A Necessary Change in the Seismic Design Provisions of the 2000 IBC

The author points out the need and provides justification for a significant change in the seismic design provisions of the first (2000) edition of the International Building Code (IBC). The code change would remove an unnecessary penalty that is now imposed on many low rise buildings – particularly those located on soft soil sites.

S. K. Ghosh, Ph.D.
President
S. K. Ghosh Associates, Inc.
Northbrook, Illinois

In 1994, the three model building code organizations – BOCA, the Building Officials and Code Administrators International, the publishers of the BOCA National Building Code (BOCA/NBC);[1] ICBO, the International Conference of Building Officials, the publishers of the Uniform Building Code (UBC);[2] and SBCCI, the Southern Building Code Congress International, the publishers of the Standard Building Code (SBC)[3] – formed the International Code Council (ICC) with the express purpose of developing a single set of construction codes for the entire United States.

Included in this family of international codes is the International Building Code (IBC), which represents a major step in a cooperative effort to bring national unity to building codes. The first edition of the IBC was published in April 2000.

The earthquake regulations of the 2000 IBC,[4] based on the 1997 NEHRP (National Earthquake Hazards Reduction Program) Provisions,[5] are substantially different from the corresponding provisions of the prior model codes. The seismic design provisions of the three most recent editions of the BOCA/NBC (1993, 1996, 1999) and the SBC (1994, 1997, 1999) are based on the 1991 edition of the NEHRP Provisions.

The last two editions of the BOCA/NBC (1996, 1999) and the SBC (1997, 1999) also permit seismic design according to Minimum Design Loads for Buildings and Other Structures, ASCE 7-95,[6] which has adopted seismic design provisions based on the 1994 NEHRP Provisions. The seismic design requirements of ASCE 7-98,[6] like those of the 2000 IBC, are based on the 1997 NEHRP Provisions.

EVOLUTION OF SEISMIC DESIGN CRITERIA

Discussed below is background information on the evolution of current seismic design criteria.

Seismic Zones

Seismic zones are regions in which earthquake ground motion in rock, corresponding to a certain probability of occurrence, is within certain ranges. In recent editions of the UBC, the United States has been divided into Seismic Zones 0 through 4, with 0 indicating the weakest earthquake ground motion and 4 indicating the strongest.

In the UBC, the seismic zone in which a structure is located determines permissible structural systems, including the level of detailing required for structural members and joints that are part of the lateral-force-resisting system and for the structural components that are not. The Seismic Zone also determines applicable limitations on the height of a structure, the permissible structural irregularities, the type of lateral analysis that must be performed as the basis of design for seismic forces, and the non-structural component requirements for seismic forces.

Seismic Performance Categories

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 depends not only on the seismicity at the site, based on rock, but also on the occupancy or use of the structure.

The 1994 and prior editions of the NEHRP Provisions (starting with the predecessor document, ATC 3[7]), use the SPC rather than the Seismic Zone as the determinant of seismic design and detailing requirements. This means that the three latest editions of the BOCA/National Building Code (BOCA/NBC) and the Standard Building Code (SBC) also use the SPC, since these model codes are based upon the 1991 NEHRP Provisions.

Through this device, a hospital in an area of moderate seismic risk must be detailed like, and be subject to the same restrictions as, an office building in an area of high seismic risk. The detailing requirements under SPC A and B are roughly equivalent to those for Seismic Zone 2 and the detailing requirements for SPC D and E are roughly equivalent to those for Seismic Zones 3 and 4.

Table 1. Correlation of seismic risk levels of ACI 318, and seismic zones or seismic performance or design categories of other model codes and resource documents.

