Update of SHRP2 R19A Activities

AASHTO COB, Burlington, VT
Technical Committee T-9 – Bridge Preservation

Mike Bartholomew, P.E., Senior Principal Bridge Engineer
Jacobs

June 25, 2018
• Service Life Introduction

• SHRP2 R19A Implementation Action Program
  – Program Goals
  – Work Focus Areas
  – Tools Developed
  – Participating Agency (Lead Adopter) Project Updates
Service Life Design (SLD)

- Design approach to resist deterioration caused by environmental actions
  - Also called Durability Design
  - Often referred to as Design for 100-year Service Life

- Not designing for the Service Limit States I, II, and III per LRFD 3.4
Common Deterioration Types

- Reinforcing steel corrosion
- Concrete cracking, spalling, delamination

- Structural steel corrosion following breakdown of protective coating systems
Environmental Exposure

• Chlorides from sea water or de-icing chemicals
• CO$_2$ from many wet / dry Cycles
• Temperature / Relative Humidity
• Freeze / Thaw Cycles
• Abrasion (ice action on piers, studded tires on decks)
• Internal / Alkali-Aggregate Reaction (AAR/ASR), DEF
Service Life Design Concepts


• Focuses on resisting deterioration from environmental exposure
Need for Service Life Design

- Increasing interest by the industry to make bridges more durable with longer expected lives
- Popular for politicians to state that a new bridge will last 100+ years...
- Evident by requirements in recent Owner’s RFPs – particularly on Design Build projects
Service Life Designed Structures

- Confederation Bridge, Canada –1997 (100 years)
Service Life Designed Structures

- Mario Cuomo Bridge, NY – 2018 (100 years)
Need More Focus on These

- Representing the majority of the 600,000+ bridges in the US
Need for Service Life Design

• Expectations of SLD requirements often unclear

• A more robust definition was needed for SLD

• FHWA in conjunction with AASHTO and TRB through the 2\textsuperscript{nd} Strategic Highway Research Program (SHRP2) initiated project R19A
  – Bridges for Service Life Beyond 100 Years: Innovative Systems, Subsystems and Components
SHRP2 Project R19A
SHRP2 R19A Team

RESEARCH – TRB

IMPLEMENTATION – FHWA/AASHTO

SUBJECT MATTER EXPERTS / LOGISTICS SME LEAD – Jacobs
TECHNICAL SMEs – COWI

LEAD ADOPTER AGENCIES
Research Work Completed

- Project R19A – Service Life Design Guide

  http://www.trb.org/Main/Blurbs/168760.aspx
IAP Lead Adopter Agencies

Central Federal Lands (project in Hawaii)
IAP Lead Adopter Agencies

Iowa

Maine

Pennsylvania

Virginia
IAP Team Leaders

• FHWA Central Federal Lands
  – Bonnie Klamerus, Mike Voth

• Iowa DOT
  – Ahmad Abu-Hawash, Norm McDonald

• Maine DOT
  – Dale Peabody

• Oregon DOT
  – Bruce Johnson, Paul Strauser, Zach Beget, Ray Bottenberg, Andrew Blower, Craig Shike

• Pennsylvania DOT
  – Tom Macioce

• Virginia DOT
  – Prasad Nallapaneni, Soundar Balakumaran
Current R19A Work Focus Areas

• Performing tests on material durability properties of concrete mix designs
  – Concrete chloride migration coefficient (NT Build 492)
  – Measurement of as-constructed concrete cover

Elcometer
Chloride Migration Test
NT Build 492

- **Chloride Migration Coefficient** from Non-Steady State Migration Experiments
  - Known as the Rapid Chloride Migration (RCM) Test
  - Determines Concrete Chloride Migration Coefficient, \( D_{RCM,0} \) used directly in fib Bulletin 34 deterioration model
  - 28 day cure, test duration usually 24 hours
NT Build 492

- **Schematic Test Setup**

  - 4” diameter x 2” thick specimen sliced from concrete test cylinder
  - 10% Solution of NaCl in water
  - Subjected to electrical current to accelerate chloride ingress

**Fig. 1.** One arrangement of the migration set-up.
NT Build 492

- Split specimen axially into 2 pieces
- Spray silver nitrate solution on broken surface
- Measure chloride penetration depth
- Calculate Chloride Migration Coefficient, $D_{RCM,0}$

Fig. 5. Illustration of measurement for chloride penetration depths.
### Cover Measurements

