General References

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.

This design handbook covers a range of topics and design examples related to the corrosion protection of steel bridges. It is intended to provide information and guidance needed to make knowledgeable decisions regarded the material selection, design, fabrication, and construction of steel bridges. It addresses several common issues regarding corrosion of steel bridges.

Kulicki, J M, Z Prucz, D F Sorgenfrei, and D R Mertz. 1990. Guidelines for Evaluating Corrosion Effect in Existing Steel Bridges. National Cooperative Highway Research Program Report 333, Washington D.C.: Transportation Research Board.

This project presents practical guidelines in assessing the effects of corrosion on structural details in highway bridges. It contains detailed guidance on performing field inspections, assessments, and structural capacity analysis for corrosion damaged components.

NACE. 2012. Corrosion Control Plan for Bridges. Houston, TX. www.nace.org.

The United States highway system is mature and sustaining the system has required significant increases in maintenance dollars. Today, many states are making dramatic cuts in service and expenditures. Creative ways to address the issue of scarce financial resources must be found. This white paper looks at bridges and what makes them corrode. It also discusses how employing relatively low-cost corrosion control measures during initial construction can produce low-maintenance bridges with service lives of 75 to 100 years. Corrosion control protects initial bridge investment and dramatically reduces maintenance expenses in the future.

Fabrication Perspectives about Various Durability Solutions, Ronnie Medlock, presented at TRB January 2017.

The author presents his thoughts on the costs of several durability solutions for steel bridges. This includes the use of weathering steel, zinc primers, polyaspartic topcoats, galvanizing, and metalizing.

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

This guide is the main product of the Second Strategic Highway Research Program (SHRP2) project, R19A. In general, design for service life is approached by utilizing individual strategies, each capable of enhancing service life of individual bridge elements. The main objective of the guide is to provide information and define procedures to systematically design for service life and durability for both new and existing bridges. The objective of the guide is to equip the user with knowledge that is needed to develop optimal solutions for bridge design.

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

The U.S. Federal Highway Administration (FHWA) released a two-year study in 2002 on the direct costs associated with metallic corrosion in nearly every U.S. industry sector, from infrastructure and transportation to production and manufacturing. The study provides current cost estimates and identifies national strategies to minimize the impact of corrosion. The study showed that the total

annual estimated direct cost of corrosion in the U.S. is $276 billion—approximately 3.1% of the nation's Gross Domestic Product (GDP). This report includes findings from the study, including costs by industry sector and preventive corrosion control strategies.

Coated Steels

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.

This report presents the results of a 10-year field study which compared environmentally acceptable coating systems for steel with standard U.S. industry and government systems. The test included four major branches:

- *Alternate Primer Pigments : 56 coatings; 840 panels (lead & chromate replacements)*
- *Alternate Surface Preparation Abrasives : 6 coatings; 730 panels (waterborne alkyds, acrylics, and styrene acrylics)*
- *Water-Borne Coatings: 35 coatings; 595 panels (silica sand replacements)*
- *Alternate Pigments and Vehicles in Vinyls: 26 coatings ; 80 panels*

*The coatings were applied to 4 x 12 x 1/4 inch (100 x 300 x 6.J mm) steel panels and exposed at three outdoor sites. The panels were rated at least once per year for surface rusting (ASTM 0610) and scribe undercutting. The major analytical method was failure-survival analysis. The failure level selected was the time to reach rust rating of 7 or scribe undercutting of 1/4 inch (6.3 mm). The report compares trends among coating groups; lists top performing coatings; assesses influence of test site, film thickness, degree of cleaning and mode of failure, (i.e., rust or scribe undercutting) and effect on performance trend*s; and recommends implementation of the findings and additional studies.

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.

Results are presented from a 5-year field study on advanced formulations and surface cleaning techniques for coating systems for steel bridges. The test branches included:

- *Alternate blast and non-blast cleaning methods: the effectiveness of alternative metallic and nonmetallic abrasives, newly developed power tools, and citric acid cleaning were evaluated for five standard coatings at three test sites. Also investigated was the effect of rust grade and pre-rust location sites.*
- *New experimental coatings: The 100 coating systems tested included lead-containing and lead- and chromate-free oil alkyds, acrylic and styrene acrylic latex, petroleum wax coatings, chlorinated rubber, water-borne epoxies, vinyl, epoxy, urethane, zinc-rich and others. Each coating was applied over hand and blast-cleaned panels and exposed at 3 test sites.*
- *Bridge site exposures: Eight highway coatings systems were exposed over blast and hand cleaned test panels and exposed at 10 representative bridge exposure sites.*

The 2800 test panels were rated over a period of 5 years for rusting and scribe undercutting. Failure/survival analysis was conducted of the relative performance of the coatings, cleaning methods, test sites, and film thickness.

