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SEISMIC DESIGN REQUIREMENTS FOR REGIONS OF MODERATE SEISMICITY

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SUMMARY

The need for earthquake-resistant construction in areas of low to moderate seismicity has been recognized through the adoption of code requirements in the US and other countries only in the past quarter century. This is largely a result of improved assessment of seismic hazard and examples of recent moderate earthquakes in regions of both moderate and high seismicity, including the San Fernando (1971), Mexico City (1985), Loma Prieta (1989), and Northridge (1994) earthquakes. In addition, improved understanding and estimates of older earthquakes in the Eastern US such as Cape Ann (1755), La Malbaie, Quebec (1925), and Ossippe, NH (1940), as well as monitoring of micro-activity in source areas such as La Malbaie, have increased awareness of the earthquake potential in areas of low to moderate seismicity. Both the hazard and the risk in moderate seismic zones (MSZs) differ in scale and kind from those of the zones of high seismicity. Eathquake hazards mitigation measures for new and existing construction need to be adapted from those prevailing in regions of high seismicity in recognition of these differences. Site effects are likely to dominate the damage patterns from earthquakes, with some sites suffering no damage not far from others, on soft soil, suffering near collapse. A number of new seismic codes have been developed in the past quarter century in response to these differences, including the New York City (1995) and the Massachusetts State (1975) seismic codes. Over the same period, the national model building codes that apply to most areas of low to moderate seismicity in the US, the BOCA Code and the Southern Standard Building Code (SSBC), have incorporated up-to-date seismic provisions. The seismic provisions of these codes have been largely inspired by the National Earthquake Hazard Reduction Program (NEHRP) recommendations. Through adoption of these national codes, many state and local authorities in areas of low-to-moderate seismicity now have reasonably comprehensive seismic design provisions. This paper will review the background and history leading up to the MSZ codes, discuss their content, and propose directions for future development.

1 INTRODUCTION

Design for earthquake resistance has only recently been required by law in regions of low to moderate seismicity relative to areas of high seismicity. So far, in the United States the major areas of focus have been the Charleston, SC, Memphis, TN, New York, NY, and Boston, MA areas. This has been a direct result of the record of historic earthquakes in each of these areas, the attention drawn by recent earthquakes in areas of high seismicity, and the improving understanding of the the likelihood and severity of earthquakes in moderate seismic zones. Similar development has occurred in parts of Europe, especially the Northern countries, eastern Australia, New Zealand, and Japan among others.

The principal characteristics of moderate seismic regions can be summarized as follows:

- Either very infrequent, major earthquakes or infrequent, moderate earthquakes are known to have occurred. In either case, the more recent seismic activity is minor. An example might be a region with a single recorded occurrence of a magnitude 7 or larger earthquake, and no damaging earthquake since (e.g.,

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Memphis, Charleston, or Boston) or a string of earthquakes of magnitude 5 to 5.5 and sufficient geologic evidence to imply the possibility of a rare larger event (e.g., New York City).

- The localities are not expecting nor generally prepared for an earthquake, and the buildings are, for the most part, not earthquake-resistant.
- Typically, these regions are located away from tectonic plate boundaries, and major faults, and so the source of earthquakes is less well understood and hazards assessments are more difficult.
- The ground shaking caused by earthquakes diminishes, or “attenuates,” much less with increasing distance from the earthquake. That means that for a given magnitude the “felt area” and extent of damage is much greater in most moderate seismic regions than in high seismic regions.

This situation is changing for a number of reasons, some of which are discussed in this paper. Generally, the awareness of the disastrous consequences of earthquakes is increasing in the US and worldwide. As even earthquakes of moderate magnitude are seen to be quite damaging, it has become clear that the risks are significant even, or perhaps especially, in those regions of moderate seismicity, since the construction and communities are unprepared, and the extent to which even a moderate earthquake will be felt will be greater. In other words, a moderate earthquake will cause more damage, over a larger area, in these regions than a similar magnitude earthquake in the high seismic regions. Nevertheless, seismic risk mitigation is a more difficult sell to developers, building owners, and other stakeholders in areas of low to moderate seismicity than it is in areas of high seismicity because of the relative infrequency of large events in such areas.

2 SEISMIC HAZARD AND SEISMIC RISK IN MODERATE SEISMIC ZONES

Speaking before the National Board of Fire Underwriters in New York on May 24, 1926, Professor Bailey Willis, a geologist at Stanford University, proposed that “in California the underwriters of earthquake insurance should estimate on a severe quake coming somewhere within the state, causing more or less loss, once every 25 years, and that in New England the underwriters should expect a disastrous quake somewhere about once in each 100 years” [Freeman, 1932]. John Freeman, from whose *Earthquake Damage and Earthquake Insurance* (1932) this quote is taken, argued further that “Manhattan Island seems one of the safest spots from earthquake hazard among all of the Atlantic seacoast cities because of its rigid bed-rock foundation.”

