Seismic Design of Non-Structural Building Components in the United States

by

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ABSTRACT

Seismic design requirements for nonstructural building components of five major building codes, including the 1994 Uniform Building Code, the 1994 Standard Building Code, the 1994 NEHRP Recommended Provisions for Seismic Regulations for New Buildings, the New Zealand Building Code, and nonstructural provisions used in Japan, were reviewed in this study. Comparisons of codes reveal wide variation in seismic force and displacement requirements for nonstructural components, both in terms of levels of stringency and levels of details. The difference in seismic force requirements between the most and least stringent codes can be more than five times.

KEYWORDS: building codes; building technology; earthquake engineering; non-structural components; seismic design suspended ceilings

1. INTRODUCTION

Nonstructural building components are elements within or attached to buildings to provide them with essential services and functions, such as heating and cooling, lighting, escalators, electrical power, etc. These components are not a part of the building structural system, and are not designed to contribute to the resistance of earthquake forces. In most building codes, nonstructural components are commonly grouped into two categories: (1) *architectural*, and (2) *mechanical and electrical*. *Architectural* nonstructural components include, for instance, cladding, suspended ceilings, exterior and interior nonbearing walls and partitions, parapets, penthouses, etc. *Mechanical and electrical* nonstructural components include most building secondary systems such as boilers, furnaces, storage tanks, HVAC systems, piping systems, elevator components, electrical systems, and lighting fixtures, etc.

In several past earthquakes, it has been documented that damage to both *architectural* and *mechanical* nonstructural building components can have a great effect on the safety of occupants, functionality of facilities, and loss of property. While statistical cost data for nonstructural damage are scarce, it is widely agreed and reported that the economic effects of all nonstructural damage combined generally exceed those of structural damage in an earthquake (U.S. Congress 1995; Seismic Safety Commission 1995). In many cases, these "indirect losses" due to damaged equipment, lost inventory and records, and revenue can be two to three times greater than the cost of replacing collapsed buildings or structures, as often reported in the 1971 San Fernando (Ayres and Sun 1973; Meehan 1973), the 1989 Loma Prieta (Shephard et al. 1990), and the 1994 Northridge earthquakes (Hall 1995).

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Nonetheless, most of the research efforts in seismic engineering to date have focused on improvements of the structural design of buildings to prevent total collapse, rather than on the performance of nonstructural components. This is consistent with the life-safety philosophy inherent in the model building codes in the United States and justifiably so, since the concern for total building collapse, which has more serious life safety implications, is naturally greater than the concern for local failure of nonstructural components. As a result, most newly constructed buildings stand a good chance that they will not collapse during an anticipated earthquake. It is only recently that more research attention has been paid to the performance of nonstructural components and secondary systems. The result is that many of the current model building codes and seismic provisions in use in the U.S., such as the 1994 Uniform Building Code (UBC 1994), the 1994 Standard Building Code (SBC 1994), and the 1994 National Earthquake Hazard Reduction Program (NEHRP) Recommended Provisions for Seismic Regulations for New Buildings (BSSC 1995a, 1995b), now contain revised and more stringent seismic design requirements for various nonstructural building components and equipment. For example, the 1994 NEHRP Recommended Provisions contains a new *Importance Factor* I_p and revised seismic force and displacement equations for nonstructural components based on recent actual earthquake performance data, which were not considered in the preceding NEHRP document (1991). However, most of the new design requirements and recommendations for nonstructural components have only recently been included in the U.S. building codes (1994 editions). The effectiveness of these new requirements or recommendations in limiting damage to nonstructural components is not yet known because implementation of these new provisions has just started, and there has not been a major earthquake in the United States since 1994 to allow a thorough assessment.

Numerous instances of damage to nonstructural components during past earthquakes have been reported (Ayres and Sun 1973; Meehan 1973; Shephard et al. 1990; Hall 1995). Typical damage includes failures of suspended ceilings, lighting fixtures, piping systems, mounting fixtures and anchors for equipment, cladding, partitions, etc. Much of this damage reportedly resulted from two main causes aside from being the direct result of structural failure. One cause is the incompatibility of movement between the building and nonstructural components and also between different nonstructural components which were installed in close proximity to one another. The other cause is the inadequacy of nonstructural components (mainly the support conditions and the mounting fixtures) to sustain seismic lateral load.

Among instances of damage due to displacement incompatibility are damage to suspended ceilings and other components located in or above suspended ceilings in commercial office buildings. These components include the suspended acoustical tile ceiling itself; fire sprinkler systems; light fixtures; and HVAC ducts. Problems arise because these components are co-located in the ceiling area, and their movements during an earthquake are often incompatible due to differences in the component flexibility. For example, fire sprinkler heads usually project through suspended acoustical tile ceilings. During an earthquake, if the movements of the suspended ceiling and the sprinkler pipes are incompatible, either the sprinkler heads or the suspended ceiling, or both, will be damaged. Not only does this decrease the ability of the sprinkler system to suppress post-earthquake fires, but it also may result in broken sprinkler heads and flooding of the building. Another example is distortion of the acoustical tile ceiling grid, which may cause ceiling tiles, lighting fixtures, and ventilation grills resting in the grid to fall.

