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CODE REQUIREMENTS FOR IMPROVED SEISMIC PROTECTION OF NONSTRUCTURAL COMPONENTS IN THE UNITED STATES

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ABSTRACT

In the United States, the building code that has been currently adopted by most jurisdictions is the “2006 International Building Code” (2006 IBC). The 2006 IBC references the 2005 edition of the standard “ASCE/SEI 7-05 Minimum Design Loads for Building and Other Structures” (ASCE 7-05) for its seismic provisions. ASCE 7-05 devotes a separate chapter (Chapter 13) to nonstructural components and contains specific seismic requirements for them that is expected to improve their seismic performance. In addition to equivalent static force provisions, specific consideration of relative displacement at points of attachments is required. ASCE 7-05 also requires that certain critical components be seismically qualified to demonstrate functionality after being subjected to design earthquake motions. In addition, special detailing requirements have been provided for anchorage, glazing, ceiling systems, lay-in access floors, mechanical equipment, glazing, lay-in ceilings and piping systems. This paper describes these requirements and the special detailing that is now required for nonstructural components in many parts of the United States.

Introduction

The most current building code enforced in most jurisdictions in the United States is the “2006 International Building Code” (IBC). The 2006 IBC references the 2005 edition of the standard “Minimum Design Loads for Buildings and Other Structures” prepared by the American Society of Civil Engineers (ASCE 7-05) for its seismic provisions. The seismic provisions of ASCE 7-05 are in turn primarily based on the 2003 Edition of the “National Earthquake Hazard Reduction Program Recommended Provisions for Seismic Regulations for Buildings and Other Structures” (NEHRP Recommended Provisions).

ASCE 7-05 was developed by the ASCE 7 Standards Committee and its Seismic Task Committee. The NEHRP Recommended Provisions were developed by the Building Seismic Safety Council’s Provisions Update Committee (PUC) on behalf of the U.S. Department of Homeland Security’s Federal Emergency Management Agency (FEMA). The seismic

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requirements for nonstructural components were developed by Technical Subcommittee 8 (TS-8) of the PUC. All ASCE and BSSC Committees are purely volunteer activities and are composed of many of the same engineering professionals.

The NEHRP Recommended Provisions were first published in 1985 and have been updated every 3 years since then. The first set of NEHRP Recommended Provisions were based on the “Tentative Provisions for the Development of Seismic Regulations for Buildings”, ATC 3-06 published by the Applied Technology Council (ATC) for the National Bureau of Standards in 1978. This landmark document (one of the first developed by ATC) was prompted by the unexpected poor performance of buildings including nonstructural components (especially hospitals) during the 1971 San Fernando Earthquake. ATC 3-06 has formed the basis for many of the concepts contained in the latest NEHRP Recommended Provisions and the ASCE 7 standard including those for nonstructural components. Special requirements were included for those components that need to function after design earthquake grounds that included seismic certification of nonstructural components by shake table tests, experience data or sophisticated analysis.

2006 IBC Seismic Requirements for Buildings and Other Structures

The seismic requirements of the 2006 IBC are contained in Chapters 16 - 23 of the IBC. Load combinations and load factors including those containing seismic loads are provided in Section 1604 of the IBC while specific requirements for seismic loads are contained in Section 1613. Chapter 17 of the IBC contains requirements for testing and inspection including special seismic requirements for nonstructural components. Chapter 18 provides requirements for foundations, and Chapters 19 - 23 contains material detailing requirements for concrete, aluminum, masonry, steel, and wood. Both the foundation and material requirements have special requirements dealing with seismic loadings.

The seismic requirements found in Section 16.13 of the 2006 IBC are rather minimal. It should be noted that the seismic requirements found in the 2000 and 2003 IBC were much more extensive. The Section 16.13 seismic requirements that are provided are as follows:

- General Charging Language
- Definitions
- Design ground motion parameter definitions and design ground motion maps
- Site soil condition classification definitions and site amplification factors are specified
- Seismic Design Categories are specified based on site ground motions and occupancy
- Reference to ASCE 7-05 for all seismic design criteria requirements
- A few minor exceptions to the ASCE 7-05 seismic design criteria requirements

The ground motion values used for the design of buildings are also used for the design of nonstructural components. Also, the Seismic Design Category that the building is assigned is one of the key factors that determines the seismic requirements for nonstructural components.

