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Steel Bridge Corrosion Prevention and Mitigation Strategies

A Literature Review

August, 2019

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Technical Report Document Page

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7. Abstract:

Corrosion in steel bridges exposed to chloride attack from exposure to marine environments or de-icing salts is a significant issue which decreases structural integrity and increases maintenance requirements. Steel bridges exposed to these conditions require regular inspection, maintenance and rehabilitation, which drastically increases life-cycle costs.

This report provides a comprehensive literature review which highlights important issues related to corrosion in steel bridges with the objective of identifying shortcomings in current practice in Pennsylvania and identifying novel methods for further study and/or possible implementation. First, common forms of corrosion in steel infrastructure are reviewed. Next, corrosion prevention, mitigation and repair strategies are discussed including strategies currently utilized in Pennsylvania and by other state DOTs. Finally, promising corrosion prevention, mitigation and repair solutions are recommended. These solutions include: (1) implementing duplex coating systems, (2) identifying and evaluating novel approaches to prevent and mitigate crevice corrosion, (3) developing AI enabled corrosion monitoring methodologies, (4) eliminating joints in existing structures using debonded link slabs, and (5) further developing in-situ repair strategies for corrosion damaged components.

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Steel Bridge Corrosion Prevention and Mitigation Strategies: Literature Review

August 2019

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IRISE

The Impactful Resilient Infrastructure Science & Engineering consortium was established in the Department of Civil and Environmental Engineering in the Swanson School of Engineering at the University of Pittsburgh to address the challenges associated with aging transportation infrastructure. IRISE is addressing these challenges with a comprehensive approach that includes knowledge gathering, decision making, material durability and structural repair. It features a collaborative effort among the public agencies that own and operate the infrastructure, the private companies that design and build it and the academic community to develop creative solutions that can be implemented to meet the needs of its members. To learn more, visit: https://www.engineering.pitt.edu/irise/.

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The views and conclusions contained in this document are those of the authors and should not be interpreted as representing official policies, either expressed or implied, of the Pennsylvania Department of Transportation, the Pennsylvania Turnpike Commission, Allegheny County, Golden Triangle Construction, or Michael Baker International.

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1 Introduction

Bridges play an important role in the transportation network in the US, and their long-term performance and integrity are critical for residential and commercial activities and the economy. According to National Bridge Inventory (NBI) 2017 data [1], there were 616,096 highway bridges in the US in 2017, with a total of 22,737 bridges (about 3.7%) in Pennsylvania. Among these bridges, many are constructed primarily of steel, as indicated in Figure 1 and Figure 2, which show that steel bridges account about 1/3 of bridges in the US and 45% of the deck area.

There are a significant number of substandard bridges currently in use in the US. According to the ASCE annual infrastructure report card, 9.1% of highway bridges in the US are in poor condition, with 3770 poor bridges in Pennsylvania alone [2]. In addition, 40% of highway bridges in the US are approaching or have exceeded their design life of 50 years as illustrated in Figure 3. Maintaining and repairing these aging bridges is an extremely challenging endeavor, as they are subjected to continuous service and environmental loading.

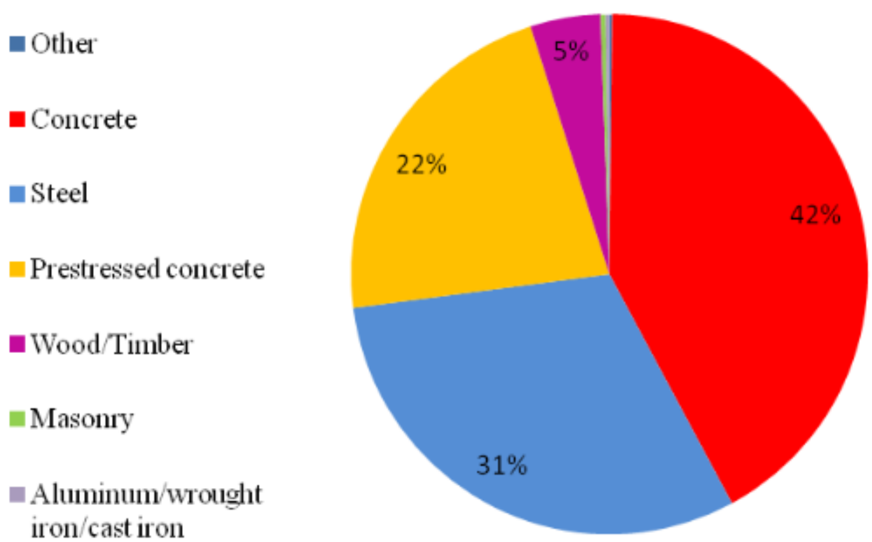


Figure 1 Distribution of Materials Used for Main Spans of US Highway Bridges by Number [3]

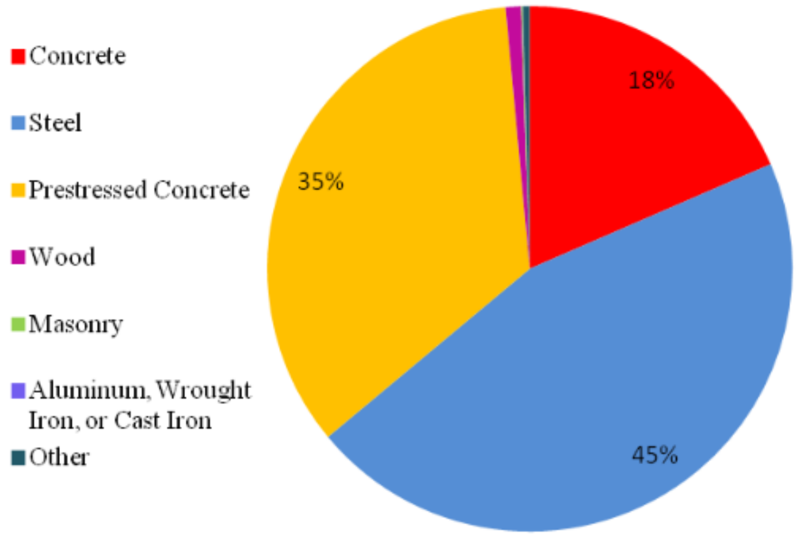


Figure 2. Distribution of Materials Used for Main Spans of US Highway Bridges, by Deck Area [3]

Corrosion is a primary cause of deterioration in steel bridges in marine environments and regions where chloride-based de-icers are commonly used. The performance of steel bridges to resist corrosion is highly associated with the surrounding “macro-” and “micro-” environments. The macro-environment is defined as local weather conditions, such as rainfall, sunshine, temperature, humidity, chloride level, and pollution. By contrast, the micro-environment accounts for the bridge design and construction, material, orientation, debris formation, etc. [4]. In general, the micro-environment plays a larger role in the corrosion-specific behaviors of steel components; however, the complex nature of both the macro- and micro-environments make it very difficult to develop a reliable and universal corrosion-protection solution. In current practice, corrosion-protection systems are selected according to a range of factors that include cost, fabrication, long-term performance, and the expected maintenance based on the environmental conditions.

The objective of this report is to provide a comprehensive literature review regarding corrosion prevention, mitigation and rehabilitation for steel bridges. First, common forms of corrosion in steel infrastructure are reviewed. Next, common corrosion prevention and rehabilitation strategies are discussed including strategies currently utilized in Pennsylvania and by other state

DOTs. Finally, promising corrosion protection, mitigation, monitoring and rehabilitation solutions are suggested for further study and/or implementation in Pennsylvania.

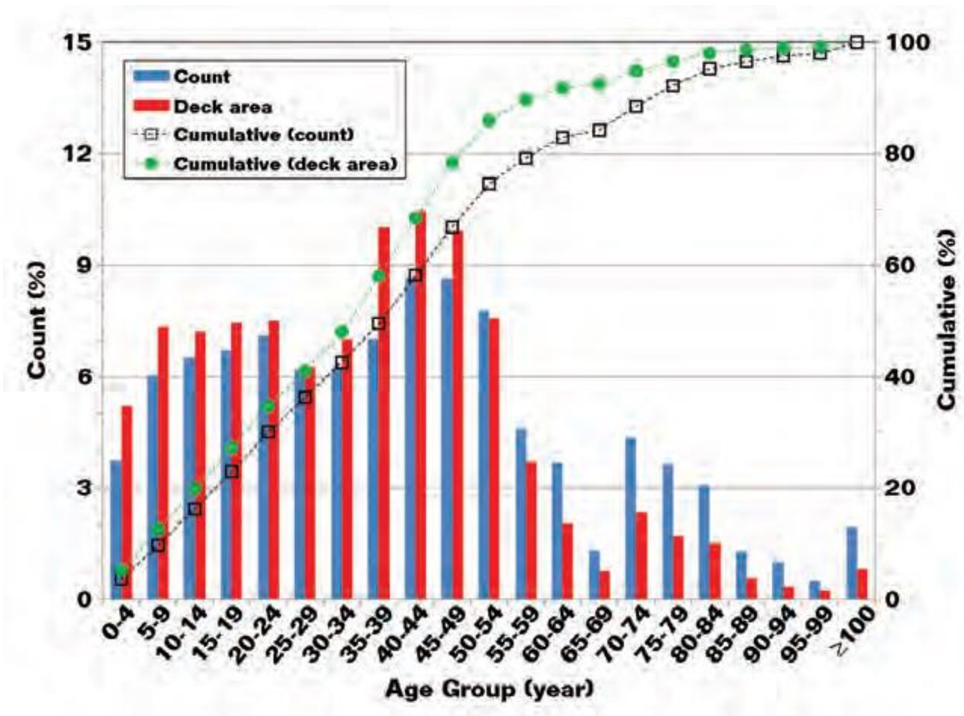


Figure 3. Distribution of Bridges by Age [5]

2 Forms of Corrosion Common to Steel Bridges

Corrosion is a primary cause of deterioration in steel infrastructure. The performance of steel bridges to resist corrosion is highly associated with its surrounding environments – with the rate of corrosion increasing in the presence of chloride ions or other corrosive chemicals. This section will summarize common modes of corrosion observed in steel bridges, and the macro- and micro-environments which lead to these modes of degradation.

2.1 Forms of Corrosion

Eight forms of corrosion are common in steel infrastructure subjected to environmental exposures [6]: (1) uniform corrosion; (2) galvanic corrosion; (3) crevice corrosion; underfill corrosion; (4) pitting; (5) intergranular corrosion; (6) selective leaching; (7) erosion corrosion (fretting); and (8) stress corrosion. The following sections discuss these forms of corrosion and the locations where they are commonly found on bridges.

2.1.1 Uniform Corrosion

Uniform corrosion is the global thinning of steel components within a bridge. This generally benign form of corrosion is observed as a uniform rust layer which can be readily identified, as illustrated in Figure 4. One obvious example of uniform corrosion in steel bridges is the formation of a rather tenacious oxide product on the surface of weathering steels (*e.g.*,COR-TEN steel). In this instance, a progression of corrosion occurs on the exposed steel until the surface is covered by its own corrosion product, which protects the steel from accelerated additional corrosion. Uniform corrosion is commonly found on steel bridge plates and shapes with large surface areas that can be uniformly attacked, including girder webs, vertical gusset plates, and trusses. Note that uniform corrosion generally occurs on bridges (or bridge components) which do not accumulate moisture.

Figure 4. Bridge with Weathering Steel Girders [7]

2.1.2 Galvanic Corrosion

Galvanic corrosion (*e.g.*, Figure 5) is caused when dis-similar metals are placed together in the presence of an electrolyte. The difference in the galvanic potential of the two metals results in a flow of electrons from one metal (the anode – the metal or region that corrodes) to the other metal (the cathode). The rate and severity of galvanic corrosion depends on the difference in galvanic potential between the two metals as well as the ratio of the exposed metal areas. In steel bridges, galvanic corrosion is commonly found where non-structural components come into contact with steel components. PennDOT has specifically identified galvanic corrosion issues with light fixtures, u-bolts on sign structures, and expansion dam troughs. Galavanic corrosion is commonly utilized to protect steel components from corroding through the application of zinc paint, which serves as a protective anodic coating that protects the cathodic steel.

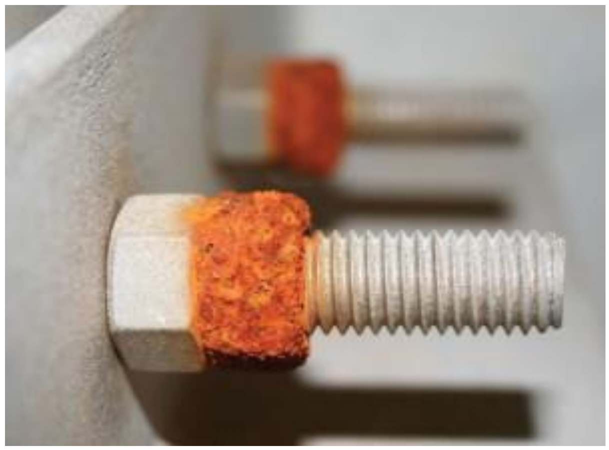


Figure 5. Galvanic Corrosion Resulting from Different Galvanic Potential in the top Nut and Surrounding Metal [8]

2.1.3 Crevice Corrosion

Crevice corrosion is a localized mode of attack that occurs at or immediately adjacent to a gap or crevice between two joining surfaces. Crevice corrosion is caused by differences in the micro-environments inside and outside the crevice, such as concentrations of oxygen, metallic ions, and/or chlorides. Crevice corrosion is one of the most common forms of corrosion found in steel bridges. It occurs, for example, along the edges of built-up members (Figure 6), between lacing bars, and between closely spaced eyebars. Crevice corrosion can also occur between dissimilar materials (*e.g.*, between steel girders and a wooden deck).

There are two specific types of crevice corrosion common in steel infrastructures: deposit attack and underfilm corrosion. *Deposit attack* occurs due to a build-up of debris deposits which carry moisture on steel components within the bridge. The debris can consist of a variety of materials including coal dust in mining areas, grain or other byproducts in agricultural regions, salts from deicers, bird nests and bird waste, and even build-ups of pack rust. *Underfilm corrosion* is a type of crevice corrosion that develops between surface treatments and the base metal. This form of corrosion typically develops in locations where the surface treatment has been damaged, and eventually causes that surface treatment to debond from the base metal.

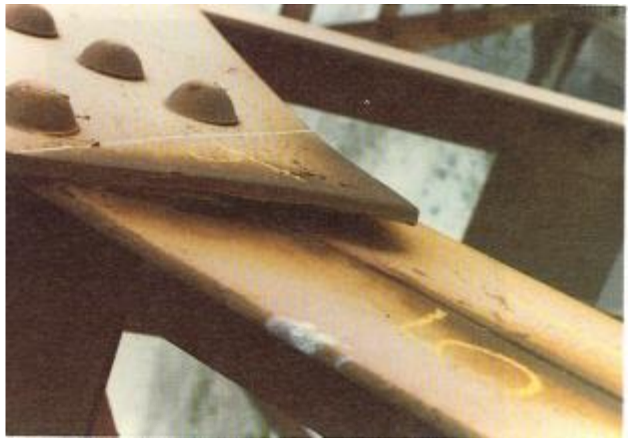


Figure 6. Crevice Corrosion, which has Caused Pack Rust and Bending Under a Gusset Plate [6]

2.1.4 Pitting Corrosion

Pitting corrosion is a form of localized corrosion which results in deep penetrations into the surface of the base metal, as indicated in Figure 7. It occurs where chemical or physical changes occur in the base-metal, at flaws or damaged regions in coatings, or in regions where foreign material has been deposited under the overcoating. In steel bridges, pitting is commonly found where debris traps moisture on the surface of the base metal and/or in regions where protective coatings are vulnerable to damage. Pitting is considered to be a stress-exacerbating mode of corrosion that can cause abrupt failures at relatively low loading conditions.

Figure 7. Pitting of Girder Web and Bottom Flange [6]

2.1.5 Intergranular Corrosion

Intergranular corrosion is a preferential mode of corrosion along grain and/or interphase boundaries of the metal. The most common form of intergranular corrosion in steel bridges is weld decay (shown in Figure 8), which is the localized deterioration of weld metal or base metal in welded regions due to a decrease in corrosion resistance in the heat-affected zone of the weld. Weld decay is not common in steel components that have been shop-fabricated in a controlled environment in which the weld heat can be carefully monitored.

2.1.6 Selective Leaching / De-alloying

Selective leaching (also referred to as de-alloying) is a corrosion form in which one component or more of the steel is selectively removed, which may result in a deterioration properties, such as the mechanical properties of the steel. This type of corrosion is not commonly found in steel bridges, however it has occasionally been observed in the form of zinc leaching from bronze bearings.

Figure 8. Weld Decay Corrosion [6]

2.1.7 Erosion Corrosion

Erosion corrosion is the degradation of a material surface due to mechanical action in the form of a fluid flow over the surface (with sufficient velocity to remove surface corrosion product) or relative motion between two metal components in close contact under a load (referred to as fretting corrosion). Fretting corrosion is the most common type of erosion corrosion in steel bridges. Fretting refers to the rubbing contact of two surfaces, where surface oxidation forms, is broken by the rubbing, and reforms. In bridges, fretting corrosion can be found at strength-relief joints, at stringer ends having sliding-contact surfaces (Figure 9) and at locations where vibrations occur.

Figure 9. Fretting Corrosion at Stringer Joint [6]

2.1.8 Stress Corrosion

Stress-corrosion cracking (shown in Figure 10) is the growth of a tensile crack in steel components in a corrosive environment. In stress-corrosion cracking, corrosion causes the development of discontinuities in the metal, which leads to crack formation. This type of corrosion is extremely dangerous, as it can lead to sudden, non-ductile failure in normally ductile materials. Stress-corrosion cracking is rare in steel bridges, but can occur in bridges in extreme environmental conditions, such as those found in industrial areas or marine environments.

Corrosion fatigue cracking is a fatigue-type cracking that is analogous to stress-corrosion cracking, where corrosion creates stress discontinuities in members which undergo repeated stresses in a corrosive environment.

