DEVELOPMENT OF THE 1997 UPDATE OF THE RECOMMENDED PROVISIONS FOR THE SEISMIC REGULATIONS OF NEW BUILDINGS

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ABSTRACT

As part of its responsibility under the National Earthquake Hazards Reduction Program (NEHRP), the Federal Emergency Management Agency (FEMA) has made a commitment to sponsor the activities necessary to improve technical quality in the field of earthquake engineering in accordance with the National Earthquake Hazards Reduction Act of 1977 (PL94-125), as amended. One of the key methods of accomplishing this goal has been the establishment of an ongoing process to develop, update, and maintain the *NEHRP Recommended Provisions for the Development of Seismic Regulations for New Buildings* through contracts with the Building Seismic Safety Council (BSSC).

The *NEHRP Recommended Provisions* are being updated in 1997, and one of the most critical issues involves the development of new seismic hazard maps and an appropriate design procedure based on those maps. To resolve this issue, the BSSC has proposed what it refers to as Project '97, a joint effort between BSSC, FEMA and the U. S. Geological Survey (USGS). The BSSC role in this project involves the development of a seismic design map and procedure based on, but separate from, the USGS seismic hazard maps being developed.

The BSSC has appointed a 15-member Seismic Design Procedure Group (SDPG) to develop the seismic design map and procedure. Unlike the current design map and procedure, which uses the outdated effective peak velocity and effective peak acceleration ground motion maps which had their origin in a 1976 USGS peak acceleration map, the revised design map and procedure will be based on the USGS spectral response maps presently being developed.

A status of technical issues related to the development of the design maps and procedure for the 1997 *Provisions* in low seismicity regions (eastern United States) is discussed below.

KEYWORDS

Seismic, regulations, hazard, risk, design, Project '97

INTRODUCTION

The primary goals of the Building Seismic Safety Council (BSSC) Project '97 are as follows:

- to develop national seismic hazard maps that represent a consensus baseline for seismic hazard definition throughout the United States (U.S.) and
- to develop national seismic risk design values for use as consensus input for the 1997 update of the National Earthquake Hazards Reduction Program (NEHRP) *Recommended Provisions for the Development of Seismic Regulations for New Buildings* (BSSC, 1994) using the seismic hazard maps as the baseline.

The main purpose of this paper is to discuss the effort to develop the national seismic risk design values for use in the *NEHRP Recommended Provisions* with emphasis on the low seismicity regions (eastern U.S.) This paper provides information about the (1) background of BSSC Project '97, (2) establishment of the Seismic Design Procedure Group (SDPG), (3) purpose of the NEHRP *Recommended Provisions*, (4) structural issues being considered, (5) recommended mapping parameters, (6) development of the design spectral response map, and (7) development of the seismic design procedure.

BACKGROUND OF BSSC PROJECT '97

As part of its responsibility under NEHRP, the Federal Emergency Management Agency (FEMA) has made a commitment to sponsor the activities necessary to improve technical quality in the field of earthquake engineering in accordance with the National Earthquake Hazards Reduction Act of 1977 (PL 94-125), as amended. One of the key methods of accomplishing this goal has been the establishment of an ongoing process to develop, update, and maintain the *NEHRP Recommended Provisions for the Development of Seismic Regulations for New Buildings* through contracts with the BSSC.

The *NEHRP Recommended Provisions* and its related *Commentary* and maps present criteria for the design and construction of new buildings subject to earthquake ground motions. The purposes of these resource documents are to minimize the risk to life for all buildings, to increase the expected performance of higher occupancy structures, and to improve the capability of essential facilities to function during and after an earthquake. The *NEHRP Recommended Provisions* provide the minimum level design requirements considered to be prudent and economically justifiable for the protection of life safety in buildings subject to earthquakes anywhere in the United States.

