


SHRP2 SOLUTIONS
STRATEGIC HIGHWAY RESEARCH PROGRAM

Service Life Design of Steel Elements

IBC Workshop: W-8 Service Life Design

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U.S. Department of Transportation
Federal Highway Administration

American Association of State Highway and Transportation Officials
AASHTO

Presentation Overview

- This part of the worked example covers:
  - Steel deterioration mechanisms
  - Steel corrosivity categories
  - Steel corrosion mitigation strategies
  - Considerations for other elements

Required Service Life Durations

Non-replaceable components	Minimum service life (years)
Foundations (piling), abutments, piers, structural steel, and deck	75
Replaceable components	**Minimum service life (years)**
Bridge bearings	50
Expansion joints	30
Painting (includes structural steel, metal rocker bearings, expansion joint extrusions, and decorative fencing	25
Barriers	50

Steel Deterioration

- Main deterioration mechanism for buried steel and steel exposed to de-icing salts is corrosion
- Mitigation methods (AASHTO LRFD 10.7.5) may include:
  - Protective coatings (painting, galvanizing, metalizing)
  - Concrete encasement
  - Cathodic protection
  - Use of special steel alloys
  - Increased steel area (corrosion allowance)

Steel Corrosivity Categories

- Corrosivity categories defined by ISO 12944-2 for atmospheric-corrosivity:

Category		Examples of typical environments, exterior
C1	Very low	-
C2	Low	Atmospheres with low level of pollution. Mostly rural areas.
C3	Medium	Urban and industrial atmospheres, moderate sulphur dioxide pollution. Coastal areas with low salinity.
C4	High	Industrial areas and coastal areas with moderate salinity.
C5-I	Very high (industrial)	Industrial areas with high humidity and aggressive atmosphere.
C5-M	Very high (marine)	Coastal and offshore areas with high salinity.

- Corrosivity categories defined by ISO 12944-2 for water and soil:

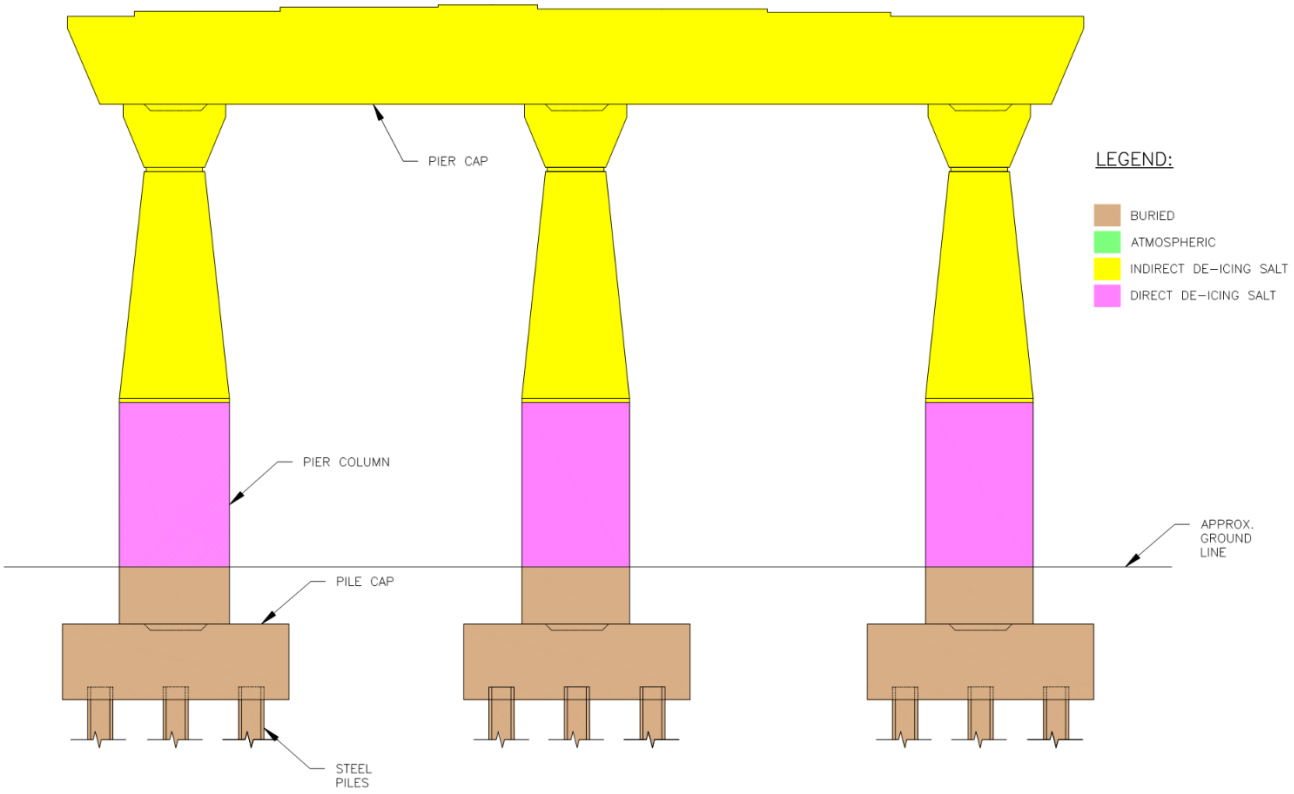
Category		Examples of typical environments and structures
Im1	Fresh water	River installations, hydro-electric power plants.
Im2	Sea or brackish water	Harbour areas with structures like sluice gates, locks, jetties; offshore structures.
Im3	Soil	Buried tanks, steel piles, steel pipes.

