, the user can calculate the length of the other leg, which represents the coating thickness. If the coating layers are different or alternating in color, then each layer can be both seen and the thickness measured through the Tooke gage ocular.

Slide 76



The contractor quality control (QC) inspector completes and submits daily records that provide a traceable, permanent record of conformance to the specification, including any deviations and non-conformities.

Slide 77



The main phases of work that are subject to QA inspection are referred to as hold points. These typically include material approvals, upon completion of surface preparation, ambient conditions prior to application of each coating, after application of each coating layer, and final acceptance.

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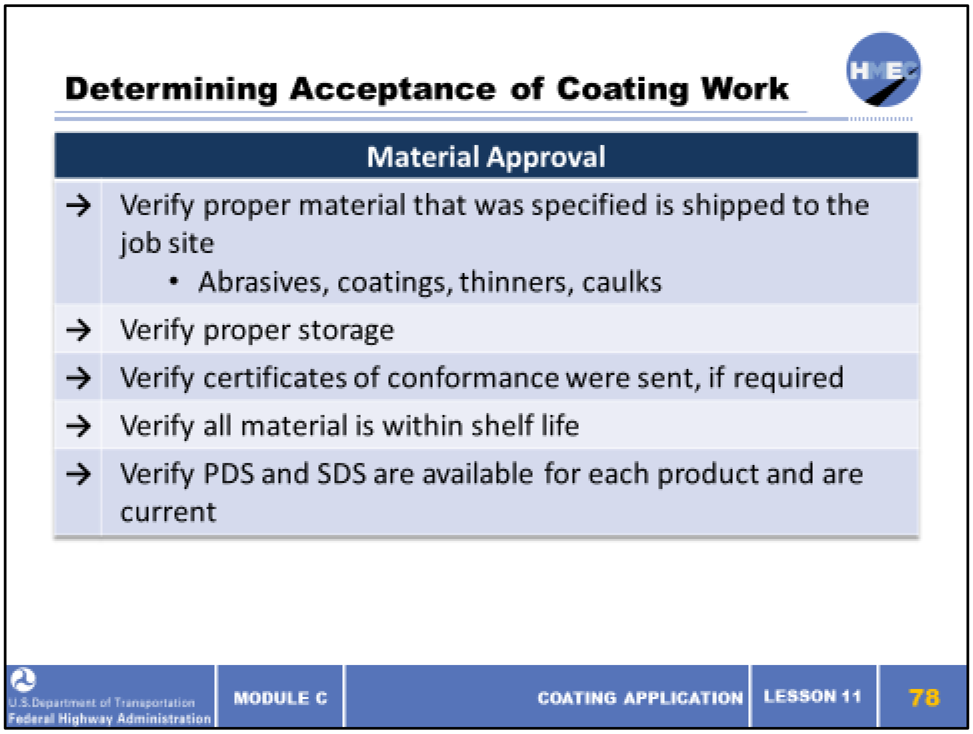
Slide 78



Determining Acceptance of Coating Work
Material Approval
→ Verify proper material that was specified is shipped to the job site
• Abrasives, coatings, thinners, caulks
→ Verify proper storage
→ Verify certificates of conformance were sent, if required
→ Verify all material is within shelf life
→ Verify PDS and SDS are available for each product and are current
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Federal Highway Administration
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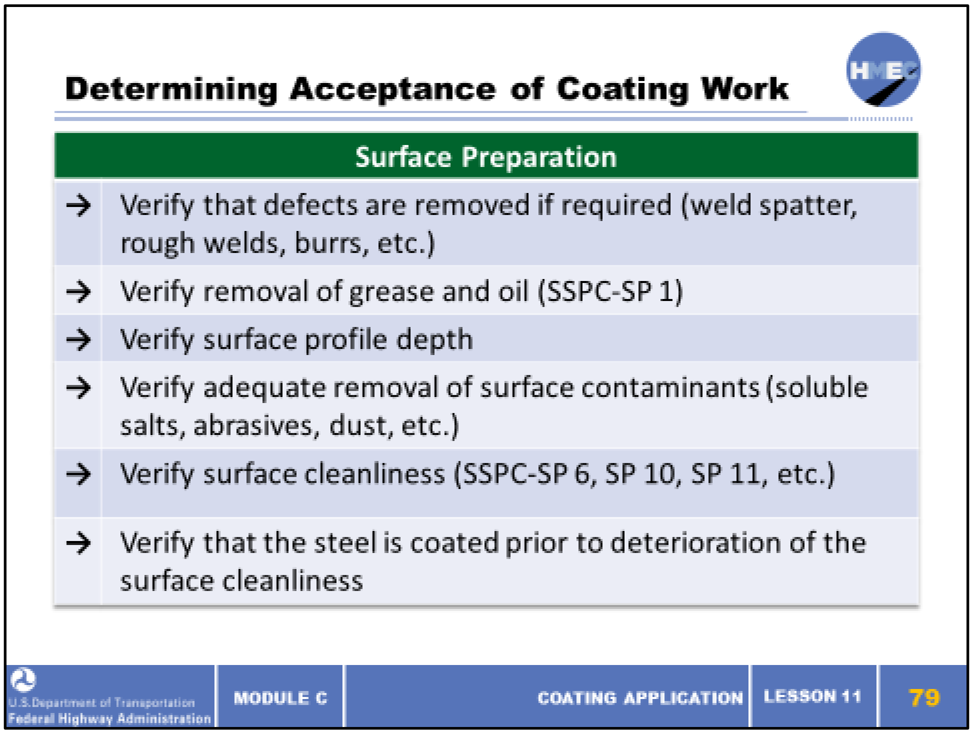
Determining Acceptance of Coating Work
HMEC
Surface Preparation
→ Verify that defects are removed if required (weld spatter, rough welds, burrs, etc.)
→ Verify removal of grease and oil (SSPC-SP 1)
→ Verify surface profile depth
→ Verify adequate removal of surface contaminants (soluble salts, abrasives, dust, etc.)
→ Verify surface cleanliness (SSPC-SP 6, SP 10, SP 11, etc.)
→ Verify that the steel is coated prior to deterioration of the surface cleanliness
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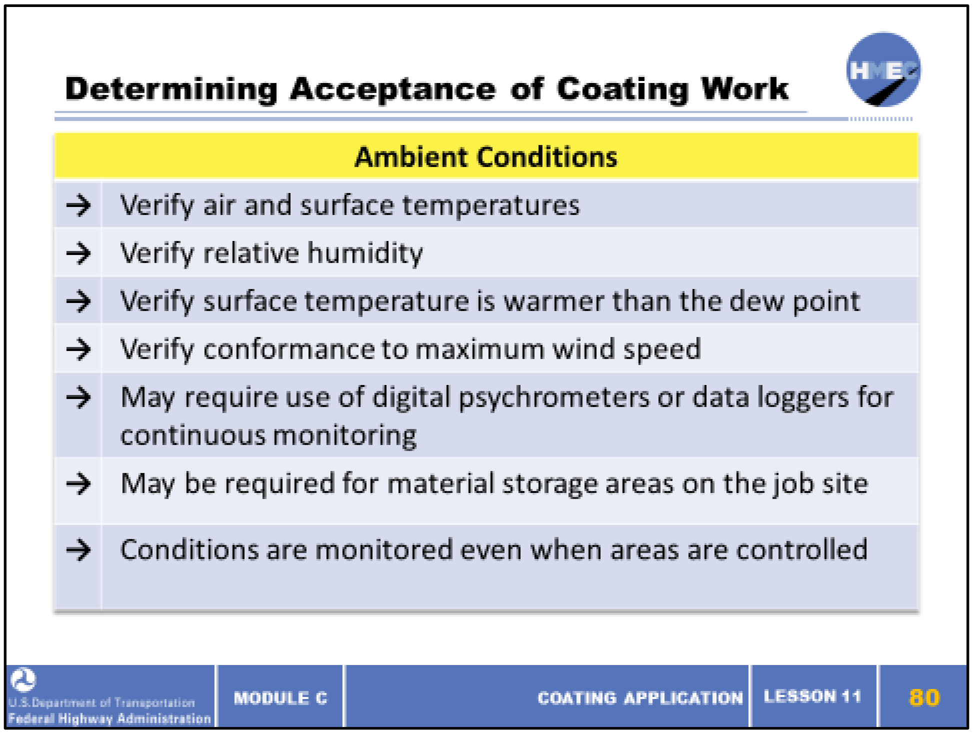
Determining Acceptance of Coating Work
HMEC
Ambient Conditions
Verify air and surface temperatures
Verify relative humidity
Verify surface temperature is warmer than the dew point
Verify conformance to maximum wind speed
May require use of digital psychrometers or data loggers for continuous monitoring
May be required for material storage areas on the job site
Conditions are monitored even when areas are controlled
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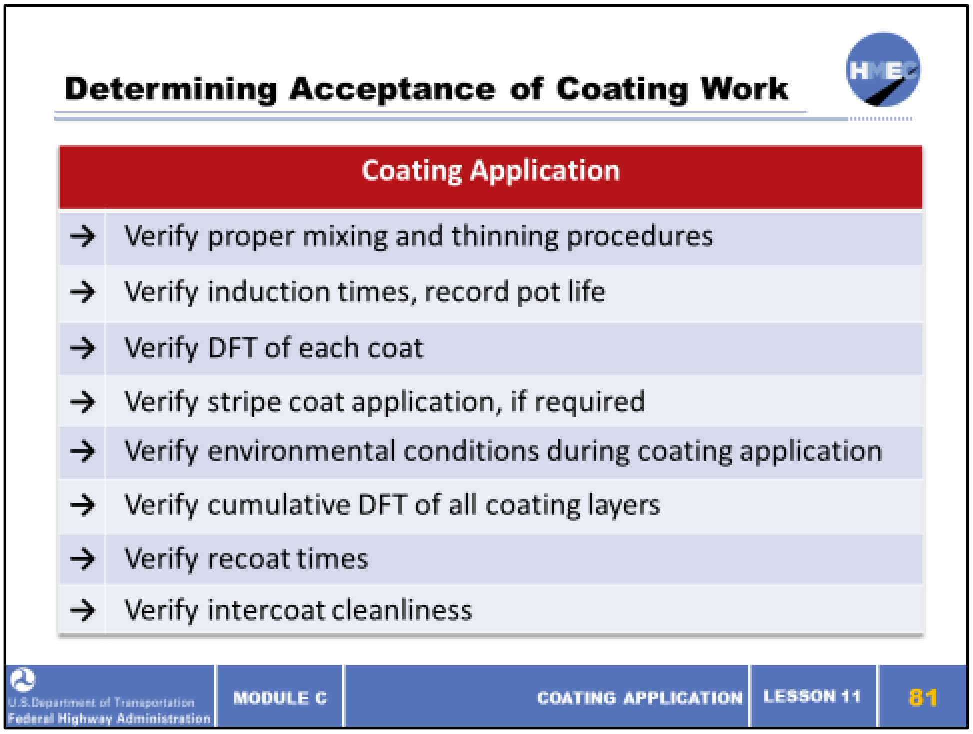

Mixing and thinning procedures, induction times, and conformance to the pot life (for each batch of coating material mixed) must be verified for conformance to the manufacturer's PDS (this information is not typically provided in a coating specification). Verify the correct DFT of each coat and the cumulative thickness of all coating layers. Verify that the stripe coat(s) were applied, if required, and verify environmental conditions are maintained throughout the coating application process. Finally, verify recoat times and intercoat cleanliness.

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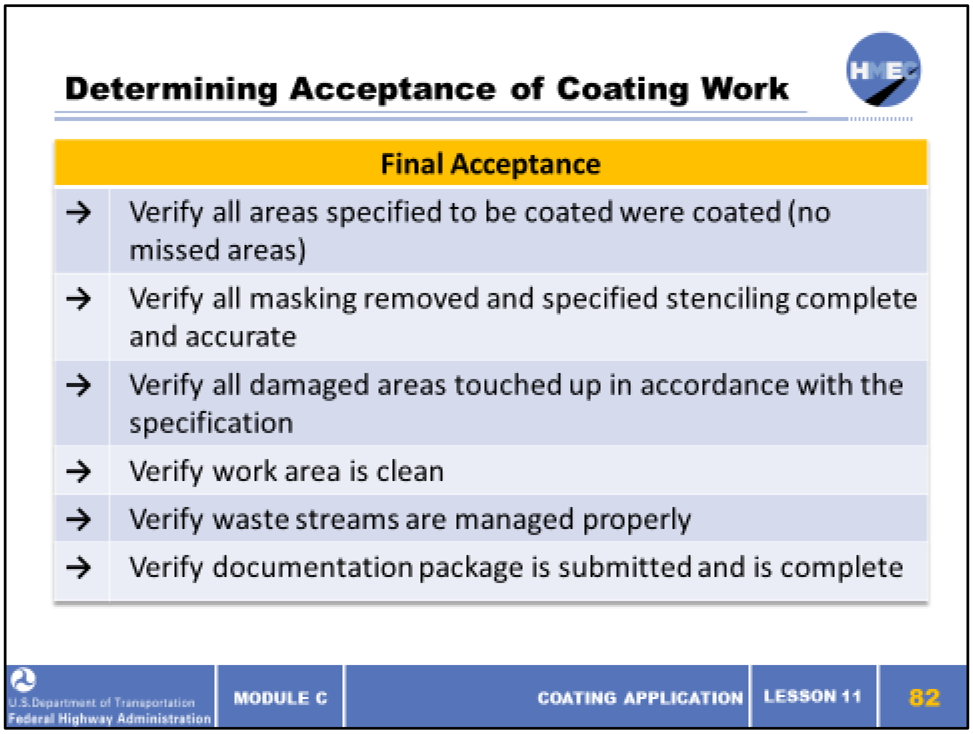
Determining Acceptance of Coating Work
HMEC
Final Acceptance
→ Verify all areas specified to be coated were coated (no missed areas)
→ Verify all masking removed and specified stenciling complete and accurate
→ Verify all damaged areas touched up in accordance with the specification
→ Verify work area is clean
→ Verify waste streams are managed properly
→ Verify documentation package is submitted and is complete
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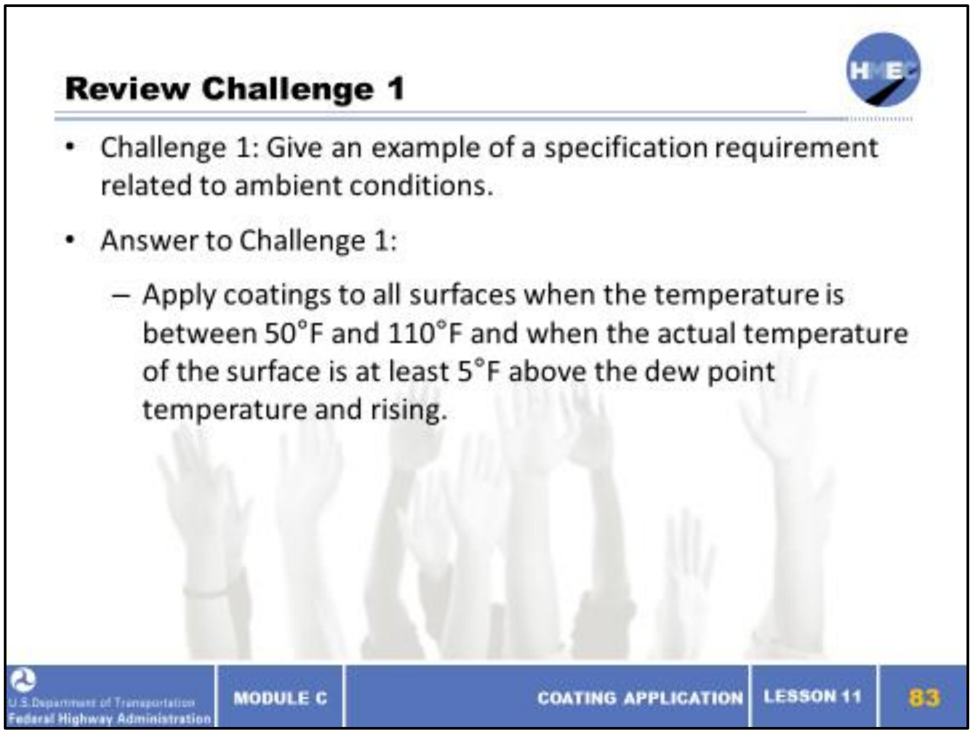
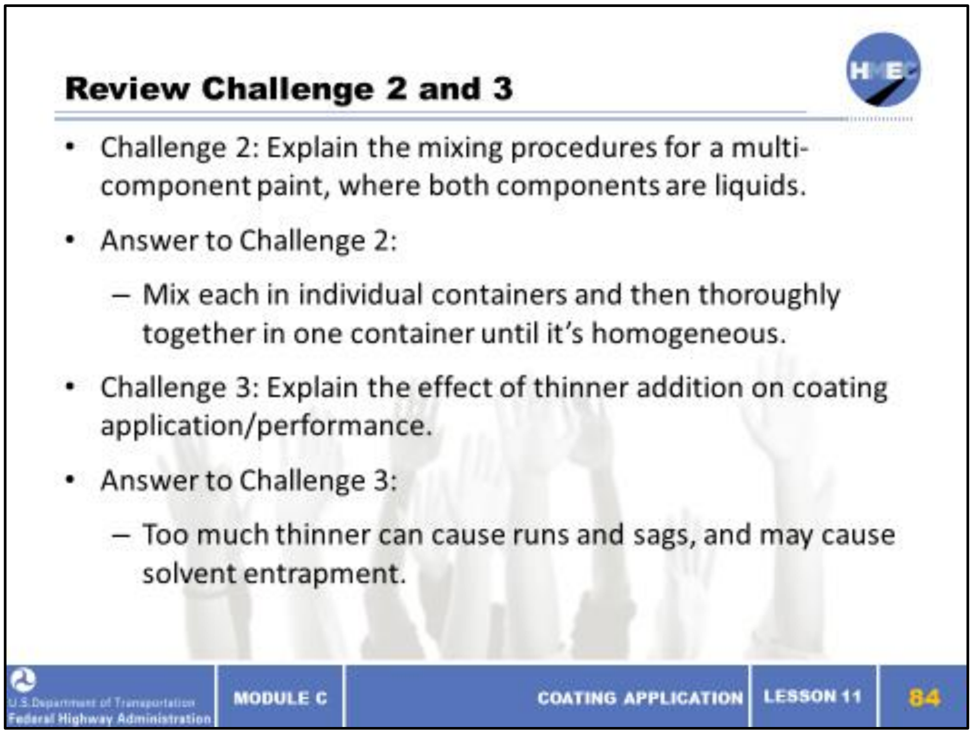


Six challenges will be posed

Slide 84


Review Challenge 2 and 3
HMEC
• Challenge 2: Explain the mixing procedures for a multi-component paint, where both components are liquids.
• Answer to Challenge 2:
– Mix each in individual containers and then thoroughly together in one container until it's homogeneous.
• Challenge 3: Explain the effect of thinner addition on coating application/performance.
• Answer to Challenge 3:
– Too much thinner can cause runs and sags, and may cause solvent entrapment.
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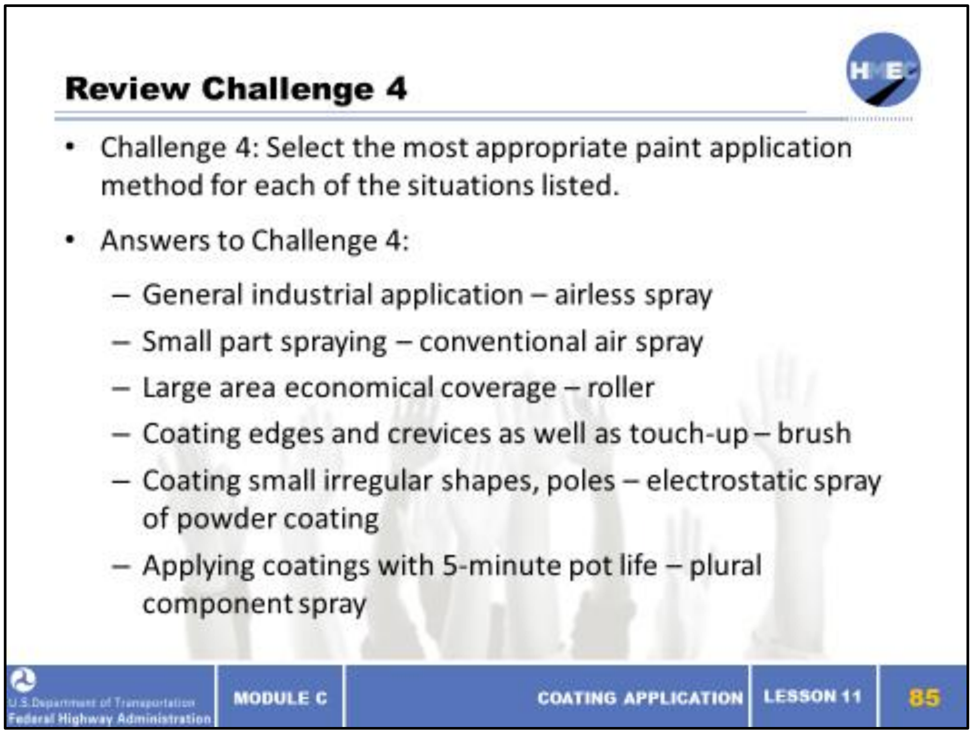
Review Challenge 4
Challenge 4: Select the most appropriate paint application method for each of the situations listed.
Answers to Challenge 4:
– General industrial application – airless spray
– Small part spraying – conventional air spray
– Large area economical coverage – roller
– Coating edges and crevices as well as touch-up – brush
– Coating small irregular shapes, poles – electrostatic spray of powder coating
– Applying coatings with 5-minute pot life – plural component spray
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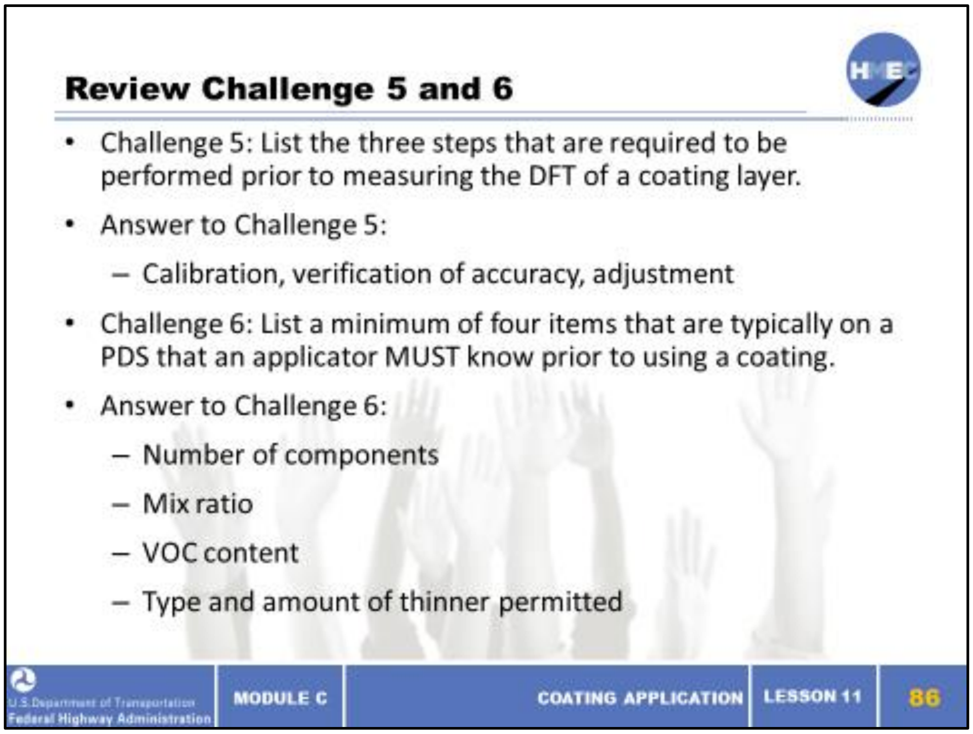
Review Challenge 5 and 6
Challenge 5: List the three steps that are required to be performed prior to measuring the DFT of a coating layer.
Answer to Challenge 5:
Calibration, verification of accuracy, adjustment
Challenge 6: List a minimum of four items that are typically on a PDS that an applicator MUST know prior to using a coating.
Answer to Challenge 6:
Number of components
Mix ratio
VOC content
Type and amount of thinner permitted
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Learning Outcomes Review

You are now able to:

- Navigate a PDS
- Explain proper mixing and thinning procedures
- Describe the differences between coating application methods
- Identify the quality procedures associated with coating application
- Calculate WFT targets
- Describe the procedures for measuring coating thickness
- Explain the requirements for the acceptance of the coating work

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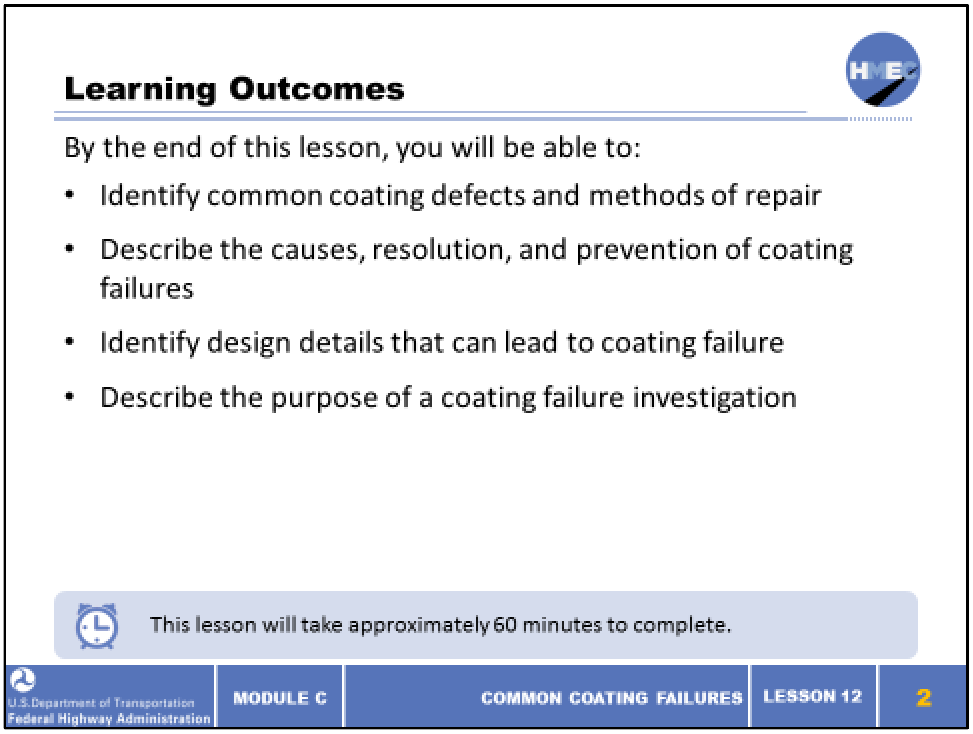
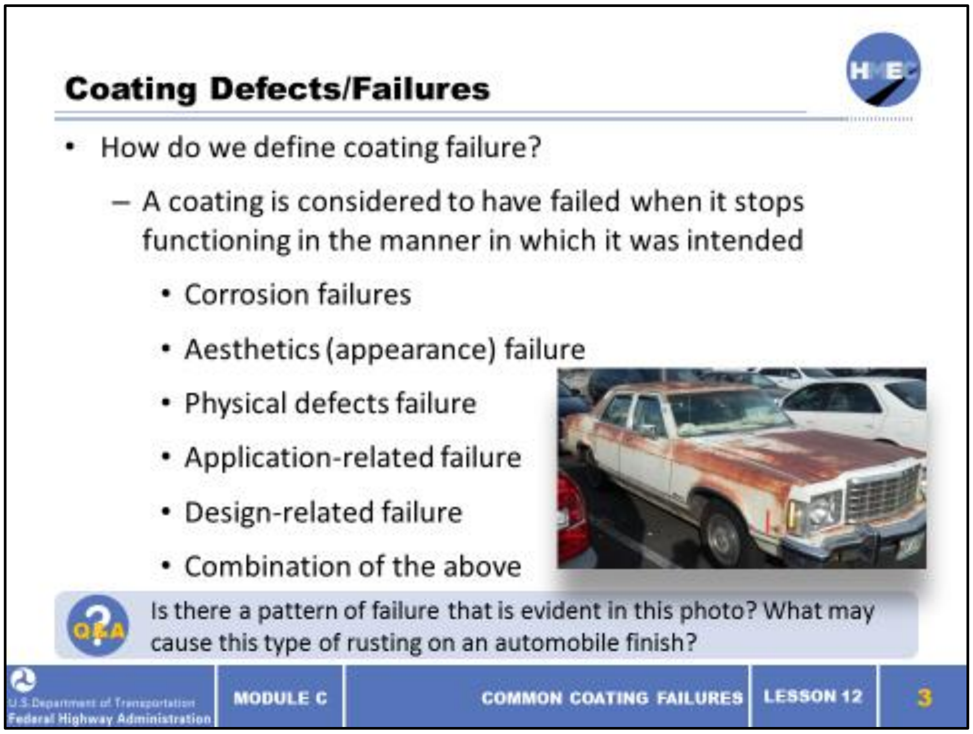
Slide 1


