


SHRP2 SOLUTIONS
STRATEGIC HIGHWAY RESEARCH PROGRAM

OREGON DEPARTMENT OF TRANSPORTATION

REGION 4 BRIDGE ENGINEERING
63055 N. Highway 97, Building M
BEND, OR 97701-5765
(541) 388-6225

OR380: Ochoco Creek Bridge Replacement

SHRP2 Service Life Design for Bridges (R19A)

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U.S. Department of Transportation
Federal Highway Administration

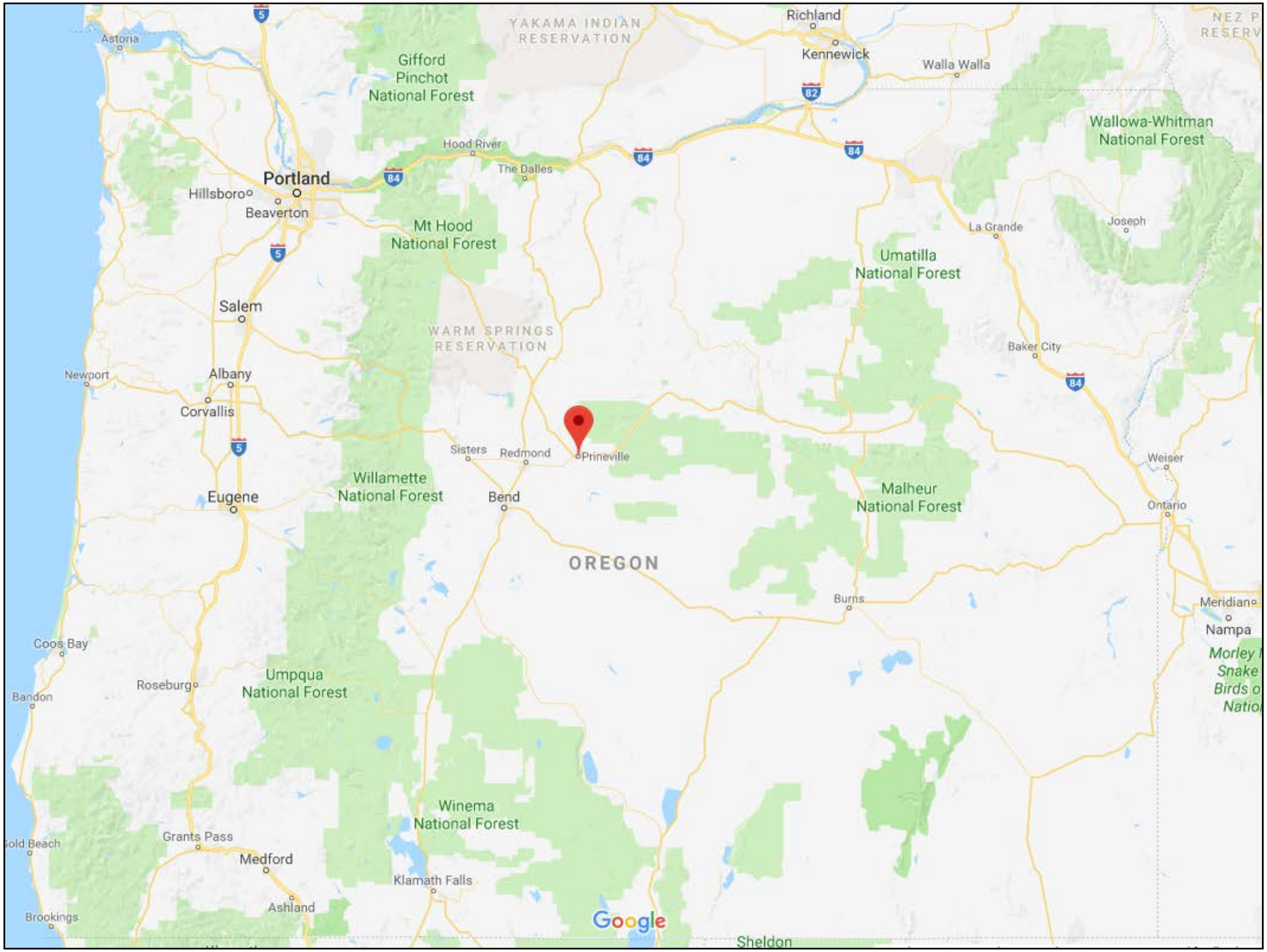
AMERICAN ASSOCIATION OF STATE HIGHWAY AND TRANSPORTATION OFFICIALS
AASHTO

OR380: Ochoco Creek Bridge Replacement

- Project Background

- Service Life Design for Routine Structures
  - Exposure Zones (Load Cases)
  - Environmental Loading (Demand)
  - Detailing (Capacity)
  - Material Properties (Capacity)
  - Capacity vs. Demand

Project Background



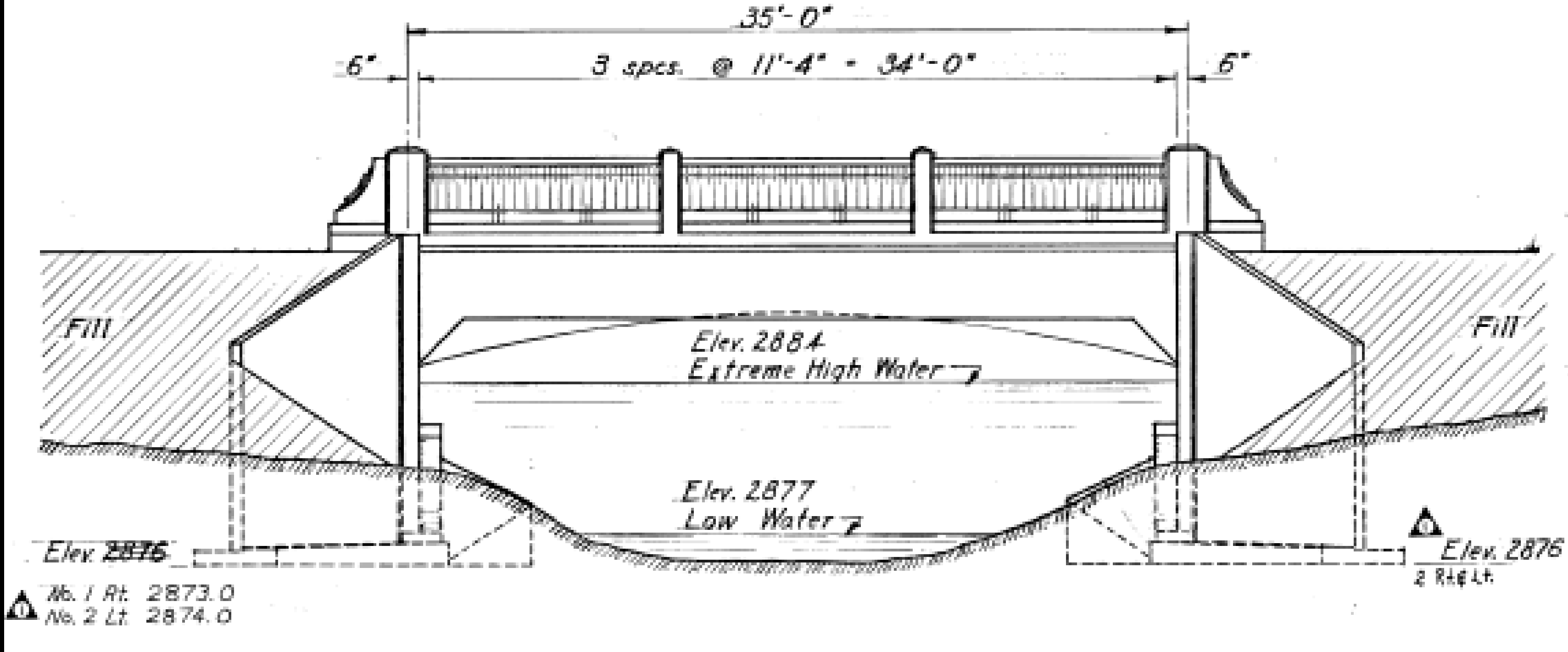
Project Background

- Oregon, Crook County, City of Prineville
- Hospital Development Review
  - Desire to add multi-use path along Combs Flat Road
  - Request to add sidewalk to existing structure 07282

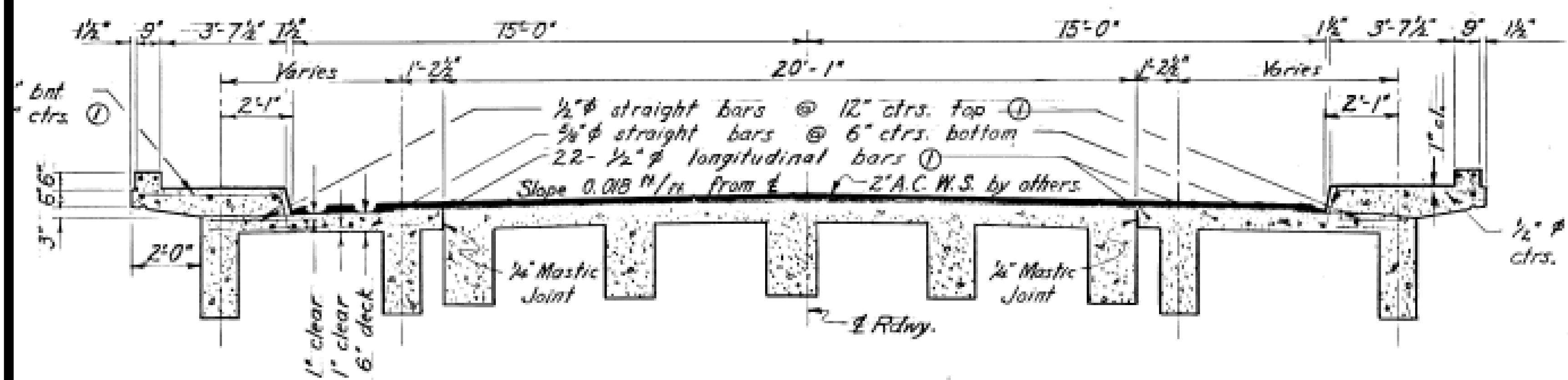
Project Background

Land being developed by Ochoco Lumber Company

Project Background



ELEVATION
Scale : 1" = 5'-0"



