


SHRP2 SOLUTIONS
STRATEGIC HIGHWAY RESEARCH PROGRAM

Service Life Design of Bridges

Workshop W05 – International Bridge Conference

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June 7, 2016

U.S. Department of Transportation
Federal Highway Administration

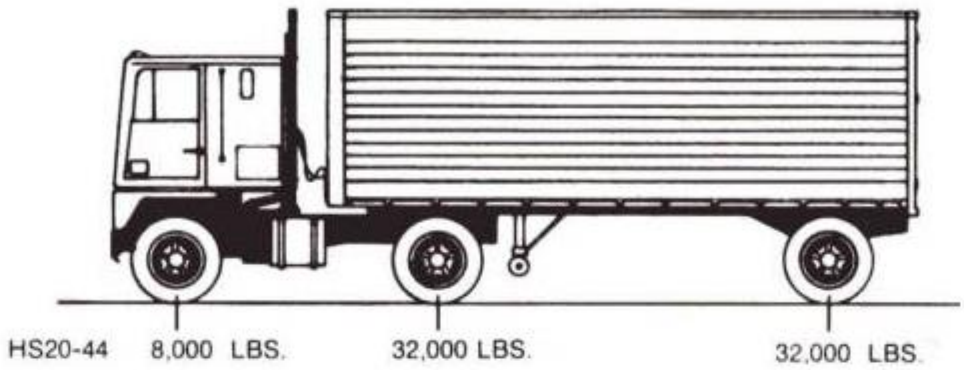
American Association of State Highway and Transportation Officials
AASHTO

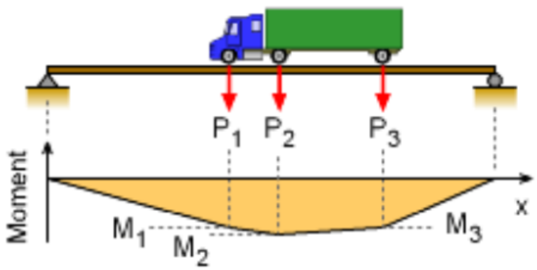
Presentation Overview

- Service Life Design – What is it?
- Historical Background – What’s been done?
- Current Status / Gaps – What’s being done?
- Proposed Research on Service Life Design – What’s next?

Service Life Background

- Bridge Design focuses on structural engineering
  - Determining loads, sizing components, and selecting materials by their strength properties (f'c, fy, etc.)



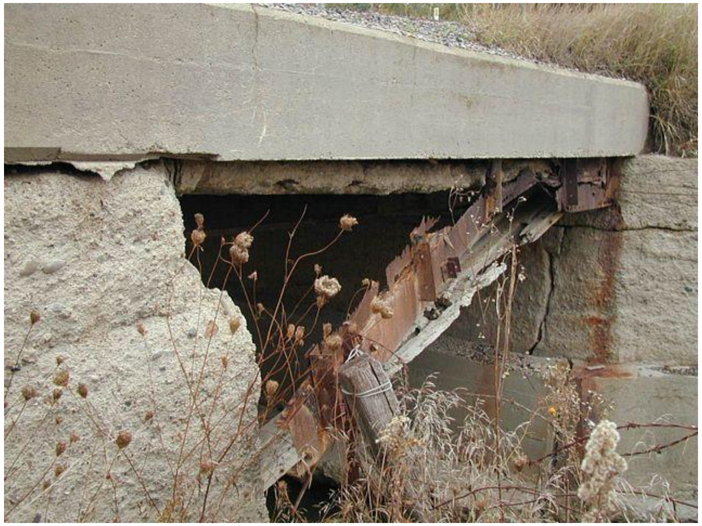


Typical Moment Diagram for a Series of Point Loads

  - Extremely important, but does little to ensure that a structure will remain in use for a given period of time

Service Life Background

- When a structure reaches the end of its life
  - The cause is primarily from material deterioration



  - Due to the environmental exposure conditions

Service Life Design Principles

- All materials deteriorate with time
- Every material deteriorates at a unique rate
- Deterioration rate is dependent on:
  - Environmental exposure conditions
  - Material’s protective systems – durability properties

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
- <u>Not</u> designing for the Service Limit States I, II, and III per LRFD 3.4

Service Life Design (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

Goals of Service Life Design

- Owners – Need assurance that a long-lasting structure will be designed, built, and operated (Effective use of public funding $$)

- Engineers/Contractors/Asset Managers – Need quantifiable scientific methods to evaluate estimated length of service for bridge components and materials

Service Life Background

- Significant research has been completed over the past 25 years on how materials deteriorate with time (particularly reinforced concrete).

- Mathematical solutions have been developed to model deterioration behaviour.

Past Practice – 1996-2000

ACI 365.1R-00

Service-Life Prediction—State-of-the-Art Report

Reported by ACI Committee 365

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This report presents current information on the service-life prediction of new and existing concrete structures. This information is important to both the owner and the design professional. Important factors controlling the service life of concrete and methodologies for evaluating the condition of the existing concrete structures, including definitions of key physical properties, are also presented. Techniques for predicting the service life of concrete and the relationship between economics and the service life of structures are discussed. The examples provided discuss which service-life techniques are applied to concrete structures or structural components. Finally, needed developments are identified.

