New FHWA Seismic Hazard Mitigation Studies for Highway Bridges

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Abstract

Earthquakes are inevitable events in our living environment. Each large magnitude earthquake located around urban area created devastated destruction of our infrastructures, including the transportation system, and claimed vast human fatalities. Since 1992, FHWA has initiated three major research projects in the seismic hazard mitigation, they are Seismic Vulnerability Study for Existing and New Highway Constructions, Seismic Vulnerability of Highway System, and the SAFETEA-LU Seismic Research Program.

This paper describes the Federal Highway Administration's (FHWA) new seismic research program to mitigate earthquake loss of highway infrastructures. This program consisted with two major research studies started in 2007 (five-year plan), the first is FHWA/MCEER project, titled, Innovative Technologies and Their Applications to Enhance the Seismic Performance of Highway Bridges, and the second one is FHWA/ UNR project, titled, Improving the Seismic Resilience of the Federal-Aid Highway System.

Introduction

Surface transportation is a vital component of our society. Our highways link airports, train stations, harbors, manufacturing plants, farms office and residences. This transportation network must continue functioning during and after a natural hazard such as an n earthquake so that the lifelines of our society may be restored as soon as possible. Of all the components of the surface transportation system bridges are the most vulnerable to earthquake damage.

About 65 percent of the approximate 600,000 bridges in the U.S. were constructed prior to 1971 with little or no consideration given to seismic resistance. Recent earthquakes such as Loma Prieta, CA in 1989, Northridge, CA in 1994 and Kobe, Japan in 1995 & Chi-Chi Earthquake, Taiwan in 1999, have demonstrated the need to find new ways to build earthquake-resistant bridges and highways, and to retrofit existing bridges.

Recognizing the shortcomings evident in both existing bridges and design

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specifications, the Federal Highway Administration (FHWA) initiated several comprehensive seismic research studies on bridges and highways since 1992. As a result, a new seismic retrofitting manual, consisting of two parts (bridges and other highway structures), was completed and published. A new comprehensive seismic design recommendation was also published under the seismic vulnerability studies.

Furthermore, FHWA also published the research products in seismic retrofitting of truss bridges, seismic isolation manual and Risks from Earthquake Damage to Roadway System (REDARS). To implement these technologies into our Federal-Aid transportation system with limited resource, cost-effective and practical methods such as accelerated bridge construction, are also essential to successfully improve the seismic safety.

Under the new Transportation Authorization SAFETEA-LU, FHWA is working with Multi-disciplinary Center of Earthquake Engineering Research (MCEER) of New York State University at Buffalo and University of Nevada at Reno (UNR) to initiate two major seismic research studies and started in 2007. The following are the summary of these two new studies:

Seismic Research Study 1 (with MCEER): The Innovative Technologies and Their Applications to Enhance the Seismic Performance of Highway Bridges

The objective of this study is to improve the seismic resistance of our highway system, by developing new innovative technologies and their applications, by developing cost-effective methods for implementing design and retrofitting technologies, and by refining and expanding applicability.

This project is to increase the mobility and safety of our surface transportation system as the FHWA envisions reducing the construction/ maintenance time of new and existing highway structures. Applying accelerated bridge construction technology to high seismicity area requires more advanced connection detail to accommodate the large ground motions. Innovative technologies and their applications are continuously sought to refine and expand their applicability to enhance the seismic performance of our surface transportation system.

The major tasks of this study are:

Developing Detailed Technology to Apply Accelerated Bridge Construction (ABC) in Seismic Regions

This task is to develop implementable seismic design guidelines applicable to the bridges located in the seismic regions. The focus of this task is on prefabricated reinforced concrete, segmentally constructed highway bridges of short to medium span length. A technical monograph for the bridge system is expected from this study. In addition, a separate subtask is set up to develop recommended design guidelines with design examples for practical applications.

Innovative Seismic Protection Technologies

In this task, innovative technologies will be explored that can enhance the seismic performances of precast R.C. Bridges with emphasis given to ABC. This task will include subtask study on:

- Design Guidelines and Demonstration of Roller Isolation Bearings,
- Lifetime Performance of Bridges with Seismic Protective System,
- Bridge Information Modeling for Seismic Aspects of Accelerated Bridge Engineering
- Development of Structural Fuse Concept for Bridges
- And Down-Scaled Bridge Pier Testing

Seismic Study 2 (with UNR): Improving the Seismic Resilience of the Federal-Aid Highway System

Background

Today *life-safety* is no longer the sole requirement for the successful design of a highway system for a major earthquake. *Resilience* is now expected by the traveling public as an integral component of any design strategy, so as to ensure rapid recovery and minimal impact on the socio-economic fabric of modern society. This realization has led to the concept of *performance-based seismic design* which is a relatively new development in the design and construction of civil infrastructure. Nevertheless substantial progress has been made in this area, particularly with respect to the performance of individual components of the built environment, such as buildings and bridges. But the real potential for performance-based design comes when these concepts are applied to systems and subsystems of the infrastructure, such as transportation networks, subject to both service load conditions and extreme events.

Since 1993, the FHWA has been researching methodologies for seismic risk analysis (SRA) under its seismic research program. The result of this effort has been the development of an earthquake loss estimation software tool called REDARS, which is now being used in pilot projects by several State Departments of Transportation. REDARS has been specifically developed for assessing the performance of highway systems taking into account the inter-connectedness of the network and vulnerability of bridges to seismic loads.

