SHRP2 R19-A Service Life Implementation Update

AASHTO SCOBS T-9 Technical Committee Meeting Spokane, WA – June 13, 2017

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Presentation Overview

- Quick Review of Service Life Design
- SHRP2 R19A Implementation Action Program
  - Program Goals
  - Work Focus Areas
  - Participating Agency (Lead Adopter) Projects
  - Lessons Learned
Review of Service Life Design
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

• Introduces concepts that extend beyond typical structural engineering design
Review of SLD

• Similar to strength design to resist structural failure caused by external loads
  – External Loads $\leftarrow \rightarrow$ Environmental Actions
  – Material Strength $\leftarrow \rightarrow$ Durability Properties

• Both strength and Service Life Designs satisfy scientifically based modeling equations
Historically, durability issues have been addressed through prescriptive specifications and practices:

- Concrete cover for different exposure zones
- Epoxy coated reinforcement
- Painting/coating structural steel

Known as “Deemed to Satisfy” method

- Approach has not been quantifiable
Review of SLD

- “Deemed to Satisfy” method often leads to inadequate performance
Review of SLD

• Durability issues have also been addressed by specifying materials with extremely high resistance to deterioration
  – Stainless Steel reinforcement

• Known as “Avoidance of Deterioration” method
  – Often at a much higher cost
  – Can result in unnecessary over design
Review of SLD

• Industry needs better ways to evaluate/predict structure performance over time
  – Deterioration behavior models
    • All materials deteriorate with time
    • Deterioration rate is dependent on:
      – Environmental exposure conditions
      – Material protective systems – durability properties
    – Known as “Design Based on Deterioration from the Environment”
Environmental Exposure

- Chlorides from sea water or de-icing chemicals
- \( \text{CO}_2 \) from many wet / dry cycles & manufacturing process emissions
- Temperature / relative humidity
- Freeze-thaw cycles
- Abrasion (ice action on piers, studded tires on decks)
- Internally from Alkali-Silica reaction
Material Resistance

• For Concrete Bridges in Chloride Exposure

• Resistance to Chloride Ingress is significantly influenced by concrete mix proportions:
  – Type of Cement
  – Water/Cement Ratio
  – Supplemental Cementitious Materials
    • Fly Ash (FA)
    • Ground Granulated Blast Furnace Slag (GGBFS)
    • Silica Fume (SF)
  – Depth of Cover
Deterioration Model

- **Chloride Ingress – Fick’s 2nd Law of Diffusion to Corrosion Initiation**

\[ C_{\text{crit}} \geq C(x = a, t) = C_0 + (C_s,_{\Delta x} - C_0) \cdot \left[ 1 - \text{erf} \left( \frac{a - \Delta x}{2\sqrt{D_{\text{app,C}} \cdot t}} \right) \right] \]

\[ D_{\text{app,C}} = k_e \cdot D_{\text{RCM,0}} \cdot k_t \cdot A(t) \]

\[ k_e = \exp \left( b_e \left( \frac{1}{T_{\text{ref}}} + \frac{1}{T_{\text{real}}} \right) \right) \]

\[ A(t) = \left( \frac{t_o}{t} \right)^\alpha \]

- **Red – Environmental Loading**
  - \( C_0 \) & \( C_s \) are the Chloride Background and Surface Concentrations
  - \( T_{\text{real}} \) is the annual mean Temperature at the project site

- **Green – Material Resistance**
  - \( D_{\text{RCM,0}} \) is the Chloride Migration Coefficient, \( \alpha \) is the Aging Exponent, both are functions of the concrete mix
  - \( a \) is the Concrete Cover
Design Standard

• International Federation of Structural Concrete
  – Establishes design procedures
    • To resist deterioration
    • From environmental actions
  – Also recognizes
    • “Deemed to Satisfy”
    • “Avoidance of Deterioration”
Review of SLD

- Growing interest by the industry to make bridges more durable with longer expected lives

- Influenced by political motivation – popular to state that a new bridge will last 100+ years…

- Evident by requirements in recent Owner’s RFPs – particularly on Design Build projects

- Expectations of SLD requirements often unclear
Review of SLD

• A more robust definition was needed for SLD

• FHWA in conjunction with AASHTO and TRB through the 2nd Strategic Highway Research Program (SHRP2) initiated project R19A

  – Bridges for Service Life Beyond 100 Years: Innovative Systems, Subsystems and Components
SHRP2 Project R19A
Research Work Completed

- Project R19A – Service Life Design Guide

  - http://www.trb.org/Main/Blurbs/168760.aspx
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, CH2M, mike.bartholomew@ch2m.com
- Anne-Marie Langlois, COWI North America, amln@cowi.com
IAP Lead Adopter Agencies