Figure 10. Stress Corrosion Cracking in Steel Pipe [6]

2.2 Common Forms of Corrosion in Girder-Type Bridges

Many of the different forms of corrosion are often found within a single bridge, and often multiple forms of corrosion develop at the same location within a bridge. The form and location of the corrosion are primarily a function of the micro-environment resulting from the design of specific components within the bridge. Structural steel elements in bridges that are generally susceptible to corrosion are summarized in Figure 11.

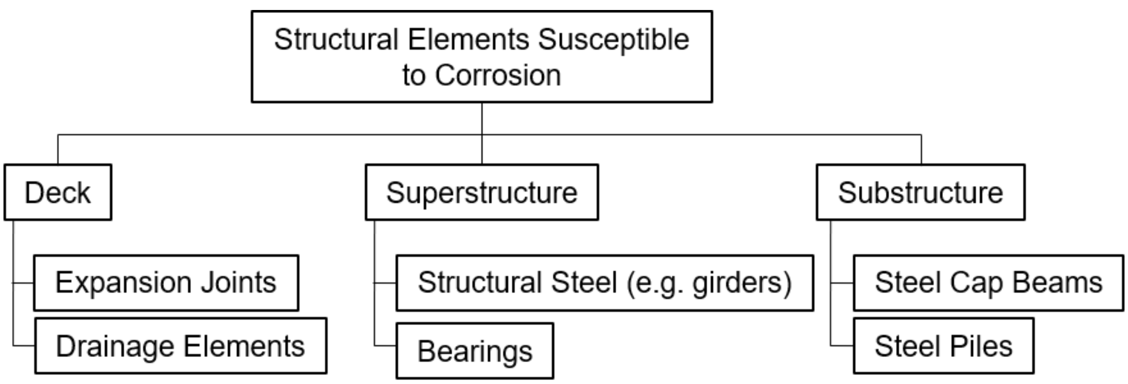


Figure 11. Steel Bridge Components Susceptible to Corrosion (Adapted from [9])

Figure 12 -Figure 14 are provided to illustrate typical forms and locations of corrosion in steel bridges. The focus here is superstructure elements on girder-type bridges. A more complete overview of common corrosion forms in steel bridges, including corrosion in truss and suspension bridges and descriptions of corrosion in substructure elements can be found in [6].

Figure 12 shows corrosion modes commonly observed on stringer spans. Crevice corrosion can occur between the concrete deck and steel stringer. This occurrence is common when the concrete is cracked and allows the ingress of water through the deck to the stringer. Deposit corrosion is common at flange-to-web joints or at stiffener joints, where debris can become trapped. This is extremely common below joints at the span ends.

Figure 13 shows regions of possible corrosion attack on through-girder spans. Crevice corrosion is common between mating metal surfaces (*e.g.*, between stiffener angles and the girder web as indicated in Section AA in Figure 13). Pitting corrosion is common in regions where the steel is repeatedly splashed with water from the roadway, as indicated in Section AA in Figure 13. Deposit corrosion is also common in regions where debris may build up, as indicated in Detail B in Figure 13.

Figure 14 shows potential locations of corrosion on deck-girder bridges. Pitting is common in regions where moisture can accumulate such as at web stiffener-to-bottom flange joints. This is especially common under expansion joints, where water can drain through the deck directly onto the girders. Uniform corrosion may develop on the girder webs, as they are exposed to moisture but do not allow water accumulation. The bearings of deck girder bridges should also be checked regularly to ensure corrosion induced bearing freezing does not develop.

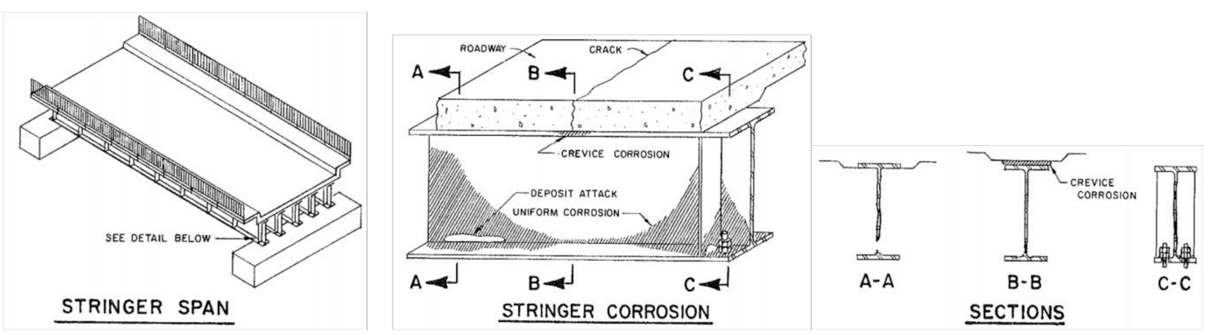


Figure 12. Common Corrosion Modes in Stringer Span Bridges [6]

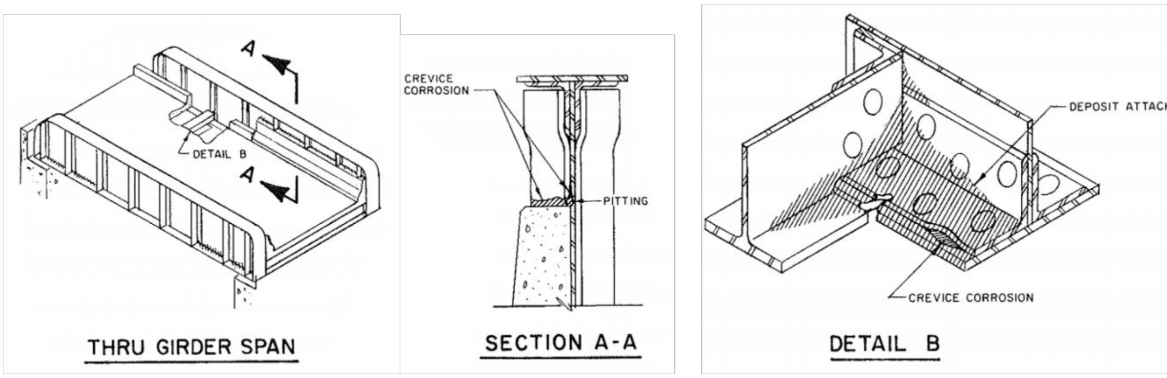


Figure 13. Common Corrosion in Through Girder Span Bridges [6]

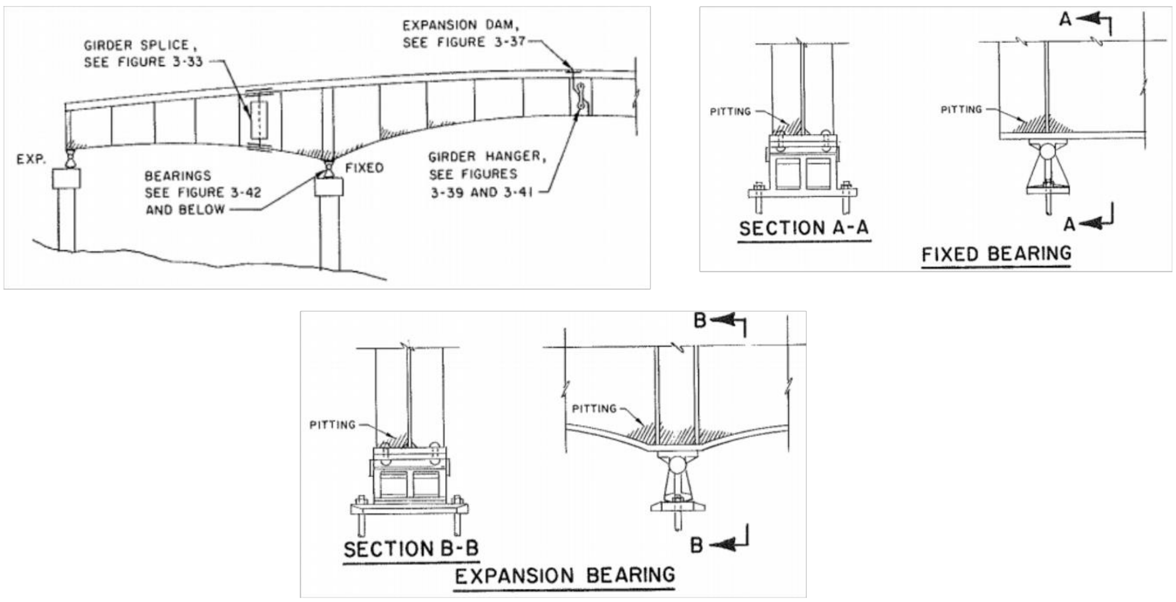


Figure 14. Common Corrosion Patterns in Deck Girder Bridges [6]

3 Corrosion Protection Approaches for Steel Bridges

The complexity of the macro- and micro-environments makes it extremely challenging to develop a reliable and universal corrosion-protection solution for steel infrastructure. This section summarizes corrosion-prevention methods commonly implemented by departments of transportation from the 1970's through 2019. A summary of several common methods are summarized in Figure 15. Note that surface treatments and material specifications are the focus of this summary (as opposed to corrosion resistant detailing).

Traditionally, the macro-environment is classified as: mild (rural); moderate (industrial); or severe (marine) [4]. These classifications do not necessarily provide an accurate estimate of the actual conditions which surround the structure, but serve as a starting point to provide a general guidance for developing a corrosion mitigation strategy. The three classifications are defined as follows:

> *Mild (Rural):* Little to no exposure to natural airborne and applied deicing salts. The surrounding environment has limited pollution from airborne and road surface, such as deicing.
>
> *Moderate (Industrial)*: An environment in which a bridge is exposed to some (occasional) airborne salts or deicing salt runoff. This is a broad macro-environment category which includes many non-coastal bridges which receive de-icing treatment irregularly.
>
> *Severe (Marine)*: High salt content from proximity to seacoast or from deicing salt, high humidity and moisture. The locations typically include coastal regions and inland area with severe weather patterns where large amounts of deicer is used.

Many bridges do not fall distinctly into one single category, and even within the same category, the corrosion behavior of different bridges will vary. E.g. superstructure components subjected to direct application of deicers may fall under the *serve* category, while components exposed to spray from passing trucks may only fall under the *moderate* category depending on the amount of truck traffic and frequency of deicer application. In regions with heavy deicer use and heavy truck traffic, components subjected to spray may fall under the *severe* category.

In standard practice, the corrosion protection approach is selected based on cost, fabrication, long-term performance, and the expected maintenance regime. Non-invasive corrosion protection methods can be classified as being within one of two groups: (1) surface modification or surface treatment, such as paint and coating/cladding and (2) alternative steel modifications, such as weathering and stainless steels. Avoiding corrosion-prone details in design and construction can also reduce the potential for material degradation resulting from corrosion, however corrosion prone detailing is not addressed in this section. The following sections will discuss several non-invasive corrosion protection methods commonly implemented by departments of transportation including: paint coating; metallic coating (e.g. galvanizing); and stainless and weathering steels.

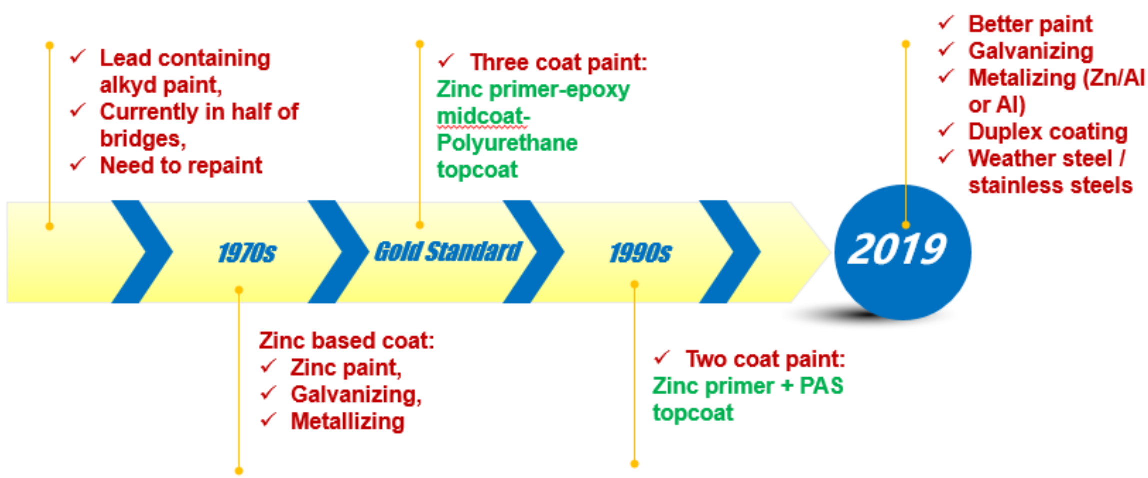


Figure 15. Development of Corrosion-Resistant Coatings for Steel Bridges

3.1 Paint Coatings

Zinc is the main alloying element used for corrosion protection in paint-coating systems. The use of zinc for corrosion protection can be traced back to the 19th century; however, detailed research and development activities were not conducted until the 1930s [10]. Prior to the 1970s, coatings were generally oil- or alkyd-based, and contained pigments which utilized zinc as well as lead and/or chromium compounds as corrosion inhibitors [11]. These coatings had an expected service life of approximately eight to ten years, at which point additional layers were applied. Due to limited experience at the time, steel surfaces were cleaned using power tools, which led to poor adhesion which resulted in failure of the coatings.

In the mid 1960's, DOTs began to apply a new generation primer which contained metallic zinc powders as pigment to provide corrosion protection. It was realized that zinc provided longer-lasting corrosion protection for steels, as it was sacrificially consumed prior to the base metals when exposed to moisture and air. Specifically, steel components are protected from corrosion attack until the complete consumption of the highly anodic zinc in the coating. Around the same time period, blast cleaning (SSPC SP 6 and SP10) replaced power tools for surface preparation, which improved coating adherence. These advances established the foundation for paint coatings used in modern steel bridges, where additional layers are applied to a zinc primer to provide added protection by limiting the ingress of moisture and oxygen to the zinc. Further advancement resulted in a stable three-coat system consisting of an inorganic zinc-rich primer, an epoxy midcoat, and a urethane topcoat [11]. The zinc primer is either inorganic zinc (IOZ) or organic zinc (OZ). IOZ mixes zinc powder with an inorganic silicate paint binder, while OZ primer consists of zinc-metal pigment and an organic paint resin such as epoxy or urethane. Departments of transportation participated in an NCHRP scan team workshop focused on successful preservation practices for steel bridge coatings [12]. Consensus from participating members estimated the service life of total removal and replacement using a three-coat paint system at between 15 and 30 years, and 10 to 20 years for overcoat projects. Further, the National Aeronautics and Space Administration's (NASA's) beachside atmospheric corrosion study reported that a single coat of inorganic zinc (IOZ) can outperform most other coatings [12].

Although the three-coat system has exhibited excellent corrosion prevention performance on thousands of bridges nationwide [10], there is demand for superior and more economic paint systems. One approach is the development of two-coat paint systems which utilize two distinct layers. Federal Highway Administration (FHWA) research and other testing have shown that the performance of newer two-coat paint systems do not provide superior performance relative to the three-coat paint system, but are capable of providing an equal performance while lowering costs and efficiency in terms of application of the paint system [10]. In addition, research has been conducted by FHWA to identify coating systems which can provide a 100-year maintenance free service life with comparable initial costs to traditional coating systems [13]. Departments of transportation have also used high performance coating systems on a limited scale, including 100% solids technology (epoxy and polyuria), fluoropolymers, and powder coatings. However the performance of these systems have not been adequately differentiated from traditional three-coat systems due to a lack of laboratory testing and historical data [14]. It is noted that zinc-free paints are typically restricted to non-aggressive environments. From a long-term performance of point of view, they cannot compete with the zinc-containing systems.

Despite the popularity of a three-coating system, its effectiveness can vary for a given steel bridge and the associated environment. There are many types of heavy-duty paints on the market, and Table 1 provides a general summary of preventive maintenance painting material characteristics and comments of their applicability to bridges. The table provides general information for the selection of a preventive maintenance painting; actual performance is bridge specific.

Table 1 Preventative Maintenance Paint Material Characteristics [15]

Coating Type	**Description**	**Advantages**	**Disadvantages**	**Relative Service Life**
Alkyd / Oil Based	Single-component synthetic oil and oil based coatings. Long use history.	Easy to apply. Can be formulated with corrosion inhibitive pigments. Less expensive.	Volatile organic compound (VOC) laws may soon phase out this type of paint. Sensitive to thickness variations.	Medium
Epoxy	Two-component materials with good barrier properties and adhesion. May be formulated as zinc primer.	Numerous variations and supplier options. Can include corrosion inhibitive pigments. Can apply higher thickness with less coats. Can be less expensive.	Requires field mixing. Poor resistance to sunlight and, hence, susceptible, to degradation by weathering.	Medium - high
High-Ratio Calcium Sulfonate	Single component corrosion inhibiting coating.	Designed for application to coatings having inferior properties.	Remains wet and/or soft for extended period. Requires planning for best application.	Medium -high
Moisture Cured Urethane (MCU)	Single-component materials with good barrier properties. May be applied in very high moisture	Wide range of formulations. Tolerance to many environmental conditions during application.	May bubble or crack at a relatively high dry film thickness (DFT). More expensive.	Medium high

	environments. May be formulated as zinc primer.			
Waterborne Acrylic	Single component materials with good finish quality and aesthetic properties.	Low VOC may be formulated with corrosion inhibitors. Excellent sunlight (i.e., weathering) resistance.	High build required for corrosion performance requires multiple coats. Limited range of environmental conditions during application.	Medium
Organic Zinc-Rich Primer	Typically epoxy or moisture cured urethane (MCU) material with high zinc pigment load. Used as a primer or spot primer over unpainted areas.	Has some cathodic protection properties. More sensitive to thickness variation than zinc-free primers.	May require field mixing. More expensive. Limited use history over corroded substrates.	High
Low Viscosity Sealers	Typically two-component epoxy materials with little to no pigmentation. Used to pre-treat spots of adhered corrosion.	Designed to penetrate and enhance adhesion of additional preventive maintenance painting materials.	May require field mixing and extended cure times.	Medium - High
Corrosion Preventing Compounds (CPCs)	Single component corrosion "treatments" such as oils, water	Penetrates crevices and effectively slow active corrosion. Assists in life	Not tested over a significant amount of corrosion conditions that may	Highly dependent on application frequency.

	displacing chemicals and other proprietary technologies. Used in equipment industry as part of routine maintenance. Many are not film forming. Not designed to “coat” the substrate.	extension programs through a simple annual preventative maintenance plan. Inexpensive simple application.	be common on bridges. Would require routine and repeated application. Not designed to cover or fully stop visible corrosion. Easy wear or washed away.	

