SESIMIC DESIGN FORCES

D2.1 – 8.1 Introduction:

The code based horizontal seismic force requirements for MEP systems and components are either calculated by the seismic restraint manufacturer as a part of the selection and certification process, or may be determined by the design professional of record for the MEP systems under consideration.

This is an informational section. It will discuss the code based horizontal seismic force demand equations and the variables that go into them. This discussion will provide a deeper understanding for the designer responsible for selecting the seismic restraints for MEP systems and their components and the nature of the seismic forces and the factors that affect them.

D2.1 – 8.2 Horizontal Seismic Design Force (Section 9.6.1.3) [Section 13.3.1][1]:

The seismic force is a mass, or weight, based force, and as such is applied to the MEP component at its center of gravity. Keep in mind that the earthquake ground motion moves the base of the building first. Then the motion of the building will accelerate the MEP component through its supports and/or seismic restraints. The horizontal seismic force acting on an MEP component will be determined in accordance with Equation 9.6.1.3-1 of ASCE 7-98/02 and Equation 13.3-1 of ASCE 7-05.

$$F_P = \frac{0.4 a_P S_{DS} W_P}{\left(\frac{R_P}{I_P}\right)}\left(1+2\frac{z}{h}\right)$$

Equation 8-1 (9.6.1.3-1) [13.3-1]

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[1] References in brackets (Section 9.6.1.3) [Section 13.3.1] refer to sections and/or tables in ASCE 7-98/02 and ASCE 7-05 respectively which forms the basis for the seismic provisions in 2000/2003 IBC and 2006 IBC respectively.

ASCE 7-98/02, and -05 define and upper and lower bound for the horizontal force that is to be applied to the center of gravity of a component. The horizontal seismic force acting on an MEP component is not required to be greater than;

$$F_P = 1.6 S_{DS} I_P W_P$$ **Equation 8-2 (9.6.1.3-2) [13.3-2]**

And the horizontal seismic force acting on an MEP component is not to be less than;

$$F_P = 0.3 S_{DS} I_P W_P$$ **Equation 8-3 (9.6.1.3-3) [13.3-3]**

Where:

F_P = the design horizontal seismic force acting on an MEP component at its center of gravity.

S_{DS} = the short period design spectral acceleration.

a_P =the component amplification factor. This factor is a measure of how close to the natural period of the building the natural period of the component is expected is expected to be. The closer the natural period of the component is to that of the building, the larger a_P will be. Conversely, the further the natural period of the component is away from that of the building, the smaller a_P will be. Typically a_P will vary from 1.0 to 2.5, and is specified by component type in ASCE 7-98/02 and -05 and listed in Table 8-3.

I_P = the component importance factor which be either 1.0 or 1.5.

W_P = the operating weight of the MEP system or component that is being restrained.

R_P = the response modification factor which varies from 1.25 to 5.0 in ASCE 7-98, 1.5 to 5.0 in ASCE 7-02, and 1.50 to 12.0 in ASCE 7-05 by component type. This factor is a measure of the ability of the component and its attachments to the structure to absorb energy. It is really a measure of how ductile or brittle the component and its attachments are. The more flexible, ductile the component and its supports and/or restraints are the larger R_P will be. And conversely, the more brittle and inflexible the component and its supports and/or restraints are, the smaller R_P will be. The values are specified by component type in Table 8-1 for ASCE 7-98, Table 8-2 for ASCE 7-02, and Table 8-3 for ASCE 7-05.

z = the structural attachment mounting height of the MEP component in the building relative to the grade line of the building.

h = the average height of the building roof as measured from the grade line of the building.

The $\mathbf{0.4}$ factor was introduced as a modifier for S_{DS} as a recognition that the MEP components inside the building would react more strongly to the long period earthquake ground motion than to the short period motion. The $\mathbf{0.4}$ factor brings the design level acceleration for the MEP components more in line with the design level acceleration that is applied to the building structure itself.

The $\left(1 + 2\frac{z}{h}\right)$ term in Equation 8-1 is recognition of the fact that all buildings and structures become more flexible as they increase in height. That is they are much stiffer, stronger, at the foundation level than the roof. Since the ground motion from an earthquake enters the building structure at the foundation level, the actual accelerations imparted an MEP component will be greater the higher in the building they are attached. A building may be likened to a vertically mounted cantilever beam that is being shaken by the bottom. It is a vibrating system that will have a certain natural period that is, in a general fashion, based on its mass and stiffness. If the natural period of the building is at, or close too, the earthquake period, the motion of the building could be extreme. This was the case in the Mexico City earthquake of September 19, 1985.

The horizontal seismic design force must be applied independently to the component in at least two perpendicular directions in the horizontal plane. The horizontal seismic design force must be applied in conjunction with all of the expected dead loads and service loads. The idea here is that the horizontal seismic design force is to be applied in the direction that causes the highest stress in the supports and restraints, and thus produces the most conservative results.