Performance measures calculated by REDARS include congestion and delay times. These measures allow system-level performance criteria to be specified for earthquakes of various sizes, such as maximum permissible traffic delay times and minimum restoration times. Accordingly the resilience of a highway system may be defined and measured in quantitative terms, such as the time it takes to restore the system’s pre-earthquake capacity, as illustrated in figure 1. In doing so, financial and societal incentives can be developed that will improve resilience and at the same time reduce risk to life and property.

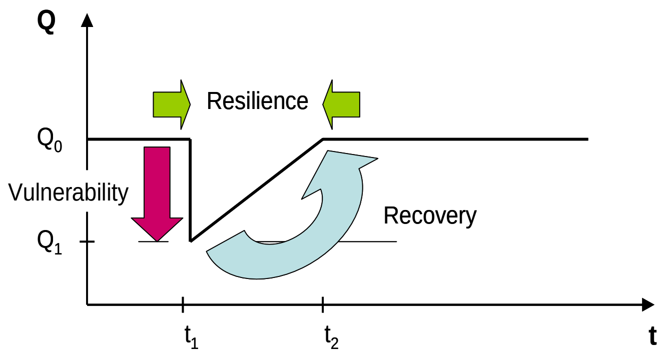

Figure 1. System resilience, after Bruneau (Buckle and Lee, 2006).

Whereas REDARS is the result of a decade-long period of development, and recently shown to adequately replicate the performance of the highway system in the San Fernando Valley following the 1995 Northridge earthquake, there is still much to be done to enable the methodology to be used with confidence and be widely applicable. REDARS has been developed with the expectation that new and more sophisticated modules will be developed overtime, in order to improve its accuracy and expand its range of application. This is considered a critical step in the drive towards quantifying the resilience of the highway system.

For example, lessons learned from recent large earthquakes, such as the 1999 Chi-Chi earthquake in Taiwan, have indicated the importance near-fault effects on bridge response. At the FHWA/NCEER Workshop on the National Representation of Seismic Ground Motion for New and Existing Highway Facilities held in San Francisco in May 1997, a consensus was reached that a response spectrum alone is not an adequate representation of near-fault ground motion characteristics, because it does not adequately represent the demand for the high rate of energy absorption imposed by near-fault pulses. This is especially true for high ground motion levels that drive structures into the non-linear range, invalidating linear elastic assumptions on which the elastic response spectrum is based. Near-fault ground motions are different from ordinary ground motions in that they often contain strong coherent dynamic long period pulses and permanent ground displacements. The dynamic motions are dominated by a large long period pulse of motion that occurs on the horizontal component perpendicular to the strike of the fault, caused by rupture directivity effects. Near fault recordings from recent earthquakes, such as Chi-Chi earthquake, indicate that this pulse is a narrow band pulse whose period increases with magnitude, as expected from analysis.

Many cities on the West Coast of the U.S. are located in near-fault environments and this should be taken into account when studying the resilience of highway systems on the West Coast in particular. Thus bridge fragility functions are required that include near-fault effects for inclusion in loss-estimation models such as REDARS. In addition practical recommendations are required for the design of highway bridges subject to near-fault effects.

The objective of this project is to study the resilience of highway systems with a view to improving the performance of these systems subject to major earthquakes. A comprehensive assessment tool to measure highway resilience shall be developed by improving current loss estimation technologies, such as REDARS; factors affecting system resilience will be identified such as damage-tolerant bridge structures and network redundancy; design aids for curved bridges and those structures in near-fault regions will be developed; new technologies will be developed for improving the seismic performance of bridges; methodologies and technologies developed herein will be implemented in REDARS to the extent practical; and outreach to improve seismic safety will be conducted.

The following are the major tasks of this study:

REDARS Customization for Resilience Studies

This task shall implement those upgrades for resilience studies that will focus on improving computation and display of important parameters for characterizing resilience.

Characterizations of Seismic Hazards for Near-Fault Bridges

This task will work on Ground Motions including Effects of Rupture Directivity and Surface Fault Rupture Hazards to improve its characterization of surface fault-rupture displacements with a focus on faults as a single straight line.

Seismic Response of Horizontally-Curved Highway Bridges

This task is to perform a comprehensive study of the seismic response of horizontally-curved highway bridges. A set of seismic design guidelines for this type of bridge shall be developed.

Near-Fault Bridge Study

This task is to develop recommendations for procedures that can be readily used to design bridges in the vicinity of faults and improve public safety throughout the United States.

Fragility Function for Curved, Near-Fault and other Bridges.

This task will focus on the development of fragility functions for both curved bridge and near-fault bridges, and other bridges.

Concluding Remarks

Risk mitigation methods to reduce earthquake losses need a great effort for development and implementation. The most difficulty with mitigating earthquake hazards is that earthquakes come without any notice. There is no way to accurately predict when an earthquake will occur, nor what its magnitude will be. Earthquakes are devastating, often resulting in a great number of deaths, injuries and extensive infrastructure damage. Losses will occur in just one or two minutes. Systematic approaches to evaluating earthquake risks, including direct and indirect losses such as economic impact, have become an important issue in our engineering community.

The above two studies focus on (1) The Innovative Technologies and Their Applications to Enhance the Seismic Performance, and (2) Improving the Seismic Resilience of the Federal-Aid Highway System. These two studies will produce many practical recommendations for bridge design in accelerated bridge construction arena, and advance the current design guidelines of curved and near-fault bridges. The study will enhance the previously developed REDARS program with more meaningful and accurate fragility functions to estimate the earthquake losses.

Reference:

FHWA Congressional Seismic Research Studies under the SAFETEA-LU Program.