3.2 Galvanized Coatings

Zinc paint systems need periodic maintenance which increases inspection and repair costs. Thus, there is a significant interest in adopting a better-performing and/or lower-cost corrosion-protection coating. To that end, the use of galvanizing and thermal spray coating is growing.

A galvanized coating is a pure zinc or zinc-rich overlay system, which is different from a mixed paint system. There are three galvanizing processes: (1) mechanically deposited galvanizing; (2) continuous (sheet) galvanizing; and (3) hot-dip galvanizing. The first two galvanizing processes are limited in the size and geometry of the component which is being treated, thus hot-dip galvanizing is the most popular process for structural steel bridge components. The hot-dip galvanizing process is a shop-process in which the steel components are dipped into a series of kettles, as illustrated in Figure 16; this process cannot be completed in the field. ASTM A123 defines the sampling requirements for hot-dipped pieces by which coating thickness is assessed and accepted [16]. For the typical thickness of plates used in bridges, a minimum galvanized coating thickness of 3.9 mils (1 mil = 0.001 inch = 25.4 μm) or thicker is typically required.

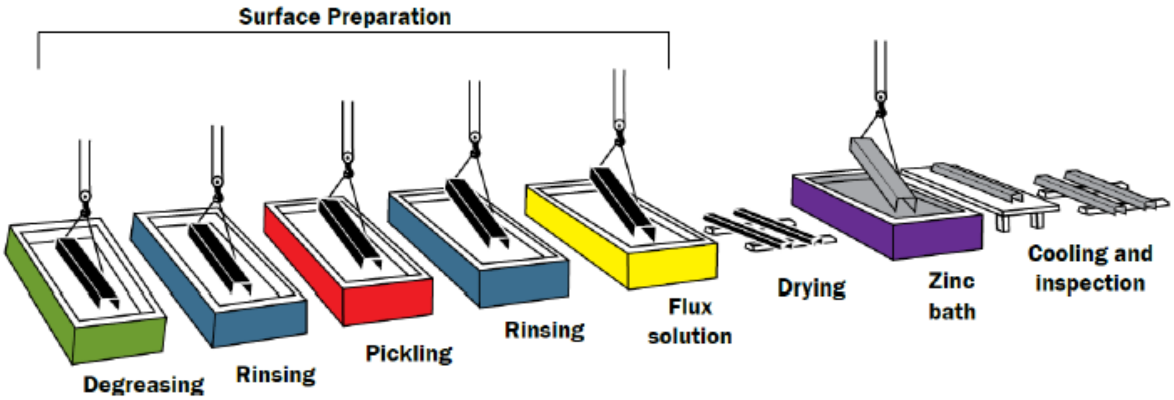


Figure 16. The hot-dip galvanizing process [17]

Galvanized components have several advantages relative to zinc-containing paint-coating systems. These include improved adherence to the base metal due to metallurgical bonded layers and complete surface coverage on components for uniform corrosion protection [18], as well as an increased service life which ranges from 75 to 100 years in an aggressive environment, as illustrated in Figure 17 [19].

Despite the potentially long lifetimes of galvanized steels, especially in mild and moderate environments, it is important to note that the micro-environments associated with a given bridge can result in decreased lifespans. It should also be noted that galvanized coatings are often top-coated for color and additional corrosion resistance, which has been shown to cause performance issues due to errors in surface preparation and application processes [4].

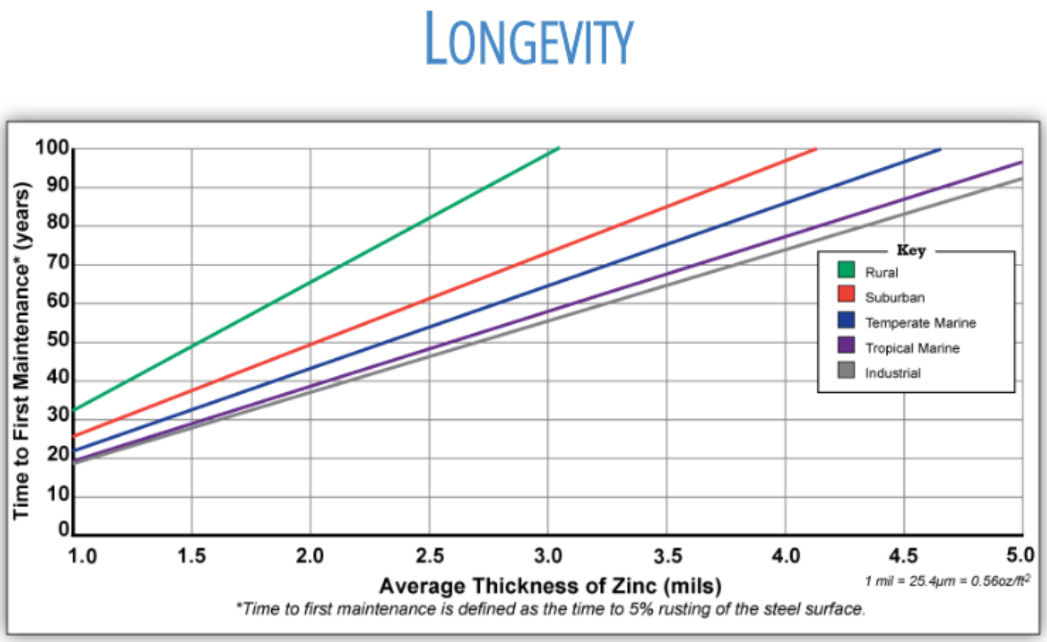


Figure 17 Lifetime prediction of galvanizing steels [19]

3.3 Thermal Spray Metallic Coatings

Similar to a galvanizing coating, a thermal spray coating is a metallic overlay system. For the thermal spray process, the metal, in powder or wire form, is fed through a spray gun with a heat source, such as flame or electric arc, which are the two most common heat sources used in steel bridge application. The molten metal is directed onto the steel surface by a compressed air jet. The molten metal rapidly solidifies when traveling to or touching the steel surface, and thus, the coating is typically considered to be physically deposited and therefore of a relatively low bond strength. To receive good bonding, it is critical to have a cleaned and roughened steel surface. Another characteristic of thermal spray coatings is that they are not 100% dense and will contain porosity which increases corrosion susceptibility, as moisture and oxygen can penetrate through the coating. To improve the corrosion resistance of these type of coatings, the surface can be sealed by applying a thin organic coating, such as epoxies and vinyl coatings [20]. Sealers may be either un-pigmented, with coloring agents or aluminum flake. Maintenance of the coatings surface seal is important in order to achieve a long and effective service life.

Metallic coating materials are typically zinc, aluminum, and zinc-aluminum alloys, such as 85/15 percent zinc/aluminum. For bridge components, thermally sprayed aluminum is usually preferred and it acts as a barrier coating. However, for rail bridges likely to be subjected to collision damage, zinc is often preferred due to its sacrificial nature. Typically specified coating thicknesses vary between 100-200 µm (4-8mils) for aluminum and 100 - 150 µm (4-6mils) for zinc [21]. One study recommended practice is to apply metalizing around 10 to 16 mils of thickness for a service life greater than 40 years [22]. A key advantage of thermally sprayed metallic coatings is that they can be applied in the shop or on site and there is no drying time required. Unlike the galvanizing process, there is no limitation on the size of the workpiece for metallic coating, and there are no distortion problems as the workpiece does not reach a high temperature during the spay process. Thermal spraying is considerably more expensive than hot-dip galvanizing.

Brevoort *et al* [23, 24] monitored the performance and maintenance of many coatings (including metalizing) from 1979 to 2014. The lives of galvanized and metalized systems reproduced from this study is shown in Table 2. The estimated life of a pure zinc coating in rural, industrial, and heavy industrial was 33, 22, and 16 years, respectively. Marine environments had a suggested life of 17.5 years. From this data, it is clear that the thermal spray metallic coating had a similar life performance as zinc-rich paint coating system, while hot-dip galvanizing showed a longer lifetime.

Table 2 Estimated Life of Metalized and Galvanized Coating Per Exposure Condition [4]

Coating System	No. of Coats	Mild (rural)/C2	Moderate (industrial)/C3	Severe (heavy industrial)/C5-1	Coastal heavy industrial/C5-M
Zinc Metalizing	1	33	22	16	16
Zinc Metalizing/sealer	2	34	24	17	18
Zinc Metalizing/sealer/polyurethan	3	39	27	22	22
4 mils hot-dipped galvanizing (1979-2008)	1	68	33	21	(blank)
4 mils hot-dipped	1	100	90	72	(blank)

galvanizing (2014)					

3.4 Weathering Steels

Weathering steels evolved with the alloying of steels with copper in the 1930's, and its application started in cars and transmission towers. The first bridge built from weathering steel was in the mid-1960's. There are three weathering steel specifications: ASTM A242 (Standard Specification for High-Strength Low-Alloy Structural Steel); A588 (Standard Specification for High-Strength Low-Alloy Structural Steel, up to 50 ksi [345 MPa] Minimum Yield Point, with Atmospheric Corrosion Resistance); and A709 (Standard Specification for Structural Steel for Bridges). The typical weathering steel is referred to as A709 Grade 50W, which is essentially the same as ASTM A588 (this is often referred to as Cor-Ten, which is a particular trademarked name). Weathering steels rely on their alloying elements to form protective oxide scales to resist environmental corrosion attack, and these alloying elements are mainly copper, nickel, chromium, silicon, and phosphorus. Under a wide range of exposure conditions, weathering steels rust, but the product that forms is continuous and remains tightly adherent to the steel substrate. Shortly after blast cleaning to remove mill scale, weathering steel turns "rusty" in appearance, but as the stable "patina" (oxide) develops over many wet and dry cycles (usually between 6 and 24 months depending on environment), the oxide layer will stabilize to a deep brown, almost purple color when the patina is fully developed [25].

Weathering steel bridges are suitable for use in most locations. However, there are certain environments where the performance of weathering steel will not be satisfactory, and these should be avoided [26]:

- Highly marine environments (coastal regions).
- Continuously wet or damp conditions.
- Certain highly industrial environments.

The use of de-icing salt on roads both over and under weathering steel bridges may lead to problems in extreme cases.

3.5 Stainless Steels

Stainless steels have very good corrosion resistance in general environments owing to the presence of at least 10.5 wt.% chromium in the steel composition. Further corrosion resistance is provided by other alloying elements like nickel, molybdenum and silicon. Stainless steels are generally categorized based on crystallography or phase constitution, i.e., austenitic, ferritic, martensitic and duplex grades of stainless steels. Mechanical, thermal and corrosion properties tend to align for a given steel category. The most important element for stainless steels is chromium, and 10.5 wt% minimum content is needed to form a protective, chromium-rich oxide layer under non-acidic conditions. Considering the macro-environments of bridges, stainless alloys would essentially not develop any rust product for most bridges, except for the very aggressive corrosive environment such as in coast area. In that case the stainless steel may be susceptible to pitting corrosion.

Stainless steels are expensive and, consequently, and have generally been considered too cost-prohibitive for the construction of an entire bridge superstructure [4]. However, the initial costs of A1010 stainless steel can be offset by the limited maintenance requirements over its service life. Figure 18 illustrates a life-cycle cost comparison between an A1010 stainless steel girder and traditional steel girder with paint coating [27]. The initial cost of the stainless steel girder is approximately \$20,000, however this cost remains constant throughout the life due to the limited maintenance requirements. Conversely, the initial cost of the carbon steel girder is approximately \$15,000, however this girder incurs maintenance costs due to repainting. Three different painting costs are illustrated in Figure 18 including \$6/ft^2 (lower bound), \$12/ft^2 (estimated actual cost), and \$18/ft^2 (upper bound). From this figure, it is clear that the initial costs associated with using an unpainted ASTM A1010 girder are recouped in just the first painting cycle, even for the lower bound cost estimate for repainting.

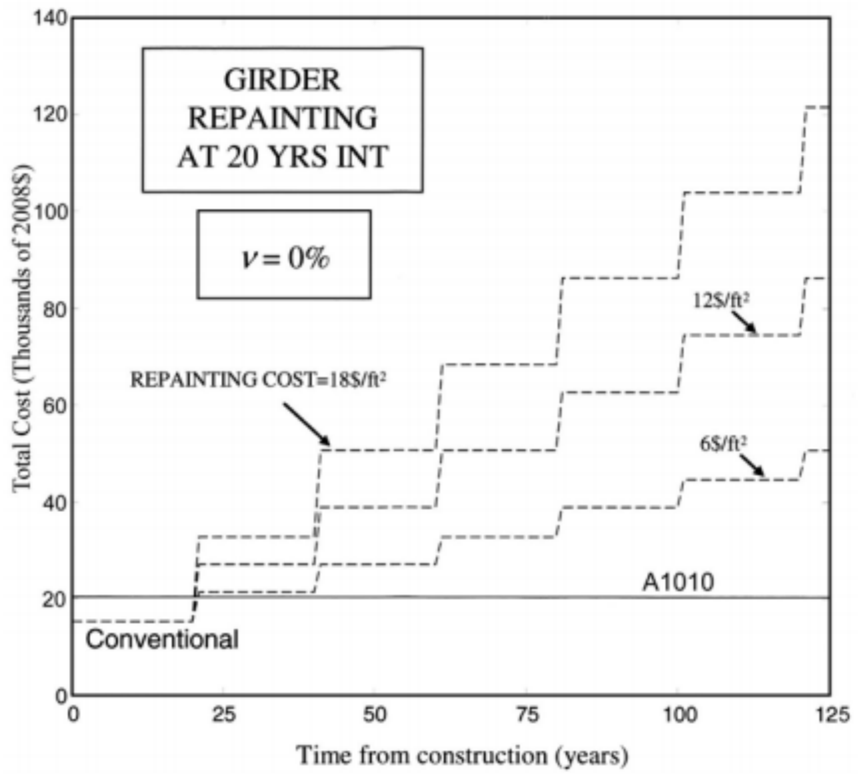


Figure 18 Life cycle cost analysis of difference bridge materials [27]

3.6 Duplex Coatings

The different corrosion protection methods described above have their own advantages and disadvantages, and the bridge designers and users are looking for an optimal solution which combines cost, feasibility, and performance factors. One option is the use of a duplex coating, which combines two or more different coating systems, such as the application of a paint system on a metallic coating system to garner greater durability in comparison with that of either individual coating system. In reality, the selection of a duplex coating relies on the synergistic effect between each of the coatings. For example, a painted hot-dip galvanizing life could be 1.5 - 2.3 times the sum of the individual coatings [28].The 1.5 factor is for an aggressive environment, and 2.3 for less aggressive environments.

Despite the benefit of a duplex coating comprised of two protective systems, some accelerated studies have shown that a zinc-rich coating on a weathering steel did not offer benefit over the same coating on a regular steel [31, 32]. However, it should be acknowledged that accelerated tests may not accurately simulate the performance in real environments.

3.7 Summary of Steel Bridge Corrosion Protection Strategies

Based on the current literature review, the following corrosion-protection approaches are considered:

(1) Stainless steels could provide the longest bridge lifetime, especially in an inland area. However, its capital investment is very high. Weathering steels provide a cost-efficient option to improve corrosion resistance, but they have not been found to provide long-term corrosion protection, such as more than 50 years, without maintenance.

(2) A galvanized coating provides promising lifetimes for steel bridges, such as 30-50 years life without touch-up. But it is limited to shop fabrication.

(3) Metallic overlay coatings have been proven to extend the steel-bridge life, but its performance is typically inferior to galvanizing.

(4) Three-coat painting systems are still the most popular approach for corrosion protection of steel bridges, but it generally needs maintenance between 15 to 30 years. Two-coat and one-coat paint systems have been developed to reduce the cost of material and application; however, their performance is inferior to three-coat paint systems. Due to a large reduction in cost and time to apply two-coat and one-coat paint systems, there is an increasing interest to further develop two-coat and one-coat paint systems.

Duplex coatings, especially a paint over a galvanized coating, could provide corrosion protection for more than 50 years on steel bridges. It is a viable solution by optimizing the coating procedure and cost.

3.8 Crevice Corrosion Protection

Crevice corrosion or pack rust is a type of localized corrosion that occurs between two components with contact but limited access to the outside environment. It is caused by the difference in the environment inside and outside of the crevice, such as significant differences in local oxygen metal ion concentrations. The presence of chloride ions also promotes crevice corrosion [31]. When the metal starts to corrode, rust can start to pack within the crevice. Pack rust can produce enough pressure to distort the surrounding metals. More specifically, pack rust is not visible until the corrosion product starts and deforms the joints to create failure.

Crevice corrosion is one of the most common forms of corrosion found with steel bridges. It occurs within gaps between metal components and metal-to-nonmetal components as small as several mils wide [6]. Steels that rely on an oxide film for protection, such as weathering steel, are particularly susceptible to crevice corrosion. The oxide films are destroyed by the high concentrations of chlorine or hydrogen ions that can accumulate in crevices. Crevice corrosion tends to occur most often in truss members, bearings, hanger assemblies, and gusset and connection plates. There have been indications that all bridge elements, except cotter pins and pilings, are susceptible to crevice corrosion [6].