<table>
<thead>
<tr>
<th>Component Name</th>
<th>Deck</th>
<th>Standard</th>
<th>Location</th>
<th>Sampling</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>German Concrete and Construction Association - DBV, Concrete Cover and Reinforcement per Eurocode 2</td>
<td>Span 1</td>
<td>Grid sampling</td>
</tr>
</tbody>
</table>

#### As-Constructed Cover Dimensions at Grid Points [in]

<table>
<thead>
<tr>
<th></th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
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<td>A</td>
<td>2.52</td>
<td>2.20</td>
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<td>3.11</td>
<td>2.83</td>
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<tr>
<td>B</td>
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<td>2.20</td>
<td>2.48</td>
<td>2.72</td>
<td>2.72</td>
<td>2.76</td>
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<td>2.99</td>
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<td>2.83</td>
<td>2.99</td>
<td>2.09</td>
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<td>2.71</td>
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<td>2.09</td>
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<td>2.24</td>
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<td>D</td>
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<td>2.09</td>
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<td>2.09</td>
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<td>3.11</td>
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<td>G</td>
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<td>H</td>
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<td>2.20</td>
<td>2.26</td>
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<td>2.65</td>
<td>2.32</td>
<td>2.48</td>
<td>2.13</td>
<td>2.75</td>
</tr>
</tbody>
</table>

#### Statistical Evaluation of Measured Cover Depths, all units [in]

**Target threshold %** 5%

**Nominal cover** $c_{\text{nom}}$ 2.5

**Safety margin** $\Delta c$ 0.6

**Req'd minimum cover** $c_{\text{min}}$ 1.9

**Sample size** $N$ 144

**Median** $X_M$ 2.44

**Min** $X_{\text{min}}$ 1.46

**Mean** $\bar{X}$ 2.47

**Std. Dev.** $s$ 0.36

**Outlier cover** $X_{\text{OG}} = 2.5X_M - 1.5X_{\text{min}}$ 3.91

**Location parameter** $r = \frac{(X + X_M)}{2}$ 2.45

**Form parameter** $k = 1.8 \frac{r}{s}$ 12.36

**Parameter $p(x)$** $p(x) = \frac{c_{\text{min}}}{r}$ 0.77

**Threshold value** $c(5\%) = \frac{r}{(19^{1/k})}$ 1.93

**% of cover depth < $c_{\text{min}}$** $F(x) = \frac{p(x)^k}{1 + p(x)^k}$ 4% OK
• Tests on existing bridges to assess environmental loading and material behavior
  – Taking concrete cores to measure chloride loading from de-icing chemicals or sea water

Source: Germann Instruments
Current Work Focus Areas

- Developing design tools and processes to aid in SLD
  - Excel spreadsheet for chloride profiling

<table>
<thead>
<tr>
<th>d</th>
<th>depth from surface</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
<th>15</th>
<th>20</th>
<th>25</th>
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<tbody>
<tr>
<td>C_m</td>
<td>Test Values</td>
<td>[mass %]</td>
<td>0.368</td>
<td>0.450</td>
<td>0.410</td>
<td>0.326</td>
<td>0.266</td>
<td>0.231</td>
<td>0.175</td>
<td>0.183</td>
<td>0.132</td>
<td>0.124</td>
<td>0.117</td>
<td>0.080</td>
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<tr>
<td>C_e</td>
<td>Fit Data to C_m, D_{app.c}</td>
<td>[mass %]</td>
<td>0.530</td>
<td>0.458</td>
<td>0.391</td>
<td>0.329</td>
<td>0.275</td>
<td>0.230</td>
<td>0.192</td>
<td>0.162</td>
<td>0.139</td>
<td>0.122</td>
<td>0.089</td>
<td>0.085</td>
</tr>
<tr>
<td>(C_m - C_e)^2</td>
<td>Sum of least squares</td>
<td></td>
<td>6.72E-05</td>
<td>3.76E-04</td>
<td>1.10E-05</td>
<td>9.01E-05</td>
<td>1.55E-06</td>
<td>2.93E-04</td>
<td>4.94E-04</td>
<td>5.00E-05</td>
<td>4.66E-06</td>
<td>8.12E-04</td>
<td>2.66E-05</td>
<td>4.90E-05</td>
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<tr>
<td>C_m</td>
<td>Initial chloride content (measured)</td>
<td>[mass %]</td>
<td>0.085</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>t</td>
<td>Exposure time</td>
<td>[yr]</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C_s</td>
<td>Chloride content at exposed face</td>
<td>[mass %]</td>
<td>0.605</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>D_{app.c}</td>
<td>Apparent coefficient of chloride diffusion</td>
<td>[mm^2/yr]</td>
<td>15.324</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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</table>
Implementation Products – Dedicated Webpage

http://shrp2.transportation.org/Pages/ServiceLifeDesignforBridges.aspx
Recent Tools/Activities

