Condition of US Bridges and Present Corrosion Technologies Used for Bridge Structures

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Presentation Outline

- Condition of US Bridges
- Corrosion Protection of
  - Reinforced Concrete Bridges
  - Steel Bridges
  - Prestressed Concrete Bridges
- Closing Remarks
Condition of US Bridges
(2010 NBI Data)
Corrosion of Superstructures
Bearing Corrosion

Courtesy of
Corrosion of Substructures
Corrosion of High Strength Wires

Photo Courtesy of Penn DOT/VDOT/Parsons & Maine DOT/LA DOT (from top left clockwise)
Degrading Bridge Coatings
Corrosion of Weathering Steel
Distribution of Total Bridges by Age
(2010 NBI data)
Distribution of SD Bridges by Age
(2010 NBI data)
Material Usage and Span Length Data
(2010 NBI data)
SD Percent and Span Length Data
(2010 NBI data)
Effect of Climate on SD Bridges
(2010 NBI data)
SD Classified by Highway Type and ADT
(2010 NBI data)
Conclusion

- The U.S. bridges with all of the following characteristics are the most likely to be structurally deficient:
  - Age 50 years or older located in the rural local areas
  - Simply supported steel stringer/multi-beam superstructure with less than 50-ft span length
  - Cast-in-place reinforced concrete deck without any deck protection system (black reinforcing steel)
  - Non-NHS with ADT of 0 to 10,000 vehicles
Corrosion Protection of Reinforced Concrete Bridges
New Construction

- Epoxy-coated reinforcing steel
- Corrosion resistant alloy bars
- Stainless steel clad bars
- FRP bars
- Corrosion inhibitors
- Cathodic prevention
Epoxy Coated Reinforcing Steel

- This is the most widely used corrosion protection system for bridge decks (40 years).
- ECR is a barrier system to avoid reaction between corrosive chloride ions and black steel.
- Before 1970’s bridges built with black steel had an average life of 15-20 years.
- Service life of ECR decks is projected to be more than black steel if both mats are ECR.
There are about 70,000 bridge decks built with ECR covering over 886M sq. ft.

In USA, about 5,000 bridges are built every year and majority of them have ECR.

ASTM and AASHTO specifications governs the quality, thickness, cathodic disbondment radius, surface cleanliness, anchor profile, etc.

CRSI have certification program to oversee the quality control aspect of the production to provide consistent quality of the rebar to the owners.
Corrosion Resistance Alloys and SS Clad Rebars

- Following products were evaluated and the performance data is analyzed in three separate FHWA reports FHWA-HRT07/039, 06/078 and 97/039
  - Solid SS: 304 and 316
  - SS Clad: two products (each 304 and 316 cladding)
  - Alloy Bars: Micro-composite steel, 2201, 2205, 2304, and 3Cr12
  - Black Steel - Control
Corrosion Resistance Alloys and SS Clad Rebars

The following conclusions were reached (after 3 years of 5 year research study) based on short term accelerated laboratory experiments in simulated pore solution and long term exposure of concrete specimens to chloride ions with wet and dry cycles for promoting the ingress of chloride ions.

- Ranking*:

SS316/Clad >> 2201 > Micro-composite > 3Cr12 > Black

* No comparison was made between alloyed/clad rebars with ECR
Another FHWA rebar study employing 12 types of #5 or #6 reinforcing materials from 11 sources evaluated corrosion resistance in 8 large scale concrete slabs.
Issues:

- Availability in USA: Made in USA clause for a clad bar product
- Cost effectiveness based on life cycle cost analysis
- More obsolete bridges than deficient ones
- It takes decades of field performance to confirm or disapprove what accelerated corrosion testing data suggest.
Cathodic Prevention

- It operates by the same principle as cathodic protection except for the timing of application:
  - Opposing chloride ingress into concrete
  - Requiring less current to achieve the protection than CP
  - Higher initial costs, but may be lower maintenance costs throughout the life of the structure
  - Very little used in US

Source: NACE Paper #06342, “performance of cathodic prevention of Sydney Opera House Underbroadwalk after 10 years of operation”
Rehabilitation