It is important to realize that the pack rust cannot be stopped by caulking or sealing the crevice. To repair the crevice corrosion, it is important to remove the pack rust completely prior to applying a sealant and a protective coating. However, it is not easy to estimate the depth of crevice corrosion. If a region of crevice corrosion is deep, it is not easy to remove the rust either.

Because chlorides, which accelerate pack rust, typically come from the regional environment, the paint to apply for crevice corrosion resistance is preferred not to absorb water. For the common paint types, acrylic paint or sealant is water absorbable while urethane-type paints are more resistant to water. As a result, it is preferred to use urethane-based paints over acrylic-base paints.

A high ratio co-polymer calcium sulfonate alkyd (HRCSA) coating belongs to the calcium sulfonate alkyd category, which is an oil-based single-coat system. To search for inexpensive and durable coating systems, the FHWA's Coatings and Corrosion Laboratory (CCL) at the Turner-Fairbank Highway Research Center initiated the FHWA 100-year coating study in 2009 [32]. The study results to date showed that the three-coat inorganic zinc control paints had the best surface retention properties in terms of holidays, rusting, and blistering, and the next best performing coating system among the candidate coating systems was identified as HRCSA. However, no crevice corrosion test was conducted in the study. A relatively recent New Zealand study [33] reported that HRCSA coating systems applied in two coats "wet on wet" at a minimum of 250 microns requiring a high-pressure water cleaning at 8000 psi or a 5000 psi hot water wash to remove salts. Crevices are pre-treated with a HRCSA penetrating primer and then caulked with an additional stripe coat of the finish coat. However, no performance results were presented in the report.

4 State of Corrosion Prevention/Mitigation Strategies Used in Pennsylvania

This section summarizes corrosion repair and prevention strategies and best-practices currently utilized on steel bridges in the Pennsylvania transportation network. Of specific focus in this section are specifications available in Pennsylvania Department of Transportation (PennDOT) publications, because these provide baseline criteria for corrosion repair and prevention strategies in Pennsylvania. The PennDOT specifications address mitigation in three primary ways:

- Use of coating systems.
- Use of corrosion-resistant steel (e.g. weathering steel).
- Avoidance or elimination of corrosion-prone details.

4.1 Coating Systems

PennDOT Design Manual Part 4 (DM-4) and Publication 408 [34] provide specifications for painting and protective coatings to prevent corrosion in structural steel, and all approved coating systems are listed in PennDOT Bulletin 15 [35]. All coating systems listed in Bulletin 15 must be approved by the Northeast Protective Coating Committee (NEPCOAT) and must be on the NEPCOAT qualified products list.

4.1.1 Shop Painting of New Structures

For a large majority of new steel bridges built in Pennsylvania, an inorganic three-coat zinc-rich painting system is used to protect fabricated structural steel (DM-4, Section 3.4.4). PennDOT Publication 408 [34] provides specifications for cleaning and shop painting structural steel. For coating plain carbon steel, only an approved, proprietary, inorganic, zinc paint system that is listed in Bulletin 15 [35] is permitted to be used (see Figure 19). The paint system must consist of self-curing, inorganic zinc primer, an epoxy or urethane intermediate coat, and an aliphatic urethane finish coat. Only products from one manufacturer shall be used for the entire system and mixing of components is not permitted.

The primer dry film thickness should be between 3 to 5-mm. The intermediate coat for an epoxy/urethane system should have a minimum dry film thickness of 4-mm. Finally, the finish coat for an epoxy/urethane system shall be a minimum of 2-mm.

Section 1060: Shop Painting Structural Steel

1060.2 Coating System for Structural Steel — **Last Revised: 6/28/2018**

NEPCOAT Approved and Maintained paint systems. (NEPCOAT - Northeast Protective Coating Committee)

Mixing portions of paint systems by hand without powered mechanical homogenization available to contractors is not recommended.

	Product	Name	Primer Coat	VOC (g/L)	Intermediate Coat	VOC (g/L)	Finish Coat	VOC (g/L)	NEPCOAT Number	Ref. No.
CARBL 15	**Carboline Company, 2150 Schuetz Road, St. Louis, MO 63146** http://www.carboline.com/									
	Three Coat Paint System (using Inorganic, Zinc-Rich Primer) *Plants in Lake Charles, LA and Green Bay, WI*		Carbonzinc 11 HS	267	Carboguard 893	207	Carbothane 133 LV	255	SCC(12) -03	2014-208QA BC

Figure 19 Approved Three Coat Paint System Supplier for Shop Painting Structural Steel [35]

4.1.2 Field Painting of Existing Structures

Section 1071 in Publication 408 and Chapter 5 in DM-4 provide specifications for the field painting of existing structures. Similar to shop painting, when painting existing structural steel, a three coat system including an organic zinc rich primer is utilized. Section 1070 also includes abrasive blasting, waste disposal, salt/chloride remediation, and application of the three coat paint system. Only an approved three coat organic zinc rich paint system listed in Bulletin 15 (see Figure 20) is permitted to be used. The prime coat shall be an organic zinc primer (epoxy or urethane), the intermediate coat (epoxy or urethane) or finish coat (aliphatic urethane) shall not contain heavy metal materials. Mixing of components is not permitted. All three paint coats must be from the same manufacturer.

All steel must be blast cleaned to a near white condition (SSPC SP10). Clean, dry compressed air is to be used for blast cleaning. Abrasives should be sized to create a surface profile from 1.5 to 3.5 mils deep. Recyclable abrasives should be used. Silica sand is not permitted to be used as an abrasive. After blast cleaning, tests should be conducted to check for chloride levels.

Section 1070: Painting Existing Structural Steel

1070.2 Coating System for Existing Structural Steel

Last Revised: 8/6/2018

NEPCOAT Approved and Maintained paint systems. (NEPCOAT - Northeast Protective Coating Committee)

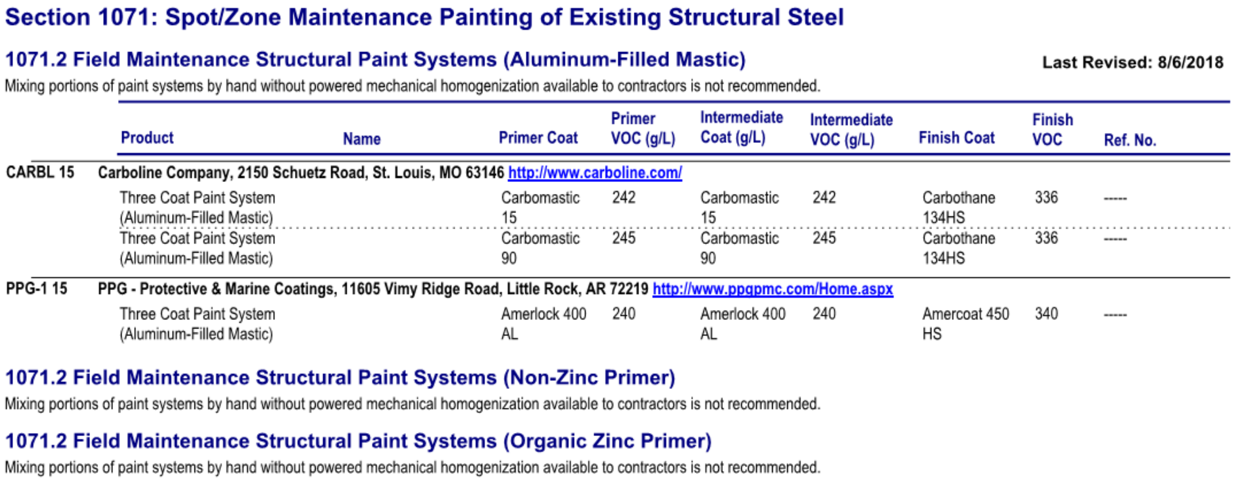
Mixing portions of paint systems by hand without powered mechanical homogenization available to contractors is not recommended.

	Product	Name	Primer Coat	VOC (g/L)	Intermediate Coat	VOC (g/L)	Finish Coat	VOC (g/L)	NEPCOAT Number	Ref. No.
CARBL 15	**Carboline Company, 2150 Schuetz Road, St. Louis, MO 63146 http://www.carboline.com/**									
	Three Coat Paint System (using Organic, Zinc-Rich Primer) *Plants in Lake Charles, LA, Green Bay, WI, and Dayton, NV*		Carbonzinc 859	322	Carboguard 893	207	Carbothane 133 VOC	316	SSC(12) -04	2015-037QA BC
INTP- 15	**International Paint LLC, 6001 Antoine Drive, Houston, TX 77091**									
	Three Coat Paint System (using Organic, Zinc-Rich Primer)		Interzinc 315B	304	Intergard 475HS	187	870 UHS	316	SSC(11) -02	2012-119QA BC
SHER0 15	**Sherwin-Williams Company, 549 E. 115th Street, Chicago, IL 60628 http://www.sherwin-williams.com/**									
	Three Coat Paint System (using Organic, Zinc-Rich Primer) *Primer Plant: Andover, KS* *Intermediate Plants: Andover, KA, Victorville, CA, and Greensboro, NC* *Finish Plants: Andover, KS, and Richmond, KY*		ZincClad III HS	330	Macropoxy 646	191	Acrolon 218 HS	280	SSC(04) -03, SSC(11) -03	2007-066QA BC

Figure 20 Approved Three Coat Paint System Suppliers for Painting Existing Structural Steel [35]

Section 1071 in Publication 408 provides specific requirements for spot/zone painting. The need for spot painting is typically identified by bridge inspectors but should be anticipated on a cyclic basis for planning maintenance activities. Typically, spot painting does not exceed 20% of the total painted area [36]. Work items that can be including in spot painting include the structural steel above the bridge seats and bearings. Zone painting refers to areas affected by accelerated corrosion including areas subject to salt spray and beam-ends. For spot/zone maintenance painting of existing structural steel, an approved, proprietary coating system from Bulletin 15 (see Figure 21) must be used.

In addition, PennDOT has recently implemented several proprietary coatings (including Termarust [37] and Polynox [38]) to provide temporary protection to elements susceptible to accelerated corrosion. Termarust was applied to a gusset plate on the Elizabeth Bridge in 2012, while Polynox was applied to the beam ends of the PA 136 overpass over PA 51 in 2013. Figure 22 shows the gusset plate on the Elizabeth Bridge just after application of the Termarust, and after approximately 7-years of service. Figure 23 shows the Polynox on the beam ends the PA 136 overpass after approximately 6 years of service. In general, both products effectively prevented additional corrosion on the bridge elements.



Section 1071: Spot/Zone Maintenance Painting of Existing Structural Steel

1071.2 Field Maintenance Structural Paint Systems (Aluminum-Filled Mastic) **Last Revised: 8/6/2018**

Mixing portions of paint systems by hand without powered mechanical homogenization available to contractors is not recommended.

	Product	Name	Primer Coat	Primer VOC (g/L)	Intermediate Coat (g/L)	Intermediate VOC (g/L)	Finish Coat	Finish VOC	Ref. No.
CARBL 15	Carboline Company, 2150 Schuetz Road, St. Louis, MO 63146 http://www.carboline.com/								
	Three Coat Paint System (Aluminum-Filled Mastic)		Carbomastic 15	242	Carbomastic 15	242	Carbothane 134HS	336	-----
	Three Coat Paint System (Aluminum-Filled Mastic)		Carbomastic 90	245	Carbomastic 90	245	Carbothane 134HS	336	-----
PPG-1 15	PPG - Protective & Marine Coatings, 11605 Vimy Ridge Road, Little Rock, AR 72219 http://www.ppgpmc.com/Home.aspx								
	Three Coat Paint System (Aluminum-Filled Mastic)		Amerlock 400 AL	240	Amerlock 400 AL	240	Amercoat 450 HS	340	-----

1071.2 Field Maintenance Structural Paint Systems (Non-Zinc Primer)

Mixing portions of paint systems by hand without powered mechanical homogenization available to contractors is not recommended.

1071.2 Field Maintenance Structural Paint Systems (Organic Zinc Primer)

Mixing portions of paint systems by hand without powered mechanical homogenization available to contractors is not recommended.

Figure 21 Approved Three Coat Paint System Suppliers for Spot Painting Existing Structural Steel [35]

(a) (b)

Figure 22 Gusset plat in Elizabeth Bridge (a) just after application of Termarust and (b) after approximately 7years of service

Figure 23 Polynox in girder ends of PA 136 Overpass over PA 51 after approximately 6 years of service

4.2 Crevice Corrosion Prevention/Mitigation

Section 1070 in Publication 408 provides specific requirements to prevent and mitigate crevice corrosion/pack rust in connected steel components. Stripe coating is specified to prevent the development of pack rust in connected components. Prior to application of the prime coat, a wet stripe coat is applied to all edges, bolts, welds, rivets, corners, crevices, and other irregularities using a brush and/or spray. The purpose of the stripe coat is to increase the build-up of film on projecting surfaces and so ensure the coating is worked sufficiently into irregular surfaces. A stripe coat is not required for the finish coat, however inspectors are instructed to ensure complete coverage of all surfaces.

In the event pack rust and/or rust scale develops in existing structures, heavy corrosion (rust scale) and loose pack rust should be removed by power tool cleaning before abrasive blast cleaning and caulking and/or recoating. This approach was used to remove pack rust on the David McDullough-16th Street bridge preservation project in Pittsburgh PA [39].

4.3 Corrosion-Resistant Steels

DM-4 provides specifications for the use of structural and weathering steel. All structural steels must conform to the specifications of ASTM A709, Grades 50 and 50W. Other grades of A709 including Grades 36 and HPS-70W may be considered for economic reasons. Written approval from the Chief Bridge Engineer is required for the use of HPS-50W, HPS-70W, and HPS-100W. Further, the use of unpainted ASTM A709, Grade 50W (weathering steel) requires written approval from the District Bridge Engineer.

The use of weathering steel varies widely between DOTs (e.g. weathering steel is widely used by the New Jersey Turnpike Authority but is prohibited by the Alabama Department of Transportation). In DM-4, PennDOT recognizes the different viewpoints regarding the use of unpainted weathering steel. Unpainted weathering steel is not permitted in acidic or corrosive environments, in locations subjected to salt spray, in depressed roadway sections where salt spray or pollutants might be trapped, in low under-clearance situations, or if the steel is buried in soil. If unpainted weathering steel is permitted, the following criteria must be met:

- The number of joints shall be minimized

- Avoid details that will retain water or debris
- The weathering steel shall be painted at least 1.5 times the web depth or a minimum of 5 feet on each side of an expansion joint
- Drip plates shall be provided and the substructure shall be protected against staining
- Zinc and cadmium galvanized carbon steel bolts are not permitted
- Load indicator washers are not recommended

In addition to these requirements, weathering steel should be used with extreme caution in areas of constant wetting or if tunneling effects from grade changes are present.

4.4 Avoidance or Elimination of Corrosion Prone Details

PennDOT Design Manual Part 4 (DM-4) [40] provides specifications for corrosion prevention through the avoidance of corrosion prone details in new construction and the elimination of corrosion prone details in existing structures. These recommendations are provided to mitigate the micro-environmental conditions which facilitate rapid deterioration due to corrosion including eliminating deck joints (where possible), appropriately detailing joints where they are required, and designing for adequate superstructure drainage

4.4.1 Deck Drainage Systems

Improper superstructure drainage is a major contributor to corrosion in steel bridges. This includes clogged or improperly installed drainage systems as well as unintended drainage through deck joints. DM-4 provides specifications to limit the corrosive impact of deck drainage on superstructure and substructure elements.

Deck drainage systems including free-falling scuppers (shown in Figure 24), downspouts and/or roadway inlets at bridge ends are required to eliminate ponding and removing drainage containing deicers. On bridge decks with flat grades (less than 2%) scuppers are required to be placed at a minimum of 50-ft, while on long bridges with a profile grade over 2%, scuppers are required at a spacing of 400-ft even if they are not hydraulically required. The end of free-falling scuppers must extend 6-in. below the bottom flange of the bridge girders. If free-falling scuppers discharge onto the bridge girders significant corrosion can occur, while contaminants can build up on bottom flanges of the girders if discharge occurs within 6-in. of the bottom of the girders.

Corrosion in the bottom flange of a girder adjacent to an improperly detailed scupper is shown in Figure 24. If free-falling scuppers cannot be used, e.g. due to the presence of roadways or railroads below the bridge, downspouting is required.

Figure 24 Improperly detailed free-falling scupper resulting in corrosion of bottom flange [41]

Roadway inlets and end structure drainage are required to control ponding at bridge ends. Specifically, DM-4 requires roadway inlets placed off the structure at the low end of the bridge to prevent ponding over abutment joints. On the high end of the structure, inlets are required if the roadway is in a cut, if significant runoff will run over the bridge, or if the roadway is curved.

4.4.2 Joints

Deck joints also contribute significantly to accelerated corrosion in bridge superstructures as bridge runoff and deicers leak through the joints and corrode beam webs, beam flanges and bearings. DM-4 provides specifications and recommendations for deck joints in new construction and during deck rehabilitation projects. In general, these specifications recommend limiting the use of joints in new construction, and eliminating joints (when feasible) during deck rehabilitation projects. This includes implementing integral abutments to eliminate joints at the span ends. PennDOT BD-664M provides details for providing continuity for I-Beam and PA Bulb Tee beam bridges, BD-665M provides deck continuity details for box beam bridges, and BD-667M provides requirements for designing integral abutments [42]. When joints are required, only joint details in PennDOT BC-767M (details for Neoprene Strip Seal Dam) and BC-762M (details for Tooth Expansion Dam for Prestress Concrete & Steel Beam Bridges) are permitted [42]. In cases when full depth precast concrete deck panels are used, ultra-high performance concrete is required to be used in the closure pour to limit the potential for joint leaking, and cast-in-place diaphragms are required where the deck panel meets the approach to ensure no runoff reaches the bridge girder or bearings.