D2.1 – 8.3 Vertical Seismic Design Force (Sections 9.5.2.7 and 9.6.1.3) [Sections 12.4.2.2 and 13.3.1]:

The MEP component, its supports, and its restraints must also be designed for a vertical seismic design force that acts concurrently with the horizontal seismic design force. This vertical seismic design force must be directed such that it also produces the highest stress in the supports and restraints, thus producing the most conservative result. This vertical seismic design force is defined as follows.

$$F_V = \pm 0.2 S_{DS} W_P$$

Equation 8-4 (9.5.2.1-1/-2) [12.4-4]

Where:

F_V = the vertical seismic design force.

D2.1 – 8.4 The Evolution of a_P and R_P Factors (Sections 9.6.1.3 and 9.6.3.2 and Table 9.6.3.2) [Sections 13.3.1 and 13.6.1 and Table 13.6-1]:

The MEP component, along with its supports, will also form a vibrating system with a natural period that depends on the mass of the component and the stiffness of the supports. The component amplification factor (a_P) is a measure of how closely the natural period of the component and its supports matches the natural period of the building. For $a_P = 1.0$ the natural periods are not close, while for $a_p = 2.5$ the natural period of the MEP component and their support is very close to that of the building.

The component response modification factor (R_P) is a measure of how much energy the MEP component along with its supports and attachments can absorb without sustaining crippling damage. A common term used throughout the HVAC industry is fragility. As the term implies, it is concerned with how fragile a component might be. That is, how easily a component may be damaged, and to what degree it might be damaged by a specified load and loading rate. The R_P factor, then, is considered to be an indicator of how fragile an MEP component might be. For $R_P = 1.0$ the component is extremely fragile. For $R_P = 12.0$, on the other hand, would be a component that is very robust.

The values for a_P and R_P are assigned by the ASCE 7 committee based on accumulated experience throughout the building industry. The evolution of these factors may be traced through Tables 8-1; 8-2, and 8-3 which represent 2000 IBC, ASCE 7-98; 2003 IBC, ASCE 7-02; and 2006 IBC, ASCE 7-05 respectively. The different values for the same items in the three tables indicate the lack of knowledge and understanding concerning these components throughout the industry. Only time, experience, and shake table testing will produce true usable values for a_P and R_P.

D2.1 – 8.5 LRFD versus ASD: (Sections 2.3 and 2.4) [Sections 2.3, 2.4 and 13.1.7]

This topic was briefly touched upon in Section 4.8 of this guide. However, more should be said about it in this section dealing the design seismic forces that will be applied to the MEP components. The Civil and Structural Engineering community has adopted the LRFD, Load Resistance Factor Design, philosophy. With this design philosophy the factors controlling the serviceability of the structure as assigned to the design loads. ASD, Allowable Stress Design, is the design philosophy which preceded LRFD. In ASD, the factors controlling the serviceability of the structure are assigned to the yield strength or to the ultimate strength of the material. Traditionally the factors controlling the serviceability of the structure have been known as the Safety Factors, or Factors of Safety.

The forces calculated using Equations 8-1, 8-2, 8-3, and 8-4 will have magnitudes that correspond to LRFD. Many standard components such a concrete anchors, bolts, screws, and etc. will have their capacities listed as ASD values. Components whose capacities are listed as ASD values may be compared to the LRFD results from Equations 8-1 through 8-4 by multiplying the ASD values by 1.4.

Table 8-1; Component Amplification and Response Modification Factors for 2000 IBC (Table 9.6.3.2)

Mechanical & Electrical Component[2]	a_P[3]	R_P[4]
General Mechanical Equipment	-----	-----
Boilers and furnaces.	1.0	2.5
Pressure vessels on skirts and free-standing.	2.5	2.5
Stacks & cantilevered chimneys	2.5	2.5
Other	1.0	2.5
Piping Systems	-----	-----
High deformability elements and attachments (welded steel pipe & brazed copper pipe).	1.0	3.5
Limited deformability elements and attachments (steel pipe with screwed connections, no hub connections, and Victaulic type connections).	1.0	2.5
Low deformability elements and attachments (iron pipe with screwed connections, and glass lined pipe).	1.0	1.25
HVAC Systems	-----	-----
Vibration isolated.	2.5	2.5
Non-vibration isolated.	1.0	2.5
Mounted-in-line with ductwork.	1.0	2.5
Other	1.0	2.5
General Electrical	-----	-----
Distributed systems (bus ducts, conduit, and cable trays).	2.5	5.0
Equipment.	1.0	2.5
Lighting fixtures.	1.0	1.25

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[2] Components mounted on vibration isolators shall be restrained in each horizontal direction with bumpers or snubbers, and the horizontal seismic design force shall be equal to $2F_P$.

[3] The value for a_P shall not be less than 1.0. Lower values shall not be used unless justified by a detailed dynamic analysis. A value of a_P=1.0 is to be applied to equipment that is rigid or rigidly attached. A value of a_P=2.5 is to be applied to equipment regarded as flexible or flexibly attached.

[4] A value of R_P=1.25 is to be used for component anchorage design with expansion anchor bolts, shallow chemical anchor, shall low deformability cast in place anchors, or when the component is constructed of brittle materials. Shallow anchors are those with an embedment depth to nominal diameter ratio that is less than 8.

