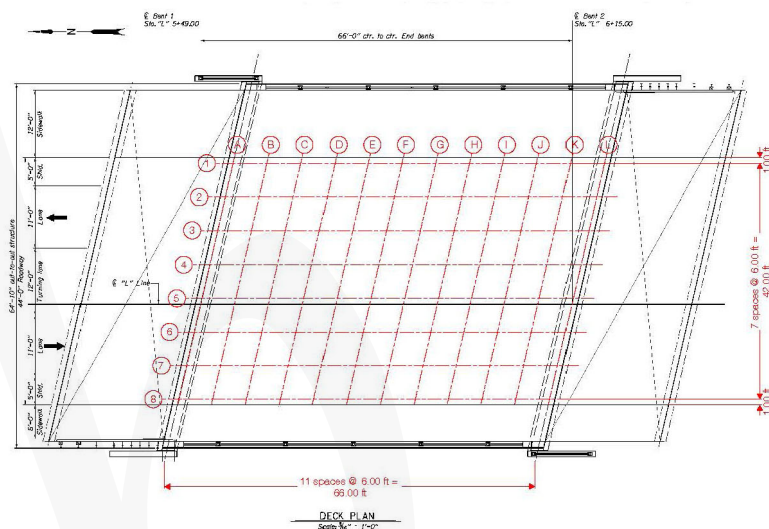




DECK PLAN
Scale: 1/8" = 1'-0"

As-Constructed Cover Dimensions at Grid Points [mm]												
	A	B	C	D	E	F	G	H	I	J	K	L
1	64	56	66	76	52	73	69	71	79	76	79	72
2	61	56	63	69	69	70	74	76	55	72	76	53
3	57	57	37	40	64	56	60	56	56	48	47	57
4	49	51	42	51	57	58	57	54	59	63	64	71
5	58	61	53	49	51	48	55	50	46	49	65	59
6	76	79	63	53	80	74	72	65	72	69	72	58
7	57	76	80	28	66	74	62	76	57	63	57	61
8	54	47	56	56	54	72	64	61	56	45	59	63

Birth Certificate and Through-Life Management Documentation

Technical report

fib 93 CEB • FIP Bulletin

Birth Certificate and Through-Life Management Documentation

Technical Report
Task Group 8.2

June 2020

Approval for this bulletin

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Preface

While it is generally accepted by owners and users that vehicles such as airplanes or cars must be subjected to a pre-defined maintenance plan during their lifetime, this is less obvious in public opinion for engineering structures and buildings. This may be related to the general feeling that “moving objects” should be more sensitive to aging and deterioration than “structures anchored in ground”! This may also relate to the fact that detailed maintenance manuals, which are considered obligatory by insurance companies, are generally for aircraft, boats and cars, but not systematically for civil engineering structures, except for iconic or major projects.

The performance-based approach to the durability design and assessment of concrete structures is also becoming increasingly popular in the construction sector. In recent years, numerous studies have been carried out worldwide in order to better assess the expected properties related to the durability of concrete. This has led to the standardization of test protocols, but also to a better understanding of the main parameters impacting the overall durability of concrete. Documentation related to durability indicators will then become increasingly necessary for the accurate implementation of a performance-based approach that enables the promotion of sustainable materials.

Durability models have a strong need for relevant in-field data feedback in order to define accurate inputs for modelling both during the design process (gathered from previous projects) and during the follow-up process to allow for re-calibration of inputs and re-assessment of durability expectations by the models if judged necessary.

A framework for data collection was therefore considered extremely importance by the *fib* Commission 8: *Durability*, and is the objective of this *fib* Technical report “Birth-certificate and Through-Life Management Documentation”. It is indeed very important to collect relevant data within a comprehensive and standardized format, as now proposed by this *fib* Bulletin. Thanks to its pre-defined format, compatible with the general *fib* framework, “Birth-certificate and Through-Life Management Documentation” will definitively be useful to owners for the maintenance plan and intervention strategies of their assets.

This operational technical report will also be very useful for designers, as it should encourage the collection of relevant information in databases to be used for future projects where a realistic assessment of expected properties is considered through largely similar concrete mix designs under given exposure conditions.

The Commission, which deals with durability aspects, hopes that this Bulletin will provide users a valuable tool and perspective on service life management issues.

Lionel Linger

Commission 8 *Durability* Chair

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Terminology

Birth certificate: 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 on completion of construction.

The birth certificate should provide and quantify specific details on parameters important to the durability and service life of the structure concerned (e.g. cover to reinforcement, concrete permeability, environmental exposure conditions, quality of workmanship achieved, etc) and the basis upon which future knowledge of through-life performance should be recorded. These parameters should be categorised as assumed, estimated, observed/measured, inferred/deduced.

The framework laid down in the birth certificate should provide a means of comparing actual in-service behaviour / performance with that anticipated at the time of design and/or the time of construction of the structure.

The birth certificate should facilitate ongoing (through-life) evaluation of the original service life which is likely to be achieved by the structure and/or individual components.

Commissioning: Start of planned use.

Condition assessment: A process of reviewing information gathered about the current condition of a structure or its components, its service environment and general circumstances, whereby its adequacy for future service may be established against specified performance requirements for a defined set of loadings and / or environmental circumstances.

Condition control: The overall through-life process for conserving the condition of a structure involving condition survey, condition assessment, condition evaluation, decision-making and the execution of any necessary interventions; performed as a part of the conservation process.

Condition survey: A process whereby information is acquired relating to the current condition of the structure with regard to its appearance, functionality, and / or ability to meet specified performance requirements with the aim of recognizing important limitations, defects and deterioration.

Conservation: Activities and measures taken which seek to ensure that the condition of a structure remains within satisfactory bounds to meet the performance requirements for the defined service life; that is in respect of structural safety, serviceability, durability and sustainability requirements, which may include considerations of relevant issues such as aesthetics.

Conservation plan: The overall plan for controlling and conserving the condition of a structure; i.e. condition survey, condition assessment, condition evaluation, decision-making and the execution of any necessary interventions.

Damage: Physical disruption or change in the condition of a structure or its components, brought about by external actions and influences, such that the current or future performance of the structure or its components will be impaired.

Decommissioning: Discontinuation or interruption of use.

Delayed birth certificate: A birth certificate document intended for use with existing structures for which no formal service life documentation was created at the time of design or construction.

Design service life: see *Specified (design) service life*.

Deterioration: Worsening of condition with time, or a progressive reduction in the ability of a structure or its components to perform according to their intended specifications. Typically deterioration of the structure or its components will be driven by chemical, mechanical, biological or physical processes or agents, or combinations thereof.

Deterioration mechanism: (Scientifically describable) process of the cause and development of deterioration.

Deterioration Model: Mathematical model that provides a quantified estimation of one or more aspects of structural performance as a function of time, taking deterioration into account.

Dismantlement: Planned demolition of a structure with separation of the structural members and structural materials, fulfilling disposal requirements.

Durability: The capability of structures, components, products or materials of continuing to be useful after an extended period of time and usage. In the context of performance-based design of structures, durability refers to the fulfilment of the performance requirements within the framework of the planned use and the foreseeable actions, without unforeseen expenditure on maintenance and repair.

Durability limit state (DLS): A limit state used to define the end of the service life of a structure. For reinforced concrete structures subjected to deterioration caused by corrosion of reinforcing steel, one or more of the following durability limit state levels may be used to define the end of service life:

- depassivation of the reinforcing steel (or initiation of corrosion)
- cracking of the cover concrete
- spalling of the cover concrete
- loss of steel cross section (and reduced structural capacity). This can be regarded as ULS
- collapse of the structure. This can be regarded as ULS

The Durability Limit State may change over time: for a new structure, depassivation may be the criterion, but after several decades spalling may have become the new criterion. Other limit states may also be defined.

Execution: All the activities and measures involved in the physical creation of a structure, including preparation for construction.

Environmental influences: Physical, chemical and biological actions resulting from the atmospheric and subsoil conditions or other characteristics of the surroundings to or internal conditions within the structure.

Ingress: The entry of substances into structural and / or non-structural components of a structure. Often the term “ingress” is associated with the entry of substances that cause deterioration (e.g., chlorides into reinforced or prestressed concrete, sulfates and carbon-dioxide (CO₂) into concretes, etc.).

Inspection: A primarily visual examination, often at close range, of a structure or its components with the objective of gathering information about their form, current condition, service environment and general circumstances. Condition is thus a subjective description (not quantified).

Intervention: A general term relating to an activity or series of activities taken to modify or preserve the future performance of a structure or its components.

Inventory: Detailed list or register of items or components, possibly classified by type, function or some other principal attributes. Inventory may be established to assist in the management of structures.

Investigation: The process of inquiry into the cause or mechanism associated with some form of deterioration of the structure and the evaluation of its significance in terms of its current and future performance. The term 'investigation' may also be employed during the assessment of defects and deficiencies. The process of inquiry might employ sampling, testing and various other means of gathering information about the structure, as well as theoretical studies to evaluate the importance of the findings in terms of the performance of the structure.

Maintenance: A set of planned (usually periodic) activities performed during the service life of the structure intended to either prevent or correct the effects of minor deterioration or mechanical wear of the structure or its components in order to keep their future durability at the level anticipated by the designer.

Maintenance activities involve recurrent or continuous measures which enable the structure to fulfil the requirements for reliability.

The term 'maintenance' is commonly applied in the context of building fabric components with a limited life, components associated with water management and rainwater run-off, items where regular intervention is required to maintain their effective operation etc. The term 'maintenance' is commonly applied to ancillary items such as gutters, drains, sealants, movement joints, bearings, etc.

Maintenance plan: Instructions for the foreseen maintenance specific to the structure considered. The plan should be flexible to allow additions or modifications to anticipated activities based on the observed in-service behaviour of the structure.

Management (of structures): Processes and procedures adopted for the maintenance, inspection, testing, assessment and repair or other remedial action of structures in order to provide effective control against durability limit state criteria to ensure the continued safe operation of individual structures or wider groupings of the inventory and related assets.

Management of structures often involves conflicting requirements and objectives, which invariably requires compromise and judgment about the action to be taken or not taken due to limitations in the available resources.

Monitoring: To keep watch over, recording progress and changes in materials and / or structural properties with time; possibly also controlling the functioning or working of an associated entity or process (e.g. warning alarms based upon parameters such as applied load, element deflection or some aspect of structural response).

Monitoring plan: Instructions for the monitoring specific to the structure.

Preventative intervention: A pro-active conservation activity concerned with applying some form of treatment or taking action prior to a change in a material property (e.g. such as that caused by the influence of carbonation or chlorides) adversely affecting the ability of the structure, or parts thereof, to meet the required performance levels because of deterioration.

Reactive intervention: A re-active conservation activity undertaken after deterioration and / or damage has become apparent / visible (e.g. cracking or spalling of concrete) such that, because of the deterioration, this has adversely affected the ability of the structure, or parts thereof, to meet the required performance levels (which may include consideration of issues such as aesthetics).

Re-Birth certificate: A dynamic document, report or technical file similar to the birth certificate for a structure, but related to the information and circumstances associated with a project for the repair / remediation / refurbishment of an existing structure or a part thereof to extend its anticipated service life beyond its original design service life.

Rehabilitation: Intervention to restore the performance of a structure or its component parts that are in a changed, defective, degraded or deteriorated state to the original level of performance, generally without restriction upon the materials or methods employed.

Remedial intervention: A conservation activity undertaken after a change in a material property (e.g. such as that caused by the influence of carbonation or chlorides) has adversely affected the ability of the structure, or parts thereof, to meet the required performance levels.

Required service life: The demand stated by the stakeholders (i.e. owners, users, contractors, society) for the period in which the required performance shall be achieved. Refer to Section 3.3.2.1 of the Model Code 2010.

Residual service life: The demand for the remaining period in which the required performance shall be achieved, used in the re-design of existing structures. A re-design may be considered when the performance at the time of inspection is significantly less than the anticipated level during the design. Refer to Section 3.3.2.1 of the Model Code 2010.

Restoration: Intervention to bring the structure or its component parts back to their original condition not only with regard to function and performance level anticipated by the designer, but also with regard to aesthetic appearance and possibly other (historical) considerations.

Service life: The period in which the required performance of a structure or structural element is achieved, when it is used for its intended purpose and under the expected conditions of use.

Serviceability limit state (SLS): State that corresponds to conditions beyond which specified service requirements for a structure or structural component are no longer met. Examples of serviceability limit states include structural deformations affecting appearance, comfort or functioning of a structure and vibrations causing discomfort or limiting effectiveness of the structure.

Specified (design) service life: The demand for the period in which the required performance shall be achieved, used in the design of new structures. Refer to Section 3.3.2.1 of the Model Code 2010.

The specified (design) service life is related to the required service life, as given by the stakeholders (i.e. owners, users, contractors, society) and/or by codes and standards and to the other implications of service criteria agreement e.g. with regard to structural analysis, maintenance and quality management.

Stakeholder: Person or organization that has a legitimate participation in a project. As a rule, the key stakeholders would be the founders, the owners, the residents, the users, the neighbours (if construction creates a nuisance for them), the contractor, the design and constructing team, the tenancy management team and the maintenance team. Other stakeholders may be the government and society.

Testing: Procedure aiming at obtaining information about the current condition or performance of a structure or its components.

Various types of testing are recognized, their classification being primarily on the basis of the amount of damage or interference caused to the structure. The main divisions are:

- non-destructive testing (NDT), which does not cause damage to the structure by the test procedure (e.g. testing with cover meter, radar, air-permeability, water absorption tests, surface moisture, electrical resistivity, acoustic emission, load testing in the elastic range, etc.),
- intrusive testing, which causes aesthetic or minor damage on the concrete surface (e.g. exposing steel for cover or carbonation tests, corrosion tests, drill powder collection for chemical analysis, etc.)
- destructive testing, which may cause damage to the structure (e.g., pull-out tests, core drilling, material sampling, load testing beyond the elastic range, etc.).

Ultimate limit state (ULS): State associated with collapse of a whole or part of a structure. Generally the ultimate limit state corresponds to the maximum load-carrying resistance of a structure or structural component. The maximum load-carrying resistance may change/decrease with time as a result of deterioration.

1. Introduction

1.1 Background

The concept of a Birth Certificate for structures was championed by Steen Rostam, former chair of Commission 5, and was first introduced in 1999 in *fib* Bulletins 1-3, *Structural Concrete Textbook*, 1st Edition¹⁻¹. The Birth Certificate was initially described as an operation and maintenance manual delivered to the Owner at the completion of construction and handover of the structure, similar to an automobile owner's manual.

Over the next nine years, the Birth Certificate was described in other *fib* Bulletins and industry reports. In May, 2008, Commission 5 established a task group to further develop the Birth Certificate concept. In 2015, Commission 5 was renamed to Commission 8 – *Durability*. That work has culminated in the publishing of this document.

1.2 Through-Life Management Concepts

Through-life management of a structure, includes planning and monitoring activities during each of the following phases in the life of the structure:

- Design
- Execution (Construction)
- Conservation (In-service Maintenance, Inspection and Intervention)
- Dismantlement (Demolition)

A well-conceived, executed, and documented through-life management plan is critical to maintaining an inventory of structures. How well each structure is designed, constructed, inspected, and maintained, all directly influence its service life. Condition information obtained during in-service use helps determine the rate of structure deterioration. Incorporating information or knowledge gained from the earlier phases in the life of the structure can assist in the decision making process for future phases. Identification of potentially weak areas (e.g. high permeability and/or shallow cover) and knowledge of the deterioration rate in advance of actual damage, allows for more accurate planning of funding requirements for future conservation, intervention, dismantlement, and if desired, replacement activities.

A timeline schematic showing the structure condition versus time throughout the various phases in the life of the structure is shown in Fig. 1-1. The Birth Certificate is shown to be issued to the Owner after the initial assessment of construction, although it is normally begun during the design phase.

This chapter was mainly authored by Bartholomew.

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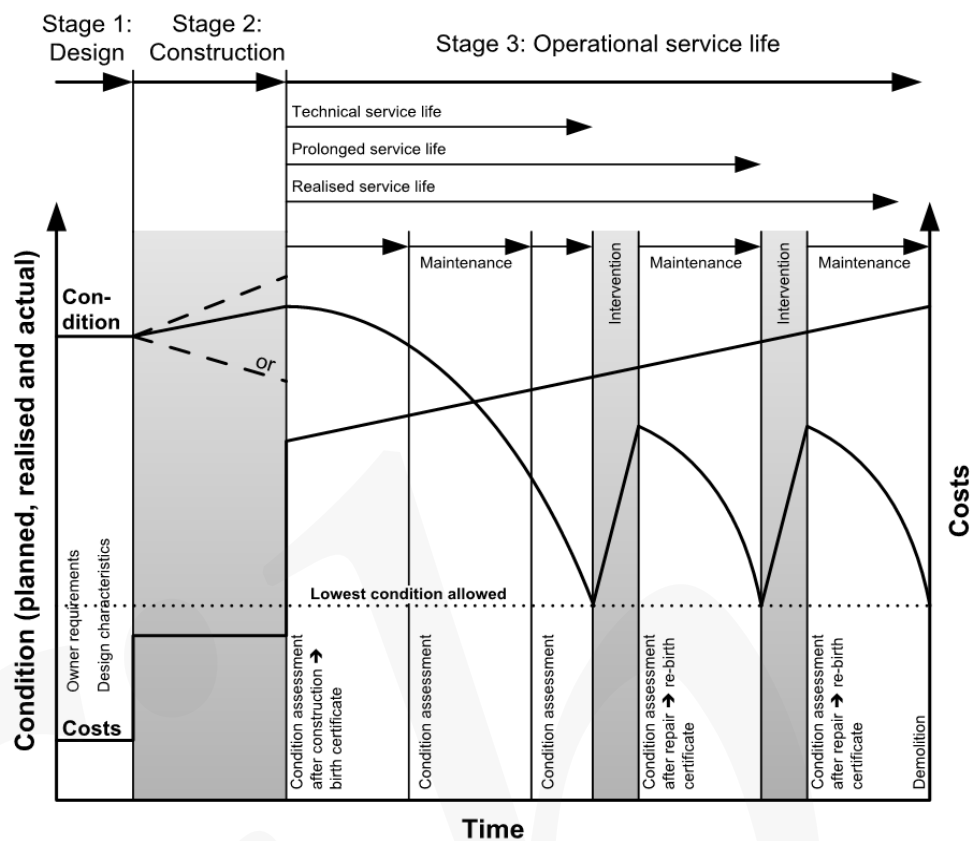


Fig. 1-1 Complete Service Life¹⁻²

Fig. 1-2 sketches de Sitter's Law of Fives¹⁻³. The meaning of the chart is that the later the intervention to correct design or construction mistakes, the higher its cost. This Law has been confirmed in practice¹⁻⁴.