The current state of knowledge (see elsewhere in this issue) embodies similar views in the approach to seismic hazard assessment and the consideration of site effects. The return periods estimated for various region’s maximum credible earthquake show that there are regional differences corresponding to a factor of 4 or 5 on the return period anticipated by current code requirements (Figure 1). A further lesson for earthquake engineering in MSZs, reaffirmed in the 1989 Loma Prieta earthquake, is the broad variation in site factors. It is apparent now, as it was in 1926, that site effects are a key determinant of damage, after only construction quality. This seems particularly true in the case of moderate earthquakes, with peak accelerations on the order of 10% of gravity and short duration. Brittle buildings may survive such earthquakes if founded on rock, but even some modern structures can be severely damaged if located on soft soils.

2.1 The Northeast United States

The recognition that earthquakes are a hazard in the Northeast US has evolved and gained greater acceptance only in the past quarter century. Concern over the possibility of damaging earthquakes in the eastern United States developed through the 1970s as a result of improved knowledge of both the history of eastern U.S. earthquake occurrences and effects, and of the underlying ground-shaking mechanisms. These subjects are treated elsewhere. Of interest here is the fact that this improved knowledge led to changes in both national and local building codes through the 70s. The 1973 Uniform Building Code (UBC, 1973) included northern New York State, Boston, Massachusetts and Charleston, South Carolina in the next-to-highest seismic zone (Zone 2 of 3). The subsequent ATC 3-06 (ATC, 1978) maps, developed for equal probabilities of occurrence and intensity nationwide, refined the zoning further. At the same time, the Nuclear Regulatory Commission was carefully evaluating the seismic hazards and risks at potential plant sites. In an advisory note (Nuclear Regulatory Commission, 1983*)*, the Nuclear Regulatory Commission commented:

“Because the geologic and tectonic features of the Charleston region are similar to those in other regions of the eastern seaboard, we conclude that although there is no recent or historical evidence that other regions have experienced strong earthquakes, the historical record is not of itself sufficient ground for ruling out the occurrence in these other regions of strong seismic ground motions similar to those experienced near Charleston in 1886 (M=7). Although the probability of strong ground motion due to an earthquake in any given year at a particular location on the eastern seaboard may be very low, deterministic and probabilistic evaluations of the seismic hazard should be made for individual sites on the eastern seaboard to establish the seismic engineering parameters for critical facilities.”

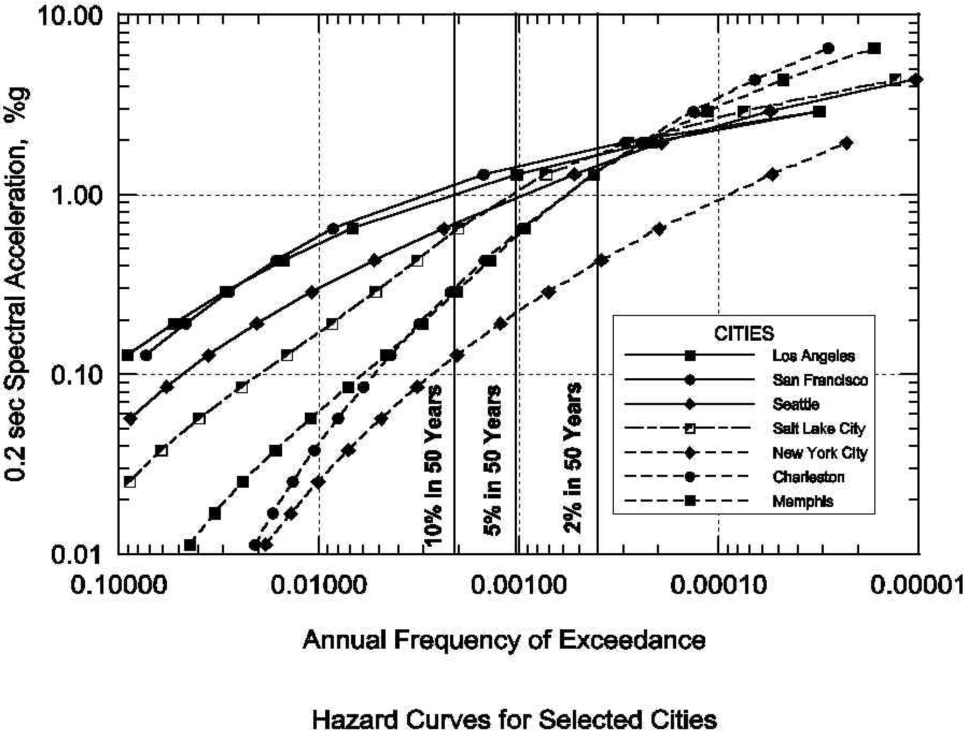

Figure 1 Hazard Curves for Selected Cities (NEHRP 1997)

