Chloride Sampling in Bridge Decks

2016 Pacific Northwest Snowfighters Conference

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Introduction
Cost of Corrosion

The estimated annual direct cost of corrosion for United States highway bridges is $13.6 billion (NACE International).

The road and highway systems in the United States include 607,380 bridges.

That means the average bridge degrades in value by $22,400 per year due to corrosion.

For bridges in corrosive areas the degradation can be much higher.

Introduction

What is corrosion?

Corrosion is the degradation of materials (such as steel and concrete) as nature tries to return them to their natural state (iron ore, aggregate). Corrosion is driven by the energy that was put into the materials to create them from their raw materials.

Rust is the product of the corrosion of steel.

In addition to the effect of chlorides on rebar corrosion, concrete can be weakened by chemical attack of magnesium ions from magnesium chloride.

Spalling and potholes are the result of corrosion of rebar and degradation of concrete.

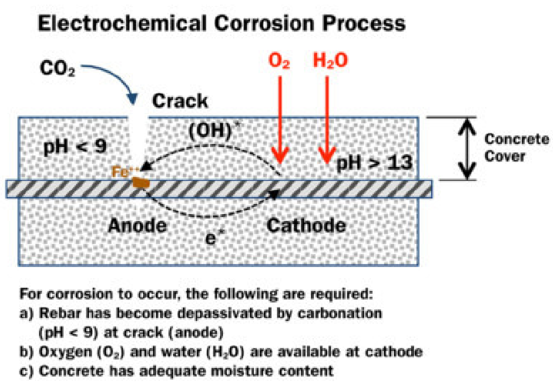
Introduction

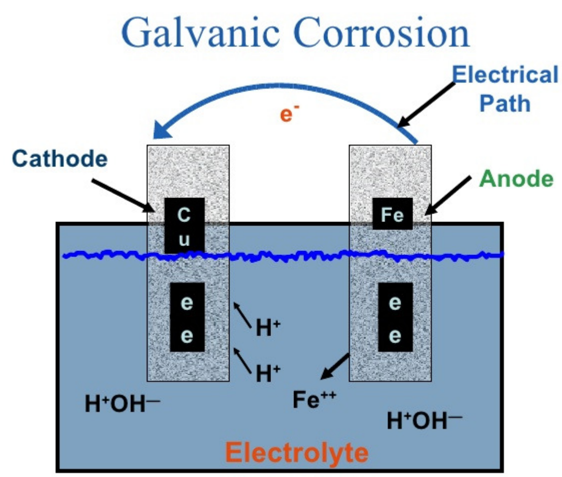
Corrosion Factors

For metallic corrosion to occur, there must be:

- Dissimilar metals (can be microscopic dissimilar sites on the surface of steel).
- Electrical connection between the dissimilar metals (provided by the steel).
- Electrolyte (provided by the moisture in the pores of concrete).

The presence of salt (chemical compounds with chlorides or sulfates) makes the electrolyte far more effective. In addition, salt directly attacks a protective layer that forms on the surface of rebar in concrete.





Introduction

Corrosion Threshold

For rebar embedded in concrete, there is a corrosion threshold or a minimum concentration of chloride that must be present before the rebar is likely to corrode.

The corrosion threshold for carbon steel rebar in concrete is approximately 1.5 pounds of chloride per cubic yard of concrete, or about 0.04% chloride by mass of concrete.

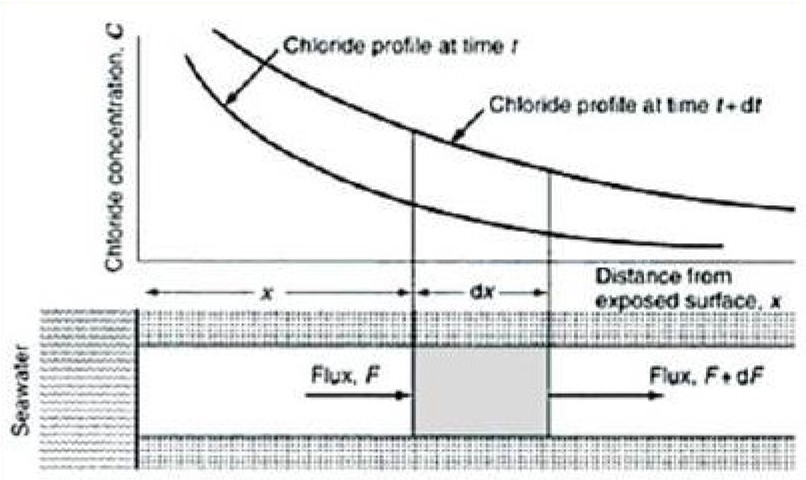
It is desirable to keep the chloride concentration in the bridge deck below the corrosion threshold.