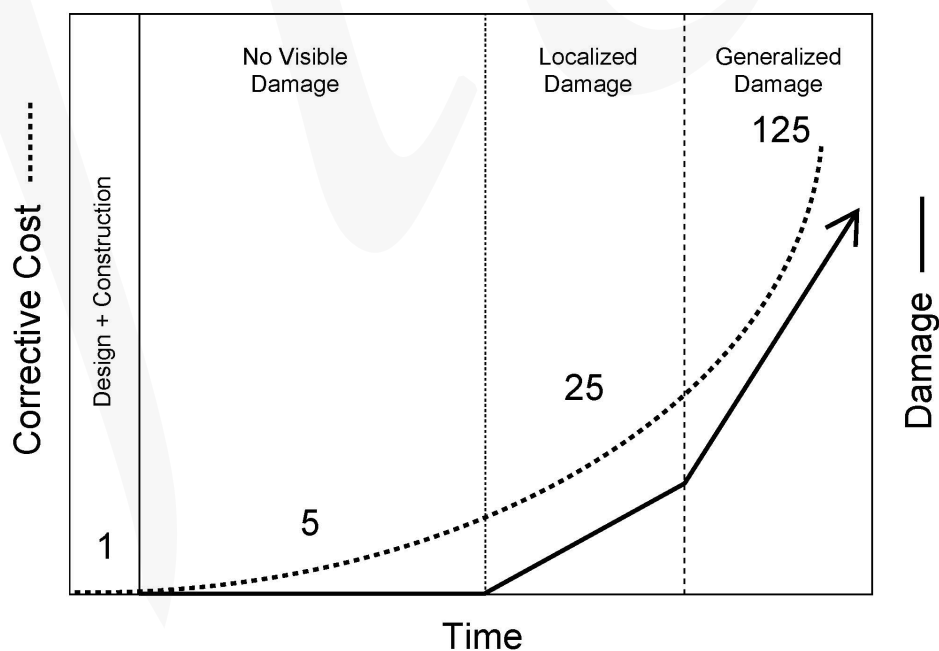


Fig. 1-2 De Sitter's Law of Fives (adapted from¹⁻³)

The Birth / Re-Birth certificate is a key component to the through-life management of structures. It provides a framework for establishing and documenting the design decisions, quality of workmanship and materials achieved during construction, and scheduled (and unscheduled) maintenance and performance and condition assessment activities that determine the remaining service life of structures in an Owner's inventory. Birth or Re-Birth certificates for each structure in an inventory form the basic building blocks for a thorough management of structures system.

1.3 Durability Design

The first phase in the Through-Life Management Plan is design for both structural integrity and durability. The latter also being known as Service Life Design.

Service Life Design is similar to Limit State or Load and Resistance Factor Design (LRFD) for structural strength. It is reliability based, like in many current codes (Eurocodes, AASHTO LRFD, etc.). In the *fib* Bulletin 34, *Model Code for Service Life Design*¹⁻⁵ and the *fib* Model Code 2010¹⁻⁶, four different approaches to Durability or Service Life Design are identified.

Full Probabilistic Method - Mathematical models are used to describe the anticipated and observed physical deterioration behaviour of the structure. Typical variables used in the model are environmental exposure actions or loads (demands), and material resistance properties (capacities). The input parameters usually represent random variables and therefore are described with a distribution function and distribution parameters (e.g. mean and standard deviation). To solve the reliability problem given with the limit state functions, approximate numerical procedures like First Order Reliability Method (FORM), Second Order Reliability Method (SORM) or the Monte-Carlo Simulation method are commonly used to obtain a solution. This type of sophisticated, highly analytical analysis is often considered to be beyond the experience level of most practicing structural design engineers, and the work effort is regarded as too time consuming and costly for structures with a low capital cost. The method has been typically reserved for large and monumental projects (large capital costs or critically important) or for projects where multiple smaller size structures are designed and completed all at once and the return on investment warrants its use, and in situations where the exposure environment significantly differs from severity described by the exposure classes. This method requires experienced engineers to select inputs for modelling. It is recommended that sensitivity studies of the critical parameters be undertaken to better understand their influence and prevent misuse of models.

Semi-Probabilistic Method → Partial Factor Method - The same mathematical model equations as the full probabilistic method are used, but the random variables are included as characteristic values combined with partial safety and / or combination factors for load and resistance variables to evaluate demand to capacity behaviour of the structure. Load and resistance factors are determined from a full probabilistic approach based on sufficient amount of data to predict the reliability level. Currently there is not enough long-term data available on deterioration rate vs. material durability behaviour to make this method usable to a sufficient level of reliability.

Deemed to Satisfy Method - This prescriptive approach is currently in use by most major codes. It is not based on mathematical modelling of deterioration, but rather is based on some minimal level of observed past performance behaviour. In general, very limited environmental loading scenarios, and very few concrete material compositions have been considered in developing the "deemed to satisfy" rules that have been used in the codes. The level of reliability achieved by rules of various design codes from around the world for chloride-induced corrosion, has been investigated and reported in *fib Bulletin 76, Benchmarking of deemed-to-satisfy provisions in standards*¹⁻⁷. The results of this study show that in many cases the reliability level provided by deemed-to-satisfy rules fall below the target reliabilities given in guidelines (e.g. ISO 2394¹⁻⁸, EN 1990¹⁻⁹). In the future, it is intended that deemed to satisfy rules will be established based on full probabilistic mathematical models or other well established research.

Avoidance of Deterioration or Design Out Method - This method applies to designs that either remove the environmental exposure actions or loads on the structure, or use materials that are presumed to have infinite resistance to the environmental loadings that the structure is exposed to. Stainless steel reinforcing is considered an example of this strategy to resist deterioration from chloride ingress. Although all materials have some rate of deterioration, stainless steel can have a critical chloride threshold of up to between two and ten times that of ordinary carbon steel reinforcement. Installation of cathodic protection systems is another avoidance strategy. In most cases, the cost of designing for Avoidance of Deterioration will be much higher and may not provide the most efficient through-life cycle solution. For other deterioration mechanisms, such as alkali-aggregate reaction, this may be the only design solution.

There are several mathematical deterioration models currently used to define the various physical deterioration mechanisms. The most widely used analytical model uses the error function solution to Fick's 2nd Law of diffusion to describe how chlorides from seawater or from road de-icing salts penetrate and diffuse from the surface of concrete structures down to the reinforcing steel layers. When a sufficient level of chloride concentration is reached at the surface of the reinforcing steel (corrosion initiation time), corrosion may begin. The corrosion initiation time is a function of the transport properties of the concrete and the cover thickness over the reinforcement. Research has shown that the apparent diffusion coefficient of the concrete is not constant, but decreases with age. This effect is partly captured by the use of an ageing factor that quantifies the reduction in the concrete diffusion coefficient over time. In order to properly determine realistic ageing factors for different concrete mix designs and exposure conditions, long-term performance data is needed.

More than one Service Life Design strategy may be employed in the design of a single structure. It is not only acceptable, but anticipated that avoidance, deemed-to-satisfy, full probabilistic, and partial factor methods will be used for different components of the same structure. There are several reasons for this. Corrosion of reinforcing steel in concrete structures from chloride ingress has been studied extensively and has an industry accepted mathematical deterioration model that allows a design solution by either the full probabilistic or partial factor methods. However, there may be instances where the chloride environment is so severe that the most practical solution is to apply the avoidance

of deterioration method by incorporating corrosion resistant stainless steel reinforcing. In other cases, deterioration models may not exist, but previous experience has shown that following a deemed-to-satisfy prescriptive specification provides a known service life.

Considering the practicality of using the Full Probabilistic Method, the lower reliability of the Deemed to Satisfy Method, and the potential excess conservatism of the Avoidance of Deterioration Method, the Partial Factor Method appears to have the most potential for use on the large population of conventional structures. The values used for the partial factors are based on assumed standard deviations of the parameters and are also dependent on the beta-value adopted in the underlying full probabilistic method. But it too has shortcomings in that adequate load and resistance factors have not been calibrated to actual performance data. One way to ensure the acquisition of long term data is to develop a process to begin collecting it now. This has led to the concept of the Birth Certificate Documents which are described in detail in this Bulletin.



2. Documents

2.1 Birth Certificate

The purpose of the Birth Certificate is to assist owners in the facilitation of through life management of a structure bearing in mind that several generations of engineers have to deal with monitoring and maintaining structures throughout their service lives. The document contains engineering documentation of the design, construction, as built quality of the structure or its elements (real cover depth, concrete strength, permeability and transport properties of concrete cover, porosity, etc.) and in-service phases in a structure's life, with the primary goal of predicting its specified design and/or remaining service life. Birth Certificates are intended to supplement three documents currently kept by most owners; as-constructed drawings, routine inspection reports, and load capacity ratings. These three documents help to identify the current capacity of the structure but do not predict how long it is expected to remain in service. In the same way that the load capacity ratings and action effects provide important information on structural design intent, design deterioration mechanisms and materials performance characteristics provide important information on serviceability intent but they are generally not included in a formal handover document.

Ideally, Birth Certificate documentation should be initiated during the design phase for a new structure. At the time of design, the site specific exposure conditions are evaluated and material properties are selected, with that information being readily accessible. Because the practice of service life design is in its infancy, many Owners already possess a significant inventory of structures, most or all 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 performed at three different times can be used to determine surface chloride concentration, the apparent coefficient of chloride diffusion, and the ageing exponent for a structure exposed to seawater or de-icing chemicals.

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 remaining service life behaviour expected for the entire group. In this case, the Delayed Birth Certificate concept can be applied to groupings of structures, and relieve the owner from having to evaluate each individual structure in their entire existing inventory.

2.2 Re-Birth Certificate

A Re-Birth Certificate is initiated for a structure which has had a condition survey and assessment performed, and has been repaired or rehabilitated with the intent of extending its residual service life.

The goal of Birth, Re-Birth, and Delayed Birth Certificates is the same – recording the information related to structure durability in order to assist in the prediction of the time that a structure is able to remain in service and define what ongoing condition assessment and maintenance is required.

Birth, Re-Birth, and Delayed Birth Certificates are organized in the same manner, and for simplicity the term Birth Certificate will be used to describe each of the documents.

2.3 Document Organization

A Birth Certificate for a structure contains separate sections as shown in Table 2-1. There may be situations where not all of the sections are necessary. For instance, a Dismantling Plan would only be required when a complex demolition sequence or a hazardous substance has been incorporated in the structure. An In-Service Conservation Plan may not be necessary for structures where an owner has a thorough system-wide inspection and maintenance 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. (Sample suggested formats for the individual sections are contained in Appendix B. An example is given in Appendix A for a highway bridge.)

Table 2-1 Birth Certificate Document Contents

Section	Title
1	Structure Identification
2	Durability Specifications & Standards
3	Environmental Exposure Conditions
4	Deterioration Mechanism & Models
5	Construction Materials
6	Durability Test Methods
7	Structure Component Durability Data
8	In-Service Conservation Plan
9	Dismantling Plan

2.3.1 Structure Identification

This introductory section to the Birth Certificate contains basic textual and graphical information to identify the structure, including the following:

- Identification
 - Owner or agency responsible for maintaining the structure
 - Structure classification (bridge, building, dam, locks, pier/wharf, tunnel, etc.)
 - Name of the structure
 - Structure inventory ID #
 - Structure type and description (include basic overall dimensions, types of construction and materials used, and any other information to adequately

describe the physical appearance and makeup of the structure. Include also a short description of the important special equipment or structural elements, such as type and manufacturer of the bearings, expansion joints for highway structures; type and manufacturer of the internal or external tendons, stay cables.

- Geographic location
- Commission Date
- Design and Construction Contract Information
 - Designer (including contact information)
 - Construction Contractor (including contact information)
 - Major material/component suppliers (including contact information)
 - Design schedule milestones (start, completion)
 - Construction schedule milestones (bid date, award date, notice to proceed, final acceptance date, opening date)
 - Form of construction procurement contract (e.g. Tender Design, Design-Build, Design-Build-Operate, Public-Private-Partnership, etc.)
 - Date and expected remaining service-life at consignment to the Owner
 - Design and Construction Cost Data for the new structure (Design fee, Engineer's Estimate, Bid Price, Final Adjusted Construction Contract Cost)
 - Design and Construction Cost Data for the repair work (Design fee, Engineer's Estimate, Bid Price, Final Adjusted Construction Contract Cost)

An overall General Plan and Elevation drawing and photograph(s) should be used to supplement the Identification of Asset sheet.

2.3.2 Durability Specifications and Standards

- Environmental Parameters
 - Macro environment (urban, rural, industrial area, marine and distance from seaside)
 - Macro Climate (Cold, Temperate, Hot wet, or Hot dry)
 - Annual Mean Temperature
 - Annual Mean Relative Humidity
 - Annual Precipitation/Snowfall
 - Prevailing winds (velocity, direction)
 - Deterioration Mechanisms (carbonation, chloride ingress, freeze-thaw, etc.)
- Design Parameters
 - Consequence Class (CC) for loss of human life, or economic, social or environmental consequences – CC1 to CC3 per Table A2-1 of the Model Code for Service Life Design (MC-SLD)²⁻¹
 - Design Supervision Level (DSL) as a function of minimum requirements for checking of the design – DSL1 to DSL3 per Table A4-1 of MC-SLD²⁻¹

- Construction Parameters
 - Execution Class (EXC) as a function of the level of construction management and inspection – EXC1 to EXC3 per Table A5-1 of MC-SLD²⁻¹
 - Quality management report
 - Non-Conformance Reports and their resolution
- In-Service Parameters
 - Condition Control Category relating to importance of the structure, its function, specified (design) service life, ease of maintenance and cost
 - Category A: Structures managed by proactive condition control activities (systematic monitoring of parameters relevant to deterioration processes critical to durability, installed sensors)
 - Category B: Structures or parts thereof which are managed by reactive activities (planned periodic inspection)
 - Category C: Structures or parts thereof for which condition control is not practical (no direct inspection/testing, e.g. foundations)
 - Condition Control Levels (CCL) as a function of the owner's planned maintenance and inspection regimes – CCL0 to CCL3 per Table A6-1 of MC-SLD²⁻¹

2.3.3 Environmental Exposure Summary

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 are 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 as-built 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.

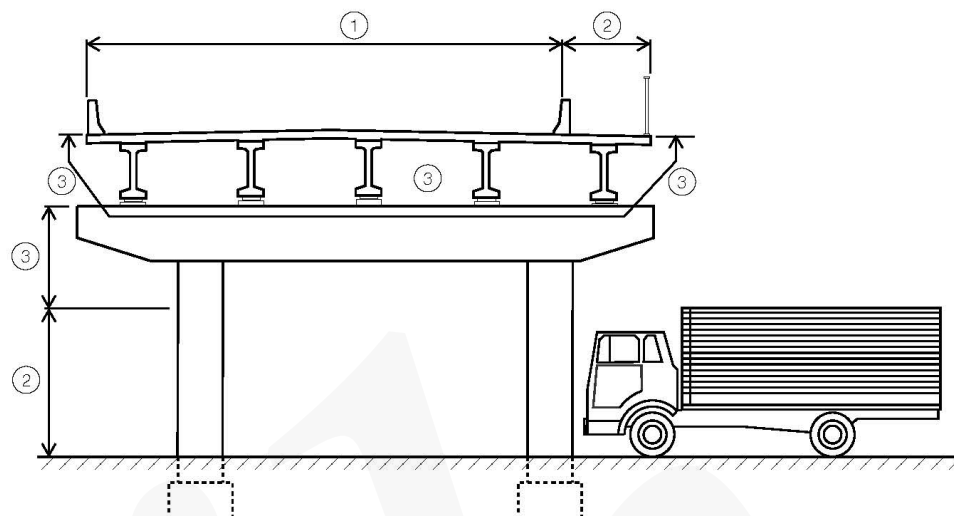
In accordance with EN 206²⁻², exposure classes and severities should be identified as follows:

Table 2-2 Environmental exposure classes

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 (see example in Fig. 2-3. 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 measuring chloride profiles.