• Academic Toolbox – guide for university professors to teach basic principles of SLD design (in final review/editing)

• IBC Workshop June 14, 2018 – Worked SLD example bridge
Academic Toolbox

• Sections
  – 1.0 Introduction (overview of SLD)
  – 2.0 Probability and Reliability Analysis
  – 3.0 Service Life Design of Concrete Components
  – 4.0 Service Life Design of Steel Components
2.1 Probability Distribution

- **Standard Normal Density Function**
  - \( \mu = 1.0 \)  
  - \( \sigma = 0.5 \)

- **Log-Normal Density Function**
  - \( \mu_{\ln(X)} = 1.5; \sigma_{\ln(X)} = 1.0 \)
  - \( \mu_{\ln(X)} = 2.2; \sigma_{\ln(X)} = 0.5 \)
2.2.2 Monte-Carlo Simulation

- Defining the problem in terms of all the random variables
- Quantifying probabilistic characteristics of the random variables and corresponding parameters
- Generating the values of these random variables
- Extracting probabilistic information from a number $N$ of such realization
- Determining the accuracy and efficiency of the simulation
- Evaluating the problem deterministically for each set of realizations of all the random variables
Example 2.3.2

The chloride content (the demand, S) at the reinforcing steel level of a concrete footing is estimated to follow a normal distribution with statistical properties as follows:

\[ \mu = 0.45 \text{ (wt\% of cement)} \quad \sigma = 0.4 \]

According to Section 2.1.1, this can also be written as \( N(0.45,0.4) \) because the variables are normal random variables. In the same way, the critical chloride threshold (the resistance, R) is estimated to be \( N(0.6,0.15) \).

<table>
<thead>
<tr>
<th>Table 2: Demand and Resistance Parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean, ( \mu )</td>
</tr>
<tr>
<td>-----------------</td>
</tr>
<tr>
<td>Chloride content</td>
</tr>
<tr>
<td>Critical chloride threshold</td>
</tr>
</tbody>
</table>

What probability of failure (corrosion initiation) is estimated using the Monte Carlo method if R and S are independent?
Example 2.3.2

Table 3: Random Numbers Generated for this Example and Calculations of Probability of Corrosion Initiation

<table>
<thead>
<tr>
<th>Random Number $z_i$</th>
<th>Resistance $r_i$</th>
<th>Random Number $z_i$</th>
<th>Demand $s_i$</th>
<th>$r &gt; s$?(*)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.9311</td>
<td>0.82</td>
<td>0.4537</td>
<td>0.40</td>
<td>1</td>
</tr>
<tr>
<td>0.7163</td>
<td>0.69</td>
<td>0.1827</td>
<td>0.09</td>
<td>1</td>
</tr>
<tr>
<td>0.4626</td>
<td>0.59</td>
<td>0.2765</td>
<td>0.21</td>
<td>1</td>
</tr>
<tr>
<td>0.7895</td>
<td>0.72</td>
<td>0.6939</td>
<td>0.65</td>
<td>1</td>
</tr>
<tr>
<td>0.8184</td>
<td>0.74</td>
<td>0.8189</td>
<td>0.81</td>
<td>0</td>
</tr>
<tr>
<td>0.3008</td>
<td>0.52</td>
<td>0.9415</td>
<td>1.08</td>
<td>0</td>
</tr>
<tr>
<td>0.3989</td>
<td>0.56</td>
<td>0.4967</td>
<td>0.45</td>
<td>1</td>
</tr>
<tr>
<td>0.0563</td>
<td>0.36</td>
<td>0.2097</td>
<td>0.13</td>
<td>1</td>
</tr>
<tr>
<td>0.1770</td>
<td>0.46</td>
<td>0.4575</td>
<td>0.41</td>
<td>1</td>
</tr>
<tr>
<td>0.2036</td>
<td>0.48</td>
<td>0.4950</td>
<td>0.44</td>
<td>1</td>
</tr>
</tbody>
</table>

(*) 0 = failure, 1 = success

| Number of samples | 10 |
| Number of failures | 2 |
| $P_f$ | 20% |
3.0 Service Life Design of Concrete Structures

3.1 Sulfate Attack

Deleterious reactions occur when Portland cement with a moderate-to-high tricalcium aluminate (C$_3$A) content is used in concrete in contact with sulfate bearing soil or groundwater. Effects include extensive cracking, expansion, loss of bond between the cement paste and aggregates, and alteration of the paste composition that will cause an overall loss of the concrete strength.
3.2 Delayed Ettringite Formation

