Appendix F
Example Birth Certificate and Recommendations for Through-Life Management Documentation

This appendix demonstrates a process for collecting and documenting information pertinent to the durability of a bridge upon construction completion and periodically throughout the life of the bridge. The document created through this process is known as the Birth Certificate or an As-built Service Life Design Report. The document may be updated during service to assist in decision-making regarding future inspection and preservation activities. A formal technical document describing this process is currently under development by the International Federation of Structural Concrete (*fib*) Commission 8 on Durability and excerpts from that document are included herein.

F1.0 Introduction

The structural Birth Certificate is intended to collect and record as-built documentation of the achieved values, including concrete cover thickness, chloride migration coefficients, and other durability-related parameters. Collected data should include, as a minimum, the direct input parameters for models used in the service life design process. Collecting this as-built information allows for confirmation of design assumptions and provides a basis for the condition control of the structure during its service life.

Suggested contents of a Birth Certificate provided in Table F1, where Sections 1 to 9 in the table, make up the original Birth Certificate upon construction completion. For projects that implement the Service Life Design process described in the main body of this Summary Guide, portions of the Birth Certificate document would be available from the Service Life Design Report and Construction Specifications, as shown in the third column of Table F1. There may be situations where not all the sections shown in Table F1 are necessary. For instance, a Dismantling Plan might only be required when a complex demolition sequence has been incorporated in the structure. Separate Maintenance, Inspection and Monitoring Plans may not be necessary for structures where an owner has a thorough system-wide plan for their typical conventional structures. In such cases, a note in the Birth Certificate table of contents could indicate the reason for eliminating the section. The section 10 described in Table F1, In-Service Monitoring, would be subject to period updating during service and comprises the through-life management documentation.

Table F1: Suggested Birth Certificate Document Contents.

Section	Section Title	Input From
1	Structure Identification	Service Life Design Report and other Design documents
2	Durability Design Parameters	
3	Environmental Exposure Zones	
4	Deterioration Mechanism and Models	
5	Durability Testing Requirements	Construction Specifications
6	Construction Materials	Material submittals
7	Structure Component Durability Data	Quality Assurance (QA)/Quality Control (QC) test reports
8	Maintenance, Inspection and Monitoring Plans	Other design documents
9	Dismantling Plan	Structural designers
10	In-Service Monitoring	Inspection and maintenance records

Implementing a structural Birth Certificate can be a valuable component in a Through-Life or Asset Management System for a structure or group of structures. These systems involve planning and monitoring each of the following phases in the life of each individual structure:

- Design
- Construction
- Preservation, including inspection, maintenance (cyclical condition-based, and/or preventative), replacement and rehabilitation
- Demolition

A schematic timeline showing these phases and the corresponding structural condition versus time is shown in Figure F1. As shown in the figure, the Birth Certificate is finished after the initial assessment of construction to document design decisions and the quality of workmanship and materials achieved during construction. Further, the Birth Certificate can be used as a framework for documenting subsequent condition assessment and maintenance activities, including to what extent the actual inspection and maintenance aligns with the design-stage plans. Comparison of the as-built quality with subsequent inspection and monitoring allows for assessment of the residual service life of structures in an owner's inventory.

A well-conceived, executed, and documented asset management plan is critical to maintaining an inventory of structures. How well each structure is designed, constructed, inspected, and preserved all directly influence its service life. Condition information obtained during inspections helps determine the rate of deterioration of individual components and the overall structure and assists in the decision-making regarding future preservation tasks. Knowledge of the deterioration rate in advance of actual damage, allows for more accurate planning of funding requirements for future preservation and eventual demolition, and if desired, replacement activities. Birth certificates for each structure in an inventory therefore form the basic building blocks for a thorough Asset Management System.

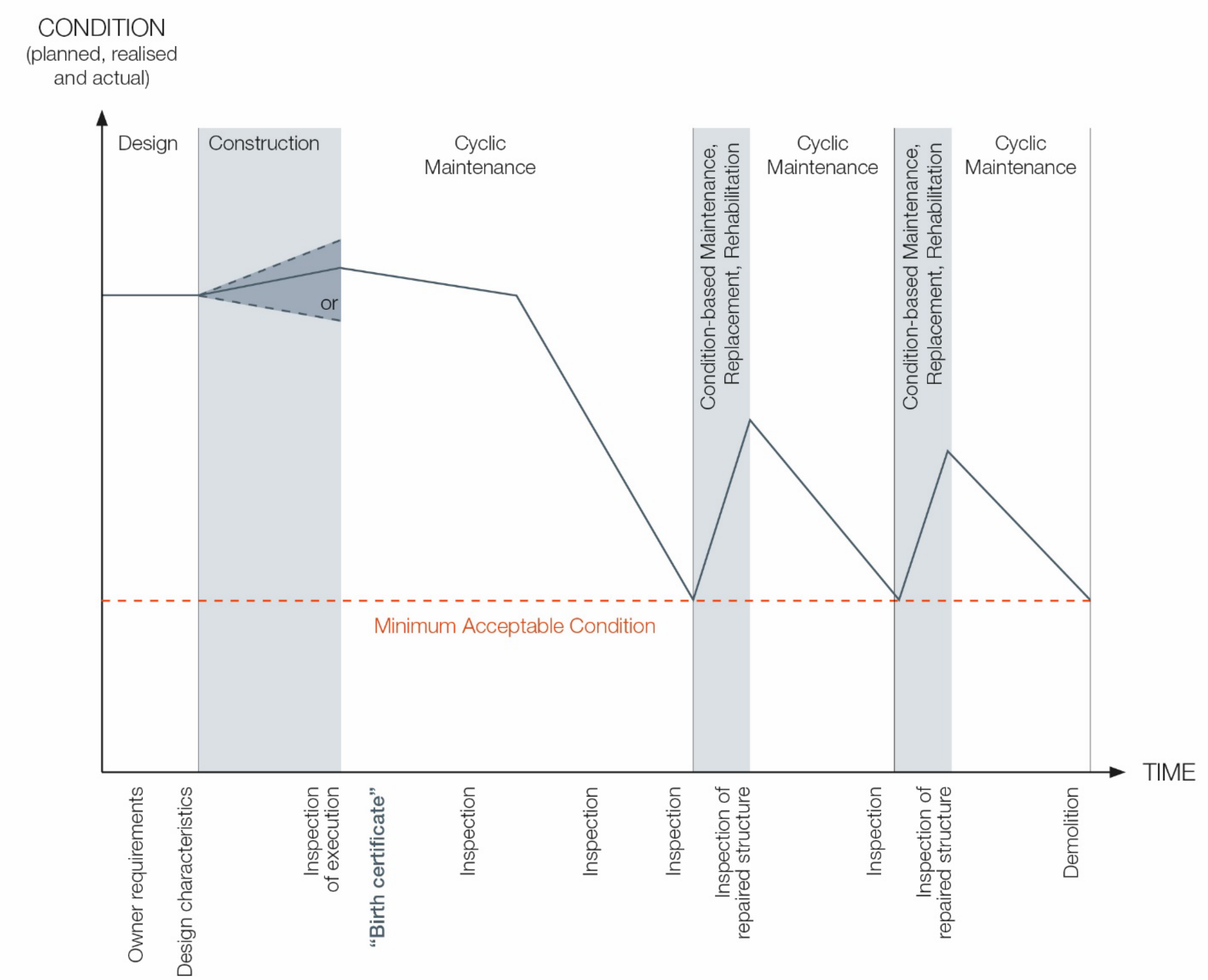


Figure F1 - Complete Service Life (adapted from Gehlen, 2006 [1])

F1.1 Scope and Purpose

The purpose of the Birth Certificate is to assist owners in the facilitation of the through-life asset management of a structure. To accomplish this, a Birth Certificate should contain engineering documentation of the design intent, achieved quality of the as-built structure or structural element(s), and in-service monitoring data collected during a structure's life. The primary goals of collecting details on the achieved as-built quality and in-service monitoring data are to document whether the structure achieved its specified design and to predict residual service life, respectively.

Birth Certificates are intended to supplement the following three documents currently kept by owners: as-constructed drawings, periodic inspection reports, and load ratings. These three documents help to identify the current load carrying capacity of the structure; not predict how long it is expected to remain in service. In the same way that the load capacity ratings provide important information on structural design intent, design deterioration mechanisms and material durability performance characteristics provide important information on serviceability intent. Historically, information regarding durability performance has not been collected or documented for most bridges. The data collected in a Birth Certificate will provide valuable information on how structures behave over time in different environments and could be used to develop better designs that last longer.

Ideally, Birth Certificate documentation should be initiated during the design phase for a new structure. At the time of design, information is readily accessible concerning the site-specific environmental exposure conditions and material durability properties.

F1.2 Delayed Birth Certificate Concept

Because the practice of service life design is relatively new in certain locations, many Owners already possess a significant inventory of structures without formal Birth Certificate documents. Most of these structures are likely classified as deemed to satisfy the standards for acceptable-specified service life design in effect at the time of their construction. For these structures, a Delayed Birth Certificate may be created many years after construction is completed, even though it is likely that minimal information important to durability design and the prediction of service life will be available. As an example, in-depth monitoring inspections where chloride profiling is done, can be used to determine surface chloride concentration, the apparent coefficient of chloride diffusion, and the aging exponent for a structure exposed to seawater or de-icing chemicals. This typically requires separate sets of profiles to be taken at three different times.

