



SHRP2 SOLUTIONS
STRATEGIC HIGHWAY RESEARCH PROGRAM

Service Life Design and Engineering of Bridges

Workshop W05 – International Bridge Conference
June 7, 2016

U.S. Department of Transportation
Federal Highway Administration

American Association of State Highway and Transportation Officials
AASHTO

TRANSPORTATION RESEARCH BOARD
OF THE NATIONAL ACADEMIES

Implementing Service Life Design

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Implementing Service Life Design

1. Concrete Structures
2. Steel Structures
3. Specifications

Service Life Design for Concrete Structures

Service Life Design for Concrete Structures

- Service Life Design Challenges
- Design Tools
- Construction Documentation

Service Life Design for Concrete Structures

- Service Life Design Challenges

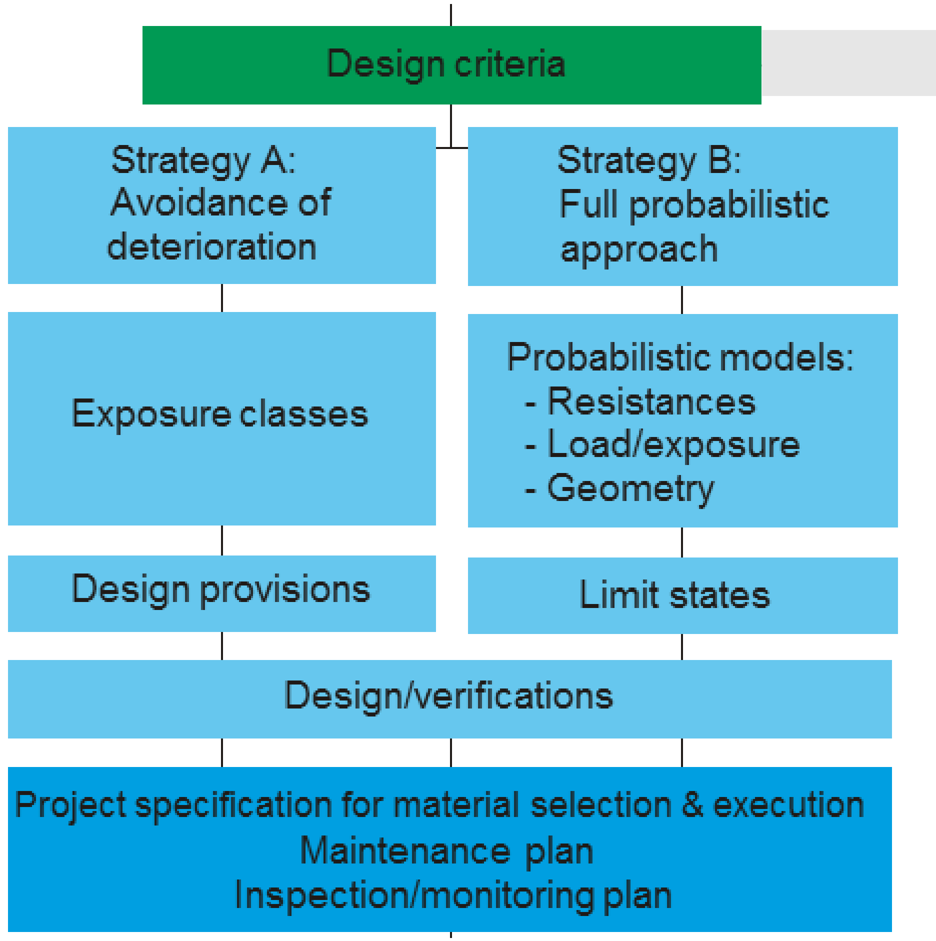
- Design Tools

- Construction Documentation

Service Life Design Challenges

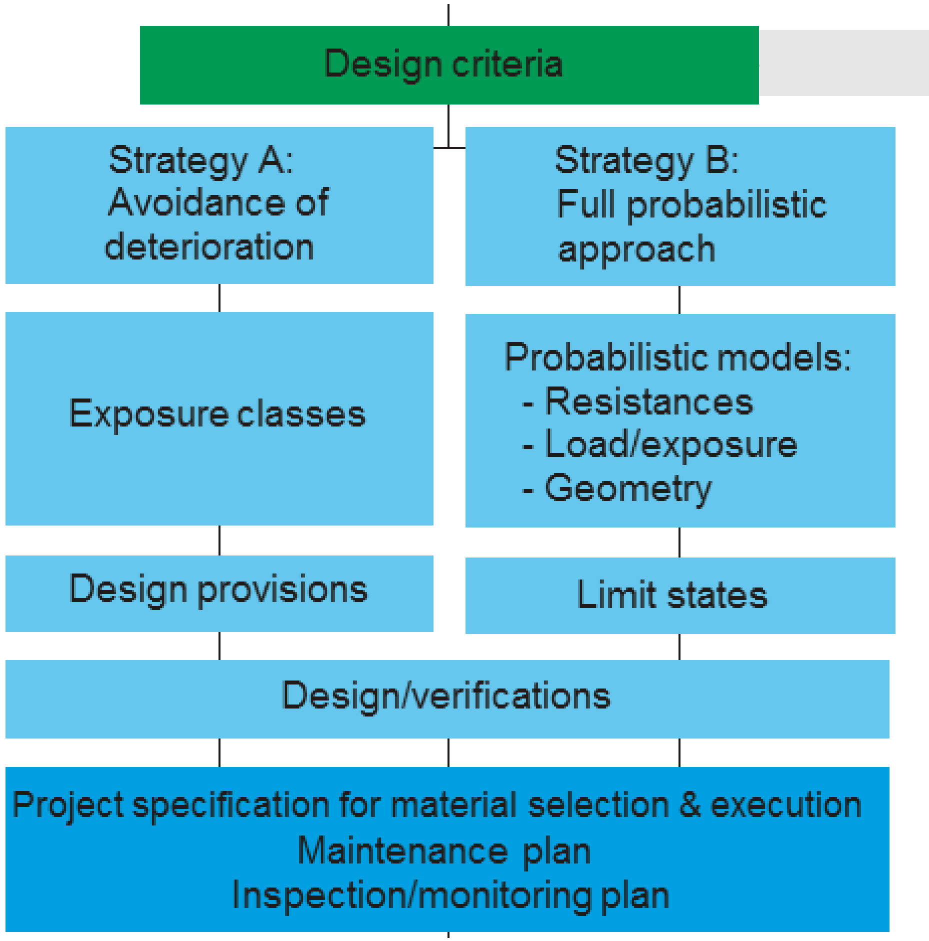
- Selecting a methodology
- Modeling chloride-induced corrosion
- What about deterioration mechanisms where no models is available?

Service Life Design Challenges



Service Life Design Challenges

Sulfate attack
DEF
AAR
Freeze/thaw
Scaling
(Carbonation-induced corrosion)

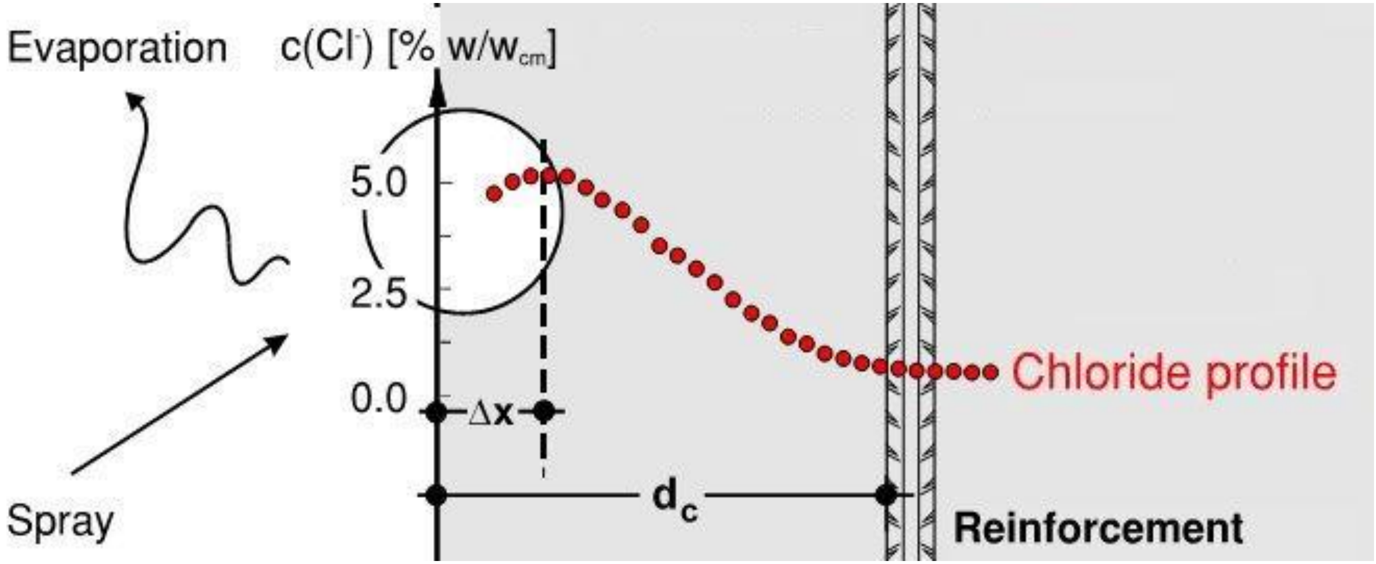


Chloride-induced corrosion
(Carbonation-induced corrosion)

