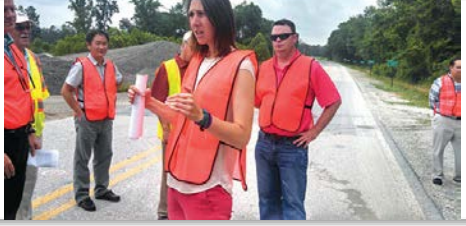





SHRP2 SOLUTIONS
STRATEGIC HIGHWAY RESEARCH PROGRAM

Bridges for Service Life Beyond 100 Years

Service Life Design for Bridges

Kelley C. Severns, PE, & Mike Bartholomew, PE / CH2M HILL

March 17, 2015

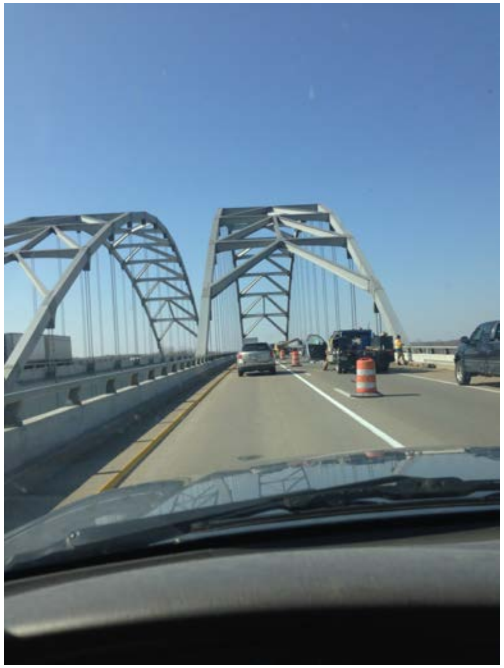
U.S. Department of Transportation
Federal Highway Administration

American Association of State Highway and Transportation Officials
AASHTO

R19A – Service Life Design for Bridges

- What are SHRP2 Solutions? – Over 100 Research Projects

- What is R19A?
  - *Comprehensive guidance to select and design durable bridge systems and components that are both easier to inspect and better-suited to their environments.*



- The Service Life Design Method for Bridges may be utilized to provide longer service life by design through durable and state-of-the-art materials, construction techniques, and utilization of emerging technologies that are ideally suited for the bridge.

Who Are We?

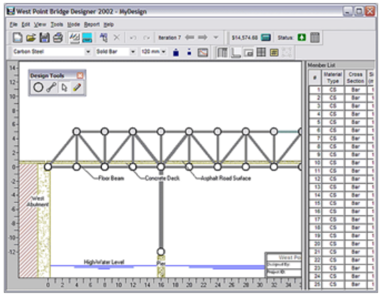
RESEARCH –
TRB

IMPLEMENTATION –
FHWA/AASHTO

SUBJECT MATTER EXPERTS / LOGISTICS –
CH2M Hill

TECHNICAL SME's –
Buckland and Taylor

150,000 Bridges Need Repair – SHRP2 is on the Job



Project Development

- Innovative Bridge Designs (R04)
- Service Life for Bridges (R19A)
- Implementing Eco-Logical (C06)
- Minimizing Risk in Rapid Renewal (R09)
- GeoTech Tools (R02)
- Railroad-DOT Mitigation Strategies (R16)
- Utilities Bundle (R15B, R01 A, R01 B)

Construction

- Innovative Bridge Designs (R04)
- Minimizing Risk in Rapid Renewal (R09)
- Performance Specifications for Rapid Renewal (R07)
- Project Management Strategies for Complex Projects (R10)
- Railroad-DOT Mitigation Strategies (R16)

Preservation

- Nondestructive Testing for Bridges and Tunnels (R06 A/G)
- Service Life Design for Bridges (R19A)

Service Life Design of Bridges

- What is it?
- What are its main objectives?
- What is being done to implement it?
- What effect will it have on the future of transportation infrastructure?