Maximum Design Earthquake Ground Motion Parameters and Ground Motion Maps

The 2006 IBC defines earthquakes in terms of Maximum Considered Earthquake (MCE) Ground Motion Parameters. The MCE design parameters are defined as those that have a 2% probability of exceedance in 50 years but with deterministic limits in areas where earthquake sources and return periods are well known. The MCE Design Parameters are defined for a rock site and are specified as 5% spectral ordinates at periods of 0.2 seconds (short period) and at a period of 1.0 seconds (long period). These spectral values are denoted as S_s and S_1 respectively.

Contour maps developed by the United States Geological Survey (USGS) are provided in Chapter 16 that provide values of S_s and S_1 for all locations in the United States. The values of S_s range from 0.0 to 3.0 gs while the values of S_1 range from 0.0 to 1.25 gs. Spectral values are also available at a USGS website (http://earthquake.usgs.gov/research/hazmaps/design/index.php) where the unique site specific values are provided based on the latitude and longitude of the site. The website is the only accurate way to determine these design values in high seismicity areas.

Site Class Definitions and Site Amplification Coefficients

It is required by the 2006 IBC to determine the soil profile classification called the Site Class for all new building sites. The Site Class is a function of the soil properties in the top 100 feet of soil at the site. Six Site Classes from A through F are identified by the 2006 IBC with Site Class A corresponding to very hard rock and Site Class F corresponding to very soft (and possibly liquefiable) soils. Where the soil profile properties at a site are unknown, it is permitted by the 2006 IBC to use Site Class D as the default soil condition.

Ground motion site amplification factors are specified in the 2006 IBC in recognition of the significant influence of the soil profile on earthquake site response. It is also recognized that the magnitude of site amplification for a given soil profile varies with the intensity of the ground motion. Factors are provided for both short period (F_a) and long period (F_v) in recognition that the amplifications are different in the acceleration sensitive portion of response as compared to the response portion of response. The specified factors vary as shown in Table 1 below.

Table 1. Site Amplification Coefficients

Site Class	$\mathbf{F_a}$			$\mathbf{F_v}$		
	$S_s \le 0.25$	$S_s = 0.75$	$S_s \ge 1.25$	$S_1 \le 0.1$	$S_1 = 0.3$	$S_1 \le 0.5$
A	0.8	0.8	0.8	0.8	0.8	0.8
B	1.0	1.0	1.0	1.0	1.0	1.0
C	1.2	1.1	1.0	1.7	1.5	1.3
D	1.6	1.2	1.0	2.4	1.8	1.5
E	2.5	1.2	0.9	3.5	2.8	2.4
F	*	*	*	*	*	*

*Site Specific Determination Required

Design Earthquake Ground Motion Parameters

The ground motion parameters that are used for design are called the Design Earthquake Ground Motion parameters. These parameters are identified as the short period spectral design acceleration S_{DS} and the one second period spectral design acceleration S_{D1}. Both these design parameters are determined from the MCE parameters and Site Amplification Coefficients as follows in Equations 1 and 2.

$$S_{DS} = \frac{2}{3} F_a S_S \quad (1)$$

$$S_{D1} = \frac{2}{3} F_v S_1 \quad (2)$$

Occupancy Category and Seismic Design Category

The 2006 IBC requires that structures be assigned an Occupancy Category and Seismic Design Category. The Occupancy Category of a structure is based on the Occupancy Category Table 1604.5 in the IBC. In the table, low hazard structures (such as agricultural facilities) are categorized as Occupancy Category I, normal structures are categorized as Occupancy Category II, higher hazard facilities (such as schools) are categorized as Occupancy Category III, and essential facilities (such as acute care hospitals) are categorized as Occupancy Category IV. The Seismic Design Category (SDC) of a structure is determined from Tables 2 and 3 below are based on the values of S_{DS} and S_{D1} at the structure's site and the Occupancy Category. The SDC ranges from SDC A to SDC F with SDC A being assigned to the structures in the lowest seismic hazard area and SDC F being to the most essential structures in the highest seismic hazard areas. In general, the higher of the categories in the two tables is the value that is assigned to the structure. There is an exception that permits the Seismic Design Category to be based only on S_{DS} for certain select short period structures.

