

## 2.5.15.3 Seismic design force

The seismic design force,  $F_c$ , applied in the horizontal direction shall be centered at the component's center of gravity and distributed relative to the component's mass distribution and shall be determined as follows:

$$F_c = \frac{\alpha_c a_h W_c I_c}{R_c} \left( 1 + 2 \frac{z}{h} \right) \quad (6.2.57)$$

Where,

$$0.75 a_h W_c I_c \leq F_c \leq 1.5 a_h W_c I_c$$

$\alpha_c$  = component amplification factor which varies from 1.0 to 2.5 (Table 6.2.22 or Table 6.2.23).

$a_h$  = expected horizontal peak ground acceleration (in g) for design = 0.67ZS

$W_c$  = weight of component

$R_c$  = component response reduction factor which varies from 1.0 to 12.0 (Table 6.2.22 or Table 6.2.23)

$z$  = height above the base of the point of attachment of the component, but  $z$  shall not be taken less than 0 and the value of  $z/h$  need not exceed 1.0

$h$  = roof height of structure above the base

The force  $F_c$  shall be independently applied in at least two orthogonal horizontal directions in combination with service loads associated with the component. In addition, the component shall also be designed for a concurrent vertical force of  $\pm 0.5 a_h W_c$ .

Where non-seismic loads on nonstructural components exceed  $F_c$  such loads shall govern the strength design, but the seismic detailing requirements and limitations shall apply.

## 2.5.15.4 Seismic relative displacements

The relative seismic displacement,  $D_c$  for two connection points on the same structure A, one at a height  $h_x$  and other at height  $h_y$ , for use in component design shall be determined as follows:

$$D_c = \delta_{xA} - \delta_{yA} \quad (6.2.58)$$

$D_c$  shall not exceed  $D_{c \max}$  given by:

$$D_{c \max} = \frac{(h_x - h_y) \Delta_{aA}}{h_{sx}} \quad (6.2.59)$$

Where,

$\delta_{xA}$  = Deflection at level x of structure A

$\delta_{yA}$  = Deflection at level y of structure A

$\Delta_{aA}$  = Allowable story drift for structure A

$h_x$  = Height (above base) of level x to which upper connection point is attached.

$h_y$  = Height (above base) of level y to which lower connection point is attached.

$h_{sx}$  = Story height used in the definition of the allowable drift  $\Delta_a$

For two connection points on separate structures, A and B, or separate structural systems, one at level x and the other at level y,  $D_c$  shall be determined as follows:

$$D_c = |\delta_{xA}| + |\delta_{yB}| \quad (6.2.60)$$

$D_c$  shall not exceed  $D_{c \max}$  given by:

$$D_{c \max} = \frac{h_x \Delta_{aA}}{h_{sx}} + \frac{h_y \Delta_{aB}}{h_{sy}} \quad (6.2.61)$$

Where,

$\delta_{yB}$  = Deflection at level y of structure B

$\Delta_{aB}$  = Allowable story drift for structure B

The effects of relative seismic relative displacements shall be considered in combination with displacements caused by other loads as appropriate.

#### 2.5.16 Design For Seismically Isolated Buildings

Buildings that use special seismic isolation systems for protection against earthquakes shall be called seismically isolated or base isolated buildings. Seismically isolated structure and every portion thereof shall be designed and constructed in accordance with the requirements of provisions presented in this Section.

#### 2.5.16.1 General requirements for isolation system

The isolation system to be used in seismically isolated structures shall satisfy the following requirements:

- (1) Design of isolation system shall consider variations in seismic isolator material properties over the projected life of structure including changes due to ageing, contamination, exposure to moisture, loadings, temperature, creep, fatigue, etc.
- (2) Isolated structures shall resist design wind loads at all levels above the isolation interface. At the isolation interface, a wind restraint system shall be provided to limit lateral displacement in the isolation system to a value equal to that required between floors of the structure above the isolation interface.
- (3) The fire resistance rating for the isolation system shall be consistent with the requirements of columns, walls, or other such elements in the same area of the structure.
- (4) The isolation system shall be configured to produce a lateral restoring force such that the lateral force at the total design displacement is at least 0.025 W greater than the lateral force at 50% of the total design displacement.
- (5) The isolation system shall not be configured to include a displacement restraint that limits lateral displacement due to the maximum considered earthquake to less than the total maximum displacement unless it is demonstrated by analysis that such engagement of restraint does not result in unsatisfactory performance of the structure.
- (6) Each element of the isolation system shall be designed to be stable under the design vertical load when subjected to a horizontal displacement equal to the total maximum displacement.
- (7) The factor of safety against global structural overturning at the isolation interface shall not be less than 1.0 for required load combinations. All gravity and seismic loading conditions shall be investigated. Seismic forces for overturning calculations shall be based on the maximum considered earthquake and the vertical restoring force shall be based on the seismic weight above the isolation interface.
- (8) Local uplift of individual units of isolation system is permitted if the resulting deflections do not cause overstress or instability of the isolator units or other elements of the structure.

