Related Commercial Resources

CHAPTER 56. SEISMIC-, WIND-, AND FLOOD-RESISTANT DESIGN

MOST inhabited areas of the world are susceptible to the damaging effects of either earthquakes, wind, or flooding. Building system components, supports, restraints, and attachments that are designed to resist one may not be adequate to resist another. Consequently, when exposure to any of these is a possibility, the strengths of each component, support, restraint, and attachment should be evaluated for all appropriate conditions.

Earthquake damage to inadequately designed and installed building systems can be extensive. Mechanical equipment that is damaged or blown off the supporting structure can degrade into projectiles, threatening life and property. Improperly located or protected system components and ventilation openings can lead to building failures and extensive water damage. The cost of properly designing, installing, and restraining the building system components is small compared to the high costs to replace or repair them, the liability for injury or loss of life, or the costs of downtime and loss of business.

The first two parts of this chapter cover the design of supports, restraints, and attachments that limit movement and keep components captive during earthquake or extreme wind events. Properly designed and installed supports and restraints have the necessary strength to withstand the imposed forces and minimize damage to the associated components. Attachments must be coordinated with the building structure to ensure neither exceeds their capacity for handling loads. Equipment that is to be restrained must also have sufficient strength to remain intact (and in some case, operational), as determined by testing and/or analysis.

Design and installation of seismic and wind resistant systems have the following primary objectives:

- To reduce the possibility of injury and threat to life
- To maintain operability of components in and connected to essential facilities
- To reduce long-term costs due to component damage or failure and resulting downtime

The *International Building Code®* (IBC) (ICC 2009) provides minimum design requirements for various building types. Since the 2000 edition, it has referenced the American Society of Civil Engineers (ASCE) *Standard* ASCE7 for all minimum design loads. *Standard* ASCE7 provides a prescriptive approach for applying equivalent static forces representing dynamic forces caused by seismic or high-wind events. Conservative safety factors are applied to reduce the complexity of earthquake and wind loading response analysis and evaluation. The following aspects are considered in a properly designed restraint system:

- *Attachment of component to support or restraint.* The component must be positively attached and have sufficient strength to withstand the imposed forces and to transfer the forces to the support or restraint.
- *Support or restraint design.* The support or restraint also must be strong enough to withstand the imposed forces as determined by testing and/or analysis.
- *Attachment of support or restraint to structure.* Attachment must be qualified for both the material and the type of loading, and may use steel bolts, lag bolts, welds, precast or post-installed concrete anchors, or screws. The structure must be capable of surviving the imposed forces at the point of attachment and to transfer the loads to ground.

1. SEISMIC-RESISTANT DESIGN

Since most jurisdictions in the United States use a version of the *International Building Code®* either as-is or with modifications to set minimum requirements for building design and construction, it is widely accepted as industry-standard practice to rely on ASCE *Standard* ASCE7 to set requirements for seismic resistant designs. Within *Standard* ASCE7, Chapter 13 Seismic Restraint for Non-structural Components, is the primary source of most prescriptive guidelines and requirements that are used with HVAC&R systems. Due to the detailed and specific manner in which the chapter is written, engineers and contractors can rely on a consistent and standardized approach to addressing earthquake effects. Local code officials can likewise count on this standardized approach to help ensure code-compliant buildings can be expected to meet their performance objectives (e.g., essential facilities will continue to function after a design-level event). In some instances, local authorities having jurisdiction (AHJs) over building projects require additional measures to be incorporated into seismic resistant designs, so as with any project, it is important to know those and include them in the work.

This standardized approach can be and has been applied to other jurisdictions outside of the United States where acceptable to the local authorities. In places like Canada, which lacks a prescriptive guideline such as ASCE7, the seismic resistant design for HVAC&R systems is left to the professional engineer in responsible charge of the work to determine the best course of action that meets the letter and intent of the applicable building code. Some jurisdictions have established best practices that borrow elements from ASCE7, NFPA *Standard* 13, and from older documents such as SMACNA.

Other sources of information used to help design and install seismic resistance systems include

- *A Practical Guide to Seismic Restraint*, 2nd ed. (ASHRAE 2012) provides useful information in determining and designing seismic resistant systems for HVAC&R systems. Note that the general guidelines are still useful though the code-specific direction applies to IBC 2012 and earlier. A third edition is currently being worked on to bring it up to date.

- The Vibration Isolation and Seismic Control Manufacturers Association (VISCMA) acting on behalf of the Federal Emergency Management Agency (FEMA) created a series of three manuals that are available on both of their websites for download:
  - VISCMA/FEMA 412, *Installing Seismic Restraints for Mechanical Equipment*
  - FEMA 413, *Installing Seismic Restraints for Electrical Systems*
  - FEMA 414, *Installing Seismic Restraints for Duct and Pipe*
- These manuals provide general guidance and do not include any code-specific requirements.
- FEMA has published other guidelines to help mitigate various extreme events, including FEMA E-74, *Reducing the Risks of Nonstructural Earthquake Damage—A Practical Guide* (2012).
- The Canada Standards Association publishes S832 *Seismic Risk Reduction of Operational and Functional Components (OFCs) of Buildings* (R2019) which provides an effective methodology for prioritizing and designing appropriate restraint systems for HVAC&R components.
- *Seismic Restraint Manual: Guidelines for Mechanical Systems*, 3rd ed. (SMACNA 2008) includes a simplified approach to standardized bracing configurations for duct, pipe, and conduit. Note, however, that it is based on older versions of building codes that are no longer used (IBC 2006 and earlier) and some of the guidelines are in conflict with current code requirements.
- NFPA *Standard* 13, Standard for the Installation of Sprinkler Systems (NFPA 2019) is the primary authoritative document for sprinkler systems in the United States. Chapter 18 of that standard determines seismic resistant system design requirements.
- *United Facilities Criteria* UFC 3-301-01 with Change 1, Structural Engineering (DoD 2022) provides the necessary information and requirements for designing seismic resistance systems for U.S. Department of Defense (DoD) buildings. For the most part, it uses ASCE7-16 as is, but with some modifications regarding seismic design values and detailing requirements (e.g., place two nuts on post-installed concrete anchors in some cases).
- Requirements for seismic resistant systems for HVAC&R systems in nuclear facilities in the United States are described in the Department of Energy *Standard* 1020, Natural Phenomena Hazards Analysis and Design Criteria for DOE Facilities (2016) and American Society of Mechanical Engineers (ASME) AG-1 *Code on Nuclear Air and Gas Treatment* (2019). The DOE document relies heavily on ASCE7-10 for its methodology.

For a number of reasons, the selection and design of seismic restraints is typically performed through a delegated design process where the mechanical engineer of record for a project stipulates the general requirements through the contract documents but leaves the technical determination to another engineer with appropriate expertise in the specialized field. Building codes in North America require the work be done by a registered professional engineer competent in the calculation of design forces in accordance with the applicable codes and standards. The delegated design engineer’s work is submitted to the engineer of record for review before being sent to the installing contractor to carry out. In many instances, the delegated design engineer is required to sign-off on the installation prior to occupancy to ensure the designs were properly installed. Additionally, many projects have special inspection requirements (either from the owner or by code) that stipulate a third-party inspection agency determine that the seismic restraint installations are code compliant. In all cases, the local authority having jurisdiction makes the final determination of acceptance.

The design of seismic resistance systems for HVAC&R components on a project using an IBC code requires a few things to be known, including the risk category (RC) of the building, the seismic design category (SDC), and the site-specific short-period ground acceleration values (S_S). These three values are all provided by the structural engineer of record for the project and are made available in the construction documents, typically on one of the first pages in the drawing set. For projects without a structural engineer, those values can be approximated following the instructions in the IBC and ASCE7 and by using websites. Projects in Canada use a similar methodology but with slightly different terminology as described in the National Building Code and each provincial building code.

1.1 TERMINOLOGY

Attachment. The physical connection between the restrained component and its support or its restraint device and building structure using bolts, screws, welds, or otherwise positive fastening without relying on frictional resistance due to gravity.

Distribution system. Piping, ductwork, and electrical conduit/cable tray systems.

Effective shear force V_{eff}. Maximum shear force of one restraint or anchorage point.

Effective tension force T_{eff}. Maximum tension force or pullout force on one restraint or anchorage point.

Component. Any non-structural element attached to or part of a building such as a piece of equipment or a distribution system.

Resilient restraint. A device attached to a component that allows some limited movement.

Resilient support. Static support of a component which is flexible, such as a vibration isolator.

Response spectra. Relationship between the acceleration response of the ground and the peak acceleration of the earthquake in a damped single degree of freedom at various frequencies. The ground motion response spectrum varies with soil conditions.

Rigid restraint. Non-resilient device attached to a component to restrict its movement.

Rigid support. Static support of a component which is considered to be non-resilient, such as a steel frame.

Shear force V. Force generated parallel to the attachment plane.

Seismic restraint. Device designed to withstand seismic forces and hold a component in place during an earthquake.

Seismic force levels. Design forces on a component determined using various factors related to its weight, construction, position, contents, and function and related to the geographic location of a project.

Snubber. Restraint device that includes resilient material positioned to prevent a component from moving beyond an established gap.

Structure. Load-carrying element of a building, designed by a structural engineer of record.

Support. An element that holds a component in place; may be an external element such as a curb or rod hanger, or internal such as the component's base frame.

Tension force *T*. Force generated axially, either perpendicular to the attachment plane or along the primary axis of a single-axis restraint such as a cable.

1.2 CALCULATIONS

Sample calculations presented here assume that the equipment support is an integrated resilient support and restraint device. When the two functions of resilient support and motion restraint are separate or act separately, additional spring loads may need to be added to the anchor load calculation for the restraint device. Internal loads within integrated devices are not addressed in this chapter. These devices must be designed to withstand the full anchorage loads plus any internal spring loads.

Table 1 IBC Seismic Analysis Requirements

Component Operation Required for Life Safety	Building Seismic Design Category*	Required Analysis Type: Anchorage	Required Analysis Type: Equipment Structural Capacity	Required Analysis Type: Equipment Operational Capacity	Required Analysis Type: Certificate of Compliance
Yes or No	A, B	Not required	Not required	Not required	Not required
No	C	Not required	Not required	Not required	Not required
No	D, E, F	Static	Dynamic or test	Not required	For mounting only
Yes	C, D, E, F	Static	Dynamic or test	Dynamic or test	For continued operation

* If in question, reference structural documents.

Both static and dynamic analyses reduce the force generated by an earthquake to an equivalent statically applied force, which acts in a horizontal or vertical direction at the component's center of gravity. The resulting overturning moment is resisted by shear and tension (pullout) forces on the tie-down bolts. Static analysis is used for both rigidly mounted and resiliently mounted equipment.

Dynamic Analysis

Dynamic analysis of the isolation and snubber systems may be based on ground-level response spectra given in the IBC and reference standard ASCE7, which can be used as input for a dynamic analysis.

Response spectra applied to nonstructural components can be developed from ICC-ES acceptance criteria AC 156 (ICC-ES 2012). Site-specific ground response spectra developed by a geotechnical or soils engineer may be used, as well. The computer analysis used must be capable of analyzing nonlinear supports and site-specific ground motions. This dynamic analysis provides the maximum seismic input accelerations to the equipment components, allowing comparison to three-dimensional shock (drop) or shaker test fragility levels to determine equipment survivability.

Using the response spectra in the code for ground-floor inputs, or the spectra in ATC 29-2 for upper floors, a dynamic analysis can yield maximum input accelerations to equipment components. Comparing them to the allowable acceleration values in the table helps the engineer assess equipment survivability. Dynamic analysis can also provide maximum movement at all connections and, when added to the floor-to-ceiling code-mandated movements, allows the engineer to design these flexible connections and avoid pull-out or shear failures at these locations.

Under some conditions, the IBC requires certificates of compliance for components and their attachments for a component importance factor I_p of 1.0 or 1.5. This is a life-safety issue as well as an essential equipment issue. Essential equipment with an I_p = 1.5 must have a certificate of compliance. Issuance of a certificate of compliance to the engineer of record and building official can be based on dynamic analysis. Most building officials require a stamp by a registered professional to be part of the calculations and certificate of compliance. Table 1 provides guidance on type of analysis (static or dynamic) and certificate of compliance documentation required. Sample dynamic analysis is beyond the scope of this chapter and should be provided by experienced registered professionals. A common approach assumes an elastic response spectrum. The results of the dynamic analysis can then be scaled up or down as a percentage of the total lateral force obtained from the static analysis performed on the building.

Table 2 Coefficients for Mechanical Components

Mechanical and Electrical Component or Element	a_p	R_p
HVAC ductwork	2.5	6
Piping		

Steel or copper pipe with welded or brazed connections	2.5	6
Steel or copper pipe with joints made by threading, bonding, compression couplings, or grooved fittings	2.5	4.5
Non-ductile pipe (e.g., cast iron, plastic)	2.5	3
HVAC equipment		
Vibration isolated with elastomers	2.5	2.5
Vibration isolated with springs	2.5	2
Rigid components (e.g., pumps, expansion tanks, water-cooled chillers)	1.0	2.5
Flexible components (e.g., units with sheet metal framing)	2.5	6

Dynamic analysis of distribution systems and equipment reflects the response of the equipment for all earthquake-generated frequencies. Especially for piping and equipment, when the earthquake forcing frequencies match the natural frequencies of the system, the resulting applied forces increase.

Static Analysis as Defined in ASCE7

ASCE7 specifies a design lateral force F_p for nonstructural components as

$$F_p = (0.4 a_P S_{DS} W_P)/R_p \times I_p(1 + 2z/h) \quad \textbf{(1)}$$

but F_p need not be greater than

$$F_p = 1.6 S_{DS} I_p W_p \quad \textbf{(2)}$$

nor less than

$$F_p = 0.3 S_{DS} I_p W_p \quad \textbf{(3)}$$

where S_{DS} is determined by

$$S_{DS} = 2/3 \times F_a S_S \quad \textbf{(4)}$$

where

a_p = component amplification factor in accordance with Table 2.

S_{DS} = design spectral response acceleration at short periods. S_S is the mapped spectral acceleration for a specific location and is available at the ASCE website: asce7hazardtool.online. (*Note*: values are specific to certain editions of ASCE7, since they are periodically updated.)

F_a = function of site soil characteristics and must be determined in consultation with either project geotechnical (soils) or structural engineer. Values for F_a for different soil types are given in Table 3. (*Note*: Without an approved geotechnical report, the default site soil classification is assumed to be site class *D*.)

R_p = component response modification factor in accordance with Table 2.

I_p = component importance factor (see ASCE7 Chapter 13 for explanation and determination of I_p).

$(1 + 2z/h)$ = height amplification factor where z is the height of attachment in the structure and h is the average height of the roof above grade. The value of z for ground level and below (e.g., basements) should be taken as 0 and z/h shall not exceed 1.

$W_p(D)$ = operating weight of component, which includes all items and contents attached or contained inside.

The forces acting on indoor components include the lateral and vertical forces at the center of gravity resulting from the earthquake movement, the force of gravity, and the forces of the restraint holding the component in place. Restraints must be designed for a concurrent vertical force F_{pv} at the center of gravity, defined as

$$F_{pv} = 0.2 S_{DS} W_p \quad \textbf{(5)}$$

Seismic coefficient values for both U.S. and Canadian locations can be found at the ASCE website (www.asce7hazardtool.online) and USGS website (www.USGS.gov). Seismic design values for many international locations that correspond with the ASCE7 methodology can be found at www.wbdg.org/additional-resources/tools/ufcsldt. Table 4 contains brief listings of historical S_s factors for international locations that may be used only for general comparisons; they have not been confirmed or updated for this publication and so should not be used for design purposes.

Table 3 Values of Site Coefficient F_a as Function of Site Class and Spectral Response Acceleration at Short Period (S_s)

Site Class	Soil Profile Name	Mapped Spectral Response Acceleration at Short Periods[a]					
		$S_s \le 0.25$	$S_s = 0.50$	$S_s = 0.75$	$S_s = 1.00$	$S_s = 1.25$	$S_s \ge 1.5$
A	Hard rock	0.8	0.8	0.8	0.8	0.8	0.8
B	Rock	0.9	0.9	0.9	0.9	0.9	0.9
C	Very dense soil and soft rock	1.3	1.3	1.2	1.2	1.2	1.5
D[c]	Stiff soil	**1.6**	**1.4**	**1.2**	**1.1**	**1.0**	**1.0**
E	Soft clay soil	2.4	1.7	1.3	[b]	[b]	[b]

F	Soils requiring site response analysis. See ASCE7-16, Chapters 11 and 20, for more information

[a] Use straight-line interpolation for intermediate values of mapped spectral acceleration at short period S_S.

[b] Site-specific geotechnical investigation and dynamic site response analyses must be performed to determine appropriate values.

[c] D is the default Site Class unless otherwise stated in the approved geotechnical report.

Table 4 S_s Numbers for Selected International Locations (Class Site B) (U.S. COE 2013)

Country	City	S_s	Country	City	S_s	Country	City	S_s	Country	City	S_s
Africa			India	Bombay	0.27	Denmark	Copenhagen	0.12	Mexico	Ciudad Juarez	0.19
Algeria	Algiers	1.01		Calcutta	0.52	England	Birmingham	0.23		Guadalajara	1.54
	Oran	0.63		Madras	0.15		Liverpool	0.24		Hermosillo	0.49
Angola	Luanda	0.06		New Delhi	0.74		Plymouth	0.21		Matamoros	0.02
Benin	Colonou	0.11	Indonesia	Bandung	1.72		Southport	0.24		Mazatlán	1.02
Botswana	Gaborone	0.03		Jakarta	1.45		South Shields	0.12		Merida	0.04
Burkina Faso	Ougadougou	0.46		Medan	1.17		Spurn Head	0.17		Mexico City	0.6
Burundi	Bujumbura	0.69		Surabaya	1.01	Finland	Helsinki	0.05		Monterrey	0.23
Cameroon	Douala	0.17	Iran	Isfahan	0.95	France	Bordeaux	0.17		Nuevo Laredo	0.16
	Yaounde	0.27		Shiraz	1.82		Lyon	0.3		Tijuana	0.97
Central African Republic				Tabriz	1.9		Marseille	0.47	**South America**		
	Bangui	0.27		Tehran	2.15		Nice	0.43	Argentina	Buenos Aires	0.38
Chad	Ndjamena	0.06	Iraq	Baghdad	1.3		Strasbourg	0.45	Bolivia	La Paz	0.51
Congo	Brazaville	0.1		Basra	1.03	Germany	Ausbach	0.25	Brazil	Belem	0.01
Democratic Republic of Congo	Bukavu	0.78		Kirkuk	1.73		Babenhausen	0.36		Belo Horizonte	0.01
	Kinshasa	0.01	Israel	Haifa	1.44		Barnberg	0.22		Brasilia	0.01
	Lubumbashi	0.039		Jerusalem	1.12		Baumholder	0.26		Manaus	0.21
Cote d'Ivoire	Abidjan	0.04		Tel Aviv	1		Berlin	0.05		Porto Alegre	0.01
Djibouti	Djibouti	1.02	Japan	Fukuoka	0.71		Bonn	0.44		Recife	0.11
Egypt	Alexandria	0.24		Itazuke AFB	0.77		Bremen	0.1		Rio de Janeiro	0.04
	Cairo	0.71		Iwo Jima	0.94		Dusseldorf	0.32		Salvador	0.33
	Port Said	0.68		Kobe	1.99		Frankfurt	0.4		Sao Paulo	0.1
Equatorial Guinea	Malabo	0.17		Misawa AFB	1.3		Hamburg	0.1	Chile	Santiago	2.21
Eritea	Asmare	0.45		Okinawa	1.73		Munich	0.27		Valparaiso	3.16
Ethiopia	Addis Ababa	0.58		Osaka	1.87		Stuttgart	0.46	Colombia	Bogota	0.99
Gabon	Libreville	0.27		Sagamihara	1.96		Vaihingen	0.41	Ecuador	Quito	2.12
Gambia	Banjul	0.1		Sapporo	1.05	Greece	Athens	0.85		Guayaquil	1.9
Ghana	Accra	0.37		Tokyo	1.96		Kavalla	1.14	Paraquay	Asuncion	0.07
Guinea Bissan	Bissau	0.31		Yokohama	1.96		Lartssa	1.47	Peru	Lima	2.3
Guinea	Conakry	0.38	Jordan	Amman	0.74		Makri	0.91		Piura	2.32
Kenya	Nairobi	0.32	Kuwait	Kuwait City	0.57		Rhodes	1.44	Uruguay	Montevideo	0.07
Lesotho	Maseru	0.07	Laos	Vientiane	0.57		Sauda Bay	1.26	Venezuela	Maracaibo	0.93
Liberia	Monrovia	0.22	Lebanon	Beirut	1.57		Thessaloniki	1.49		Caracas	1.07
Libya	Tripoli	0.6	Malaysia	Kuala Lumpur	0.59	Hungary	Budapest	0.49	**Caribbean Sea**		
Madagascar	Antananarivo	0.19	Nepal	Kathmandu	2.58	Iceland	Keflavik	1.05	Bahamas	Eleuthero Island	0.02

