


SHRP2 SOLUTIONS

STRATEGIC HIGHWAY RESEARCH PROGRAM

SHRP2 R19-A Service Life Implementation Update

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

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U.S. Department of Transportation

Federal Highway Administration

American Association of State Highway and Transportation Officials

AASHTO

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 ← → Environmental Actions
  - Material Strength ← → Durability Properties
- Both strength and Service Life Designs satisfy scientifically based modeling equations

Review of SLD

- 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

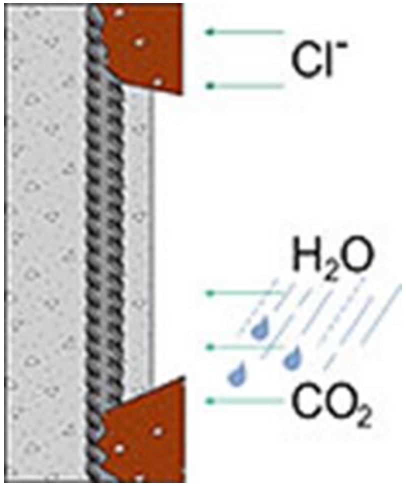
- Durability issues have also been addressed by specifying materials with extremely high resistance to deterioration
  - Stainless Steel reinforcement
- Known as “Avoidance of Deterioration” method
  - Often at a much higher cost
  - Can result in unnecessary over design

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
- 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

$$\boxed{C_{crit} \geq C(x = a, t) = C_o + (C_{s,\Delta x} - C_o) \cdot \left[1 - \mathrm{erf}\left(\frac{a - \Delta x}{2\sqrt{D_{app,C} \cdot t}}\right)\right]}$$

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

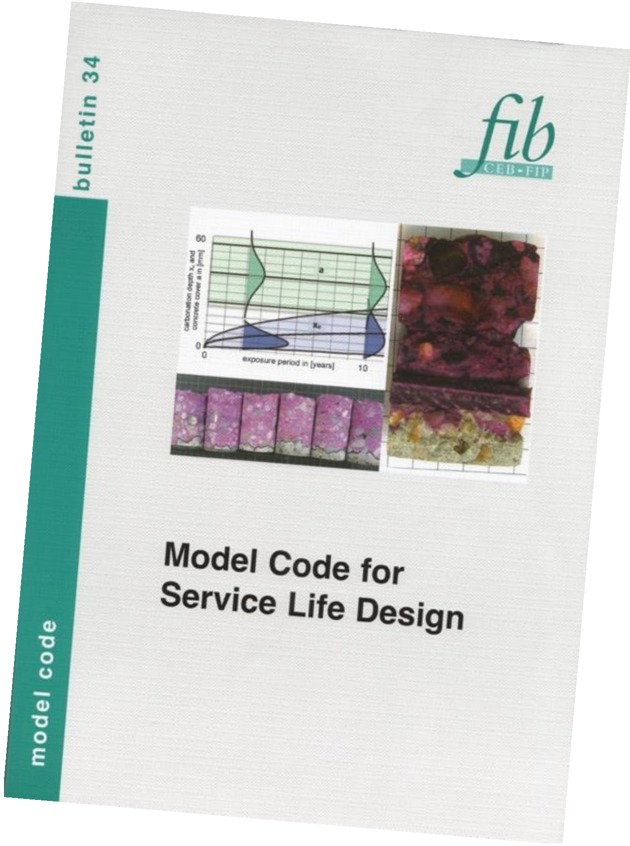
$$k_e = \exp\left(b_e\left(\frac{1}{T_{ref}} + \frac{1}{T_{real}}\right)\right)$$

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

- **Red – Environmental Loading**
  - C_o & C_s are the Chloride Background and Surface Concentrations
  - T_{real} is the annual mean Temperature at the project site
- **Green – Material Resistance**
  - $D_{RCM,0}$ is the Chloride Migration Coefficient, α is the Aging Exponent, both are functions of the concrete mix
  - a is the Concrete Cover

Design Standard

- International Federation of Structural Concrete
- *fib* Bulletin 34 – Model Code for Service Life Design (2006)
  - 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 2^{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 Process

