SUMMARY**REPORT**

U.S. Department of Transportation
Federal Highway Administration

Turner-Fairbank
Highway Research Center

Research, Development, and Technology
Turner-Fairbank Highway Research Center
6300 Georgetown Pike
McLean, VA 22101-2296

https://highways.dot.gov/research

Best Practices for Corrosion Control and Mitigation

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FHWA Contact: Frank Jalinoos, HRDI-30, (202) 493-3082, frank.jalinoos@dot.gov

INTRODUCTION

This report was prepared in response to House Report 115-237 and House Report 115-750, which requests that the Secretary of Transportation submit a report on the status of corrosion control planning by State departments of transportation (State DOTs) and the status of corrosion control best practice requirements in State regulations and in bid specifications for bridge projects using Federal taxpayer money. Exhibit A contains the language from the House Reports.

This report attempts to give visibility to the processes by which the Federal Highway Administration (FHWA) and States ensure the use of best practices for bridge corrosion prevention and control. This report is not intended to cover corrosion control technologies with any technical depth; for that, the reader is referred to the list of references in Exhibit B. For the purposes of this report, "best practices" are techniques, methodologies, or processes that are proven to lead to efficient and effective desired outcomes. Furthermore, the bridge corrosion issue of concern is limited to corrosion of structural steel and steel reinforcement in structural concrete, bridge decks, and tensioned steel reinforcement.

To develop this report, FHWA reviewed its bridge design and preservation activities, the literature regarding corrosion control for bridges, national standards, and individual State DOT construction requirements/specifications. In addition, FHWA corresponded with representatives from various States, trade associations, and industry suppliers.

The FHWA and the bridge industry have been actively working to improve approaches to mitigate the effects of corrosion for over 30 years. This report highlights the current state of bridge corrosion control practices in three areas – Best Practices for Corrosion Prevention and Control, Corrosion-related Training and Certification, and Corrosion Control Planning. The following is a summary of the findings in these three areas:

1. **Status of Corrosion Control Best Practices.** Corrosion control best practices are codified in American Association of State Highway and Transportation Officials (AASHTO) specifications. The FHWA provides technical updates to State agencies regarding industry best practices on corrosion control through technical working groups and guidance documents. Over the past 40 years, FHWA has sponsored research on four major bridge corrosion issues – improvements to lead-based paints for corrosion protection, corrosion protection of steel reinforcement, development of corrosion-resistant steels (weathering steels and stainless steels), and prevention of post-tensioning strand corrosion.

2. **Corrosion Control Training and Certification.** The FHWA has worked through the National Highway Institute (NHI) and industry to develop a variety of training and certification programs that cover corrosion control issues. The NHI and industry association programs provide the bridge industry with access to tens of thousands of individuals with corrosion training. This training feeds into individual and company certification programs.

3. **Status of Corrosion Control Planning.** Corrosion control planning for bridges is currently integrated with structure design and preservation activities. The FHWA has worked with AASHTO and State agencies to establish bridge design specifications based on the service needs and design life of the structure. These specifications identify materials that are sufficiently durable to achieve the target design service life; corrosion resistance is a significant factor in the durability analysis of steel and reinforced concrete elements. To preserve bridges in service, FHWA requires an integrated asset management approach (Transportation Asset Management Plan or TAMP), which considers corrosion of bridge elements as a factor in preservation planning. Individual State DOTs prepare TAMP, which is submitted to FHWA for approval.

BACKGROUND

In 2002, a FHWA study investigated the cost of corrosion to various industry sectors, including bridges.[1] At that time, the direct cost of corrosion for highway bridges was estimated to be $8.3 billion per year. This estimate only considered costs to replace and maintain bridges due to the effects of corrosion. In addition to the direct costs, addressing corrosion has significant user costs due to traffic delays and lost productivity.

According to forthcoming FHWA data, from 2004 to 2014 total capital outlays on bridges grew from $11 to $16 billion. Within these amounts, the percentage of capital outlays on bridge rehabilitation grew from 87 percent to 90 percent, while percentage of capital outlays on building new bridges fell from 13 percent to 10 percent, reflecting a slight shift in focus toward preserving existing bridges. Increasing bridge rehabilitation and preventative maintenance funding over this period mirrored an improvement in bridge conditions over the same period. However, the report cautions that an increasing number and size of bridges approaching the limits of their design life will likely place greater demands on bridge owners. Continued improvements in efficient management of bridge condition will be necessary to meet the needs of our Nation's bridges.

The FHWA is an agency within the U.S. Department of Transportation that supports State and local governments in the design, construction, and maintenance of the Nation's highway system (Federal-aid highway program) and various federally and Tribal owned lands (Federal Lands Highway Program). Through financial and technical assistance to State and local governments, FHWA is responsible for ensuring that America's roads and highways continue to be among the safest and most technologically sound in the world.

In 1999, FHWA established a Transportation Asset Management office to transition bridge maintenance approaches from a "worst first" strategy toward more cost-effective asset management approaches. As part of this initiative, each State DOT is required by law to prepare a TAMP to improve or preserve the condition of assets on the National Highway System (NHS) within their jurisdiction. The FHWA Division Offices have the role of TAMP process certification, recertification, and annual plan consistency review.

The Nation is continuing its transition to performance-based management of highway infrastructure with the January 2017 publication of an FHWA rule including national performance management measures for assessing the condition of bridges on the NHS.[2] Performance management rules will help ensure that the Nation's bridges are in good condition and that their overall quality is improved through targeted investments.