Malawi	Blantyre	0.49	Oman	Muscat	1.3		Reykjavik	0.96		Grand Bahama Island	0.02
	Lilongwe	0.28	Pakistan	Islamabad	1.35		Thorshofn	0.51		Grand Turk Island	0.61
	Zomba	0.51		Karachi	0.77					Great Exuma Island	0.2
Mali	Bamako	0.1		Lahore	1.23	Italy	Aviano AFB	1.25		Nassuau	0.07
Mauritania	Nouakchott	0.08		Peshawar	1.1		Brindisi	0.21	Barbados	Bridgetown	0.39
Morocco	Casablanca	0.26	Qatar	Doha	0.06		Florence	0.62	Cuba	Havana	0.27
	Kenitra	0.28	Saudi Arabia	Dhahran	0.1		Genoa	0.35		Guantanamo Bay	1.32
	Rabat	0.27		Jeddah	0.51		Ghedi	0.75	Dominica	Santo Domingo	1.82
	Tangier	0.47		Jubail	0.37		Milan	0.27	Grenada	Saint George’s	1.13
Mozambique	Maputo	0.11		Khamis Mushayt	0.06		Naples	0.79	Guadeloupe	Basse-Terre	1.37
Niger	Niamey	0.01		Qadimah	0.25		Palermo	0.84	Haiti	Port-au-Prince	1.89
Nigeria	Ibadan			Riyadh	0.06		Rome	0.52		Cap-Haitien	1.5
	Kaduna	0.06		Tabuk	0.29		Siculiana	0.29	Jamaica	Kingston	1.52
	Lagos	0.01	Singapore	All	0.39		Trieste	0.55	Martinique	Fort-de-	1.02
Rwanda	Kigali	0.29	Sri Lanka	Colombo	0.03		Turin	0.28		France	
Senegal	Dakar	0.08	South Korea	Camp Casey	0.16	Luxembourg	Luxembourg	0.22	Montserrat	Plymouth	1.7
Sierra Leone	Freetown	0.37		Camp Hialeah	0.31	Malta	Valletta	0.3	Saint Croix	Frederiksted	0.84
				Camp Hunpreys	0.2	Netherlands	Amsterdam	0.14	Saint John	Bethany	1.17
Somalia	Mogadishu	0.1		Chinhae	0.18		North Brunssum	0.58	Saint Kitts and Nevis	Basseterre	0.82
South Africa	Cape Town	0.27		Kimhae	0.19	Northern Ireland	Belfast	0.09	Saint Lucia	Castries	0.94
	Durban	0.3		Kimpo AFB	0.16	Norway	Oslo	0.16	Saint Thomas	Charlotte Amalie	1.17
	Johannesburg	0.03		Kunsan/Kunsan City	0.18	Norway	Stavanger	0.34	Saint Vincent and the Grenadines	Port Elizabeth	0.56
	Natal	0.07		Kwangju	0.14	Poland	Krakow	0.2	Tinidad & Tobago	Scarborough	1.17
	Pretoria	0.03		Osan AFB	0.2		Poznan	0.06		Trinidad	1.74
Swaziland	Mbabane	0.19		Pohang	0.015		Waraszawa	0.12		Port of Spain	1.8
Tanzania	Dar es Salaam	0.18		Seoul	0.18	Portugal	Azores/Lajes Field	1.73	Vieques	Isabel Segunda	0.99
	Zanzibar	0.12		Taegu	0.3		Lisbon	0.71	**Indian Ocean Area**		
Togo	Lome	0.39		Uijongbu	0.18		Oporto	0.68	British	NSF Diego Garcia	0.73
Tunisia	Tunis	0.95		Yongsan/Seoul	0.18	Republic of Ireland	Dublin	0.1	**Pacific Ocean Area**		
Uganda	Kampaia	0.46	Syria	Aleppo	0.68	Romania	Bucharest	1.1	Australia	Brisbane	0.32
Zambia	Lusaka	.0.23		Damascus	0.83	Russia	Moscow	0.07		Canberra	0.49
Zimbabwe	Harare	0.06	Taiwan	Changhua	2.88		St. Petersburg	0.07		Melbourne	0.49
Asia			Taiwan	Kao-hsiung	2.63	Scotland	Aberdeen	0.1		Perth	0.47
Afghanistan	Bagram	1.46		Tsinan	2.51		Edinburgh	0.18		Sydney	0.46

	Gardeyz	0.63		Taipei	3.41		Glasgow	0.22	Caroline Islands	Koror, Palau	0.73
	Herat	0.62		Tsoying	2.63		Renfrew	0.23		Ponape	1.08
	Jalalabad	1.06	Thailand	Bangkok	0.29		Stornoway	0.1		Yap	0.82
	Kabul	1.11		Chiang Mai	0.29	Serbia	Belgrade	1.02	Fiji	Suva	0.6
	Kandahar	0.32		Songkhia	0.31		Zagrebac	1.09	Johnson Island	All	1.43
	Lashkar Gah	0.16		Udom	0.25	Spain	Barcelona	0.63			
	Mazar-e Sharif	0.78	Turkey	Ankara	1.04		Bilbao	0.34	Marcus Islands	All	1
	Pol-e Charkhi	1		Istanbul	1.53		Madrid	0.13	**Atlantic Ocean Area**		
	Qalat	0.79		Izmir	2.54		Rota	0.76	Greenland	All	0.33
Bahrain	Manama	0.28		Karamursel	1.46		Seville	**0.13**			
Bangladesh	Dhaka	0.73	United Arab Emirates	Abu Dhabi	1.12	Sweden					
Brunei	Bandar Seri Begawan	0.39		Dubai	1.77	Sweden	Goteborg	0.15			
			Viet Nam	Da Nang	0.19		Stockholm	0.08			
				Ho Chi Minh City (Saigon)	0.15	Switzerland	Bern	**0.46**			
			Yemen	Sanaa	0.36		Geneva	**0.49**			
Burma	Mandalay	2.11	**Europe**				Zurich	**0.41**			
	Rangoon	0.81	Albania	Tirana	1.17	Ukraine	Kiev	**0.07**			
China	Beijing (Peking)	0.58	Austria	Salzburg	0.44	**Central America**					
	Chengdu	0.46		Vienna	0.52	Belize	Belmopan	0.56			
	Chongqing	0.09	Belgium	Antwerp	0.21	Canal Zone	All	0.97			
	Guangzhou (Canton)	0.14		Brussels	0.34	Costa Rica	San Jose	2.94			
	Harbin	0.13		Kester	0.38	El Salvador	San Salvador	1.79			
	Nanjing	0.25		Kleine Brogel	0.33	Guatemala	Guatemala	1.77			
	Shanghai	0.18		Shape-Cjoevres	0.57	Honduras	Tegucigalpa	1.05			
	Shengyang	0.93	Boznia-Herzegovina	Tuzla AFB	0.97						
	Tianjin (Tientsan)	0.76	Bulgaria	Sofia	1.22						
	Wuhan	0.08	Cyprus	Nicosia	1.24						
Hong Kong	Hong Kong	0.13	Czech Republic	Prague	0.13						

1.3 APPLYING STATIC ANALYSIS

The prescriptive method in ASCE7 allows that an equivalent static force can be calculated that represents the dynamic motions of an earthquake. The static forces acting on a piece of equipment are vertical and lateral forces acting on the center of gravity resulting from the earthquake, the force of gravity, and forces at the restraints that hold the equipment in place. The analysis assumes that the equipment moves with the structure during the earthquake and that the relative accelerations between its center of gravity and the ground generate forces that must be balanced by reactions at the restraints. Guidance from the code allows equipment to be analyzed as though it were a rigid component; however, a factor a_p is applied in the computation to address flexibility issues on particular equipment types or flexible mounting arrangements. (*Note*: for dynamic analysis, it is common to use a 5% damping factor for equipment and a 1% damping factor for piping.) Although the basic force computation is different, the details of load distribution in the examples that follow apply independently of the code used.

Table 5 Load Combinations (Equation Numbers as Referenced in ASCE7-16)

ASD		LRFD	
5.	$D + (0.6W \text{ or } 0.7E)$	4.	$1.2D + 1.0W + L + 0.5(L_r \text{ or } S \text{ or } R)$

6. $D + 0.75L + 0.75(0.6W) + 0.75(L_r \text{ or } S \text{ or } R)$	5. $0.9D + 1.0W$
7. $0.6D + 0.6W$	6. $1.2D + E_v + E_h + L + 0.2S$
8. $1.0D + 0.52E_v + 0.52E_h + 0.75L + 0.75S$	7. $0.9D - E_v + E_h$
9. $1.0D + 0.525E_v + 0.525E_h + 0.75L + 0.75S$	
10. $0.6D - 0.7E_v + 0.7E_h$	

Note: D = dead load; W = wind, L = live, L_r = live load on roof, S = snow, R = rain, and E_v and E_h = vertical and horizontal seismic loads, respectively.

Once the overall seismic forces F_p and F_{pv} have been determined (as indicated in the section on Static Analysis as Defined by ASCE7 or per local code requirement), the loads at the restraint points can be calculated.

The primary forces acting on the restraints include both shear and tensile components. The application direction of the lateral seismic acceleration can vary and is unknown. Depending on its direction, it is likely that not all of the restraints will be affected or share the load equally. It is important to determine the worst-case combination of forces at all restraint points for any possible direction that the lateral wave front can follow to ensure that the attachment is adequate.

Under some instances (particularly those relating to life-support issues in hospital settings), code requirements indicate that critical equipment must be seismically qualified to ensure its continued operation during and after a seismic event. Special care must be taken in these situations to ensure that equipment has been shake-table-tested or otherwise certified to meet the maximum anticipated seismic load. Table 5 illustrates some load combination calculations.

1.4 COMPUTATION OF LOADS AT BUILDING CONNECTION

ASCE *Standard* 7 is based on **load- and resistance-factor design (LRFD)**. In the past, building codes have been based on **allowable stress design (ASD)**. Both are allowed for seismic restraint design. Load factors and load combinations that must be considered in design are defined in Chapter 2 of ASCE7 (see Table 5). If a component is anchored with post-installed anchors, the design is usually accomplished using provisions of LRFD. It is rare now to find components or attachments rated based on their ASD capacity; nonetheless, it is important to recognize the difference between the two and apply the appropriate factors based on the design method and component rating system to ensure that they are consistent.

Restraints holding components in position must withstand shear and tensile forces. Restraint selection and design requires determining the number of fasteners, such as anchors and bolts, that are affected by earthquake forces. The lateral seismic design force can be applied in any horizontal direction and should be evaluated in at least two specific directions, as shown in Figure 1. Note that as many as all of the attachments, or as few as a single attachment, may be affected, depending on the restraint configuration and load direction. The simple case example following provides a basic design method and is made more complicated if the center of gravity (CG) is shifted or if the anchor spacing is not symmetrical. This basic method is called the **polar method** and is the most commonly used for seismic restraint design.

Some restraint designs consider how the mass is distributed and address all possible horizontal directions with some modification of the ASCE prescriptive design methodology. This is called the **lump mass method**.

Remember that vibration-isolated equipment will be restrained by snubbers that incorporate operating clearances. As the load is applied at all possible angles and the equipment tilts in response to these loads, not all of the snubbers will make contact and as such not all will be able to contribute to the resistance of vertical loads. Every restraint arrangement will experience differing abilities to share these loads, and the worst-case reactions at each restraint point should account for these factors.

When analyzing rigid equipment, it is reasonable to assume that vertical or horizontal loads will be shared among all restraints. Typically, the force that is generated by overturning or the rotational load created by an offset CG is shared among all restraint points. For lateral forces, the amplitude is equally divided over all the restraints. For rotational motion, the amplitude of the restraint force at each location is proportional to the distance that restraint point is from the geometric center of the mounting pattern. The worst-case load for the location at the maximum distance can be obtained by generating appropriate I_{xx} and I_{yy} terms for the restraint pattern and using that as indicated in the examples below.

When analyzing isolated equipment however, the ability to share rotational or rocking (compression/tension) loads beyond the four corner locations will become a function of the stiffness of the equipment. Some equipment, like packaged air handling units, is relatively flexible and will distort and spread the rotational and overturning loads among a number of restraints. Equipment with rigid bases, like a concrete inertia base mounted pump, will tend to distribute the load based on the rotational axis as described previously.

Simple Case

Figure 1 shows a rigid floor-mount installation of a piece of equipment with the center of gravity at the approximate center of the restraint pattern. To calculate the shear force, the sum of the forces in the horizontal plane is

$$0 = F_p - V \tag{6}$$

The equipment shown in Figure 1 has two bolts on each side, so that four bolts are in shear. Using a single-axis moment equation to calculate the tension force, the sum of the moments for overturning results in an overturning moment (OTM) and resisting moment (RM).

For Figure 1, two bolts are in tension. See Example 1 for applications of the OTM and RM. See ASCE *Standard* 7 for load combinations that adjust the D (dead load) and E (earthquake load). If the equipment is located outdoors, be sure to consider the W (wind load) forces as well. Shear and tension forces V and T should be calculated independently for both axes, as shown in the front and side views. See the examples for complete analysis.

General Case

The classic method used to distribute seismic loads equally distributes lateral loads among the restraints and then modifies these loads as a function of the weight eccentricity. Worst-case weight, vertical seismic load, and overturning components are combined to determine a maximum vertical load component in two horizontal directions. This **polar method** is in common use and works well for most applications.

Equipment can be directly attached to the building structure or to a structural base made of steel shapes (like angles or I-beams). Using a structural base distributes the seismic loads more evenly and may reduce the size of the anchors by reducing the peak load. This results in less stress on the equipment point of attachment, which may not have sufficient strength to transfer the seismic load to the structure. If vibration isolation devices are used, stresses on the equipment points of attachment increase which may then require the use of a structural base.

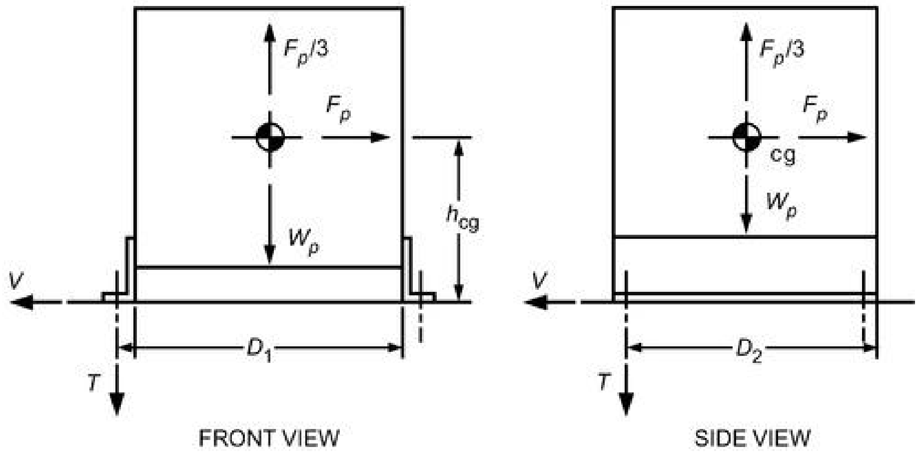


Figure 1. Equipment with Rigidly Mounted Structural Bases

Larger equipment will have more than four anchor points at each of the corners. Depending on the weight distribution and anchor spacing, the seismic loads at the corners may be lower than the seismic loads in the middle.

Although only two methods of computing seismic forces are illustrated here, there are likely many other valid methods that can be used to distribute the restraint forces. It is important that any method used include the ability to account for equipment weight, seismic uplift or compression forces, overturning forces, and the impact of any offset of the center of gravity within the equipment.

Polar Method

Lateral forces are assumed to be equally distributed among the restraints. If the equipment's center of gravity does not coincide with its geometric center, a rotational factor is added to account for the imbalance. This factor is determined in three steps. First, compute the true chord length in the horizontal plane between the equipment's center of gravity and the geometric center of the restraints. Second, multiply the equipment total seismic lateral force by this length (to obtain a rotational moment). Third, divide this figure by the number of moment-resisting restraints times their distance from the geometric center. (The moment-resisting restraints are those farthest and equally spaced from the geometric center.) The resulting load can then be added to the original (balanced) figure. This method transfers all imbalance loads to the corner restraints and provides a valid method of restraint as long as the equipment acts as a rigid body. The assumption that a piece of equipment can transfer these loads out to the corners becomes less accurate as the equipment becomes less rigid.

Calculation of the tensile/compressive forces at the restraints is more complex than that for determining the shear loads, and must include weight, vertical seismic force, overturning forces, and (if isolated) the type of isolator/restraint system used. The total tensile and compressive forces are the worst-case summation of each of these components. For clarity, each component is addressed here as a separate entity.

The nominal weight component at each restraint is simply the total operating weight divided by the number of restraints. The vertical seismic force is simply the weight component at each location multiplied by the vertical seismic force factor in terms of the total F_{pv} load expressed in gs, the gravitational constant (F_{pv}/W_p, where F_{pv} is the vertical seismic load component as defined by the code and W_p is the total operating weight of the equipment). This can be directed either upward or downward when summing forces.

Lump Mass Method

In the lump mass method, the total equipment weight is distributed among the restraints in a manner that reflects the equipment's actual weight distribution. There are many methods of determining the distribution analytically or by testing, although they are not addressed in this section. It is often possible that a weight distribution can be obtained from the equipment manufacturer, especially for equipment meant to be hoisted by crane.

Once the static point loads are obtained or computed for each restraint location, they can be multiplied by the lateral seismic acceleration factor (F_p/W_p) to determine lateral forces at each restraint point. Thus, if the weight at each restraint point is W_n, then

$$V_{eff} = (F_p/W_p)W_n \tag{7}$$

This method considers the loads at all the restraints individually and computes the overturning forces for each in 1° increments for a full 360° of possible approach angles; it is only practical to perform using a spreadsheet or computer routine. The methodology involves breaking the seismic force F_p into x- and y-axis components for each possible approach direction. These forces are multiplied by the height of the equipment center of gravity above the point of restraint h_{cg}. The resulting moments are then resolved into forces at each restraint based on the x- and y-axis moment arms associated with the particular restraint location and the distance between those restraint elements that will actually make contact to resist the overturning loads and the geometric center of the restraint layout.

Resilient Support Factors

If the equipment being restrained is isolated, the following three factors must be considered:

- For all forces that are not directed along the principal axes, only the corner restraints may be considered to be effective, depending on the rigidity of the equipment. Thus, for either distribution method, only the corner restraints may be considered capable of absorbing vertical loads.
- If the restraints are independent (separate entities) from the spring isolation elements and if, when exposed to uplift loads, vertical spring forces are not absorbed within the housing of an integral isolator/restraint assembly, the weight factor determined in the first step of the vertical load analysis should be ignored. (This is because any effect that a weight reduction has on the attachment hardware forces is replaced by an approximately equal vertical force component from the spring.)
- If the gap in the restraint element exceeds 1/4 in., the final computed forces must be doubled as required by the IBC.

Building Attachment

The most common attachment arrangements are securing with steel bolts, attaching with lag screws, welding, or anchoring to concrete using various kinds of post-installed anchors. To evaluate the combined effective tensile and shear forces that act simultaneously on these connections, a separate analysis that considers the relationship between the restraint device's snubbing element (if vibration isolated) and the structural connection geometry is required.

If the connection to structure is made using concrete anchors, additional factors may affect or increase seismic loads. See the following section for details on concrete anchors.

If allowable stress design (ASD) capacity data are used to select restraint or attachment hardware while using the load-resistant factor design (LRFD) IBC codes, the loads may be reduced by a factor of 1.4. These must be identified at the beginning of the design effort and using the appropriate load combination equations. If LRFD capacity data is used when selecting hardware, the 1.4 factor does not apply.

ACI *Standard* 318 is the basis for sizing concrete anchors. All allowable capacities used for concrete post-installed anchor bolts selection should be drawn from ICC-ES test reports. These values reflect test data on a single anchor and anchor capacity determined from the various configuration arrangements affected by embedment, edge distances, spacing, and whether the anchor is installed in the soffit (underside) or top side of concrete on metal deck. Anchor manufacturers have selection software to determine anchor bolt capacities that consider installation conditions, including presence of other nearby anchors and vertical offset (as with elevated baseplates with grout infill). Also, note that the values published in ES reports may be either ASD or LRFD values and may need to be converted for compatibility with the (LRFD) IBC code being used.

1.5 STEEL BOLTS

For direct attachment with through bolts using ASD criteria, the design capacity of the attachment hardware should be based on criteria established in the American Institute of Steel Construction (AISC) manual. Based on the use of A307 bolts, the basic formula for computing allowable tensile stress when shear stresses are present is

$$T_{allow} = 26{,}000 - 1.8S_v \tag{8}$$

where S_v is the shear stress in the bolt in psi. T_{allow}, the maximum allowable tensile stress, must not exceed 20,500 psi.

However, because these stresses are appropriate for dead- plus live-load combinations, they can be appropriately inflated by 1.33 when allowable stress design provisions are used and when they are used to resist wind and seismic loads as well. Peak bolt loads are based on the maximum permitted stress multiplied by the nominal bolt area.

1.6 LAG SCREWS INTO TIMBER

Acceptable loads for lag screws into timber can be obtained from the *National Design Specification®* (NDS®) *for Wood Construction* (AWC 2015). Selected fasteners must be secured to solid lumber, not to plywood or other similar material. Withdrawal force design values are a function of the screw size, penetration depth, and wood density and can be increased by a factor of 1.6 for short-term seismic or wind loads. NDS identifies withdrawal forces on a force/embedment depth basis. Note that the values published in this table are capacities in both ASD and LRFD. In addition, NDS introduces deration factors for reduced edge distance and bolt spacing.

In timber construction, the interaction formula given in Equation (8) does not apply. Instead, per the NDS, the equation is

$$Z_a' = (W'p)Z'/[(W'p)\cos^2\alpha + Z'\sin^2\alpha] \tag{9}$$

where

Z' = shear capacity drawn from Table 9.3A

W' = side grain withdrawal force = $1800G^{3/2}D^{3/4}$

G = specific gravity of the timber

D = diameter

p = embedment depth of screw

α = angle of composite force measured flat with surface of timber

1.7 CONCRETE ANCHORS

Concrete anchors can be divided into two main categories: cast-in-place and post-installed. The former are positioned prior to the concrete being poured and can be suitable for wood formwork, metal deck, or being fixed in place with rebar or other means. Post-installed anchors allow positioning after the concrete has cured and allow more flexibility in determining attachment point locations during construction.

Capacities are manufacturer and anchor-type specific and determined through testing using ACI *Standard* 355.2 or 355.4 for mechanical or adhesive anchors, respectively. Capacity data should be obtained from the most recent ICC-ES report available from the anchor manufacturer. The report will provide capacity strengths at specific installation conditions for use with strength-based design (LRFD) methods. For other installation conditions and for groups of anchors, special factors are required and American Concrete Institute *Standard* 318-11 should be consulted.

ASCE7 requires the use of an overstrength factor Ω_0, called “omega-naught” or “omega sub-zero,” applied to the demand side of the equation for attachments to concrete. This assumes the anchor failure mode may be brittle (a concrete breakout or pullout failure). The value of this overstrength factor has varied over the years with different codes. The ASCE7-16 version requires a value of 2 be used for most HVAC&R equipment with one exception, so-called fin-fans or condensing units that commonly come mounted on integral cold-formed sheet metal legs require an overstrength factor of 1.5 when attached to concrete. This factor is applied to F_p at the center of gravity. For some deep or cast-in-place anchors, the anchor failure mode may be determined to be in the steel anchor body in which case the overstrength factor need not be applied.

ASD Applications

Interaction Formula. To evaluate the combined effective tension and shear forces that act simultaneously on the bolt, use the either of the following equations:

$$(T_{eff}/T_{allow\ ASD})^{5/3} + (V_{eff}/V_{allow\ ASD})^{5/3} \le 1.0 \quad \textbf{(10)}$$

or

$$(T_{eff}/T_{allow\ ASD}) + (V_{eff}/V_{allow\ ASD}) \le 1.2 \quad \textbf{(11)}$$

However, if T_{eff} ≤ 0.2; $T_{allow\ ASD}$ the full T_{eff} can equal $T_{allow\ ASD}$, or if V_{eff} ≤ 0.2; $V_{allow\ ASD}$ the full V_{eff} can equal $V_{allow\ ASD}$.

LRFD Applications

The engineer must select an anchor for use from a current evaluation report for anchors that satisfy provisions of ACI 318 Appendix D or ACI 355 (the provisions are the same). From ACI 318, the capacity of the anchor must be reduced in accordance with the following:

$$T = 0.75\phi N \quad \textbf{(12)}$$

$$V = 0.75\phi V \quad \textbf{(13)}$$

The interaction equation for LFRD is modified as follows:

$$(T_{eff}/T_{allow}) + (V_{eff}/V_{allow}) \le 1.2 \quad \textbf{(14)}$$

Types of Concrete Post-Installed Anchors

There are several types of anchor bolts for use in concrete; each type has different installation and capacity characteristics. All anchors used to resist seismic loads much be tested and rated specifically for seismic loads. The manufacturer’s instructions for installing the anchors must also be followed. Published reports (e.g., ICC-ESRs) have further information on allowable forces for design. Use all appropriate design factors as required by the published reports and by applicable codes.