RESEARCH – **TRB**

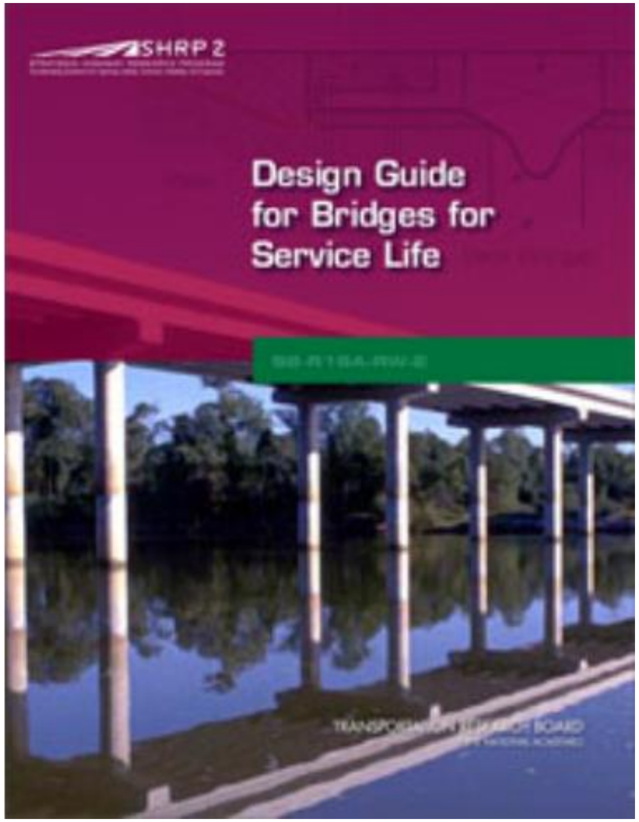
IMPLEMENTATION – **FHWA/AASHTO**

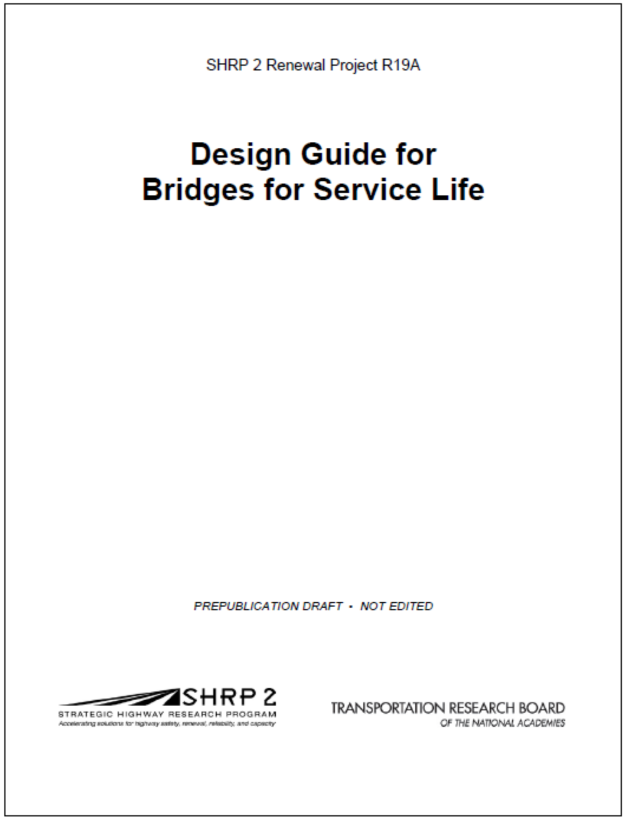
SUBJECT MATTER EXPERTS /
LOGISTICS SME LEAD – **CH2M**
TECHNICAL SMEs –
COWI

LEAD ADOPTER AGENCIES

Research Work Completed

- Project R19A – Service Life Design Guide





SHRP 2 Renewal Project R19A

Design Guide for Bridges for Service Life

PREPUBLICATION DRAFT • NOT EDITED

SHRP 2
STRATEGIC HIGHWAY RESEARCH PROGRAM
Accelerating solutions for highway safety, renewal, reliability, and capacity

TRANSPORTATION RESEARCH BOARD
OF THE NATIONAL ACADEMIES

  - http://www.trb.org/Main/Blurbs/168760.aspx

IAP Contacts

Implementation Leads:

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Subject Matter Expert Team:

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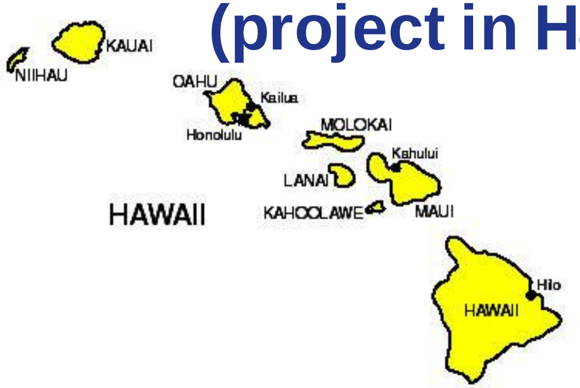
- Anne-Marie Langlois, *COWI North America,* amln@cowi.com