Code, standard or resource document and edition	**Level of seismic risk or assigned seismic performance or design categories as defined in code section**		
	Low ACI 318-99 Sec. 21.2.1.2	Moderate/Intermediate ACI 318-99 Sec. 21.2.1.3	High ACI 318-99 Sec. 21.2.1.4
BOCA National Building Code 1993, 1996, 1999	SPC* A, B	SPC C	SPC D, E
Standard Building Code 1994, 1997, 1999	SPC A, B	SPC C	SPC D, E
Uniform Building Code 1991, 1994, 1997	Seismic Zone 0, 1	Seismic Zone 2	Seismic Zone 3, 4
International Building Code 2000	SDC† A, B	SDC C	SDC D, E, F
ASCE 7-93, 7-95	SPC* A, B	SPC C	SPC D, E
NEHRP 1991, 1994	SPC* A, B	SPC C	SPC D, E
NEHRP 1997, ASCE 7-98	SDC† A, B	SDC C	SDC D, E, F

* SPC = Seismic Performance Category as defined in code, standard or resource document
† SDC = Seismic Design Category as defined in code, standard or resource document

Seismic Design Categories

The most recent development of structural classification has been the establishment of Seismic Design Categories to determine seismic detailing requirements. Recognizing that building performance during a seismic event depends not only on the severity of subsurface rock motion, but also on the type of soil upon which a structure is founded, the Seismic Design Category (SDC) is a function of seismicity at the site, based on rock, building occupancy, and soil type. The 1997 NEHRP Provisions, the 2000 IBC, and ASCE 7-98 have replaced the SPC with the SDC. For an assessment of the impact of this major change, see References 8 and 9.

Interface with ACI 318

The provisions of ACI 318 Chapter 21 relate detailing requirements to type of structural framing, earthquake risk level at the site, and the level of energy dissipation intended in structural design. Earthquake risk levels have traditionally been classified as low, moderate and high. A correlation between the seismic risk levels of ACI 318 and the Seismic Zones of the UBC or the Seismic Performance or Design Categories of the other model codes and resource documents is given in Table 1.

Table 2 gives the actual ACI 318-99 detailing requirements for different levels of seismic risk or assigned Seismic Performance or Design Categories. For structures assigned to SPC or SDC A or B, there are no special seismic detailing requirements. For structures assigned to SPC or SDC C, an intermediate level of seismic detailing per Section 21.10 is required, but only for frame members. For structures assigned to SPC D or E, or SDC D, E or F, a whole host of special seismic detailing requirements is triggered.

DETERMINATION OF SEISMIC DESIGN CATEGORY

Discussed below is a proposal for modifying the manner in which the Seismic Design Category is determined based on the fundamental period of a structure.

Current Requirement

According to current IBC requirements, the Seismic Design Category

Table 2. Proportioning and detailing requirements – ACI 318-99.

Structural component	Level of seismic risk or assigned seismic performance or design categories as defined in code section		
	Low Sec. 21.2.1.2	Intermediate* Sec. 21.2.1.3	High* Sec. 21.2.1.4
Frame members	Chaps. 1 – 18	21.10†	21.2 – 21.5
Structural walls and coupling beams	Chaps. 1 – 18, 22	None	21.2, 21.6
Structural diaphragms and trusses	Chaps. 1 – 18	None	21.2, 21.7
Foundations	Chaps. 1 – 18, 22	None	21.2, 21.8
Frame members not proportioned to resist forces induced by earthquake motions	None	None	21.2, 21.9

* Requirements of Chapters 1 – 18 for structures at intermediate seismic risk Sec. 21.2.1.3 and Chapters 1 – 17 for structures at high seismic risk, Sec. 21.2.1.4 must also be satisfied.
† Must also comply with Sec. 21.2.2.3.