- Cathodic Protection Systems*
  - Impressed Current
  - Sacrificial Anode
- Electrochemical Chloride Removal*
- Electrochemical Re-alkalization*
- Overlays/Sealers/Patch Repair

* Same principle, but difference in amount of cathodic current and the duration of the treatments
Electrochemical Chloride Removal

- This technique removes chloride ions in the chloride contaminated concrete and rebar surface by applying CP current and restores passivity on the steel.
- 1 to 2 A/m² for 6 to 8 weeks

Source: Norcure Electrochemical Chloride Extraction PDF (left) and FHWA-HRT-10-069 (right)
Overlays/Sealers/Patch Repair

- Overlays and Membranes
- Sealers
- Patch Repair – often use with point sacrificial anodes to extend the life of patches

Source: VCTIR Report 07-R35
Corrosion Protection of Steel Bridges
Unpainted Weathering Steel
Unpainted Weathering Steel

Urban Interstate Highway Overpass
Unpainted Weathering Steel

Urban Interstate Highway Overpass
Unpainted New Alloy Steel

- FHWA initiated three studies in the fall of 2007 to develop improved/economical corrosion resistant steels that do not require supplemental coatings.
  - Northwestern University
  - Mittal Steel
  - Lehigh University

- The improved weathering steel shall be (1) readily produced; (2) structural properties equal to ASTM A709; (3) ease of weldability and fabrication; and (4) similar costs as A709 steels unless it has higher strengths to reduce amount of steel.
Northwestern University

The objective of this study was to suggest a science based weathering steels composition whose performance is superior to A709 steel.

Weathering characteristics of steels could be improved by increasing the concentration of the elements commonly found in steel (Si, Mn, Cu, Ni, Cr, Mo, P, etc.). ASTM G101 relationship (or similar relationships) between the corrosion rate and concentration of the alloying elements could be used.

Ti, Al, P, W, rare earth alloyed to A710 grade B steel may improve corrosion resistance
Mittal Steel

The objective of this study was to modify the composition of ASTM A1010 steel at lower cost without significantly reducing its atmospheric corrosion resistance.

The researchers achieved the corrosion resistance better than ASTM A709 steels by decreasing the chromium content from A1010, but the physical and mechanical properties of newly alloyed steels did not meet the requirements for bridge construction.
The objective was to produce corrosion resistant weathering steels better than existing grades at the same costs, not much more than HPS -100 W by modifying the alloyed composition with small amounts of Cu, Ni, Si, P, Cr, etc.

The researchers could only achieve modest gain on the corrosion resistance when Cr content was low. When Cr was increased, much better results observed, but made the steel too brittle to meet the design criterion including other mechanical properties. Out of 24 different compositions, one optimal corrosion resistant steel found to have all the required physical properties for construction.
FHWA Coating Research Programs

- 2002 - 2005: Fast Dry 2-Coat Study
- 2004 – 2007: Overcoating Study
- 2006 – 2010: One-Coat Study
- 2009 – 2012: 100-Year Coating Study (some outdoor testing has been continued to date)
Fast Dry 2-Coat Study

- New 2-coat systems were sought to paint steel bridges/overpasses fast compared to the conventional 3-coats.
- Studied were a total of 11 coating systems consisting of three 3-coats and eight 2-coats.
- Each 2-coat system had a zinc-rich primer and a fast-dry, high-build top coat (six commercial products).
- It was concluded that the 2-coat systems tested could replace the 3-coats because of their comparable performance while reducing paint costs and traffic congestion.
Overcoating Study

- Removal of old alkyd paints containing harmful lead and chromate is an expensive and hazardous work under the current environmental regulations.
- Overcoating of the local deteriorated areas became a very economical (<1/3 of full removal cost) and less hazardous maintenance strategy.
- A total of 17 overcoating systems were evaluated over three steel conditions of aged alkyd coating, IOZ/vinyl coating, and SSPC-SP 3 (power cleaning).
Overcoating Study

- Coating thickness played a critical role in development of surface rust-through.
- The CSA was the best performer at the scribe, regardless of surface condition, and the remaining overcoat materials showed different levels of corrosion protection.
- It was thought that the CSA had a unique high affinity to less perfect steel surfaces and provided high resistance to corrosion.
The objective of the study was to evaluate one-coat systems that could replace the conventional 3-coat system as an economically viable solution.

