Relationship of the NEHRP Provisions and 2006 IBC

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Piño Suarez building, Mexico City Earthquake, September 19, 1985. Photo courtesy of USGS Photographic Archive.

In the course of wrestling with a building design and attempting to comply with the code, have you ever wondered where some obscure design provision came from? Why it was in the code? How you could possibly understand the provision? Who hasn't?

For many design requirements it is impossible to answer these questions. Most code provisions obscure or otherwise have their roots in many years of tradition, with endless layers of evolution since their first appearance. Many provisions in the building code are experiential in nature. That is, someone designed a building in a certain way, the building was constructed and experienced a loading event, and the building failed. Following observation of the failure, people decided it wasn't a good idea to design buildings like this anymore, so they developed a code requirement prohibiting this particular design feature. There are many examples of this, a few of which are described in *Table 1*.

Other requirements in the building code are the result of analytical and laboratory research and the application of rational analysis of hypothetical problems. In these cases, although a failure may not actually have occurred or been observed, some concerned researcher or engineer observed a design practice that seemed inappropriate, performed research to determine if this would be a problem and then developed recommendations, that later became code requirements to avoid future problems. Several examples of these types of code requirements are contained in *Table 2*. Regardless of the origin of a particular design requirement, we are likely to do a better job of complying with the requirements and designing our structures if we can understand the basis for the code, the types of failures that occurred and the conditions that have resulted or could result in such failures. But where can we find this information?

It is nearly impossible to find the origin of many code requirements, as the research papers and disaster investigation reports on which they were based have long since faded into obscurity, and, only a few old-timers remember anymore. Fortunately, this is not the case for seismic design requirements.

For many years, the seismic design requirements in U.S. building codes were based on the recommendations of the Structural Engineers Association of California (SEAOC) publication, *Recommended Lateral Force Requirements and Commentary* commonly called the "blue book." For more than 50 years, SEAOC

Table 1 - Representative Experience-based Seismic Design Requirements in the 2006 IBC.

Code Requirement	Historic Incident	Observed Failure
Complete load carrying space frame required in buildings exceeding 160 feet in height in Seismic Design Categories D, E, & F	1906 San Francisco Earthquake	All masonry buildings in San Francisco financial district, except those with steel frames failed, either from the earthquake or ensuing fire
Prohibition on use of unreinforced (plain) masonry bearing walls in Seismic Design Categories C, D, E, & F	1933 Long Beach Earthquake	Collapse of many unreinforced masonry bearing wall buildings
Positive direct connection required between walls of concrete or masonry and diaphragms and continuous ties required in flexible diaphragms	1971 San Fernando Earthquake	Collapse of many tiltup buildings due to separation of load bearing precast walls from supported roof system
Requirement to size columns beneath discontinuous walls or frames for overstrength (Ω_o) of structure above	1979 Imperial Valley Earthquake	Failure of columns in Imperial County Services Building
Steel columns in braced frames required to have the strength to resist the component forces resulting from development of yielding of all tributary braces	1985 Mexico City Earthquake	Collapse of the 22-story Piño Suarez building because the braces overwhelmed the columns
Requirement to use notch-tough weld filler metals in seismic force resisting systems of steel frames	1994 Northridge Earthquake	Brittle fracture damage of welded connections in many steel moment frame buildings

Table 2- Representative Rational Design Requirements in the 2006 IBC

Code Requirement	Concern	Research Type
Requirement to use dynamic analysis procedures to determine design seismic forces in tall and irregular structures	Dynamic response of such structures is not well predicted by static lateral force equations	Analytical investigation of the dynamic response of representative buildings to earthquake shaking
Design forces for anchorage of concrete and masonry walls to flexible diaphragms that are 4 to 5 times larger than the seismic design forces for the structure	Failure of wall to diaphragm ties	Nonlinear dynamic analysis of typical buildings and evaluation of strong motion records from instrumented buildings
Requirements to provide extensive confinement reinforcing in beams, columns and joints of concrete special moment resisting frames	Crushing of concrete under extreme cyclic loading	Cyclic laboratory testing of numerous beams, columns, and beam-column joints
Requirement to use plate washers under heads of anchor bolts on sill plates of wood walls	Splitting of sill plate under lateral force induced rocking of walls	Cyclic laboratory testing of shear wall panels

volunteers would develop recommendations for seismic design, together with an explanation of the reasons for these recommendations and publish it in the blue book. The *Uniform Building Code* typically adopted these recommendations directly into the body of the code. As a result, it was possible for engineers designing buildings to find a direct explanation as to why the code required what it did.