2.3 Central and Southeast United States

Beginning in December 1811 and for the next year, a succession of earthquakes occurred in the central Mississippi Valley “New Madrid” region, which includes southeastern Missouri, northeastern Arkansas, and western Kentucky and Tennessee. According to Myron L. Fuller, author of *The New Madrid Earthquake, a Scientific Field Account* (Fuller, 1912), “These shocks have not been surpassed or even equaled for number, continuance of disturbance, are affected, and severity by the more recent and better known shocks at Charleston and San Francisco.” The 1811-12 events caused ground motions equivqalent to MMI VI as far away as northern Illinois, mid-Georgia, and central Ohio. Because the New Madrid region was relatively unsettled at the time, damage was low and events received little attention in the common history of the region. However, hazards and seismological studies in the past two decades have confirmed the great magnitude of these events and the potential for a repeat event, albeit of low probability. As if the ground motion of the 1811-12 New Madrid events alone are not sufficient reason for comprehensive seismic design requirements in the Central US, the extent of soil liquefaction was staggering. Work by M.L. Fuller in the early 1900s shows that in the 1811-12 New Madrid events, liquefaction was pervasive in a zone extending from Memphis 150 km to the north, and over a width of 50 to 60 km. Extensive ground fissuring (up to 8 km in length), ejection of sand and water, settlement, and landslides were common in this zone (Wesnousky, 1989).

Early recognition by building authorities of the seismic hazard in the New Madrid region came from the Memphis Building Code Advisory Board in 1965 (Howe, 1989). However, the Board had little to draw upon but the high-hazard practices of the West Coast. With the development of the ATC-3-06 Tentative Provisions in 1978 (ATC, 1978), a national view of seismic hazard and design advanced that was useful for application in the Central US, but West Coast vs. Central and Eastern US practice remained. For example, it was in the late 1970s well known that in many regions of California, the design seismic hazard maps were “truncated” at 0.4g. Enhanced ductility provisions were relied upon to cover any shortfall created by truncation. In the balance of the country, including the Central US, however, the design maps were not truncated, and, hence, code developers assumed that some indeterminately lower level of ductility would suffice. Such West Coast vs. elsewhere issues served to confuse and delay the adoption of seismic provisions in Memphis and other parts of the Central and Eastern US (Howe, 1989).

Charleston was shaken by a devastating event in 1886 resulting in 60 deaths and estimated damage (in 1886 terms) exceeding $5 million (Lindbergh, 1986). As in Memphis, the 1886 event caused widespread liquefaction. In fact, research by Obermeier et al. indicates that at least three liquefaction-inducing earthquakes have taken place within the past 7200 years near Charleston (Obermeier, 1989).

Proponents of seismic design in the Charleston area recognized the political sensitivity of such provisions and recommended two important strategies for dealing with the problem:

(1)Educate building officials and other stakeholders about seismic hazard and risk mitigation.

(2)Focus first on the highest priorities: schools and essential facilities (Lindberg, 1986).

Again, the absence of large events since has produced some complacency about the urgency of seismic hazard in the Charleston area, which has lead to resistance to recognition of the true hazards in local building codes.

2.4 General Considerations

A number of probabilistic seismic hazards assessments developed for sites in the Northeast US, and other moderate seismic zones, led to a number of other observations. The estimated ground motion parameters, either spectral accelerations or velocities, for increasing average return periods, maintained a steeper slope in the moderate than in the higher seismic zones. This difference in “marginal hazard” or “exceedence ratio” (Nordenson 1986, Reaveley & Nordenson, 1990*)* implies that buildings designed in each region in terms of the same return period or percent probably of exceedence over a given time period would not provide the same level of safety (see Table 1 and Figure 1)

Table 1 - Ratio of Spectral Acceleration at 0.2 Seconds for 2%/50 yr Hazard to 10%/50 yr Hazard

Los Angeles	1.7
San Francisco	1.7
New York City	3.3
Charleston	5.0
Memphis	5.1

An important implication of this idea of marginal hazard is that the prevailing notion embodied in the materials design provisions of building codes prior to the 1990s, that less ductility is required in regions lower seismically, is mistaken. In fact, the marginal hazard characteristic of moderate seismic zones dictates that greater ductility and energy-dissipating capacity should be required of structures designed for forces corresponding to 10%/50 yr hazards.