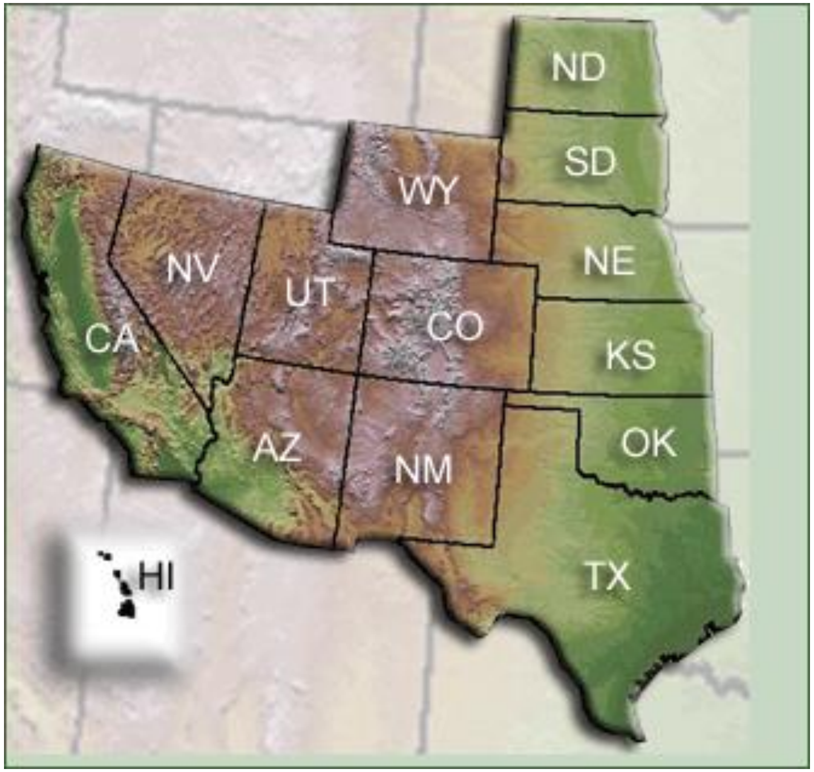
IAP Lead Adopter Agencies

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

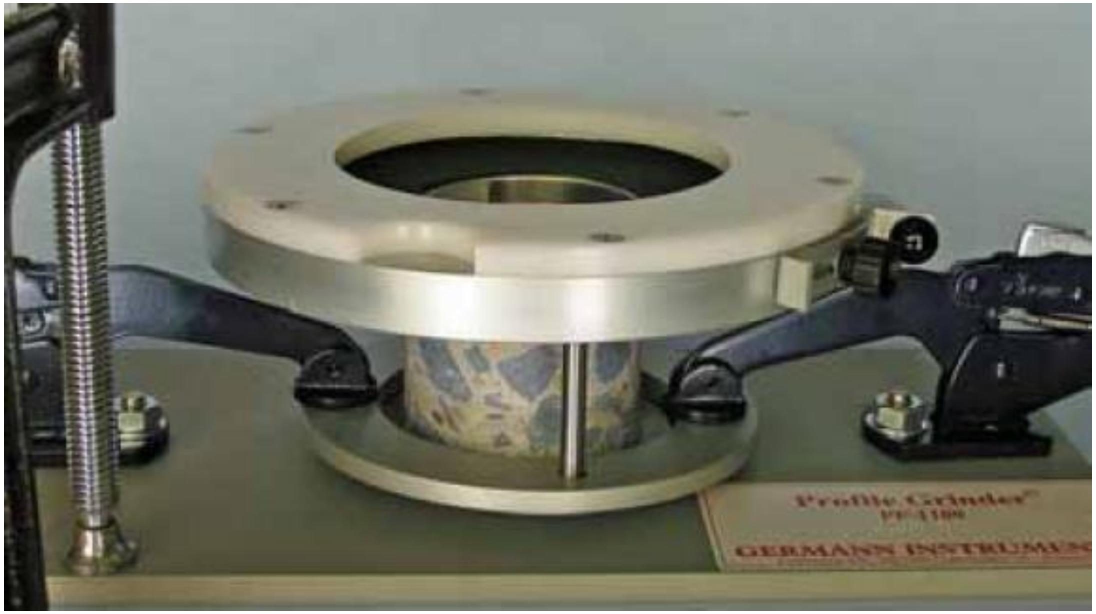
Current Work Focus Areas

- 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



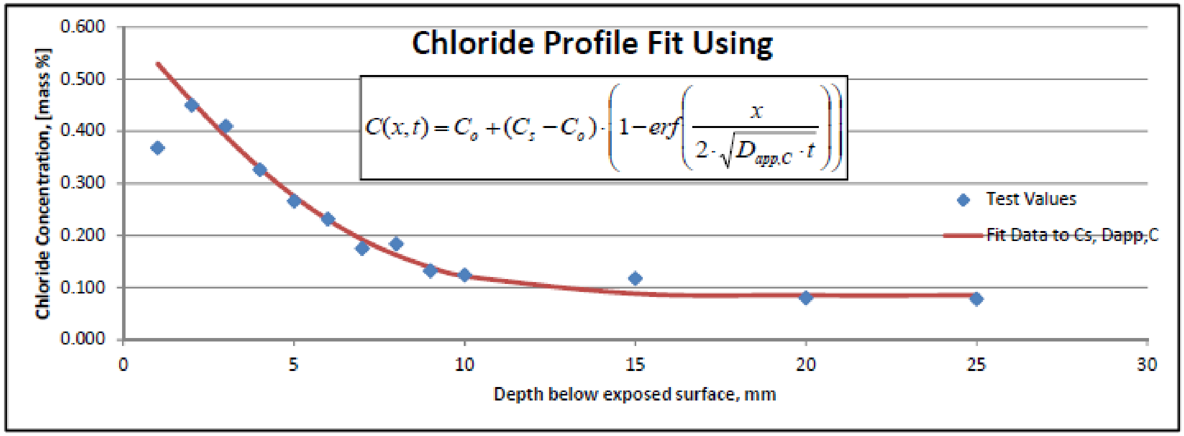
Source: Germann Instruments

Current Work Focus Areas

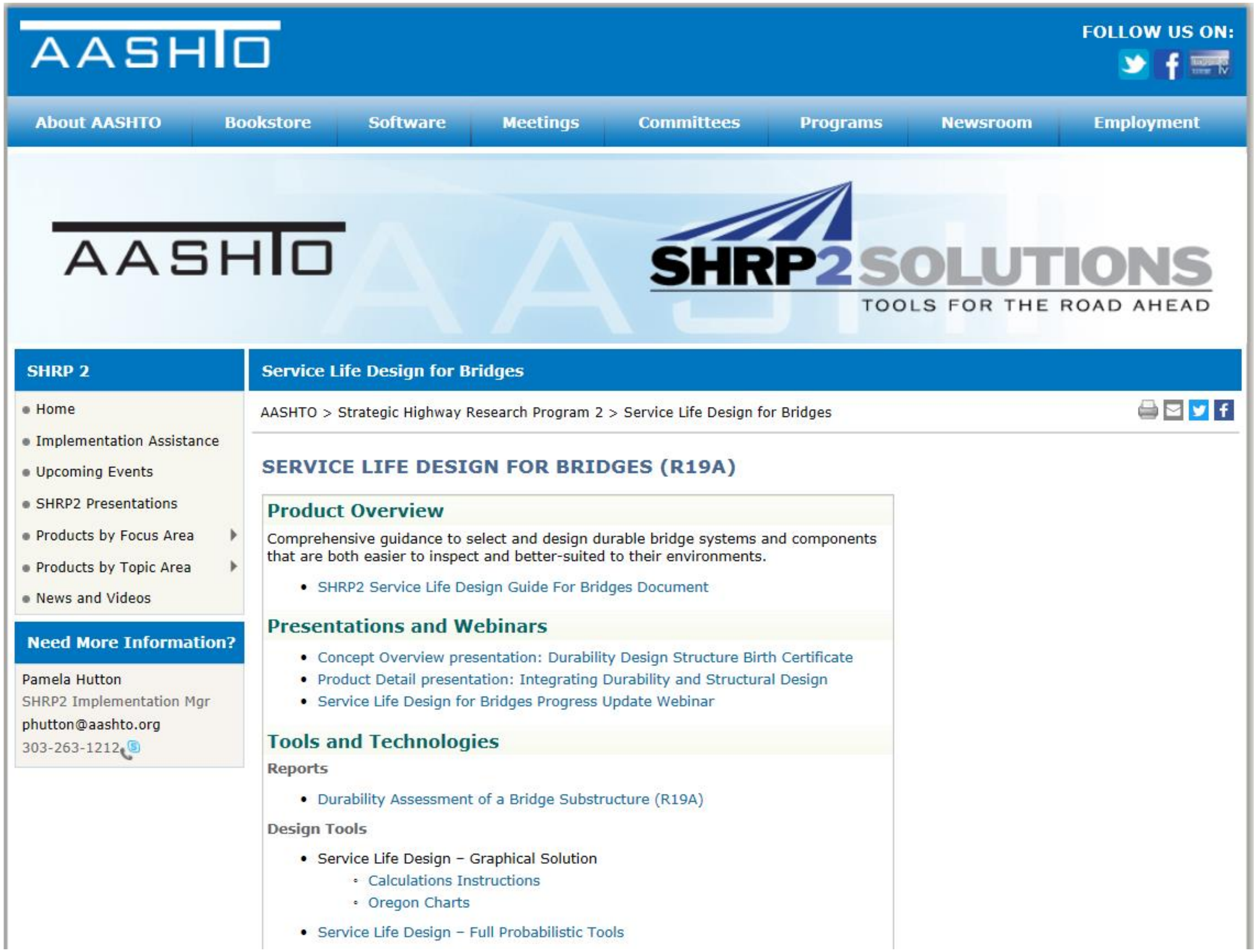
- Developing design tools and processes to aid in SLD
  - Excel spreadsheet for chloride profiling

d	depth from surface	[mm]	1	2	3	4	5	6	7	8	9	10	15	20	25	
C_m	Test Values	[mass %]	0.368	0.450	0.410	0.326	0.266	0.231	0.175	0.183	0.132	0.124	0.117	0.080	0.078	
C_c	Fit Data to C_s, $D_{app,C}$	[mass %]	0.530	0.458	0.391	0.329	0.275	0.230	0.192	0.162	0.139	0.122	0.089	0.085	0.085	$\sum (C_m - C_s)^2$
