Modern Corrosion Protection Systems

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Outline

1. The “Toolbox” of Corrosion Protection Systems
2. Detailing Consideration
3. Performance Expectations
4. Cost Considerations
Corrosion Mechanism and Mitigation

**BARRIER PROTECTION**
Isolate the anode/cathode from electrolyte

**CATHODIC PROTECTION**
Provide sacrificial element
Toolbox

Engineer’s Arsenal for corrosion protection
- UWS
- Liquid Applied Coatings
- Thermal Spray Coatings
- Hot-Dip Galvanizing

Toolbox – Uncoated Weathering Steel (UWS)

From ASTM A709 - 2018

<table>
<thead>
<tr>
<th>Grade</th>
<th>Yield Strength (ksi)</th>
</tr>
</thead>
<tbody>
<tr>
<td>36</td>
<td>36</td>
</tr>
<tr>
<td>50</td>
<td>50</td>
</tr>
<tr>
<td>50S</td>
<td>50</td>
</tr>
<tr>
<td>50W</td>
<td>50</td>
</tr>
<tr>
<td>HPS 50W</td>
<td>50</td>
</tr>
<tr>
<td>HPS 70W</td>
<td>70</td>
</tr>
<tr>
<td>HPS 100W</td>
<td>100</td>
</tr>
<tr>
<td>50CR</td>
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<td>QST 50</td>
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<td>QST 65</td>
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<tr>
<td>QST 70</td>
<td>70</td>
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</tbody>
</table>

Grade designations ending in “W” are weathering grades

i.e. they develop a stable rust-layer (aka. “patina”) that provides barrier corrosion protection
Toolbox – Uncoated Weathering Steel (UWS)

Well formed “patina” has a dark-chocolate, almost purple hue. Does have fine pinholes too.

Source: FHWA

Just “barrier” protection

Toolbox – Uncoated Weathering Steel

ASTM A709 Grade 50CR

- ~11% chrome
- Ferrite / tempered martensite (formally it’s a martensitic stainless steel)
- Develops a brown colored patina like weathering steel

6 yr. exposure
McLean, VA (vertical)

3 yr. exposure
Hampton Roads, VA (horizontal)

9 mo. and 3 yr. (inset)
exposure North Topsail, NC (vertical)

Source: FHWA

Source: VDOT

Source: FHWA

Source: Crampton et. al., 2013
Toolbox - Liquid Applied Coatings

Primarily “barrier” protection, zinc-rich primer provides “cathodic” protection if exposed.

Toolbox - Liquid Applied Coatings

Inorganic zinc (IOZ) vs. Organic Zinc (OZ)

IOZ
Zinc in ethyl silicate binder

OZ
Zinc in epoxy binder

Source: FHWA
**Toolbox - Liquid Applied Coatings**

![Graph showing coating thickness and dry/recoat time](image)

Source: Random selection of qualified systems from http://data.ntpep.org/SSC (except for single-coat IOZ)


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**Toolbox - Thermal Spray Coatings (TSC)**

**Common Alloys**

- **Aluminum**
  - 85/15 Zn/Al: Most corrosion resistance
  - Balance between the two

- **Zinc**: Most application friendly

Source: FHWA

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Source: R. Kogler
Toolbox - Thermal Spray Coatings (TSC)

TSC are porous – sealing typically performed

Sealers are low-viscosity, liquid applied coatings meant to penetrate through pores

Mostly “cathodic” protection
**Toolbox - Hot-Dip Galvanizing**

Dipping steel in ~840°F zinc creates chemical bond

*Both “barrier” and “cathodic” protection*

**Detailing Considerations**

Where does the water flow?

Always ask if your detailing will be free draining, or cause trapping/ponding...
Detailing Considerations UWS

FHWA Technical Advisory 5140.22
Consider UWS “with caution” if:

Environment
1. Marine coastal areas. How far?
2. Frequent high rainfall, high humidity or How much?
   persistent fog (condensing conditions).
3. Industrial areas where concentrated chemical How far, what type?
fumes may drift directly onto the structure.