2.5 Wind vs Seismic Resistance

When considering the introduction of a seismic code in moderate seismic zones, the question arises whether the requirements for wind resistance, especially for tall buildings, can provide adequate earthquake resistance. As part of a study of the impact of the ATC 3-06 guidelines (ATC, 1978), and in a study sponsored by BSSC (Nordenson, 1984), an approach was proposed for comparing wind and seismic resistance, based on the building density. A building of height H, and depth parallel to the wind D will have a total wind base shear W equal to

$$W = p\ H\ D \qquad (1)$$

in units of force per unit building width, where p is the average wind pressure. The seismic base shear E would be equal to

$$E = C\ \rho\ H\ D \qquad (2)$$

per unit building width, where D is the building depth, or dimension parallel to the wind direction and C is the seismic coefficient including zone, soil, structural system “ductility” and dynamic response factors. ρ is the average building density. C relates to the building period which can be calculated approximately as

$$T = C_t\ H^{3/4}$$

Ct is an empirical coefficient between 0.02 and 0.03. In general, building density ranges from 10-15 pounds per cubic floor (pcf) for steel structures to 20-25 pcf for masonry and concrete structures. Combining equations (2) and (1), one may express the earthquake demand, E, as a function of wind resistance, W:

$$E/W = C\,\rho\,D/p \quad (3)$$

For many structures in the Central and Eastern US, $E/W \leq 1.0$. For others E/W >> 1.0 It is clear from equation (3) that heavier, deeper structures designed for relatively low wind pressures will be more at risk to earthquake damage than other structures. When considering older buildings, especially pre-World War II, it is also important to remember that many were built without a complete lateral load resisting system in the "longitudinal" direction but instead relied on the infill masonry to stiffen the semi-rigid frames against the small wind loads acting on the narrow face of the building. This asymmetry is of course detrimental to seismic resistance.

3 CURRENT ASSESSMENT OF SEISMIC HAZARD

The most recent developments in seismic hazard assessment for MSZ's are discussed elsewhere in this issue. The 1997 NEHRP Provisions have incorporated a radical revision to the hazards assessments that are based on the Building Seismic Safety Council Project '97 mapping project. As part of Project '97, the United States Geological Survey (USGS) prepared new seismic hazard maps that are a radical departure in objective and method from previous natural hazards assessments. Two notable features of this new hazards assessment are (1) the mapping of spectral values at 0.2 and 1.0 second, and (2) the use of 2%/50 yr hazard levels, rather than the previous 10%/50 yr values. In the 1997 NEHRP Provisions (which will follow in the IBC 2000 Provisions), 2%/50 yr values will be multiplied by two-thirds to recognize the margin against collapse inherent in current design procedures. The base shears resulting from 2/3 x (2%/50 yr values) are about equivalent to the 10%/50 yr values in areas of high seismicity, but as much as 100 to 200 % greater in areas of low to moderate seismicity. Thus the seismic risk posed by large, rare events in areas of low-to-moderate seismicity is beginning to be recognized. The effect of this on seismic risk is discussed in the next section.

4 SEISMIC RISK

4.1 General Considerations of Risk

As opposed to the Western US, the seismicity of the Central and Eastern US (CEUS) is characterized by rare, damaging earthquakes. Frequently occurring events (around M=4.5) damage only the most fragile structures. Studies of the cost of building seismic resistance into structures in the Northeast and the benefits to be derived therefrom generally show that the increased cost of seismic resistance is not justified on the basis of economic considerations, but that life safety is the key objective. When one considers risk as the product of hazard and vulnerability, it is vulnerability of structures to the rare, damaging events that drives seismic design in the CEUS. Over the last several years there has been considerable debate over whether design ground motions with a 10% probability of exceedence in 50 years provides adequate protection against life safety when much larger events are reasonably foreseeable at lower risk levels (say 2% in 50 years). This has resulted, as mentioned above, in the adoption in the 1997 NEHRP Provisions of a basic design ground motion that is 2/3 of the 2% in 50 year ground motion. The impact of this on seismic performance in the CEUS is discussed in the section below.

4.2 Consideration of Total Hazard

Drawing on the Commentary of the NEHRP provisions, the total seismic risk can be assessed by integrating the product of hazard and vulnerability to obtain an annual probability of failure as follows:

$$f = \int P[F|a]\,\frac{d\gamma}{d\,a}\,d\,a$$

where:

f = annual probability of failure

$P[F|a]$ = conditional probability of failure, given a spectral acceleration, a

d a = annual rate at which intensities of shaking are exceeded, i.e., the slope of the hazard curve

With this method, the contribution of total seismic hazard to risk of failure is obtained.