Examples of damage due to the inadequacy of nonstructural components to sustain seismic lateral force include failures of anchors to hold equipment in place, such as water tanks and boilers. This results in equipment sliding off supports, spilling of contents, and disruption of service. Other nonstructural damage of this type includes failure of light fixtures and suspended ceilings at points of connection, and cracks in partition walls.

The objectives of this paper are to assess the current state of knowledge in seismic design of nonstructural building components, as reflected in various model building codes currently in use in the United States and other countries.

2. CODES FOR SEISMIC DESIGN OF NONSTRUCTURAL COMPONENTS

This section summarizes the seismic requirements for the design of nonstructural components, in terms of lateral force and displacement, of four building codes with earthquake provisions currently in use in three countries; the United States, New Zealand, and Japan. In the U.S., the codes reviewed include two of the national model codes, namely the 1994 Uniform Building Code (UBC 1994) of the International Conference of Building Officials, and the 1994 Standard Building Code (SBC 1994) of the Southern Building Code Congress International. In New Zealand, the 1992 New Zealand Standard (NZS 1992) is reviewed. And in Japan, two seismic building codes are reviewed: (1) the Guideline for Seismic Design of Building Nonstructural Components published by Public Buildings Association in 1987 (see IAEE 1992), and (2) Guideline for Seismic Design of Building Equipment published by Building Center of Japan in 1984 (see Hirosawa et al. 1991). Also reviewed is the 1994 NEHRP Recommended Provisions for Seismic Regulations for New Buildings (BSSC 1995a, 1995b). The NEHRP Recommended Provisions contain seismic design provisions to be considered for adoption in a future version of the national model codes. The following review of codes and recommended provisions is intended to reveal the variation in seismic design requirements for nonstructural components between different codes of practice. Provisions and design information relevant to the design of nonstructural components of each of the above listed documents are summarized below.

2.1 Uniform Building Code (UBC 1994)

2.1.1 Seismic Force Requirement

Permanent nonstructural components and their attachments shall be designed to resist the total design lateral seismic force, F_p, prescribed below:

$$F_p = ZI_pC_pW_p \quad \text{(UBC 1994 equation 30-1)}$$

where:

Z is the seismic zone factor, which ranges between 0.075 (seismic zone 1) to 0.40 (seismic zone 4). Values of Z for different seismic zones and seismic zone designation are given in UBC 1994 Table 16-I and UBC 1994 Figure 16-2.

I_p is the seismic importance factor for nonstructural components and their attachments. Values of I_p corresponding to different UBC occupancy categories are listed in UBC 1994 Table 16-K.

C_p is the horizontal force factor. Values of C_p for nonstructural components are given in UBC 1994 Table 16-O. C_p varies between 0.75 (for most mechanical and electrical equipment) to 2.0 (for exterior and interior ornamentation and appendages, signs and billboards, etc.).

W_p the weight of an element or component.

2.1.2 Seismic Displacement Requirement

UBC 1994 is less specific with requirements for seismic displacements of nonstructural components. In general, UBC 1994 requires that, for Essential and Hazardous Facilities (building categories 1 and 2), the lateral-force design shall consider the effects of relative motion of the points of attachment to the structure.

2.2 Standard Building Code (SBC 1994)

2.2.1 Seismic Force Requirement

The 1994 SBC provides two different sets of seismic force requirement for nonstructural components, one for architectural components and their attachments, and one for mechanical, electrical components and their attachments.

For architectural components and their attachments, the design seismic force F_p is determined as follows:

$$F_p = A_v C_c P W_c$$

For mechanical, electrical components and their attachments, the design seismic force F_p is determined as follows:

$$F_p = A_v C_c P a_c W_c$$

where:

A_v is the effective peak velocity-related acceleration ($0.05 \leq A_v \leq 0.40$), to be selected from 1994 SBC Figure 1607.1.5A, *Contour Map of Effective Peak Velocity-Related Acceleration Coefficient.*

C_c is the Seismic Coefficient from 1994 SBC Tables 1607.6.3 (for architectural components and their attachments) and 1607.6.4A (for mechanical, electrical components and their attachments).

P is the Performance criteria factor, varied with seismic hazard exposure group (I to III) and determined from 1994 SBC Tables 1607.6.3 for architectural components and their attachments and 1607.6.4A for mechanical, electrical components and their attachments. Table 1607.1.6 of the 1994 SBC lists the seismic hazard exposure group for buildings.

a_c is the attachment amplification factor, determined in accordance with 1994 SBC Table 1607.6.4B. The value of a_c is either 1.0 or 2.0.

W_c is the operating weight of the nonstructural component.

