Seismic Design Considerations in Model Codes

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Reinforced concrete masonry wall.

Ground motion resulting from earthquakes presents unique challenges to the design of structures. Earthquakes produce large-magnitude forces of short duration that must be resisted by a structure without causing collapse and preferably without significant damage to the structural elements. The lateral forces due to earthquakes have a major impact on structural integrity. Lessons from past earthquakes and research have provided technical solutions that will minimize loss of life and property damage associated with earthquakes. Special detailing is required, and for materials without inherent ductility, such as concrete and masonry, a critical part of the solution is to incorporate reinforcement in the design and construction to assure a ductile response to lateral forces.

Code Issues

Building codes establish minimum requirements for building design and construction with a primary goal of assuring public safety and a secondary goal, much less important than the primary one, of minimizing property damage and maintaining function during and following an earthquake. With respect to earthquake hazards, the underlying issues to be considered in the development of code criteria are the levels of seismic risk and the establishment of appropriate design requirements commensurate with those levels of risk. Since the risk of severe seismic ground motion varies from place to place, it logically follows that seismic code provisions will vary depending on location.

Table 1. Basis for Seismic Design Criteria in Model Codes and Standards

	Seismic Zones	Seismic Performance Categories	Seismic Design Categories
Classifications	0, 1, 2, 3, 4	A, B, C, D, E	A, B, C, D, E, F
Criteria for Classification	Location	Location & Building Use	Location, Building Use, & Soil Type
Used by Model Codes & Standards	UBC 1997 SBC 1991 BOCA/NBC 1990 MSJC 1992	SBC 1999 BOCA/NBC 1999 MSJC 1999	IBC 2000

The variable aspect of code provisions for seismic design has been accentuated by the fact that local and regional building code jurisdictions in the United States have typically based their provisions on one of three model building codes: the Uniform Building Code (predominant in the west), the Standard Building Code (predominant in the southeast), and the BOCA National Building Code (predominant in the northeast).Given the greater frequency and intensity of earthquakes in the west, it is not surprising that the Uniform Building Code (UBC) has traditionally placed more emphasis on seismic design provisions than the Standard Building Code (SBC) or the BOCA National Building Code (BOCA/NBC). However, this situation is changing.

Representatives from the three model code sponsoring organizations agreed to form the International Code Council (ICC) in late 1994, and, in April 2000, the ICC published the first edition of the International Building Code (IBC). It is intended that IBC will eventually replace the previous three model codes. The IBC includes significant changes in seismic design requirements from the three existing model building codes, particularly in how the level of detailing requirements for a specific structure is determined.

Evolution of Seismic Design Criteria

Seismic Zones. Until relatively recently, seismic design criteria in building codes depended solely upon the seismic zone in which a structure was located. Zones were regions in which seismic ground motion, corresponding to a certain probability of occurrence, was within

Table 2. Determining the Seismic Design Category

Step	Column 2 Consider short-period ground motion	Column 3 Consider long-period ground motion
Determine spectral response accelerations from contour maps or CD-ROM	At short period, S_S (Site Class B)	At 1 second period, S_1 (Site Class B)
Determine Site Class:		
• If Site Class (by IBC criteria) is F	Do site-specific design	Do site-specific design
• If data available for shear wave velocity, standard penetration resistance, and undrained shear strength	Choose from Site Class A–E	Choose from Site Class A–E
• If no data available	Use Site Class D	Use Site Class D
Determine site coefficient for acceleration or velocity	F_a Table 1615.1.2(1)	F_V Table 1615.1.2(2)
Determine soil-modified spectral response acceleration	$S_{MS} = F_a S_S$	$S_{M1} = F_V S_1$
Calculate the design spectral response acceleration	$S_{DS} = 2/3 S_{MS}$	$S_{D1} = 2/3 S_{M1}$
Determine Seismic Use Group (SUG) of structure	SUG I, standard occupancy buildings SUG II, assembly buildings SUG III, essential facilities	SUG I, standard occupancy buildings SUG II, assembly buildings SUG III, essential facilities
Determine Seismic Design Category	A, B, C, or D* as a function of SUG and S_{DS} from Table 1616.3(1)	A, B, C, or D* as a function of SUG and S_{D1} from Table 1616.3(2)
Choose most severe SDC	Compare Col. 2 with Col. 3 from previous line	

*It is possible for E or F to be the Seismic Design Category, per footnotes to Tables 1616.3 (1) and 1616.3 (2).

certain ranges. The United States was divided into Seismic Zones 0 through 4, with 0 indicating the weakest earthquake ground motion, and 4 indicating the strongest. The level of seismic detailing (including the amount of reinforcement) for masonry structures was then indexed to the Seismic Zone.

