E. Lifeline Earthquake Engineering (Tom O'Rourke)

E. 1 General

Lifelines provide the networks for delivering resources and services necessary for the economic well-being and security of modern communities. They are frequently grouped into six principal systems: electric power, gas and liquid fuels, telecommunications, transportation, waste disposal, and water supply. Since Hurricane Katrina, there has been increasing attention to regional systems of levees and floodwalls as important lifelines. Examples include work to evaluate and remediate the earthquake vulnerability of levees in the Sacramento River delta. Taken individually, or in aggregate, lifeline systems are essential for emergency response and restoration after an earthquake, and are indispensable for community resilience.

E.2 Achievements

Lifelines have received increasing attention with respect to national security. For example, National Infrastructure Protection Plan includes 17 different sectors of critical infrastructure that include or are directly related to the lifeline systems traditionally studied under NEHRP. Emphasis has been placed on the development of high-performance computational models that simulate the regional response of complex networks. For example, the Great Southern California ShakeOut, which was the largest earthquake preparedness drill in US history, examined the consequences of a 7.8 M_W earthquake on the southern San Andreas Fault through a variety of computational models. Earthquake impacts on water supplies, energy generation and delivery systems, and transportation networks were an important part of the exercise. Over half of the fatalities and a substantial part of $210 billion in economic losses arising from the scenario earthquake resulted from fires that were exacerbated by lack of water in damaged water distribution systems.

A multi-year study has been undertaken by the National Infrastructure Simulation and Analysis Center under the DHS Office of Infrastructure Protection of the impact of a major earthquake in the New Madrid Seismic Zone. The study includes damage to lifeline systems and the interdependencies among various systems, with assessments of electric power outages, transportation network disruptions, and degradation of natural gas and petroleum/refined products supply systems. Complementing the regional studies are assessments of system-wide earthquake performance undertaken by water utility companies, including the East Bay Municipal Utility District, Los Angeles Department of Water and Power, and the San Francisco Public Utilities Commission, as basis for planning and rehabilitation of their systems. These assessments have used advanced system simulations and seismic hazard characterization using the results of NEHRP-supported research and development programs.

A significant trend in lifeline and geotechnical earthquake engineering has been the implementation of large-scale and centrifuge testing facilities to assess lifeline response to earthquake loading. Examples include the large-scale and centrifuge experiments currently underway at NEES, as well as shake-table and full-scale tests at various universities, including those supported by the Earthquake Engineering Research Centers.

Both the process and specific applications developed for lifeline earthquake engineering are being applied to other hazards, including natural hazards and human threats. Studies of lifeline system response to the World Trade Center Disaster emphasize the remarkable degree of interdependence that exists among lifeline systems. The investigation of lifeline interdependencies has been a cornerstone of NEHRP-based research and modeling. Because of the cascading effects that can result from lifeline disruption, local lifeline damage can rapidly expand to have a regional, national, and even an international impact. Examples include the disruption of the New York Stock Exchange due to loss of telecommunications and electricity after the World Trade Center Disaster and the impact of Hurricane Katrina on the U.S. petroleum and natural gas delivery infrastructure affecting the worldwide cost of both commodities.

Since Hurricane Katrina, there has been growing emphasis on developing hazard resilient communities. NEHRP-supported programs have led the way to understanding and planning for the disruption of critical lifeline services and to providing important tools and modeling procedures for multi-hazard applications. Notable accomplishments include models for the economic and community consequences of earthquake damage and the integration of these models to predict indirect economic losses and community disruptions on a regional basis.

Substantial emphasis has been placed on electric power systems by the American Recovery and Reinvestment Act, with $ 4.5 billion directed to development of the smart grid. At the same time, initiatives have been undertaken to enhance renewable energy through wind and solar contributions to the U.S. electric power system, with legislation passed in many states to achieve 20% of electric power through renewable energy within 10 to 20 years.

E.3 Issues and Challenges

Substantial work is needed to address lifeline system preparedness, improve performance, and coordinate improvements to achieve enhanced community resilience. Significant issues and areas of high priority include:

- NEHRP lost its only dedicated source of support for implementing lifeline risk reduction measures in practice when FEMA funding was terminated in 2007 for the American Lifelines Alliance. Support for implementation needs to be restored, with a new model for the collaborative setting of priorities and programmatic support for measures to mitigate lifeline earthquake hazards.
- A national workshop should be convened to obtain balanced and multidisciplinary advice from the lifelines community on the development of a coordinated approach to lifeline earthquake risk reduction. The workshop should address the multi-hazard aspects of lifeline performance and should result in a consensus on how NEHRP activities can advance multi-hazard resilience. NIST is the most appropriate host of such a workshop.

- Consistent with the Grand Challenges, NEHRP-related activities to improve lifeline earthquake engineering should support efforts to recognize and reduce the vulnerabilities arising from interdependencies among different lifeline systems.
- Support should be sought for critical lifelines from governmental agencies not part of NEHRP, such as the Departments of Energy, Transportation, and Defense. There should be collaboration between NERHP and the DHS Office of Infrastructure Protection to address earthquake hazards and the integration of NEHRP-supported technology and approaches to an all hazards approach and broader definition of homeland security. Common lessons from earthquakes, hurricanes, floods, severe accidents, and human threats should be synthesized and general principles adopted for improving hazard-related lifeline component and system performance.
- The broad changes underway for U.S. electric power should be scrutinized with respect to their influence on system resiliency, particularly the effects of increasing reliance on renewable energy sources. The contributions of the smart grid to earthquake response and recovery should be explored, with recommendations for using the distributed intelligence of the smart grid to make better decisions about the locations of potential damage and the optimal restoration of post earthquake power.