

ACI 365.1R-17

Report on Service Life Prediction

Reported by ACI Committee 365



American Concrete Institute
Always advancing



Report on Service Life Prediction

Copyright by the American Concrete Institute, Farmington Hills, MI. All rights reserved. This material may not be reproduced or copied, in whole or part, in any printed, mechanical, electronic, film, or other distribution and storage media, without the written consent of ACI.

The technical committees responsible for ACI committee reports and standards strive to avoid ambiguities, omissions, and errors in these documents. In spite of these efforts, the users of ACI documents occasionally find information or requirements that may be subject to more than one interpretation or may be incomplete or incorrect. Users who have suggestions for the improvement of ACI documents are requested to contact ACI via the errata website at <http://concrete.org/Publications/DocumentErrata.aspx>. Proper use of this document includes periodically checking for errata for the most up-to-date revisions.

ACI committee documents are intended for the use of individuals who are competent to evaluate the significance and limitations of its content and recommendations and who will accept responsibility for the application of the material it contains. Individuals who use this publication in any way assume all risk and accept total responsibility for the application and use of this information.

All information in this publication is provided “as is” without warranty of any kind, either express or implied, including but not limited to, the implied warranties of merchantability, fitness for a particular purpose or non-infringement.

ACI and its members disclaim liability for damages of any kind, including any special, indirect, incidental, or consequential damages, including without limitation, lost revenues or lost profits, which may result from the use of this publication.

It is the responsibility of the user of this document to establish health and safety practices appropriate to the specific circumstances involved with its use. ACI does not make any representations with regard to health and safety issues and the use of this document. The user must determine the applicability of all regulatory limitations before applying the document and must comply with all applicable laws and regulations, including but not limited to, United States Occupational Safety and Health Administration (OSHA) health and safety standards.

Participation by governmental representatives in the work of the American Concrete Institute and in the development of Institute standards does not constitute governmental endorsement of ACI or the standards that it develops.

Order information: ACI documents are available in print, by download, on CD-ROM, through electronic subscription, or reprint and may be obtained by contacting ACI.

Most ACI standards and committee reports are gathered together in the annually revised ACI Manual of Concrete Practice (MCP).

American Concrete Institute
38800 Country Club Drive
Farmington Hills, MI 48331
Phone: +1.248.848.3700
Fax: +1.248.848.3701

www.concrete.org

Report on Service Life Prediction

Reported by ACI Committee 365

Evan C. Bentz, Chair

Kyle D. Stanish, Secretary

Muhammed P. A. Basheer
Neal S. Berke
Shrinivas B. Bhide
David N. Bilow
Larry D. Church
Carolyn M. Hansson
R. Doug Hooton
O. Burkan Isgor

Anthony N. Kojundic
Zoubir Lounis
Tracy D. Marcotte
David B. McDonald
Matthew A. Miltenberger
Mohamad Nagi
Dan J. Naus
Karthik H. Obla

Bruce G. Smith
Michael D. A. Thomas
Paul G. Tourney
Wael A. Zatar
Shengjun Zhou
Consulting Members
Antonio J. Aldykiewicz Jr.
James P. Archibald

Francois Chapdelaine
David G. Manning
Charles D. Pomeroy
Jesus Rodriguez
Alexander M. Vaysburd
Yash Paul Virmani

This report presents information to the owner and design professional on the service life prediction of new and existing concrete structures. Key factors controlling the service life of concrete and methodologies for evaluating the condition of the existing concrete structures, including definitions of key physical properties, are also presented. This report assists in the application of available methods and tools to predict the service life of existing structures and provides procedures that can be taken at the design and construction stage to increase the service life of new structures. Techniques for predicting the service life of concrete and the relationship between economics and the service life of structures are discussed. Examples provided discuss which service life techniques are applied to concrete structures or structural components. Needed developments to improve the reliability of service life predictions are also identified.

Keywords: chemical attack; construction; corrosion; design; durability; rehabilitation; repair; service life; sustainability.

CONTENTS

CHAPTER 1—INTRODUCTION AND SCOPE, p. 2

- 1.1—Introduction, p. 2
- 1.2—Scope, p. 3

CHAPTER 2—DEFINITIONS AND NOTATION, p. 3

- 2.1—Definitions, p. 3
- 2.2—Notation, p. 4

CHAPTER 3—ENVIRONMENT, DESIGN, AND CONSTRUCTION CONSIDERATIONS, p. 5

- 3.1—Introduction, p. 5
- 3.2—Environmental considerations, p. 5
- 3.3—Design and structural loading considerations, p. 10
- 3.4—Interaction of structural load and environmental effects, p. 11
- 3.5—Construction-related considerations, p. 12

CHAPTER 4—IN-SERVICE INSPECTION, CONDITION ASSESSMENT, AND REMAINING SERVICE LIFE, p. 13

- 4.1—Introduction, p. 13
- 4.2—Preliminary condition assessment, p. 14
- 4.3—Detailed structural assessments, p. 17
- 4.4—Inspection and maintenance to maintain or predict structural reliability, p. 18

CHAPTER 5—METHODS FOR PREDICTING THE SERVICE LIFE OF CONCRETE STRUCTURES, p. 19

- 5.1—Introduction, p. 19
- 5.2—Approaches for predicting service life of new concrete structures, p. 20
- 5.3—Prediction of remaining service life of existing concrete structures, p. 26
- 5.4—Predictions for existing structures based on extrapolations, p. 27

ACI Committee Reports, Guides, and Commentaries are intended for guidance in planning, designing, executing, and inspecting construction. This document is intended for the use of individuals who are competent to evaluate the significance and limitations of its content and recommendations and who will accept responsibility for the application of the material it contains. The American Concrete Institute disclaims any and all responsibility for the stated principles. The Institute shall not be liable for any loss or damage arising therefrom.