- (9) Access for inspection and replacement of all components of the isolation system shall be provided.
- (10) The designer of the isolation system shall establish a quality control testing program for isolator units. Each isolator unit before installation shall be tested under specified vertical and horizontal loads.
- (11) After completion of construction, a design professional shall complete a final series of inspections or observations of structure separation areas and components that cross the isolation interface. Such inspections and observations shall confirm that existing conditions allow free and unhindered displacement of the structure to maximum design levels and that all components that cross the isolation interface as installed are able to accommodate the stipulated displacements.
- (12) The designer of the isolation system shall establish a periodic monitoring, inspection, and maintenance program for such system.
- (13) Remodeling, repair, or retrofitting at the isolation interface, including that of components that cross the isolation interface, shall be performed under the direction of a design professional experienced in seismic isolation systems.

**Table 6.2.22: Coefficients  $\alpha_c$  and  $R_c$  for Architectural Components**

Architectural Component or Element	$\alpha_c^a$	$R_c$
Interior Nonstructural Walls and Partitions		
Plain (unreinforced) masonry walls	1.0	1.5
All other walls and partitions	1.0	2.5
Cantilever Elements (Unbraced or braced to structural frame below its center of mass) Parapets and cantilever interior nonstructural walls	2.5	2.5
Chimneys and stacks where laterally braced or supported by the structural frame	2.5	2.5
Cantilever Elements (Braced to structural frame above its center of mass)		
Parapets	1.0	2.5
Chimneys and Stacks	1.0	2.5
Exterior Nonstructural Walls	1.0	2.5

Architectural Component or Element	$\alpha_c^a$	$R_c$
Exterior Nonstructural Wall Elements and Connections		
Wall Element	1.0	2.5
Body of wall panel connections	1.0	2.5
Fasteners of the connecting system	1.25	1.0
Veneer		
Limited deformability elements and attachments	1.0	2.5
Low deformability elements and attachments	1.0	1.5
Penthouses (except where framed by an extension of the building frame)	2.5	3.5
Ceilings		
All	1.0	2.5
Cabinets		
Storage cabinets and laboratory equipment	1.0	2.5
Access Floors		
Special access floors	1.0	2.5
All other	1.0	1.5
Appendages and Ornamentations	2.5	2.5
Signs and Billboards	2.5	2.5
Other Rigid Components		
High deformability elements and attachments	1.0	3.5
Limited deformability elements and attachments	1.0	2.5
Low deformability materials and attachments	1.0	1.5
Other Flexible Components		
High deformability elements and attachments	2.5	3.5
Limited deformability elements and attachments	2.5	2.5
Low deformability materials and attachments	2.5	1.5

<sup>a</sup> A lower value for  $\alpha_c$  is permitted where justified by detailed dynamic analysis. The value for  $\alpha_c$  shall not be less than 1.0. The value of  $\alpha_c$  equal to 1.0 is for rigid components and rigidly attached components. The value of  $\alpha_c$  equal to 2.5 is for flexible components and flexibly attached components.