In terms of performance management, bridge corrosion is addressed throughout the life cycle by proper design, construction, preventative maintenance, and preservation activities. During bridge design and construction, standard specifications ensure that robust corrosion protection measures are selected and installed to achieve the intended design life. Throughout the bridge lifetime, activities such as bridge cleaning, painting steel bridges, sealing concrete, and repairing or replacing deck joints help to control corrosion. These activities became eligible for Federal bridge program funding in 2006. This led FHWA to establish Bridge Preservation policies and guidance as well as establish an expert task group. Bridge Preservation programs help State DOTs cost effectively preserve and maintain their bridges to support overall highway mobility.

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[1] FHWA-RD-01-156, Corrosion Cost and Preventive Strategies in the United States, March 2002.

[2] 82 FR 5886. Published on January 18, 2017, and available at: https://www.federalregister.gov/documents/2017/01/18/2017-00550/national-performance-management-measures-assessing-pavement-condition-for-the-national-highway

BEST PRACTICES FOR CORROSION PREVENTION AND CONTROL

Corrosion prevention and control for bridges is addressed throughout the structure life-cycle. The bridge designer considers the life cycle impact of material choices. The materials, design details, and construction practices specified by the designer can individually or collectively have significant life-cycle cost implications on bridge maintenance. Best practices involve selecting materials that can provide the intended service life with a reasonable level of effort for preventive maintenance and preservation throughout the bridge life cycle. Best practices are established in each State's standard specifications. These specifications are informed by AASHTO guidance yet tailored to meet the unique needs of each State.

The AASHTO serves as a liaison between State DOTs and the Federal Government. The first broadly-recognized national standard for the design and construction of bridges in the United States was published in 1931 by the American Association of State Highway Officials, the predecessor to AASHTO. The AASHTO standards are issued for design, construction of highways and bridges, materials, and many other technical areas. Appendix C lists selected AASHTO corrosion control publications.

The AASHTO Load and Resistance Factor Design (LRFD) Bridge Design Specifications[3] are intended for the design, evaluation, and rehabilitation of both fixed and movable highway bridges. The specifications are intended to provide the minimum requirements necessary to provide for public safety. Corrosion control guidance is provided throughout the document for a variety of bridge elements. The AASHTO LRFD Bridge Construction Specifications[4] are companion specifications intended for use in the construction of bridges. They include corrosion control guidance for reinforcing steel and a section on protective coatings for exposed steel.

The current best practices for corrosion control predominantly rely on industry expertise and past performance to identify corrosion control technologies and approaches that will economically achieve the desired service life. There are currently efforts to move corrosion design toward approaches that allow engineers to calculate expected service life based on a set of input parameters. For example, the current LRFD specifications contain design calculations to optimize mechanically stabilized earth reinforcement based on soil corrosivity and design service life. As another example, the concrete mix for the Governor Mario M. Cuomo Bridge was formulated based on predicted relationships between material composition and service life.[5]

Approaches to corrosion control during bridge preservation and maintenance involve similar technologies, though the considerations are different. There is considerable guidance to bridge owners regarding corrosion control in the AASHTO Maintenance Manual for Roadways and Bridges[6] and the FHWA Bridge Preservation Guide.[7]

The FHWA provides leadership in sponsoring, sustaining, and guiding highway research. Traditionally, FHWA has worked closely with State research and technology programs, the National Cooperative Highway Research Program (NCHRP), University Transportation Center programs, and many private-sector activities to facilitate shared efforts of its partners and stakeholders. Research into bridge corrosion prevention and control technologies informs current best practices in addition to identifying and validating new technologies. Sometimes the research prompts FHWA to issue a Technical Advisory which provide technical guidance and recommendations to State DOTs on a topic of specific importance. Exhibit B lists representative Technical Advisories and technical reports on bridge corrosion.

The following sections discuss steel bridge corrosion and reinforcing steel corrosion technologies separately. This report is not intended to cover corrosion control technologies with any technical depth; instead each section briefly describes the corrosion concern and lists best practices and innovative approaches to controlling corrosion. Best practices are in regular use by many State DOTs while innovative approaches have been developed to the point of demonstration on bridge project(s). For varying reasons, the innovative approaches are not yet ready for widespread use, but their development and demonstration on in-service structures is the culmination of significant investment by FHWA and the bridge industry that will ultimately lead to more corrosion resistant bridges.

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[3] AASHTO LRFD Bridge Design Specifications, 8th Edition, LRFD-8, American Association of State Highway and Transportation Officials, Washington, DC.

[4] AASHTO LRFD Bridge Construction Specifications, 4th Edition, LRFDCONS-4, American Association of State Highway and Transportation Officials, Washington, DC.

[5] These two approached to bridge design are sometime referred to as "deemed to satisfy" design criteria and "partial probabilistic" design criteria.

[6] AASHTO Maintenance Manual for Roadways and Bridges, 4th Edition, MM-4, American Association of State Highway and Transportation Officials, Washington, DC.

[7] Bridge Preservation Guide, Maintaining a Resilient Infrastructure to Preserve Mobility, Federal Highway Administration, Spring 2018.

STRUCTURAL STEEL CORROSION

Iron ore is a more stable material than iron. When steel is exposed in the atmosphere, the iron tends to want to revert to rust, a stable oxide like iron ore. Steel corrosion rate depends on the corrosivity of the atmosphere, the chemical composition of the steel alloy, and the protective measures employed. In some instances, steel structures are designed to withstand the expected metal loss due to corrosion. In other cases, the steel must be protected from corrosion to retain structural integrity and/or the desired appearance. Durable organic coatings are commonly used for corrosion protection of structural steel.

Table 1 lists the most prevalent corrosion control technologies for steel bridges. The current best practice for corrosion prevention of steel bridges is either a 3-coat liquid coating system with a zinc-based anticorrosive primer or the use of uncoated weathering grade steels which are designed to tolerate corrosion through the design service life.