4.5 Structural Repairs

One of the most common types of structural repair for steel girder bridges in Pennsylvania is focused on corrosion of the beam-ends below a leaking deck joint. Significant section loss to the beam web and bottom flange can occur, resulting in a loss of capacity. The PennDOT Bridge Maintenance Manual [36] provides recommendations to repair steel girder damaged due to corrosion at the beam ends. The repair procedure is as follows: (1) The structure is modified to accept jacking loads, (2) Temporary supports are constructed and the superstructure is lifted, (3) The deteriorated section is removed and a new section is installed using full penetration groove welds and (4) The temporary supports are removed and the new steel section is sandblasted and painted. An overview of this procedure is provided in Figure 25.

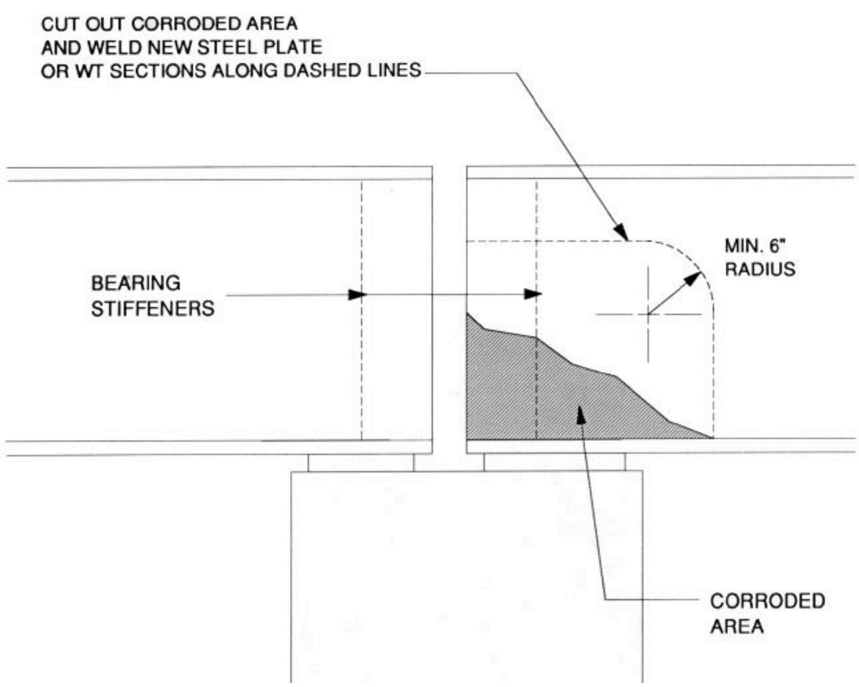


Figure 25 Corroded Steel Girder End Repair Detail [36]

5 US DOT Corrosion Prevention and Mitigation Strategies

This section summarizes corrosion repair and prevention strategies currently utilized on steel bridges nationwide. Of specific focus here are coating and/or material specifications utilized by other State DOTs as well as novel corrosion mitigation strategies.

5.1 Coating Systems

5.1.1 State DOT Coating Requirements

The coating requirements for each State Department of Transportation were surveyed and are summarized in Appendix A. Thirty-five states require a three-coat paint system for new structural steel consisting of a primer, intermediate coat, and top-coat. Seven states allow for a two-coat paint system (California, Colorado, Connecticut, Massachusetts, Missouri, and Rhode Island) and nine states (Delaware, Idaho, Maine, Massachusetts, Missouri, New Jersey, **Pennsylvania**, Rhode Island, and Utah) specify NEPCOAT qualified products. Finally, many states allow galvanizing as an alternative to painting if part length is not an issue.

5.1.2 Trends in Coating Systems

Figure 26 shows the preferences of coating systems used in steel bridges; the most popular coating system used to protect steel bridges are three-coat paint systems which account for about 80% of all protections systems used. The KTA-Tator 2014 survey [43] was conducted for maintenance service and did not consider galvanizing coating systems. From the survey data procured, galvanizing and metallized spray coatings are two major approaches to provide protection to steel bridges. For field maintenance, zinc-free liquid paint coating was occasionally used for new components and often used for spot painting or overcoating of existing structures.

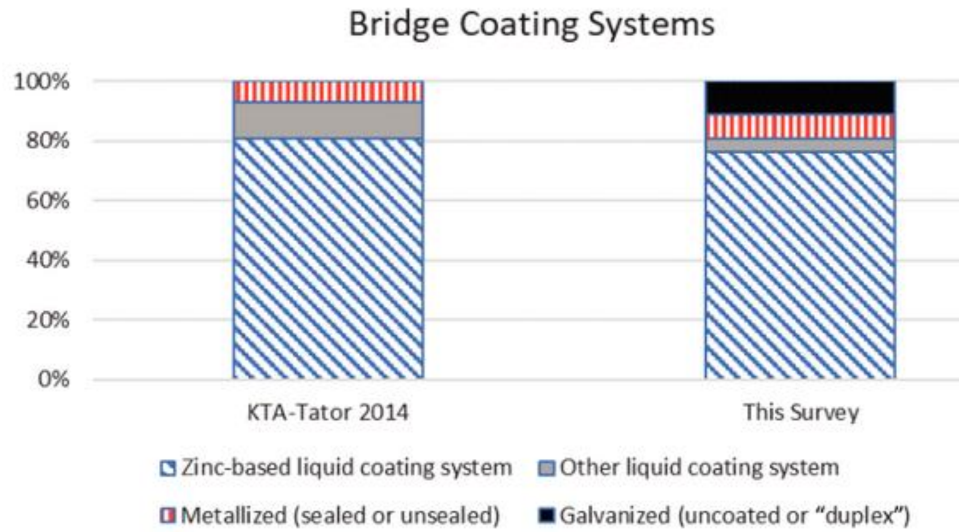


Figure 26 Application popularity of different coating systems [44]

It is noted that Figure 26 does not consider advanced corrosion-resistant materials, such as weathering and stainless steels. With material development, advanced materials are used to build new bridges more and more. Figure 27 shows the popularity of different corrosion protection approaches used for new steel bridges; it is seen that weathering steel has been used in nearly half of new steel bridges according to 2018 data.

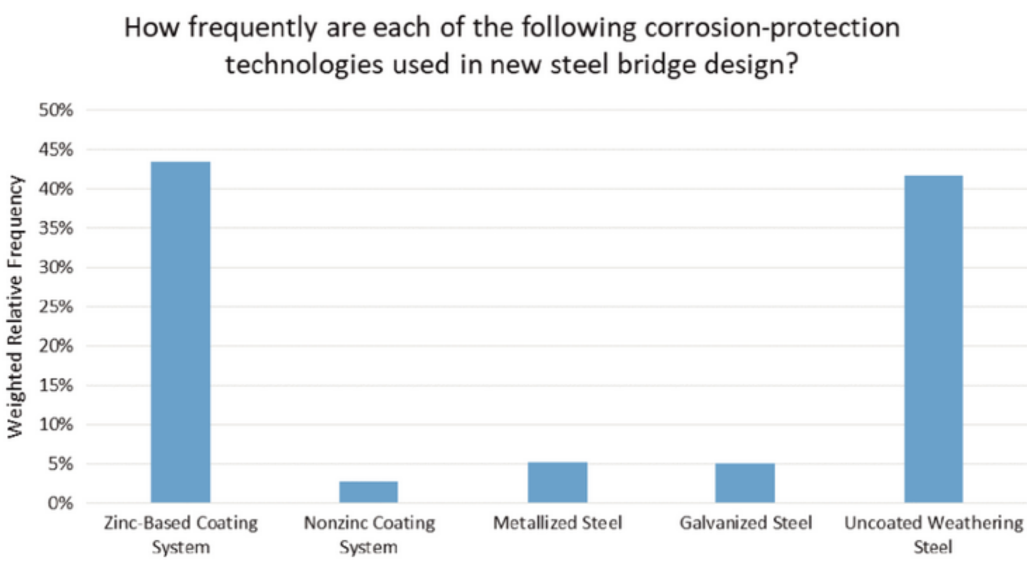


Figure 27 Corrosion protection technologies used for new steel bridges [44]

5.1.3 *Single Overcoat Maintenance*

Several State DOTs (VDOT, MDDOT, PennDOT and NYDOT) have implemented a single overcoat maintenance strategy using a proprietary material ,Termarust [37], to minimize costs and downtime due to coating [44–47]. Using this strategy, Termarust is applied as a single overcoat to all steel components in the structure. The general procedure in all case-studies reviewed was as follows: (1) All steel components were pressure washed using a 5000-psi pressure washer with clean water containing an additive to remove non-visible salts, (2) All connections were blow dried using compressed air, (3) Termarust penetrant was applied to all connections between steel members where pack rust could form, (4) A stripe coat of Termarust topcoat was applied in all areas where the penetrant had been applied, (5) Areas of bare steel and tightly adhered rust were spot primed using Termarust overcoat, and (6) Overcoat was applied to all components. Photographs of a Lancaster County PA of bridge before and after Termarust application are shown in Figure 28 [48].

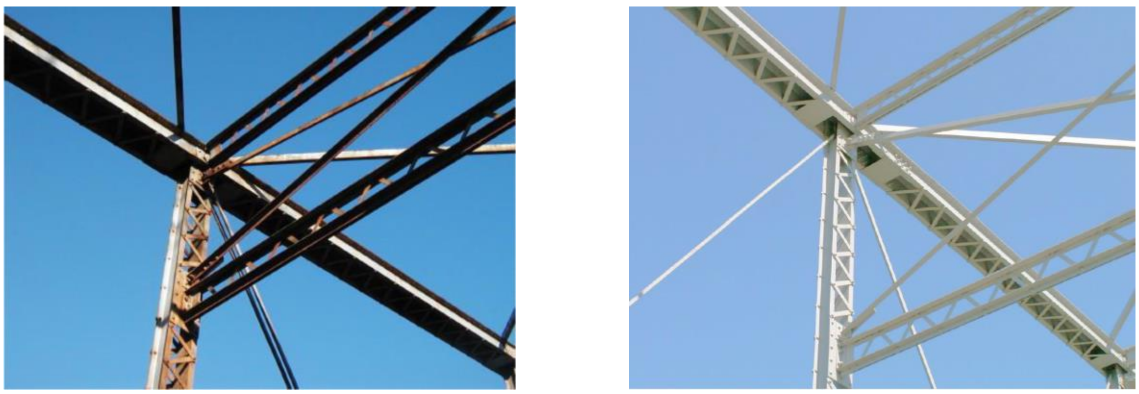
Very limited data is available to quantify the long-term performance of the Termarust single overcoat maintenance approach; however several structures have showed very promising results. Figure 29 shows the Bollman Bridge in Williamsport MD immediately following the application of Termarust and after three years of service [47], and Figure 30 shows the performance of the Termarust coating after twelve years on a truss bridge in Augusta County VA [46]. In both cases, the coating appears to be holding up without any issues. However additional data is required to draw definitive conclusions regarding the long-term performance of the single overcoat system.

(a) Before Painting (b) After Painting

Figure 28 Lancaster Country PA truss bridge before and after Termarust application [48]

(a) Immediately after Painting (b) After 3 Years of Service

Figure 29 Bollman Bridge in Williamsport MD immediately following application of Termarust and after three years of service [47]



(a) Before Painting (b) After 12 Years of Service

Figure 30 Augusta Country VA truss bridge immediately following application of Termarust and after twelve years of service [46]

5.2 Weathering Steel

There are more than 2,000 non-painted weathering steel bridges in the Federal Highway System. Among the 50 states and the District of Columbia, there are only four states - Arizona, Hawaii, Nevada, and South Dakota - that do not use weathering steels [25]. Hawaii does not use it because concrete is more economical than steel. In the other three states, the climate is so dry that paint systems provide sufficient protection to the steel bridges. In a 1989 research report [25], it was summarized that 14 former users no longer specify weathering steel for new bridges because of the following reasons: (a) excessive corrosion of bridges in their state—Indiana, Iowa, Michigan, Washington, and West Virginia; (b) concerned by experiences in other states—Alabama, Florida, Georgia, Oklahoma, and South Dakota; (c) aesthetic reasons - New Mexico and South Carolina; and (d) economic reasons—California and North Dakota. Some states have more than one reason for no longer using weathering steel. For example, New Mexico and North

Dakota also have a semi-arid climate in which paint systems are sufficient. Among the 33 remaining users there is a great variety in degree of usage for new bridges, from almost exclusively (Vermont) to practically none (**Pennsylvania** and Tennessee). Recognizing the limitations of the material, most remaining users now follow their own design criteria for enhancing the corrosion performance, such as: using weathering steel mainly in rural areas, remote areas, or where the bridge is not visible to the public (8 states); using it mainly over streams (5 states) and over railroad tracks (3 states); not using it for grade separation structures (4 states), nor in cities and where the average daily traffic exceeds 10,000 (1 state); not using it along the coast (6 states), on heavily salted highways (4 states), or high humidity areas (3 states); painting steel 1.5 to 3 in (5 to 10 ft) on each side of joints (10 states); blast cleaning all steel before erection (2 states); keeping drainage water from running over substructure and protecting concrete against rust staining (5 states); galvanizing scuppers, bearings, and expansion devices (1 state); galvanizing finger plates (1 state); not using hinges or sliding plates (1 state); and making decks jointless, and building bridges integrally with abutments where conditions permit (1 state).

5.3 Stainless Steels

The Virginia Department of Transportation recently completed construction of the first bridge in the United States to implement ASTM A1010 stainless steel in the girders, bolted splices and cross frames [49]. Using ASTM 1010 (which is a lean grade stainless steel with lower Cr content) can reduce cost while providing corrosion resistance. The composition of an ASTM A1010 Steel (Mittal Steel USA Duracorr®), with over 11 wt.% chromium, gives a martensitic grade that is still more resistant to corrosion than a weathering steel. Figure 31 shows that A1010 stainless steel had the best corrosion resistance performance compared relative to weathering steel and metallic coatings in a test study comparing structural steels [50].

In addition, although outside the scope of this study, implementing stainless steel reinforcing in bridge decks has received an increasing amount of attention due to its highly superior corrosion resistance in corrosive environments. As of 2015, at least 80 bridge decks in the US were constructed with solid stainless-steel reinforcing [4], and as of 2018 the Virginia Department of Transportation has required stainless steel reinforcing (as opposed to epoxy coating reinforcing) in bridge decks and other corrosion susceptible elements [51].

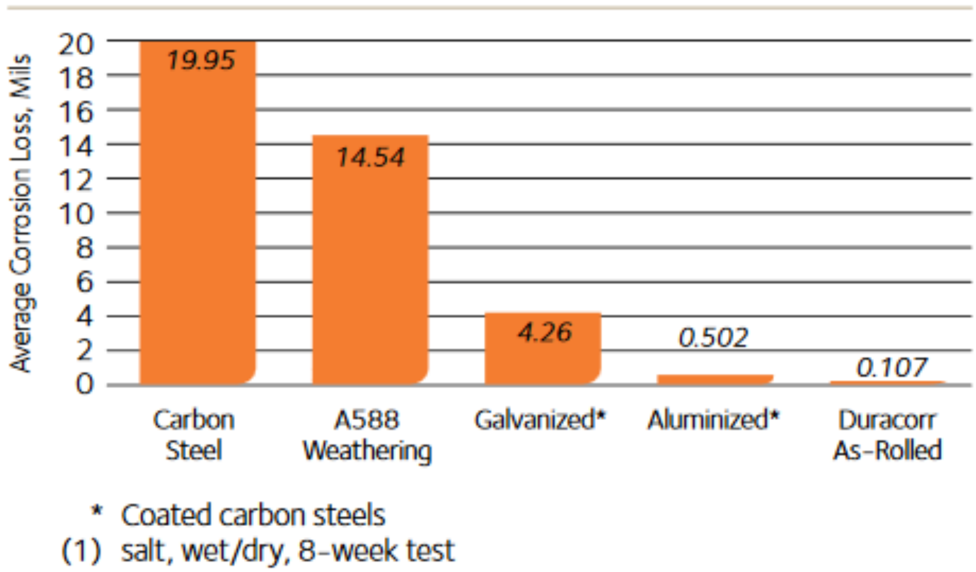


Figure 31 Corrosion Performance in SAEJ2334 Test [50]

5.4 Crevice Corrosion

Stripe coating to mitigate the crevice corrosion is the most popular strategy recommended by 24 state DOT painting specifications. Thirteen states recommended caulking and eight states recommended the use of penetrating sealers [31].

The general nation-wide approach to remove crevice-corrosion products is to use air tools, which can get 1 - 2 inches deep, ultra-high pressure (>20,000 psi) washing (PennDOT District 11 has utilized 30,000 psi pressure washing with some success), or soak rust and apply heat to remove [12]. The Michigan DOT demonstrated an alternative pack rust mitigation method in which the pack rust was heated to 800 degrees F and loosened with a rivet hammer. The loosened material was then blasted out, and the remaining steel was clamped and heat straightened as necessary [52]. Figure 32 shows a bridge section rehabilitated using the alternative mitigation strategy. Note that the long-term performance of this strategy has not been evaluated.

(a) Before (b) After

Figure 32 Alternative Pack Rust Mitigation Strategy Implemented by Michigan DOT [52]

5.5 Removal of Corrosion Prone Details

Many State DOTs require the avoidance of corrosion prone details in new construction and the elimination of these details in existing structures where feasible. One of the most effective measures to reduce the potential for corrosion on steel superstructure components is the removal of deck joints through which corrosive materials can leak. While this is relatively straightforward in new construction, where the structure can be designed as a continuous system, closing joints in existing simple-span structures is more complex. Closing the joints in these systems by creating continuous spans (as specified in PennDOT BD-664M and BD-665M) changes the demands in the piers and girders, which can require additional retrofit.