Oregon

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
- Oregon DOT
  - Bruce Johnson, Paul Strauser, Zach Beget, Ray Bottenberg, Andrew Blower, Craig Shike
- Pennsylvania DOT
  - Tom Macioce
- Virginia DOT
  - Prasad Nallapaneni
- Maine DOT
  - Dale Peabody
IAP Goals

• Promote SLD concepts through:
  – Marketing, outreach & training
  – 5 regional Peer Reviews planned for 2017-18

• Assist Lead Adopter agencies in developing in-house SLD skills

• Build a strong technical foundation
  – Develop training & reference materials
  – Develop “Academic Toolbox”
  – Lessons learned summaries
Current Work Focus Areas

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

Elcometer
Current Work Focus Areas

- 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
Implementation Products – Dedicated Webpage

- http://shrp2.transportation.org/Pages/ServiceLifeDesignforBridges.aspx
IAP Projects - Round 4
Initiated Fall 2014
• Tropical Coastal Exposure on North Shore, Island of Kauai, HI
  – 3 bridge replacements - 500’ to 1,000’ from the coastline
• Testing brackish water salinity

• Coring of existing abutments at water line / splash zone for surface chloride concentration

• NT Build 492 tests being performed on baseline concrete mix designs at the University of Hawaii
New Bridge at Site with Extreme De-Icing Spray Exposure

- Using A1010 High Chromium Structural Steel
- Lab and field testing A1010 for steel corrosion resistance performance
• Replacement of Twin Structures on I-35 over South Skunk River near Ames

– Chloride profile testing on existing structures
– NT Build 492 tests on concrete mix designs
– SB Bridge – Constructed to current Iowa DOT policies
– NB Bridge – Currently under design using SLD “Avoidance of Deterioration” methodology
Replacement of Twin Structures on I-35 over South Skunk River near Ames

- Final Product – Side-by-side comparison report to include:
  - Estimate of Service Life Duration and Cost
  - Comparison of both structures
• **Bridge Deck Evaluation in Various Chloride Exposure Zones**
  
  - Performed chloride profile testing and categorization of chloride loading by geographic/climatic zones (Pacific Coast, Willamette Valley, Cascade Mountains and east)
• I-5 Columbia River Crossing Design/Build – Portland to Vancouver
  – Evaluate/modify RFP requirements for contractor to design/document to a 100-year service life

• Replacement Bridge over Ochoco Creek in Prineville
- NT Build 492 Test (Chloride Migration Coefficient, \(D_{RCM}\)) performed on all concrete elements during construction (~33 cylinders total)
  - Deck – HPC4000 w/Flyash
    - \(D_{RCM} = 0.64 \text{ in}^2/\text{yr}\)
  - Deck (Alternative) – HPC4000 w/Slag
    - \(D_{RCM} = 0.54 \text{ in}^2/\text{yr}\)
Service Life Design - Graphical Solution

Calculations as per fib Bulletin 34 - fully probabilistic design
Service Life = 100 years
Beta = 1.3, Probability of failure = 10%
Critical chloride concentration: black bars - 0.6%cem,
Initial chloride concentration : 0.1%cem.

Temperature: mean = 49.1F, std = 12.1F
Exposure Zones: Splash/Deicing Salts
Concrete Type: OPC + >20%FA
Age factor 0.6 = mean, std = 0.25

Capacity 1.6% wt. cement

2.5" Cover

Demand,
C_s = 0.6% wt. cement

HPC 4000
D_{RCM} = 0.64 in²/yr
Calculations as per fib Bulletin 34 - fully probabilistic design
Service Life = 100 years
Beta = 1.3, Probability of failure=10%
Critical chloride concentration: black bars - 0.6%cem.
Initial chloride concentration : 0.1%cem.

Temperature: mean = 49.1°F, std = 12.1°F
Exposure Zones: Splash/Deicing Salts
Concrete Type: OPC+30% GGBS
Age factor: mean = 0.40, std = 0.15

Capacity 0.8% wt. cement
2.5" Cover
Demand, C_s = 0.6% wt. cement
HPC 4000 (Alt.)
D_{RCM} = 0.54 in²/yr
• Statewide Evaluation of Chloride Resistance of Concrete
  – Performed NT Build 492 tests on 106 samples from 7 ready mix and 2 precast concrete suppliers