Service Life Background

- Bridge Design has historically been focused solely on structural engineering aspects

  – Selecting materials by their strength properties (f'c, fy) and sizing components to resist loads

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

Service Life Background

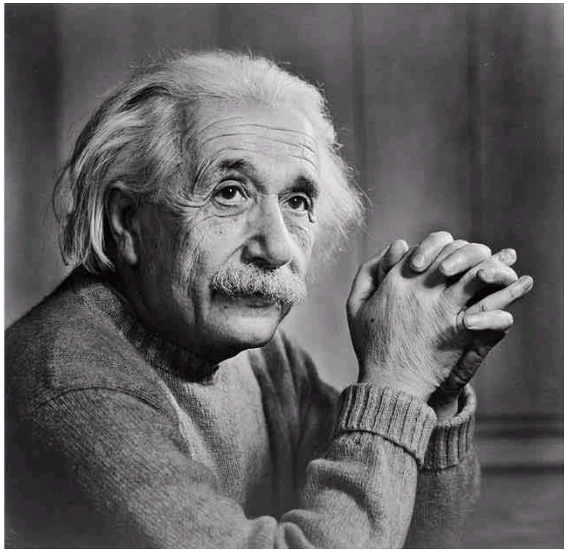
- When a structure reaches the end of its life
  - The cause is primarily because the material components have begun to deteriorate
    - Not from unanticipated loads
    - But by loss of strength from steel corrosion and concrete cracking/spalling, as a result of the environmental exposure conditions

Service Life Background

- Over 600,000 bridges in the US
- Many (%?) nearing the end of their useful life
- Limited transportation funding has led to a focused awareness to develop ways to extend the expected service life for all infrastructure, often to 100+ years
- This has and will continue to be a dilemma

A reflection upon problems and their solutions

"We can't solve problems by using the same type of thinking we used when we created them!"



Albert Einstein

Service Life Background

- Significant research has been completed over the past 25 years on how materials deteriorate with time (particularly reinforced concrete)
- Mathematical models have been developed to model deterioration
- Service Life Design provides a means for designing for durability based on deterioration from the environmental exposure

Service Life Design Principles

- All Materials Deteriorate with Time
- Every Material Deteriorates at a Unique Rate
- Deterioration Rate is Dependent on
  - The Environmental Exposure Conditions
  - The Material's Protective Systems

Service Life Designed Structures

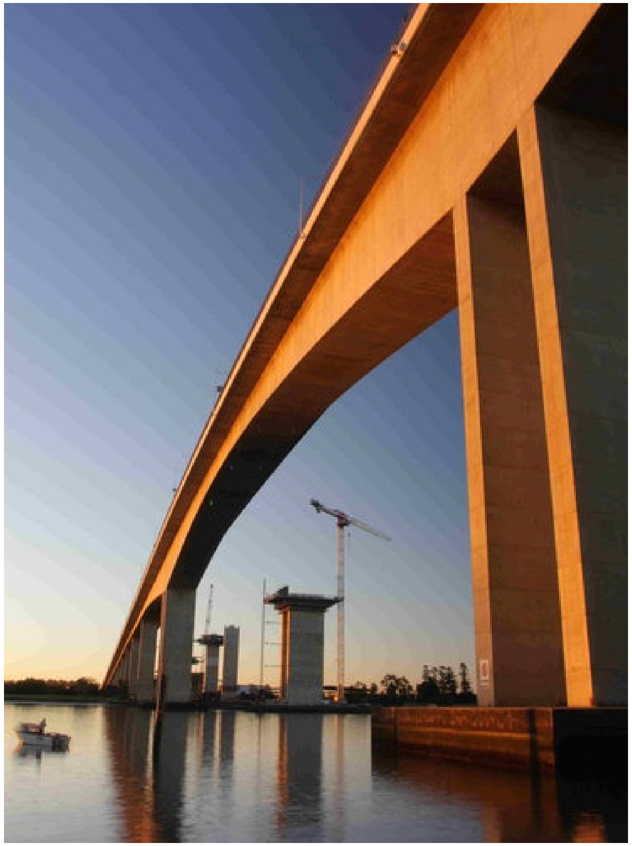
- Confederation Bridge, Canada –1997 (100 years)

Service Life Designed Structures

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

Service Life Designed Structures

- Gateway Bridge, Brisbane – 2010 (300 years)



