Earthquake Risk and U.S. Highway Infrastructure: Frequently Asked Questions

William J. Mallett
Specialist in Transportation Policy

Nicole T. Carter
Specialist in Natural Resources Policy

Peter Folger
Specialist in Energy and Natural Resources Policy

March 30, 2011

Congressional Research Service
7-5700
www.crs.gov
R41746

CRS Report for Congress
Prepared for Members and Committees of Congress

Contents

Introduction 1
What Are the Components of Seismic Risk? 1
How Vulnerable Is the U.S. Highway System to Earthquakes? 2
How Vulnerable Are Highway Bridges to Earthquakes? 4
How Vulnerable Are Other Highway Components to Earthquakes? 5
What Are the Options for Improving the Seismic Resilience of Existing Highway Infrastructure? 5
How Much Would It Cost to Retrofit Vulnerable Highway Infrastructure? 6
Who Pays to Retrofit Highway Infrastructure? 6
What Role Does the U.S. Department of Transportation Have in Enhancing Seismic Resiliency of the Highway System? 7
What Role Do Other Federal Agencies Play? 7

Figures

Figure 1. U.S. Bridge Seismic Hazard 3

Contacts

Author Contact Information 8

Introduction

The 9.0 magnitude earthquake that struck off the coast of Sendai, Japan, on March 11, 2011, has renewed concerns about the seismic risk to America's infrastructure, including its highways. Concerns about the U.S. highway system's seismic risk stem from interest in protecting public safety, facilitating response and recovery efforts, and minimizing economic loss and social disruption. Seismic resilience of the U.S. highway system has improved in recent decades as investments have been made to build new, more resilient infrastructure and to retrofit existing structures. However, not all existing highway infrastructure has been retrofitted, and no infrastructure can be cost-effectively constructed to be immune from the most intense earthquakes, so some seismic risk to the U.S. highway system remains.

Although earthquake hazards in the United States generally are well documented, little national or federal data exist about the seismic risk to U.S. highway infrastructure; instead, seismic highway risks typically are assessed and addressed by state and local entities which are generally responsible for building and maintaining that infrastructure. The federal government supports these nonfederal efforts by providing data on the seismic hazard for different locations, assisting in the development of construction standards and guidelines, and undertaking research, training, and the development of tools to assist in risk reduction. In limited circumstances, the federal government invests directly in improving resiliency of specific highway structures.

This report addresses frequently asked questions about the risk from earthquakes to highway systems, including bridges, tunnels, pavements, and other highway components. Particular attention is given to highway bridges, which often are the most vulnerable highway structures.[1] The report also discusses federal and nonfederal actions to reduce seismic risk to the U.S. highway system.

Japan is generally regarded as the country with the most earthquake-resilient infrastructure. Research into the performance of Japan's highway structures and systems during and after the massive Sendai earthquake and resulting tsunami is ongoing. Japanese and U.S. earthquake science and engineering researchers have well-established collaborations aimed at gathering empirical data and drawing lessons from significant events. It is too soon to know how the events in Japan will affect understanding of the seismic risk of U.S. highway infrastructure, and whether changes in U.S. seismic highway design standards and guidance will result.

What Are the Components of Seismic Risk?

Seismic risk to a highway system is determined by three factors:

- likelihood of seismic events of varying magnitudes, and related physical events, often referred to as the hazard;
- vulnerability of highway structures to damage from such events; and
- potential consequences of that vulnerability (e.g., lives lost, economic disruption).

[1] Wen-Huei (Phillip) Yen, "Earthquake!," *Public Roads*, vol. 74, no. 2 (September/October 2010).

Seismic hazard is assessed by determining the probability of different intensities of shaking of a highway structure caused by earthquakes. Although some seismic hazard exists everywhere in the United States, the magnitude of the hazard varies greatly across the country and within individual states (see **Figure 1**). Seismic hazards are greatest in the western United States, particularly in California, Washington, Oregon, and Alaska and Hawaii.[2] While the areas of the country most prone to earthquakes are well known, the timing, magnitude, and other characteristics of a specific seismic event, such as the intensity and duration of shaking, cannot be accurately predicted. Maps depicting U.S. seismic hazards periodically are updated as more and better data are obtained and earthquake science improves. Other events that can occur in response to an earthquake, including soil liquefaction, landslides, tsunamis, flooding, and fires, also contribute to the hazard exposure of a highway.

