0657

COMMENTS ON DESIGN EARTHQUAKE SPECIFIED IN THE 1997 NEHRP PROVISIONS

Howard HWANG[1]

SUMMARY

The design earthquake specified in the 1997 NEHRP Provisions for the design of buildings in the United States has been dramatically revised. This paper presents a few comments on this revision, using Memphis, Tennessee, as an example. In the 1997 NEHRP Provisions, the design earthquake is defined as 2/3 of the maximum considered earthquake, which corresponds to an earthquake with a probability of exceeding 2 percent in 50 years (a return period of about 2500 years) in the eastern United States. The use of an earthquake with a return period of 2500 years as the basis for the design of buildings has created several issues. The first is related to how safe is safe (acceptable risk). The second is the use of occupancy importance factors. The third is the great uncertainty in estimating ground motion with a long return period. The fourth is strength versus ductility in seismic resistant design. These issues have raised a doubt about the appropriateness of using an earthquake with a return period of 2500 years as the basis for the design of buildings in the eastern United States. It is recommended that the code committees should re-examine the approach used to define the design earthquake in the 1997 NEHRP Provisions. In the writer's opinion, buildings in the eastern United States should be designed for serviceability against a design earthquake with a short return period, which can be estimated with less uncertainty. Then, the buildings should be provided with sufficient ductility to resist large infrequent earthquakes.

INTRODUCTION

The NEHRP Recommended Provisions for Seismic Regulation of New Buildings and Other Structures is a document published by the Federal Emergency Management Agency (FEMA) as a result of a FEMA-sponsored effort to improve the seismic performance of new structures in the United States. It is intended to serve as a resource document for implementing seismic design criteria in model building codes. The NEHRP Provisions is updated every three years. In the 1997 NEHRP Provisions [1], the specification of the design earthquake has been dramatically revised from earlier editions. This paper presents a few comments on this revision, using Memphis, Tennessee, as an example.

SPECIFICATION OF THE DESIGN EARTHQUAKE

In the 1997 NEHRP Provisions, the maximum considered earthquake (MCE) is used as the basis to represent ground-shaking hazard in the United States. In the eastern United States, the MCE is defined as an earthquake with a probability of exceeding 2 percent in 50 years (a return period of about 2500 years). The design earthquake is then set as 2/3 of MCE. For a reference firm rock site in the Memphis area, the typical short period (0.2 sec) spectral acceleration value resulting from MCE is 1.25g, and the equivalent peak ground acceleration (PGA) value is 0.5g. Thus, the design ground motion for the Memphis area is 0.33g. According to the 1994 NEHRP Provisions, the design ground motion is 0.2g. Hence, the design earthquake specified in the 1997 NEHRP Provisions represents a 65 percent increase over the current design value. This dramatic increase

[1] *Center for Earthquake Research and Information, The University of Memphis, Memphis, USA, Email: hwang@ceri.memphis.edu*

was caused by the concern about large infrequent earthquakes that might occur in the eastern United States. An earthquake with a return period of 2500 years was selected by the code committees to represent large infrequent earthquakes. The ground-shaking hazard in a study area is usually expressed in terms of a seismic hazard curve, which displays the probability of exceedance versus a ground shaking parameter, for example, peak acceleration or spectral accelerations. The seismic hazard curves for various cities in the United States are different. Taken from the documentation of the U. S. National Seismic Hazard Maps [4], the seismic hazard curves for Memphis and San Francisco under a reference firm rock site condition are shown in Figure 1.