Keywords: construction; corrosion; design; durability; rehabilitation; repair; service life.

CONTENTS

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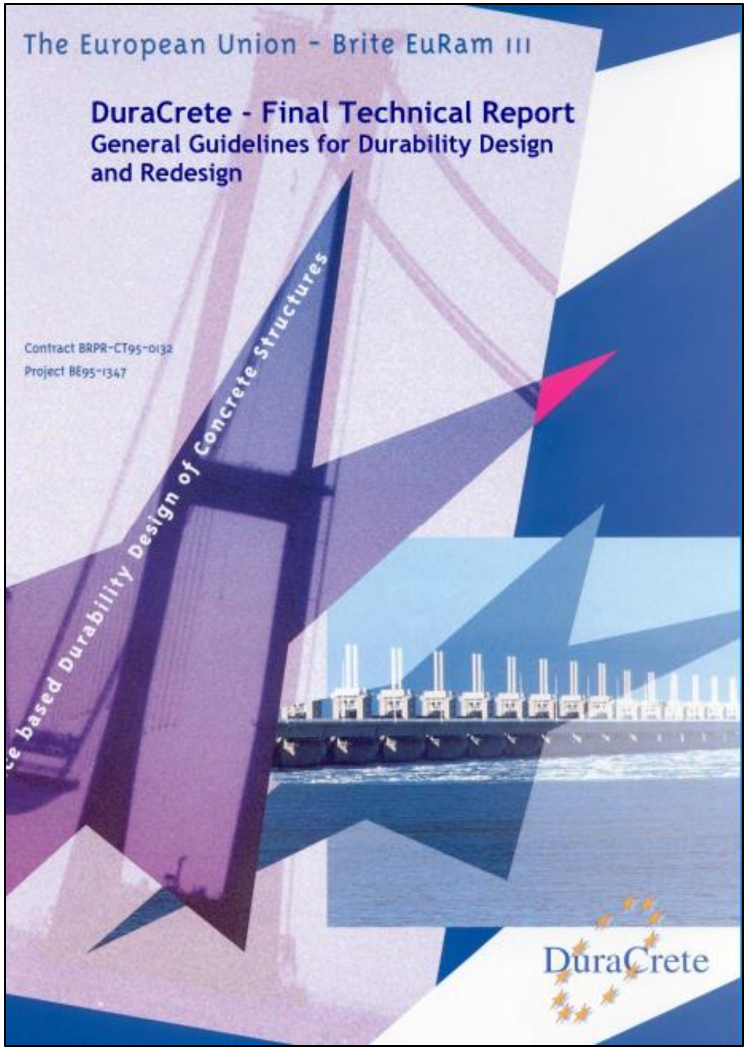


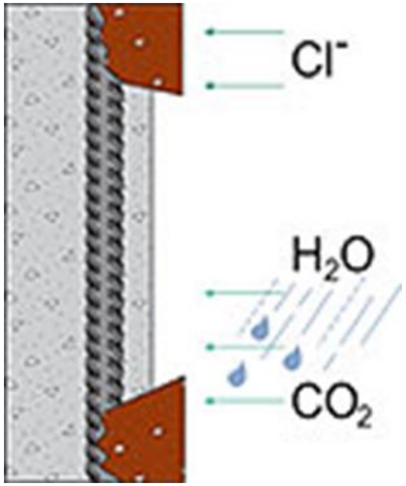
Common Deterioration Types

- 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)



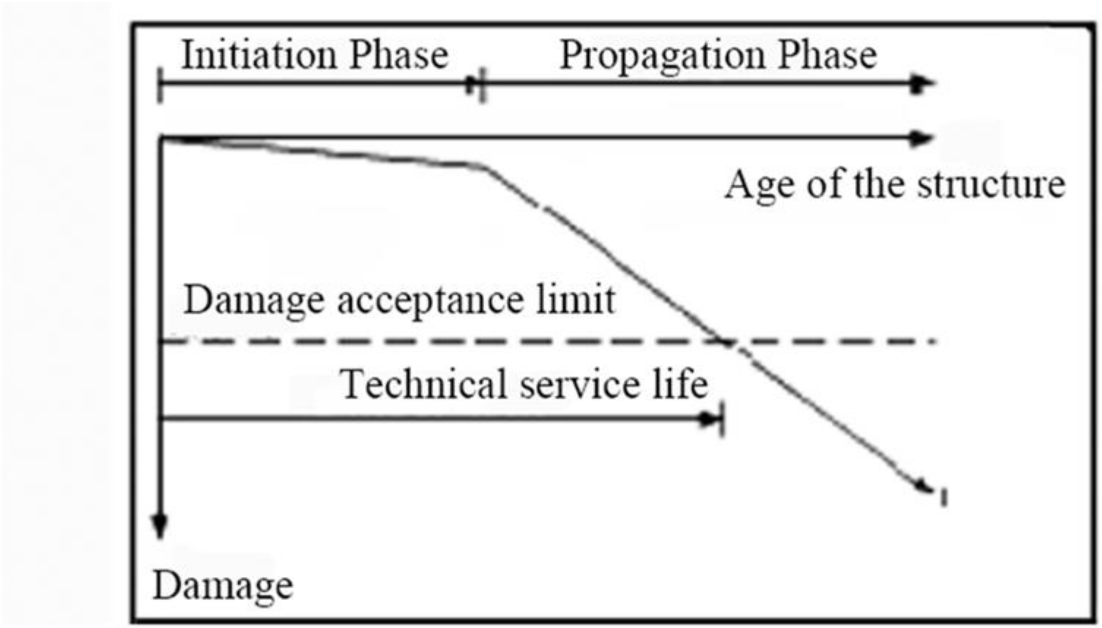
Material Resistance

- Reinforced Concrete
  – Adequate reinforcing steel cover dimension
  – High-quality concrete in the cover layer