Vulnerability is determined by the design and current condition of the specific highway element. Consequences depend on the role of a highway in the transportation system and how its availability or damage affects public safety, recovery efforts, economic and social disruption, and national defense. While seismic hazard is a function of plate tectonics and cannot be controlled, actions can be taken to manage vulnerability and consequences.

How Vulnerable Is the U.S. Highway System to Earthquakes?

No national database exists on the seismic design and retrofit status of highway system components; thus, a national level perspective on vulnerability is unavailable. However, many states with large seismic hazards have compiled data on the vulnerability of highway components within their borders, ranked highway infrastructure based on this vulnerability, and used these data as part of the decision-making process for distributing highway funding. The industry standards and guidelines for construction and retrofitting of highway components also now call for increased seismic resiliency of highway infrastructure. These standards were developed and adopted by the American Association of State Highway and Transportation Officials (AASHTO) in consultation with the U.S. Department of Transportation (DOT) and other stakeholders, and incorporated by reference into the *Code of Federal Regulations* (23 C.F.R. § 625). Seismic design guidelines for bridges, developed by Federal Highway Administration (FHWA) and the California Department of Transportation, were adopted by AASHTO in 1983, and these guidelines became a national standard in 1992. There are no national seismic design standards for tunnels, culverts, pavements, and other highway components, although there have been retrofitting guidelines available from FHWA since 2006.

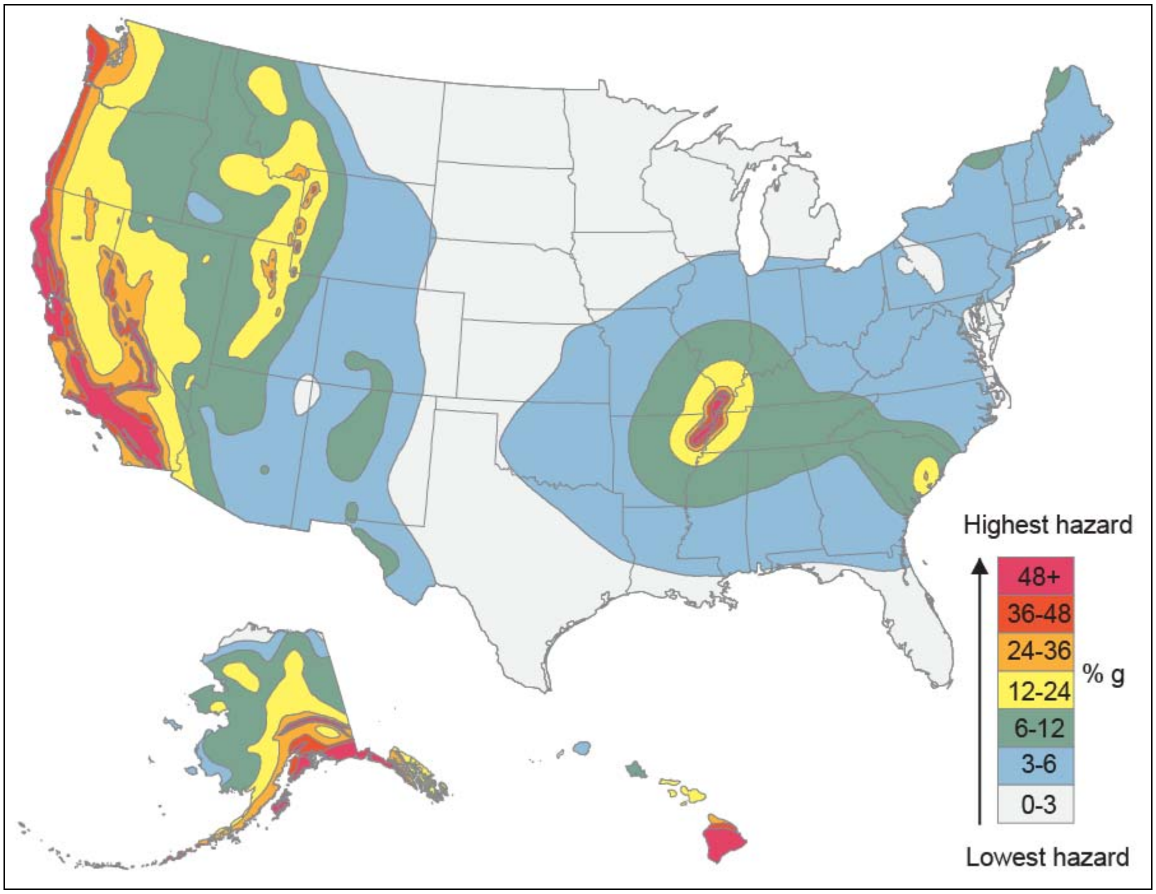
From the early 1970s to the late 1990s, much of the effort to reduce seismic vulnerability focused on improving the resiliency of the most vulnerable highway *structures*. More recently, efforts to understand and address highway risks have been broadened from structures to highways *systems*. For example, under a program authorized by Congress in the Transportation Equity Act for the 21st Century (TEA-21; P.L. 105-178), FHWA developed a software package to estimate the loss of highway systems capacity in particular localities due to earthquakes. The software is available