The *NEHRP Recommended Provisions* has succeeded in meeting its original goals of becoming a resource document that is widely used by practicing design professionals and building officials. The techniques and technologies contained in this resource document are diffusing widely into the three model building codes used in the United States and several national standards. Specifically, in 1992, both the Building Officials and Code Administrators International (BOCA) *National Building Code* and the Southern Building Code Congress International (SBCCI) *Standard Building Code* adopted seismic requirements directly based on the *NEHRP Recommended Provisions.* The International Conference on Building Officials (ICBO) *Uniform Building Code* has contained seismic requirements for many years but recently changes have been and continue to be made that bring it closer to the *NEHRP Recommended Provisions.* Further, all three of the model building codes have been determined to be substantially equivalent to the *NEHRP Recommended Provisions* and now provide minimum design requirements that are tailored to the different seismic hazards present throughout the country.

Among the key reasons for the success of the *NEHRP Recommended Provisions* is that it has been developed using a consensus process and a planned periodic update cycle, which ensures continuing attention to unresolved problems from one update cycle to the next. Thus far, FEMA has agreed to a three-year *Provisions* update cycle in order to match the established cycle of the nation's model building codes. Without this three-year cycle, it is likely that the *NEHRP Recommended Provisions* would lose its consensus backing. The result would be that the *NEHRP Recommended Provisions* would not remain within the model codes and would no longer be used in the same broad manner it is today.

With regard to the 1997 update of the *NEHRP Recommended Provisions*, one of the most critical issues involves the development of new seismic hazard maps and an appropriate design procedure based on those maps. To resolve this issue, the BSSC has developed Project '97, a joint effort between BSSC, FEMA and the U. S. Geological Survey (USGS). As part of its participation in Project '97 the USGS is developing revised seismic hazard maps. During Project '97, the USGS will address current ground motion issues using public forums and resolve the ground motion issues in an appropriate manner. The BSSC role in this project involves the development of a seismic design map and procedure for use by engineers and architects based on, but separate from, the USGS seismic hazard maps. A Seismic Design Procedure Group (SDPG) has been formed to develop the seismic design map and procedure using the USGS maps. The BSSC also will ensure that the process used to develop the procedure involves a mechanism to provide for public input, and the resulting procedure will be submitted to the BSSC consensus procedure.

The overall goal of Project '97 is to replace the present 20+ year old maps that all acknowledge are out-of-date. To do that, it is necessary to improve both the maps and the public's perception of the maps.

The BSSC, with input from FEMA and USGS, has appointed a 5-member Management Committee (MC) to guide conduct of Project '97. The MC membership is geographically balanced insofar as practicable and has two seismic hazard definition experts and three engineering design experts, including the chairman of the BSSC 1997 Provisions Update Committee (PUC). The MC established a Resource Group (RG) consisting of interested members from the design, construction, and earth science communities. Resource group membership includes representatives of at least the following organizations and agencies: Applied Technology Council, Building Officials and Code Administrators International, Center for Earthquake Research and Information, Earthquake Engineering Research Center, FEMA, International Conference of Building Officials, National Center for Earthquake Engineering Research, National Institute of Standards and Technology, National Science Foundation, Southern Building Code Congress International, relevant Structural Engineers Associations (i.e. California, Illinois, Washington), and USGS.

SEISMIC DESIGN PROCEDURE GROUP

The SDPG membership consists of 15 appointed individuals, with input from FEMA, USGS, Management Committee, and the Resource Group. The membership is composed of representatives of different segments of the design community as well as two earth science members designated by the USGS, and the membership is representative of the different geographical regions of the country. The SDPG is working closely with the USGS in defining their mapping needs and to understand how the maps should be used for design purposes.

The goals of the SDPG are as follows:

1. To replace the existing effective peak velocity and acceleration design maps with a new design spectral response map using the USGS spectral response hazard maps.

2. To develop the new design map staying within the existing framework of the *Provisions* with emphasis on equal risk versus the existing equal hazard approach.

3. To develop a design procedure for use with the new design spectral response map.

PURPOSE OF THE NEHRP RECOMMENDED PROVISIONS

The purpose of the *NEHRP Recommended Provisions* is to present criteria for the design and construction of new buildings subject to earthquake ground motions in order to minimize the risk to life for all buildings, to increase the expected performance of higher occupancy structures as compared to ordinary structures, and to improve the capability of essential facilities to function after an earthquake. To this end, the *Provisions* provides the minimum criteria considered prudent and economically justified for the protection of life safety in buildings subject to earthquakes at any location in the United States.

