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Seismic Evaluation and Retrofit Techniques for Concrete Bridges

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American Concrete Institute
38800 Country Club Drive
Farmington Hills, MI 48331
U.S.A.
Phone: 248-848-3700
Fax: 248-848-3701

www.concrete.org

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Adolfo Matamoros, associate member of the main committee and subcommittee member, also contributed substantially to this document. His effort is gratefully acknowledged.

*Member of subcommittee that prepared this report.
†Co-Chair of subcommittee that prepared this report.

This document provides a summary of seismic evaluation and retrofit techniques for reinforced concrete bridges. The document is intended to be useful to practicing engineers and academic researchers. Three primary phases of a retrofit program are described: seismic vulnerability evaluation, evaluation of the seismic demands and capacities, and selection and design of the retrofit measures. General descriptions of appropriate linear and nonlinear analysis methods to evaluate the seismic response of an existing bridge are provided. Various retrofit measures for individual bridge components are described. In all cases, the information is presented at the conceptual level rather than providing detailed descriptions of the design method. A rich resource of references is included in each section of the document for obtaining more specific information on the subject matter.

Keywords: abutment; bridges; column; expansion joint; footing; hinge; joint; pier; pile; seismic analysis; seismic evaluation; seismic isolation; seismic retrofit.

CONTENTS

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CHAPTER 1—INTRODUCTION

Performance of bridges in past earthquakes indicates that existing bridge structures can be susceptible to severe structural damage. This vulnerability is evident in regions of high seismic risk, as demonstrated by extensive damage in bridge structures in the 1971 San Fernando Earthquake (Fung et al. 1971), the 1989 Loma Prieta Earthquake (EERI 1989) and the 1994 Northridge Earthquake (Moehle 1995). In those earthquakes, damage included pounding at expansion joints, severe spalling and cracking in bridge columns and joints, and structural collapse. The 2001 Nisqually Earthquake in the state of Washington resulted in damage to columns, restrainers, and the superstructure due to pounding, indicating that some bridges in the United States may be susceptible to damage even in moderate earthquakes (Ranf and Eberhard 2002).

The bridge damage resulting from the San Fernando earthquake caused concern about the seismic vulnerability of bridges and initiated research into and development of seismic retrofit guidelines and measures (Applied Technology Council (ATC) 1983; Zelinski 1985; Buckle et al. 1986; Selna et al. 1989a,b). These earlier guidelines and procedures for seismic retrofit of bridges used strength-based evaluation approaches in which the forces were used as a basis for the evaluation. If the seismic force demand exceeds the elastic strength of the structure, the structural system may be subjected to large inelastic displacements and subsequent strength degradation, instability, or both, of the system that could lead to structural collapse. In this case, retrofit measures solely based on a strength-based approach may not provide adequate deformation capacity to ensure structural stability. Damage to bridges in the Loma Prieta and Northridge earthquakes emphasized the need to address both strength and deformation capacities in bridge seismic retrofit programs, which has resulted in more comprehensive seismic retrofit prioritization schemes as well as improved evaluation procedures and retrofit measures.

A comprehensive retrofit measure for a concrete bridge requires detailed evaluation of the probable strength and stiffness characteristics at member and structure levels, structural displacement and component deformation capacities, and earthquake hazard potential. As such, deformation-based retrofit approaches may be more appropriate to ensure survival of the structure without experiencing collapse under extreme earthquakes. Alternatively, energy-based approaches may be adopted as long as these approaches sufficiently address all required elements of the complete retrofit plan. Seismic retrofit guidelines started to include these approaches in the early 1990s (Maroney 1990; Lwin and Henley 1993).

Retrofit measures have traditionally been developed to improve seismic performance in extreme events where the primary concern was ensuring structural stability to prevent collapse. More recently, engineers have focused on designing to reduce damage in more frequent events (Lehman et al. 2004; MCEER-ATC 2003). The pairing of a capacity or performance level with a seismic hazard level is called a performance objective. Engineering a structure using multiple performance objectives is termed performance-based earthquake engineering. For example, in addition to ensuring structural stability at the maximum considered earthquake, the performance of the structure at the operational limit states (that is, no damage needing repair) and delayed operational limit states (that is, permitting repairable damage) may also be considered to ensure satisfactory structural performance under the appropriate seismic hazard levels (for example, frequent and moderate earthquakes, respectively). Using a performance-based approach may be advantageous for the retrofit of existing structures in that a designer, for economical reasons, may choose to upgrade the structure to a performance level that is less than that implied by the current code. Performance-based engineering procedures are under development, and the performance of available retrofit strategies under different multiple hazard levels has yet to be evaluated and, therefore, is not directly addressed herein.

This document presents a summary of seismic evaluation and retrofit techniques suitable for ensuring structural stability. A comprehensive seismic retrofit program consisting of multiple retrofit stages will permit efficient and cost-effective retrofit solutions where each stage consists of bridges that will meet a state-specific prioritization criteria (Lwin and Henley 1993). As illustrated in Fig. 1.1, the primary phases of a seismic bridge retrofit program should include:

1. Seismic vulnerability evaluation;
2. Seismic demand-capacity evaluation;
3. Selection of efficient retrofit measures and their design; and
4. Implementation.

This document briefly describes the phases of a seismic retrofit program followed by sections that provide a more thorough treatment of key aspects of the first three phases. The vulnerability evaluation, demand-capacity evaluation, and retrofit measures presented are described for monolithic reinforced concrete bridges, but may be applicable to other bridge types. In the subsequent sections, emphasis is placed on providing a general understanding of the development and execution of each phase, with a focus on achieving structural stability performance. Seismic retrofit measures are presented at a conceptual level for the critical members responsible for ensuring ductile seismic response. Design and analysis methods vary within the research and design communities, and therefore specifics of each method are not provided in this document. A rich resource of appropriate references, however, is given in each section. For more specific and detailed retrofit design and analysis information,