In the case of existing inventories, there are often many similar structures located in the same environmental exposures, put into service in the same time frame, and constructed with similar material properties and dimensions. It may be advantageous to select a sampling of structures and perform condition surveys to assess the current condition of the structures. The results obtained from the sampling can be used to predict the residual service life behavior expected for the entire group. In this case, the Delayed Birth Certificate concept can be applied to groupings of structures to relieve the owner from having to evaluate each individual structure in their entire existing inventory.

F2.0 Example

An example bridge Birth Certificate has been developed as part of the Oregon Department of Transportation's SHRP2 R19A Implementation Action Program work. The bridge is a single span precast, prestressed concrete slab over the Ochoco Creek in the town of Prineville in central Oregon. As this example comprises a concrete bridge, it is noted that the example provided focuses primarily on concrete-related considerations. However, the Birth Certificate concept demonstrated herein is equally suitable and useful for steel bridges or steel components.

The Birth Certificate has been created in Microsoft Excel, where the data can be best presented in a tabular format. The individual sections of the Birth Certificate will have a short description herein and be followed by the corresponding pages converted to Microsoft Word format. The spreadsheet format is included as a separate document that can be adapted more easily for use on other projects. While other formats for a Birth Certificate can be envisioned, the basic content described herein should remain the same.

For the purposes of this example, some commentary is provided initially for each section followed by the actual content of the Birth Certificate.

F2.1 Section 1 – Structure Identification

In this section key features of the bridge are identified, including Owner-developed bridge identification number; project and construction contract numbers; the structure's function and general features, where it is located, when it was built, who designed it, who constructed it, who were the major material suppliers; and the form of construction procurement used. A photo of the structure and an overall general plan and elevation view should be included. Optionally, cost data can be recorded.

Section 1 - Structure Identification

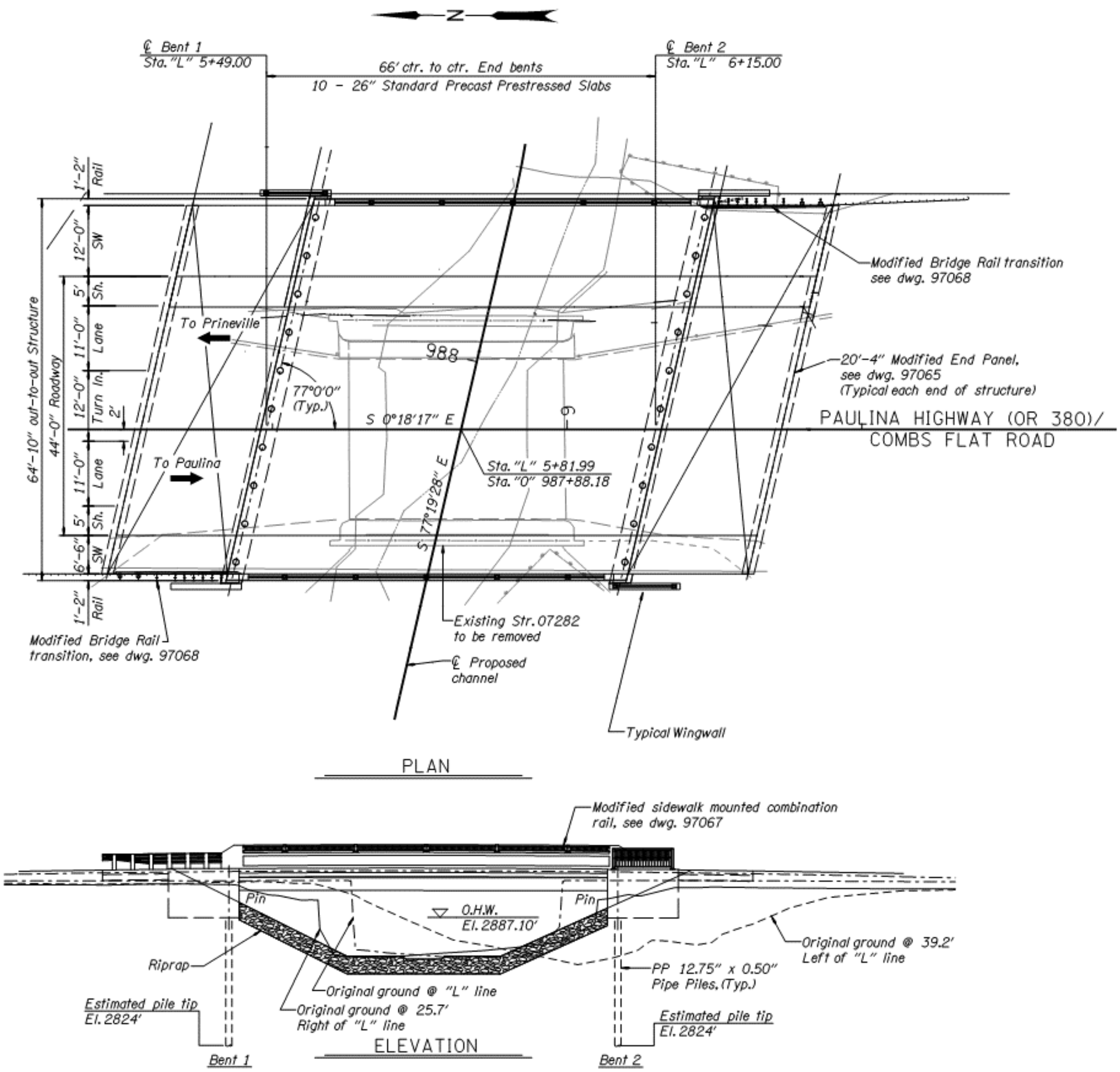
Owner	Oregon Department of Transportation
Structure Classification	Bridge
Structure Name	Ochoco Creek Bridge
Inventory ID #	22324
Structure Description	64'-10" wide by 66'-0" long bridge with cast-in-place concrete deck on 26" deep spread, precast, prestressed concrete slabs, supported by precast concrete 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

Section 1 - Structure Identification

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
Precast Concrete	Knife River Prestress 23505 Peoria Rd. Harrisburg, OR 97446 (541) 995-6327
Reinforcing Steel	(Name) (Address 1) (Address 2) (Phone)
Prestressing Steel	(Name) (Address 1) (Address 2) (Phone)

Section 1 - Identification of Structure

Structure Plan & Elevation



F2.2 Section 2 – Durability Design Parameters

This section identifies a list of the applied service life design codes or guides used during the design and construction of the bridge. As there are no all-encompassing service life design standards, there may be several identified for use on the structure.

This section also presents the following basic parameters considered in the service life design process:

- Macro-environmental exposure conditions and climate/weather data
- Applicable deterioration mechanisms at the bridge site based on exposure conditions
- Parameters defining the quality of design, construction, and in-service management

These parameters are identified to assist in evaluating the level of reliability achieved.

The following lists provide some of the design codes that may be used in developing the service life design. See Section 4 of the main body of this Summary Guide and Appendix D, Design Examples, for additional details on how to apply these codes to complete a service life design for a bridge.

For Concrete Structures and components:

- *fib* Bulletin 34 – Model Code for Service Life Design [2]
- *fib* Model Code 2010 [3]
- ISO 16204 – Durability – Service Life Design of Concrete Structures [4]
- EN 206 Section 4.1 [5] (for defining exposure zones)
- ACI 318 [6] Chapter 19

For Steel Structures or components:

- ISO 12944 – Paints and varnishes – Corrosion protection of steel structures by protective paint systems – Part 2: Classifications of environments [7]
- Eurocode 3: Design of Steel Structures, Part 5: Piling – Section 4.4 [8]
- FDOT Structures Design Guidelines [9] – Section 3.1
- NACE Paper 7422 [10]
- Steel Structures Painting Council, SSPC-VIS 2 [11]

Climate/weather data can be obtained from the National Oceanographic and Atmospheric Administration (NOAA) National Center for Environmental Information's web page at:

- https://www.ncdc.noaa.gov/cdo-web/

Data can be collected for annual mean temperature, precipitation, snowfall, relative humidity, and number of freeze-thaw cycles occurring at weather stations near the bridge site. See Section 4.2 in the Summary Guide for additional recommendations.

Deterioration mechanisms for concrete structures considered in service life design have been identified in the SHRP2 R19A Academic Toolbox. Another excellent source for deterioration is found in the Design of Durable Concrete Structures [12].

Section 2 - Durability Design Parameters

Structure Name / ID# Ochoco Creek Bridge / 22324

Durability Specifications
Model Code for Service Life Design, *fib* Bulletin 34, 2006
EN-206 (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 (°F)		63.6	2.42
Low Temperature (°F)		31.7	2.24
Average Temperature (°F)		47.7	2.33
Relative Humidity (%)			
Precipitation (in)		9	3.3
Time of Wetness (ToW)	No. of days per year with rainfall exceeding 0.1 in	25	8.75
Snowfall (in)		12.1	8.1

Deterioration Mechanisms		
Reinforcing Steel Corrosion	**C**arbonation, **D**e-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

Section 2 - Durability Design Parameters

Structure Name / ID# Ochoco Creek Bridge / 22324

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 processes 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)	

F2.3 Section 3 – Environmental Exposure Zones

This section is used to graphically portray the structure and the driving environmental exposure conditions to which it is subjected. Schematic drawings of the structure in plan, elevation, and cross-section views can be used to describe the various exposure conditions occurring within the structure. Small structures may require only one figure; larger structures may require multiple figures to adequately describe the variation of conditions. Original drawings from the contract documents will likely have too many detailed dimensions and notes to be useful but could be used and simplified to show only major dimensions and identification of structure components. Color coding on the drawings is often used to delineate the limits of each exposure zone, as exemplified in Design Examples provided in Appendix D. The method of describing exposure zones and classes for concrete structures used in this example is shown in Table F2.