Service Life Design Challenges

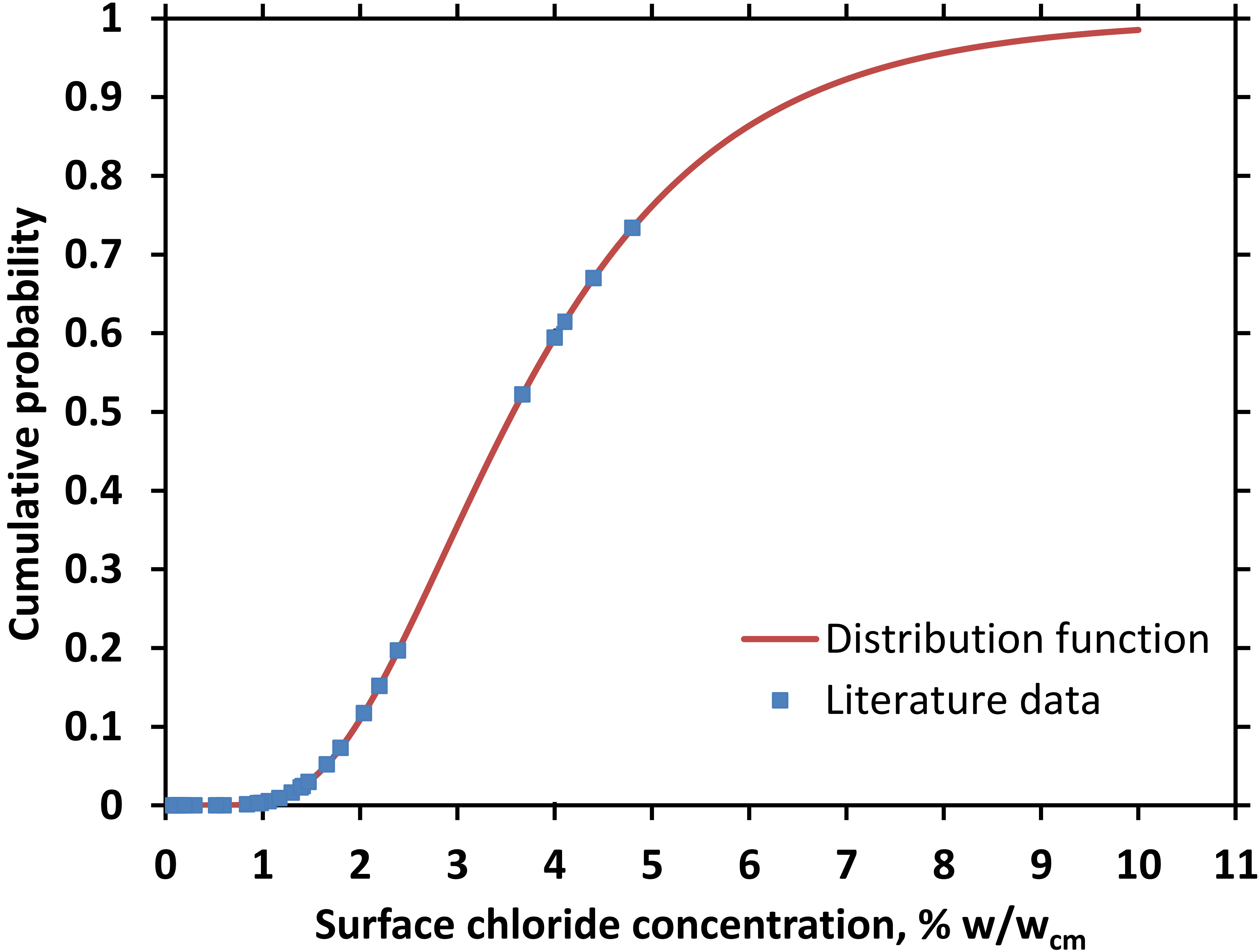
- Selecting input parameters for modeling chloride-induced corrosion

- Corrosion is a complicated process



Service Life Design Challenges

- Input parameters for full probabilistic approach:
  - Temperature
  - Cover thickness
  - Chloride threshold value
  - Chloride migration coefficient
  - Ageing factor, based on cementing materials type
  - Chloride surface concentration



Cumulative probability
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
1
2
3
4
5
6
7
8
9
10
11
Surface chloride concentration, % w/w$_{cm}$
Distribution function
Literature data

Service Life Design Challenges

- For deterioration mechanisms with no models:
  - Need to rely on past experience
  - Control and prevention measures are not correlated to a specific length of service life
  - Lack of reliable tests that correlate with field performance over time

Service Life Design Challenges

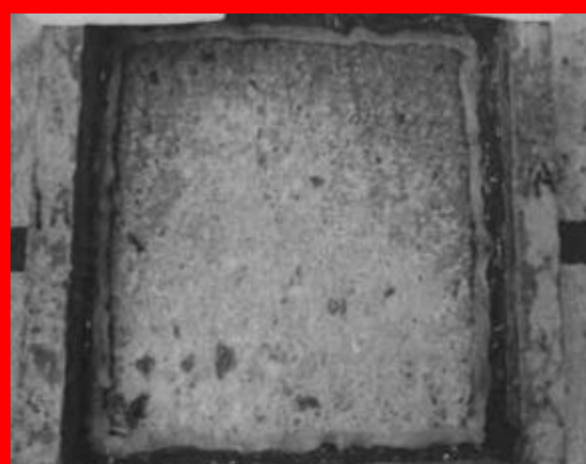
- Scaling resistance of concrete surfaces exposed to deicing chemicals
  - ASTM C672
  - Test duration: 50 days after a 28 day cure
  - Test known to be very severe
  - Test result is a visual rating (subjective?)

Rating	Condition of surface
0	No scaling
1	Very slight scaling (3mm depth, max, no coarse agg. visible)
2	Slight to moderate scaling
3	Moderate scaling (some coarse aggregate visible)
4	Moderate to severe scaling
5	Severe scaling (coarse aggregate visible over entire surface)

Service Life Design Challenges

Mix A
Passed

Mix B
Fail



Service Life Design Challenges

- How could we improve this situation?
  - Add a quantitative requirement to the ASTM C672:
    - ex: maximum of 0.5 kg/m^2 of mass loss
  - Use an alternative test
    - measurable requirement
    - better correlation to in-situ performance
    - CSA A23.2-22CCSA

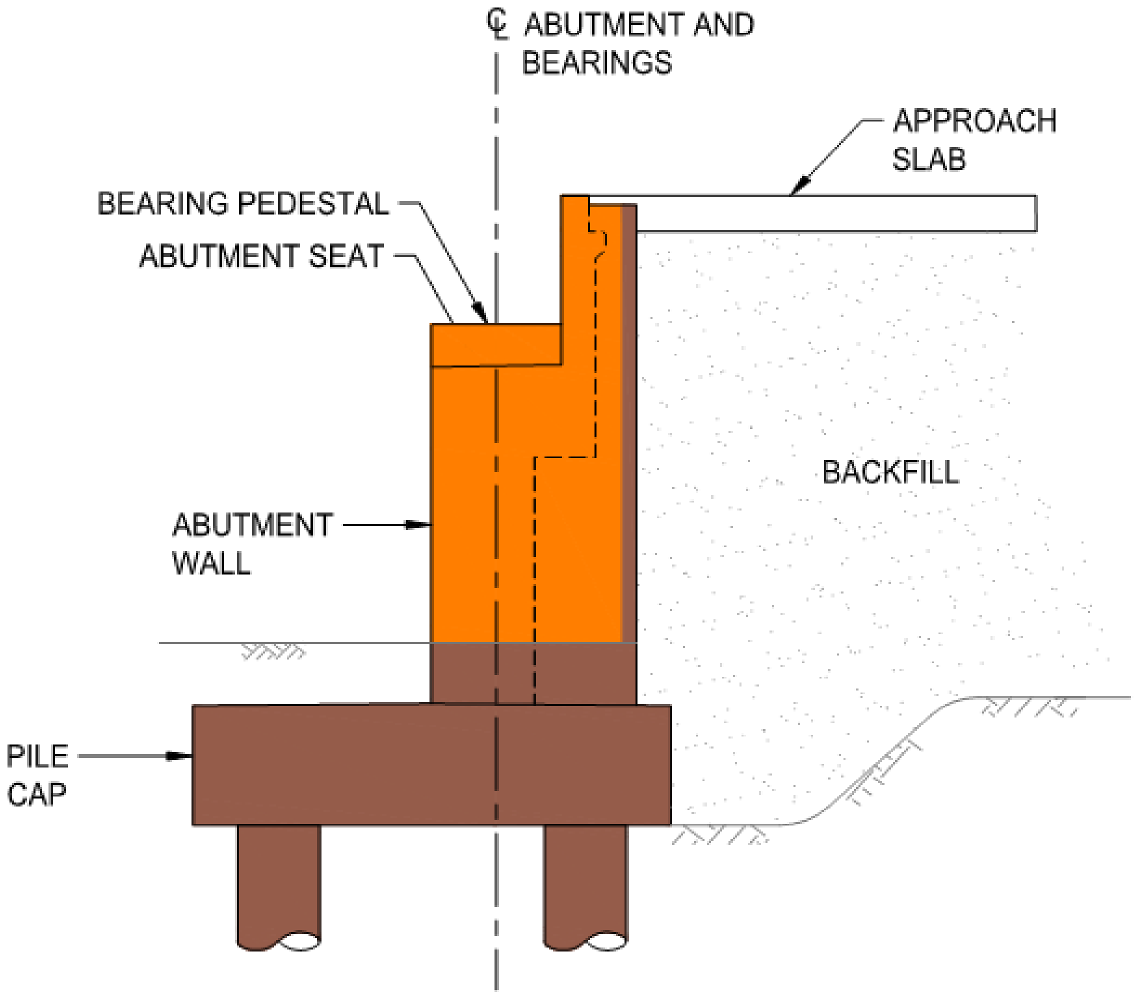
Service Life Design for Concrete Structures