Steel Corrosivity Categories for Bridge Components

Exposure Zone	Examples of Elements	Exposure Conditions	Steel Corrosivity Category ISO 12944-2 [2]
Buried	Steel piles at pier.	Limited chloride exposure in soil. Limited O_2. Freeze-thaw above frost line. Sulfates.	Im3: soil

Exposure Zones Color Code

- Exposure zones for substructure:



Steel Corrosivity Categories for Bridge Components

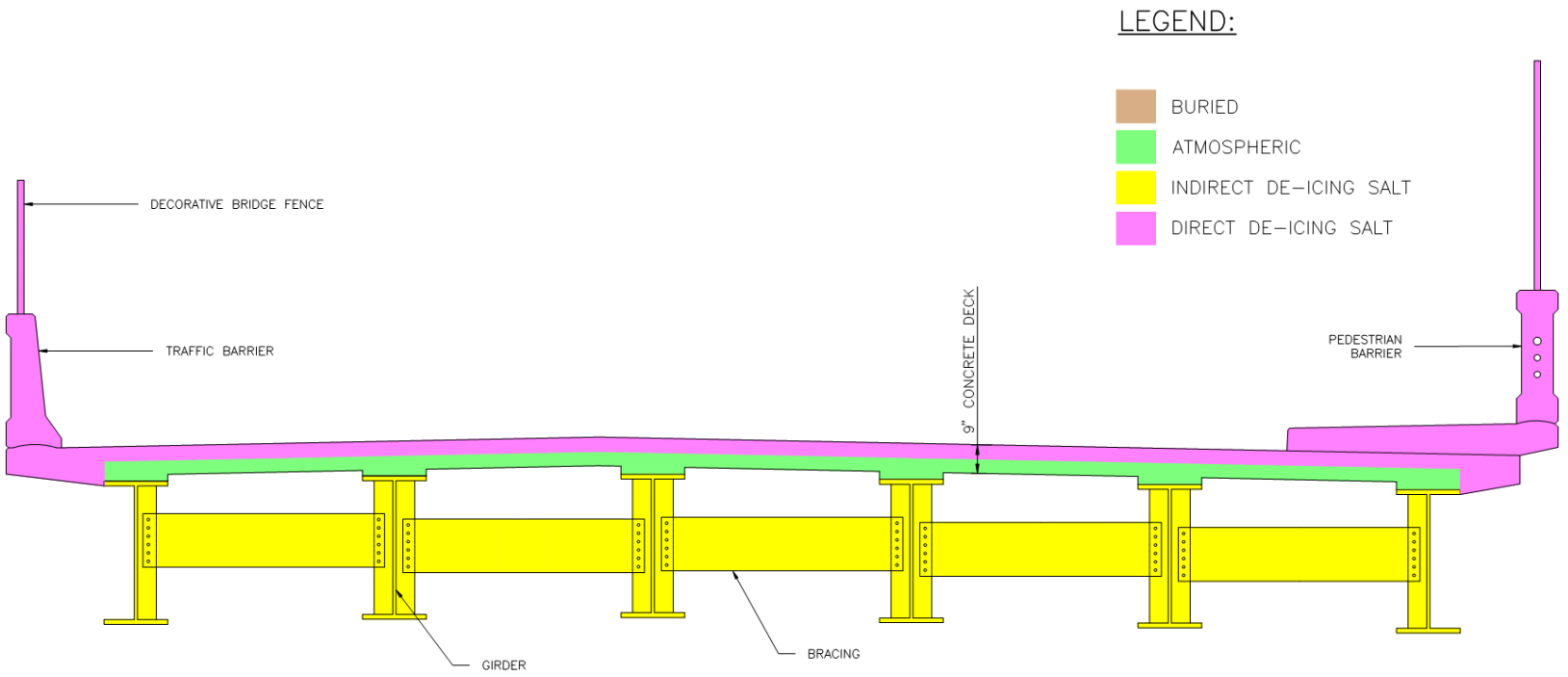
Exposure Zone	Examples of Elements	Exposure Conditions	Steel Corrosivity Category ISO 12944-2 [2]
Indirect De-icing Salts	Girders.	Alternating wetting and drying. Atmospheric O_2 and CO_2. Freeze/thaw with indirect exposure to de-icing salts, leakage from deck joints, temperature and humidity variations.	C4: Temperate zone, atmosphere with moderate salinity

Steel Corrosivity Categories for Bridge Components

Exposure Zone	Examples of Elements	Exposure Conditions	Steel Corrosivity Category ISO 12944-2 [2]
Direct De-icing Salts	Decorative fence.	Alternating wetting and drying. Atmospheric O2 and CO_2. Freeze/thaw with direct exposure to de-icing salts applications, temperature and humidity variations.	C5-M: Temperate zone, aggressive atmosphere

Exposure Zones Color Code

- Exposure zones for superstructure:



Deterioration Mitigation Methods

All mitigation design strategies are “Deemed to Satisfy”

Steel component	Exposure zone	Corrosivity category ISO 12944-2	Mitigation method
