Service Life Design for Alternative Project Delivery

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ASBI ANNUAL CONVENTION

NOVEMBER 8-9, 2016

LONG BEACH, CA

Discussion Topics

Introduction

Service Life Design Refresher

Goals of RFP Specifications

RFP Specifications from Recent APD Projects

Suggested RFP Content

Summary

Introduction

Goal of Service Life Design is more durable, long lasting bridges

Industry initiatives promoting implementation of Service Life Design

- FHWA Highways for Life – Emphasis on 100 year life
- SHRP2 R19A – Service Life Design of Bridges
- NCHRP 12-108 – Guide Specification for Service Life Design of Highway Bridges

Growing tendency for large Design/Build and PPP projects to have Service Life requirements included in RFP

- Gerald Desmond, 2 Ohio River Bridges in Louisville, Tappan Zee, Goethals, Kosciuskzo (all Cable Stayed)

Variation & inconsistencies in specification requirements for RFPs

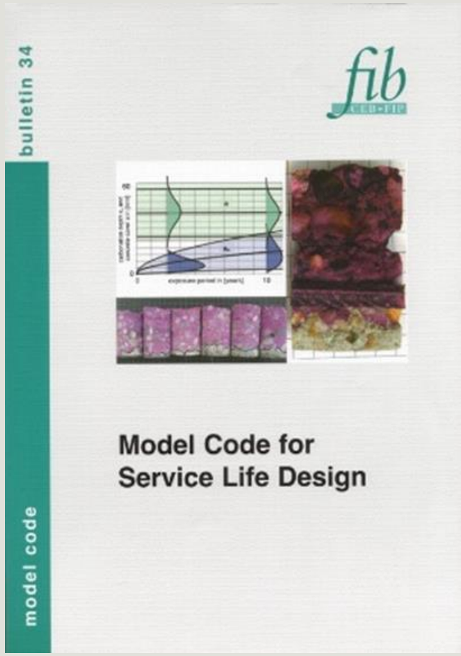
Service Life Design Refresher

Design approach to resist Deterioration caused by Environmental Actions

- Also called Durability Design & often Design for 100-year Service Life
- Uses Scientific or Quantitative Mathematical Procedures
- Documented in *fib* Bulletin 34

Similar to design against Structural Failure caused by External Loads

- What we know as Strength Design



Deterioration Exposure

Reinforcing Steel Corrosion

Cracks, Spalls, Delamination

Chloride/Carbonation Ingress

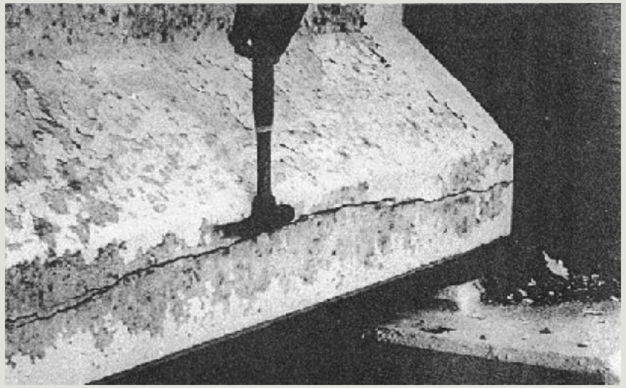
Material Strength Loss
- Alkali-Silica Reaction (ASR)
- Sulfate Attack

Chemically Reactive Aggregate

Sulfates in soil / groundwater

Deterioration | Exposure

Deterioration	Exposure
Cracks from Delayed Ettringite Formation (DEF)	Elevated Curing Temperatures
Scaling	Freeze-Thaw Cycles/Chlorides
Abrasion	Ice Action on Piers/Studded Tires or Chains on Decks



Service Life Design Strategies

Avoidance of deterioration – Strategy A

- Eliminate exposure to contaminants (e.g., non-reactive aggregates)
- Provide materials well beyond required (e.g., stainless steel)

Design Based on Deterioration from the Environment – Strategy B

- Deemed to satisfy provisions – Prescriptive rules of thumb
- Full probabilistic design – Reliability based mathematical models
- Semi-probabilistic or deterministic design – Not calibrated sufficiently for use