- Service Life Design Challenges
- Design Tools
- Construction Documentation

Design Tools

- SHRP2 R19A: Design tools for fully probabilistic model for chloride-induced corrosion
  - Excel spreadsheet
  - Design charts

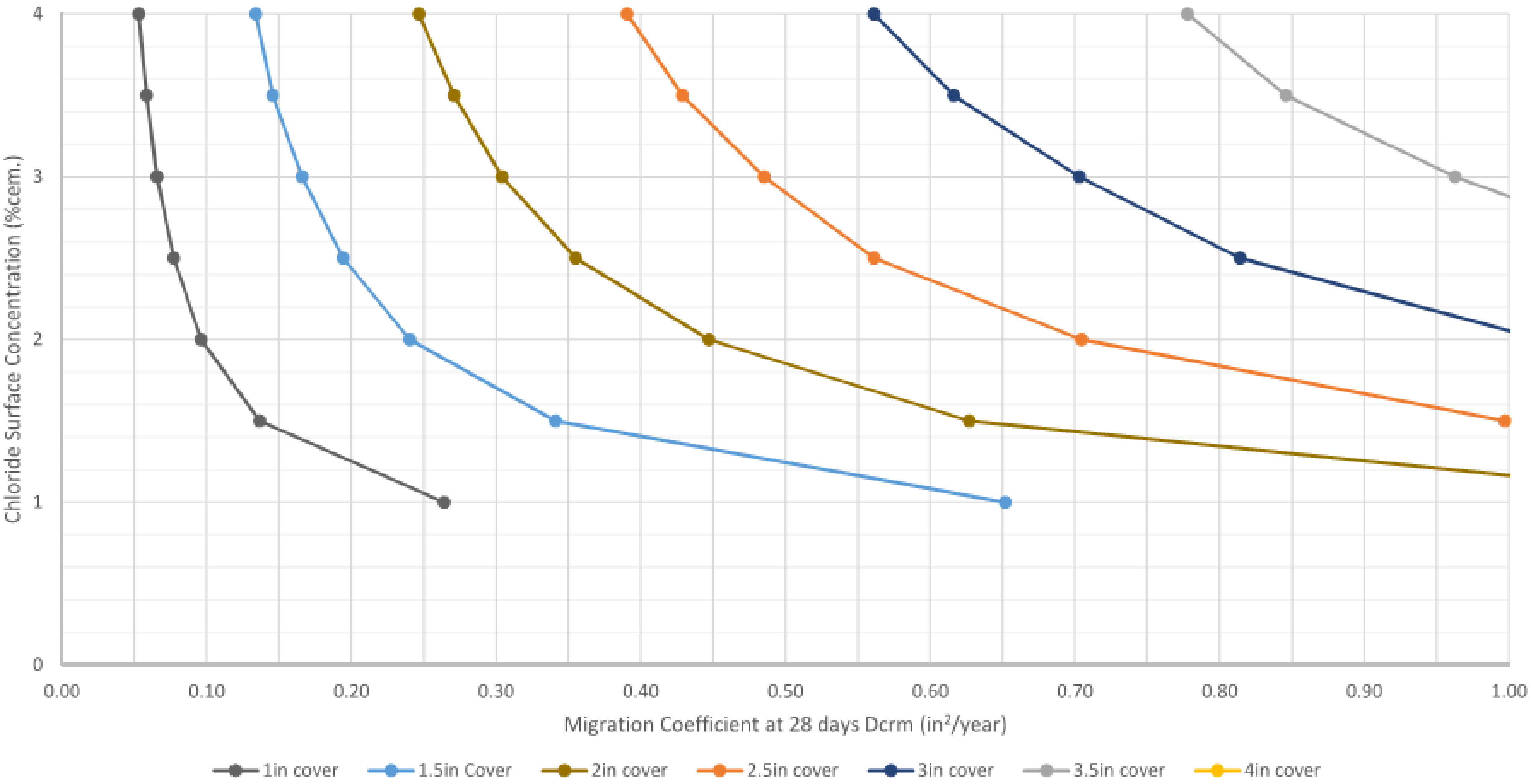
Design Tools



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: Buried/Submerged
Concrete Type: OPC + >20%FA



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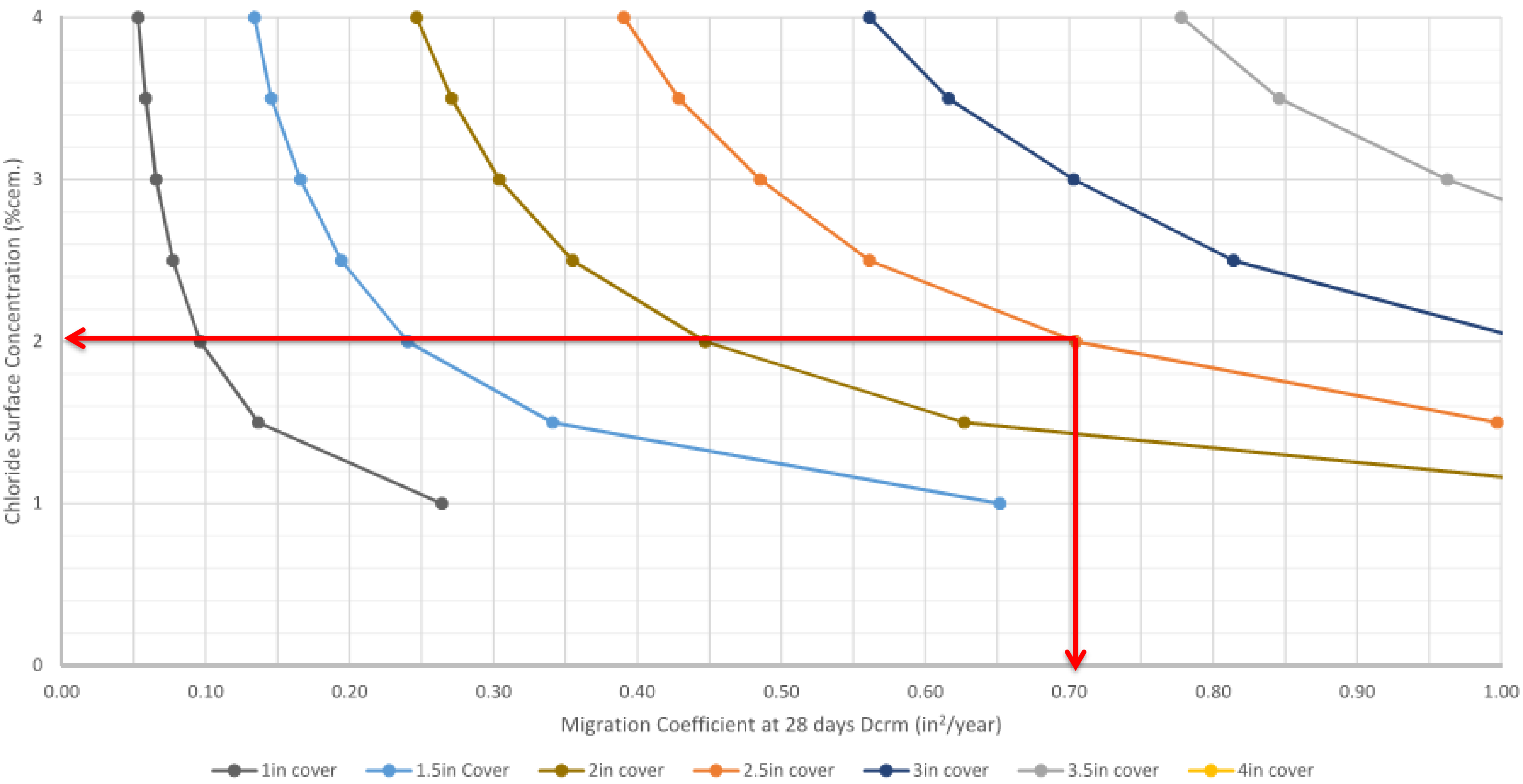