2.2.2 Seismic Displacement Requirement

The 1994 SBC provides two sections dealing with seismic displacement requirements for nonstructural building components, one for *architectural* components (1994 SBC section 1607.6.3.2) and the other for the attachment of *mechanical and electrical* (1994 SBC section 1607.6.4.2) components. For *architectural components*, deformation due to design story drift Δ_m, computed as the difference between story-level displacements δ_{xm}, shall be considered. δ_{xm} is computed as follows (1994 SBC section 1607.5.6):

$$\delta_{xm} = C_d \delta_{xem}$$

and,

$$\delta_{xem} = (g/[4\pi^2])(T_m{}^2 F_{xm}/w_x)$$

Where:

δ_{xem} is the deflection of level x in the m^th^ mode at the center of the mass at level x.

C_d is the deflection amplification factor (given in 1994 SBC Table 1607.3.3).

g is the acceleration due to gravity (feet per second^2).

T_m is the modal period of vibration, in seconds, of the m^{th} mode of the building.

F_{xm} is the portion of the seismic base shear in the m^{th} mode, induced at level x.

w_x is the portion of the total gravity load of the building, W, located or assigned to level x.

For *mechanical and electrical* components, the 1994 SBC requires that relative seismic displacements between two points of support (or points of attachment) of these components be considered and accommodated. In calculating the relative seismic displacements between points of support, the difference in elevation between the supports and the out-of-phase displacements across portions of the building that are capable of moving in a differential manner such as at seismic and expansion joints, are to be considered (1994 SBC section 1607.6.4.2). Displacements at points of support shall be computed as described above.

$$\delta_{xem} = (g/[4\pi^2])(T_m{}^2 F_{xm}/W_x)$$

Where:

δ_{xem} is the deflection of level x in the m^{th} mode at the center of the mass at level x.

g is the acceleration due to gravity (feet per second^2).

T_m is the modal period of vibration, in seconds, of the m^{th} mode of the building.

F_{xm} is the portion of the seismic base shear in the m[th] mode, induced at level x.

W_x is the portion of the total gravity load of the building, W, located or assigned to level x.

2.3 New Zealand Standard (NZS 4203: 1992)

2.3.1 Seismic Force Requirement

The horizontal seismic force, F_{ph}, on nonstructural components of a building (referred to as parts of the building) shall be determined from:

$F_{ph} = C_{ph} W_p R_p$ (NZS eqn. 4.12.1)

The vertical seismic force, F_{pv}, on nonstructural components of a building shall be determined from:

$F_{pv} = C_{pv} W_p R_p$ (NZS eqn. 4.12.2)

where:

W_p is the weight of the nonstructural components or their attachments.

R_p is the risk factor for nonstructural components or attachments, NZS Tables 2.3.2 and 4.12.1.

C_{ph} is the seismic coefficient, which shall be taken equal to the basic horizontal coefficient C_{pi} (basic horizontal coefficient for nonstructural components and attachments at level i). C_{pi} shall be computed as follows:

$C_{pi} = C_b(T_{pe}, \mu_p) C_{fi}/0.4$ (NZS eqn. 4.12.7)

and,

μ_p is the structural ductility factor for the nonstructural components. Values for μ_p corresponding to various nonstructural component are listed in NZS 4203 Table C4.12.1. μ_p = 1.0 for connections for machinery, switch gear and the like.

$C_b(T_{pe}, \mu_p)$ is the basic seismic acceleration coefficient for intermediate soil and T_{pe} is the equivalent period of the nonstructural components given by = $0.2\ T_p/T_1$ but not to be taken less than 0.4 s. T_1 is the fundamental translational period of vibration of the structure (NZS 4203 Section 4.5.2).

Tabulated values of C_b corresponding to different values of T_p and μ_p are given in NZS 4203 Table 4.6.1.

C_{fi} is the floor acceleration coefficient at levels between the building base and the uppermost principal seismic weight. C_{fi} shall be determined by either the equivalent static method (NZS equation 4.12.5) or the modal response spectrum method (NZS equation 4.12.6) listed below:

$$C_{fi} = \frac{C_b(T_1, \mu_0)}{C_b(T_1, 1)} C_{fo} \left(1 - \frac{h_i}{h_n}\right) + C_{fn} \left(\frac{h_i}{h_n}\right)$$

(NZS 4203 equation 4.12.5)

or

$$C_{fi} = \frac{C_b(T_1, \mu_0)}{C_b(T_1, \mu)} \frac{F_1}{W_1}$$

(NZS 4203 equation 4.12.6)

μ_0 is the structural ductility factor calculated using the overstrength values (NZS 4203 Section 4.12.2). C_{fo} is the floor acceleration coefficient at and below the base of the building. C_{fo} may be computed as follows:

$C_{fo} = 0.4\ RZL_s$ for the serviceability limit state (NZS equation 4.12.3(a)), or
$C_{fo} = 0.4\ RZL_u$ for the ultimate limit state (NZS 4.12.3(b)).

C_{fn} is the floor acceleration coefficient at the level of the uppermost principal seismic weight. C_{fn} may be computed as follows:

$$C_{fn} = \frac{C_b(T_1, \mu_0)}{C_b(T_1, \mu)} \frac{F_n}{W_n}$$

R is the building risk factor, listed in NZS Tables 2.3.1 and 4.6.3.

Z is the zone factor ($0.4 \le Z \le 0.8$), shown in NZS Figure 4.6.2.