- Structural Steel
  – Chemical composition for corrosion resistance
  – Protective Coatings

Deterioration Modeling

- Reinforcing Steel Corrosion is defined with a two-phase deterioration model
  - Initiation – No visible damage is observed
  - Propagation – Corrosion begins and progresses



Service life of concrete structures. A two-phase modelling of deterioration. [Tuutti model (1982)]

Example Deterioration Model

- Chloride Ingress – Fick's 2nd Law of Diffusion for Corrosion Initiation

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

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

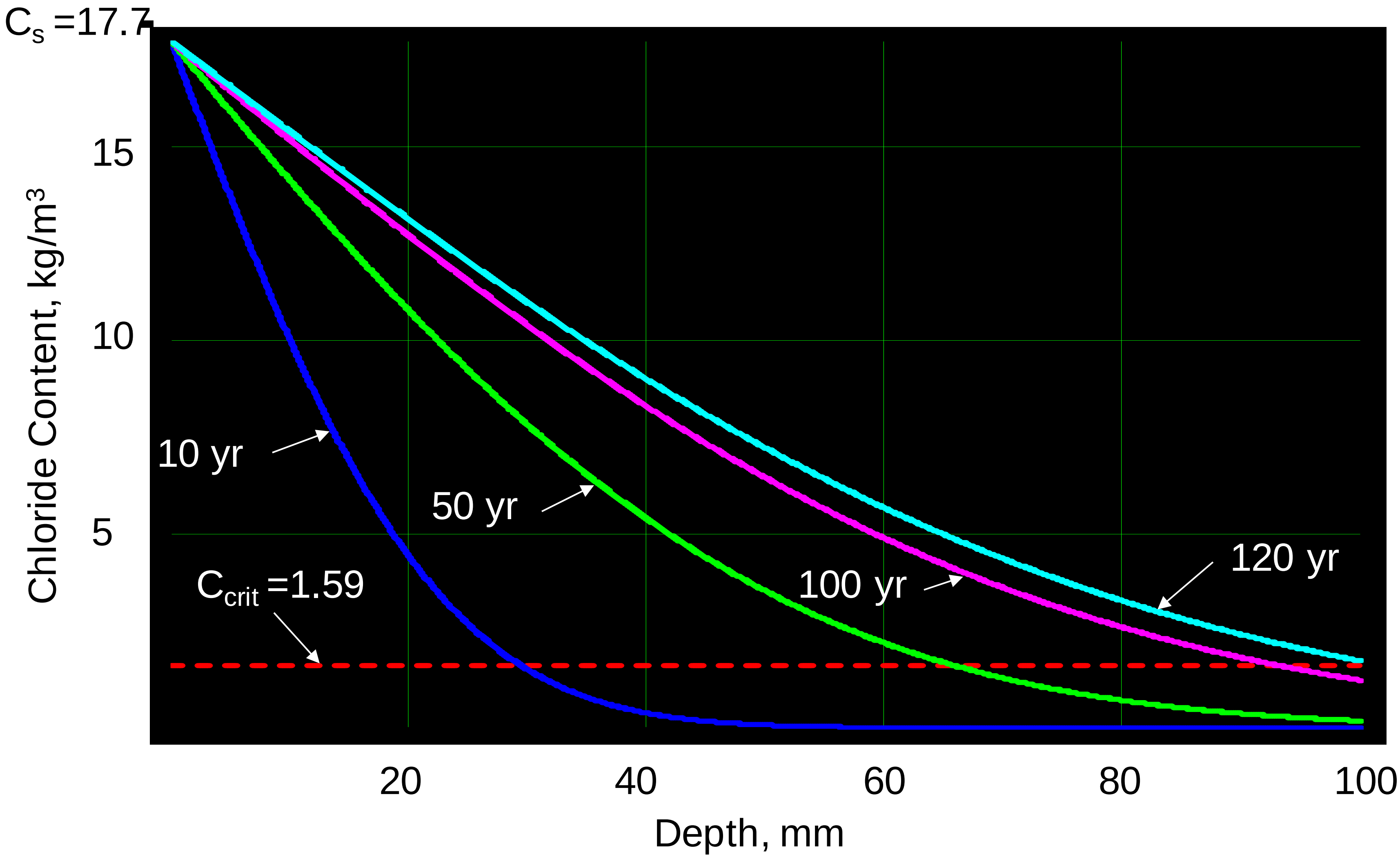
$$k_e = \exp\left(b_e\left(\frac{1}{T_{ref}} + \frac{1}{\mathbf{T_{real}}}\right)\right)$$