Wedge anchors have an expanding conical portion, or wedge, at one end with a loose clip around the wedge. After a hole is drilled, the bolt is inserted and the nut tightened to draw the anchor up. As the nut is tightened to a specific torque, the wedge expands the small clip, which bites into the concrete.

Undercut anchors expand to seat against a shoulder cut in the bottom of the anchor hole. These often have the highest capacity of commonly available anchor types, though since some require an extra operation to cut the shoulder in the hole, their use on projects can be limited.

Screw anchors are one-piece anchors that have a concrete cutting thread. These anchors are designed to be installed with a specified torque to ensure contact at the rated embedment

Adhesive anchors are a combination of rods or rebar with special chemicals that, when mixed, form a strong bond with concrete. Pure epoxy, polyester, or vinyl ester resin adhesives are used with a threaded rod supplied by the contractor or the adhesive manufacturer. Some adhesives have a problem with shrinkage; others are degraded by heat. However, some adhesives have been tested without protection to 1100°F before they fail (all mechanical anchors will fail at this temperature). Where required, or if there is a concern, anchors should be protected with fire retardants similar to those applied to steel decks in high-rise buildings.

Stainless steel anchors (for any of the preceding types) are required for use in outdoor applications where exposed to weather.

Other common types of post-installed concrete anchors are used in the construction industry, but are not rated for seismic loads and should only be used with caution.

Drop-in expansion anchors are hollow cylinders with a tapered end. After they are inserted in a hole, a small rod is driven through the hollow portion, expanding the tapered end. These anchors are not rated for seismic restraint applications and are used only for shallow installations because they have no reserve expansion capacity.

A **sleeve anchor** is a bolt covered by a threaded, thin-wall, split tube. As the bolt is tightened, the thin wall expands. Additional load tends to further expand the thin wall. The bolt must be properly preloaded or friction force will not develop the required holding force. These anchors are typically not used in seismic applications because of the limited reserve capacity.

1.8 WELD CAPACITIES

Weld capacities may be calculated to determine the size of welds needed to attach equipment to a steel plate or to evaluate raised support legs and attachments. A static analysis provides the effective tension and shear forces. The capacity of a weld is given per unit length of weld based on the shear strength of the weld material. For steel welds, the allowable shear strength capacity is 21,000 psi on the throat section of the weld. The section length is 0.707 times the specified weld size.

For a 1/16 in. weld, the length of shear in the weld is 0.707 × 1/16 = 0.0442 in. The allowable weld force $(F_w)_{allow}$ for a 1/16 in. weld is

$$(F_w)_{allow} = 0.0442 \times 16{,}000 = 700 \text{ lb per inch of weld} \tag{15}$$

For a 1/8 in. weld, the capacity is 1400 lb/in.

The effective weld force is the sum of the vectors calculated in terms of effective shear and tension shall be reduced. Because the vectors are perpendicular, they are added by the method of the square root of the sum of the squares (SRSS), or

$$(F_w)_{eff} = \sqrt{(T_{eff})^2 + (V_{eff})^2} \tag{16}$$

The length of weld required is given by the following equation:

$$\text{Weld length} = (F_w)_{eff}/(F_w)_{allow} \tag{17}$$

1.9 SEISMIC SNUBBERS

Seismically rated snubbers allow floor-mounted restrained components to move within controlled limits and to be supported with resilient mounts such as spring or elastomer isolators. Several types of snubbers are manufactured or field fabricated. All snubber assemblies should meet the following minimum requirements to avoid imparting excessive accelerations to HVAC&R components:

- Impact surfaces should include elastomeric materials at least 1/8 in. thick and be no more than 1/4 in. away.
- Resilient material should be accessible to inspect for deterioration and damage.
- Snubber system must provide restraint in all directions.
- Snubber capacity should be verified either through test (e.g., ASHRAE *Standard* 171) or by analysis.

Examples of typical snubbers and isolators with integral snubbers are shown as Types A through J in Figure 2. Types A through D are snubber styles corresponding to one isolator type referred to in Chapter 49 as Type 4 Restrained Spring Isolator and are referred to in ASHRAE *Standard* 171 as multidirectional, multi-axis, with integral isolation. Note that Table 47 of Chapter 49 uses the letters A through D to denote base mounting types which should not be confused with the snubber types below. Snubber Type E is a combination isolator and snubber referred to in that chapter as a Type 2 Rubber Mount and is also referred to in ASHRAE *Standard* 171 as multidirectional, multi-axis, with integral isolation. Typically all hold-down and mounting bolts are protected from housings and other components using elastomeric grommets and washers to minimize vibration short-circuiting and reduce seismic acceleration forces. Care must be taken during installation to ensure these bolts remain out of contact and free to move under normal operation. Snubbers types F through J are often used in conjunction with isolators that do not have integral snubbers. Per ASHRAE *Standard* 171, Types F, G, H, and J are called multidirectional, multi-axis with operating clearances, and Type I is called single-directional, single-axis, single angle.

- **Type A.** Completely enclosed spring isolator with elastomeric grommet.
- **Type B.** Spring isolator typically used for low seismic loads and with components with rigid bases; the spring sits on a base plate that includes hold-down hardware that includes elastomeric grommets.

- **Type C.** Housed spring isolator used for low to high seismic loads with built-in hold-down bolts that act as all-directional restraints.
- **Type D.** Housed spring isolator used for low to moderate seismic loads similar to Type A.
- **Type E.** Elastomeric mount capable of withstanding seismic loads in all directions.
- **Type F.** All-directional snubber using a single bolt attached to a restrained component.
- **Type G.** Two-axis snubber.
- **Type H.** All-directional snubber using interlocking steel assemblies lined with elastomeric material.
- **Type I.** Single-axis snubber, also called a bumper.
- **Type J.** A heavy-duty version of Type F used for higher seismic loads.

1.10 SEISMIC RESTRAINTS FOR SUSPENDED COMPONENTS

For suspended equipment, pipes, ducts, conduits, and raceways, it is necessary to restrain lateral movement resulting from seismic acceleration applied to the component. Unrestrained, suspended equipment and related systems may sway violently back and forth, impacting nearby building elements and possibly overstressing the hanger rod supports or their attachments, leading to collapse. To prevent this swaying, suspended components are braced or restrained, typically by one of two methods: a wire rope system, or a rigid brace system using steel struts, angles, or other rigid elements.

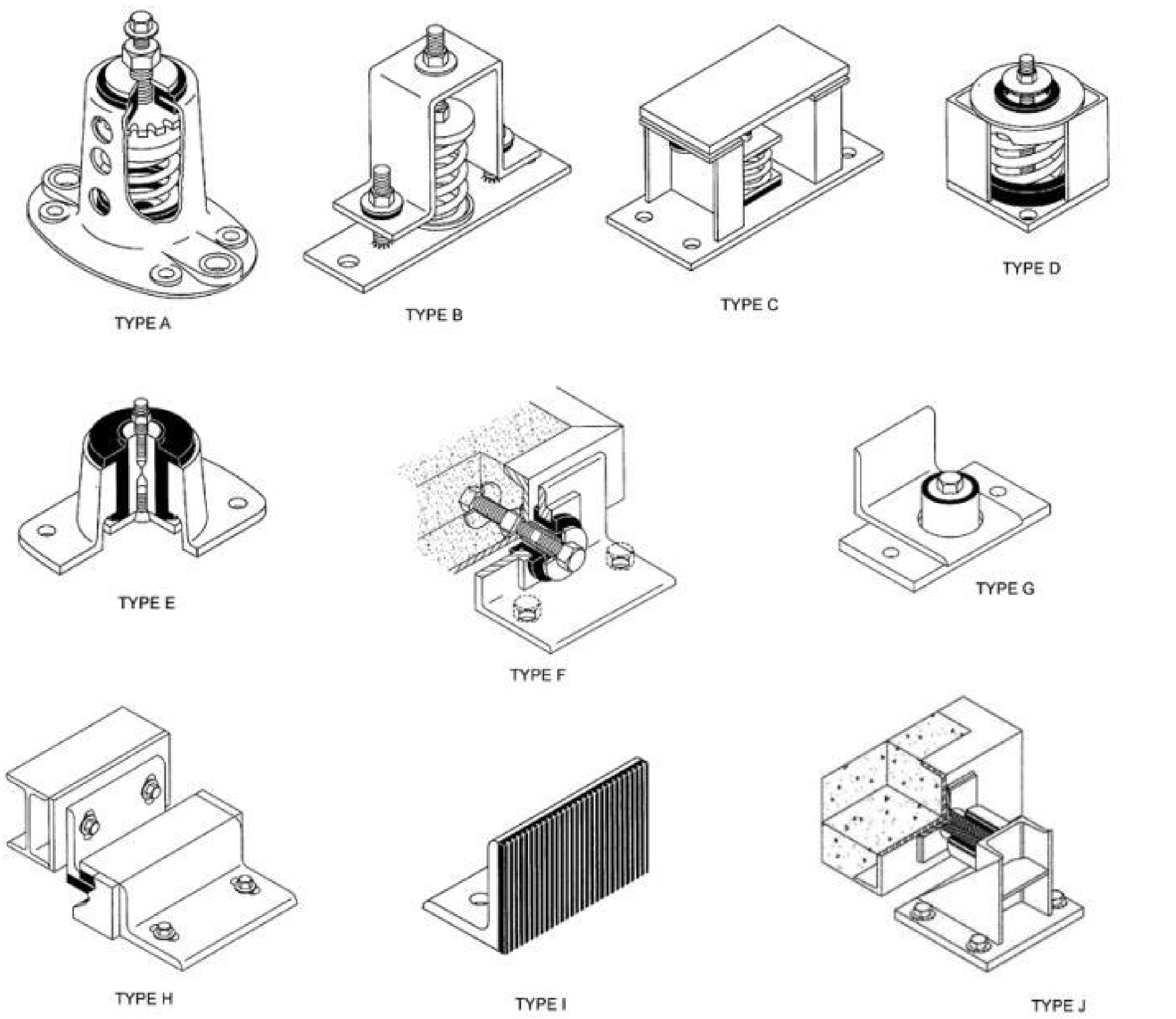


Figure 2. Seismic Snubbers

Wire rope restraints are restraint assemblies typically used for suspended components consisting of galvanized steel wire rope (also known as aircraft cable). A typical cable restraint system is shown in Figure 3. Cable restraints should be tested for capacity in accordance with ASHRAE *Standard* 171. Cables are installed to prevent excessive seismic motion and arranged so they do not engage during normal operation. Equipment suspended with vibration isolators must use cable restraints instead of rigid restraints to avoid shorting out or degrading the isolation. Rod stiffeners are added as necessary, as shown in Figure 4, to prevent the hanger rods from buckling.

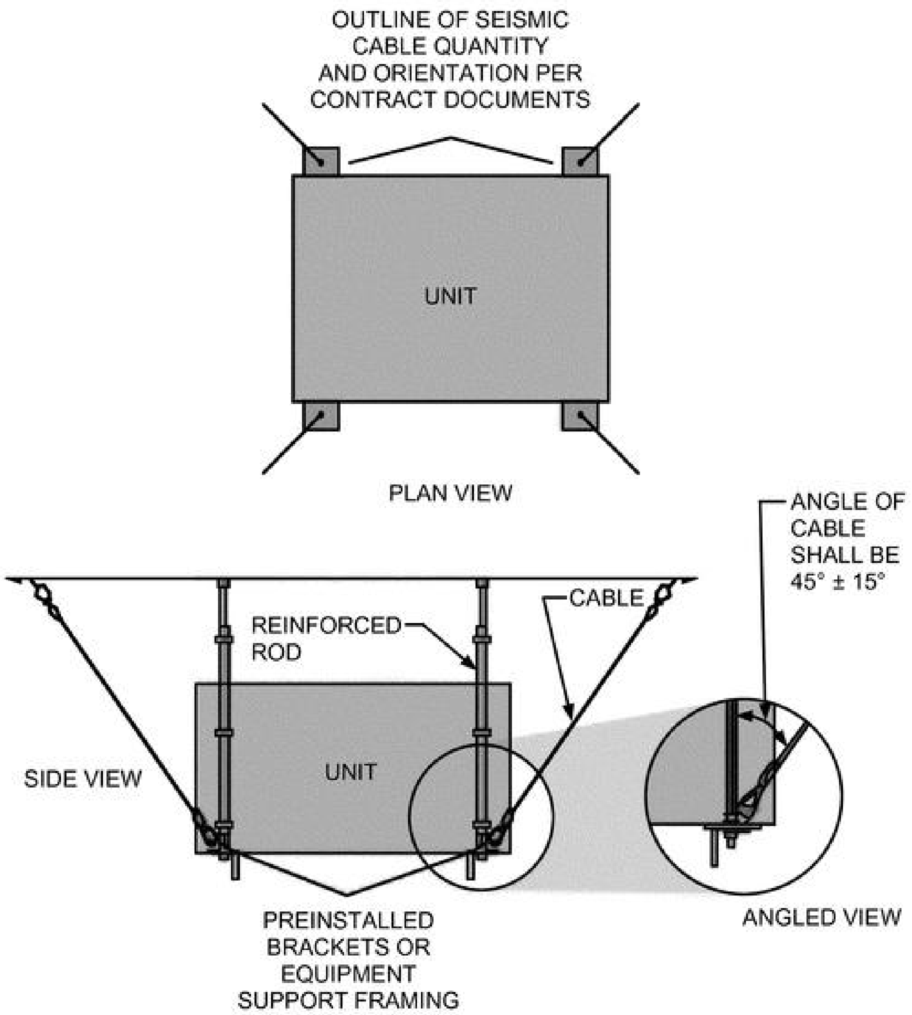


Figure 3. Cable Restraint

Secure the cable to structure and to the braced component through a bracket or stake eye designed to meet the cable restraint rated capacity. Cables ends are typically terminated using one of the following methods:

- Factory-installed permanent stake eye
- Looped around thimble through bracket and secured with wire rope clips (also called Crosby cable clamps), oval compression sleeve (or ferrule or swage sleeve), or other proprietary securement device
- Factory brackets with integral cable clamps

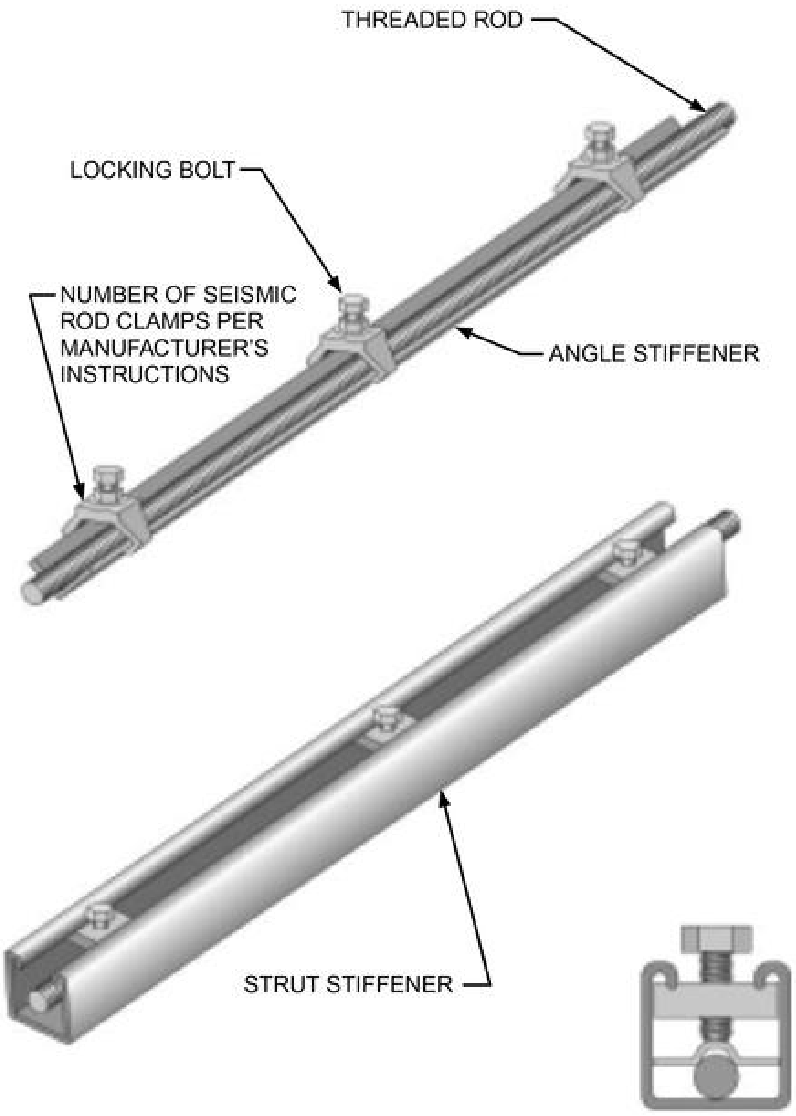


Figure 4. Rod Stiffener

When cables are looped through a bracket or support hole, a teardrop-shaped cable thimble matching the wire size should be used to protect the cable. Some specialty brackets are designed specifically for allowing a looped cable through without a thimble. Figure 5 shows typical cable restraint details with various attachment methods. Typical attachment methods to secure rigid braces to structures and components are shown in Figure 6.

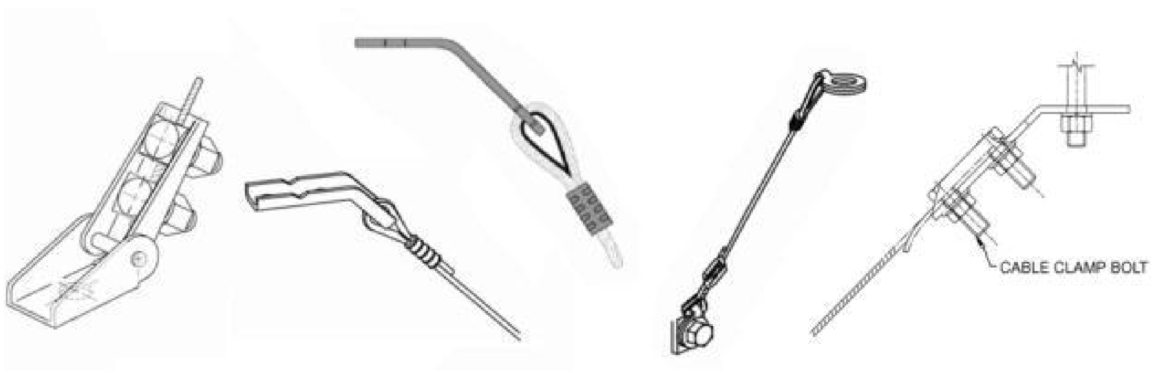


Figure 5. Types of Cable Connections

1.11 RESTRAINT OF PIPE AND DUCT RISERS

When piping and ductwork run vertically through a structure, they are identified as risers. They are subject to the same seismic and (less commonly) wind forces as are piping and ductwork oriented horizontally. The primary difference is that the forces that act along the axis of the riser are the summation of the vertical seismic forces and gravity loads, whereas on horizontal systems, the axial forces are simply the horizontal seismic or wind force.

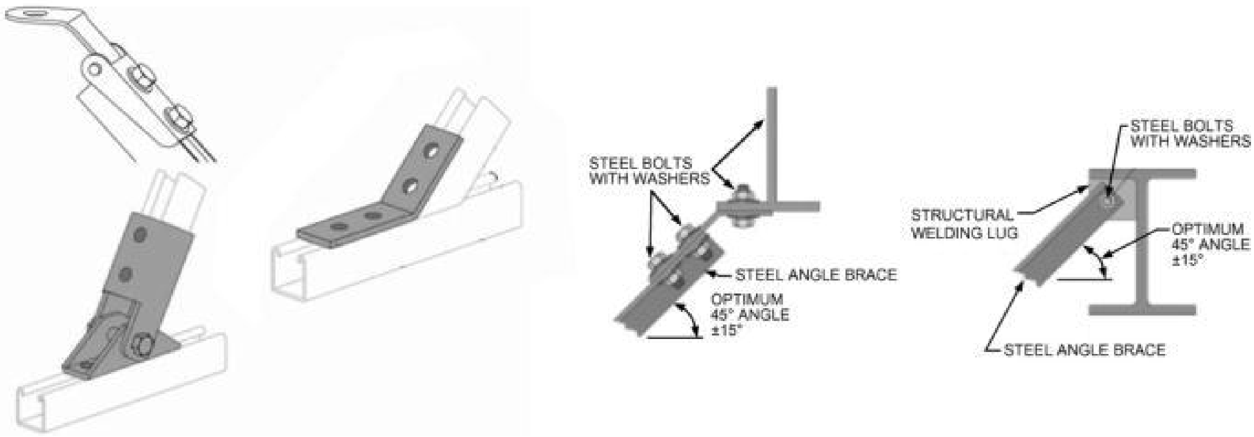


Figure 6. Strut End Connections

It is also important to recognize that restraining risers of any significant length and variation in temperature require support that allows thermally driven changes in the riser's overall length to be accommodated. Because the vertical seismic and wind forces are small compared to gravity forces, axial restraint for the riser can normally be provided with only minor increases in the size of the specialized components used to support the system. Because of the potential of damage to the restraint or support systems as the system grows or shrinks due to thermal changes, it is not recommended that axial restraint systems be fitted to a riser. Instead, the primary support system should be designed or selected to meet the project design loads.

Risers of significant length are also fitted with some type of stabilization devices. These can be as simple as snug-fitting holes in the floors that the risers penetrate or specialized brackets or guiding devices that maintain the alignment of the piping or duct while still allowing it to expand or contract. As is the case with the vertical forces, the components used for guidance can frequently be used to provide resistance against seismic or wind events if they are sized and attached adequately.

If, in the lateral load case, the components used to provide guidance are not adequate to resist the design seismic or wind load conditions, additional seismically qualified restraint systems should be fitted to perform this task.

All axial and lateral restraints fitted to risers must be effective against forces that may act in any horizontal or vertical direction as applicable. In addition, the attachment hardware used must include seismically qualified components (e.g., anchors), installed in accordance with seismically qualified procedures.

1.12 EXAMPLES

The following examples should not be considered to cover all installation cases; they are a selection of simple cases that can be used for illustrative purposes. Many, if not most, cases are more complex and will require the engineer performing the analysis to consider the details of the application when creating a model. There are many potential configurations (far more than can be illustrated here) that impact the load path and add forces/moments at the restraint points. Efforts have been made in the examples to indicate qualifications and limitations specific to the particular model being used.

The following examples are provided to assist in the design of component anchorage to resist seismic forces. For Examples 1 through 4, assume the provisions contained in ASCE7-16 apply, I_p = 1.5, S_s = 0.85, site soil class is C, and the equipment is located at the top of a 50 ft building. Also include a vertical force component $F_{pv} = 0.2 S_{DS} D$ where D is the dead load for all examples. Examples 1 through 5 are solved using the polar method of analysis while Example 6 is solved by the lump mass method.