Introduction

Corrosion Factors

Chloride from snow and ice control products can move within concrete. Concrete is porous and contains water and minerals. Chloride transport in concrete is a steady process that depends on:

- The amount of snow and ice control products on the surface of concrete, or severity of marine exposure
- The permeability of the concrete
- Moisture content of the concrete
- Temperature



Introduction

Corrosion Factors

Environment:

- Coastal environment is salt-laden.
- Industrial areas can have sulfates due to air pollution.
- Use of snow and ice control products containing chlorides.

Introduction
Corrosion Factors

Bridge Detailing:
- Epoxy-coated rebar.
- Stainless steel rebar.
- Fiber Reinforced Plastic rebar.
- High performance concrete.
- Drainage.
- Waterproofing membranes.
- Expansion Joint Seals.
- Impact Panel Connections.

Introduction
Corrosion Factors

Bridge Maintenance:
- Deck sealing.
- Waterproofing membrane.
- Expansion joint seal maintenance.
- Patching of potholes and spalls.
- Bridge washing.
- Painting of steel structures.
- Cleaning bridge drains.

Introduction

Corrosion and Snow & Ice Control

Snow and ice control is important. After at least 20 years of snow and ice control in the PNW, the public now expects clear roads without ice. Failure to meet that expectation would endanger public safety.

However, at the same time snow and ice control creates major issues for our inventory of bridges. As a bridge engineer these issues are some of my largest challenges.

New Bridges

Corrosion Prevention

In most areas of snow and ice control, new bridges are built with epoxy-coated rebar and high performance concrete.

The epoxy coating is supposed to provide a barrier to keep water and chlorides from attacking the steel. To a degree, this works. When it doesn't work it makes the problem worse. And it effectively eliminates one possible method of future corrosion control.

High performance concrete has lower permeability, which means chlorides can't move as easily within undamaged concrete.

Existing Bridges

Corrosion Prevention

Existing bridges typically were built with ordinary carbon steel rebar and ordinary concrete.

This equates to minimal corrosion prevention. The bridge deck in the picture is approximately 15 years old.

Existing Bridges

Corrosion Prevention

For existing bridges our options for corrosion prevention are limited.

Our options depend on the degree of chloride contamination.

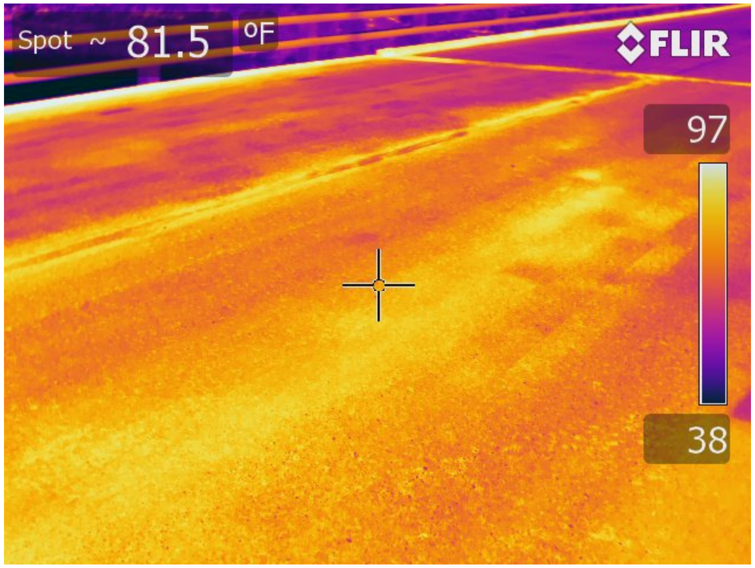
- If you apply sealer or waterproofing membrane before there is too much contamination, the amount of chlorides around the rebar may never reach the corrosion threshold.
- If you apply sealer or waterproofing membrane after there is too much contamination, corrosion of the rebar will continue unabated.