- Delayed ettringite formation (DEF) is a form of internal sulfate attack that can occur in concrete cured at elevated temperatures such as in precast units or mass concrete placements.
- Maximum temperatures allowed during curing to mitigate risks of DEF are typically 150 to 160 degrees Fahrenheit (°F).
– 3.3 Alkali-Aggregate Reaction (ASR, ACR)

– 3.4 Freeze-Thaw
3.6 Corrosion

For concrete structures, a two-phase service life model can be used to represent the development of corrosion over time as illustrated in Figure 11. Often, the nominal service life is assumed equal to the corrosion initiation time, which is at the end of the initiation phase...

Figure 11: Two-phase modelling approach of corrosion deterioration
3.6.2 Chloride-Induced Corrosion

3.6.2.1 Chloride-Induced Corrosion Modeling

One established service life design methodology that is built on a broad base of experience and that resides in the public domain is the *fib* Model Code for Service Life Design (2006). Three different design strategies for concrete structures are typically adopted:

- **Strategy A:** Avoid the potential degradation mechanism.
- **Strategy B:** Apply protective measures that are deemed-to-satisfy the durability requirements.
- **Strategy C:** Select material composition and structural detailing to resist, for the required period, the potential degradation mechanism based on a full probabilistic approach.
– 3.6.2.2 Definition of Exposure Zones and Degradation Mechanisms
3.6.2.3 Selection of the Limit State

- The limit states vary based on the project requirements. For example, a limit state can be corrosion initiation with a confidence level of 90 percent that corrosion will not be initiated within the targeted service life. This corresponds to a reliability index of 1.3 and is consistent with guidance provided in the Model Code for Service Life Design (fib, 2006).

3.6.2.4 Determination of the Design Parameters Required through the Mathematical Modelling

\[ C(x,t) = C_0 + (C_{S,\Delta x} - C_0) \left(1 - \text{erf}\left[\frac{x - \Delta x}{2 \sqrt{D_{\text{app},C} \cdot t}}\right]\right) \]
3.6.2.5 Chloride Profiles

Figure 13: Example of chloride profile from the Danish Farø Bridge at t=9 years
Example 3.9.2

Calculate the probability of failure (time to corrosion initiation) for $t = 25, 50, 75, 100$ years using a full probabilistic approach with the input values, according to:

### Table 6: Input Parameters for the Chloride Ingress Mathematical Tool

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>Standard deviation</th>
<th>Unit</th>
<th>Type of Statistical Distribution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cover</td>
<td>55</td>
<td>8.3</td>
<td>mm</td>
<td>Lognormal</td>
</tr>
<tr>
<td>$C_{s,\Delta x}$</td>
<td>2.64</td>
<td>0.83</td>
<td>wt% / c</td>
<td>Lognormal</td>
</tr>
<tr>
<td>$C_0$</td>
<td>0.12</td>
<td></td>
<td>wt% / c</td>
<td>Deterministic</td>
</tr>
<tr>
<td>$C_{crit}$</td>
<td>0.65</td>
<td>0.15</td>
<td>wt% / c</td>
<td>Lognormal</td>
</tr>
<tr>
<td>$D_{RCM, 0}$</td>
<td>6</td>
<td>0.38</td>
<td>$10^{-12}$ m² / s</td>
<td>Lognormal</td>
</tr>
<tr>
<td>$a$</td>
<td>0.47</td>
<td>0.2</td>
<td></td>
<td>Beta (lower limit=0 and upper limit=1)</td>
</tr>
<tr>
<td>$\Delta x$</td>
<td>8.9</td>
<td>5.6</td>
<td>mm</td>
<td>Beta (lower limit=0 and upper limit=50)</td>
</tr>
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<td>$b_e$</td>
<td>4800</td>
<td>700</td>
<td>Kelvin</td>
<td>Normal</td>
</tr>
<tr>
<td>$T_{real}$</td>
<td>286.5</td>
<td>4.2</td>
<td>Kelvin</td>
<td>Normal</td>
</tr>
<tr>
<td>$T_{ref}$</td>
<td>293</td>
<td></td>
<td>Kelvin</td>
<td>Deterministic</td>
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<tr>
<td>$t_0$</td>
<td>28</td>
<td></td>
<td>days</td>
<td>Deterministic</td>
</tr>
<tr>
<td>$t$</td>
<td>25, 50, 75, 100</td>
<td></td>
<td>years</td>
<td>Deterministic</td>
</tr>
</tbody>
</table>
Example 3.9.2 Answer