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

- **Red – Environmental Loading**
  - $\mathbf{C_o}$ & $\mathbf{C_s}$ are the Chloride Background and Surface Concentrations
  - $\mathbf{T_{real}}$ 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 (*W/C* ratio, SCMs)
  - a is the Concrete Cover

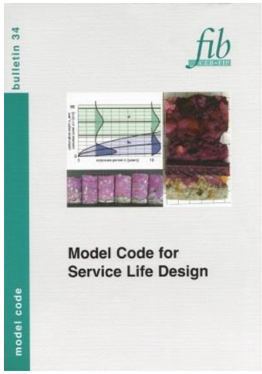
Chloride Profiles vs. Age

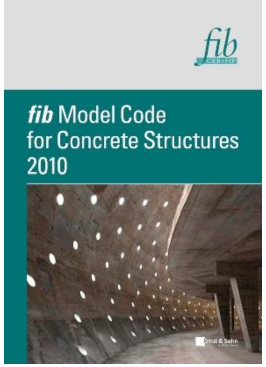
constant $D_{app,c}$ = 15.1 mm^2/yr



Current Specifications

- *fib* Bulletin 34 – Model Code for Service Life Design (2006)
- *fib* Model Code for Concrete Structures 2010
- ISO 16204 – Durability – Service Life Design of Concrete Structures (2012)
- All focus on Concrete Structures only, little available for Steel






INTERNATIONAL STANDARD

ISO 16204

First edition
2012-09-01

Durability — Service life design of concrete structures

Durabilité — Conception de la durée de vie des structures en béton

Through-Life Management

- Integrating all stages in the life of a structure
  - Design
  - Construction
  - In-Service Maintenance & Inspection
  - Intervention (Repair & Rehabilitation)
  - Dismantling
- Future oriented toward sustainable, life-cycle thinking

Through-Life Stages

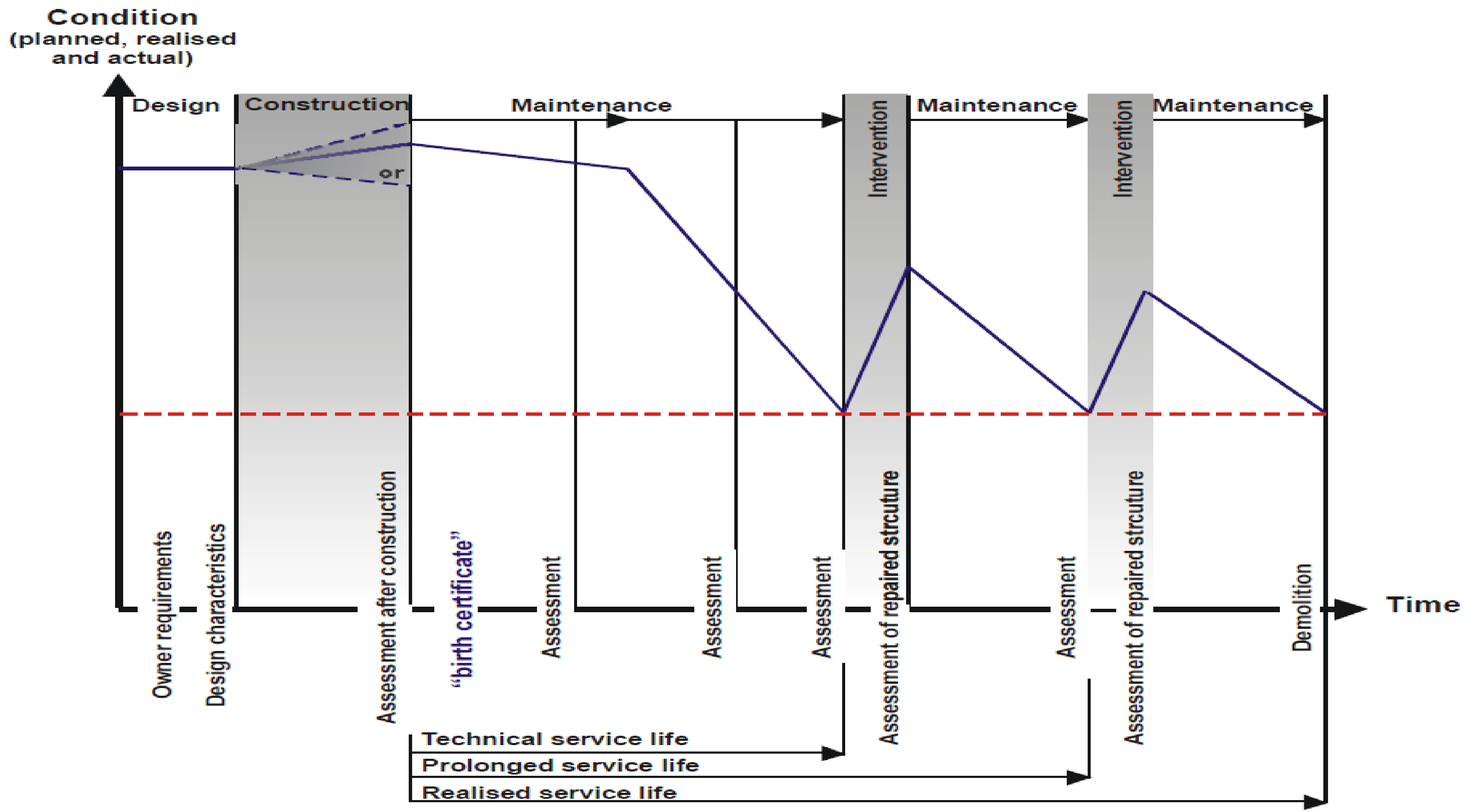


Fig. 2-1: Complete service life from birth to death, adapted from [28]