Some sealers and waterproofing membranes are better than others.

Monitoring Existing Bridges

Sounding, GPR, and Infrared Imagery

Traditionally, delaminated areas were detected by hammer sounding or chain drag. In recent years ground penetrating radar and infrared imagery have become useful techniques.



Delaminated areas heat up faster during rising temperature and cool down faster during dropping temperature. These images were taken in the morning.

Monitoring Existing Bridges
Chloride Sampling

For coastal bridges ODOT has been measuring chloride content since the 1970s.

The first procedure was to drill into the concrete to pre-set depths, saving drilling debris using hand tools such as dust pans and brushes. The collected concrete dust samples were sent to the laboratory for analysis of chloride content.

In the early 1990s the procedure was improved by the use of a hollow drill bit connected by tubing to a filter system and vacuum cleaner. Pre-set depths were maintained using hollow spacers. The filters were sent to the laboratory for analysis of chloride content. Results were much more consistent due to better sample collection.

Monitoring Existing Bridges

Chloride Sampling

In 2011, ODOT Bridge Preservation engineers designed and built an improved chloride sample collection system which combined the vacuum cleaner and sample collection filters in one unit. The sample collection unit is connected to the hollow drill bit with tubing. Pre-set depths are maintained using hollow spacers.

The filters are sent to the laboratory for analysis of chloride content.

Monitoring Existing Bridges
Chloride Sampling

In 2015, ODOT began using coring to obtain concrete samples for chloride analysis. The cores are sent to outside laboratories for analysis of acid-soluble chloride content per ASTM C1152 as a function of depth. In head-to-head comparisons the chloride results from coring appear more consistent than the results from drilling and collecting the dust.

SHRP2 Project R19A

Implementation of Service Life Design for Bridges

ODOT Bridge Section received a grant to participate in Project R19A implementation, with three parts.

- Design one new bridge using service life design methods.
- Analyze chloride content of samples from a number of existing bridges and correlate experience with Service Life Design recommendations.

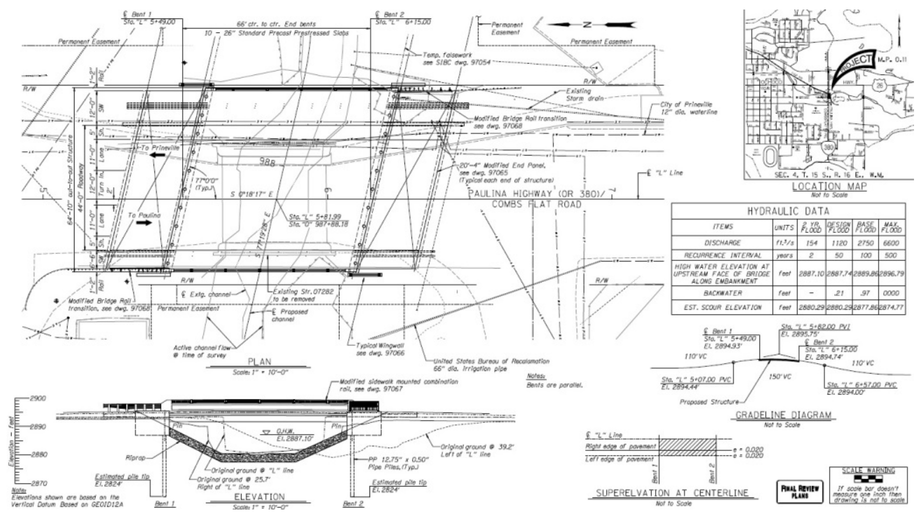
SHRP2 Project R19A

New Bridge Design

Ochoco Creek Bridge in Prineville was selected.

ODOT’s bridge designers specified concrete mix design according to Service Life Design methods. Mix design was tested using NTBuild 492 test method to determine chloride transport properties and verify that these properties meet goals.

Bids were opened April 28, 2016.