Table 2.
Seismic Design Category Based on
Short Period Response Acceleration

Value of S_{DS}	**Occupancy Category**		
	I or II	III	IV
$S_{DS} < 0.167$ g	A	A	A
0.167 g $\leq S_{DS} < 0.33$g	B	B	C
0.33 g $\leq S_{DS} <$ 0.50g	C	C	D
0.50g $\leq S_{DS}$	D	D	D

Table 3.
Seismic Design Category Based on
1-Second Response Acceleration

Value of S_{DS} or S_1	**Occupancy Category**		
	I or II	III	IV
$S_{D1} < 0.067$g	A	A	A
0.067g $\leq S_{D1} <$ 0.133g	B	B	B
0.133g $\leq S_{D1} <$ 0.20g	C	C	D
0.20g $\leq S_{D1}$	D	D	D
$S_1 \geq 0.75$	E	E	F

2006 IBC / ASCE 7-05 Seismic Requirements for Nonstructural Components

Nonstructural components are architectural, electrical, or mechanical components and systems that are permanently attached to structures and that are not considered as part of the primary seismic force resisting structural system. The 2006 IBC references ASCE 7-05 for the seismic design requirements for nonstructural components and their supports and attachments to the primary structure. The seismic requirements for nonstructural components are contained in Chapter 13 of ASCE 7-05. Chapter 13 provides the following:

- Charging Language, Importance Factor Definition and Exemptions
- General Design Requirements including special seismic certification requirements for designated seismic systems
- Seismic Demands on Nonstructural Components
- Nonstructural Component Anchorage Requirements
- Prescriptive detailing requirements for Architectural Components
- Prescriptive detailing requirements for Mechanical and Electrical Components

Nonstructural components are assigned to the same Seismic Design Category as the structure that they occupy or to which they are attached. In addition to assigning a Seismic Design Category, nonstructural components are also assigned an Importance Factor I_p . The Seismic Design Category of the component and the component importance factor determine the level of prescriptive seismic detailing requirements and special certification requirements. The I_p factor is also considered when determining the design forces on nonstructural components.

Nonstructural Component Seismic Importance Factor

The nonstructural component importance factor is taken as 1.0 unless one of the following conditions exist in which case it is taken as 1.5.

1. The component is required to function after an earthquake for life-safety purposes after and earthquake, including fire protection systems.
2. The component contains hazardous materials.
3. The component is in or attached to an Occupancy IV structure and it is needed for continued operation of the facility or its failure could impair the continued operation of the facility.

Designated Seismic System

A designated seismic system is defined as a nonstructural seismic system which has an importance factor equal to 1.5. This terminology was introduced in ATC 3-06, and its definition has morphed over time. However, the concept of Designated Seismic Systems of the seismic criteria for these systems has not changed. Designated Seismic Systems are extremely important systems that require special treatment. It is expected in future editions of ASCE 7 that the term “Designated Seismic Systems” will be replaced simply with “when I_p = 1.5”.

Exemptions

Nonstructural components and their anchorage and bracing may be exempt from the seismic design requirements of Chapter 13 of ASCE 7-05 depending on the Seismic Design Category they have been assigned. Nonstructural components are exempt if one of the following conditions apply:

1. They are assigned to SDC A.
2. They are architectural components assigned to SDC B other than certain parapets provided that $I_p = 1.0$.
3. They are mechanical and/or electrical components assigned to SDC B.
4. They are mechanical and/or electrical components assigned to SDC C provided that $I_p = 1.0$.
5. Mechanical and electrical equipment assigned to SDC D, E or F provided that $I_p = 1.0$ and one of the two following conditions exist:
    a. Components weigh 400 pounds or less, are mounted 4 feet or less above the floor, and there are flexible connections between the components and associated ducting, piping, and bracing.
    b. Components weigh 20 pounds or less or distributed systems weigh less than 5 lbs/foot or less and there are flexible connections between the components and associated ducting, piping, and bracing.

Seismic Demands on Nonstructural Components

In Chapter 13 of ASCE 7-05, two types of nonstructural demands are specified. These are equivalent static lateral forces identified as F_p and relative displacement demands identified as D_p. The F_p forces are at the strength level and need to be multiplied by 0.7 when used with allowable stress load combination and allowable increases. The D_p demands are based on the estimated relative displacements of the structure to which is attached when subjected to Design Earthquake level demands.

The F_p forces are determined by Equation 3 below:

$$F_p = \frac{0.4\, a_p\, S_{DS}}{\left(\frac{R_p}{I_p}\right)} \left(1 + 2\frac{z}{h}\right) W_p \tag{3}$$

Where:

F_p	Seismic design force centered at the component's center of gravity and distributed relative to component's mass distribution
a_p	Component amplification factor
S_{DS}	Design earthquake spectral response acceleration at short period

R_p Component response modification factor
I_p Component importance factor
z Height in structure at point of attachment of component
h Average roof height of structure relative to the base elevation
W_p Component operating weight.