Exposure Classifications per EN-206

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 airborne chlorides				
		Surfaces exposed to de-icing chlorides				
		Bridge deck/sidewalk			0.70	0.35
		Bridge railing (beyond 3m from curb)			0.56	0.28

Fig. 2-1 Environmental Exposure Classes/Zones

2.3.4 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*²⁻¹, and *fib* Model Code 2010²⁻³, define industry standard models for the initiation phase of deterioration due to 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, choice of parameters and justification, 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 sub-section should be used for each deterioration model assumed in the

structure. Table 2-3 provides an example pertaining to the full probabilistic deterioration model for chloride induced corrosion of reinforcing steel.

Table 2-3 Full Probabilistic Deterioration Model for Chloride Induced Corrosion²⁻¹

Deterioration Mechanism/Model

Deterioration Mechanism	Full probabilistic design method for chloride induced corrosion - uncracked concrete		
Deterioration Model	Fick's 2 nd Law (analytical model with assumptions on boundary and initial conditions)		
Source	fib Bulletin 34 - Model Code for Service Life Design, Appendix B2		
$C_{crit} \geq C_o + (C_{S,\Delta x} - C_o) \cdot \left[1 - \operatorname{erf} \left(\frac{a_{cov} - \Delta x}{2\sqrt{D_{app,C} \cdot t}} \right) \right]$			Equation (B2.1-1)
$D_{app,C} = K_e \cdot D_{RCM,0} \cdot K_t \cdot A(t)$			Equation (B2.1-2)
$k_e = \exp \left(b_e \left(\frac{1}{T_{ref}} - \frac{1}{T_{real}} \right) \right)$			Equation (B2.1-3)
$A(t) = \left(\frac{t_o}{t} \right)^\alpha$			Equation (B2.1-4)
Function Variables	Description	Units	Distribution Function
t	Time	[yr]	n/a
x	Depth with corresponding content of chlorides $C(x,t)$	[mm]	n/a
C_{crit}	Critical chloride content	[wt.-%/cem]	Beta, a=0.2, b=2.0
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 2 nd law of diffusion)	[mm]	Beta, a=0, b=50
a_{cov}	Concrete cover	[mm]	Log-Normal
$D_{app,C}$	Apparent coefficient of chloride diffusion through concrete	[mm ² /yr]	n/a
$D_{RCM,0}$	Chloride migration coefficient	[mm 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	[K]	Normal
$A(t)$	Subfunction considering the ageing	[-]	n/a
t_o	Reference point of time	[yr]	Constant = 0.0767
α	Ageing exponent	[-]	Beta, a=0.0, b=1.0

Deterioration mechanisms that have not yet been developed into mathematical models are generally treated with the Avoidance of Deterioration or the Deemed to Satisfy design approaches, and will be addressed in Section 7 of the Birth Certificate.

2.3.5 Construction Materials

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 identified. This includes the proportions of cement (brand and type), water, coarse and fine aggregates, supplementary cementing materials such as silica fume, fly ash or blast furnace slag, and all other admixtures. A sample mix design is shown in Table 2-4.

Table 2-4 Concrete Mix Design

Concrete Mix Data

Structure Name Ochoco Creek Bridge

Inventory ID # 22324

Mix Producer	Central Oregon Redi-Mix			
Mix ID	266TZ1F5CS			
Concrete Specification	Oregon DOT Standard Specifications, 2015 - Section 00540			
Concrete Class	4000 (27.5 N/mm ²) HPC Deck			
Materials	Type/Specification	Supplier	Wt. (kg)	
Cementitious				
Cement	Type I-II/ AASHTO M85	Cal Portland	195	
Supplemental Cementitious Materials (SCMs)				SCM %
Fly Ash (FA)				
Slag (GGBFS)		Ash Grove	88	0.30
Silica Fume (SF)		BASF	11	0.04
		Total Cementitious	294	
Aggregates				
Coarse	19 mm - # Round	Lone Pine Pit	735	
Coarse	9.5 mm Pea Rock	Lone Pine Pit	93	
Fine	Sand	Lone Pine Pit	514	
Fiber Mesh	Novomesh 950		2	
		Sub-total	1'344	
Aggregate Moisture Water			-40	
		Total Aggregate	1'304	
Admixtures				
				Wt. (gm)
Air Entrainment	AEA-90	BASF		369
Hi Range Water Reducer	PS-1466	BASF		1'106
			1	1'475
Water				
Batch Water			78	
Aggregate Moisture Water			40	
Admixture Water			1	
		Total Water	119	
Total Batch				
Total Batch Weight			1'717	
Batch Volume			0.765	m ³
Relative Yield				0.730
Density			1'638	kg/m ³
Adjusted Cementitious Content			281	kg/m ³
Water/Cement Ratio		w/c=	0.40	

A summary table which includes durability test results for all concrete mixes is shown in Table 2-5. This includes concretes used for pre-construction trial batches during design, as well as actual test results monitored during construction.

Table 2-5 Concrete Material Properties Summary

Concrete Mix Design Summary

Structure Name
Ochocho Creek Bridge

Inventory ID #
22324

Cementitious Materials				Durability Design Properties (per <i>fib</i> Bulletin 34)											
Concrete Class	Mix Designation	28-day Strength, f'_c (N/mm ²)	Unit weight (kg/m ³)	Cement	Supplemental Cementitious Materials (SCMs)				Cement + SCM Unit weight	Water/Cement Ratio w/c	Chloride Migration Coefficient, D_{RCM} (mm ² /yr) - (Normal Distribution function)	Aging Exponent, α - (values assumed with Beta Distribution function, $a=0$, $b=1$)			
					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	%	(kg/m ³)
				Design - Trial Batch				Type							
4000 HPC	NT-1b	27.5	2245	M85/C150	I	30				295	0.39	416	166	0.6	0.15
4000	NT-2b	27.5	2291	M85/C150	I		30			320	0.39	228	91	0.45	0.20
3300	NT-3	23	2236	M85/C150	I		30			260	0.49	302	121	0.45	0.20
4000	26S6KNG8M7	23	2199	M85/C150	I/II		30			260	0.46	463	185	0.45	0.20
4000 HPC	266TZ1F5CS	27.5	2140	M85/C150	I/II		30		4	281	0.40	410	164	0.45	0.20
Construction															
4000 HPC	6TZ1F5CS	27.5	2140	M85/C150	I/II		30			311	0.41	384	154	0.45	0.20
8280	KRP H71Y3	57	2311	M85/C150	III					322	0.36	297	119	0.30	0.12

AASHTO M85/ASTM C150 - Portland Cement

AASHTO M240/ASTM C595 - Blended Hydraulic Cements

ASTM C1157 - Hydraulic Cement (classification for special characteristics/options)

Each type and grade of reinforcing or prestressing steel should be identified with the critical chloride threshold assumed to cause corrosion initiation. Table 2-6 identifies typical reinforcing and prestressing steels used in the United States. Values reported for the critical chloride threshold for galvanized and stainless steels are given for comparative purposes only and are not considered as industry validated.

Table 2-6 Reinforcing / Prestressing Steel Material Properties

Type	AASHTO/ ASTM Spec	Yield Strength, F _y (N/mm ²)	Tensile Strength, F _u (N/mm ²)	Alloy Type	UNS Designation	Critical Chloride Threshold (% wt of cementitious)	
						Beta Distribution function, a=0.20, b=2.0	
						Mean, μ	Std Dev, σ
Plain Carbon Low Alloy	M31/A615	415	620	n/a	n/a	0.60	0.15
Plain Carbon Low Alloy	M31/A706	415	620	n/a	n/a	0.60	0.15
Plain Carbon - Epoxy Coated	M31/A615	415	620	n/a	n/a	0.60	0.15
Plain Carbon - Epoxy Coated	M31/A706	415	620	n/a	n/a	0.60	0.15
Plain Carbon - Galvanized	M31/A615	415	620	n/a	n/a	1.00	0.25
Plain Carbon - Galvanized	M31/A706	415	620	n/a	n/a	1.00	0.25
Low-Carbon Chromium (690)	M334/A1035	690	1'030	CM	K42050	1.20	0.30
Low-Carbon Chromium (830)	M334/A1035	830	1'030	CS	K81550	2.40	0.60
Austenitic Stainless	M334/A955	415	620	316LN	S31653	6.00	1.50
Duplex Stainless	M335/A955	415	620	2'205	531803	6.00	1.50
Deformed Bar - Type II	M275/A722	830	1'035	n/a	n/a	0.40	0.15
7-Wire Strand (low relaxation)	M203/A416	1'675	1'860	n/a	n/a	0.40	0.15

2.3.6 Durability Tests

While virtually all material 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. There are a number of standardized tests that have been developed to quantify the durability performance. In general, the standard contract specifications will need to be supplemented with these durability testing requirements. 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. Several of the more common standardized test specifications are given in Tables 2-7 and 2-8.

Table 2-7 Durability tests used during the design phase

Objective	Potential Testing Specifications	Information Obtained
Determine design chloride loading from concrete cores taken from existing/nearby structures	Nordtest Method NT Build 443 / Accelerated Chloride Penetration (Bulk Diffusion Test) ²⁻⁴	C_s or $C_{s,\Delta x}$ and Δx Chloride Surface Concentration, used in chloride deterioration model
	CEN/TS 12390-11 / Testing hardened concrete – Part 11: Determination of the chloride resistance of concrete unidirectional diffusion ²⁻⁵	
	ASTM C1556 / Determining the Apparent Chloride Diffusion Coefficient of Cementitious Mixtures by Bulk Diffusion (used with ASTM C1543) ²⁻⁶	
	Nordtest Method NT Build 492 / Chloride Migration Coefficient from Non-Steady-State Migration Experiments (Rapid Chloride Migration, RCM) ²⁻⁷	
Determine design chloride durability resistance properties from trial batch mix designs	Nordtest NT Build 208 / Chloride Content by Volhard Titration ²⁻⁸	$D_{RCM,0'}$ Chloride Migration Coefficient used in chloride deterioration model
Determine initial chloride content of concrete from trial batch mix designs	ASTM C1152 / Acid Soluble Chloride in Mortar and Concrete ²⁻⁹	$C_{O'}$ Initial Chloride Content used in chloride deterioration model
	ASTM D512 / Chloride Ion in Water ²⁻¹⁰	
Determine design chloride loading in brackish water	ASTM D516 / Sulfate Ion in Water ²⁻¹¹	$C_{eqv'}$ Natural Chloride Content of Sea Water used in chloride deterioration model
Determine presence of chemicals (sulfates) in soil and water	ASTM C1580 / Water-Soluble Sulfate in Soil ²⁻¹²	Sulfate content (% mass SO_4 in sample)
	RILEM CPC-18 / Measurement of Hardened Concrete Carbonation Depth ²⁻¹³	
Determine carbonation durability resistance properties from trial batch mix designs	Accelerated Carbonation Test (ACC) / DARTS: Durable and Reliable Tunnel Structures: Data European Commission, Growths 2000, Contract G1RD-CT-2000-00476, Project GrD1-25633, 2004 ²⁻¹⁴	$R_{ACC,0}^{-1}$, Inverse Effective Carbonation Resistance used in carbonation deterioration model
	CEN/TS 12390-10 / Testing hardened concrete – Part 10: Determination of the carbonation resistance of concrete at atmospheric levels of carbon dioxide ²⁻¹⁵	
	Nordtest Method NT Build 357 / Concrete, Repairing Materials and Protective Coating: Carbonation Resistance ²⁻¹⁶	

Table 2-8 Durability tests used during construction

Objective	Potential Testing Specifications	Information Obtained
Verify chloride durability resistance properties during production*	Nordtest Method NT Build 492 (Rapid Chloride Migration, RCM) ²⁻⁷	As-built $D_{RCM,0}$ Chloride Migration Coefficient used in chloride deterioration model
Determine initial chloride content of concrete during production	Nordtest NT Build 208 ²⁻⁸ ASTM C1152 ²⁻⁹	As-built C_{O_i} Initial Chloride Content used in chloride deterioration model
Verify concrete carbonation durability resistance properties during production	RILEM CPC-18 ²⁻¹³ Accelerated Carbonation Test (ACC) / DARTS ²⁻¹⁴ CEN/TS 12390-10 Carbonation Resistance ²⁻¹⁵	As-built $R_{NAC,0}^{-1}/R_{ACC,0}^{-1}$, Inverse Effective Carbonation Resistance used in the carbonation deterioration model
Verify clear concrete cover in completed structure	BS1881:204 Testing concrete. Recommendations on the use of electromagnetic covermeters ²⁻¹⁷ ACI 228.2R-2.51 / ACI Concrete Practices Non-Destructive testing: Covermeters ²⁻¹⁸ The German Concrete and Construction Association, Technical Report, Concrete Cover and Reinforcement per Eurocode 2. Deutscher Beton- und Bautechnik-Verein, DBV-Merkblatt, Betondeckung und Bewehrung nach Eurocode 2 (in German) ²⁻¹⁹	Calibration of covermeters Statistical evaluation of measured cover dimensions in hardened concrete
Determine potential for reactivity of aggregates in concrete	RILEM TC 191-ARP / Alkali-reactivity and prevention – Assessment, specification and diagnosis of alkali-reactivity. ²⁻²⁰ AASHTO R80 / Determining the Reactivity of Concrete Aggregates and Selecting Appropriate Measures for Preventing Deleterious Expansion in New Concrete Construction ²⁻²¹ ASTM C1260 / Potential Alkali Reactivity of Aggregates (Mortar-Bar Method) ²⁻²²	Expansion % of aggregates for classification of reactivity / Class 1 very unlikely / Class 2 uncertain / Class 3 very likely Determine risk of ASR from reactivity of aggregates and exposure, and determination of supplemental cementitious materials (SCMs) to provide various levels of prevention Average length change in concrete specimens

Determine freeze-thaw and salt scaling susceptibility	CEN/TS 12390-9 / Testing hardened concrete – Part 9: Freeze-thaw resistance – Scaling (pre-standard), 2006 ²⁻²³	Scaling % by weight or mass per volume
	RILEM TC 176-IDC / Recommendation: CIF Test, Test method of frost resistance of concrete (Capillary suction, internal damage and freeze-thaw test) reference method and alternative methods A and B, 2004. ²⁻²⁴	
	ASTM C457 / Microscopical Determination of Parameters of the Air-Void System in Hardened Concrete ²⁻²⁵	Air/void spacing and percentage
	ASTM C231 / Air Content of Freshly Mixed Concrete by the Pressure Method ²⁻²⁶	Air content of concrete sample and/or air content of mortar portion
	ASTM C173 / Air Content of Freshly Mixed Concrete by the Volumetric Method ²⁻²⁷	
Verify chloride durability resistance using alternative air-permeability testing	SIA 262/1 / Air-Permeability Site test ²⁻²⁸	As-built air-permeability of concrete cover zone
	Romer, M., Final Recommendation of RILEM TC 189-NEC ²⁻²⁹	

* The Rapid Chloride Permeability Test (RCPT), ASTM C1202²⁻³⁰, is a very popular worldwide standard to assess concrete's ability to resist chloride ion penetration by measuring its electrical conductance (coulombs). The RCPT test is typically faster and less expensive than the RCM test. However, there is not a universally accepted correlation of the RCPT test results to the Chloride Migration Coefficient used in the *Model Code for Service Life Design* (fib Bulletin 34)²⁻¹ deterioration model for chloride ingress. The RCPT test can be performed in conjunction with the RCM test to develop a correlation between electrical conductance (coulombs) and the Chloride Migration Coefficient for specific concrete mix designs. This correlation could allow the RCPT test to be used for verification purposes during construction.

2.3.7 Structure 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, and/or the remaining service life of components of structures in service. A summary table listing all structure component types is used to identify:

- Each component type's intended service life
- Whether it is replaceable or non-replaceable during the intended life
- Environmental exposure class and level
- Metal/reinforcement deterioration mechanism (e.g., chlorides and/or carbonation)

- Concrete deterioration mechanisms (e.g., freeze-thaw, internal/external chemicals)
- Service Life Design Strategy/Methodology
 - Strategy A – Avoidance (Avoiding deterioration by the design-out method)
 - Strategy B – Deterioration Modelling (Providing resistance to deterioration mechanisms active in the service environment)
 - B1. Deemed to satisfy provisions
 - B2 Partial-factor design (semi-probabilistic design)
 - B3 Full probabilistic reliability-based methodology, and Reliability Index, β
- Primary Protection Strategies, including material's own resistance and multiple layer protection (e.g., coatings, overlays, and Post-Tensioning Protection Levels PL1 to PL3 per *fib Bulletin 33 Durability of post-tensioning tendons*²⁻³¹)
- Durability Limit state(s) defining end of service life, relating to the extent of acceptable damage (e.g., depassivation, cracking, spalling, loss of section)

Structures typically have many major components. For a bridge, the major components are abutments, piers, and spans, which generally describe the location of the component within the structure. Sub-components for abutments and piers are typically piles, footings or pile caps, columns or walls, and pier caps or cross beams. Sub-components of spans are girders, diaphragm, bridge decks and traffic railings. Sub-components 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. 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. An example schematic drawing is shown in Figure 2-2.

Table 2-9 lists a summary of the concrete components and their service life design requirements and methodologies for steel reinforcement deterioration. Table 2-10 shows similar information for concrete deterioration. The purpose of the summary tables are to consolidate the Service Life Design intent in one easy to access location.

The main concrete structural members are generally designed to be non-replaceable. Many of the other material components may not achieve the full service life expected of the main components, and are designated as replaceable at specified intervals. Separate summary tables for concrete components and other non-concrete material components is recommended and has been developed for the Birth Certificate example in Appendix A.