DECK SECTION
Scale : ⅝" = 1'-0"

Project Background

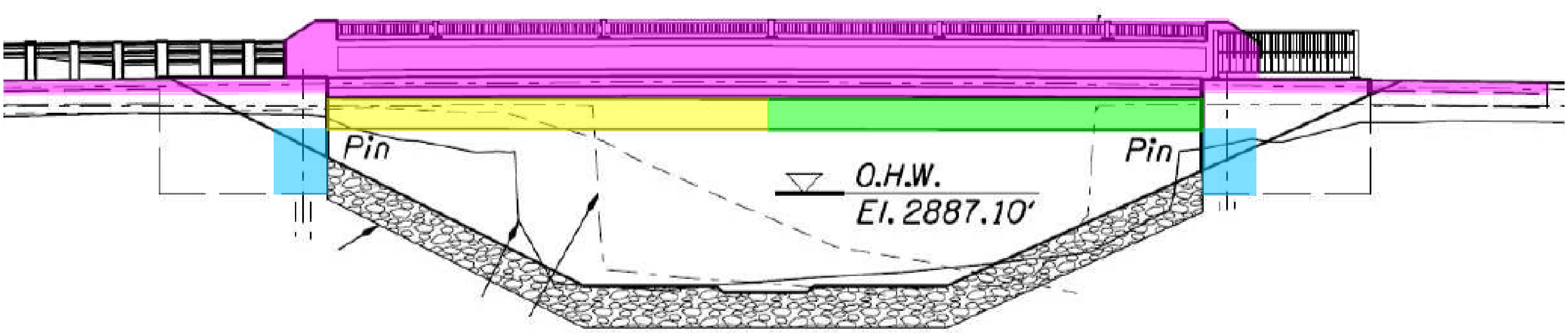
Project Background

Project Background

- Existing Structure
  - No load rating
  - Load rating update
    - Shows insufficient capacity to add sidewalk
    - ….or simply carry legal live loads.
  - Short term solution implemented (strengthening)
  - Long term solution planning (replacement)
    - SHRP2 Simplified Risk Assessment (R09)
      - Negotiate road closure with local stakeholders
      - Slide in bridge construction
    - SHRP2 Service Life Design for Bridges

Service Life Design

- Define Exposure Zones
  - Buried Zone w/ Seasonal GWT — Pile Cap
  - Atmospheric w/o Deicing — Int. Slabs
  - Atmospheric w/ Mod. Decing — Ext. Slabs/End Dia.
  - Atmospheric w/ Direct Deicing — Deck/Rail/Panel



EXPOSURE CONDITIONS AND DETERIORATION MECHANISMS FOR REINFORCED CONCRETE ELEMENTS									
Exposure Zone	Elements	Exposure conditions	Potential Deterioration Mechanisms						
			Materials		Environmental				
			AAR	DEF	Sulfate	Freeze-Thaw	Leaching	Carbonation -induced corrosion	Chloride-induced corrosion
Atmospheric zone without de-icing solutions	Interior PC/PS Slabs	Atmospheric O_2 and CO_2.	x	x		x		x	x
Atmospheric zone with moderate or indirect de-icing solutions.	Exterior PC/PS Slabs CIP End Diaphragm	Atmospheric O_2 and CO_2. Indirect exposure to chlorides from de-icing solutions with alternating wetting and drying. Freeze and thaw.	x	x		x	x	x	x
Atmospheric zone with direct application of magnesium chloride de-icing solutions	Bridge Railing CIP Conrete Deck & Sidewalk Precast Concrete End Panels	Atmospheric O_2 and CO_2. Direct exposure to chlorides from de-icing solutions with alternating wetting and drying. Freeze and thaw.	x	x		x		x	x
Buried zone with seasonal groundwater	Pile Cap	Soil contact and seasonal exposure to groundwater with limited chlorides and sulfates.	x	x	x	x	x		x

AAR - Alkali-aggregate reaction

DEF - Delayed ettringite formation

Service Life Design

- Chloride Induced Corrosion (Load Case)
  - Focal point of the service life design
  - Demand dictated by chloride surface concentration
    - Soil
    - Deicing

- Environmental Loading (Demand)
  - Qualitative before quantitative
  - District Transportation Maintenance Manager
    - Medium deicer application rate (H/M/L)
    - 30 Gallons magnesium-chloride per lane mile
    - 30-40 applications per year
  - Expect moderate surface concentration.

Service Life Design

- Environmental Loading (Demand)
  - Test Existing Structure
    - Four cores taken from curb
    - Bulk Diffusion Test (NT Build 443)
      - Determines chloride contents at depths
      - Useful for determining chloride surface concentrations
  - Highest concentration recommended for use
    - Limited sample size
    - Location of sampling
    - Expected concentration from qualitative assessment.
  - SHPR2 Tool Chloride Profile Fit

Service Life Design

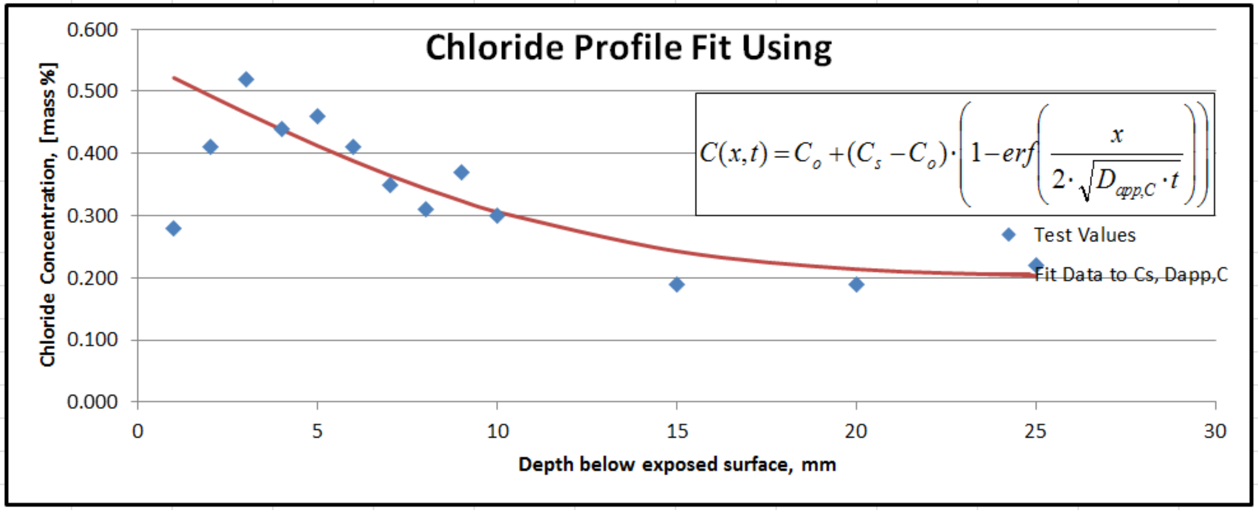


Table 2.1 - Chloride Content in Existing Bridge				
Test Sample	Chloride Mass		Chloride Surface Concentration	
Core #1 (NW)	0.50	kg cl- /m^3	0.15%	chloride / cement
Core #2 (SW)	*1.31*	*kg cl- /m^3*	*0.39%*	*chloride / cement*
Core #3 (SE)	0.55	kg cl- /m^3	0.16%	chloride / cement
Core #4 (NE)	0.29	kg cl- /m^3	0.09%	chloride / cement
Mean	0.66	kg cl- /m^3	0.27%	chloride / cement

Service Life Design

- Environmental Load
  - Demand assessment complete
- Service Life Design (Capacity)
  - Detailing
    - Reinforcement Cover
  - Material Selection
    - Concrete
    - Reinforcement Type
- Key Question - How do ODOT mixes perform?
  - NTBuild 492 Test for Chloride Migration Coefficient