Design Tools

Trial	$D_{RCM,0}$ (mm²/yr) rand 0-1	RESULT
1	0.202	233.97
2	0.538	286.23
3	0.907	355.22
4	0.372	262.51
5	0.111	212.23
6	0.004	131.77
7	0.152	223.01
8	0.312	253.25
9	0.790	326.21
10	0.514	282.85
11	0.371	262.37
12	0.499	280.75
13	0.706	311.24
14	0.843	337.45
15	0.646	301.87

fib Bulletin 34, Section B2 - Full probabilistic design method for chloride induced corrosion - uncracked concrete

Fick's 2nd Law

$$C_{crit} = C(x = a, t) = C_o + (C_{s,\Delta x} - C_o)\left[1 - \operatorname{erf}\left(\frac{a - \Delta x}{2\sqrt{D_{app,C} \cdot t}}\right)\right]$$ Equation (B2.1-1)

$$D_{app,C} = k_e D_{RCM,0} k_t A(t)$$ Equation (B2.1-2)

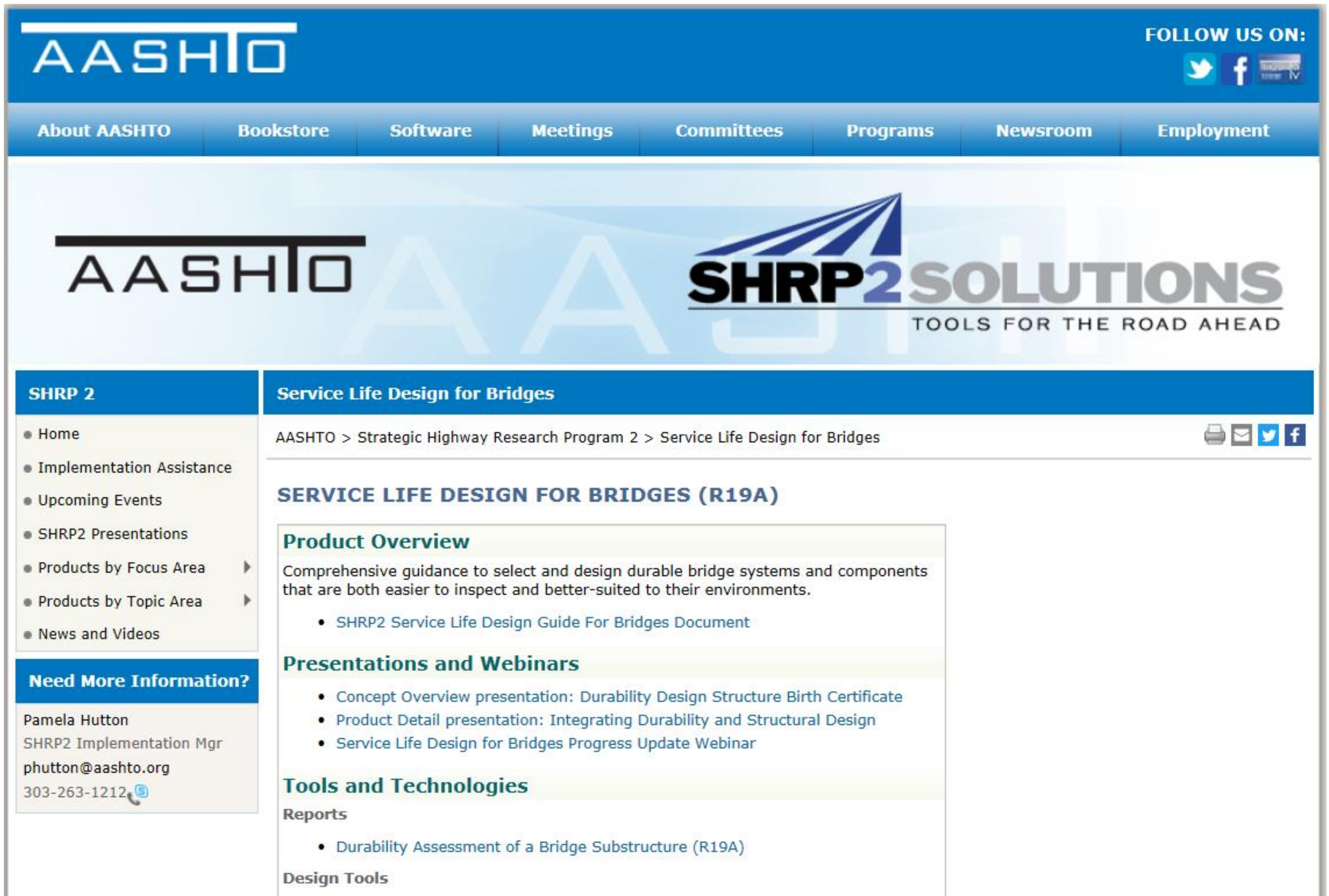
$$k_e = \exp\left(b_e\left(\frac{1}{T_{ref}} + \frac{1}{T_{real}}\right)\right)$$ Equation (B2.1-3)

$$A(t) = \left(\frac{t_o}{t}\right)^{\alpha}$$ Equation (B2.1-4)

Parameter	Description	Units	Distribution Function	Normal Distr Coefficients: Mean, μ	Std Dev, σ	Coeff of Variation, σ/μ
$D_{RCM,0}$	Chloride Migration Coefficient (from Nordtest NT Build 492 results)	m²/sec	Normal	8.90E-12	1.78E-12	0.20
		mm²/yr		280.9	56.2	
		in²/yr		0.435	0.087	

Design Tools

- SHRP2 Website:
- http://shrp2.transportation.org/Pages/ServiceLifeDesignforBridges.aspx



Service Life Design for Concrete Structures

- Service Life Design Challenges
- Design Tools
- Construction Documentation

Construction Documentation

Discussion Topics

- Introduction
- Design Issues
  - Environmental Loading
  - Material Properties / Component Dimensions
- Construction Monitoring & Testing Issues
  - Concrete Tests for Durability
  - Concrete Cover Dimension Verification
- In-Service Issues
  - Verification of Actual Performance vs. Planned Performance
- Birth Certificate Documentation
- Summary

Introduction

- Owners are specifying Service Life Design, particularly for projects using alternative project delivery
  - Design-Build (DB)
  - Design-Build-Operate-Maintain (DBOM)
  - Public Private Partnership (P3)
- Service Life Design is not just about design for durability
- It's about management of durability issues throughout the life of the structure
- Designers & Contractors need to be aware of new design, construction, and operations requirements