To overcome this limitation, the Michigan and Virginia Departments of Transportation, as well as several Departments of Transportations in Canada, have implemented *link slab* closure pours to eliminate joints in existing simple-span structures [43–45]. Using this approach, a continuous concrete deck is placed over simply supported steel or concrete girders at the pier to eliminate existing joints. There are two types of link slab systems:

<u>Semi continuous link slab system</u> - Simply supported spans are converted into a semi-continuous deck system for live-load by encasing the girder ends in a monolithic transverse concrete diaphragm that is fully connected to the girders using shear studs.

Flexible link slab system - The link slab is debonded from the girders for a length at each girder end (as illustrated in Figure 33) to provide the link slab with flexibility to accommodate the end-rotations of the girders.

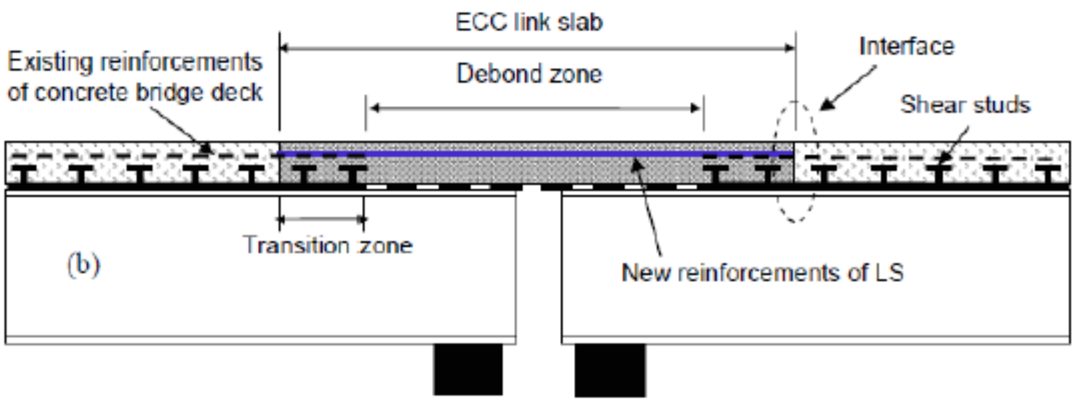


Figure 33 Debonded Link Slab System [54]

6 Novel Structural Rehabilitation Methods Evaluated in Research

This section reviews novel structural rehabilitation methods for corrosion-damaged steel girders. Of specific interest here are methods that do no require jacking of the superstructure or closing of the bridge. Jacking of the bridge is time consuming, requires the use of expensive equipment, strenuous labor, and is a relatively expensive process, which can drastically affect the overall cost of rehabilitating the bridge. Also, for bridges coated with lead-based paint, surface preparation involving lead abatement is required prior to commencement the of repair process [56].

6.1 Carbon Fiber Reinforced Polymers (CFRP)

Miyashita et al. [57] investigated the use of carbon fiber reinforced polymer (CFRP) sheets to repair corroded web panels with reduced shear carrying capacity. In the proposed approach, CFRP sheets were bonded to both sides of the girder in the damaged region, with fibers placed at $\pm 45^{o}$ from horizontal to align with the direction of principal shear stresses as illustrated in Figure 34. Experimental results showed that this approach can effectively increase the shear carrying capacity above that of an undamaged girder as illustrated in Figure 35.

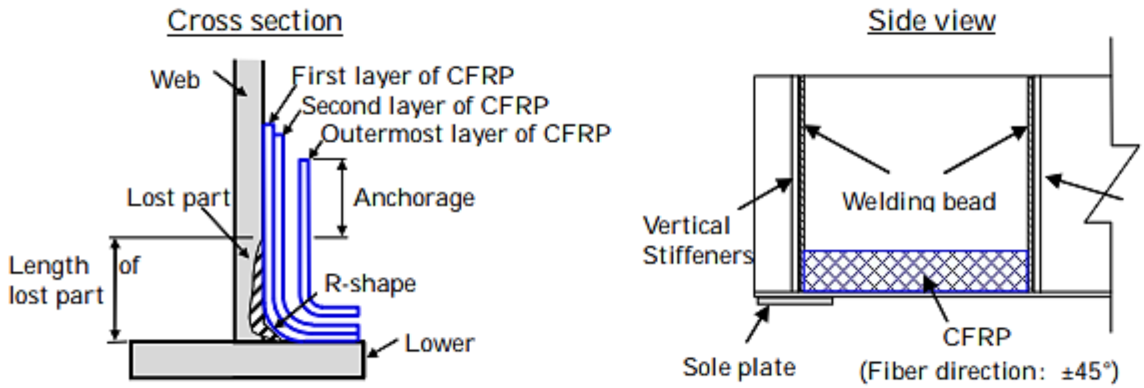


Figure 34 Details of proposed CFRP repair method on corroded webs [57]

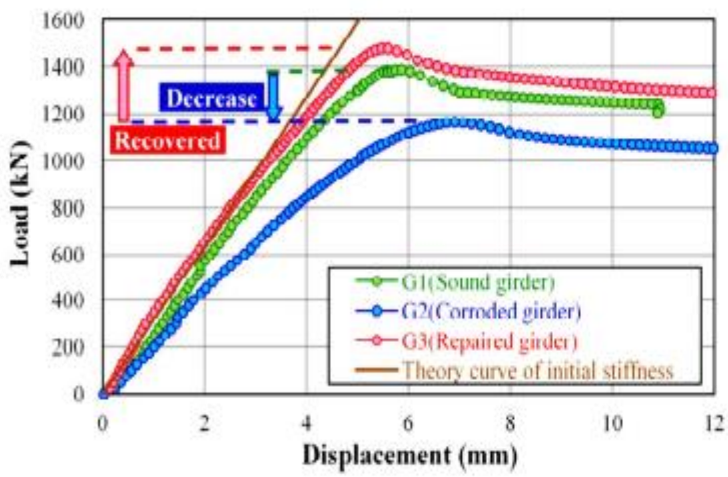
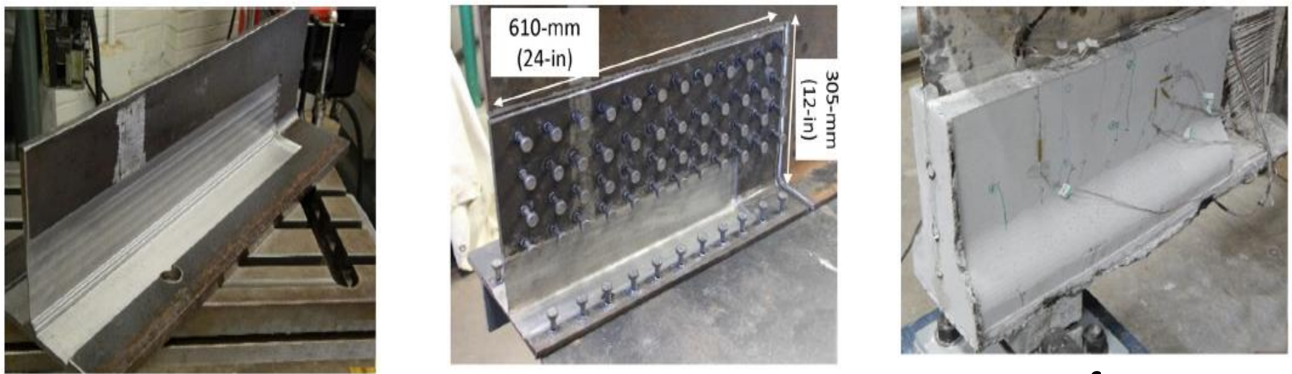


Figure 35 Load-displacement plot for shear buckling tests on corroded girders repaired using CFRP sheets [57]

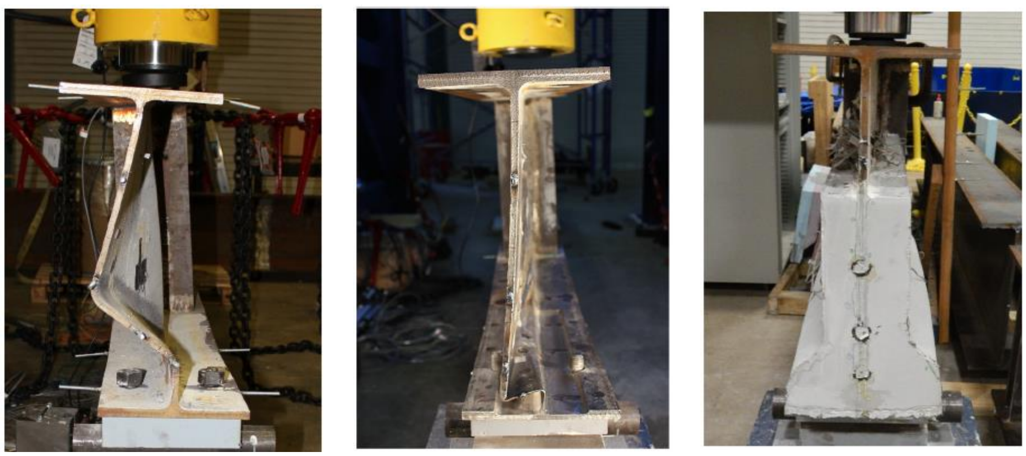
6.2 Ultra-High Performance Concrete (UHPC)

Zmetra et al. [56], investigated the use of ultra-high performance concrete (UHPC) as a repair method for corroded ends of steel girders. In the proposed repair method, the corroded region of the steel girder is encased in UHPC, and shear studs are used to transfer force from the steel girder to the UHPC encasement as illustrated in Figure 36; jacking of the superstructure is not required. Note that Figure 36 shows the experimental specimens tested by Zmetra et al. [56], and the corroded region has been simulated via machining of the web and bottom flange of the girder. Experimental results showed that this approach can effectively restrain buckling (as illustrated in Figure 37) while increasing the capacity of the corroded specimen beyond that of an undamaged girder (as shown in Figure 38).



a b c

Figure 36 **(a)** Corrosion simulation on girder; **(b)** Shear Studs; **(c)** UHPC Encasement [58]



a b c

Figure 37 Final conditions of girders showing **(a)** Web buckling of undamaged girder; **(b)** localized web buckling of damaged girder; **(c)** flexural yielding of repaired girder [58]

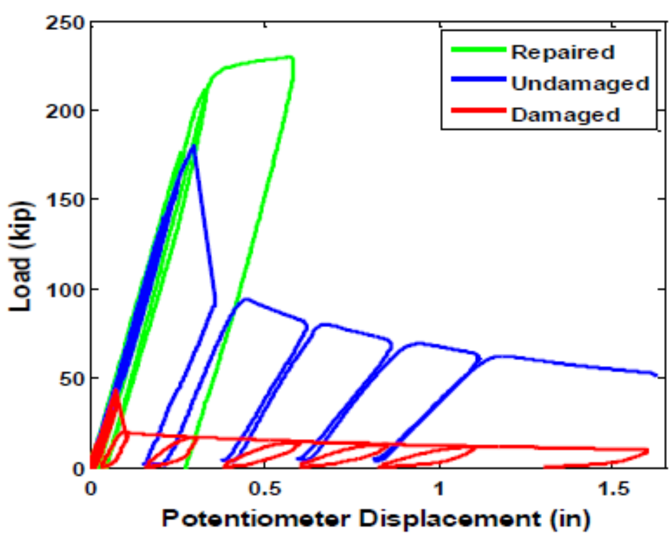


Figure 38 Force-displacement response of corroded girder repaired using UHPC encasement [58]

7 Summary and Recommendations for Future Study and/or Implementation

This report provided a comprehensive literature review focused on issues related to corrosion in steel bridges. First, challenges facing departments of transportation nationwide regarding degrading steel infrastructure were introduced. Next, common forms of corrosion in steel bridges and their causes were reviewed. Then, corrosion prevention and mitigation strategies including those used in Pennsylvania and other State DOTs were discussed.

Based on the findings in this literature review, the following corrosion repair and prevention strategies are recommended for further study and/or implementation on Pennsylvania bridges:

(a) Corrosion resistant coating selection
(b) Crevice corrosion mitigation strategies
(c) Corrosion monitoring
(d) Elimination of joints in existing structures

7.1 Corrosion Resistant Coating/Material Selection

7.1.1 Duplex Coatings

Duplex coating systems should be seriously considered for use on Pennsylvania bridges. Research has shown that duplex systems can replace three-coat systems to protect steel structures without sacrificing much corrosion resistance, while reducing painting costs and closure durations [44]. Several duplex coating systems have been approved by NEPCOAT, and several State DOTs already allow the use of these systems, as indicated in Appendix A. Further studies are recommended to quantify potential cost savings which could be realized by switching to a duplex system in Pennsylvania.

7.1.2 Stainless Steels

PennDOT currently allows the use of stainless steel reinforcing, mesh and hardware. However there are no specifications for corrosion resistant structural members fabricated from stainless steels. Previous research has demonstrated the reduced life-cycle costs associated with fabricating structural members using stainless steel [27], and a recent project completed by the Virginia Department of Transportation demonstrated the concept of utilizing ASTM A1010 stainless steel to design and construct a corrosion resistant plate girder bridge [49]. Based on these findings, using structural stainless steel in bridge superstructures should be considered for use in Pennsylvania. Further research studies in this area are recommended to (1) quantify the lifecycle costs associated with designing stainless steel bridges in Pennsylvania, and (2) to develop design specifications for designing bridge superstructures using stainless steels.

7.2 Crevice Corrosion Mitigation Strategies

Crevice corrosion is common in steel bridges in Pennsylvania. Discussions with PennDOT engineers throughout this project have indicated that current crevice corrosion mitigation strategies could be improved. In particular, several deficiencies have been noted in a proprietary product utilized to mitigate crevice corrosion in the Elizabeth Bridge in the Pittsburgh area [59]. Further studies are recommended to: (1) evaluate novel methods to effectively remove pack rust (e.g. the alternative method proposed by MDOT) and (2) identify and evaluate effective methods (proprietary and/or non-proprietary) to prevent further crevice corrosion after maintenance has taken place.

7.3 Corrosion Monitoring

Discussions with PennDOT engineers throughout this project have indicated that a robust corrosion monitoring system – where the level of corrosion in critical regions can be accurately measured and mitigated prior to severe degradation – could increase the life of highway infrastructure while decreasing overall maintenance costs. Corrosion in steel bridges is complicated, as it depends on many factors, including bridge material, bridge design, and environment. SSPC-VIS 2/ASTM D610 [60] provides an overall structural rating guidelines to determine the degree and distribution of rusting on painted steel surfaces. However, it is highly challenging to monitor steel bridges that use different corrosion protection approaches. The corrosion monitoring should include visual inspection and physical testing to determine the corrosion conditions and subsequent maintenance plan. After coating application, it is typical to visually monitor the coating condition at regular intervals, such as 2-3 years [61]. However, the difficulty for visual inspection includes the limitation of laborers, such as vision limitation and insufficient training, and work scopes, such as large and complex components of steel bridges. With the increase number and age of steel structures, new inspection technologies should be developed to monitor steel bridge corrosion more inefficiently. One promising technique is the use of AI enabled imaging analysis using high-resolution image capturing devices. Using this approach, initial corrosion damage and/or critical corrosion degradation is identified by the AI technology, and professional engineers can be alerted and develop a corrosion damage and maintenance plan. Recent research within the Department of Mechanical and Materials Science at the University of Pittsburgh has demonstrated the feasibility of such an approach, however further studies are necessary in this area.

7.4 Elimination of Corrosion-Prone Detailing

7.4.1 Deck Joints

Eliminating deck joints in existing bridges is one of the most effective methods to decrease the corrosion potential of steel superstructure components, especially in beam-ends. However, eliminating joints in simple-span bridges by creating continuous spans is not always efficient or economical, as altering the load path can require additional strengthening of adjacent components. To overcome this issue, the development of debonded link slab details (as illustrated in Figure 33) for use in Pennsylvania bridges is recommended. These slabs have been effectively used to create jointless decks by the Michigan and Virginia Departments of Transportation, as well as several Canadian Departments of Transportation. Of specific interest in this study would be implementing UHPC to improve the flexibility and corrosion resistance of the link slab.

7.4.2 Free Falling Scuppers

DM-4 currently requires that free-falling scuppers extend 6-in. below the bottom flange of bridge girders to ensure the discharge is released below the bottom flange. However, PennDOT engineers have observed corrosion resulting from wind blowing scupper discharge back onto superstructure girders in cases where the scuppers extend 6-in. Based on this observation, increasing the scupper extension length to at least 12-in in DM-4 is recommended.

7.5 In-Situ Repairs for Corrosion Damaged Steel Girders

For severe cases where strengthening or replacement is required (as is commonly seen in girder bearing regions below deck joints), further research should be conducted on developing repair strategies which do not require jacking of the superstructure or closure of the roadway. This study would expand upon the UHPC encasement repair strategy which showed promising results in terms of restoring stability and load carrying capacity. Of specific interest here would be incorporating more economical materials including non-proprietary UHPC and more traditional cementitious materials.

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Appendix A – US DOT Coating Systems

State	DOT Abbreviation	Paint System
Alabama	ALDOT	System 1: zinc primer with various types (acrylic, epoxy, urethane) of intermediate and top coats System 2: acrylic primer, intermediate and top coats System 3: epoxy mastic
Alaska	ADOT	Remote Sites: Use metalizing (spray thermal metal coating) or hot-dip galvanizing for all steel bridges. Use metalizing where field sections are greater than 50 feet in length. For field sections less than 50 feet in length, hot-dip galvanizing may be used. All Other Sites: For all other steel bridges, use galvanized steel with or without a painted top coat unless site conditions suggest that unpainted weathering steel will work.
Arizona	AZDOT	Acceptable paint systems: Three coat paint system, Aluminum and Zinc Paints, and Acrylic Emulsion Paint A three-paint coating system shall include a primer (Paint Number 1), intermediate coat (Paint Number 2), and topcoat (Paint Number 3) from the same system. When specified, a two-part aluminum paint shall be applied as the topcoat.
Arkansas	ARDOT	The prime coat shall be an inorganic zinc-rich paint. The finish system shall be a two coat system composed of an epoxy tie coat and a coat of urethane paint.
California	CalTrans	Use inorganic and organic zinc-rich primer with exterior grade latex paint.
Colorado	CODOT	All structural steel shall be painted using a two coat system with inorganic zinc-rich primer (shop coat) and high-build urethane top coat.
Connecticut	ConnDOT	New structural steel bridges may be either coated or uncoated. Uncoated steel shall be weathering steel. Coated steel shall be either shop galvanized or metallized and top coated. Uncoated weathering steel should be the first choice for structural steel bridges with life-cycle cost as a consideration.
Delaware	DelDOT	Furnish paint systems for coating structural steel that are Northeast Protective Coating Committee (NEPCOAT)-approved and listed on the NEPCOAT Qualified Products List (QPL). Use a paint system from NEPCOAT Qualified Products List A for shop-painted new structural steel.