Service Life Design

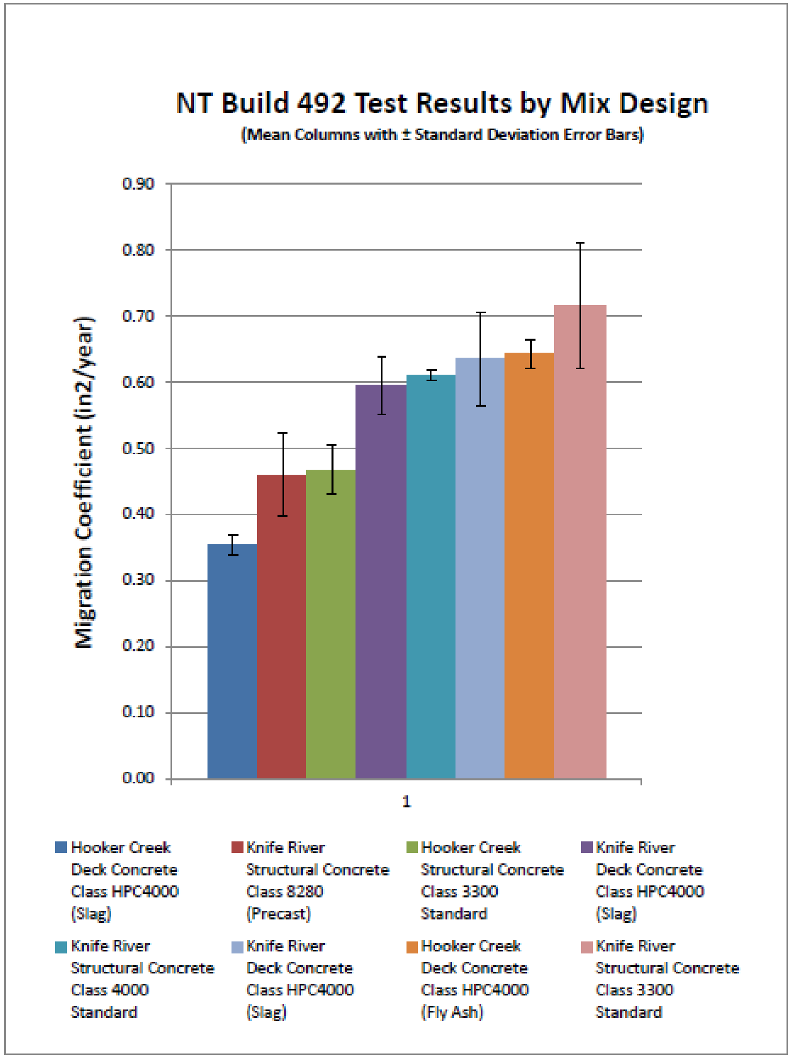


Figure 3.2 – NT Build 492 Test Results by Mix Design

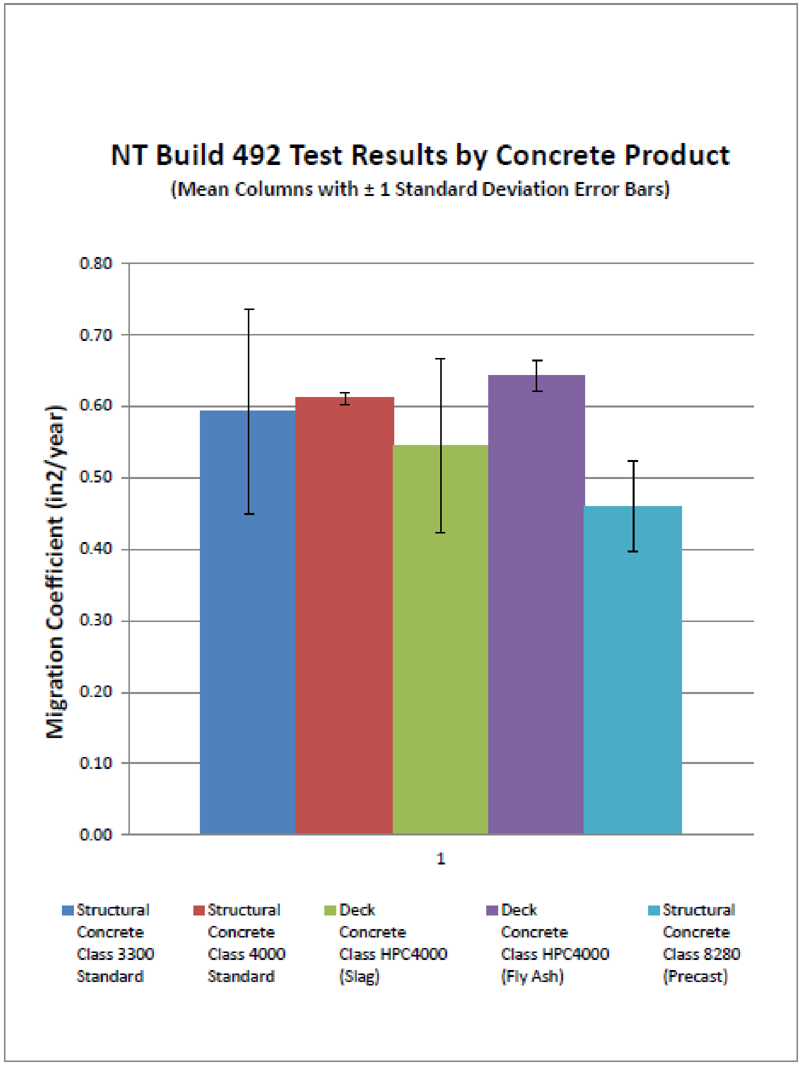


Figure 3.1 – NT Build 492 Test Results by Concrete Product

Service Life Design

- Test Result
  - "By Mix Design"
    - Single supplier
    - Single mix design
- Lab Data Commentary
  - Structural Concrete, 3300
    - Similar Mix Designs
      - 401# & 402# Cement
      - 172# Dura Slag
      - 0.49 & 0.465 W/C
    - Different Results
      - 3rd vs 8th (Last)
  - Uniform data per row, but not by specified mat.

NT Build 492 Test Results By Mix Design			
Mix Design	Mean Migration Coefficient (in^2/year)	Standard of Deviation (in^2/year)	CV = σ/μ
Deck Concrete Class HPC4000 (Hooker Creek - Slag)	0.35	0.02	5%
Structural Concrete Class 8280 (Knife River - Precast)	0.46	0.06	14%
Structural Concrete Class 3300 (Hooker Creek - Slag)	0.47	0.04	8%
Deck Concrete Class HPC4000 (Knife River - Slag)	0.60	0.04	7%
Structural Concrete Class 4000 (Knife River – Slag)	0.61	0.01	1%
Deck Concrete Class HPC4000 (Knife River - Slag)	0.64	0.07	11%
Deck Concrete Class HPC4000 (Hooker Creek - Fly Ash)	0.64	0.02	3%
Structural Concrete Class 3300 (Knife River - Slag)	0.72	0.10	13%

Service Life Design

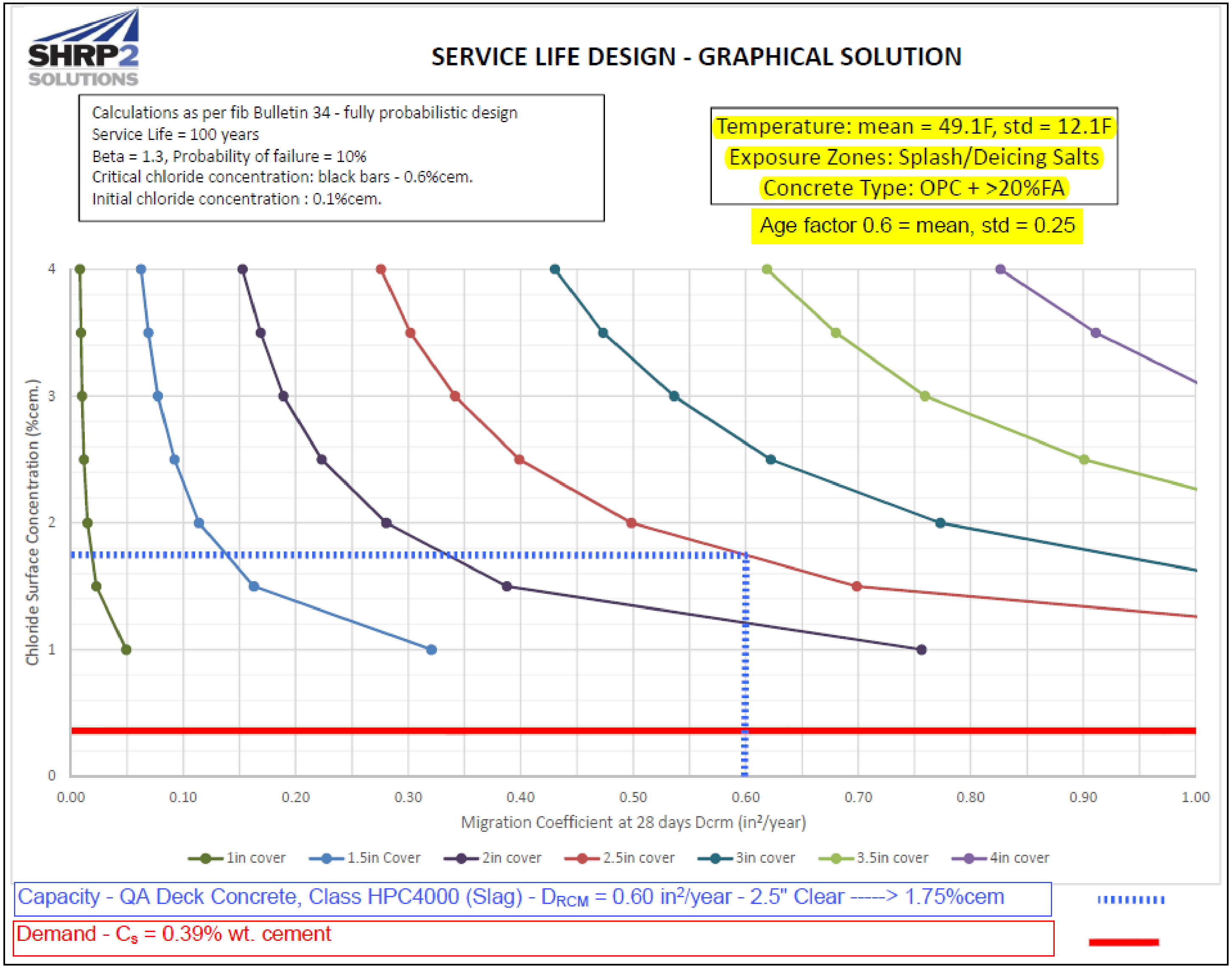
- Test Result
  - By "Concrete Product" or Specified Material
  - Coef. of Variation affected by number of suppliers
  - HPC4000 w/ Fly Ash is worst performer.