Using hazard curves developed by USGS for Project ’97 and published on the Web and using generic fragility curves from a number of sources (Anagnos et al., 1995; EERI, 1993; ATC, 1985) we performed such integrations for ten geographic locations in the US for two scenarios: (1) design spectral acceleration based on a 10% in 50 year probability and (2) design spectral acceleration based on two-thirds of the 2% in 50 year probability. The former represents the basis of most of the national codes up to the present. The latter represents the approach taken by the 1997 NEHRP provisions as described above. The results for the 10%/50 year and 2/3 x 2%/50 year bases respectively, indicate that anchoring the design seismic hazard at 10% in 50 years results in significant disparity: areas of low-to-moderate seismicity are at considerably more risk than areas of high seismicity, while the newer approach provides a better balance of risk across geographic areas.

5 CURRENT SEISMIC CODES FOR MSZ’S

5.1 Massachusetts State Building Code and THE BOCA Code

Massachusetts was the first eastern state to adopt specially developed seismic design provisions. The provisions, first published in 1975, were slightly modified over the next five years, but essentially remained unchanged for 17 years. They were based, in part, on the provisions of the 1973 Uniform Building Code (UBC) with modifications to reflect local knowledge and concerns.

These provisions represented the recommendations of an ad-hoc committee jointly appointed by the Boston Society of Civil Engineers and the Massachusetts Section of the American Society of Civil Engineers in July 1973. The committee considered the results of seismic risk and cost-benefit analyses previously conducted as part of the Seismic Design Decision Analysis project at M.I.T. The primary finding of these studies was that the probable maximum earthquake intensities for Massachusetts were as large as those for UBC Zone 3 in California, but had much longer return periods (lower hazard levels). The cost-benefit analyses suggested that the protection of life safety could best be achieved for new construction at minimal incremental cost by comprehensive ductility requirements rather than by requirements for large lateral resistance.

In fact, the stated purpose of the original seismic design provisions of the MSBC was “to protect life safety by limiting structural failure” (MSBC, 1925). This contrasted with the intent of the UBC provisions embodied in the SEAOC Recommendations at that time, which was to “resist minor earthquakes without damage; to resist moderate earthquakes without structural damage, but with some nonstructural damage; and to resist major earthquakes without collapse, but with some structural as well as nonstructural damage” (SEAOC, 1973). The seismic provisions developed for Massachusetts were intended solely to protect life safety and not to reduce expected damage. This recognized the low probability of occurrence of damaging earthquakes in Massachusetts and the economic impracticality of providing improved asset protection in new construction.

The seismic studies defined a nominal design earthquake with a peak ground acceleration on firm soil of 0.12 g (acceleration of gravity), corresponding to an epicentral intensity of between MM VII and MM VIII. In 1975, the return period for this nominal earthquake was estimated to be approximately 5,000 years, with bounds of 2,000 years and 10,000 years reflecting the uncertainty in seismic risk. The adoption of a zone factor of 1/3 in the 1973 UBC base shear formulation along with special design requirements to ensure ductility and specific foundation design requirements formed the basis of the 1975 MSBC seismic provisions.

5.1.1 Detailing Requirements

Seismic detailing provisions in the MSBC are in some cases more stringent or at least different from the corresponding provisions in 1993 BOCA. The primary reason is not to weaken the detailing requirements of previous editions of the MSBC for similar structural systems and to recognize the damaging potential of large, rare events.

Specifically, earlier editions of the MSBC had detailing provisions for a single type of concrete moment frame, which were similar but not identical to the provisions for intermediate moment frames of reinforced concrete in the 1993 BOCA. Therefore, the detailing requirements for intermediate moment frames of reinforced concrete in the latest MSBC are slightly more stringent than those in the 1993 BOCA to be consistent with earlier editions of the MSBC. Detailing requirements for special moment frames of reinforced concrete in the latest MSBC follow those in 1993 BOCA.

The MSBC requirements for minimum reinforcement for masonry bearing walls, interior partitions, exterior walls, parapets, chimneys, and nonstructural partitions enclosing stairwells, exits, and elevator shafts for both Seismic Performance Categories C and D differ from those in 1993 BOCA. Generally, the requirements are greater or equal to those in 1993 BOCA and are consistent with earlier editions of the MSBC.

The seismic design provisions in the MSBC for steel moment resisting frames reflect the experience gained from the performance of special moment resisting steel frames in the 1994 Northridge, CA earthquake. During the development of the latest MSBC, “Interim Guidelines: Evaluation, Repair, Modification and Design of Steel Moment Frame Structures” (FEMA, 1997) represented the current state of knowledge. Accordingly, the latest MSBC allows the use of ordinary steel moment resisting frames provided they are configured in accordance with Section 8, Commentary of AISC’s “Seismic Provisions for Structural Steel Buildings” (AISC, 1992). Additionally, special provisions require notch toughness of weld metal, removal of bottom flange backer bars, and fillet weld reinforcement of all full penetration welds.