Service Life Design Strategies

A single bridge may have multiple deterioration mechanisms

…

Resulting in use of several service life design strategies, e.g.,

- Full Probabilistic – Components subjected to Chlorides
- Avoidance – Use of non-reactive materials to mitigate ASR
- Deemed to Satisfy – Air entrainment to mitigate Freeze-Thaw

Full Probabilistic strategy requires a definition for limit state and accepted level of reliability, e.g.,

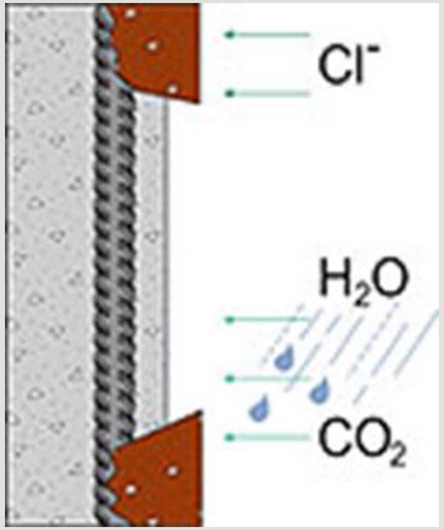
- 10% chance of corrosion initiation in 100 years (or $\beta = 1.3$)

Mathematical Deterioration Models

Models to assess Durability behavior versus Time

Models exist for Concrete Structures:

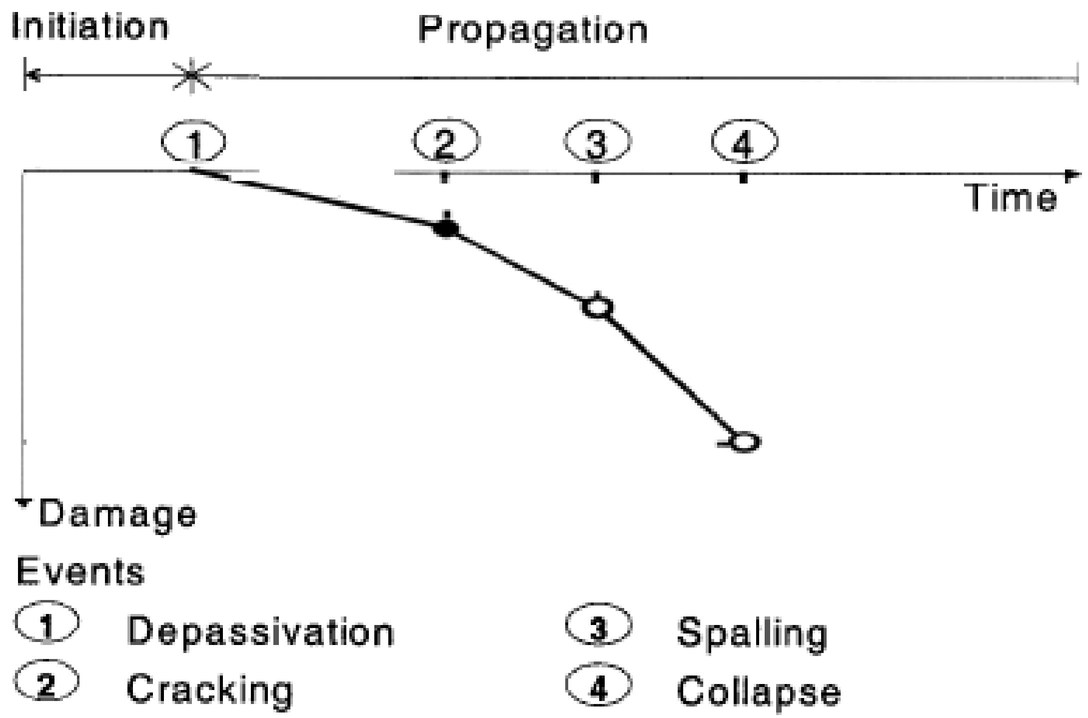
- Chloride Ingress to Initiate Reinforcing Corrosion
- Carbonation Ingress to Initiate Reinforcing Corrosion



Universally accepted models do not exist for:

- Propagation Damage of Corrosion from Chlorides & Carbonation
- ASR, DEF, Freeze-Thaw Scaling, Sulfate Attack, Abrasion, etc.