$(C_m - C_s)^2$	Sum of least squares			6.72E-05	3.76E-04	1.10E-05	9.01E-05	1.55E-06	2.93E-04	4.34E-04	5.00E-05	4.66E-06	8.12E-04	2.66E-05	4.90E-05	2.22E-03

C_o	Initial chloride content (measured)	[mass %]	0.085
t	Exposure time	[yr]	1
C_s	Chloride content at exposed face	[mass %]	0.605
$D_{app,C}$	Apparent coefficient of chloride diffusion	[mm^2/yr]	15.324



Implementation Products – Dedicated Webpage

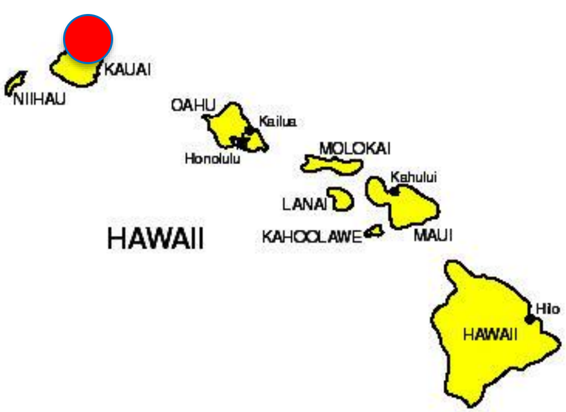


- http://shrp2.transportation.org/Pages/ServiceLifeDesignforBridges.aspx

IAP Projects - Round 4
Initiated Fall 2014

FHWA Central Federal Lands

- **Tropical Coastal Exposure on North Shore, Island of Kauai, HI**
  - 3 bridge replacements - 500’ to 1,000’ from the coastline