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.

This study sought to compile data on accelerated and natural exposure of coating and corrosion test panels and relate their deterioration to exposure conditions. The report recommends the use of zinc-rich coating systems to protect steel and prevent cutback. It also recommends cleaning steel substrates prior to painting to prevent blistering. The study concludes that loss of loss is related to southern latitudes and color change is related to high relative humidity. For weathering steel, it was concluded that most high-chloride marine sites are unsuitable environments.

Chang, L., and Seunghyun Chung. 1999. Steel Bridge Protection Policy Volume II of V Evaluation of Bridge Coating System for INDOT Steel Bridges. West Lafayette, IN.

This study investigates the use of metallized coatings for bridges in INDOT. A survey is completed to investigate the popularity of metallized coatings on US steel bridges. The study recommends metalizing in-shop rather than in-field due to the stringent process control required to successfully implement metallized coatings. Guidance is given on how to carry out the entire metallizing process, covering areas such as surface preparation, spraying parameters, recommended coating characteristics, and quality assurance methods.

Chang, L., and Maged Georgy. 1999. Steel Bridge Protection Policy Volume III Metallization of Steel Bridges: Research and Practice.

The study identifies various painting systems that are successfully used in Indiana's surrounding states and other industries. After comparing INDOT's inorganic zinc/vinyl system, waterborne acrylic system, moisture cure urethane coating system, and 3-coat zinc-epoxy-urethane systems, it is determined that the new 3-coat system fulfills INDOT's needs with the most benefits. In addition, a cost comparison between the full-removal and overcoating of lead-based paint is completed.

Chang, L., and Maged Georgy. 1999. Steel Bridge Protection Policy Volume V of V Warranty Clauses for INDOT Steel Bridge Paint Contracts.

To assure the quality of paint material and workmanship after completion of the painting contract, the development of legally binding and dependable warranty clauses is initiated in this study. A literature review and survey of existing warranty forms and clauses is completed. It was found that several areas need further evaluation, such as the definition of "defect", amount of warranty bond, and warranty period.

Chong, Shuang-Ling, and Yuan Yao. 2006. "Are Two Coats as Effective as Three?" Public Roads 70/2 (September/October 2006). https://www.fhwa.dot.gov/publications/publicroads/06sep/06.cfm.

This research investigates two-coat protection systems as possible alternatives to three-coat systems. The FHWA researchers concluded that two-coat systems exist that perform comparably to predominant zinc-epoxy-polyurethane systems. This conclusion is based on the results of laboratory testing and a two-year exposure.

KTA-Tator Inc. 2014. Transportation Agency Practices Currently Employed for Bridge Maintenance Painting Operations: Findings from a National Survey.

KTA-Tator, Inc. investigated practices for maintenance painting of steel bridges employed by other transportation agencies throughout the United States on behalf of the Minnesota Department of Transportation (MnDOT). Survey data was received from forty-two agencies on five topic areas, including 1) Coating Condition Assessments; 2) Bridge Coating Maintenance Strategies; 3) Surface Preparation Methods; 4) Coating Systems; and 5) Use of In-house Painting Forces versus Contractors. A summary of the data for each of the topic areas, comparisons to the practices currently employed by MnDOT, and recommendations are provided in the Summary and Recommendations section of the report.

Lau, Kingsley. 2015. Corrosion Evaluation of Novel Coatings for Steel Components of Highway Bridges. Tallahassee, FL.

The Florida Department of Transportation (FDOT) had expressed interest in gauging the available coating technologies that may have suitable applications for steel components in highway bridges. Chemically bonded phosphate ceramics (CBPC) and the thermal diffusion galvanizing (TDG) process were identified for further testing, which was mainly short-term outdoor exposures. The CBC coatings displayed a propensity for significant undercoating surface oxidation that was observed may compromise long-term durability. Meanwhile TDG coatings required robust topcoats for long-term durability.