Service Life Design Strategies

- Avoidance of deterioration – Strategy A
- Design based on deterioration from the environment – Strategy B
  - Full probabilistic design
  - Deemed to satisfy provisions
  - Semi-probabilistic or deterministic design
- "One size does not fit all" – Multiple strategies may be used on a single bridge

Avoidance of Deterioration

- Also called the “Design-Out” approach
- Achieved by either:
  - Eliminating the environmental exposure actions
    - e.g., Use of alkali-non-reactive aggregates
  - Providing materials with resistance well beyond the requirements needed
    - e.g., Use of stainless steel reinforcement
    - Not always the most cost-effective solution

Full Probabilistic Design

- Uses mathematical models to describe observed physical deterioration behavior
- Model variables are:
  - Environmental exposure actions (demands)
  - Material resistances (capacities)
- Variables represented by mean values and distribution functions (std. deviations, etc.)
- Probabilistic, Monte-Carlo type analysis to compute level of reliability

Full Probabilistic Design

- Reliability based like that used to develop AASHTO LRFD code for structural design
- Sophisticated analysis often considered beyond the expertise of most practicing bridge engineers
- Work effort may be regarded as too time consuming for standard structures
- Has been reserved for use on large projects

Deemed to Satisfy Method

- Prescriptive approach used in most major design codes, like AASHTO LRFD sections 2.5.2.1 & 5.12
- Based on some level of past performance – “Rules of Thumb”
- No mathematical deterioration modeling
- Simplistic and not quantifiable
- Lowest level of reliability

AASHTO LRFD Provisions

- 2.5.2.1 – Durability
  - Contract documents shall call for quality materials and … high standards of fabrication and erection.
  - Structural steel shall be self-protecting, or have long-life coating systems or cathodic protection.
- Good intention, but hardly quantifiable

AASHTO LRFD Provisions

- 5.12.1 – Durability – General
  - Concrete structures shall be designed to provide protection of the reinforcing and prestressing steel against corrosion throughout the life of the structure.
  - Special requirements that may be needed to provide durability shall be indicated in the contract documents.
- Again, not very much guidance

AASHTO LRFD Provisions

- 5.12.3 – Durability – Concrete Cover
  - Cover for unprotected prestressing and reinforcing steel shall not be less than that specified in Table 5.12.3-1 and modified for *W/C* ratio…
  - Modification factors for *W/C* ratio shall be the following:
    - For W/C $\leq$ 0.4 ………………………………………….. 0.8
    - For W/C $\geq$ 0.5 ………………………………………….. 1.2

AASHTO LRFD Provisions

- Specified concrete cover dimensions

SECTION 5: CONCRETE STRUCTURES

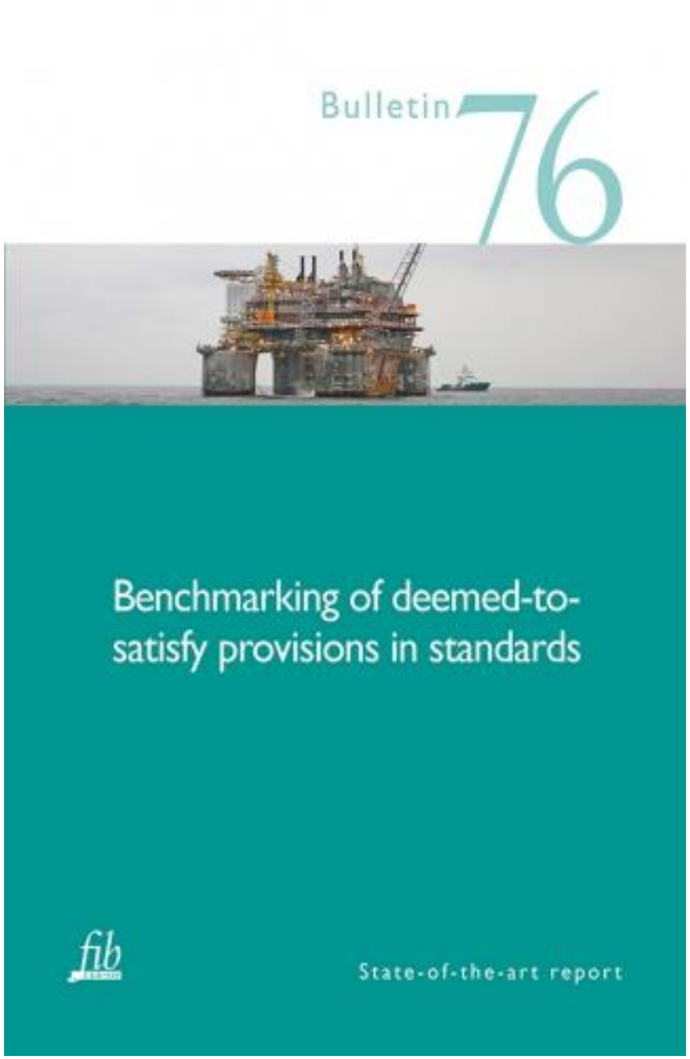
Table 5.12.3-1—Cover for Unprotected Main Reinforcing Steel (in.)