FHWA Central Federal Lands

- 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

Iowa DOT

- **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

Iowa DOT

- **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

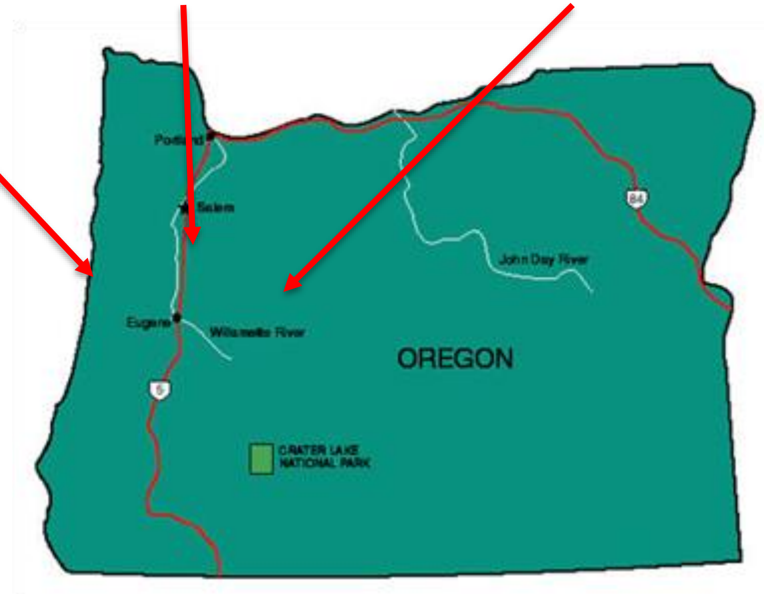
Iowa DOT

- **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

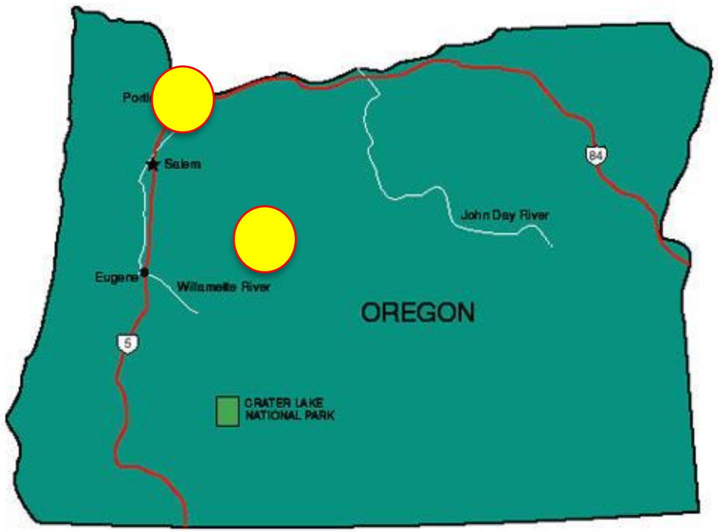
Oregon DOT

- **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)