Deterioration Model / Limit States



Events related to the service life.

Deterioration Model for Chloride Ingress – Fick's 2nd Law of Diffusion

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

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

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

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

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 (*W/C* ratio, SCMs)
- a is the Concrete Cover

Chloride Migration Coefficient Test

nordtest method

NT BUILD 492

Approved 1999–11

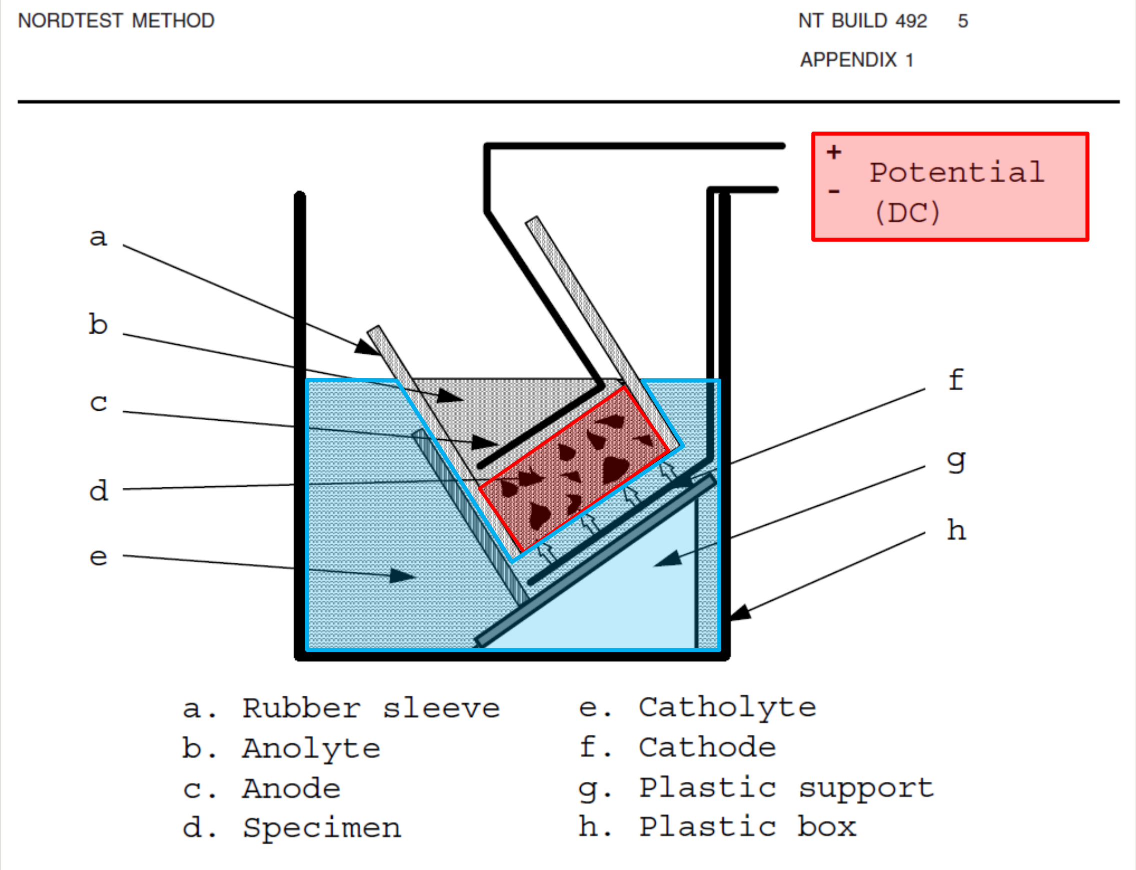
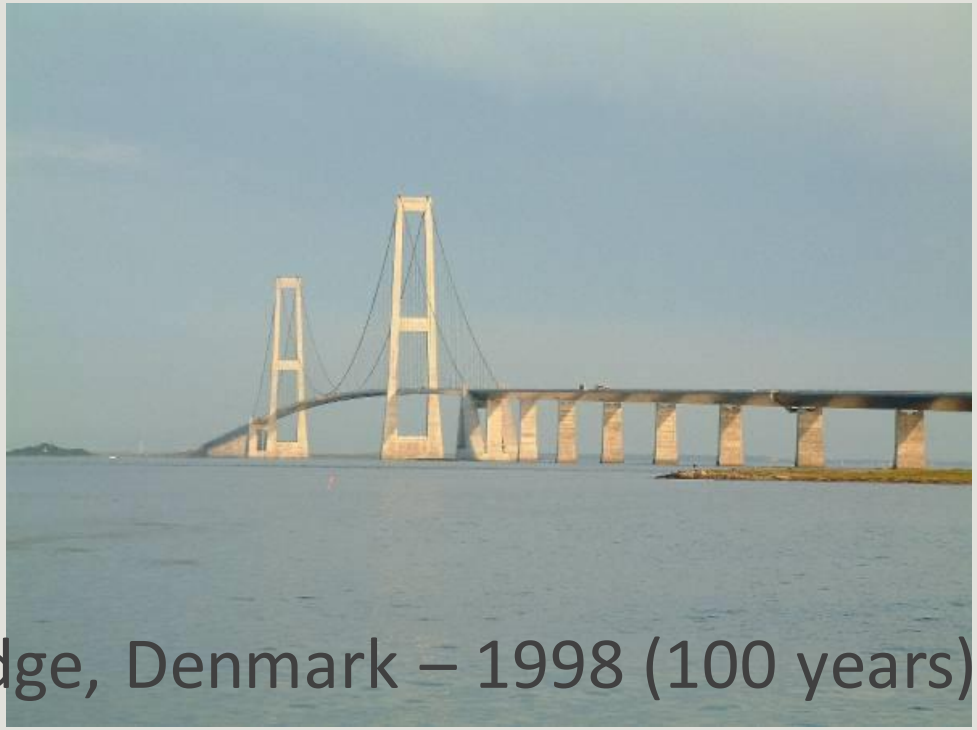