Lindsley, Melissa. 2015. Galvanized Steel Bridges. http://www.galvanizeit.org/.

This presentation included an introduction to galvanized and duplex coating system for steel bridges. It names specifications, design guidance documents, and inspection and repair documentation that can be referred to for further information. Finally, some case studies of bridges employing galvanizing are presented.

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

To address cost issues associated with shop application of conventional three-coat systems, the Federal Highway Administration completed a study to investigate the performance of eight one-coat systems and two control coatings for corrosion protection of highway bridges. Based on prior performance, a three-coat system and a two-coat system were selected as the control coating systems. The performance of all coating systems was evaluated under accelerated laboratory and outdoor exposure conditions. A calcium sulfonate alkyd coating system was found to perform equally in comparison with the three-coat system; however, curing was a major concern. Regression analysis was used to identify correlations between color, gloss, adhesion strength, and coating defects for one-coat systems

KTA-Tator, "Investigation of the Effect of Chlor*Rid on Removing Chloride and Sulfate Contamination." November 1995.

*KTA-Tator, Inc. completed independent testing evaluate the effect of Chlor*Rid for removing chloride and sulfate from rusted steel panels. The testing demonstrated that the use of a soluble salt remover*

can reduce surface chlorides versus water washing after abrasive blasting steel panels in a lab scenario.

Johnson, “Is Plain Water Washing Effective Enough?” JPCL, September 2003.

Though the coatings industry has widely acknowledged that salts other than chlorides, such as sulfates and nitrates, contribute to premature coating failure, little if any actual field data have been gathered. Less is known about the degree of contamination in these various environments, or if standard washing practices are effective at removing them. Early in 2001, to address these issues, research began on existing salt contamination levels on highway bridges in Illinois. The data were collected through field testing locations representing the diversity of environments across Illinois. Chloride, nitrate, and sulfate salt concentrations were measured. The results demonstrate that pressurized water washing may leave a substantial quantity of soluble salt on the surface. Salt removal was enhanced with the addition of the chemical salt remover.

Palle, Younce, and Hopwood II, “Investigation of Soluble Salts on Kentucky Bridges,” January 2003.

Soluble salts present on steel highway structures can promote corrosion even after maintenance painting. The objectives In this study were to determine the levels of soluble salts on Kentucky Transportation Cabinet (KYTC) bridges, study the effects of various cleaning methods, and determine whether salt levels can be reduced low enough to prevent damage to bridges or their coating systems. Three bridges were selected for field testing of cleaning methods. It was recommended to add contract language requiring salt levels around 10µg/cm^2 prior to painting.

Van Eijnsbergen, J. F. H. (1994) Duplex Systems – Hot-dip Galvanizing plus Painting. Elsevier. Amsterdam, Netherlands.

This book is a comprehensive discussion of duplex systems (the generic term for painted hot-dip galvanized steel). Duplex systems are based on the synergistic effect of galvanizing and painting, offering additional protection against corrosion of steel surfaces in environments where galvanized steel alone cannot provide a sufficiently long resistance against rust formation. Coating pieces after both the traditional batch hot-dip galvanizing process and the modern sheet galvanizing processes are covered. Methods to avoid adhesion problems by using special paint products, surface pretreatments, and modern surface analyzing methods are presented. Economic impacts are presented including comparison to alternatives such as corrosion resistant alloys and impacts on maintenance needs.

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.

The objective of this research was to develop a guide for highway agency personnel on the selection and use of TSMCs on highway pilings that would be suitable as an AASHTO reference. Applicable portions of existing materials were used in the preparation of the guide. This study also sought to resolve any issues that were unclear concerning the use of TSMCs on steel pilings. These issues have included sealer materials, the effects of abrasive mixes, standoff distances, gun-to-surface angles, steel hardness, edges, coating defects, and surface contamination. The study confirmed the positive impact of the use of sealers and that all of the sealers tested in the study would be beneficial in

improving performance. Tests on grit and shot/grit mixtures show that 100-percent grit provides the best adhesion, followed by the shot/grit mixtures, and then by 100-percent shot.

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.