Oregon DOT

- **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**

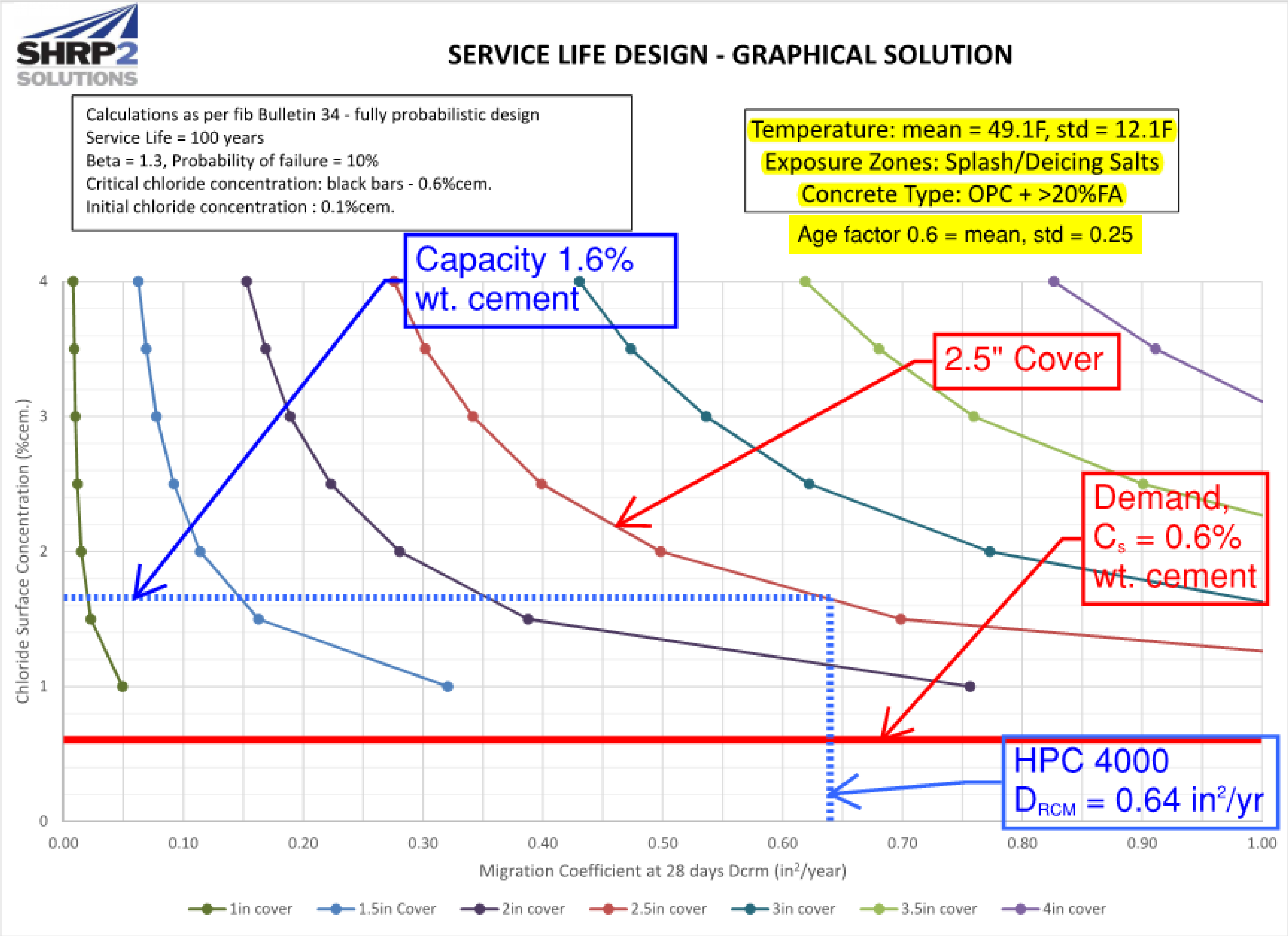


Oregon DOT – Ochoco Creek

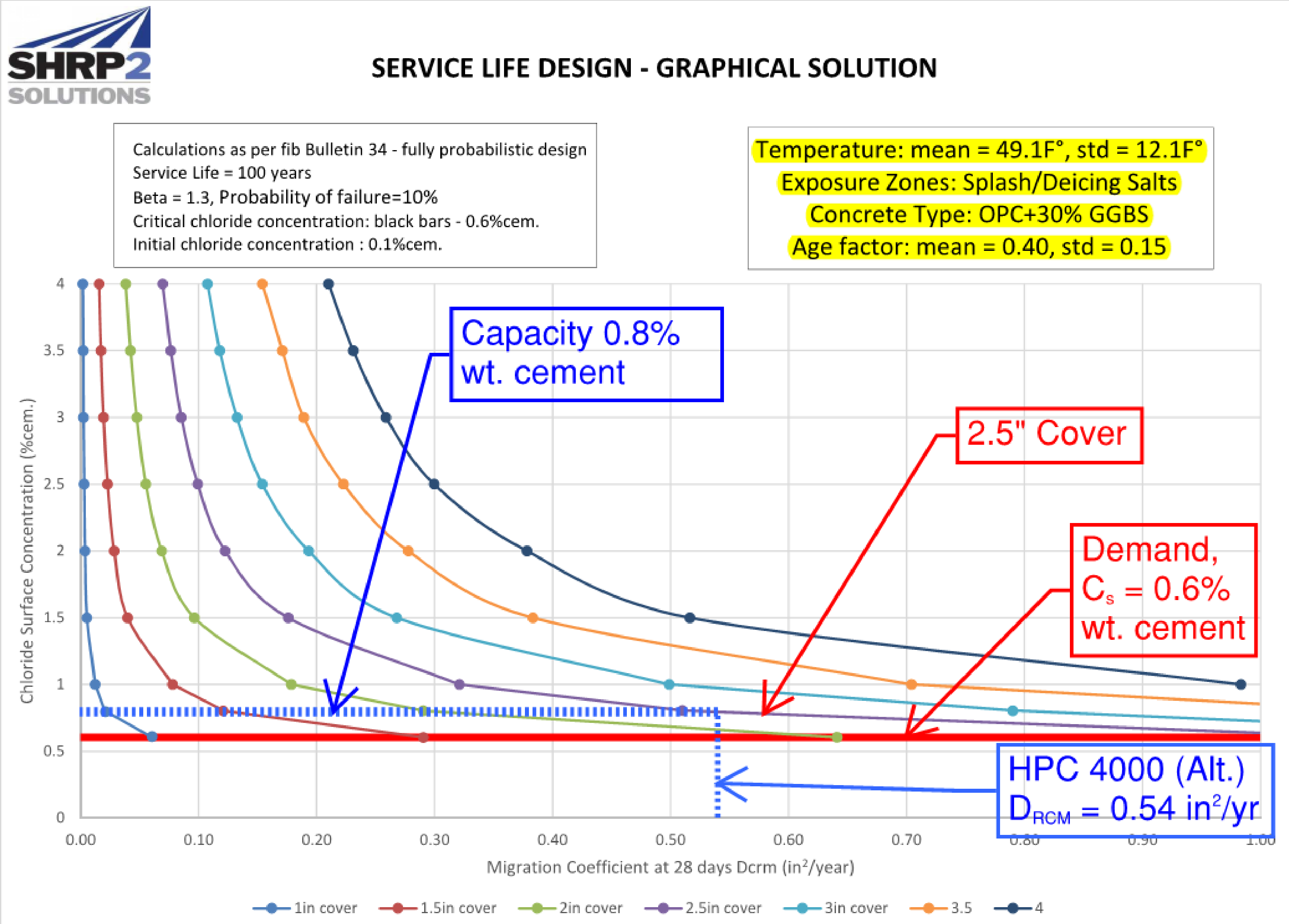
Oregon DOT – Ochoco Creek

- **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 in^2/yr
  - Deck (Alternative) – HPC4000 w/Slag
    - D_{RCM} =0.54 in^2/yr

Oregon DOT – Ochoco Creek



Oregon DOT – Ochoco Creek



Pennsylvania DOT

- **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

Pennsylvania DOT

- **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)