SHRP2 Project R19A

Analyze Samples from Existing Bridges

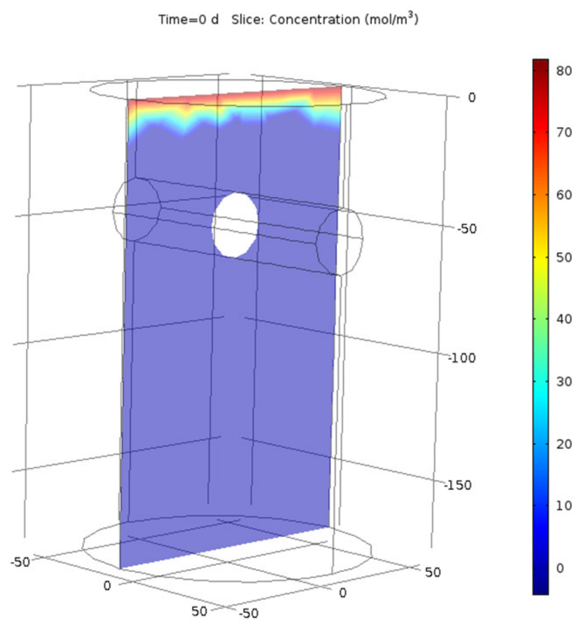
ODOT Bridge Section acquired coring equipment, then took approximately 50 core samples from approximately 11 existing bridges. The chloride content of these samples was analyzed in the laboratory of Siva Corrosion Services, Inc.

SHRP2 Project R19A

Analyze Samples from Existing Bridges

ODOT Bridge Section acquired a multiphysics finite element software (COMSOL) with the capability of modeling the transport of chlorides in concrete.

COMSOL was then used to estimate the chloride transport properties and the chloride exposure of the existing bridges, by an iterative process.



SHRP2 Project R19A

Results

ODOT bridge designers now have experience with Design for Service Life, including the mix design parameters and testing.

ODOT was able to correlate the chloride concentrations in existing bridges back to chloride exposure and chloride transport properties of the concrete.

With COMSOL it is now possible to determine how fast chlorides will reach the rebar in existing bridges with some contaminated concrete surface removed and overlaid or sealed.

ODOT Bridge Design and Maintenance

Future Work

COMSOL capabilities will be used to create guidance for maintenance and rehabilitation of existing bridges.

- Take a core from existing deck.
- Have the core analyzed.
- Guidance will advise course of action required as a function of existing chloride content.

COMSOL capabilities and chloride exposure data will be used to confirm or refine recommendations for corrosion protection in new bridges.

ODOT Bridge Maintenance

Future Bridge Deck Rehabilitation Methods

Possibilities include:
Overlay or sealing. This option can work only if there isn't enough contamination in the existing concrete to eventually reach the corrosion threshold near the rebar.

Removal of a layer of contaminated concrete prior to overlay or sealing. This option can work only if enough contamination can be removed to prevent the chlorides already in the concrete from reaching the corrosion threshold near the rebar.

Full deck replacement, which is expensive.

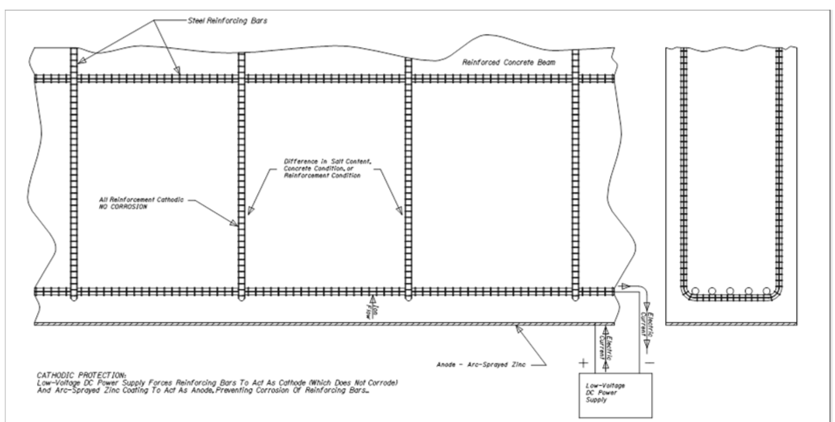
ODOT Bridge Maintenance

Future Bridge Deck Rehabilitation Methods

Additional possibilities include:

Cathodic protection, a method of preventing corrosion by applying a small direct current between the rebar and an anode such as a conductive overlay, in the opposite direction as the electrical current created by corrosion.