Three 3-coat moisture-cured (MC) urethane commercial products formulated for protecting new steel (SSPC-SP 10) and power tool-cleaned steel (SSPC-SP 3) surfaces against corrosion were evaluated. Zinc-rich MC-urethane primers were used for SSPC-SP 10 steel surfaces whereas the primers for SSPC-SP 3 surfaces contained zero or a small amount of zinc. The same midcoats and topcoats were used for both steel surfaces. Sealers were also studied for any potential effect on coating performance for power tool-cleaned surfaces. The laboratory test results in conjunction with the chemical analysis results suggested that pigment particle size distribution in the primers played a more important role than other factors in the formation of creepage at the scribe. Furthermore, the addition of a sealer to the primer/midcoat/topcoat systems unexpectedly impaired the performance at the scribe on SSPC-SP 3 steel surfaces when compared with those systems without a sealer.

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.

The subject program investigated the applicability of various materials and methods for repair and overcoating of existing steel bridge paint systems. The program included a literature review, material selection, laboratory screening testing, and extended field exposure testing phases. Results indicate varying performance between coatings tested. A few coatings failed by disbondment between the overcoat and original coating after one or two winter cycles. Other coatings suffered from significant pinpoint or edge rusting through the overcoat film. It is recommended that the chance of early coating failure be considered prior to investing in overcoating maintenance.

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.

Maintenance of lead-based coating systems requires the work to be performed in compliance with environmental and worker health/safety regulations. Conforming to these regulations has had a significant impact on procedures and cost. A comprehensive study was performed to evaluate the various factors involved with lead-paint removal. Containment and ventilation systems were studied and recommendations were developed for containment materials, design of joints, design of air inputs, negative pressure, and air flow within containment. Tests were also performed on hazardous waste characterization, waste minimization, methods of generating non-hazardous waste, and long-term stability of lead-containing wastes and stabilized wastes. Alternate surface preparation methods and costs were evaluated. Recyclable steel abrasive was found to be cost-competitive and to reduce the amount of debris by approximately 90% compared to expendable abrasive. Other surface preparation methods tested were found to have advantages and disadvantages. The cost of meeting environmental and worker health regulations has increased the cost of the average project by a factor of two or three.

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.

Environmental regulations concerning volatile organic compounds (VOCs) and certain hazardous heavy metals have had a large impact on the bridge painting industry. As a response to these regulations, many of the major coating manufacturers have begun to offer "environmentally acceptable" alternative coating systems to replace those traditionally used on bridge structures. In the interest of determining the relative corrosion control performance of these newly available coating systems, the Federal Highway Administration contracted for a seven-year study. As a precursor to long-term, natural exposure testing of various environmentally acceptable coating systems, a battery of accelerated laboratory screening tests were performed. These tests included 13 high solids or waterborne, conventionally applied coatings; 14 powder coating or metallized coatings; and 7 high VOC control coatings. The results of various tests were used to develop a matrix of test coatings to be used in the follow-on, long-term natural exposure testing. In the accelerated laboratory screening tests, several of the low VOC coating systems performed as well, or better than the high VOC controls. In general, the low VOC zinc-based systems (both inorganic and organic zinc) and the epoxy mastic type systems performed the best in the accelerated tests.

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.

The recently promulgated environmental regulations concerning volatile organic compounds (VOC) and certain hazardous heavy metals have had a great impact on the bridge painting industry. As a response to these regulations, many of the major coaling manufacturers now offer "environmentally acceptable" alternative coating systems to replace those traditionally used on bridge structures. The Federal Highway Administration sponsored a 7-year study to determine the relative corrosion control performance of these newly available coating systems. A battery of accelerated laboratory tests were performed on candidate coating materials with a maximum VOC content of 340 g/L (2.8 lbs/gal). Accelerated tests included cyclic salt fog/ natural marine exposure, cyclic brine immersion/natural marine exposure, and natural marine exposure testing. Natural exposure test panels were exposed and evaluated for a total of 6.5 years. The most promising coating systems were selected for long-term field evaluation based on accelerated test performance.

The long-term exposure testing was conducted for 5 years in three marine locations. Panels were exposed on two bridges, one in New Jersey, and one in southern Louisiana. The third long-term exposure location was in Sea Isle City, New Jersey. Thirteen coating systems were included for long-term exposure testing. These Included 2 high-VOC controls and 11 test systems having a VOC level of 340 g/L (2.8 lbs/gal) or less. Five of the test systems contained high-solids primers, two of the test systems contained waterborne primers, one system was based on a powder coating, and three systems were metallizing.