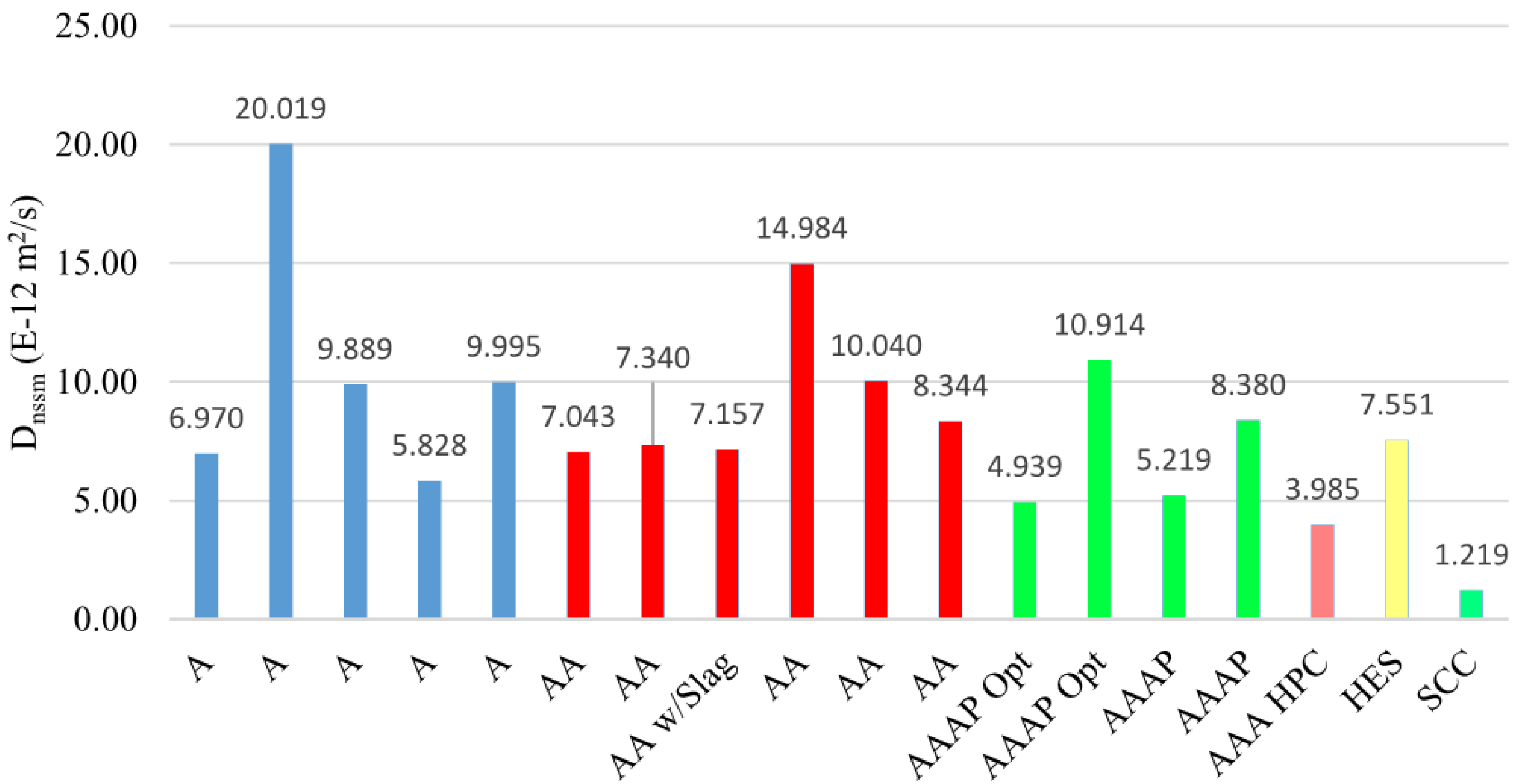
Pennsylvania DOT

TABLE A
Cement Concrete Criteria

Class of Concrete	Use	Cement Factor[3][5] (lbs/cu. yd.)		Maximum Water Cement Ratio[6] (lbs/lbs)	Minimum Mix[2,9] Design Compressive Strength (psi)			Proportions Coarse[1] Aggregate Solid Volume (cu. ft./cu. yd.)	28-Day Structural Design Compressive Strength (psi)
					Days				
		Min.	Max.		3	7	28		
AAAP	Bridge Deck	560	690	0.45	—	3,000	4,000	—	4,000
HPC	Bridge Deck	560	690	0.45	—	3,000	4,000	—	4,000
AAA[4]	Other	634.5	752	0.43	—	3,600	4,500	—	4,000
AA	Slip Form Paving[7]	587.5	752	0.47	—	3,000	3,750	11.00-13.10	3,500
AA	Paving	587.5	752	0.47	—	3,000	3,750	9.93-13.10	3,500
AA	Accelerated Patching[8]	587.5	800	0.47	—	—	3,750	9.93-13.10	3,500
AA	Structures and Misc.	587.5	752	0.47	—	3,000	3,750	9.93-13.10	3,500
A		564	752	0.50	—	2,750	3,300	10.18-13.43	3,000
C		394.8	658	0.66	—	1,500	2,000	11.45-15.10	2,000
HES		752	846	0.40	3,000	—	3,750	9.10-12.00	3,500