SHRP2 R19A Targeted Bridges

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

Service Life Design Process

- Identify Environmental Exposure Classes / Deterioration Mechanisms
- Select Expected Service Life
  - (75, 100, 150, … years)
- Select Design Guide/Code and Strategy
- Select a Limit State & Reliability Level
  - (corrosion initiation, concrete cracking or spalling, loss of structural capacity)
- Specify Materials, Member Dimensions & Tests
- Produce Contract Documents

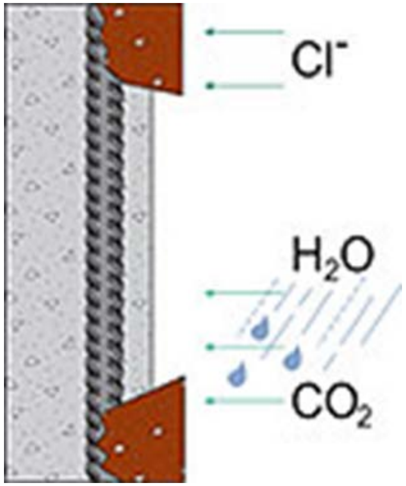
Environmental Exposure

Exposure Classes – European Standard EN-206-1

Class/Level	Description
X0	No Risk of Corrosion or Attack
XC1-XC4	Corrosion Induced by Carbonation
XD1-XD3	Corrosion induced by chlorides other than from sea water
XS1-XS3	Corrosion induced by chlorides from sea water
XF1-XF4	Freeze/thaw attack with or without de-icing agents
XA1-XA3	Chemical attack

Deterioration

- Material Deterioration Mechanisms
  - Reinforcing Steel Corrosion due to:
    - Chloride Ingress
    - Carbonation
  - Concrete Deterioration due to:
    - Freeze-Thaw
    - Abrasion
    - Alkali-Silica Reaction (ASR)



Deterioration

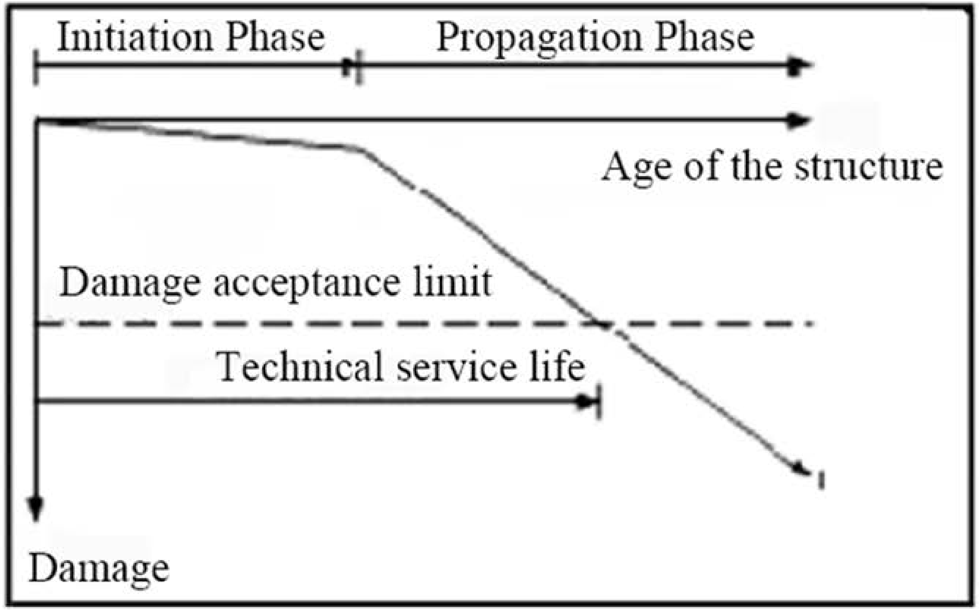
- Structural Steel
  - Corrosion after Breakdown of Protective Coating Systems

Material Resistance

- For Reinforced Concrete
  - Adequate reinforcing steel cover dimension
  - High quality concrete in the cover layer
- For Structural Steel
  - Chemical composition for corrosion resistance
  - Protective Coatings