Concrete Product	Structural Concrete Class 8280 (Precast)	Deck Concrete Class HPC4000 (Slag)	Structural Concrete Class 3300 (Slag)	Structural Concrete Class 4000 (Slag)	Deck Concrete Class HPC4000 (Fly Ash)
Mean (m2/sec)	9.413E-12	1.115E-11	1.211E-11	1.250E-11	1.316E-11
Mean (in2/year)	0.46	0.55	0.59	0.61	0.64
σ (in2/year)	0.06	0.12	0.14	0.01	0.02
CV = σ / μ	0.14	0.22	0.24	0.01	0.03
Number of Tests	24	12	6	3	3
Suppliers	1	2	2	1	1
Tested During Design or Construction?	Construction	Design Construction	Design	Construction	Design

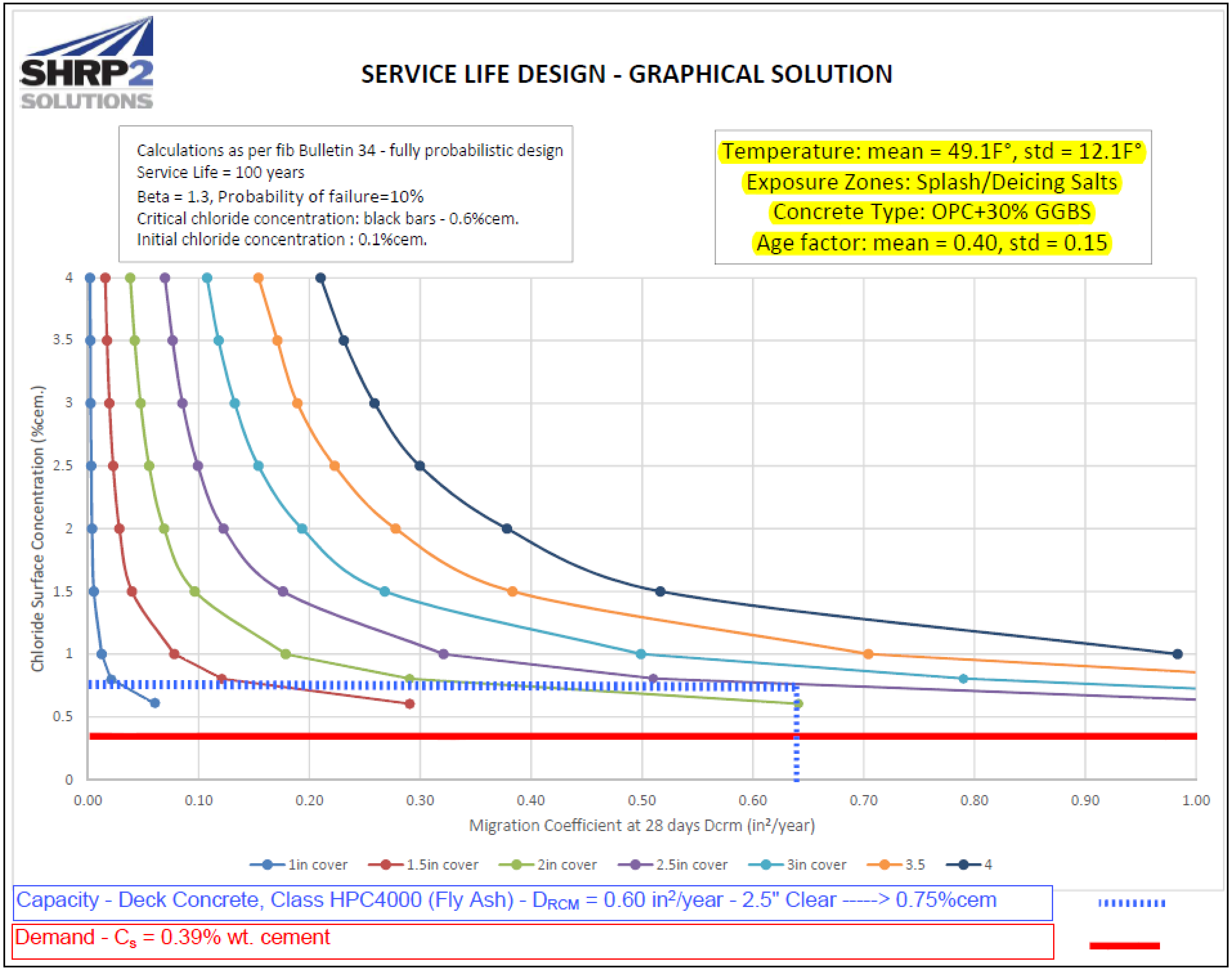
Service Life Design

- Service Life Design (Capacity)
  - Detailing
    - Reinforcement Cover — Defined
  - Material Selection
    - Concrete
      - Resistance to chloride intrusion — Defined
    - Reinforcement Type
      - Corrosion threshold — Defined
  - Next Step → Chart Solutions

Service Life Design



Service Life Design



Service Life Design

- Service Life Design Outcome
  - Chart solution shows 100+ year service life due to chloride ingress

Service Life Design

- QA During Construction
  - Concrete Materials Testing:
    - Expensive ($1000 EA Core)
    - Time sensitive (Must occur at 28 days)
  - Reinforcement Cover:
    - Verified by GPR after deck placement.
    - Very simple and cost effective.

- QA Outcomes
  - Concrete testing may be best suited for establishing statewide practices, not conducted on specific projects.
  - Reinforcement cover verification could be easily added to the contract with incentive, similar to paving bonus.

OR380: Ochoco Creek Bridge Replacement Project

SHRP2 Service Life Design for Bridges (R19A)

SHRP2 SOLUTIONS
STRATEGIC HIGHWAY RESEARCH PROGRAM

Ochoco Creek Birth Certificate

Oregon DOT Workshop – Portland, OR

Mike Bartholomew, P.E.
Regional Discipline Lead, North American Bridges
CH2M (now Jacobs)

January 17, 2018

U.S. Department of Transportation
Federal Highway Administration

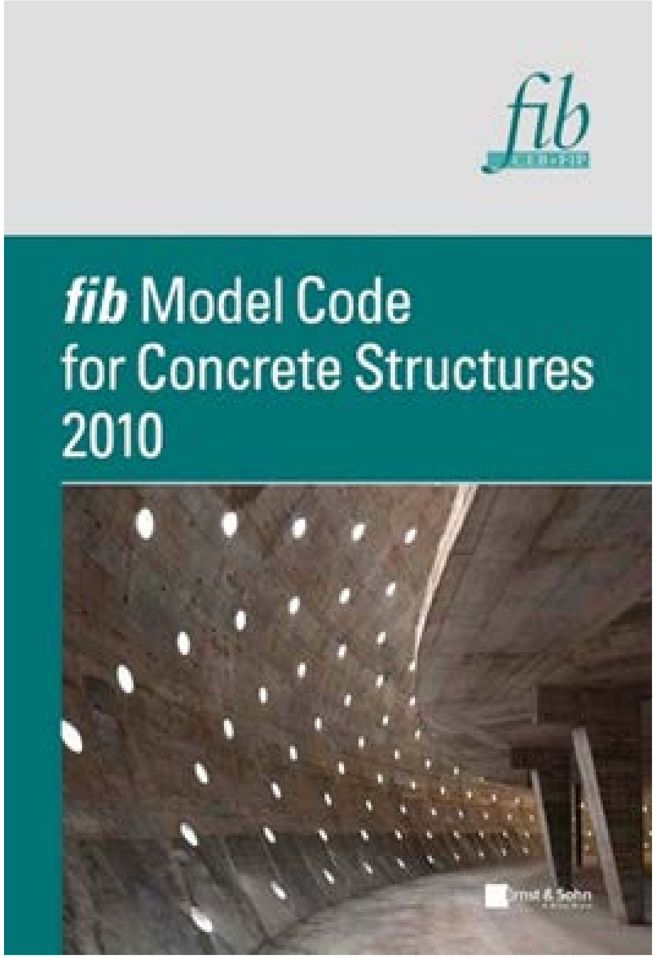
American Association of State Highway and Transportation Officials
AASHTO

Presentation Overview

- Birth Certificate
  - Definition & Purpose
  - Process
  - Document Organization
- Example for Ochoco Creek Bridge
- Summary

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
    - Chloride Diffusion Coefficient
    - Steel Reinforcement / Prestressing Grades
    - Cover Dimensions
- Updated after Maintenance, Inspection & Long Term Performance Monitoring

Birth Certificate Table of Contents

- Identification of Structure
- Durability Design Parameters
- Environmental Exposure Conditions
- Deterioration Mechanisms & Models
- Durability Testing Requirements
- Material Durability Properties
- Structure Element Data
- In-Service Conservation Plan
- Dismantling Plan