Note: These examples assume that I_p = 1.5. This assumes that the component being considered is required for the continued function an essential facility following an earthquake or contains hazardous materials. ASCE7-16 Section 13.2.2 requires that this component be certified as being operable after the design earthquake. Codes based on ASCE7 require that the anchor failure mode be considered when selecting an appropriate anchor. If, when using the baseline factors indicated above, it is found that the limiting failure mode of the anchor/restraint component is a brittle failure associated with the anchor (i.e., a concrete or anchor pullout failure) rather than a ductile (steel) failure, the analysis of the anchorage needs to be selected with the F_p load increased by the Ω_0 factor, which in most cases is 2. The general math is the same, but the force magnitudes will increase from those shown in the sample cases.

Example 1. Anchorage design for equipment rigidly mounted to the structure (see Figure 7). This model is appropriate only for rigid-mounted equipment with four restraint points and the CG centered geometrically on the restraint point pattern. The equations can be adjusted when the equipment center of gravity is offset from the geometric center. There are other examples provided for vibration-isolated equipment.

From Equations (1) to (4), calculate the lateral seismic force and its vertical component. For rigidly mounted mechanical equipment (period < 0.06 s or > 16.7 Hz), a_p from Table 2 is 1.0, otherwise a_p = 2.5.

The first step in the load determination process is to determine S_{DS} using the following equation and F_a = 1.1 (from Table 3, site class C). Linear interpolation is allowed and the actual F_a for this application could be reduced to (1.0 – 0.75)/0.25 × 0.1 +

1.0, or 1.06. For this example, though, F_a = 1.1 is used.

$$S_{DS} = 2F_aS_s/3 = 2 \times 1.1 \times 0.85/3 = 0.623$$

Using this value for S_{DS} Equation (1) gives

$$F_P = \left[\frac{0.4 \times 1.0 \times 0.623 \times 1000}{\frac{2.5}{1.5}}\right]\left(1 + 2 \times \frac{50}{50}\right) = 450 \text{ lb}$$

Equation (2) shows that F_p need not be greater than

$$1.6 \times 0.623 \times 1.5 \times 1000 = 1495 \text{ lb}$$

Equation (3) shows that F_p must not be less than

$$0.3 \times 0.623 \times 1.5 \times 1000 = 280 \text{ lb}$$

Therefore F_p = 450 lb.

When considering provisions of LRFD, a vertical acceleration component must be considered per ASCE7, Section 12.4.2.2.

$$F_{PV} = 0.2 \times S_{DS} \times D = 0.2 \times 0.623 \times 1000 = 125 \text{ lb}$$

A simplified method of calculating the resisting moment (RM) involves looking only at the diagonally opposite corners. For hard-mounted equipment, opposite corners could also be considered. The simplified method is shown next for both ASD and LRFD cases.

For Allowable Stress Design (ASD)

The load combinations of Section 2.4 of ASCE7-16 must be considered in the design. For rigidly mounted components, and when looking at worst-case tensile (uplifting) loads on the restraint component, Combination 8 is generally the critical combination to be considered.

Calculate the overturning moment OTM:

$$\text{OTM} = F_P h_{cg} = 450 \times 40 = 18{,}000 \text{ in} \cdot \text{lb} \quad \textbf{(18)}$$

Calculate the resisting moment RM:

$$\text{RM} = W_P\left(\frac{d_{min}}{2}\right) = 1000\left(\frac{28}{2}\right) = 14{,}000 \text{ in} \cdot \text{lb} \quad \textbf{(19)}$$

$$T = [18{,}000(0.7) - 14{,}000(0.6)]/28 = 150 \text{ lb} \quad \textbf{(20)}$$

Calculate T_{eff} per bolt:

$$T_{eff} = 150/2 = 75 \text{ lb per bolt} \quad \textbf{(21)}$$

Calculate shear force per bolt:

$$V_{eff} = 450/(4 \times 1.4) = 78 \text{ lb per bolt} \quad \textbf{(22)}$$

Load and Resistance Factor Design (LRFD)

The load combinations of Section 2.3 of ASCE7-16 must be considered in the design. For rigidly mounted components, and when looking at the worst-case tensile (uplifting) loads on the restraint component, consider the most critical combination.

$$\text{RM} = (W_p - F_{pv})d_{min}/2 = (1000 - 125)28/2 = 12{,}250 \text{ in} \cdot \text{lb} \quad \textbf{(23)}$$

$$T_{eff} = [18{,}000 - 0.9(12{,}250)]/28(2) = 125 \text{ lb} \quad \textbf{(24)}$$

Case 1. *Equipment attached to a timber structure*

Before computing interaction forces, the computed loads must be reduced by a factor of 1.4 to make them compatible with the capacity data listed in the *National Design Specification®* (*NDS®*) *for Wood Construction* (AWC 1997). The lateral load V_{eff}

becomes 112.5/1.4 or 80.4 lb per bolt and the pullout load T_{eff} becomes 103/1.4 = 73.5 lb per bolt. For the capacity of the connection, a resulting combined load and angle relative to the mounting surface must be computed. The combined load is

$$T\alpha_{eff} = \sqrt{(T_{eff})^2 + (V_{eff})^2} = \sqrt{(80.4)^2 + (73.5)^2} = 109 \text{ lb}$$

The angle α = arcs in (T_{eff}/Z'_α) = 42.5°, where $Z\alpha$ is the allowable lag screw load multiplied by applicable factors and $Z'_\alpha\alpha$ is the factored allowable lag screw load at angle α from the mounting surface.

Selected fasteners must be secured to solid lumber, not to plywood or other similar material. The following calculations are made to determine whether a 1/2 in. diameter, 4 in. long lag screw in redwood will hold the required load. For this computation, it is assumed that bolt spacing, edge distance, temperature, and other factors do not reduce the bolt capacity (see NDS for further details) and that the load allowable factor for short-term wind or seismic loads is 1.6.

From Table 9.3A in the NDS, for redwood, G = 0.37, and Z perpendicular to the grain is 512 lb.

From Table 9.2A in the NDS, for G = 0.37 and 3.5 in. full thread, W = 385 × 3.5 = 1350 lb.

Substituting into the combined load for lag bolts [Equation (9)] gives

$$Z'_\alpha = \frac{(385 \times 3.5)512}{(385 \times 3.5)42.5 + 512 \sin^2 42.5} = 714 \text{ lb}$$

Therefore, a 1/2 in. diameter, 4 in. long lag screw can be used at each corner of the equipment.

Case 2. *Equipment attached to steel*

For equipment attached directly to a steel member, analysis is the same as that shown in case 1. Capacities for the attaching bolts are given in the *Manual of Steel Construction* (AISC). See Chapter J of the AISC Specification for design provisions.

For this example T_{eff}/T_{ASD} = 125/4410 = 0.02 < 0.2; therefore a combined tension shear check need not be performed on the connection.

Therefore, 1/2 in. diameter bolts can be used.

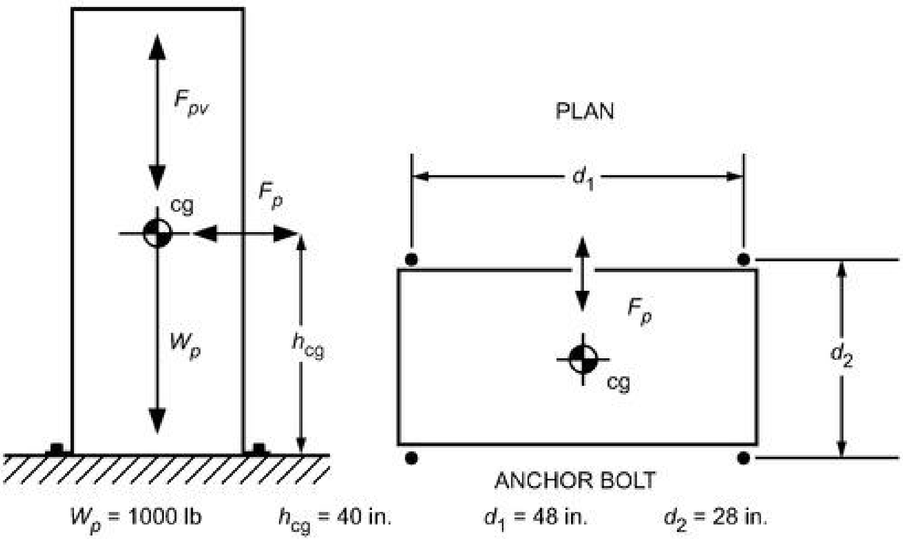


Figure 7. Equipment Rigidly Mounted to Structure (Example 1)

Example 2. Anchorage design for equipment supported by external spring mounts (Figure 8) and attached to concrete using seismically rated post-installed anchors.

A mechanical or acoustical consultant may choose the type of isolator or snubber or combination of the two (restrained isolator), typically in collaboration with the product vendor to should select the actual spring and/or snubber devices appropriate for the application.

Note that there are different values for R_p and a_p in different versions of ASCE7. This example uses Table 1, which is drawn from ASCE7-16. S_{DS} remains as in Example 1. For resiliently floor-mounted mechanical equipment, R_p = 2.0 and a_p = 2.5.

The basic force equation is then

$$F_p = 0.4 \times 2.5 \times 0.623 \times 1000(1 + 2 \times 50/50) = 1402 \text{ lb}$$

Equation (2) indicates that F_p need not be greater than

$$1.6 \times 0.623 \times 1.5 \times 1000 = 1495 \text{ lb}$$

Equation (3) indicates that F_p must not be less than

$$0.3 \times 0.623 \times 1.5 \times 1000 = 280 \text{ lb}$$

The vertical force F_{pv} equals

$$F_{PV} = 0.2 S_{DS} D = 0.2 \times 0.623 \times 1000 = 125 \text{ lb}$$

Assume that the center of gravity CG of the equipment coincides with the geometric center of the isolator group.

If T = maximum tension on a restrained isolator and C = maximum compression on a restrained isolator, then

$$\begin{aligned} T, C &= \frac{-W_P + F_{PV}}{4} \pm F_P h_{cg} \frac{\cos\theta}{2b} + F_P h_{cg} \frac{\sin\theta}{2a} \\ &= \frac{-W_P + F_{PV}}{4} \pm \frac{F_P h_{cg}}{2}\left(\frac{\cos\theta}{b} + \frac{\sin\theta}{a}\right) \end{aligned} \tag{25}$$

Note that the above equations hold true for all cases with four or more restraints on rigid equipment, assuming that the system is vibration isolated. This is because, for a very brief period of time, there is little or no load sharing with restraints that are not located on the diagonal corners as any remaining restraints would be operating in the clearance range of the snubbing elements and there would be no contact that would allow additional restraints to share the load.

To find maximum T or C, set $dT/d\theta = 0$:

$$\frac{dT}{d\theta} = \frac{F_P h_{cg}}{2}\left(\frac{\cos\theta}{b} + \frac{\sin\theta}{a}\right) = 0 \tag{26}$$

$$\theta_{max} = \tan^{-1}(b/a) = \tan^{-1}(28/48) = 30.26° \tag{27}$$

$$T = \frac{-W_P + F_{PV}}{4} + \frac{F_P h_{cg}}{2}\left(\frac{\cos\theta_{max}}{b} + \frac{\sin\theta_{max}}{a}\right) \tag{28}$$

$$C = \frac{-W_P + F_{PV}}{4} - \frac{F_P h_{cg}}{2}\left(\frac{\cos\theta_{max}}{b} + \frac{\sin\theta_{max}}{a}\right) \tag{29}$$

$$T = \frac{-1000 + 250}{4} + \frac{2990 \times 40}{2}\left(\frac{\cos 30.26}{28} + \frac{\sin 30.26}{48}\right) = 2285 \text{ lb}$$

$$C = \frac{-1000 + 250}{4} + \frac{2990 \times 40}{2}\left(\frac{\cos 30.26}{28} + \frac{\sin 30.26}{48}\right) = -2660 \text{ lb}$$

Calculate the shear force per isolator:

$$V = (F_P/N_{iso}) = 2990/4 = 748 \text{ lb} \tag{30}$$

This shear force is applied at the centroid of the elevation of the snubbing element in the restraint device. Uplift tension T on the vibration isolator is the worst condition for the design of the anchor bolts. The compression force C must be evaluated to check the adequacy of the structure to resist the loads.

$$(T_1)_{eff} \text{ per bolt} = T/2 = 2285/2 = 1143 \text{ lb} \tag{31}$$

The value of $(T_2)_{eff}$ per bolt due to overturning on the isolator is

$$(T_2)_{eff} = V \times \text{operating height}/dN_{bolt} \tag{32}$$

where d is the distance from edge of isolator base plate to center of bolt hole.

$$(T_2)_{eff} = (748 \times 8)/(3 \times 2) = 997 \text{ lb} \quad \textbf{(33)}$$

$$(T_{max})_{eff} = (T_1)_{eff} + (T_2)_{eff} = 1143 + 997 = 2140 \text{ lb} \quad \textbf{(34)}$$

$$V_{eff} = 748/2 = 374 \text{ lb} \quad \textbf{(35)}$$

See Example 1 for the design of the connections to the structural system.

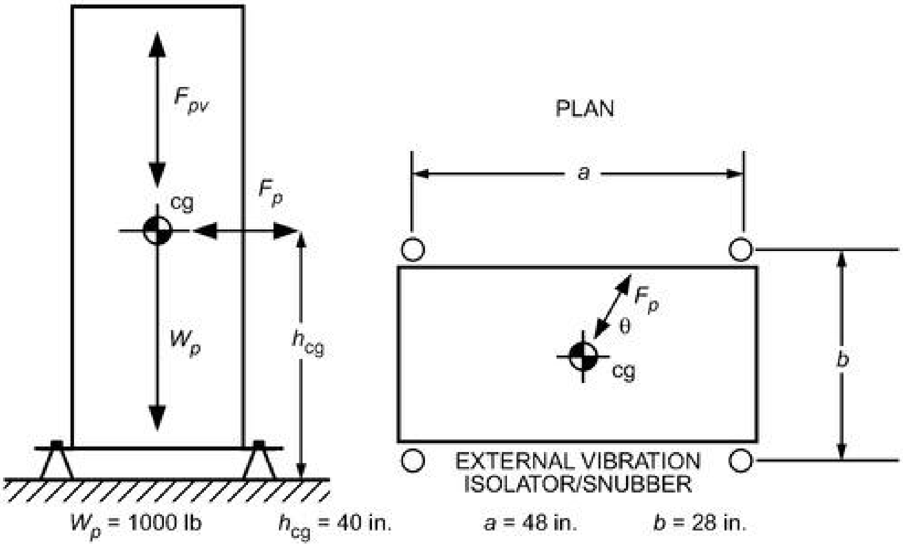


Figure 8. Equipment Supported by External Spring Mounts

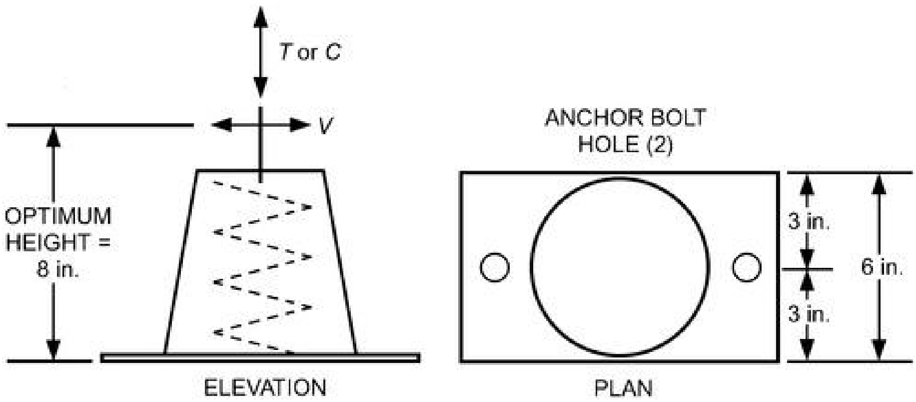


Figure 9. Spring Mount Detail (Example 2)

Example 3. Anchorage design for equipment with a center of gravity different from the geometric center of the restrained isolator group (Figure 10).

Anchor properties

$$I_x = 4B^2 \quad I_y = 4L^2 \quad \textbf{(36)}$$

Angles:

$$\theta = \tan^{-1}(B/L) \quad \textbf{(37)}$$

$$\alpha = \tan^{-1}(e_x/e_y) \quad \textbf{(38)}$$

$$\beta = 180\,|\alpha - \theta\,| \quad \textbf{(39)}$$

$$\phi = \tan^{-1}(LI_x/BI_y) \quad \textbf{(40)}$$

Vertical reactions

(41)

$$(W_n)_{max/min} = W_p \pm F_{pv}$$

Vertical reaction caused by overturning moment

$$T_m = \pm F_P \left(\frac{Bh_{cg}}{I_x} \cos\theta + \frac{Lh_{cg}}{I_y} \sin\theta \right) \tag{42}$$

Vertical reaction caused by eccentricity

$$(T_e)_{max/min} = (W_n)_{max/min} \left(\frac{Be_y}{I_x} + \frac{Le_y}{I_y} \right) \tag{43}$$

Vertical reaction caused by W_p

$$(T_w)_{max/min} = (W_n)_{max/min}/4 \tag{44}$$

$$T_{eff} = T_m + (T_e)_{max} + (T_w)_{max} \text{ (always compression)} \tag{45}$$

$$T_{eff} = -T_m + (T_e)_{min} + (T_w)_{min} \text{ (tension if negative)} \tag{46}$$

Horizontal reactions

Horizontal reaction caused by rotation

$$V_{rot} = F_P \left(\frac{e_x^2 + e_y^2}{16(B^2 + L^2)} \right)^{0.5} \tag{47}$$

$$V_{dir} = F_p/4 \tag{48}$$

$$V_{max} = (V_{rot}^2 + V_{dir}^2 - 2V_{rot}V_{dir}\cos\beta)^{0.5} \tag{49}$$

See Example 1 for the design of the connections to the structural system.

The values of T_{min} and V_{max} are used to design the anchorage of the isolators and/or snubbers, and T_{max} is used to verify the structure's adequacy to resist the vertical loads.

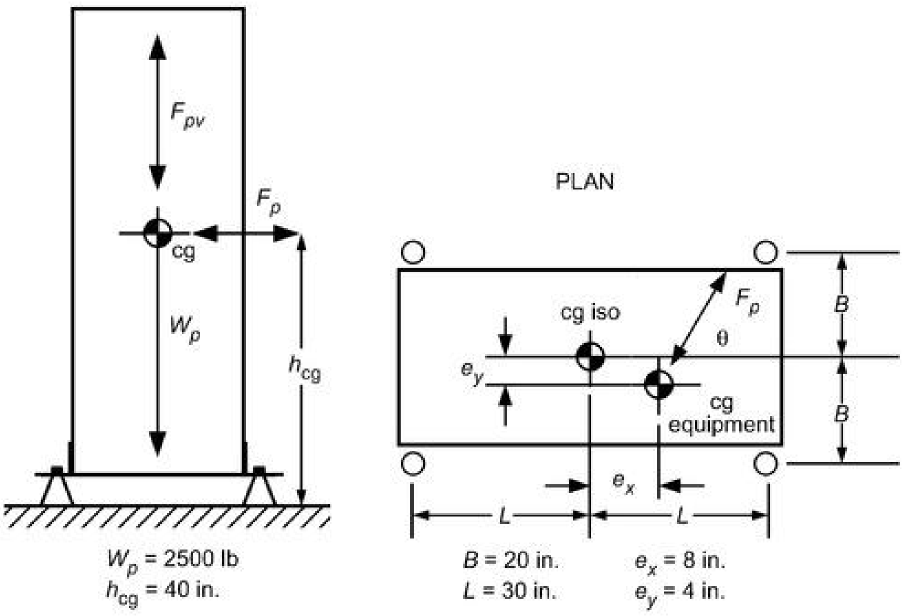


Figure 10. Equipment with Center of Gravity Different from Restrained Isolator Group (in Plan View)

Example 4. Anchorage design for equipment with supports and bracing for suspended equipment (Figure 11). Equipment weight W_p = 500 lb.

Note that post-installed anchors may not withstand published allowable static loads when subjected to vibratory loads, so vibration isolators may be used between the equipment and the structure to damp vibrations generated by the equipment.

Anchor properties

$$I_x = 4B^2 \qquad I_y = 4L^2 \tag{50}$$

Note that I_x and I_y will vary with the number of restraints for hard-mounted equipment, but since only the corner restraints come into play during initial contact caused by rocking or rotation, they will remain as indicated for vibration-isolated systems, no matter how many restraints are present.

Angle

$$\phi = \tan^{-1}(LI_x/BI_y) = 36.86° \tag{51}$$

From Equation (43),

$$(W_n)_{max/min} = 500 \pm 124 = 624 \text{ lb or } 376 \text{ lb}$$

From Equation (44),

$$T_m = \pm 1122(0.132 + 0.075) = \pm 233 \text{ lb}$$

From Equation (45),

$$T_e = 0$$

From Equation (46),

$$(T_w)_{max/min} = 156 \text{ lb or } 94 \text{ lb}$$

From Equation (47),

$$(T_{eff})_{max} = 233 + 0 + 156 = 389 \text{ lb (downward)}$$

From Equation (48),

$$(T_{eff})_{max} = -233 + 0 + 94 = -139 \text{ lb (upward)}$$

Forces in the hanger rods:

$$\text{Maximum tensile} = 389 \text{ lb}$$

$$\text{Maximum compression} = 139 \text{ lb}$$

Force in the splay brace = $F_P\sqrt{2}$ = 1587 lb at a 1:1 slope.

Because of the force being applied at the critical angle, as in Example 2, only one splay brace is effective in resisting the lateral load F_p.

Design of hanger rod/vibration isolator and connection to structure

When post-installed anchors are mounted to the underside of a concrete beam or slab, the allowable tension loads on the anchors must be reduced to account for cracking of the concrete. A general rule is to use half the allowable load. Some manufacturers have ICC reports that provide allowable values for anchors installed under the slab.

Determine whether a 1/2 in. wedge anchor with special inspection provisions will hold the required load.

$$T_{allow} = 600 \times 0.5 \times 2 = 600 \text{ lb} > T_{eff} = 389 \text{ lb}$$

Therefore, a 1/2 in. rod and post drill-in anchor should be used at each corner of the unit.

For anchors installed without special inspection,

$$T_{allow} = 600 \times 0.5 = 300 \text{ lb} > T_{eff} = 389 \text{ lb}$$

Therefore, a larger anchor should be chosen.

Determine if the 1/2 in. hanger rod would require a stiffener if it is 36 in. long.