The *Provisions* document generally considers property damage as it relates to occupant safety for ordinary buildings. For high occupancy and essential facilities, damage limitation criteria are more strict in order to better provide for the safety of occupants and the continued functioning of the facility.

Some structural and nonstructural damage can be expected as a result of the "design ground motions" because the *Provisions* allow inelastic energy dissipation by utilizing the deformability of the structural system. For ground motions in excess of the design levels, the intent is that there be a low likelihood of collapse.

The existing *Provisions* are based on design earthquake grounds with an estimated 90 percent probability of not being exceeded in a 50-year period (10% chance of being exceeded in 50 years). However, it is recognized that larger earthquakes are possible and may occur during the life of a structure. In some areas such as coastal California (areas near active known faults with high seismicity), the difference between the design earthquake (DE) and the "maximum capable" earthquake (MCE) is not significantly different, but this is not true in many other earthquake-prone parts of the U. S. (areas with moderate/low seismicity where known fault sources are not defined, such as the eastern U. S.). In the eastern U.S., the MCE ground motions often may be two or more times larger than the DE based on a 10% chance of being exceeded in 50 years. This significant difference in ground motion in the eastern U. S. warrants consideration of a larger DE in order to meet the intent of having a low likelihood of collapse, and to provide a more equal risk against collapse in all areas of the U. S.

STRUCTURAL ISSUES

Based on the above purpose of the *Provisions,* a brief summary of the structural issues being considered by the SDPG are as follows:

1. Mapping Parameters-This issue pertains to what ground motion parameters the structural engineer would prefer to use in the seismic design procedure, i.e., peak ground acceleration, peak spectral acceleration, etc. The present *Provisions* use effective peak acceleration and velocity.
2. Equal Hazard/Equal Risk - Presently, the existing policy in the provisions is to obtain equal hazard by using the mapped values representing the 10 % chance of exceedence in 50 years. Since the hazard curves are different for regions located near known active faults, from those of other regions, equal risk might not be achieved using the existing provisions.
3. Probabilistic/Deterministic-These issues are closely related to the equal hazard/equal risk and mapping parameters issues. The question is, whether probabilistic-based maps, or deterministic- based maps, or some combination of probabilistic and deterministic maps should be used to obtain design values.
4. Performance Criteria-The existing performance criteria in the provisions is primarily to ensure occupant safety, although in some situations continued functioning of certain buildings are addressed. The issue is whether to continue with the existing criteria, or to develop other performance criteria. The work by other groups, plus the short time which the SDPG has to develop the seismic design procedure dictates that the existing performance criteria be the framework for the SDPG's work for the 1997 Provisions.
5. Detailing Requirements - The existing provisions provide triggers (based on effective peak acceleration and velocity) to define the detailing requirements. The higher the values, the more detailing is required.

The SDPG is recommending that detailing requirements should be the same independent of the earthquake ground motion.

6. Ceilings (Upper bound values) - The existing and proposed maps predict high ground motion values close to the known active faults capable of generating large magnitude earthquakes. The issue is how to address these high values in the design process and remain economical. The existing provisions use a ceiling of an "effective" peak ground acceleration of 0.4G and emphasize detailing requirements. The justification provided in the provisions is that these high ground motion values do not contain enough energy to damage structures because of a short duration, and that requiring more detailing is more cost-effective than designing for higher forces.
7. Floors (Lower bound values) - The specific values of the floors should consider the technical, economic, and political aspects. Technically, the existing provisions provide a lower bound, since they are defined as minimum requirements, but there could be economic reasons to design for a larger value when the cost differential is insignificant, or because there is a large uncertainty in the mapped values.
8. Uncertainty - The uncertainty in both the mapped values and the structural design needs to be considered in developing the overall seismic design procedure.
9. Near Field - Special requirements may be needed in the near field areas close to a known active fault capable of generating large magnitude earthquakes. To address this issue the near field distance and the faults need to be defined.
10. Earthquake Experience - These issues are self-explanatory and could affect all the issues discussed above. For example, what does earthquake experience indicate about buildings designed for ceilings and located in near field regions, what ground motion parameters cause damage, do the maps adequately predict recorded ground motion in recent earthquakes, etc.? The SDPG is reviewing the ground motion and structural damage in Kobe, Japan and Northridge, California to assist in defining the design map and procedure.

