Development of Next-Generation Performance-based Seismic Design Procedures For New and Existing Buildings

The ATC-58 Project in Brief

The Applied Technology Council, under sponsorship of the Federal Emergency Management Agency of the Department of Homeland Security, is currently engaged in a project (ATC-58) to develop next-generation performance-based seismic design procedures and guidelines. This paper presents a brief overview of the performance-based design concept, its advantages, the current state of practice, the project vision for the next generation procedures and the project implementation plan.

Performance-based Design Concepts

Most buildings today are designed to resist earthquakes through conformance to procedures specified by the building codes. These code-specified procedures are intended to protect life safety in the most severe earthquakes ever likely to affect buildings and reduce property damage and loss in more frequent, moderate earthquakes. However, the procedures seek to accomplish this through indirect means, the designer never actually evaluates a design's performance capability, and the resulting designs may or may not provide the degree of protection envisioned by the owner and, as recent experience has shown, often produce large property and economic loss.

Performance-based seismic design is a process that permits design of new buildings or upgrade of existing buildings with a realistic understanding of the risk of life, occupancy and economic loss that may occur as a result of future earthquakes. The process is performed by modeling a building's design, then simulating the performance of that design for various earthquake events. Each simulation provides information on the level of damage, if any, sustained by the structure, which, in turn, permits estimation of the amount of life, occupancy and economic loss that may occur. The design of the building can then be adjusted until the projected risks of loss are deemed acceptable, given the cost of achieving this performance.

An important component of performance-based seismic design procedures is that the performance expected of a structure is explicitly stated. This provides building owners, tenants, lenders, insurers, regulators and other stakeholders the opportunity to specify the desired performance which can then be used by design professionals as the design basis.

Advantages of Performance-based Design

The performance-based design process offers a number of advantages over traditional code-procedures. Specifically, this process may be used to design individual facilities that:

- are more loss-resistant than typical buildings designed using the code procedures;
- have a higher confidence that they will actually be able to perform as intended;
- are capable of providing the desired performance at lower construction cost than would otherwise be possible; and,

- use new materials and structural systems not adequately covered by the code procedures.

Another important benefit of performance-based design is that it can be used to improve current building code procedures allowing buildings to more reliably meet society's expectations regarding their future performance. While this project will initially focus on seismic design, it will also seek to coordinate with and incorporate similar material to address wind, blast and fire effects as well.

The Current State of Practice

Current performance-based design practice employs first-generation procedures formalized in the 1990s. These were developed for and are embodied in the national guidelines and standards for seismic evaluation and upgrade of existing buildings. They are sometimes used to design new buildings but are not really intended for that purpose. In these procedures, building performance is communicated by reference to a series of standard performance levels that range from states of negligible damage and impact on safety, occupancy and use to states of near complete damage in which there is extensive risk to life, complete loss of economic value and permanent loss of use and function. Under these procedures, decision makers must select the desired performance levels (e.g., *fully functional*, *immediate occupancy*, *life safety*, *collapse prevention*), and the earthquakes for which these performance levels are to be achieved. As an example, one could specify that a building be designed to provide *immediate occupancy* performance for a 100-year earthquake and *collapse prevention* performance for a 2,500-year earthquake. Once such decisions are made, engineers can develop a building design, analyze a model of the design to predict how much it will deform and be stressed by the selected earthquake, and use engineering acceptance criteria specified by the guidelines and standards to determine it the desired performance is achieved.

Decision makers selecting performance under these first-generation procedures must do so without direct quantitative information on the possible life and economic losses of their decisions. Engineers can assist in this process, but must rely heavily on independent judgment and personal experience to relate the standard performance levels to quantified life and economic losses and potential time of facility occupancy and use interruption.

Vision for the Next-generation Procedures

The next-generation performance-based seismic design procedures developed under this project will express performance directly in terms of the quantified risks that the building owner or decision maker will be able to understand. In a workshop held in the early stages of this project, a representative sample of these users indicated their preference to define these risks in terms of the future life loss, facility repair costs and downtime that could result from design decisions. These risks may be expressed in a variety of formats including: expected loss for a given earthquake event, probable maximum loss over a given number of years, the probability of loss exceeding a specified value over a period of years, the net present value of future potential losses, average annualized loss, and others as best suits the needs of individual decision makers. Stakeholder guidance will be developed to assist decision makers in selecting appropriate risk levels as the basis of design and upgrade projects. Engineering guidelines will be prepared to assist design professionals to develop building designs that are reliable and capable of meeting the selected risk criteria.

Project Implementation Plan

This project will develop the next-generation procedures in two major phases. The first phase will comprise development of performance verification procedures that will permit an engineer to evaluation the performance of an existing building or of a proposed design for a new building using the same terms defined by decision makers. Verification procedures will include rules to model buildings and simulate their response to a range of earthquake events, each having different intensity. The simulations will provide information on the probable range of stress and deformation induced in the building by each earthquake intensity level. Procedures will include guidelines for converting estimates of stress and deformation into measures of damage experienced by the structure as well as the architectural, mechanical and electrical components and systems supported by the structure. Finally, the procedures will provide methods to convert measures of damage, for example crack widths, into measures of probable loss, including repair costs, business interruption time and life endangerment. By considering the probability that earthquakes of different intensity may occur, the likely range of response of buildings at each intensity level, and the probable damage and losses for various levels of damage, engineers will be able to predict the loss potential for existing buildings or new designs in the same terms used by decision makers to evaluate and specify acceptable seismic risk. These procedures will be immediately useful in the implementation of improved performance-based designs of new buildings and upgrade of existing buildings.

The goal of the second phase will be to develop design and stakeholder guidance to use performance-based design. To do this, the project will implement the performance verification procedures to evaluate the performance capability of typical structures designed using current code procedures. The acceptability of current code performance will be evaluated and appropriate minimum performance levels for structures of differing occupancies will be recommended. Based on the above, methods for selecting structural systems and installing nonstructural components and systems capable of reliably attaining various performance objectives will then be developed. These will be set forth in the form of design guidelines and resource documents for use in developing future building codes.