

IN-LB

Inch-Pound Units

SI

International System of Units

Concrete Structure Design for Fatigue Loading—Report

Reported by ACI Committee 215

ACI PRC-215-21



American Concrete Institute
Always advancing



Concrete Structure Design for Fatigue Loading—Report

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, 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 the ACI Collection of Concrete Codes, Specifications, and Practices.

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

www.concrete.org

Concrete Structure Design for Fatigue Loading—Report

Reported by ACI Committee 215

Martin Noël, Chair

John S. Popovics, Secretary

Rania Al-Hammoud
Mario Cristian Gaedicke Hornung
Kent A. Harries
Clifford N. MacDonald

Evan Marshall
Fadi Oudah
Klaus Alexander Rieder
Steve Schaefer

Sandeep Shah
Miguel Angel Vicente

Consulting Members

P. N. Balaguru
John N. Cernica
John M. Hanson
Hubert K. Hilsdorf
Elin A. Jensen

Lembit Kald
Stephen J. Kurtz
Conrad Paulson
Raymond S. Rollings
Rajan Sen

Kolluru V. Subramaniam
William J. Venuti
Knut Waagaard

The committee would like to thank H. Hadad for his contribution to this report.

Fatigue is a mechanical degradation process caused by repeated loads, such as traffic loading or wind loads on a bridge, that results in irreversible damage in concrete structures. Many types of concrete elements are subjected to repeated loads, such as airport and roadway pavements, bridge girders, bridge decks, wind turbines, and prestressed concrete railroad ties. This document provides information that will benefit practicing engineers interested in the design or rehabilitation of concrete structures subjected to high-cycle fatigue—that is, stress cycles in which the material behavior remains within the elastic range. The effects of repeated loads on plain concrete, reinforcing materials, and reinforced concrete systems are discussed based on a summary of available literature. This report does not contain detailed design procedures but rather should be considered

a general resource providing a comprehensive overview of fatigue issues in reinforced concrete structures.

Keywords: design; fabric-reinforced cementitious matrix; fatigue; fiber-reinforced concrete; fiber-reinforced polymers; prestressed concrete; rehabilitation; reinforced concrete; reinforcing materials; service life.

CONTENTS

CHAPTER 1—INTRODUCTION AND SCOPE, p. 2

1.1—Introduction, p. 2

1.2—Scope, p. 3

CHAPTER 2—NOTATION AND DEFINITIONS, p. 3

2.1—Notation, p. 3

2.2—Definitions, p. 4

CHAPTER 3—PLAIN CONCRETE, p. 4

3.1—Scope, p. 4

3.2—General, p. 4

3.3—Fatigue as a degenerative process, p. 4

ACI Committee Reports and Guides 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 PRC-215-21 supersedes ACI 215R-74(97) and was adopted and published April 2022.

Copyright © 2022, 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.

- 3.4—Fatigue life models, p. 6
- 3.5—Important parameters, p. 6

CHAPTER 4—REINFORCING MATERIALS, p. 9

- 4.1—Scope, p. 9
- 4.2—Fatigue of steel, p. 9
- 4.3—Fatigue of fiber-reinforced polymer composites, p. 14

CHAPTER 5—CONCRETE REINFORCED WITH BARS, p. 16

- 5.1—Scope, p. 16
- 5.2—Concrete reinforced with steel bars, p. 16
- 5.3—Concrete reinforced with FRP bars, p. 18

CHAPTER 6—CONCRETE REINFORCED WITH PRESTRESSING REINFORCEMENT, p. 19

- 6.1—General, p. 19
- 6.2—Definitions, p. 19
- 6.3—Fatigue of fully prestressed concrete, p. 19
- 6.4—Fatigue of partially prestressed concrete, p. 20
- 6.5—Fatigue serviceability aspects, p. 22

CHAPTER 7—CONCRETE REINFORCED WITH DISCRETE FIBERS, p. 23

- 7.1—Scope, p. 23
- 7.2—General, p. 23
- 7.3—Fiber types, p. 24

CHAPTER 8—CONCRETE REINFORCED WITH EXTERNAL SHEETS OR LAMINATES, p. 25

- 8.1—Scope, p. 25
- 8.2—Steel-reinforced concrete strengthened with external FRP materials, p. 25
- 8.3—Fatigue of adhesive systems for externally bonded FRP, p. 26
- 8.4—Steel-reinforced concrete strengthened with external FRCM materials, p. 27

CHAPTER 9—REFERENCES, p. 28

- Authored references, p. 28

CHAPTER 1—INTRODUCTION AND SCOPE

1.1—Introduction

Fatigue is a mechanical degradation process caused by repeated loads, such as traffic loading or normal wind loads on a bridge, that results in irreversible damage in concrete structures. Because individual application of these service loads would not cause significant deformation or damage, fatigue damage occurs gradually from the cumulative effects of thousands or millions of load cycles. This report does not discuss the effects of high-amplitude load cycles associated with extreme events such as an earthquake or unintentional overload.

Many types of concrete elements are subjected to repeated low stress loads; common examples include airport and roadway pavements, bridge girders, bridge decks, wind

turbines, and prestressed concrete railroad ties. Although in-service fatigue failures of concrete structures and their components are rare, the fatigue behavior of reinforced concrete structures is important to consider for numerous reasons. For example, fatigue behavior can be a controlling parameter that determines the service life of concrete pavements. In other cases, fatigue damage can lead to increased cracking with resulting loss of stiffness and strength in concrete members under service loads, which can lead to failure. In statically indeterminate structural systems changes in stiffness caused by fatigue will also influence the distribution of loads. In summary, fatigue behavior affects the serviceability, safety, and durability of concrete structures, and its effects should be recognized in design to ensure that in-service cyclic stress ranges remain at an acceptably low level.

Live load amplitudes applied to a structure tend to grow over time, while new structures are becoming more lightweight through greater design optimization and the use of high-performance materials; this increases the ratio of live to dead loads. As a result, the importance of transient, cyclic stresses in proportion to a member's total load capacity is likely to increase over the service life of a structure. Furthermore, increasing use of construction materials such as post-tensioned concrete, fiber-reinforced polymers (FRPs), and fiber-reinforced concrete (FRC) requires engineers to have a broad understanding of the fatigue characteristics of various materials and systems.

Although service loads nominally produce stresses that are within the elastic range of the material or structure, small defects or geometric discontinuities can result in local amplified stress concentrations that exceed the elastic capacity of the material and form small damage zones or nucleation sites. The preliminary stage of the degradation process, where the development of these damage zones occurs, is often referred to as the initiation period. As these loads may be repeatedly applied thousands or millions of times, the damage zones grow in size (propagation) or in number (accumulation), leading to changes in the behavior of the larger material or composite component. In reinforced concrete members, this damage manifests through the formation of cracks in the concrete, reinforcement, or at their interface. The result of propagation and accumulation is usually a net reduction in the effective cross section of the member, its reinforcement, or in the bond strength between the reinforcement and the concrete, typically resulting in a loss of member stiffness and strength.

Although real live loads vary greatly in magnitude and application time sequence, for the purposes of design, an equivalent constant amplitude load cycle (for example, a sine function) with a well-defined maximum and minimum stress or strain level is normally assumed. This constant amplitude fatigue model presents many advantages for fatigue analysis, including the use of $S-N$ curves for presenting and interpreting fatigue life data. In those curves, S represents normalized applied stress or strain amplitude and is plotted on a vertical axis using a linear (or sometimes logarithmic) scale against N , which is the number of load cycles to failure