EXECUTIVE SUMMARY

Earthquake damage to components in a highway system (e.g., bridges, tunnels, roadways, etc.) can cause major traffic disruption which, in turn, can adversely impact the region’s economic recovery and emergency response. These impacts will depend not only on the seismic performance of the components in the system, but also on the properties of the system itself such as its network configuration and roadway characteristics (e.g., locations, redundancies, and traffic-carrying capacities). Unfortunately, such traffic impacts are usually not considered in seismic risk reduction activities at state transportation agencies. One reason for this has been the lack of a technically-sound and practical method for estimating these impacts.

To address this deficiency, a new methodology for seismic risk analysis (SRA) of highway systems nationwide has been developed as part of the two six-year seismic research projects that have been carried out at MCEER under the sponsorship of the Federal Highway Administration. During the first project, the methodology was initially developed and demonstrated in an application to the highway system in Shelby County, Tennessee. Under the second (current) multi-year project, the methodology was validated, its models were updated, and it was programmed into a public-domain software package named REDARS™ 2 (Risks from Earthquake DAmage to Roadway Systems). A demonstration application of the software to the Los Angeles, California highway system was also conducted.

For any given earthquake, REDARS™ 2 uses state-of-knowledge models to estimate: (a) seismic hazards (ground motions, liquefaction, and surface fault rupture) throughout the highway system; (b) the resulting damage states for each component in the system; and (c) how each component’s damage will be repaired, including its repair costs, downtimes, and time-dependent traffic states (i.e., its ability to carry traffic as the repairs proceed over time after the earthquake). Next, REDARS™ 2 includes these traffic states into a highway-network link-node model, in order to form a set of system-states that reflect the extent and spatial distribution of link closures at various times after the earthquake. Then, REDARS™ 2 applies network analysis procedures to each system-state, in order to estimate how these closures affect system-wide travel times and traffic flows. Finally, REDARS™ 2 estimates corresponding economic losses and increases in travel times to/from key locations or along key lifeline routes. These steps can be applied for single earthquakes and no uncertainties (deterministic analysis), or for multiple earthquakes and simulations in which uncertainties in earthquake occurrence and in estimates of seismic hazards and component damage are considered (probabilistic analysis).

REDARS™ 2 can serve as a pre- or post-earthquake decision-guidance tool. As a pre-earthquake planning tool, it can be used to: (a) estimate the effectiveness of various seismic-upgrade options in reducing earthquake losses; (b) compare costs and benefits (e.g., reduction in traffic-related losses/risks) for each option; and (c) enable decision-makers to use these results in order to make a more informed selection of a preferred option to implement. As a post-earthquake emergency-response tool in real time, REDARS™ 2 can incorporate actual damage data from the field, and can then develop results to enable officials to assess the relative abilities of various repair options and traffic-management options to facilitate traffic flows.

This report contains eight chapters and eleven appendices, whose contents are summarized below:
Chapter 1. Introduction. Chapter 1 includes a statement of the problem addressed by this research, and a discussion of the research benefits and the anticipated users of the research.

Chapter 2. Seismic Risk Analysis Methodology. Chapter 2 describes the main features of the REDARS™ 2 SRA methodology, including its analysis modules and procedures, and how its results can be used to guide seismic-improvement decision making. Appendix A describes the REDARS™ 2 probabilistic framework, and Appendix C summarizes a REDARS™ 2 Import Wizard that was developed under this research program to greatly simplify the development of input data for a SRA application. Appendix J describes a new statistical-analysis procedure that was developed under this project to estimate confidence limits in probabilistic SRA results.

Chapter 3. Earthquake Modeling and Hazards Module. Chapter 3 summarizes: (a) the “walkthrough” process that is used in REDARS™ 2 for probabilistic SRA applications; (b) the development of scenario-earthquake walkthrough tables for this process; and (c) the models that are currently used in REDARS™ 2 to estimate ground-motion, liquefaction, and surface-fault-rupture hazards. Appendix B describes the development of earthquake walkthrough tables for coastal California and the central United States under this project, and Appendices D, E, and F further describe the above ground-motion, liquefaction, and surface-fault-rupture hazard models.

Chapter 4. Component Module. Chapter 4 describes how REDARS™ 2 uses either default or user-specified models to estimate component damage and repair requirements, and how such models are developed for deterministic and probabilistic SRA applications. In addition, the chapter summarizes the default models that are now included in REDARS™ 2 to estimate damage states and repair requirements for bridges, approach fills, roadways, and tunnels. Appendices G and H provide further detail on the default modeling methods for these component types, and Appendix K describes how the model for estimating bridge damage due to ground shaking was calibrated against Northridge Earthquake bridge-damage observations.

Chapter 5. Transportation Network Analysis. Chapter 5 summarizes the features of the REDARS™ 2 transportation network analysis procedure, including its variable-demand model, its minimum-path algorithm for reducing run times, and its approach for considering multiple trip types. Appendix I provides further details on this network analysis procedure.

Chapter 6. Economic Module. Chapter 6 describes the approach used in REDARS™ 2 to develop default estimates of economic losses due to repair costs, travel-time delays, and trips foregone, and how user-specified parameters can be used to override these default estimates.

Chapter 7. Demonstration Application. Chapter 7 describes a demonstration application of the REDARS™ 2 software to carry out deterministic and probabilistic SRA of a large segment of the Los Angeles highway-roadway system. The chapter also includes a “hindsight” probabilistic economic analysis of a prior bridge retrofit program within this system, in order to illustrate one way that REDARS™ 2 results can be used to guide seismic-risk-reduction decision making.

Chapter 8. Conclusion. Chapter 8 contains concluding comments and recommended directions for continued development and application of the REDARS™ 2 methodology and software.