A second order reliability method was used to calculate the following probability of failure:

<table>
<thead>
<tr>
<th>Service Life (years)</th>
<th>$P_f$ (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>25</td>
<td>20</td>
</tr>
<tr>
<td>50</td>
<td>31</td>
</tr>
<tr>
<td>75</td>
<td>37</td>
</tr>
<tr>
<td>100</td>
<td>40</td>
</tr>
</tbody>
</table>

The use of the Monte Carlo approach yields similar results.
• 4.0 Service Life Design of Steel Components
  – 4.3 Galvanized Steel

Figure 19: End of service life for various thicknesses of hot-dip galvanizing and environments
Source: American Galvanizers Association
IBC Workshop – Worked Design Example
<table>
<thead>
<tr>
<th>Time</th>
<th>Topic</th>
<th>Speakers</th>
</tr>
</thead>
</table>
| 8:00 – 8:10 am | Welcome and SHRP2 Introduction  
  - 1 – FHWA Introduction (10 min)                                      | Raj Ailaney, FHWA                |
| 8:10-9:15    | Service Life Design Background  
  - 2 – Introduction to Service Life Design (35 min)  
  - 3 – Introduction to fib Bulletin 34, Model Code for Service Life Design (30 min) | Mike Bartholomew, Jacobs  
              Neil Cumming, COWI |
| 9:15-9:45 am | Introduction to Example Bridge  
  - 4 – Design Criteria and Exposure Zones (30 min)                    | Mike Bartholomew, Jacobs         |
| 9:45-10:00 am| Break                                                                 |                                   |
| 10:00-11:00 am | Design  
  - 5 – Service Life Design of Concrete Elements (30 min)  
  - 6 – Service Life Design of Steel Elements (30 min)                  | Neil Cumming, COWI  
                    Mike Bartholomew, Jacobs |
| 11:00-11:45 am | Construction  
  - 7 – Implementation of Testing During Construction (20 min)  
  - 8 – Documenting Service Life Design & Construction Parameters (20 min) | Neil Cumming, COWI  
                      Mike Bartholomew, CH2M |
| 11:45-12:00 pm | Questions & Wrap-Up                                                   |                                   |
Project Description

• Location:
  – New York City.
  – Highway under the bridge.
  – Urban environment with periods of snow and freeze-thaw cycles.
  – Annual mean temperature of 11.5°C (52.7°F).
  – Heavy use of de-icing salts.
  – Some sulfate present in soil: 0.14% by mass of water soluble sulfate was measured.
General Bridge Layout

- 264 ft. steel girder bridge with two spans (139 ft. and 125 ft.).
- Over the abutments, the girders are supported on elastomeric bearings and at the piers, the girders are supported on fixed bearings.
- Deck and girders are continuous over the pier.
- Uncoated reinforcement (black steel) used everywhere.
Superstructure Description

- Roadway is 30 ft. wide with two traffic lanes and shoulders, and a 6 ft. sidewalk.
- Composite cast-in-place, high performance concrete deck on steel girders.
- Deck is 9 in. thick with 2 ¾” in. top cover and no wearing surface.
• The central pier has three columns each supported by a pile cap and steel piles driven into bedrock:

• Uncoated reinforcement (black steel) used everywhere.
• No mass concrete.
## Expected Service Life

<table>
<thead>
<tr>
<th>Non-replaceable components</th>
<th>Minimum service life (years)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Foundations (piling), abutments, piers, structural steel, and deck</td>
<td>75</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Replaceable components</th>
<th>Minimum service life (years)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bridge bearings</td>
<td>50</td>
</tr>
<tr>
<td>Expansion joints</td>
<td>30</td>
</tr>
<tr>
<td>Painting (includes structural steel, metal rocker bearings, expansion joint extrusions, and decorative fencing)</td>
<td>25</td>
</tr>
<tr>
<td>Barriers</td>
<td>50</td>
</tr>
</tbody>
</table>
Main deterioration mechanism for buried steel and steel exposed to seawater or de-icing salts is corrosion.