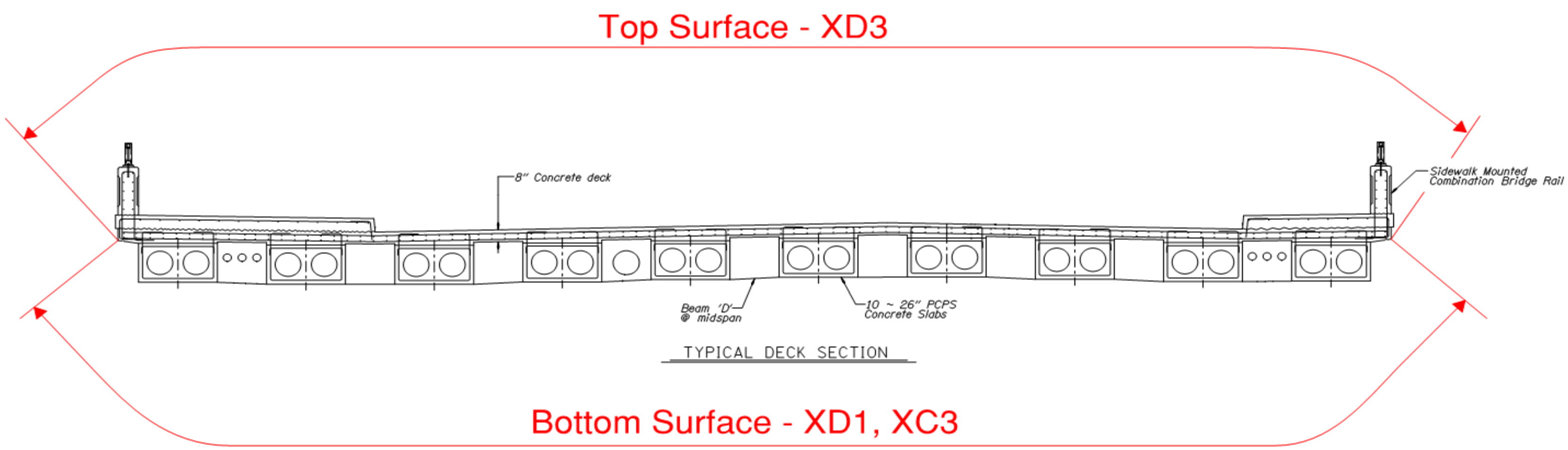
Table F2 - Exposure zones from EN 206

Class	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

The exposure classes, descriptions, and limits for each deterioration mechanism applicable to the structure should be clearly marked on the drawings. The magnitude of environmental loadings, such as surface chloride concentrations, should also be identified. For design, values are mainly obtained from previously published data for structures in similar environments, or from sampling of nearby structures. For in-service conditions, values can be determined by taking cores and developing chloride profiles.

Section 3 – Environmental Exposure Zones

Structure Name / Inventory ID # Ochoco Creek Bridge / 22324



Exposure Classifications

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			0.70	0.35

F2.4 Section 4 – Deterioration Mechanisms and Models

Based on the type of exposure conditions present and the limit states chosen to define specified design service life, this section of the Birth Certificate identifies the deterioration models used in the service life analysis. The *fib* Bulletin 34 - Model Code for Service Life Design [2] and *fib* Model Code 2010 [3], define industry standard models for the initiation phase of deterioration because of carbonation, chloride ingress, freeze/thaw, and chemical attack. While mechanisms for the propagation phase of deterioration are under development, there are no mathematical models considered standard to the industry at this time. Within this section, the deterioration mechanism, mathematical model and source reference, the equations of deterioration and their variables should be clearly defined, as the subsequent sections will reference the models and identify values for the variables that have been assumed in the design and achieved in the construction phase. A separate subsection should be used for each deterioration model assumed in the structure.

Section 4 - Deterioration Mechanism & Model

Deterioration Mechanism	Full probabilistic design method for chloride induced corrosion - uncracked concrete
Deterioration Model	Fick's 2nd Law
Source	*fib* Bulletin 34 - Model Code for Service Life Design, Appendix B2

Equation (B2.1-1) $$C_{crit} = C(x=c,t) = C_0 + (C_{S,\Delta x} - C_0) \cdot \left[1 - \mathrm{erf}\left(\frac{c - \Delta x}{2\sqrt{D_{app,C} \cdot t}}\right)\right]$$

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) $$A(t) = \left(\frac{t_0}{t}\right)^a$$

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
c	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 aging	[-]	n/a
t_o	Reference point of time	[yr]	Constant = 0.0767
a	Aging exponent	[-]	Beta, A=0.2, B=2

F2.5 Section 5 – Durability Testing Requirements

While virtually all standard material and contract specifications include the testing requirements for the performance properties related to the structural strength of the material, most do not currently have similar testing requirements related to the expected durability performance of the material. As several standardized tests exist to quantify the durability performance of building materials and such tests are commonly overlooked in standard specification, this section of the Birth Certificate records details on the durability-related testing implemented during the design and construction of the bridge. In general, the standard contract specifications will need to be supplemented with these durability testing requirements as described in Section 5.0 of this Summary Guide. An example Supplementary Concrete Specification is also provided in Appendix E. In addition to the specification to identify the test, it will also be necessary to identify the frequency that the tests are to be performed. Durability tests should be specified based on the type of deterioration mechanism anticipated for the structure and consistent with the design methodology used.

This section of the Birth Certificate should therefore compile the durability-related test methods carried out during the design and construction of the bridge, including the objective of the test, the test specification followed, the information obtained, and the required testing frequency.

Section 5 - Durability Testing Requirements

Structure Name / Inventory ID Ochoco Creek Bridge / 22324

Objective	Testing Specification	Information Obtained	Test Location / Frequency
Design Phase Testing			
Determine design chloride loading from concrete cores taken from existing/nearby structures	ASTM C1543 - Determining the Penetration 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	4 cores taken in sidewalk curbs of existing bridge
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	Single test (3 cylinders) from each trial batch mix design
Construction Phase Testing			
Verify chloride durability resistance properties during production	Nordtest Method NTBuild 492	As constructed Chloride Migration Coefficient, $D_{RCM,0}$ used in chloride deterioration model	Single test (3 cylinders) from each concrete component cast per day
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	German Concrete and Construction Association (DBV). Concrete Cover and Reinforcement	As constructed clear cover dimensions in hardened concrete	Minimum of 20 points per concrete surface
In-Service Monitoring Testing			
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	

F2.6 Section 6 – Construction Materials

This section of the Birth Certificate compiles details on the materials used in the construction of the bridge. Each of the materials used in the structure should be identified by its applicable construction specification or standard.

For concrete, each of the actual mix designs used in the structure should be reported. This includes the proportions of cement (and type), water, coarse and fine aggregates, supplementary cementing materials such as silica fume, fly ash or blast furnace slag, and all other admixtures. When chloride-induced reinforcement corrosion is relevant, durability test results for chloride migration coefficient from Nordtest NT Build 492 [13] tests should also be collected, with the results reported in a mix design summary table. Other durability-related testing, as required by the Construction Specifications and outlined in Section 5 of the Birth Certificate, should also be compiled.

Each type and grade of reinforcing or prestressing steel should be identified. When the deterioration mechanism is corrosion because of chloride ingress, the critical chloride threshold values assumed in service life design models should be included. In general, grade 60 plain carbon low alloy reinforcing steel has an assumed mean value of the threshold of 0.60% wt. of cementitious materials in accordance with the selected design code used in this example (i.e., Model Code for Service Life Design, *fib* Bulletin 34, 2006). Appendix C summarizes critical chloride thresholds for several grades of stainless steel including low carbon chromium, austenitic, and duplex (austenitic-ferritic).