Through-Life Stages

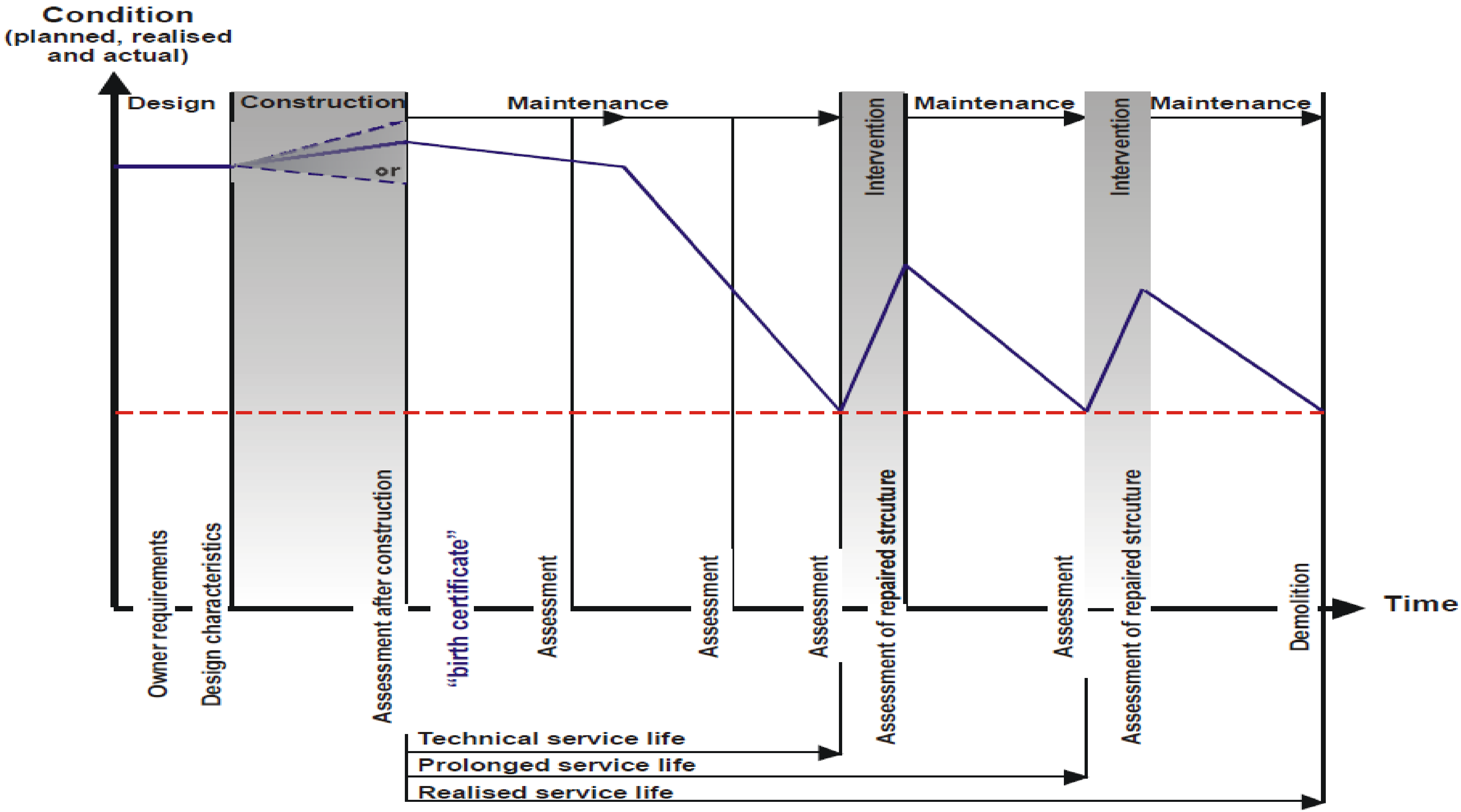


Fig. 2-1: Complete service life from birth to death, adapted from [28]

Example Deterioration Model

- Chloride Ingress – Fick's 2nd Law of Diffusion to 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**
  - 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

New Design Issues

- Environmental exposure of coastal marine bridges
  - Chloride loading (C_s) based on natural salinity of sea water
  - Data collected from existing documentation or perform salinity tests
- Environmental exposure from de-Icing chemicals
  - Chloride loading (C_s) much more difficult to assess
  - Best source of data is from test coring existing structures in similar environment

New Design Issues

- Deterioration other than from chlorides
- Environmental exposure from Carbonation (CO_2)
  - CO_2 (C_s) concentration from the atmosphere (known)
  - Data collected for CO_2 concentration from emission sources in industrial areas

Determining Chloride Loading

Designation: C1543 – 10

Standard Test Method for Determining the Penetration of Chloride Ion into Concrete by Ponding[1]

- Known as the Salt Ponding Test
- Used to develop chloride profiles in test specimens or existing concrete taken from cores
- Results include Surface Chloride Concentration (C_s) and Concrete Apparent Coefficient of Diffusion ($D_{app,C}$) at age of core

Determining Chloride Loading

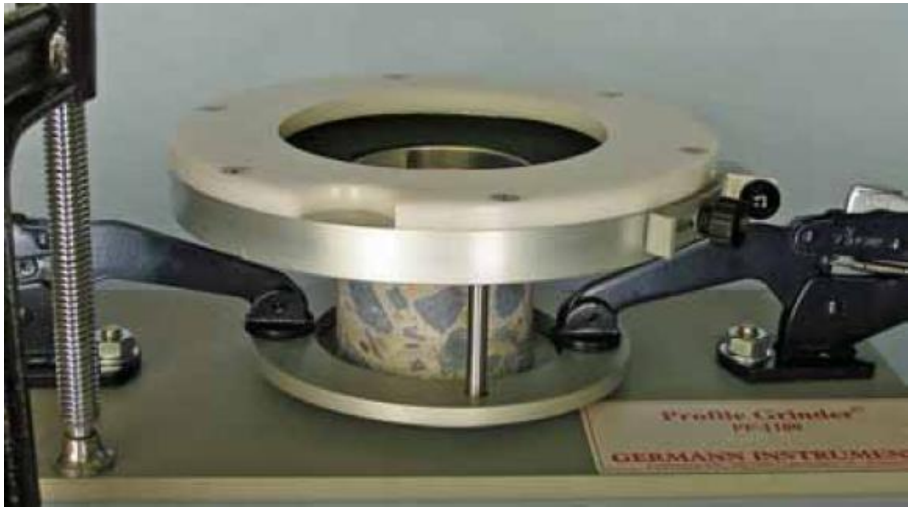
nordtest method

NT BUILD 443
Approved 1995–11

Concrete Hardened: Accelerated Chloride Penetration

- Known as the Bulk DiffusionTest
- Used to develop chloride profiles in test specimens or existing concrete taken from cores
- Results include Surface Chloride Concentration (C_s) and Concrete Apparent Coefficient of Diffusion ($D_{app,C}$) at age of core

Chloride Profile Grinding



Source: Germann Instruments

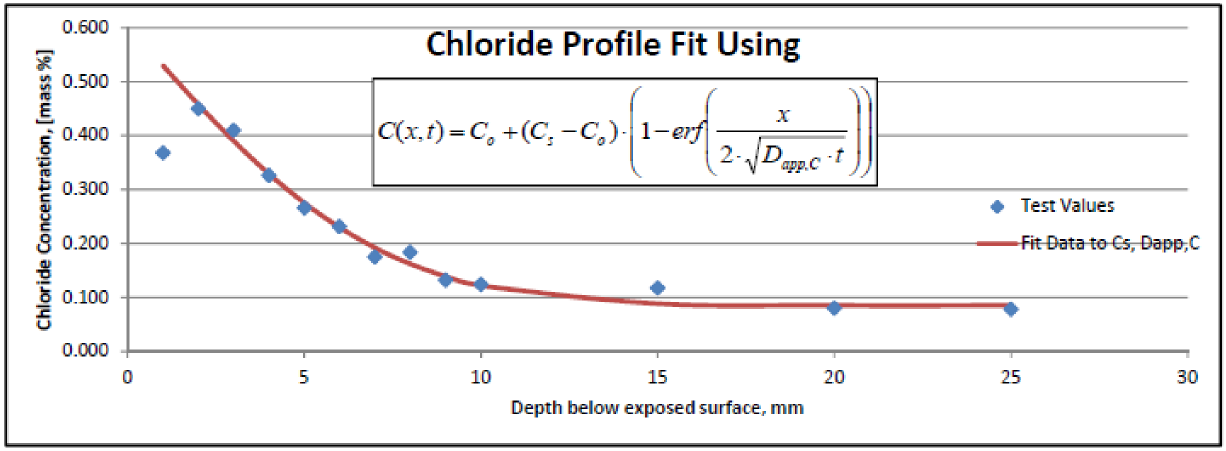
Determining Chloride Loading

Designation: C 1556 – 04

Standard Test Method for Determining the Apparent Chloride Diffusion Coefficient of Cementitious Mixtures by Bulk Diffusion[1]

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	$\sum (C_m\text{-}C_s)^2$
$(C_m - C_s)^2$	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



New Design/Construction Issues

- **Resistance to Chloride Ingress by Diffusion** is a function of the:
  - Concrete Chloride Migration Coefficient ($D_{RCM,0}$)
  - Cover Depth (a)

- **Resistance to Carbonation is a function** of the:
  - Inverse Carbonation Resistance ($R_{ACC,0}^{-1}$)
  - Cover Depth

New Design/Construction Issues

- Resistance to both Chloride Ingress and Carbonation 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)