Situation	Cover (in.)
Direct exposure to salt water	4.0
Cast against earth	3.0
Coastal	3.0
Exposure to deicing salts	2.5
Deck surfaces subject to tire stud or chain wear	2.5
Exterior other than above	2.0

- Cover minimally related to concrete properties

Deemed to Satisfy Evaluation

- *fib* Commission 8 – Durability
  - Used full probabilistic methods to evaluate level of reliability for deemed to satisfy code provisions for chloride ingress
  - 9 countries evaluated, including US
  - Results published in 2015



Reliability Levels

Summary of Reliability Index, β versus Probability of Failure, P_f			
P_f	Reliability	$\beta = -\phi_U^{-1}(P_f)$	where $-\phi_U^{-1}(P_f)$ is defined as the inverse standard normalized distribution function
			Example
10%	90%	1.3	fib Bulletin 34 Model Code for Service Life, corrosion initiation
6.7%	93.3%	1.5	Eurocode EN 1990 (service limit state calibrated for a 50 year design life)
1.0%	99%	2.3	
0.1%	99.9%	3.1	
0.02%	99.98%	3.5	AASHTO LRFD Strength I (calibrated for 75 year design life)
0.007%	100%	3.8	Eurocode EN 1990 (ultimate limit state calibrated for a 50 year design life)
50%	50%	0.0	
80%	20%	-0.8	fib TG8.6 Deemed to Satisfy for exposure XD3 (chlorides other than seawater) in USA - 50 year design life

Semi-Probabilistic Design

- Uses same mathematical model as Full Probabilistic Design
- Load factors on environmental demands
- Resistance factors on material properties
- Direct solution to model equations
- Not enough data to properly determine appropriate factors and reliability level
- Method expected to be adopted by codes in the future

Service Life Designed Structures

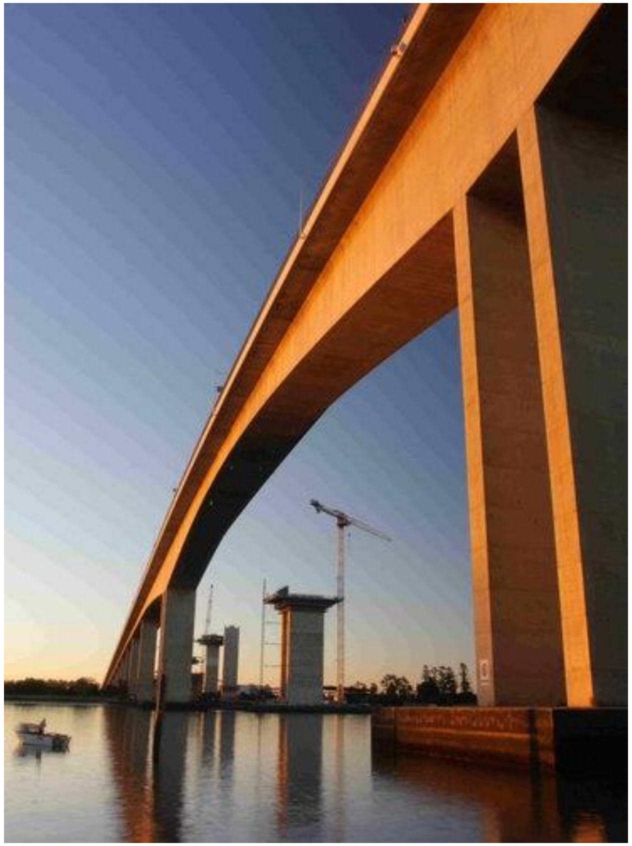
- Confederation Bridge, Canada –1997 (100 years)

Service Life Designed Structures

- Great Belt Bridge, Denmark – 1998 (100 years)

Service Life Designed Structures

- Gateway Bridge, Brisbane – 2010 (300 years)



Service Life Designed Structures

- Ohio River Bridge, KY – 2016 (100 years)

Service Life Designed Structures

- Tappan Zee Bridge, NY – 2018 (100 years)

courtesy of New York State Thruway Authority

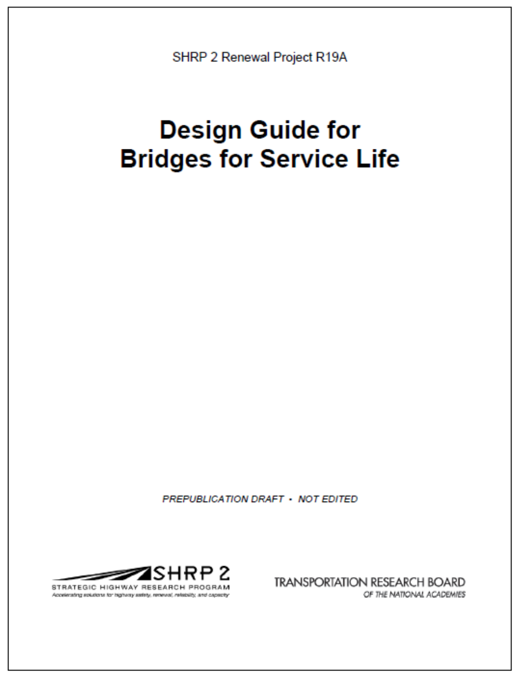
Need More Focus on These

- Representing the majority of the 600,000+ bridges in the US

What’s Currently Being Done

Second Strategic Highway Research Program (SHRP2)