Innovative corrosion control approaches being developed include longer lasting coatings and more corrosion resistant steels. These approaches have been demonstrated in the field but are not yet mature enough for widespread use. For example, stainless steel bridges have been constructed in California, Iowa, Oregon, and Virginia. Metal spray coatings have been used on bridges in the northeast as longer lasting alternatives to conventional coatings. Obstacles to overcome generally involve reducing constructability risk and developing the life-cycle cost design approaches. These obstacles are being addressed by establishing engineering and construction standards, identifying reliable supplier networks, and developing the policies/practices to justify the use of corrosion control technologies that provide a lower life-cycle cost despite the higher initial (construction) cost. As the technologies become more common, costs are expected to decrease thus allowing expanded use.

REINFORCING STEEL CORROSION

Steel embedded in concrete normally does not corrode because the concrete passivates the steel surface. However, over time the protective properties of the concrete diminish due to ingress of moisture, oxygen, and aggressive ions (e.g., chlorides from deicing salts). As the embedded steel corrodes, it expands. The expansion causes the concrete to crack, allowing more contaminants to reach the steel surface. The process repeats until concrete spalling occurs. Spalling concrete can fall to the ground, posing safety hazards as well as structural concerns. Pre-stressed or post-tensioned concrete may contain steel tendons which are encased in grout-filled ducts. In cases where the duct leaks or the grout does not perform as intended, the steel may experience sufficient corrosion to reduce its load-carrying capacity and may ultimately break. This is thought to have been the cause of a cable failure on the Wando River Bridge in South Carolina.

Approaches to preventing reinforced concrete corrosion involve either improved materials or treatments. Material improvements may be made to the reinforcing material, concrete or grout that contacts the steel (e.g., high performance concrete, corrosion inhibitive grouts, stainless steel reinforcements). Treatments may also be applied to either the steel (e.g., epoxy coating or galvanizing) or to the concrete (e.g., protective coatings, concrete overlays, or penetrating corrosion inhibitors).

Table 2 lists the most prevalent available technologies for protecting reinforcing steel in concrete bridges and decks. The current best practice for corrosion prevention and control of concrete reinforcing steel is the use of epoxy coated reinforcing steel, designing concrete that inhibits corrosion, and/or using corrosion inhibitive grouts to protect steel tendons. The FHWA is currently developing guidelines to identify grout conditions and materials that may not provide the desired long-term corrosion protection.

Table 1. Corrosion Control Options for Steel Bridges.

	New Construction	Preservation
Best Practices	• Three-coat liquid coating system with zinc primer applied over abrasive-blasted steel • Uncoated, weathering-grade steel (designed to corrode in appropriate environments)	• Abrasive blast clean and apply a 3-coat, zinc-based liquid coating system • Spot painting corroded areas (with or without overcoating the entire structure for uniform appearance) • Washing to remove contaminants • Inspect and repair as necessary based on biennial inspection data
Innovative Approaches	• Metallized or galvanized steel with protective organic coating • Higher-Strength Martensitic Stainless Steel • Duplex Stainless Steels	• Use galvanized steel for replacement elements • Field metallizing of existing structures

Table 2. Corrosion Control Options for Concrete Bridges and Decks.

	New Construction	Preservation
Best Practices	• Epoxy coated reinforcing steel • Concrete mix design (Corrosion inhibitors, low w/c ratio to minimize water permeability) • Corrosion inhibitive grouts	• Patch and repair • Sacrificial anode cathodic protection • Protective coatings • Membranes • Polymer modified concrete overlays
Innovative Approaches	• Corrosion resistant reinforcing materials (e.g., MMFX, stainless steel, fiber reinforcement) • Galvanized reinforcing steel • Cathodic protection • Protective coatings on concrete • Alternative Deck Materials (e.g., aluminum, fiber-reinforced plastic or corrosion-resistant steel)	• Penetrating corrosion inhibitors • Concrete sealers • Polymer wearing surfaces

Several innovative approaches have been developed for concrete reinforcing steel. In special circumstances, reinforcing steel can be cathodically protected or concrete can be coated to help protect the reinforcing steel. A few corrosion-resistant reinforcing materials are in varying phases of technology transfer including corrosion resistant steels, fiber materials, and galvanized steels. Corrosion-resistant reinforcing materials have been used in several concrete bridge decks on a demonstration basis. Aluminum bridge decks are in service in Virginia and New York. While more corrosion resistant, these materials also tend to be significantly more expensive. These corrosion-resistant materials will potentially see more use in the coming decades as the life-cycle economics of using more expensive materials are better understood.

CORROSION TRAINING AND CERTIFICATION

There are several corrosion-specific training and certification programs available that have been developed by industry with the support of FHWA. Many of these programs relate to the use of protective coatings for exposed steel. Individual training and certification programs, developed by trade associations in consultation with FHWA, have provided the industry with tens of thousands of trained and certified individuals in the areas of coating inspection, coating application, and corrosion engineering expertise. Coating contractor certification programs offer bridge owners third-party verification (through credential review and on-site project auditing) that contractors have practices and procedures designed to ensure a quality coating application and provide a form of third-party mediation when a dispute arises. Over the past 30 years, these programs have greatly improved the quality of personnel and contractors in the bridge coating industry. Most States now require certified contractors be used on all but the smallest jobs.

The following corrosion-related training has also been addressed by industry with the support of FHWA:

- Corrosion of reinforcing steel is largely addressed as a subtopic within broader training for concrete structure design and construction, though some courses specifically address cathodic protection of reinforced concrete structures.
- General industry corrosion control planning courses and benchmarking programs are available, though they are not specific to highway bridges.
- Bridge-specific corrosion issues are covered in courses for bridge design, construction, preservation and maintenance.

The following sections discuss training and/or certification provided by five industry organizations.