Chloride Migration Test
NT Build 492

nordtest method

NT BUILD 492

Approved 1999–11

- **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 – Test Setup

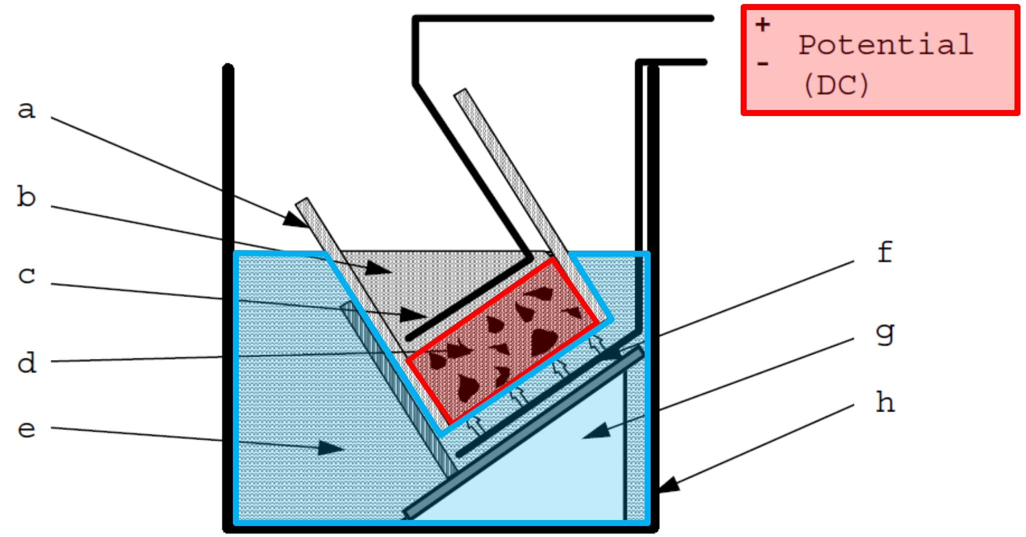
NT Build 492

- 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

NORDTEST METHOD

NT BUILD 492 5

APPENDIX 1



a. Rubber sleeve
b. Anolyte
c. Anode
d. Specimen
e. Catholyte
f. Cathode
g. Plastic support
h. Plastic box

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, $D_{RCM,0}$

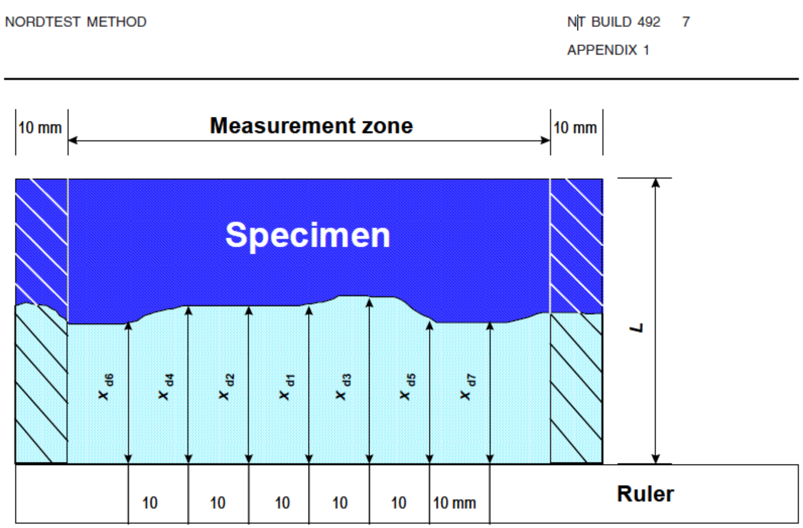


Fig. 5. Illustration of measurement for chloride penetration depths.

NT Build 492 Test Summary

- Important to perform test at 28 days
- Test takes 24 hours
- One test includes 3 specimens
- Cost of a single test is approximately $1,000

Other Rapid Chloride Tests

- **The RCM Test (NT Build 492)** is not to be confused with:
  - **ASTM C1202/AASHTO T 277** – Standard Test Method for Electrical Indication of Concrete's Ability to Resist Chloride Ion Penetration
  - **AASHTO TP-64** – Predicting Chloride Penetration of Hydraulic Cement Concrete by the Rapid Migration Procedure

ASTM C1202

- Known as the Rapid Chloride Permeability Test (RCPT)
- Measures electrical charge (Coulombs) passed through concrete specimen
- Specimens are not split/measured for chloride depth

ASTM C1202 Results

- Qualitative not Quantitative

Table: Chloride Permeability Based on Charge Passed

Charge Passed (Coulombs)	Chloride Permeability	Typical of
>4,000	High	High W/C ratio (>0.60) conventional PCC
2,000–4,000	Moderate	Moderate W/C ratio (0.40–0.50) conventional PCC
1,000–2,000	Low	Low W/C ratio (<0.40) conventional PCC
100–1,000	Very Low	Latex-modified concrete or internally-sealed concrete
<100	Negligible	Polymer-impregnated concrete, Polymer concrete

Source: Grace Technical Bulletin TB-0100

AASHTO TP-64

- Test procedures appear similar to NT Build 492, but there are subtle differences
- Uses different
  - Duration of test (18 hours)
  - Preconditioning
  - Temperature
  - Voltage
- *fib* Bulletin 34 calibrated to NT Build 492 only

Carbonation Tests

- Accelerated Carbonation Test (ACC) – DARTS – Durable And Reliable Tunnel Structures: Deterioration Modelling, 2004
  - Documented in *fib* Bulletin 34, pages 50-53
  - Specimens cured 28 days in water
  - Placed in carbonation chamber for 28 days and exposed to CO2 concentration of Cs = 2.0 vol.-%
  - Tests performed at 56 days
  - Specimens split, exposed surfaces treated with phenolphthalein and measured for penetration depth
  - Inverse Carbonation Resistance ($R_{ACC,0}^{-1}$) is calculated

Carbonation Test Chamber

Carbonation Tests

- Sample showing carbonated concrete in purple

Concrete Cover Depth

- Lack of U.S. standards for measuring cover depth in hardened concrete
- Service Life goal is for complete mapping
  - Min/Max Depths
  - Used to Calculate Mean & Standard Deviations
- International Standard
  - British Standard 1881-204:1988 – Testing Concrete. Recommendations on the use of electromagnetic covermeters

Covermeters

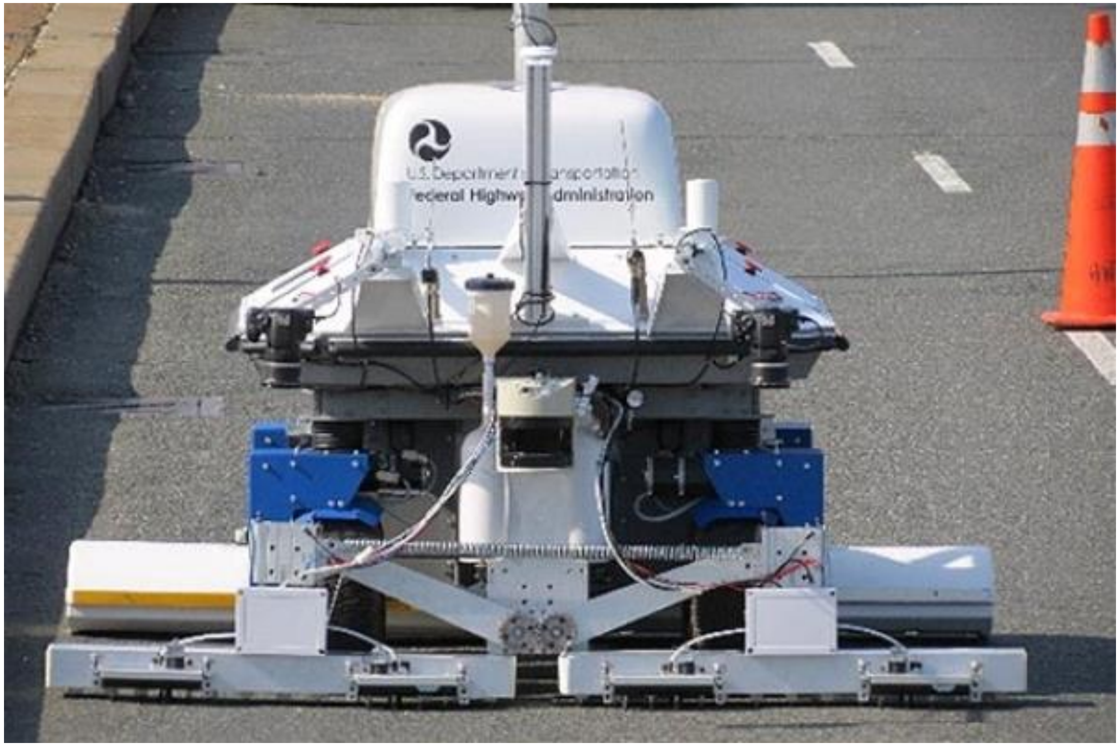
- Sources: Proceq   Elcometer

Concrete Cover Depth

- New Hampshire DOT 2010 Standard Specifications
  - Section 520.3.1.6.3.6 Concrete Cover
    - "Concrete cover over reinforcing steel will be evaluated by the Bureau of Materials and Research.
    - "Concrete cover will be determined with a GSSI SIR2 radar rebar depth measuring unit."