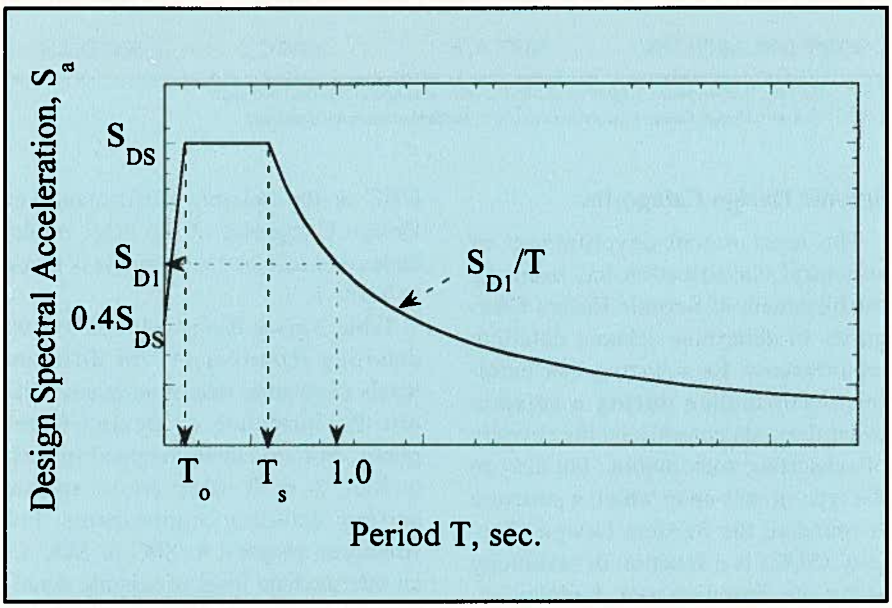

Fig. 1. Design response spectrum of the 2000 International Building Code.

Table 3. Seismic Design Category of 2000 IBC vs. Seismic Performance Category of 1999 BOCA / NBC.

Place	State	1997 BOCA/NBC SPC	2000 IBC Site class A	B	C	D	E
			Seismic Design Category*				
Washington	DC	A	A	A	B (A)	B	C (B)
Chicago	Illinois	A	A	A	B (A)	B	C (B)
Baltimore	Maryland	A	A	A	B (A)	B	C (B)
Boston	Massachusetts	C	B	B	B	C	D (C)
New York	New York	C	B	B	C	C	D
Cincinnati	Ohio	B	A	A	B (A)	C (B)	D (B)
Philadelphia	Pennsylvania	B	B	B	B	C	C
Richmond	Virginia	B	A	B	B	B	C

* Seismic Design Categories within parentheses are based on S_{DS} only.

for a structure needs to be determined twice – first as a function of S_{DS}, the design spectral response acceleration at short periods, and a second time as a function of S_{D1}, the design spectral response acceleration at 1 second period. The more severe category governs.

As shown in Fig. 1, S_{DS} and S_{D1} define the design response spectrum of the 2000 IBC. S_{DS} defines the "flat top" or acceleration-governed part of the spectrum, while S_{D1} defines the period-dependent descending branch or the velocity-governed part.

The design spectral acceleration, S_a, on the vertical axis of Fig. 1 is directly related to the design base shear, V. V is simply equal to S_a times mass or (S_a/g) times weight, except that for design purposes it is reduced by (R/I_E), where R is the response modification factor (dependent upon the structural system used to resist seismic forces), and I_E is the seismic load importance factor (dependent upon the use or occupancy of the structure).

Adverse Impact of Current Requirement

The current IBC requirement means that many structures designed for forces corresponding to the flat portion of the design spectrum (T equal to or less than T_s in Fig. 1) have their Seismic Design Category determined from the value of S_{D1} rather than S_{DS}. To illustrate how this affects the SDC assigned to a structure, Tables 3, 4 and 5 have been prepared.

Table 3 features a number of specific prominent locations in BOCA/NBC territory. The Seismic Performance Categories of standard-occupancy (Seismic Hazard Exposure Group I) structures at those locations are first listed. The Seismic Design Categories based solely on the short-period design spectral response acceleration (S_{DS}) are shown within parentheses in Table 3.

Table 4 features a number of chosen specific locations in UBC territory and is similar to Table 3, except that the Seismic Zone, rather than the Seismic Performance Category assigned to a standard-occupancy structure, is given for each location.

Table 5 is similar to Table 3, but is

for SBC, rather than BOCA/NBC, territory.

It should be clear that many short-period buildings are unnecessarily penalized under the IBC because the Seismic Design Category based on the long-period spectral response acceleration (S_{D1}) makes it necessary to provide a higher level of detailing for these structures than would have been required if the SDC were allowed to be determined by S_{DS} alone. While such a penalty appears to be less common in UBC territory, it is obviously a significant problem in parts of the United States where the BOCA/NBC and the SBC are typically adopted.