L_s, L_u are limit state factors for serviceability state (1/6) and ultimate state (1.0), respectively.

F_i is the equivalent static lateral force at level i; or inertial force at level i found from combination of modal inertial force.

F_n is the inertial force at the height of the uppermost principal seismic weight, h_n.

h_i is the height of level i above the level where the ground provides lateral restraint to the structure.

h_n is the height from the base of the building to the level of the uppermost principal seismic weight.

C_{pv} is taken as RZL_s for the serviceability limit state and RZL_u for the ultimate limit state.

An alternate method for obtaining C_{ph} (or C_{pi}) without having to use NZS equation 4.12.7 is to read the normalized values of C_{ph} from NZS Table C4.12.2. These values were calculated for the following assumptions:

- Each structure has equal story heights and weights.
- The fundamental period, T_1, is not less than the greater of 0.6 s and 0.10*n*, where *n* is the number of stories.
- The nonstructural components, with their connections, are stiff ($T_p = 0$, $T_{pe} = 0.45$ s).
- The structures are sited on flexible or deep soil sites.

2.3.2 Seismic Displacement Requirement

The seismic displacement requirement of NZS 4203 is less specific than the seismic force requirement. In general, NZS requires that "*deflections of parts (nonstructural components) under the prescribed seismic forces shall be limited so as not to impair their strength or function, or lead to damage to other building components*" (NZS 4203 Section 4.12.1.7). Connections between nonstructural components and the building structure shall be designed to accommodate the interstory deflections determined by either the equivalent static method (NZS 4203 section 4.8), the modal response spectrum method (NZS 4203 section 4.9), or the numerical integration time history method (NZS 4203 section 4.10).

2.4 1994 NEHRP Recommended Provisions for Seismic Regulations for New Buildings (BSSC 1995a, 1995b)

The seismic force and displacement requirements for nonstructural building components (including architectural, mechanical, and electrical components) prescribed in this document (1994 edition) were completely revised from the previous edition (NEHRP 1991). The changes include introduction of the component importance factor I_p and new force and displacement equations. Specific requirements for relative seismic displacement are recommended and a more rational basis for connection design is provided.

2.4.1 Seismic Force Requirement

All nonstructural components and their attachments shall be designed for the seismic force, F_p, centered at the component's center of gravity and distributed relative to the component's mass distribution, described herein (1994 NEHRP section 3.1.3):

$$F_p = 4.0C_aI_pW_p \quad \text{(NEHRP eqn. 3.1.3-1)}$$

Alternately, F_p may be computed in accordance with the following equations:

$$F_p = a_pA_pI_pW_p/R_p \quad \text{(NEHRP eqn. 3.1.3-2)}$$

and

$$F_{p(min)} = 0.5C_aI_pW_p \quad \text{(NEHRP eqn. 3.1.3-5)}$$

where:

C_a is the seismic coefficient at grade, expressed as a fraction of acceleration of gravity and determined based on Soil Profile type (A to E) and the effective peak ground acceleration coefficient A_a (determined from NEHRP seismic ground acceleration map 1). C_a may be obtained as described in NEHRP section 1.4.2.3 or from NEHRP Table 1.4.2.4a. The maximum value of C_a is 0.44 (for soil type D).

I_p is the component importance factor which represents the greater of the life-safety importance of the component and the hazard exposure importance of the structure. I_p is either 1.0 or 1.5. I_p is 1.0 for all nonstructural components and their attachments except for those components listed below, in which case I_p is 1.5:

- Life-safety component that is required to function after an earthquake.
- Component contains material that would be significantly hazardous if released.
- Component poses a significant life-safety hazard if separated from primary structure (e.g., parapets, exterior wall panels).
- Component can block a means of egress if damaged (e.g., exit stairs).

W_p is the component operating weight.

a_p is the component amplification factor which represents the dynamic amplification of the component relative to the fundamental period of the structure (T). a_p varies from a minimum value of 1.0 to a maximum of 2.5. NEHRP provides two sets of a_p values, one for architectural components and their attachments as listed in NEHRP Table 3.2.2 and one for mechanical and electrical components and their attachments as listed in NEHRP Table 3.3.2. In both cases, the value of $a_p = 1$ is for components generally regarded as rigid or rigidly attached. The value of $a_p = 2.5$ is for components generally regarded as flexible or flexibly attached.

R_p is the component response modification factor, representing the energy absorption capability of the component's structure and attachments. Current R_p values, listed in NEHRP Tables 3.2.2 for architectural components and their attachments and NEHRP Table 3.3.2 for mechanical and electrical components and their attachments, are judgmentally determined based on the experience of the responsible committee and vary from 1.5 to 6.0. In general, a higher value of R_p is associated with more ductile materials and detailing.