Imperial Valley, California Earthquake, October 15,1979. East end of Imperial County Services Building showing a row of columns that failed during the main shock. Photo by C. Rojahn, courtesy of USGS photographic archive

Seismic design requirements in U.S. building codes are no longer based on the SEAOC recommendations. However, the model established by SEAOC and the *Uniform Building Code* more than 50 years ago is still in place. Following the 1971 San Fernando earthquake, which caused extensive damage in the Los Angeles area, structural engineers, building officials, and legislators became concerned that the volunteer efforts of SEAOC were not sufficient to assure the safety of Americans in earthquakes. In response to this concern, the National Earthquake Hazards Reduction Program (NEHRP) was established to provide funding for earthquake engineering research and to develop reliable seismic design criteria for inclusion in building codes. Under NEHRP funding, the National Institute of Building Sciences established a non-profit council, the Building Seismic Safety Council (BSSC) and charged this group with developing and maintaining nationally-applicable consensus guidelines, and a companion commentary for the design of structures for seismic resistance. BSSC developed a process and model similar to that which had traditionally been used by SEAOC in their publication of the blue book to accomplish this purpose. BSSC volunteers were empanelled into a committee, termed the Provisions Update Committee, patterned after SEAOC's seismology committee.

In parallel with the BSSC effort, the NEHRP also provides substantial funding to the United States Geologic Survey (USGS) to study the risk of experiencing destructive ground shaking in various parts of the United States. On a periodic basis, the USGS has published a series of design ground motion maps that portray the best current scientific consensus as to the levels of ground shaking that may be experienced around the United States, and which levels should be used as the basis for design of buildings and bridges. The first edition of these maps was published in the mid-1970s. These maps represented a major change in portraying seismic haz-

One of four damaged reinforced concrete columns along the east end of the Imperial County Services Building. Imperial Valley, California Earthquake, October 15, 1979. Photo courtesy of USGS photographic archive.

San Francisco, California Earthquake, April 18, 1906. View showing damage to the San Francisco City Hall. Photo courtesy of USGS Photographic Archive

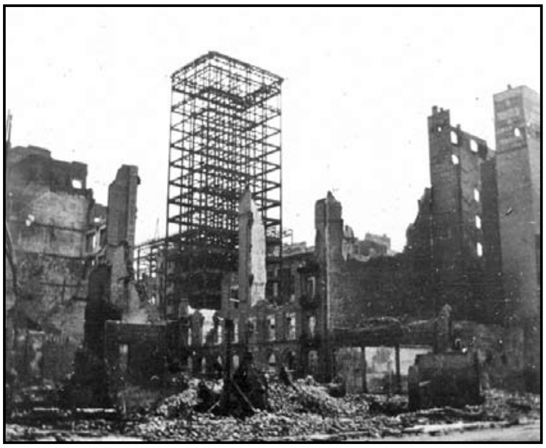
ards in that, rather than showing seismic zones, the maps portrayed peak spectral response acceleration and response velocity contours from which design spectra could be constructed. The initial series of maps were based on 500-year ground shaking. However, by the mid-1990s, seismologists felt that these shaking maps were inadequate to capture a repeat of some of the more severe recorded earthquakes, including the 1811-1812 New Madrid events and the 1898 Charleston earthquake. In 1996, the 500-year shaking maps were replaced with a series of design maps based on 2,500-year shaking. These maps were next updated in 2002 to incorporate updated seismologic information but remained at the 2,500-year hazard level.