Design of splay brace and connection to structure

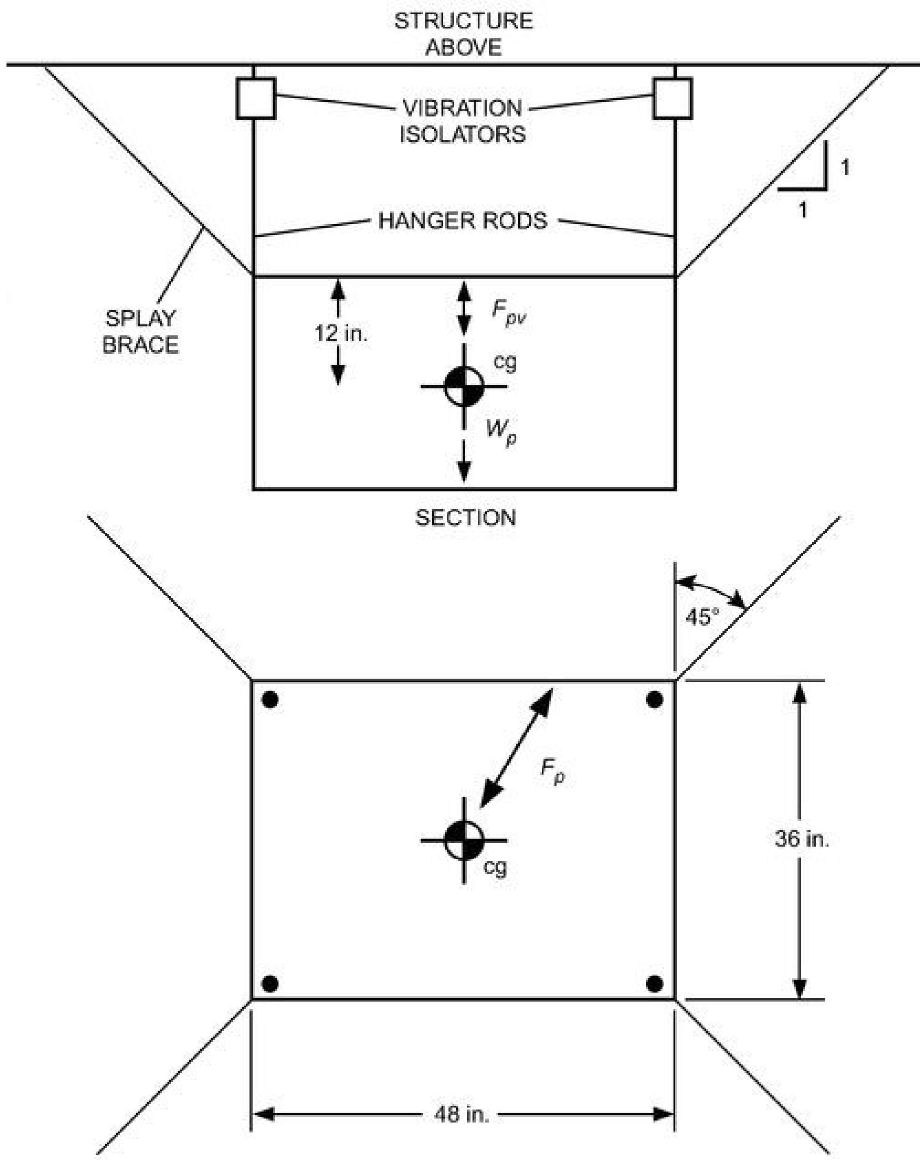
Force in the slack cable = 1587 lb.

Because all of the load must be resisted by a single cable, the forces in the connection to the structure are

$$V_{max} = 1122 \text{ lb} \qquad T_{max} = F_p = 1122 \text{ lb}$$

Because the cable forces are relatively small, a 3/8 in. aircraft cable attached to clips with cable clamps should be used. The clips, in turn, may be attached to either the structure or the equipment.

The design of a post-installed anchor installation is similar to that shown in Example 1. Anchors installed through a metal deck will have lower capacities than anchors installed in a flat slab because of limited embedment depths. Take care to ensure that the design also satisfies the requirements contained in the evaluation report for the anchor specified.



Note: Splay braces are prestretched aircraft cables with enough slack so that isolators can fully function vertically.

Figure 11. Supports and Bracing for Suspended Equipment

Example 5. This example is the same case as Example 1 (Figure 7), except that the lump mass method is used as a basis of analysis. Load combinations listed here are for LRFD, although the analysis can also be done using ASD in a similar manner to Example 1. The anchorage design is for equipment attached to concrete using seismically rated post-installed anchors. This model is also appropriate for vibration isolated equipment with no more than four restraint points and the CG centered geometrically on the restraint point pattern. It is not acceptable for systems where the CG is shifted away from the geometric center of the restraint point pattern.

When using the method, the F_p and F_{pv} acceleration terms are computed in the manner as when using the polar analysis; however the weight term would not be present. As such, the basic S_{DS} Equation (1) gives

$$F_{P(g)} = \left[\frac{0.4 \times 1.0 \times 0.601}{2.5/1.5}\right]\left(1 + 2 \times \frac{50}{50}\right) = 0.433\ (\text{g})$$

Equation (2) shows that F_p(g) need not be greater than

$$1.6 \times 0.601 \times 1.5 = 1.442\ (\text{g})$$

Equation (3) shows that F_p(g) must not be less than

$$0.3 \times 0.601 \times 1.5 = 0.271\ (\text{g})$$

Therefore F_p(g) = 0.433 (g).

When considering provisions of LRFD, a vertical acceleration component would still be considered per ASCE7, Section 12.4.2.2:

$$F_{PV}(\text{g}) = 0.2 \times S_{DS} \times D = 0.2 \times 0.601 = 0.120\ (\text{g})$$

The static mass load computation at each restraint location can be computed in many ways or may be provided by the equipment manufacturer. In this case the equipment is balanced, so the static mass load at each restraint point would equal the local weight/4:

$$\text{Static mass load (typ.)} = 1000/4 = 250\ \text{lb}$$

Horizontal design force.

This is driven by the static mass load; at each of the four corners would be the mass load × $F_p(g)$:

$$V_{eff} = 250 \times 0.433 = 108\ \text{lb}$$

If the equipment were both vibration isolated and the CG was off center, a T_m component as shown in Equation (44) would be computed, divided by 4 for the four corners that would split the load and that would be added to the mass driven load.

Vertical seismic design force.

This is also driven by the static mass load at each of the four corners would be plus or minus the mass load x $F_{pv}(g)$:

$$T_{seismic} = \pm 250 \times 0.120 = \pm 30\ \text{lb}$$

Dead load terms.

The maximum dead load terms would be the mass load × 1.2 per LRFD (Equation [5]):

$$D_{max} = -250 \times 1.2 = -300\ \text{lb}$$

The minimum dead load terms would be the mass load × 0.9 per LRFD (Equation [7]):

$$D_{min} = -250 \times 0.7 = -225\ \text{lb}$$

Overturning forces.

Per code for vertically cantilevered equipment, the overturning forces, must be computed for each possible seismic wavefront angle (from 0 to 360° in the plan view). This is accomplished by performing x and y axis static analyses using forces that are broken from the parent force F_p based on the angle of attack. The reaction forces for the load components are then summed for each restraint location and the worst-case upward and downward forces are retained. The method requires a spreadsheet or computer program to be accomplished efficiently. As such, the math behind a single load point and angle will be illustrated here.

Sample computation for the restraint in the bottom left hand corner as shown in Figure 8 at a wavefront angle θ = 30 degrees:

The x component of the F_p force = F_{px} = F_p(− cos θ)

$$F_{px} = 1000 \times 0.433 \times (-\cos 30) = -375\ \text{lb}$$

F_{px} would generate a reaction on the corner restraint of

$$-375 \times 40/(48 \times 2) = -156\ \text{lb}$$

Similarly, the y component of the F_p force = F_{py} = F_p × (− sin θ)

$$F_{py} = 1000 \times 0.433 \times (-\sin 30) = -217 \text{ lb}$$

F_{py} would generate a reaction on the corner restraint of

$$-217 \times 40/(28 \times 2) = -155 \text{ lb}$$

Summing, the overturning reaction at this restraint and this angle would be

$$-156 - 155 = -311 \text{ lb}$$

After all 360° are analyzed an Overturning$_{max}$(+) and Overturning$_{min}$(–) would result.

For each restraint point, the peak vertical loads would be

$$\text{Max. anchor tensile load} = T_{eff(max)} = D_{min} + T_{seismic} + \text{Overturning}_{\text{max}}$$

$$\text{Max. anchor compressive load} = T_{eff(min)} = D_{max} - T_{seismic} - \text{Overturning}_{\text{max}}$$

Prescriptive provisions of ASCE7 can be summarized as follows:

- Formulas for relative displacement of floor and ceiling can be conservatively estimated at 1% of the floor-to-ceiling height. This displacement must be used to determine the required horizontal flexibility of the pipe, duct, or electrical connections at the equipment interface.
- In ASCE7, using all-directional snubbers with clearance of more than 1/4 in. increases F_p by a factor of 2.
- Component supports must be designed to accommodate component movement to prevent pounding on the structure or other components. This applies to internal isolators and snubbers.
- Equipment components exposed to seismic impact forces and using nonductile housings must be designed using 25% of material yield stresses.
- Nonessential equipment, failure of which can cause essential equipment failure, must be designed as essential equipment.
- If the structure's site class (soil) is not provided in the contract documents, assume site class D, subject to change by the building official.
- Pipe and ducts may not be required to have sway braces, depending on size, material content, and importance factor. These conditions are defined in Chapter 13 of ASCE7.

1.13 INSTALLATION PROBLEMS

The following should be considered when installing seismic restraints.

- The proximity of anchors to edges and other anchors can significantly reduce their capacity. Concrete anchors should be located away from edges, stress joints, or existing fractures. The evaluation report for the chosen anchor should be followed as a guide for edge distances and center-to-center spacing.
- Supplementary steel bases and frames, concrete bases, or equipment modifications may void some manufacturers' warranties. Snubbers, for example, should be properly attached to a subframe.
- Static analysis does not account for the effects of resonant conditions within a piece of equipment or its components. Because all equipment has different resonant frequencies during operation and nonoperation, the equipment itself might fail even if the restraints do not. Equipment mounted inside a housing should be seismically restrained to meet the same criteria as the exterior restraints.
- Snubbers used with spring mounts should withstand motion in all directions. Some snubbers are only designed for restraint in one direction; sets of snubbers or snubbers designed for multidirectional purposes should be used.
- Vibration-isolated equipment must be strong enough to withstand the high deceleration forces developed by generated motion as the equipment oscillates and closes the gap on the isolated components, resulting in a large deceleration.
- Flexible connections should be provided between equipment that is braced and piping and ductwork that need not be braced.
- Flexible connections should be provided between isolated equipment and braced piping and ductwork.
- Bumpers installed to limit horizontal motion should be outfitted with resilient neoprene pads to soften the potential impact loads of the equipment.
- Anchor installations must be inspected (usually required for anchors resisting seismic forces); in many cases, damage occurs because bolts were not properly installed. To develop the rated restraint, bolts should be installed according to manufacturer's recommendations.

- Brackets in structural steel attachments should be matched to reduce bending and internal stresses at the joint.
- Friction that results from gravity forces cannot be considered when evaluating restraint capacity. With the exception of heavy-duty clamps used to attach longitudinal restraints to piping systems, cable clamps, or other devices where clamping forces are predictable and have been verified to be adequate, friction must not be relied on to resist any load. All connections should be positive and all holes should be tight-fitting or grouted to ensure minimal clearance at the attachment points.

1.14 CERTIFICATION OF HVAC&R COMPONENTS FOR SEISMIC

HVAC&R equipment in seismic design Categories C to F require certifications of compliance of HVAC&R components for seismic resistance. Certification of compliance for components, defined in ASCE7, Section 13.2.1, is based on analysis, testing, or experience data. These components include seismic restraint devices or force resisting systems in equipment. Equipment that is defined as **designated seismic systems** (essential for operation, I_p = 1.5) in ASCE7, Section 13.2.2, must meet special certification requirements. Certification of this essential equipment in seismic design Categories C through F is as follows (all section references in the following refer to ASCE7):

1. Active mechanical and electrical equipment that must remain operable following the design earthquake and where there are active parts or energized components shall be certified by the supplier as operable based exclusively on approved shake table testing per 13.2.5 or experience data per 13.2.6, unless it can be shown that the component is inherently rugged by comparison with similar seismically qualified components.
2. Components with hazardous contents shall be certified by the supplier as maintaining containment following the design earthquake by (1) analysis, (2) approved shake table testing, or (3) experience data.
3. Non-active and non-energized components may be certified through analysis as long as the demand load uses R_p/I_p equal to 1.0.

IBC Section 1703.5 identifies requirements for certification by an approved agency with in-plant inspections and labeling. The IBC further describes how the certification for seismically qualified equipment is supported with the in-plant inspections by an inspector knowledgeable to recognize the critical characteristics for seismic applications.

2. WIND-RESISTANT DESIGN

Damage done to HVAC&R equipment by both sustained and gusting wind forces has increased concern about the adequacy of equipment protection defined in design documents. Two main areas of the HVAC&R system are exposed to wind events: the HVAC&R equipment and the exterior wall-mounted cladding components, such as intake and exhaust louvers. For HVAC&R equipment, the following calculative procedure generates the same type of total design lateral force used in static analysis of the seismic restraint. The value determined for the design wind force F_w can be substituted for the total design lateral seismic force F_p when evaluating and choosing restraint devices. For wall-mounted components, a design wind pressure P is determined, which can be used to specify equipment performance levels and design anchors to adequately brace wall-mounted cladding components to the building structure.

Table 6 Definition of Surface Roughness and Exposure Categories

Exposure B. For buildings or other structures with a mean roof height less than or equal to 30 ft, Exposure B shall apply where the ground surface roughness, as defined by Surface Roughness B, prevails in the upwind direction for a distance greater than 1,500 ft. For buildings or other structures with a mean roof height greater than 30 ft, Exposure B shall apply where Surface Roughness B prevails in the upwind direction for a distance greater than 2600 ft or 20 times the height of the building or structure, whichever is greater.
Exposure C. Exposure C shall apply for all cases where Exposure B or D does not apply.
Exposure D. Exposure D shall apply where the ground surface roughness, as defined by Surface Roughness D, prevails in the upwind direction for a distance greater than 5000 ft or 20 times the building or structure height, whichever is greater. Exposure D shall also apply where the ground surface roughness immediately upwind of the site is B or C, and the site is within a distance of 600 ft or 20 times the building or structure height, whichever is greater, from an Exposure Condition as defined in the previous sentence.
For a site located in the transition zone between Exposure Categories, the category resulting in the largest wind forces shall be used.
EXCEPTION. An intermediate exposure between the preceding categories is permitted in a transition zone, provided that it is determined by a rational analysis method defined in the recognized literature.

The state of Florida has special wind requirements; for wind-loaded equipment there, design using the Florida Building Code for the exact location in the state.

The American Society of Civil Engineers' (ASCE) *Standard* 7-16 includes design guidelines for wind, snow, rain, and earthquake loads. Note that the equations, guidelines, and data presented here only cover nonstructural components. The current standard (200516) includes more comprehensive and rigorous procedures for evaluating wind forces and wind restraint. Refer to the latest version of ASCE7 adopted by the local jurisdiction.

2.1 TERMINOLOGY

Classification. Buildings and other structures are classified for wind load design exposure according to Table 6.

Basic wind speed. The fastest mile-per-hour wind speed at 33 ft above the ground of Terrain Exposure C (see Table 6) having an annual probability of occurrence of 0.02. Data in ASCE *Standard* 7 or regional climatic data may be used to determine basic wind speeds. ASCE data do not include all special wind regions (such as mountainous terrains, gorges, and ocean promontories) where records or experience indicate that the wind speeds are higher than what is shown in appropriate wind data tables. For these circumstances, regional climatic data may be used provided that both acceptable extreme-value statistical analysis procedures were used in reducing the data and that due regard was given to the length of record, averaging time, anemometer height, data quality, and terrain exposure. One final exclusion is that tornadoes were not considered in developing the basic wind speed distributions.

Components and Cladding. Elements of the building envelope that do not qualify as part of the main wind-force resisting system.

Corner Zone. Areas of building walls and roofs adjacent to building corners that experience increased external pressure from wind.

Design wind force. Equivalent static force that is assumed to act on a component in a direction parallel to the wind and not necessarily normal to the surface area of the component. This force varies with respect to height above ground level.

Importance factor *I*. A factor that accounts for the degree of hazard to human life and damage to HVAC components (Table 7). For hurricanes, the value of the importance factor can be linearly interpolated between the ocean line and 100 miles inland because wind effects are assumed negligible at this distance inland.

Gust response factor *G*. A factor that accounts for the fluctuating nature of wind and the corresponding additional loading effects on HVAC components.

Minimum design wind load. The wind load may not be less than 16 lb/ft^2 multiplied by the area of the HVAC component projected on a vertical plane that is normal to the wind direction.

Table 7 Wind Importance Factor *I* (Wind Loads)

Category	*I*
I	0.87
II	1
III	1.15
IV	1.15

Note: See Table 8 for categories.

Table 8 Exposure Category Constants

Exposure Category	α	z_g, ft	Gust Factor *G*
B	7	1200	0.85
C	9.5	900	0.85
D	11.5	700	0.85

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Note: See Table 7 for definitions of exposure categories.

2.2 CALCULATIONS

Two procedures are used to determine the design wind load on HVAC components. The **analytical procedure**, described here, is the most common method for standard component shapes, based on the requirements in ASCE7. The second method, the **wind-tunnel procedure**, is used in the analysis of complex and unusually shaped components or equipment located on sites that produce wind channeling or buffeting because of upwind obstructions. The analytical procedure produces design wind forces that are expected to act on HVAC components for durations of 1 to 10 s. The various factors, pressure, and force coefficients incorporated in this procedure are based on a mean wind speed that corresponds to the fastest wind speed.

Table 9 Force Coefficients for HVAC Components, Tanks, and Similar Structures

Cross Section	Type of Surface	C_f for *h*/*D* Values of 1	7	25
Square (wind normal to face)	All	1.3	1.4	2.0
Square (wind along diagonal)	All	1.0	1.1	1.5
Hexagonal or octagonal $D\sqrt{Q_z} > 2.5$	All	1.0	1.2	1.4
Round $D\sqrt{Q_z} > 2.5$	Moderately smooth	0.5	0.6	0.7
	Rough ($D'/D = 0.02$)	0.7	0.8	0.9
	Very rough ($D'/D = 0.08$)	0.8	1.0	1.2
Round $D\sqrt{Q_z} \le 2.5$	All	0.7	0.8	1.2

Notes:

1. The design wind force calculated based on the area of the structure projected on a vertical plane normal to the wind direction. The force shall be assumed to act parallel to the wind direction.
2. Linear interpolation is permitted for h/D values other than shown.
3. Nomenclature:

D = diameter of circular cross-section and least horizontal dimension of square, hexagonal, or octagonal cross-sections at elevation under consideration, ft

D' = depth of protruding elements such as ribs and spoilers, ft

h = height of structure, ft

Q_z = velocity pressure evaluated at height z above ground, in lb/ft^2

Analytical Procedure

The design wind force is determined by the following equation:

$$F_w = Q_z G C_f A_F \quad \textbf{(52)}$$

where

F_w = design wind force, lb

Q_z = velocity pressure evaluated at height z above ground level, lb/ft^2

G = gust response factor for HVAC components evaluated at height z above ground level

C_f = force coefficient (Table 9)

A_f = area of HVAC component projected on a plane normal to wind direction, ft^2

Certain of the preceding factors must be calculated from equations that incorporate site-specific conditions that are defined as follows:

Velocity Pressure. The design wind speed must be converted to a velocity pressure that is acting on an HVAC component at a height z above the ground. The equation is

$$Q_z = 0.00256 K_z K_{zt} K_d V^2 I \quad \textbf{(53)}$$

where

K_z = velocity pressure exposure coefficient from Table 11

K_{zt} = topographic factor = 1.0

K_d = wind directionality factor = 1.0

V = velocity from Figure 11, mph

I = importance factor from Table 7

The force generated by the wind is calculated by

$$F_w = Q_z G C_f A_f \quad \textbf{(54)}$$

where

F_w = design wind force, lb

Q_z = velocity pressure evaluated at height z above ground level, lb/ft^2

G = gust response factor for HVAC components evaluated at height z above ground level

C_f = force coefficient (Table 9)

A_f = area of HVAC component projected on a plane normal to wind direction, ft^2

The following example calculations are for a 400 ton cooling tower:

. Tower height h = 10 ft

Tower width D = 10 ft

Tower length l = 20 ft

Tower operating weight W_p = 19,080 lb

Tower diagonal dimension = $\sqrt{10^2 + 20^2}$ = 22.4 ft

Area normal to wind direction A_f = 10 × 22.4 = 224 ft^2

From Table 10, C_f = 1.0 for wind acting along diagonal with h/D = 10/10 = 1.

Example 5. Suburban hospital in Omaha, Nebraska. The top of the cooling tower is 100 ft above ground level. Building width normal to the wind B = 3000 ft, and building height H = 90 ft.

Solution:

From Figure 12, the design wind speed is found to be 90 mph.

From Table 8, use Category IV.

From Table 6, use Exposure B.

From Table 7, I = 1.15.

From Table 11, K_z = 0.99.

From Figure 13, K_d = 0.9.

From Table 8, G = 0.85.

Substitution into Equation (58) yields

$$Q_z = 0.00256 \times 0.99 \times 1.0 \text{ x } 0.9 \times (90)^2 \times 1.15 = 21.25 \text{ lb/ft}^2 = 2881 \text{ psi}$$

Building height is greater than 60 ft; therefore, E_f = 1.0.

Substitution into Equation (54) yields the design wind force as

$$F_w = 21.25 \times 0.85 \times 1.0 \times 224 \times 1.0 = 4046 \text{ lb}$$

Example 6. Office building in New York City. Top of tower is 600 ft above ground level. Building wall normal to the wind B = 600 ft and building height H = 590 ft.

Solution:

From Figure 12, the design wind speed is 120 mph.

From Table 8, use Category II.

From Table 6, use Exposure B.

From Table 7, I = 1.0.

From Figure 13, K_d = 0.9.

Because z > 500 ft, K_z must be determined from Note 2 of Table 11.

From Table 8, α = 7.0, z_g = 1200, and G = 0.85.

Substituting into the first equation in Note 2 yields

$$K_z = 2.10(Z/Z_g)^{2/\alpha} = 1.72$$

Substituting into Equation (55) yields

$$Q_z = 0.00256 \times 1.72 \times 1.0 \times 0.9 \times (120)^2 \times 1.15 = 65.6 \text{ lb/ft}^2$$

Building height is greater than 60 ft, therefore E_f = 1.0.

Substituting into Equation (56) yields the design force wind as

$$F_W = 65.6 \times 0.85 \times 1.0 \times 224 \times 1.0 = 12{,}490 \text{ lb}$$

The basic wind speed for design based on ASCE7-16 now uses individual maps based on whether a building is in design category I, II, III, or IV. Figures 12A to 12H (at the end of this chapter in the Appendix) show the basic wind speeds to be used.

Example 7. Church in Key West, Florida. The top of the tower is 50 ft above ground level. Building wall normal to the wind B = 300 ft and building height H = 40 ft.

Solution:

From Figure 12, the design speed is found to be 150 mph.

From Table 8, use Category III.

From Table 5, use Exposure C (as this is a hurricane-prone region).

From Table 15, I = 1.15.

From Table 16, G = 0.85.

From Table 12, K_d = 0.9.

From Table 11, K_z = 1.09 (for exp category C).