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Section 6 – Construction Materials – Concrete Mix Design Summary

Structure Name / Inventory ID #   Ochoco Creek Bridge / 22324

			Cementitious Materials										Chloride Migration Coefficient, $D_{RCM,0}$ (in²/yr)	
			Cement		Supplemental Cementitious Materials (SCMs)									
					Fly Ash (FA) AASHTO M295/ ASTM C618		Slag (GGBFS) AASHTO M302/ ASTM C989		Silica Fume (SF) AASHTO M307/ ASTM C1240		Cement + SCM Unit weight	Water/ Cement Ratio w/c	RCM Test per Nordtest - NTBuild 492	
Concrete Class	Mix Designation	28-day f'c (PSI)	AASHTO/ ASTM Spec.	Type	%	Class C/F/N	%	Grade 100/120	%		(lb/yd³)		Mean, μ	Std Dev, σ
Design - Trial Batch														
4000 HPC	NT-1b	4000	M85/C150	I	30				4		651	0.39	0.644	0.258
4000	NT-2b	4000	M85/C150	I			30				691	0.39	0.354	0.142
3300	NT-3	3300	M85/C150	I			30				556	0.49	0.468	0.187
4000	26S6KNG8M7	4000	M85/C150	I/II			30				574	0.465	0.717	0.287
4000 HPC	266TZ1F5CS	4000	M85/C150	I/II			30		4		649	0.401	0.636	0.254
Construction														
4000	26S6KNG8M7	4000	M85/C150	I/II			30				574	0.465	0.611	0.244
4000 HPC	6TZ1F5CS	4000	M85/C150	I/II			30		4		649	0.401	0.596	0.238
8280	KRP H71Y3	8280	M85/C150	III							710	0.36	0.46	0.184

Section 6 - Concrete Mix Data

Structure Name / Inventory ID # Ochoco Creek Bridge / 22324

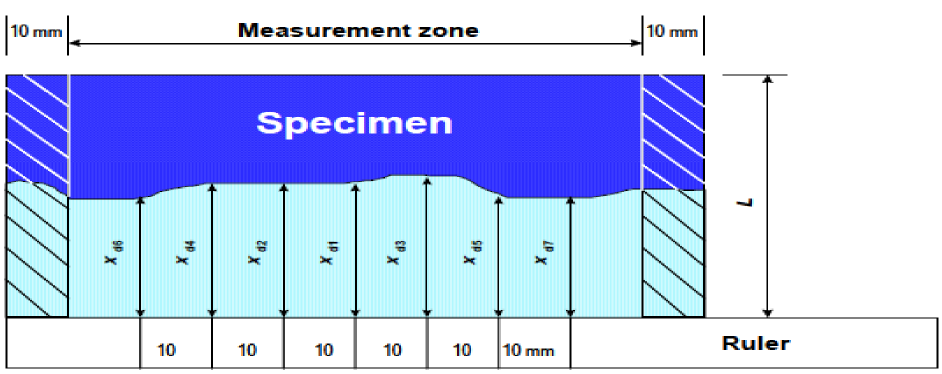
Mix Producer	Central Oregon Redi-Mix			
Mix ID	266TZ1F5CS			
Concrete Specification	Oregon DOT Standard Specifications, 2015 - Section 00540			
Concrete Class	4000 HPC Deck			
Materials	Type/Specification	Supplier	Wt. (lbs)	
Cementitious				
Cement	Type I-II/ AASHTO M85	Cal Portland	429	
Supplemental Cementitious Materials (SCMs)				SCM %
Fly Ash (FA)				
Slag (GGBFS)		Ash Grove	195	30%
Silica Fume (SF)		BASF	25	4%
		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	
Admixtures				
				Wt. (oz)
Air Entrainment	AEA-90	BASF		13
High Range Water Reducer	PS-1466	BASF		39
			3	52
Water				
Batch Water			171	
Aggregate Moisture Water			89	
Admixture Water			3	
		Total Water	263	
Total Batch				
Total Batch Weight			3788	
Batch Volume			1	yd^3
Relative Yield				0.954
Density			133.8	lb/ft^3
Adj. Cementitious Content			619	lb/yd^3
Water/Cement (w/c) Ratio		w/c=	0.405	

Section 6 - Chloride Migration Test Results

Laboratory	Siva Corrosion Services, Inc. 1313 Wilmington Pike, Suite 2B West Chester, PA 19382	Report ID Report Date Test Purpose Test Method	100103-01-2 12/17/15 Chloride Migration NT Build 492
Organization	Oregon DOT (owner) 4040 Fairview Industrial Drive, SE MS-4 Salem, OR 97302	Production Date Arrival Date Test Date	11/17/15 12/02/15 12/15/15
Project Component Material Type	Ochoco Creek Bridge Bridge Deck - Span 1 Concrete - Class 4000 HPC Deck	Specimen Age Mix ID	28 days 266TZ1F5CS

		Sample #		
Specimen Data	Units	1	2	3
Length	[mm]	202	202	202
Diameter	[mm]	102	102	102
Thickness, **L**	[mm]	48.1	46.7	50.6
Diameter	[mm]	102	102	102
Test Data				
Applied Voltage, **U**	[volts]	25	25	20
Test Duration, **t**	[hours]	24	24	24
Initial Current	[mA]	69.5	69.5	66.7
Final Current	[mA]	75.9	73.6	70.7
Initial Temperature	[°C]	24	24	24
Final Temperature	[°C]	21	21	21
Average Temperature, **T**	[°C]	22.5	22.5	22.5

Chloride Penetration Depth, x_d - all [mm]								
	x_{d6}	x_{d4}	x_{d2}	x_{d1}	x_{d3}	x_{d5}	x_{d7}	$\mathbf{x_d}$ (ave.)
Test Sample 1	23.7	23.2	23.3	25.1	25.3	23.2	19.4	23.3
Test Sample 2	21.5	23.3	n/a	20.5	25.3	22.3	20.1	22.2
Test Sample 3	18.2	24.6	16.9	20.5	24.4	23.6	23.6	21.7



		Sample #					
Test Results	Units	1	2	3		ave.	
D_{nssm}, non steady state migration coefficient	[10^{-12} m^2/s]	12.59	11.60	15.30		13.16	= $D_{RCM,0}$
	[in^2/yr]	0.616	0.567	0.748		0.644	

Section 6 - Reinforcing Steel Data

Structure Name / Inventory ID # Ochoco Creek Bridge / 22324

Type	AASHTO/ ASTM Spec	Yield Strength, F_y (MPa)	Tensile Strength, F_u (MPa)	Critical Chloride Threshold (% wt of cementitious) used in design calculations	
				Mean, μ	Std Dev, σ
Plain Carbon Low Alloy	M31/A615	60	90	0.60	0.15
Plain Carbon Low Alloy	M31/A706	60	90	0.60	0.15
Plain Carbon - Epoxy Coated	M31/A615	60	90	0.60	0.15
Plain Carbon - Epoxy Coated	M31/A706	60	90	0.60	0.15
7-Wire Strand (low relaxation)	M203/A416	243	270	0.40	0.10

F2.7 Section 7 – Structural Component Durability Data

This section of the Birth Certificate contains the data that will be used to evaluate the service life of components of new structures. A summary table listing all structure component types identifies the following:

- The intended service life of each component
- Whether the component is replaceable or non-replaceable during the intended life
- Environmental exposure zone description
- Metal/reinforcement deterioration mechanism (corrosion from chlorides and/or carbonation)
- Concrete deterioration mechanisms (freeze-thaw, internal/external chemicals)
- Applied Durability Strategy for the applicable deterioration mechanisms, selected from (see Section 2.5 of the Summary Guide for more information):
  - Avoidance approach
  - Design to resist approach by:
    - Deemed to satisfy provisions
    - Partial-factor design (semi-probabilistic design)
    - Full probabilistic reliability-based methodology, and Reliability Index, β
- Primary Protection Strategies, including material's own resistance and multiple layer protection (coatings, overlays, and Post Tensioning Protection Levels PL1 to PL3 in accordance with *fib* Bulletin 33 [14])
- Durability limit state(s) defining end of service life, relating to the extent of acceptable damage (depassivation, cracking, spalling, loss of section)

The purpose of the summary tables is to consolidate the Service Life Design intent in one easy to access location. It is recommended to provide separate summary tables for the non-replaceable main structural components, replaceable components, and other ancillary material components. Schematic drawings of these components are used to link the more general information shown in the summary tables to more specific detailed service life data tables created for each component.

It may be necessary to divide the bridge into major components, subcomponents, and localized areas. In this example, the major structural components are abutments, piers, and spans. Subcomponents for abutments and piers are typically piles, footings or pile caps, columns or walls, and pier caps or cross beams. Subcomponents of spans are girders, diaphragms, bridge decks and traffic railings. Subcomponents may also be categorized into localized areas where the exposure classes are different or where specific details are known to behave differently. Examples would be the ends of girders at locations directly under potentially leaky expansion joints or tall pier columns of overpass structures, where the lower section of column is in a de-icing splash zone and the upper section is in an atmospheric zone. Concrete components should be identified by environmental exposure, concrete class and mix design, reinforcement type and grade, and critical cover dimension.

For the full probabilistic and partial factor Service Life Design strategies, the component's intended service life duration, environmental loading magnitude, and concrete and reinforcing steel durability properties are required. In the case of chloride-induced corrosion deterioration, the required parameters are surface chloride concentration, average annual temperature at the site, initial concrete chloride content, chloride migration coefficient with aging exponent, and critical chloride content to initiate corrosion of the reinforcing.