Electrochemical chloride extraction, similar to cathodic protection except that a large direct current is used and most of the chlorides are removed over a few months. The deck can then be sealed.



Cathodic Protection Of Reinforced Concrete

ODOT Bridge Preservation Program

Corrosion Effects on Structural Steel

The bridge exists within 5 km of the Pacific Ocean. Marine salt damages the structural steel by providing an electrolyte and a catalyzing effect for corrosion.

ODOT Bridge Preservation Program

Corrosion Effects on Reinforced Concrete

Marine salt damages the reinforced concrete by providing electrolyte and a catalyzing effect for corrosion of reinforcement which in turn causes spalling of concrete.

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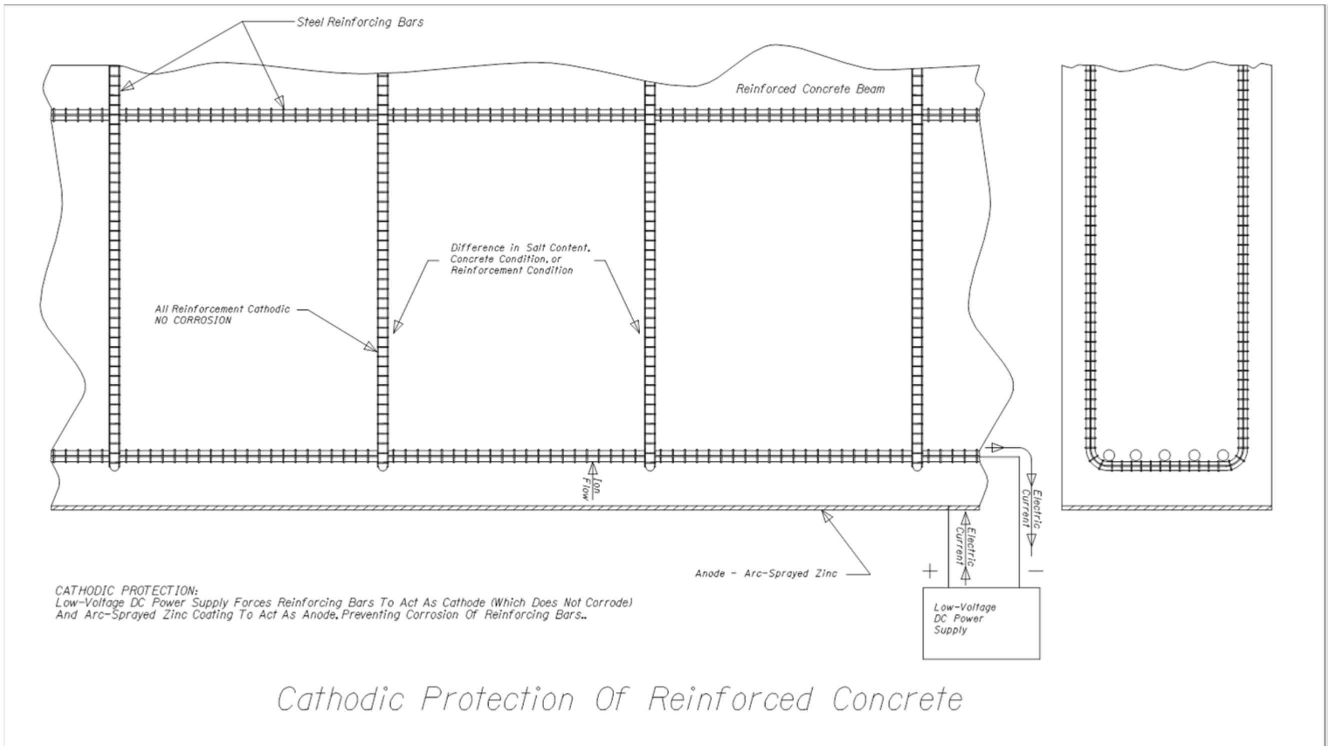
Typical Bridge Preservation Actions

Impressed Current Cathodic Protection



ODOT's Bridge Preservation Program was founded in the 1980s to save historic coastal bridges using impressed current cathodic protection. Low-voltage direct current passes from the zinc coating on the reinforced concrete surface to the reinforcement, driving corrosion to occur at the zinc coating rather than the steel.