A_p is the component acceleration coefficient at point of attachment to the structure, expressed as a fraction of gravity. A_p may be computed using the following equations :

$$A_p = C_a + (A_r - C_a)(x/h)$$

(NEHRP eqn. 3.1.3-3)

where:

A_r is the component acceleration coefficient, expressed as a fraction of gravity, at the structure roof level. A_r may be computed as follows:

$A_r = 2.0A_s \leq 4.0C_a$ (NEHRP eqn. 3.1.3-4)

A_s is the structure response acceleration coefficient, expressed as a fraction of gravity. A_s shall be computed for each principle horizontal direction of the structure using the equation listed below. The larger value of A_s shall be used in computing A_r.

$$A_s = 1.2\frac{C_v}{T^{2/3}} \leq 2.5C_a$$

(NEHRP eqn. 3.1.3-7)

C_v is the seismic coefficient, expressed as a fraction of acceleration of gravity and determined based on Soil Profile Type (A to E) and the effective peak velocity-related acceleration A_v (may be obtained from NEHRP map 2). C_v may be obtained in accordance with 1994 NEHRP section 1.4.2.3 or from 1994 NEHRP Table 1.4.2.4b. The maximum value of C_v is 0.96 (for Soil Profile Type E).

T is the effective fundamental period of the structure.

x is the elevation of nonstructural component relative to grade elevation.

h is the average roof elevation of structure relative to grade elevation.

2.4.2 Seismic Displacement Requirement

Seismic relative displacement D_p between two connection points on the same building or structural system shall be designed to accommodate the smaller of the following two equations (1994 NEHRP section 3.1.4):

$$D_p = \delta_{xA} - \delta_{yA}$$

(NEHRP equation 3.1.4-1)

or

$$D_p = (X - Y)\Delta_{aA}/h_{sx}$$

(NEHRP equation 3.1.4-2)

For two connection points on separate buildings or structural systems (e.g.

connection points across an expansion joint), D_p shall be designed to accommodate the smaller of the following equations:

$$D_p = |\delta_{xA}| + |\delta_{yB}|$$

(NEHRP equation 3.1.4-3)

or

$$D_p = X\Delta_{aA}/h_{sx} + Y\Delta_{aB}/h_{sx}$$

(NEHRP equation 3.1.4-4)

where:

δ_{xA} is the deflection at building level x of Building A, determined from elastic analysis and multiplied by the deflection amplification factor C_d. C_d values for different structural systems are listed in 1994 NEHRP Table 2.2.2.

δ_{yA} is the deflection at building level y of Building A, determined from elastic analysis and multiplied by the C_d factor.

δ_{xB} is the deflection at building level x of Building B, determined from elastic analysis and multiplied by the C_d factor.

δ_{yB} is the deflection at building level y of Building B, determined from elastic analysis and multiplied by the C_d factor.

X is the height of upper support attachment at level x as measured from grade.

Y is the height of lower support attachment at level y as measured from grade.

Δ_{aA} is the allowable story drift for Building A as defined in 1994 NEHRP Table 2.2.7.

Δ_{aB} is the allowable story drift for Building B as defined in 1994 NEHRP Table 2.2.7.

h_{sx} is the story height used in the definition of the allowable drift, Δ_a, in 1994 NEHRP Table 2.2.7. Δ_a/h_{sx} is the allowable drift index.

The 1994 NEHRP Recommended Provisions also prescribe required clearances for suspended ceiling and other ceiling components such as fire sprinkler heads and light fixtures.

2.5 Seismic Building Codes of Japan (IAEE 1992 and Hirosawa et al. 1991)

Seismic design requirements for building mechanical equipment and nonstructural components are provided by two documents: (1) *Guideline for Aseismic Design and Construction of Building Equipment*, published by the Building Center of Japan (1984) and (2) *Guideline for Aseismic Design for Architectural Nonstructural Elements*, published by Public Building Association (1987). The coefficients used in determining the design seismic force are similar between these two guidelines when the *Modified Seismic Coefficient Method* is used as the design method. The requirements for nonstructural components and building equipment are described below.

2.5.1 Seismic Force Requirement

Nonstructural components and their attachments shall be designed to resist the total lateral design seismic force, F_H, which was prescribed based on the modified seismic force coefficients method:

$$F_H = K_H W$$

and

$$K_H = ZIK_1K_2k_0$$

where:

K_H is the lateral design seismic force coefficient.

W is the weight of the nonstructural component or equipment (in units of kgf).

Z is the seismic zone factor. $Z = 1.0$ for Seismic Zone A, 0.85 for Seismic Zone B, and 0.70 for Seismic Zone C.

I is the seismic importance reduction factor. $I = 1.0$ for important building equipment, and 2/3 for general building equipment. Building owners and structural designers can determine importance and select the appropriate value for I.

K_1 is the floor response amplification factor of a building, which varies between 1.0 and 3.33. $K_1 = 1.0$ at the basement floor and 3.33 at the roof level.

K_2 is the response amplification factor of the nonstructural component or equipment. Specific values of K_2 are provided for some architectural components. In general, K_2 ranges between 1.0 and 2.0.

k_0 is the standard design seismic force coefficient (0.3).

The value of $I \cdot K_1 \cdot K_2 \cdot k_0$ shall be not less than 0.6 for important nonstructural components and 0.3 for ordinary nonstructural components.

The vertical design seismic force, F_v, shall be determined by the following formula:

$$F_V = K_V W$$

where K_V is the vertical design seismic force coefficient ($K_V = K_H/2$).