RECOMMENDATIONS FOR MAPPING PARAMETERS

The SDPG has requested the USGS to consider the following mapping parameters in developing their seismic hazard maps:

1. Probabilistic spectral maps for the 10% chance of exceedance in 50 years, 5% chance in 50 years and 2% chance in 50 years.
2. Probabilistic spectral maps be developed for the peak ground acceleration and spectral response acceleration at periods of 0.1, 0.2, 0.3, 0.4, 0.5, 1.0 and 2.0 seconds.
3. Deterministic spectral maps at certain locations along with the source zones, faults, magnitudes, and attenuation functions considered in developing the maps.
4. Probabilistic spectral maps for exceeding certain damage thresholds
5. Maps of dominant magnitude and distance
6. Definition of uncertainty for probabilistic and deterministic maps
7. Spectral maps for long period motions (at least to 4.0 seconds)

This mapping information is being used by the SDPG to develop the design spectral response map and the design procedure.

DEVELOPMENT OF DESIGN SPECTRAL RESPONSE MAP

The following is a summary of the approach which is currently being used to develop the design spectral response map. It is subject to change with the BSSC ballot process before inclusion in the *Provisions*.

To develop design spectral response maps using the USGS spectral maps, four regions are being considered. These regions are:

- Region DC -high seismicity near known fault sources
- Region P -high/moderate seismicity where known fault sources are not defined
- Region DF -low seismicity
- Region O -negligible seismicity; very low probability of damage

The bases for defining these regions are the differences in fault source and seismicity characteristics between the regions, and the recognition that these differences will impact how the design spectral response map is developed for each region.

The focus of this paper is on Region P, DF, and O, therefore, the approach being developed for Region DC is not presented.

As noted in the recommendations for mapping, both probabilistic and deterministic hazard maps are being considered to develop the design spectral response map. In Region P, the earthquake sources in general are large areal sources with undefined fault sources and maximum magnitude estimates. Based on this, probabilistic hazard maps are considered as the best means to represent the uncertainties and to define the design spectra for Region P. The next question then, is what probabilistic hazard map to use to define the design spectra. As discussed earlier, the purpose of the *Provisions* and the goal is to select a DE level such that when a building is designed to that level, occupant life safety is ensured, plus there is a low likelihood of collapse for ground motion in excess of the DE levels. Also one of the goals is to develop the maps to provide equal risk against collapse. Therefore, the approach being developed is to first determine the MCE level, and then based on the estimated margins in the structural design process determine the DE level.

The maximum earthquakes in Region P occur very infrequently and the annual probability of their associated ground motion is generally less than 1×10^{-4} (or a 0.5% chance of exceedance in 50 years). Defining the MCE from a deterministic estimate of the ground motion using a maximum earthquake in Region P or from a probabilistic estimate using annual probabilities less than 1×10^{-4} is not warranted due to such infrequent occurrences and less than a 0.5% chance of exceedance in 50 years. The earthquake levels from such infrequent events are similar to the earthquake levels used for design of critical facilities such as dams and nuclear power plants. The use of ground motions from such unlikely events would not be cost-beneficial for design of normal buildings.

Based on the above the MCE for Region P is defined as the ground motion with a 2% chance of exceedance in 50 years. This definition is based on the judgement that this is a reasonable MCE and is more consistent with the historical frequency of the largest earthquakes in Region P. Also the uncertainty in the ground motions begins to increase significantly and control the calculated ground nmotions with less than a 2% chance of exceedance in 50 years. Kennedy et al. (1994) indicates that the structural design process provides a margin of safety of about 2.0 beyond the annual exceedance probability of the seismic design event. Based on the hazard curves used by Kennedy et al. (1994), the change in ground motion, associated with the factor of 2.0 in annual exceedance probability, is about 1.5 . The 1.5 factor is estimated as a reasonable number to represent the margins in the structural design process of the *Provisions.* Therefore, the DE spectra will be determined by dividing the MCE spectra by 1.5.