Concrete Cover Depth

- FHWA's Robotic Assisted Bridge Inspection Tool (RABIT) with Ground Penetrating Radar (GPR)



In Service Issues

- Monitoring actual performance vs. design
- Sampling structure for Chloride Ingress
  - Chloride Profiling to ASTM C1543 & C1556 or NT Build 443
  - NT Build 492 not used (Test only meant for testing new concrete)
- Sampling structure for carbonation
  - Can use same testing procedure as for Accelerated Carbonation Test (ACC), but eliminating the carbonation chamber exposure

In Service Issues

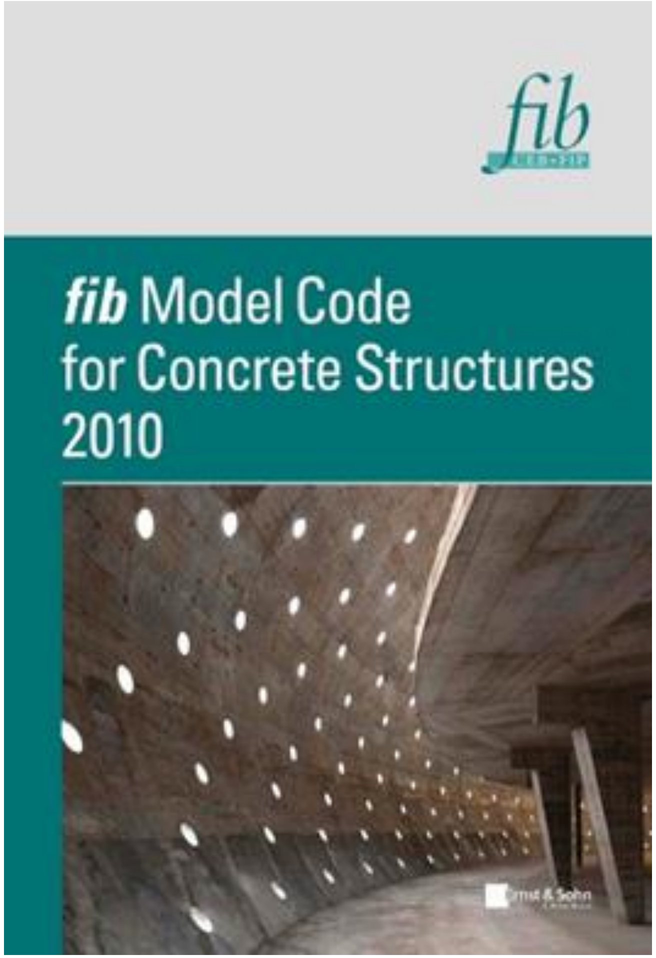
- Monitoring tests are often destructive (taking cores)
- Alternative to coring is to cast additional test specimens and store on project site in same environmental exposure
- Frequency of testing – suggest 10-20 year intervals

Documentation

- Design
  - Tests to be performed
  - Material durability & geometric design properties
- As-Built Construction
  - Achieved material durability & geometric properties
- In-Service
  - Measured performance

Birth Certificate Definition

- A document, report or technical file (depending on the size and complexity of the structure concerned) containing engineering information formally defining the form and the condition of the structure after construction.



Birth Certificate Purpose

- Documents parameters important to the durability & service life of the structure
- Provides means of comparing actual behavior/performance vs. design
- Facilitates ongoing (through-life) evaluation of the service life

Birth Certificate Purpose

- Outlines an operational schedule for:
  - Routine maintenance
  - Regular inspections
  - Durability performance monitoring
  - Replacement activities

- Similar to an automobile Owner's Manual

- Identifies potential demolition schemes

Birth Certificate Process

- Initially developed during design phase
  - Records the intended design
- Updated at completion of construction
  - As-Built material properties and test results
    - Concrete Classes/Mix Designs
    - Steel Reinforcement/Prestressing Grades
    - Chloride Migration Coefficient
    - Cover Dimensions
- Updated after maintenance, inspection & long term performance monitoring

Birth Certificate Table of Contents

- Asset identification & description
- Design & construction parameters
- Environmental exposure conditions
- Deterioration mechanisms & models
- Testing requirements
- Structure & replaceable element data
- In-service conservation plan
- Dismantling plan

BC Asset Identification

Identification of Asset

Owner	Public Works and Government Services Canada
Structure Classification	Bridge
Structure Name	Confederation Bridge (or Fixed Link)
Inventory ID #	XXX
Structure Description	11.6 m wide by 12.9 km long precast, post-tensioned segmental concrete structure with West and East Approaches and a Main Bridge Unit. Typical spans are 93 m for the Approaches and 250 m for the Main Bridge Unit.
Geographic Location	Carries NB 16/PEI 1 (Trans-Canada Highway) over Northumberland Straits between Borden–Carleton, PEI and Cape Jourimain, NB
Date Placed in Service	31-May-1997

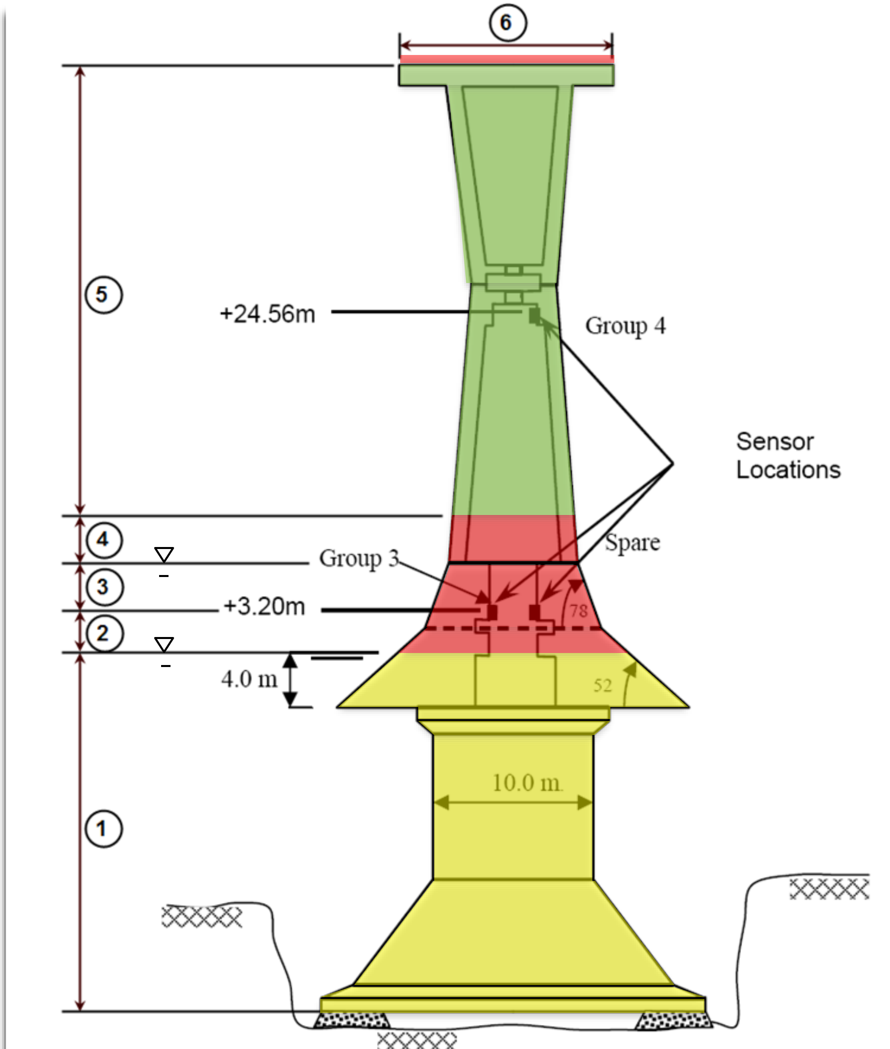
BC Design/Construction Parameters

Design Parameters		
Consequence Class (CC) of Failure or Malfunction	CC3 - High consequence for loss of human life, or economic, social or environmental consequences very great	(Table A2-1 of MC-SLD)
Design Supervision Level (DSL)	DSL3 - Extended Supervision (Third party checking: Checking performed by an organisation different to that which has performed the design)	(Table A4-1 of MC-SLD)
Service Life Design Strategy /	Strategy B - Providing resistance to the deterioration mechanisms active in the service environment	
Methodology	Method B4. A reliability-based methodology (Full probabilistic design)	
Primary Protection Strategies	Material's own resistance	
	Basic resistance using a single protection strategy	
Durability Limit State (DLS)	DLS1 - Depassivation of reinforcing	
Target Service Life	100 years	

BC Environmental Parameters

Environmental Parameters		
Macro-Environment	Coastal Marine	
Macro-Climate	Cold	
Mean High Temperature	28 °C	CHBDC CAN/CSA S6-88
Mean Low Temperature	-28 °C	"
Mean Relative Humidity	80%	"
Deterioration Mechanisms	Chloride Ingress	
	Freeze-Thaw	
	Ice Abrasion	
Exposure Classes	XS: Corrosion of reinforcement induced by chlorides from sea water	(EN 206-1)
	XD: Corrosion of reinforcement induced by chlorides other than from sea water	
	XF: Freeze - thaw attack upon concrete	