Fig. 1. One arrangement of the migration set-up.

Service Life Designed Structures

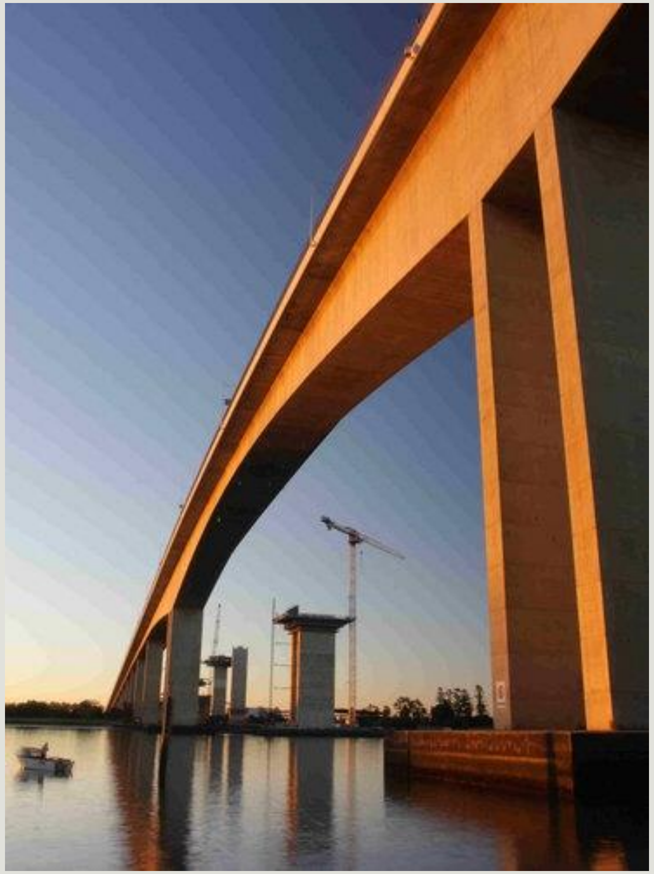
Confederation Bridge, Canada – 1997 (100 years)