The best performing systems were the three metallized coatings. These were initially less aesthetic than coating systems with high-gloss topcoats, but they displayed near-perfect corrosion performance after 5-to 6.5-year exposure periods. Of the traditional liquid applied coating systems, those incorporating inorganic zinc primers performed the best over near-white blasted and power-

tool cleaned surfaces. High-solids epoxy coatings had a tendency to undercut at intentional scribes and rust worse than coatings with zinc-rich primers over less than ideal surface preparations. Current bridge painting methodologies and corrosiveness of various bridge substructures were investigated. Various bridge maintenance painting options were evaluated on a life-cycle cost basis using data developed in the program. The analysis points to the potential advantages of long-term durable coatings such as metallizing and alternative painting practices such as zone painting.

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

The median age of the existing inventory now exceeds 40 years, and a large percentage of coating systems protecting steel bridges have met or exceeded their useful service lives. There is currently an increasing demand for maintenance and replacement of coating systems on steel bridge structures. Bridge painting is a cost-effective means of extending the functional performance of steel bridges. It should be in the toolkit of every state highway agency; all state highway agencies will be required to use it due to its economic impact to the taxpayer and its function viability. The applied polymeric coating (where pertinent) should serve in an aesthetic and corrosion preventive manner for an extended period of time; based on the results of this scan, at least 15 years and up to 30 years. The scan team identified several factors that would result in premature coatings failure (singly or in combination with others) and offers several observations taken during coating failure mitigation workshops.

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

Regulatory impact in environmental impact and worker safety and changes in coating material technology have led to rapid changes in the bridge maintenance coating market. The FHWA commissioned a team to pursue technology transfer to the steel bridge maintenance coating methods with the European highway community. This report highlight the methods and materials identified during this technology transfer. Topics include contracting operations, surface preparation methods, worker health and safety, environmental considerations, agency-contractor relations, bridge management systems, and metallizing.

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

This study investigated possible causes for failure of water-based inorganic zinc (WBJOZ) coatings. Literature review revealed a general consensus that failures relate to improper cure of the WBJOZ primer. This improper cure was hypothesized to related to environmental conditions. This report demonstrates that environmental conditions may contribute to failures of the WBJOZ, but are not the primary cause. Rather, it is concluded that freckle rusting can be caused by substrate salt contamination or improper mixing while acrylic topcoat delamination can occur if alkaline compounds are present on the WBJOZ primer surface.

SSPC TU-3, Technology Update No. 3, Overcoating, SSPC: The Society for Protective Coatings, 2004.

This technology update discusses the risks associated with the maintenance painting practice known as overcoating. Factors affecting overcoating application, service and costs are discussed. This *document is intended to serve as a resource for facility owners and others charged with developing and implementing maintenance painting programs. This document is not intended to provide a detailed description or comparison of the relative merit and cost considerations of overcoating versus other maintenance painting options. For a more complete and detailed discussion of maintenance painting practices, the reader should refer to SSPC-PA Guide 5, Guide to Maintenance Painting Programs.*

Farschon, C; Hewins, M; and Moran, C. Repainting Bridges During Rehabilitation Projects: Sequencing Options. Journal of Protective Coatings & Linings Vol 23, Iss 1. Pittsburgh PA. (January 2006)

This article outlines the scope and sequencing of a steel bridge rehabilitation project. A steel bridge rehabilitation project is used to restore the safe load-carrying capacity of a bridge, to handle the designed traffic, and to extend the useful life of the structure. The problems tackled during a bridge rehabilitation can include the condition of the bridge deck, expansion joints and other structures, and the ability of the existing paint system to protect the bridge from corrosion. The authors focus on four case histories of bridge rehabilitation: the Marine Parkway Gil Hodges Memorial Bridge (New York, NY), the Calvin Coolidge Memorial Bridge (Northampton, MA), the Great Channel Bridge (Wildwood, NJ), and the William Stickel Bridge (Newark, NJ). The authors review the painting of relevant projects and list issues related to combining repainting with other steel bridge rehabilitation tasks. The authors conclude that planning the sequence of painting is a vital part of the overall bridge rehabilitation project design. A thoroughly prepared design scheme can produce a satisfactory project while minimizing external impacts, costs, and overall construction time

Uncoated Steels

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.

