

Performance Based Earthquake Design of Buildings and Structures

An Online Continuing Education Course for Engineers

Course Number: S-2009

Credit: 2 Hours / 2 PDH / 2 CPD

Performance-based seismic design is a relatively new concept that reflects a natural evolution in engineering design practice. It is based on investigations of building performance in past earthquakes and laboratory research, and is enabled by improvements in analytical tools and computational capabilities. Performance-based seismic design concepts have been made possible by the collective intellect of an interested profession and significant financial resources provided in large part by the federally funded National Earthquake Hazards Reduction Program.

To introduce the subject, we begin with a description of the process by which seismic codes are developed and implemented, followed by a discussion of the expected performance of new buildings designed in accordance with current seismic codes. Interestingly enough, as discussed in Section 3, currently applied concepts in performance-based seismic design were developed for the rehabilitation of existing buildings, as opposed to the design of new buildings. These concepts, however, apply equally well to new buildings, and model codes for new building seismic design are beginning to adopt and adapt the performance-based concepts created for seismic rehabilitation of existing buildings. As described in Section 4, work is also underway to develop next-generation performance-based seismic design guidelines for new and existing buildings.

1 SEISMIC DESIGN PROVISIONS IN BUILDING CODES

Building design codes for cities, states, or other jurisdictions throughout the United States are typically based on the adoption and occasional modification of a model building code. Up until the mid-1990s, there were three primary model building code organizations: Building Officials and Code Administrators International, Inc. (BOCA), International Conference of Building Officials (ICBO), and Southern Building Code Congress International, Inc. (SBCCI). In 1994, these three organizations united to found the International Code Council (ICC), a non-profit organization dedicated to developing a single set of comprehensive and coordinated national model construction codes. The first code published by ICC was the *2000 International Building Code* (IBC; ICC, 2000).

Building code adoption is a complicated process, especially in regions with significant exposure to natural hazards such as earthquake, wind, or flood. In some earthquake-prone regions of the United States, the seismic design provisions outlined in the 2000 IBC have not been adopted. Instead, the provisions of the *Uniform Building Code (UBC)*, the model building code published by IBCO from 1949 through 1997 (ICBO, 1997), are still used. The seismic provisions in the UBC are based primarily on the provisions contained in the Structural Engineers Association of California (SEAOC) *Recommended Lateral Force Requirements and Commentary*, known as the *Blue Book* and published from 1959 through 1999 (SEAOC, 1999). In addition, the 1997 UBC relies on the provisions contained in the 1994 edition of the *NEHRP Recommended Provisions for Seismic Regulations for New Buildings* (BSSC, 1995), while the 2000 IBC relies on the more recent 1997 edition of the *NEHRP Recommended Provisions for Seismic Regulations for New Buildings and Other Structures* (BSSC, 1998).

The *NEHRP Provisions* have been published regularly since the National Earthquake Hazards Reduction Program (NEHRP) was created in 1978 as a response to Congress passing P.L. 95-124, the Earthquake Hazards Reduction Act of 1977. The Federal Emergency Management Agency (FEMA) was mandated to implement P.L. 95-124 and NEHRP, and the Building Seismic Safety Council (BSSC) was formed to provide a broad consensus mechanism for regularly updating the *NEHRP Recommended Provisions for Seismic Regulations for New Buildings* (hereinafter referred to as the *NEHRP Recommended Provisions*), first published in 1978 by the Applied Technology Council as *Tentative Provisions for the Development of Seismic Regulations for Buildings*, (ATC-03 Report; ATC, 1978). The most recent version of the *NEHRP Recommended Provisions* is the 2003.

The remainder of the course explores seismic design issues related to current building codes, specifically the intent of current codes with respect to the performance of structural and nonstructural building systems.

Performance-based engineering, an emerging design tool for managing seismic risk, and the impact that the emergence of performance-based design strategies will have on future buildings and their seismic performance, are discussed later in this course.

2 EXPECTED PERFORMANCE WHEN DESIGNING TO CURRENT CODES

The basic intent of current seismic design provisions is best summarized by the SEAOC *Recommended Lateral Force Requirements and Commentary*, which states:

These Requirements provide minimum standards for use in building design regulation to maintain public safety in the extreme ground shaking likely to occur during an earthquake. These Requirements are primarily intended to safeguard against major failures and loss of life, not to limit damage, maintain functions, or provide for easy repair.

In other words, current seismic design codes are essentially aimed at the preservation of life and safety for the benefit of the community. The recommended provisions express expectations and provide no guarantees; they assume that there may be damage to a building as a result of an earthquake. For example, the SEAOC *Recommended Lateral Force Requirements and Commentary* includes a general set of performance statements to qualify the nature of expected damage, as follows:

Structures designed in accordance with these recommendations should, in general, be able to:

- Resist a minor level of earthquake ground motion without damage
- Resist a moderate level of earthquake ground motion without structural damage, but possibly experience some nonstructural damage.
- Resist a major level of earthquake ground motion having an intensity equal to the strongest either experienced or forecast for the building site without collapse, but possibly with some structural as well as nonstructural damage.