Appendix A – US DOT Coating Systems

<table>
<tr><td>Florida</td><td>FDOT</td><td><u>High Performance Coating Systems (Color Pigmented)</u>
Prime Coat: Zinc dust pigment shall be a minimum of Type II in accordance with ASTM D520. Inorganic zinc rich primers shall meet the requirements of the Society for Protective Coatings (SSPC) Paint 20, Type I, Level 2.
Intermediate Coat: Intermediate coatings, when required by the manufacturer, shall be a component of the full coating system.
Finish Coat: The finish coat shall provide the color and gloss required for the completed coating system.
<u>Inorganic Zinc Coating System</u>
Zinc dust pigment shall be a minimum of Type II in accordance with ASTM D 20. Inorganic zinc rich primers shall meet the requirements of SSPC Paint 20, Type I, Level 2. The performance requirements for gloss and color retention are not applicable.</td></tr>
<tr><td>Georgia</td><td>GDOT</td><td>A three coat paint system is used. Minimum requirements are defined in tables. An example table is show below.
<table>
<tr><th>Requirement</th><th>Maximum</th><th>Minimum</th></tr>
<tr><td colspan="3">Zinc dust, percent by weight</td></tr>
<tr><td>Zinc</td><td>—</td><td>99.00</td></tr>
<tr><td>Lead</td><td>0.6</td><td>—</td></tr>
<tr><td>Percent by weight of zinc in dried paint film</td><td>—</td><td>85</td></tr>
<tr><td>Elcometer Adhesion of dried paints, psi (MPa)</td><td>—</td><td>300 (2.1)</td></tr>
<tr><td colspan="3">Note: The primer shall be self-curing and shall consist of two components, Zinc dust and Ethyl Silicate vehicle. A manufacturer's product data sheet and a material safety data sheet (MSDS) shall accompany each shipment of Inorganic Zinc Rich Primer. The product data sheet shall contain the following information for the mixed primer: Unit Weight, Viscosity, Volatile Organic Content (VOC), Pot Life, Percent Solids by Volume.</td></tr>
</table></td></tr>
<tr><td>Hawaii</td><td>HiDOT</td><td>Paint steel with one shop or prime coat and not less than two field coats.
Zinc paints and primers shall conform to the follow:
(A) Zinc Dust-Zinc Oxide Primer MIL-P-24441/20
(B) Zinc Oxide-Zinc Dust Paint Federal Specifications MIL-E-15145
(C) Zinc Dust Primer Coating Federal Specifications MIL-PRF-26915D
(D) High Zinc Dust Content Paint Federal Specifications MIL-P-21035B</td></tr>
<tr><td>Idaho</td><td>ITD</td><td>The Engineer will accept the applicable National Transportation Product Evaluation Program (NTPEP) and the North East Protective Coating Committee (NEPCOAT) QPL paint formulations for products applied to structural steel specified formulations and paint systems.</td></tr>
</table>

Appendix A – US DOT Coating Systems

Illinois	IDOT	Inorganic System The inorganic zinc-rich primer shall be according to AASHTO M 300 Type I. The Volatile Organic Compounds (VOC) shall not exceed 2.8 lb/gal (340 g/L) for both shop and field painting as applied when tested according to ASTM D 3960. Aluminum epoxy mastic shall be a two component epoxy primer containing aluminum pigment designed as a one coat high build complete protective coating system with excellent adhesion to rusted steel, inorganic zinc, and old paint after such surfaces have been properly cleaned. The acrylic primer and finish coat shall be a two coat, waterborne acrylic paint system for direct to metal application on prepared structural steel and for top coating previously painted surfaces. Organic System The organic zinc-rich paint system shall consist of an organic zinc-rich primer, an epoxy or urethane intermediate coat, and aliphatic urethane finish coats.
Indiana	INDOT	This coating system shall consist of an inorganic zinc primer, an epoxy intermediate paint, and a polyurethane finish coat for the painting of steel bridges and other structural steel. All of the coatings within any coating system shall be manufactured by the same manufacturer and shall be compatible with one another.
Iowa	IOWA DOT	Primer: Use a Zinc-rich Epoxy, Zinc-rich Aromatic Moisture Cured Urethane, or Zinc-rich Silicate Intermediate Coat: Use an Aluminum Epoxy Mastic or Aromatic Moisture Cured Urethane Finish Coat: Use an Aliphatic Polyurethane, Aliphatic Moisture Cured Urethane, or Waterborne Acrylic
Kansas	KDOT	Apply 1 coat of inorganic zinc primer to the structural steel in the shop. Apply 2 primer coats (not less than 6 mils total thickness) to surfaces that are not in contact with the concrete, but that will be inaccessible after assembly or erection. Apply an acrylic or a polyurethane finish coat after the primed structural steel is erected.

Appendix A – US DOT Coating Systems

Kentucky	KYTC	Select structural steel coatings systems conforming to this section and included on the Department's List of Approved Materials. A sample is shown below. **Manufacturer** — **Coating System** CARBOLINE — PRIME: CARBOZINC 11HS; INTERMEDIATE: CARBOGUARD 893; FINISH: CARBOTHANE 133HB SHERWIN WILLIAMS — PRIME: ZINC-CLAD II PLUS B69-VZ12; INTERMEDIATE: MACROPOXY 646 B58-600; FINISH: ACROLON 218HS B65-650 ICI-DEVOE — PRIME: CATHA-COAT 304V; INTERMEDIATE: BAR RUST 231; FINISH: DEVTHANE 379UVA
Louisiana	LaDOTD	The zinc paint system shall be from the Approved Materials List. A sample is shown below. **Product Category :** Zinc Paint Systems for Structural Steel **MATERIAL : 1008M00050 Paint, Bridge - Evaluation** **APS00010040 – The Sherwin-Williams Company - Morrow, GA** 6795 South Main Street, Morrow, GA 30260 **Phone :** 985-290-0066 **Ext. # :** **Fax :** 504-348-7670 **Contact :** Sean Riley (sean.riley@sherwin.com) **Additional Info :** Contact Address: 7471 Tom Drive, Baton Rouge, LA 70806 **Product** — **Approved On** — **Remarks** Bridge Paint Eval Sys - Sherwin Williams — 1-15-2015 — This system consists of the following products: Macropoxy 920 Pre-prime @ 1.5 - 2 mils DFT; Macropoxy HS @ 5 - 6 mils DFT
Maine	MaineDOT	Coatings systems shall be from the Northeast Protective Coating Committee (NEPCOAT) Qualified Products List (QPL), list A or B.
Maryland	MDOT	Acceptable Primers : Inorganic Zinc Rich, Aluminum Epoxy Mastic, Organic Zinc Rich, Zinc Rich Moisture Cured Urethane, Micaceous Iron Oxide and Aluminum Filled Moisture Cured Urethane Acceptable Intermediate Coats: Acrylic, Epoxy Polyamide, Micaceous Iron Oxide Moisture Cured Urethane Acceptable Finish Coats: Acrylic, Aliphatic Urethane, Moisture Cured Aliphatic Urethane
Massachusetts	MassDOT	The paint system used shall be approved by the Northeast Protective Coating Committee (NEPCOAT).
Michigan	MDOT	Select a complete coating system from the Qualified Products List for each structure. The system must consist of a tinted organic zinc-rich primer, a white intermediate coat, and a urethane top coat matching the Federal Standards No. 595B color number.

Appendix A – US DOT Coating Systems

<table>
<tr><td>Minnesota</td><td>MnDOT</td><td>Must be from the Approved Products List. An organic three coat system, an inorganic three coat system, a moisture cured urethane, and a two coat system is listed. A sample is shown below.
<table>
<tr><th colspan="7">Three Coat Systems - Organic</th></tr>
<tr><th>Manufacturer</th><th>Primer</th><th>Intermediate Coat</th><th>Finish Coat</th><th>Corrosion Inhibiting Penetrating Sealer *</th><th>Paint Supplier's Recommended Caulk</th><th>Approval Date</th></tr>
<tr><td>PPG/PMC Amercoat</td><td>Amercoat 68 HS</td><td>Amercoat 385 Multi-Purpose</td><td>Amercoat 450 HSG</td><td>-</td><td>Sikaflex 1</td><td>6/2009</td></tr>
<tr><td>Carboline Co.</td><td>Carbozinc 859</td><td>Carboguard 893</td><td>Carbothane 133 VOC</td><td>-</td><td>Vulkem</td><td>4/2015</td></tr>
<tr><td>Sherwin Williams</td><td>Zinc Clad III HS</td><td>Macropoxy 646</td><td>Acrolon 218 HS</td><td>Macropoxy 5000</td><td>Stampede or 3M 730 Clear</td><td>11/2005</td></tr>
<tr><td>Sherwin Williams</td><td>Zinc Clad IV</td><td>Recoatable Epoxy B67 Series</td><td>Acrolon 218 HS</td><td>Macropoxy 5000</td><td>Stampede or 3M 730 Clear</td><td>3/2001</td></tr>
<tr><td>International Paint</td><td>Interzinc 315B</td><td>Intergard 475HS</td><td>Interthane 870UHS Semi-Gloss</td><td>-</td><td>NA</td><td>4/2010</td></tr>
</table>
</td></tr>
<tr><td>Mississippi</td><td>MDOT</td><td>Must be from the Approved Products List. A sample is shown below.
<table>
<tr><th>Category</th><th>Material Name</th><th>Producer/Supplier</th></tr>
<tr><td>PAINT - STRUCTURAL COATING SYSTEM</td><td>(PRIME) CARBOZINC 11 HS</td><td>CARBOLINE COMPANY - STRUCTURAL COATINGS</td></tr>
<tr><td>PAINT - STRUCTURAL COATING SYSTEM</td><td>(TOP) CARBOCRYLIC 3350</td><td>CARBOLINE COMPANY - STRUCTURAL COATINGS</td></tr>
<tr><td>PAINT - STRUCTURAL COATING SYSTEM</td><td>(TOP) CARBOCRYLIC 3350</td><td>CARBOLINE COMPANY - STRUCTURAL COATINGS</td></tr>
<tr><td>PAINT - STRUCTURAL COATING SYSTEM</td><td>(INT) AQUANAUT ENAMEL</td><td>INDURON COATINGS - STRUCTURAL COATINGS</td></tr>
</table>
</td></tr>
<tr><td>Missouri</td><td>MoDOT</td><td>Prior to approval and use of the specified coating system, the manufacturer shall submit to Construction and Materials a one-gallon unit of each coat of the coating system proposed. Alternate Approval: If approved by Construction and Materials, compliance with all specified requirements for the system under NTPEP or Northeast Protective Coating Committee (NEPCOAT).</td></tr>
</table>

Appendix A – US DOT Coating Systems

<table>
<tr><td>Montana</td><td>MDT</td><td>Epoxy Zinc Rich Primer: Meets AASHTO M 300 Type I or II requirements
Intermediate Coat: Use a two-component polyamide epoxy
Finish Coat: Provide urethane paint</td></tr>
<tr><td>Nebraska</td><td>NDOT</td><td>The paint materials and paint systems authorized for use shall be on the Department’s Approved Products List. A sample is shown below.
<table>
<tr><th>Manufacturer Name</th><th>Product Name</th></tr>
<tr><td>Carboline</td><td>Carboline Zinc/Epoxy/Urethane System</td></tr>
<tr><td>Devoe High Performance Coatings</td><td>Devoe Zinc/Epoxy/Urethane System</td></tr>
<tr><td>International</td><td>International Zinc/Epoxy/Urethane Syste</td></tr>
<tr><td>PPG High Performance Coatings</td><td>PPG Zinc/Epoxy/Urethane System</td></tr>
</table>
</td></tr>
<tr><td>Nevada</td><td>NDOT</td><td>Submit for approval a letter indicating choice of the complete coating system from one of the approved coating systems listed in the Qualified Products List. The list is shown below.
<table>
<tr><th colspan="5">714.03.01b COATING SYSTEMS FOR BRIDGES</th></tr>
<tr><th>Vendor Name / Address</th><th></th><th>Product Name</th><th>Remarks</th><th></th></tr>
<tr><td>Carboline Company
Agatha McFarland
2150 Schuetz Road
Maryland Heights MO 63146
amcfarland@carboline.com</td><td>Phone: (314) 644-1000
Cell: (770) 846-1318
Fax: (314) 587-2693
www.carboline.com</td><td>Use the System in Remarks</td><td>Shop Coat: Carbozinc 11, Part A: Base Part B: Zinc Filler.1st Field Coat: Carboguard 893 Cycloaliphatic Amine Epoxy-Part A: Resin Part B: Catalyst. Top Coat: Carbothane 134 HS Aliphatic Acrylic Polyurethane-Part A: Resin Part B: Urethane Converter 811</td><td>approved
12/30/1998</td></tr>
<tr><td>PPG Protective & Marine Coatings
Tod Savage
6359 Rancho Mission Rd #2
San Diego CA 92108
nyemiller@msn.com</td><td>Phone: (714) 337-1953
Cell: (619) 633-8406
Fax:
www.ppgpmc.com</td><td>Use the System in Remarks</td><td>Shop Coat: Dimetcote 9 Inorganic Zinc, Part A: Base Part B: Zinc Dust
1st Field Coat: Amercoat® 385 Multi-Purpose Epoxy - PartA: Resin Part B: Cure
Top Coat: Amercoat 450 H Aliphatic Polyurethane - Part A: Resin Part B: Cure</td><td>approved
5 /21/2008</td></tr>
</table>
</td></tr>
<tr><td>New Hampshire</td><td>NHDOT</td><td>Shop painting shall conform to the requirements of AASHTO “ LRFD Bridge Construction Specifications” Section 13 and SSPC-PA 1 and the special provision, whichever provisions are more stringent.</td></tr>
</table>

Appendix A – US DOT Coating Systems

<table>
<tr><td>New Jersey</td><td>NJDOT</td><td>Use paint systems for coating structural steel that are Northeast Protective Coating Committee (NEPCOAT) approved and listed on the Qualified Products List (shown below). Use an inorganic zinc, epoxy, urethane (IEU) paint system for coating new structural steel.

Product Name: IEU-25 Carboline System
Manufacturer: Carboline Co. - Maple Shade, NJ
Comments:
Carbozinc 11HS - Primer
Carbogard 893 - Intermediate
Carbothane 133 LV - Top Coat</td></tr>
<tr><td>New Mexico</td><td>NMDOT</td><td>Weathering steel is a material that should be considered for steel structures in New Mexico. Before shipping, weathering steel should be sand blasted to SSPC SP 6 requirements with all shop markings removed, wet down, and then dried to provide a clean steel with a protective surface.
Painting:
Inorganic Zinc-Rich Primer, Epoxy Intermediate Coat, Polyurethane Topcoat
Galvanizing is acceptable</td></tr>
<tr><td>New York</td><td>NYSDOT</td><td>Paint shall appear on the Department’s Approved List, “Structural Steel Paints - Class 1.” A sample is shown below.
<table>
<tr><th>MANUFACTURER AND LOCATION</th><th>COAT</th><th>PRODUCT DATA/
APPLICATION INSTRUCTIONS</th></tr>
<tr><td rowspan="3">Carboline Company
St. Louis, MO</td><td>Primer</td><td>Carbozinc® 859[3]</td></tr>
<tr><td>Intermediate</td><td>Carboguard® 893</td></tr>
<tr><td>Finish</td><td>Carbothane 133 VOC</td></tr>
<tr><td rowspan="3">International Paint
Houston, TX</td><td>Primer</td><td>Interzinc® 315B</td></tr>
<tr><td>Intermediate</td><td>Intergard® 475HS[4]</td></tr>
<tr><td>Finish</td><td>Interthane® 870UHS</td></tr>
<tr><td rowspan="3">PPG Protective & Marine Coatings
Pittsburgh, PA</td><td>Primer</td><td>Amercoat® 68 HS</td></tr>
<tr><td>Intermediate</td><td>Amercoat® 399</td></tr>
<tr><td>Finish</td><td>Amercoat® 450 H</td></tr>
</table>
</td></tr>
</table>