**Table 6.2.23: Coefficients  $\alpha_c$  and  $R_c$  for Mechanical and Electrical Components**

<b>Mechanical and Electrical Components</b>	<b><math>\alpha_c^a</math></b>	<b><math>R_c</math></b>
Air-side HVAC, fans, air handlers, air conditioning units, cabinet heaters, air distribution boxes, and other mechanical components constructed of sheet metal framing.	2.5	6.0
Wet-side HVAC, boilers, furnaces, atmospheric tanks and bins, chillers, water heaters, heat exchangers, evaporators, air separators, manufacturing or process equipment, and other mechanical components constructed of high-deformability materials.	1.0	2.5
Engines, turbines, pumps, compressors, and pressure vessels not supported on skirts and not within the scope of Chapter 15.	1.0	2.5
Skirt-supported pressure vessels	2.5	2.5
Elevator and escalator components.	1.0	2.5
Generators, batteries, inverters, motors, transformers, and other electrical components constructed of high deformability materials.	1.0	2.5
Motor control centers, panel boards, switch gear, instrumentation cabinets, and other components constructed of sheet metal framing.	2.5	6.0
Communication equipment, computers, instrumentation, and controls.	1.0	2.5
Roof-mounted chimneys, stacks, cooling and electrical towers laterally braced below their center of mass.	2.5	3.0
Roof-mounted chimneys, stacks, cooling and electrical towers laterally braced above their center of mass.	1.0	2.5
Lighting fixtures.	1.0	1.5
Other mechanical or electrical components.	1.0	1.5
<b>Vibration Isolated Components and Systems<sup>b</sup></b>		
Components and systems isolated using neoprene elements and neoprene isolated floors with built-in or separate elastomeric snubbing devices or resilient perimeter stops.	2.5	2.5
Spring isolated components and systems and vibration isolated floors closely restrained using built-in or separate elastomeric snubbing devices or resilient perimeter stops.	2.5	2.0
Internally isolated components and systems.	2.5	2.0
Suspended vibration isolated equipment including in-line duct devices and suspended internally isolated components.	2.5	2.5
<b>Mechanical and Electrical Components</b>	<b><math>\alpha_c^a</math></b>	<b><math>R_c</math></b>
Air-side HVAC, fans, air handlers, air conditioning units, cabinet heaters, air distribution boxes, and other mechanical components constructed of sheet metal framing.	2.5	6.0
Wet-side HVAC, boilers, furnaces, atmospheric tanks and bins, chillers, water heaters, heat exchangers, evaporators, air separators, manufacturing or process equipment, and other mechanical components constructed of high-deformability materials.	1.0	2.5

<b>Mechanical and Electrical Components</b>	$\alpha_c^a$	$R_c$
Engines, turbines, pumps, compressors, and pressure vessels not supported on skirts and not within the scope of Chapter 15.	1.0	2.5
Skirt-supported pressure vessels	2.5	2.5
<b>Distribution Systems</b>		
Piping in accordance with ASME B31, including in-line components with joints made by welding or brazing.	2.5	12.0
Piping in accordance with ASME B31, including in-line components, constructed of high or limited deformability materials, with joints made by threading, bonding, compression couplings, or grooved couplings.	2.5	6.0
Piping and tubing not in accordance with ASME B31, including in-line components, constructed of high-deformability materials, with joints made by welding or brazing.	2.5	9.0
Piping and tubing not in accordance with ASME B31, including in-line components, constructed of high- or limited-deformability materials, with joints made by threading, bonding, compression couplings, or grooved couplings.	2.5	4.5
Piping and tubing constructed of low-deformability materials, such as cast iron, glass, and non-ductile plastics.	2.5	3.0
Ductwork, including in-line components, constructed of high-deformability materials, with joints made by welding or brazing.	2.5	9.0
Ductwork, including in-line components, constructed of high- or limited-deformability materials with joints made by means other than welding or brazing.	2.5	6.0
Ductwork, including in-line components, constructed of low-deformability materials, such as cast iron, glass, and non-ductile plastics.	2.5	3.0
Electrical conduit, bus ducts, rigidly mounted cable trays, and plumbing.	1.0	2.5
Manufacturing or process conveyors (non-personnel).	2.5	3.0
Suspended cable trays.	2.5	6.0

<sup>a</sup> A lower value for  $\alpha_c$  is permitted where justified by detailed dynamic analysis. The value for  $\alpha_c$  shall not be less than 1.0. The value of  $\alpha_c$  equal to 1.0 is for rigid components and rigidly attached components. The value of  $\alpha_c$  equal to 2.5 is for flexible components and flexibly attached components.

<sup>b</sup> Components mounted on vibration isolators shall have a bumper restraint or snubber in each horizontal direction. The design force shall be taken as  $2F_c$  if the nominal clearance (air gap) between the equipment support frame and restraint is greater than 6 mm. If the nominal clearance specified on the construction documents is not greater than 6 mm, the design force may be taken as  $F_c$ .