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)

Tappan Zee Bridge, NY – 2018 (100 years)

Goals – Service Life Design Specifications

Define the Owner's Expectations

Provide a Common Set of Criteria to Evaluate Proposals

Prescriptive Enough

- Defines the Design Guides/Codes to be followed
- Defines the Key Environmental Loading and Durability Resistance Parameters to be met

Flexible Enough

- Allows the Contractor ability to innovate (by selecting materials & details)

Service Life Design Process – Defines RFP Requirements

Select Design Guide & Strategies (Avoidance, Full Probabilistic, etc.)

Select a Level of Reliability (for Full Probabilistic Strategies)

Identify Environmental Exposure Parameters

Select a Deterioration Limit State by Component
- (Corrosion initiation, cracking, spalling, loss of section)

Select an Expected Service Life Duration
- Main Structural Components (Without major maintenance / rehabilitation)
- Replaceable Components (Joints, bearings, railings, overlays, etc.)

Specify Durability Testing Requirements during Construction

What Owner's Should Be Aware Of

100 Year Service Life Design is a popular phrase branded by the bridge community (FHWA, NCHRP, SHRP2, DOTs)

100 Year Service Life is a lofty goal that is being specified before its process is fully defined in the industry

There is no current AASHTO standard for 100 Year Service Life Design

Specifying a 100 Year Service Life in a Design/Build RFP requires detailed definition

Common Specification Oversights

Asking the Contractor to

- State what Service Life Duration they are providing, or
- State the level of Reliability achieved

Requiring Full-Probabilistic approach with inadequate definition of Limit State or Level of Reliability

Requiring the use of Proprietary Software that may not be based on universally accepted deterioration models or methodologies

Example RFP
- Insufficient Requirements

Project special provisions contained one reference to Service Life

[redacted] Contractor Concrete Mix Design

The Contractor shall provide designs for all concrete mixes used in construction of Bridges No. [redacted]. Design the mixes to produce a 100-year bridge service life.

No specifics for:

- Design Guide/Strategy or Level of Reliability
- Environmental Exposure or Deterioration Limit
- Concrete Durability Tests

Example RFP - Columbia River Crossing

Oregon Department of Transportation

Both options sound similar. A better way to state this is, "... by designing based on deterioration from the environment, or by the avoidance of deterioration method."

b) **Design for Durability** –The Design-Builder shall meet the required design service life either by selecting materials with reduced corrosion potential, by selecting materials and details which resist degradation, or by other means acceptable to the Agency. The Design-Builder shall assume Bridges will be subjected to severe corrosive conditions due to the periodic use of de-cing salts. For reinforced concrete elements the service life shall be determined using the STADIUM (Software for Transport and Degradation in Unsaturated Materials) model.

Example RFP - Columbia River Crossing

Oregon Department of Transportation

This is vague. What other means are acceptable to the Agency? This may be difficult to enforce. Should delete.

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Example RFP - Columbia River Crossing

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This is leaving it up to the D/B team to determine environmental loading. To ensure consistent proposals, Owner should provide level of chloride surface loading based on expected de-icing salt application rate.

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Example RFP - Columbia River Crossing

Oregon Department of Transportation

This forces the use of proprietary software that may be difficult to verify against common published deterioration modeling methods. There are numerous downsides to this methodology including the verification from an independent engineer.

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Example RFP - Columbia River Crossing

1) Non-Replaceable Components – Minimum service life requirements for non-replaceable components are as follows:

Table 141.11-1		
Non-Replaceable Component	**Columbia River Bridges and I-5 Mainline Highway Approaches**	**All Other Bridges**
Shafts or piles	100 years	75 years
Shaft or pile caps	100 years	75 years
Piers (wall-type, pile bents, or columns)	100 years	75 years
Pier caps and cross beams	100 years	75 years
Girders, floor beams, stringers, diaphragms, cross frames	100 years	75 years
Concrete deck	100 years	75 years

What is the Service Life Limit State Definition? Corrosion Initiation, Cracking, Spalling, etc.?