BC Environmental Parameters



Component	Figure ID	Exposure Class (EN206)
Substructure		
Submerged Zone	1	XS2
Tidal Zone	2	XS3
Splash Zone	3	XS3
Spray Zone	4	XS3
Atmospheric Zone	5	XS1
Superstructure		
Atmospheric Zone	5	XS1
Roadway & Traffic Barrier	6	XD3

BC Deterioration Models

BIRTH CERTIFICATE DOCUMENT
Deterioration Mechanisms & Models

Inventory ID	X10625
Structure Name	Hwy. 5 Overcrossing Hwy. 12
Deterioration Mechanism	Chloride ingress
Deterioration Model	Fick's 2nd Law
Source	fib Bulletin 34 - Model Code for Service Life Design

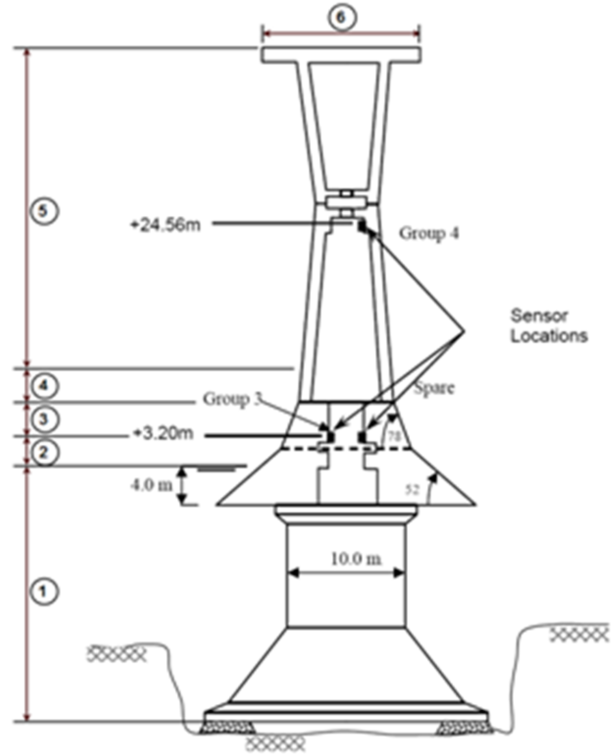
$$C_{crit} = C(x = cov, t) = C_o + (C_{s,\Delta x} - C_o) \cdot \left(1 - erf\left(\frac{cov - \Delta x}{2 \cdot \sqrt{D_{app,C} \cdot t}}\right)\right)$$

Function Variables	Description	Units
t	Time	[yr]
x	Depth with corresponding content of chlorides C(x,t)	[mm]
C_{crit}	Critical chloride content	[wt.-%/c]
C_o	Initial chloride content of the concrete	[wt.-%/c]
$C_{s,\Delta x}$	Chloride concentration at surface or a depth Δx	[wt.-%/c]
Δx	Depth of the convection zone (concrete layer, up to which the process of chloride penetration differs from Fick's 2nd law of diffusion)	[mm]
cov	Concrete cover	[mm]
$D_{app,C}$	Apparent coefficient of chloride diffusion through concrete	[mm^2/yr]

BC Structure Component Data

Structure Component Monitoring

Inventory ID	XXX
Structure Name	Confederation Bridge (or Fixed Lin
Component Name	Pier
Location	# 20
Deterioration Model	Fick's 2nd Law



Sub-Component	Figure ID	Status	Exposure		Concrete			Reinforcing Steel		C_{crit} [kg/m³]	Remaining Service Life [yrs]
			Class	$C_{s,\Delta x}$ [kg/m³]	Class/ Grade [MPa]	C_i [kg/m³]	$D_{app,C}$ [mm²/yr]	Type/ Grade [MPa]	cov [mm]		
Ice Shield, splash zone	3	Design	XS3	17.7	HPC/55	0	15.1	Plain/400	100	1.59	115
		As-Built	XS3	17.7	HPC/55	0.085	15.324	Plain/400	95	1.59	100
		In-Service									
		#1 (10 yr)	XS3	17.04	HPC/55	0.05	15.7	Plain/400	95	1.59	99

Inspection & Monitoring Plan

- Initial (End of Construction)
  - Birth Certificate documentation
- Routine inspections (current ~ 2 yrs)
- Special inspections (Scour, FCM)
- Damage (EQ, Flood, Fire, Collision)
- In-depth monitoring (~ 10-20 yr)
  - Chloride penetration tests
  - Depth of Carbonation tests

BC Maintenance Schedule

Structure Name	Confederation Bridge (or Fixed Link)		**Initials**		
Inventory ID #	XXX		**Actual Date**		
Geographic Location	Carries NB 16/PEI 1 (Trans-Canada Highway) over Northumberland Straits between Borden–Carleton, PEI and Cape Jourimain, NB		**Sched. Date**	31-Aug-97	3-Mar-98
Date Placed in Service	31-May-97		**Yr**	1	
Routine Maintenance Action	**Location/Component**	**Frequency**			
Clean / Clear					
Sweep roadway deck surface		6 months			
Clear bridge deck drains		6 months			
Flush drainage piping		6 months			
Pressure wash		1 year			
Clean abutment seats		1 year			

Service Life Design for Steel Structures

SLD: Steel Structures

- Typical elements that are considered:
  - Coatings for structural steel
  - Bearings
  - Expansion joints

- No models, no documents similar to what is produced for concrete structures

- A system that will provide the required service life is designed
  - System requires maintenance
  - Rely on information from suppliers and past experience from Owners

Resources

- *Expected Service Life and Cost Considerations for Maintenance and New Construction Protective Coating Work*, Helsel, Jayson L. et al, NACE Corrosion 2008 Conference & Expo Paper #08279, 2008.
- ISO 12944-2 Paints and varnishes - Corrosion protection of steel structures by protective paint systems, Part 2: Classification of environments.
- ISO 9223: 2012, Corrosion of metals and alloys. Corrosivity of atmospheres. Classification, determination and estimation.
- ASTM G101-04. *Standard guide for estimating the atmospheric corrosion resistance of low-alloy steel*, American Society for Testing and Materials, 2004.
- The American Galvanizers Association, http://www.galvanizeit.org/hot-dip-galvanizing/how-long-does-hdg-last/in-the-atmosphere/time-to-first-maintenance

Service Life Design Specifications

What Is the Objective?

- Longer time before obsolescence and/or major rehabilitation:
  - Reduced maintenance and rehabilitation costs
  - Reduced disruption to users
  - Less reliance on outside contractors to do the work
  - No surprises re maintenance and rehab requirements

- Lower full-life costs… with reasonable initial cost premium

- Design, construction and quality management that provides confidence that the objectives will be achieved

- Scope: concrete, structural steel, cables, M&E systems, pavements and wearing courses

What Do We Need for Specifications?

- Definition for service life
- Design methodology
- A limit state
- Avoid vague statements like:

  - *"Bridges are to be designed with consideration given to the Department's 100-year-bridge life initiative*."

  - *"The service life of the structure shall be 100 years."*

Definition of Service Life

- CSA A23.1-14 and S6: Service life — the time during which the structure performs its design function without unforeseen maintenance or repair.
- ACI 365: Service life (…) is the period of time after (…) placement during which all the properties exceed the minimum acceptable values when routinely maintained.
- AASHTO LRFD: The period of time that the bridge is expected to be in operation.
- *fib* Bulletin 34 - Model Code for Service Life Design: Design Service Life – assumed period for which a structure or a part of it is to be used for its intended purpose.

Design methodology

- fib Bulletin 34 Model Code for Service Life Design
- fib Model Code for Concrete Structures 2010
- ISO 16204:2012 Service Life Design of Concrete Structures

Limit State

- Concrete components must resist chloride ingress such that corrosion is not initiated within the service life based on a target confidence level of 90%.

- Specific service lives for different components:
  - Non-replaceable components
  - Replaceable components:
    - Bearings
    - Expansion joints
    - Concrete barriers
    - Coatings for structural steel (paint system)

Specifications

- Service life is the actual period of time during which a structure performs its design function without unforeseen costs for maintenance and repair.
- Non-replaceable components (state which ones) shall be designed for a 100 year service life.
- The service life of concrete components shall be in accordance with *Bulletin 34, Model Code for Service Life Design,* written by the International Federation for Structural Concrete (fib), February 2006.
- Concrete components must resist chloride ingress such that corrosion is not initiated within the service life based on a target confidence level of 90%.

Specifications

- Testing during construction can be specified:
  - Monitoring the concrete durability properties
    - Rapid chloride migration NTBuild 492
    - Acid soluble chloride content ASTM C1152
    - Plastic air content
    - Hardened air content
    - Aggregates properties (AAR)
  - Monitoring as-built concrete covers

Questions?

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Additional Resources:

AASHTO SHRP2 R19A Website:
http://shrp2.transportation.org/Pages/ServiceLifeDesignforBridges.aspx

FHWA GoSHRP2 Website:
www.fhwa.dot.gov/GoSHRP2/