Ochoco Creek Bridge

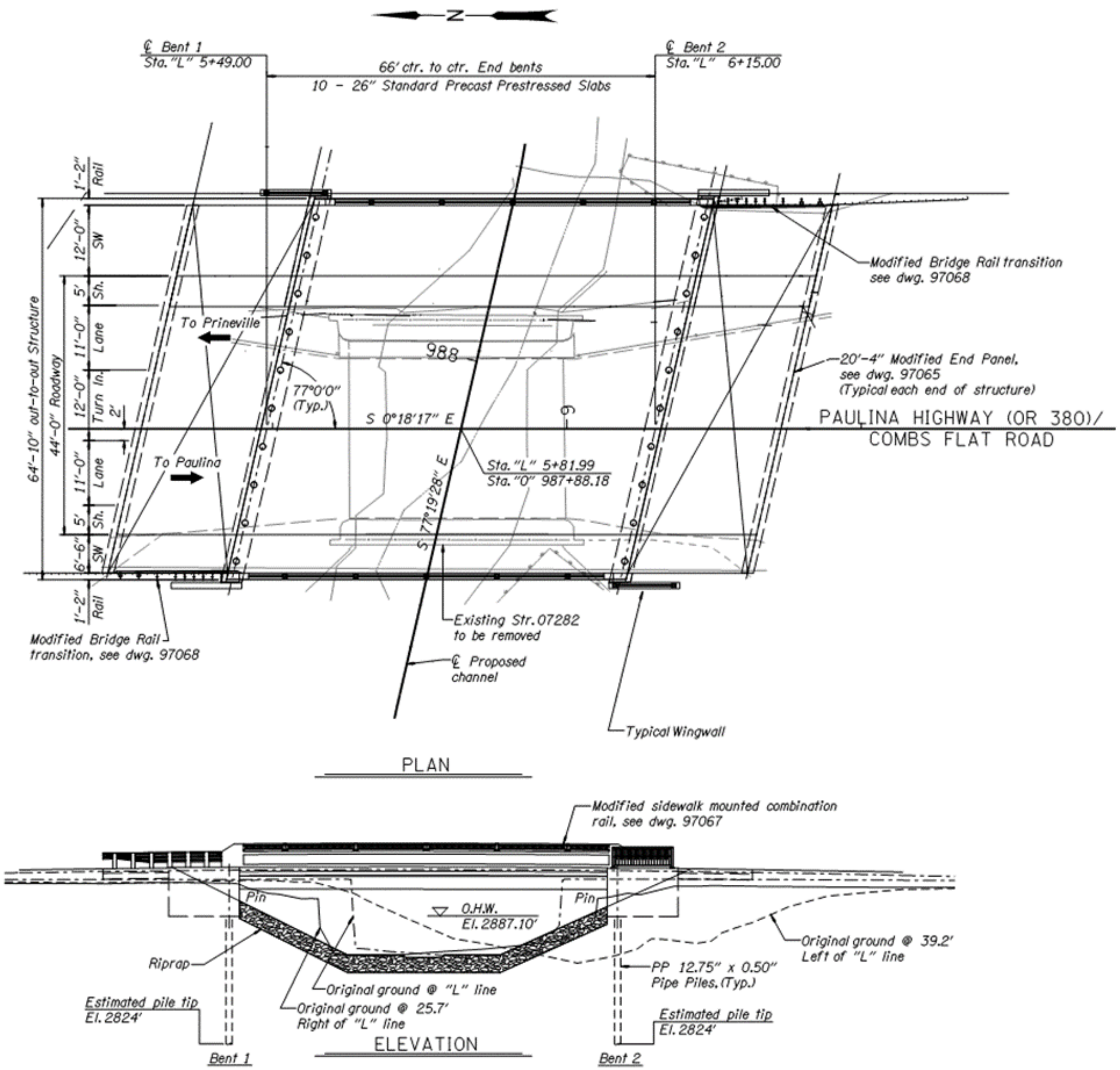
Identification of Structure

Owner	Oregon Department of Transportation
Structure Classification	Bridge
Structure Name	Ochoco Creek Bridge
Inventory ID #	22324
Structure Description	64'-10" wide by 66'-0" long bridge with cast-in-place concrete deck on 26" deep spread, precast, prestressed concrete slabs, supported by precast concrete abutments and steel pipe piles.
Geographic Location	Carries Paulina Highway 380 (Combs Flat Rd.) over Ochoco Creek at Milepost 0.11 in Prineville, Crook County, OR
Date Placed in Service	15-Dec-2016

Identification of Structure

Design	
Project #	STP-S380(002), PCS/Key # 19209
Designer	Oregon Department of Transportation, Region 4 Bridge Engineering 63055 N. Highway 97, Building M, Bend, OR (541) 388-6225
Independent Checker	n/a
Design Start Date	1-Jan-2015
Design End Date	1-Feb-2016
Execution (Construction)	
Contract ID #	14900
Bid Date	28-Apr-2016
Construction Start Date	9-May-2016
Construction End Date	15-Dec-2016
Contractor	Carter & Company Inc. 4676 Commercial St. SE #203 Salem, OR 97302 (503) 371-4582
Sub-Contractors / Suppliers	
Cast-in-Place Concrete	Knife River - Central Oregon Ready-Mix 64500 O.B. Riley Rd. Bend, OR 97701 (541) 693-5900

Identification of Structure



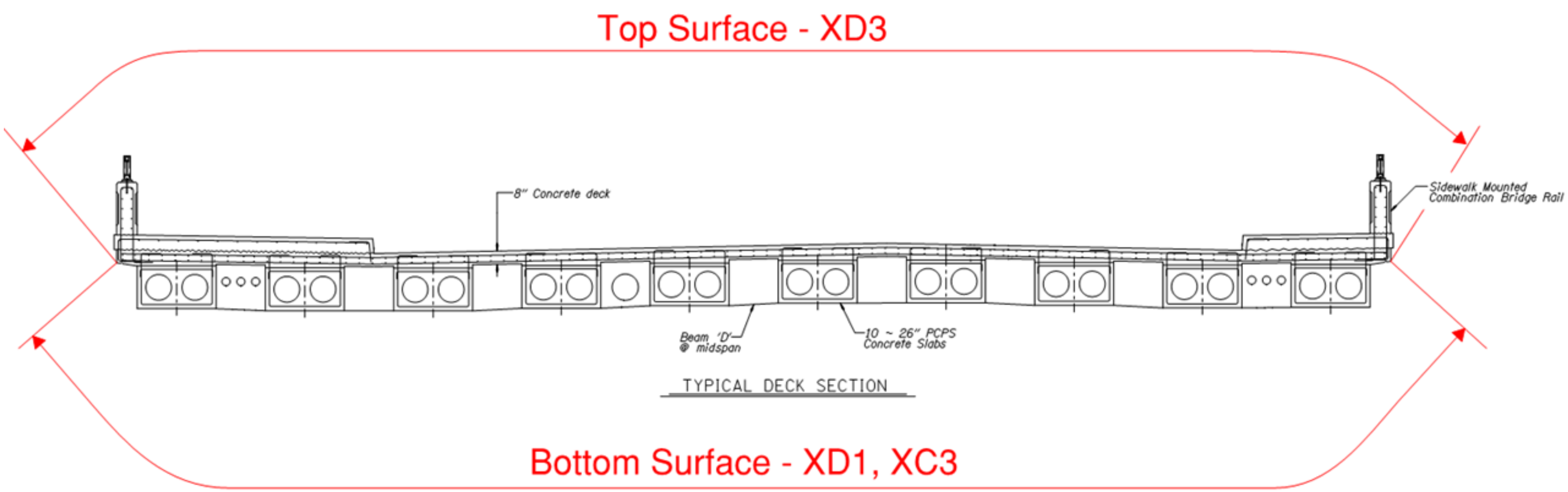
Durability Design Parameters

Durability Specifications			
Model Code for Service Life Design, fib Bulletin 34, 2006			
EN-206-1 (for definition of exposure classes)			
Environmental Exposure Conditions			
Macro Environment	Rural, Urban, Industrial, Coastal Marine	Urban	
Macro Climate	Cold, Temperate, Tropical (hot/humid), Arid (hot/dry)	Temperate	
Annual Climate/Weather Data	Source: NOAA Station ID: GHCND:USC00356883, Prineville, OR (1/1/1897-12/31/2015)	Mean, μ	Std Dev, σ
High Temperature (°C)		63.6	2.42
Low Temperature (°C)		31.7	2.24
Average Temperature (°C)		47.7	2.33
Relative Humidity (%)			
Precipitation (mm)		9	3.3
Time of Wetness (ToW)	No. of days per year with rainfall exceeding 0.1 in	25	8.75
Snowfall (mm)		12.1	8.1
Deterioration Mechanisms			
Reinforcing Steel Corrosion	**C**arbonation, **De**-icing Chlorides, **S**ea water	yes, D	
Freeze/Thaw Damage		yes	
Salt Scaling Damage		yes	
Abrasion/Erosion	**R**utting, **I**ce action	yes, R	
External Chemical Attack	**S**ulfate, **A**cid, **L**eaching	no	
Internal Chemical Attack	**ASR, AAR, DEF**	no	
Coating Breakdown		no	

Durability Design Parameters

Design Parameters		
Consequence Class (CC) - Loss of human life, economic, social or environmental	CC1 - Low	CC2
	CC2 - Normal	
	CC3 - High	
Design Supervision (DSL) - Checking of the design	DSL1 - Self	DSL2
	DSL2 - Same organization	
	DSL3 - Independent 3rd party	
Construction (Execution) Inspection Parameter		
Execution Class EXC) - Construction inspection	EXC1 - Self	EXC2
	EXC2 - Same organization	
	EXC3 - Independent 3rd party	
In-Service Conservation Parameters		
Condition Control & Conservation Class - periodic inspection & maintenance	A - Proactive (systematic monitoring of parameters relevant to deterioration proccesses critical to durability)	B
	B - Reactive (planned periodic inspection)	
	C - None (no direct inspection/testing)	
Condition Control Levels (CCL)/Inspection Regimes	CCL0 - None (not possible, e.g., buried)	CCL2
	CCL1 - Normal (arbitrary, no systematic regime)	
	CCL2 - Normal (regular visual inspection)	
	CCL3 - Extended (monitoring of parameters relevant to deterioration process critical to durability)	