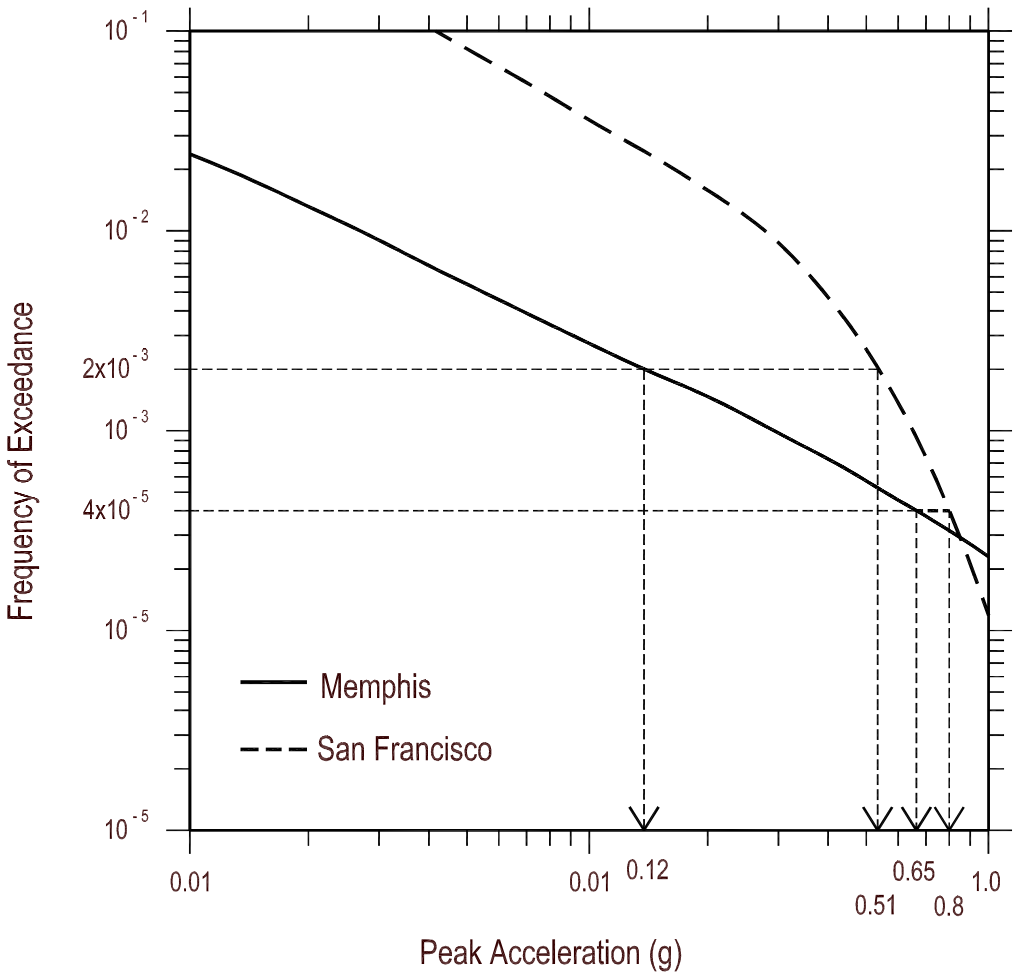

Figure 1: Comparison of Seismic Hazard Curves for Memphis and San Francisco

From these two seismic hazard curves, the peak acceleration (PA) values corresponding to two return periods for Memphis and San Francisco were determined and are shown in Table 1. For a 500-year return period, the expected ground motion in Memphis is only about one-quarter (24%) of that in San Francisco. However, for a 2500-year return period, the expected ground motion in Memphis is increased to about the same level (81%) of that in San Francisco.

Table 1. Comparison of Seismic Hazards in Memphis and San Francisco

Return Period (yrs)	PA (g)		
	Memphis (MEM)	San Francisco (SF)	MEM/SF
500	0.12	0.51	0.24
2500	0.65	0.80	0.81

From this comparison, it is clear that one ground motion level cannot be used to represent the entire range of seismic hazard. Ideally, the design of buildings should take the entire seismic hazard curve into consideration, as proposed in the life cycle design approach [6, 12]. In practice, the design earthquake is chosen at one particular level to expedite the design process. The selection of such a level needs to consider the risk level acceptable to a building owner and to a community.

ACCEPTABLE RISK LEVEL

The acceptable risk level in general can be established based on the usage of a building and the consequence of building failure in a seismic event. However, the determination of acceptable risk level involves not only science and engineering but also economics and social/cultural perception. At present, the acceptable risk level is not explicitly specified in the NEHRP Provisions or in most building codes. The only exception is the DOE Standard, Natural Phenomena Hazards Design and Evaluation Criteria for Department of Energy Facilities [3], issued by the U.S. Department of Energy (DOE). The performance goals and acceptable risk levels for various structures, systems, or components (SSC) specified in this DOE Standard are summarized in Table 2.

