Part 2 ASCE/SEI 7-05

General Seismic Design Requirements for Buildings

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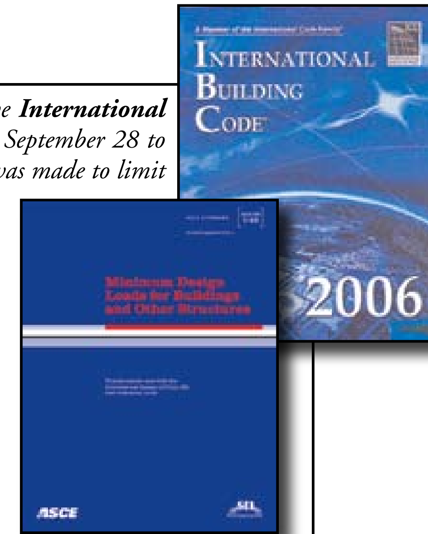
The vast majority of the general seismic design requirements for buildings are no longer included in the ***International Building Code*** *(IBC). The 2006 IBC was finalized at the 2005 Final Action Hearings that were held September 28 to October 2, 2005, in Detroit, Michigan. Over the past several code development cycles, a concerted effort was made to limit the seismic design provisions in the IBC and to reference ASCE/SEI 7-05,* ***Minimum Design Loads for Buildings and Other Structures****, for the vast majority of the seismic design requirements. While the IBC process was underway, a parallel effort was being undertaken by the American Society of Civil Engineers (ASCE) to reformat the provisions of their standard and update its technical provisions. The reformatting effort resulted in locating of all the general seismic design requirements into one chapter (Chapter 12). The updated technical provisions were first promulgated in the Building Seismic Safety Council's (BSSC's) 2003 National Earthquake Hazards Reduction Program (NEHRP)* ***Provisions*** *update cycle. While numerous technical updates were proposed in the BSSC process, only those that were successfully balloted were sent on to ASCE for possible inclusion into the standard.*

The focus of this article is to describe the important technical changes that occurred since the previous version of the standard (ASCE/SEI 7-02), and to summarize notable changes to the seismic design requirements for buildings that have been made over the past several development cycles of the code and standards.



Technical Changes Relative to ASCE/SEI 7-02

Seismic Design Category

A building's Seismic Design Category (SDC) is based on the seismicity at the site (S_{DS} and S_{D1}) and the occupancy category. The SDC is an important parameter that affects the building's seismic system selection and limitations (such as story height), the seismic design requirements for elements within the structure (diaphragms, chords, collectors), the applicability of the horizontal and vertical irregularities, and the detailing of specific components (discontinuous elements).

In ASCE/SEI 7-02, a building is assigned to the more severe SDC as determined by S_{DS} and S_{D1} – that is, whichever seismic spectral response acceleration parameter produces the higher category, regardless of the fundamental period of the structure (T). The technical change to this provision in ASCE/SEI 7-05 allows the determination of the SDC to be based solely on S_{DS} with the following limits:

- S_1 is less than 0.75.
- In each of the two orthogonal directions, the approximate fundamental period of the structure (T_a) determined in accordance with Section 12.8.2.1 is less than 0.8 T_s, where T_s is determined in accordance with Section 11.4.5.
- In each of two orthogonal directions, the fundamental period of the structure used to calculate the story drift is less than T_s.
- Equation 12.8-2 is used to determine the seismic response coefficient C_s.
- The diaphragms are rigid as defined in Section 12.3.1; or for diaphragms that are flexible, the distance between vertical elements of the seismic force-resisting system does not exceed 40 feet.

The reason behind the change is to allow the SDC of a short-period structure to be based on the structure's controlling seismic spectral response acceleration parameter (S_{DS}) and not arbitrarily based on S_{D1}, which does not reflect the structure's true behavior.

Seismic Base Shear

One of the major technical changes from ASCE/SEI 7-02 was the modification to the base shear equations. While the basic formulation of the equation remained the same ($V = C_sW$), some changes were made to the equations for C_s.