– 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

TRANSPORTATION RESEARCH BOARD OF THE NATIONAL ACADEMIES

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

SHRP2 R19A Team

RESEARCH – **TRB**

IMPLEMENTATION – **FHWA/AASHTO**

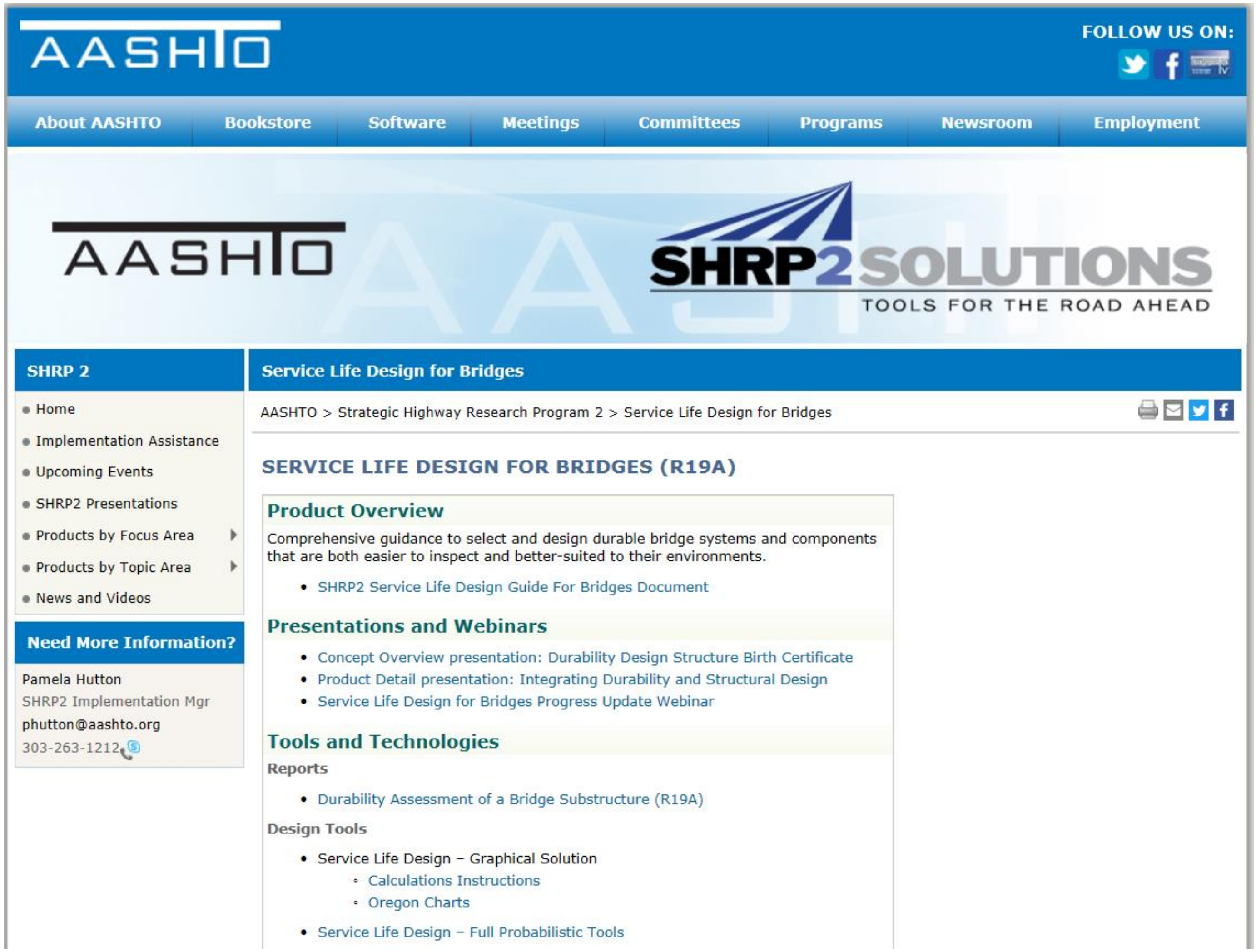
SUBJECT MATTER EXPERTS / LOGISTICS SME LEAD – **CH2M**

TECHNICAL SME's – **COWI**

SHRP2 R19A Implementation Assistance Program Goals

- Promote Service Life Design concepts
  - Marketing, Outreach & Training
  - Target 15% of State DOTs by 2016
- Produce basic elements for inclusion in an AASHTO Service Life Design Guide
  - Coordinate with SCOBS and T-9
- Build a strong technical foundation
  - Develop training & reference materials
  - Lessons learned summaries

SHRP2 R19A Implementation



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SHRP 2

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Need More Information?