From Equation (55):

$$Q_z = 0.00256 \times 1.09 \times 1.0 \times 0.9 \times (150)^2 \times 1.15 = 65 \text{ lb/ft}^2$$

Building height is less than 60 ft, A_f / (B × H) = 224/(300 × 40) = 0.02, therefore, E_f = 1.9

Substituting into Equation (56) gives the design wind force as

$$F_w = 65 \times 0.85 \times 1.0 \times 224 \times 1.9 = 23{,}514 \text{ lb}$$

2.3 WALL-MOUNTED HVAC&R COMPONENT CALCULATIONS (LOUVERS)

For many projects, the structural engineer of record will determine the components and cladding wind pressures provided on the structural notes drawing. If these wind pressures are not provided, the two following procedures (described previously) are used to determine the design wind load on HVAC cladding components.

Analytical Procedure

Velocity Pressure. The design wind speed must be converted to a velocity pressure that is acting on an HVAC component at height z above the ground. This is done using Equation (54). Once the velocity pressure has been determined, the design wind pressure can be calculated.

Low-Rise Buildings and Buildings with h ≤ *60 ft*

The design wind pressure for cladding is determined by the following equation:

$$P_w = Q_h(GC_p - GC_{pi}) \quad \textbf{(55)}$$

where

P_w = design wind pressure, lb/ft^2

Q_h = velocity pressure evaluated at mean roof height h above ground level, lb/ft^2

GC_p = external pressure coefficient given in Figure 13

GC_{pi} = internal pressure coefficient given in Table 13

Buildings with h > *60 ft*

The design wind pressure is determined by the following equation:

$$P_w = Q(GCp) - q_i(GC_{pi}) \quad \textbf{(56)}$$

where

P_w = design wind pressure, lb/ft^2

Q_z = velocity pressure for windward walls calculated at height z above the ground of the component being examined

Q_h = velocity pressure for leeward walls, side walls and roofs, evaluated at height h of the roof

Q_i = velocity pressure for windward walls, side walls, leeward walls, and roofs, evaluated at height h of the roof

GC_p = external pressure coefficient given in Figure 14

GC_{pi} = internal pressure coefficient given in Table 13

Example 8. Office building in Houston, Texas. The top of the building is 30 ft above grade located in a newly developed suburban area. It is necessary to determine the wind pressures on louver 1 and louver 2 shown on the building elevation in Figure 15.

Solution:

From Figure 12, the design speed is found to be 120 mph.

From Table 8, use Category II.

From Table 6, use Exposure C.

From Table 7, I = 1.0.

From Table 11, K_z = 0.98, at roof height, h = 30 ft.

From Table 12, K_d = 0.85.

K_{zt} assumed to be 1.0.

Determine GC_p: Building height h is less than 60 ft; therefore, Equation (55) is used for the pressure evaluations. GC_p must be determined from Figure 15 for each of the louvers.

Louver 1: from the notes on Figure 15, it is necessary to determine the *a* dimension, which establishes the corner zone 5. The least horizontal dimension coming into the corner is 32 ft from the plan view. Ten percent of this value is 3.2 ft. The minimum value for the corner dimension is 3 ft. Louver 1 is located 1 ft 2 11/16 in. from the corner and is therefore in corner zone 5.

From Figure 15, GC_p = +0.95 or –1.3 for a 20 ft^2 wind area. A positive GC_p indicates a positive pressure on the windward side of the building. A negative GC_p indicates a suction pressure on the leeward side of the building. Both cases must be evaluated.

Louver 2: based on the corner calculation, louver 2 is in noncorner zone 4. From Figure 15, GC_p = +0.9 or –1.0 for a 30 ft^2 wind area.

Determine GC_{pi}: See Figure 14. Most buildings without significant wall openings are enclosed buildings. For the purposes of this example, an enclosed building is assumed. GC_{pi} = +0.18 or –0.18. A positive sign indicates pressure outward on all structure walls. A negative sign indicates pressure inward on all structure walls.

Determine velocity pressure at roof elevation h from Equation (55):

$$Q_h = 0.00256 \times 0.98 \times 1.0 \times 0.85 \times (120)^2 \times 1.0 = 30.7 \text{ lb/ft}^2$$

Determine design wind pressure P from Equation (56):

Louver 1, case 1: positive external, positive internal

$$P = 30.7 \times (0.95 - 0.18) = 23.6 \text{ lb/ft}^2$$

Louver 1, case 2: positive external, negative internal

$$P = 30.7 \times [0.95 - (-0.18)] = 34.7 \text{ lb/ft}^2$$

Louver 1, case 3: negative external, positive internal

$$P = 30.7 \times [(-1.3) - 0.18] = -45.4 \text{ lb/ft}^2$$

Louver 1, case 4: negative external, negative internal

$$P = 30.7 \times [(-1.3) - (-0.18)] = -34.4 \text{ lb/ft}^2$$

The controlling values for P for louver 1 are 34.7 lb/ft^2, – 45.4 lb/ft^2 and should be used to specify equipment performance levels.

Louver 2, case 1: positive external, positive internal

$$P = 30.7 \times (0.90 - 0.18) = 22.1 \text{ lb/ft}^2$$

Louver 2, case 2: positive external, negative internal

$$P = 30.7 \times [0.90 - (-0.18)] = 33.2 \text{ lb/ft}^2$$

Louver 2, case 3: negative external, positive internal

$$P = 30.7 \times [(-1.0) - 0.18] = -36.2 \text{ lb/ft}^2$$

Louver 2, case 4: negative external, positive internal

$$P = 30.7 \times [(-1.0) - (-0.18)] = -25.2 \text{ lb/ft}^2$$

The controlling values for P for louver 2 are 33.2 lb/ft^2, – 36.2 lb/ft^2 and should be used to specify equipment performance levels.

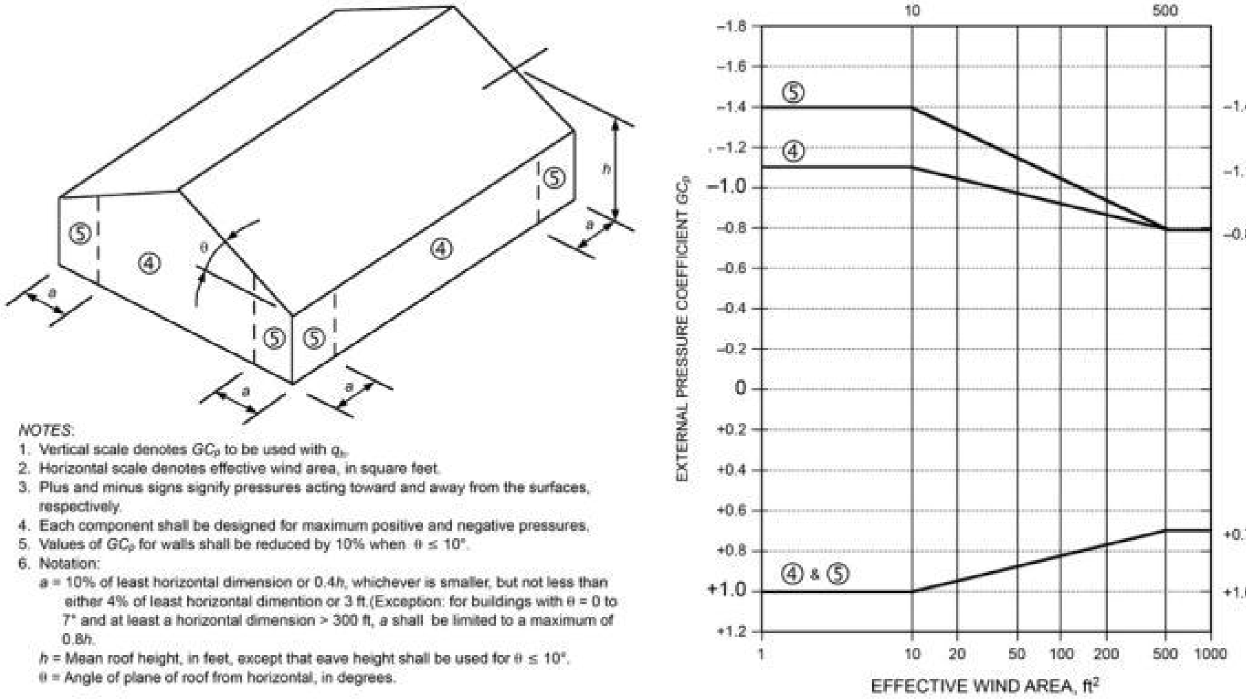
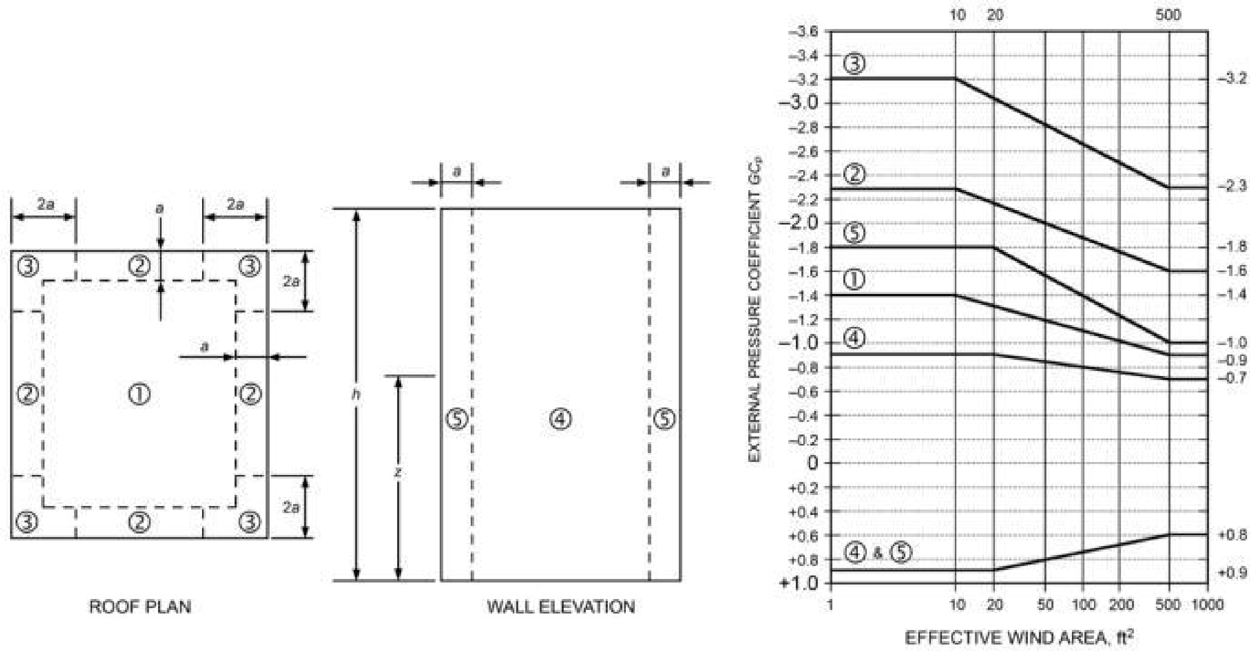


Figure 13. External Pressure Coefficient GC_p for Walls for h < 60 ft Reprinted with permission from ASCE (2016)



NOTES:
1. Vertical scale denotes GC_p to be used with appropriate q_z or q_h.
2. Horizontal scale denotes effective wind area A, in square feet.
3. Plus and minus signs signify pressures acting toward and away from the surfaces, respectively.
4. Use q_z with positive values of GC_p and q_h with negative values of GC_p.
5. Each component shall be designed for maximum positive and negative pressures.
6. Coefficients are for roofs with angle $\theta \le 7°$. For other roof angles and geometry, use GC_p values from Figure 30.3 2A–2I and Figure 3.3-5A, 5B, and attendant q_h based on exposure defined in Section 26.7.
7. If a parapet equal to or higher than 3 ft is provided around the perimeter of the roof with $\theta \le 10°$, Zone 3 shall be treated as Zone 2.
8. Notation:
   a: 10% of least horizontal dimension, but not less than 3 ft.
   h: Mean roof height, in feet, except that eave height shall be used for $\theta \le 10°$.
   z: Height above ground, in feet.
   θ: Angle of plane of roof from horizontal, in degrees.

Figure 14. External Pressure Coefficient GC_p for Walls for h > 60 ft Reprinted with permission from ASCE (2005)

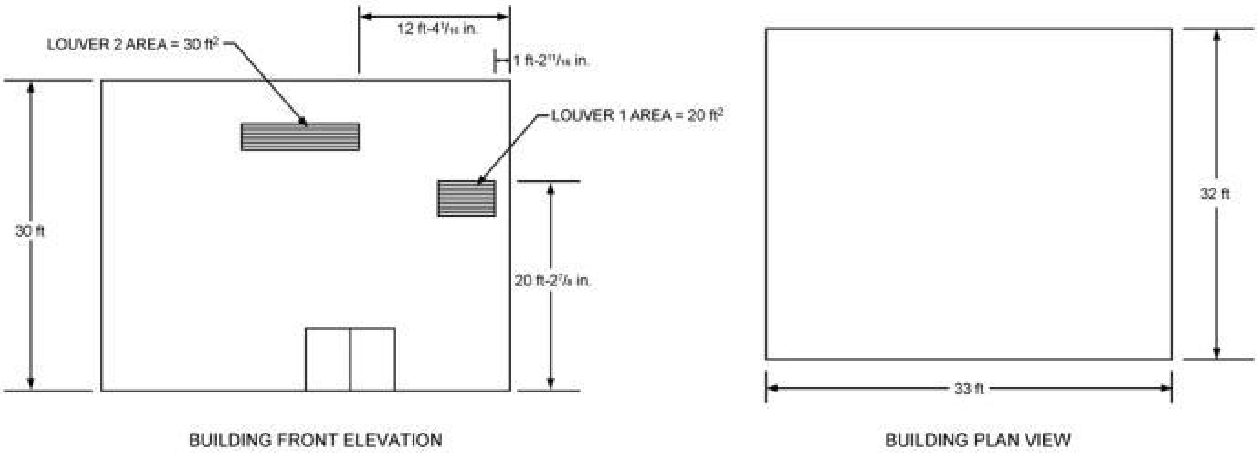


Figure 15. Office Building, Example 8

Table 10 Classification of Buildings and Other Structures for Wind Loads

Nature of Occupancy	Category
Buildings and other structures that represent a low hazard to human life in event of failure, including, but not limited to, agricultural facilities, certain temporary facilities, and minor storage facilities	I
All buildings and other structures except those listed in Categories I, III, and IV	II
Buildings and other structures that represent a substantial hazard to human life in event of failure, including, but not limited to, • - Buildings and other structures where more than 300 people congregate in one area. • - Buildings and other structures with elementary and secondary schools, day care facilities with capacity greater than 250 • - Buildings and other structures with capacity greater than 500 for colleges or adult education facilities • - Health care facilities with capacity of 50 or more resident patients, but not having surgery or emergency treatment facilities • - Jails and detention centers • - Power generating stations and other public utility facilities not included in Category IV • - Buildings and others structures containing sufficient quantities of toxic or explosive substances to be dangerous to the public if released	III
Buildings and other structures designated as essential facilities including, but not limited to, • - Hospitals and other health care facilities with surgery and emergency treatment facilities • - Fire, rescue, and police stations and emergency vehicle garages • - Designated earthquake, hurricane, or other emergency shelters • - Communication center and other facilities required for emergency response • - Power generating stations and other public utility facilities required in an emergency • - Buildings and other structures with critical national defense functions	IV

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2.4 CERTIFICATION OF HVAC&R COMPONENTS FOR WIND

Some jurisdictions require certifications of performance of HVAC&R components for wind resistance. These certifications focus on (1) the equipment's ability to remain intact and/or (2) the equipment restraints and anchors to keep the item in place during a wind event.

Table 11 Velocity Pressure Exposure Coefficient K_z

	Exposure		
Height above ground level *z*, ft	**B**	**C**	**D**
0 to 15	0.57	0.85	1.03
20	0.62	0.90	1.08
25	0.66	0.94	1.12
30	0.70	0.98	1.16
40	0.76	1.04	1.22
50	0.81	1.09	1.27
60	0.85	1.13	1.31
70	0.89	1.17	1.34
80	0.93	1.21	1.38
90	0.96	1.24	1.40

100	0.99	1.26	1.43
120	1.04	1.31	1.48
140	1.09	1.36	1.52
160	1.13	1.39	1.55
180	1.17	1.43	1.58
200	1.20	1.46	1.61
250	1.28	1.53	1.68
300	1.35	1.59	1.73
350	1.41	1.64	1.78
400	1.47	1.69	1.82
450	1.52	1.73	1.86
500	1.56	1.77	1.89

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Use 0.70 in ASCE7 Chapter 28, Exposure B, when $z < 30$ ft.
Notes:

1. Velocity pressure exposure coefficient K_z may be determined by the following:
   - For 15 ft ≤ $z \le z_q$, $K_z = 2.01(z/z_q)^{2/\alpha}$
   - For $z < 15$ ft, $2.01(15/z_q)^{2/\alpha}$
2. α and z_q are tabulated in ASCE7's Table 26.11-1.
3. Linear interpolation for intermediate values of height z is acceptable.
4. Exposure categories are defined in ASCE7's Section 26.7.

In the United States, the State of Florida and the Building Code Compliance Office of Miami-Dade County have certification requirements that affect HVAC&R system designers. The HVAC products may have special requirements for wind performance and may need approval of the State of Florida. In addition to wind performance, the Florida Building Code (ICC 2007) requires impact resistance and wind-pressure resistance for items that protect openings in buildings in windborne debris regions. HVAC products provided for projects located in these regions may be required to have testing and product certification from the State of Florida before installation. Other states, such as Texas, also have requirements for wind-pressure and impact testing. To ensure that the HVAC&R equipment supplied is compliant, designers should contact the local building code official in their project location.

Table 12 Directionality Factor K_d

Structure Type	Directionality Factor K_d*
Buildings	
Main wind-force-resisting system	0.85
Components and cladding	0.85
Arched roofs	0.85
Chimneys, tanks, and similar structures	
Square	0.90
Hexagonal	0.95
Octagonal	1.0*
Round	1.0*
Attached signs	
Open signs and single-plane open frames	0.85
Trussed towers	
Triangular, square, rectangular	0.85
All other cross sections	0.95

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* Directionality factor $K_d = 0.95$ shall be permitted for round or octagonal structures with nonaxisymmetric structural systems.

Table 13 Internal Pressure Coefficient GC_{pi}

Enclosure Classification	Criteria for Enclosure Classification	Internal Pressure	GC_{pi}
Enclosed buildings	A_o is less than the smaller of $0.01A_g$ or 4 ft^2 and $A_{oi}/A_{gi} \le 0.2$.	Moderate	+0.18 −0.18

Partially enclosed buildings	$A_o > 1.1A_g$ and A_o is greater than the lesser of $0.01A_g$ or 4 ft^2 and $A_{oi}/A_{gi} \leq 0.2$.	High	+0.55 –0.55
Partially open buildings	Building does not comply with enclosed, partially enclosed, or open classifications.	Moderate	+0.18 –0.18
Open buildings	Each wall is at least 80% open.	Negligible	0.00

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Notes:

1. Plus and minus signs signify pressures acting toward and away from the internal surfaces, respectively.
2. Values of GC_{pi} shall be used with q_z or q_h as specified in 6.5.12.
3. Two cases shall be considered to determine the critical load requirements for the appropriate condition:
   a. (i) a positive value of GC_{pi} applied to all internal surfaces, or
   b. (ii) a negative value of GC_{pi} applied to all internal surfaces

3. FLOODING RESILIENCE

Flooding is the most common natural hazard in the United States, affecting more than 20,000 local jurisdictions and representing more than 70 percent of Presidential disaster declarations. Several evaluations have estimated that 7 to 10 percent of U.S. land area is subject to flooding. Some communities have very little flood risk, while others lie entirely within areas designated by FEMA as special flood hazard areas (SFHAs). This section addresses design of HVAC systems to minimize flood effects before the flood occurs and what items may be required during the flood. This chapter does not address restoration after the flood.

Flooding events are generally subcategorized as either riverine or coastal. Riverine flooding results when the volume of rainfall or runoff exceeds the capacity of waterway channels and spreads out over the adjacent land. Flooding depth, duration, and velocity are functions of many factors, including watershed size and slope, degree of upstream development, soil types and nature of vegetation, topography, and characteristics of storms (or depth of snowpack and rate of melting).

In North America, coastal flooding occurs along the Atlantic, Gulf, and Pacific coasts, and along the shores of the Great Lakes. There is significant flooding throughout many countries. Coastal flooding is influenced by storm surges associated with tropical cyclonic weather systems (hurricanes, tropical storms, tropical depressions, typhoons), extratropical systems (nor'easters and other large low-pressure systems), and tsunamis (surges induced by seismic activity). Coastal flooding is characterized by wind-driven waves.

The intensity of both riverine and coastal flooding events is measured by the depth and velocity of flood waters, the duration for which the waters remain above normal levels, and whether any debris damage, wave action, and erosion or scour occurred.

ELECTRICAL POWER GRID

Overhead lines are generally not at a significant risk for flood damage. Energized power lines are elevated to prevent people from accidentally coming into contact with them, and the elevation protects much of an overhead electrical system from flood inundation damage. However, some portions of an overhead electrical system (most notably substations) are not elevated. Such portions of an overhead system may be vulnerable to inundation, particularly when located in low-lying areas or in SFHAs. Structures that support overhead lines can be damaged by moving floodwaters from scour, erosion, and hydrodynamic loads. Structures can be damaged by floating debris or soil saturation.

Underground portions of power lines are generally resistant to damage from freshwater flooding. Aboveground components of underground power line systems, such as pad-mounted transformers, medium-voltage sectionalizing switches, and pad-mounted switchgear, are vulnerable to floods. Like the supporting structures for overhead lines, pad-mounted equipment can be damaged by hydrostatic forces, hydrodynamic forces, flood-borne debris impact, scour, and erosion. Submersion can also short-circuit energized pad-mounted equipment, particularly the older style live-front equipment.

BUILDING SYSTEMS

For many facilities, flood poses a risk of damage to building systems and can prevent a facility from functioning. Major components of buildings systems, such as boilers, electrical service and distribution equipment, fuel tanks and fuel pumps, other pumps, and IT servers, are often located in the lowest level of a building, which is the level most vulnerable to flooding. Another area that is vulnerable to flooding is rooftop equipment that is prone to overturning during high windstorms and can leave a hole in the roof curbs, thus allowing flooding of the building when it is raining.

The risk of flood damage is particularly high for buildings that were constructed before flood risks were quantified in the 2006 *International Building Code* (IBC). The 2006 *International Building Code* (IBC) is when the code first referenced ASCE 24-05, *Flood Resistant Design and Construction* (ASCE, 2005). ASCE 24-05 requires that building systems (referred to as "utilities" in that standard) either be elevated above design flood elevations or provided with flood protection.

Flooding historically has been disastrous for emergency power systems. Floodwater can damage or inundate fuel tanks that supply diesel generators, fuel oil pumping equipment, and emergency power distribution equipment, such as transfer switches, panels, and feeders. Many post-flood event investigations have shown that components of the emergency power and distribution system are often placed at lower elevations than components of the normal power distribution system and therefore are more vulnerable to flooding.