In 1985, BSSC published the first edition of the *NEHRP Recommended Provisions for Seismic Regulation of Buildings*, based on the extensive ATC3.06 report prepared by the Applied Technology Council under National Science Foundation funding. BSSC developed NEHRP *Provisions* using a committee of volunteer engineers, industry representative and building officials, funding only the costs associated with travel, meetings, and publication. BSSC has updated and republished the NEHRP *Provisions* on a 3-year cycle since the first publication in 1985. The 1991 edition, which still referenced the 500-year design shaking maps was adopted by the 1992 editions of both the BOCA and SBCCI codes as the basis for their seismic requirements, initiating a controversy as to the proper return period for design earthquake shaking that remains unsolved today. In 1997, the document underwent extensive revision including use of the updated (1996) seismic hazard maps, introduction of new formulations of the design force equations, expansion to include extensive requirements for nonbuilding structures and was retitled: *NEHPR Recommended Provisions for Seismic Regulation of Buildings and Other Structures*. The 1997 edition was adopted as the basis for seismic design requirements in the 2000 IBC and ASCE 7-98. The 2000 edition of the NEHRP *Provisions* provides the basis for seismic design requirements in 2003 IBC and ASCE 7-02, except that both of these documents refer to the updated 2002 USGS design maps. The 2003 edition forms the basis for the 2006 IBC and ASCE 7-05 requirements.

All editions of the NEHRP *Provisions* to date have been published in two volumes: Volume 1 – Provisions, and Volume 2 – Commentary. Volume 1 is a complete statement of the code requirements, although there are often significant editorial and minor technical deviations between the version published in the BSSC document and the actual requirements adopted in ASCE-7 and IBC. Volume 2 provides explanation of the basis for each requirement, the experiential or research basis for the requirement and discussion as to how the requirement can be properly applied. Both volumes are available for free download from the BSSC's web site, **www.bssconline.org**.

Increasingly, the building codes have been relying on national consensus standards such as ASCE-7, ACI-318, and the AISC specifications as resources for structural design and construction requirements. Older editions transcribed most of the requirements contained in these standards into the body of the code, often with amendment and modification. The 2006 IBC does this to a much lesser extent and references these standards, almost without transcription, as the basis for structural code requirements. For the purposes of seismic design, the IBC refers primarily to ASCE 7-05 Although ASCE 7-05 is primarily a loading standard, in the case of seismic design, ASCE-7 also adopts by reference the applicable criteria contained in the materials standards published by ACI, AISC, AFPA and TMS. The ASCE-7 seismic task committee, which develops the seismic requirements contained in the standard, operates in close cooperation with the BSSC Provisions Update Committee. By mutual consent and agreement, all major updates and changes to seismic design requirements contained in ASCE-7 are initiated in the BSSC Provisions Update process. Therefore, although minor editorial and technical differences may exist between the NEHRP requirements and those that actually appear in the building code, the NEHRP commentary still provides a highly relevant and useful resource for designers interested in understanding the basis of the code requirements.

After many years of rapid evolution and change in the seismic design requirements contained in the *Provisions* and the building codes, it appears that we have entered a period of relative quiescence in which major changes are not being introduced as rapidly. There are several reasons for this, including: concern that the rapid and



San Francisco, California, Earthquake April 18, 1906. View showing damage of Shreve Building which was constructed using a steel frame. Photo courtesy of USGS photographic archive.

San Fernando, California, Earthquake February 1971. Two fallen structurally-separated stair towers and the collapsed basement at Olive View Hospital. View is north. Photo courtesy of USGS photographic archive.

continual changes to the code requirements have inhibited engineers' ability to understand and properly implement the requirements; belief that the current NEHRP *Provisions* provide reasonably reliable construction; and, the fact that there have been no recent damaging earthquakes to provide data on inadequacies in the present code. In recognition of these factors, the next update of the NEHRP *Provisions* will not be published until 2008. Also, the major emphasis in the development of the 2008 NEHRP *Provision* will be in improving and enhancing the commentary so that it will be more useful for designers. Important changes being incorporated into the commentary include a reformatting so that it directly references requirements using the section designations contained in the standards. Further, the commentary is being enhanced to provide more descriptive material on intended application of the requirements.

Several important technical enhancements are presently being considered for inclusion in upcoming editions of the *Provisions*. These include an updated series of seismic hazard maps, currently under development by the United States Geologic Survey, and development of a rational and defensible basis for the R, C_d and Ω_o factors and system limits contained in the *Provisions*. Although no decisions have been finalized as of this writing, it appears likely that the next set of ground shaking hazard maps adopted by the *Provisions* will be based on a reduced hazard relative to current maps, perhaps 1,000 years. This will likely reduce the severity of seismic design requirements in many regions of the U.S.

Every engineer designing buildings or other structures for seismic resistance in accordance with the International Building Code should obtain a copy of the NEHRP *Provisions*. It is an invaluable resource and repository of information on the basis and intent of the code requirements.■

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