NATIONAL HIGHWAY INSTITUTE

The NHI was established by Congress in 1970 as the training and education arm of FHWA. The NHI is part of FHWA's Office of Technical Services (OTS), and works in partnership with FHWA's Resource Center to provide targeted training and technical assistance to support the highway community. The NHI's course catalog includes hundreds of trainings in more than 18 transportation industry-related program areas that are offered though both distance-learning and classroom courses. The NHI is recognized as an accredited training provider by the International Association of Continuing Education and Training, so participants can earn Continuing Education Units for NHI training courses. Exhibit D lists several NHI courses which contain corrosion prevention and control material.

The NHI-130079, Bridge Coatings Inspection, was discontinued in 2008. Since then, there has not been a comprehensive course specific to the topic of bridge coatings inspection. However, NHI-130107B Maintenance Practices of Bridge Painting is currently being developed as a replacement course. The 4-hour Web-based training is targeted towards members of Federal, State, and local departments of transportation, as well as contractors performing work on behalf of these agencies. It is geared for individuals involved in onsite bridge maintenance activities and those that supervise and manage these activities. Learners will gain basic knowledge of the corrosion process, paint and corrosion evaluations, maintenance coating design options, and the most frequently used methods for surface preparation and application of maintenance painting materials.

TC3: TRANSPORTATION CURRICULUM COORDINATION COUNCIL

The Transportation Curriculum Coordination Council (TC3) was established in 2000 as a partnership among multiple stakeholders, including FHWA, to improve training opportunities for transportation technical workers, while applying innovative measures to reduce duplication of efforts and costs. The Council has more than 190 online training courses available in the areas of construction, maintenance, and materials. Since 2015, the training courses have been hosted by an AASHTO-based learning management system for easier user access, course tracking and evaluation. In September 2018, TC3 launched its first corrosion course, Corrosion of Structures. This course covers the corrosion effects on reinforcing steel, reinforced concrete, and structural steel and girders used in transportation structures. The training is meant to provide information and support to employees who are looking for an introduction to corrosion of structures.

SSPC: THE SOCIETY FOR PROTECTIVE COATINGS

The Society for Protective Coatings (SSPC) was founded in 1950 as the Steel Structures Painting Council, a non-profit professional society concerned with the use of coatings to protect industrial steel structures. Today, SSPC is focused on the protection and preservation of concrete, steel and other industrial and marine structures and surfaces through the use of high-performance protective, marine and industrial coatings. Their services include training and certification courses as well as painting contractor certification programs.

The SSPC offers nearly 50 different training classes which lead to various individual certifications in the areas of applying, inspecting, and specifying coatings. Selected courses are listed in Exhibit D. The SSPC representatives indicated that "most" States require a certified individual (either NACE CIP-1 or SSPC BCS-1) on a coatings project as an inspector and/or quality control specialist where there is a QC/Inspection requirement.

The SSPC also provides eight different contractor certification programs. These are nationally recognized independent contractor evaluation programs with over 400 qualified contractors. The SSPC representatives indicated that over half of the States require a qualified contractor for bridge painting projects, including most States with a significant inventory of coated steel bridges in coastal or northern climates. Unless waived by the owner, these programs require contractors to have coating applicator specialist certified personnel and certified coating inspectors on "larger" projects.

NACE INTERNATIONAL

NACE International (NACE) has a stated mission to equip society to protect people, assets and the environment from the adverse effects of corrosion. The NACE was established in 1943 by 11 corrosion engineers from the pipeline industry as the "National Association of Corrosion Engineers." Today, NACE serves nearly 36,000 members in over 130 countries and is recognized globally as the premier authority for corrosion control solutions. The organization offers technical training and certification programs, conferences, industry standards, reports, publications, technical journals, government relations activities, and more. Selected classes that relate to bridge corrosion are listed in Exhibit D.

The NACE International Institute is an independent affiliate of NACE specifically focused on certification activities and supports the growth of corrosion control experts and their profession. The Institute administers 23 certifications plus the Coating Inspector Program (CIP) endorsements. There are more than 36,000 NACE certification holders worldwide. A Coating Inspector Certification is available that is specific to the bridge industry.

The NACE International Institute Contractor Accreditation Program (NIICAP) is an accreditation program that validates a contractor's quality assurance program, support practices, and production processes. Accreditations are made based on a review of the contractors' business policies, on-site inspection of business practices and a project site audit overseen by third-party auditors with experience and expertise in the practices being audited.

AMERICAN CONCRETE INSTITUTE (ACI)

The American Concrete Institute (ACI) is a trade association dedicated to development, distribution and adoption of consensus-based standards, technical resources, educational programs for individuals and organizations involved in concrete design, construction, and materials. ACI also offers nearly 20 online learning courses on topics related to reinforcing steel corrosion; four of the most relevant are identified in Exhibit D.

NATIONAL TRANSPORTATION PRODUCT EVALUATION PROGRAM (NTPEP)

The National Transportation Product Evaluation Program (NTPEP) was established to minimize the amount of duplicative testing of transportation materials performed by State laboratories.[8] The NTPEP currently has programs for 19 product types including Structural Steel Coatings (SSC). The SSC program evaluates protective coating systems intended for use on new and existing structural steel prepared by abrasive blast cleaning. The program provides the end user with test results which can be used to make performance judgments on coating systems for long environmental exposures. The testing program was developed around a three-coat system consisting of a zinc primer, epoxy or urethane intermediate, and an aliphatic urethane finish coat, however coating systems are not required to meet any specific compositional requirements for submission and testing. The NTPEP exists purely for testing materials and providing test results. The evaluation of the test results is left up to each State. Currently, two thirds of the States use NTPEP to inform their structural steel coating selection.