Example RFP - Columbia River Crossing

2) Replaceable Components – Minimum service life requirements for replaceable components are as follows:

Table 141.11-2		
Replaceable Component	**Columbia River Bridges and I-5 Mainline Highway Approaches**	**All Other Bridges**
Drainage systems	40 years	30 years
Concrete bridge rails	40 years	30 years
Steel bridge rail elements	40 years	30 years
Deck wearing surface	25 years	15 years
Bridge bearings	40 years	30 years
Overhead sign structures	40 years	30 years
Internal access ladders, platforms, etc	40 years	30 years
Traveler systems	40 years	30 years

Example RFP - Columbia River Crossing

3) **Service Life and Corrosion Protection Plan** – The Design-Builder shall prepare a detailed Service Life and Corrosion Protection Plan for the Bridges. At a minimum, the plan must include the following:

- A conceptual approach to achieving the required service life for non-replaceable members;
- Identification of each bridge component with the corresponding environmental exposure conditions for each component (e.g., buried, submerged, exposed to atmosphere, exposed to corrosive chemicals);

Splash/spray zones which are not mentioned here, are typically the most aggressive.

Example RFP - Columbia River Crossing

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- A conceptual approach to achieving the required service life for non-replaceable members;

What universally accepted degradation or deterioration mechanisms are allowed?

- Identification of relevant degradation and protective mechanisms for each bridge component. Quantify degradation processes and resistances to these processes with respect to time. Models shall use a probabilistic approach to evaluate the time-related changes in performance depending on the component, environmental conditions, and any proposed protective measures. Models shall be listed in the plan;

Example RFP - Columbia River Crossing

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- A conceptual approach to achieving the required service life for non-replaceable members;

Needs more clarity. Is this full-probabilistic or semi-probabilistic (load factor)?

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Example RFP - Columbia River Crossing

Level of reliability should be specified as a requirement by the Owner. The method stated allows different D/B teams to propose different levels of reliability, which will make it difficult to evaluate the proposals.

- Confirmation of the expected service life of each bridge component based on the proposed material, exposure condition, relevant degradation mechanism, and any proposed protective measures, taking into account the proposed inspection/maintenance schedule. List any corrosion allowances and thresholds used. Include the level of reliability or probability of the predicted Service Life of each element as well as the expected interval of replacement or renewal of the protective measures within the service life duration (e.g., thickness of coats, number of times to recoat paint that protects steel members);

Summary – Expectations of an RFP for Service Life in Design/Build Projects

Owner Provides a Performance Specification, including:

- Design Guide Specification to be used
  - fib Bulletin 34, fib 2010 Model Code, ISO 16204
- Expected Structure Life Duration
  - for Main Structural Components (75, 100, 125, or more years)
  - for Replaceable Components (expansion joints, bearings, overlays, etc.)
- Deterioration Mechanisms to be addressed
  - Chloride Ingress, Carbonation, ASR, DEF, Abrasion, etc.
- Design Strategies to be used for each Deterioration Mechanism
  - Avoidance, Full Probabilistic, Deemed to Satisfy, etc.

Summary – Expectations of an RFP for Service Life Design

- For Full Probabilistic Strategies
  - Acceptable Mathematical Deterioration Models
  - Environmental Exposure Design Criteria (e.g., Surface Chloride Concentration)
  - Definition of End of Service Life and Deterioration Limit State
    - Initiation of Corrosion, cracking, spalling, etc.
  - Level of Reliability
    - % Probability of Achieving No Corrosion at End of Service Life
    - 90% or Reliability Index, $\beta = 1.3$
- For Avoidance and Deemed to Satisfy Strategies
  - List of Acceptable Materials and their Specifications
  - And corresponding Concrete Cover Dimensions

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Purpose and Learning Objectives

Purpose

The Convention provides an educational forum to learn new techniques used in successful projects, lessons learned from development projects, and showcases a case study allowing for discussion of the project.

Learning Objectives

At the end of this presentation you will:

- Be Knowledgeable About Planning, Design, and Segmental Construction
- Learn About Post-Tensioning Durability
- Hear About Inspection and Evaluation

Thank you for your time!

QUESTIONS?

This conclude the educational content of this activity

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