3.1 TERMINOLOGY

Base Flood. A term used in the National Flood Insurance Program to indicate the minimum size flood to be used by a community as a basis for its floodplain management regulations; presently required by regulation to be that flood which has a 1% chance of being equaled or exceeded in any given year. Also known as a 100-year flood or 1% chance flood.

Base Flood Elevation (BFE). The resulting elevation of the flood water at specific areas within identified in the FEMA flood maps based on the Base Flood.

Base Floodplain. The floodplain that would be inundated by a 100-year (1% chance) flood.

Critical Facilities. Structure or related infrastructure that if flooded may result in significant hazards to public health and safety or interrupt essential services and operations for the community at any time before, during and after a flood.

Deep. Deep flooding is where large amount of water flowing is restricted by barriers also known as a channel (natural occurring hills or buildings). As the water flow increases, the water levels raise and increase in water velocities causing major erosion.

FEMA. Federal Emergency Management Agency, the agency responsible for administering the National Flood Insurance Program (NFIP), or successor agency. FHAD (Flood Hazard Area Delineation) a flood study often prepared on a watershed basis by the Urban Drainage and Flood Control District. FHADs are adopted by the State and affected communities like LOMCs. FHADs are eventually submitted to FEMA as PMRs and become part of the updated FEMA FIRM map.

Flash Flood. Large amount of water is directed into natural occurring ravines. Flash flooding can be caused by heavy rains, snow melt, ice jams, or when dams or levees break.

Floatable Materials. Material that is not secured in place or completely enclosed in a structure, so that it could float off site during the occurrence of a flood and potentially cause harm to downstream property owners, or that could cause blockage of the channel or drainageway, a culvert, bridge, or other drainage facility. This includes, without limitation, lumber, vehicles, boats, equipment, trash dumpsters, tires, drums or other containers, pieces of metal, plastic or any other item or material likely to float.

Flood Duration. The length of time a stream is above flood stage or overflowing its banks.

Flood Hazard Boundary Map. An official map of a community issued by the Federal Insurance Administration on which the boundaries of the floodplain (i.e., subject to the 100-year flood), mudslide and/or flood-related erosion areas having special hazards have been drawn.

Flood Profile. A graph or plot of the water surface elevation against distance along a channel drawn for a specific flood or level of flooding.

Floodplain Regulations. A general term for the full range of codes, ordinances, and other regulations relating to the use of land and construction within stream channels and floodplain areas. The term encompasses zoning ordinances, subdivision regulations, building and housing codes, encroachment line statutes, open-space regulations, and other similar methods of control affecting the use and development of these areas.

Ground Water Recharge. The infiltration of water into the earth. It may increase the total amount of water stored underground or only replenish supplies depleted through pumping or natural discharge.

Hydrodynamic Loads. Forces imposed on structures by floodwaters due to the impact of moving water.

Hydrostatic Loads. The infiltration of water into the earth. It may increase the total amount of water stored underground or only replenish supplies depleted through pumping or natural discharge.

Letter of Map Amendment (LOMA). A letter from FEMA officially amending the effective National Flood Insurance Rate Map, which establishes that a property is not located in a FEMA SFHA.

Obstruction. Any physical barrier, structure, material or impediment in, along, across or projecting into a watercourse that may alter, impede, retard or change the direction or velocity of the flow of water, or that may, due to its location, have a propensity to snare or collect debris carried by the flow of water or to be carried downstream. Obstruction shall include, but not be limited to, any dam, wall, wharf, embankment, levee, dike, pile, abutment, protection, excavation, channelization, bridge, conduit, culvert, building, wire, fence, rock, gravel, refuse, fill, structure, and vegetation in, along, across or projecting into a watercourse.

Probable Maximum Flood. The most severe flood that may be expected from a combination of the most critical meteorological and hydrological conditions. It is used in designing high-risk flood facilities that shall be protected with minimal risk of flooding. The probable maximum flood is usually much larger than the 100-year flood.

Reservoir. A natural or artificially created pond, lake or other space used for storage and control of water. May be either permanent or temporary.

Shallow. Shallow flooding is defined as flooding with an average depth of one to three feet. Shallow flooding usually is where the water flow in the area is lower and covers more area. Water seepage in the ground is more prevalent and all construction below water level is subject to water pressure.

Special Flood Hazard Area (SFHA). Land subject to 1% or greater chance of flooding in any given year (i.e. the 100-year floodplain; see Figure 16 and Table 14). It is the land area covered by the floodwaters of the base flood on the Flood Insurance Rate Maps. The SFHA is the area where the National Flood Insurance Program's floodplain management regulations must be enforced and the area where the mandatory purchase of flood insurance applies. The SFHA includes Zones A, AO, AH, AE, A99, AR, AR/AE, AR/AO, AR/AH, and AR/A.

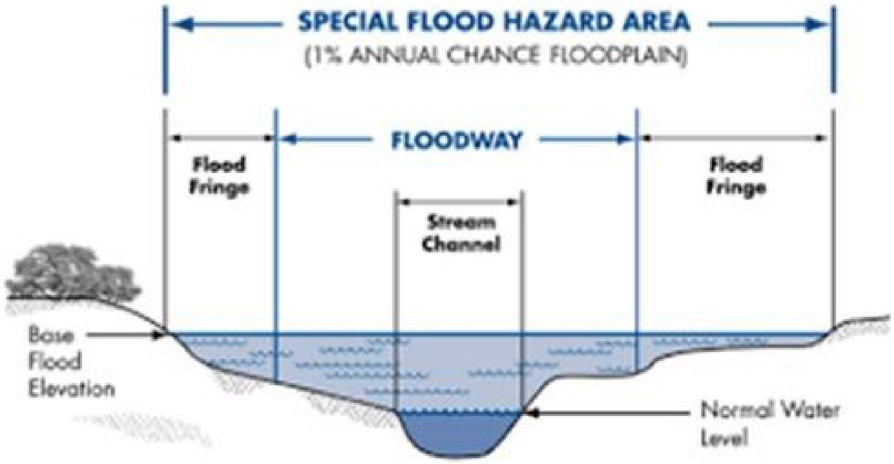


Figure 16. Flood Levels

Structural Measures. Flood control works such as dams and reservoirs, levees and floodwalls, channel alterations, seawalls, and diversion channels which are designed to keep water away from specific developments and/or populated areas or to reduce flooding in such areas.

Subsidence. Sinking of the land surface, usually due to withdrawals of underground water, oil, or coal.

3.2 REGULATIONS AND CODES

FEMA is the main agency that provides insurance for damage associated with flooding. Since this is a government agency, there are several prerequisites that need to be followed to receive government funding in terms of insurance coverage. Congress established the NFIP on August 1, 1968, with the passage of the National Flood Insurance Act (NFIA) of 1968, which has been modified over the years. The National Flood Insurance Program (NFIP) is managed by the FEMA and is delivered to the public by independent insurance companies.

Floods can happen anywhere, and just an inch of floodwater can cause significant damage. Most homeowners' insurance does not cover flood damage. Flood insurance is a separate policy that can cover buildings, the contents in a building, or both, so it is important to protect these important financial assets. FEMA publication 348, *Protecting Building Utilities from Flooding damage,* is a good document to help protect HVAC, electrical, and plumbing systems for flooding. It provides principles and practices for the design and construction of flood resistant building utility systems.

The NFIP provides flood insurance to property owners, renters, and businesses. They work with communities required to adopt and enforce floodplain management regulations that help mitigate flooding effects. Flood insurance is available to anyone living in participating NFIP communities. Homes and businesses in high-risk flood areas with mortgages from government-backed lenders are required to have flood insurance. The National Flood Insurance Program's (NFIP) offer guidance on conducting daily operations for existing and new NFIP sellers and servicers. Information on the Write-Your-Own program, reinsurance, Risk Rating 2.0, plus the *Flood Insurance Manual* and other tools are available online. There also are publications, videos, graphics, and online tools that help policyholders, agents, and other servicers navigate the flood insurance process before, during and after disaster.

Table 14 Flooded Area for Different Flood Zones

FEMA Flood Zone	Flooded Area in Analyzed Image, mi^2	Flooded Area in Image, %
AE (100 year)	17.97	61.2
A (100 year)	1.57	5.3
X (500 year and minimal risk)	6.87	23.3
VE (coastal)	0.004	~0
Non-flood hazard zones	2.99	10.2

Most states adopt the FEMA regulations as written without any changes or additional regulations as it applies to buildings within the FEMA flood maps. Florida is the exception. Starting with the 2010 edition, the *Florida Building Code* (FBC) includes flood provisions that meet or exceed the NFIP requirements for buildings and structures. All counties, cities and towns are required to enforce the FBC. Many Florida communities enforce some higher standards than those required by the FBC.

The *International Building Code®* (IBC) has minimal requirements for flooding. There are two locations that apply to HVAC equipment:

- **1202.4.4, Flood hazard areas.** For buildings in flood hazard areas as established in Section 1612.3, the openings for under-floor ventilation shall be deemed as meeting the flood opening requirements of ASCE 24 provided that the ventilation openings are designed and installed in accordance with ASCE 24.
- **G1001.6, Protection of mechanical, plumbing, and electrical systems.** Mechanical, plumbing, and electrical systems, including plumbing fixtures, shall be elevated to or above the design flood elevation. The exceptions are electrical systems, equipment and components; heating, ventilating, air conditioning and plumbing appliances; plumbing fixtures, duct systems and other service equipment shall be permitted to be located below the design flood elevation provided that they are designed

and installed to prevent water from entering or accumulating within the components and to resist hydrostatic and hydrodynamic loads and stresses, including the effects of buoyancy, during the occurrence of flooding to the design flood elevation in compliance with the flood-resistant construction requirements of this code. Electrical wiring systems shall be permitted to be located below the design flood elevation if they conform to the provisions of NFPA *Standard* 70.

3.3 HVAC AND UTILITIES

HVAC and utility systems are a potential target for flooding events. The first design question that is always the best is if the equipment and systems can be moved above the **design flood elevation (DFE)**. Moving the equipment above the DFE is preferable. Check the local codes for restrictions when moving the equipment above the DFE. Moving equipment requires additional space above the DFE that is already assigned to other priorities. The spaces may require modifications to allow the equipment to be relocated. The design professionals should be involved with all relocation design application.

Table 15 Example Checklist for Flood Protection

	Residence with Basements or Split Level	Slab on Grade	Residence with Crawlspace	Elevated Foundations	Garage
Ensure exterior HVAC system components are protected from debris impact, velocity flow, wave action, erosion, and water inundation.	X	X	X	X	
Ensure that ductwork located below the DFE is relocated or protected to prevent water infiltration.	X		X	X	
Ensure water heaters and boilers are protected or relocated to prevent inundation by floodwaters.	X		X	X	
Ensure that water and sewer lines are protected from backflow.	X	X	X	X	
Ensure water, sewer and fuel pipes are adequately protected to prevent damage caused by erosion, debris impact, and wave action.	X	X	X	X	
Electrical equipment located below the DFE should be protected from inundation.	X	X	X	X	X
Ensure wiring is relocated above the DFE, or that wires below the DFE are installed to minimize the risk of water infiltration and damage.	X		X	X	X
Ensure that exterior fuel tanks are properly protected against erosion, buoyancy, debris impact, velocity flow, and wave action.	X	X	X	X	X

HVAC systems have several potential targets for flooding including equipment (boilers, furnaces, compressors, fans, and filters), piping, ductwork, and penetrations. Table 15 gives some examples of concerns for various building types. Some equipment that is below the DFE can be sealed with waterproof materials. Heat exchange or fuel-burning equipment would require barriers that reach above the DFE. Sealing ductwork is possible but expensive. Any ductwork affected by flood waters and not sealed would have to be replaced. Cleaning is not recommended because of the potential of bacterial left by the flood. Flood waters are contaminated, and equipment can be cleaned or refurbished. Flood waters also contain corrosive material. Most outdoor equipment has waterproof electrical connections at the compressor, but the controls may not be protected, and new control boxes needed for the refurbishment.

Penetrations like all normal building construction is not watertight. Even concrete construction has seams that allow a long-term flooding event to challenge. Normal construct walls are not watertight. Areas that need to be protected below the DFE will require as best as possible flood waterproofing, continuous monitoring during a flood (which means access to the areas), and a sump pump that removes any flood water entering the protected areas. HVAC, electrical, and piping penetrations need to be sealed.

Potable water systems outside of the buildings are protected by the nature of the piping systems are sealed. Any water access to the outside from the inside of the buildings and below the DFE may be contaminated and should be protected with a backflow preventer. The water supply can also be contaminated by the flooding condition. Contact local authorities for any restrictions on potable water systems during and after a flood. External piping above grade should be evaluated for potential impact of debris where water is moving.

Sewage systems are very different form potable water systems. Underground piping systems outside of the building are not sealed and will be contaminated by the flood conditions. Collection systems should be located above the DFE or protected with backflow preventers. Plugs or other methods to seal penetrations (sewage openings) in the building need to be sealed during and may be required sometime after a flooding event.

Fuel systems need attention for flooding events. Gas piping is sealed and usually protected from normal underground moisture. Aboveground thick-walled piping is susceptible to degrading from moving flood waters but will not require any additional special waterproofing treatment. Fuel tanks are outside and always a target for flooding events. Aboveground tanks need to be anchored to prevent flotation. Even if the tanks are full, at some time the fuel may be used during the flooding event and the tank to float. Protecting aboveground tanks from moving debris is also a concern and may require protection barriers (permanent to temporary).

Tanks installed below grade are anchored for potential water table issues. Waterproofing is usually performed below grade but not above grade. The access ports in a below grade tank need to be sealed and there is always a vent that needs to be elevated above the DFE. The other concern is refueling for long term events. If fuel and the generator/heating systems are required to be operational for long periods, that only solution is to move all the equipment and fuel tanks to a location that is above the DFE and accessible for refueling.

Electrical systems have many issues with flooding events. The main potential is short circuiting equipment, tripping breakers, and taking power supply systems offline. The potential targets are meters, panels, circuit breakers, appliances, electrical receptacles ground fault protection, and cables. This equipment is not waterproof and should be protected or moved is possible. Refurbishment of the electrical systems is required after a flooding event to determine all the devices that need to be replaced.

3.4 BUILDING SYSTEMS

Fire protection systems are robust and not susceptible to damage or malfunction during a flood. Because of flooding, fires may start from the short circuiting of electrical systems. Design and construction of the electrical system can minimize but may never mitigate the issues associated with electrical systems and the risk of surges, sparks, and electrocution. If water is a threat from a flood or other potential water surge in the area, then the electrical system should be isolated as possible to stop all electrical circuits. Unplug electrical appliances and HVAC as appropriate. Isolate flammable or chemical substances (tanks and gas lines).

Emergency power and heating systems may be implemented at the facility. These items shall be designed and installed with flood mitigation features. These are in case of major power outages. Main power lines can also cause electrical shorts and fires in the area which could affect the building systems.

Building wall and floor construction as mentioned previously may be watertight. This is a rare case, and all construction buildings shall be evaluated to determine if the structure is worth and/or needs to be protected from flooding with flood mitigating features. Buildings can be constructed on piers to raise the building above the DFE (ASCE 24).

Wall construction made from standard non-concrete (perishable material) is susceptible to damage during flooding. These structures are not watertight and all inside contents are subject to water damage up to the DFE. When the flooding event is over, all material affected by the water damage must be remediated. This will include wood (structural framing, floors and any cabinetry), drywall, insulation, electrical (cables and receptacles), and HVAC systems (including ductwork).

Soil considerations in building system construction and design is important. Most important is when soil is saturated with water, it may heave and cause damage. No soil will protect building from water saturation and water seeking the DFE water level in all areas affected by the flood. And cavity (building space) below the DFE will see water seeping through the ground and into building structure. This water is contaminated and acidic in nature. Degradation of the building structure below grade is susceptible to damage. Cases have shown water flowing below grade can eat away metal due to electrolysis. Other considerations are degradation of the building foundation to be evaluated by design professionals. Soil outside of the building may be contaminated and treated before planting foliage.

3.5 BUILDING CATEGORIES

Building categories looks at the different types of buildings and provides insight associated with that specific building type. Many items associated with systems have been discussed above about the systems and building construction. This section is in addition to the items previously discussed.

Most **hospitals** are designated to be functional during a flooding event. Before a flooding event, all aspects of the HVAC and utility design should have addressed mitigating the flooding potential effects. The items that need to be functional shall be protected or are located above the DFE plus 6 ft. Local codes may require more stringent requirements. Mold resistant materials should be used for the infrastructure HVAC and utility systems. This will reduce potential mold affects after a flooding event but may not eliminate all mold issues. All life safety equipment shall be protected including electrical, phones, data centers, and emergency trauma units. After a flooding event, the HVAC systems shall be evaluated for cleanliness. All equipment shall be evaluated for functionality. Mold should be removed and treated with UV systems or other types of removal. This treatment can be permanent or temporary/portable equipment. See Chapters 62 and 64 for information on UV and moisture management, respectively.

Clinics are emerging and needs to be reviewed for Flood mitigation as defined by the local authority having jurisdiction.

Museums are an important part of society and needs to be protected from a flooding event. All displays shall be moved to an elevation of the DFE plus 12 ft. All displays not being used shall be stored is a remote area that is not in any flood zone. After an event, all moisture and mold shall be quickly addressed as discussed in the hospital building category. Any displays that are susceptible to moisture degradation shall be moved or protected during and after a flooding event.

Airports, rail stations, and bus stations are in potential flood zones. These have been established and require flood mitigation evaluations. Before a flooding event airports or facilities (due to their size) shall have a plan for emergency access and egress. Areas and runways below the DFE need to be protected by levees (see ASCE 24). Planes, trains, and buses are a capital investment and will be moved as defined by their air carrier or owner. Alternate airport, train, or bus operation shall be negotiated prior to the event for continued operation. HVAC and utility systems shall be evaluated for emergency use during the flooding event. Those items necessary for safe operation of the airport or facilities shall be moved or protected from the flooding event plus 6 feet. This includes access to the airport control tower. The infrastructure that support airport operations such as baggage handling shall be addressed by each airline carrier.

Emergency facilities include incident command centers, emergency call centers, flood shelters, and potential sport stadiums that will house many displaced people during a flood shall be evaluated for mitigation during a flooding event. Emergency facilities category includes police stations, prisons, and detention centers. Before a flooding event emergency facilities shall be evaluated for a flooding event. HVAC and utility systems shall be evaluated for emergency use during the flooding event. Those items necessary for safe operation of the facilities shall be moved or protected from the flooding event plus 6 ft or as defined by the local authority have jurisdiction. This includes access of emergency personnel and operational personnel to oversee operating equipment. The infrastructure that support operations of all emergency facility functions shall be reviewed for mitigation features.

Petrochemical and industrial facilities have unique issues associated with flooding events. Caustic materials are a potential public hazard if the hazardous material is in contact with flood waters. Any potential water hazard or other airborne hazard that could be affected by a flooding event shall be evaluated for mitigation and protection of any toxic release.

Commercial and tall buildings are a potential target for a flooding event. These facilities do not usually have special requirements except for emergency egress. Some structural elements such as floating floors (isolation systems) are subject to water damage and should be mold resistant. For example, wood, plywood, fiberglass, perimeter boards, caulking material, and other elements be located above the DFE plus 6 ft.

Universities and dormitories have experienced damage from flooding. Each university shall review the infrastructure and identify the assets that need to be protected from flooding. Many facilities have the infrastructure HVAC and systems and shall evaluate the need to move or protect these items from a flooding event.

Residential and condominiums are governed by the local authority have jurisdiction.

3.6 FLOODING RESPONSE PLAN

A flood response plan is the most valuable tool when responding to a flooding event. The plan has step by step procedures for each facility to be implemented before an event and a timeline for implementing the procedures. The timeline to accomplish flood mitigation must be less that the amount of warning that would be received from the national emergency weather service. Each procedure must be validated so that it can be fully implemented in the time defined. The validation will identify if the flood doors really fit and if all the potential flooding vulnerabilities are addressed. The decision to implement the flooding procedures in not done lightly or without financial penalty. Waiting too long to implement the flooding procedures has a bigger financial penalty.

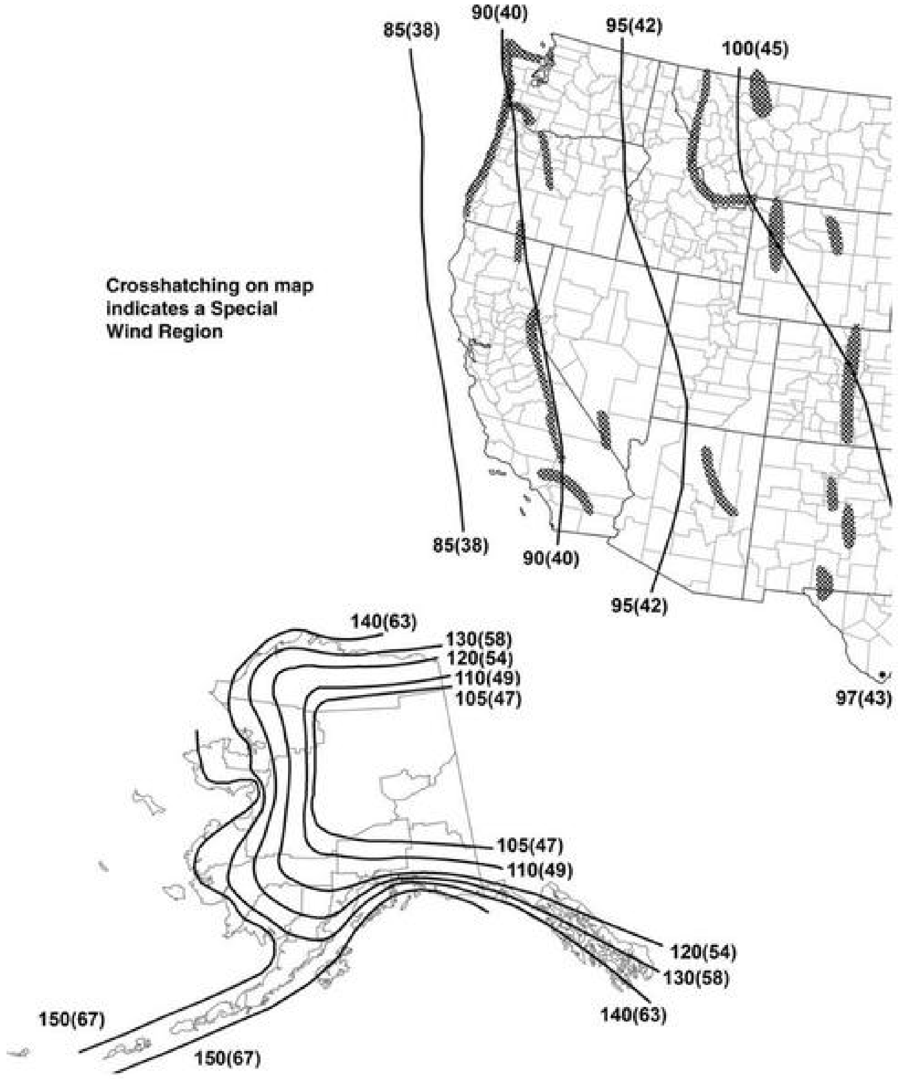
The response plan must address the equipment and personnel required to implement the flooding procedures, address the equipment and personnel that is required during the flood to keep all flood equipment (pumps and generators) running including delivery of fuel. Shift turnover must be addressed. The response plan shall address the actions required following a flooding event to restore the facilities to an operational status.