Table 4. Seismic Design Category of 2000 IBC versus Seismic Zone of 1997 UBC.

		1997 UBC	2000 IBC				
			Site class				
		Seismic	A	B	C	D	E
Place	State	Zone	Seismic Design Category†				
Berkeley ($N_a = 1.5$, $N_v = 2.0$)	California	4	E	E	E	E	*
West L.A. ($N_a = 1.3$, $N_v = 1.6$)	California	4	E	E	E	E	*
Sacramento	California	4	B	C	D (C)	D	D
San Francisco	California	4	D	D	D	D	*
Denver	Colorado	1	A	A	A	B	C
St. Paul	Minnesota	0	A	A	A	A	B
Portland	Oregon	3	D	D	D	D	D
Houston	Texas	0	A	A	A	B (A)	B

* Site-specific geotechnical investigation and dynamic site response analysis must be performed ($S_S \geq 1.25$ or $S_1 \geq 0.5$).
† Seismic Design Categories within parentheses are based on S_{DS} only.

Proposed Change

During the development of the International Residential Code (IRC),[10] it was decided that only the value of S_{DS} would be considered in assigning an SDC to a structure. This decision was based on the fact that the scope of the IRC is limited to residential buildings no more than three stories in height. These structures invariably have a fundamental period, T, less than T_S (see Fig. 1).

In a code change submitted by the Portland Cement Association (PCA) for inclusion in the 2002 Supplement to the IBC, the following exception was proposed to the Seismic Design Category determination of Section 1616.3 of the 2000 IBC:

Exception: Where the approximate fundamental period of the structure, T_a, in each of two orthogonal directions determined in accordance with Section 1617.4.2, is less than T_S determined in accordance with Section 1615.1.4, and Equation 16-35 is used to determine the seismic response coefficient, C_S, the Seismic Design Category is permitted to be determined based solely on the Seismic Use Group and short period spectral response acceleration, S_{DS}, in accordance with Table 1616.3 (1).

Where the approximate fundamental period, T_a, of a structure is less than T_S, Equation 16-35, corresponding to the flat-top part of the design response spectrum, must be used to determine the seismic response coefficient, C_S (equal to the design base shear, V, divided by the seismic weight of the structure, W):

$$C_S = S_{DS}/(R/I_E) \quad \text{(IBC Eq. 16-35)}$$

The only justification for not allowing the Seismic Design Category to be determined by S_{DS} in that case is that the "real" period of the structure may exceed T_S, and that the structure may after all have its seismic response determined by the long-period ground motion parameter, S_{D1}.

The PCA proposal would allow SDC to be determined by S_{DS} alone as long as T_a, rather than T, is less than or equal to T_S; however, the seismic design coefficient, C_S, must be determined using Equation 16-35, meaning that design forces corresponding to the flat top of the design spectrum must be used in the design. In other words, in cases where $T_a \leq T_S$, but T might be larger than T_S, a strength penalty is imposed on a structure for its SDC to be determined by S_{DS} alone. This is felt to be a reasonable and a sensible approach.

To illustrate application of the PCA proposal, consider a Seismic Use Group I building to be erected in Charlotte, North Carolina. Table 6 shows that a structure sited on soil classified as Site Class C or D will be assigned to SDC C or D, respectively. The same information is also contained in Table 5. The SDC in both cases is determined by S_{D1}.

Under the PCA proposal, for short-period buildings with T_a less than T_S, the SDC will be allowed to be determined based on S_{DS}, and in the cases of the two Site Classes shown in Table 6, will be reduced to B or C, respectively. The last three columns in Table 6 show the heights (in feet) of build-

Table 5. Seismic Design Category of 2000 IBC versus Seismic Performance Category of 1999 SBC.