2.5.2 Seismic Displacement Requirement

Similar to other codes, seismic displacement requirements are not as specific as the seismic force requirements. The current building codes of Japan require that for pipes, vertical pipes shall be subjected to a maximum story drift of 1/200 radian times the story height. Pipes through expansion joints shall be designed for possible maximum relative displacement between two structures.

2.6 Summary of Codes

Provisions relevant to the seismic design requirements for nonstructural building components of five seismic engineering documents, which include the 1994 Uniform Building Code, the 1994 Standard Building Code, the 1994 NEHRP Recommended Provisions, the 1992 New Zealand Standard (NZS 4203), and the 1982 and 1987 Japanese codes, are reviewed and summarized in sections 2.1 to 2.5. The review shows wide variations in seismic design requirements between codes, both in terms of seismic force and displacement calculations and in listings of nonstructural components and corresponding coefficients.

For the *seismic force requirement*, the building codes use three basic coefficients to account for the following factors in prescribing the design force:

- Seismicity of the region where the building is located (*seismic zone factor,* or *effective peak-velocity acceleration,* or *component acceleration coefficient*).
- Functionality of nonstructural components and buildings in terms of life-safety importance (*seismic importance factor*, or *component risk factor*, or *component performance criteria*).
- Response characteristics of nonstructural components to seismic lateral load (*component seismic coefficient*, or *component horizontal force factor*, or *component response amplification factor*).

The above three factors are considered in the seismic force requirements of the 1994 UBC, 1994 SBC, and in equation 3.1.3-1 of the 1994 NEHRP Recommended Provisions. Other factors not explicitly included in the seismic design requirements of the above three codes, but which are explicitly considered in the 1992 NZS 4203, the 1982 and 1987 Japanese building codes, and in equation 3.1.3-2 of the 1994 NEHRP Recommended Provisions are:

- Response characteristics of the building to seismic lateral load (*building seismic coefficient*).
- Site soil profile (*building seismic coefficient*).
- Component location relative to building height (*floor response amplification factor*).

Table 2.1 summarizes the coefficients affecting the calculation of seismic lateral force of the codes reviewed. In terms of level of detail, the seismic design requirements of the 1994 NEHRP Recommended Provisions (equation 3.1.3-2) and the 1992 NZS 4203 appear to require the most detailed information for the calculation of design lateral force for nonstructural components. Of all five documents reviewed, only the 1994 NEHRP Recommended Provisions provides two alternate methods for computing the seismic lateral force requirement.

For the *seismic displacement requirement*, the 1994 SBC and the 1994 NEHRP Recommended Provisions are more specific than other building codes in prescribing the required seismic lateral displacement. Both of these documents provide formulas for calculating the displacement at points of support for nonstructural components. The 1994 NEHRP Provisions also specifically prescribe detailed requirements for clearance between co-located ceiling components, such as clearance between suspended ceiling and fire sprinkler heads. The 1994 UBC, New Zealand Standard NZS 4203, and the 1982 and 1987 seismic building codes of Japan are less precise in prescribing seismic displacement requirements for nonstructural building components. In general, all codes require that attention be paid to the relative displacement between connection points of nonstructural components, especially connection points that are located on separate structural systems or buildings (anchors for piping systems crossing expansion joints, for example).

3. COMPARISON OF CODE SEISMIC DESIGN REQUIREMENTS

3.1 Introduction

As was shown in Section 2, there are noticeable variations in code requirements for nonstructural building components, both in terms of level of detail in the requirements and in the calculation procedures. Some codes have more detailed descriptions of nonstructural building components and assign more specific coefficients to various components, while others are less specific in listing the applicable components. In such cases the seismic coefficients necessary for computing seismic lateral force and displacement requirements must be estimated.

In the following sections, comparison of cases where maximum seismic forces are required by the codes reviewed in Section 2 will be conducted. The difference in seismicity in different countries is accounted for by using the maximum local seismic zone factors for the appropriate countries. Comparison of seismic displacement requirement also will be discussed.

3.2 Comparison of Maximum Seismic Force Requirement

Table 3.1 summarizes the seismic lateral force requirements and the conditions which result in maximum seismic force requirements for various nonstructural components by the four building codes and the 1994 NEHRP Recommended Provisions. The components listed in Table 3.1 are selected from the 1994 SBC list of nonstructural components, since this code appears to have the most detailed list and description of the components. For uniformity, different terminologies between codes which refer to the same quantity are made consistent in Table 3.1. For example, W_p is used for all codes in Table 3.1 to refer to the weight of nonstructural components, instead of W_c as used in the 1994 SBC. The 1994 NEHRP Recommended Provisions provide two different methods for computing the seismic lateral force requirement for nonstructural building components. One is given in NEHRP equation 3.1.3-1 which does not consider the component's amplification and response modification factors, while the other, given in NEHRP equation 3.1.3-2, considers these factors. Thus, two columns which list seismic force requirements according to the two methods of 1994 NEHRP Recommended Provisions are provided in Table 3.1.

