

Development of Next-Generation Performance-Based Structural Design Criteria

by Ronald O. Hamburger, S.E., SECB

Performance-based seismic design is coming of age. The concept was first developed in the mid-1990s, primarily as a means of attaining practical, reliable and cost-efficient seismic upgrades of existing buildings. Most of the early development of this approach was conducted by the Applied Technology Council (ATC), a nonprofit organization originally established by the Structural Engineers Association of California (SEAOC) to perform urgently needed work to develop and recommend improvements to structural engineering design procedures and building code provisions. Funding for performance-based seismic engineering efforts has largely been provided by the four National Earthquake Hazards Reduction Program (NEHRP) agencies—most notably the National Science Foundation (NSF), which has funded basic research at our nation's universities—while the Federal Emergency Management Agency (FEMA) has funded the development of design guidelines and educational materials.

The early FEMA/ATC partnerships resulted in the publication of performance-based methods in the 1980s and 1990s to evaluate the likely performance of buildings in earthquakes, now embodied in American Society of Civil Engineers (ASCE) 31, *Seismic Evaluation of Existing Buildings*. In the mid- to late 1990s, FEMA/ATC partnership produced the FEMA 273/274, *NEHRP Guidelines for the Seismic Rehabilitation of Buildings*, which was standardized in 2006 as ASCE 41, *Seismic Rehabilitation of Existing Buildings*.

In 1995, SEAOC published its "Vision 2000: Performance-Based Seismic Engineering of Buildings" report calling for performance-based procedures for use in the design of new construction. While the 2006 *International Code Council Performance Code for Buildings and Facilities* (ICC PC) incorporates some of the Vision 2000 recommendations, there are no authoritative documents other than ASCE 41 (which, as indicated by its title, is intended for the upgrade of existing buildings) available to support application of the code.

The lack of authoritative documents has not prevented engineers from engaging in performance-based design of new buildings. Los Angeles and San Francisco, California, and Seattle, Washington, have permitted the construction of tall buildings that use performance-based approaches similar to those given in ASCE 41 as the basis for design. These procedures have also been used to justify the seismic design of a number of large low-rise buildings.

Despite the growing application of the ASCE 41 procedures for seismic design of new buildings, implementation is somewhat problematic. Building officials have been challenged to define equivalent performance to that attained by the prescriptive code procedures within the paradigm of ASCE 41; the procedures associated with nonstructural systems and components are not actually performance based; and no one actually knows the reliability of structures designed to the procedures—that is, whether they will actually be capable of attaining the desired performance.

The ATC-58 Project

Since 2001, ATC has been engaged through its ATC-58 Project in the development of next-generation performance-based seismic design criteria applicable both to the design of new buildings and the upgrade of existing buildings. Funding is provided by FEMA; however, FEMA's sister NEHRP agencies, the NSF, the National Institute of Standards and Technology, and the U.S. Geologic Survey, have been supportive of the project and funded parallel tasks to assist in its development.

The next-generation procedures for performance-based seismic design will represent a major evolutionary step. Perhaps most important, rather than using standard but qualitative measures of performance such as the immediate occupancy, life safety and collapse prevention damage states used by the ASCE 31/41 procedures, the next-generation procedures express performance as the probability that casualties (deaths and serious injuries), repair/replacement costs (in dollars) and occupancy interruption (in hours/days/months) will be experienced.

San Francisco's One Rincon Hill complex comprises two high-rise condominium structures designed using performance-based procedures.

Under the new procedures, performance can be expressed in three formats: intensity-based, scenario-based and time-based. Intensity-based performance will indicate the probability of incurring casualties, repair/replacement costs and occupancy interruption given that a building experiences a specific intensity of ground motion; for example, the maximum considered earthquake or design earthquake intensities of shaking defined in Chapter 16 of the *International Building Code* (IBC).

Scenario-based performance will indicate the probability of incurring these types of losses given that a specific magnitude earthquake occurs at a particular distance from the building site. This type of performance measurement is anticipated to be useful for buildings close to major active faults in the U.S. because the ground motion maps provided in the IBC are based on such scenarios for near-fault sites.