It is expected that structural damage, even in a major design level earthquake, will be limited to a repairable level for most structures that meet these Requirements. In some instances, damage may not be economical to repair. The level of damage depends upon a



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number of factors, including the intensity and duration of ground shaking, structure configuration, type of lateral force resisting system, materials used in the construction, and construction workmanship.



Codes do not provide the designer with the difference in performance between different structural systems.

Designers use codes as a resource, as they provide minimum acceptable consensus standards. Codes provide no guidance on the selection of materials and systems, rather only criteria for their use once selected. Codes also do not provide the designer with the difference in performance between systems; for example, the difference between the stiffness of shear walls and frames and the importance of this characteristic for the overall seismic performance of the building. Lastly, codes do not discuss that the use of some structural systems will result in more nonstructural damage than others, even though the structural systems perform equally well in resisting the earthquake forces. The following sub-sections describe the expected performance of structural and nonstructural components, respectively.



Current seismic design provisions for non-essential facilities are intended to provide resistance to collapse in a major earthquake (typically the design ground motion). Resistance to collapse means that the structure may have lost a substantial amount of its original lateral stiffness and strength, but the gravity-load-bearing elements still function and provide some margin of safety against collapse.

Expected Performance of Structural Components

As mentioned earlier, current seismic design provisions for non-essential facilities are intended to provide life safety, i.e., no damage in a minor earthquake, limited structural damage in a moderate earthquake, and resistance to collapse in a major earthquake (typically the design ground motion). Resistance to collapse means that the structure may have lost a substantial amount of its original lateral stiffness and strength, but the gravity-load-bearing elements still function and provide some margin of safety against collapse. The structure may have permanent lateral offset and some elements of the seismic-force resisting system may exhibit substantial cracking, spalling, yielding, buckling, and localized failure. Following a major earthquake, the structure is not safe for continued occupancy until repairs are done. Shaking associated with strong aftershocks could threaten the stability of the structure. Repair to a structure in this state is expected to be feasible, however it may not be economically attractive to do so. Section 3 includes further discussion of the seismic behavior of specific structural systems in the context of describing performance-based design objectives.

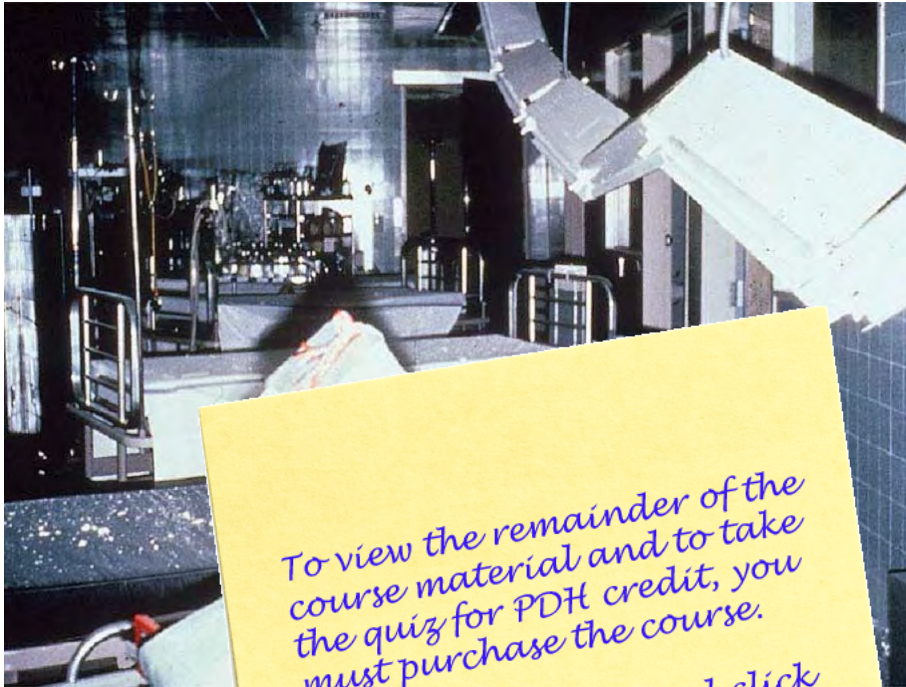


Figure 1 Photo during ATC-2

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Expected Performance

While current seismic performance standards do not address performance of nonstructural components such as room partitions, filing cabinets, hanging lighting and ceilings, entryway canopies, and stairwells; nor do they address performance of mechanical, electrical, or plumbing systems including fire sprinklers, heating and air conditioning equipment or ductwork, and electrical panels or transformers. The vast majority of damage and resulting loss of building functionality during recent damaging earthquakes has been the result of damage to nonstructural components and systems (Figure 1). Many building owners have been surprised when a building withstands the effects of a moderate earthquake from a structural perspective, but is still rendered inoperable from a nonstructural standpoint.

Current seismic design provisions typically require that nonstructural components be secured so as to not present a falling hazard; however, these components can still be severely damaged such that they can not function. Loss of electric power, breaks in water supply and sewer out-



While current seismic design provisions provide minimum structural performance standards in terms of resistance to collapse, they typically do not address performance of nonstructural components.