Deterioration Modeling

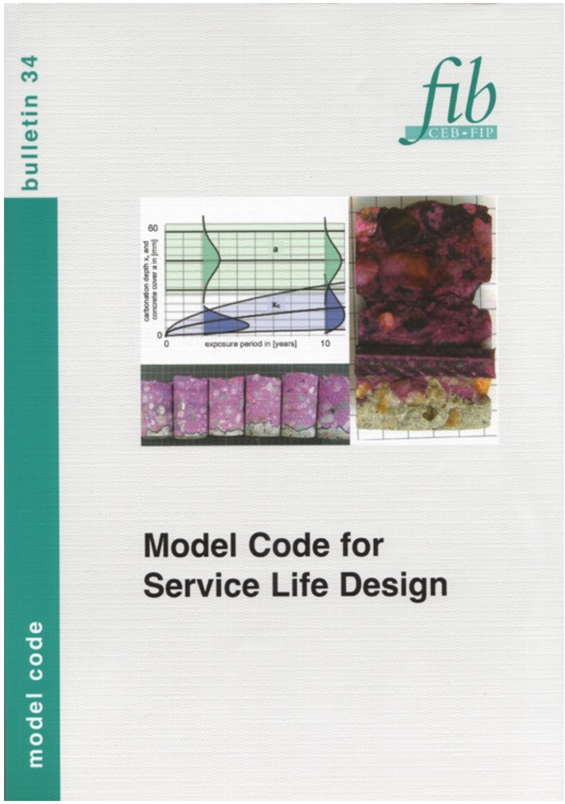
- Reinforcing Steel Corrosion is Defined with a Two-Phase Deterioration Model
  - Initiation – No Visible Damage is Observed
  - Propagation – Corrosion Begins and Progresses



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

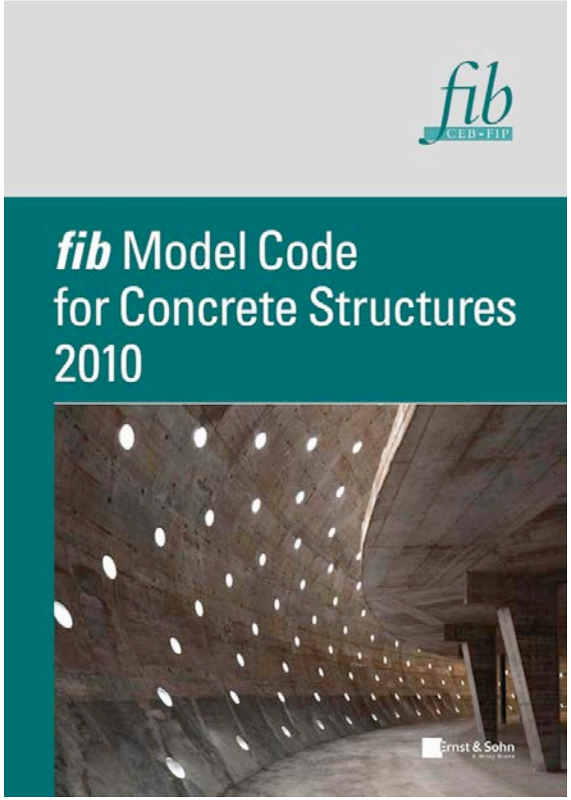
International Standards

- International Federation of Structural Concrete
- *fib* Bulletin 34 – Model Code for Service Life Design (2006)
  - Establishes design procedures
    - to Resist Deterioration
    - from Environmental Actions



International Standards

- *fib* Model Code for Concrete Structures (2010)
  - Section 7.8
  - Incorporates Bulletin 34



International Standards

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

SHRP2 Project R19A

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

Service Life Design Strategies

- Avoidance of deterioration – Strategy A
- Design Based on Deterioration from the Environment – Strategy B
  - Deemed to satisfy provisions
  - Full probabilistic design
  - Semi-probabilistic or deterministic design

Avoidance of Deterioration

- Also called the “Design-Out” approach
- Achieved by either:
  - Eliminating the environmental exposure actions
    - (e.g., interior of buildings with controlled temperature & humidity)
  - Providing materials with resistance well beyond the requirements needed
    - (e.g., stainless steel reinforcement)
- Not always the most cost effective solution