Table 1: Requirements for Each Story Resisting More than 35% of the Base Shear (Table 12.3-3 from ASCE/SEI 7-05

Lateral Force-Resisting Element	Requirement
Braced Frames	Removal of an individual brace, or connection thereto, would not result in more than a 33% reduction in story strength, nor does the resulting system have an extreme torsional irregularity (horizontal structural irregularity Type 1b).
Moment Frames	Loss of moment resistance at the beam-to-column connections at both ends of a single beam would not result in more than a 33% reduction in story strength, nor does the resulting system have an extreme torsional irregularity (horizontal structural irregularity Type 1b).
Shear Walls or Wall Pier with a height-to-length ratio of greater than 1.0	Removal of a shear wall or wall pier with a height-to-length ratio greater than 1.0 within any story, or collector connections thereto, would not result in more than a 33% reduction in story strength, nor does the resulting system have an extreme torsional irregularity (horizontal structural irregularity Type 1b).
Cantilever Columns	Loss of moment resistance at the base connections of any single cantilever column would not result in more than a 33% reduction in story strength, nor does the resulting system have an extreme torsional irregularity (horizontal structural irregularity Type 1b).
Other	No requirements.

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The basic acceleration- and velocity-controlled base shear equations (*Equations 12.8-2* and *12.8-3*) remain the same:

$$C_s = \frac{S_{DS}}{\left(\frac{R}{I}\right)} \qquad (Equation\ 12.8\text{-}2)$$

$$C_s = \frac{S_{D1}}{T\left(\frac{R}{I}\right)} \quad for\ T \le T_L \qquad (Equation\ 12.8\text{-}3)$$

However, a limit was placed on the velocity-controlled equation (*Equation 12.8-3*); this equation now is applicable when T is less than or equal to T_L. T_L, defined as the long-period transition period(s) determined in Section 11.4.5, is the transition period between the velocity- and displacement-controlled portions of the design spectrum. Introducing this new parameter allows for the following new equation (*Equation 12.8-4*) that better captures the demand associated with long-period structures:

$$C_s = \frac{S_{D1}\,T_L}{T^2\left(\frac{R}{I}\right)} \quad for\ T > T_L \qquad (Equation\ 12.8\text{-}4)$$

For the majority of high seismic regions, this new equation will rarely control. However, in low to moderate seismic regions, this new equation may govern for tall buildings.

The previous minimum value of C_S (= $0.044S_{DS}I$) was eliminated and replaced with the new minimum value:

$$C_s = 0.01 \qquad (Equation\ 12.8\text{-}5)$$

The final change to the base shear equation was associated with the trigger for what is generally defined as the "near source" equation. The new trigger is for buildings where S_1 is equal to or greater than 0.6g, requiring that C_s shall not be less than:

$$C_s = \frac{0.5S_1}{\left(\frac{R}{I}\right)} \qquad (Equation\ 12.8\text{-}6)$$

An equally important aspect of the changes to the base shear equations is the requirement that the building drift be assessed for whichever equation governs the design. In previous codes and standards, neither *Equation 12.8-5* nor *Equation 12.8-6* was required to be used when checking allowable story drift. It is still permitted to use the actual building period when checking allowable story drift, which is important when either *Equation 12.8-3* or *Equation 12.8-4* controls the building design.

Table 2: Importance Factors (Table 11.5-1 from ASCE/SEI 7 05)

Occupancy Category	Importance Factor (I)
I or II	1.0
III	1.25
IV	1.5

Table 3: Allowable Story Drift, $\Delta_a^{a,b}$ (Table 12.12-1 from ASCE/SEI 7-05)

Structure	Occupancy Category		
	I or II	III	IV
Structures, other than masonry shear wall structures, four stories or less with interior walls, partitions, ceilings and exterior wall systems that have been designed to accommodate the story drifts	$0.025h_{sx}$[c]	$0.020h_{sx}$	$0.015h_{sx}$
Masonry cantilever shear wall structures [d]	$0.010h_{sx}$	$0.010h_{sx}$	$0.010h_{sx}$
Other masonry shear wall structures	$0.007h_{sx}$	$0.007h_{sx}$	$0.007h_{sx}$
All other structures	$0.020h_{sx}$	$0.015h_{sx}$	$0.010h_{sx}$