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Service Life Design for Bridges

AASHTO > Strategic Highway Research Program 2 > Service Life Design for Bridges

SERVICE LIFE DESIGN FOR BRIDGES (R19A)

Product Overview

Comprehensive guidance to select and design durable bridge systems and components that are both easier to inspect and better-suited to their environments.

- SHRP2 Service Life Design Guide For Bridges Document

Presentations and Webinars

- Concept Overview presentation: Durability Design Structure Birth Certificate
- Product Detail presentation: Integrating Durability and Structural Design
- Service Life Design for Bridges Progress Update Webinar

Tools and Technologies

Reports

- Durability Assessment of a Bridge Substructure (R19A)

Design Tools

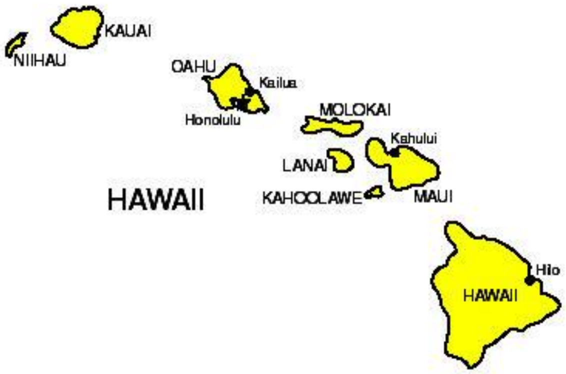
- Service Life Design – Graphical Solution
  - Calculations Instructions
  - Oregon Charts
- Service Life Design – Full Probabilistic Tools

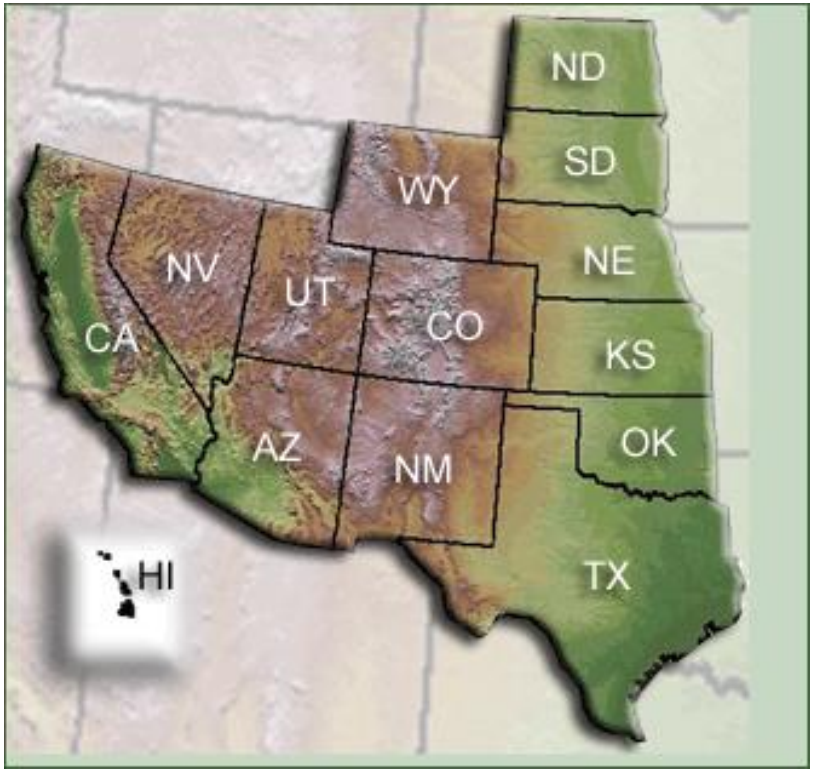
- http://shrp2.transportation.org/Pages/ServiceLifeDesignforBridges.aspx

Who Are the Lead Agencies?

Oregon

Central Federal Lands
(project in Hawaii)





Who Are the Lead Agencies?

Iowa

Pennsylvania

Virginia

R19A IAP Funding

- State Agencies were awarded $150,000 each as Lead Adopters
- FHWA CFL was awarded $75,000
- Funding for technical assistance from the SME team is through SHRP2, and NOT part of agency awards

R19A Next Steps

- Round 7 Implementation Assistance
  - $500,000 in Lead Adopter awards made available
  - 2 Applications received on April 30, 2016 are currently being reviewed

Future Research

- AASHTO T-9 – Bridge Preservation Technical Committee sponsoring NCHRP Research Project 12-108 (Pending)
- Uniform Service Life Design Guide Specification
  - Conduct Literature Review
  - Synthesize Gaps in Current Practice
  - Develop a Methodology considering:
    - Multiple Analysis Methods
    - Deterioration Processes and Exposure Zones and Loads
    - Service Life Target Based on Functional Requirements
    - Selection of Alternative Designs to Achieve Target Service Life
    - Evaluate Effectiveness of Design, Construction, Inspection Strategies and Management Practices
  - Produce Report and Guide Specification

Summary

- Durability or Service Life Design is:
  - A design approach to resist deterioration caused by environmental actions
- Design Guides/Codes are available:
  - fib Bulletin 34 – Model Code for Service Life Design
- Current implementation
  - SHRP2 R19A projects (FHWA CFL, IA, OR, PA, VA)
- AASHTO T-9 Initiated Research
  - NCHRP 12-108 Uniform Service Life Design Guide

Questions?

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