Location
1. Grade separations in “tunnel-like” conditions. How high/wide/depth?
2. Low level water crossings. How often?
   a. ≤ 10 ft. over stagnant, sheltered water.
   b. ≤ 8 ft. over moving water.

Detailing Considerations UWS – Tunnel Effect

Theorized to be driven by ADT, thus manifest in urban areas
Detailing Considerations UWS

1. Eliminate bridge joints where possible.
2. Use a trough under the deck joint to divert water away.
3. Eliminate details that serve as water and debris "traps".
4. Minimize the number of bridge deck scuppers.
5. "Seal" box members when possible, or provide holes for drainage/circulation.
6. Cover openings in unsealed boxes.
7. Seal overlapping surfaces exposed to water.

IRONICALLY, none of this is unique to UWS

8. Paint within 1.5(girder depth) from bridge joints.
Detailing Considerations UWS

9. Protect substructure to minimize staining.

10. Do not use welded drip bars where fatigue stresses may be critical.
Performance Expectations

Not easy to answer!

1) Systems are qualified by accelerated “torture” tests
2) Bridges exist in rural, industrial, and marine environments
3) Right or wrong, perception rules the world
4) Workmanship is a huge factor!
Performance Expectations

Exactly what an Engineer would need in design.

*Next 10 slides hopefully show why not*

<table>
<thead>
<tr>
<th>Coating System</th>
<th>Mild (rural)</th>
<th>Moderate (industrial)</th>
<th>Severe (Industrial)</th>
<th>Severe (marine)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3-coat (OZ / E / U)</td>
<td>27</td>
<td>18</td>
<td>12</td>
<td>12</td>
</tr>
<tr>
<td>3-coat (IOZ / E / U)</td>
<td>30</td>
<td>21</td>
<td>15</td>
<td>15</td>
</tr>
<tr>
<td>2-coat (OZ / Polyaspartic)</td>
<td>24</td>
<td>17</td>
<td>12</td>
<td>12</td>
</tr>
<tr>
<td>1-coat IOZ</td>
<td>27</td>
<td>17</td>
<td>12</td>
<td>12</td>
</tr>
<tr>
<td>TSC Zn</td>
<td>33</td>
<td>22</td>
<td>16</td>
<td>16</td>
</tr>
<tr>
<td>Hot-Dip Galv. (4 mil)</td>
<td>100</td>
<td>90</td>
<td>72</td>
<td>72</td>
</tr>
<tr>
<td>UWS</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

Source:

Performance Expectations – UWS

AASHTO LRFD BDS Article 6.7.3
“Where the metal is expected to be exposed to severe corrosive influences ... sacrificial metal thickness shall be specified”

Source:

Also see:
Performance Expectations – UWS

** Using 2016 NBI data and including GA, NJ, IN, OH, NV, and HI **


Performance Expectations – 50CR

Rochester, NY Moore Dr. over I-394

A709 Grade 50CR (4 years exposure) 0.58 mil/yr

A709 Grade 50W (8 years exposure) 2.43 mil/yr

Source: FHWA

Mathis Bridge Project
- 66 spans over intercoastal between Seaside Heights and Toms River.
- Vertical clearance 5 to 33 ft. over salt water.
- In 1987, 47 different coatings systems applied to individual spans.
- Evaluations performed at 1, 8, and 20 years.

Source:
Performance Expectations – Liquid Applied Coating

**2-Coat Systems**
- AASHTO NTPEP accelerated testing found 2-coat polyaspartic and polysiloxane were equivalent to 3-coat systems
- Max. 18 years in-service experience
- Used in VA, MA, CT, MI, MD, PA, NC, ME, and KY
- CT found 30% reduction in application cost

Source: Helsel et. al. (2014) estimates 12-24 years for 5-10% coating failure

Source:
- AASHTO NTPEP DataMine
Performance Expectations – Liquid Applied Coating

1-Coat IOZ
- I only know of FL and TX accelerated testing
- Used on bridges in WA, WV and MO (probably more)
- The preferred system at NASA Kennedy

Helsel et. al. (2014) estimates 12-27 years for 5-10% coating failure

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Performance Expectations – Zinc