Appendix A – US DOT Coating Systems

<table>
<tr>
<td>North Carolina</td>
<td>NCDOT</td>
<td>Use a self-curing inorganic zinc paint meeting the Type I Inorganic Zinc Primer paint 18 specified in AASHTO M 300. See below for approved paints.
<table>
<tr><th>Product ID</th><th>Plant ID</th><th>Company Name</th><th>Product Group</th><th>Product Category</th><th>Product Name</th></tr>
<tr><td>NP04-4352</td><td>PM6</td><td>PPG Protective and Marine Coatings</td><td>Paints (1080)</td><td>Self-Curing Inorganic Zinc (1080-5)</td><td>Dimetcote D9 VOC</td></tr>
<tr><td>NP99-3423</td><td>PM6</td><td>PPG Protective and Marine Coatings</td><td>Paints (1080)</td><td>Self-Curing Inorganic Zinc (1080-5)</td><td>Dimetcote 9</td></tr>
<tr><td>NP99-3425</td><td>PM5</td><td>Carboline Company</td><td>Paints (1080)</td><td>Self-Curing Inorganic Zinc (1080-5)</td><td>Carbozinc 11</td></tr>
<tr><td>NP13-6533</td><td>PM5</td><td>Carboline Company</td><td>Paints (1080)</td><td>Self-Curing Inorganic Zinc (1080-5)</td><td>Carbozinc 11 HS</td></tr>
<tr><td>NP13-6534</td><td>PM5</td><td>Carboline Company</td><td>Paints (1080)</td><td>Self-Curing Inorganic Zinc (1080-5)</td><td>Carbozinc 11 VOC</td></tr>
<tr><td>NP16-7396</td><td>PM5</td><td>Carboline Company</td><td>Paints (1080)</td><td>Self-Curing Inorganic Zinc (1080-5)</td><td>Carbozinc 11 FC</td></tr>
<tr><td>NP03-4190</td><td>PM7</td><td>Sherwin-Williams Co.</td><td>Paints (1080)</td><td>Self-Curing Inorganic Zinc (1080-5)</td><td>Zinc Clad II Plus</td></tr>
<tr><td>NP03-4191</td><td>PM7</td><td>Sherwin-Williams Co.</td><td>Paints (1080)</td><td>Self-Curing Inorganic Zinc (1080-5)</td><td>Zinc Clad II LV</td></tr>
<tr><td>NP13-6367</td><td>PM7</td><td>Sherwin-Williams Co.</td><td>Paints (1080)</td><td>Self-Curing Inorganic Zinc (1080-5)</td><td>Zinc Clad DOT</td></tr>
</table>
</td>
</tr>
<tr>
<td>North Dakota</td>
<td>ND DOT</td>
<td><u>Primer</u>
Use an organic zinc-rich epoxy primer that is a multi-component, solvent based, chemically-curing, polyamide epoxy system. Use zinc dust pigment meeting the requirements of ASTM D 520, Type II.
<u>Intermediate Coat</u>
Use a two component chemically-curing polyamide epoxy for the intermediate coat.
<u>Finish Coat</u>
Use a compatible two-component, aliphatic polyurethane finish coat with a weather resistant finish and the gloss and color as specified in the plans.</td>
</tr>
<tr>
<td>Ohio</td>
<td>ODOT</td>
<td><u>Primer</u>
Provide an organic zinc prime coat consisting of a zinc dust filled, two or three-component epoxy polyamide, and selected additives as required.
<u>Intermediate Coat</u>
Provide a two-part epoxy intermediate coat composed of a base component and curing agent suitable for application over the zinc rich primer.
<u>Finish Coat</u>
Provide a two-component urethane finish coat composed of a polyester and/or acrylic aliphatic urethane and suitable for use as a finish coat over the white epoxy polyamide intermediate coat.</td>
</tr>
</table>

<table>
<tr><td>Oklahoma</td><td>ODOT</td><td>Provide a paint system from the Department's Materials Division approved products list (shown below).
<table>
<tr><th>APPROVED PRODUCT NAME</th><th>MANUFACTURER</th></tr>
<tr><td>A01--(A01C1,A01C2,A01C3) 3 COAT SYSTEM:</td><td>Sherwin-Williams Co.</td></tr>
<tr><td>A01C1=IZ=ZINC CLAD II HS</td><td>Sherwin-Williams Co.</td></tr>
<tr><td>A01C2=E=RECOATABLE EPOXY PRIMER</td><td>Sherwin-Williams Co.</td></tr>
<tr><td>A01C3=U=HI-SOLIDS POLYURETHANE</td><td>Sherwin-Williams Co.</td></tr>
<tr><td>A02--(A02C1,A02C2,A02C3) 3 COAT SYSTEM:</td><td>Carboline</td></tr>
<tr><td>A02C1=IZ=CARBOZINC 11 HS</td><td>Carboline</td></tr>
<tr><td>A02C2=E=CARBOGUARD 893</td><td>Carboline</td></tr>
<tr><td>A02C3=U=CARBOTHANE 134 HG</td><td>Carboline</td></tr>
<tr><td>A03--(A03C1,A03C2,A03C3) 3 COAT SYSTEM:</td><td>International Paint, L.L.C.</td></tr>
<tr><td>A03C1=IZ=INTERZINC 22HS</td><td>International Paint, L.L.C.</td></tr>
<tr><td>A03C2=E=INTERGARD 475HS</td><td>International Paint, L.L.C.</td></tr>
<tr><td>A03C3=U=INTERTHANE 990HS</td><td>International Paint, L.L.C.</td></tr>
<tr><td>A04--(A04C1, A04C2, A04C3) 3 COAT SYSTEM</td><td>Sherwin-Williams Co.</td></tr>
<tr><td>A04C1=IZ=ZINC CLAD II PLUS</td><td>Sherwin-Williams Co.</td></tr>
<tr><td>A04C2=E=RECOATABLE EPOXY PRIMER</td><td>Sherwin-Williams Co.</td></tr>
<tr><td>A04C3=U=HI-SOLIDS POLYURETHANE</td><td>Sherwin-Williams Co.</td></tr>
<tr><td>A05--(A05C1, A05C2, A05C3) 3 COAT SYSTEM</td><td>ICI Devoe Paints</td></tr>
<tr><td>A05C1=IZ=CATHA-COAT 304V</td><td>ICI Devoe Paints</td></tr>
<tr><td>A05C2=E=BAR-RUST 231</td><td>ICI Devoe Paints</td></tr>
<tr><td>A05C3=U=DEVTHANE 379 UVA</td><td>ICI Devoe Paints</td></tr>
</table></td></tr>
<tr><td>Oregon</td><td>ODOT</td><td>For shop coating of steel or iron surfaces, furnish a three-coat system with organic or inorganic zinc primer. See below for approved suppliers.
<table>
<tr><th>Product Name</th><th>Category</th><th>Manufacturer</th></tr>
<tr><td>SYSTEM SC-3</td><td>SHOP COATING</td><td>WASSER 800/627-2968</td></tr>
<tr><td>SYSTEM SC-1</td><td>SHOP COATING</td><td>CARBOLINE 800/848-4645 -2064</td></tr>
<tr><td>SYSTEM SC-2</td><td>SHOP COATING</td><td>SHERWIN WILLIAMS 360/609-1879</td></tr>
</table></td></tr>
<tr><td>Pennsylvania</td><td>PennDOT</td><td>When shop painting structural steel, use only Bulletin 15 approved paint shops that are certified by the AISC under its Sophisticated Paint Endorsement (SPE) quality program or by the Society for Protective Coatings (SSPC) under its QP3 quality.</td></tr>
<tr><td>Rhode Island</td><td>RIDOT</td><td>The paint shall be selected from the NEPCOAT Qualified Products List.</td></tr>
</table>

Appendix A – US DOT Coating Systems

South Carolina	SCDOT	Use material from the Department's most recent edition of SCDOT Qualified Product List 19 (shown below).

Manufacturer	Inorganic Zinc Primer	Aluminum Epoxy Mastic Top Coat	Acrylic Latex Top Coat	Polyurethane Top Coat
International Paint, Inc 1716 Labor Camp Road Mt. Pleasant, SC 29464 John Carson 843-693-9412	Interzinc 22 Interzinc 22HS	Interseal 670 HS Aluminum	Intercyl 530 Warterborne Acrylic	Interthane 870 Urethane
PPG Protective and Marine Coatings 1377 Oakleigh Drive East Point, GA 30344 Tom Pearse 404-374-9573	Dimetcote 9 Dimetcote 9 VOC	Amerlock 400 AL Amerlock 2 AL	DOT Acrylic Series	Amercoat 450H
Carboline 350 Hanley Ind. Court St. Louis, MO 63144 Trent Woodward 803-640-7126	Carbo Zinc 11 Carbo Zinc 11 HS Carbo Zinc 12 VOC	Carbomastic 15-LO Carbomastic 90	Carbocrylic 3350	Carboline 133 HB
Elite Coatings 120 Tremon Street Gordon, GA 31031 Tammy Seckinger 478-628-2111	1312 P-139	7510 E-433	*2012 *W-109 (Intermediate) *W-261 (Top Coat)	4100 Shinethane HS
Sherwin Williams 1415 East Bessemer Greensboro, NC 27405 Mark A. Hudson 724-272-0082	Zinc Clad II Zinc Clad II Plus	Epoxy Mastic Aluminum	DTM Acrylic Coating B66 Series	Hi-Solids Acrylic Aliphatic Polyurethane B65-300/B60V30

South Dakota	SD DOT	Coatings, including primer, intermediate (if used), finish, and field repair coats shall all be from the same manufacturer and shall be one of the systems from the Department's Approved Product List for shop paint (new construction) (see below).

Product Type:	Bridge Shop Paint: Three Coat Organic Zinc		
Standard Product:	**Product Name:**	**Manufacturer:**	**Approval Date:**
Organic Zinc Shop Paint System	Amercoat 68HS (P) / Amercoat 399 (I) / Amercoat 450H (TC)	PPG Industrial Coatings PittsburghPA (888)774-2001	1/3/2017
Organic Zinc Shop Paint System	Carbozinc 859 (P) / Carboguard 893 (I) / Carbothane 133 VOC (TC)	Carboline Co. St. LouisMO (800)848-4645 http://www.carboline.com	1/3/2017
Organic Zinc Shop Paint System	Interzinc 315B (P) / Intergard 475HS (I) / Interthane 870 UHS (TC)	International Paint JeffersonvilleIN (281)684-5203	1/3/2017
Organic Zinc Shop Paint System	Zinc Clad III HS (P) / Macropoxy 646 (I) / Acrolon 218 HS (TC)	Sherwin Williams AndoverKS (316)733-1361 http://www.sherwin.com	1/3/2017

Appendix A – US DOT Coating Systems

Tennessee	TDOT	The Department will place paint meeting requirements on its QPL, and will require recertification every 2 years. See below for a sample of the QPL. **89900149 - Carboline** 2150 Schuetz Rd, St Louis, MO 63146, United States of America Trade Name — Evaluation # 1 Primer: Carbozinc 859 Organic Zinc — SSC(12)-04 -- 2 Interm: Carboguard 893 Epoxy Int — SSC(12)-04 -- 3 Topcoat: Carbothane 133 VOC Aliphatic — SSC(12)-04 Footnote: 6 mils max DFT, 4 days min cure, 10% vol max thin **89900493 - International Paint Inc** 6001 Antione Dr, Houston, TX 77091, United States of America Trade Name — Evaluation # 1 Primer: Interzinc 315B Epoxy Zinc Rich — SSC(11)-02 -- 2 Intermed: Intergard 475HS Epoxy — SSC(11)-02 -- 3 Topcoat: Interthane 870 UHS — SSC(11)-02 Footnote: 4 mils max DFT, 48 hours min cure, zero thinner **89900830 - Sherwin Williams Company** 101 Prospect Ave NW, Cleveland, OH 44115, United States of America Trade Name — Evaluation # 1 Primer: Zinc Clad 4100 Organic Zinc — SSC(15)-07 -- 2 Interm:Macropoxy 646 Fast Cure Epoxy — SSC(15)-07
Texas	TxDOT	<u>Inorganic Zinc Primer</u> Supply the coating as either a two- or a three-component system consisting of one container of zinc dust and one or two containers of liquid components. <u>Epoxy Zinc Primer</u> Supply this primer as a three-component system with one of the components being the dry zinc dust. <u>Epoxy Intermediate Coating</u> This coating is a polyamide-cured or polyamide/aminecured epoxy containing inhibitive type pigments. <u>Urethane Appearance Coat</u> This appearance coat is a glossy, acrylic-cured aliphatic urethane-appearance coat recommended by the manufacturer for marine service. <u>Acrylic Latex Appearance Coat</u> This appearance coat is a water-borne acrylic latex coating designed for long-term durability on structures.
Utah	UDOT	Select a complete three-part coating system consisting of a zinc primer, epoxy or urethane intermediate coat, and aliphatic urethane top coat from the NEPCOAT Qualified Products List.

<table>
<tr><td>Vermont</td><td>VTrans</td><td>Acceptable structural coating systems shall be one of the Structural Coating Systems listed on the Agency's Approved Products List (see below).

<table>
<tr><th>Spec No.</th><th>Material Name</th><th>Product Name</th><th>Manufacturer Name</th></tr>
<tr><td>708.03</td><td>Structural Steel Coating Systems</td><td>SSC(04)-03/SSC(11)-03</td><td>Sherwin-Williams</td></tr>
<tr><td>708.03</td><td>Structural Steel Coating Systems</td><td>SSC(10)-05</td><td>Wasser Coatings, Inc.</td></tr>
<tr><td>708.03</td><td>Structural Steel Coating Systems</td><td>SSC(11)-01</td><td>Sherwin-Williams</td></tr>
<tr><td>708.03</td><td>Structural Steel Coating Systems</td><td>SSC(11)-02</td><td>International Paint, Inc.</td></tr>
<tr><td>708.03</td><td>Structural Steel Coating Systems</td><td>SSC(12)-04</td><td>Carboline</td></tr>
<tr><td>708.03</td><td>Structural Steel Coating Systems</td><td>SSC(15)-07</td><td>Sherwin-Williams</td></tr>
</table>
</td></tr>
<tr><td>Virginia</td><td>VDOT</td><td>Paint shall be selected from the Materials Division Approved Products List, List No. 13. See below for a sample of the list.

System Type: Organic zinc primer, polyamide epoxy intermediate, aliphatic acrylic urethane topcoat, organic zinc repair primer
<table>
<tr><td colspan="5"><u>MANUFACTURER – PPG Industries, Inc. – Roswell, GA</u></td></tr>
<tr><th>COAT</th><th>PAINT</th><th>COLOR</th><th>DRY FILM THICKNESS (mils)</th><th>VOC lb/gal</th></tr>
<tr><td>Primer(s)</td><td>Amercoat 68 HS</td><td>Redish-Gray</td><td>3.0-5.0</td><td>2.4</td></tr>
<tr><td>Intermediate(s)</td><td>Amercoat 399</td><td>White</td><td>4.0-8.0</td><td>1.5</td></tr>
<tr><td>Topcoat(s)</td><td>Amercoat 450 H</td><td>As Specified</td><td>2.0-5.0</td><td>2.6</td></tr>
<tr><td>Primer Repair(s)</td><td>Amercoat 68 HS</td><td></td><td>3.0-5.0</td><td>2.4</td></tr>
<tr><td colspan="5">NTPEP Test No.: SSC(10)-03 Approval Date 11/08 Review date Fall 2015</td></tr>
</table>

System Type: Organic zinc primer, polyamide epoxy intermediate, aliphatic acrylic polyester polyurethane topcoat, organic zinc repair primer
<table>
<tr><td colspan="5"><u>MANUFACTURER – Sherwin Williams – Richmond, VA (804) 387-4050</u></td></tr>
<tr><th>COAT</th><th>PAINT</th><th>COLOR</th><th>DRY FILM THICKNESS (mils)</th><th>VOC lb/gal</th></tr>
<tr><td>Primer(s)</td><td>Zinc Clad III HS</td><td>Gray-Green</td><td>3.0-5.0</td><td>2.8</td></tr>
<tr><td>Intermediate(s)</td><td>Macropoxy 646</td><td>White</td><td>5.0-10.0</td><td>2.0</td></tr>
<tr><td>Topcoat(s)</td><td>Acrolon 218 HS</td><td>As Specified</td><td>3.0-6.0</td><td>2.3</td></tr>
<tr><td>Primer Repair(s)</td><td>Zinc Clad III HS</td><td></td><td>3.0-5.0</td><td>2.8</td></tr>
<tr><td colspan="5">NTPEP Test No.: SSC(04)-03 Approval Date 11/05 Review date 12/15</td></tr>
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</td></tr>
</table>

Appendix A – US DOT Coating Systems

Washington	WSDOT	The paint system applied to new steel surfaces shall consist of the following: Primer Coat Intermediate Coat Intermediate Stripe Coat Top Coat
West Virginia	WVDOH	Paint systems: 3 COAT: Primer, Intermediate, Top Coat 2 COAT: Primer, Top Coat 1 COAT: Epoxy Mastic only
Wisconsin	WisDOT	The epoxy system consists of a prime or shop coat of organic zinc-rich paint, an intermediate shop coat of high-build epoxy paint, and a protective shop coat of urethane paint. Furnish an epoxy coating system from the department's APL for new structural steel (see below). **Carboline** 350 Hanley Industrial St. Louis, MO 63144 (314)-644-1000 **1st** **Carbozinc 859** **2nd** **Carboguard 893** **3rd** **Carbothane 133 VOC** **International Paint, Inc.** 6001 Antoine Drive Huston, TX 77091 (920)-869-6373 **1st** **Interzinc 315B** **2nd** **Interguard 475 HS** **3rd** **Interthane 870UHS** **PPG Protective and Marine Coatings** (Ameron) One PPG Place Pittsburgh, Pa 15272 (800) 441-9695 **1st** **Amercoat 68HS** **2nd** **Amercoat 399** **3rd** **Amercoat 450H** **Sherwin-Williams** 1051 Perimeter Drive Schaumburg, IL 60173 (847)-330-1562 **System 1** **1st** **Zinc Clad III HS** **2nd** **Macropoxy 646** **3rd** **Acrolon 218HS** **System 2** **1st** **Zinc Clad III HS** **2nd** **Steel Spec Epoxy Intermediate** **3rd** **Hi-Solids Polyurethane** **System 3** **1st** **Zinc Clad 4100** **2nd** **Macropoxy 646** **3rd** **Hi-Solids Polyurethane 250**

Wyoming	WyDOT	Primer Ensure the provision and use of an inorganic zinc, high-solids alkyl-silicate primer that is shop applied in accordance with manufacturer's recommendations by brush or spray on new structural steel. Intermediate Field Coat Ensure the provision and use of a two-part, epoxy polyamide paint as field primer or intermediate field coat and suitable for brush or spray application when reconstructing or over coating existing structures. Alkyd-type paint is not allowed. Topcoat Provide and use an industrial, single-component, ready-to-use, semi-gloss, 100 percent acrylic latex, waterborne-type paint.

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