Table 8-2; Component Amplification and Response Modification Factors for 2003 IBC (Table 9.6.3.2)

Mechanical & Electrical Component[5]	a_P [6]	R_P
General Mechanical Equipment	-----	-----
Boilers and furnaces.	1.0	2.5
Pressure vessels on skirts and free standing.	2.5	2.5
Stacks and cantilevered chimneys.	2.5	2.5
Other	1.0	2.5
Piping Systems	-----	-----
High deformability elements and attachments (welded steel pipe & brazed copper pipe).	1.0	3.5
Limited deformability elements and attachments (steel pipe with screwed connections, no hub connections, and Victaulic type connections).	1.0	2.5
Low deformability elements and attachments (iron pipe with screwed connections, and glass lined pipe).	1.0	1.5
HVAC Systems	-----	-----
Vibration isolated.	2.5	2.5
Non-vibration isolated.	1.0	2.5
Mounted-in-line with ductwork.	1.0	2.5
Other	1.0	2.5
General Electrical	-----	-----
Distribution systems (bus ducts, conduit, and cable trays).	2.5	5.0
Equipment	1.0	2.5
Lighting fixtures.	1.0	1.5

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[5] Components mounted on vibration isolators shall be restrained in each horizontal direction with bumpers or snubbers. If the maximum bumper/snubber clearance, or air gap, is greater than 1/4 in., the horizontal seismic design force shall be equal to $2F_P$. If the maximum bumper/snubber clearance, air gap, is less than or equal to 1/4 in., the horizontal seismic design force shall be taken as F_P.

[6] The value for a_P shall not be less than 1.0. Lower values shall not be used unless justified by a detailed dynamic analysis. A value of a_P=1.0 is to be applied to equipment that is rigid or rigidly attached. A value of a_P=2.5 is to be applied to equipment regarded as flexible or flexibly attached.

Table 8-3; Component Amplification and Response Modification Factors for 2006 IBC [Table 13.6-1]

MECHANICAL AND ELECTRICAL COMPONENTS	a_P[7]	R_P[8]
Air-side HVAC – fans, air handlers, and other mechanical components with sheet metal framing.	2.5	6.0
Wet-side HVAC – boilers, chillers, & other mechanical components constructed of ductile materials.	1.0	2.5
Engines, turbines, pumps compressors, and pressure vessels not supported on skirts.	1.0	2.5
Skirt supported pressure vessels.	2.5	2.5
Generators, batteries, transformers, motors, & other electrical components made of ductile materials.	1.0	2.5
Motor control cabinets, switchgear, & 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 braced below their C.G.	2.5	3.0
Roof-mounted chimneys, stacks, cooling and electrical towers braced below their C.G.	1.0	2.5
Lighting fixtures.	1.0	1.5
Other mechanical & electrical components.	1.0	1.5
Vibration Isolated Components & Systems	-----	-----
Components & systems isolated using neoprene elements & neoprene isolated floors with elastomeric snubbers or resilient perimeter stops	2.5	2.5
Spring isolated components & systems & vibration isolated floors closely restrained with elastomeric snubbing devices or resilient perimeter stops.	2.5	2.0
Internally isolated components or systems.	2.5	2.0
Suspended vibration isolated equipment including in-line duct devices & suspended internally isolated components.	2.5	2.5
Distribution Systems	-----	-----
Piping in accordance with ASME B31, this includes in-line components, with joints made by welding or brazing.	2.5	12.0
Piping in accordance with ASME B31, this includes 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 & tubing that is not in accordance with ASME B31, this includes in-line components, constructed with high deformability materials with joints made by welding or brazing.	2.5	9.0
Piping & tubing that is not in accordance with ASME B31, this includes 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 & tubing of low deformability materials, such as cast iron, glass, or 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
Duct work constructed of low deformability materials such as cast iron, glass, or non-ductile plastics.	2.5	3.0
Electrical conduit, bus ducts, rigidly mounted cable trays, & plumbing.	1.0	2.5
Suspended cable trays.	2.5	6.0

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[7] The value for a_P shall not be less than 1.0. Lower values shall not be used unless justified by a detailed dynamic analysis. A value of a_P=1.0 is to be applied to components that are rigid or rigidly attached. A value of a_P=2.5 is to be applied to components regarded as flexible or flexibly attached.

[8] Components mounted on vibration isolators shall be restrained in each horizontal direction with bumpers or snubbers. If the maximum bumper/snubber clearance, or air gap, is greater than 1/4 in., the horizontal seismic design force shall be equal to $2F_P$. If the maximum bumper/snubber clearance, air gap, is less than or equal to 1/4 in., the horizontal seismic design force shall be taken as F_P.

D2.1 – 8.6 Summary:

This section has provided an insight into the way in which the seismic design forces for MEP systems and components are to be computed. It is generally not necessary for a designer to actually run the computations for the seismic design forces. These forces are normally computed by the manufacturer of the seismic restraint devices as part of the selection and certification process to ensure that the proper components are selected per the code and the specification.