Mitigation methods (AASHTO LRFD 10.7.5) may include:

- Protective coatings (painting, galvanizing, metalizing)
- Concrete encasement
- Cathodic protection
- Use of special steel alloys
- Increased steel area (corrosion allowance)
Exposure Classification

• Defined Exposure Conditions

• 5 Classification of environments
  – Table 1 – Atmospheric-corrosivity categories and examples of typical environments
  – Table 2 – Categories for Soil and Water
## ISO 12944 Exposure Categories

### Table 1 — Atmospheric-corrosivity categories and examples of typical environments

<table>
<thead>
<tr>
<th>Corrosivity category</th>
<th>Mass loss per unit surface/thickness loss (after first year of exposure)</th>
<th>Examples of typical environments in a temperate climate (informative only)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Low-carbon steel</td>
<td>Zinc</td>
</tr>
<tr>
<td></td>
<td>Mass loss</td>
<td>Thickness loss</td>
</tr>
<tr>
<td>C3 medium</td>
<td>&gt; 200 to 400</td>
<td>&gt; 25 to 50</td>
</tr>
<tr>
<td>C4 high</td>
<td>&gt; 400 to 650</td>
<td>&gt; 50 to 80</td>
</tr>
<tr>
<td>C5-M very high (marine)</td>
<td>&gt; 650 to 1 500</td>
<td>&gt; 80 to 200</td>
</tr>
</tbody>
</table>
## ISO 12944 Exposure Categories

### Table 2 — Categories for water and soil

<table>
<thead>
<tr>
<th>Category</th>
<th>Environment</th>
<th>Examples of environments and structures</th>
</tr>
</thead>
<tbody>
<tr>
<td>Im1</td>
<td>Fresh water</td>
<td>River installations, hydro-electric power plants</td>
</tr>
<tr>
<td>Im2</td>
<td>Sea or brackish water</td>
<td>Harbour areas with structures like sluice gates, locks, jetties; offshore structures</td>
</tr>
<tr>
<td>Im3</td>
<td>Soil</td>
<td>Buried tanks, steel piles, steel pipes</td>
</tr>
</tbody>
</table>
Substructure Exposure Zones

LEGEND:
- BURIED
- ATMOSPHERIC
- INDIRECT DE-ICING SALT
- DIRECT DE-ICING SALT

PIER CAP
PIER COLUMN
PILE CAP
STEEL PILES
APPROX. GROUND LINE
<table>
<thead>
<tr>
<th>Exposure Zone</th>
<th>Examples of Elements</th>
<th>Exposure Conditions</th>
<th>Steel Corrosivity Category ISO 12944-2 [2]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Buried</td>
<td>Steel piles at pier.</td>
<td>Limited chloride exposure in soil. Limited O₂. Freeze-thaw above frost line. Sulfates.</td>
<td>Im3: soil</td>
</tr>
</tbody>
</table>
Superstructure Exposure Zones

Legend:
- BURIED
- ATMOSPHERIC
- INDIRECT DE-ICING SALT
- DIRECT DE-ICING SALT

Definitions:
- Decorative Bridge Fence
- Traffic Barrier
- Girder
- Bracing
- 5’ Concrete Deck
- Pedestrian Barrier
# Steel Girders

<table>
<thead>
<tr>
<th>Exposure Zone</th>
<th>Examples of Elements</th>
<th>Exposure Conditions</th>
<th>Steel Corrosivity Category ISO 12944-2 [2]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Indirect De-icing Salts</td>
<td>Girders.</td>
<td>Alternating wetting and drying. Atmospheric $O_2$ and $CO_2$. Freeze/thaw with indirect exposure to de-icing salts, leakage from deck joints, temperature and humidity variations.</td>
<td>C4: Temperate zone, atmosphere with moderate salinity</td>
</tr>
<tr>
<td>Exposure Zone</td>
<td>Examples of Elements</td>
<td>Exposure Conditions</td>
<td>Steel Corrosivity Category ISO 12944-2 [2]</td>
</tr>
<tr>
<td>------------------------</td>
<td>--------------------------</td>
<td>--------------------------------------------------------------------------------------</td>
<td>-------------------------------------------</td>
</tr>
</tbody>
</table>
All mitigation design strategies are “Deemed to Satisfy”

<table>
<thead>
<tr>
<th>Steel component</th>
<th>Exposure zone</th>
<th>Corrosivity category ISO 12944-2</th>
<th>Mitigation method</th>
</tr>
</thead>
<tbody>
<tr>
<td>Steel H piles</td>
<td>Buried</td>
<td>Im3</td>
<td>Corrosion allowance</td>
</tr>
<tr>
<td>Girder</td>
<td>Indirect de-icing salts</td>
<td>C4</td>
<td>Painting</td>
</tr>
<tr>
<td>Decorative fence</td>
<td>Direct de-icing salts</td>
<td>C5-M*</td>
<td>Painting</td>
</tr>
</tbody>
</table>
Corrosion Allowance References