In addition, the following minimum and maximum values for F_p are specified:

F_p shall not be taken less than $0.3\ S_{DS}\ I_p\ W_p$ and

F_p need not be taken greater than $1.6\ S_{DS}\ I_p\ W_p$

The values of a_p and R_p are specified in Tables in Chapter 13 of ASCE 7-05 for various nonstructural components. The values of a_p range from 1.0 to 2.5 while the values of R_p range from 1.0 to 12.0. The 12.0 value is specified for butt welded steel piping systems. The a_p values represent the expected dynamic amplification of flexible components to expected floor motion. A component is deemed to be rigid and therefore no dynamic amplifications need to be considered if it has a fundamental period of less than 0.06 seconds. In essence, the F_p equation is providing a floor spectra demand on the component, and the component forces can be reduced by an R factor similarly to how equivalent forces are determined for building structures. Unlike building structures however, the forces are not reduced at longer periods. This is because high mode effects may result in increased amplification. However, there is an alternate procedure in Chapter 13 that permits the value of F_p to be determined based on a dynamic analysis where the building and nonstructural component are modeled together in a single model.

The F_p force is primarily used for design anchorage and bracing of the component. However, when the component is a designated seismic system (i.e., has an I_p factor of 1.5), it is required that the component itself be designed for the forces. For example, a piping system that has an I_p factor of 1.5 would need to be analyzed for its adequacy not just the systems anchorage and bracing.

The relative displacement demand D_p is simply determined from the analysis of the structure in which the components are being attached. The analysis displacements need to include the deflection amplification factor C_d. As a default, if the relative displacements are unknown, the relative displacement demands may be taken as the maximum allowable drift displacements allowed for the structure by ASCE 7-05. The relative displacement demand is used to determine the effects on displacement sensitive components caused by relative anchor movements. For such components inelastic deformations are acceptable, but failure of the component which can cause life-safety hazard is not.

Special Requirements for Designated Seismic Systems

Designated seismic systems are expected to have a reasonably high probability of functioning following design earthquake level motions. To improve the probability of achieving this expectation, Chapter 13 of ASCE 7-05 has more stringent requirements for these systems. As noted earlier, these requirements include designing anchorage, bracing, and the component itself for higher level seismic forces and explicitly evaluating seismic anchor movement effects. In addition, special certification is required indicating that the components will perform as intended if the components are assigned Seismic Design Category C - F. Certification is required for:

- Essential Active Mechanical and Electrical Equipment which are required to demonstrate and certify compliance by either shake table testing or experience data.
- Components containing hazardous material are required to demonstrate and certify compliance by shake table testing, experience data, or analysis.

In addition, Chapter 13 requires consequential damage considerations such that failure of nonessential nonstructural components will not cause the failure of essential nonstructural components.

Shake Table Testing Requirements

In Chapter 13, seismic qualification by testing is required to be based upon a nationally recognized test standard procedure such as International Code Council Evaluation Services (ICC-ES) Acceptance Criteria 156 (AC-156). AC-156 "Seismic Qualification by Shake Table Testing of Nonstructural Components" was developed specifically to satisfy the seismic requirements of ASCE 7-05. Two levels of qualification are possible. The first level of qualification which is consistent with an I_p factor of 1.0 demonstrates that the component remains structurally stable when subjected to the qualifying motion. The second level of qualification which is consistent with an I_p factor of 1.5 demonstrates that the component is still operable after being subjected to the qualifying motion.

The qualifying motion is consistent with the F_p equation demand. The response spectra for the generic test motion is shown in Figure 1. The test motion (generally developed artificially) is required to envelope the test spectra up to a frequency of 1 hz and for a duration of 30 seconds. From personal observations, the motion is quite severe. Both vertical and horizontal motions should be tested which limits the number of testing tables that are available to do such testing. Also, because many nonstructural components need to be evaluated in both horizontal directions, it is probably much more practical to use a table with at least three degrees of freedom (two horizontal and one vertical) since this will greatly increase the efficiency of seismic qualification testing. This testing approach eliminates the need for test specimens to be reoriented to verify the other horizontal direction. However, this limitation further limits the number of existing tables that can perform such testing. Suggested considerations for seismically qualifying equipment to satisfy AC-156 are provided in a paper by Caldwell in the ATC-29-2 Seminar. Note that the testing is considered valid where the fundamental frequency of the item is less than 1 hz.

In Figure 1, the values of A_{FLX}, A_{RIG} are directly related to the F_p equation parameters and are discussed in the AC-156 document. The values of f_o and f_{FLX} are constants equal to 8.3 Hz and 1.3 Hz respectively. AC-156 can be downloaded from the following website http://www.icc-es.org/criteria/pdf_files/ac156.pdf. The latest version of AC-156 is dated January 2007.