HMEC
Highway Materials Engineering Course
Lesson 12: Common Coating Failures
Steel, Welding, and Coatings
U.S.Department of Transportation
Federal Highway Administration
MODULE
C

Slide 2

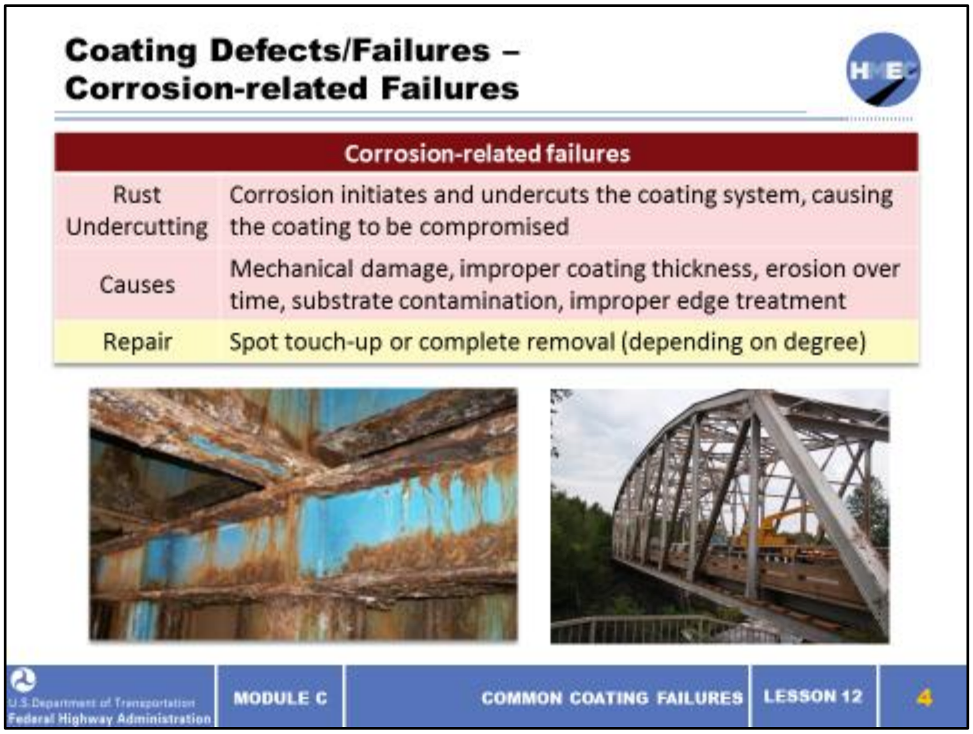

Learning Outcomes
HMEC
By the end of this lesson, you will be able to:
• Identify common coating defects and methods of repair
• Describe the causes, resolution, and prevention of coating failures
• Identify design details that can lead to coating failure
• Describe the purpose of a coating failure investigation
This lesson will take approximately 60 minutes to complete.
U.S. Department of Transportation Federal Highway Administration
MODULE C
COMMON COATING FAILURES
LESSON 12
2

Slide 3



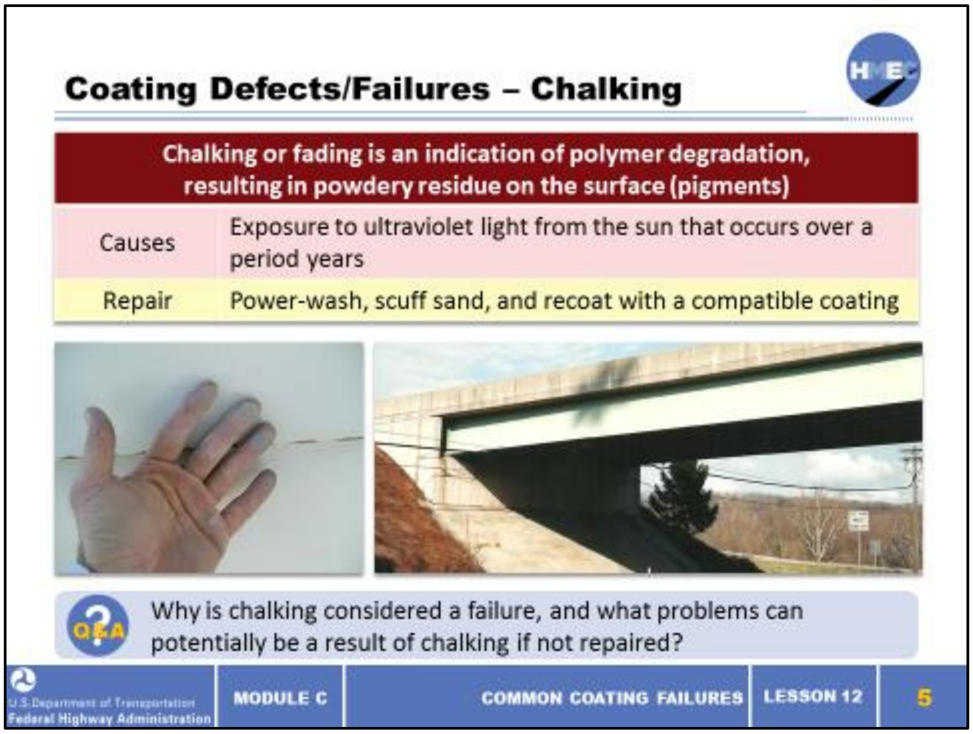
A coating is considered to have failed when it stops functioning in the manner in which it was intended. Coating failure can be caused by several factors.

Slide 4



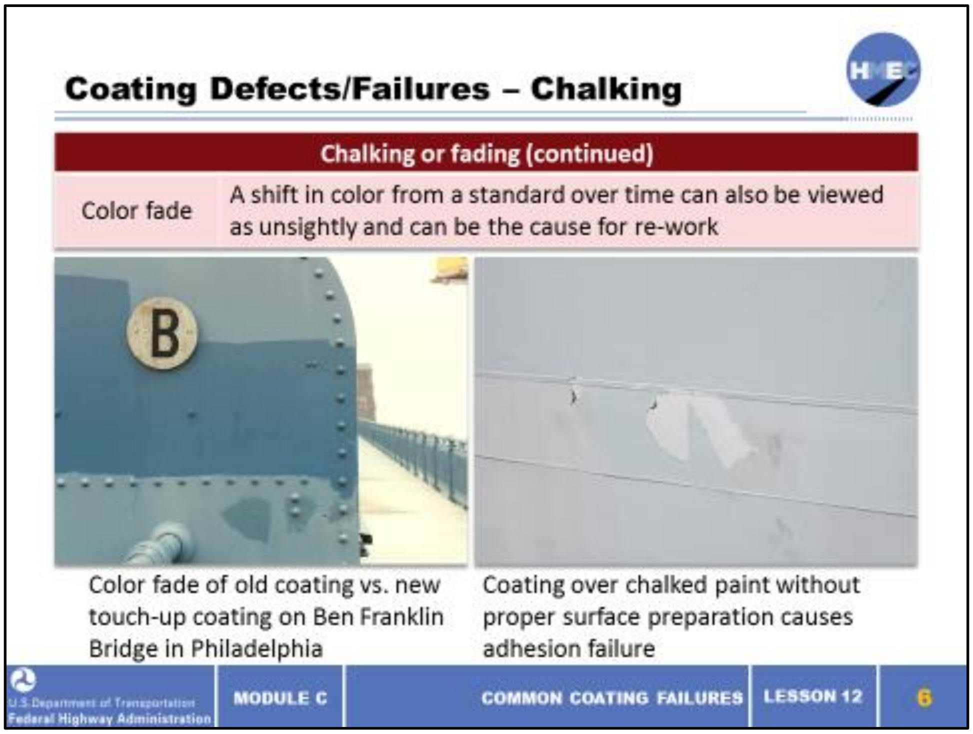
Corrosion can compromise a coating's adhesion due to undercutting. The initial breach in the coating film can be caused by a number of factors, such as mechanical impact damage from road debris, or lack of film build on edges. Corrosion will continue to undercut the coating system unless an effective maintenance strategy is implemented.

Slide 5



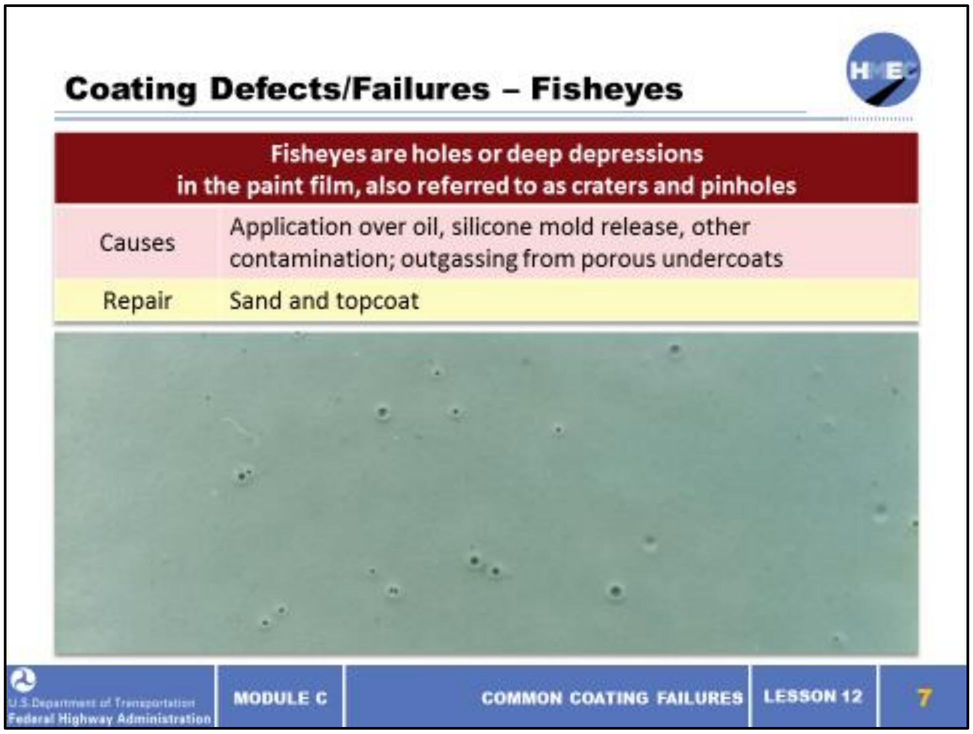
Chalking is actually the sun's harmful ultraviolet light (solar radiation) breaking down the polymer matrix of the coating's resin, freeing the pigment. Eventually, rain washes away the chalking, exposing fresh undercoats, and the process continues. Coating over chalking without proper preparation (pressure washing with surface agitation) will result in rapidly disbonding coating. The bridge overpass in the photo was originally a deep green color, but after years of exposure to the sunlight it has faded to a pale green. Darker colors are more prone to fading than lighter colors.

Slide 6



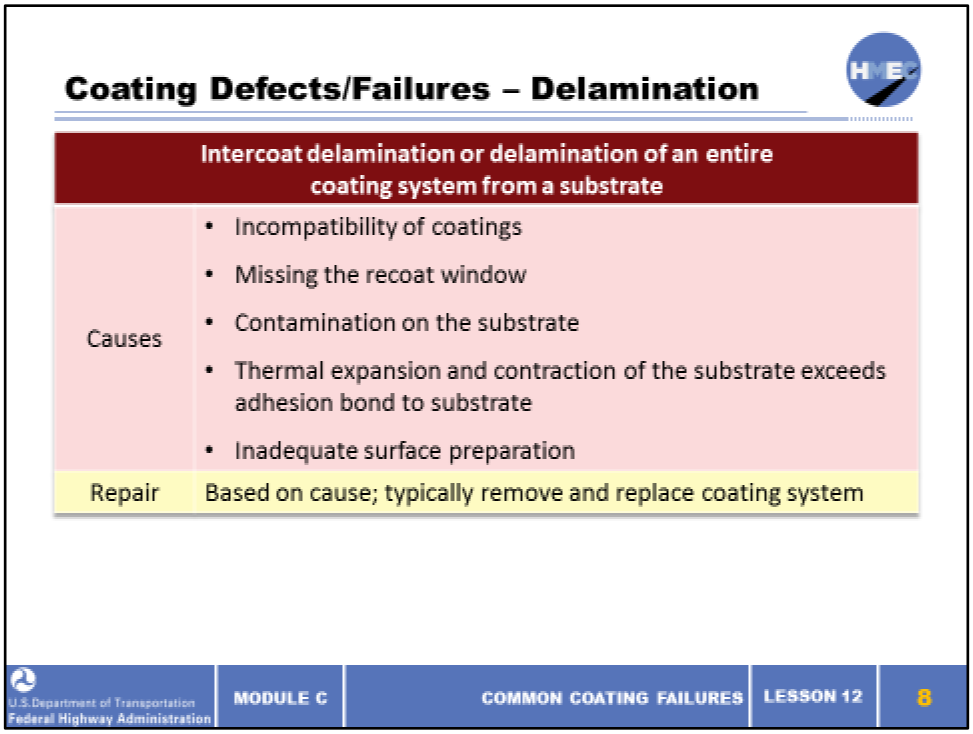
Chalking is a noticeable shift in appearance from the initial (baseline) color over time, usually due to exposure to the sun and elements. A reduction in gloss may also be apparent (provided the finish coat was glossy to begin with; some aren't). The chalking must be removed in order to ensure adhesion of subsequent overcoats.

Slide 7



Fisheyes, craters, or pinholes are typically caused by application of the coating over surface contamination that prevents the coating from fully wetting the surface and flowing/knitting together. Pinholes and subsequent fisheyes can also be caused by outgassing of entrapped air when porous coatings like zinc-rich primers and metalizing are topcoated. These defects may or may not penetrate to the substrate. Defects like those shown in the photo can travel to the substrate, creating a pathway for oxygen and electrolytes and causing spot corrosion. Since this type of defect is often widespread, repairing them can be challenging. Typically the surface is scuff sanded and then coated.

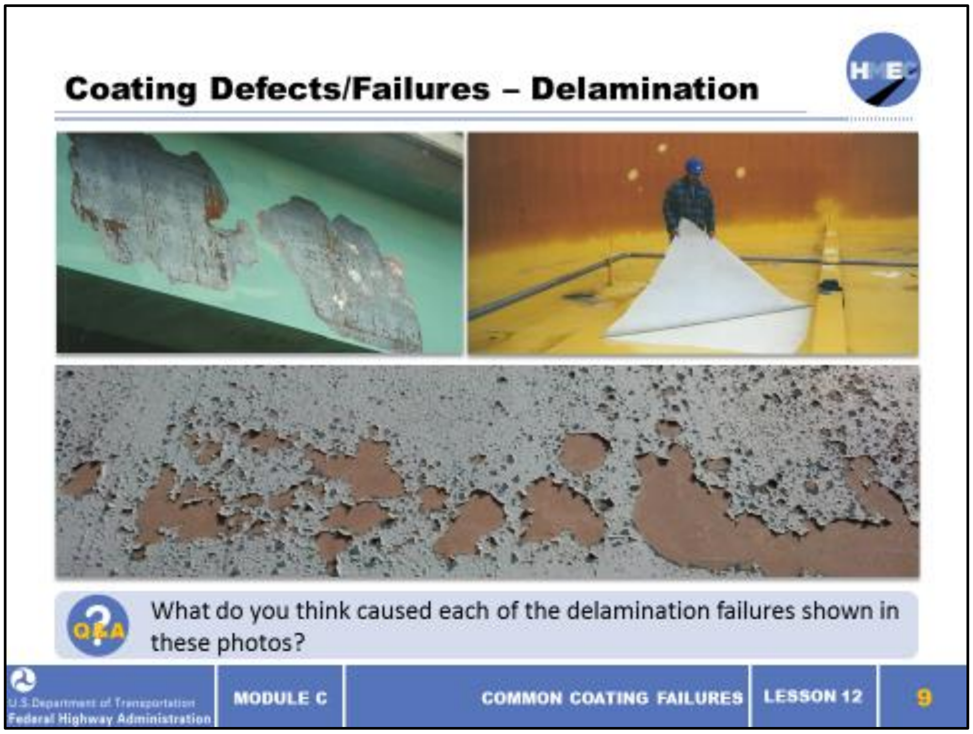
Slide 8



Delamination can be intercoat (between two coating layers) or the separation of an entire coating system from the substrate. Delamination can be caused by many factors, including incompatibility of coating layers, missing the recoat window, contamination on the substrate (such as coating over chalking, described earlier in this lesson), thermal expansion and contraction of the substrate that exceeds the adhesion strength of the coating (this happens to aged coating systems due to degradation of the resin system over time), and inadequate surface preparation (substrate or underlying layers).

Repairing delamination-type coating failure is on a case-by-case basis. It can be as simple as scuff sanding and overcoating, or as complex as complete removal and replacement of the existing coating system.

Slide 9


Coating Defects/Failures – Delamination
What do you think caused each of the delamination failures shown in these photos?
U.S. Department of Transportation
Federal Highway Administration
MODULE C
COMMON COATING FAILURES
LESSON 12
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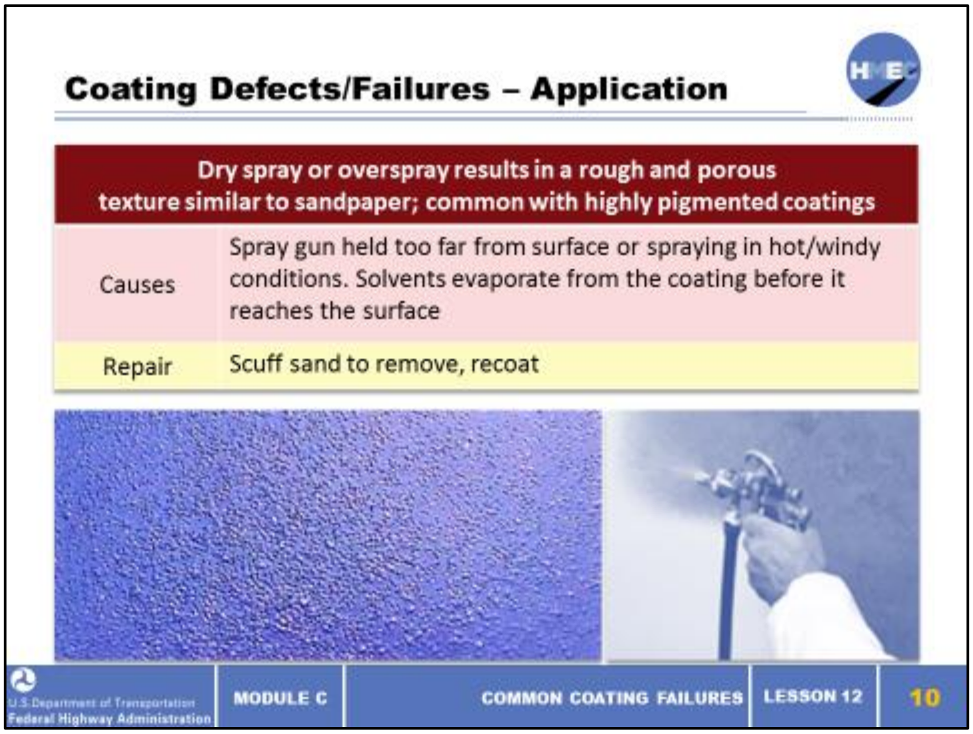
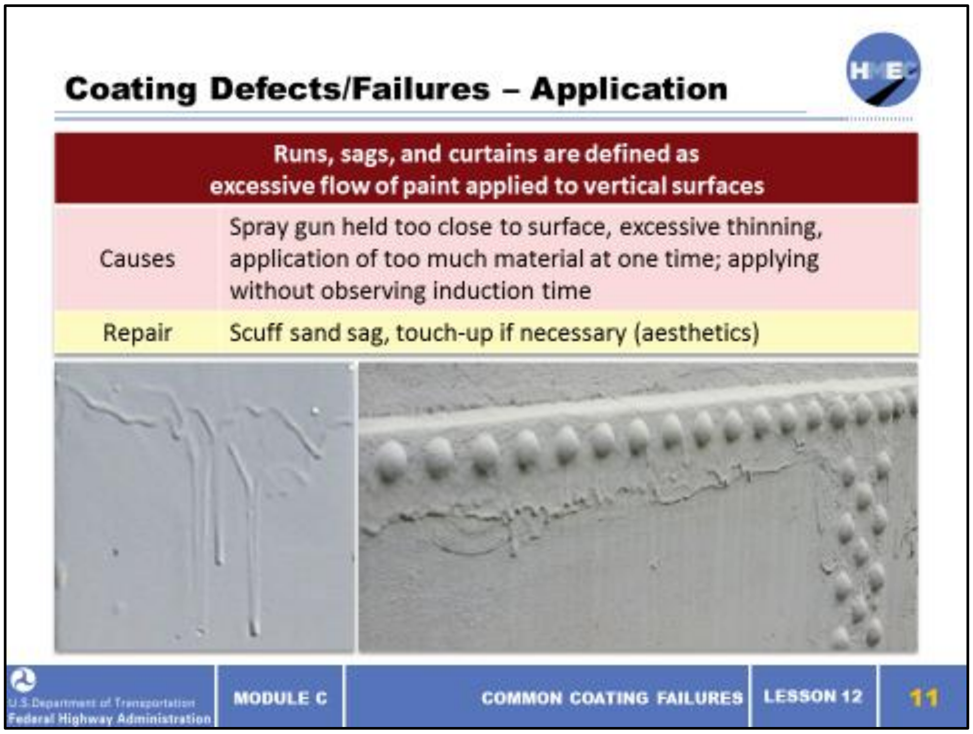
Slide 10



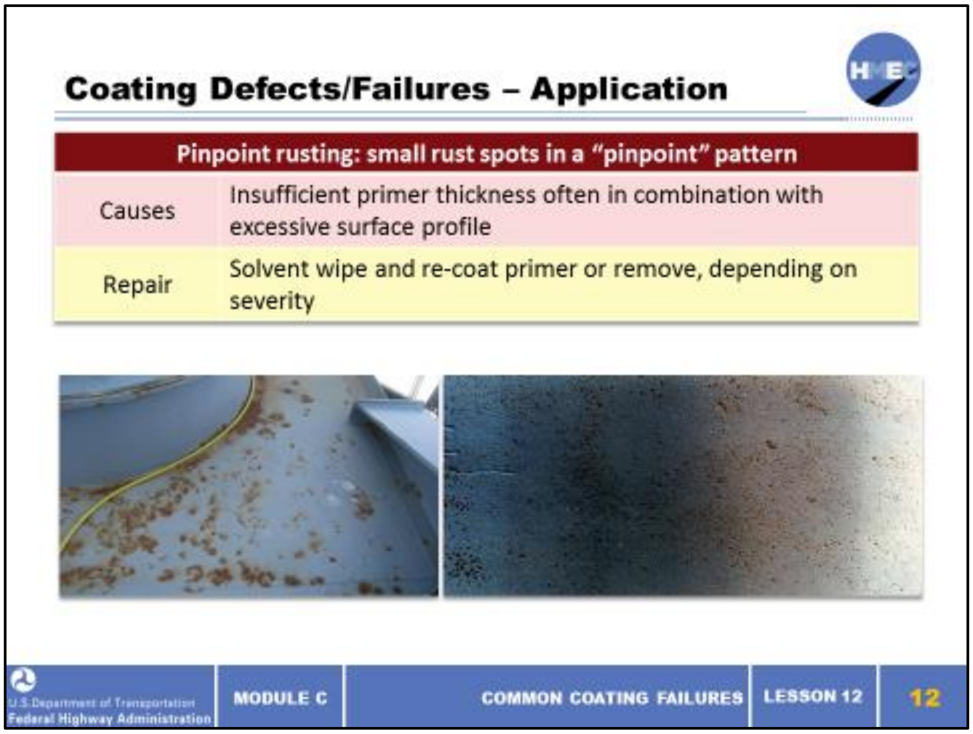
Dry spray or overspray is common with highly pigmented coatings like zinc-rich primers and is caused by positioning the spray gun too far from the surface and/or applying the coating during hot and/or windy conditions. In both cases, the solvents evaporate from the atomized coating before it reaches the surface. The lack of solvent prevents the coating from wetting the surface and flowing/knitting together. It is a loosely-adhering, non-continuous product that must be removed or intercoat delamination may result. Many coating manufacturers will recommend a different thinner if spraying must be done in hot/windy conditions; however, proper application technique (i.e., gun distance) is a critical component to preventing dry spray and overspray.

Slide 11



Coatings are formulated to “hang” on vertical surfaces when they are applied properly. That is, they have sag resistance. Factors that may cause sagging include holding the spray gun too close to the surface, over-thinning, applying too much paint at one time (exceeding the recommended wet film thickness, WFT, in a single application), or not observing the induction time (if required by the manufacturer) with multi-component coatings. Experienced applicators will “brush-out” runs and sags while the paint is still wet, eliminating the need to sand and re-work the defect. However, if runs and sags are not repaired during application, they may be sanded and a touch-up coat may be applied if necessary (for aesthetics). Some specifications do not allow runs, drips, or sags in the applied coatings.

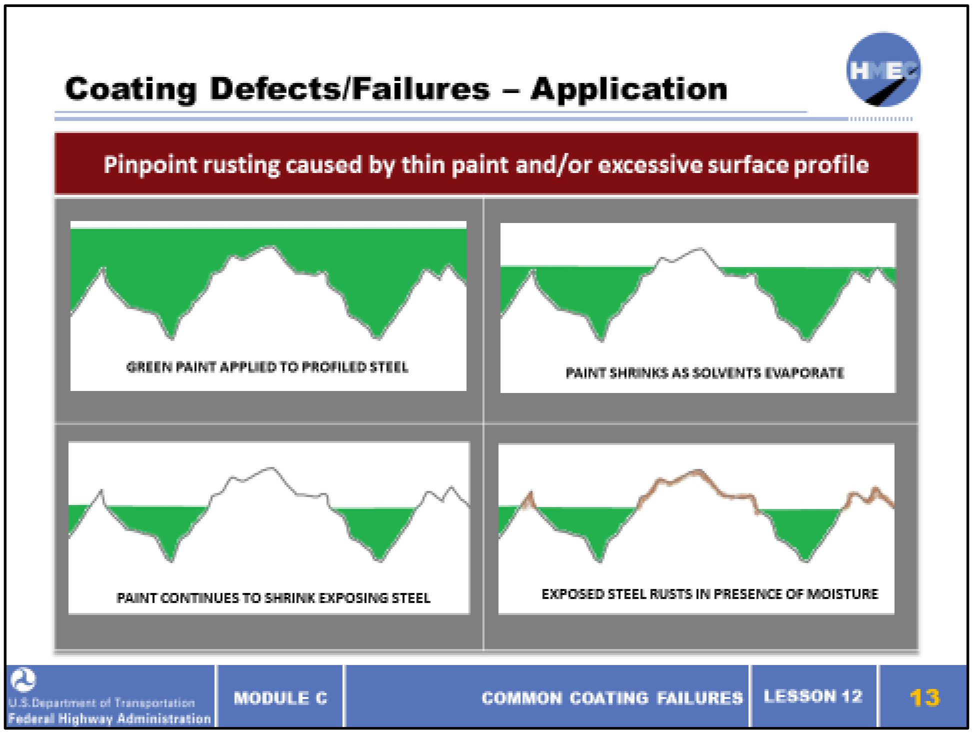
Slide 12



Pinpoint rusting is often caused by insufficient primer thickness, and may be in combination with an excessive surface profile. Contamination from steel shavings created by nearby grinding operations, or stray steel grit or shot laying on the surface of the coating (that becomes damp) can create a rust stain that may be mistaken for pinpoint rusting.