A total of ten coating systems including one 3-coat and one 2-coat control systems were evaluated in the accelerated laboratory testing for 6,840 hours and outdoor exposure conditions for up to 24 months.
One Coat Study

- The 3-coat control demonstrated very good performance in almost all aspects and slightly better than the 2-coat control.

- None of the one-coat systems performed better than the 3-coat in accelerated lab and outdoor exposure conditions.

- High-Ratio Calcium Sulfonate Alkyd (HRCSA) performed well in both laboratory test and outdoor exposure testing despite its softness and very weak adhesion strength.
Performance of One Coat Test Panels

- **3-coat**
  - [0 hr]
  - [6,840 hrs]

- **HRCSA**
  - [0 hr]
  - [6,840 hrs]

- **SLX**
  - [0 hr]
  - [4,320 hrs]

- **UM**
  - [0 hr]
  - [4,320 hrs]
The objective of this study was to identify and evaluate coating materials that could provide 100 years of virtually maintenance-free service life for the steel bridge structures.

A total of eight coating systems including two 3-coat control coatings were tested under accelerated laboratory testing for 3,600 hours and three outdoor exposure conditions for more than 50 months (on-going).
100-Year Coat Study

- None of them including the control coatings will provide maintenance-free corrosion protection to steel bridges for 100 years.

- Until future research and development efforts produce coating systems with extended service life, it should be our goal to use the proven legacy coating systems correctly by reducing human errors and choosing right materials for the intended applications.
Performance of 100-Yr Coating Test Panels

3-Coat Control (Inorganic Zinc-rich Epoxy/Epoxy/Aliphatic Polyurethane)

NW (34 months)  NWS (34 months)  GGB (40 months)

2-Coat (Experimental Zinc Primer/Linear Epoxy)

NW (34 months)  NWS (34 months)  GGB (40 months)
Corrosion Protection of Prestressed Concrete Bridges
Pre-tensioned Concrete Girders

- Beam end coatings
- Patch repair
- Cathodic protection using metallized zinc or zinc-aluminum alloy coating
- However, there are no practical and economical corrosion protection systems.
Post-tensioned Tendons and Stay Cables

- Concrete for internal tendon only
- Duct (metallic, plastic, plus wrapping tape for cables)
- Cementitious grout

[External PT Tendon] [Stay Cable]
Corrosion Damage Detection of External PT Tendons & Cables

- Once corrosion damage occurs, there are no economical corrosion mitigation methods other than replacing the affected members.

- There are no accurate NDE technologies to assess the condition of the affected tendons and cables.

- Currently, two NDE technologies for detecting corrosion problems in the tensioned wires are available:
  - Magnetic Flux Leakage (MFL) Method
  - Magnetic Main Flux Method (MMFM)
Magnetic Main Flux Method (MMFM)
MMFM Test Results

\[ y = 0.999x - 0.1935 \]
\[ R^2 = 0.9918 \]

~810 mm (32 in.) from wall

~1,900 mm (75 in.) from wall

2,110 mm (83 in.) from wall

Partial section loss observed on several wires

Partial section loss observed on several wires

One wire broken and heavy section loss observed on several wires

Lab Data

Field Data
Closing Remarks
Where Do We Need More Research?

- Corrosion resistant alloys cost more
- Better performing alloys than presently used weathering steels for steel bridges requiring no paint
- Rehabilitation of 5,000 bridge decks built with ECR top mat and black steel bottom mat to reduce concrete spalling from underside of the deck
- Sensing technologies for chloride ingress and rebar corrosion in concrete
Where Do We Need More Research?

- Determination of allowable residual chloride contents and development of surface tolerant coating systems for steel bridges
- Corrosion resistant high strength strands/wires for pre-tensioned concrete, post-tensioned tendons, cable stays, and suspension cables
- Suitable alternative materials for filling the ducts and also corrosion resistant to the enclosed strands
- Durable duct materials for 100-150 years without cracks and corrosion
THANK YOU!