[2] For more on earthquake hazards, see CRS Report RL33861, *Earthquakes: Risk, Detection, Warning, and Research*, by Peter Folger.

to federal and nonfederal entities for use in their evaluations and prioritizations of highway investments.[3]

Figure 1. U.S. Bridge Seismic Hazard

Shaking Expected for Tall Structures like Bridges from Seismic Events with 1,000-Year Return Period



Source: Map produced for CRS by U.S. Geological Survey (USGS), March 2011, with minor formatting changes made by CRS.

Note: The color legend shows the shaking expected in tall structures—expressed as a percentage of the acceleration due to gravity (g).

[3] The software is called REDARS (Risks from Earthquake Damage to Roadway Systems).

How Vulnerable Are Highway Bridges to Earthquakes?

The performance of highway bridges is a critical determinant of the seismic performance of a highway system. Some western states have been following seismic design practices since the early 1970s, after the 1971 San Fernando (CA) earthquake. By contrast, states in the New Madrid seismic zone (AR, IL, IN, KY, MO, MS, TN), which have serious hazards but less recent experience with significant earthquakes than the West Coast, did not adopt seismic design standards until the early 1990s.[4]

National seismic bridge design standards have been in place since 1992, based on guidelines developed in the 1970s and 1980s. These standards are regularly updated to incorporate lessons learned from the behavior of bridges during earthquakes in the United States and abroad. Because many highway bridges predate national standards, numerous bridges remain vulnerable to more frequent seismic hazards. For example, roughly 73% of all bridges in the New Madrid seismic zone were built prior to 1990 and likely were not designed to withstand the region's seismic hazards.[5]

The current industry minimum standard for new U.S. bridges and retrofits is to design for no collapse in a span or part of a span for the most intense earthquake anticipated during a 1,000-year period, which is known as the 1,000-year return period event (or 0.1% annual probability event).[6] The magnitude of the assumed 1,000-year earthquake varies by location depending on the earthquake hazard present, and, in general terms, determines the need for and cost of seismic bridge design and retrofitting (see **Figure 1**).[7] If the projected magnitude of the 1,000-year event is correct, the probability of an earthquake that exceeds that magnitude during the 75-year theoretical design life of the bridge is roughly 7%. This seismic design standard was adopted by AASHTO in consultation with DOT and other stakeholders, and is incorporated into the *Code of Federal Regulations* by reference (23 C.F.R. § 625). Some states, such as South Carolina and California, have adopted stricter standards.[8]

---

[4] Some scientists have called into question whether the earthquake hazard as depicted in the USGS maps is too high for the New Madrid Seismic Zone. These researchers challenge whether the benefits of building structures to conform with earthquake probability estimates merit the costs, in light of the uncertainty in making those probability estimates. For a fuller discussion of the scientific controversy, see CRS Report RL33861, *Earthquakes: Risk, Detection, Warning, and Research*, by Peter Folger.

[5] Timothy Wright, Reginald DesRoches, and Jamie E. Padgett, "Bridge Seismic Retrofitting Practices in the Central and Southeastern United States," *Journal of Bridge Engineering*, January/February 2011, pp. 82-92.

[6] The probability of flooding events is commonly referred to in similar terms. For example, the 100-year flood event has a 1% annual probability, or a 1/100 chance of occurring each year. If the 100-year flood occurs one year, the probability of the same magnitude flood remains 1/100 for the next year. It does not mean that another 100-year flood will not occur for 99 more years, a common misperception.

[7] **Figure 1** produced by USGS for CRS is a simplified and color version of the map produced by USGS and used by AASHTO.