Reference to this document shall not be made in contract documents. If items found in this document are desired by the Architect/Engineer to be a part of the contract documents, they shall be restated in mandatory language for incorporation by the Architect/Engineer.

ACI 365.1R-17 supersedes ACI 365.1R-00 and was adopted and published September 2017.

Copyright © 2017, American Concrete Institute.

All rights reserved including rights of reproduction and use in any form or by any means, including the making of copies by any photo process, or by electronic or mechanical device, printed, written, or oral, or recording for sound or visual reproduction or for use in any knowledge or retrieval system or device, unless permission in writing is obtained from the copyright proprietors.

5.5—Multi-species approaches, p. 27

5.6—Summary, p. 28

CHAPTER 6—ECONOMIC CONSIDERATIONS, p. 28

6.1—Introduction, p. 28

6.2—Life cycle cost analysis, p. 29

6.3—Governing parameters in LCC analysis, p. 31

6.4—Service life prediction and LCCA of concrete structures, p. 32

6.5—Example, p. 32

CHAPTER 7—EXAMPLES OF SERVICE LIFE TECHNIQUES, p. 33

7.1—Introduction, p. 33

7.2—Example 1: Relationship of amount of steel corrosion to time of spalling, p. 34

7.3—Example 2: Use of multiple inputs to calculate life of structure, p. 35

7.4—Example 3: When to repair or rehabilitate, p. 36

7.5—Example 4: Use of reaction rate to calculate life of sewer pipe, p. 38

7.6—Example 5: Estimating service life and maintenance demands of diaphragm wall exposed to saline groundwater, p. 38

7.7—Example 6: Application of time-dependent reliability concepts to concrete slab, p. 39

7.8—Example 7: Use of stochastic cumulative damage models to predict service life of concrete structures, p. 40

7.9—Example 8: Probabilistic service life prediction, p. 41

7.10—Example 9: Predicting chloride ingress in a marine environment for concrete with different cementitious materials, p. 42

7.11—Example 10: Multi-ionic finite element transport model (parking structure), p. 43

CHAPTER 8—ONGOING WORK AND NEEDED DEVELOPMENTS, p. 45

8.1—Introduction, p. 45

8.2—Designing for durability, p. 46

8.3—Needed developments, p. 47

CHAPTER 9—REFERENCES, p. 47

Authored documents, p. 49

CHAPTER 1—INTRODUCTION AND SCOPE

1.1—Introduction

Service life concepts for buildings and structures date back to when early builders found that certain materials and designs lasted longer than others (Davey 1961). Since then, service life predictions of structures, equipment, and other components have been generally qualitative and empirical. An understanding of the mechanisms and kinetics of many degradation processes of concrete has formed a basis for making quantitative predictions of the service life of concrete structures and components. In addition to actual or potential structural collapse, other factors can govern the service life of a concrete structure. This document reports

on these service life factors for new and existing concrete structures and components.

Historically, three types of service life have been defined (Sommerville 1992):

(1) Technical service life is the time in service until a defined unacceptable state is reached, such as spalling of concrete, unacceptable safety level, or failure of elements. Examples of technical end of service life include:

- (a) Structural safety is unacceptable due to material degradation or exceeding the design load-carrying capacity
- (b) Severe material degradation, such as extensive corrosion of steel reinforcement
- (c) Excessive deflection under service loads due to decreased stiffness

(2) Functional service life is the time in service until the structure no longer fulfills the functional requirements or becomes obsolete due to change in functional requirements. Examples include:

- (a) Need for increased clearance, higher axle and wheel loads, or road widening
- (b) Aesthetics become unacceptable—for example, excessive corrosion staining
- (c) Functional capacity of the structure is no longer sufficient—for example, a football stadium with insufficient seating capacity

(3) Economic service life is the time in service until replacement of the structure or part of it is more economical than keeping it in service. Examples include:

- (a) Maintenance requirements exceed available resource limits
- (b) Replacement to improve economic opportunities—for example, replacing an existing parking garage with a larger one due to increased demand

Essentially, decisions concerning the end of service life are related to public safety, serviceability, functionality, and economic considerations.

In most cases, the performance, appearance, or capacity of a structure can be upgraded to an acceptable level bearing in mind costs, which are addressed in Chapter 6 of this report.