Typical Bridge Preservation Actions

Impressed Current Cathodic Protection

Includes work platforms and containment. Safespan work platform is shown with containment provided by tarps.

Typical Bridge Preservation Actions

Impressed Current Cathodic Protection

Includes work platforms and containment. A rigid frame work platform and containment system is shown with its heating and ventilating system.

Typical Bridge Preservation Actions

Impressed Current Cathodic Protection

Includes visual inspection and sounding of concrete to identify spalled or delaminated areas.

Typical Bridge Preservation Actions
Impressed Current Cathodic Protection

Includes removal of spalled and delaminated concrete

Typical Bridge Preservation Actions

Impressed Current Cathodic Protection

Includes repair of damaged reinforcing bars.

Typical Bridge Preservation Actions

Impressed Current Cathodic Protection

Includes establishing electrical continuity between all reinforcing bars.

Typical Bridge Preservation Actions

Impressed Current Cathodic Protection

Includes concrete patching.

Typical Bridge Preservation Actions
Impressed Current Cathodic Protection

Includes installation of reference cells for future corrosion monitoring.

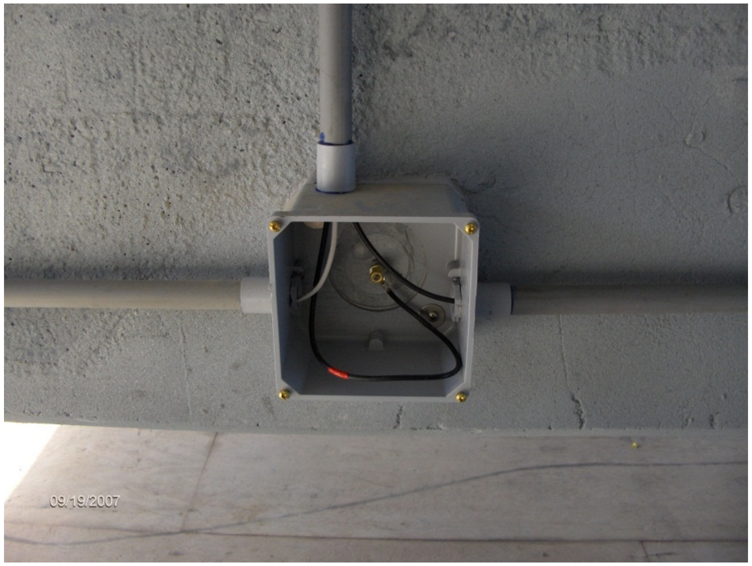
Typical Bridge Preservation Actions

Impressed Current Cathodic Protection ation

Includes abrasive blast surface preparation followed by arc-sprayed zinc coating of the concrete surfaces.

Typical Bridge Preservation Actions

Impressed Current Cathodic Protection



Includes installation of anode terminal plates.

Typical Bridge Preservation Actions

Impressed Current Cathodic Protection

Includes installation of wiring and electrical equipment to power, control, and monitor the cathodic protection system.

Typical Bridge Preservation Actions

"Stealth" Rail

Since 2002 ODOT has been installing "stealth" railings on historic coastal bridges. The appearance of the original rail is replicated and strength is improved by embedding structural steel. A local precaster has built his business around this work.

Typical Bridge Preservation Actions

Seismic Retrofit

Since the 1990s ODOT has been installing Phase 1 seismic retrofits (keep superstructure seated on substructure) on historic coastal bridges. The bearing seats are extended, rocker-type bearings are replaced with elastomeric pads, lateral shear blocks are added, and longitudinal cables tie the spans together.