Deemed to Satisfy Method

- Prescriptive approach used in most major design codes
  - e.g., In severe environment, use concrete with w/c ratio < 0.40, 2½" cover
- Based on some level of past performance
- No mathematical deterioration modeling
- Simplistic and not quantifiable
- Lowest level of reliability

ACI-318 Durability Requirements

TABLE 4.2.1 — EXPOSURE CATEGORIES AND CLASSES

Category	Severity	Class	Condition	
F Freezing and thawing	Not applicable	F0	Concrete not exposed to freezing-and-thawing cycles	
	Moderate	F1	Concrete exposed to freezing-and-thawing cycles and occasional exposure to moisture	
	Severe	F2	Concrete exposed to freezing-and-thawing cycles and in continuous contact with moisture	
	Very severe	F3	Concrete exposed to freezing-and-thawing and in continuous contact with moisture and exposed to deicing chemicals	
			Water-soluble sulfate (SO_4) in	Dissolved su
permeability	Required		permeability is required.	
C Corrosion protection of reinforcement	Not applicable	C0	Concrete dry or protected from moisture	
	Moderate	C1	Concrete exposed to moisture but not to external sources of chlorides	
	Severe	C2	Concrete exposed to moisture and an external source of chlorides from deicing chemicals, salt, brackish water, seawater, or spray from these sources	

*Percent sulfate by mass in soil shall be determined by ASTM C1580.
†Concentration of dissolved sulfates in water in ppm shall be determined by ASTM D516 or ASTM D4130.

TABLE 4.3.1 — REQUIREMENTS FOR CONCRETE BY EXPOSURE CLASS

Exposure Class	Max. *w/cm**	Min. f'_c, psi	Additional minimum requirements	
			Air content	Limits on cementitious materials
F0	N/A	2500	N/A	N/A
F1	0.45	4500	Table 4.4.1	N/A
F2	0.45	4500	Table 4.4.1	N/A

Exposure Class	Max. *w/cm**	Min. f'_c, psi	Maximum water-soluble chloride ion (Cl^-) content in concrete, percent by weight of cement#		
			Reinforced concrete	Prestressed concrete	Related provisions
C0	N/A	2500	1.00	0.06	None
C1	N/A	2500	0.30	0.06	None
C2	0.40	5000	0.15	0.06	7.7.6, 18.16**

*For lightweight concrete, see 4.1.2.
†Alternative combinations of cementitious materials of those listed in Table 4.3.1 shall be permitted when tested for sulfate resistance and meeting the criteria in 4.5.1.
‡For seawater exposure, other types of portland cements with tricalcium aluminate (C_3A) contents up to 10 percent are permitted if the *w/cm* does not exceed 0.40.

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 beyond typical experience level for most practicing bridge engineers
- Work effort may be regarded as too time consuming for standard structures
- Has been reserved for use on large projects

