2 Trends and Developments in Science and Engineering

2.4 Structural Earthquake Engineering

2.4.1 General

Recent developments in structural engineering include efforts to develop performance-based engineering and methods to develop tools for health monitoring and rapid assessment of structural condition following earthquakes.

Performance-based engineering comprises two primary parts: (1) the development of practical and reliable means of predicting the probable behavior of buildings and structures in earthquakes and the effects of this behavior on society at the local, regional and national levels; and (2) the development of design methodologies and technologies that can effectively control and limit earthquake damage and consequences in both new and existing structures.

Following earthquake disasters, local and regional agencies have a need to identify those buildings and structures that are safe for continued occupancy and for use as centers for recovery, as well as those structures damaged to an extent that renders them unsafe or otherwise unusable. In the past, assessment of structural condition could be conducted only through the efforts of individual engineers with the knowledge and skills to rapidly assess damage and make reliable judgments as to structural condition. In a large disaster, such as a major earthquake affecting Charleston, Los Angeles, Memphis, Seattle, San Francisco, or Salt Lake City, thousands of buildings and lifeline structures will be affected. There are not enough sufficiently trained engineers or government officials to perform the needed assessments in a rapid manner. Failure to identify safe, useable, and unusable structures places citizens in the affected regions at greater risk and hinders the ability of government to marshal the resources necessary to speed aid to the affected region. Tools for health monitoring and rapid assessment of building's structural condition are an important development in addressing this issue.

2.4.2 Achievements

The ability to predict before an earthquake occurs how individual buildings and structures, as well as entire portfolios of buildings and structures, will behave is essential to any program intended to increase the nation's earthquake resiliency. Without this capability, it is impossible to understand the risks or to effectively allocate resources to mitigate these risks. Twenty years ago, such performance assessments could be made only by a very few expert engineers who had the knowledge and judgment to effectively perform this task. These experts numbered far too few to permit consistent, widespread and routine assessment of the risks.

The development and introduction of HAZUS approximately 10 years ago provided the capability to realistically assess earthquake risks at a community level, but did not provide engineers with the ability to reliably predict the likely performance of individual structures. Work undertaken at the three NSF-sponsored EERCs has begun to provide engineers with the tools needed to reliably predict the performance of individual buildings and structures in terms of the likely damage and, more importantly, the human, economic, and societal losses resulting from this damage. This work has been extended by the FEMA-sponsored ATC-58 Project *Development of Next-Generation Performance-Based Seismic Design Procedures for New and Existing Building*. The first phase of the project is to develop a Performance Assessment Methodology, which will be accompanied by a Performance Assessment Calculation Tool (PACT). The 75% Draft of this phase is due to be complete in 2010 with final completion time due in 2011. This methodology and accompanying calculation tool will be available for use by practicing professionals to assist in their design process and by academia for future research ideas and as a teaching tool.

Many other important projects have been developed by NEHRP Agencies in the past five years that are providing structural engineers a better understanding of the likely seismic performance of buildings or are providing guidance for the proper seismic design of building systems or components. The following list highlights several of these research efforts:

- FEMA's P-695, *Quantification of Building Seismic Performance Factors*
- NIST's Techbrief series being implemented by the NEHRP Consultants Joint Venture
- USGS's U.S. National Seismic Hazard Maps, which have been incorporated into the *2009 NEHRP Recommended Seismic Provisions for New Buildings and Other Structures* (FEMA P-750) and ASCE/SEI 7-05 *Minimum Design Loads for Buildings and Other Structures*
- NSF-Sponsored George E. Brown, Jr. Network for Earthquake Engineering Simulation (NEES) Operations and Research

Once earthquake risks to society have been identified, it is essential that engineers have cost-effective construction technologies capable of limiting damage to acceptable levels if they are to be effectively controlled. Twenty years ago, seismic isolation and passive energy dissipation technologies were known and available but proved to be prohibitively expensive to implement in many structures. Structural engineering researchers have focused much attention in recent years on the development of alternative damage-resistant structural systems that are more economical to implement. Some noteworthy success has been achieved, including development and adoption by the building codes of buckling-restrained braced steel frames and precast-hybrid concrete frames, both damage-resistant systems. In addition, new methods of constructing traditional structural systems are becoming available, providing a capability to design and build a more damage-resistant environment. Work is continuing in both areas. Perhaps equally important, researchers are also developing methods to reduce risk associated with a variety of nonstructural components and systems, including storage racks, ceiling systems, interior partitions, electrical systems, piping systems and similar items. This is particularly important because most of the economic losses associated with recent U.S. earthquakes have resulted from nonstructural rather than structural damage.

2.4.3 Issues and Challenges

Substantial additional work is required to enable effective implementation of performance-based engineering procedures to achieve resilient structures. Needs include the following:

- Development of fragilities and consequence functions for the many types of structural systems and nonstructural components found in buildings and structures so that the performance of new and existing buildings and structures, and the losses associated with their performance, can be accurately predicted.

- Development of reliable means of predicting structural collapse so that existing structures that are truly hazardous can be identified and so that new structures can be reliably designed to protect, as a minimum, life safety.

- Continued development of performance-based engineering tools that will enable engineers and other design professionals to reliably assess structural performance and design buildings and structures for improved performance.

- Development of quantifiable performance definitions and goals to achieve resilient structures.

- Development of practical and effective structural systems that can be used to minimize damage and loss in both new and existing structures focusing on achieving resilient designs.

- Implementation of design intent into the built environment.

- Development of tools that will enable the data collected from ANSS and privately-owned health monitoring instruments in buildings to instantaneously collect, process, and interpret the data so as to make rapid assessments on structural condition.

- Education of the design professional community so that they can effectively use these new tools.