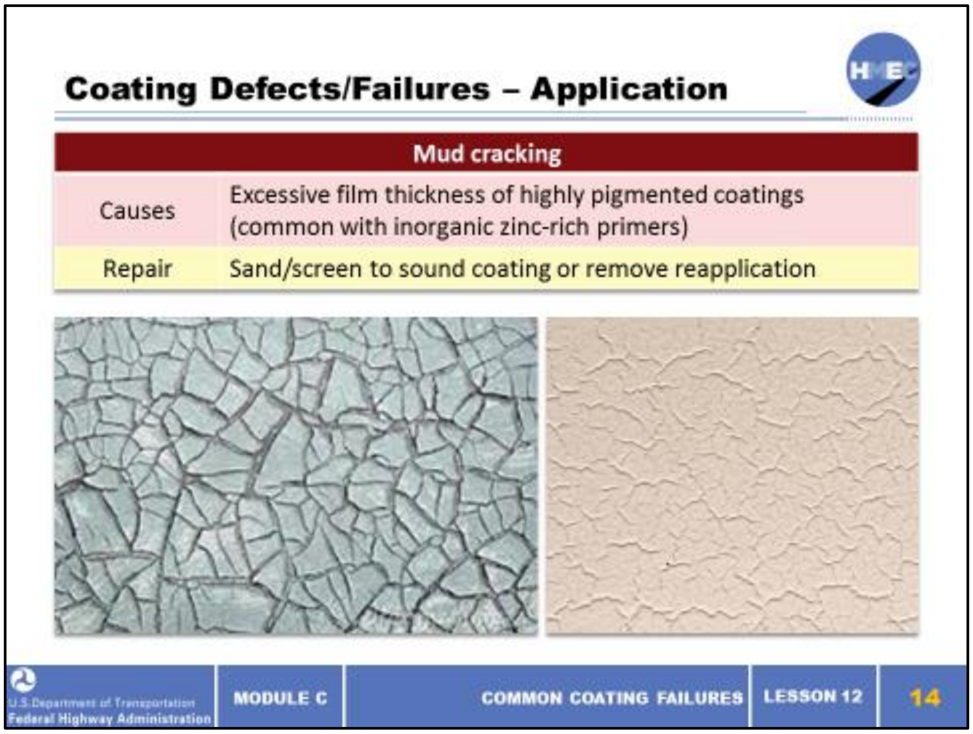
Depending on the severity of the pinpoint rusting, it may be repaired by solvent wiping and re-coating, or may the primer may need to be completely removed and the surface recoated.

Slide 13



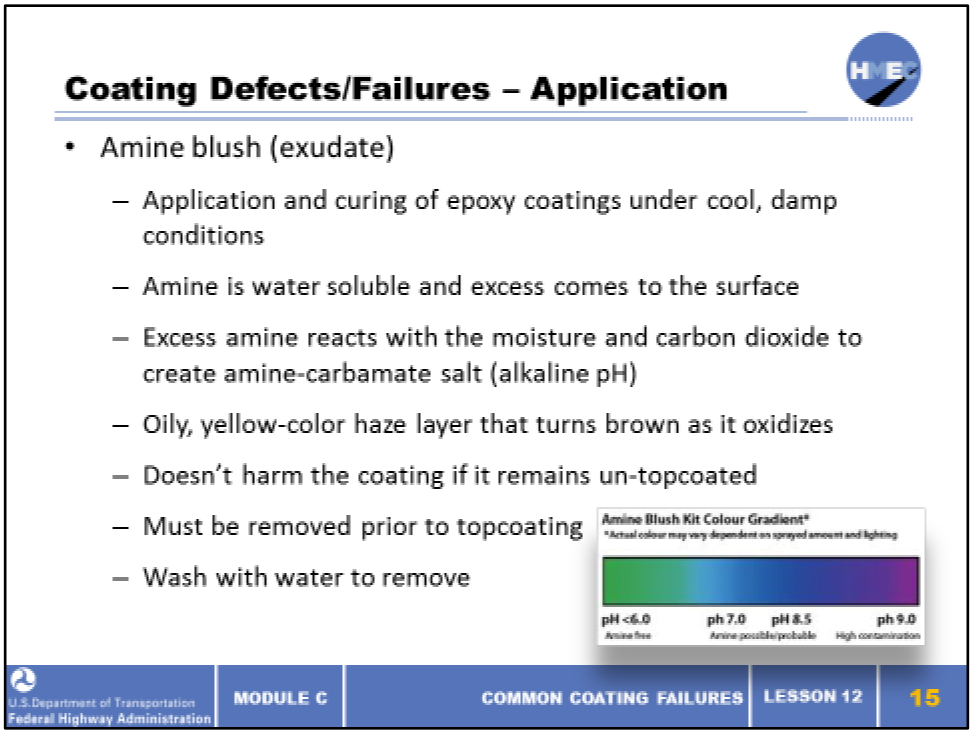
The green in the illustration represents a low-medium solids solvent-borne coating, which shrinks as the solvent evaporates and curing occurs, slowly exposing the peaks of the surface profile. If those peaks are exposed to moisture such as overnight dew (an electrolyte), pinpoint rusting will occur.

Slide 14



Mud cracking refers to a pattern of overly thick coatings, which irregularly crack once the solvents evaporate. These are usually heavily pigmented coatings such as inorganic zinc or other highly pigmented coatings. The excessive thickness combined with a relatively low resin content causes the coating to crack cohesively. It resembles mud that has cracked in a dry lake bed. Depending on the severity of the mud cracking, it may be repaired by sanding or screening until sound coating is revealed, or it may need to be completely removed and the coating reapplied.

Slide 15



Amine blush (exudate) can occur when epoxy coatings are applied and cured under cool, damp conditions. Amine is water soluble and any excess amine that wasn’t consumed during the reaction process comes to the surface of the coating. The excess amine reacts with the moisture in the air and carbon dioxide to create an amine-carbamate salt, which has an alkaline pH. It first appears as an oily (to the touch), yellow-color haze layer that eventually turns brown and becomes tacky as it oxidizes. It does not look good but doesn’t harm the coating per se. However, if the epoxy is scheduled to be topcoated (always the case with bridge coating systems), the amine blush must be removed, otherwise catastrophic intercoat disbonding will usually occur, depending on the amount of blush on the surface. Unfortunately, no one has been able to quantify the amount and determine how much is too much. Therefore, this bloom needs to be removed by washing with fresh water (use of warm water and the addition of a detergent helps) prior to subsequent application of coatings.

Test kits are available for detecting amine blush.

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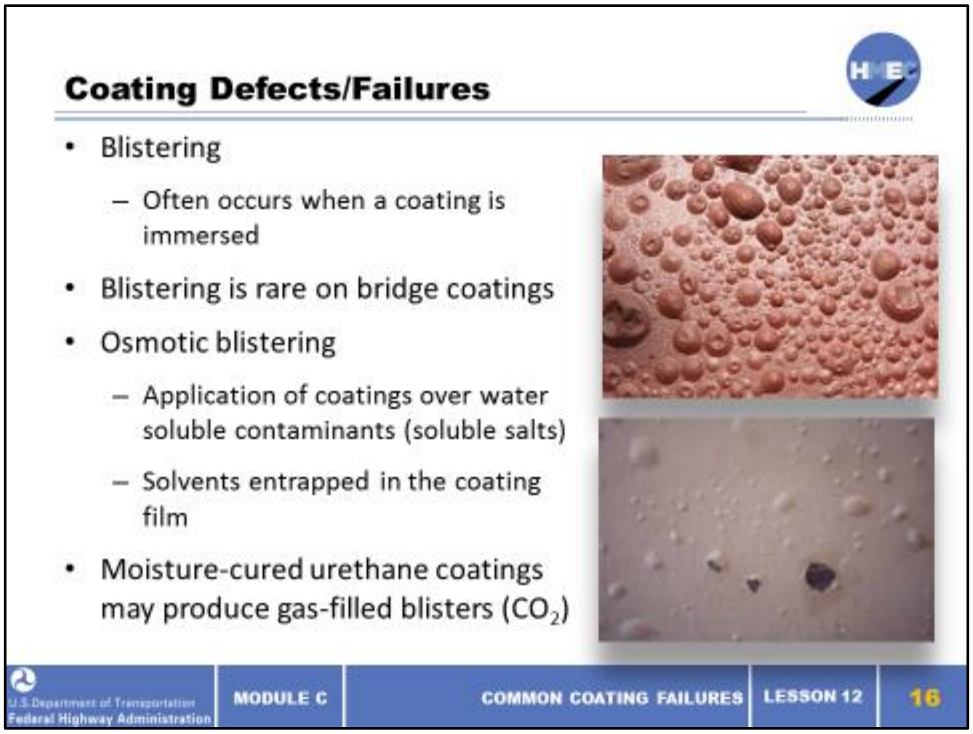
Slide 16



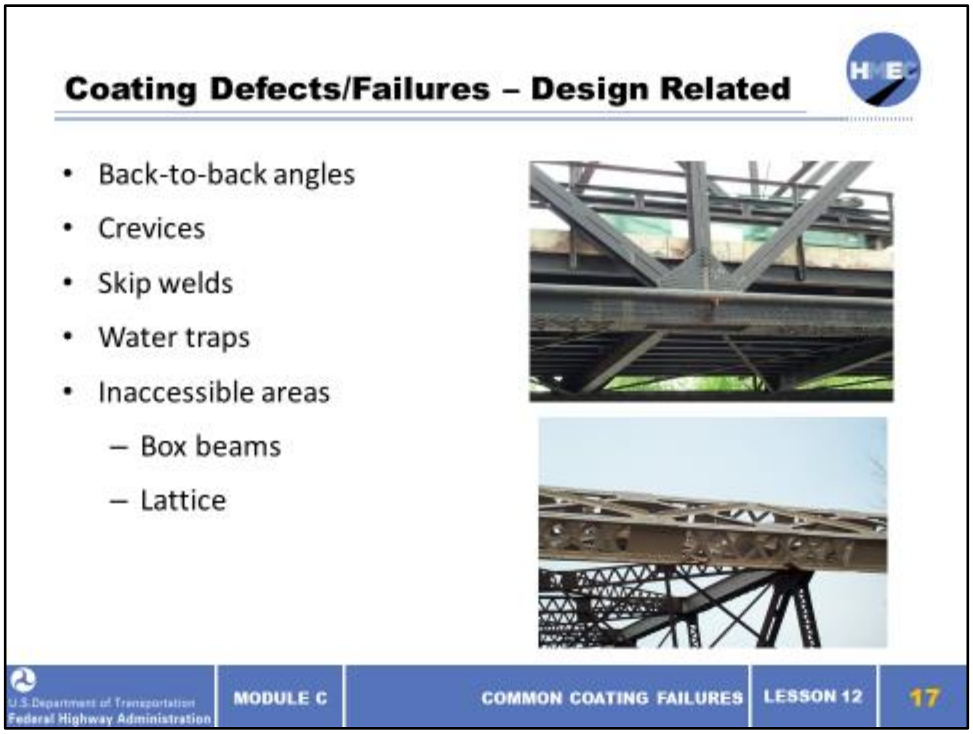
Blistering of coating systems can occur on bridges, but it is not common since most of the coated structural steel is exposed to the atmosphere and not to an immersion environment. Osmotic blistering can occur when coatings are applied over soluble salt contaminated substrates—the most common are chloride, sulfate, and nitrate. Many solvents are water soluble and if they become trapped in the coating, then osmotic blistering can occur as well. But again, there must be enough water present to initiate the process of osmosis.

With immersion or high moisture concentration on a surface, soluble salts or entrapped solvents can draw moisture through the coating film so that the concentrations on either side of the coating film reach equilibrium. When the water pressure under the paint exceeds the adhesion strength, a blister forms. Retained solvent can also pull moisture through a paint film resulting in blistering. When the blisters are broken, oxygen is able to contact the steel and corrosion is initiated.

Blistered coatings must be removed and replaced.
Moisture-cured urethane coatings release carbon dioxide as they react with moisture to cure. If the surface of the coating dries before the carbon dioxide escapes the film, then small blisters

can develop. Since these are gas-filled and not liquid-filled blisters, they can typically be sanded and a cosmetic coat applied if necessary.

Slide 17

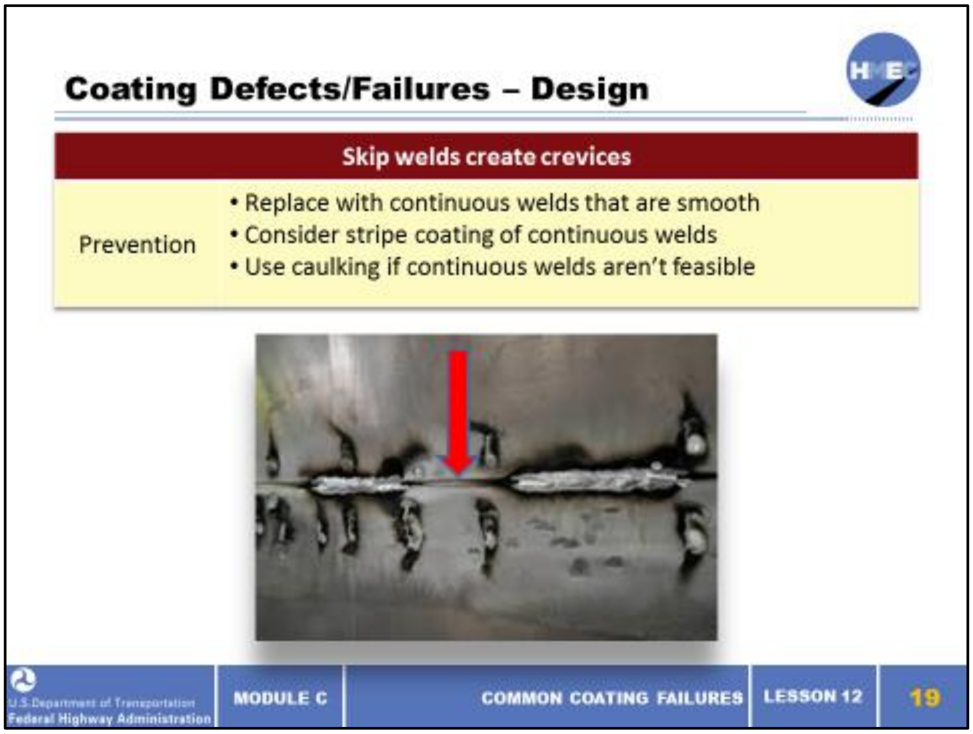


Design challenges for coatings can include back-to-back angles, crevices, skip welds, water traps, and inaccessible areas like box beams and lattice work.

Slide 18

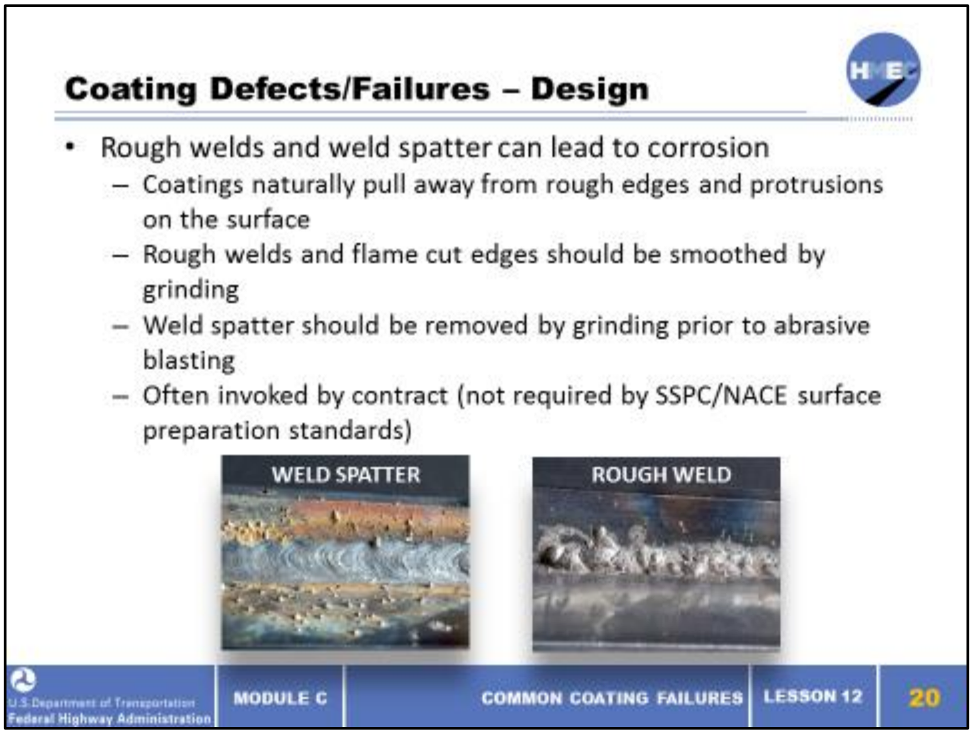
It is nearly impossible to paint inside the crevice or to prepare and coat the inside of back-to-back angles with a gap of less than ½ in., so it is best to treat the crevice faces prior to erecting the structure. For existing structures, sealing the crevice with caulking to prevent further moisture intrusion may provide corrosion protection and minimize rust staining. However, fully sealing a joint may trap moisture, so leaving the bottom open (on a vertical joint) allows moisture to drain out. Also, while many caulks are paintable, as the calking expands and contracts, the coating often cracks and disbonds. The use of clear caulking (post-finish coat application) may eliminate the need to paint the caulking without sacrificing aesthetics.

Slide 19



Coating failure often occurs at skip welds (also called stitch welds) due to the coating's inability to bridge the gap or crevice where no weld bead is present. Continuous welding is recommended. Stripe coating of the welds after preparation will provide an added barrier of protection, especially if the welds aren't smooth and blended. As described earlier in this lesson, caulking materials can be used if continuous welds aren't feasible.

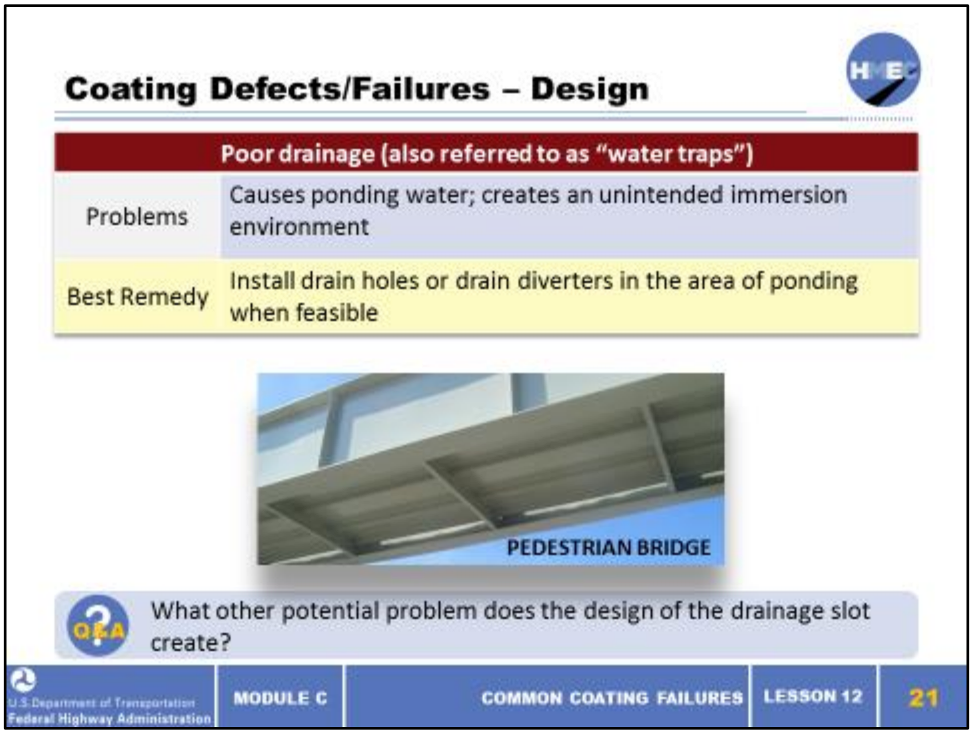
Slide 20



Rough welds and weld spatter can lead to premature corrosion. Coatings naturally pull away from rough edges and protrusions on the surface during curing. To enable coatings to perform better, rough welds and flame cut edges should be smoothed by grinding, and weld spatter should be removed by grinding prior to abrasive blast cleaning. While these requirements may be invoked by contract, it is important to recognize that they are not required by the SSPC/NACE surface preparation standards that were discussed in Lesson 8.

NACE Standard Practice SP0178-2007 addresses preparation of welds for coating; however, the document and the accompanying weld replica guide is for preparation of welds that will be coated and placed in immersion service. It does not apply to bridge structures unless steel pilings will be in immersion.

Slide 21

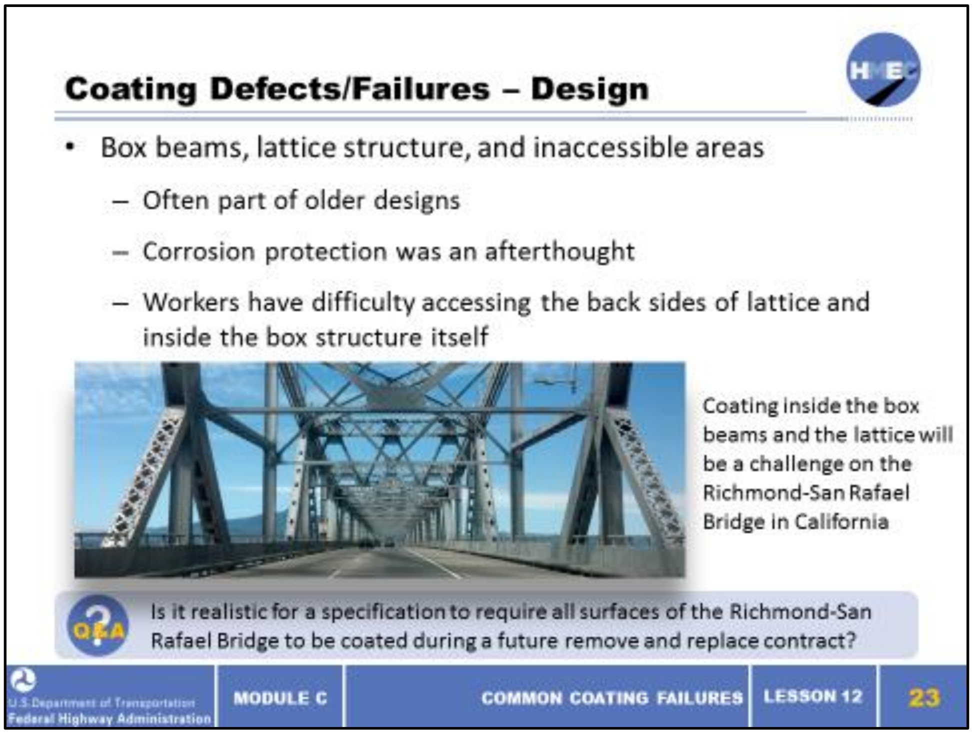


Poor drainage or lack of drainage can cause ponding water and create an immersion environment for coatings that may not be designed for immersion. The photo of the pedestrian bridge shows a drainage slot along the far edge to prevent long-term ponding, which would lead to corrosion of the structure.

Slide 22

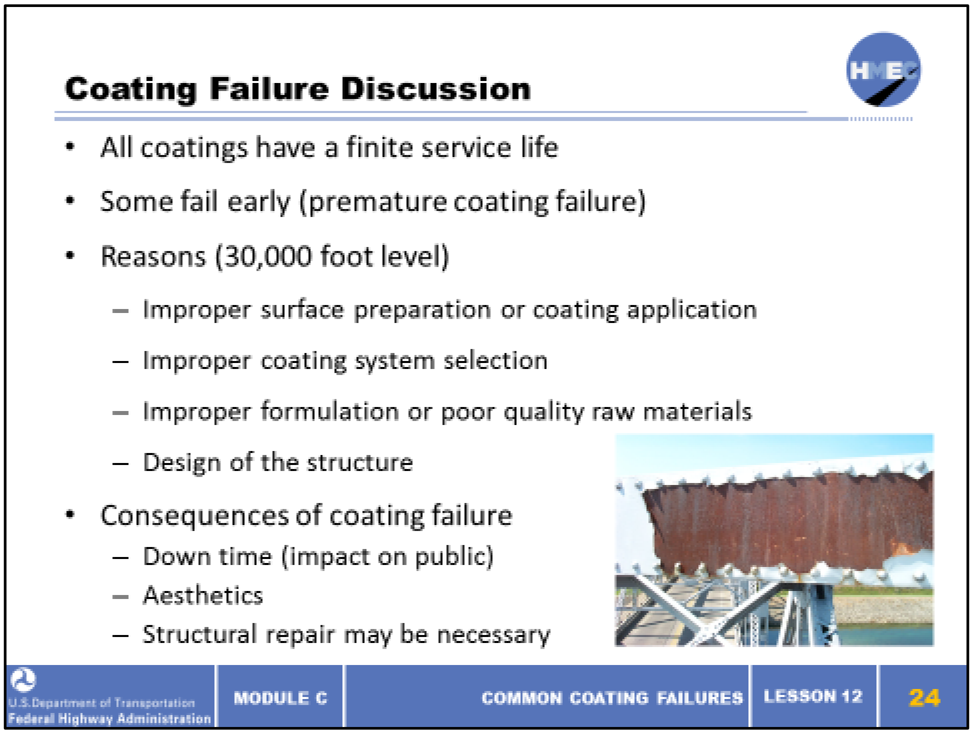
The upper-left photo illustrates back-to-back I-beams (with soil-to-air interface) on an older bridge structure located in Hawaii, while the upper-right photo illustrates lattice on a railroad bridge. The lower left and right photos illustrate a pre-fabricated bridge in Hawaii at the mouth of the ocean with many difficult areas to access and paint when the time comes for maintenance of the existing coating system.

Slide 23



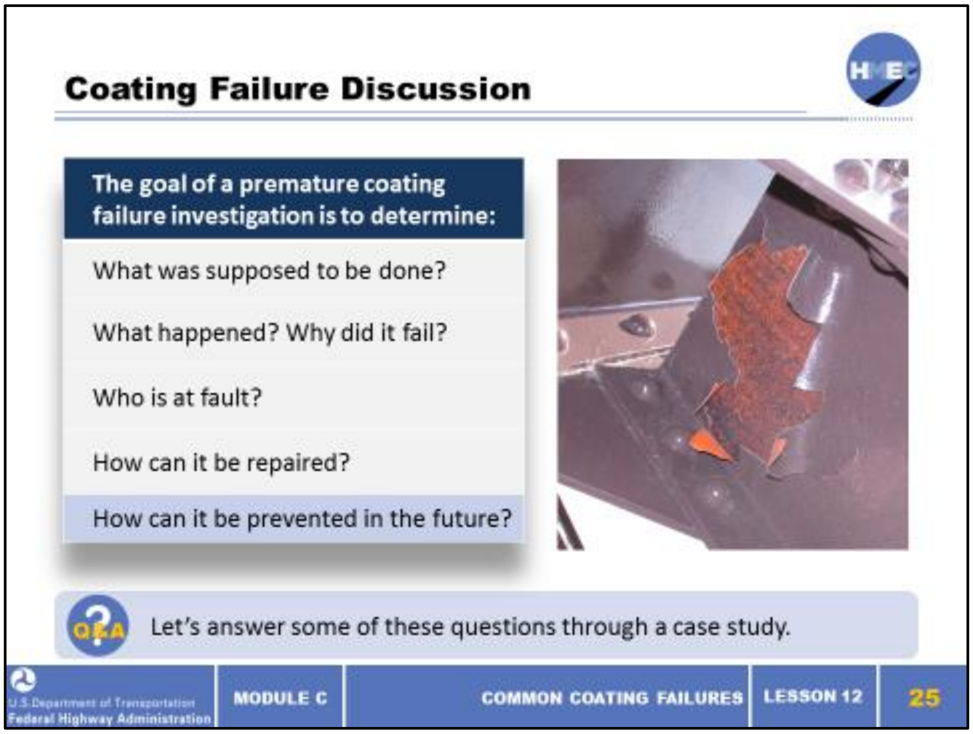
These are usually part of older bridges constructed long ago. The challenge is accessibility to all of the surfaces, especially the back sides of lattice and inside the box. Workers can rarely access the lightening holes of the box beams, and when feasible, they are considered confined spaces under the new OSHA Confined Space Standard for the Construction Industry (29 CFR 1926.1201 thru 1213).

Slide 24



Some coating systems fail long before their intended service life is expired, which is referred to as premature coating failure. The reasons for coating failure are numerous; however, they generally fall into one of four categories including improper surface preparation or coating application, improper coating system selection, improper formulation or poor quality raw materials, or the design of the structure. There are consequences to coating failure that impact bridge owners despite who's to blame for the failure. The traveling public is impacted by rework and the perception of misused tax dollars, the poor appearance of failing paint and corrosion (shown in the photo), and the potential for structural repair if the coating failure isn't addressed in a timely manner. The costs associated with diagnosis, repair, and potential litigation can be staggering.