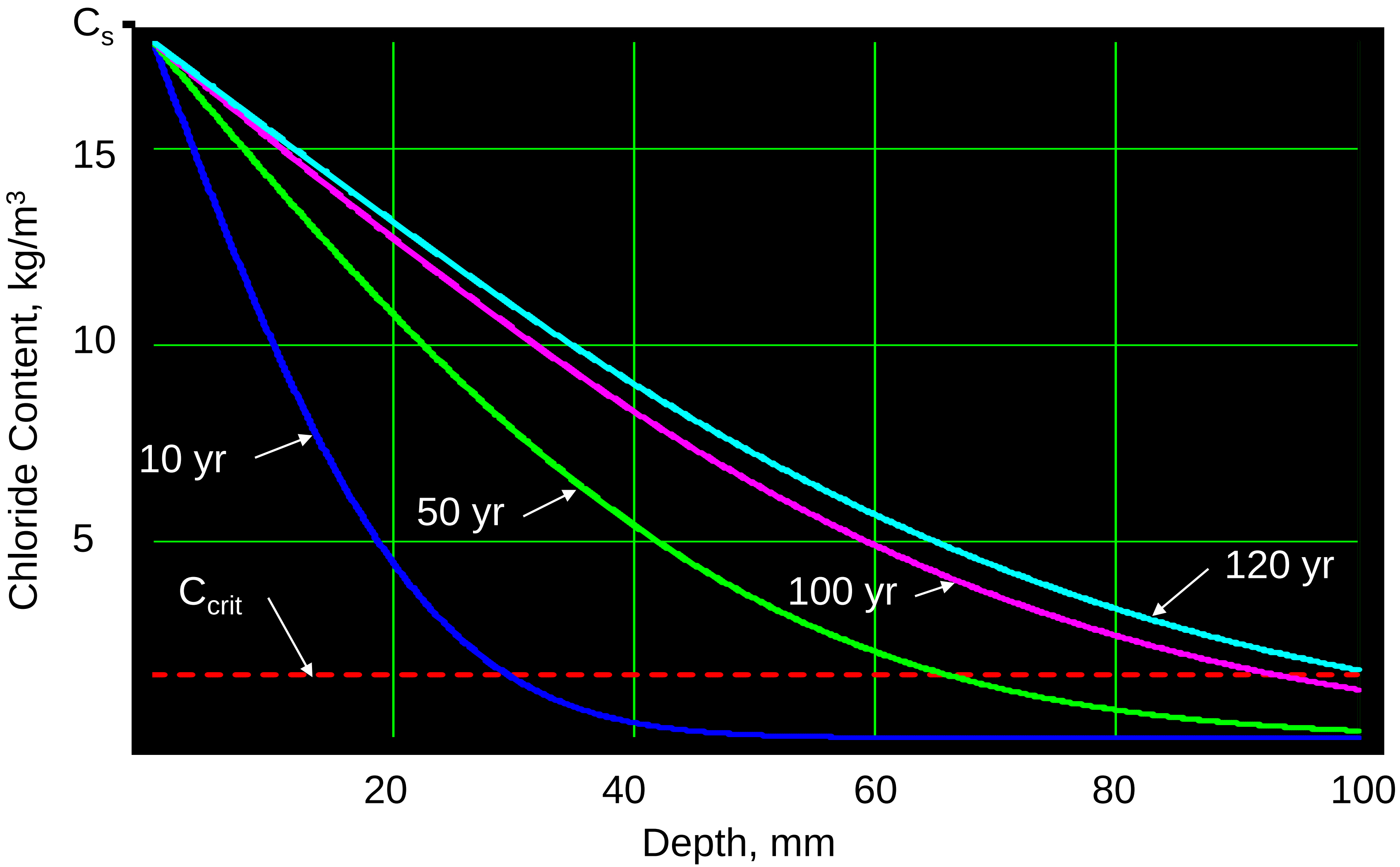
Deterioration – Chloride Ingress

- Fick's 2nd Law Models Time to Initiate Corrosion in Uncracked Concrete (Cracks < 0.3 mm or 0.012")

$$C(x,t) = C_o + (C_s - C_o)\cdot\left(1 - \mathrm{erf}\left(\frac{x}{2\cdot\sqrt{D_{app,c}\cdot t}}\right)\right) \leq C_{crit}$$

$C(x,t)$	Chloride concentration at depth & time	kg/m^3
x, t	Depth from surface / time	mm, yr
erf	Mathematical error function	-
C_{crit}	Critical chloride content (to initiate corrosion)	kg/m^3
C_o	Initial chloride content of the concrete	kg/m^3
C_s	Chloride concentration at surface	kg/m^3
$D_{app,C}$	Apparent coefficient of chloride diffusion in concrete	mm^2/yr

Chloride Profiles



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

Through Life Management

- Integrating All Stages in structure’s life:
  - Design
  - Construction
  - Conservation (In-service Maintenance, Inspection and Intervention)
  - Dismantlement
- Future Oriented – Toward Sustainable, Life-Cycle Thinking