This report contains the findings of a comprehensive assessment of the performance of weathering steel in bridges based on a review of the literature, a survey of practice in highway agencies and other organizations, and contact with selected individuals knowledgeable on the subject. It includes an introduction to weathering steel alloys, effects of alloying elements, strengthening and fatigue characteristics, guidance on painting and welding, and field experiences.

ArcelorMittal. 2016. Duracor/ASTM A1010: Bridge Applications and Fabrication Guidelines. September. Accessed December 29, 2016. usa.arcelormittal.com.

This document provides application and fabrication guidelines for the use of A1010 steel for bridge applications. It contains guidance on formability, heat forming, shearing, welding, and fastener compatibility. It also contains information on appearing upon weathering and example applications of A1010 on bridges.

ASTM A1010/A1010M. West Conshocken: ASTM International. 2013.

This specification covers martensitic stainless steel alloys for various applications. It contains the chemical composition and strength requirements for A1010 alloys.

ASTM A709/A709M. West Conshocken: ASTM International. 2016.

This specification covers carbon and high-strength low alloy steel structural shapes, plates, and bars and quenched and tempered alloy steel for structural plates intended for use in bridges. Seven grades are available in four yield strength levels.

ASTM G101. West Conshocken: ASTM International. 2004.

This guide presents two methods for estimating the atmospheric corrosion resistance of low-alloy weathering steels, such as those described in Specifications A242/A242M, A588/A588M, A606 Type 4, A709/A709M grades 50W, HPS 70W, and 100W, A852/A852M, and A871/A871M. One method gives an estimate of the long-term thickness loss of a steel at a specific site based on results of short-term tests. The other gives an estimate of relative corrosion resistance based on chemical composition.

Crampton, D.D., K.P. Holloway, and J. Frazek. 2013. Assessment of Weathering Steel Bridge Performance in Iowa and Development of Inspection and Maintenance Techniques. No. 5300C, Ames, IA: Iowa Department.

The performance of weathering steel depends on the proper formation of a surface patina, which consists of a dense layer of corrosion product used to protect the steel from further atmospheric corrosion. The development of the weathering steel patina may be hindered by environmental factors such as humid environments, wetting/drying cycles, sheltering, exposure to de-icing chlorides, and design details that permit water to pond on steel surfaces. This project is focused on the evaluation of weathering steel bridge structures, including possible methods to assess the quality of the weathering steel patina and to properly maintain the quality of the patina.

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

Several steel alloys were designed to achieve the low corrosion rates typical of ASTM A1010 steels at a reduced cost. Cyclic corrosion testing and exposure testing were used to study the corrosion behavior of the novel alloys and compared them to ASTM A1010 stainless and ASTM A588 weathering steel. Life-cycle cost analyses of a steel girder was used to examine the benefits of using a maintenance free steel, such as ASTM A1010 versus the conventional painted steel. It is concluded that over a 40 year lifetime, the ASTM A1010 alloy is the cheaper alternative.

Fletcher, F B, A D Wilson, J Strasky, J N Kilpatrick, T Mlcoch, and J S Wrysinski. 2005. "Stainless Steel for Accelerated Bridge Construction." FHWA Accelerated Bridge Construction Conference. San Diego, CA.

This report includes a review of ASTM A1010 production and corrosion properties. It then presents a mutli-cell box girder bridge design using A1010 in Colusa Country, California.

Fletcher, F B, H E Townsend, and A D Wilson. 2003. "Corrosion Performance of Improved Weathering Steels for Bridges." National Steel Bridge Alliance World Steel Bridge Symposium. Orlando.

In this report, the results of long term field exposure of ASTM A709 grades 50W, 70W, and HPS-100W are presented along with three Japanese grades and ASTM A1010. The exposures were carried out in rural, light industrial and coastal seaside locations. It is concluded that the weathering steels exhibit greater corrosion resistance than plain carbon structural steel.

Hara, S., T. Kamimura, H. Miyuki, and M. Yamashita. 2007. "Taxonomy for Protective Ability of Rust Layer Using its Composition Formed on Weathering Steel Bridge." Corrosion Science (Elsevier Ltd.) 49: 1131-1142.

This project studies the relationship between the corrosion rate of the weathering steel and the compositions of rust layers formed. A protective ability index is developed to classify the corrosion rates as a function of the mass ratios of present oxide types in the rust layers.