As seen from Table 3.1, significant variations in maximum lateral force requirements exist between codes. In terms of *maximum seismic force requirements*, the 1994 NEHRP Recommended Provisions equation 3.1.3-1 appears to be most stringent. Next are the 1992 New Zealand Standard NZS 4203 and the Japanese building codes (1982 and 1987). The 1994 SBC is as stringent as NEHRP equation 3.1.3-1 and even more stringent than the NZS 4203 and the Japanese codes when dealing with safety equipment such as fire protection equipment and pipe systems. For other components, the 1994 SBC seismic force requirements are in general less conservative than those of the above codes. The 1994 UBC appears to be the least stringent of all building codes and recommended provisions reviewed. The difference in level of seismic force requirement between the codes can be more than five times for some components. For example, maximum seismic force requirements for fire protection equipment and system vary from $0.45W_p$ to $2.64W_p$ between the 1994 UBC and equation 3.1.3-1 of the 1994 NEHRP Recommended Provisions.

3.3 Comparison of Seismic Displacement Requirement

Numerical comparison of code-prescribed seismic displacement requirements is not possible since the calculation for displacement of nonstructural building components requires case-specific information such as building mode of vibration, modal period, and base shear, etc. Thus comparisons similar to section 3.2 are not conducted here. Instead, only a general discussion is presented here for comparative purposes.

The 1994 NEHRP Recommended Provisions provide the most detailed seismic displacement requirements compared to other building codes reviewed. Besides formulas prescribing the relative seismic displacement between connection points for nonstructural components on the same building (NEHRP equations 3.1.4-1 and 3.1.4-2) and on separate buildings (NEHRP equations 3.1.4-3 and 3.1.4-4), NEHRP Provisions also prescribe clearances for co-locating systems such as suspended ceiling and fire sprinkler heads.

The 1994 SBC provides specific formulae for computing seismic displacement for nonstructural components. SBC's *architectural components* are required to accommodate design story drift, which is computed as the difference between story-level displacements. In computing story-level displacement, SBC considers *deflection amplification* of different seismic resisting systems.

Seismic displacement requirements of other codes besides the 1994 NEHRP and the 1994 SBC are much less specific. In general, all codes require that differences in elevations and in structural systems between connection points shall be considered in computing seismic displacement of connection points.

4. CONCLUSIONS

Widespread damage sustained by nonstructural components, especially components related to ceilings, during recent earthquakes has illustrated the continuing need for evaluation of existing seismic design requirements and for development of methods to mitigate losses caused by damage to these nonstructural components. Despite the widespread damage reported in post earthquake surveys, only a handful of studies focusing on nonstructural performance has been identified.

There are wide variations in seismic design requirements for nonstructural building components between the two current U.S. national model building codes (the 1994 UBC, which is adopted in part by much of the western U.S., and the 1994 SBC, which is adopted in part by the southeastern U.S.), the 1992 New Zealand Standard NZS 4203, the current building codes of Japan (1982 and 1987), and the 1994 NEHRP Recommended Provisions for Seismic Regulations for New Buildings.

In terms of levels of detail, the 1994 UBC, 1994 SBC and 1994 NEHRP equation 3.1.3-1 appear to be simplest, with three factors considered for calculation of the seismic force requirement: (1) factor to account for *seismicity of regions*, (2) factor to account for *functionality of nonstructural components and buildings*, and (3) factor to account for *response characteristics of nonstructural components*. While the 1994 NEHRP equation 3.1.3-2, the 1992 NZS 4203, and the Japanese building codes require, in addition to the above three factors, more detailed information such as the *seismic response characteristics of the building*, *site soil profile* information, and *component location* relative to building height. Also, the 1994 SBC and the 1994 NEHRP Provisions are more specific in prescribing the seismic displacement requirements and clearances for nonstructural components than other building codes reviewed in this report.

In terms of levels of stringency, the variation between the most and least stringent seismic force requirement can be more than five times. The most stringent seismic force requirement is that of the 1994 NEHRP document. Next in stringency is the 1992 New Zealand Standard NZS 4203, and then the Japanese building codes. The least conservative code with respect to seismic force requirements for nonstructural building components is the 1994 UBC. The UBC also appears to lack the flexibility in assigning different levels of importance to different nonstructural components.

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Table 2.1 **Coefficients Affecting Seismic Force Requirements in Various Building Codes**

Coefficients to account for ⇓	**1994 UBC**	**1994 SBC**	**1994 NEHRP Eq. 3.1.3-1**	**1994 NEHRP Eq. 3.1.3-2**	**NZS 4203**	**Japan**
1) Seismicity of Region Where Buildings are Located	• Seismic Zone Factor: Z (0.075 - 0.4)	• Effective Peak-Velocity Acceleration: A_v (0.05 - 0.4)	• Seismic Coefficient: C_a (0.04 - 0.44) (varies with soil type)	• Component Acceleration Coefficient: A_p ($\leq 4.0\ C_a$)	• Seismic Zone Factor: Z (0.4 - 0.8)	• Seismic Zone Factor: Z (0.7 - 1.0)
2) Functionality of Components in Terms of Life-Safety Importance	• Seismic Importance Factor: I_p (1.0 - 1.5) (varies with Occupancy Category)	• Performance Criteria Factor: P (0.5 - 1.5) (varies with Seismic Hazard Exposure Group)	• Component Importance Factor: I_p (1.0 - 1.5) (varies with degree of affect on life-safety)	• Component Importance Factor: I_p (1.0 - 1.5) (varies with degree of affect on life-safety)	• Component Risk Factor: R_p (1.0 - 1.1) (varies with degree of affect on life-safety). • Building Risk Factor: R (0.6 - 1.3)	• Seismic Importance Reduction Factor: I (1.0 or 2/3)