Service Life Stages

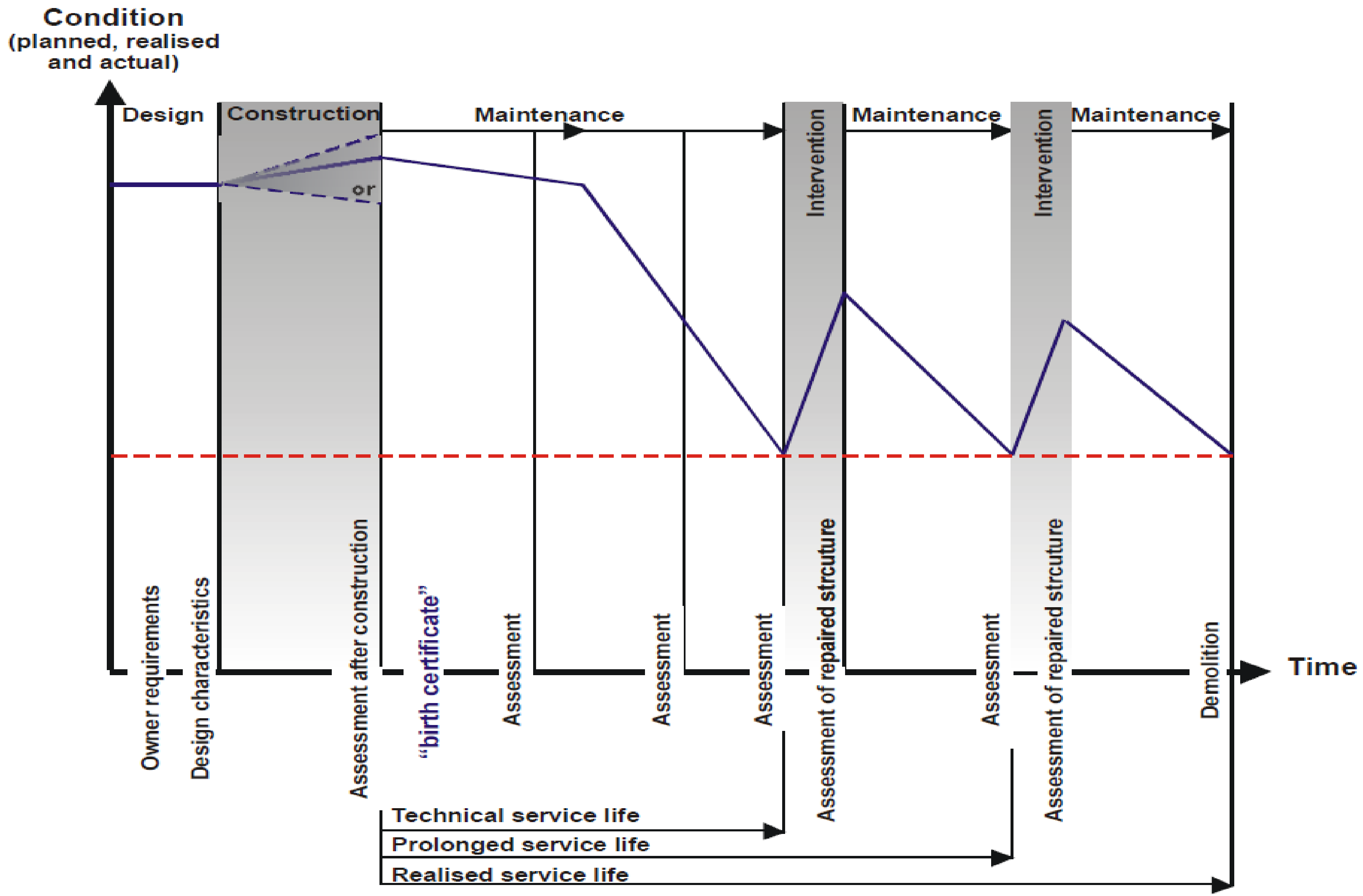


Fig. 2-1: Complete service life from birth to death, adapted from [28]

Contract Documents

- Identify Additional Tests and Data Collection Requirements
  - Concrete Coefficient of Chloride Diffusion
  - Cover Dimension to Reinforcing Steel
- Incorporate Appropriate Tests in Contract Special Provisions
  - State the Extent of Concrete Test Samples Taken
  - State the Frequency of Cover Dimensions Taken
  - Identify Means to Deal With Variations from Design Intent

Construction Test Requirements

- Concrete Coefficient of Chloride Diffusion – Long Term Tests
  - **ASTM C1543/AASHTO T259** – Standard Test Method for Determining the Penetration of Chloride Ion into Concrete by Ponding (**Salt Ponding Test** – 28 day cure, 90 day exposure)
  - **Nordtest Method NT Build 443** – Accelerated Chloride Penetration (**Bulk Diffusion Test** – 28 day cure, 35 day minimum exposure, 90 days for higher quality concrete)
  - **Nordtest Method NT Build 355** – Chloride Diffusion Coefficient from **Migration Cell Experiments** (90 day cure)