The DOE Standard also states that the design and evaluation criteria for structures in Performance Category 1 are similar to those for general facilities (ordinary buildings) in the Uniform Building Code (UBC). Thus, the DOE Standard implies that the acceptable risk level for the collapse of ordinary buildings is 10-3 per year. Other studies, for example Hwang and Hsu [6], also suggested the same acceptable risk level; that is, the probability of collapse of ordinary buildings is about 10-3 per year. If we agree with these studies, the maximum considered earthquake specified in the NEHRP Provisions does not need to be an earthquake with a return period more than 1000 years. In other words, it is not necessary to define an earthquake with a return period of 2500 years as the basis for the design of ordinary buildings.

Table 2. Performance Goals for Various Performance Categories

Performance Category	Performance Goal Description	Acceptable Annual Probability of Exceedance
1	Maintain occupant safety	10-3 of the onset of SSC damage to the extent that occupants are endangered
2	Occupant safety, continued operation with minimal interruption	5×10-4 of SSC damage to the extent that the component cannot perform its function
3	Occupant safety, continued operation, hazard confinement	10-4 of SSC damage to the extent that the component cannot perform its function
4	Occupant safety, continued operation, confidence of hazard confinement	10-5 of SSC damage to the extent that the component cannot perform its function

EFFECT OF OCCUPANCY IMPORTANCE FACTORS

In the 1997 NEHRP Provisions, the occupancy importance factors "I" are utilized in the design of buildings. Table 3 shows the occupancy importance factors assigned for various seismic use groups.

Table 3. Occupancy Importance Factors for Various Seismic Use Groups

Seismic Use Group	Buildings	Importance Factors
I	Ordinary	1.0
II	High Risk	1.25
III	Essential	1.5

For the design of a high risk building (seismic use group II) in the Memphis area, the design ground motion including the effect of the occupancy importance factor is 0.81g (1.25*0.65g). From Figure 1, the return period for such an earthquake is 3333 years. Similarly, the design ground motion including the effect of the occupancy importance factor for an essential building (seismic use group III) is 0.98g (1.5*0.65g) and the corresponding return period is 4717 years. Thus, the use of MCE with a return period of 2500 years and the occupancy importance factors will result in an unrealistically high acceleration value and a very long return period for the design of high risk buildings or essential buildings. With the use of occupancy importance factors in the design of buildings, the design earthquake can be specified based on an earthquake with a return period shorter than 2500 years.

UNCERTAINTY IN ESTIMATING GROUND MOTION WITH A LONG RETURN PERIOD

The ground motion intensity specified in the 1997 NEHRP Provisions was based on the 1996 national hazard maps prepared by the U.S. Geological Survey (USGS). From the deaggregation of seismic hazards in the Memphis area, it is revealed that the MCE ground motion is dominated by the characteristic earthquake assumed for the New Madrid fault. To produce the 1996 national hazard maps, an M 8 characteristic earthquake with a recurrence time of 1000 years was assumed for the New Madrid fault. This assumption involves significant uncertainties. First of all, the location and geometry of the New Madrid fault is not well defined, because no fault traces are observed on the ground surface. Crone [2] suggested that the New Madrid fault ends near Marked Tree, Arkansas. Extending the New Madrid fault beyond Marked Tree will substantially increase the ground shaking intensity estimated in the Memphis area. Next, the moment magnitude of 8.0 was chosen because it is approximately that of the larger events in the 1811-12 sequence as determined by Johnston [8]. Some researchers, for example Speidel [11], have suggested that the magnitude of characteristic earthquake is about 7 instead of 8. Furthermore, the recurrence time of 1000 years was derived from paleoliquefaction evidence of past earthquakes [10]. However, some researchers, for example Newman et al. [9], have suggested a much longer recurrence time.

It is well known that great uncertainty is involved in the estimation of ground motion with a long return period (e.g., 2500 years) in the eastern United States. Thus, it is not appropriate to use such an earthquake as a basis for the design of buildings. Since seismologists have more confidence in the estimation of ground motion from earthquakes with shorter return periods, it is more reasonable to use such an earthquake as the basis for defining the design earthquake.