[a] *h_{sx} is the story height below Level x.*
[b] *For seismic force–resisting systems comprised solely of moment frames in Seismic Design Categories D, E, and F, the allowable story drift shall comply with the requirements of Section 12.12.1.1.*
[c] *There shall be no drift limit for single-story structures with interior walls, partitions, ceilings, and exterior wall systems that have been designed to accommodate the story drifts. The structure separation requirement of Section 12.12.3 is not waived.*
[d] *Structures in which the basic structural system consists of masonry shear walls designed as vertical elements cantilevered from their base or foundation support which are so constructed that moment transfer between shear walls (coupling) is negligible.*

Redundancy

Redundancy provisions were first introduced into codes and standards via the 1997 *Uniform Building Code* (UBC). Since their original inception, the redundancy provisions have created controversy with respect to their interpretation and implementation. As part of the 2003 NEHRP *Provisions* update cycle, Technical Subcommittee 2 (TS 2) was charged with reviewing not only the UBC provisions but also the need for the parameter altogether. After much debate, TS 2 concluded that redundancy provisions are important to include in codes and standards but the basic formulation had to change. Once the new formulation was accepted, the newly constituted redundancy provisions were sent to ASCE for potential adoption. Fundamental to the change were the following issues:

- A sliding redundancy value based on the force in only one of the elements of the system was too precise and not technically justified. It was concluded that either an appropriate level of redundancy is provided in the system or it is not. Redundancy values of either 1.0 or 1.3 were selected as the two values to be assigned.
- A better approach to determining redundancy is to base it on whether the loss or removal of an important component within the system (*Table 1*) would result in more than a 33% reduction in story strength, or would the resulting system have an extreme torsional irregularity (horizontal structural irregularity Type 1b).
- Checking redundancy throughout the entire building height is not necessary. Only those stories resisting more than 35% of the base shear in the direction of interest need to be checked.
- Well-distributed perimeter systems automatically qualify for a value of 1.0 — specifically, "structures that are regular in plan at all levels provided that the seismic force — resisting systems consist of at least

two bays of seismic force-resisting perimeter framing on each side of the structure in each orthogonal direction at each story resisting more than 35% of the base shear. The number of bays for a shear wall shall be calculated as the length of shear wall divided by the story height or two times the length of shear wall divided by the story height for light-framed construction."

To further clarify when the redundancy factor is permitted to be taken as 1.0, the following list is provided in ASCE/SEI 7-05:

1. Structures assigned to SDC B or C.
2. Drift calculation and P-delta effects.
3. Design of nonstructural components.
4. Design of non-building structures that are not similar to buildings.
5. Design of collector elements, splices, and their connections for which the load combinations with overstrength factor of Section 12.4.3.2 are used.
6. Design of members or connections where the load combinations with overstrength of Section 12.4.3.2 are required for design.
7. Diaphragm loads determined using Equation 12.10-1.
8. Structures with damping systems designed in accordance with Section 18.

Modal Response Spectrum Analysis

The modal response spectrum analysis section has been greatly reduced from ASCE/SEI 7-02. The majority of the change is editorial. Eliminated from the requirements is the mode-by-mode presentation of the modal response spectrum analysis process. Since the vast majority of modal response spectrum analyses are performed with computer software, eliminating the equations was essentially deemed editorial.

Two technical clarifications were also made. First, a modal response parameters section was added to clarify that the design spectra needs to be divided by the quantity R/I and that the displacement and drift quantities need to be multiplied by the quantity C_S/I. The section regarding scaling design values was changed to clarify that only the force-related parameters need to be scaled based on a maximum period of $(C_u)(T_a)$ but the drift quantities do not. This second clarification was made to ensure that the drifts resulting from the Modal Response Spectrum Analysis method are consistent with those resulting from an Equivalent Lateral Force (ELF) procedure.

Notable Changes Relative to Previous Codes and Standards

Value of the Importance Factors

While importance factors have been around for over 30 years in building codes and standards, the values assigned to the various occupancy categories have undergone change. For the majority of the last 30 years, the importance factor for "Essential Facilities," now defined as Category IV occupancies in ASCE/SEI 7-05, has been 1.5. For the past several UBC editions, the value was reduced to 1.25. As indicated in *Table 2*, the value has been changed back to 1.5. In addition to this change, the value for Occupancy Category III buildings, which includes buildings that with an occupancy greater than 5,000 and college buildings with a capacity greater than 500 students, is now 1.25, while in previous codes it has been 1.0. There is a new emphasis in attempting to control the amount of ductility demand for these occupancies.