5.2 The New York City Seismic Code

5.2.1 Background

The 1982 edition of ANSI A58.1, *Minimum Design Loads in Buildings and Other Structures* (ANSI, 1982) included a new seismic design section, modeled after the UBC and ATC 3-06, which placed New York City in Seismic Zone 2 (vs. 4 for California). This would, in turn, have triggered the application of the ductile design provisions of the ACI-318 code for concrete design. The New York City Building Commissioner asked the New York Association of Consulting Engineers (NYACE) to review the matter. The initial response, in the summer of 1984, was to recommend that such requirements be omitted. However, after some discussion, NYACE decided that a group of seismologists and engineers should review the issues and advise NYACE. The Committee’s conclusions have been reported in Section 2.1 above. Following this, the NYACE Board unanimously recommended to the Commissioner, in June 1987, that seismic design be mandated in New York City, and that these should follow the 1988 UBC (UBC, 1988).

At the same time (1986), the National Center for Earthquake Engineering Research (NCEER) was established in Buffalo, New York. Several conferences were organized as a result (Jacob and Turkstra, 1989) which addressed the particular issues of seismic hazard and design in the Eastern U.S. Following these, the Commissioner appointed, in April 1989, a Seismic Code Committee to draft seismic code provisions for New York City. This Committee included engineers, seismologists, and representatives of the building industries and real estate community. The Seismic Code Committee voted unanimously to submit its final report to the Commissioner in early 1991, and the report was submitted on 18 April 1991.

5.2.2 Principles and Approach

The development of the New York City Code was guided by several agreed principles:

- to focus on provisions for the prevention of life threatening collapse of buildings and components and not the protection of property *per se*
- to seek improvements, not radical changes in construction practices
- to modify the characterization of the loading to reflect local seismicity

The Committee divided its efforts into (1) Geotechnical (2) Loads and Systems (3) Detailing (4) Economic Implications, and (5) Nonstructural Subcommittees dealing with consideration. After several months deliberation, the Committee decided to adapt the 1988 UBC, following the above stated principles, for inclusion in the New York City Building Laws. NYC was deemed to be in Seismic Zone 2A with a factor, or effective zero-period acceleration of 0.15 in S_1 type rock. Building separation is limited to 1 inch for every 50 feet of total building height. Thus, a building 400 feet tall would, at the typical 120 foot zoning setback elevation, be separated by 8 inches from the adjacent building. The provision notes that “smaller separation may be permitted when the effects of pounding can be accommodated without collapse of the building.” This provision is intentionally empirical to reflect the uncertain knowledge of the effects of pounding on building collapse.

Mayor Rudolph Guiliani signed the New York City Seismic Code, known as Local Law 17, on 21 February 1995 to take effect a year from that day.

5.3 New Madrid Region

The New Madrid region includes the major metropolitan areas of Memphis, Tennessee and St Louis, Missouri. The coincidental confluence of three states in this region (Tennessee, Missouri, and Illinois) as well the region's central location in the US has lead to a variety of practices and approaches to code requirements, in general, and seismic design, in particular. Code enforcement for new construction is established at the local or county level, depending on jurisdiction, and, presently, all three national model (BOCA, SBBC, and UBC) codes have been adopted in some area of the New Madrid region.

In contrast to Massachusetts and the New York City, none of the jurisdictions in the New Madrid region, to the authors' knowledge, have developed their own seismic codes, but rather have adopted one of the national model codes, in total or with some modification. On urging of years' of organized effort by local engineers, the City of Memphis and Shelby County enacted their first seismic design requirements for new construction in 1992 by adopting the SBBC. But, resistance from developers, building owners, and structural engineers along with arguments that seismic design provisions *would double the cost of construction*, resulted compromise: the basic ground acceleration was reduced to two-thirds of the SBBC value. Today, the City of Memphis and Shelby County uses the current version of the SBBC without modification. As stated elsewhere in this paper, however, these requirements greatly underestimate the damage potential of large, rare events.

Following common practice in much of Missouri, the city of St Louis uses the 1997 UBC for seismic design.

5.4 Charleston, South Carolina and Vicinity

Engineers and seismologists in the Charleston area have long recognized that potential for large, rare events in their region, but recognition of this potential in code requirements has been a slow process. Charleston is generally governed by the SBBC, which, for many years, had optional seismic requirements in its appendix. These optional requirements were adopted only by special designation in local areas, and in Charleston such a special designation was made in June 23, 1981 through Bulletin No. 81-01. In 1991 engineers in the Southeast were successful in convincing SBBC to move these optional seismic provisions in the SBBC to the main body of the Code, thus making them mandatory unless specifically exempted by local authorities. Thus the City of Charleston adopted its first seismic design requirements.