Slide 25



Several key questions are asked during a coating failure investigation: What was supposed to be done (the specification)?; What was done and what happened?; Why did the coating fail and who is at fault?; How can it be repaired?; and How can we prevent it from happening again?

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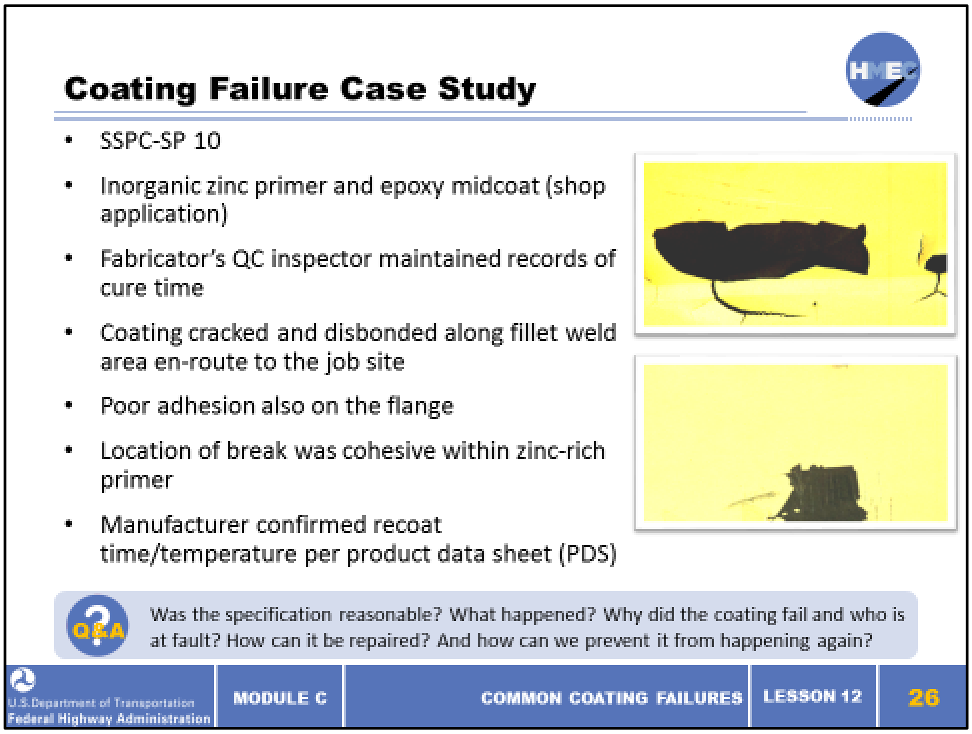
Slide 26



The project specification required abrasive blast cleaning to achieve a near-white blast per SSPC-SP 10/NACE 2 and the application of an inorganic zinc primer to structural steel components in the fabrication shop. Application of the intermediate coat was also performed in the shop, while the topcoat was scheduled for application in the field after erection and bolting of the steel. The work was done in the winter months and the shop was heated. The fabricator's quality control (QC) specialist kept documentation revealing that they had conformed to the thickness and recoat times recommended by the coating manufacturer's technical representative who visited the shop during coating application activities. The steel was loaded onto trucks and shipped to the site. Upon arrival at the construction site, spontaneous cracking of the coating along the fillet weld (where the web and flange are joined) was discovered (top photo). An adhesion test was performed on the top of the bottom flange (lower photo) and was rated "poor." Examination of disbonded coating chips revealed the presence of zinc primer on the back side of the chips and on the steel surface, indicating that the location of break was cohesive within the zinc primer.

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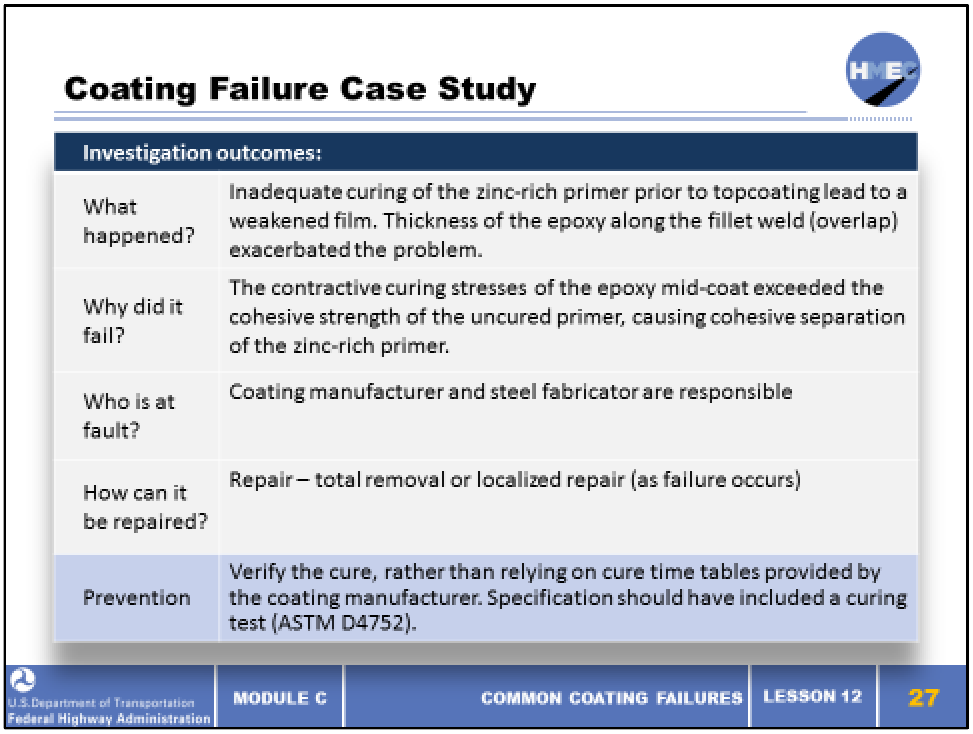
Slide 27

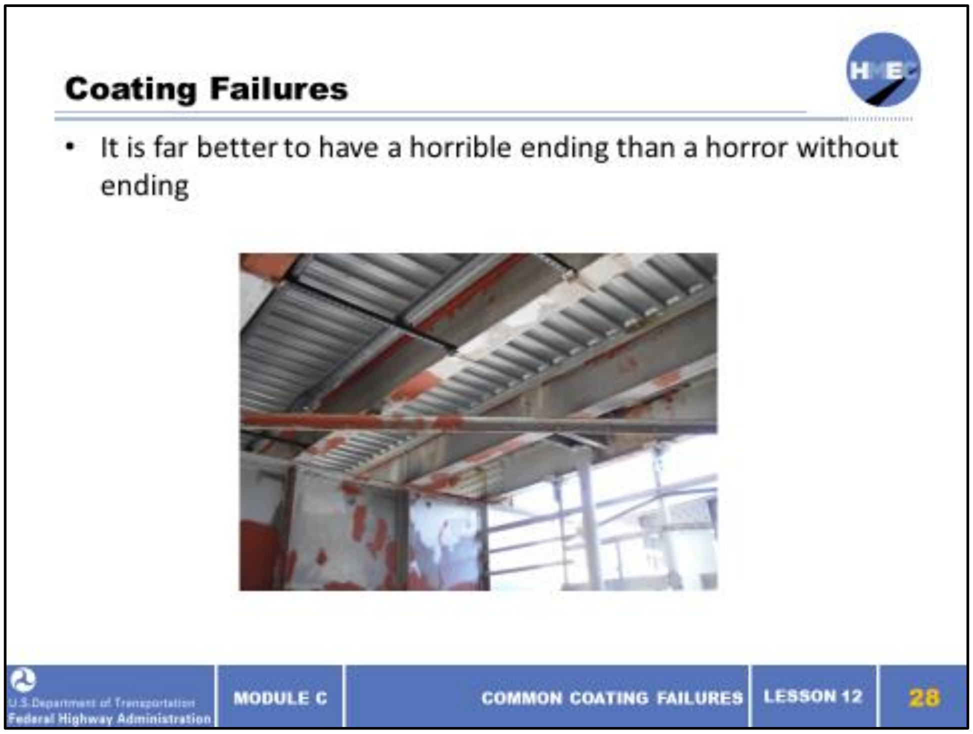


Ethyl silicate type inorganic zinc-rich primers require moisture to cure. In this case, an insufficient length of time was allowed before the application of the epoxy midcoat. Once the epoxy was applied, no more moisture could react with the primer, since it was effectively sealed off by the epoxy. The zinc primer remained in a dry, but uncured (and weakened state). The solvents from the epoxy midcoat penetrated the uncured primer, and the contractive curing stresses imparted by the epoxy caused the zinc primer to cohesively split. Since the web and flange are adjacent to one another, the thickness of the epoxy was slightly higher along the fillet weld area. The higher thickness exacerbated the problem and resulted in the cracking and detachment. When other areas were evaluated, it became evident that the entire system was at risk for failure.

Inorganic zinc-rich primers dry very quickly (especially in heated environments); however, they may not cure for many hours or even days if the humidity is too low within the prevailing environment. The key is to verify the conditions of temperature and humidity (listed on the PDS) are present in the shop prior to application and to verify the cure has been achieved, rather than relying on cure time tables provided by the coating manufacturer, or assuming that drying and curing are synonymous. QC inspection by the fabricator should have included a curing test. In fact, there is one specifically designed for the type of coating described by this case study

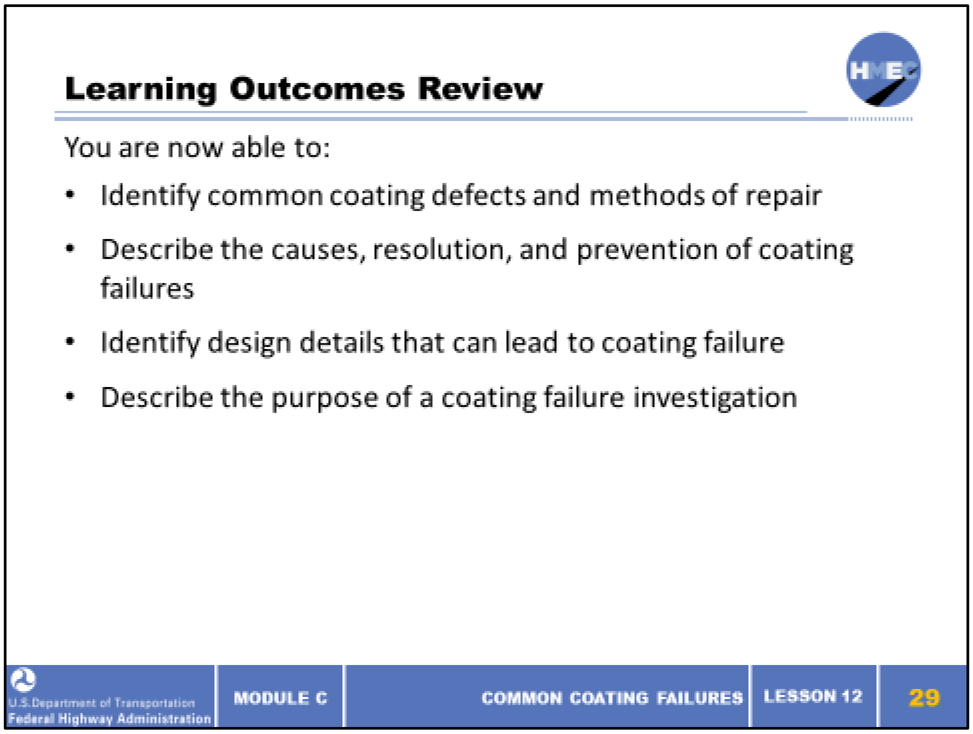
(ASTM D4752, Measuring MEK Resistance of Ethyl Silicate (Inorganic) Zinc-Rich Primers by Solvent Rub). Once a resistance rating of 4 or 5 is achieved (after 50 double rubs), the zinc-rich primer can be considered cured and ready for recoating.

Slide 28



When a coating failure occurs, it is better to find out as soon as possible what happened, have it fixed, and learn from the experience. It may be painful, but the failure won't fix itself and it won't go away. And while the reason for the failure may not be good, it is better to have a horrible ending than a horror without ending.

Slide 29


Learning Outcomes Review
You are now able to:
• Identify common coating defects and methods of repair
• Describe the causes, resolution, and prevention of coating failures
• Identify design details that can lead to coating failure
• Describe the purpose of a coating failure investigation
U.S. Department of Transportation
Federal Highway Administration
MODULE C
COMMON COATING FAILURES
LESSON 12
29

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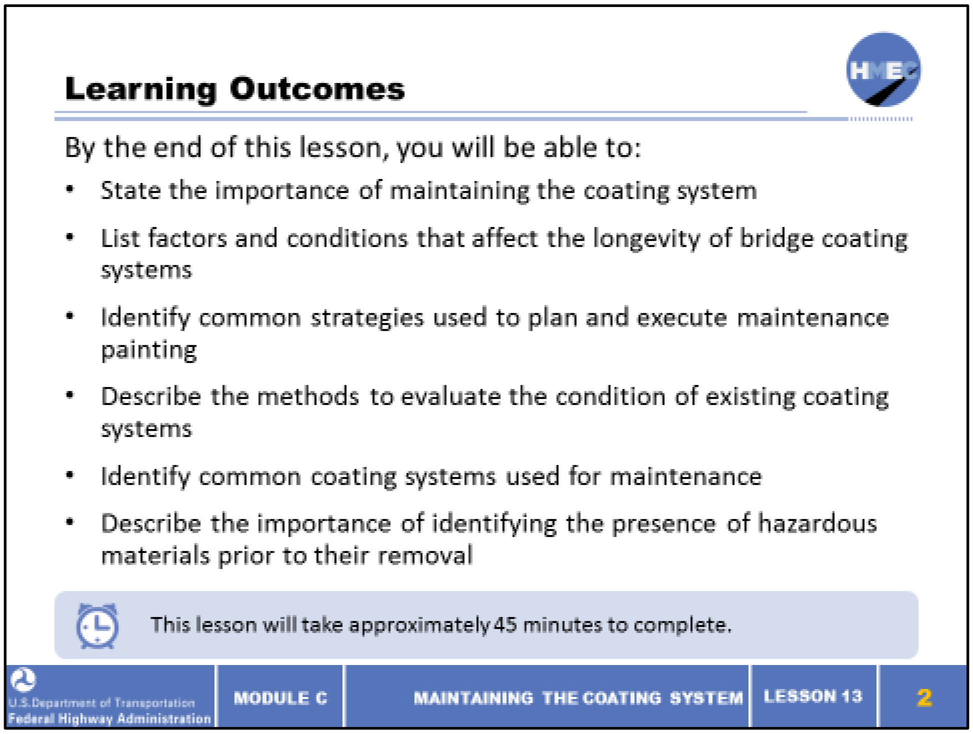
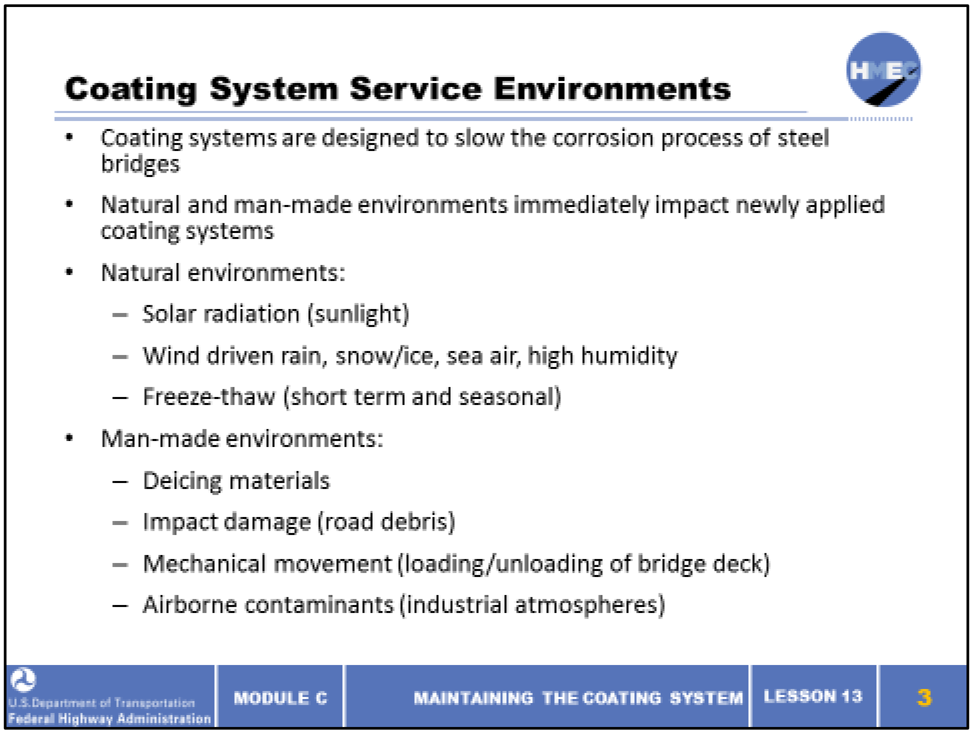
Slide 1


HMEC
Highway Materials Engineering Course
Lesson 13: Maintaining the Coating System
Steel, Welding, and Coatings
U.S.Department of Transportation
Federal Highway Administration
MODULE
C

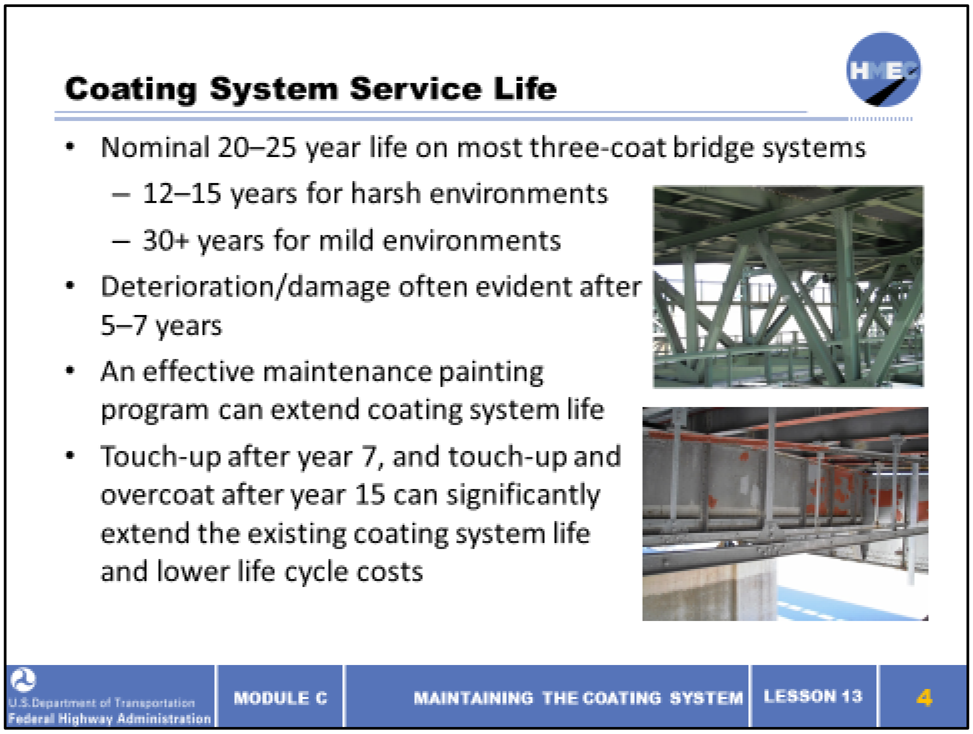
Slide 2


Learning Outcomes
By the end of this lesson, you will be able to:
• State the importance of maintaining the coating system
• List factors and conditions that affect the longevity of bridge coating systems
• Identify common strategies used to plan and execute maintenance painting
• Describe the methods to evaluate the condition of existing coating systems
• Identify common coating systems used for maintenance
• Describe the importance of identifying the presence of hazardous materials prior to their removal
This lesson will take approximately 45 minutes to complete.
U.S. Department of Transportation
Federal Highway Administration
MODULE C
MAINTAINING THE COATING SYSTEM
LESSON 13
2

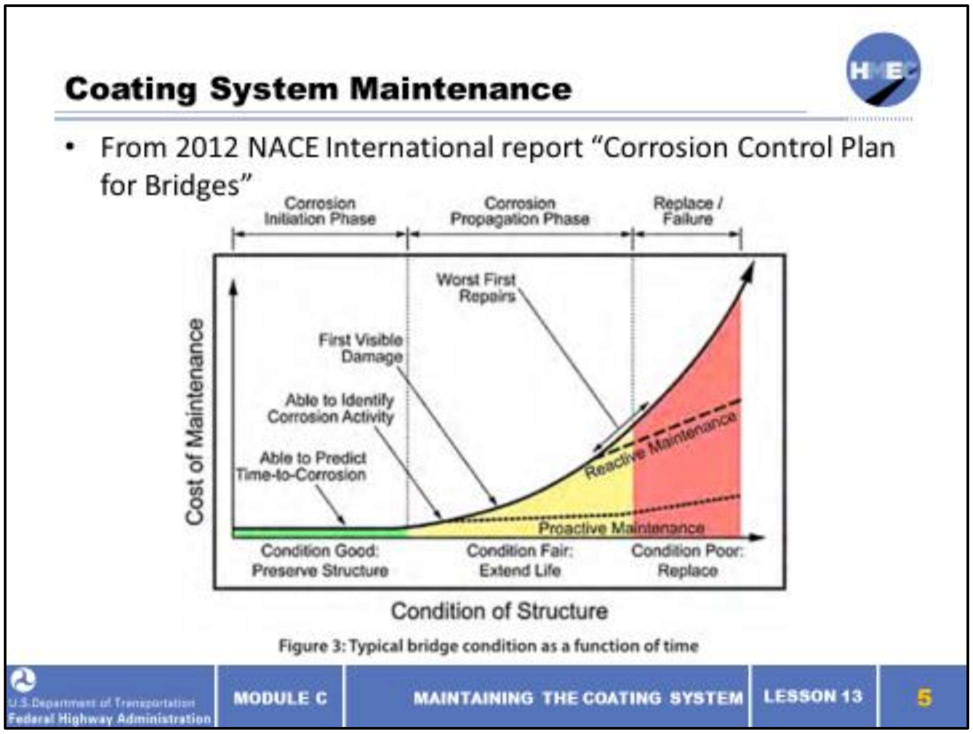
Slide 3


Coating System Service Environments
HMEC
• Coating systems are designed to slow the corrosion process of steel bridges
• Natural and man-made environments immediately impact newly applied coating systems
• Natural environments:
– Solar radiation (sunlight)
– Wind driven rain, snow/ice, sea air, high humidity
– Freeze-thaw (short term and seasonal)
• Man-made environments:
– Deicing materials
– Impact damage (road debris)
– Mechanical movement (loading/unloading of bridge deck)
– Airborne contaminants (industrial atmospheres)
U.S. Department of Transportation
Federal Highway Administration
MODULE C
MAINTAINING THE COATING SYSTEM
LESSON 13
3

Slide 4

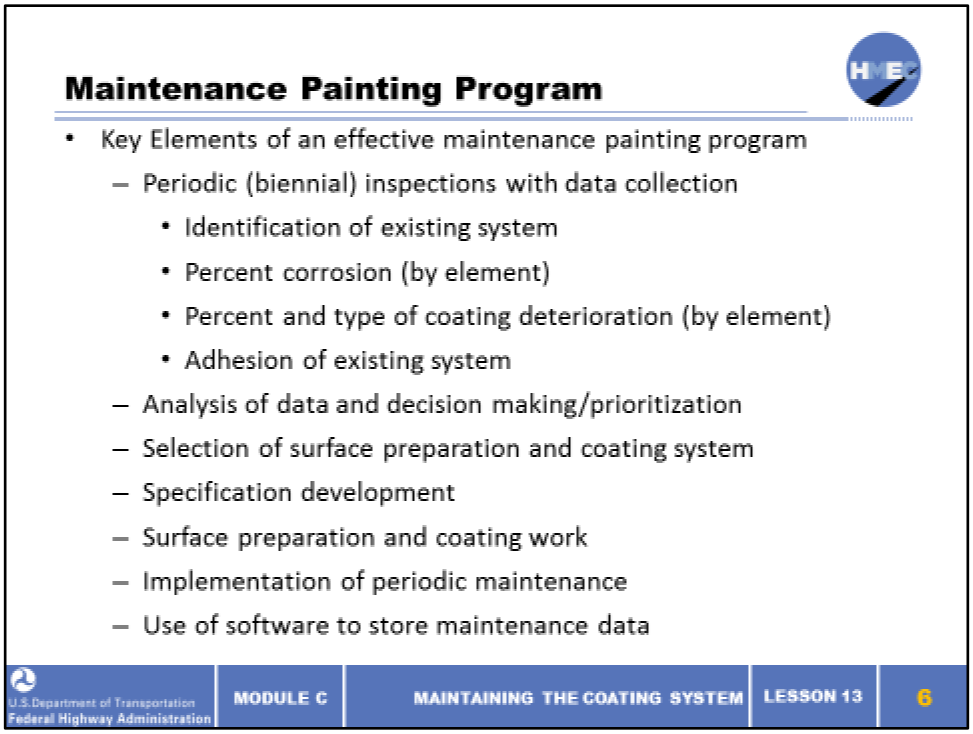

Coating System Service Life
HMEC
• Nominal 20–25 year life on most three-coat bridge systems
– 12–15 years for harsh environments
– 30+ years for mild environments
• Deterioration/damage often evident after 5–7 years
• An effective maintenance painting program can extend coating system life
• Touch-up after year 7, and touch-up and overcoat after year 15 can significantly extend the existing coating system life and lower life cycle costs
U.S. Department of Transportation
Federal Highway Administration
MODULE C
MAINTAINING THE COATING SYSTEM
LESSON 13
4

Slide 5



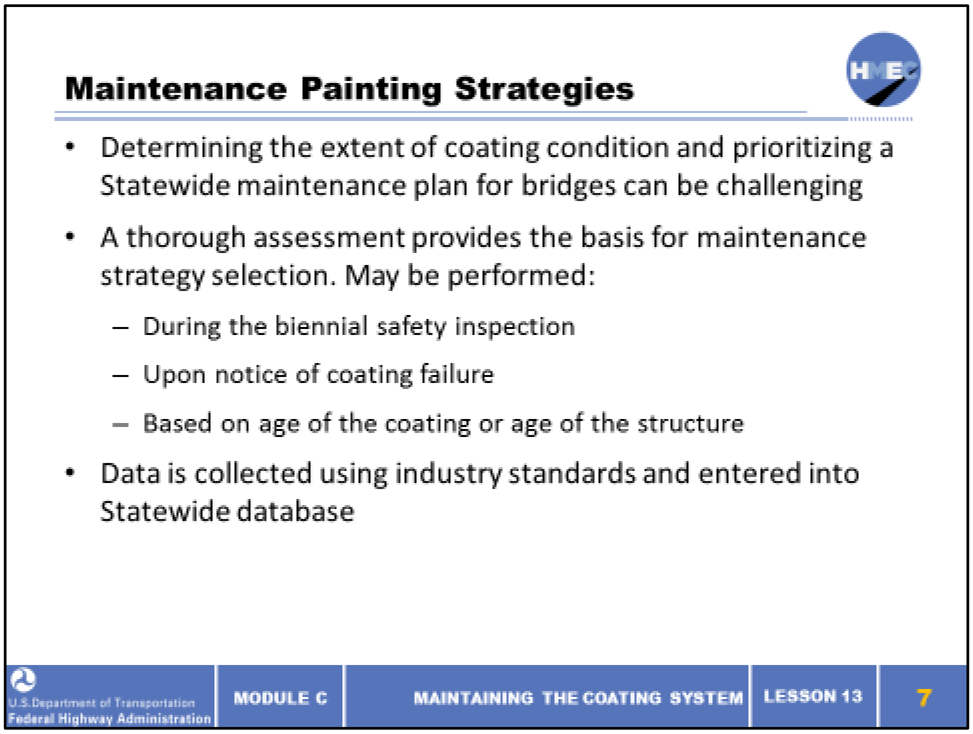
Note that the cost of maintenance to a structure increases drastically if the agency waits until visible damage propagates to the point where the structure is deemed "poor." The steel may need to be replaced in these cases, so the idea is to perform maintenance painting in between major repainting efforts—proactive maintenance, rather than taking the reactive maintenance approach.

Slide 6



A maintenance painting plan should be structured to include several key elements. The foundation for the plan is the accurate assessment of the condition of the existing coating system on the bridge structures within a given district. This is traditionally done during the biennial bridge inspections.

Slide 7



Many agencies have hundreds of bridges containing coating systems in various condition states that must be maintained. Determining the extent of coating condition and prioritizing a Statewide maintenance plan for bridges can be challenging, and even overwhelming. However, a thorough assessment provides the basis for selecting a maintenance strategy.