ACI 562, a performance-based code for the repair of structural concrete buildings, has taken the terms for “durability” and “service life,” and defined “design service life” (refer to Chapter 2 of this report) such that licensed design professionals can design rehabilitation and repair programs for owners, allowing for extension of service life for a given structure. Regardless of the service life concept, the terms “durability” and “service life” are often erroneously interchanged. The distinction between the two terms is that durability is about performance for a given time frame in a given environment, and service life is the amount of time to be expected in a given environment or a specific structure.

Service life evaluation methodologies have application both in the design stage of a structure—where certain parameters are established, such as selection of the water-cementitious materials ratio (w/cm), concrete cover, and admixtures—and in the operation phase where inspection and maintenance strategies are developed in support of life cycle cost analyses (LCCA) (Zatar 2014). During the

design stage, there is typically a design service life that is anticipated. This is either implicitly established or explicitly considered. The implicit design life relies on code minimums to achieve satisfactory performance for a typical life of a concrete structure. Explicitly considering a design service life allows the owner more control over the long-term expectations for the performance of the structure, although code minimums still need to be met.

Service life design includes the architectural and structural design, selection and design of materials, maintenance plans, and quality assurance and quality control plans for a future structure (RILEM 1986). Service life can be predicted based on mixture proportioning, including selection of concrete constituents; known material properties; expected service environment; structural detailing, such as concrete cover; construction methods; projected loading history; and the definition of end-of-life. This allows concrete structures to have a reasonable assurance of meeting the specified design service life (Jubb 1992; Clifton and Knab 1989; Sommerville 2003). The acceptance of advanced materials, such as high-performance concrete, can depend on life cycle cost (LCC) analyses that consider predictions of their increased service life.

Methodologies are being developed that predict the service life of existing concrete structures (Ahmad 2003; Zatar 2014). To make these predictions, information is required on the present condition of concrete and reinforcement, rates of degradation, past and future loading, and definition of the end-of-life (Clifton 1991). Based on remaining life predictions, economic decisions can be made on whether a structure should be repaired, rehabilitated, or replaced. Service life evaluations have also been used to establish inspection frequencies to minimize expected expenditures (Mori and Ellingwood 1994a,b). For rehabilitation and repair programs, this methodology becomes complicated and is not yet well understood, as estimating the service life of a repaired component or structure depends on the type and quality of repair (ACI 546R) as well as the performance of the initial structure, and the materials and systems can vary from traditional concrete and its deterioration mechanisms.

Service life comparisons can also be performed by defining a study period over which alternative durability approaches are considered. Parameters of interest—for example, structural capacity, functionality or initial/repair costs—can then be monitored over the study period so that either a certain level of performance is maintained or the value is optimized over the entire study period.

1.1.1 Service life and sustainability—Service life calculation and performance estimation tools should be an integral part of sustainability design for concrete structures (Schokker 2010; ASTM E2921). Several techniques presented in this report for determining the expected service life are also effective methods for green building design. The key sustainability criteria of carbon dioxide (CO₂) emission, embodied energy, and other parameters are greatly impacted by the expected service life of a structure. The overall impact of construction activities is reduced the longer materials last and the more maintenance repair events are minimized.

Sustainable design of concrete structures is thereby dependent on using appropriate methods for predicting service life.

Model building codes and sustainability codes in Europe, Canada, and many other parts of the world have established minimum service life performance criteria for buildings. In the United States, the codes have only recently included sustainability requirements that are primarily energy- and water-related, leaving the owners, designers, and contractors responsible for establishing the service life criteria. Sustainable design or green building design takes a holistic approach to the observation of the entire life cycle of the facility. Green design principles, when combined with service life design, can provide justifications for exceeding design code minimums. Often, the appropriate selection of construction materials and techniques can result in a service life of more than 75 years with normal maintenance.

1.2—Scope

This report begins with an overview of important factors controlling the service life of concrete, including past and current design of structures; concrete materials issues; field practices involved with placing, consolidating, and curing of concrete; and in-service stresses induced by degradation processes and mechanical loads. Methodologies used to evaluate the structural condition of concrete structures and the condition and properties of in-service concrete materials are presented. Methods are reviewed for predicting the service life of concrete, including comparative methods, use of accelerated aging (degradation) tests, application of mathematical modeling and simulation, and application of reliability and stochastic concepts.

This is followed by a discussion of relationships between economics and the life of structures, such as when it is more economical to replace a structure than to repair or rehabilitate. Examples are described in which service life prediction techniques are applicable to concrete structures or structural components. Finally, needed developments to improve the reliability of service life predictions are presented.

CHAPTER 2—DEFINITIONS AND NOTATION

2.1—Definitions

ACI provides a comprehensive list of definitions through an online resource, “ACI Concrete Terminology,” <https://www.concrete.org/store/productdetail.aspx?ItemID=CT13>. Definitions provided herein complement that source.

design service life (of a building, component, or material)—is the period of time after installation or repair during which the performance satisfies the specified requirements if routinely maintained but without being subjected to an overload or extreme event.

durability—the ability of a material or structure to resist weathering action, chemical attack, abrasion, and other conditions of service, and maintain serviceability over a specified time or service life.

service life—an estimate of the remaining useful life of a structure based on the current rate of deterioration or distress, assuming continued exposure to given service conditions without repairs.