

ACI 341.2R-14

Report on Analysis and Design of Seismic- Resistant Concrete Bridge Systems

Reported by ACI Committee 341



American Concrete Institute
Always advancing



Report on Analysis and Design of Seismic-Resistant Concrete Bridge Systems

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 Analysis and Design of Seismic-Resistant Concrete Bridge Systems

Reported by ACI Committee 341

Sri Sritharan*, Chair

Mark A. Aschheim, Secretary

Hossam M. Abdou
Nagi A. Abo-Shadi
Robert B. Anderson**
Bassem Andrawes
Dino Bagnariol
Abdeldjelil Belarbi
Sarah L. Billington
JoAnn P. Browning
Rigoberto Burgueno
W. Gene Corley‡
Shukre J. Despradel*
Angel E. Herrera
David Hieber
Riyadh A. Hindi

Eric Michael Hines
Ahmed M. M. Ibrahim
Mervyn J. Kowalsky
Sena Kumarasena*
Dawn E. Lehman
Kevin R. Mackie
Adolfo B. Matamoros
Stavroula J. Pantazopoulou
Bradley N. Robson
Mario E. Rodriguez*
M. Saïid Saïidi
Ayman E. Salama*
David H. Sanders
Pedro F. Silva

Glenn R. Smith
Bozidar Stojadinovic
Matthew J. Tobolski
Raj Valluvan*
Ronald J. Watson
Nadim I. Wehbe
Maged A. Youssef
Qun Zhong-Brisbois

Consulting Members
Y. Frank Chen
Edward P. Wasserman
Stewart C. Watson

*Task Group members who prepared this report.

†Task Group leader

‡Deceased

The committee would like to thank the following people for their contributions to this report: M. Aydemir, P. Amin, V. Chandra, W.-F. Chen, B. Chung, T. Cooper, E. He, M. Hosseini, N. Johnson, P. Lipscombe, E. M. Lui, E. Matsumoto, H. Mutsuyoshi, V. Nugent, M. Raof, P. Somerville, S. Zhu, and N. Zoubi.

This report is intended for use by practicing engineers and provides a summary of the state-of-the-art analysis, modeling, and design of concrete bridges subjected to strong earthquakes. It is intended to supplement and complement existing documents from the American Association of State Highway and Transportation Officials (AASHTO), California Department of Transportation (Caltrans), and various building codes and guidelines. Procedures and philosophies of codes and guidelines are summarized. Linear and nonlinear seismic analysis methods are also discussed, and important modeling considerations for different bridge elements, including curved girders and skewed abutments, are highlighted. The report also includes a summary of general seismic-resistant design and construction considerations for concrete bridges, as well as analysis and design considerations for bridges with seismic isolation.

Keywords: abutment; bridge; column; connections; design; earthquake; footing; girder; hinge; restrainer; seismic; seismic analysis; seismic isolation.

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.

CONTENTS

CHAPTER 1—INTRODUCTION, p. 2

1.1—General, p. 2

1.2—Lessons learned from earthquake damage to bridges, p. 3

CHAPTER 2—NOTATION AND DEFINITIONS, p. 6

2.1—Notation, p. 6

2.2—Definitions, p. 6

CHAPTER 3—CODES, p. 7

3.1—Historical perspective, p. 7

CHAPTER 4—SEISMIC HAZARDS, p. 7

4.1—Introduction, p. 7

4.2—Probabilistic seismic hazard analysis, p. 8

4.3—Multi-level earthquake ground motions, p. 9

4.4—USGS probabilistic ground motion maps and design value maps, p. 9

4.5—Vertical accelerations, p. 10

4.6—Near-fault ground motions and residual ground displacements near faults, p. 10

4.7—Load combinations, p. 11

ACI 341.2R-14 supersedes ACI 341.2R-97(03) and was adopted and published June 2014.

Copyright © 2014, 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.