STRENGTH VERSUS DUCTILITY

In the 1997 NEHRP Provisions, an earthquake with a return period of 2500 years is used as the basis for the design of buildings. As a result, the design base shear is greater than that determined by following the 1994

NEHRP Provisions. According to Hwang and Burr [7], the design base shear is increased up to three times the current value for several types of buildings affected by the New Madrid seismic zone. The increase of design base shear will require an increase in the member cross sections of a structure and hence an increase in the construction cost. The approach adopted in the 1997 NEHRP Provisions is basically to increase the strength instead of the ductility of a structure. Such an approach has been proved to be ineffective in the event of an earthquake. On the other hand, it is not difficult to provide ductility for structures in the eastern United States. Hwang and Hsu [5] have demonstrated that a reinforced concrete building designed with intermediate moment-resisting frames can provide sufficient seismic resistance during the service life of the structure.

CONCLUSIONS

This paper presents a few comments on the design earthquake specified in the 1997 NEHRP Provisions. Several issues related to the specification of the design earthquake have been discussed. The first is related to how safe is safe in the design of a building. The second is the use of occupancy importance factors. The third is the great uncertainty in estimating ground motion with a long return period. The fourth is strength versus ductility in seismic resistant design. These issues have raised a doubt about the appropriateness of using an earthquake with a return period of 2500 years as the basis for the design of buildings in the eastern United States. It is recommended that the code committees should re-examine the approach used to define the design earthquake in the 1997 NEHRP Provisions. In the writer’s opinion, buildings in the eastern United States should be designed for serviceability against a design earthquake with a short return period, which can be estimated with less uncertainty. Then, the buildings should be provided with sufficient ductility to resist large infrequent earthquakes.

REFERENCES

1. BSSC (1998), NEHRP Recommended Provisions for Seismic Regulations for New Buildings. 1997 edition, FEMA 302, Federal Emergency Management Agency, Washington, D.C.
2. Crone, A. J. (1998), “Defining the southwestern end of the Blytheville Arch, Northeastern Arkansas: delimiting a seismic source zone in the New Madrid region,” Seismological Research Letters, 69(4), 350-358.
3. DOE-STD-1020-94 (1996), Natural Phenomena Hazards Design and Evaluation Criteria for Department of Energy Facilities, U.S. Department of Energy, Washington, D.C.
4. Frankel, A., Mueller, C., Barnhard, T., Perkins, D., Leyendecker, E.V., Dickman, N., Hanson, S., and Hopper, M. (1996), National Seismic Hazard Maps, Documentation, Open-File Report 96-532, U.S. Geological Survey, Denver, CO.
5. Hwang, H. and Hsu, H.M. (1992), "Seismic performance of code-designed reinforced concrete frame structures," in Designing Concrete Structures for Serviceability and Safety, E.G. Nawy and A. Scanlon (eds.), SP-133, American Concrete Institute, 321-342.
6. Hwang, H. and Hsu, H.M. (1993), "Seismic LRFD criteria for RC moment-resisting frame buildings," Journal of Structural Engineering, ASCE, 119(6), 1807-1824.
7. Hwang, H. and Burr, B. (1998), “Comments on Seismic Design Criteria in the 1997 NEHRP Provisions,” in Abstracts for the ASCE Tennessee Section Annual Meeting, Nashville, TN.
8. Johnston, A. (1996), “Seismic moment assessment of earthquakes in stable continental regions – III, New Madrid, 1811-1812, Charleston, 1886, and Lisbon, 1775”, Geophysical Journal International, 126, 314-344.
9. Newman, A., Stein, S., Weber, J., Engeln, J., Mao, A., and Dixon, T. (1999), “Slow deformation and lower seismic hazard at the New Madrid seismic zone,” Science, 284, 619-621.
10. Schweig E.S. and Tuttle, M.P. (1999), “How often do large New Madrid earthquakes occur?” in Proceedings of Mid-America Highway Seismic Conference, St. Louis, MO.
11. Speidel, D.H. (1998), “Seismicity patterns and the characteristic earthquake in the Central Mississippi Valley, USA,” Engineering Geology, 50, 1-8.
12. Wen, Y. K. and Kang, J. K. (1998), "Minimum Life-Cycle Cost Design Criteria,” in Proceedings of the seventh International Conference on Structural Safety and Reliability (ICOSSAR’97), Kyoto, Japan, Nov. 24-28, 1997, II, 1047-1054.