Steel H piles	Buried	lm3	Corrosion allowance
Girder	Indirect de-icing salts	C4	Painting
Decorative fence	Direct de-icing salts	C5-M*	Painting

Deterioration Mitigation References

- AASHTO LRFD Section 10.7.5
- FHWA Design and Construction of Driven Piles Foundations, V1 – Section 6.12.1
- FDOT Structures Design Guidelines – Section 3.1
- EN 1993-5, Eurocode 3: Design of Steel Structures, Part 5: Piling – Section 4.4

AASHTO LRFD 10.7.5

- Addresses soil conditions indicative of pile deterioration or corrosion
  - Resistivity less than 2,000 ohm-cm
  - pH less than 5.5
  - pH between 5.5 and 8.5 in soils with high organic content
  - Sulfate concentrations greater than 1,000 ppm
  - Landfills and cinder fills
  - Soils subject to mine or industrial drainage
- Does not provide guidance on corrosion rates and associated section loss

FHWA Design and Construction of Driven Pile Foundations, V1

- Section 6.12.1
  - Aggressive non-marine subsurface environment
    - Conservative rate - 0.003 in/year
    - For 75 year life = 75 x 0.003 in = 0.225 in
    - Unclear if this is a thickness reduction, or applied to each exposed face (x 2 = 0.45 in)
  - No recommendations for less aggressive environment
  - Recommends soil testing for pH and resistivity using AASHTO Standard R 27-01 – *Assessment of Corrosion of Steel Piling for Non-Marine Applications*