[8] South Carolina Department of Transportation, *2008 Seismic Design Specifications for Highway Bridges, Version 2*, July 2008, http://www.scdot.org/doing/bridge/pdfs/specs_2008.pdf; California Department of Transportation, *Seismic Design Criteria*, November 2010, http://www.dot.ca.gov/hq/esc/earthquake_engineering/SDC_site/2010-11-17_SDC_1.6_Full_Version_OEE_Release.pdf.

Many of the most vulnerable older bridges, particularly in West Coast states, have been retrofitted to improve seismic resilience. In contrast, many older bridges in the New Madrid seismic zone have not been retrofitted.[9]

How Vulnerable Are Other Highway Components to Earthquakes?

While seismic damage to bridges often is more visible than damage to other highway structures, the performance of these other structures may significantly influence system performance and the consequences of a seismic event.

Tunnels are generally considered to be less vulnerable to seismic hazards than bridges, unless the tunnel crosses a geologic fault. If a tunnel is damaged, the consequences can be significant. Tunnels often link highway systems with little or no redundancy if the tunnel fails. While pavements, retaining walls, and embankments may not pose the greatest risk to lives during a seismic event, these structures and their rapid repair are receiving increasing attention as significant for highway system performance. Damaged culverts through or beneath highways can contribute to erosion of highways or flooding of the highway and surrounding area.

In 2006, FHWA published a manual providing guidance on the seismic evaluation and retrofit for these other types of highway structures. The FHWA guidance provides for a two-tier design approach. The guidance recommends a performance level of fully operational for the more likely 100-year return period event (a 1% annual probability event) for most infrastructure components.[10] Fully operational means that damage is negligible and full service is available for emergency and non-emergency vehicles after inspection and clearance of debris. Also, any damage is repairable without interruption to traffic. The FHWA guidance also recommends a performance level of providing for life safety (i.e., no collapse and no loss of life) for most infrastructure, and for some essential infrastructure to be operational, for the more rare 1,000-year return period earthquake. AASHTO has no formal seismic standards for highway structures other than bridges.

What Are the Options for Improving the Seismic Resilience of Existing Highway Infrastructure?

Existing highway structures vulnerable to earthquake hazards can be replaced, retrofitted, abandoned, or simply left alone. The decision with respect to each structure generally is up to state governments and other infrastructure owners; most importantly, state governments determine whether to pursue retrofitting or replacement as they set priorities for using federal and state highway funds. Highway structures are assessed on structural vulnerability, site

[9] Wright, et al.

[10] U.S. Department of Transportation, Federal Highway Administration, *Seismic Retrofitting Manual for Highway Structures: Part 1- Bridges*, FHWA-HRT-06-032, McLean, VA, Jan. 2006, and Federal Highway Administration, *Seismic Retrofitting Manual for Highway Structures: Part 2- Bridges*, FHWA-HRT-05-067, McLean, VA, January 2006.

characteristics, and other factors to determine the priority for retrofitting. Other factors may include a structure's importance to the highway system, its non-seismic deficiencies, and its remaining useful life.[11]

How Much Would It Cost to Retrofit Vulnerable Highway Infrastructure?

Because no national data exist on the status of retrofitting existing highway bridges or other infrastructure, no national estimates exist of what it might cost to retrofit the most vulnerable structures. California's Bridge Seismic Retrofit Program, undoubtedly the largest in the country, provides some indication of the magnitude of the task. California's retrofit program, which has been ongoing for several decades, involves about 4,700 bridges and is estimated to cost about $14 billion.[12] Nearly $10 billion of the total is to retrofit just nine very large, complex toll bridges.[13] A recent study of the New Madrid seismic zone found nearly 13,000 vulnerable bridges in seven states that would likely require retrofitting to satisfy the current seismic bridge design standards for new bridges.[14] The study did not estimate the cost of these retrofits.

Who Pays to Retrofit Highway Infrastructure?

Seismic retrofitting of highway infrastructure is an eligible expense for federal highway funds apportioned to states (i.e., distributed by formula), via the Surface Transportation Program and the Highway Bridge Program, and as preventive maintenance under other federal-aid highway programs.[15] For a specific project, a state generally must provide at least 20% of the money, or at least 10% if the project is on the interstate system. Although federal funds may help states with the cost of retrofitting, any federal money directed to this purpose by a state is not available for other uses; that is, there is an opportunity cost of using the funds for retrofitting in lieu of other highway improvements. State and local governments and other highway and bridge owners also may use their own funds for seismic retrofitting. In some situations additional federal funds have been provided for infrastructure improvements, including seismic retrofitting. For example, TEA-21, enacted in 1998, authorized $25 million in FY1998 for the seismic retrofit of the Golden Gate Bridge.