Environmental Exposure Zones



Class Designation	Description of the Environment	Specific Exposure				
1 - Corrosion induced by carbonation			not controlling			
XC3	Moderate Humidity	External concrete sheltered from rain				
2 - Corrosion induced by chlorides other than seawater			Surface chloride concentration [wt-%/cem]			
			C_S		$C_{S,\Delta x}$	
			Mean, μ	Std Dev, σ	Mean, μ	Std Dev, σ
XD1	Moderate Humidity	Surfaces exposed to airborne chlorides	0.2	0.1		
XD3	Cyclic Wet and Dry	Surfaces exposed to de-icing chlorides			0.78	0.39

Deterioration Mechanism/Models

Deterioration Model	Fick's 2nd Law
Source	fib Bulletin 34 - Model Code for Service Life Design, Appendix B2

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

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

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

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

Deterioration Mechanism/Models

Function Variables	Description	Units	Distribution Function
t	Time	[yr]	n/a
x	Depth with corresponding content of chlorides C(x,t)	[in]	n/a
C_{crit}	Critical chloride content	[wt.-%/cem]	Beta, a=0.2, b=2
C_o	Initial chloride content of the concrete	[wt.-%/cem]	Constant
$C_{S,\Delta x}$	Chloride concentration at surface or a depth Δx	[wt.-%/cem]	Log-Normal
Δx	Depth of the convection zone (concrete layer, up to which the process of chloride penetration differs from Fick's 2nd law of diffusion)	[in]	Beta, a=0, b=50
cov	Concrete cover	[in]	Log-Normal
$D_{app,C}$	Apparent coefficient of chloride diffusion through concrete	[in^2/yr]	n/a
D_{RCMO}	Chloride migration coefficient	[in^2/yr]	Normal
k_t	Transfer parameter	[-]	Constant = 1
k_e	Environmental transfer variable	[-]	n/a
b_e	Regression variable	[°K]	Normal
T_{ref}	Standard test temperature	[°K]	Constant = 292.9
T_{real}	Temperature of the structural element or the ambient air	[°F]	Normal
A(t)	Subfunction considering the ageing	[-]	n/a
t_o	Reference point of time	[yr]	Constant = 0.0767
α	Aging exponent	[-]	Beta, a=0.2, b=2

Durability Testing Requirements

Objective	Testing Specification	Information Obtained
Design		
Determine design chloride loading from concrete cores taken from existing/nearby structures	ASTM C1543 - Determining the Peneration of Chloride Ion into Concrete by Ponding (Salt Ponding Test) / with ASTM C1152 and ASTM C1556	Chloride Surface Concentration, C_S (or $C_{S,\Delta x}$ and Δx) used in chloride deterioration model
Determine design chloride durability resistance properties from trial batch mix designs	Nordtest Method NT Build 492 / Chloride Migration Coefficient from Non-Steady-State Migration Experiments (Rapid Chloride Migration, RCM)	Design Chloride Migration Coefficient, $D_{RCM,0}$ used in chloride deterioration model
Construction		
Verify chloride durability resistance properties during production	Nordtest Method NTBuild 492	As constructed Chloride Migration Coefficient, $D_{RCM,0}$ used in chloride deterioration model
Determine initial chloride content of concrete during production	ASTM C1152 - Acid Soluble Chloride in Mortar and Concrete	As constructed Initial Chloride Content, C_O used in chloride deterioration model
Verify clear concrete cover in completed structure	BS1881:204 Testing concrete. Recommendations on the use of electromagnetic covermeters	As constructed clear cover dimensions in hardened concrete
In-Service Monitoring		
Develop chloride profiles from concrete cores taken from structure to verify concrete chloride durability resistance properties and chloride loading	ASTM C1543 / with ASTM C1152 and ASTM C1556	Determine Apparent Chloride Diffusion Coefficient, $D_{app,C}$ as it changes with time, and verify Chloride Surface Concentration, C_S or $C_{S,\Delta x}$ and Δ_x

Material Properties - Concrete

Concrete Class	Mix Designation	Cementitious Materials									
		Cement		Supplemental Cementitious Materials (SCMs)						Cement + SCM Unit weight	Water/ Cement Ratio w/c
		AASHTO/ ASTM Spec.	Type	Fly Ash (FA) AASHTO M295/ ASTM C618		Slag (GGBFS) AASHTO M302/ ASTM C989		Silica Fume (SF) AASHTO M307/ ASTM C1240			
				%	Class C/F/N	%	Grade 100/120	%		(lb/yd^3)	
Design - Trial Batch											
4000 HPC	NT-1b	M85/C150	I	30				4		651	0.39
4000	NT-2b	M85/C150	I			30				691	0.39
3300	NT-3	M85/C150	I			30				556	0.49
4000	26S6KNG8M7	M85/C150	I/II			30				574	0.465
4000 HPC	266TZ1F5CS	M85/C150	I/II			30		4		649	0.401
Construction											
4000	26S6KNG8M7	M85/C150	I/II			30				574	0.465
4000 HPC	6TZ1F5CS	M85/C150	I/II			30		4		649	0.401
8280	KRP H71Y3	M85/C150	III							710	0.36

Material Properties - Concrete

Concrete Class	Mix Designation	Durability Design Properties (per fib Bulletin 34)			
		Chloride Migration Coefficient, $D_{RCM,0}$ (in^2/yr) - (Normal Distribution function)		Aging Exponent, α - (Beta Distribution function, a=0, b=1)	
		RCM Test per Nordtest - NTBuild 492			
		Mean, μ	Std Dev, σ	Mean, μ	Std Dev, σ
Design - Trial Batch					
4000 HPC	NT-1b	0.644	0	0.6	0.15
4000	NT-2b	0.354	0	0.45	0.2
3300	NT-3	0.468	0	0.45	0.2
4000	26S6KNG8M7	0.717	0	0.45	0.2
4000 HPC	266TZ1F5CS	0.636	0	0.45	0.2
Construction					
4000	26S6KNG8M7	0.611	0.244	0.45	0.20
4000 HPC	6TZ1F5CS	0.596	0.238	0.45	0.20
8280	KRP H71Y3	0.46	0.184	0.30	0.12

Concrete Mix Design

Mix Producer	Central Oregon Redi-Mix			
Mix ID	266TZ1F5CS			
Concrete Specification	Oregon DOT Standard Specifications, 2015 - Section 00540			
Concrete Class	4000 HPC Deck			
Materials	Type/Specification	Supplier	Wt. (lbs)	
Cementitious				
Cement	Type I-II/ AASHTO M85	Cal Portland	429	
Supplemental Cementious Materials (SCMs)				SCM %
Fly Ash (FA)				
Slag (GGBFS)		Ash Grove	195	0.30
Silica Fume (SF)		BASF	25	0.04
		Total Cementitious	649	
Aggregates				
Coarse	3/4" - # Round	Lone Pine Pit	1621	
Coarse	3/8" Pea Rock	Lone Pine Pit	205	
Fine	Sand	Lone Pine Pit	1134	
Fiber Mesh	Novomesh 950		5	
			2965	
Aggregate Moisture Water			-89	
		Total Aggregate	2876	
Water				
Batch Water			171	
Aggregate Moisture Water			89	
Admixture Water			3	
		Total Water	263	

Material Properties - Reinforcement

Type	AASHTO/ ASTM Spec	Yield Strength, Fy (MPa)	Tensile Strength, Fu (MPa)	Alloy Type	UNS Designation	Critical Chloride Threshold (% wt of cementitious)	
						Beta Distribution function, a=0.2, b=2	
						Mean, μ	Std Dev, σ
Plain Carbon Low Alloy	M31/A615	60	90	n/a	n/a	0.60	0.15
Plain Carbon Low Alloy	M31/A706	60	90	n/a	n/a	0.60	0.15
Plain Carbon - Epoxy Coated	M31/A615	60	90	n/a	n/a	0.60	0.15
Plain Carbon - Epoxy Coated	M31/A706	60	90	n/a	n/a	0.60	0.15
7-Wire Strand (low relaxation)	M203/A416	243	270	n/a	n/a	0.60	0.15

Concrete Component Summary

	Deck	Prestressed Slabs	Abutment Walls	Footings/ Pile Caps	Concrete Traffic Barriers
Service Life Requirements					
Non-Replaceable	x	x	x	x	x
Replaceable					
Service Life Duration (years)	100	100	100	100	40
Reinforcement Deterioration Mechanisms					
Corrosion from Chlorides	x	x	x	x	x
Corrosion from Carbonation					
Environmental Exposure (per EN 206-1)					
Class (**XC**arbonation/ **XD**e-icing/ **XS**eawater)	XD	XD	XD	XD	XD
Level (1-4)	3	1	1	1	3
Design Strategy					
Avoidance					
Deterioration Modeling	Fick's 2nd Law (fib 34, annex B2)				
Deemed-to-satisfy					
Partial Factor					
Full-Probabilistic	x	x	x	x	x
Reliability Index, β=	1.3	1.3	1.3	1.3	1.3
Protection Strategy					
Material's own resistance	x	x	x	x	x
Multi-stage system (overlay/coating)					
Use non-reactive materials (CRR)					
Cathodic Protection					

Concrete Component Summary

	Deck	Prestressed Slabs	Abutment Walls	Footings/ Pile Caps	Concrete Traffic Barriers
Concrete Deterioration Mechanisms					
Freeze-Thaw					
Salt Scaling					
Abrasion/Erosion	x				
Chemical Attack (**S**ulfate/**A**cid/**L**eaching)					
Internal Chemical Attack (**AAR**/**ASR**/**DEF**)					
Environmental Exposure (per EN 206-1)					
Class (**XF**reeze-Thaw/Chemical **XA**ttack)					
Level (1-4)					
Design Strategy					
Avoidance					
Deterioration Modeling					
Deemed-to-satisfy	x				
Partial Factor					
Full-Probabilistic					
Reliability Index, β=					
Protection Strategy					
Use non-reactive materials					
Restrict material sources					
Air Entrainment					
Thermal Curing Plan					
Protective Barrier (overlay)					