Florida DOT Structures Design Guidelines

Table 3.1-1Usage Limitations and Corrosion Mitigation Measures for Steel Piles and Wall Anchor Bars

Steel Component	Embedment	Corrosion Protection	Minimum Required Sacrificial Thickness (inches) and Usage Limitations Based on Substructure Environmental Classification and Pile/Wall Anchor Bar Location			
			Slightly Aggressive	Moderately Aggressive	Extremely Aggressive	
			Land and/or Water	Land and/or Water	Land	Water
Pipe and H-Piles	Completely Buried	None[1]	0.075	0.15	0.225[2]	Use Internally Redundant Pipe Piles Only, See ***SDG*** 3.1.F.2
	Partially Buried	***Specifications*** Section 560	0.09	0.18	0.27[2]	N/A
		None[1]	0.15	0.30	Use Internally Redundant Pipe Piles Only, See ***SDG*** 3.1.F.2	
Anchored or Cantilever Sheet Piles	All	***Specifications*** Section 560	0.045	0.09	0.135	
Wall Anchor Bars	All	See Footnote[3]	0.09	0.18	0.27	

Florida DOT Structures Design Guidelines

- Environmental Classification versus Corrosion Rate per side
  - For partially buried piles and wall anchor bars:
    - Slightly Aggressive: 0.001 inches/year
    - Moderately Aggressive 0.002 inches/year
    - Extremely Aggressive 0.003 inches/year
  - For completely buried piles:
    - Slightly Aggressive: 0.0005 inches/year
    - Moderately Aggressive 0.001 inches/year
    - Extremely Aggressive 0.0015 inches/year
  - Design Life – 75 years

Florida DOT Structures Design Guidelines

- H-Piles
  - HP 12 x 53 (flange and web thickness = 0.435 inch) required for strength and geotechnical requirements
  - Moderately aggressive environment (1400 ppm sulfates)
  - Fully buried
  - 0.001 inches/year x 75 years x 2 sides = 0.15 inch thickness loss
  - Required thickness for corrosion loss = 0.585 inch
  - Replace with HP 12 x 74 (flange = 0.610 inch, web = 0.605 inch)

EN 1993-5, Eurocode 3: Design of Steel Structures, Part 5: Piling

Table 4-1: Recommended value for the loss of thickness [mm] due to corrosion for piles and sheet piles in soils, with or without groundwater

Required design working life	5 years	25 years	50 years	75 years	100 years
Undisturbed natural soils (sand, silt, clay, schist, ...)	0,00	0,30	0,60	0,90	1,20
Polluted natural soils and industrial sites	0,15	0,75	1,50	2,25	3,00
Aggressive natural soils (swamp, marsh, peat, ...)	0,20	1,00	1,75	2,50	3,25
Non-compacted and non-aggressive fills (clay, schist, sand, silt, ...)	0,18	0,70	1,20	1,70	2,20
Non-compacted and aggressive fills (ashes, slag, ...)	0,50	2,00	3,25	4,50	5,75

2.25 mm = 0.09” per exposed face = 0.18” total

EN 1993-5, Eurocode 3: Design of Steel Structures, Part 5: Piling

- H-Piles
  - HP 12 x 53 (flange and web thickness = 0.435 inch) required for strength and geotechnical requirements
  - Polluted natural soils and industrial sites (1400 ppm sulfates)
  - 2.25 mm x 2 sides = 0.177 inch thickness loss
  - Required thickness for corrosion loss = 0.612 inch
  - Replace with HP 14 x 89 (flange and web = 0.615 inch)