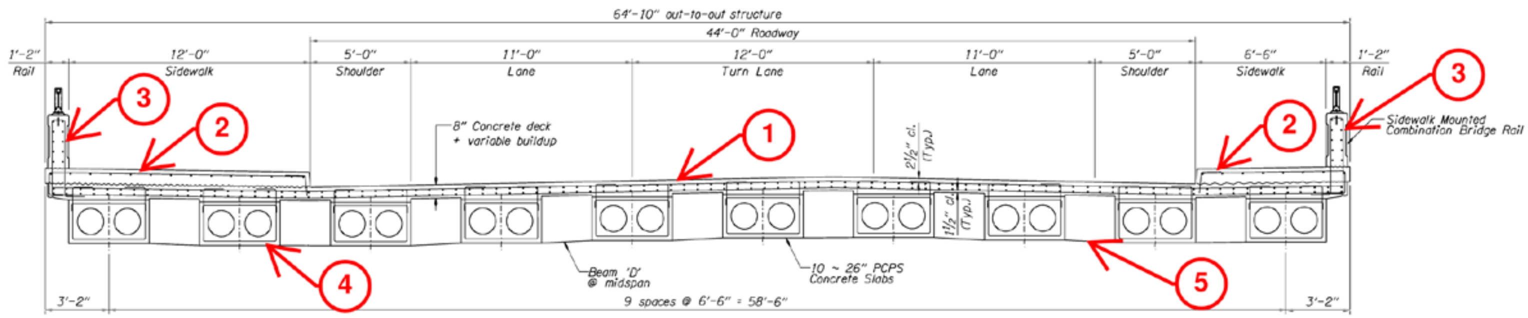
During design, materials and structure dimensions are selected to satisfy the owner's Service Life Design intent. Reliability based, full probabilistic calculations are performed to establish the expected service life duration of each different component type. As part of the SHRP2 R19A project, a full probabilistic spreadsheet tool has been developed for this purpose and is available on the dedicated project web page.

At this time, no universally accepted codes or standards have quantified appropriate load and resistance factors to be used for current Service Life Design deterioration models. However, in Appendix D Example #4, a process has been developed to compute load and resistance factors based on repeated full probabilistic analyses. The purpose of that exercise was to show how the partial factor calculation procedure can be easily undertaken.

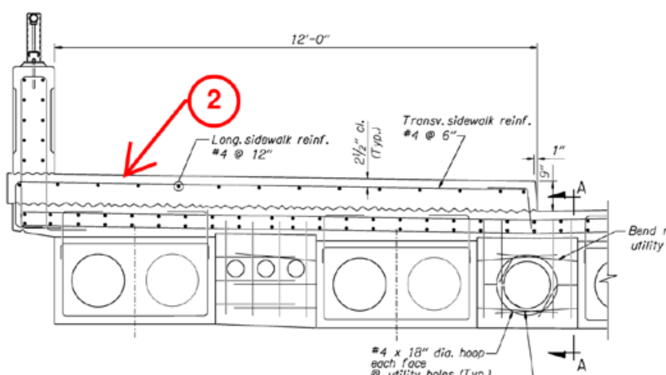
Since the deemed-to-satisfy and avoidance of deterioration Service Life Design strategies do not use mathematical modelling to evaluate service life duration, these components can be grouped together in two separate tables. For the deemed-to-satisfy strategy, the justifying code provisions should be identified. For the avoidance strategy, the mitigating design methodology should be listed.

Section 7 - Structural Component Identification - Superstructure

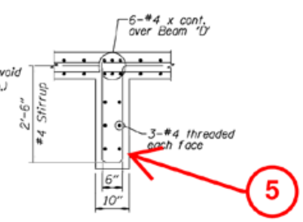
Structure Name / Inventory ID # Ochoco Creek Bridge / 22324



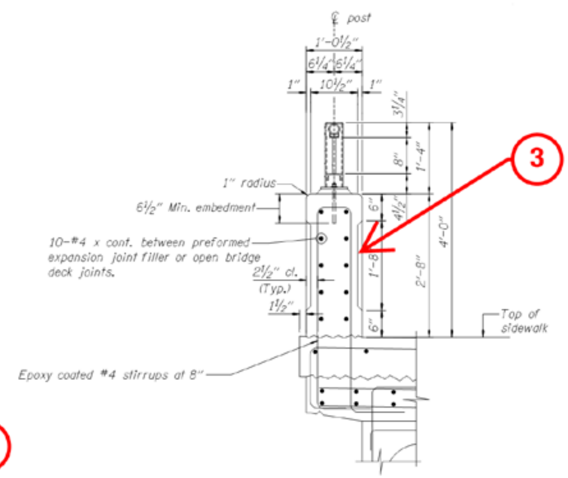
TYPICAL DECK SECTION



PARTIAL DECK DETAIL



BEAM 'D' - SECTION A-A



TYPICAL SECTION

1 - Bridge Deck 2 - Sidewalk 3 - Traffic Railing 4 - Prestressed Slabs 5 - Diaphragm

Section 7 - Component Service Life Design Summary

Structure Name / Inventory ID# Ochoco Creek Bridge / 22324

Concrete Components	1 - Deck	2 - Sidewalk	3 - Traffic Barriers	4 - Prestressed Slabs	5 - Diaphragms	6 - Abutment Walls	7 - Footings/ Pile Caps	
Service Life Requirements								
Non-Replaceable	x	x	x	x	XD	x	x	
Replaceable								
Service Life Duration (years)	100	100	40	100	100	100	100	
Reinforcement Deterioration Mechanisms								
Corrosion from Chlorides	x	x	x	x	XD	x	x	
Corrosion from Carbonation								
Environmental Exposure (per EN 206)								
Class (**XC**arbonation/ **XD**e-icing/ **XS**eawater)	XD	XD	XD	XD	XD	XD	XD	
Level (1-4)	3	3	3	1	1	1	1	
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	x	x	
Reliability Index, β=	1.3	1.3	1.3	1.3	1.3	1.3	1.3	
Protection Strategy								
Material's own resistance	x	x	x	x	x	x	x	
Multi-stage system (overlay/coating)								
Use non-reactive materials (CRR)								
Cathodic Protection								
Limit State								
Corrosion initiation (Depassivation)	x	x	x	x	x	x	x	
Corrosion Propagation (cracking)								
Corrosion Propogation (spalling)								
Corrosion Propagation (section loss)								

Section 7 - Component Service Life Design Summary

Structure Name / Inventory ID# Ochoco Creek Bridge / 22324

Concrete Components	1 - Deck	2 - Sidewalk	3 - Traffic Barriers	4 - Prestressed Slabs	5 - Diaphragms	6 - Abutment Walls	7 - Footings/ Pile Caps	
Concrete Deterioration Mechanisms								
Freeze-Thaw	x	x	x	x	x	x	x	
Salt Scaling	x	x	x					
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)	XF	XF	XF	XF	XF	XF	XF	
Level (1-4)								
Design Strategy								
Avoidance								
Deterioration Modeling								
Deemed-to-satisfy	x	x	x	x	x	x	x	
Partial Factor								
Full-Probabilistic								
Reliability Index, β=								
Protection Strategy								
Use non-reactive materials								
Restrict material sources								
Air Entrainment	x	x	x	x	x	x	x	
Thermal Curing Plan								
Protective Barrier (overlay)								
Limit State								
Critical degree of saturation								
Critical freezing temperature								

Section 7 – Component Service Life Design Summary

Structure Name / Inventory ID# Ochoco Creek Bridge / 22324

Non-Concrete Components	8 - Expansion Joint (Seals)	9 - Elastomeric Bearings	10 - Steel Railings	10 - 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)								
Class (**XC**arbonation/ **XD**e-icing/ **XS**eawater)			XD					
Level (1-4)			3					
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				
Other Material Deterioration Mechanisms								
Abrasion/Erosion								
Coating failure			x					
Ultraviolet breakdown								
Other (see component details)								
Design Strategy								
Avoidance								
Deterioration Modeling								

Section 7 – Component Service Life Design Summary

Structure Name / Inventory ID# Ochoco Creek Bridge / 22324

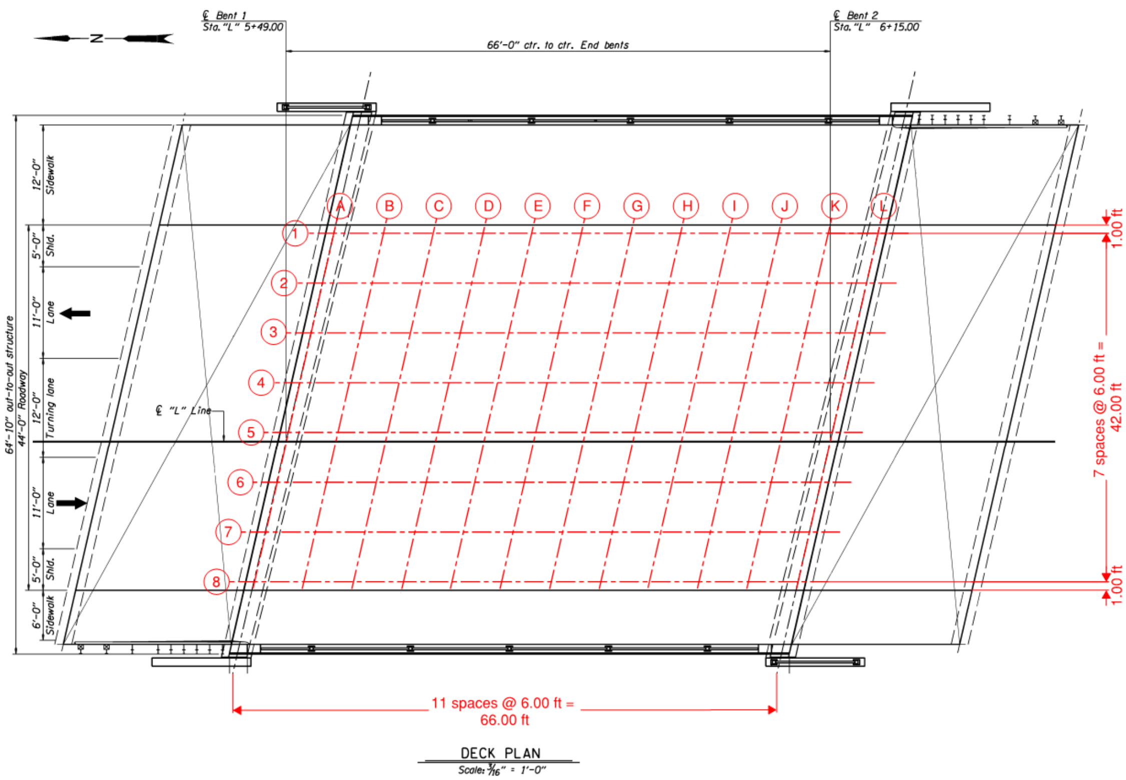
Non-Concrete Components	8 - Expansion Joint (Seals)	9 - Elastomeric Bearings	10 - Steel Railings	10 - Steel Piles				
Deemed-to-satisfy (Historical user data)	x	x						
Partial Factor								
Full-Probabilistic								
Reliability Index, β=								
Protection Strategy								
Protective coatings			x					
Other (see component details)								
Limit State								
Initiation of joint leakage	x							
__% surface coating defects								