As mentioned in section 1.3, it is expected that more than one Service Life Design strategy may be used in the design of a single structure.

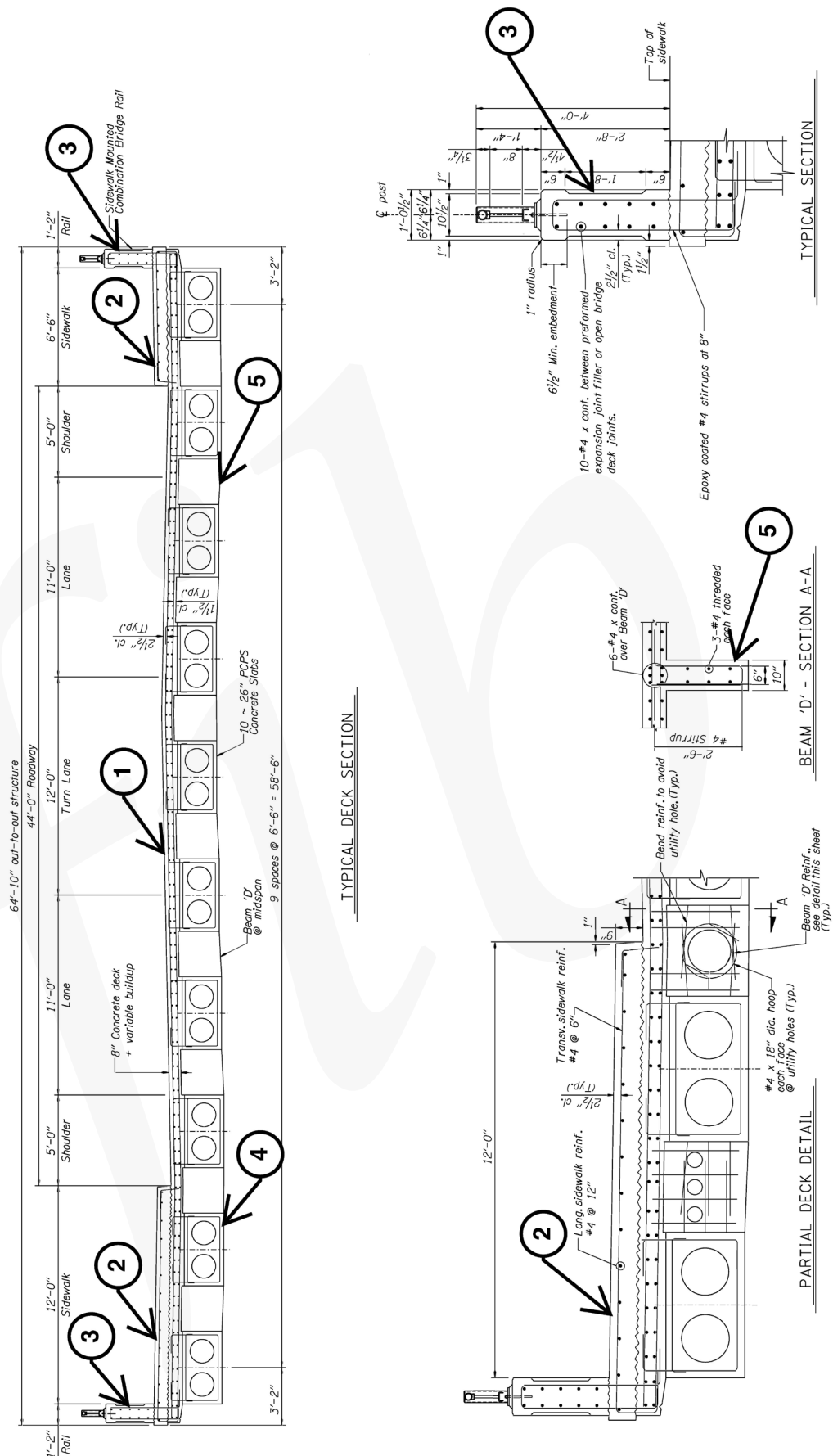


Fig. 2-2 Structure Component Identification [Courtesy Oregon Department of Transportation]

Table 2-9 Concrete Component Design Summary (Reinforcing Corrosion)

	Deck	Box Girder	Pier Caps	Columns	Abutment Walls	Footings/ Pile Caps	Concrete Piles/ Drilled Shafts	Concrete Traffic Barriers
Service Life Requirements								
Non-Replaceable	x	x	x	x	x	x	x	
Replaceable								x
Service Life Duration (years)	100	100	100	100	100	100	100	40
Reinforcement Deterioration Mechanisms								
Corrosion from Chlorides	x	x	x	x	x	x	x	x
Corrosion from Carbonation								
Environmental Exposure (per EN 206-1)								
Class (XCarbonation/ XDe-icing/ XSeawater)	XS	XS	XS	XS	XS	XS	XS	XS
Level (1-4)	1	1	1	3	1	3	2	1
Design Strategy								
Avoidance								
Deterioration Modeling	Fick's 2 nd Law (fib 34, annex B2)							
Deemed-to-satisfy								
Partial Factor								
Full-Probabilistic	x	x	x	x	x	x	x	x
Reliability Index, $\beta=$	1.3	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	x
Multi-stage system (overlay/coating)	x							
Use non-reactive materials (CRR)								
Cathodic Protection								
Limit State								
Corrosion initiation (Depassivation)	x	x	x	x	x	x	x	x
Corrosion Propagation (cracking)								
Corrosion Propagation (spalling)								
Corrosion Propagation (section loss)								

Table 2-10 Concrete Component Design Summary (Concrete Deterioration)

	Deck	Box Girder	Pier Caps	Columns	Abutment Walls	Footings/ Pile Caps	Concrete Piles/ Drilled Shafts	Concrete Traffic Barriers
Concrete Deterioration Mechanisms								
Freeze-Thaw								
Salt Scaling								
Abrasion/Erosion	x							
Chemical Attack (Sulfate/Acid/Leaching)								
Internal Chemical Attack (AAR/ASR/DEF)			DEF	DEF		DEF		
Environmental Exposure (per EN 206-1)								
Class (XFreeze-Thaw/Chemical XAttack)								
Level (1-4)								
Design Strategy								
Avoidance								
Deterioration Modeling								
Deemed-to-satisfy	x		x	x		x		
Partial Factor								
Full-Probabilistic								
Reliability Index, β =								
Protection Strategy								
Use non-reactive materials								
Restrict material sources								
Air Entrainment								
Thermal Curing Plan			x	x		x		
Protective Barrier (overlay)	x							
Limit State								
Critical degree of saturation								
Critical freezing temperature								

Structures contain ancillary components that may have a shorter expected service life than the main structural components. For a bridge structure, ancillary components include bearings, expansion joints, deck protective membrane systems, deck drainage collection systems, pedestrian handrails, safety barriers, and noise protection barriers. These components are typically non-concrete, but are still important to the overall service life of the structure. Table 2-11 identifies typical ancillary structure components and their design and protection strategies.

Table 2-11 Non-concrete component design summary

	Deck Wearing Surface	Post-Tensioning (GROUTED)	Post-Tensioning (Flexible Filler)	Expansion Joint (Seals)	Bearings (Sliding Surface/Elastomers)	Steel Railings	Steel Drainage Pipe Systems	Steel Piles
Service Life Requirements								
Non-Replaceable		x						x
Replaceable	x		x	x	x	x	x	
Service Life Duration (years)	25	100	75	10	30	40	40	100
Metal Deterioration Mechanisms								
Corrosion from Chlorides				x	x	x	x	x
Corrosion from Water/Moisture		x	x					
Environmental Exposure (per EN 206-1)								
Class (XC Carbonation/ XD De-icing/ XS Seawater)	XS	XS	XS	XS	XS	XS	XS	XS
Level (1-4)	1	1	1	1	1	1	1	2
Design Strategy								
Avoidance								
Deterioration Modeling								
Deemed-to-satisfy		x	x					
Partial Factor						x	x	x
Full-Probabilistic								
Reliability Index, $\beta=$								
Protection Strategy								
Material's own resistance	x			x	x	x	x	x
Use non-reactive materials								
PT Corrosion Protection Level (PL1/PL2/PL3)		PL2	PL2					
Protective Coating						x	x	
Limit State								
Corrosion Propagation (xx% section loss)						x	x	x
Other Material Deterioration Mechanisms								
Abrasion/Erosion								
Coating failure								
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, $\beta=$								
Protection Strategy								
Protective coatings						x	x	
Other (see component details)								
Limit State								
Initiation of joint leakage				x				
% surface coating defects						x	x	

Each individual concrete component should be identified by its 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 (e.g., 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 ageing exponent, and critical chloride threshold to initiate corrosion of the reinforcing). Table 2-12 is an example of the full probabilistic service life design methodology. The component references the schematic drawing item number 1 for the bridge deck shown in Figure 2-3.

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 characteristic values and load and resistance factors. At the time of publication, no universally accepted codes or standards have quantified appropriate load and resistance factors to be used for current Service Life Design deterioration models. Both strategies should identify the reliability index, β , associated with the durability limit state.

Since the deemed-to-satisfy and avoidance of deterioration Service Life Design strategies do not use mathematical modelling to evaluate service life duration, all of 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.

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.

During construction, material testing of the concrete durability properties is performed to compare to the design intent. Concrete cover dimensions are taken on the as-built structure and recorded as shown in Table 2-13. Cover dimensions should be measured on each face of the component. The statistical mean and standard deviation for each component is computed and recorded. The method shown for analysing the concrete cover data is from the German Concrete and Construction Association, DBV²⁻¹⁹.

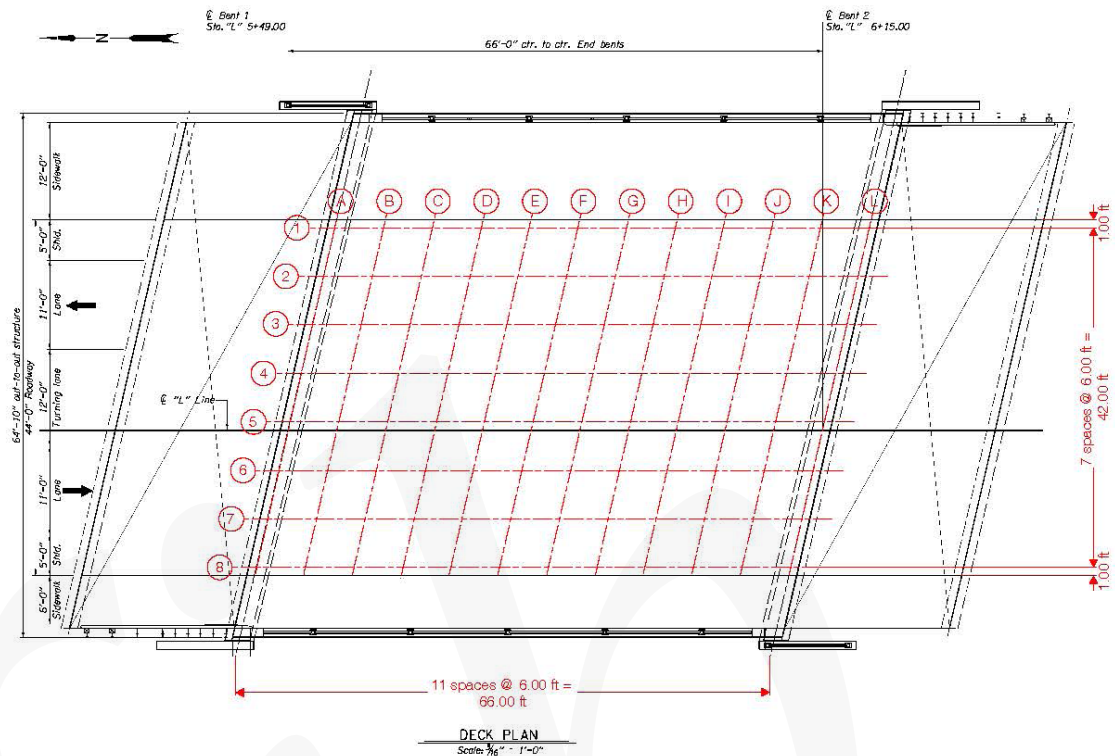
After all construction data is collected and recorded, calculations are again performed to compute as-built service life duration of each individual component. For example, during the design of a multi-span bridge, all piers would have the same design parameters and thus have the same expected service 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 lower or higher as-built service life.

Table 2-12 Individual 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										
Property	Variable	Units	Distribution	Design Mean, μ Std Dev, σ	As-Constructed Mean, μ Std Dev, σ					
Environmental Parameters										
Exposure Class	XD2									
Surface Chloride Concentration	$C_{s,ix}$	[wt-%/cm]	Log-Normal	0.72 8.9	0.36 5.6					
Transfer Function	Δx	[mm]	Beta a=0, b=50	8.9	5.6					
Temperature at Site	T_{real}	[°C]	Normal	8.7	1.29					
		[°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									
Initial Chloride Content	C_o	[wt-%/cm]	Constant	0.1	NT1B					
Chloride Migration Coefficient	$D_{RCM,0}$	[mm ² /yr]	Normal	416 166	384 154					
Aging Exponent	α	n/a	Beta a=0, b=1	0.60 0.15	0.4 0.18					
RCM Testing age (28 days)	t_o	[yr]	Constant	0.0767						
Transfer Parameter	k_t	n/a	Constant	1.0						
Properties										
Reinforcing Type/ Grade	Carbon	M31/A615								
Critical Chloride Threshold	C_{crit}	[wt-%/cm]	Beta a=0.2, b=2	0.6 0.15						
Clear Cover	a_{cov}	[mm]	Log-Normal	63.5 9	61 10.6					
In-Service Monitoring				Chloride Diffusion Coefficient at age t, $D_{app,C}(t)$	Surface Chloride Concentration, $C_{s,ix}$ or C_o	Aging Exponent, α	Service Life, t_{SL}	End of Service Date		
Life Cycle Stage	Testing Date	Age, t [yr]	No. Samples	Test Method	Mean, μ [mm ² /yr] Std Dev, σ	Mean, μ [wt-%/cm] Std Dev, σ	Mean, μ n/a Std Dev, σ	[yr]	[yyyy]	
Design/Construction		0.0767			218.81 2.96	87.52 0.72	0.36 0.36	0.60 0.15	>100 2117	
Assumed Design (Trial Batch)		100		NT Build 492	201.98	80.79	0.72	0.36	0.40 0.18	100 2117
As-Constructed	6/1/2017	0.0767	3	NT Build 492	11.46					

Component Name Deck
Location Span 1 top mat

Standard German Concrete and Construction Association - DBV,
Concrete Cover and Reinforcement per Eurocode 2
Sampling Grid sampling (equally spaced measurement points)



	A	B	C	D	E	F	G	H	I	J	K	L
1	64	56	66	76	52	73	69	71	79	76	79	72
2	61	56	63	69	69	70	74	76	55	72	76	53
3	57	57	37	40	64	56	60	56	56	48	47	57
4	49	51	42	51	57	58	57	54	59	63	64	71
5	58	61	53	49	51	48	55	50	46	49	65	59
6	76	79	63	53	80	74	72	65	72	69	72	58
7	57	76	80	28	66	74	62	76	57	63	57	61
8	54	47	56	56	54	72	64	61	56	45	59	63

Target threshold %		5%	Qualitative Procedure				
Nominal cover	c_{nom}	63	# measurements < c_{min}	8	# allowed per N	7	NG
Safety margin	Δc	15	Quantitative Procedure				
Req'd minimum cover	c_{min}	48	Outlier cover	X_{OG}	$= 2.5X_M - 1.5X_{min}$	107	
Sample size	N	96	Location parameter	r	$= (X + XM)/2$	60.27	
Median	X_M	60	Form parameter	k	$= 1.8 r/s$	10.22	
Min	X_{min}	28	Threshold value	$c(5\%)$	$= r/(19^{1/k})$	45.17	
Mean	X	61	Parameter $p(x)$	$p(x)$	$= c_{min}/r$	0.80	
Std. Dev.	s	10.6	% of cover depth < c_{min}	$F(x)$	$= p(x)k/(1+p(x)k)$	8%	>5% NG

Fig. 2-3 Concrete cover measurements [Courtesy Oregon Department of Transportation]

After the structure is placed in-service, periodic monitoring of the deterioration process is essential to evaluating the performance over time. The Birth Certificate document should provide predictions of future performance against which the performance of the structure could be assessed during its lifetime in order to encourage pro-active maintenance, see Figure 2-4.