Construction Test Requirements

- Concrete Coefficient of Chloride Diffusion – Short Term Tests
  - **ASTM C1202/AASHTO T 277** – Standard Test Method for Electrical Indication of Concrete's Ability to Resist Chloride Ion Penetration (**Rapid Chloride Permeability Test** – 56 day cure, ~24 hour conditioning, 6 hour test)
  - **AASHTO TP 64** – Predicting Chloride Penetration of Hydraulic Cement Concrete by the **Rapid Migration Procedure** (~24 hour conditioning, 18 hour test)
  - **Nordtest Method NT Build 492** – **Chloride Migration Coefficient** from Non-Steady State Migration Experiments (28 day cure, test duration 6 to 96 hours, usually 24 hours)

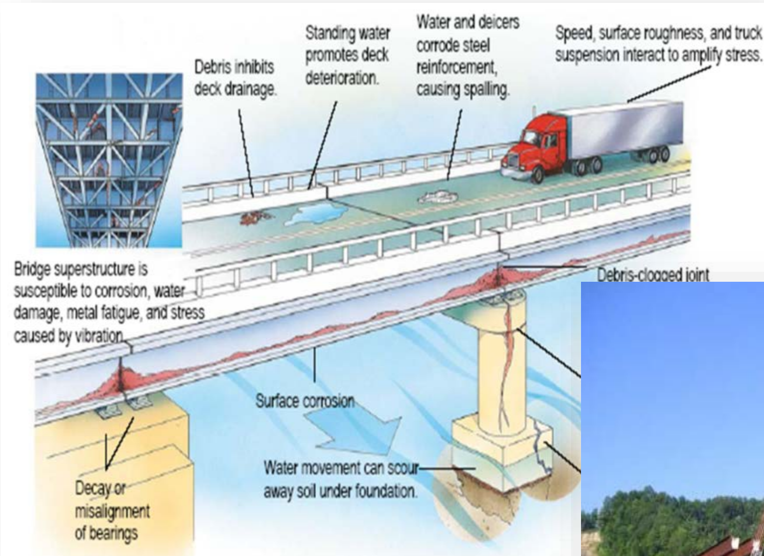
Construction Test Requirements

- Cover Meters for Steel Reinforcement Cover Measurements
- Complete Mapping
  - Min/Max Depth
- Calculate Parameters
  - Mean & Std. Deviation
- ACI 228.2R-2.51
- BSI 1881:204

Implementation of R19a - Bridges for Service Life Beyond 100 Years

Service Life Design for Bridges

SHRP2 Implementation Assistance Program



Proof-of-Concept Pilot

Lead Adopter

User Incentive

Implementation Assistance States

- Applied in January 2014

30 IAP Bridge-Related Projects Underway

- Iowa
- Pennsylvania
- Oregon
- Virginia
- Central Federal Lands - Hawaii

What are the Lead States Doing?

- Oregon
  - Existing Bridges
  - Design Build RFP Criteria
  - New Design - example

- Virginia
  - New bridge design example – use of stainless steel – life cycle cost?
- Iowa
  - Parallel Bridges – one designed with traditional methods, one designed for service life

What can you do?

- Look for tools from the Implementation Program

- Next Round of Implementation
  - June 2015
  - Round 6

  http://www.fhwa.dot.gov/goshrp2/ImplementationAssistance#round6

  Look for instructions and applications at the SHRP2 website
  - User Incentives

Questions?

Anwar Ahmad, FHWA anwar.ahmad@dot.gov **202-366-8501**

Patricia Bush, AASHTO pbush@aashto.org **202-624-8181**

Kelley (Rehm) Severns, PE kelley.rehm@ch2m.com **859-433-9623**

Mike Bartholomew, PE mbarthol@ch2m.com **541-768-3334**

Pam Hutton

AASHTO SHRP2 Implementation Manager

phutton@aashto.org

http://www.fhwa.dot.gov/goSHRP2/

http://shrp2.transportation.org