Not satisfied that SBBC or any of the other national model codes properly recognized the damage potential of large, rare events in Charleston, local engineers pushed state and local agencies to modify the provisions of the SBBC to include updated hazard maps and/or two-level design. These efforts met with resistance as state and local authorities were unwilling to depart from national standards. Today, Charleston uses the current version of the SBBC.

In the metropolitan St. Louis area, seismic design for new construction became mandatory through the earthquake provisions of the 1987 BOCA Code. Smaller counties in the surrounding regions did not adopt seismic provisions until much later. While adopted by Code, actual implementation was variable from design office to office through the late 1980s and early 1990s. Today, seismic provisions in the region are dictated through the 1996 BOCA Code, and while execution has much improved since 1987, local engineers still report less than full compliance.

6 CONCLUSIONS

Design considerations for seismic resistance of buildings in areas of moderate seismicity are in many ways different than in areas of high seismicity. As most codes and earthquake design procedures have advanced through consideration of areas of high seismicity and by the strong leadership of professionals with high-seismicity experience, such codes have not readily been adaptable to areas of low-to-moderate seismicity, leading to some resistance to adoption of seismic design procedures. As a consequence, jursidictions like the City of New York and the Commonwealth of Massachusetts have prepared and adopted their own seismic design requirements. Other regions of the Central and Eastern US (CEUS) adopted one of the national model codes with or without modification but more slowly than areas that prepared region-specific codes. Some of the special considerations for areas of moderate seismicity compared to high seismicity are:

- The large magnitudes of rare events (2% probabilities in 50 years) as compared to the typical design basis ground motions used in most present national model codes of 10% in 50 years. Specialized seismic codes, such as those developed for New York City and Massachusetts, have addressed this by maintaining relatively conservative design ground accelerations. The 1997 NEHRP Provisions and the IBC 2000 address this through the adoption of design spectra corresponding to 2%-in-50-year hazards.

- Attenuation of earthshaking is generally different in the CEUS than the western US. In fact, in the CEUS, the "felt areas" of moderate events have been quite large, up to one million square miles. This difference in attenuation was recognized in the recent USGS national hazards mapping project.
- There is no defensible rationale for allowing new structures in moderate seismicity to have less ductility than structures in regions of high seismicity when using design accelerations based on 10%/50 year hazards. On the contrary, the large magnitudes of the rare earthquakes in regions of moderate seismicity require even greater ductility.
- In many instances, good seismic resistance for new construction in areas of low to moderate seismicity can be obtained for small incremental costs in construction. In fact, the wind load requirements for many structures in these regions will frequently exceed the seismic base shear, requiring only the addition of details yielding ductility and toughness.
- Seismic sources and hazard are less readily defined in the low-to-moderate seismicity regions of the CEUS. This fact, coupled with the relatively low incremental construction cost to provide seismic resistance in areas of low-to-moderate seismicity, argues for more conservatism in these regions.
- The existing building stock in areas of low to moderate seismicity, most of which have not had the benefit of seismic design in their original construction, present tremendous seismic risk.

Recent efforts such as the 1997 USGS hazard mapping project, the 1997 NEHRP Provisions and the preparation of IBC 2000 will advance greatly the cause of a uniform and integrated national approach to seismic design across areas of low, moderate and high seismicity. The authors' recommendations for further advancement are given in Section 7 below.

7 FUTURE DEVELOPMENTS

We hope that future efforts by local groups will continue to advance some of the special issues in areas of low-to-moderate seismicity and that ongoing national efforts will integrate these efforts with a uniform and consistent national practice. Future directions should include:

- The ability to more readily achieve seismic resistance in areas of low to moderate seismicity by limited tradeoff between force and ductility, allowing the designer to optimize the cost/benefit relationship.
- Improved provisions for assessment of existing buildings and the ability to maintain and improve existing buildings without undue economic hardship that would make saving or improving existing buildings cost prohibitive.
- The advancement and codification of progressive design and analysis techniques, such as non-linear static procedures.
- The adoption of the great improvements in seismic design philosophy and procedures in the 1997 NEHRP provisions and the IBC 2000 should be adopted across the country.
- Increasing public awareness of the earthquake hazards and risks in areas of low to moderate siemicity is particularly challenging because of the long return periods of moderate to large events. Ongoing efforts to ensure timely codification of good seismic design procedures as well as emergency preparedness are essential. We can use the silver linings of such tragedies as have occurred in Turkey, Greece and Taiwan in 1999 to heighten such awareness.