CORROSION CONTROL PLANNING

Corrosion control planning encompasses program management, engineering, logistics, test and evaluation, budget/funding, and procurement/contracting elements that might impact the effective use of corrosion prevention and control practices throughout the life cycle of a bridge. For bridges, corrosion control falls under the larger categories of asset management and bridge preservation. The next two sections discuss how corrosion control planning is integrated into these categories. A final section presents industry guidance and programs for corrosion control planning.

TRANSPORTATION ASSET MANAGEMENT

Transportation Asset Management (TAM) is a strategic and systematic process of operating, maintaining, and improving physical assets, with a focus on engineering and economic analysis based upon quality information, to identify a structured sequence of maintenance, preservation, repair, rehabilitation, and replacement actions that will achieve and sustain a desired state of good repair over the lifecycle of the assets at minimum practicable cost (23 U.S.C. 101(a)(2)). Each State DOT is required by law to prepare a TAMP to improve or preserve the condition of assets on the NHS within their jurisdiction. The FHWA is responsible for review and certification of the TAMP.[9] Each State TAMP must be publicly available; the AASHTO TAM Portal is a convenient location to access most State TAMPs.[10]

While not specifically addressed in the law, corrosion control planning is an integral consideration in development of a TAMP. For bridges, TAMPs rely on bridge element inspection data to characterize the bridge condition. The AASHTO Manual for Bridge Element Inspection includes elements for corrosion, protective coatings, and reinforcing steel protection systems. The corrosion-related elements are considered along with the other inspected elements to determine a cost-effective approach to maintain acceptable performance of the bridge inventory within the State.

FHWA BRIDGE PRESERVATION INITIATIVES

For existing structures, corrosion issues are addressed under the umbrella of bridge preservation. The FHWA Bridge Preservation Guide defines Bridge Preservation as "actions or strategies that prevent, delay, or reduce deterioration of bridges or bridge elements; restore the function of existing bridges; keep bridges in good or fair condition; and extend their service life. Preservation actions may be cyclic or condition-driven."[8] Since steel corrosion is a mechanism of bridge deterioration, bridge preservation activities include those intended to prevent, delay or reduce corrosion.

Preservation activities such as bridge cleaning, painting steel bridges, sealing concrete and repairing or replacing deck joints became eligible for Federal bridge program funding in 2006. To help oversee how States used Federal funding for preservation, FHWA developed bridge preservation-related definitions and corresponding commentaries, as well as the framework for a systematic approach to a preventive maintenance program guidance. A FHWA Bridge Preservation Guide was originally published by FHWA in August 2011, when SAFETEA-LU was in effect and bridge repair and rehabilitation activities were funded by the Highway Bridge Program. The FHWA Bridge Preservation Guide is continually revised as required to be consistent with new laws and revised FHWA policy (e.g., MAP-21, FAST Act).

The FHWA also established a Bridge Preservation Expert Task Group (BPETG) to "advance and improve the state of the practice in the area of highway bridge preservation by working collaboratively with Federal, State and local agencies, professional associations (AASHTO, TRB, etc.), industry, and academic interests." The 2016 BPETG strategic plan identifies a number of actions to address four overarching strategic objectives.[11] Corrosion prevention

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[8] See www.ntpep.org for additional information.

[9] See https://www.fhwa.dot.gov/asset/ for additional information on Asset Management.

[10] See http://www.tam-portal.com/ for additional information.

[11] See https://www.fhwa.dot.gov/bridge/preservation/ for additional information.

and control activities such as painting, cleaning, deck corrosion protection are directly addressed as part of bridge preservation.

ADDITIONAL CORROSION INDUSTRY GUIDANCE

The SSPC and NACE International have developed a joint standard for corrosion prevention and control planning.[12] The standard defines the key elements that may be involved in corrosion prevention and control planning for design, manufacturing, construction, operation and sustainability of products and facilities. The standard is built around checklists that provide a listing of the basic elements of Corrosion Prevention and Control planning which should be considered. The user may select some or all of the elements for any specific program/project using the standard. Each element in the checklist has a corresponding requirement statement and non-mandatory guidance specific to that element.

NACE International has developed its own set of corrosion management tools branded as IMPACT PLUS. The tools comprise "an integrated platform for corrosion management professionals who desire to move their companies to higher levels of corrosion management performance." A key element of the process is the Corrosion Management Maturity Model which provides a framework for understanding the extent of corrosion management operations and practices in an organization. Based on an organization's level of maturity in each of ten domains, the model can place an organization into one of five levels of maturity as well as identify domains where improvement is needed to reach a higher level of maturity. Figure 1 shows the five levels of maturity. While the bridge industry has reportedly not been evaluated using the model, efforts by FHWA in the area of TAM, standardization throughout the States (in cooperation with AASHTO and other industry organizations), and development of state of the art technologies (through programs such as pooled fund studies and National Cooperative Highway Research Program) would seem to indicate a fairly high level of maturity relative to corrosion management.

SUMMARY

Corrosion is a complex problem, affecting many different aspects of new and existing bridge structures. Numerous methods exist to manage and mitigate corrosion's damaging effects; new methods of prevention are constantly being developed and evaluated by Government, industry and academia. Due to the complexity of the problem, there is no one-size-fits-all approach. Consequently, while there is no single, overarching program dedicated to bridge corrosion, the bridge industry has been actively improving corrosion prevention, control and planning practices for

Figure 1. Five Levels of Maturity for Corrosion Management within an Organization.