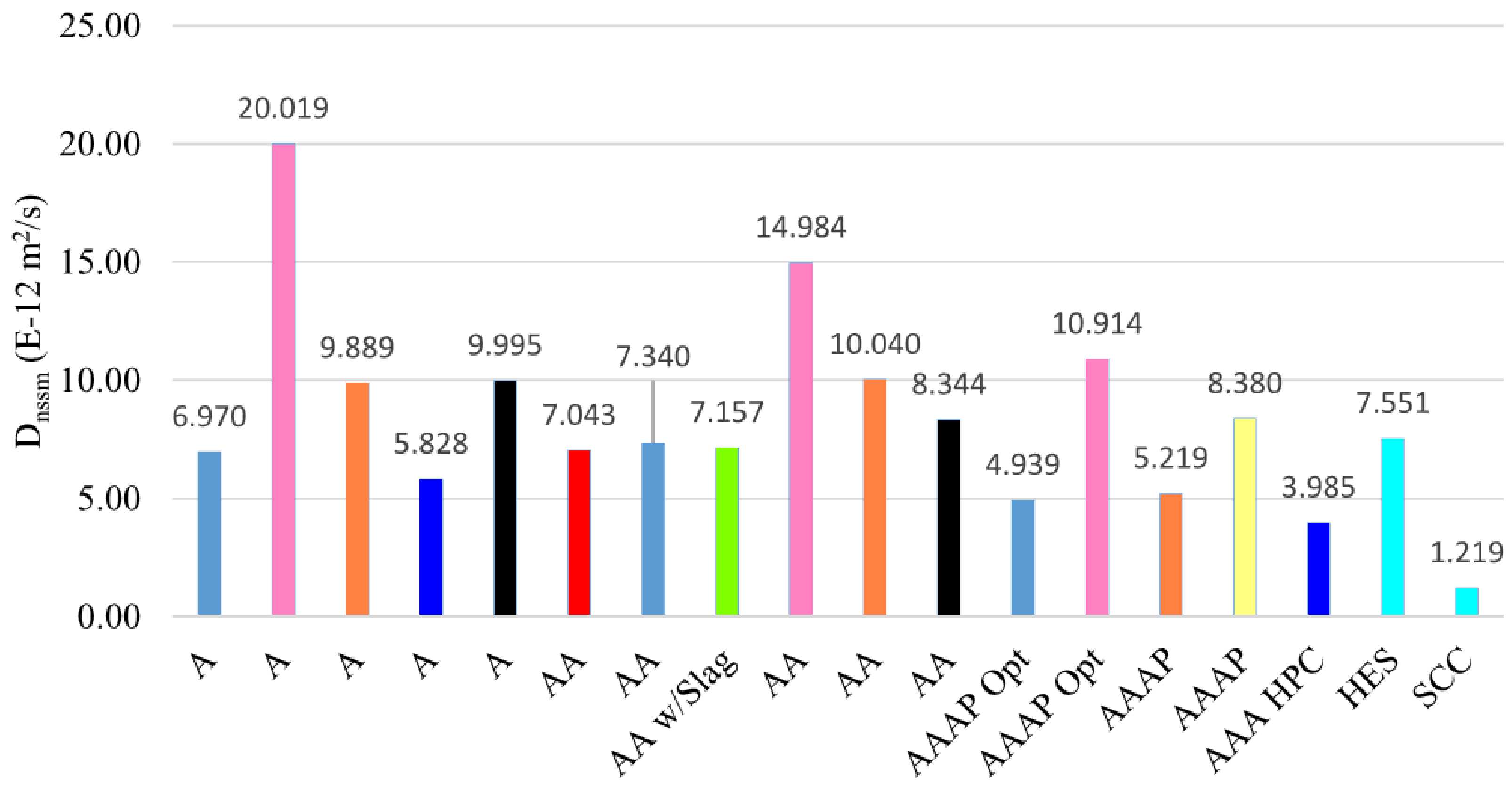
Pennsylvania DOT

Chloride Migration Coefficient by Concrete Class



Pennsylvania DOT

Chloride Migration Coefficient by Concrete Supplier



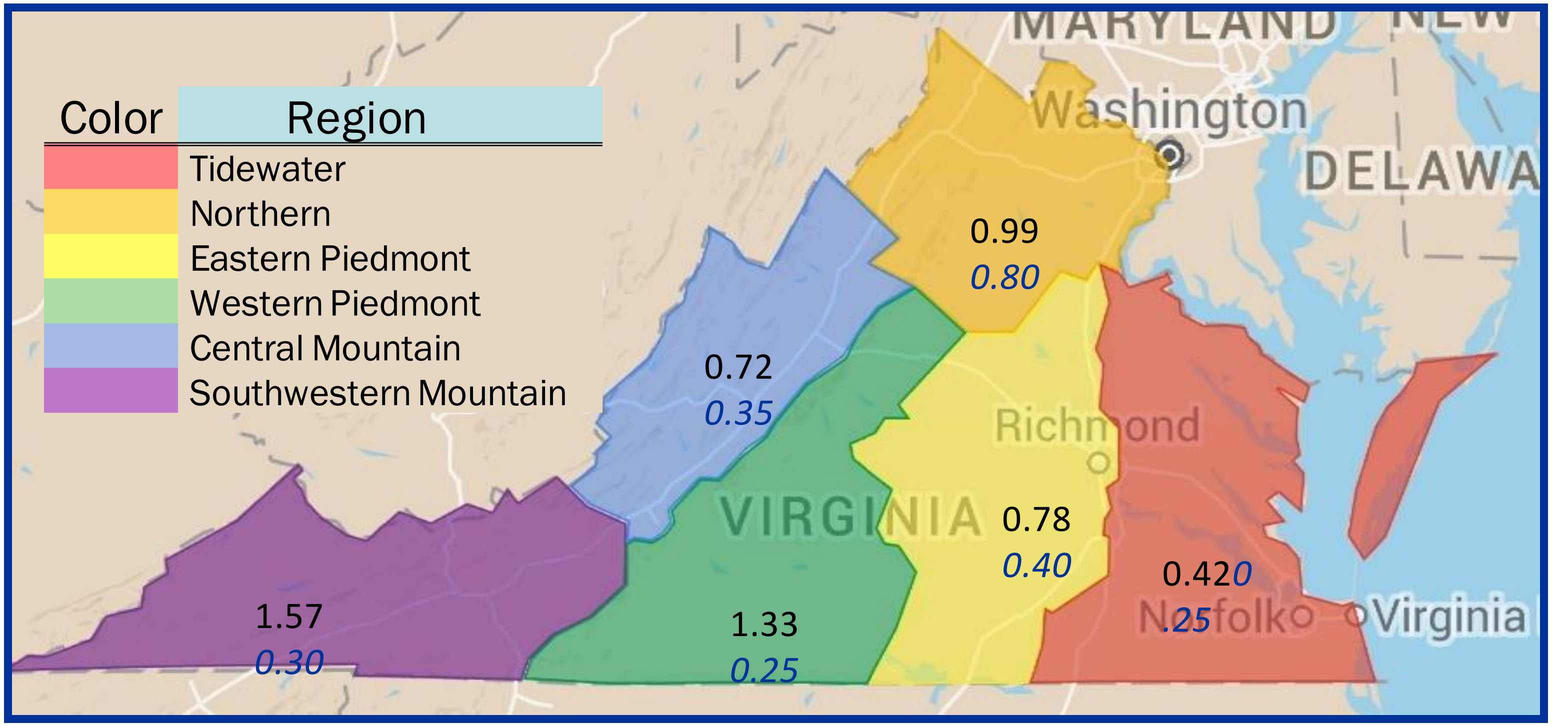
Pennsylvania DOT

- **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

Virginia DOT

- **Categorization of chloride loading by zones**



- Historical data (Williamson, 2007)
- *fib 34-predicted*

$$\left(\%\,\frac{mass\ Cl^{-}}{mass\ binder}\right)$$

- **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

Questions?

Thank You

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