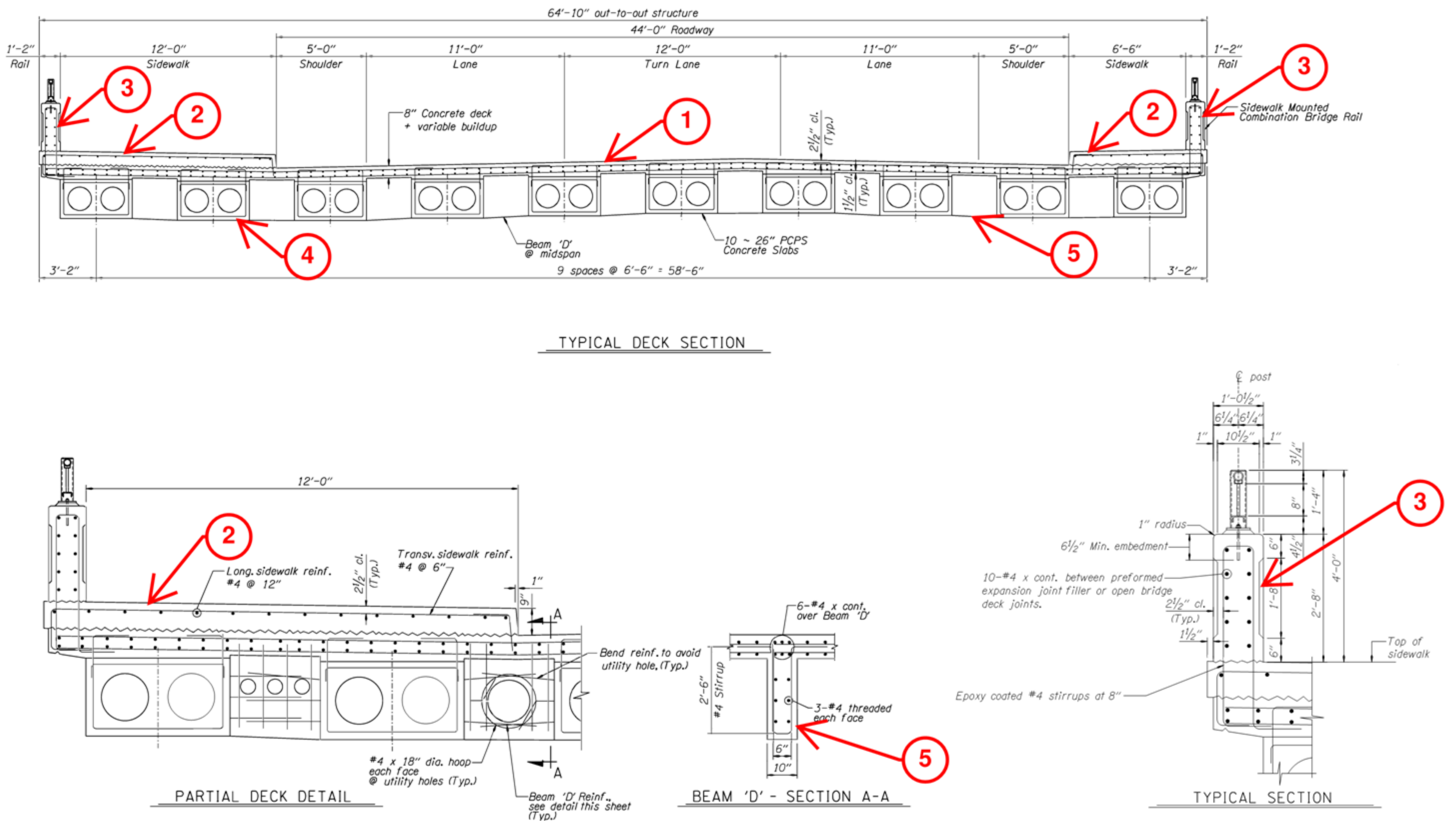
Non-Concrete Component Summary

	Expansion Joint (Seals)	Elastomeric Bearings	Steel Railings	Steel Piles
Service Life Requirements				
Non-Replaceable				x
Replaceable	x	x	x	
Service Life Duration (years)	30	40	40	100
Metal Deterioration Mechanisms				
Corrosion from Chlorides			x	
Corrosion from Water/Moisture				x
Environmental Exposure (per EN 206-1)				
Class (**XC**arbonation/ **XD**e-icing/ **XS**eawater)			XD	XD
Level (1-4)			3	1
Design Strategy				
Avoidance				
Deterioration Modeling				
Deemed-to-satisfy			x	x
Partial Factor				
Full-Probabilistic				
Reliability Index, β=				
Protection Strategy				
Material's own resistance				x
Use non-reactive materials				
PT Corrosion Protection Level (**PL1/PL2/PL3**)				
Protective Coating			x	
Limit State				
Corrosion Propagation (% section loss)				x

Non-Concrete Component Summary

	Expansion Joint (Seals)	Elastomeric Bearings	Steel Railings	Steel Piles
Other Material Deterioration Mechanisms				
Abrasion/Erosion				
Coating failure			x	
Ultraviolet breakdown				
Other (see component details)				
Design Strategy				
Avoidance				
Deterioration Modeling				
Deemed-to-satisfy (Historical user data)	x	x		
Partial Factor				
Full-Probabilistic				
Reliability Index, β=				
Protection Strategy				
Protective coatings			x	
Other (see component details)				
Limit State				
Initiation of joint leakage	x			
__% surface coating defects				

Structural Component Identification



1 Bridge Deck

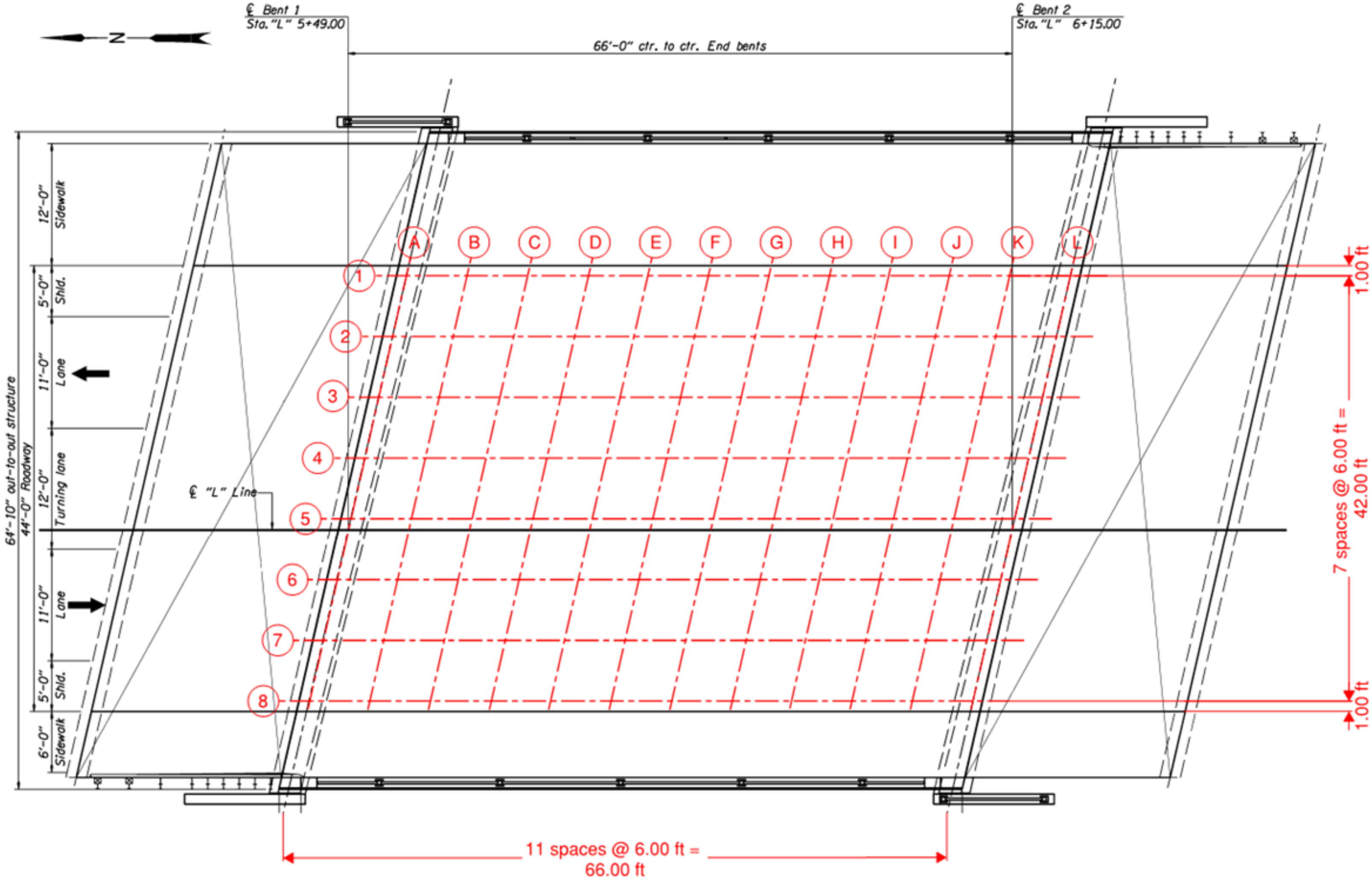
2 Sidewalk

3 Railing

4 Prestressed Slabs

5 Diaphragm

Structural Component Data – Cover



DECK PLAN

Scale: 3/16" = 1'-0"