<table>
<thead>
<tr>
<th>Location</th>
<th>Macro-Environment</th>
<th>Zinc Loss (mils per side per 2 yr.)</th>
<th>Zinc Life for 4 mil initial coating (years)</th>
<th>Zinc Life for 12 mil initial coating (years)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Phoenix, AZ</td>
<td>Rural</td>
<td>0.02</td>
<td>400</td>
<td>1200</td>
</tr>
<tr>
<td>South Bend, PA</td>
<td>Semi-Rural</td>
<td>0.14</td>
<td>57</td>
<td>171</td>
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<tr>
<td>Columbus, OH</td>
<td>Urban</td>
<td>0.17</td>
<td>47</td>
<td>141</td>
</tr>
<tr>
<td>Bayonne, NJ</td>
<td>Industrial</td>
<td>0.38</td>
<td>21</td>
<td>63</td>
</tr>
<tr>
<td>East Chicago, IN</td>
<td>Industrial</td>
<td>0.14</td>
<td>57</td>
<td>171</td>
</tr>
<tr>
<td>Brazos River, TX</td>
<td>Ind. Marine</td>
<td>0.14</td>
<td>57</td>
<td>171</td>
</tr>
<tr>
<td>Point Reyes, CA</td>
<td>Marine</td>
<td>0.12</td>
<td>67</td>
<td>200</td>
</tr>
<tr>
<td>Kure Beach, NC</td>
<td>Marine</td>
<td>0.16</td>
<td>50</td>
<td>150</td>
</tr>
<tr>
<td>Kure Beach, NC</td>
<td>Marine</td>
<td>0.50</td>
<td>16</td>
<td>48</td>
</tr>
<tr>
<td>Cape Kennedy, FL</td>
<td>Marine</td>
<td>0.09</td>
<td>89</td>
<td>267</td>
</tr>
<tr>
<td>Cape Kennedy, FL</td>
<td>Marine</td>
<td>0.33</td>
<td>24</td>
<td>73</td>
</tr>
</tbody>
</table>

Performance Expectations – Thermal Spray Coatings

19-yr American Welding Society Study (1953)
• Placed panels at ASTM sites
  [Brazos River, TX; Columbus, OH; East Chicago, IN; Kure Beach 80 feet, NC; Kure Beach 800 feet, NC; Bayonne, NJ; Point Reyes, CA]
• 3 mils of Al, no base metal attack
• 9 mils of Zn, no base metal attack

Cambridge University Study (1951)
• 53-years of exposure at Kure Beach (800 ft.)
  • 3 mils of Al rust-free
  • 3 mils of Zn rust-free

AASHTO/NSBA S8.2
8 mil minimum

Helsel et. al. (2014) estimates 33 years for 5-10% coating failure

Steel Cost
From March 2013

![Steel Cost Graph]

Source: FHWA

A709 Gr. 50CR
A709 HPS 70W
A709 HPS 100W
A709 Gr. 50
A709 Gr. 50W
A709 HPS 50W
Lean Duplex (UR2202)
Duplex (2205/A240)

Relative Pricing of Plate ($/ton)
2013 Coating Cost

How much to fabricate this girder?

Source: FHWA

2013 Coating Cost

Relative % cost increase over ASTM A709 Grade 50 (unpainted)

Four fabricators reporting
2020 Coating Cost

Relative % increase over ASTM A709 Grade 50W (uncoated)

- 5 different fabricators east of the Mississippi River
- 5 different bridges
  - 2 span (130 tons)
  - 1 span (430 tons)
  - 1 span (119 tons)
  - 4 span (900 tons)
  - 3 span (1040 tons)

Source: NSBA

Ongoing/Planned NSBA Work

Coatings Performance Study (on-going)
- Research would bring more confidence in corrosion protection systems
- Would provide better guidance on when to prescribe various systems and associated costs.

Durability Design Guide (planned)
- In addition to specifying the corrosion protection system, this guide would also address other parts of the bridge that can adversely affect lifespan.
THE BASICS OF STEEL BRIDGE DESIGN WORKSHOP