An assessment may be performed during the biennial safety inspection, when coating failure becomes evident, or based on the age of the coating or the age of the structure. The data is collected using industry standardized methods and can be entered into a Statewide database.

Slide 8

The amount of corrosion present and the condition of the existing coating system(s) is assessed using visual techniques. The amount of corrosion is evaluated using SSPC VIS 2, Evaluating the Degree of Rusting of Painted Steel Surfaces, which was developed based on ASTM D610. Additional detail on SSPC VIS 2 is provided on the following two slides.

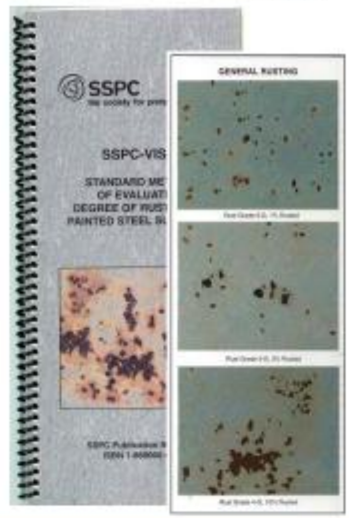
Corrosion and coating deterioration do not form uniformly on bridge elements, so the ASTM rusting standard and visual guide can be challenging to use, and an approximate percentage of corrosion is recorded. In order to improve the quality of the corrosion assessments, some agencies have created custom photographic guides illustrating multiple condition states of various bridge elements.

Physical attributes include coating thickness measurements using gages we learned about in Lesson 11, and tape/knife or knife adhesion testing to assess the inter-coat adhesion properties of the existing coatings. ASTM D3359 describes a method wherein an X-cut (Method A, for coating systems in excess of 5 mils) is made through all coating layers to the substrate, then adhesive tape is applied to the X-cut and removed. The amount of coating disbonding is rated on a scale of 5A to 0A, with 5A indicating no loss of adhesion and 0A indicating very poor adhesion.

Slide 9

Maintenance Painting Program

- SSPC-VIS 2
- 27 color photos and black/white images
  - Nine percentages of corrosion (< 0.01% to > 50%)
  - Rating Scale (10–0)
    - 10: < 0.01% corrosion
    - 0: > 50% corrosion
- Three types of corrosion
  - General rust (G)
  - Spot rust (S)
  - Pinpoint rust (P)



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Slide 10

Some agencies have created custom photographic guides illustrating multiple condition states of various bridge elements. The slide illustrates four condition states (good, fair, poor, and severe) of coated fascia beams. Each condition state has a corresponding percentage of corrosion or coating defects:

- Good: ≤ 0.01–0.3% (equivalent to ratings 10–7 in SSPC VIS 2);
- Fair: > 0.3–3% (equivalent to ratings 6–5 in SSPC VIS 2);
- Poor: > 3–16% (equivalent to ratings 4–2 in SSPC VIS 2); and
- Severe: > 16% (equivalent to ratings 1–0 in SSPC VIS 2).

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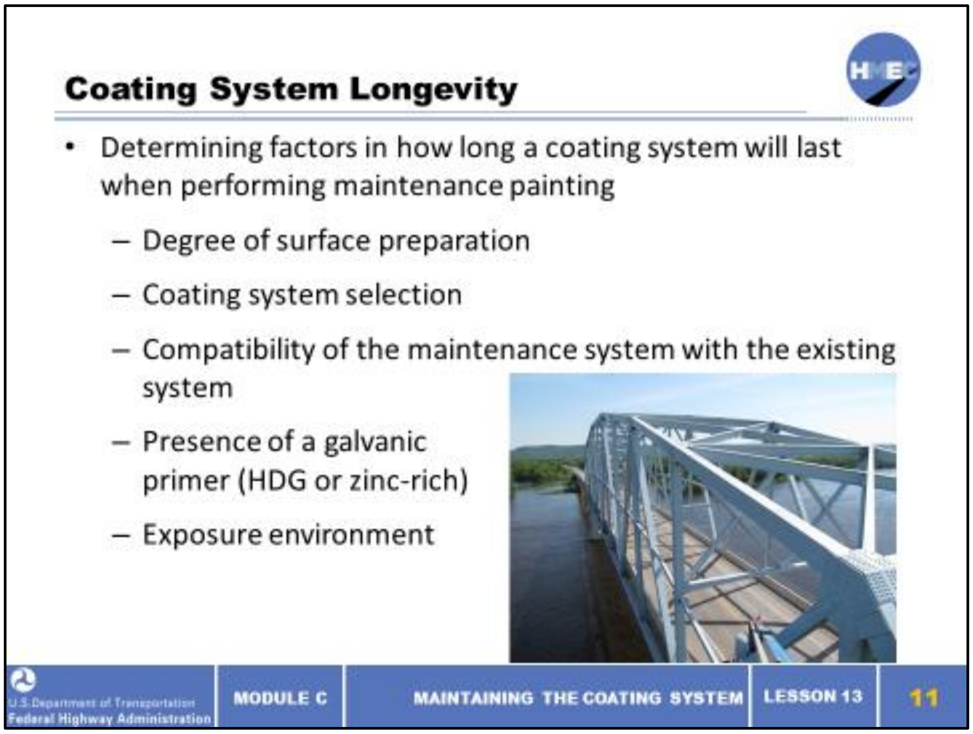
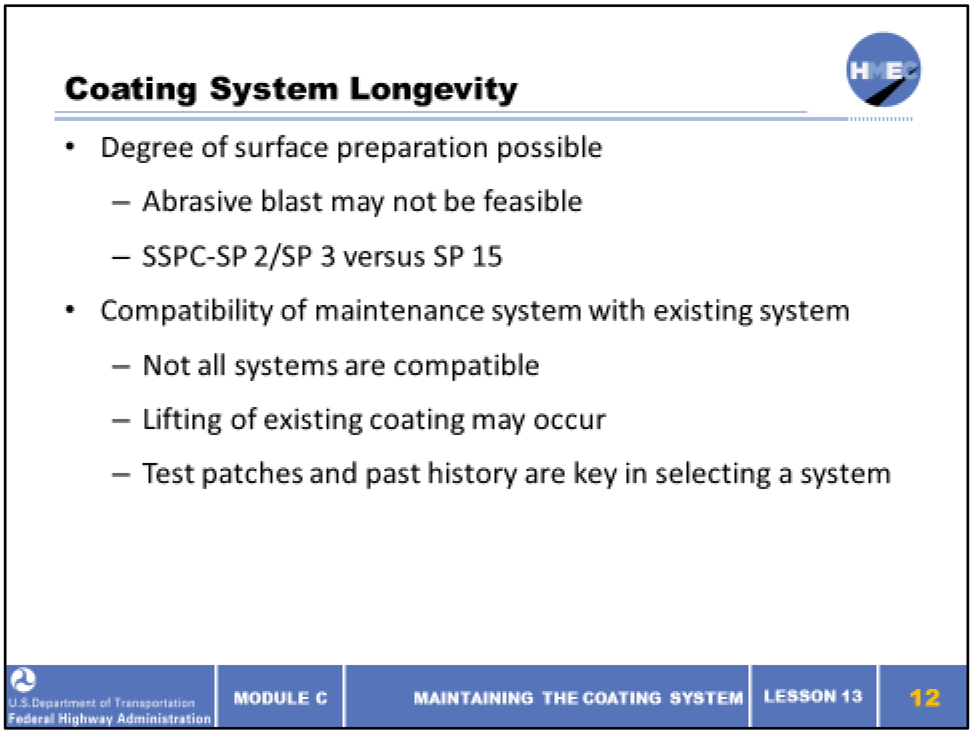
Slide 11



There are several factors that impact the longevity of an installed maintenance coating system that extend beyond the generic type of system itself. Additional factors include the degree of surface preparation possible, the selection of a coating system that is compatible with the degree of surface preparation possible, compatibility of the maintenance system with the existing system when touch-up or touch-up/overcoat is selected as the maintenance strategy, whether a galvanic primer (hot-dipped galvanizing or zinc-rich) is present, and finally, the service environment.

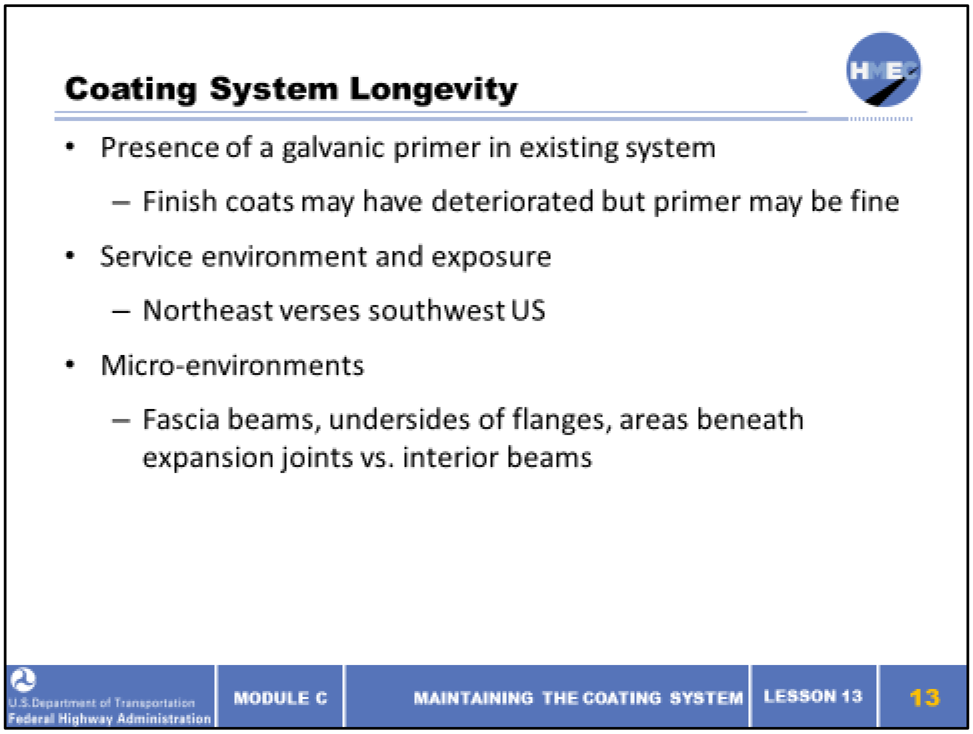
Slide 12



Degree of surface preparation possible: Mobilizing abrasive blast cleaning equipment, installation of containment, and ventilation systems and management of the waste streams, not to mention potential for overblast damage may eliminate abrasive blast cleaning from consideration. Hand- or power-tool cleaning (SSPC-SP 2/SP 3) or commercial grade power-tool cleaning (SSPC-SP 15) may be better options; obviously, SP 15 will generate a cleaner surface, but at a higher cost.

Compatibility of maintenance system with existing system: Not all coating systems are compatible. The application of an incompatible overcoat system can cause lifting of the existing coating. Installation of test patches and/or accurate records of previous coating systems can help prevent selecting an incompatible coating system. Laboratory analysis of the existing coating by infrared spectroscopic analysis can also reveal the generic type of coating(s) present.

Slide 13



Presence of a galvanic primer in existing system: Frequently, a zinc-rich primer or galvanizing that is present beneath the coating film is performing well; however, the finish coats may have deteriorated. It can be very difficult to selectively remove the finish coats unless they are peeling and disbonding. If the finish coat can withstand the stresses of an overcoat layer, then it may be possible to extend the life of the system.

Service environment and exposure: The service environment has a tremendous impact on the longevity of a coating system. For example, the same coating system applied to a steel bridge in the northeast US and a steel bridge located in the southwest US will perform differently, as the climatic conditions alone vary considerably. There are also micro-environments on a single structure; for example, the exposure environment of fascia beams, beam ends, and bearings beneath expansion joints, and the undersides of the bottom flanges will be different than the exposure environment of interior beams on the same structure.

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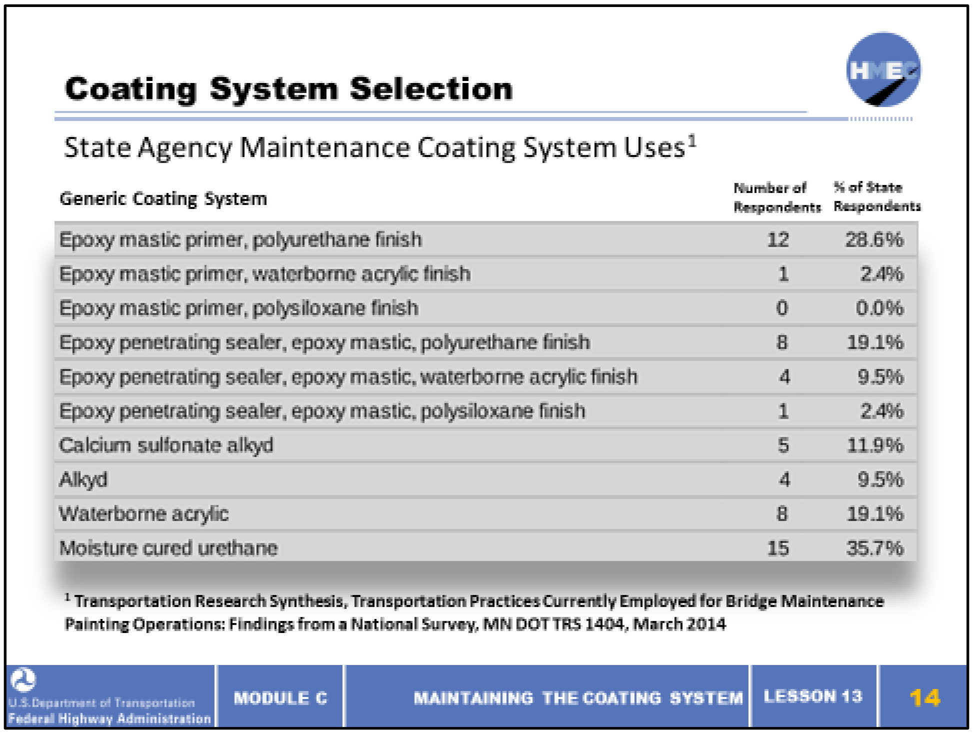
Slide 14



Coating System Selection

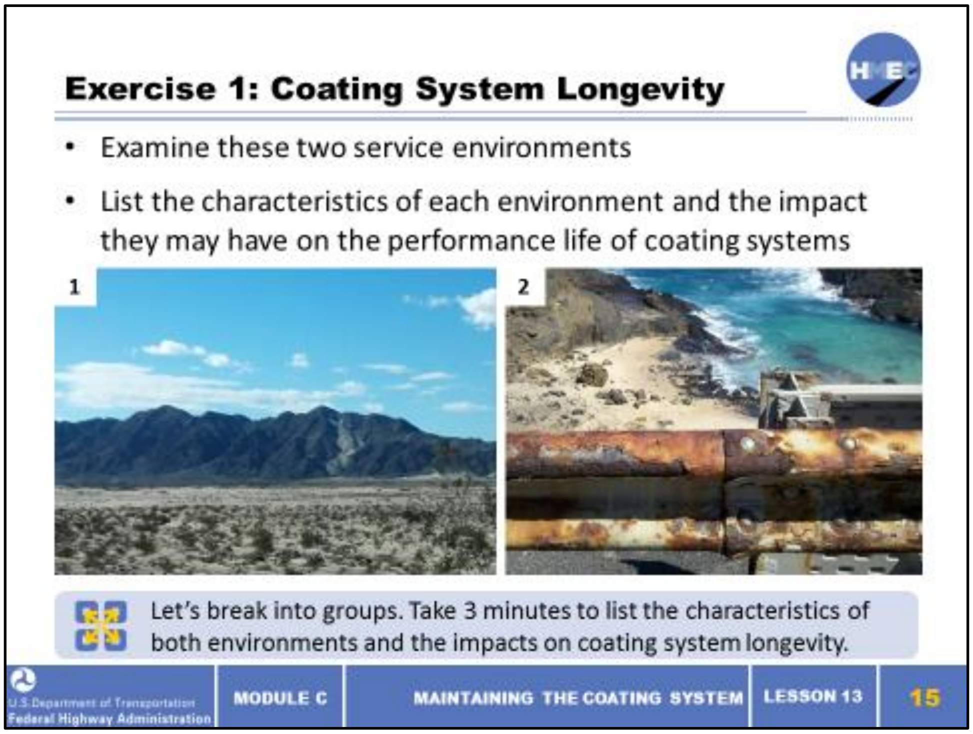
State Agency Maintenance Coating System Uses[1]

Generic Coating System	Number of Respondents	% of State Respondents
Epoxy mastic primer, polyurethane finish	12	28.6%
Epoxy mastic primer, waterborne acrylic finish	1	2.4%
Epoxy mastic primer, polysiloxane finish	0	0.0%
Epoxy penetrating sealer, epoxy mastic, polyurethane finish	8	19.1%
Epoxy penetrating sealer, epoxy mastic, waterborne acrylic finish	4	9.5%
Epoxy penetrating sealer, epoxy mastic, polysiloxane finish	1	2.4%
Calcium sulfonate alkyd	5	11.9%
Alkyd	4	9.5%
Waterborne acrylic	8	19.1%
Moisture cured urethane	15	35.7%

[1] Transportation Research Synthesis, Transportation Practices Currently Employed for Bridge Maintenance Painting Operations: Findings from a National Survey, MN DOT TRS 1404, March 2014

This chart shows the types of maintenance coating systems used by State agencies across the US. Based on this survey, the two most common systems for touch-up and overcoating include an epoxy mastic primer/polyurethane finish coat (approximately 29%) and a moisture-cured urethane system (approximately 36%).

Slide 15



The picture on the left is along Interstate 15 through the Mojave Desert in California. The photo on the right is along a coastal roadway on the island of Oahu in Hawaii. List the characteristics of both environments and their potential impact on coating system longevity.

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Slide 16

Maintenance Painting Strategies

Maintenance Painting Strategy Options	
Do nothing	No action necessary; coating in good condition or structure to be replaced soon
Spot repair	Prepare/paint discrete areas only that show coating failure/spot-corrosion (not aesthetically pleasing)
Zone painting	Removal/replacement of coatings in a defined area, which sees a more aggressive corrosion environment than other areas on the structure (e.g., splash zone)
Spot repair and overcoat	After spot repair, install new topcoat for added protection and improved aesthetics
Full removal and replacement	When widespread corrosion and deterioration are evident

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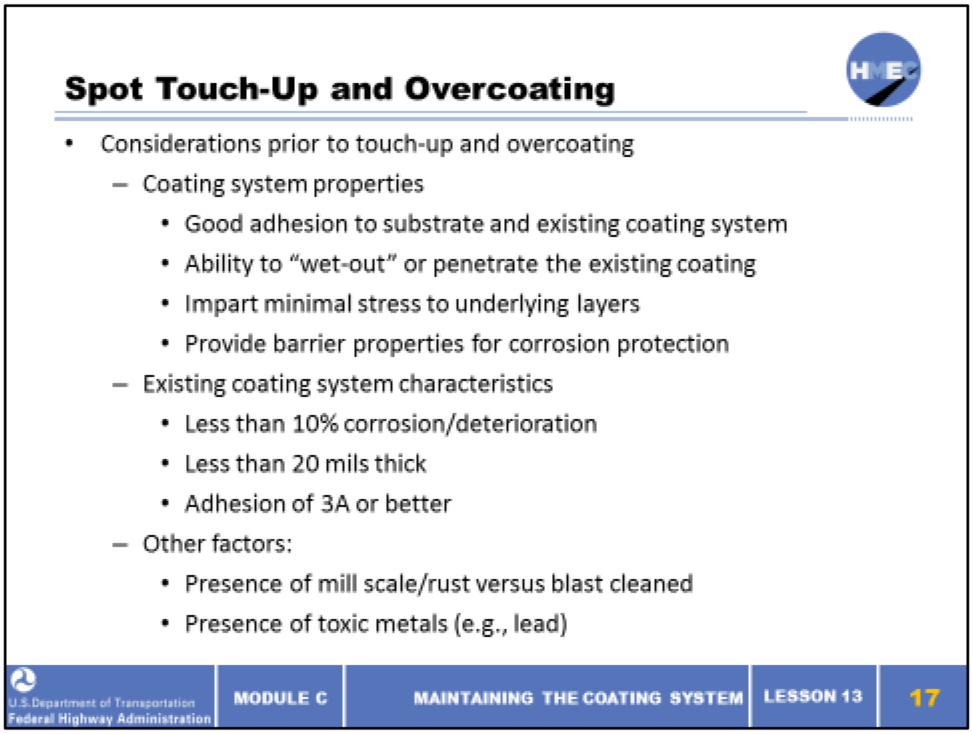
Slide 17

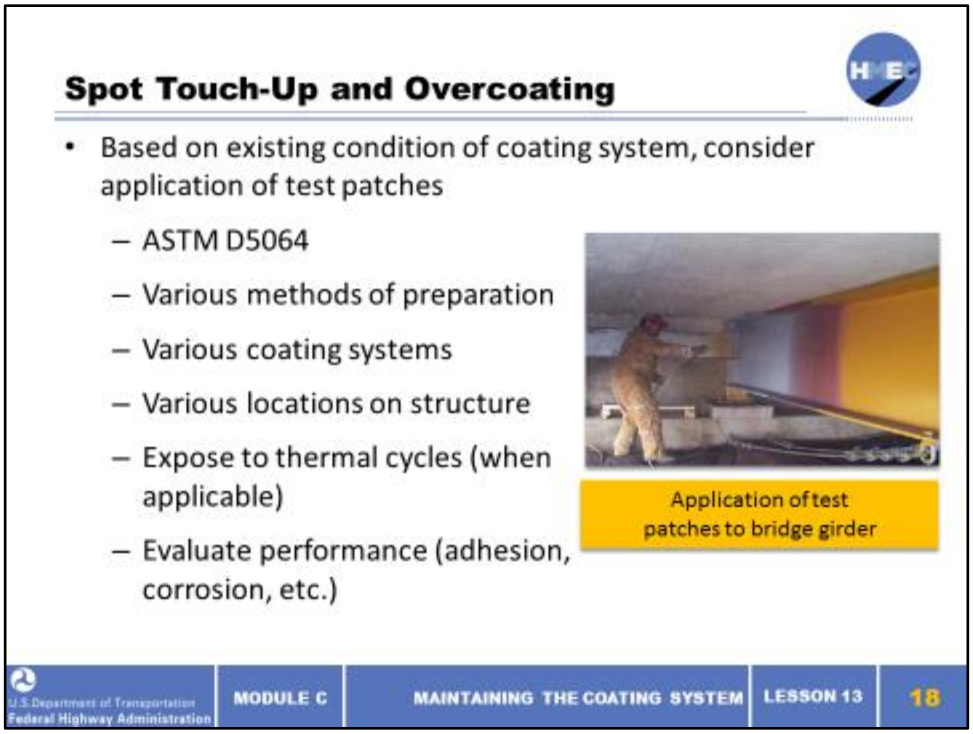


There are several considerations prior to deciding whether touch-up and overcoating is a viable maintenance strategy.

Properties of the new coating system: The coating system to be installed over the existing system must have good adhesion to spot touch-up areas as well as the existing coating system. It must be able to "wet-out" the surface and bond to the existing surfaces. Since the existing system is typically aged, it should not impart stress to underlying layers. Finally, it needs to provide corrosion protection, typically by barrier protection.

Characteristics of the existing coating system: In order for an existing coating system to be considered a candidate for overcoating, it must have certain properties. As mentioned in the previous slide, if the amount of corrosion or coating deterioration exceeds 10% of the total surface area of the bridge structure, spot repairs can be cost prohibitive. So the coating should exhibit less than 10% corrosion/deterioration. The existing coating should be less than 20 mils thick and its adhesion properties should be rated 3A or better.

Slide 18



ASTM D5064, Standard Practice for Conducting a Patch Test to Assess Coating Compatibility, provides guidance on the installation and evaluation of test patches. Control of vehicle traffic and access to the structure to install test patches can be costly, so once access is gained, several variables can be investigated. Those variables include several methods of surface preparation and varying degrees of surface cleanliness and various coating systems (by manufacturer and/or generic type) applied to various micro-environments on the structure. When possible, the test patches should be subjected to several thermal cycles (where appropriate) to stress the bond of the new system to the old (expansion and contraction). Evaluation is typically by adhesion and visual assessment for peeling, cracking, or evidence of corrosion.

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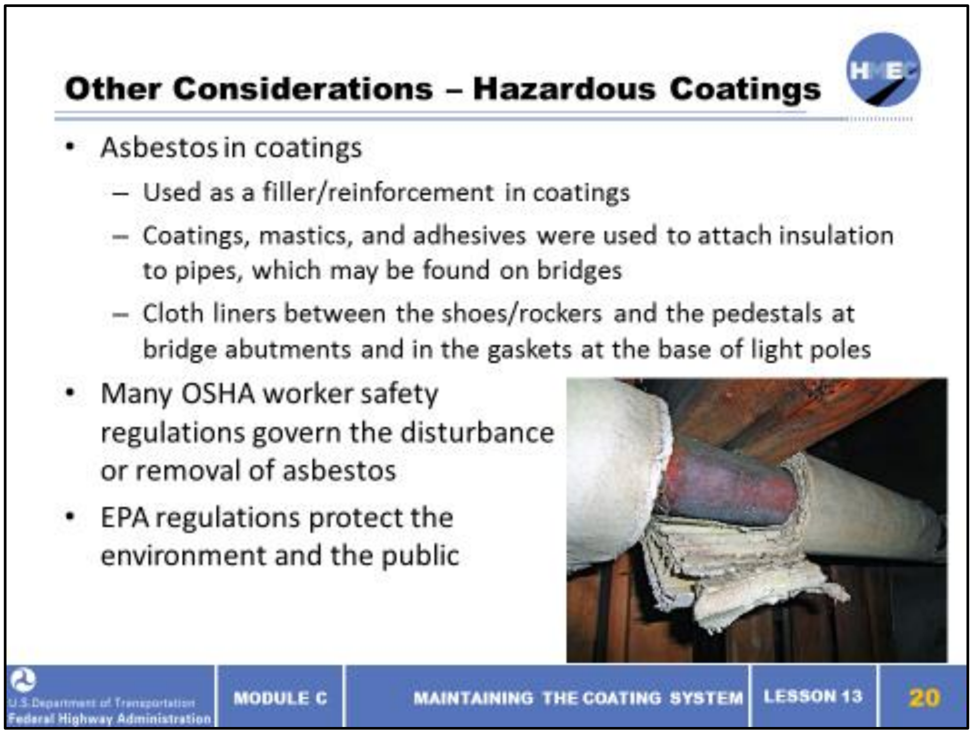
Slide 19

The presence of lead or other toxic metals in coatings such as cadmium and chromium will influence maintenance painting decisions since the hazards must be controlled when these materials are "disturbed." This includes worker protection, environmental protection, and management of the resulting waste streams.

Slide 20



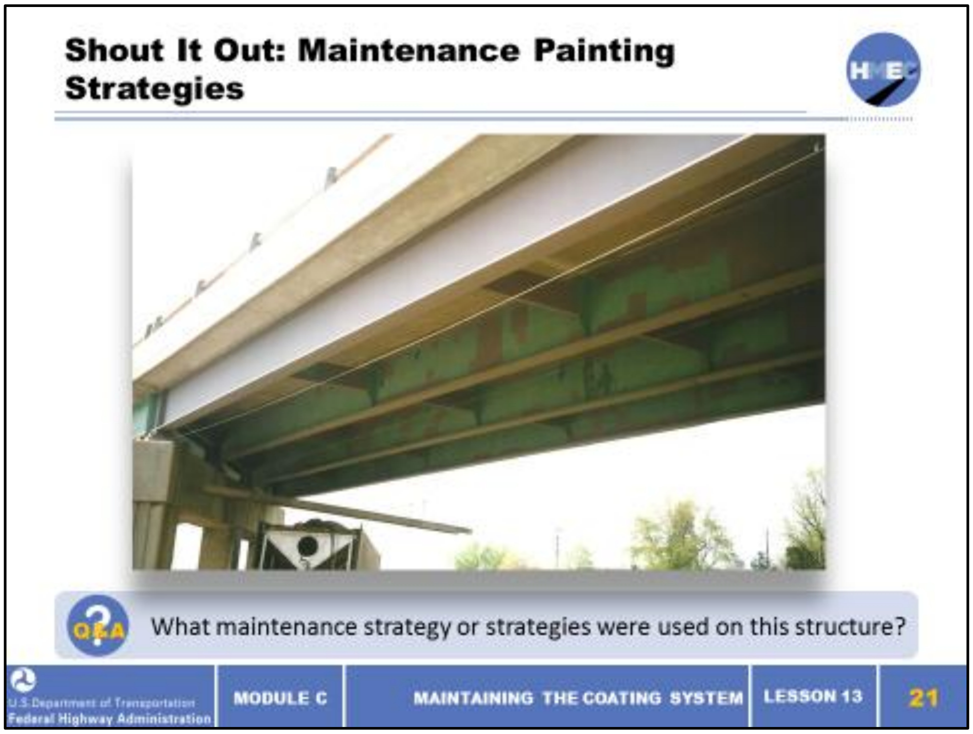
At one time, asbestos was used as a filler or a reinforcing fiber in coatings. These types of coatings were used on bridges and other industrial structures. In addition, asbestos was used in insulation and in mastics and adhesives used to attach the insulation to pipe. Many of these pipe crossings (typically carrying utilities) are located on the underside of bridges. Asbestos has also been found in the cloth liners between the shoes/rockers and the pedestals at bridge abutments and in the gaskets at the base of light poles on bridges. The asbestos fibers become airborne when the asbestos-containing materials are disturbed and pose an inhalation hazard. Mesothelioma, a form of lung cancer, can result from inhalation of asbestos fibers. A survey for the presence of asbestos may be required prior to maintenance activities so that these surfaces are isolated, or the asbestos is abated in conformance with OSHA and EPA regulations. Surveys are always required by the EPA prior to the demolition of any structures, including bridges. When surveys are required, they must be performed by a State-certified asbestos building inspector.