Finally, time-based performance measures will indicate the probable losses over a period of time considering all of the earthquakes that could occur during that time period and the probability of each. This will enable policy makers to compare the risks associated with earthquakes with the risks from other hazards, such as fire, hurricane and flooding.

Performance, whether measured in casualties, repair/replacement costs or downtime, are expressed in the form of loss curves showing the probability, ranging from 0 to 1, that losses will exceed different levels. The reason performance is expressed probabilistically is because there are many uncertainties that prevent exact calculation of a building's performance before it is constructed and the damaging event occurs. These uncertainties relate to the quality of the building's construction, its condition at the time of the event, its occupancy and the specific character of the event that affects it, as well as inaccuracies that are inherent in our present ability to predict performance.

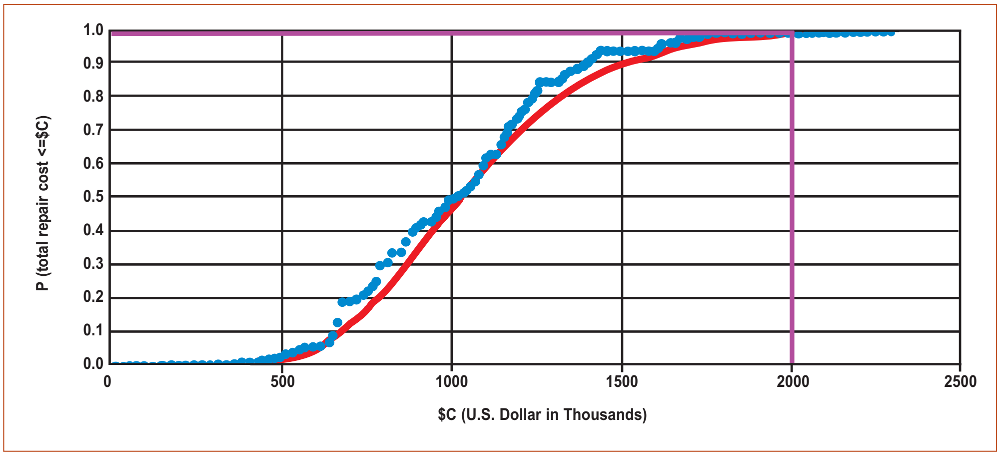

Figure 1. Loss curve showing the probability of incurring repair costs exceeding various amounts given the occurrence of a scenario earthquake.

Calculation of these loss curves involves a process known as Monte Carlo simulation in which an analytical model of the building is subjected to many representations of earthquakes; consideration of the possible variations in construction quality, occupancy, condition and other factors that affect the loss; and assessment of the loss each time. The blue dots in Figure 1 represent the results of such simulations, while the red line represents a smooth curve fitted through this data. In addition to producing loss curves, the calculation procedures allow designers to understand the sources of the various losses—exterior curtain walls, structural failures, plumbing leaks, etc.—enabling them to effectively improve designs to reduce losses associated with the various systems.

Implementation

ATC anticipates publication of guideline documents for the new procedures in late 2011 or early 2012. The guideline documents will provide engineers and building officials with procedures that can be used to model buildings, analyze their response to earthquakes, predict the losses associated with their designs and then iterate the process until acceptable performance is predicted.

One of the key challenges facing the building regulation community will be to determine how to use these new measures of performance and compare them against the performance obtained from code-conforming structures. As an adjunct task to development of the guidelines, ATC plans to conduct studies of typical code-conforming buildings to project their performance in terms compatible with the new procedures. This will enable building officials to determine appropriate performance criteria for new buildings designed using alternative, performance-based procedures.

The latest, detailed information about the progress of the ATC-58 project is available on ATC's website, *www.atcouncil.org*. ◆

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Hamburger is Project Technical Director for the ATC-58 Project and has chaired committees engaged in the development of seismic design standards and codes for ATC, ICC, SEAOC the American Society of Civil Engineers, the American Institute of Steel Construction, the American Welding Society, the Building Seismic Safety Council, the National Fire Protection Association and other industry groups.