#### 2.5.16.2 Equivalent static analysis

The equivalent static analysis procedure is permitted to be used for design of a seismically isolated structure provided that:

- (1) The structure is located on Site Class SA, SB, SC, SD or SE site;
- (2) The structure above the isolation interface is not more than four stories or 20 m in height
- (3) Effective period of the isolated structure at the maximum displacement,  $T_M$ , is less than or equal to 3.0 sec.
- (4) The effective period of the isolated structure at the design displacement,  $T_D$ , is greater than three times the elastic, fixed-base period of the structure above the isolation system as determined in Sec. 2.5.7.2
- (5) The structure above the isolation system is of regular configuration; and
- (6) The isolation system meets all of the following criteria:
  - (a) The effective stiffness of the isolation system at the design displacement is greater than one third of the effective stiffness at 20 percent of the design displacement,
  - (b) The isolation system is capable of producing a restoring force as specified in Sec. 2.5.16.1,
  - (c) The isolation system does not limit maximum considered earthquake displacement to less than the total maximum displacement.

Where the equivalent lateral force procedure is used to design seismically isolated structures, the requirements of this Section shall apply.

2.5.16.2.1 Displacement of isolation system: The isolation system shall be designed and constructed to withstand minimum lateral earthquake displacements that act in the direction of each of the main horizontal axes of the structure and such displacements shall be calculated as follows:

$$D_D = \frac{S_a g}{4\pi^2} \left( \frac{T_D^2}{B_D} \right) \quad (6.2.62)$$

Where,

$S_a$  = Design spectral acceleration (in units of  $g$ ), calculated using Eq. 6.2.34 for period  $T_D$  and assuming  $R=1$ ,  $I=1$ ,  $\eta=1$  (Sec 2.5.4.3) for the design basis earthquake (DBE).

$g$  = acceleration due to gravity

$B_D$  = damping coefficient related to the effective damping  $\beta_D$  of the isolation system at the design displacement, as set forth in Table 6.2.24.

$T_D$  = effective period of seismically isolated structure at the design displacement in the direction under consideration, as prescribed by Eq. 6.2.63:

$$T_D = 2\pi \sqrt{\frac{W}{k_{D\min}g}} \quad (6.2.63)$$

Where,

$W$  = seismic weight above the isolation interface

$k_{D\min}$  = minimum effective stiffness of the isolation system at the design displacement in the horizontal direction under consideration.

**Table 6.2.24: Damping Coefficient,  $B_D$  or  $B_M$**

Effective Damping, $\beta_D$ or $\beta_M$ <sup>a, b</sup> (%)	$B_D$ or $B_M$
$\leq 2$	0.8
5	1.0
10	1.2
20	1.5
30	1.7
40	1.9
$\geq 50$	2.0

<sup>a</sup> The damping coefficient shall be based on the effective damping of the isolation system

<sup>b</sup> The damping coefficient shall be based on linear interpolation for effective damping values other than those given.

The maximum displacement of the isolation system,  $D_M$ , in the most critical direction of horizontal response shall be calculated in accordance with the following formula:

$$D_M = \frac{S_{aM} g}{4\pi^2} \left( \frac{T_M^2}{B_M} \right) \quad (6.2.64)$$

Where:

$S_{aM}$  = Maximum spectral acceleration (in units of  $g$ ), calculated using Eq. 6.2.34 for period  $T_D$  and assuming  $R=1$ ,  $I=1$ ,  $\eta=1$  (Sec 2.5.4.3) for the maximum considered earthquake (MCE).

$B_M$  = numerical coefficient related to the effective damping  $\beta_M$  of the isolation system at the maximum displacement, as set forth in Table 6.2.24.

$T_M$  = effective period of seismic-isolated structure at the maximum displacement in the direction under consideration as prescribed by:

$$T_M = 2\pi \sqrt{\frac{W}{k_{M \min} g}} \quad (6.2.65)$$

Where,

$k_{M \min}$  = minimum effective stiffness of the isolation system at the maximum displacement in the horizontal direction under consideration.

The total design displacement,  $D_{TD}$ , and the total maximum displacement,  $D_{TM}$ , of elements of the isolation system shall include additional displacement due to inherent and accidental torsion calculated considering the spatial distribution of the lateral stiffness of the isolation system and the most disadvantageous location of eccentric mass.