5 – Innovative & Leading	**Progressive; Inclusive**
• Highly engaged and driving the state-of-the-art of corrosion management • Anticipatory, agile, and embedded in the flow of the work	
4 – Optimized & Proactive	**Visible; Improving**
• Corrosion management program implemented • Lessons learned activities built into CM processes to capture and apply learnings to improve CM processes • May have some anticipatory capabilities	
3 – Managed & Integrated	**Comprehensive; Enterprise-wide**
• Corrosion management is well-structured management approach • Aligned end-to-end across enterprise	
2 – Defined & Compliant	**Locally Consistent**
• Corrosion management defined but only compliant with the standard or bare minimum • Some CM processes defined, but may still be isolated and not part of the integrated management approach	
1 – Reactive	**Basic; Individual**
• Need for corrosion management identified, but no strategic focus • Corrosion management activities occur on as-needed basis but no systematic plan in place to address more consistently	

[12] SSPC/NACE JOINT STANDARD PRACTICE SSPC-CPC 1/NACE SP21412-2016, Corrosion Prevention and Control Planning, available from SSPC and NACE International.

over 30 years. This report attempts to give visibility to the disparate activities in the field of corrosion prevention and mitigation. Corrosion control is addressed in industry training programs, industry standards, and FHWA policies. The FHWA ensures that best corrosion control and prevention practices are used on projects funded with Federal funds through several mechanisms including:

- FHWA sponsors and participates in research to develop new and innovative methods to combat bridge corrosion.
- FHWA provides technical updates to State agencies regarding industry best practices on corrosion control through technical working groups and guidance documents.
- FHWA works with NHI and industry associations to develop a variety of training and certification programs that cover corrosion control issues.
- FHWA works with AASHTO and State agencies to establish bridge design specifications based on the service needs and design life of the structure.
- FHWA requires each State to develop an integrated asset management approach (TAM Plan or TAMP) which considers corrosion of bridge elements as a factor in preservation planning.

EXHIBIT A – LANGUAGE IN HR 115-237 AND HR 115-750

- *Bridge corrosion control best practices (Explanatory Statement, 2018, p. 18)* —The agreement directs the Secretary to submit the report required in House Report 115-237 on bridge corrosion control best practices, but does not direct the Secretary to use a third-party organization to determine the qualification of contractors and subcontractors.
- *Bridge corrosion control best practices (House Report 115–237, p. 35)* —The Committee is concerned with the large number of bridges in poor conditions in the U.S. and recognizes that corrosion is a leading cause of bridge failure. The Committee also recognizes that the use of industry best practices in corrosion planning and prevention can greatly lengthen the lifecycle of a bridge, saving taxpayer money and protecting public safety and the environment. Therefore, the Committee directs the Secretary to consult with State transportation departments Dots to ensure that contractors and subcontractors hired for bridge construction, alteration or maintenance projects using Federal taxpayer money, other than those involving minor repair work, are utilizing industry best practices to prevent, mitigate and control corrosion. Industry best practices include surface preparation, protective coatings, materials selection, cathodic protection, corrosion engineering, and personnel training. The Secretary should ensure that State DOTs are using contractors and subcontractors that are qualified, as determined by a third-party organization, as capable of meeting industry best practices. The Committee expects the Secretary to report back to the Committee, and to the House Transportation and Infrastructure Committee and the Senate Environment and Public Works Committee, within one year of enactment of this legislation, on the status of corrosion control planning by State DOTs, and the status of corrosion control best practice requirements in State regulations and in bid specifications for bridge projects using Federal taxpayer money. The Committee expects the report to highlight what steps the Secretary has taken, in consultation with State DOTs, to ensure that contractors and subcontractors hired for bridge construction, alteration or maintenance projects using Federal taxpayer money are qualified and utilizing industry best practices to prevent, mitigate and control corrosion in bridge projects.
- *Structurally deficient bridges (House Report 115–750, p. 34)* —The Committee is concerned with the large number of bridges in poor conditions in the U.S. and recognizes that corrosion is a leading cause of bridge failure. The Committee also recognizes that the use of industry best practices in corrosion planning and prevention can greatly lengthen the life cycle of a bridge, saving taxpayer money, and protecting public safety and the environment. Therefore, the Committee directs the Secretary to consult with State DOTs to ensure that contractors and subcontractors hired for bridge construction, alteration, or maintenance projects using Federal taxpayer money, other than those involving minor repair work, are utilizing industry best practices to prevent, mitigate, and control corrosion. Industry best practices include surface preparation, protective coatings, materials selection, cathodic protection, corrosion engineering, and personnel training. The Secretary should ensure that State DOTs are using qualified contractors and subcontractors capable of meeting industry best practices in the prevention of corrosion in bridge projects. The employment of appropriately trained applicator specialists, the use of certified cathodic protection specialists, and the use of industry-certified coatings and cathodic protection inspectors can improve the chances that best practices are followed. The Secretary shall report to the House and Senate Committees on Appropriations, the House Transportation and Infrastructure Committee, and the Senate Environment and Public Works Committee within one year of enactment of this Act on the status of corrosion control planning by State DOTs and corrosion control best practice requirements in State regulations and bid specifications for bridge projects using Federal funding. The Secretary shall also report on what steps have

been taken, in consultation with State DOTs, to ensure that contractors and subcontractors hired for bridge construction are qualified and utilizing industry best practices to prevent, mitigate, and control corrosion. The Committee is also concerned about the demands being placed on bridges in poor conditions. The June 2015 Comprehensive Truck Size and Weight Technical Reports Summary found that 4,845 bridges would need to be strengthened or replaced to handle the additional stress if Federal truck weights were increased to 91,000 pounds. A significant increase in Federal truck size could create greater funding needs and cost implications should be weighed by the Department and Congress before any change in national policy is considered.