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9 REFERENCES

American Institute of Steel Construction, Inc. (AISC), 1992, Seismic Provisions for Structural Steel Buildings, Chicago, 146 pp.

American National Standards Institute (ANSI), 1982, Minimum Design Loads for Buildings and Other Structures, A58.1-1982, New York.

Anagnos, T., Rojahn, C., and Kiremidjian, A.S., 1995, NCEER-ATC Joint Study on Fragility of Buildings, NCEER-95-0003, Buffalo, New York.

Applied Technology Council (ATC), 1978, Tentative Provisions for the Development of Seismic Regulations for Buildings, ATC 3-06, ATC, California, 505 pp.

ATC, 1978, Tentative Provisions for the Development of Seismic Regulations for Buildings, ATC 3-06, US Government Printing Office, Washington, DC.

ATC, 1985, Earthquake Damage Evaluation Data for California, ATC-13, ATC, California, 492 pp.

Earthquake Engineering Research Institute (EERI) Ad Hoc Committee on Seismic Performance, 1993, Expected Seismic Performance of Buildings, Unpublished draft report.

Executive Order 12941, 1994, Seismic Safety of Existing Federally Owned or Leased Buildings.

Federal Emergency Management Agency (FEMA), 1997, Interim Guidelines: Evaluation, Repair, Modification and Design of Welded Steel Moment Frame Structures, FEMA 267 and 267A, SAC Joint Venture, California.

Freeman, J.F., 1932, Earthquake Damage and Earthquake Insurance, McGraw-Hill, New York.

Fuller, Myron L., 1912, The New Madrid Earthquake, WashingtonGovernment Printing Office, 119 pp.

Howe, W., 1989, Seismic Building Code Efforts in the Central United States, Earthquake Hazards and the Design of Constructed Facilities in the Eastern United States, Annals of the New York Academy of Sciences, Volume 558, New York, New York.

Jacob, Klaus H., and Turkstra, Carl J., eds., 1989, Earthquake Hazards and the Design of Constructed Facilities in the Eastern United States, Annals of the New York Academy of Sciences, 558, New York, 457 pp.

Lindbergh, Charles, ed., 1986, Earthquake Hazards, Risk, and Mitigation in South Carolina and the Southeastern United States, The South Carolina Seismic Safety Consortium, Charleston, South Carolina, 207 pp.

Massachusetts State Building Code, 1975, Commonwealth of Massachusetts, 2nd edition.

Nordenson, GJP 1984, BSSC Trial Design Program - Buildings NY-5, NY-20A and NY-32, Weidlinger Associates Report to the National Institute of Building Science and Building Seismic Safety Council No 182-016, ATC-3-06 Trial Design Program, NY

Nordenson, GJP and CT Statton, 1986, Seismicity and Seismic Hazard in the New York City Area, Proceedings 3rd US National Conference on Earthquake Engineering Charleston SC

Nordenson, GJP, 1987, Seismic Hazard Evaluation for New York City, Report of the NY Association of Consulting Engineers Ad-hoc Seismology Committee, New York

Nordenson, GJP and LD Reaveley, 1990, ‘Acceptable Damage in Low and Moderate Seismic Zones, Applied Technology Council ATC 15-3, 4th US-Japan Workshop on the Improvement of Building Structural Design Practices, Kailua-Kona HI Aug 1990

Nuclear Regulatory Commission, 1983, Division of Engineering Geosciences Plan to Address USGS Clarification Relating to Seismic Design Earthquakes in the Eastern Seaboard of the United States, Memorandum from Richard H Vollmer to Harold R Denton

Obermeier, S.F., Weems, R.E., Jacobson, R.B., and Gohn, G.S., 1989, Liquefaction Evidence for Repeated Holocene Earthquakes in the Coastal Region of South Carolina, Earthquakes Hazards and the Design of Constructed Facilities in the Eastern United States, Annals of the New York Academy of Sciences, Volume 558, New York, New York.

Seismology Committee Structural Engineers Association of California (SEAOC), 1973, Recommended Lateral Force Requirements and Commentary, California, 146 pp.

Uniform Building Code (UBC), 1988, International Conference of Building Materials, Whittier, California, 926 pp.

Uniform Building Code (UBC), 1997, International Conference of Building Materials, 2, Whittier, California, 492 pp.

Uniform Building Code (UBC), 1973, International Conference of Building Officials, Whittier, California, 704 pp.

Wesnousky, S.G., Schweig, E.S., and Pezzopane, S.K., 1989, Extent and Character of Soil Liquefaction during the 1811-12 New Madrid Earthquakes, Earthquake Hazards and the Design of Constructed Facilities in the Eastern United States, Annals of the New York Academy of Sciences, Volume 558, New York, New York.