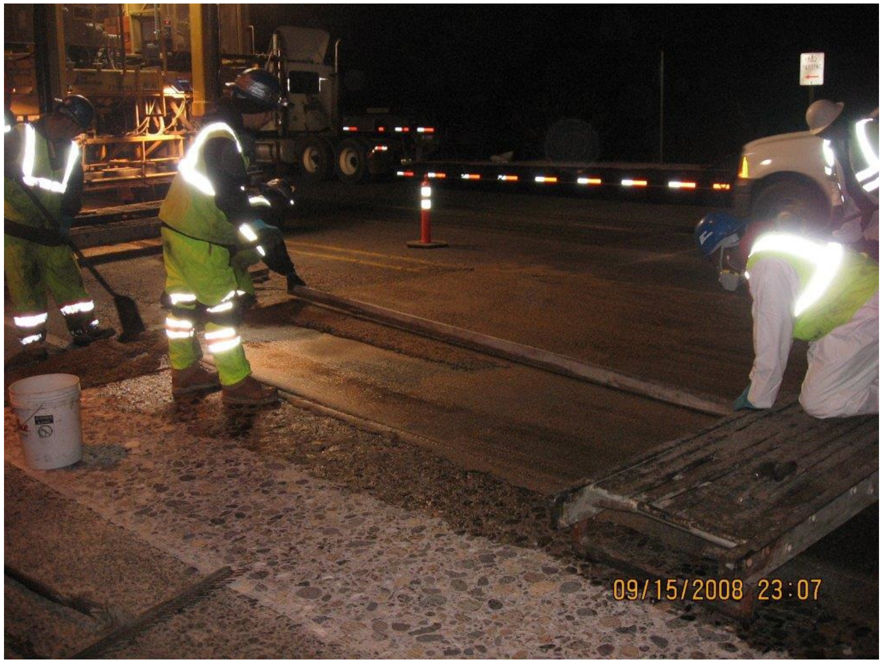
Typical Bridge Preservation Actions

Bridge Drains

Existing small-diameter drains are replaced with 203 millimeter (8 inch) diameter PVC drains with modern inlets.

Typical Bridge Preservation Actions

Sealing/Overlay of Deck



Roadway wearing surface is typically renewed with 19 millimeter (3/4 inch) thick premixed/screeded polyester polymer concrete over methacrylate primer, and expansion joint seals are typically replaced or retrofitted.

Typical Bridge Preservation Actions

Protective Coatings

Structural steel repaint cycle is about 15-20 years in the marine environment, less with poor workmanship. ODOT prefers abrasive blast surface preparation to SSPC SP-10, and recoating with 3-coat moisture-cured urethane system with zinc in the primer. Corroded rivets are replaced with high strength steel bolts, and sometimes there is a need for repair of section loss. Access and containment are costly.

Preservation Work on the Coos bay Bridge

Structural Steel Recoating

The bridge recoating project was completed in 2001 with less than satisfactory results. The bonding company paid on warranty and ODOT applied the funds to coating repairs performed during South end cathodic protection project.

Preservation Work on the Coos bay Bridge

Cathodic Protection (South End)

The south approaches of the bridge received impressed current cathodic protection between 2007 and 2012. This project included coating repairs resulting from 2001 project, cathodic protection, Phase 1 seismic retrofit, larger bridge drains, “stealth” rail, expansion joint seal replacement, and sealing/overlay of wearing surface. Construction cost $30.0 Million.

Preservation Work on the Coos bay Bridge

Cathodic Protection (North End)

The north approaches of the bridge are receiving impressed current cathodic protection in a project that started in 2013. This project includes cathodic protection, Phase 1 seismic retrofit, expansion joint seal replacement, and larger bridge drains. “Stealth” rail and overlay were completed by change orders on the 2007-2012 project. Bid $22.9 Million.

The Value of Bridge Preservation

Historic preservation – state and federal laws.
Aesthetic value to the communities.
Reduced traffic impacts.
Reduced environmental impacts.
Good stewardship of public funds.

One cathodic protection project changed a $30 Million bridge replacement with 100 year design life into a $3.6 Million rehabilitation project with 20 year design life.

Replacement Cost
$1,220,000 per year annualized at 4% interest

Rehabilitation Cost
$265,000 per year annualized at 4% interest.

Coos Bay (McCullough Memorial) Bridge Rehabilitation

Questions?

Thank you.