EXHIBIT B – SELECTED FHWA CORROSION PREVENTION AND CONTROL DOCUMENTS

FHWA Technical Advisories

Technical Advisory 5140.33: Recommendations for Assessing and Managing Long-Term Performance of Post-Tensioned Bridges having Tendons Installed with Grout Containing Elevated Levels of Chloride. (11/12/2013)

Technical Advisory 5140.25: Cable Stays of Cable-Stayed Bridges (6/17/94)

Technical Advisory 5140.22: Uncoated Weathering Steel in Structures. (10/3/89)

Technical Advisory 5140.17: Portland Cement Concrete Mix Design and Field Control (7/14/94)

FHWA Research and Technology Reports

An FHWA Special Study: Post-Tensioning Tendon Grout Chloride Thresholds (FHWA-HRT-14-039), 2014

Appleman, Bernard R., Joseph A. Bruno, and Raymond E. F. Weaver. Performance of Alternate Coatings in the Environment (PACE) – Part I: Ten-Year Field Data (Report No. FHWA-RD-89-127), Federal Highway Administration, Washington, DC, June 1989.

Appleman, Bernard R., Raymond E. F. Weaver, and Joseph A. Bruno, Jr. Performance of Alternate Coatings in the Environment (PACE) – Volume II: Five-Year Field and Bridge Data of Improved Formulations (Report No. FHWA-RD-89-235), Federal Highway Administration, Washington, DC, December 1989.

Ault, Peter, Jim Ellor, John Repp, and Brad Shaw. Characterization of the Environment (Report No. FHWA-RD-00-030), Federal Highway Administration, Washington, DC, August 2000.

J. Peter Ault, Christopher Farschon, Adhesion Criteria between Water-Based Inorganic Zinc Coatings and their Topcoats for Steel, FHWA-RD-98-170, March 1999.

Chong, Shuang-Ling, and Yuan Yao. Laboratory and Test-Site Testing of Moisture- Cured Urethanes on Steel in Salt-Rich Environment (Report No. FHWA-RD-00-156), Federal Highway Administration, Washington, DC, December 2000.

Corrosion Cost and Preventive Strategies in the United States; FHWA-RD-01-156; September 30, 2001.

Corrosion Monitoring Research of New York City Bridges (FHWA-HRT-14-023), 2014.

Farschon, Christopher, Robert Kogler, and Peter J. Ault. Guidelines for Repair and Maintenance of Bridge Coatings: Overcoating (Report No. FHWA-RD-97-092), Federal Highway Administration, Washington, DC, August 1997.

FHWA Study Tour for Bridge Maintenance Coatings, International Technology Research Institute, June 1996.

Fletcher, F B. 2011. Improved Corrosion-Resistant Steel for Highway Bridge Construction. Technical Report No. FHWA-HRT-11-062, McLean: Federal Highway Administration.

William H. Hartt, Rodney G. Powers, Diane K. Lysogorski, Virginie Liroux, Y. Paul Virmani, Corrosion Resistant Alloys for Reinforced Concrete Publication No. FHWA-HRT-07-039, July 2007

William H. Hartt, Rodney G. Powers, Francisco Presuel Marino, Mario Paredes, Ronald Simmons, Hui Yu, Rodrigo Himiob, Y. Paul Virmani, Corrosion Resistant Alloys for Reinforced Concrete Publication No. FHWA-HRT-09-020, April 2009

Kogler, R. 2015. Steel and Bridge Design Handbook: Corrosion Protection of Steel Bridges. Technical Report No. FHWA-HIF-16-002-Vol. 19, Washington D.C.: Federal Highway Administration.

Kogler, Robert, and William Mott. Environmentally Acceptable Materials for the Corrosion Protection of Steel Bridges: Task C, Laboratory Evaluation (Report No. FHWA-RD-91-060), Federal Highway Administration, Washington, DC, September 1992.

Kogler, Robert, J. Peter Ault, and Christopher Farschon. Environmentally Acceptable Materials for the Corrosion Protection of Steel Bridges (Report No. FHWA-RD-96-058), Federal Highway Administration, Washington, DC, January 1997.

Seung-Kyoung Lee, Laboratory Evaluation of Corrosion Resistance of Various Metallic Dowel Bars, FHWA-HRT-15-079, 2015.

Seung-Kyoung Lee, Comparative Laboratory Study of Metallic Reinforcing Steels for Corrosion Protection of Reinforced Concrete Bridge Structures, FHWA-HRT-15-078

Smith, J.L. and Virmani, Y.P. Materials and Methods for Corrosion Control of Reinforced and Prestressed Concrete Structures in New Construction, FHWA-RD-00-081, August 2001.

Smith, Lloyd M., and Gary L. Tinklenberg. Lead-Containing Paint Removal, Containment, and Disposal (Report No. FHWA-RD-94-100), Federal Highway Administration, Washington, DC, February 1995.

Virmani, Paul, Multiple Corrosion-Protection Systems for Reinforced Concrete Bridge Components, FHWA Publication No: FHWA-HRT-11-059, 2011

Yo, Yuan, Pradeep Kodumuir, and Seung-Kyoung Lee. 2011. Performance Evaluation of One-Coat Systems for New Steel Bridges. FHWA.

National Cooperative Highway Research Program Reports

Albrecht, P. and A.H. Naeemi. 1984. Performance of Weathering Steel in Bridges. National Cooperative Highway Research Program Report 272, Washington D.C.: National Research Council.

J. Peter Ault and Justin D. Dolph, Corrosion Prevention for Extending the Service Life of Steel Bridges: A Synthesis of Highway Practice, NCHRP Synthesis 517, Washington, DC, 2018

Azizinamini, A et. al., Design Guide for Bridges for Service Life, SHRP 2 Report S2- R19A-RW-2, Transportation Research Board 2014.

Ellor, James A., John Repp, and Walter A. Young. Thermally Sprayed Metal Coatings to Protect Steel Piling: Final Report and Guide (NCHRP Report 528), Transportation Research Board, Washington, DC, 2004.