		1999 SBC	2000 IBC				
			Site class				
			A	B	C	D	E
Place	State	SPC	Seismic Design Category†				
Birmingham	Alabama	B	B	B	B	C (B)	D (C)
Little Rock	Arkansas	B	B	B	C	D (C)	D
Orlando	Florida	A	A	A	A	B (A)	B
Atlanta	Georgia	B	A	B	B	C (B)	D (C)
New Orleans	Louisiana	A	A	A	A	B (A)	B
Charlotte	North Carolina	C	B	B	C (B)	D (C)	D
Charleston	South Carolina	C	D	D	D	D	*
Nashville	Tennessee	B	B	B	C (B)	D (C)	D (C)

* Site-specific geotechnical investigation and dynamic site response analysis must be performed ($S_S \geq 1.25$ or $S_1 \geq 0.5$).
† Seismic Design Categories within parentheses are based on S_{DS} only.

Table 6. Seismic Design Categories for standard-occupancy buildings in Charlotte, North Carolina.

Site class	S_S	S_1	F_a	F_v	S_{DS}/SDC	S_{D1}/SDC	T_S	Height h_n based on $T_a = T_S$ for various C_T		
								0.035*	0.03†	0.02‡
C	0.35	0.145	1.20	1.66	0.28/B	0.16/C	0.57	41	51	87
D	0.35	0.145	1.52	2.22	0.35/C	0.21/D	0.60	44	54	93

S_S = mapped spectral response accelerations at short periods
S_1 = mapped spectral response acceleration at 1 second period
F_a = short-period site coefficient, function of S_S and Site Class
F_v = long-period site coefficient, function of S_1 and Site Class
$S_{DS} = (2/3) F_a S_S$
$S_{D1} = (2/3) F_v S_1$
$T_S = S_{D1} / S_{DS}$
$T_a = C_T h_n^{3/4}$
h_n = height above base to highest level in building, ft
* Buildings utilizing steel moment frames for lateral resistance.
† Buildings utilizing concrete moment frames for lateral resistance.
‡ All other buildings.

ings with various types of seismic-force-resisting systems corresponding to approximate fundamental period, T_a, equal to T_S. Buildings in Charlotte, North Carolina, with heights less than these values will be able to utilize the exception.

Approval

The PCA-proposed code change has not been approved for inclusion in the 2002 Supplement to the IBC. Significant opposition came from the Structural Engineers Association of Central California (SEAOCC). However, their opposition had little to do with the merits of the proposed change. The reason for the SEAOCC opposition can best be understood by reference to Table 4.

It can be seen from Table 4 that standard-occupancy structures in or around Sacramento, that are founded on Site Class B (Site Class A does not exist in or around Sacramento), would be assigned Seismic Design Category C, thus requiring detailing equivalent to that in UBC Zone 2. This is because the seismicity of the Central Valley of California is lower in the IBC than in the 1997 and recent prior editions of the UBC. The lowering is based on more contemporary source zone/attenuation data compiled by the U. S. Geological Survey.

Despite the USGS seismic maps, which formed the basis of the IBC design value maps, some structural engineers within SEAOCC believe that the equivalent of Zones 3 and 4 detailing should continue to be mandated for all of California. If the PCA-proposed code change is approved, standard-occupancy structures with T_a less than T_S on Site Class C, which are now assigned SDC D, would also be assigned SDC C, thus also requiring the equivalent of UBC Zone 2 detailing only.

The above outcome is found to be totally unacceptable by some structural engineers within SEAOCC. Their objection obviously lies with the IBC maps for short-period and long-period ground motion. They should preferably not try to partly solve that problem by opposing a logical code change that would remove an unnecessary penalty affecting a significant volume of construction in many parts of the United States.

CONCLUSION

Following the precedent set by the International Residential Code, the International Building Code should allow the Seismic Design Category of short-period buildings to be determined solely on the basis of the short-period ground motion parameters, S_{DS}, subject to certain safeguards.

According to current requirements, the SDC of many short-period buildings is determined by the long-period ground motion parameter, S_{D1}, imposing an unnecessary penalty on these buildings of more stringent detailing requirements which cost time, effort and money.

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