Corrosion Allowance Summary

References	Total corrosion allowance for 75 years for fully buried H-Piles (2 sided exposure) in different exposure zones		
	Slightly Aggressive	Moderately Aggressive	Extremely Aggressive
FHWA Design and Construction of Driven Piles Foundations, V1 – Section 6.12.1	-	-	0.45" for fill or disturbed natural soils
FDOT Structures Design Guidelines – Section 3.1	0.075”	0.15"	0.225”
EN 1993-5, Eurocode 3: Design of Steel Structures, Part 5: Piling – Section 4.4	0.07” for undisturbed natural soils	0.18" for polluted natural soils and industrial sites	0.35" for non-compacted and aggressive fills

Protective Coatings

- All steel located in direct and indirect de-icing salts or atmospheric zone will be painted to prevent corrosion.

- Corrosion of steelwork will be prevented as long as the paint is properly maintained.

- Service life verification is driven by the service life of the coating system.

Service Life of Coating Systems

- Primary reference used for estimating coating system life

Paper No.
7422

Expected Service Life and Cost Considerations for Maintenance and New Construction Protective Coating Work

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Pittsburgh, PA 15275

Service Life of Coating Systems

- NACE Paper No. 7422 Includes a table of Estimated Service Life for 53 Coating Systems
  - Different corrosion exposure conditions
  - Various combinations of Acrylic, Alkyd, Epoxy, Epoxy Zinc, Organic and Inorganic Zinc, Metalizing, and Moisture Curing Polyurethane coats
  - Hand, Power Tool, and Sandblasted surface preparation
  - 1, 2, and 3 coat systems
  - Based on surveys of Coating Suppliers, Galvanizers, Steel Fabricators, Painting Contractors, and Owners

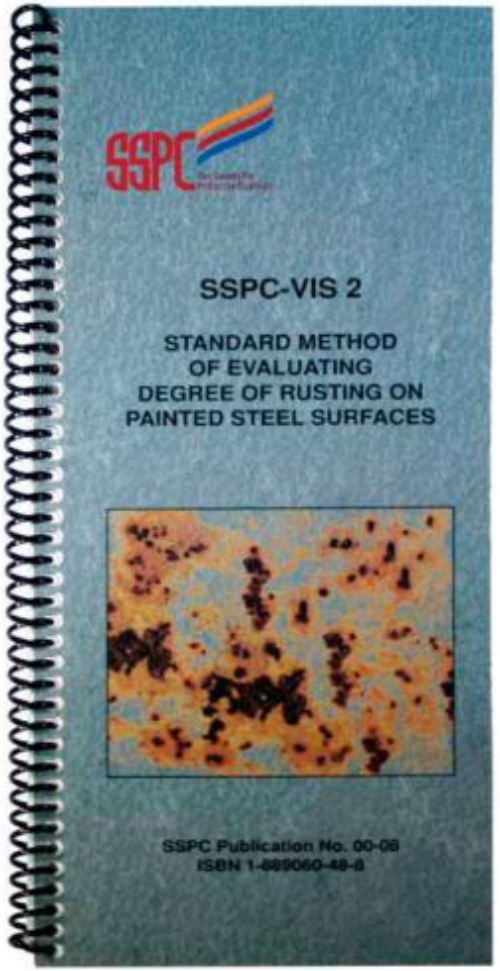
NACE 7422 Practical Service Lives

Table 1A: Estimated Service Life for Practical Maintenance Coating Systems for Atmospheric Exposure
(in years before first maintenance painting)[4]