• AASHTO LRFD Section 10.7.5

• FHWA Design and Construction of Driven Piles Foundations, V1 – Section 6.12.1

• FDOT Structures Design Guidelines – Section 3.1

• EN 1993-5, Eurocode 3: Design of Steel Structures, Part 5: Piling – Section 4.4
### Table 3.1-1 Usage Limitations and Corrosion Mitigation Measures for Steel Piles and Wall Anchor Bars

<table>
<thead>
<tr>
<th>Steel Component</th>
<th>Embedment</th>
<th>Corrosion Protection</th>
<th>Minimum Required Sacrificial Thickness (inches) and Usage Limitations Based on Substructure Environmental Classification and Pile/Wall Anchor Bar Location</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Slightly Aggressive</td>
</tr>
<tr>
<td>Pipe and H-Piles</td>
<td>Completely Buried</td>
<td>None(^1)</td>
<td>0.075</td>
</tr>
<tr>
<td></td>
<td>Partially Buried</td>
<td>Specifications Section 560</td>
<td>0.09</td>
</tr>
<tr>
<td></td>
<td></td>
<td>None(^1)</td>
<td>0.15</td>
</tr>
<tr>
<td>Anchored or Cantilever Sheet Piles</td>
<td>All</td>
<td>Specifications Section 560</td>
<td>0.045</td>
</tr>
<tr>
<td>Wall Anchor Bars</td>
<td>All</td>
<td>See Footnote(^3)</td>
<td>0.09</td>
</tr>
</tbody>
</table>

\(^1\) Corrosion protection not required for embedded steel components.

\(^2\) For conditions that are not specified, consult the Florida DOT Structures Design Guidelines (SDG) for guidance.

\(^3\) Additional corrosion mitigation measures may be required for wall anchor bars, as specified in the SDG.
Florida DOT Structures Design Guidelines

- Environmental Classification versus Corrosion Rate per side
  - For partially buried piles and wall anchor bars:
    - Slightly Aggressive: 0.001 inches/year
    - Moderately Aggressive 0.002 inches/year
    - Extremely Aggressive 0.003 inches/year
  
  - For completely buried piles:
    - Slightly Aggressive: 0.0005 inches/year
    - Moderately Aggressive 0.001 inches/year
    - Extremely Aggressive 0.0015 inches/year

- Design Life – 75 years
• H-Piles
  – HP 12 x 53 (flange and web thickness = 0.435 inch) required for strength and geotechnical requirements
  – Moderately aggressive environment (1400 ppm sulfates)
  – Fully buried
  – 0.001 inches/year x 75 years x 2 sides = 0.15 inch thickness loss
  – Required thickness for corrosion loss = 0.585 inch
  – Replace with HP 12 x 74 (flange = 0.610 inch, web = 0.605 inch)
Service Life of Coating Systems

- Primary reference used for estimating coating system life

Paper No. 7422

Expected Service Life and Cost Considerations for Maintenance and New Construction Protective Coating Work

Jayson L. Helsel, P.E.
Robert Lanterman
KTA-TATOR, Inc.
115 Technology Drive
Pittsburgh, PA 15275
• NACE Paper No. 7422 Includes a table of Estimated Service Life for 53 Coating Systems
  – Different corrosion exposure conditions (ISO 12944)
  – Various combinations of Acrylic, Alkyd, Epoxy, Epoxy Zinc, Organic and Inorganic Zinc, Metalizing, and Moisture Curing Polyurethane coats
  – Hand, Power Tool, and Sandblasted surface preparation
  – 1, 2, and 3 coat systems
  – Based on surveys of Coating Suppliers, Galvanizers, Steel Fabricators, Painting Contractors, and Owners
Table 1A: Estimated Service Life for Practical Maintenance Coating Systems for Atmospheric Exposure (in years before first maintenance painting)\textsuperscript{4}