2.5.16.2.2 Lateral seismic forces: The structure above the isolation system shall be designed and constructed to withstand a minimum lateral force,  $V_s$ , using all of the appropriate provisions for a non-isolated structure. The importance factor for all isolated structures shall be considered as 1.0, also the response reduction factor  $R_I$  considered here (for computing design seismic forces) is in the range of 1.0 to 2.0.  $V_s$  shall be determined in accordance with Eq. 6.2.66 as follows:

$$V_s = \frac{k_{D \max} D_D}{R_I} \quad (6.2.66)$$

Where,

$k_{D\ max}$  = maximum effective stiffness of the isolation system at the design displacement in the horizontal direction under consideration.

$D_D$  = design displacement at the center of rigidity of the isolation system in the direction under consideration as prescribed by Eq. 6.2.62.

$R_I$  = response reduction factor related to the type of seismic-force-resisting system above the isolation system.  $R_I$  shall be based on the type of seismic-force-resisting system used for the structure above the isolation system and shall be taken as the lesser of  $\frac{3}{8}R$  (Table 6.2.19) or 2.0, but need not be taken less than 1.0.

In no case shall  $V_s$  be taken less than the following:

- (1) The lateral force required by Sec 2.5.7 for a fixed-base structure of the same weight,  $W$ , and a period equal to the isolated period,  $T_D$ ;
- (2) The base shear corresponding to the factored design wind load; and
- (3) The lateral force required to fully activate the isolation system (e.g., the yield level of a softening system, the ultimate capacity of a sacrificial wind-restraint system, or the break-away friction level of a sliding system) multiplied by 1.5.

The isolation system, the foundation, and all structural elements below the isolation system shall be designed and constructed to withstand a minimum lateral force,  $V_b$  using all of the appropriate provisions for a non-isolated structure.  $V_b$  shall be determined in accordance with Eq. 6.2.67 as follows:

$$V_b = k_{D\ max} D_D \quad (6.2.67)$$

In all cases,  $V_b$  shall not be taken less than the maximum force in the isolation system at any displacement up to and including the design displacement.

2.5.16.2.3 Vertical distribution of lateral forces: The total lateral force shall be distributed over the height of the structure above the isolation interface in accordance with Eq. 6.2.68 as follows:

$$F_x = V_s \frac{w_x h_x}{\sum_{i=1}^n w_i h_i} \quad (6.2.68)$$

Where:

$V_s$  = Total seismic lateral design force on elements above the isolation system.

$h_i, h_x$  = Height above the base, to Level i or Level x, respectively.

$w_i, w_x$  = Portion of W that is located at or assigned to Level i or Level x, respectively.

At each Level x the force,  $F_x$  shall be applied over the area of the structure in accordance with the distribution of mass at the level. Stresses in each structural element shall be determined by applying the lateral forces,  $F_x$  at all levels above the base to an analytical model.

2.5.16.2.4 Storey drift: The storey drift shall be calculated as in Sec 2.5.7.7 except that  $C_d$  for the isolated structure shall be taken equal to  $R_I$  and importance factor equal to 1.0. The maximum storey drift of the structure above the isolation system shall not exceed  $0.015h_{sx}$ .

#### 2.5.16.3 Dynamic analysis

Response spectrum analysis may be conducted if the behavior of the isolation system can be considered as equivalent linear. Otherwise, non-linear time history analysis shall be used where the true non-linear behaviour of the isolation system can be modeled. The mathematical models of the isolated structure including the isolation system shall be along guidelines given in Sections 2.5.9.1 and 2.5.11.1, and other requirements given in Sec 2.5.16.

The isolation system shall be modeled using deformational characteristics developed and verified by testing. The structure model shall account for: (i) spatial distribution of isolator units; (ii) consideration of translation in both horizontal directions, and torsion of the structure above the isolation interface considering the most disadvantageous location of eccentric mass; (iii) overturning/uplift forces on individual isolator units; and (iv) effects of vertical load, bilateral load, and the rate of loading if the force-deflection properties of the isolation system are dependent on such attributes.

A linear elastic model of the isolated structure (above isolation system) may be used provided that: (i) stiffness properties assumed for the nonlinear components of the isolation system are based on the maximum effective stiffness of the isolation system, and (ii) all elements of the seismic-force-resisting system of the structure above the isolation system behave linearly.