Iowa Department of Transportation. 2015. "Evaluation of Performance of A1010 Bridge Steel, RB10-016." TRID: the TRIS and ITRD database. December 1. Accessed January 4, 2017. https://trid.trb.org/view/2016/P/1376311.

This project is currently on-going. The general goal of the work is to evaluate the fundamental corrosion behavior of ASTM A1010 girders and evaluate the in-situ performance of the Woodbury Country Bridge.

McConnell, Jennifer, Harry W Shenton III, and Dennis R Mertz. 2014. "Evaluation of Unpainted Weathering Steel Highway Bridge Performance." LTBP News, May.

The long term performance of unpainted weathering steel bridges is being assessed. In this report, the results of a survey of bridge owners has been completed and simple field evaluation techniques were investigated for inclusion into national bridge condition index database.

McDad, B, D C Laffrey, M Dammann, and R D Medock, P.E. 2000. Project 0-1818: Performance of Weathering Steel in TxDOT Structures. TxDOT.

A brief history of the development and application of weathering steel is presented. A survey and field inspections were conducted to gather the performance of weathering steel in TxDOT. Finally, recommendations are given on achieving good performance with weathering steel bridges.

Willet, T O. 1989. Technical Advisory 5140.22: Uncoated Weathering Steel in Structures. Technical Advisory, Washington D.C.: FHWA.

This is a technical advisory released by the Federal Highway Administration to provide engineers with guidelines in the proper application and maintenance of uncoated weathering grade steels in highway structures.

N. Baddoo, "Steel Design Guide 27: Structural Stainless Steel," American Institute of Steel Construction, 2013.

This Design Guide is written for engineers experienced in the design of carbon steel structural components but not necessarily in the design of stainless steel structures. It is aligned with the design provisions in the 2010 AISC Specification for Structural Steel Buildings (AISC, 2010c), hereafter referred to as the AISC Specification. This guide addresses material properties, material selection and durability, design requirements, design guidance, fabrication, construction, fatigue properties, testing guidance, and commentary.

G. Gedge, "Use of Duplex Stainless Steel Plate for Durable Bridge Construction," in IABSE Symposium Weimar 2007, Weimar, 2007.

The paper considers the use of alternative materials for bridge construction to provide owners with long term durable structures requiring minimum maintenance. The materials considered are a family of stainless steels referred to as duplex stainless steels. The paper considers the history of development of duplex steels and reports on the latest generation of steels with lean alloy contents that provide good levels of corrosion resistance without the excessive cost premium often associated with stainless steels. The paper includes examples of recent uses of these steels on bridge structures and outlines where further research is required to provide the greater confidence needed to encourage owners and designers to adopt the steels more widely.

AZoM, "Stainless Steels - Introduction to the Grades and Families," AZoM, 16 May 2001. [Online]. Available: https://www.azom.com/article.aspx?ArticleID=470. [Accessed 22 August 2017].

This online article is an introduction to stainless steel designations, classification, and general properties.

K. Kuchta and I. Tylek, "Application of Stainless Steels in Building Structures," Technical Transactions, Vols. 3-B, 2013.

In the paper, structural stainless steels consistent with EN 10088 are characterized. Stainless steel categories, production process, basic properties, and joining techniques are addressed. Some examples of stainless steel applications realized in the last few years are presented.

T. Bell, "Steel Grades and Properties: What are the different types of steel?," the balance, 01 July 2017. [Online]. Available: https://www.thebalance.com/steel-grades-2340174. [Accessed 22 August 2017].

This online article is a first level introduction to the different types of steel. It presents typical chemical compositions, material properties, and applications.

Atlas Steels Technical Department, Atlas Steels Technical Handbook of Stainless Steels, Atlas Steels, 2013.

This Technical Handbook has been produced as an aid to all personnel of Atlas Steels, their customers and the engineering community generally. It is intended to be both background reading for technical seminars conducted by Atlas Steels Technical Department, and also as a source of ongoing reference data. It contains information on chemical composition, fabrication, applications, metallurgical properties, typical heat treatments, material properties, and corrosion resistance of stainless steel alloys.

European Standard, "en 1993-1-4. eurocode 3 – Design of steel structures – part 1–4: General rules – supplementary rules for stainless steels.".