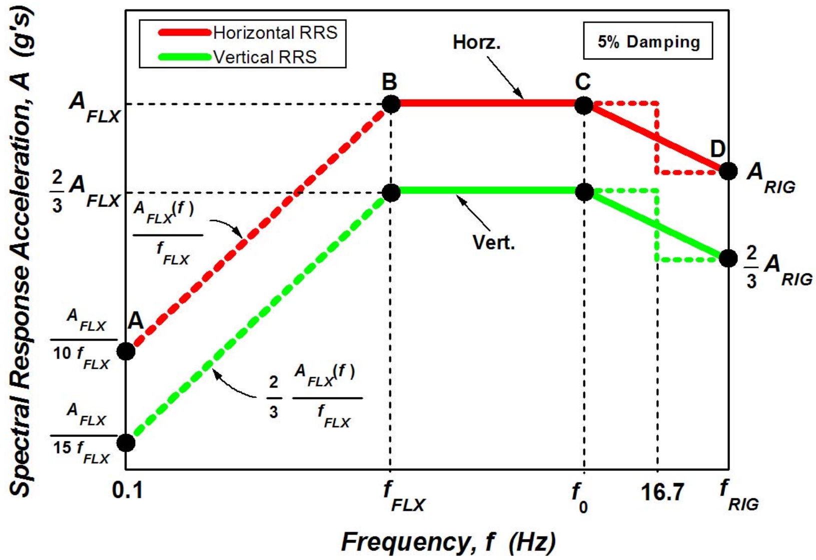

Figure 1. AC156 Required Response Spectrum Normalized for Nonstructural Components

It should be pointed out, as with all code seismic design criteria, individual structures will experience floor spectra that will likely exceed that specified in AC-156 in at least some period ranges and that the spectra in AC-156 is not considered to be a bounding spectra but a "line in the sand". We are learning that by providing an objective shake table demand standard that is tied with code force demands, suppliers can proceed on evaluating their nonstructural components and systems in an objective manner which also allows them to easily judge design changes and improvements. In fact in many cases, suppliers are learning how to reduce the cost of their current systems and actually improve seismic performance.

The code F_p force upper limits upon which much qualification testing is based has two basic assumptions. These assumptions are that the structure is behaving nonlinearly and that the nonstructural component is behaving nonlinearly at the upper limit values. The upper limit values are based on judgment and consider that the structure design is code based. It should be noted that most academic papers on this subject focus on linear elastic response of both the structure and nonstructural component and in most cases don't consider if both the structure and nonstructural response are behaving nonlinearly or whether there is a low probability that the nonstructural components have natural periods which are exactly in tune with the structure modes of vibration. In developing the F_p equations and AC-156, the effects of these rational considerations were made by judgment.

Prescriptive Seismic Requirements

Chapter 13 of ASCE 7-05 contains many prescriptive seismic requirements for nonstructural components. These include requirements for:

- Glazing and Curtain Walls – minimum glass clearances increases with higher importance factors.

- Suspended Ceilings – many alternate prescriptive requirements for SDC D - F which consider interaction with other ceiling components especially sprinkler drops.
- Special Requirements for Electrical and Mechanical Equipment for SDC D - F.
- Sprinkler systems are now deemed to comply if they satisfy NFPA 13-2007.

Requirements for Special Inspection for Nonstructural Components

The 2006 IBC contains several special requirements for special inspection of nonstructural components especially if they are designated seismic systems. In the U.S., the responsibility for the design common nonstructural components is typically left to installation contractors often with little seismic detail in the contract documents. Thus the proper design and installation of these components is mostly left unattended since no one appears to take responsibility. The usual practice is that installation subcontractors provide their typical installation with very little regard to what is provided on the plans or in the specifications. One exception to this way of doing business is the Office of Statewide Health Planning and Development (OSHPD) in California. OSHPD has recognized the importance of nonstructural components in the seismic performance of a hospital and provides prequalification of seismic installation designs, design reviews and inspections to insure compliance with approved designs.

Conclusion

Until recently in the United States, building codes treated nonstructural components as black boxes and were only concerned with their anchorage and bracing. The most current building code not only is concerned about anchorage and bracing but for essential facilities, the functioning of nonstructural components following design earthquake level ground motions. This concern has resulted in requiring seismic qualification of critical components in essential facilities by shake table testing or experience data that will likely result in more reliable performance of systems when they will be most critically needed following major earthquakes.

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