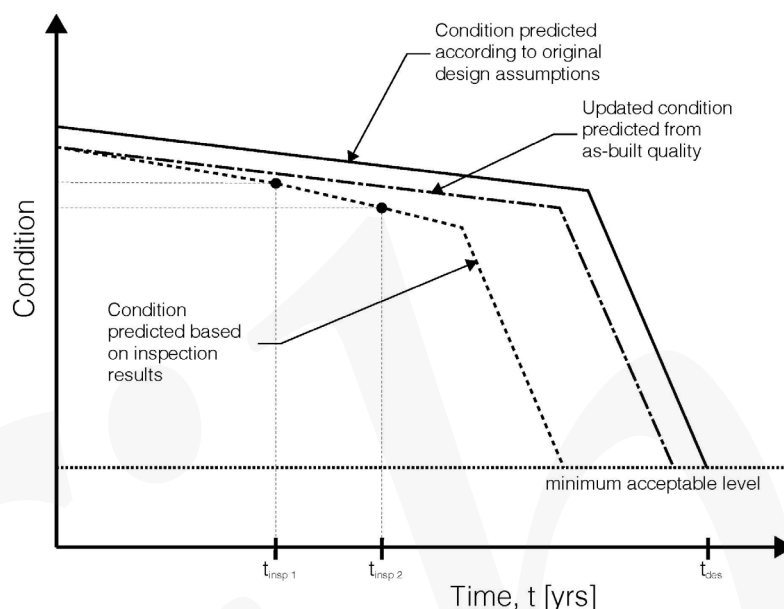


Fig. 2-4 Condition vs. Age (Design, As-Built, In-Service)

The monitoring and evaluation process is best described using the case of chloride induced reinforcing steel corrosion. Monitoring methods require concrete core samples to be taken from the structure. The samples are analysed 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 particular age of the structure. The change/decrease of the apparent chloride diffusion coefficient with time, t , is defined empirically by a power function, $A(t) = (t_0/t)^\alpha$, where α is the ageing exponent. During design, the value for the ageing exponent is assumed based on the properties of the concrete mix being used and the micro-environmental conditions. However, the variability in water/cement ratio and supplementary cementitious materials in concrete mix designs, and the lack of sufficient long term data correlating those properties, makes the ageing exponent one of most influential variables used in the deterioration model. This in turn has the most significant effect on the computed service life duration. For in-service behaviour, a regression analysis is used to determine the ageing exponent by considering chloride diffusion coefficients for at least three different points in time. The procedure is shown graphically in Figure 2-5 with the data from four intermediate testing dates shown in Table 2-13. A detailed explanation is given in *fib Bulletin 76*²⁻³², and is not repeated here. In this example, which uses theoretical chloride diffusion coefficient data anticipated for future dates, the concrete assumed in design had a higher ageing exponent than what was used during construction, and the in-service testing yielded a slightly lower ageing coefficient, resulting in a shorter expected life.

Table 2-13 In-Service Monitoring

In-Service Monitoring						Aging Exponent, α		Service Life, t_{sl}	End of Service Date
Life Cycle Stage	Testing Date	Age, t [yr]	No. Samples	Test Method	Chloride Diffusion Coefficient at age t, $D_{app,C}(t)$		Surface Chloride Concentration, C_s or $C_{s,av}$		
					Mean, μ	Std Dev, σ	Mean, μ	Std Dev, σ	[yyyy]
Design/Construction									
Assumed Design (Trial Batch)		0.0767		NT Build 492	219	87.5	0.70	0.35	2117
		100			2.96				
As-Constructed	01.06.17	0.0767	3	NT Build 492	202	80.8	0.70	0.35	2115
		100			13.71				
In Service Durability Monitoring						Measured Properties from Chloride Profiling Tests		Regression Calculation	
Monitoring Inspection 1	01.06.19	2			60.00		0.70	0.35	97
Monitoring Inspection 2	01.06.21	4			40.00		0.70	0.35	115
Monitoring Inspection 3	01.06.25	8			35.00		0.70	0.35	100
Monitoring Inspection 4	01.06.37	20			20.00		0.70	0.35	122
Monitoring Inspection 5									
Monitoring Inspection 6									
Monitoring Inspection 7									
Monitoring Inspection 8									
Monitoring Inspection 9									
Monitoring Inspection 10		100							



Fig. 2-5 Log-log Plot of Apparent Concrete Chloride Diffusion Coefficient vs. Age

2.3.8 Conservation Plan (In-Service Maintenance, Inspection & Monitoring, or Condition Survey & Assessment)

An overall Conservation 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 Conservation 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 sub-components of the structure that will likely be the first to exhibit signs of deterioration. The format for the Conservation 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 Conservation Plan is created during the design phase of a structure, it is intended that the plan will be constantly updated through the life of the structure.

The Conservation Plan is divided into separate maintenance and inspection sub-sections to complement the differing skill sets of the crews performing these work activities.

2.3.8.1 Maintenance Plan

Routine maintenance and minor repair activities are normally performed by the Owner and are divided into the following categories:

- Clean/Clear Sweep, remove debris from drains, pressure wash
- Reset Reposition bearings, caulk joints

- Coat/Seal Spot apply protective coating
- Repair/Patch Patch damaged concrete surfaces
- Replace Replace expansion joint seals
- Modify Alter walking bearing attachments

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/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.

2.3.8.2 Inspection Plan

All structures should be assessed for fitness of use based on the assessed requirements for this by the designers. Routine safety inspections is a requirement for all structures in some countries like Singapore. In many western countries it is only public facilities that are required by law to be inspected and assessed on a periodic basis to ensure they are fit for use. Yet in other countries no inspections are a legal requirement.

Regardless of regulations laid down by government, the design engineer should assume responsibility for the structure over its design life by including in the Birth Certificate the requirements for condition assessment and maintenance that will ensure the structure will remain fit for use. This should be based on an appropriate risk assessment procedures. Whilst routine inspection of public bridges might be appropriate because of the high consequence of failure, many privately owned buildings also have a potential for devastating failures.

The types of inspection that have been developed to satisfy government regulations provide a useful guide as to the types of inspection designers can consider for inclusion in Birth Certificates. These include:

- Initial: Once (prior to commissioning)
- Routine Safety: Periodic (frequent – annual, biennial)
- In-Depth Monitoring: Periodic (less frequent – every 5-10 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 non-destructive testing procedures in order to obtain sufficient data to monitor and assess the long term behaviour of the structure. Each of the above inspection types has a different primary focus. A separate plan should be developed for each inspection type. Typical inspection activities include identification of:

- Items to be visually inspected with special instructions on how to perform
- Potential “hot spots” or locations of earliest anticipated deterioration in the structure
- Items requiring in-depth non-destructive testing and the locations they are to be performed and the test methods to be used

- With each parameter, the sampling or test method, the associated standard, and the frequency and location of tests should be given in the Inspection Plan.
- The as-built 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 remaining 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.

2.3.8.3 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 management concept, data gathered from the Initial Inspection is used to establish the condition of the structure immediately after construction is completed. The data to be collected in an Initial Inspection correlates 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 and permeability
- Cathodic protection currents and polarisations
- Coating thickness measurements (during construction this should have been verified as part of quality assurance but spot checks at this point give added confidence)
- Data from monitoring systems (strain gauges, corrosion monitors, deflection gauges, tell tales etc). The increased ease of use, greater depth of information provided and unique ability to provide warning of early deterioration has meant that monitoring systems are finding greater use in areas where the risks associated with failure are higher.
- In recent years dynamic testing techniques have been developed that can be usefully used to provide a signature of the structures response. This signature can then be used to compare the structures response in the future. On a global basis the use of interferometric radar to monitor deflections to natural loading while on a local level impulse response can provide reference data on critical local areas.

2.3.8.4 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 annually or biennially. They often include underwater inspections. Most Owners have detailed written procedure for Routine Inspections. The Routine Inspection Plan should incorporate the Owner's standards and be supplemented by unique details required by the structure under consideration.

Where monitoring systems are installed results can be assessed as part of the routine inspection.

2.3.8.5 In-Depth Inspection

The purpose of an In-Depth Inspection is to collect data to be used to monitor the reaction of the structure to the actual environmental loading parameters that exist at the site. The end goal is to compare the actual behaviour against the deterioration and structural models that were anticipated during the design, and to update the Remaining Service Life of the structure. In-Depth Inspections are performed on a longer recurrence interval than Routine Inspections. Typical tests to be performed and the parameters to be measured are shown in Table 2-14.

Table 2-14 Durability tests performed during in-service phase

Objective	Potential Testing Specifications	Information Obtained
Develop chloride profiles from concrete cores taken from structure to verify concrete chloride durability resistance properties and chloride loading	Nordtest Method NT Build 443 (Bulk Diffusion Test) ²⁻⁴	$D_{app,C'}_{app}$ Apparent Chloride Diffusion Coefficient as it changes with time, and C_s or $C_{s,\Delta x}$ and Δx to verify Chloride Surface Concentration. Used to determine α , the aging exponent in the chloride deterioration model
	CEN/TS 12390-11 Chloride Resistance ²⁻⁵	
	ASTM C1556 ²⁻⁶	
Measure carbonation depth	RILEM CPC-18 ²⁻¹³	$x_c(t)$, Carbonation depth versus time, t , used in the carbonation deterioration model
	Accelerated Carbonation Test (ACC) / DARTS ²⁻¹⁴	
	CEN/TS 12390-10 Carbonation Resistance ²⁻¹⁵	
	Nordtest Method NT Build 357 ²⁻¹⁶	
Petrographic analysis	ASTM C856 / Standard Practice for Petrographic Examination of Hardened Concrete ²⁻³³	Reactions occurring in the concrete, e.g., alkali aggregate, sulfate attack, leaching.
Surface half-cell electrical potentials	ASTM C876 / Standard Test Method for Corrosion Potentials of Uncoated Reinforcing Steel in Concrete ²⁻³⁴	Variation in surface electrical potential as generated by the reaction of the reinforcement with its local environment vs. a standard reference electrode
In-situ 4 pin Wenner probe concrete resistivity (natural and after concrete saturation, e.g., by spraying with water for an hour)	AASHTO TP 95 / Surface Resistivity Indication of Concrete's Ability to Resist Chloride Ion Penetration ²⁻³⁵	Natural gives areas of dampness where corrosion is a higher risk. Saturated gives an indication of the concrete quality and likely corrosion rate that would be supported.
Saturated core 4 pin Wenner probe concrete resistivity		Indication of concrete quality and likely corrosion rate that would be supported.
Ultrasonic pulse echo, impact echo and radar along post-tensioning line where grout specifications are suspect	Guidelines - "Improved Inspection Techniques for Steel Prestressing/ Post-tensioning Strand" / Florida DOT Contract No. BDK80 977-13, June 2012 ²⁻³⁶	Post-tensioning grouting adequacy. Degree of duct filling to identify if further inspection and grout filling is required.
Crack width measurement	None	Ultimate crack width. Indication of whether corrosion at cracks is likely to become an issue.

The type of test can be planned based on the service life prediction. It will be of no use to determine chloride profiles soon after completion, or to perform potential mapping at a time when there is little likelihood that any depassivation has occurred.

2.3.8.6 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.

2.3.8.7 Damage Inspection

Damage Inspections are performed after an extreme event such as an earthquake, hurricane, flood, fire, explosion, 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 remaining service life of the structure.

2.3.8.8 Dismantling Plan

The final section of the Birth Certificate addresses what decommissioning 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. The dismantling plan should include:

- 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 relining of tunnels)
- 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, steel)
- 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)

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Appendix A

Identification of Structure

Owner	Oregon Department of Transportation
Structure Classification	Bridge
Structure Name	Ochoco Creek Bridge
Inventory ID #	22324
Structure Description	19.76 m wide by 20.12 m long bridge with cast-in-place concrete deck on 660 mm 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

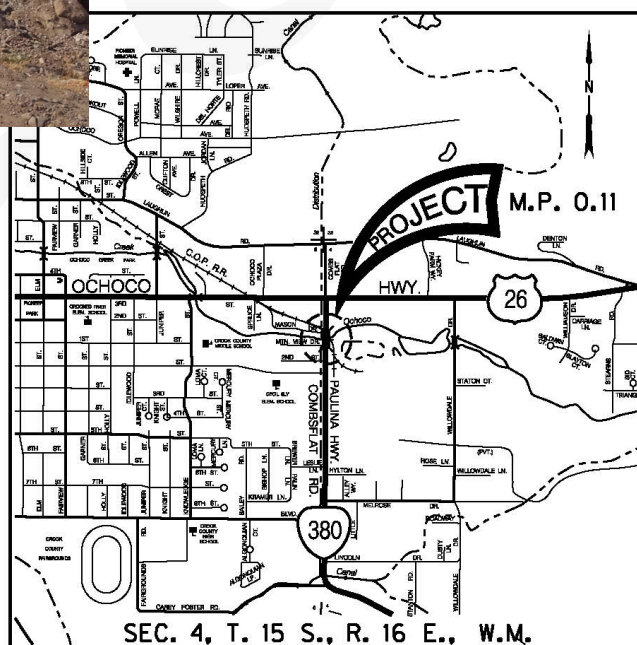


Fig. A-1 Ochoco Creek Bridge. Fig. A-2 Project map

This chapter was mainly authored by Bartholomew.

<https://doi.org/10.35789/fib.BULL.0093.Ch03>

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
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)

Identification of structure

Structure plan & Elevation

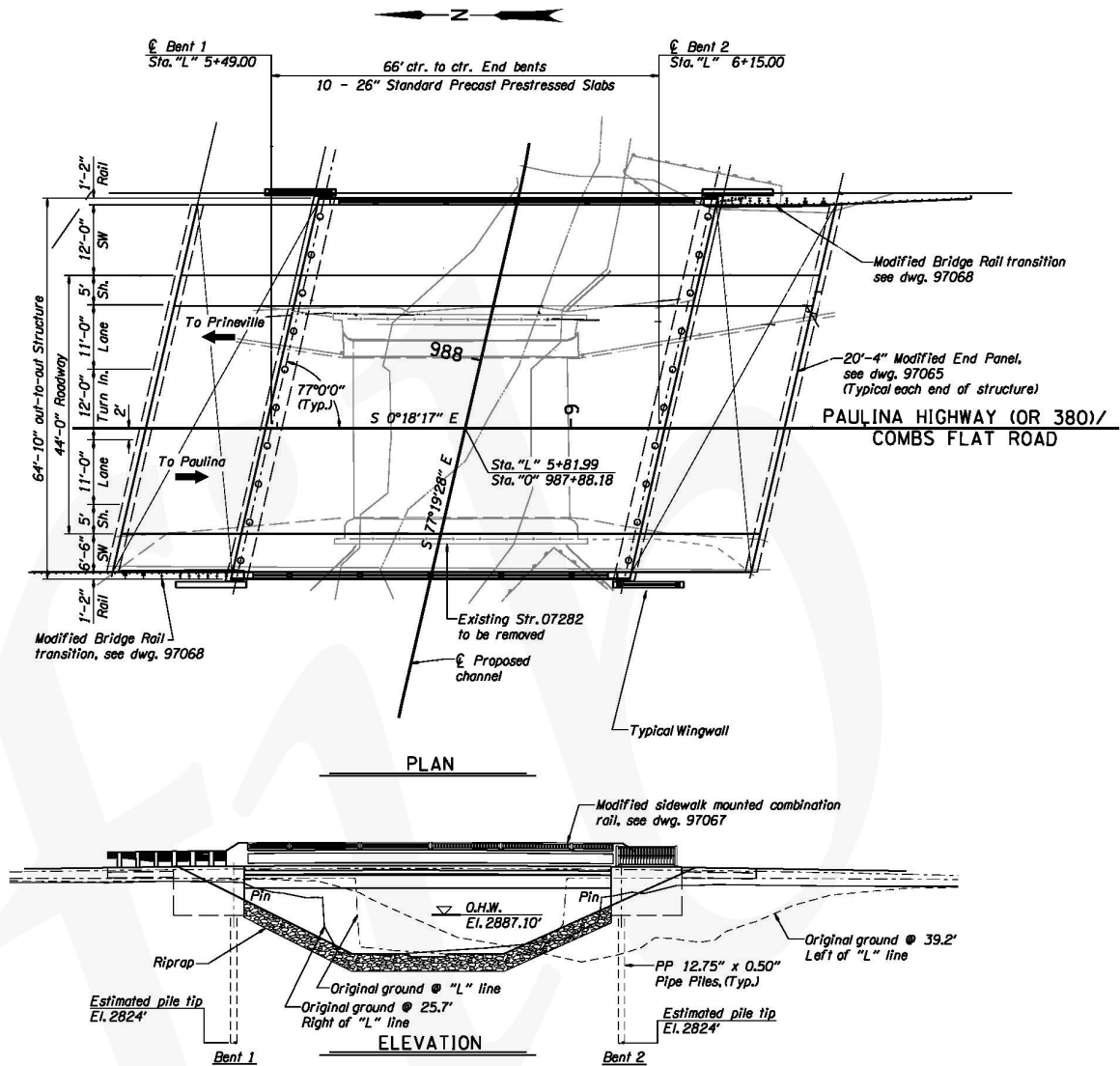


Fig. A-3 Structure plan & Elevation

Durability Design Parameters

Structure Name Ochoco Creek Bridge

Inventory ID # 22324

Durability Specifications			
Model Code for Service Life Design, <i>fib</i> 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 (°C)		17.6	1.3
Low Temperature (°C)		-0.2	1.2
Average Temperature (°C)		8.7	1.3
Relative Humidity (%)		58	
Precipitation (mm)		230	84
Time of Wetness (ToW)	No. of days per year with rainfall exceeding 2.5 mm	25	8.75
Deterioration Mechanisms			
Reinforcing Steel Corrosion	Carbonation, De-icing Chlorides, Sea water	yes, D	
Freeze/Thaw Damage		yes	
Salt Scaling Damage		yes	
Abrasion/Erosion	Rutting, Ice action	yes, R	
External Chemical Attack	Sulfate, Acid, Leaching	no	
Internal Chemical Attack	ASR, AAR, DEF	no	
Coating Breakdown		no	
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 3 rd party		
Construction (Execution) Inspection Parameter			
Execution Class (EXC) - Construction inspection	EXC1 - Self	EXC2	
	EXC2 - Same organization		
	EXC3 - Independent 3 rd 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)	