Type	Coating Systems for Atmospheric Exposure (primer/midcoat/topcoat)	Surface Preparation[2]	Number of Coats	DFT Minimum (mils)	Service Life[1,3]			
					Mild (rural)/C2	Moderate (industrial)/C3	Severe (heavy industrial)/C5-I	Seacoast Heavy Industrial/C5-M
Acrylic	Acrylic Waterborne/Acrylic WB/ Acrylic WB	Hand/Power	3	6	12	8	5	5
Acrylic	Acrylic Waterborne/Acrylic WB/ Acrylic WB	Blast	3	6	17	12	9	9
Alkyd	Alkyd/Alkyd	Hand/Power	2	4	6	3	2	2
Alkyd	Alkyd/Alkyd/Alkyd (AWWA OCS-1C)	Blast	3	6	11	6	3	3
Alkyd	Alkyd/Alkyd/Urethane Alkyd	Blast	3	6	12	7	4	4
Alkyd	Alkyd/Alkyd/Silicone Alkyd (AWWA OCS-1D)	Blast	3	6	14	9	5	5
Epoxy	Surface Tolerant Epoxy (STE)	Hand/Power	1	5	12	8	5	5
Epoxy	Surface Tolerant Epoxy/STE	Hand/Power	2	10	17	12	9	9
Epoxy	Surface Tolerant Epoxy/STE	Blast	2	10	21	15	12	12

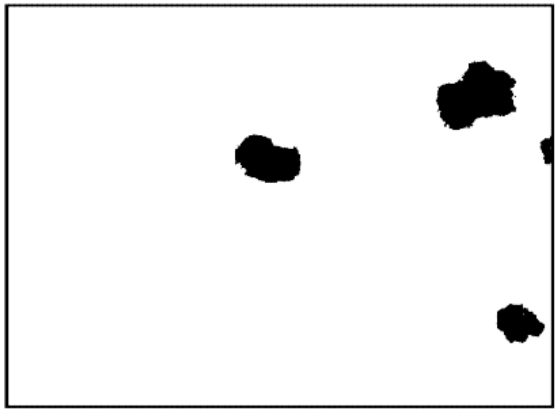
Service Life of Coating Systems

- Practical Life
  - Time until 5-10% coating breakdown occurs and active rusting of the substrate is present
  - Corresponds to rust scale grade 4 in accordance with Steel Structures Painting Council, SSPC-VIS 2 (also ASTM D610)



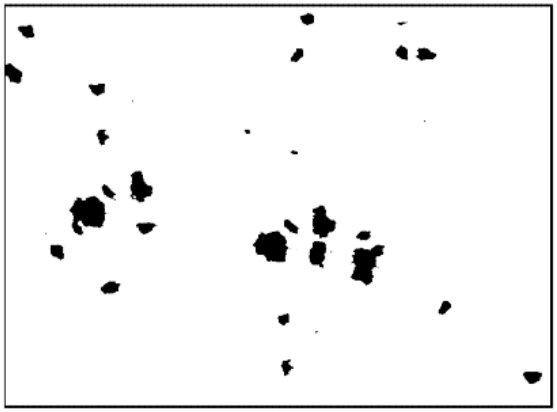
Rust Grades 5 (3%) and 4 (10%)