This Part 1.4 of EN 1993 gives supplementary provisions for the design of buildings and civil engineering works that extend and modify the application of EN 1993-1-1, EN 1993-1-3, EN 1993-1-5, and EN 1993-1-8 to austenitic, austenitic-ferritic and ferritic stainless steels. It contains a guidance table for suggested grades of stainless steel based on atmospheric conditions.

N. Baddoo and A. Kosmac, "Sustainable Duplex Stainless Steel Bridges," in Duplex 2010, 2010.

Duplex stainless steels are increasingly used as structural materials in building and architecture because of their exceptional mechanical properties. Several recent examples of using duplex stainless steels in bridge construction are presented.

J. Tagnoli, "The Harbor Drive Pedestrian Bridge," Structure, October 2013.

This magazine acritical spotlights the Harbor Drive Pedestrian Bridge in San Diego, CA.

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

After an extensive study of ASTM A1010 steel and developing a weld procedure for fabrication of A1010 steel girders, ODOT decided to construct a bridge utilizing this steel. FHWA supported the concept and awarded an Innovative Bridge Research and Development (IBRD), grant for design and fabrication of high corrosion resistant steel plate girders. There are currently two ASTM A1010 steel bridges in service in the State of Oregon. This paper describes critical aspects and characteristics of ASTM A1010 steel and presents the results of ODOT's investigation into the suitability of A1010 steel in the design and construction.

Sharp, Stephen, William Via, and Audrey Moruza. Virginia's Initial Experience with an ASTM A1010 Plate Girder Bridge. TB 96th Annual Meeting. Virginia Department of Transportation. 2017.

This presentation discusses the lessons learned on the fabrication and welding practices of ASTM A1010 construction. An ASTM A1010 plate girder bridge was successfully installed.

Bridge Cleaning

Jeffrey Berman, Charles Roeder, Ryan Burgdorfer. Determining the Cost/Benefit of Routine Maintenance Cleaning on Steel Bridges to Prevent Structural Deterioration, September 2013.

The objective of this study is to identify the key variables necessary in estimating the impact of regular washing of steel bridges on the paint and service life, recommend methods for recording data to most effectively estimate the benefits of bridge washing, and to develop a framework for assessing the impact of bridge washing on paint life. A literature review was conducted to gather information from previous studies on bridge washing, the effects of washing on corrosion, and gain general knowledge on corrosion of steel, how paint condition is recorded, and environmental considerations. From the initial survey and information from the follow-up surveys it seems that very few studies relating to bridge washing and paint life have been performed. It also shows that any correlation drawn from the data received would be hypothetical at best. However, there are agencies that have demonstrated long bridge lives with a maintained washing program in addition to other routine maintenance and painting.
It is suggested that WSDOT set up an experiment that specifically monitors sets of bridges in the different areas of the state. With routine inspections and well documented information WSDOT will be able to determine whether to move forward with an annual bridge washing program.

Evaluation of Bridge Cleaning Methods on Steel Structures, Final Report, Kevin Alland, Julie M. Vandenbossche (PI), P.E., Ph.D., Radisav Vidic, P.E., Ph.D., and Xiao Ma. University of Pittsburgh, FHWA-PA-2013-007-PIT WO 2.

Corrosion due to soluble salts is a major factor in the lifespan of the bridges and there protective coating. Therefore, it is beneficial to develop a bridge washing program, which can remove soluble salts from steel bridge members. This study evaluated the Pennsylvania Department of Transportation procedures for bridge washing. It was found that water is effective at removing soluble salt from steel bridges as long as good practices are used. From a programming stand point, it was found that members directly above a roadway contained high concentrations of soluble salts and are not cleaned in the current specification. Contrary to this, the full length of truss and arch members below the bridge deck are currently being cleaned despite not having high surface salt concentrations. It was also determined that the bridge washing process did not adversely affect the surrounding environment.

Bridge Inspection / Washing Program & Bridge Drainage Program, Rhode Island Department of Transportation - Operations Division, February 2002

This report discusses Rhode Island's approach to bridge washing and drainage maintenance. Three major benefits of bridge washing are described including Bridge Inspection Quality, Bridge Inspector Safety, and Structural Benefits. An appendix to the report contains an evaluation of PONTIS data that suggests an average savings of $20,000 per bridge every eight years if they were washed and cleaned on a regular basis.