Environmental Exposure Zones

Structure Name Ochoco Creek Bridge
Inventory ID # 22324

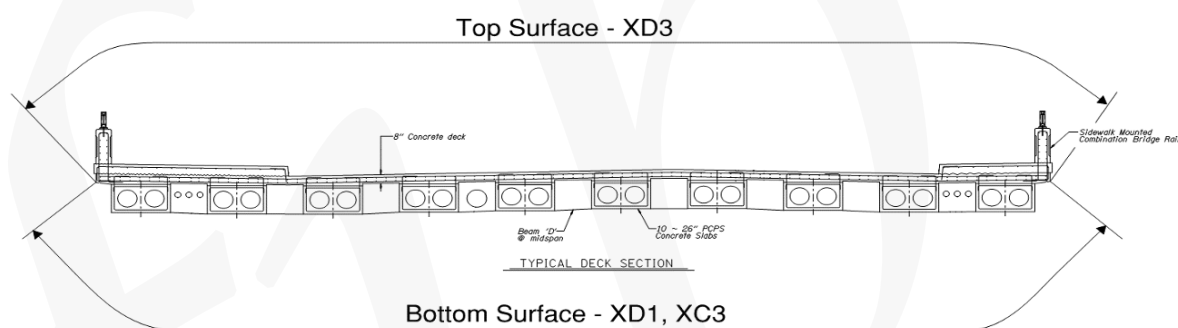


Fig. A-4 Exposure Zone Map

Exposure Classifications per EN-206

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 airborne chlorides				
		Surfaces exposed to de-icing chlorides				
		Bridge deck/sidewalk			0.70	0.35
		Bridge railing (beyond 3m from curb)			0.56	0.28

Deterioration Mechanism/Model

Deterioration Mechanism	Full probabilistic design method for chloride induced corrosion - uncracked concrete		
Deterioration Model	Fick's 2 nd Law (analytical model with assumptions on boundary and initial conditions)		
Source	fib Bulletin 34 - Model Code for Service Life Design, Appendix B2		
$C_{crit} \geq C_o + (C_{S,\Delta x} - C_o) \cdot \left[1 - \operatorname{erf} \left(\frac{a_{cov} - \Delta x}{2\sqrt{D_{app,C}} \cdot t} \right) \right]$			
			Equation (B2.1-1)
$D_{app,C} = K_e \cdot D_{RCM,0} \cdot K_t \cdot A(t)$			
			Equation (B2.1-2)
$k_e = \exp \left(b_e \left(\frac{1}{T_{ref}} - \frac{1}{T_{real}} \right) \right)$			
			Equation (B2.1-3)
$A(t) = \left(\frac{t_o}{t} \right)^\alpha$			
			Equation (B2.1-4)
Function Variables	Description	Units	Distribution Function
t	Time	[yr]	n/a
x	Depth with corresponding content of chlorides $C(x,t)$	[mm]	n/a
C_{crit}	Critical chloride content	[wt.-%/cem]	Beta, a=0.2, b=2.0
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)	[mm]	Beta, a=0, b=50
a_{cov}	Concrete cover	[mm]	Log-Normal
$D_{app,C}$	Apparent coefficient of chloride diffusion through concrete	[mm²/yr]	n/a
D_{RCMO}	Chloride migration coefficient	[mm²/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	[K]	Normal
$A(t)$	Subfunction considering the ageing	[-]	n/a
t_o	Reference point of time	[yr]	Constant = 0.0767
α	Ageing exponent	[-]	Beta, a=0.0, b=1.0

Durability Testing Requirements

Structure Name
Inventory ID #
Ochoo Creek Bridge
22324

Objective	Testing Specification	Information Obtained	Test Location / Frequency
Design			
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 $C_{s,ax}$ 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, $D_{RCM,q}$ used in chloride deterioration model	Single test (3 cylinders) from each trial batch mix design
Construction			
Verify chloride durability resistance properties during production	Nordtest Method NTBuild 492	As constructed Chloride Migration Coefficient, $D_{RCM,q}$ 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	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 $C_{s,ax}$ and Δx	

Concrete Mix Design Summary

Structure Name

Ochoco Creek Bridge

Inventory ID #

22324

Cementitious Materials										Durability Design Properties (per <i>fib</i> Bulletin 34)								
Concrete Class	Mix Designation	28-day Strength, f'_c (N/mm ²)	Unit weight (kg/m ³)	Supplemental Cementitious Materials (SCMs)						Cement + SCM Unit weight	Water/Cement Ratio w/c	Chloride Migration Coefficient, D_{RCM}^{RCM} (mm ² /yr) - (Normal Distribution function)		Aging Exponent, α - (values assumed with Beta Distribution function, $a=0$, $b=1$)				
				AASHTO/ASTM Spec.	Type	Fly Ash (FA) AASHTO M295/ASTM C618	Slag (GGBFS) AASHTO M302/ASTM C989	Silica Fume (SF) AASHTO M307/ASTM C1240	RCM Test per Nordtest - NTBuild 492 (measured at $t_0 = 28$ days)			Mean, μ	Std Dev, σ	Mean, μ	Std Dev, σ			
										%	Class C/F/N					%	Grade 100/120	%
Design - Trial Batch																		
4000 HPC	NT-1b	27.5	2245	M85/C150	I	30			4	295	0.39	416	166	0.6	0.15			
4000	NT-2b	27.5	2291	M85/C150	I		30			320	0.39	228	91	0.45	0.20			
3300	NT-3	23	2236	M85/C150	I		30			260	0.49	302	121	0.45	0.20			
4000	26S6KNG8M7	23	2199	M85/C150	I/II		30			260	0.46	463	185	0.45	0.20			
4000 HPC	266TZ1F5CS	27.5	2140	M85/C150	I/II		30		4	281	0.40	410	164	0.45	0.20			
Construction																		
4000 HPC	6TZ1F5CS	27.5	2140	M85/C150	I/II		30			311	0.41	384	154	0.45	0.20			
8380	KRP H71Y3	57	2311	M85/C150	III					322	0.36	297	119	0.30	0.12			

AASHTO M85/ ASTM C150 - Portland Cement

AASHTO M240/ ASTM C595 - Blended Hydraulic Cements

ASTM C1157 - Hydraulic Cement (classification for special characteristics/options)

Concrete Mix Data

Structure Name Ochoco Creek Bridge

Inventory ID # 22324

Mix Producer	Central Oregon Redi-Mix			
Mix ID	266TZ1F5CS			
Concrete Specification	Oregon DOT Standard Specifications, 2015 - Section 00540			
Concrete Class	4000 (27.5 N/mm ²) HPC Deck			
Materials	Type/Specification	Supplier	Wt. (kg)	
Cementitious				
Cement	Type I-II/ AASHTO M85	Cal Portland	195	
Supplemental Cementitious Materials (SCMs)				SCM %
Fly Ash (FA)				
Slag (GGBFS)		Ash Grove	88	0.30
Silica Fume (SF)		BASF	11	0.04
		Total Cementitious	294	
Aggregates				
Coarse	19 mm - # Round	Lone Pine Pit	735	
Coarse	9.5 mm Pea Rock	Lone Pine Pit	93	
Fine	Sand	Lone Pine Pit	514	
Fiber Mesh	Novomesh 950		2	
		Sub-total	1'344	
Aggregate Moisture Water			-40	
		Total Aggregate	1'304	
Admixtures				
				Wt. (gm)
Air Entrainment	AEA-90	BASF		369
Hi Range Water Reducer	PS-1466	BASF		1'106
			1	1'475
Water				
Batch Water			78	
Aggregate Moisture Water			40	
Admixture Water			1	
		Total Water	119	
Total Batch				
Total Batch Weight			1'717	
Batch Volume			0.765	m ³
Relative Yield				0.730
Density			1'638	kg/m ³
Adjusted Cementitious Content			281	kg/m ³
Water/Cement Ratio		w/c=	0.40	

Concrete Mix Data

Structure Name Ochoco Creek Bridge

Inventory ID # 22324

Mix Producer	Knife River / Hooker Concrete			
Mix ID	NT1-b			
Concrete Specification	Oregon DOT Standard Specifications, 2015 - Section 00540			
Concrete Class	4000 (27.5 MPa) HPC			
Materials	Type/Specification	Supplier	Wt. (kg)	
Cementitious				
Cement	Type I-II/ AASHTO M85		197	
Supplemental Cementitious Materials (SCMs)				SCM %
Fly Ash (FA)			89	30%
Slag (GGBFS)				
Silica Fume (SF)			12	4%
		Total Cementitious	298	
Aggregates				
Coarse	07-047-4 25 mm No. 4		868	
Fine	07-047-4 PCC Fine Agg.		463	
Fiber Mesh	Novomesh 950		2	
		Sub-total	1'333	
Aggregate Moisture Water			-13	
		Total Aggregate	1'320	
Admixtures				
				Wt. (gm)
Air Entrainment	AE-90	BASF		227
Mid-Range Water Reducer	Polyheed 997	BASF		936
Hi Range Water Reducer	PS-1466	BASF		936
	MasterLife	BASF		1'814
			4	3'913
Water				
Batch Water			99	
Aggregate Moisture Water			13	
Admixture Water			4	
		Total Water	116	
Total Batch				
Total Batch Weight			1'734	
Batch Volume			0.765	m ³
Relative Yield				0.757
Density			1'716	kg/m ³
Adjusted Cementitious Content			295	kg/m ³
Water/Cement Ratio		w/c=	0.39	

Concrete Mix Data

Structure Name Ochoco Creek Bridge

Inventory ID # 22324

Mix Producer	Knife River - Tumalo/Redmond			
Mix ID	26S6KNG8M7			
Concrete Specification	Oregon DOT Standard Specifications, 2015 - Section 00540			
Concrete Class	General Structure 4000			
Materials	Type/Specification	Supplier	Wt. (kg)	
Cementitious	Type I-II/ AASHTO M85	Cal Portland Ssangyong	182	
Supplemental Cementitious Materials (SCMs)				SCM %
Fly Ash (FA)				
Slag (GGBFS)		Ash Grove Dura Slag	78	30%
Silica Fume (SF)				
		Total Cementitious		
Aggregates				
Coarse	3/4 - #4	07-051-4	703	
Coarse	3/8 - #8	07-051-4	91	
Fine	#4 - 0	07-051-4	541	
			1'335	
Aggregate Moisture Water				
		Total Aggregate	1'335	
Admixtures				
				Wt. (gm)
Air Entrainment	Master Air AE-90			147
Hi Range Water Reducer				975
Retarder				814
			2	1'936
Water				
Batch Water			118	
Aggregate Moisture Water				
Admixture Water			2	
		Total Water	120	
Total Batch				
Total Batch Weight			1'715	
Batch Volume			0.765	m ³
Relative Yield				0.765
Density			2'244	kg/m ³
Adjusted Cementitious Content			260	kg/m ³
Water/Cement Ratio		w/c=	0.46	

Concrete Mix Data

Structure Name Ochoco Creek Bridge

Inventory ID # 22324

Mix Producer	Knife River - Tumalo/Redmond			
Mix ID	6TZ1F5CS			
Concrete Specification	Oregon DOT Standard Specifications, 2015 - Section 00540			
Concrete Class	Structural HPC 4000			
Materials	Type/Specification	Supplier	Wt. (kg)	
Cementitious				
Cement	Type I-II/ AASHTO M85	Cal Portland Ssangyong	218	
Supplemental Cementitious Materials (SCMs)				SCM %
Fly Ash (FA)				
Slag (GGBFS)		Ash Grove Dura Slag	93	30%
Silica Fume (SF)				
		Total Cementitious	311	
Aggregates				
Coarse	1.5 - 3/4	07-051-4	93	
Coarse	3/4 - #4	07-051-4	704	
Coarse	3/8 - #8	07-051-4	45	
Fine	#4 - 0	07-051-5	470	
			1'312	
Aggregate Moisture Water				
		Total Aggregate	1'312	
Admixtures				
				Wt. (gm)
Air Entrainment	Master Air AE-90	BASF		584
Water Reducer	Master Glenium 1466	BASF		1'165
Retarder	MasterSet Delvo	BASF		1'165
			3	2'914
Water				
Batch Water			114	
Aggregate Moisture Water				
Admixture Water			3	
		Total Water	117	
Total Batch				
Total Batch Weight			1'740	
Batch Volume			0.765	m ³
Relative Yield				0.765
Density			2'278.0	kg/m ³
Adjusted Cementitious Content			311	kg/m ³
Water/Cement Ratio		w/c=	0.38	

Concrete Mix Data

Structure Name Ochoco Creek Bridge

Inventory ID # 22324

Mix Producer	Knife River Prestress			
Mix ID	KRP H71Y3			
Concrete Specification	Oregon DOT Standard Specifications, 2015 - Section 00540			
Concrete Class	8280			
Materials	Type/Specification	Supplier	Wt. (kg)	
Cementitious				
Cement	Type III/ AASHTO M85	Ash Grove	322	
Supplemental Cementitious Materials (SCMs)				SCM %
Fly Ash (FA)				
Slag (GGBFS)				
Silica Fume (SF)				
		Total Cementitious	322	
Aggregates				
Coarse	3/4 - 1/2	22-018-2	450	
Coarse	1/2 - #4	22-018-2	549	
Fine	#4 - 0	22-018-2	740	
			1'739	
Aggregate Moisture Water				
		Total Aggregate	1'739	
Admixtures				
				Wt. (gm)
Air Entrainment	MB AE-90	BASF		201
Hi Range Water Reducer	MB Glenium-3400NV	BASF		1'208
Workability-Retention	MB Rheotec Z60	BASF		1'208
			3	2'617
Water				
Batch Water			113	
Aggregate Moisture Water				
Admixture Water			3	
		Total Water	116	
Total Batch				
Total Batch Weight			2'177	
Batch Volume			0.765	m ³
Relative Yield				0.765
Density			2'311.0	kg/m ³
Adjusted Cementitious Content			322	kg/m ³
Water/Cement Ratio		w/c=	0.36	

Reinforcing Steel

Structure Name Ochoco Creek Bridge

Inventory ID # 22324

Type	AASHTO/ ASTM Spec	Yield Strength, F _y (N/mm ²)	Tensile Strength, F _u (N/mm ²)	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	420	620	n/a	n/a	0.60	0.15
Plain Carbon Low Alloy	M31/A706	420	620	n/a	n/a	0.60	0.15
Plain Carbon - Epoxy Coated	M31/A615	420	620	n/a	n/a	0.60	0.15
Plain Carbon - Epoxy Coated	M31/A706	420	620	n/a	n/a	0.60	0.15
7-Wire Strand (low relaxation)	M203/A416	1675	1860	n/a	n/a	0.60	0.15

Service Life Design Summary - Concrete Components

Structure Name Ochoco Creek Bridge

Inventory ID # 22324

Service Life Design Summary - Concrete Components	Deck	Prestressed Slabs	Abutment Walls	Footings/Pile Caps	Concrete Traffic Barriers														
Service Life Requirements																			
Non-Replaceable	x																		
Replaceable		x	x	x	x														
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)																			
Class (XCarbonation/ XDe-icing/ XSeawater)	XD	XD	XD	XD	XD														
Level (1-4 XC, 1-3 XD XS)	3	1	1	1	3														
Design Strategy																			
Avoidance																			
Deemed-to-satisfy																			
Partial Factor																			
Full-Probabilistic	x	x	x	x	x														
Reliability Index, $\beta=$	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																			
Limit State																			
Corrosion initiation (Depassivation)	x	x	x	x	x														
Corrosion Propagation (cracking)																			
Corrosion Propagation (spalling)																			
Corrosion Propagation (section loss)																			
Concrete Deterioration Mechanisms																			
Freeze-Thaw																			
Salt Scaling																			
Abrasion/Erosion	x																		
Chemical Attack (Sulfate/Acid/Leaching)																			
Internal Chemical Attack (AAR/ASR/DEF)																			
Environmental Exposure (per EN 206)																			
Class (XFreeze-Thaw/Chemical XAttack)																			
Level (1-4 XF, 1-3 XA)																			
Design Strategy																			
Avoidance																			
Deterioration Modeling																			
Deemed-to-satisfy	x																		
Partial Factor																			
Full-Probabilistic																			
Reliability Index, $\beta=$																			
Protection Strategy																			
Use non-reactive materials																			
Restrict material sources																			
Air Entrainment																			
Thermal Curing Plan																			
Protective Barrier (overlay)																			
Limit State																			
Critical degree of saturation																			
Critical freezing temperature																			

Service Life Design Summary - Non-Concrete Material Components

Structure Name Ochoco Creek Bridge

Inventory ID # 22324

	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)																	
Class (XC Carbonation/ XDe-icing/ XSeawater)			XD	XD													
Level (1-4 XC, 1-3 XD, XS)			3	1													
Design Strategy																	
Avoidance																	
Deemed-to-satisfy			x	x													
Partial Factor																	
Full-Probabilistic																	
Reliability Index, $\beta=$																	
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																	
Deemed-to-satisfy (Historical user data)	x	x															
Partial Factor																	
Full-Probabilistic																	
Reliability Index, $\beta=$																	
Protection Strategy																	
Protective coatings			x														
Other (see component details)																	
Limit State																	
Initiation of joint leakage	x																
___% surface coating defects																	