Figure 1: Company location map relative to PennDOT districts
• **PennDOT Concrete Classifications tested**
  – Class A – Structures & Misc., 3000 psi (31 samples)
  – Class AA – Structures & Misc., 3500 psi (36 samples)
  – Class AAAP – Bridge Decks, 4000 psi (30 samples)
  – Class HES – High Early Strength, 3500 psi (3 samples)
  – SCC – Self-Consolidating, must meet requirements of above classifications (6 samples)
# TABLE A
Cement Concrete Criteria

<table>
<thead>
<tr>
<th>Class of Concrete</th>
<th>Use</th>
<th>Cement Factor$^{(3),(5)}$ (lbs/cu. yd.)</th>
<th>Maximum Water Cement Ratio$^{(6)}$ (lbs/lbs)</th>
<th>Minimum Mix$^{(2),(9)}$ Design Compressive Strength (psi)</th>
<th>Proportions Coarse$^{(1)}$ Aggregate Solid Volume (cu. ft./cu. yd.)</th>
<th>28-Day Structural Design Compressive Strength (psi)</th>
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<tr>
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<td>Max.</td>
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<td>Bridge Deck</td>
<td>560</td>
<td>690</td>
<td>0.45</td>
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<tr>
<td>HPC</td>
<td>Bridge Deck</td>
<td>560</td>
<td>690</td>
<td>0.45</td>
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<td>3,000</td>
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<tr>
<td>AAA$^{(4)}$</td>
<td>Other</td>
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<td>752</td>
<td>0.43</td>
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<td>AA</td>
<td>Slip Form Paving$^{(7)}$</td>
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<td>752</td>
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</table>
Chloride Migration Coefficient by Concrete Class

Pennsylvania DOT

![Bar chart showing chloride migration coefficients by concrete class]

- **Concrete Class A**: 6.970 E-12 m²/s
- **Concrete Class AA**: 7.043 E-12 m²/s
- **Concrete Class AA w/Slag**: 7.157 E-12 m²/s
- **Concrete Class AA Opt**: 4.939 E-12 m²/s
- **Concrete Class AAAP**: 5.219 E-12 m²/s
- **Concrete Class AAA HP**: 3.985 E-12 m²/s
- **Concrete Class HES**: 7.551 E-12 m²/s
- **Concrete Class SCC**: 1.219 E-12 m²/s
Chloride Migration Coefficient by Concrete Supplier

![Graph showing chloride migration coefficients for different concrete suppliers](image-url)
Final Service Life Design Workshop held late August 16, 2016

- Overview of Service Life Design for Bridges
- Chloride Induced Corrosion Modeling
- Concrete Deterioration Mechanisms
- Implications of Cracks in Concrete on Service Life
- Service Life Design Requirements for RFPs
- Service Life Design for Steel Structures
• Statewide Evaluation of Chloride Surface Loading and Resistance of Concrete
  – Compared historic chloride surface loading to fib-34 methods
  – Performed NT Build 492 tests on over 20 ongoing bridge construction projects around the state
  – Developing a database of reference values specific to Virginia for use in modeling
• Categorization of chloride loading by zones

- Historical data (Williamson, 2007)
- fib 34-predicted
• **Final Service Life Design Workshop Agenda scheduled for late August, 2017**

  – Overview of SLD – SME Team
  – Concrete Material Testing Program – Virginia Tech
  – Chloride Profiling of Existing Bridges – Virginia Tech
  – Specifications on Corrosion Resistant Reinforcing – VDOT
  – SLD Tools developed – SME Team
  – SLD for Alternative Delivery Projects – SME Team
  – R19A work done by other agencies – SME Team
IAP Projects - Round 7
Selected Summer 2016
Iowa DOT

- Thin Deck Overlays as a Bridge Preservation Action
  - Evaluation of structures on US-18 corridor
  - Kick-off Meeting to take place on June 20, 2017
Maine DOT

• Replacement of Beals Island Bridge in cold weather coastal environment
  – Chloride profiling on existing bridge
  – NT Build 492 tests on proposed concrete specifications
Lessons Learned
Lessons Learned

• Chloride profiling on core samples produce much better results than powder samples from rotary drilling
• Deicing application is minimal in the Willamette Valley – Corrosion from chlorides insignificant
• Need to develop contour maps of de-icing chloride loading
• Chloride migration tests (NT Build 492) are relatively easy to implement
  – Virginia and Iowa performing in-house testing
Lessons Learned

• Many state concrete classifications are flexible in w/c ratio, and % fly ash or slag replacing cement
• Mix design flexibility ≠ Consistent durability properties
  – Chloride migration test values (NT Build 492)
  – Aging coefficients (need ≥ 20% flyash to benefit)
• Need to develop guidelines for more consistent concrete specifications for SLD
Thank You

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