Method for Determining Story Drift

Estimation of the maximum drift under the design earthquake has been a part of our design process for decades. The change that has occurred in building codes and standards is the method for estimating the maximum drift. In ASCE/SEI 7-05, the term C_d replaces $3R_w/8$ (from the UBC) as the multiplier. For the majority of systems, there is no change in the resulting value. However, for some systems — especially flexible systems — this change increases the estimated maximum drift. The values for C_d are system-dependent and are listed in the "R factor" table.

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Table 4: Values of Approximate Period Parameters C_t and x (Table 12.8-2 from ASCE/SEI 7-05)

Structure Type	C_t	x
Moment-resisting frame systems in which the frames resist 100% of the required seismic force and are not enclosed or adjoined by components that are more rigid and will prevent the frames from deflecting where subjected to seismic forces:		
Steel moment-resisting frames	0.028 (0.0724)[a]	0.8
Concrete moment-resisting frames	0.016 (0.0466)[a]	0.9
Eccentrically braced steel frames	0.03 (0.0731)[a]	0.75
All other structural systems	0.02 (0.0488)[a]	0.75

[a] Metric equivalents are shown in parentheses.

Modified Allowable Drift Requirements

ASCE/SEI 7-05 includes a significant change regarding allowable story drifts. For the first time, allowable story drifts are based on building occupancy category. The more significant (or "essential") the occupancy, the more restrictive the allowable story drift. For occupancy category IV buildings ("essential" facilities), the allowable story drift has been reduced by a factor of two relative to recent versions of the UBC. The current requirement specifies an allowable story drift of 0.01, while the UBC value was 0.02. Depending on the selected building system, this can have a significant effect on the seismic design.

Modified Method for Calculating T_a and the Upper Limit on Calculated Period

The estimation of building period using empirical formulas has been a part of the seismic design requirements since their inception. As more information became available about the actual periods of various building types, the formulation of calculating T_a has been modified. Relative to the formulation included in the UBC, the format for calculating T_a has changed to be more specific to the various systems. The basic formulation is now $T_a = C_t h_n^x$. *Table 4* lists the values for C_t and *x* for the various systems.

In addition, the calculation of the upper limit on calculated period, $C_u T_a$, has also been modified, allowing for a larger increase at locations of lower seismic hazard. The new information is shown in *Table 5*.

Table 5: Coefficient for upper limit on calculated period (Table 12.8-1 from ASCE/SEI 7-05

Design Spectral Response Acceleration Parameter at 1 s, S_{D1}	Coefficient C_u
≥ 0.4	1.4
0.3	1.4
0.2	1.5
0.15	1.6
≤ 0.1	1.7

New Height Limits for Certain Systems and Requirements for Increasing Limitation

In the 1997 UBC, the height limits for several notable systems categorized as "Building Frame Systems," including steel eccentrically braced frames, concrete shear walls, and steel concentrically braced frames, were set at 240 feet for high seismic zones. ASCE/SEI 7-05 changed the height limit in high seismic regions to 160 feet for these systems but allows the height limit to be increased to 240 feet if the following two requirements are met.

1. The structure shall not have an extreme torsional irregularity as defined in Table 12.3-1 of ASCE/SEI 7-05 (horizontal structural irregularity Type 1b).
2. The braced frames or shear walls in any one plane shall resist no more than 60% of the total seismic forces in each direction, neglecting accidental torsional effects.

Conclusions

In addition to a complete re-format, ASEC/SEI 7-05 has incorporated the most current seismic design requirements. These recent changes, along with the changes that have been made over the past couple of standard development cycles, result in some requirements that have changed significantly from recent practice, especially those specified in the 1997 UBC. Since the 2006 IBC now references the seismic requirements specified in ASCE/SEI 7-05, the use and understanding of the requirements of ASCE/SEI 7-05 will be paramount to engineers in the coming years.▪

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