Structure Component Identification - Superstructure

Structure Name Ochoco Creek Bridge
Inventory ID # 22324

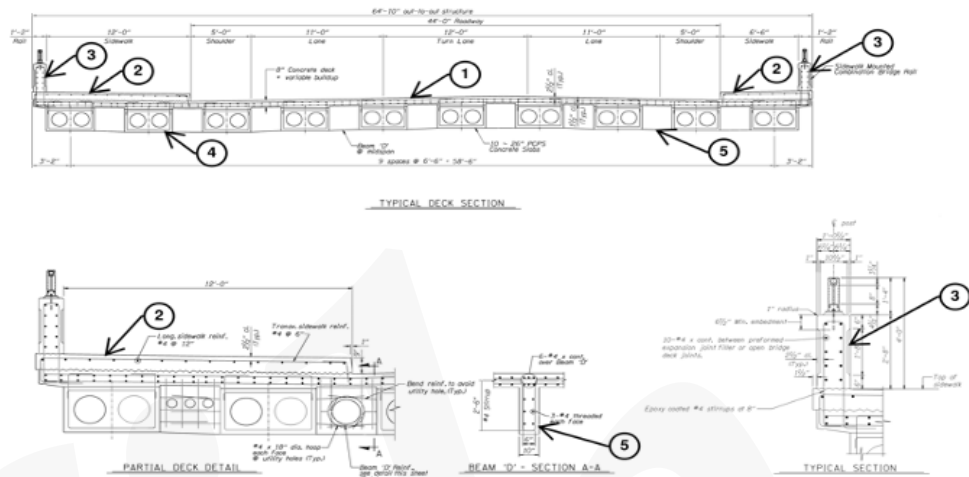


Fig. A-5 Structure Component Map

Structure Component Data - Cover Measurements

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

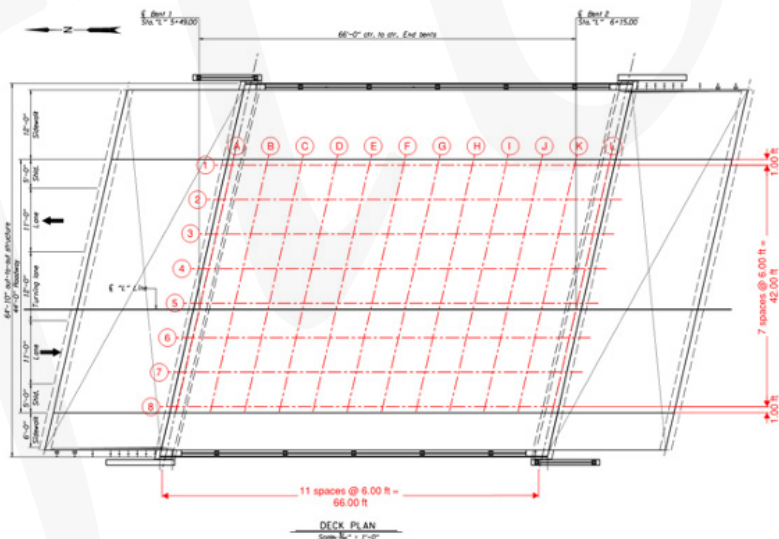


Figure A-6 Cover Measurement Grid Sampling

As-Constructed Cover Dimensions at Grid Points [mm]												
	A	B	C	D	E	F	G	H	I	J	K	L
1	64	56	66	76	52	73	69	71	79	76	79	72
2	61	56	63	69	69	70	74	76	55	72	76	53
3	57	57	37	40	64	56	60	56	56	48	47	57
4	49	51	42	51	57	58	57	54	59	63	64	71
5	58	61	53	49	51	48	55	50	46	49	65	59
6	76	79	63	53	80	74	72	65	72	69	72	58
7	57	76	80	28	66	74	62	76	57	63	57	61
8	54	47	56	56	54	72	64	61	56	45	59	63

Statistical Evaluation of Measured Cover Depths, all units [mm]							
Target threshold %		5%	Qualitative Procedure				
Nominal cover	c_{nom}	63	# measurements < c_{min}	8	# allowed per N	7	NG
Safety margin	Δc	15					
Req'd minimum cover	c_{min}	48	Quantitative Procedure				
Sample size	N	96	Outlier cover	X_{OG}	$= 2.5X_M - 1.5X_{min}$	107	
Median	X_M	60	Location parameter	r	$= (X + XM)/2$	60.27	
Min	X_{min}	28	Form parameter	k	$= 1.8 r/s$	10.22	
Mean	X	61	Threshold value	$c(5\%)$	$= r/(19^{1/k})$	45.17	
Std. Dev.	s	10.6	Parameter $p(x)$	$p(x)$	$= c_{min}/r$	0.80	
			% of cover depth < c_{min}	$F(x)$	$= p(x)k/(1+p(x)k)$	8%	>5% NG

Structure Component Data

Component Name Deck Figure ID Superstructure 1
Location Span 1

100 [yrs]

Required Service Life

1.3

Reliability Index, β

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	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	[mm]	Beta a=0, b=50	8.9	5.6				
Temperature at Site	T_{real}	[°C]	Normal	8.7	1.29				
		[K]		281.9	1.29				
Standard RCM Test Temperature	T_{ref}	[K]	Constant	281.9					
Temperature Regression Variable	b_e	[K]	Normal	292.9	700				
Concrete Properties									
Class/Mix Design	HPC4000								
Initial Chloride Content	C_o	[wt-%/cem]	Constant	0.1			NT1B		6TZ1F5CS
Chloride Migration Coefficient	$D_{RCM,0}$	[mm ² /yr]	Normal	416	166			384	154
Aging Exponent	α	n/a	Beta a=0, b=1	0.60	0.15			0.375	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								
Critical Chloride Threshold	C_{crit}	[wt-%/cem]	Beta a=0.2, b=2	0.6	0.15				
Clear Cover	a_{cov}	[mm]	Log-Normal	63.5	9			61	10.6

$$C_{crit} = C(x = a_{cov}, t) = C_0 + (C_{s,\Delta x} - C_0) \cdot \left[1 - \operatorname{erf} \left(\frac{a_{cov} - \Delta x}{2\sqrt{D_{app,C} \cdot t}} \right) \right]$$

Equation (B2.1-1)

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

Equation (B2.1-2)

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

Equation (B2.1-3)

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

Equation (B2.1-4)

In-Service Monitoring					Chloride Diffusion Coefficient at age t , $D_{app,C}(t)$			Surface Chloride Concentration, C_s or $C_{s,AV}$			Aging Exponent, α		Service Life, t_{sl}	End of Service Date
Life Cycle Stage	Testing Date	Age, t [yr]	No. Samples	Test Method	[mm ² /yr] Mean, μ	Std Dev, σ		[wt-%/cem] Mean, μ	Std Dev, σ		n/a Mean, μ	Std Dev, σ	[yr]	[yyyy]
Design/Construction Assumed Design (Trial Batch)														
		0.0767		NT Build 492	219	87.5		0.70	0.35		0.6	0.15	>100	2117
					2.96									
As-Constructed	01.06.17	0.0767	3	NT Build 492	202	80.8		0.70	0.35		0.375	0.17	98	2115
		100			13.71									
In Service Durability Monitoring					Measured Properties from Chloride Profiling Tests			Regression Calculation		Monte Carlo Calculation				
Monitoring Inspection 1	01.06.19	2			60.00			0.70	0.35		0.372	0.169	97	2114
Monitoring Inspection 2	01.06.21	4			40.00			0.70	0.35		0.398	0.180	115	2132
Monitoring Inspection 3	01.06.25	8			35.00			0.70	0.35		0.387	0.175	100	2117
Monitoring Inspection 4	01.06.37	20			20.00			0.70	0.35		0.405	0.183	122	2139
Monitoring Inspection 5														
Monitoring Inspection 6														
Monitoring Inspection 7														
Monitoring Inspection 8														
Monitoring Inspection 9														
Monitoring Inspection 10		100												

Structure Component In-Service Data Analysis

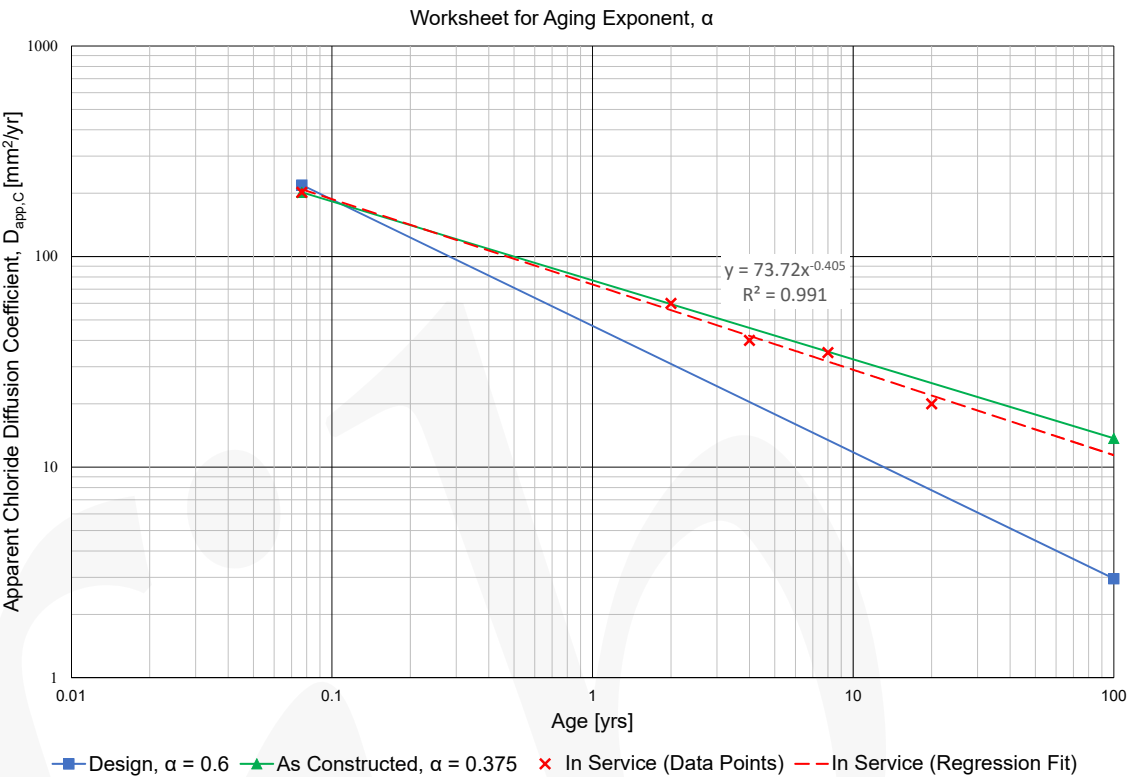


Fig. A-7 Log-Log Plot of Apparent Concrete Chloride Diffusion Coefficient vs. Age

Appendix B

Identification of Structure

Owner	
Structure Classification	
Structure Name	
Inventory ID #	
Structure Description	
Geographic Location	
Date Placed in Service	

(Photo of asset)



Identification of structures	
Design	
Project #	
Designer	(Name)
	(Address 1)
	(Address 2)
	(Phone)
Independent Checker	
Design Start Date	
Design End Date	
Execution (Construction)	
Contract ID #	
Bid Date	
Construction Start Date	
Construction End Date	
Contractor	
Sub-Contractors / Suppliers	
Cast-in-Place Concrete	(Name)
	(Address 1)
	(Address 2)
	(Phone)
Precast Concrete	(Name)
	(Address 1)
	(Address 2)
	(Phone)
Reinforcing Steel	(Name)
	(Address 1)
	(Address 2)
	(Phone)
Prestressing Steel	(Name)
	(Address 1)
	(Address 2)
	(Phone)

Identification of structures

Structure plan & Elevation



Durability Design Parameters

Structure Name

Inventory ID #

Durability Specifications			
Model Code for Service Life Design, <i>fib</i> 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:	Mean, μ	Std Dev, σ
High Temperature (°C)			
Low Temperature (°C)			
Average Temperature (°C)			
Relative Humidity (%)			
Precipitation (mm)			
Time of Wetness (ToW)	No. of days per year with rainfall exceeding 0.1 mm		
Deterioration Mechanisms			
Reinforcing Steel Corrosion	Carbonation, De-icing Chlorides, Sea water		
Freeze/Thaw Damage			
Salt Scaling Damage			
Abrasion/Erosion	Rutting, Ice action		
External Chemical Attack	Sulfate, Acid, Leaching		
Internal Chemical Attack	ASR, AAR, DEF		
Coating Breakdown			
Design Parameters			
Consequence Class (CC) - Loss of human life, economic, social or environmental	CC1 - Low		
	CC2 - Normal		
	CC3 - High		
Design Supervision (DSL) - Checking of the design	DSL1 - Self		
	DSL2 - Same organization		
	DSL3 - Independent 3 rd party		
Construction (Execution) Inspection Parameter			
Execution Class EXC) - Construction inspection	EXC1 - Self		
	EXC2 - Same organization		
	EXC3 - Independent 3 rd 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 - Reactive (planned periodic inspection)	
	C - None (no direct inspection/testing)	
Condition Control Levels (CCL)/Inspection Regimes	CCL0 - None (not possible, e.g., buried)	
	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

Structure Name

Inventory ID #

(Replace graphic with specific project)

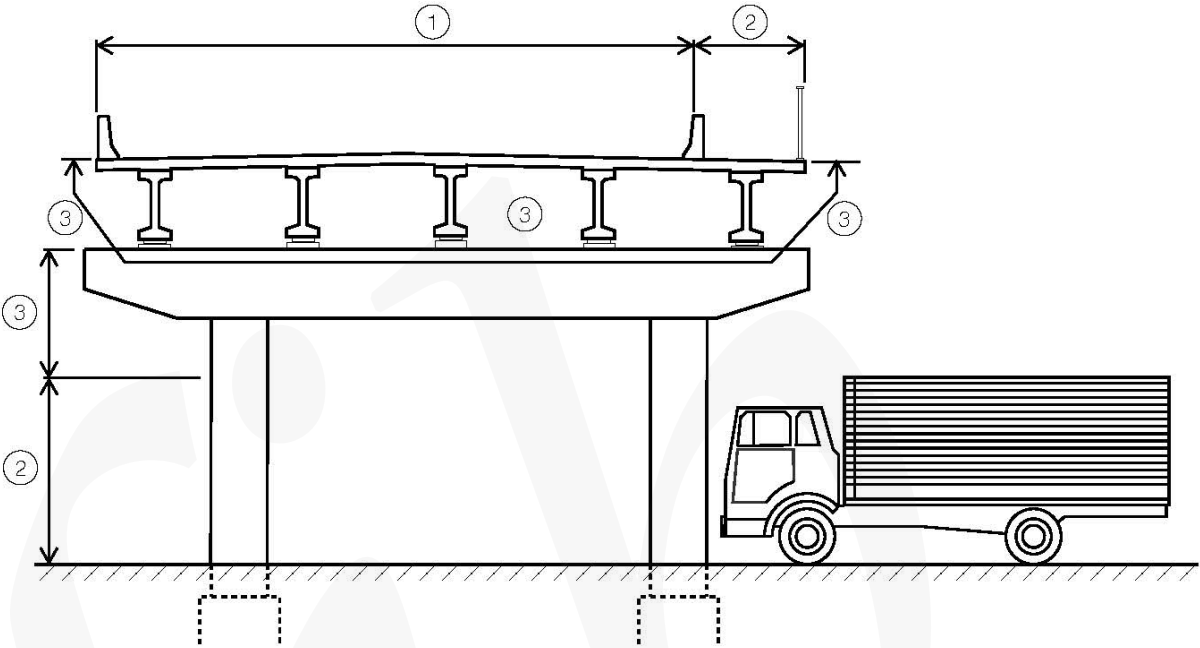


Fig. B-1 Exposure Zone Map

Exposure Classifications (per EN-206)							
Class Designation	Figure #	Description of the Environment	Specific Exposure	Environmental loading			
Model Based Deterioration (e.g. Chlorides or Carbonation)				Concentration		Other parameters	
				[units]		[units]	
				Mean, μ	Std Dev, σ	Mean, μ	Std Dev, σ
Non Model Based Deterioration (e.g. Deemed to Satisfy or Avoidance)							

Deterioration Mechanism/Model

Deterioration Mechanism	Full probabilistic design method for chloride induced corrosion - uncracked concrete		
Deterioration Model	Fick's 2 nd Law (analytical model with assumptions on boundary and initial conditions)		
Source	fib Bulletin 34 - Model Code for Service Life Design, Appendix B2		
$C_{crit} \geq C_o + (C_{s,\Delta x} - C_o) \cdot \left[1 - \operatorname{erf} \left(\frac{a_{cov} - \Delta x}{2\sqrt{D_{app,C} \cdot t}} \right) \right]$			Equation (B2.1-1)
$D_{app,C} = K_e \cdot D_{RCM,0} \cdot K_t \cdot A(t)$			Equation (B2.1-2)
$k_e = \exp \left(b_e \left(\frac{1}{T_{ref}} - \frac{1}{T_{real}} \right) \right)$			Equation (B2.1-3)
$A(t) = \left(\frac{t_o}{t} \right)^\alpha$			Equation (B2.1-4)
Function Variables	Description	Units	Distribution Function
t	Time	[yr]	n/a
x	Depth with corresponding content of chlorides C(x,t)	[mm]	n/a
C_{crit}	Critical chloride content	[wt.-%/cem]	Beta, a=0.2, b=2.0
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 2 nd law of diffusion)	[mm]	Beta, a=0, b=50
a_{cov}	Concrete cover	[mm]	Log-Normal
$D_{app,C}$	Apparent coefficient of chloride diffusion through concrete	[mm ² /yr]	n/a
$D_{RCM,0}$	Chloride migration coefficient	[mm 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	[K]	Normal
A(t)	Subfunction considering the ageing	[-]	n/a
t_o	Reference point of time	[yr]	Constant = 0.0767
α	Ageing exponent	[-]	Beta, a=0.0, b=1.0