The purpose of Region O is to recognize there are certain areas with negligible seismicity such that no earthquake design is necessary. Region O is being defined by (1) determining areas where the seismic hazard is controlled by earthquakes with $M_b \leq 5.5$ and (2) examining the recorded ground motions associated with Modified Mercalli V. The bases for the first premise is that in the eastern U. S., there are a number of examples of earthquakes with $M_b \approx 5.5$ which caused only localized damage in regions without seismic design. The basis for the second premise is that Modified Mercalli V ground motions do not cause structural damage. Examination of both premises results in a MCE of 0.25g in the short-period spectral response (T ≈ 0.3 second) and 0.10g in the long-period spectral response (T ≈ 1.0 second). Therefore Region O is defined as areas having ground motion with a 2% chance of exceedance in 50 years for the *Provisions* Soil Profile Type E equal to or less than 0.25g (short period) and 0.10g (long-period).

Region DF is a transition zone between Region O and Region P. The MCE for Region DF has been established as a minimum deterministic floor for which seismic design is considered meaningful (after reduction for the response modification factor, R). The MCE level has been tentatively defined as 0.50g for the short-period spectral response and 0.20g for the long-period spectral response. This results requiring a minimum base shear of about 0.05W to 0.025W (where W is the weight of the structure and R= 8.0). It is felt that designing for ground motions lower than this is not necessary or meaningful.

Based on the above the design map, for the moderate/low seismicity areas of the U. S., will be changed from an equal hazard map (10%chance of exceedance in 50 years) to an equal risk map. The DE from the equal risk map will be based on the MCE (2% chance of exceedance in 50 years) divided by 1.5.

DEVELOPMENT OS SEISMIC DESIGN PROCEDURE

The existing *Provisions* define the seismic base shear as a function of the outdated effective peak velocity and peak acceleration. It is recommended that the base shear be defined as a function of the DE spectral response as defined above for Region P and DF.

The base shear equation will be

$$V = \frac{S_a(1.0)}{RT^n} W \tag{1}$$

and not to exceed

$$V = \frac{S_a\,(short\text{-}period)}{R} W \tag{2}$$

where

where	S_a (1.0)	=	spectral acceleration for the 1.0 second period reflecting the appropriate soil profile modification
	R	=	response modification factor
	T	=	fundamental period of the building
	n	=	coefficient reflecting the shape of the design spectra
	S_a (short-period)	=	spectral acceleration for the short period reflecting the appropriate soil profile modification
	W	=	total dead load and applicable portions of other loads

The short period to be used has not been determined to date, but it is recognized that the short period motions occur at lower periods in Region P areas than in Region DC areas.

It is also recommended that changes in detailing requirements be made for use with the design spectra maps. The key changes are as follows:

1. Same detailing requirements are required in all seismic regions, unless different R values than those in the *Provisions* are justified.
2. For Region O, all floors and roofs shall be evaluated as horizontal diaphragms to transfer the wind or seismic forces generated on the walls to the lateral force resisting system. A minimum lateral seismic force will be specified (suggested as 0.01W) and compared to the lateral wind force to ensure a sufficient lateral force resisting system.

CONCLUSIONS

The recommendations being developed for the 1997 *Recommended Provisions* will result in changes for the moderate/low seismicity regions of the U. S. The major changes are as follows:

1. The design spectral response map will be based on achieving equal risk across the U. S. versus equal hazard.
2. The design spectral response map will be based on spectral response hazard maps versus effective peak velocity and acceleration.
3. The design spectral response map for the DE will be based on the ground motions for the MCE (2% chance of exceedance in 50 years) divided by 1.5.

$$DE = \frac{MCE}{1.5} \tag{3}$$

4. Detailing requirements will be improved for all areas.

REFERENCES

Building Seismic Safety Council (1994). NEHRP Recommended Provisions for Seismic Regulations for New Buildings, prepared by the Building Seismic Safety Council for the Federal Emergency Management Agency, Washington, D. C.

Kennedy, R. P. and Short, S. A., (1994). Basis for seismic provisions of DOE-STD-1020. UCRL-CR-111478.