Table 2.1 (**continued**)

Coefficients to account for ⇓	1994 UBC	1994 SBC	1994 NEHRP Eq. 3.1.3-1	1994 NEHRP Eq. 3.1.3-2	NZS 4203	Japan
3) Component Seismic Response Characteristics	• Horizontal Force Factor: C_p (0.75 - 2.0)	• Component Seismic Coefficient: C_c (0.6 - 3.0) • Attachment Amplification Factor: a_c (1.0 - 2.0)	• Implied in constant: 4.0	• Component Amplification Factor: a_p (1.0 - 2.5) • Component Response Modification Factor: R_p (1.5 - 6.0)	• Implied in Seismic Coefficient: C_{ph} (through component ductility factor μ_p)	• Response Amplification Factor: K_2 (1.0 - 2.0)
4) Building Response Characteristics and Soil Site Profile	• Not explicitly considered	• Not explicitly considered	• Not explicitly considered	• Implied in Component Acceleration Coefficient: A_p	• Implied in Seismic Coefficient: C_{ph}	• Not explicitly considered
5) Component Location Relative to Building Height	• Not considered	• Not considered	• Not considered	• Implied in Component Acceleration Coefficient: A_p	• Implied in Seismic Coefficient: C_{ph}	• Floor Response Amplification Factor: K_1 (1.0 - 10/3) (varies with height)

Table 3.1 **Comparison of maximum seismic force requirement of various codes**

CODES	1994 UBC	1994 SBC	NZS 4203 (1992)	1994 NEHRP		1987 JAPAN
CONDITIONS FOR MAXIMUM SEISMIC FORCE REQUIREMENTS	• Structures are located in Seismic Zone 4 (Z=0.4). • Structures are Essential & Hazardous facilities, or Standard Occupancy Structures with anchorage of machinery and equipment for life-safety systems (I_p=1.5).	• Structures are located in regions where Effective Peak Velocity-related Acceleration Coefficient, A_v = 0.4. • Structures are of Seismic Hazard Exposure Group III. • Resilient mounting systems are of the types which cause Attachment Amplification Factor a_c to be 2.0.	• Structures are located in regions of maximum Zone Factor (Z=0.8). • Components and attachments are designated as P.I and P.II (R_p = 1.1).	• Structures are located at sites with Soil Profile Type D and Effective Peak Ground Acceleration Coefficient A_a = 0.4 (C_c = 0.44). • Structures are located in regions where Effective Peak Ground Acceleration Coefficient A_a = 0.4.		• Structures are located in seismic zone A (Z = 1.0). • Equipment/ components are designated as Important Building Equipment. • Equipment/ components are located at top level of building (K_i = 10/3).
1. Exterior nonbearing walls	$0.45W_p$	$0.54W_p$	$0.60W_p$	$1.76W_p$[d]	$0.88W_p$[e]	$1.33W_p$
2. Wall attachments	$1.2W_p$	$1.8W_p$	$2.2W_p$	$1.76W_p$[d]	$0.88W_p$[e]	$1.33W_p$
3. Veneer connections	$1.2W_p$	$1.2W_p$	$2.2W_p$	$1.76W_p$[d]	$1.76W_p$[e]	$1.33W_p$
4. Fire protection equipment and systems	$0.45W_p$	$2.4W_p$	$2.2W_p$[a]	$2.64W_p$[d]	$1.65W_p$[e]	$2.0W_p$
5. Pipe systems	$0.45W_p$	$2.4W_p$[b]	$2.2W_p$[a]	$2.64W_p$[d]	$1.65W_p$[e]	$2.0W_p$
6. Suspended ceilings	$0.45W_p$	$0.54W_p$[c]	$2.0W_p$[a]	$2.64W_p$[d]	$1.76W_p$[e]	$1.33W_p$
7. Lighting fixtures	$0.45W_p$	$0.804W_p$	$2.0W_p$[a]	$1.76W_p$[d]	$1.76W_p$[e]	$1.33W_p$

Notes: [a] Computed with μ_p assumed to equal 1.0 since values of μ_p for these components are not available in the 1992 NZS 4203.
[b] Pipe systems for gas and high hazard piping.
[c] For fire-rated membrane.
[d] Computed using 1994 NEHRP equation 3.1.3-1, $F_p = 4.0 C_a I_p W_p$.
[e] Computed using 1994 NEHRP equation 3.1.3-2, $F_p = a_p A_a I_p W_p / R_p$