4.8—Combining effects of orthogonal components of earthquakes, p. 11

4.9—Ground motion time histories, p. 11

4.10—Geotechnical considerations, p. 12

CHAPTER 5—ANALYSIS, p. 12

5.1—Overview, p. 12

5.2—Single-mode spectral analysis, p. 13

5.3—Pushover analysis, p. 13

5.4—Multi-mode spectral analysis, p. 14

5.5—Time-history analysis, p. 14

5.6—Nonlinear analysis, p. 14

CHAPTER 6—MODELING, p. 20

6.1—General, p. 20

6.2—Superstructure modeling, p. 22

6.3—Substructure modeling, p. 23

6.4—Abutment and foundation modeling, p. 23

6.5—Bearings, p. 27

CHAPTER 7—DESIGN, p. 27

7.1—General, p. 27

7.2—Multi-level seismic design, p. 27

7.3—AASHTO force-based design methods, p. 28

7.4—Displacement-based design methods, p. 29

7.5—Seismic conceptual design, p. 30

7.6—Design considerations, p. 31

7.7—Seismically isolated bridges, p. 35

7.8—Construction, p. 39

CHAPTER 8—REFERENCES, p. 39

Authored references, p. 39

CHAPTER 1—INTRODUCTION

1.1—General

The stated objectives of seismic design provisions in major codes have evolved considerably over the last 20 years. The initial focus of preventing structural collapse under the design earthquake to prevent loss of life has shifted to broader design objectives, such as achieving a level of serviceability following a major earthquake that allows for emergency response and ensures that transportation lifelines remain operational. These newer design objectives focus on the need for structures to remain operational after an earthquake, particularly for structures important to emergency response and those housing emergency and high-risk facilities. Critical structures include bridges on key response routes, hospitals, public safety headquarters, communication centers, and nuclear power stations.

Bridge seismic design philosophies may use a traditional single seismic design level (AASHTO 2012; AASHTO LRFSEIS-2-M) or a two-level approach (MCEER-ATC-49) where both functional-level and safety-level hazards are considered. Performance objectives for each level are composed of a performance level or functional requirement at a seismic hazard level. The functional-level event considered in this two-level approach is typically a lower-level event

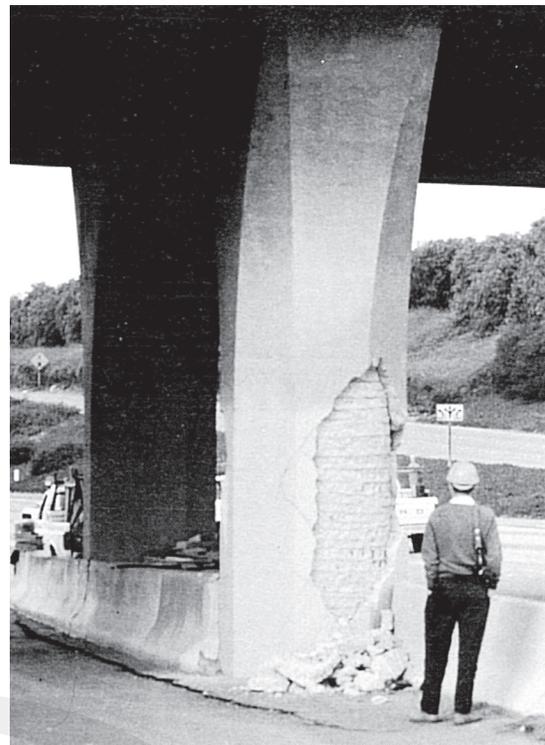


Fig. 1.1—Acceptable damage (spalling of cover concrete) to a bridge column for large earthquake.

with relatively high probability of exceedance (PE), and the safety-level event is typically a major seismic event with a very low PE. The typical performance objectives for the two-level approach tolerate only slight damage to ensure uninterrupted service of the bridge under the lower-level event, and allow only easily repairable damage under the higher-level event to ensure minimal or no disruption of lifelines.

In setting minimum performance standards, design codes recognize that it is not practical to design a structure to resist a large earthquake elastically; therefore, some degree of damage is typically permitted under the higher-level event (Fig. 1.1). For critical structures, however, depending on expectations of how quickly the particular structure can be put back in service and repaired, the damage can be further restricted by tighter requirements defined by the owner.

Design performance level requirements have become more general and are not always tied to traditional notions of force and strength. Thus, analysis requirements have also evolved beyond the traditional methods involving equivalent static forces representing the design event. The extent of damage in different bridge components is commonly quantified using performance quantities such as strains, curvatures, and displacements. Limiting damage requires imposing appropriate limits on these parameters in the critical sections of the structural members. In addition, the response of the structural system should be evaluated as a whole to assess functionality and operability. This requires a higher level of sophistication in both system modeling as well as sectional and material-level analysis. Reinforced concrete structural members, in particular, require greater attention to detail when moving beyond elastic or equivalent elastic analysis