[11] Yen.

[12] Several elements of the program are complete. Much of the remaining work involves several hundred local agency bridges and a few large toll bridges.

[13] Frieder Seible, "Safety of California's Transportation Structures" Chair, Caltrans Seismic Advisory Board, Presentation to the California Transportation Commission, January 14, 2009, http://www.dot.ca.gov/hq/transprog/ctcliaison/2009/0109/PP_Tab51_Seible_Seismic.pdf. See also, California Department of Transportation, *Fourth Quarter 2010, Non-Toll Seismic Retrofit Program Quarterly Report*, http://www.dot.ca.gov/docs/reports/4thqtr_non-toll_seismic_report.pdf.

[14] Wright, et. al.

[15] U.S. Department of Transportation, Federal Highway Administration, "Preventive Maintenance Eligibility," Memorandum, October 8, 2004, http://www.fhwa.dot.gov/preservation/100804.cfm.

What Role Does the U.S. Department of Transportation Have in Enhancing Seismic Resiliency of the Highway System?

Apart from its role in administering federal-aid highway funds that may be used for seismic retrofitting, DOT and its FHWA also play a role in seismic hazard research and training, and coordinate with other federal agencies working on enhancing resilience. The Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users, enacted in 2005 (SAFETEA; P.L. 109-59), directed DOT to work with the Multidisciplinary Center for Earthquake Engineering Research (MCEER) at the University of Buffalo and the Center for Civil Engineering Research at the University of Nevada, Reno. Congress authorized $2.5 million per year for seismic research and also designated $3 million to MCEER. FHWA's National Highway Institute (NHI) currently offers several courses on bridge seismic design and retrofitting, and, according to FHWA, several additional courses are nearing completion and will be available shortly.

What Role Do Other Federal Agencies Play?

Numerous federal agencies perform activities that contribute to improving the highway system's seismic resiliency. Under the National Earthquake Hazards Reduction Program (NEHRP),[16] the federal government supports efforts to assess and monitor earthquake hazards and risk in the United States. Four federal agencies responsible for long-term earthquake risk reduction coordinate their activities under NEHRP: the U.S. Geological Survey (USGS), the National Science Foundation (NSF), the Federal Emergency Management Agency (FEMA), and the National Institute of Standards and Technology (NIST). FHWA coordinates with and contributes to the activities of the NEHRP agencies.

As part of a NEHRP reauthorization in 1990 (P.L. 101-614), Congress authorized USGS to monitor seismic activity in the United States. To this end, USGS operates a nationwide network of seismographic stations; it also operates a notification system to disseminate information regarding the location, magnitude, and epicenter of earthquakes. These data have multiple uses related to highway systems. For instance, data from the network can be used soon after an earthquake by those responsible for bridges and highways to prioritize inspections and response efforts, especially for critical lifeline highway systems. This can improve highway services for local, state, and federal emergency responders.

Another example of how federal agencies can enhance seismic resiliency of highway systems is through its pre-disaster efforts. For example, FEMA developed a methodology and software called the Hazards U.S. Multi-Hazard (HAZUS-MH). The software combines existing scientific knowledge about earthquakes, available engineering information (including for highway structures), and other data to produce maps and estimates of economic losses. The program can be used by local and state decision makers to estimate losses from damaging earthquakes,

[16] The authorization for appropriations for this program expired in 2009; legislation for its reauthorization was proposed but not enacted in the 111th Congress (H.R. 3820 of the 111th Congress).

hurricane winds, and floods before a disaster occurs. The output of HAZUS-MH can inform the development of mitigation plans and policies, highway and other infrastructure investment decisions, and emergency preparedness and response actions.

Author Contact Information

William J. Mallett
Specialist in Transportation Policy
wmallett@crs.loc.gov, 7-2216

Nicole T. Carter
Specialist in Natural Resources Policy
ncarter@crs.loc.gov, 7-0854

Peter Folger
Specialist in Energy and Natural Resources Policy
pfolger@crs.loc.gov, 7-1517