Cover dimensions on the hardened concrete are made on the as-built structure and recorded as shown on the following two pages. During construction, the as-built cover dimensions were measured and found to meet or exceed the minimum required cover. However, the data were lost when transferring from the covermeter. The cover measurements shown are not the actual measured dimensions, but values chosen specifically to show how low covers may affect the service life of the structure. The statistical mean and standard deviation for each component is computed and recorded. The method shown for analyzing the concrete cover data is from the German Concrete and Construction Association, DBV [15]. A minimum of 20 points is necessary to use the procedure. Recorded values are mapped on a grid and can be color coded based on their magnitude. In the example, values in red and orange are cover dimensions less than required, whereas values in green are larger than required. The map gives a good indication of potential problem areas where the cover dimensions are low and can be used as a guide to areas where corrosion "hot spots" would likely occur sooner.

For this example, the nominal cover dimension specified in the contract documents was 2.5 inches (in.) with a safety margin of 0.6 in. to account for placement tolerances. This establishes a minimum required cover of 1.9 in. The qualitative procedure to evaluate whether the component cover is acceptable, is to count the number of measurements that are less than the minimum required cover. The maximum number of points allowed is a function of the sample size. For 96 points, 7 nonconforming measurements are allowed. In this example, 10 points do not conform, meaning the component does not satisfy qualitative requirements. However, a quantitative procedure can then by applied to see if better results can be achieved. As seen on the following page, the statistical percentage of measurements below the required minimum is 9% which exceeds the target threshold of 5%. In this case, the component does not comply. Depending on the magnitude of the deficiency, the Owner may require the Contractor to perform remediation or pay a penalty, similar to what is done when concrete cylinder strength tests do not meet specifications. The acceptance criteria must be included in the contract specifications.

Section 7 – Structure Component Data - Cover Measurements

Component	Deck	Standard	German Concrete and Construction Association - DBV, Concrete Cover and Reinforcement per Eurocode 2
Location	Span 1 top mat		
		Sampling	Grid (equally spaced measurement points)



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 / N	7	Fail
Safety margin	Δc	0.6					
Req'd min 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	
			% cover depth < c_{min}	F(x)	$= p(x)^k/(1+p(x)^k)$	9%	Fail

The properties used during the design of the project, as well as those achieved during construction testing are to be recorded on the Birth Certificate. The amount of data being recorded dictates the use of separate tables for each component. The full probabilistic method requires mean property values, standard deviations, and statistical distribution type for each variable, whereas the partial factor method requires mean values and load and resistance factors.

After all construction data are collected and recorded, calculations are again performed to compute as-built service life duration of each component. For example, during the design of a multi-span bridge, all piers would have the same design parameters and thus have the same expected service life. However, during construction, each pier could have different measured cover depth or test results for concrete durability properties, and any deficiency or surplus could result in a shorter or longer predicted as-built service life.

In this example, the bridge deck concrete assumed in design was a 30% fly ash mix that had a chloride migration coefficient of 0.644 square inch per year (in^2/yr) and an aging exponent of 0.60 in^2/yr. At the construction stage, it was decided to change to a 30% slag mix that had a chloride migration coefficient of 0.596 in^2/yr. Data on aging exponents are documented in *fib* Bulletins 34 [2] and 76 [16] for different cement and supplemental cementitious materials. For cement with 6% to 20% slag, aging is 0.35 with a standard deviation of 0.16, and with 36% to 65% slag, aging is 0.40 with a standard deviation of 0.18. An interpolated value of 0.38 with 0.17 standard deviation was chosen for the 30% slag mix. When substituted, the slag mix design with the assumed 2.5 in. cover provided for a 100-year service life. However, at the end of construction the actual mean cover was 2.4 in., resulting in a reduced service life of 85 years. This shows the significance of achieving required covers.

The structure component data sheets are set up to allow future in-service monitoring data and remaining service life calculations to be updated and recorded. The procedure for that is developed in Section 10.

Section 7 - Structure Component Data

Component Name	Deck	Figure ID	Superstructure 1	Required Service Life	100 [yrs]
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 (same as Design unless noted)	
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	0.70	0.35		
Transfer Function		Δx	[in]	Beta A=0, B=50	0.35	0.22		
Temperature at Site		T_{real}	[°F]	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	0.596	0.238
Aging Exponent		a	n/a	Beta A=0, B=1	0.60	0.15	0.38	0.17
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	0.15		
Clear Cover		c	[in]	Log-Normal	2.5	0.35	2.4	0.42

Equation (B2.1-1)

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

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)

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

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, a		Service Life, t_{SL}	End of Service Date
	Testing	Age, t	No.		[in^2/yr]		[wt-%/cem]		n/a		[yr]	[yyyy]
Life Cycle Stage	Date	[yr]	Samples	Test Method	Mean, μ	Std Dev, σ	Mean, μ	Std Dev, σ	Mean, μ	Std Dev, σ		
Design/Construction												
Assumed Design (Trial Batch)		0.0767		NT Build 492	0.339	0.1	0.70	0.35	0.60	0.15	>100	2117
		100			0.005							
As-Constructed	6/1/2017	0.0767	3	NT Build 492	0.314	0.1	0.70	0.35	0.38	0.17	85	2102
		100			0.021							
In Service Durability Monitoring					Measured Properties from Chloride Profiling Tests				Regression Calculation		Monte Carlo Calculation	
Monitoring Inspection 1												
Monitoring Inspection 2												
Monitoring Inspection 3												
Monitoring Inspection 4												
Monitoring Inspection 5												
Monitoring Inspection 6												
Monitoring Inspection 7												
Monitoring Inspection 8												

F2.8 Section 8 – Maintenance, Inspection and Monitoring Plans

An overall Preservation Plan is one of the most critical components in the Birth Certificate document. It is used to identify the unique activities to be performed on the structure to help ensure its safe and efficient use during its operational service life. The Preservation Plan should be written by the Owner, with input from the engineer responsible for the design, the resident engineer responsible for construction inspection, and the Owner's structures maintenance manager. These individuals should have the first-hand knowledge and practical experience to be able to identify the critical components and subcomponents of the structure that will likely be the first to exhibit signs of deterioration. The format for the Preservation Plan is best suited as a table with the required dates for each type of inspection and maintenance activities to be performed, similar to an automobile owner's manual or aircraft maintenance manual. Although the Preservation Plan is created during the design phase of a structure, it is intended that the plan will be constantly updated throughout the life of the structure.

The Preservation Plan is divided into separate inspection and maintenance subsections to complement the differing skill sets of the crews performing these work activities.

Inspection Plan

State transportation departments typically have a dedicated bridge inspection manual that defines inspection activities and frequencies to be performed. The Oregon DOT Bridge Inspection Manual [17] identifies seven types of inspections as follows:

Initial	Once (prior to commissioning)
Routine Safety	Periodic (biennial)
Underwater	Periodic (maximum of 5 years based on condition)
Fracture Critical	Periodic (biennial)
In-Depth Monitoring	Periodic (less frequent – every 5 to 10 years)
Special	As required (not originally planned, or before expiration of the warranty guarantee period)
Damage	After extreme event (flood, fire, earthquake)

The Inspection Plan should identify visual examination and other nondestructive testing procedures to obtain sufficient data to monitor and assess the long-term behavior of the structure. Each of the seven inspection types has a different primary focus. A separate plan should be developed for each inspection type. A typical Inspection Plan includes identification of:

- Items to be visually inspected with special instructions on how to perform inspection.
- Potential "hot spots" or locations of earliest anticipated deterioration in the structure.

- Items requiring in-depth destructive or non-destructive testing and the locations and frequency they are to be performed and the test methods to be used. For each parameter investigated, the standard for sampling and testing should be given in the Inspection Plan.

The as-built and in-service material resistance parameters are to be compared to the parameters anticipated during the design, and any changes will be reflected with an update to the predicted residual service life. Variations from the design assumptions may initiate the need for altering the schedule and scope of future inspections. The documentation of the results from the initial inspection forms the basis for the Birth Certificate.