OSHA and EPA have worker and environmental protection regulations when asbestos is disturbed. Some of these include:

• EPA 40 CFR 763 Subpart G, Asbestos Worker Protection;

- EPA 40 CFR 763 Subpart I, Prohibition of Manufacture, Importation, Processing, and Distribution in Commerce of Certain Asbestos-Containing Products;
- National Emission Standards for Hazardous Air Pollutants (NESHAP) for Asbestos - 40 CFR §61.145—Standard for Demolition and Renovation;
- OSHA 29 CFR 1910.1001 (General Industry; and
- OSHA 29 CFR 1926.1101 (Construction Industry).

Slide 21


Shout It Out: Maintenance Painting Strategies
What maintenance strategy or strategies were used on this structure?
U.S. Department of Transportation
Federal Highway Administration
MODULE C
MAINTAINING THE COATING SYSTEM
LESSON 13
21

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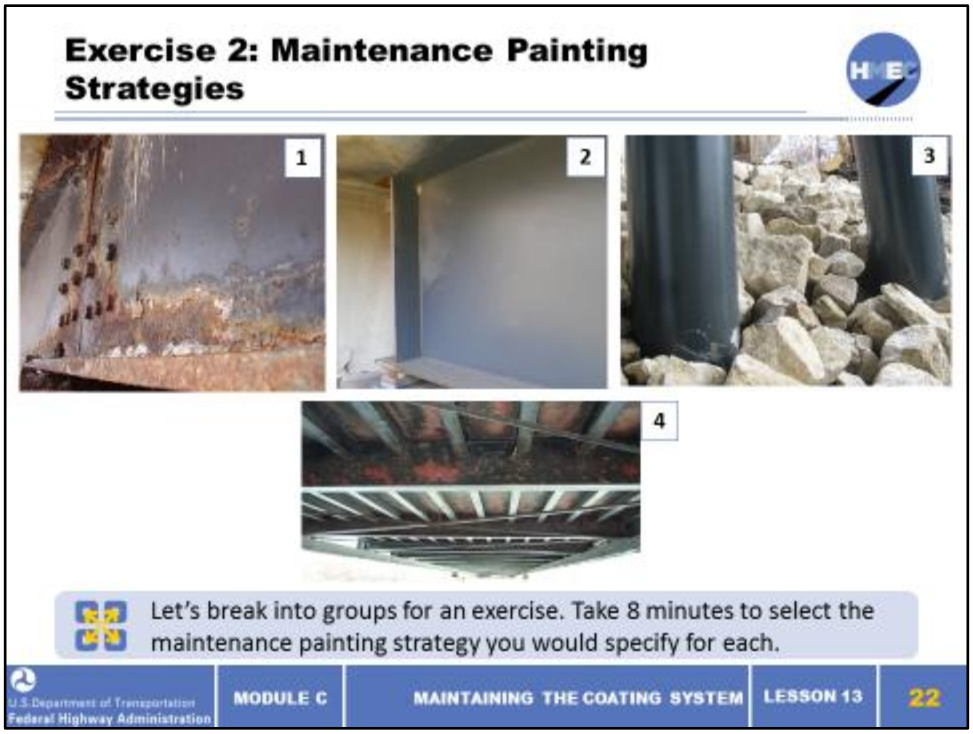
Slide 22



Based on the condition (visual only) of each bridge element, select the maintenance painting strategy that you would specify.

- Element 1: Fascia;
- Element 2: Beam end and bearing;
- Element 3: Cast-in-place piling; and
- Element 4: Interior beams.

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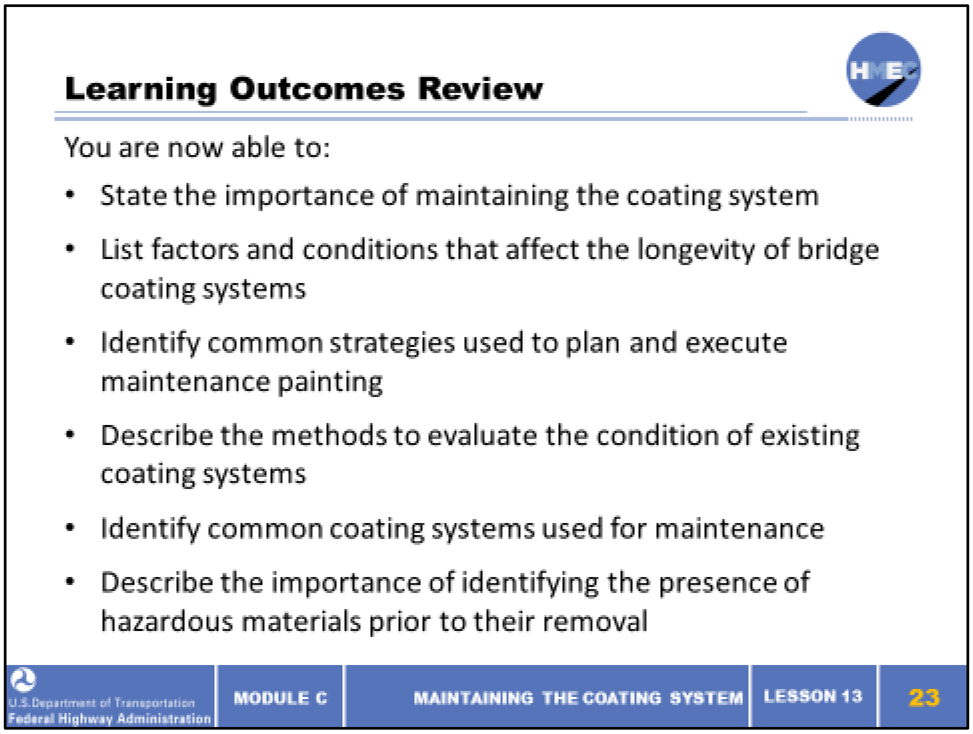
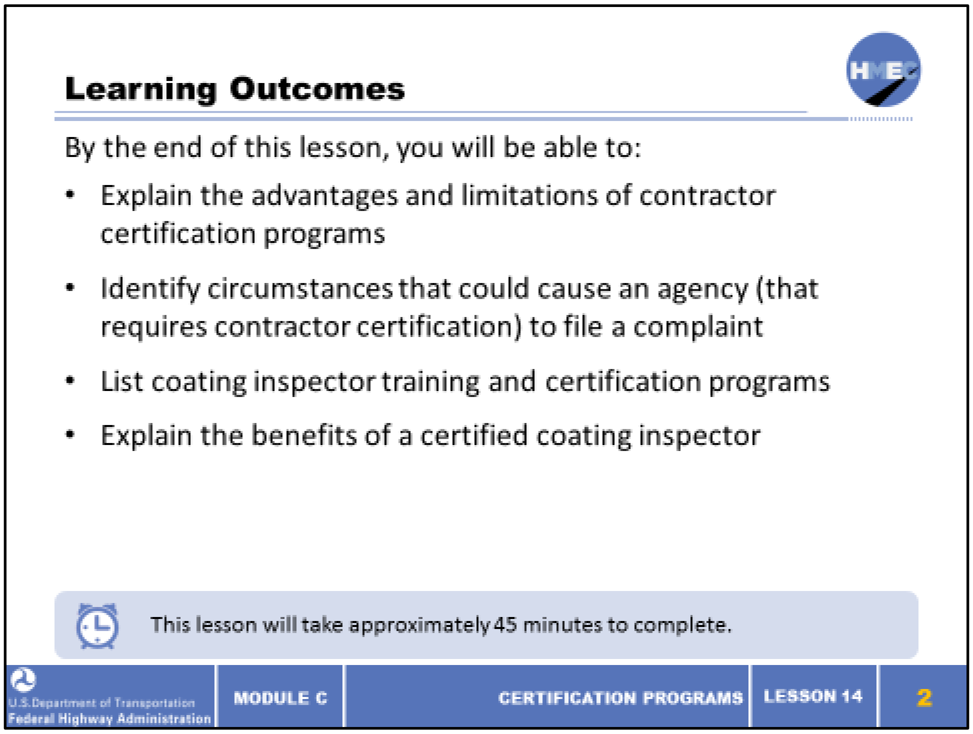
Slide 23


Learning Outcomes Review
HMEC
You are now able to:
• State the importance of maintaining the coating system
• List factors and conditions that affect the longevity of bridge coating systems
• Identify common strategies used to plan and execute maintenance painting
• Describe the methods to evaluate the condition of existing coating systems
• Identify common coating systems used for maintenance
• Describe the importance of identifying the presence of hazardous materials prior to their removal
U.S. Department of Transportation
Federal Highway Administration
MODULE C
MAINTAINING THE COATING SYSTEM
LESSON 13
23

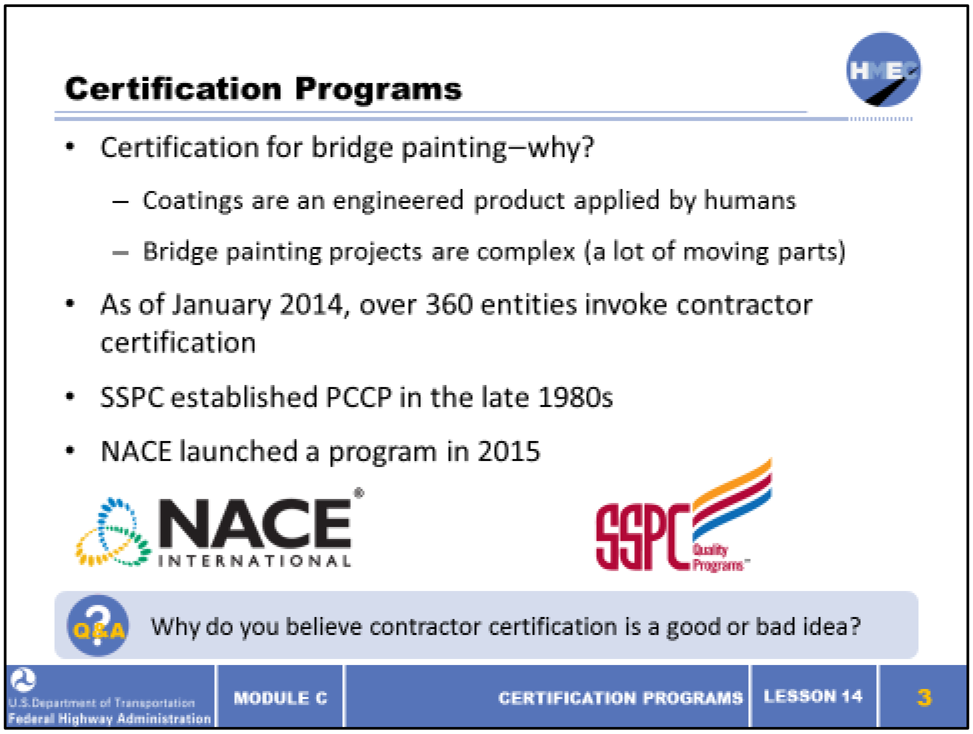
Slide 1


HMEC
Highway Materials Engineering Course
Lesson 14: Certification Programs
ILT
Steel, Welding, and Coatings
U.S.Department of Transportation
Federal Highway Administration
MODULE
C

Slide 2


Learning Outcomes
HMEC
By the end of this lesson, you will be able to:
• Explain the advantages and limitations of contractor certification programs
• Identify circumstances that could cause an agency (that requires contractor certification) to file a complaint
• List coating inspector training and certification programs
• Explain the benefits of a certified coating inspector
This lesson will take approximately 45 minutes to complete.
U.S. Department of Transportation
Federal Highway Administration
MODULE C
CERTIFICATION PROGRAMS
LESSON 14
2

Slide 3



Think of it this way: a coating manufacturer spends years testing, reformulating, and retesting products to make sure they will work together as a system and protect a steel structure for decades, not to mention without harming the environment during application (low VOCs) or during future maintenance activities (no toxic metals as pigments). They spend considerable time and money getting the system tested through AASHTO NTPEP and approved on a State level. They prepare product data sheets (PDS) and safety data sheets (SDS) to make sure their products are used correctly without harming individuals. State agencies painstakingly prepare technical specifications to help ensure that these coatings will protect the structure from the deteriorating effects of the environment (natural and man-made). The projects are put out for bid. Without prequalified contractors, an agency may have house painters, commercial building painters, or other trades that also “paint” bidding the work. All of this effort can be wasted if the surface preparation and coating application work is left to an unqualified firm who simply offered the best price.

Bridge painting projects are very complex in that many different activities must be coordinated and executed with minimal impact on the public, including traffic control, equipment placement, surface preparation and painting, worker protection, environmental protection, waste handling, etc. Specifications for bridge painting work are complicated, and are designed to help ensure that the work is completed properly. Government agencies award the work to the lowest bidder. By requiring all bidders to be certified (prequalification), the lowest bid can be awarded without sacrificing quality or safety. Implementing a contractor certification program helps to ensure that contractors are properly equipped and properly staffed to perform the work according to the requirements of the specification. Requiring contractor certification lessens the opportunity for disputes, poor quality, environmental pollution, accidents, and schedule delays.

As of January 2014, over 360 State DOTs, municipalities, defense organizations (US Navy, US Army Corps of Engineers), private companies, cities, and public works departments require contractor certification as a prerequisite to bidding on painting projects (reference: http://www.sspc.org/media/documents/QP/Facility_Owners_Requiring_QP_0114.pdf). The Society of Protective Coatings (SSPC) established a painting contractor certification program (PCCP) in the late 1980s. NACE International launched a similar program in 2015. Today, there are hundreds of certified contractors throughout the US.

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Slide 4

Note that this is only a partial listing of SSPC certification programs. We will focus on three of the programs that are listed in this Lesson (QP1, QP2, and QP3).

Each of these programs requires submission of an application, an office and a field audit, training of personnel and written compliance programs/procedures for production, quality, and safety in order to achieve and maintain certification. More information on the SSPC PCCP is available online (www.sspc.org/qp-programs/qp-programs-home).

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Slide 5

A QP1 certification is considered to represent the minimum level of service and quality in the industrial coatings industry. The program is designed to provide facility owners and specification writers a means to determine whether the painting contractor has the capability to perform surface preparation and coating application in the field on complex industrial and marine structures. To be certified by SSPC, industrial contractors must demonstrate competence in four key areas: management procedures, technical capability, quality control, and safety and environmental compliance.

Slide 6

SSPC QP2 qualifies those engaged in hazardous coating removal, such as coatings that contain lead.

Certification requires demonstrated competence in four key areas: management of hazardous paint removal projects, technical capabilities related to hazardous paint removal, personnel qualifications and training, and safety and environmental compliance. SSPC QP1 is a prerequisite to attaining QP2 certification, since none of the competency areas address quality.

Slide 7

The requirements for SSPC QP3 are similar to those for SSPC QP1, except they are specifically focused on shop coating operations. SSPC QP3 is a nationally recognized program that evaluates the practices of shop painting facilities in key areas of business. These standards are considered to be the minimum level of service and quality for today's coatings industry.

QP3 is segmented according to the type of shop:
• Enclosed shop, where work is not subject to outdoor weather conditions;
• Covered shop, where work is conducted out of direct exposure to outdoor weather; and
• Open shop, where work is exposed to outdoor weather conditions and blowing dust.

To be certified by SSPC, industrial contractors must demonstrate competence in management procedures, technical capabilities, quality control, and health, safety, and environmental compliance.

SSPC QP3 and the American Institute of Steel Construction (AISC) Sophisticated Painting Endorsement (SPE) standards merged into a single qualification standard that is now used by both organizations. It is known as AISC 420-10/SPE-QP3, Certification Standard for Shop Application of Complex Protective Coating Systems.

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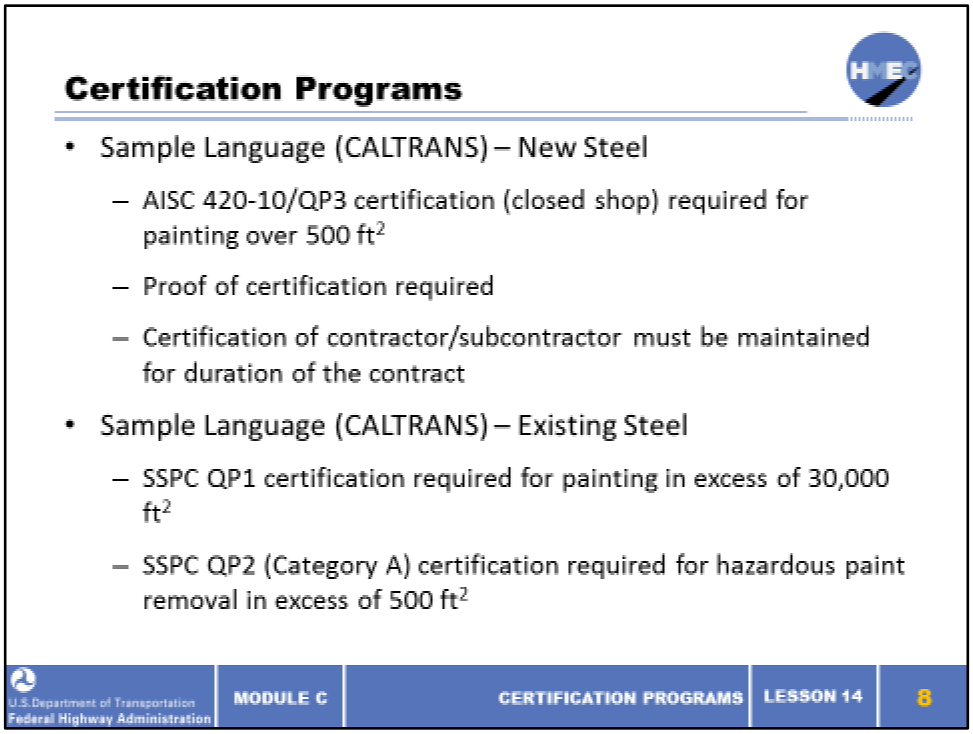
Slide 8



If shop painting takes place for new or replacement steel and the work is over 500 ft^2, the contractor will need to have AISC 420-10/QP3 enclosed shop certification to bid the work. If it is under 500 ft^2, no certification is required; however, work must be performed in accordance with the AISC 420-10/SPE-QP3 Certification Standard for Shop Application of Complex Protective Coating Systems. The contractor or subcontractor must provide proof of certification and must maintain the certification(s) for the duration of the contract.

For existing structures greater than 30,000 ft^2, the SSPC QP1 certification requirement is invoked. If it is under 30,000 ft^2, no certification is required; however, work must be performed in accordance with the general qualification requirements of QP1. If hazardous paint removal is involved, QP2 is required for structures over 500 ft^{2}t; for work less than 500 ft^2, the elements of QP2 must be adhered to, although a certification is not required.

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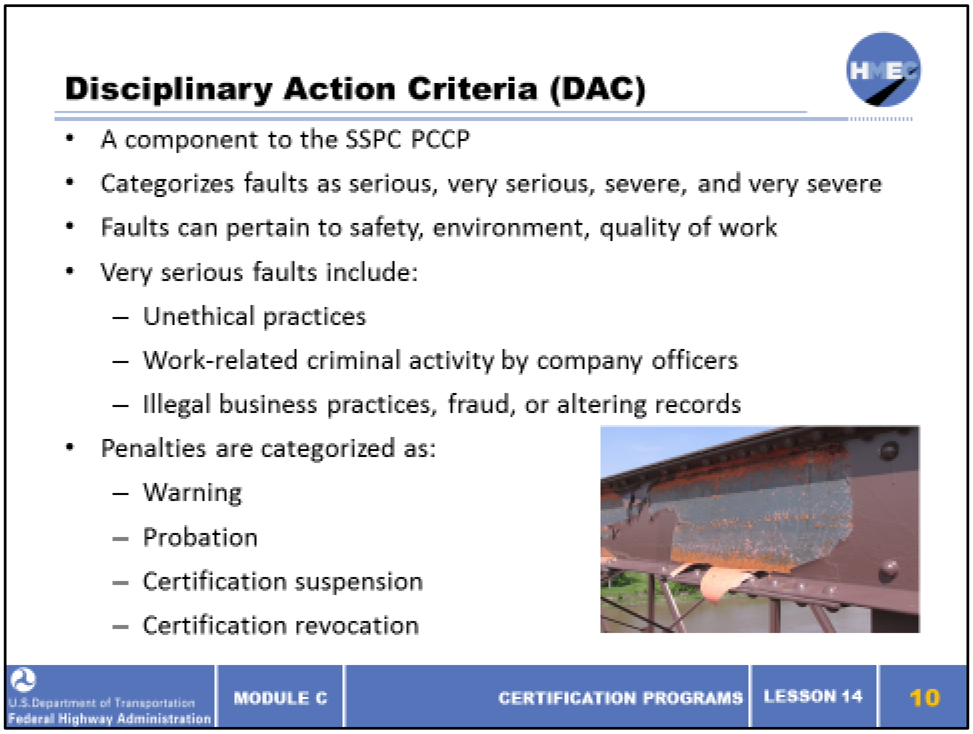
Slide 9

By specifying contractor certification as a bid-eligible prerequisite, there is a greater opportunity for quality coating work. However, it is the company and not the individuals assigned to a project that hold the certification. The workmanship is only as good as the foreman/supervisor and the crew they are leading. Therefore, verifying conformance to the specification (quality assurance, or QA) remains a key component to the success of a painting project. The QA inspector should verify that the certified contractor is controlling the quality of the work and documenting the results of the quality control inspections.

By the year 2020, 75% of each crew of an SSPC QP1-certified contractor must be certified according to the requirements of NACE No. 13/SSPC ACS-1 Standard Practice, Industrial Coating and Lining Application Specialist Qualification and Certification.

Slide 10



The SSPC PCCP DAC categorizes faults as serious, very serious, severe, and very severe. The faults can pertain to safety violations, environmental pollution, and/or quality of workmanship and a neglect to conform to the specification. Very serious faults include:

- Unethical practices;
- Work-related criminal activity by company officers;
- Illegal business practices;
- Fraud; or
- Altering records.

Penalties are categorized as warning, probation, certification suspension, and certification revocation.

The reason for instituting a DAC is quite simple. From time to time, contractors do not perform or they demonstrate lack of good judgment. The DAC provides a means to discipline the contracting company, according to the severity of the fault(s). In a worse case, a contractor's certification can be revoked, making them ineligible to bid future work requiring PCCP.

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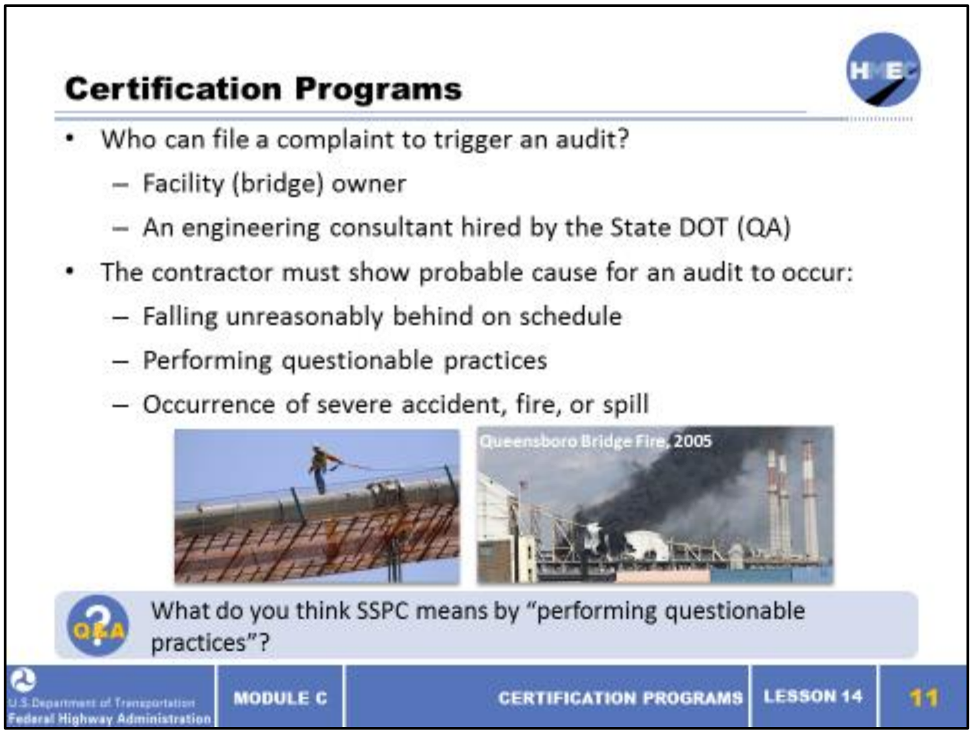
Slide 11



There may be several reasons why a complaint would be filed and an audit triggered. The reason could be for complaints stemming from a gross inability to meet the construction schedule due to events within the contractor's control. Severe accidents, spills, fires, or even fatalities can trigger investigations and disciplinary action.

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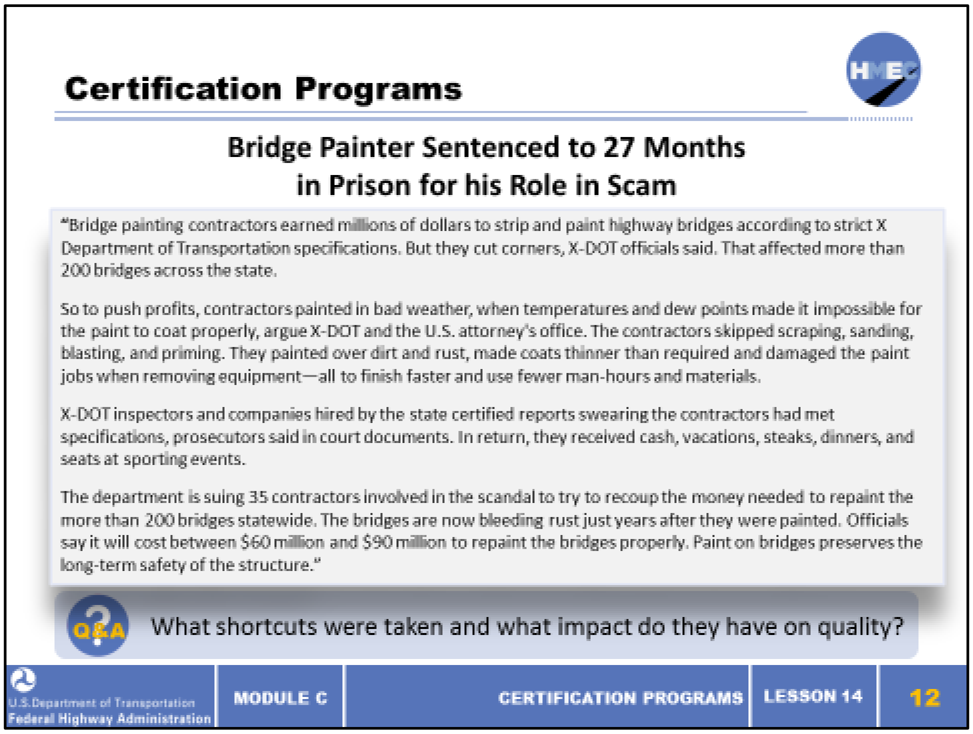
Slide 12


Certification Programs
HMEC
Bridge Painter Sentenced to 27 Months in Prison for his Role in Scam
"Bridge painting contractors earned millions of dollars to strip and paint highway bridges according to strict X Department of Transportation specifications. But they cut corners, X-DOT officials said. That affected more than 200 bridges across the state.
So to push profits, contractors painted in bad weather, when temperatures and dew points made it impossible for the paint to coat properly, argue X-DOT and the U.S. attorney's office. The contractors skipped scraping, sanding, blasting, and priming. They painted over dirt and rust, made coats thinner than required and damaged the paint jobs when removing equipment—all to finish faster and use fewer man-hours and materials.
X-DOT inspectors and companies hired by the state certified reports swearing the contractors had met specifications, prosecutors said in court documents. In return, they received cash, vacations, steaks, dinners, and seats at sporting events.
The department is suing 35 contractors involved in the scandal to try to recoup the money needed to repaint the more than 200 bridges statewide. The bridges are now bleeding rust just years after they were painted. Officials say it will cost between $60 million and $90 million to repaint the bridges properly. Paint on bridges preserves the long-term safety of the structure."
Q&A
What shortcuts were taken and what impact do they have on quality?
U.S. Department of Transportation
Federal Highway Administration
MODULE C
CERTIFICATION PROGRAMS
LESSON 14
12

Slide 13

Contractors are responsible for controlling the quality of their work as it proceeds and facility owners are responsible for verifying the adequacy of the contractor's quality control program through QA. Agencies may elect to use in-house staff to perform QA inspection, or they may elect to contract with a third-party firm for the QA inspection. SSPC has a certification program for independent coating and lining inspection companies known as QP5. Naturally, individual inspector certification is a key component to the QP5 program.