<table>
<thead>
<tr>
<th>Type</th>
<th>Coating Systems for Atmospheric Exposure (primer/midcoat/topcoat)</th>
<th>Surface Preparation</th>
<th>Number of Coats</th>
<th>DFT Minimum (mils)</th>
<th>Service Life\textsuperscript{1,3}</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Mild (rural)/C2</td>
</tr>
<tr>
<td>Acrylic</td>
<td>Acrylic Waterborne/Acrylic WB/Acrylic WB</td>
<td>Hand/Power</td>
<td>3</td>
<td>6</td>
<td>12</td>
</tr>
<tr>
<td>Acrylic</td>
<td>Acrylic Waterborne/Acrylic WB/Acrylic WB</td>
<td>Blast</td>
<td>3</td>
<td>6</td>
<td>17</td>
</tr>
<tr>
<td>Alkyd</td>
<td>Alkyd/Alkyd</td>
<td>Hand/Power</td>
<td>2</td>
<td>4</td>
<td>6</td>
</tr>
<tr>
<td>Alkyd</td>
<td>Alkyd/Alkyd/Alkyd (AWWA OCS-1C)</td>
<td>Blast</td>
<td>3</td>
<td>6</td>
<td>11</td>
</tr>
<tr>
<td>Alkyd</td>
<td>Alkyd/Alkyd/Urethane Alkyd</td>
<td>Blast</td>
<td>3</td>
<td>6</td>
<td>12</td>
</tr>
<tr>
<td>Alkyd</td>
<td>Alkyd/Alkyd/Silicone Alkyd (AWWA OCS-1D)</td>
<td>Blast</td>
<td>3</td>
<td>6</td>
<td>14</td>
</tr>
<tr>
<td>Epoxy</td>
<td>Surface Tolerant Epoxy (STE)</td>
<td>Hand/Power</td>
<td>1</td>
<td>5</td>
<td>12</td>
</tr>
<tr>
<td>Epoxy</td>
<td>Surface Tolerant Epoxy/STE</td>
<td>Hand/Power</td>
<td>2</td>
<td>10</td>
<td>17</td>
</tr>
<tr>
<td>Epoxy</td>
<td>Surface Tolerant Epoxy/STE</td>
<td>Blast</td>
<td>2</td>
<td>10</td>
<td>21</td>
</tr>
</tbody>
</table>
Service Life of Coating Systems

• Practical Life
  – Time until 5-10% coating breakdown occurs and active rusting of the substrate is present
  – Corresponds to rust scale grade 4 in accordance with Steel Structures Painting Council, SSPC-VIS 2 (also ASTM D610)
Rust Grades 5 (3%) and 4 (10%)
**NACE 7422 Painting Practices**

- **Spot Touch-Up and Repair** is when first time coating repairs are made and occurs at the Practical Life (P).
- **Maintenance Repaint (M)** includes spot priming and a full overcoat.
- **Full Repaint (F)** involves total coating removal and replacement and marks the actual end of service life.

<table>
<thead>
<tr>
<th>Operation</th>
<th>Painting occurs in year</th>
</tr>
</thead>
<tbody>
<tr>
<td>Original Painting</td>
<td>0</td>
</tr>
<tr>
<td>Spot Touch-Up and Repair</td>
<td>Practical life (P)</td>
</tr>
<tr>
<td>Maintenance Repaint</td>
<td>$M = P \times 133%$</td>
</tr>
<tr>
<td>Full Repaint</td>
<td>$F = P \times 183%$</td>
</tr>
</tbody>
</table>
Planned Tools/Activities

• Life Cycle Cost Analysis – comparison of initial and long-term costs using different materials and protection strategies

• 5 Peer Exchanges
  – Northwest in Portland, OR – July 24
  – Southeast in Richmond, VA – August
  – Midwest in Ames, IA – September
  – Northeast in Philadelphia, PA – October
  – Southwest in Denver or Salt Lake City - November
Planned Tools/Activities

• Develop 2 complete SLD Design Examples
  – Steel bridge in de-icing environment in NE US
  – Prestressed concrete bridge in coastal environment in SE US
  – Other deterioration types will be documented (AAR, DEF, freeze-thaw, coating failure, etc.)

• Develop calculations to determine example load and resistance factors to be used with chloride deterioration model
Planned Tools/Activities

• Develop 2 RFP example specifications for design-build projects
  – Multiple conventional highway bridges on a new or reconstructed corridor project
  – Major bridges (segmental, arch, cable-stayed)
IAP Next Steps

• Conduct Agency Final Training Workshops for CFL, IA, ME

• Develop Reference Material Documentation / add to AASHTO/SHRP2 web page
  – Life Cycle Cost Example
  – Summary Guide to Service Life Design
  – Lessons Learned Summaries

• Develop 5 FHWA Peer Exchanges in non-IAP states
Questions?

Implementation Leads:

• Patricia Bush, AASHTO Program Manager for Engineering, pbush@aashto.org
• Raj Ailaney, FHWA Senior Bridge Engineer, Raj.Ailaney@dot.gov

Subject Matter Expert Team:

• Mike Bartholomew, Jacobs, mike.bartholomew@jacobs.com
• Anne-Marie Langlois, COWI North America, amln@cowi.com

Resource: AASHTO’s R19A Product Page

• http://shrp2.transportation.org/Pages/ServiceLifeDesignforBridges.aspx