Cover Measurements

As-Constructed Cover Dimensions at Grid Points [in]												
	A	B	C	D	E	F	G	H	I	J	K	L
1	2.52	2.20	2.60	2.99	2.05	2.87	2.72	2.80	3.11	2.99	3.11	2.83
2	2.40	2.20	2.48	2.72	2.72	2.76	2.91	2.99	2.17	2.83	2.99	2.09
3	2.24	2.24	***1.46***	***1.57***	2.52	2.20	2.36	2.20	2.20	***1.89***	***1.85***	2.24
4	1.93	2.01	***1.65***	2.01	2.24	2.28	2.24	2.13	2.32	2.48	2.52	2.80
5	2.28	2.40	2.09	1.93	2.01	***1.89***	2.17	1.97	***1.81***	1.93	2.56	2.32
6	2.99	3.11	2.48	2.09	3.15	2.91	2.83	2.56	2.83	2.72	2.83	2.28
7	2.24	2.99	3.15	***1.10***	2.60	2.91	2.44	2.99	2.24	2.48	2.24	2.40
8	2.13	***1.85***	2.20	2.20	2.13	2.83	2.52	2.40	2.20	***1.77***	2.32	2.48

Statistical Evaluation of Measured Cover Depths, all units [in]

Target threshold %		5%	Qualitative Procedure				
Nominal cover	c_{nom}	2.5	# measurements < c_{min}	10	# allowed per N	7	NG
Safety margin	Δc	0.6					
Req'd minimum cover	c_{min}	1.9	Quantitative Procedure				
Sample size	N	96	Outlier cover	X_{OG}	$= 2.5X_M - 1.5X_{min}$	4.20	
Median	X_M	2.34	Location parameter	r	$= (X + X_M)/2$	2.37	
Min	X_{min}	1.10	Form parameter	k	=1.8 r/s	10.21	
Mean	X	2.40	Threshold value	c(5%)	$= r/(19^{1/k})$	1.78	
Std. Dev.	s	0.42	Parameter p(x)	p(x)	$= c_{min}/r$	0.80	
			% of cover depth <c_{min}	F(x)	$= p(x)^k/(1+p(x)^k)$	9%	>5% NG

Structural Component Data

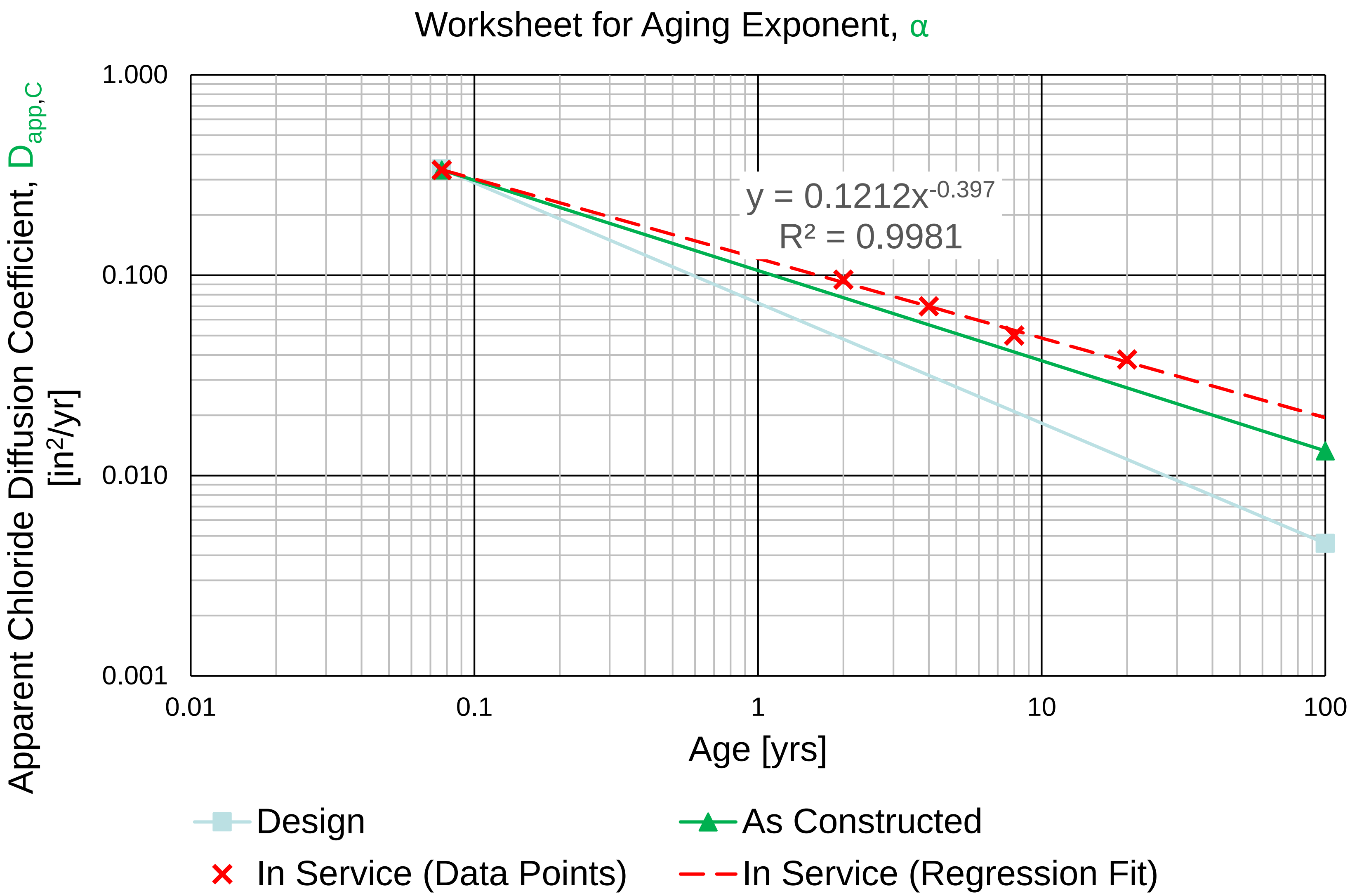
Component Name	Deck	Figure ID	Superstructure 1	Required Service Life [yr]	100
Location	Span 1			Reliability Index, β	1.3

Deterioration Model - fib Bulletin 34, Annex B2, Full probabilistic design method for chloride induced corrosion - uncracked concrete					Design		As-Constructed	
Property		Variable	Units	Distribution	Mean, μ	Std Dev, σ	Mean, μ	Std Dev, σ
Environmental Parameters								
Exposure Class	XD3							
Surface Chloride Concentration		$C_{S,\Delta x}$	[wt-%/cem]	Log-Normal	0.78	0.39		
Transfer Function		Δx	[in]	Beta a=0, b=50	0.35	0.22		
Temperature at Site		T_{real}	[°C]	Normal	47.7	2.33		
			[°K]		281.9	1.29		
Standard RCM Test Temperature		T_{ref}	[°K]	Constant	292.9			
Temperature Regression Variable		b_e	[°K]	Normal	4800	700		
Concrete Properties								
Class/Mix Design	HPC4000					NT1B		6TZ1F5CS
Initial Chloride Content		C_o	[wt-%/cem]	Constant	0.1			
Chloride Migration Coefficient		$D_{RCM,0}$	[in^2/yr]	Normal	0.644	0.258	0.636	0.254
Aging Exponent		α	n/a	Beta a=0, b=1	0.60	0.15	0.45	0.20
RCM Testing age (28 days)		t_o	[yr]	Constant	0.0767			
Transfer Parameter		k_t	n/a	Constant	1.0			
Steel Reinforcement Properties								
Reinforcing Type/ Grade	Carbon	M31/A615						
Critical Chloride Threshold		C_{crit}	[wt-%/cem]	Beta a=0.2, b=2	0.6	0.4		
Clear Cover		cov	[in]	Log-Normal	2.5	0.35	2.4	0.42

Strucural Component Data

In-Service Monitoring			Chloride Diffusion Coefficient at age t, $D_{app,C}(t)$		Surface Chloride Concentration, C_S or $C_{S,\Delta x}$		Aging Exponent, α		Service Life, t_{SL}	End of Service Date
			[in^2/yr]		[wt-%/cem]		n/a		[yr]	[yyyy]
Life Cycle Stage	Age, t [yr]	Test Method	Mean, μ	Std Dev, σ	Mean, μ	Std Dev, σ	Mean, μ	Std Dev, σ		
Design/Construction										
Assumed Design	0.0767	NT Build 492	0.339	0.136	0.78	0.39	0.6	0.15	>100	2117
	100		0.005							
As-Constructed	0.0767	NT Build 492	0.335	0.134	0.78	0.39	0.45	0.2	100	2117
	100		0.013							
In Service Durability Monitoring			Measured Properties from Chloride Profiling Tests				Regression Calculation		Monte Carlo Calculation	
Inspection 1	2	ASTM C1556	0.095	0.038	0.78	0.39	0.386	0.171	67	2084
Inspection 2	4	ASTM C1556	0.07	0.028	0.78	0.39	0.393	0.174	70	2087
Inspection 3	8	ASTM C1556	0.05	0.02	0.78	0.39	0.403	0.179	74	2091
Inspection 4	20	ASTM C1556	0.038	0.015	0.78	0.39	0.397	0.176	72	2089
Inspection 5										
Inspection 6										
Inspection 7										
Inspection 8										
Inspection 9	100									

Structural Component Data



Summary

- Birth Certificate documents durability properties to assist in evaluating durability performance

- Birth Certificate provides a means for collecting data for future development of deterministic code provisions

Questions?

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Resource: AASHTO's R19A Product Page

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