Seismic Performance Categories. However, given that public safety is a primary code objective, and that not all buildings in a seismic zone are equally crucial to public safety, a new system of classification called the Seismic Performance Category (SPC) was developed. The SPC classification included not only the seismicity at the site but also the occupancy of the structure. The SPC, rather than the Seismic Zone, became the determinant of seismic design and detailing requirements, thereby dictating that seismic design requirements for a hospital be more restrictive than those for a small business structure constructed on the same site. The detailing requirements under Seismic Performance Categories A & B, C, and D & E were roughly equivalent to those for Seismic Zones 0 & 1, 2, and 3 & 4, respectively.

Seismic Design Categories. The most recent development in structural classification has been the establishment of Seismic Design Categories as the determinant of seismic detailing requirements. Recognizing that building performance during a seismic event depends not only on the severity of sub-surface rock motion, but also on the type of soil upon which a structure is founded, the SDC is a function of location, building occupancy, and soil type.

Table 1 summarizes how building codes and the Masonry Standards Joint Committee's design standard, *Building Code Requirements for Masonry Structures* (ACI 530/ASCE 5/TMS 402), have addressed seismic design over the past decade. Dates list the last edition in which a given classification system was used by a model code or standard. As indicated, IBC 2000 is the first model code to use Seismic Design Categories.

Impact of Changes

Clearly, the procedure for establishing the seismic classification of a structure has become more complex. Determining the Seismic Zone simply required establishing the location of the structure on Seismic Zone maps that were contained in model codes. Determining the Seismic Performance Category of a structure required: 1) the interpolation of a ground motion parameter on a contour map, based on the location of the structure, 2) determining the use classification of the structure, and 3) consulting a table. As shown in Table 2, the process leading to the classification of the Seismic Design Category involves several steps.

Site-specific soil data must be gathered to establish the site class; otherwise, the default site class is D. The classification procedure requires evaluation of SDC for a short-period and a long-period ground motion parameter. After working through the calculations, the most severe SDC determined from the two conditions is selected.

Table 3. Seismic Design Category of 2000 IBC vs. Seismic Classification under Previous Codes

Location	Model Code	Seismic Zone or Category	IBC Site Class				
			A	B	C	D	E
			Seismic Design Category				
Washington, DC	1997 BOCA/NBC	SPC - A	A	A	A	B	C
New York, NY	1997 BOCA/NBC	SPC - C	B	B	B	C	D
Philadelphia, PA	1997 BOCA/NBC	SPC - B	B	B	B	C	C
Atlanta, GA	1997 SBC	SPC - B	A	B	B	C	D
Orlando, FL	1997 SBC	SPC - A	A	A	A	B	B
Charlotte, NC	1997 SBC	SPC - C	B	B	C	D	D
San Francisco, CA*	1997 UBC	Zone 4	D	D	D	D	**
Denver, CO	1997 UBC	Zone 1	A	B	B	B	C
Seattle, WA	1997 UBC	Zone 3	D	D	D	D	**

* Downtown, 4th and Market Streets.
** Site specific geotechnical investigation and dynamic site response analysis must be performed.

Table 3 provides a snapshot of the potential impact of the difference in seismic classification of a structure under the new IBC criteria, as compared to prior editions of the BOCA/NBC, the SBC, and the UBC. This table assumes a Seismic Use Group I (standard-occupancy) classification for a structure. Note that Site Class D is the default soil classification, which must be used unless soil testing indicates that a different classification is applicable. It is evident that the trend in regions previously under BOCA/NBC or SBC jurisdiction would be to require a higher level of detailing and reinforcement under the new IBC provisions unless soil testing indicates a Site Class of A, B, or C. However, regions previously under UBC jurisdiction would tend to remain unchanged in detailing requirements for the default Site Class D and would sometimes be permitted to be designed with a reduced level of detailing and reinforcement for Site Classes A, B, or C.

Conclusion

SDC ratings can be more or less stringent than the previous ratings. The soil condition at the site is the additional variable that must now be dealt with. While this adds another element to an already complicated procedure, it does incorporate established knowledge about the effect of soil properties during an earthquake into seismic design criteria. There is an associated economic impact to these changes. When a structure is assigned to a higher Seismic Design Category under the IBC than what its Seismic Performance Category would have been under the BOCA/NBC or the SBC, more restrictive code provisions increase the cost of design, materials, and construction.

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