Deterioration Mechanism/Model

Mechanism	Full probabilistic design method for carbonation induced corrosion - uncracked concrete		
Model	Fick's 1 st Law		
Source	fib Bulletin 34 - Model Code for Service Life Design, Appendix B1		
$g(a, xc(t)) = a - xc(t) = a - \sqrt{2 \cdot k_e \cdot k_c (k_t \cdot R_{ACC,0}^{-1} + \varepsilon_t) \cdot C_s} \cdot \sqrt{t} \cdot W(t)$			Equation (B1.1-1)
$K_e = \frac{\left(1 - \left(\frac{RH_{real}}{100}\right)^{f_e}\right)^{g_e}}{\left(1 - \left(\frac{RH_{ref}}{100}\right)^{f_e}\right)^{g_e}}$			Equation (B1.2-1)
$K_c = \left(\frac{t_c}{7}\right)^{b_c}$			Equation (B1.2-2)
$R_{ACC,0}^{-1} = \left(\frac{X_c}{T}\right)^2$			Equation (B1.2-3)
$R_{NAC,0}^{-1} = K_t \cdot R_{ACC,0}^{-1} + \varepsilon_t$			Equation (B1.2-4)
$C_s = C_{s,atm} + C_{s,emi}$			Equation (B1.2-5)
$W(t) = \left(\frac{t_0}{t}\right)^{\frac{(p_{sr} ToW)^{b_w}}{2}}$			Equation (B1.2-7)
$ToW = \frac{\text{days per year with rainf all } h_{Ncl} \geq 2.5\text{mm}}{365}$			Equation (B1.2-8)
Function Variables	Description	Units	Distribution Function
a	Cover depth	[mm]	Log-Normal
t	Time, Design service life	[yr]	n/a
$x_c(t)$	Measured carbonation depth in the ACC compliance test	[mm]	n/a
τ	Time constant for described test conditions	[yr]	Constant = 420
k_e	Environmental function (based on Relative Humidity)	[-]	n/a
RH_{real}	Relative humidity of the carbonated layer	[%]	Beta, a=40, b=100
RH_{ref}	Reference relative humidity	[%]	Constant = 65
f_e	Exponent	[-]	Constant = 5
g_e	Exponent	[-]	Constant = 2.5
k_c	Execution transfer parameter (function of curing time)	[-]	n/a
b_c	Exponent of regression	[-]	Normal
t_c	Period of curing	[day]	Constant
$R_{NAC,0}^{-1}$	Inverse effective carbonation resistance of dry concrete, determined at time t_0 on specimens with the Normal Carbonation Test (NAC)	[(mm ² /yr)/ (kg/m ³)]	n/a
$R_{ACC,0}^{-1}$	Inverse effective carbonation resistance of dry concrete, determined at time t_0 on specimens with the Accelerated Carbonation Test (ACC)	[(mm ² /yr)/ (kg/m ³)]	Log-Normal
k_t	Regression parameter	[-]	Normal
ε_t	Error term	[(mm ² /yr)/ (kg/m ³)]	Normal
C_s	CO ₂ -Concentration	[kg/m ³]	Normal
$C_{s,atm}$	CO ₂ -Concentration of the atmosphere	[kg/m ³]	Normal
$C_{s,emi}$	CO ₂ -Concentration due to emission sources	[kg/m ³]	Normal
$W(t)$	Weather function	[-]	n/a
t_0	Reference time	[yr]	Constant = 0.0767
p_{sr}	Probability of driving rain	[-]	Constant
ToW	Time of Wetness = Days with rainfall > 2.5 mm / 365	[-]	Constant
b_w	Exponent of regression	[-]	Normal

Deterioration Mechanism/Model

Mechanism	Alkali-Aggregate Reactivity (AAR)
Model	None
Design Strategy	Avoidance of Deterioration
	Deemed to Satisfy
Reference	AASHTO R80 - Determining the Reactivity of Concrete Aggregates and Selecting Appropriate Measures for Preventing Deleterious Expansion in New Concrete Construction
Concrete/Aggregate Materials	
Concrete Class	
Mix Design	
Field Performance History	
Determination/Classification of Aggregate Potential Reactivity - attach test report	
Petrographic examination of aggregates, ASTM C295	aggregates non-reactive, no further action required
	aggregates potentially reactive
	chemical composition potentially alkali-carbonate reactive
Tests for Potential Alkali–Carbonate Reaction (ACR) - attach test reports	
Chemical Composition Test, CSA-A23.2-26A	aggregate NOT quarried carbonate
	aggregate IS quarried carbonate, but NOT potentially expansive
	aggregate IS potentially expansive quarried carbonate, Test by ASTM C1105
Concrete Prism Test, ASTM C1105	1) Alkali content < 1.8 kg/m ³
	2) Expansion of cement-aggregate < 0.025% at 6 months OR 0.03% at 1 year
	Both conditions 1) and 2) met - continue test for alkali-silica reaction
	Condition 1) or 2) not met - ACR - DO NOT USE
Tests for Potential Alkali-Silica Reaction (ASR) - attach test reports	
Accelerated Mortar Bar Test (AMBT), ASTM C1260	14 day expansion < 0.10% - NOT reactive
	14 day expansion > 0.10% - perform ASTM C1293 OR perform risk assessment
Concrete Prism Test (CPT), ASTM C1293	1 year expansion < 0.04% - NOT reactive
	1 year expansion > 0.04% - IS reactive - perform risk assessment

ASR Prescriptive Approach - Risk Assessment

Concrete Class

Mix Design

Aggregate Source

ASR Test Results	n/a	AMBT 14-day expansion				
Aggregate Reactivity Class		CPT 1-year expansion	0.07%			
Aggregate Reactivity Class		R0 - nonreactive	CPT < 0.04%		AMBT < 0.10%	
		R1 - moderately reactive	0.04% < CPT <0.12%		0.10% < AMBT < 0.30%	
		R2 - highly reactive	0.12% < CPT <0.24%		0.30% < AMBT < 0.45%	
		R3 - very highly reactive	CPT > 0.24%		AMBT > 0.45%	
Level of ASR Risk		Size and Exposure Conditions	Aggregate Reactivity Class			
			R0	R1	R2	R3
		Non-massive concrete in a dry environment	Risk Level 1	Risk Level 1	Risk Level 2	Risk Level 3
		Massive concrete (least dimension > 0.9 m) in a dry environment	Risk Level 1	Risk Level 2	Risk Level 3	Risk Level 4
		All concrete exposed to humid air, buried, or immersed	Risk Level 1	Risk Level 3	Risk Level 4	Risk Level 5
		All concrete exposed to alkalis in service (seawater, de-icing salts)	Risk Level 1	Risk Level 4	Risk Level 5	Risk Level 6
Classification of Structure		Class	Safety, Economic, or Environmental Consequence of ASR		Acceptability of ASR	
		S1 - Non-load bearing elements, temporary structures (<5 years)	small or negligible		some deterioration tolerated	
		S2 - Sidewalks, curb and gutters (< 40 years)	some		moderate risk acceptable	
		S3 - Culverts, traffic railings, rural low volume bridges (40-75 years)	significant		minor risk acceptable	
		S4 - Major bridges, tunnels, difficult to repair elements (>75 years)	serious		not tolerated	
Level of Prevention		Level of ASR Risk	Classification of Structure			
			S1	S2	S3	S4
	Risk Level 1	V	V	V	V	
	Risk Level 2	V	V	W	X	
	Risk Level 3	V	W	X	Y	
	Risk Level 4	W	X	Y	Z	
	Risk Level 5	X	Y	Z	ZZ	
	Risk Level 6	Y	Z	ZZ	not acceptable	
Prevention Measures		Level of Prevention	Required Actions			
		V	No special measures or further actions required			
		W, X, Y, Z, ZZ	Determine ASR Prevention Requirements			

ASR Prescriptive Approach - Prevention Requirements

Concrete Class

Mix Design

Risk Prevention Level

Component	Source	% of Total Cementitious	Weight	Sodium Oxide, Na ₂ O	Potassium Oxide, K ₂ O	Equivalent Alkali Content (Na ₂ Oe) = Na ₂ O + 0.658·K ₂ O	
			[kg/m ³]	%	%	%	[kg/m ³]
Cement Type I	Cal Portland						
SCMs							
Fly Ash (FA)							
Slag (GGBFS)	Ash Grove						
Silica Fume (SF)							
	Total		0			Total	0.00

Table 5		Actual Alkali Content of Concrete [kg/m ³] = KGA
Prevention Level	Maximum Alkali Content (Na ₂ Oe) of Concrete [kg/m ³]	
V	no limit	
W	3	
X	2.4	
Y	1.8	
Z	Table 8	
ZZ	Table 8	

Table 6						
Type of SCM	Alkali Level of SCM	Min. Replacement Level (% by Mass of Cementitious)				
		Level W	Level X	Level Y	Level Z	Level ZZ
Fly Ash (CaO < 18%)	%Na ₂ Oe ≤ 3.0	15	20	25	35	Table 7
	3.0 < %Na ₂ Oe ≤ 4.5	20	25	30	40	Table 7
Slag	%Na ₂ Oe ≤ 1.0	25	35	50	65	Table 7
Silica Fume (SiO ₂ ≥ 85%)	%Na ₂ Oe ≤ 1.0	2.0 KGA	2.5 KGA	3.0 KGA	4.0 KGA	Table 7
		0.0	0.0	0.0	0.0	

Table 7		
Cement Alkalis	Level of SCM	0.00%
%Na ₂ Oe ≤ 0.7	Reduce the min. amount of SCM given in Table 6 by one protection level	<= use
0.7 < %Na ₂ Oe ≤ 1.0	Use minimum level of SCMs given in Table 6	
1.0 < %Na ₂ Oe ≤ 1.25	Increase the min. amount of SCM given in Table 6 by one protection level	
%Na ₂ Oe > 1.25	No guidance given (increased risk of damaging ASR)	

Table 8			
	SCM Sole Prevention	Limiting Concrete Alkali Content Plus SCM	
Prevention Level	Minimum SCM Level	Maximum Alkali Content, [kg/m ³]	Minimum SCM Level
Z	SCM level shown for Level Z in Table 6	1.8	SCM level shown for Level Y in Table 6
ZZ	not allowed	1.8	SCM level shown for Level Z in Table 7

Concrete Mix Design Summary

Structure Name
Inventory ID #

Concrete Class	Mix Designation	28-day Strength f'_c (N/mm ²)	Unit weight (kg/m ³)	Cementitious Materials						Durability Design Properties					
				Cement		Supplemental Cementitious Materials (SCMs)			Cement + SCM Unit weight (kg/m ³)	Water/Cement Ratio w/c	Chloride Migration Coefficient, $D_{RCM,0}$ (mm ² /yr)	Aging Exponent, α			
				Type	Unit weight (kg/m ³)	Fly Ash %	Slag %	Silica Fume %							
														Mean, μ	Std Dev, σ
Design - Trial Batch															
Construction															

Material Specifications	
Portland Cement	List appropriate specification
Fly Ash (FA)	List appropriate specification
Slag (GGBFS)	List appropriate specification
Silica Fume (SF)	List appropriate specification

Concrete Mix Data

Structure Name

Inventory ID #

Mix Producer				
Mix ID				
Concrete Specification				
Concrete Class				
Materials	Type/Specification	Supplier	Wt. (kg)	
Cementitious				
Cement	Type I-II/ AASHTO M85	Cal Portland		
Supplemental Cementitious Materials (SCMs)				SCM %
Fly Ash (FA)				
Slag (GGBFS)				
Silica Fume (SF)				
		Total Cementitious		
Aggregates				
Coarse				
Coarse				
Fine				
Fiber Mesh				
		Sub-total		
Aggregate Moisture Water				
		Total Aggregate		
Admixtures				
				Wt. (gm)
Air Entrainment				
Hi Range Water Reducer				
Water				
Batch Water				
Aggregate Moisture Water				
Admixture Water				
		Total Water		
Total Batch				
Total Batch Weight				
Batch Volume				m ³
Relative Yield				
Density				kg/m ³
Adjusted Cementitious Content				kg/m ³
Water/Cement Ratio		w/c=		

Reinforcing Steel

Type	Specification	Yield Strength, Fy (N/mm ²)	Tensile Strength, Fu (N/mm ²)	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							
Plain Carbon - Epoxy Coated							
Plain Carbon - Galvanized							
Low-Carbon Chromium							
Austenitic Stainless							
Duplex Stainless							

Prestressing Steel

Type	Specification	Yield Strength, Fy (N/mm ²)	Tensile Strength, Fu (N/mm ²)	Alloy Type	UNS Designation	Critical Chloride Threshold (% wt of cementitious)	
						Beta Distribution function, a=0.2, b=2	
						Mean, μ	Std Dev, σ
Deformed Bar - Type II							
7-Wire Strand (low relaxation)							

Service Life Design Summary - Concrete Components

Structure Name

Inventory ID #

[illegible]

Service Life Design Summary - Non-Concrete Material Components

Structure Name

Inventory ID #

[illegible]

Structure Component Identification - Superstructure

Structure Name

Inventory ID #

(insert drawing of structure / portion of structure to identify individual components)



Structure Component Data

Component Name

Figure ID

Required Service Life

[yrs]

Location

Reliability Index, β

Deterioration Model - *fib* Bulletin 34, Annex B2, Full probabilistic design method
for chloride induced corrosion - uncracked concrete

Property	Variable	Units	Distribution	Design	Mean, μ	Std Dev, σ	As-Constructed	Mean, μ	Std Dev, σ
Environmental Parameters									
Exposure Class									
Surface Chloride Concentration	$C_{s,av}$	[wt-%/cm]	Log-Normal						
Transfer Function	Δx	[mm]	Beta a=0, b=50						
Temperature at Site	T_{real}	[°C]	Normal						
Standard RCM Test Temperature	T_{ref}	[K]	Constant	292.9					
Temperature Regression Variable	b_e	[K]	Normal	4'800	700				
Concrete Properties									
Class/Mix Design									
Initial Chloride Content	C_o	[wt-%/cm]	Constant						
Chloride Migration Coefficient	$D_{RCM,0}$	[mm ² /yr]	Normal						
Aging Exponent	α	n/a	Beta a=0, b=1						
RCM Testing age (28 days)	t_o	[yr]	Constant	0.0767					
Transfer Parameter	k_i	n/a	Constant	1.0					
Steel Reinforcement Properties									
Reinforcing Type/ Grade	Carbon								
Critical Chloride Threshold	C_{crit}	[wt-%/cm]	Beta a=0.2, b=2						
Clear Cover	a_{cov}	[mm]	Log-Normal						

$$C_{crit} = C(x = a_{cov}, t) = C_0 + (C_{s,av} - C_0) \cdot \left[1 - \operatorname{erf} \left(\frac{2 \sqrt{D_{app,C}} \cdot t - \Delta x}{2 \sqrt{D_{app,C}} \cdot t} \right) \right]$$

Equation (B2.1-1)

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

Equation (B2.1-2)

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

Equation (B2.1-3)

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

Equation (B2.1-4)

In-Service Monitoring					Chloride Diffusion Coefficient at age t , $D_{app,C}(t)$ [mm ² /yr]		Surface Chloride Concentration, C_s or $C_{s,Av}$ [wt-%/cem]		Aging Exponent, α		Service Life, t_{sl}	End of Service Date
Life Cycle Stage	Testing Date	Age, t [yr]	No. Samples	Test Method	Mean, μ	Std Dev, σ	Mean, μ	Std Dev, σ	n/a	Mean, μ	[yr]	[yyyy]
Design/Construction												
Assumed Design (Trial Batch)		0.0767										
		0										
As-Constructed		0.0767										
		0										
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												
Monitoring Inspection 9												
Monitoring Inspection 10												

Structure Component In-Service Data Analysis



Fig. B-2 Log-Log Plot of Apparent Concrete Chloride Diffusion Coefficient vs. Age

Design, $\alpha =$

As constructed, $\alpha =$

Structure Component Data - Cover Measurements

Component Name Standard German Concrete and Construction Association - DBV, Concrete Cover and Reinforcement per Eurocode 2

Location Sampling

(insert drawing of structure component showing grid sampling locations)

As-Constructed Cover Dimensions at Grid Points [mm]												
	A	B	C	D	E	F	G	H	I	J	K	L
1												
2												
3												
4												
5												
6												
7												
8												

Statistical Evaluation of Measured Cover Depths, all units [mm]							
Target threshold %		5%	Qualitative Procedure				
Nominal cover	c_{nom}		# measurements < c_{min}		# allowed per N		
Safety margin	Δc						
Req'd minimum cover	c_{min}		Quantitative Procedure				
Sample size	N		Outlier cover	X_{OG}	$= 2.5X_M - 1.5X_{min}$		
Median	X_M		Location parameter	r	$= (X + X_M)/2$		
Min	X_{min}		Form parameter	k	$= 1.8 r/s$		
Mean	X		Threshold value	$c(5\%)$	$= r/(19^{1/k})$		
Std. Dev.	s		Parameter $p(x)$	$p(x)$	$= c_{min}/r$		
			% of cover depth < c_{min}	$F(x)$	$= p(x)^k/(1+p(x)^k)$		

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