Initial Inspection

The primary purpose of the Initial Inspection is to verify the structure complies with the design specification before it is placed into service. In the through-life asset management concept, data gathered from the Initial Inspection are used to establish the condition of the structure immediately after construction is completed. The data to be collected in an Initial Inspection correlate directly with the basic material resistance parameters that were used to define the required (design) service life of the structure. Typical parameters to be measured are:

- Concrete cover dimensions
- Chloride migration or diffusion coefficients
- Coating thickness measurements (during construction this should have been verified as part of quality assurance but spot checks during Initial Inspection give added confidence)

Routine Safety Inspection

A Routine Safety Inspection is a regularly scheduled inspection consisting of observations and/or measurements needed to determine the physical and functional condition of the structure, to identify any changes from initial or previously recorded conditions, and to ensure that the structure continues to satisfy present service requirements. Routine Safety Inspections are primarily visual in nature and performed biennially. Most Owners have detailed written procedure for Routine Inspections. The Routine Inspection Plan should be supplemented by unique details required by the structure under consideration.

In-depth Inspection

An In-depth Inspection is important for the concept of evaluating durability performance of the bridge. The Birth Certificate is used to collect and record data that will be used to monitor the behavior of the structure to the measured environmental loading parameters that exist at the site. Then a comparison can be made to the deterioration and structural models that were anticipated during the design, and to update the residual service life of the structure. That procedure is discussed under Section 10 of this document. In-depth Inspections are suggested to be performed on a 10-year to 20-year recurrence interval.

Special Inspection

Special Inspections are performed at the discretion of the Owner based on engineering advice and are used for monitoring a known or suspected deficiency. Deficiencies are generally not anticipated during design and therefore not identified in the original Inspection Plan.

Damage Inspection

Damage Inspections are performed after an extreme event such as an earthquake, hurricane, flood, fire, or vehicle or vessel collision, and are performed on an as-needed basis. The purpose of a Damage Inspection is to determine the extent of structural damage and the need for closure or reduced usage. Some forms of minor damage, like concrete cracking, may have little or no effect on a structure's load-carrying capacity. However, the damage may have some adverse effect on the durability resistance of the structure, which would then be reflected in the birth certificate as a modification to the residual service life of the structure.

Maintenance Plan

The FHWA Bridge Preservation Guide [18] provides definitions for routine, cyclical, condition-based and preventative maintenance and preservation activities typically performed on highway bridges.

The Maintenance Plan should identify activities specific to the structure and activities common to all structures, including the frequency the activity is to be performed. Major maintenance and repair activities such as bridge deck overlays or total deck replacement, although typically not performed by the Owner's maintenance crews, are included in the Maintenance Plan.

A detailed plan was not developed for this example.

F2.9 Section 9 – Dismantling Plan

This section of the Birth Certificate addresses what actions to take with the structure at the end of its service life. In the general scheme of sustainability of facilities, a dismantling plan completes the full circle of through-life design. With a required (design) service life of 75 years and up, structures will invariably outlive their designers, necessitating the capture of designers' knowledge to be used by the ensuing caretakers of the facility. Therefore, the Dismantling Plan should include the following:

- List of long-lived elements that might be used in future structures (e.g. foundations) and design evaluation procedures for reuse.
- List of provisions made for end of design life restorations (e.g. provision for future installation of cathodic protection).
- List of potential hazardous materials used in the construction and their location.
- List of recyclable components and materials and methods for disposal (e.g., asphalt wearing surfaces, concrete, and steel).
- Anticipated disposal strategies.
- Special demolition details required by the type of structural systems used (e.g., pre- or post-tensioning).
- Special details required to maintain structural stability during demolition (e.g., structures originally constructed on falsework, or by special cantilevering methods).
- Future structure replacement strategies (e.g., within same footprint, staging of new construction and demolition of existing structure).

Because of the simplicity and size of this example structure, no demolition plan was developed.

F2.10 Section 10 – In-service Monitoring

After the structure is placed in-service, periodic monitoring of the deterioration process is essential to evaluating the performance over time. In this section of the documentation, the results of in-service testing and subsequent calculations regarding the residual service life are stored. As described in Section F2.7, in-service documentation can be added to the Structure Component Data sheets provided in Section 7 of the Birth Certificate. The Birth Certificate document may also provide predictions of future performance, against which the performance of the structure could be compared during its lifetime.

The monitoring and evaluation process is best described using the case of chloride-induced reinforcing steel corrosion. In this example, monitoring methods comprise taking concrete core samples from the structure. The samples are analyzed to establish the chloride profile versus depth, which in turn allows the evaluation of the surface chloride content (the environmental loading), and the apparent chloride diffusion coefficient (the material resistance) at that specific age of the structure. ASTM C823, Standard Practice for Examination and Sampling of Hardened Concrete in Constructions [19] can be used as a guide to determine the number of samples necessary to be considered as statistically significant for a specific component. A minimum of five samples is suggested.

The variation of chloride diffusion coefficient with time, t, is defined mathematically by a power function, $A(t) = (t_o/t)^a$, where "a" is the aging exponent. During design, the value for the aging exponent is assumed based on the properties of the concrete mix being used and the micro-environmental conditions. For in-service behavior, a regression analysis is used to determine the aging exponent by considering chloride diffusion coefficients for at least three different points in time. When the diffusion coefficient is plotted versus time on a log-log scale, the data points are approximately linear, and the slope of the line represents the aging exponent. The procedure is shown graphically on the Structure Component In-Service Data Analysis figure with the data from four intermediate testing dates. A detailed explanation of the process is given in *fib* Bulletin 76 [16].

Since the structure was completed in 2016, there is no in-service data available yet. Hypothetical data was therefore developed to exemplify the approach. Data includes chloride profile test results for chloride surface concentration and chloride diffusion coefficients after 10, 20, 30, and 40 years. At the time of each monitoring inspection, a regression analysis is used to determine an aging exponent. Then a full probabilistic calculation is performed with the newly calculated aging exponent, to estimate the age when the service life limit state is projected to be exceeded. This calculation is performed based on the reliability index of $\beta = 1.3$ established during design. The selected reliability index is equivalent to a probability of exceeding the limit state (i.e., depassivation of the reinforcement) of 9.68%. The updated estimates of age when the service limit state is exceeded is presented in this example as a single value. The chloride surface concentration was assumed to be 0.70 wt. % cement during the design, and the hypothetical in-service data considered this value to vary from 0.68 to 0.72 wt. % cement. The chloride diffusion coefficients vary with time and in this hypothetical case the aging exponent was found to be higher than the original assumed value. Nevertheless, the as-built concrete cover was less than originally designed and combined with the other hypothetical in-service data, the estimated age of the bridge when the limit state is exceeded varied over time from 84 to 98 years.

In this example it was decided to present a single value for the estimate of age when the service limit state is exceeded; however, updated model calculations might be assessed by other means. Figure F2 presents computed time-dependent changes in the reliability index (top) and the corresponding probability of failure (bottom) to comply with the design limit state of reinforcement depassivation. The input data used for these calculations includes the as-constructed chloride migration coefficient and aging factor data documented in Section 7 of this example. Other input data used the original design values. To demonstrate the impact of potential differences between the design and as-constructed values, the average cover thickness is varied from 2.4 in. to 2.6 in.

The figures demonstrate that, for the given chloride migration coefficient inputs, a cover of 2.5 in. yields a reliability index of 1.3 at 100 years, complying with the target value of 1.3. A 2.4 in. cover provides a reliability index of 1.25 at 100 years and the 1.3 target reliability index is exceeded between 85 to 90 years. A slight increase in the average cover up to 2.6 in. yields a reliability index of 1.35 after 100 years and the 1.3 target is not exceeded until 110 to 115 years.

Alternatively, the assessment of updated model calculations might consider the change in the probability of failure to comply with the limit state (i.e., reinforcement depassivation). The target reliability index of 1.3 corresponds to a probability of failure of 9.68%[1], which is shown in the bottom part of Figure F2, as a broken red line. The different average covers considered in Figure F2 results in the following probabilities of failure after 100 years:

- 10.5% for the 2.4 in. average cover
- 9.6% for the 2.5 in. average cover
- 8.9% for the 2.6 in. average cover

[1] Often this value is rounded to 10%, which in fact corresponds to a reliability index of approximately 1.28.