Hopwood II, Theodore, Palle, Sudhir, Meade, Bobby, et.al., Spot Painting to Extend Highway Bridge Coating Life, NCHRP Web-Only Document 251, 2018.

Kulicki, J.M., Guidelines for Evaluating Corrosion Effects in Existing Steel Bridges, NCHRP Report 333, 1989.

Seradj, Hormoz. Oregon's Experience with ASTM A1010. TRB 2015 Annual Meeting. Oregon Department of Transportation. 2015.

Sohanghpurwala, A.A., Manual on Service Life of Corrosion-Damaged Reinforced Concrete Bridge Superstructure Elements, NCHRP Report 558, 2005.

Successful Preservation Practices for Steel Bridge Coatings, Scan Team Report NCHRP Project 20-68A, Scan 15-03, National Cooperative Highway Research Program, October 2016.

EXHIBIT C – SELECTED AASHTO GUIDES, STANDARDS AND REFERENCES COVERING CORROSION CONTROL

Standard Specifications

- Standard Specifications for Highway Bridges, 17th Edition (2002)
- AASHTO LRFD Bridge Design Specifications, 8th Edition (2017)
- AASHTO LRFD Bridge Construction Specifications, 4th Edition (2017)
- Standard Specifications for Transportation Materials and Methods of Sampling and Testing, and AASHTO Provisional Standards (2018)

Publications by AASHTO committees and task forces

- Guide for Painting Steel Structures (1997)
- ASHTO Maintenance Manual: The Maintenance and Management of Roadways and Bridges (2007)
- Guide Specifications for Cathodic Protection of Concrete Bridge Decks (1994)
- Manual for Corrosion Protection of Concrete Components in Bridges (1992)

AASHTO-NSBA Collaboration Publications

- Guide Specification for Application of Coating Systems with Zinc-Rich Primers to Steel Bridges, S 8.1-2006
- Guideline Specification for Application of Thermal Spray Coatings for Steel Bridges S8.2-2017
- Guideline Specification for Hot Dip Galvanizing S8.3 (currently being balloted)

AASHTO-TC3 Training

- Corrosion of Structures

EXHIBIT D – SELECTED INDUSTRY RESOURCES FOR CORROSION TRAINING AND CERTIFICATION

NHI Courses involving Corrosion-Related Issues for Bridges

- 130055 Safety Inspection of In-Service Bridges
- 130103 Post-Tensioning Tendon Installation and Grouting – WBT
- 130111 Nondestructive Evaluation Fundamentals for Bridge Inspection (Web-based)
- 130112A NDE for Concrete Bridge Elements (Web-based)
- 130095 LRFD and Analysis of Curved Steel Highway Bridges
- 130095B Design and Fabrication of Curved and Skewed Steel Bridges

- 131117 Basic Materials for Highway and Structure Construction and Maintenance
- 130107A Fundamentals of Bridge Maintenance WBT
- 134067 Construction Inspection of Bridge Rehabilitation Projects
- 130106A Bridge Preservation Fundamentals
- 130106B Establishing a Bridge Preservation Program
- 130107A Fundamentals of Bridge Maintenance WBT
- 130108 Bridge Maintenance (ILT)

Transportation Curriculum Coordination Council

- Corrosion of Structures (2 PDHs)

SSPC: The Society for Protective Coatings

- Bridge Coatings Inspector Program (BCI)
- Bridge Maintenance: Conducting Coating Assessments (BRIDGE)
- Concrete Coating Inspector Program (CCI)
- Protective Coatings Specialist (PCS) Program
- Quality Control Supervisor (QCS)
- Coating Application Specialist Certification Program (CAS)

NACE International

- Coating Inspector Program
  - CIP Level 1
  - CIP Level 2
  - CIP Peer Review
  - CIP Bridge eCourse
- Cathodic Protection Program
  - CP 1 – Cathodic Protection Tester
  - CP 2 – Cathodic Protection Technician
  - CP 3 – Cathodic Protection Technologist
  - CP 4 – Cathodic Protection Specialist
- General Coatings Program
  - PCS 1 Basic Principles
  - PCS 2 Advanced
- Selected other training
  - Corrosion Prevention and Control Management eCourse
  - Corrosion & Protection of Concrete Structures & Buildings
  - Industrial Coating Application (ICA) eCourse

American Concrete Institute (ACI)

- Corrosion-Inhibiting Admixtures for Concrete
- Corrosion Protection Systems for Reinforcing Steel
- Rehabilitation of Structure with Reinforcement Section Loss
- ACI 515.2R-13 Guide to Selecting Protective Treatments for Concrete (3 parts)

The report herein was sent by Secretary Elaine L. Chao to the chairman and Vice Chairman of the Senate Committee on Appropriations; the Chairman and Ranking Member of the House Committee on Appropriations; the Chairman and Ranking Member of the Senate Subcommittee on Transportation, Housing and Urban Development, and Related Agencies; the Chairman and Ranking Member of the House Subcommittee on Transportation, Housing and Urban Development, and Related Agencies; the Chairman and Ranking Member of the House Committee on Transportation and Infrastructure; and the Chairman and Ranking Member of the Senate Committee on Environment and Public Works.

Researchers—This Summary Report was developed by Chip Becker (FHWA) and Pete Ault (sub-contractor of SES Group and Associates, LLC) under FHWA's Corrosion and Coatings Program (Infrastructure Materials Laboratories Contract No. DTFH61-17-D-00017). SES Group and Associates, LLC served as the contractor to FHWA. For additional information, contact Frank Jalinoos, in the FHWA Office of Infrastructure Research and Development, located at 6300 Georgetown Pike, McLean, VA 22101-2296.

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