First line, in-process inspection should be performed by the contractor's QC inspector and any deficiencies should be corrected before QA inspection by the facility owner (or the third-party inspector) occurs. Oftentimes, QC and QA inspections are done concurrently. Coating inspector training is critical for both roles, and individual inspector certification brings added value to the quality process.

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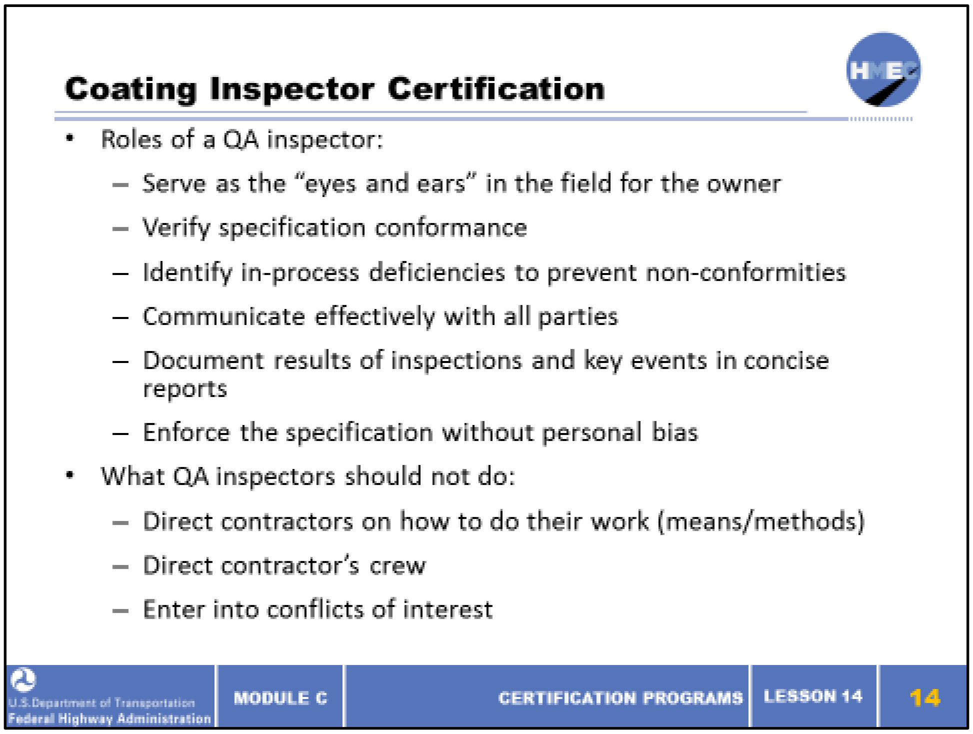
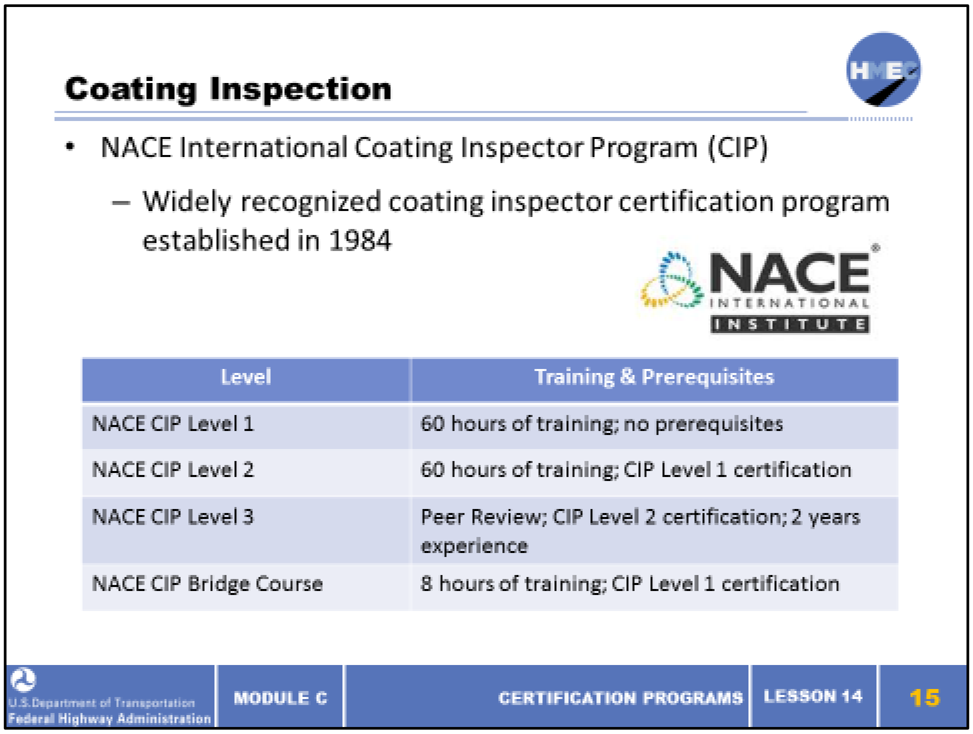
Slide 14



The QA inspector is the eyes and ears of the facility owner during surface preparation and coating application processes. Their role is analogous to a police officer—they enforce the law (the specification) without personal bias. They help the contactor produce a quality coatings job by identifying deficiencies as they occur so that they can be corrected as the project progresses, thereby reducing or even eliminating non-conformities. QA inspectors must be good communicators (both verbal and written), and be able to document the results of their inspections clearly and concisely.

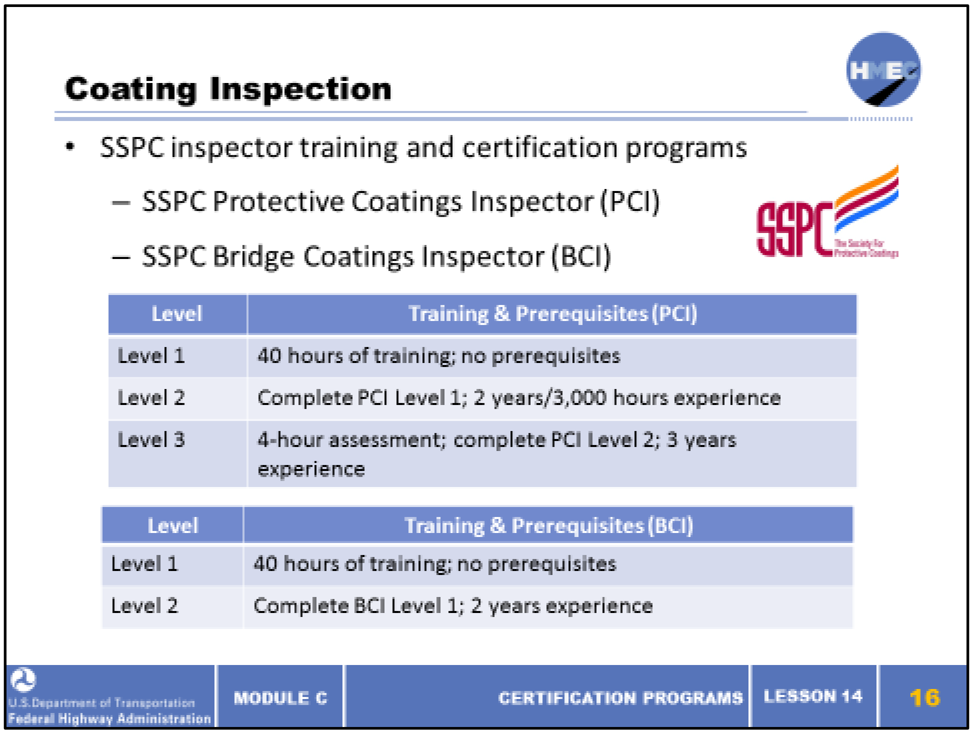
Conversely, QA inspectors should not direct the work or the contractor's crew, nor should they inspect projects where there is a conflict of interest.

Slide 15



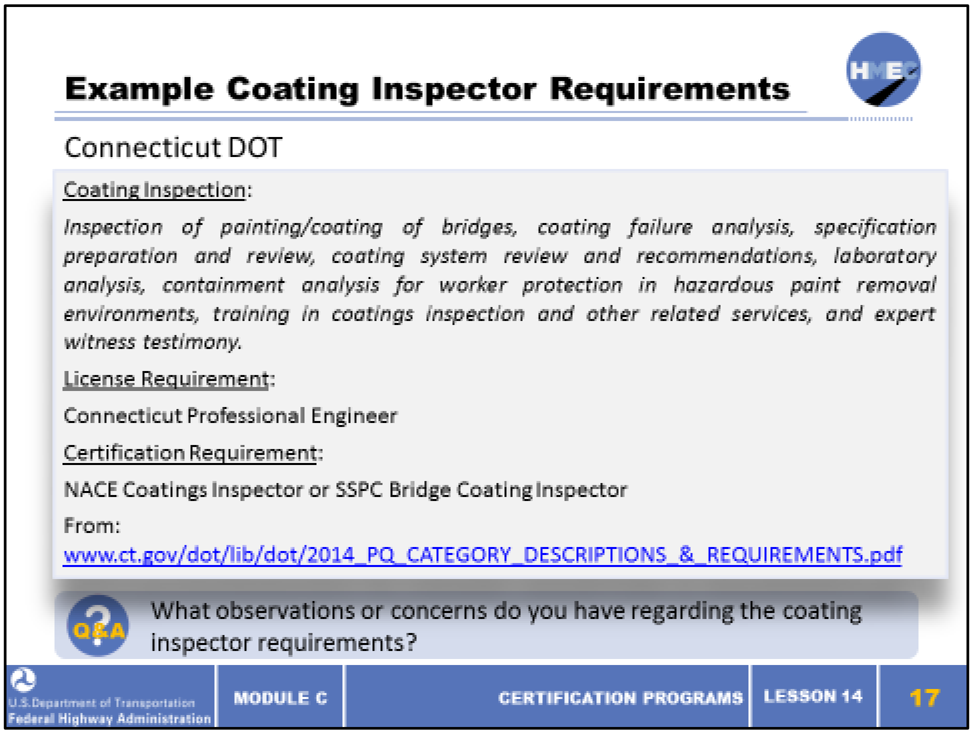
NACE International established the Coating Inspector Program (CIP) back in 1984. Today, there are over 26,000 certified inspectors (Levels 1, 2, 3) worldwide. The various levels and the training and prerequisites are shown in the table on the slide.

Slide 16

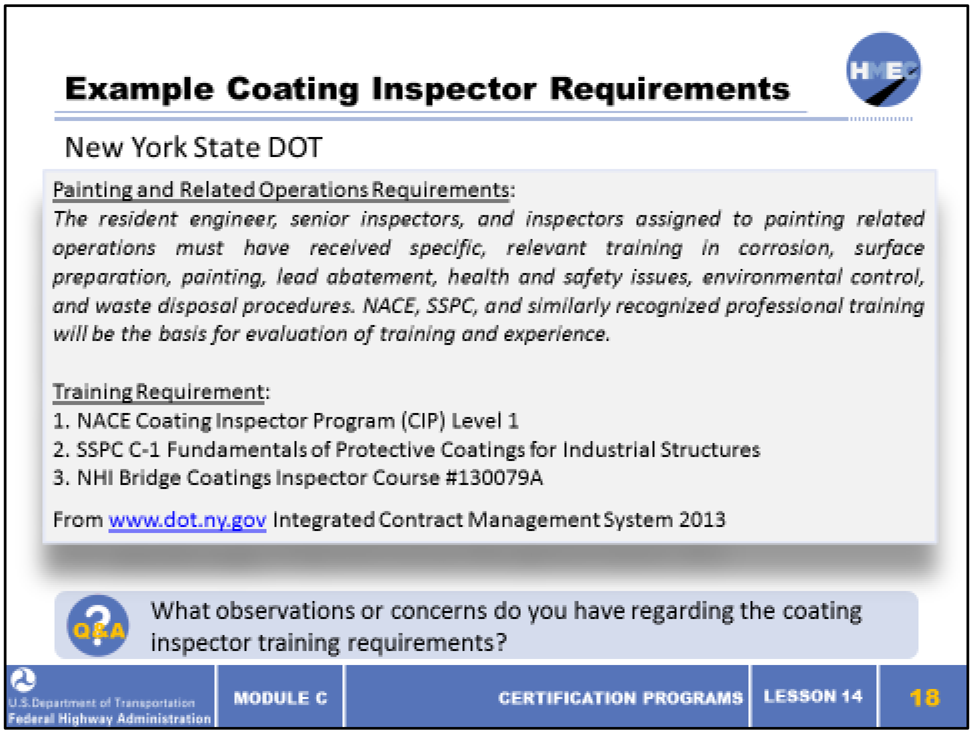


The various levels and the training and prerequisites are shown in the table on the slide for both the PCI training and certification programs as well as the BCI training and certification program. SSPC also has a Concrete Coating Inspector (CCI) training program for inspection of coatings applied to concrete surfaces. Neither the PCI or the BCI courses address concrete structures.

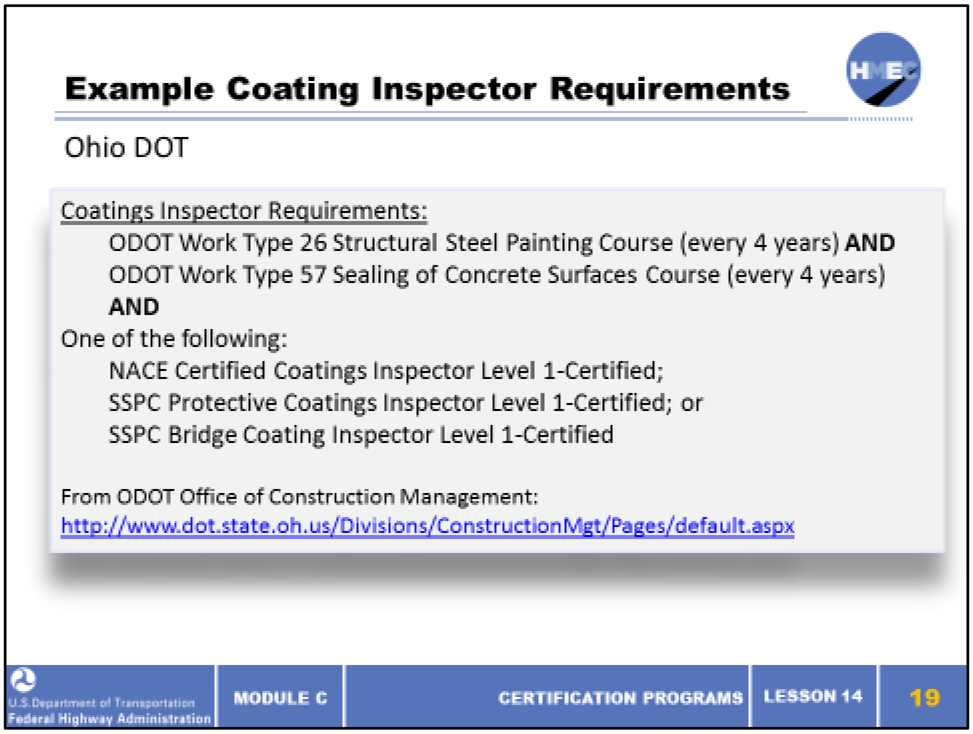
Slide 17


Example Coating Inspector Requirements
HMEC
Connecticut DOT
Coating Inspection:
Inspection of painting/coating of bridges, coating failure analysis, specification preparation and review, coating system review and recommendations, laboratory analysis, containment analysis for worker protection in hazardous paint removal environments, training in coatings inspection and other related services, and expert witness testimony.
License Requirement:
Connecticut Professional Engineer
Certification Requirement:
NACE Coatings Inspector or SSPC Bridge Coating Inspector
From:
www.ct.gov/dot/lib/dot/2014_PQ_CATEGORY_DESCRIPTIONS_&_REQUIREMENTS.pdf
Q&A
What observations or concerns do you have regarding the coating inspector requirements?
U.S. Department of Transportation
Federal Highway Administration
MODULE C
CERTIFICATION PROGRAMS
LESSON 14
17

Slide 18

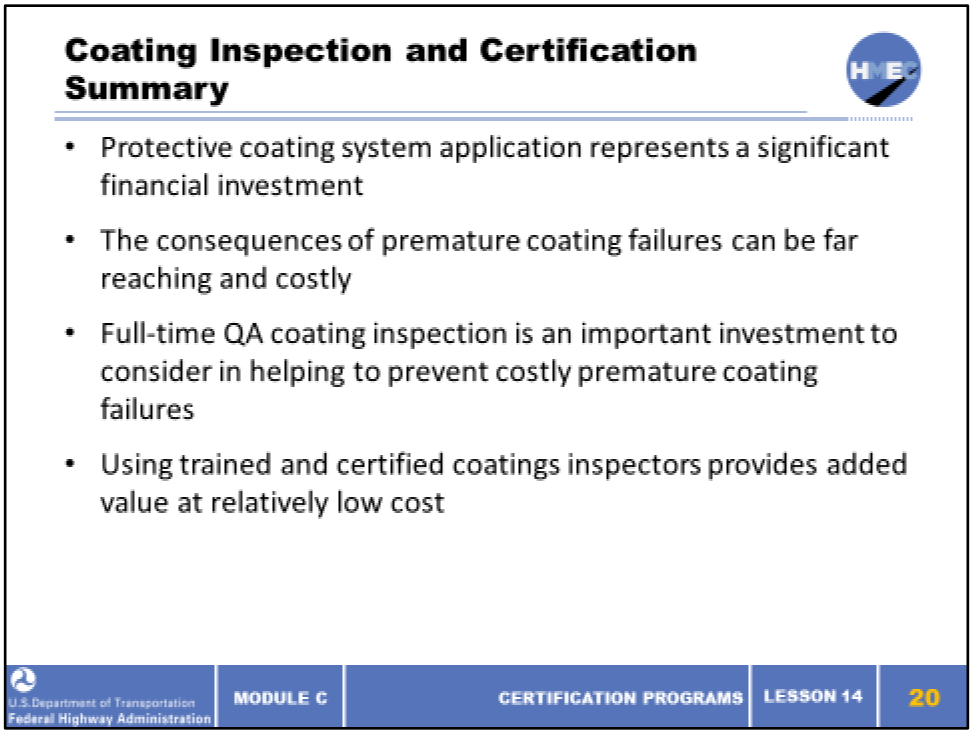

Example Coating Inspector Requirements
HMEC
New York State DOT
Painting and Related Operations Requirements:
The resident engineer, senior inspectors, and inspectors assigned to painting related operations must have received specific, relevant training in corrosion, surface preparation, painting, lead abatement, health and safety issues, environmental control, and waste disposal procedures. NACE, SSPC, and similarly recognized professional training will be the basis for evaluation of training and experience.
Training Requirement:
1. NACE Coating Inspector Program (CIP) Level 1
2. SSPC C-1 Fundamentals of Protective Coatings for Industrial Structures
3. NHI Bridge Coatings Inspector Course #130079A
From www.dot.ny.gov Integrated Contract Management System 2013
Q&A
What observations or concerns do you have regarding the coating inspector training requirements?
U.S. Department of Transportation
Federal Highway Administration
MODULE C
CERTIFICATION PROGRAMS
LESSON 14
18

Slide 19



Ohio DOT for example. They have their own structural steel painting course and sealing of concrete course that contractors must register for and successfully complete, plus a requirement to be certified to one of the following: NACE CIP Level 1, SSPC PCI Level 1, or SSPC BCI Level 1.

Slide 20



For most facility owners, protective coatings systems represent a significant financial investment that clearly warrants a QA effort to help ensure that their investment is sound. The consequences of premature coatings failures can be far reaching and generally result in damages several times that of the original installation cost due to impacts on operations, lost revenues, damage to the structure, and possibly complete removal and replacement of the failed coatings. Although coating selection is a critical factor, today's high-performance protective coatings systems are complex materials that can be challenging to apply. Full-time coating inspection is the single-best investment that can be made toward preventing costly premature coatings failures. The price tag of full-time, on-site inspection ranges from 2 to 10% of the total project, based on the size of the bridge structure. A simple grade-separation overpass will be a higher percentage compared to a large suspension bridge, where the overall percentage of the cost attributed to QA inspection will be extremely low. Using trained and certified coatings inspectors helps to ensure that the contractor is conforming to the specification.

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Slide 21

Learning Outcomes Review

You are now able to:

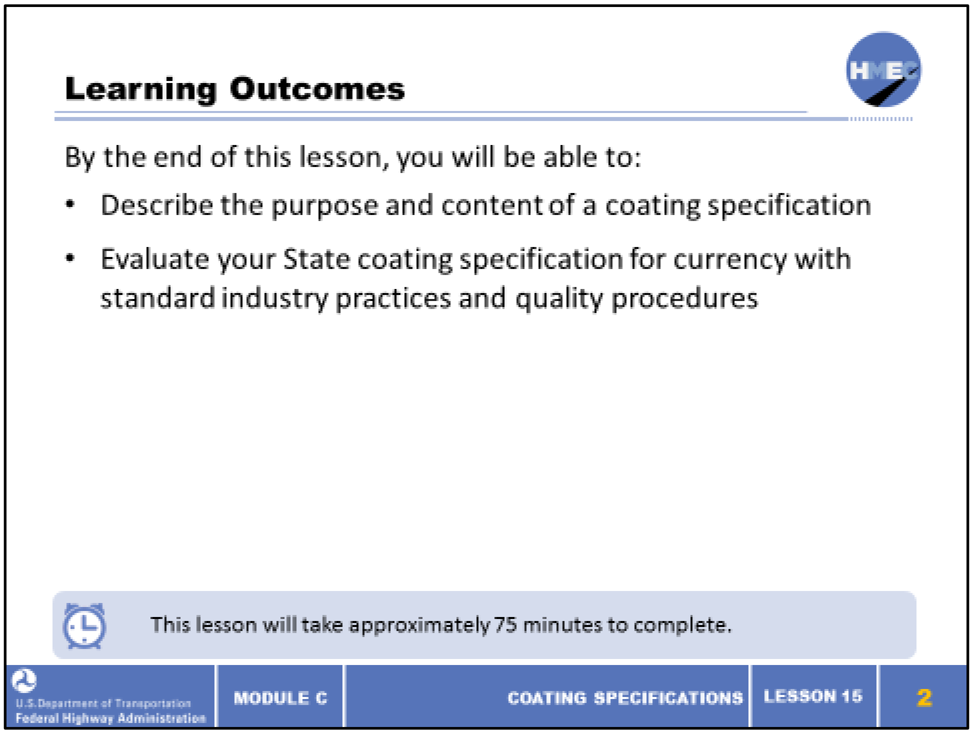
- Explain the advantages and limitations of contractor certification programs
- Identify circumstances that could cause an agency (that requires contractor certification) to file a complaint
- List coating inspector training and certification programs
- Explain the benefits of a certified coating inspector

U.S. Department of Transportation Federal Highway Administration | MODULE C | CERTIFICATION PROGRAMS | LESSON 14 | 21

Slide 1


ILT
HMEC
Highway Materials Engineering Course
Lesson 15: Coating Specifications
Steel, Welding, and Coatings
U.S.Department of Transportation
Federal Highway Administration
MODULE
C

Slide 2


Learning Outcomes
HMEC
By the end of this lesson, you will be able to:
• Describe the purpose and content of a coating specification
• Evaluate your State coating specification for currency with standard industry practices and quality procedures
This lesson will take approximately 75 minutes to complete.
U.S. Department of Transportation
Federal Highway Administration
MODULE C
COATING SPECIFICATIONS
LESSON 15
2

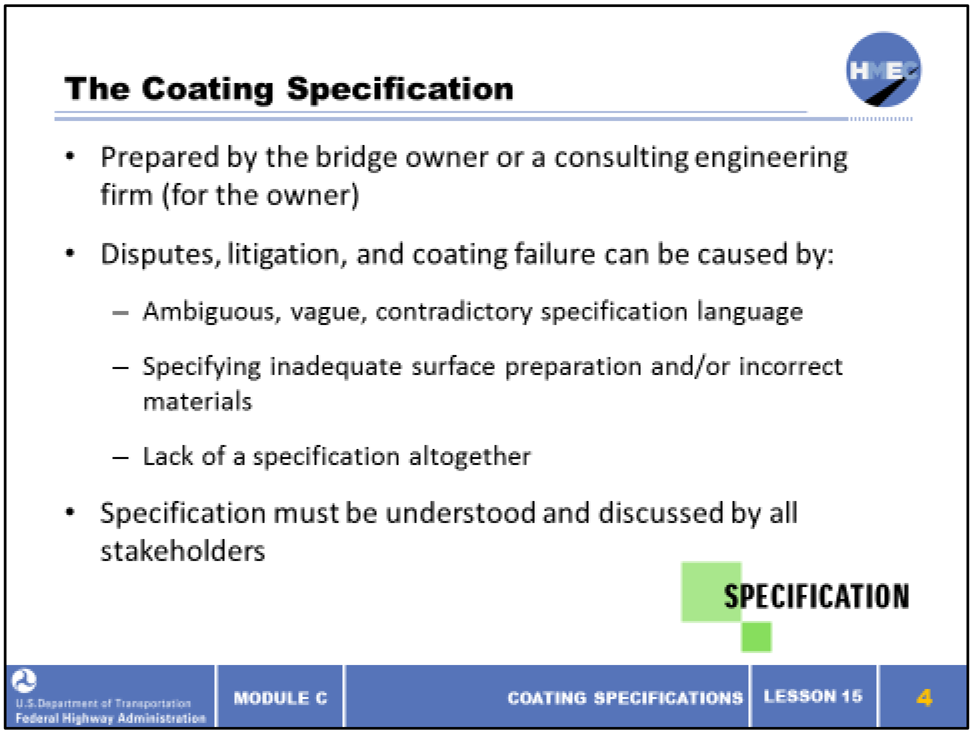
Slide 3

The Coating Specification

- The coating specification for a bridge painting project:
  - Forms the basis for bid solicitation from contractors
  - Describes the project scope and the objective of the coating system
  - Lists industry standards and regulations invoked
  - Describes the required materials and intended appearance
  - Itemizes the quality control inspection requirements and the acceptance criteria
  - Becomes an integral component of the contract once the work is awarded
  - Becomes a critical document if/when litigation occurs

U.S. Department of Transportation Federal Highway Administration | MODULE C | COATING SPECIFICATIONS | LESSON 15 | 3

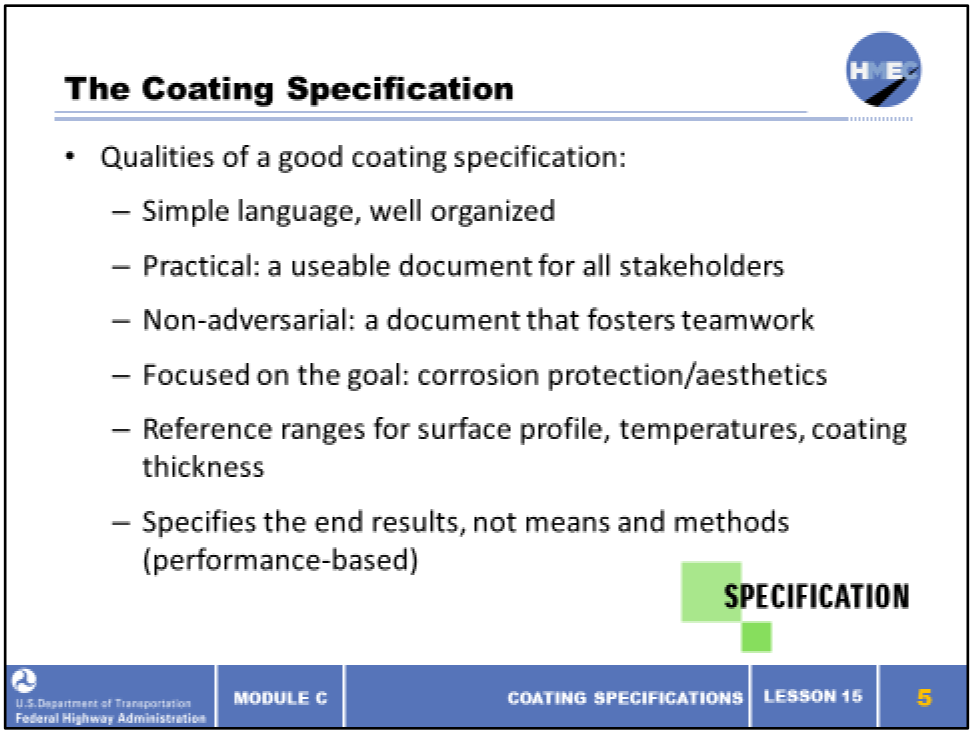
Slide 4



The coating specification for a specific bridge project is prepared by the bridge owner or a consulting engineering on behalf of the owner. Specification writers need to recognize that disputes, litigation, and coating failure can be caused by ambiguous, vague, or contradictory specification language, specifying inadequate surface preparation and/or incorrect materials, or attempting to contract for work without any specification (i.e., rely on a manufacturer's product data sheet, or PDS, that contain recommendations).