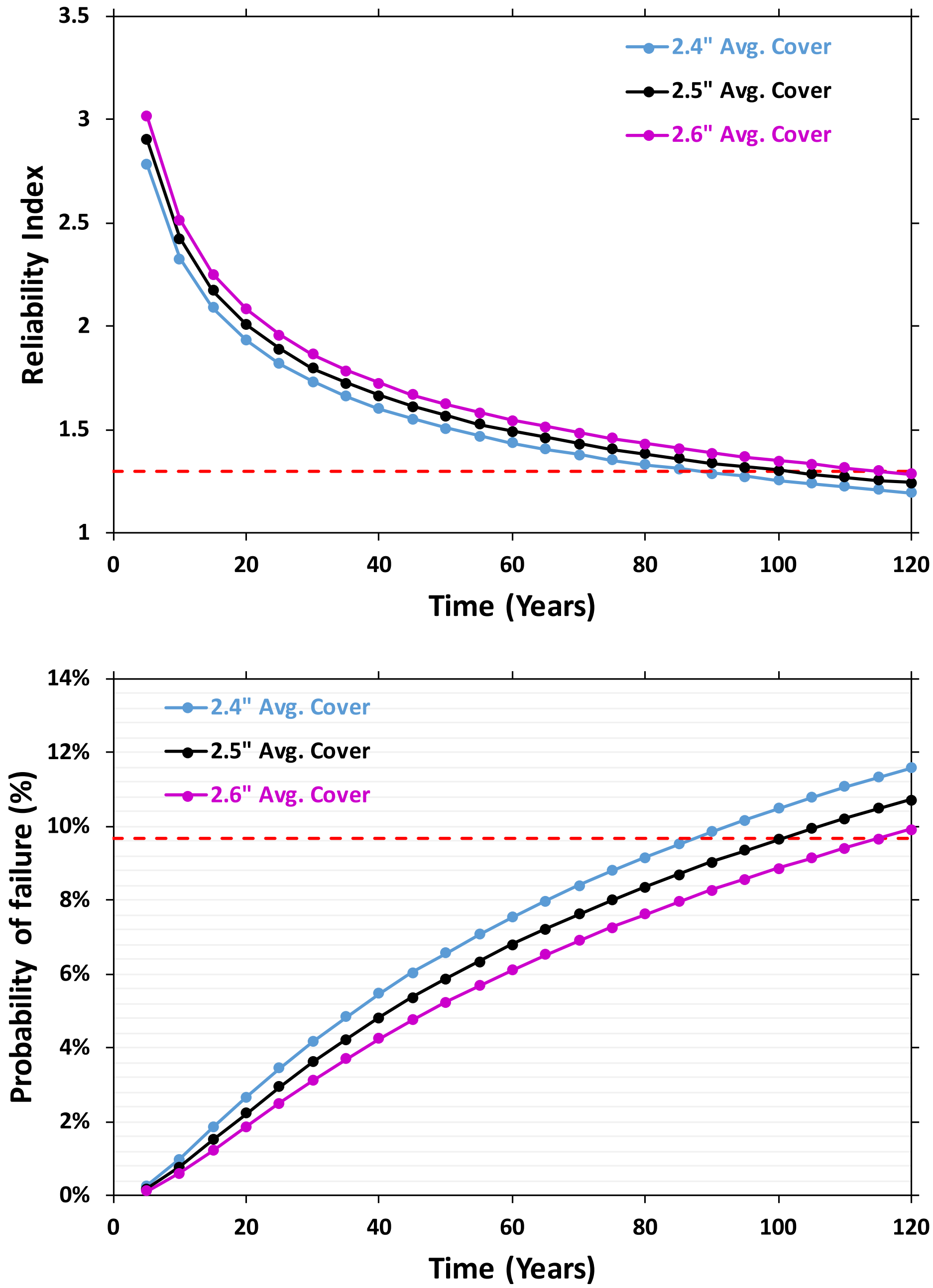


Figure F2 – Time-dependent change in reliability index (top) and corresponding probability of failure to comply with the design limit state (bottom). Input data used comprises the original design input values documented in Section 7 of Birth Certificate Example, except the As-Constructed chloride migration coefficient and age factor input values are used and the average cover thickness is varied for demonstration.

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Section 7 - Structure Component Data

Component Name	Deck	Figure ID	Superstructure 1	Required Service Life	100 [yrs]
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 (same as Design unless noted)	
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	0.70	0.35		
Transfer Function		Δx	[in]	Beta A=0, B=50	0.35	0.22		
Temperature at Site		T_{real}	[°F]	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	0.596	0.238
Aging Exponent		a	n/a	Beta A=0, B=1	0.60	0.15	0.38	0.17
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	0.15		
Clear Cover		c	[in]	Log-Normal	2.5	0.35	2.4	0.42

Equation (B2.1-1)

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

Equation (B2.1-2)

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

Equation (B2.1-3)

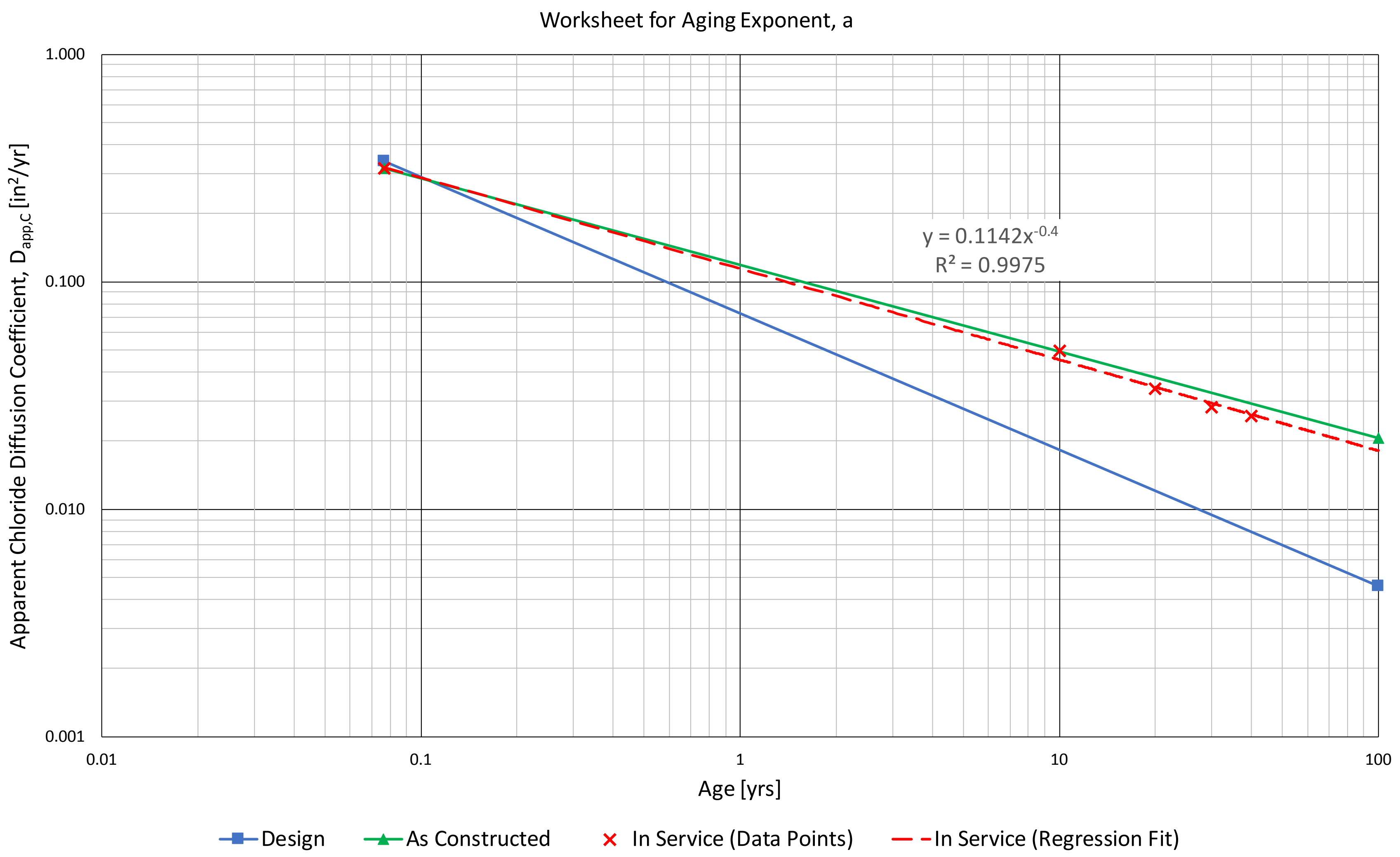
$$k_e = \exp\left(b_e\left(\frac{1}{T_{ref}} - \frac{1}{T_{real}}\right)\right)$$

Equation (B2.1-4)

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

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, a		Service Life, t_{SL}	End of Service Date
					[in^2/yr]		[wt-%/cem]		n/a		[yr]	[yyyy]
Life Cycle Stage	Testing Date	Age, t [yr]	No. Samples	Test Method	Mean, μ	Std Dev, σ	Mean, μ	Std Dev, σ	Mean, μ	Std Dev, σ		
Design/Construction												
Assumed Design (Trial Batch)		0.0767		NT Build 492	0.339	0.1	0.70	0.35	0.60	0.15	>100	2117
		100			0.005							
As-Constructed	6/1/2017	0.0767	3	NT Build 492	0.314	0.1	0.70	0.35	0.38	0.17	85	2102
		100			0.021							
In Service Durability Monitoring					Measured Properties from Chloride Profiling Tests				Regression Calculation		Monte Carlo Calculation	
Monitoring Inspection 1	6/1/2027	10			0.0498	0.0199	0.68	0.34	0.38	0.17	94	2111
Monitoring Inspection 2	6/1/2037	20			0.0338	0.0135	0.68	0.34	0.39	0.18	98	2115
Monitoring Inspection 3	6/1/2047	30			0.0282	0.0113	0.70	0.35	0.40	0.18	94	2111
Monitoring Inspection 4	6/1/2057	40			0.0256	0.0102	0.72	0.37	0.40	0.18	84	2101
Monitoring Inspection 5												
Monitoring Inspection 6												
Monitoring Inspection 7												
Monitoring Inspection 8		100										

Section 7 - Structure Component In-Service Data Analysis



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