S-Spot



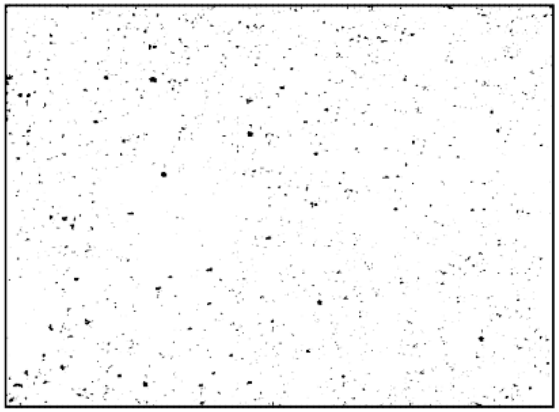
Rust Grade 5-S, 3% Rusted

G-General

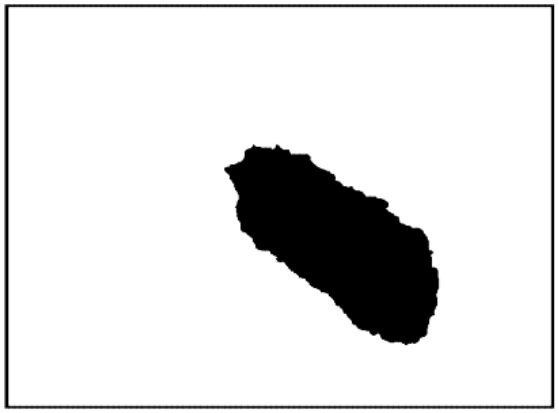


Rust Grade 5-G, 3% Rusted

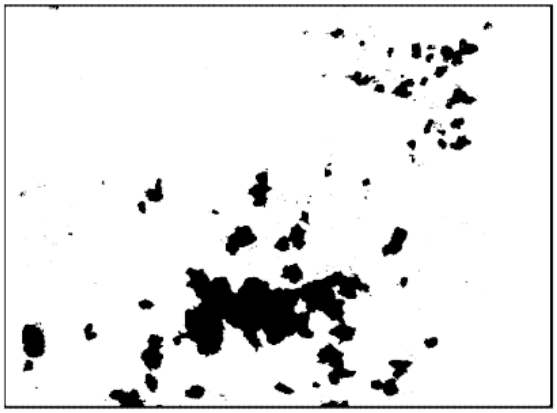
P-Pinpoint



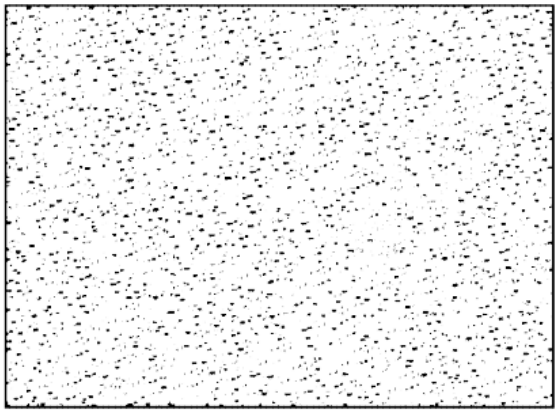
Rust Grade 5-P, 3% Rusted



Rust Grade 4-S, 10% Rusted



Rust Grade 4-G, 10% Rusted



Rust Grade 4-P, 10% Rusted

NACE 7422 Painting Practices

- Spot Touch-Up and Repair is when first time coating repairs are made and occurs at the Practical Life (P)
- Maintenance Repaint (M) includes spot priming and a full overcoat
- Full Repaint (F) involves total coating removal and replacement and marks the actual end of service life

Operation	Painting occurs in year
Original Painting	0
Spot Touch-Up and Repair	Practical life (P)
Maintenance Repaint	M = P x 133%
Full Repaint	F = P x 183%

NACE 7422 Paint Systems

- Practical lives are provided for two different coating systems for corrosivity categories C3 and C5-M
- Category C4 Practical Life is average of C3 and C5-M

Paint system*	Surface preparation **	No. of coats	Min. DFT*** (mils)	Corrosivity category ISO 12944-2		
				C3	C4	C5-M
Inorganic zinc/ Epoxy/ Polyurethane	Blast	3	11	21	18	15
Organic zinc/ Epoxy/ Polyurethane	Blast	3	6	18	15	12

Design of Paint System

- Summary of time until maintenance replacement and full repaint is determined for the different coated steel components:

Component	Paint system	Touch-up (years)		Maintenance Repaint (years)		Full Repaint (years)	
		C4	C5-M	C4	C5-M	C4	C5-M
Girder	Inorganic Zinc/ Epoxy/ Polyurethane	18	-	24	-	33	-
Decorative Fence		-	15	-	20	-	27
Girder	Organic Zinc/ Epoxy/ Polyurethane	15	-	20	-	27	-
Decorative Fence		-	12	-	16	-	22

Considerations for Other Elements

- Fixed Bearings – Metal Rocker
  - Bearing Plate – Galvanized
  - Rocker Plate – Epoxy Coating System
- Expansion Joints – Strip Seal
  - Metal Extrusion
  - Elastomeric Seals

Questions?

Implementation Leads:

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Resource: AASHTO's R19A Product Page

- http://shrp2.transportation.org/Pages/ServiceLifeDesignforBridges.aspx