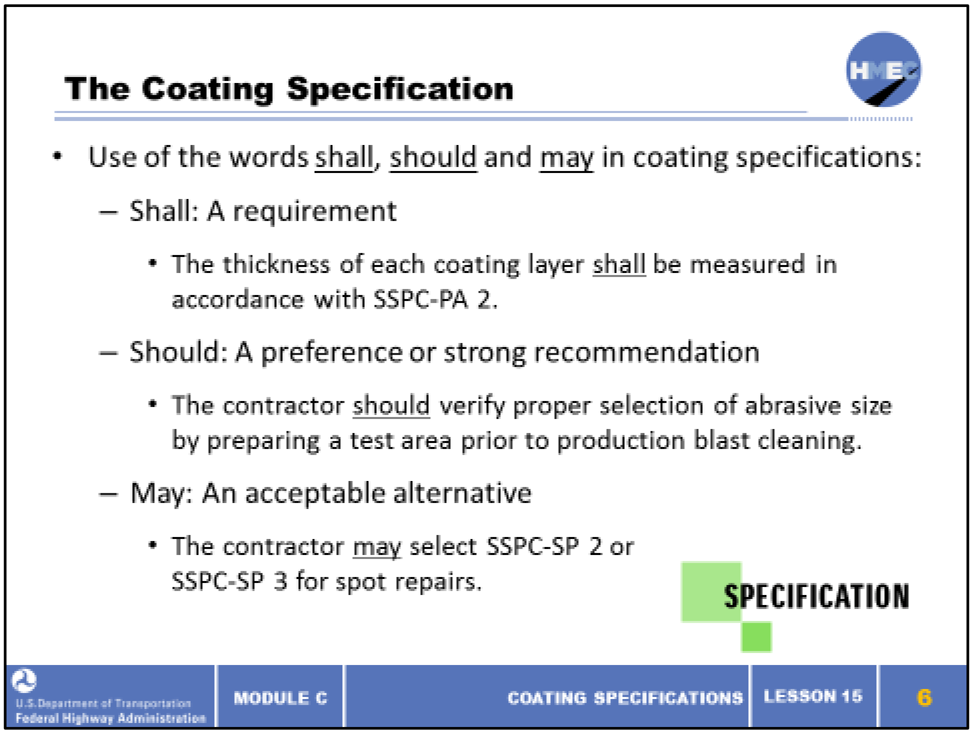
Specification must be understood and discussed by all stakeholders. To this end, it is very difficult to write specifications so that there is no room for interpretation and no loopholes. Currently, there is no accreditation or license to write a specification, although there are training courses available. This is why the quality of specifications vary widely.

Slide 5



A well-written coating specification uses simple language and is well organized. It should be a practical, useable document for all stakeholders that contains minimal legal language. It should be non-adversarial (i.e., avoid language that infers "follow the specification or pay the consequences"), and a document that fosters teamwork and remains focused on the goal: corrosion protection and aesthetics. It is important that the specification include ranges for requirements like surface profile, temperatures, coating thickness, etc. and to specify the end results as opposed to dictating the means and methods used by the contractor to achieve the end results. These are known as performance-based specifications.

Slide 6



The use of shall, should, and may must be carefully considered by the specification writer as these words hold specific meaning in a coating specification. When a specifier uses the term “shall,” it is a requirement and there is no interpretation required or options available. There is no ambiguity to that statement. It is a contractual requirement.

When a specifier uses the term “should,” it is a strong preference or recommendation, but not a contractual requirement. Implementing this recommendation is in the best interest of the contractor, but if the contractor elects not to do it, there are no repercussions.

Finally, when a specifier uses the term “may,” it is an acceptable alternative. Since SSPC-SP 2 hand-tool cleaning and SSPC-SP 3 power-tool cleaning both have the same acceptance criteria (remove the loosely adhering materials), the contractor can select either one (or both) based on preference. The end result is all that matters.

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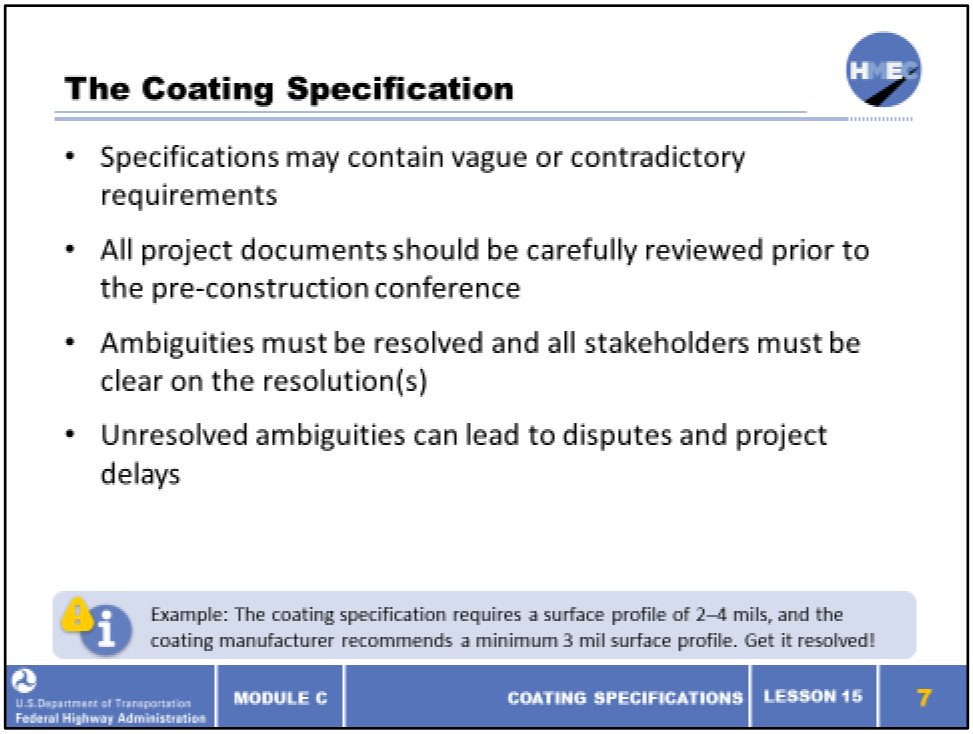
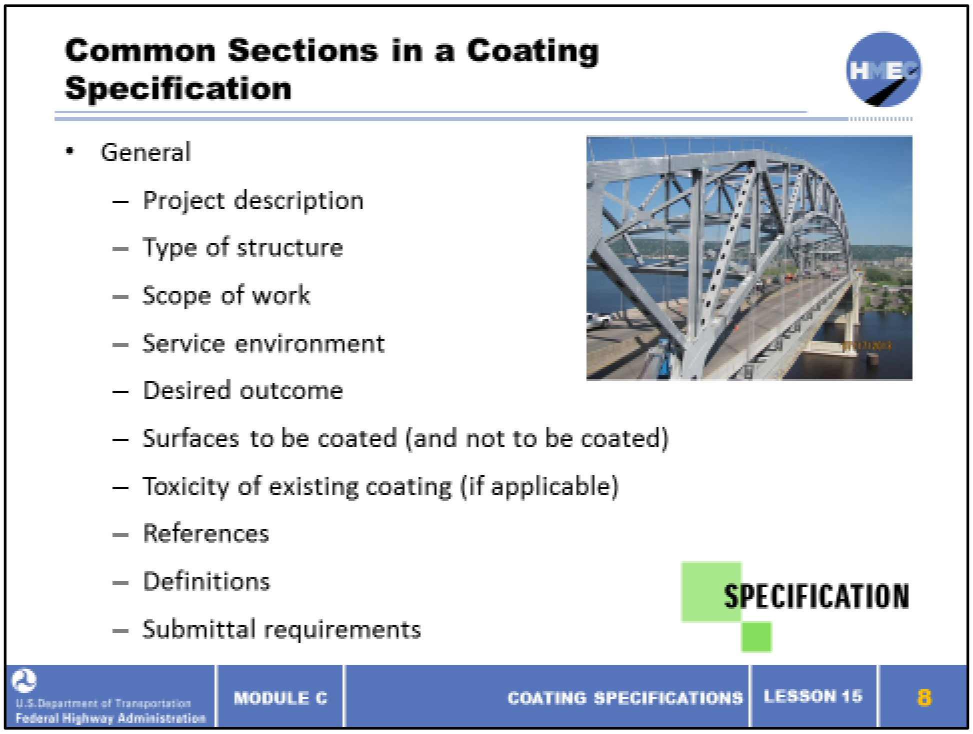
Slide 7



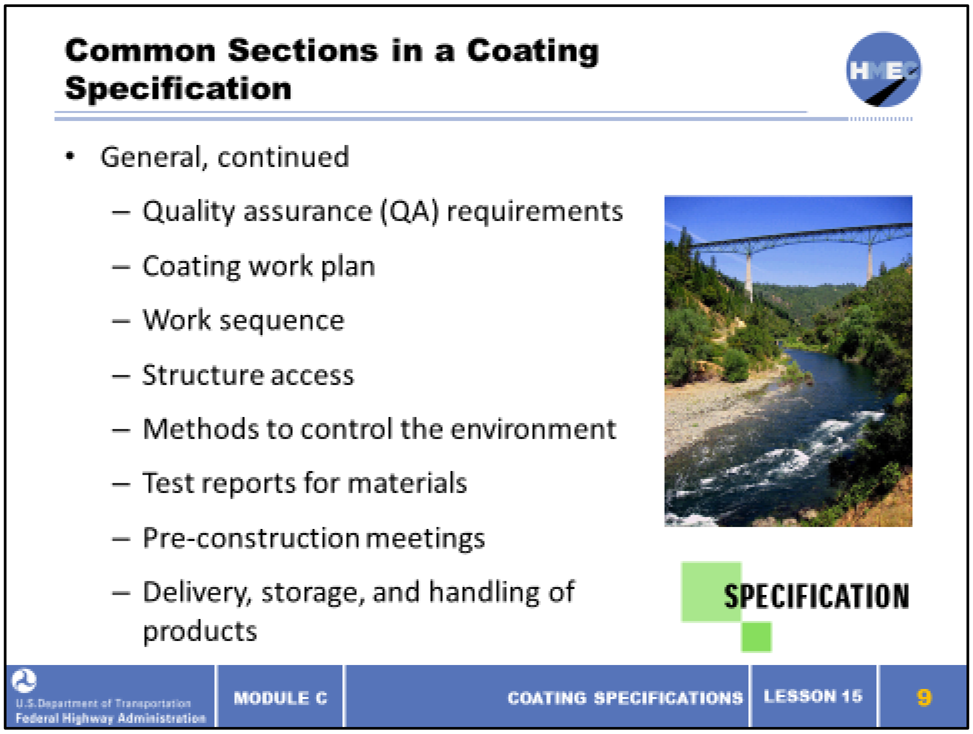
It is important to carefully review all project-related documents prior to the pre-job conference, highlight ambiguities, and propose resolutions. Ultimately these ambiguities will need to be resolved prior to production activities and all of the project stakeholders (owner, contractor, coating manufacturer, and inspector) must clearly understand the resolution(s). These should be in writing and become amendments to the coating specification. Unresolved disputes will inevitably lead to disputes during the project and potential delays while they are being resolved.

Slide 8



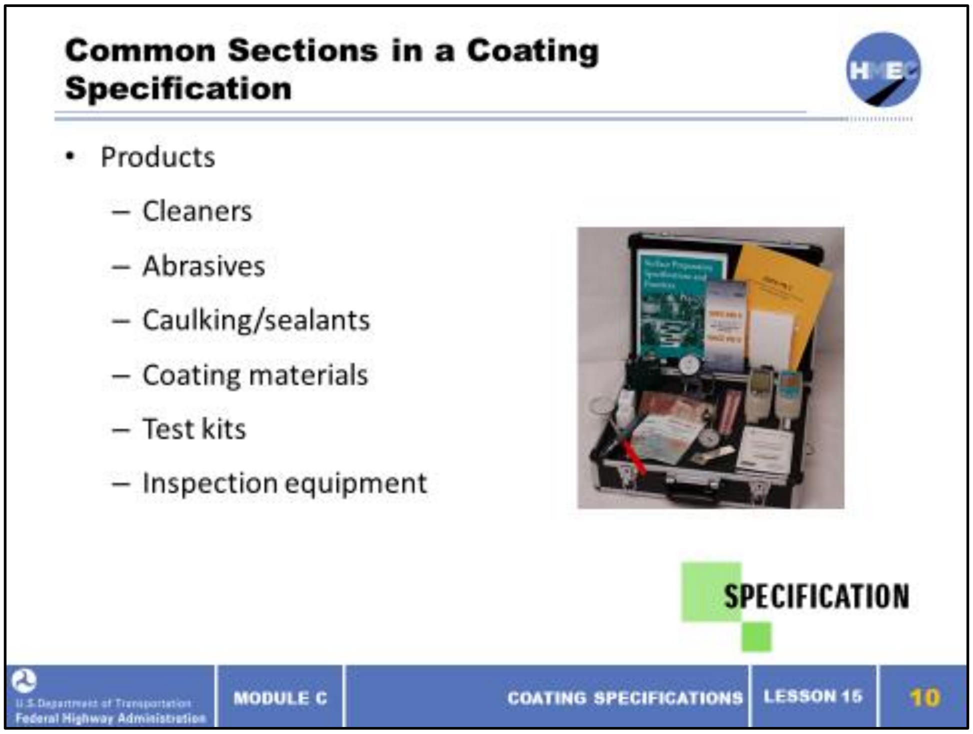
The general section describes the project, including the type of structure, scope of work, service environment, desired outcome, surfaces to be coated (and not to be coated), and toxicity of existing coating (if applicable). It also lists references, definitions, and submittal requirements such as the project schedule, work plan, quality control (QC) plan, safety plan, environmental plan, waste plan, material certifications, company and personnel qualifications, and qualifications of subcontractors.

Slide 9



The general section also lists the quality assurance (QA) requirements, requirements for the development of a coating work plan, the work sequence, structure access, methods to control the environment, test reports for materials, pre-construction meetings, and the delivery, storage, and handling of products.

Slide 10



The products section describes the various products used for the project such as cleaners, abrasives, caulking/sealants, coating materials, test kits, and inspection equipment. When referring to coating materials, the specification may list a coating system by "select from the qualified products list," "performance criteria," or "formulation." The last two are rarely used today. The use of qualified products lists (QPL) or approved products lists (APL) is very common among DOTs.

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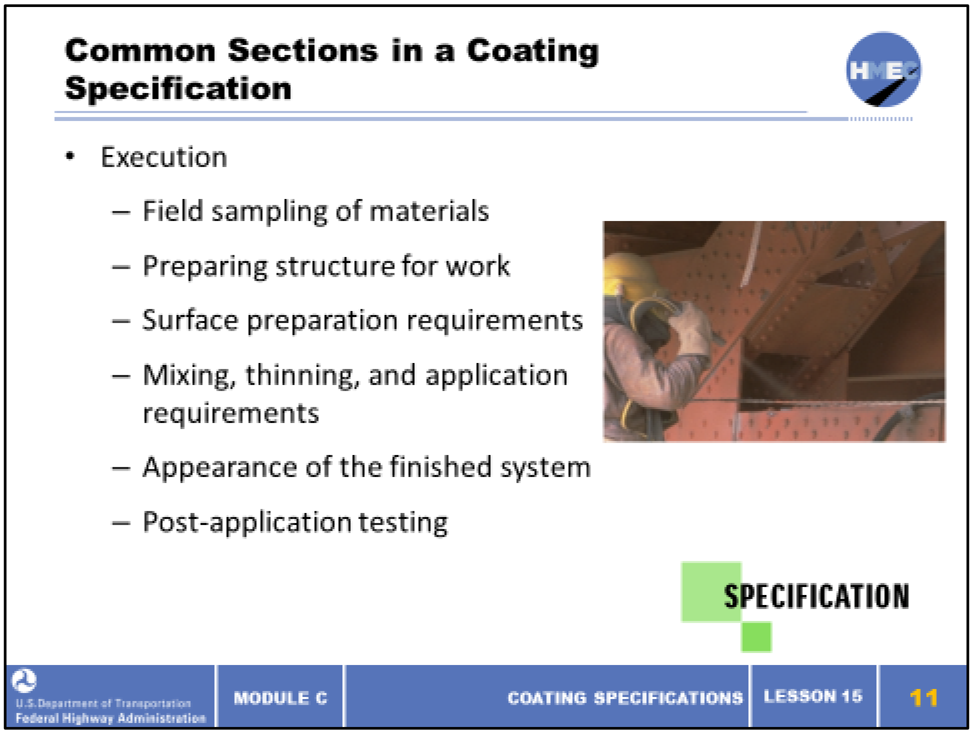
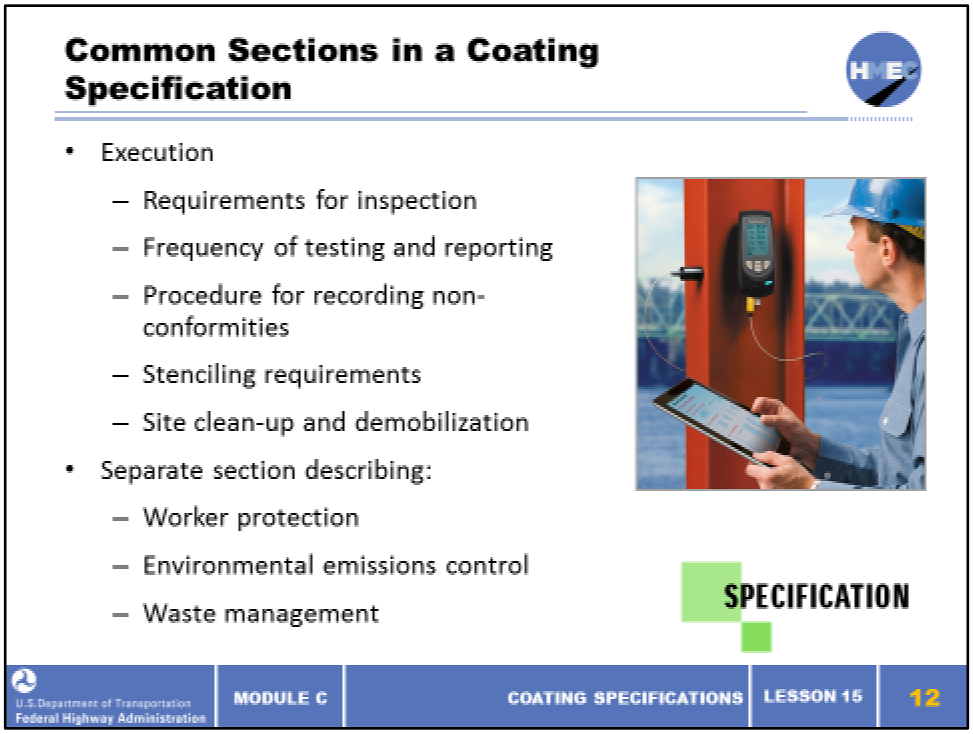
Slide 11



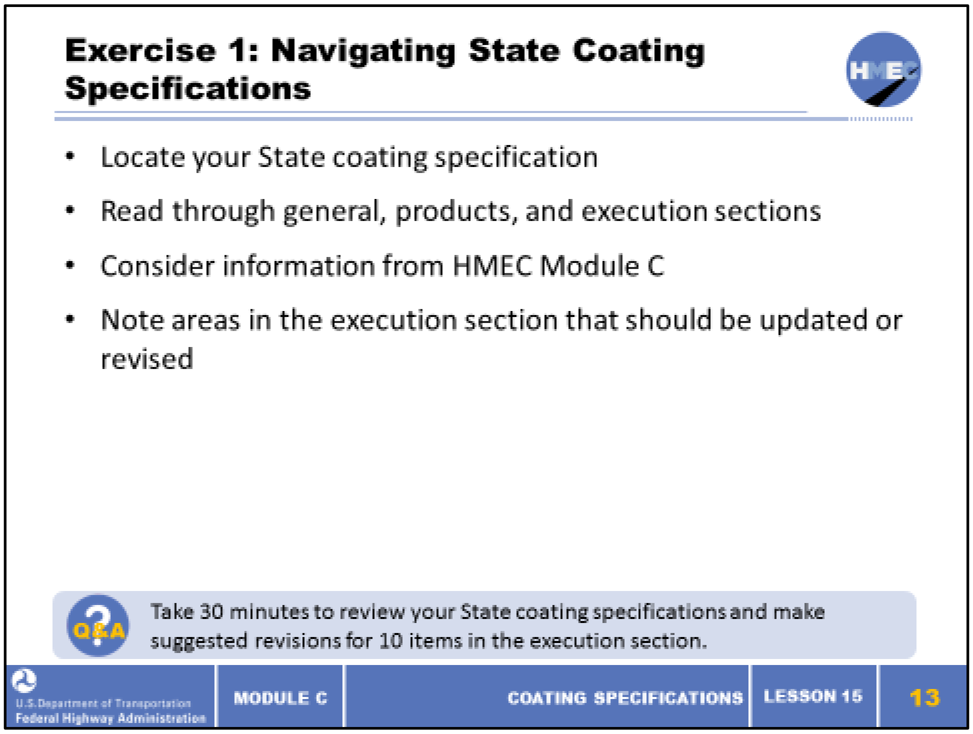
The execution section details the coating work and describes field sample collection of materials, preparing structure for work, surface preparation requirements, mixing, thinning and application requirements, appearance of the finished system, and post-application testing.

Slide 12



The execution section also details requirements for inspection and includes a list of hold points/check points, frequency of testing and reporting, procedure for recording non-conformities, stenciling requirements, site clean-up, and demobilization. There may be a separate section detailing worker protection, environmental emissions control, and waste management.

Slide 13


Exercise 1: Navigating State Coating Specifications
HMEC
• Locate your State coating specification
• Read through general, products, and execution sections
• Consider information from HMEC Module C
• Note areas in the execution section that should be updated or revised
Q&A
Take 30 minutes to review your State coating specifications and make suggested revisions for 10 items in the execution section.
U.S. Department of Transportation Federal Highway Administration
MODULE C
COATING SPECIFICATIONS
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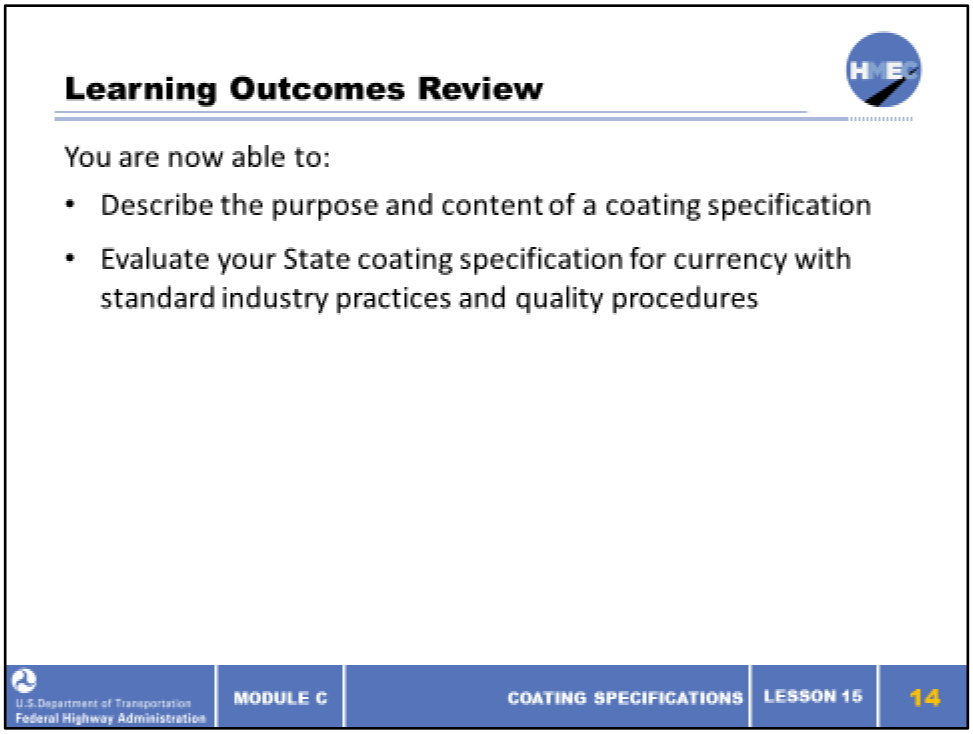
Slide 14



The purpose of a coating specification is to communicate the technical and contractual requirements of a project. A coating specification is generally composed of three sections: general, products, and execution.

Standard DOT specifications can become outdated. A good practice is to review these specifications routinely (e.g., every five years or so) and verify that they contain current information related to product technology and quality, and are not too restrictive or prescriptive.

Slide 1


ILT
HMEC
Highway Materials Engineering Course
Lesson 16: Hot Topics
Steel, Welding, and Coatings
U.S.Department of Transportation
Federal Highway Administration
MODULE
C

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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 C can be found in the following sources.

Primary Resources

- *The Procedure Handbook of Arc Welding,* 14th edition (or later), 2000 (James F. Lincoln Arc Welding Foundation, Cleveland, OH)
- AASHTO and ASTM Material Specifications:
    - AASHTO M270 (ASTM A709) for bridge steels
    - AASHTO M164 (ASTM A325) for high strength bolts
    - AASHTO M253 (ASTM A490) for high strength bolts
    - ASTM A370
    - ASTM E8
    - ASTM A6
    - ASTM G101
- NHI-131023 Steel, Welding, and Coatings Module
- AWS D1.5 Bridge Welding Code
- Corrosion School, existing course materials (PPT format), Carboline presentation material (Coatings Only)
- FHWA Steel Bridge Designers Handbook:
    - Volume 1: Bridge Steels and their Mechanical Properties
    - Volume 2: Steel Bridge Fabrication
    - Volume 19: Corrosion Protection of Steel Bridges
- AASHTO/NSBA Steel Bridge Collaboration:
    - S2.1 Steel Bridge Fabrication Guide Specification
    - S4.1 Steel Bridge Fabrication QC/QA Guide Specification
    - S8.1 Guide Specification for Application of Coating Systems with Inorganic Zinc-Rich Primer

Additional Resources

- AMRL Videos to cover the Steel Testing and Bolt Testing labs
- Northeast Protective Coating (NEPCOAT) standards
- Society for Protecting Coatings (formerly Steel Structures Painting Council), or SSPC (Lesson 9)
    - SSPC AB-1
    - SSPC AB-2
    - SSPC AB-3
    - SSPC QP-1
    - SSPC QP-2
    - SSPC QP-3
- NACE (General corrosion and coatings)
- Research Council on Structural Connections (RCSC)
- Studies from FHWA, NCHRP, and other sources on coating life expectancy

- Federal Regulations referenced in this course, at a minimum, include:
    - Clean Air Act
    - Clean Water Act
    - Drinking Water Standards
    - EPA Method 1311
    - EPA Method 3050
    - EPA regulations concerning lead in soil
    - Land Ban
    - Resource Conservation and Recovery Act