Flood plans and procedures will address the mitigation features for protecting capital assets and maintaining emergency functions. All the service within a flood target must be defined and addressed to ensure they will remain operational during a flooding event. The environment and air filtration are required to maintain air quality for all occupied areas. Outside areas that require personnel to be in flood waters shall be protected with personnel safety equipment (ropes and harnesses), handrails and nets, or elevated walkways.

Areas that are protected in the flood plans address potential entry points for water which include doors, drains, and any seam in a concrete structures. Permanent or temporary flood barriers are installed with gaskets, sealing material, and other isomeric products. Active pumping stations are implemented along with portable electrical power stations to provide power to pumps. Gas and diesel-driven pumps are usually outdoors and require hourly observation and refilling. Follow all equipment precautions for operating and refueling for safe operation of the equipment.

Flood plans will address permanent flood mitigation such a levees defined in ASCE 24. Mitigation will identify permanent or temporary barriers required to protect outdoor equipment from moving debris.

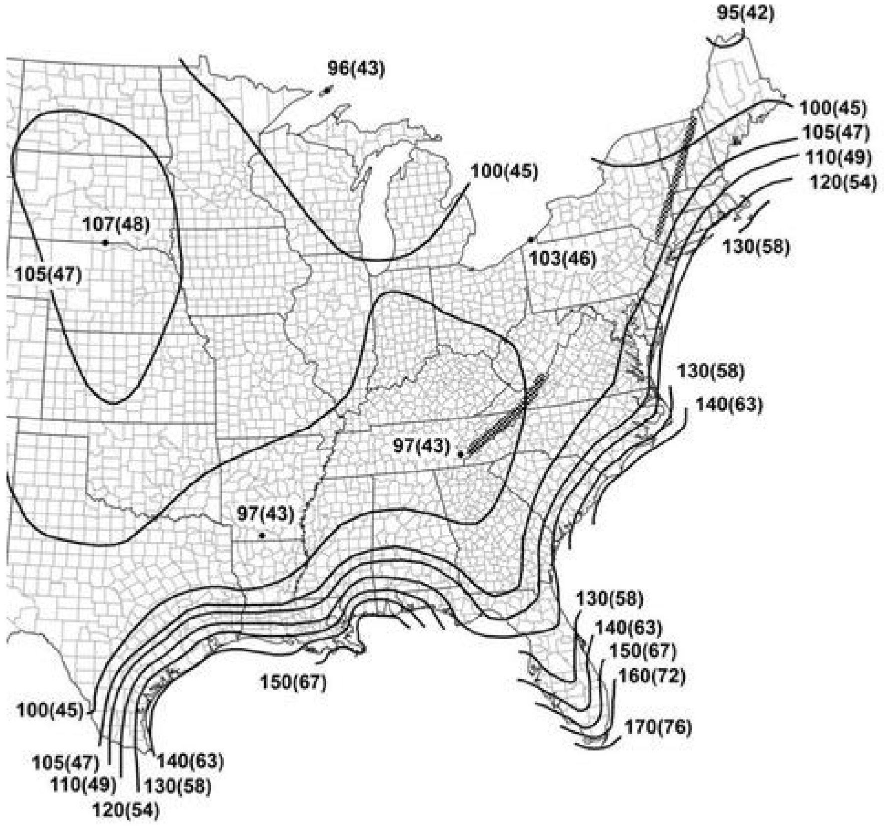
APPENDIX: FIGURES 12A TO 12H



NOTES

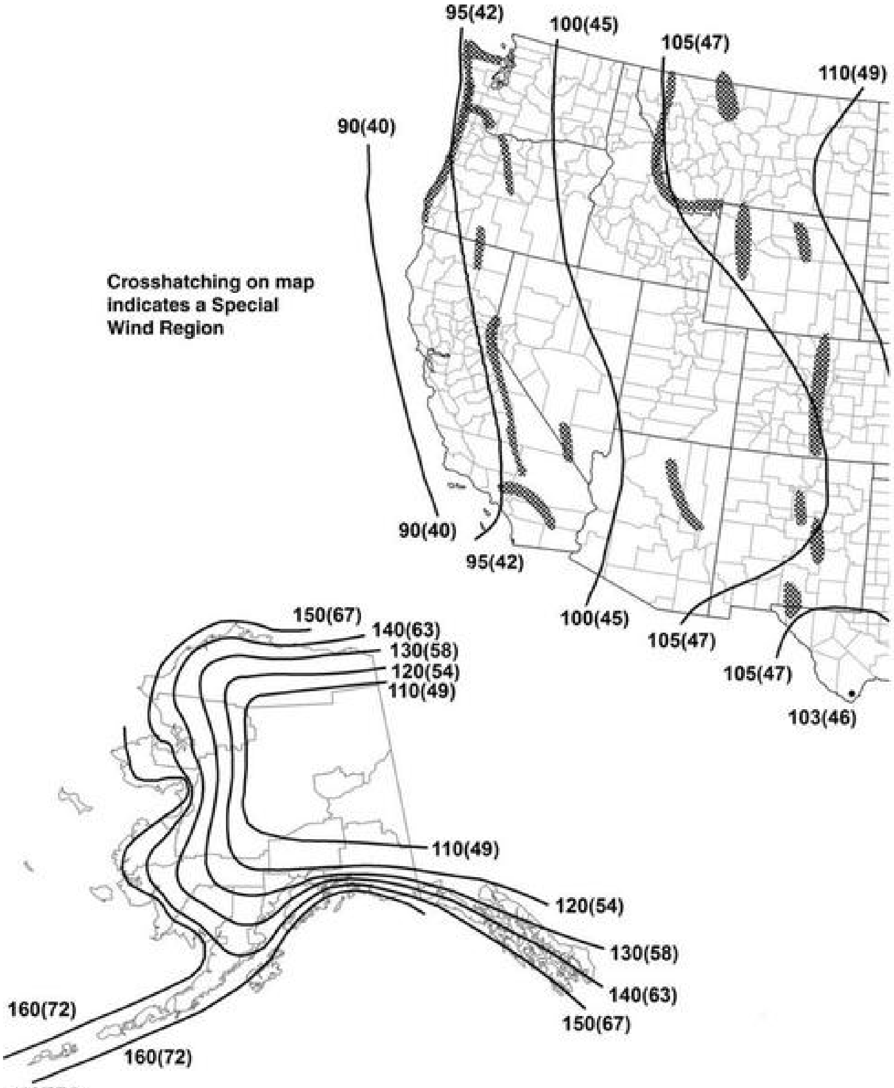
1. Values are nominal design 3 s gust wind speeds in mph (m/s) at 33 ft (10 m) above ground for Exposure Category C.
2. Linear interpolation is permitted between contours. Point values are provided to aid with interpolations.
3. Islands, coastal areas, and land boundaries outside the last contour shall use the last wind speed contour.
4. Mountainous terrain, gorges, ocean promontories, and special wind regions shall be examined for unusual wind conditions.
5. Wind speeds correspond to approximately a 15% probability of exceedance in 50 years (Annual exceedance probability = 0.00333, MRI = 300 years).
6. Location-specific basic wind speeds can be determined using www.atcouncil.org/windspeed.

Figure 12A. Basic Wind Speeds for Risk Category I Buildings and Other Structures, 15% Probability of Exceedance in 50 Years



Location	Vmph	(m/s)
Guam	180	(80)
Virgin Islands	150	(67)
American Samoa	150	(67)
Hawaii	(See Figure 26.5-2A)	

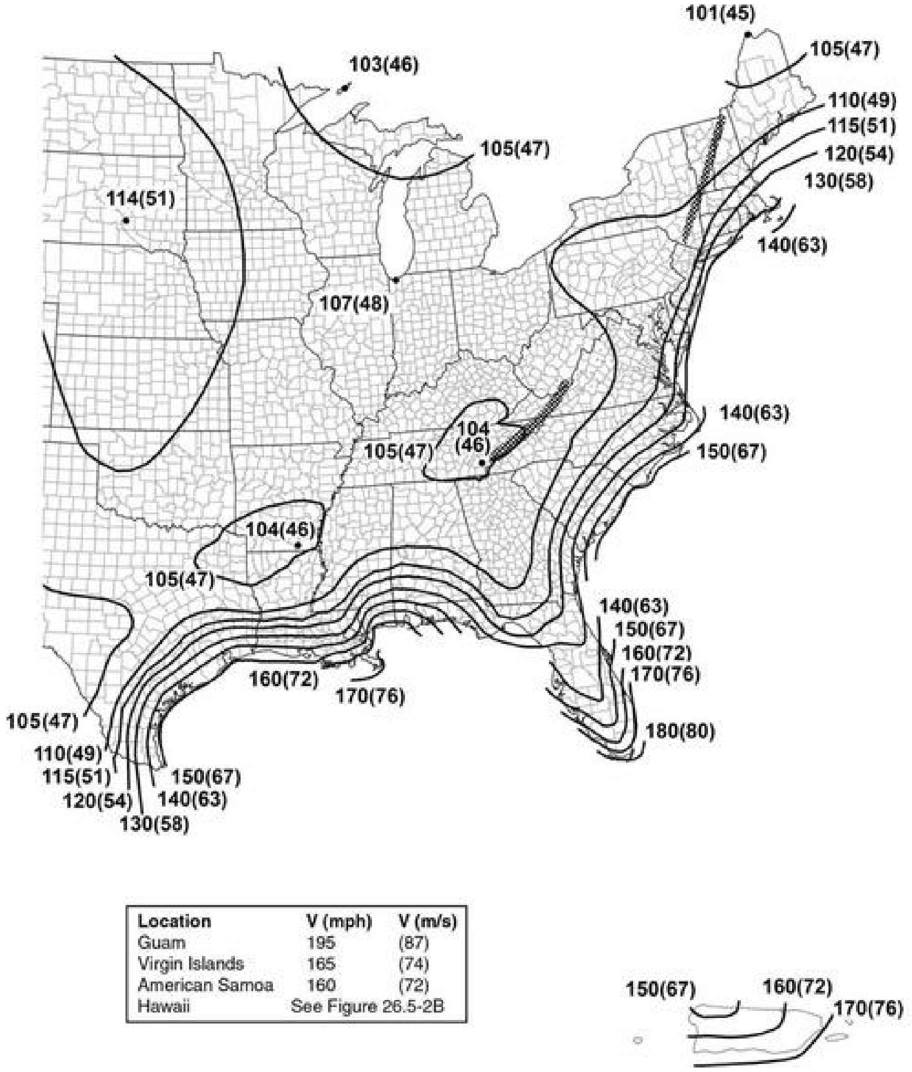
Figure 12B. Basic Wind Speeds for Risk Category I Buildings and Other Structures



NOTES:

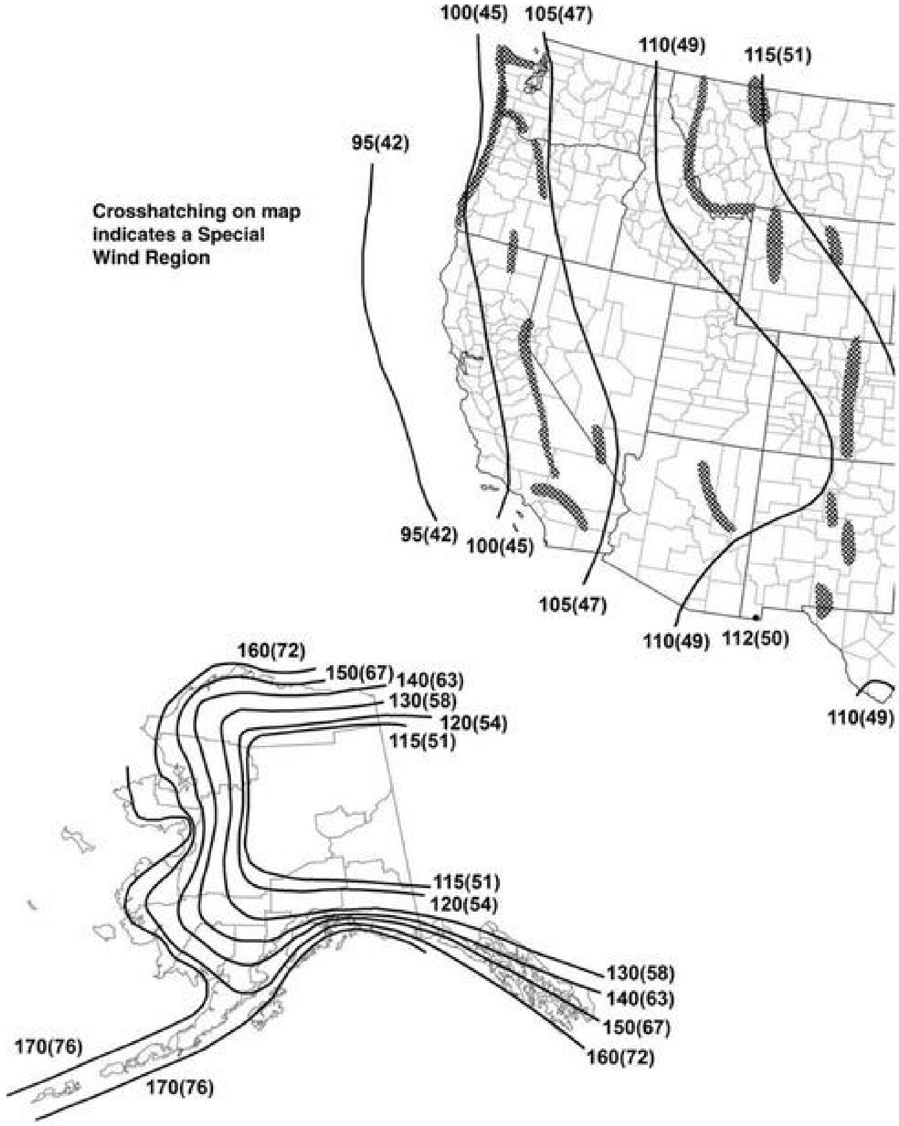
1. Values are nominal design 3 s gust wind speeds in mph (m/s) at 33 ft (10 m) above ground for Exposure Category C.
2. Linear interpolation is permitted between contours. Point values are provided to aid with interpolation.
3. Islands, coastal areas, and land boundaries outside the last contour shall use the last wind speed contour.
4. Moutainous terrain, gorges, ocean promontories, and special wind regions shall be examined for unusual wind conditions.
5. Wind speeds correspond to approximately a 7% probability of exceedance in 50 years (Annual exceedance probability = 0.00143, MRI = 700 years).
6. Location-specific basic wind speeds can be determined using www.atcouncil.org/windspeed.

Figure 12C. Basic Wind Speeds for Risk Category II Buildings and Other Structures, 7% Probability of Exceedance in 50 Years



Location	V (mph)	V (m/s)
Guam	195	(87)
Virgin Islands	165	(74)
American Samoa	160	(72)
Hawaii	See Figure 26.5-2B	

Figure 12D. Basic Wind Speeds for Risk Category II Buildings and Other Structures



NOTES

1. Values are nominal design 3 s gust wind speeds in mph (m/s) at 33 ft (10 m) above ground for Exposure Category C.
2. Linear interpolation is permitted between contours. Point values are provided to aid with interpolations.
3. Islands, coastal areas, and land boundaries outside the last contour shall use the last wind speed contour.
4. Mountainous terrain, gorges, ocean promontories, and special wind regions shall be examined for unusual wind conditions.
5. Wind speeds correspond to approximately a 3% probability of exceedance in 50 years (Annual exceedance probability = 0.000588, MRI = 1700 years).
6. Location-specific basic wind speeds can be determined using www.atcouncil.org/windspeed.

Figure 12E. Basic Wind Speeds for Risk Category III Buildings and Other Structures, 3% Probability of Exceedance in 50 Years

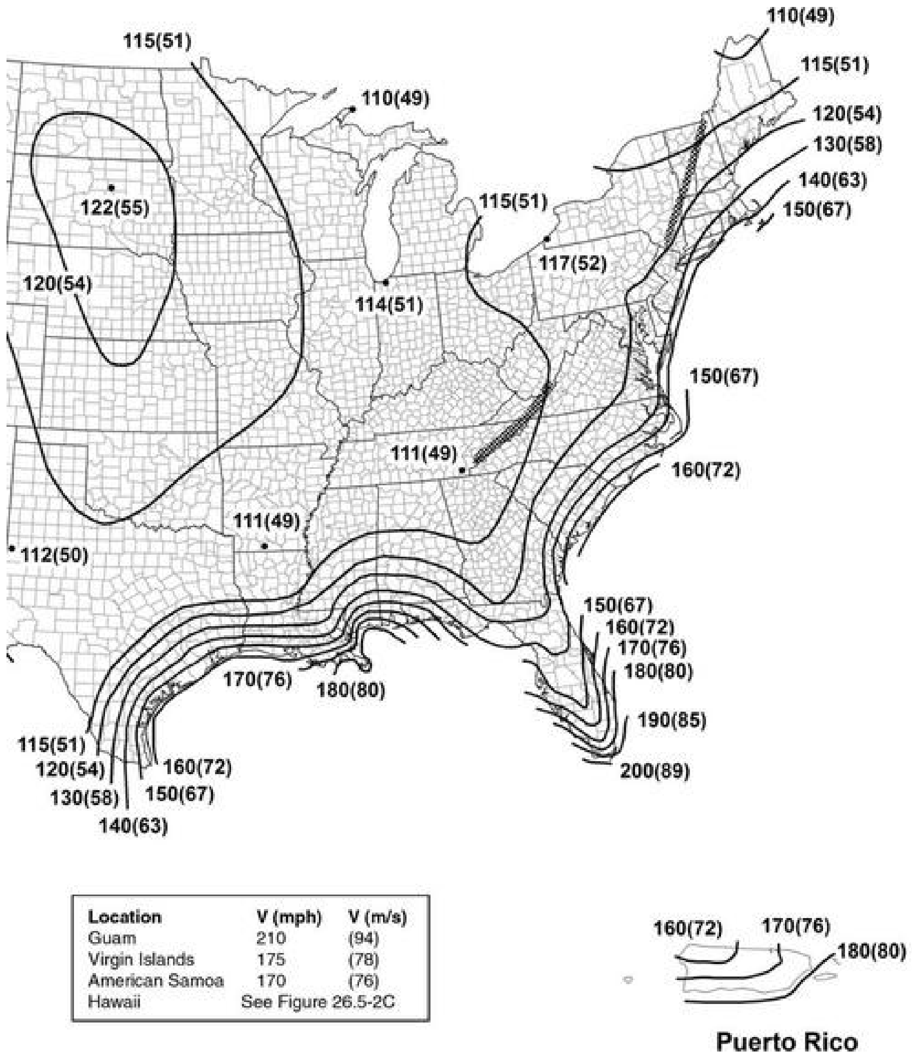
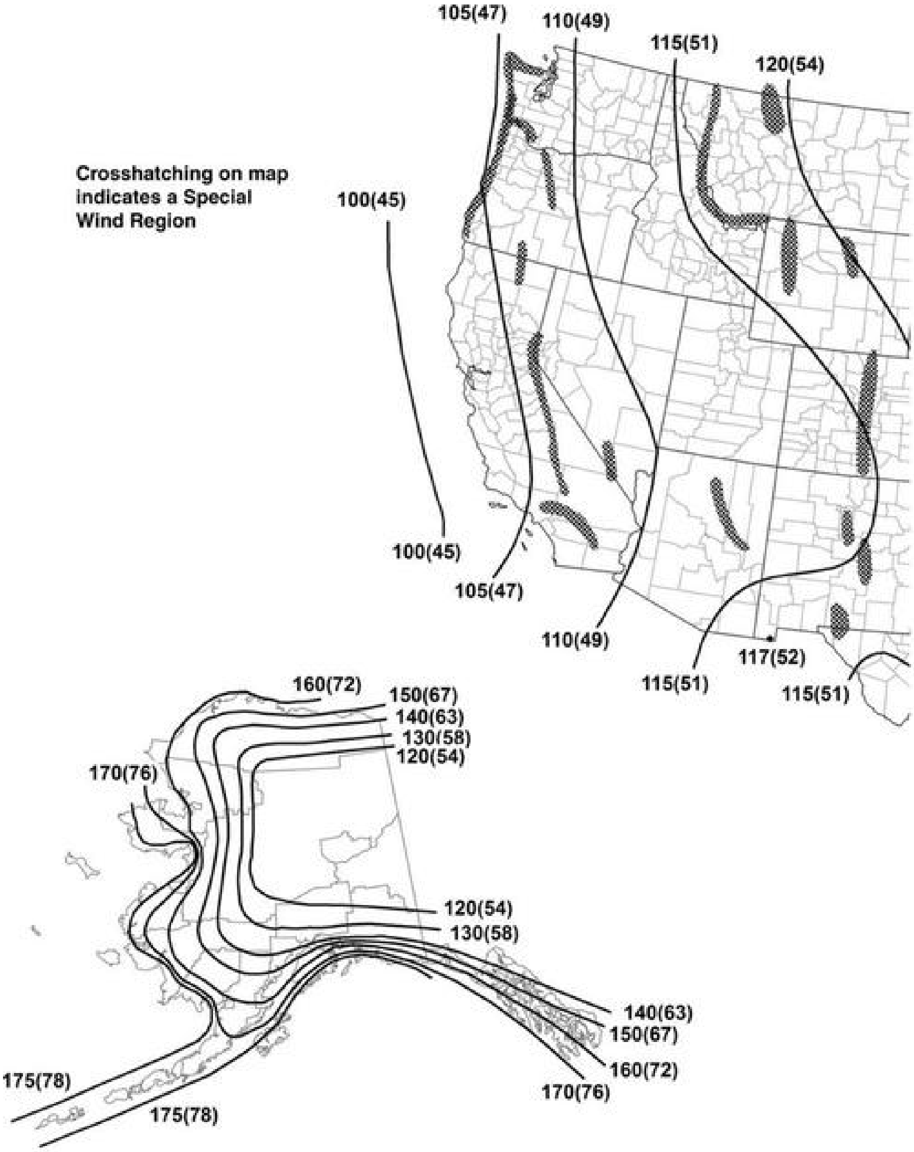


Figure 12F. Basic Wind Speeds for Risk Category III Buildings and Other Structures



NOTES

1. Values are nominal design 3 s gust wind speeds in mph (m/s) at 33 ft (10 m) above ground for Exposure Category C.
2. Linear interpolation is permitted between contours. Point values are provided to aid with interpolations.
3. Islands, coastal areas, and land boundaries outside the last contour shall use the last wind speed contour.
4. Mountainous terrain, gorges, ocean promontories, and special wind regions shall be examined for unusual wind conditions.
5. Wind speeds correspond to approximately a 1.6% probability of exceedance in 50 years (Annual exceedance probability = 0.00033, MRI = 3000 years).
6. Location-specific basic wind speeds can be determined using www.atcouncil.org/windspeed.

Figure 12G. Basic Wind Speeds for Risk Category IV Buildings and Other Structures, 1.6% Probability of Exceedance in 50 Years

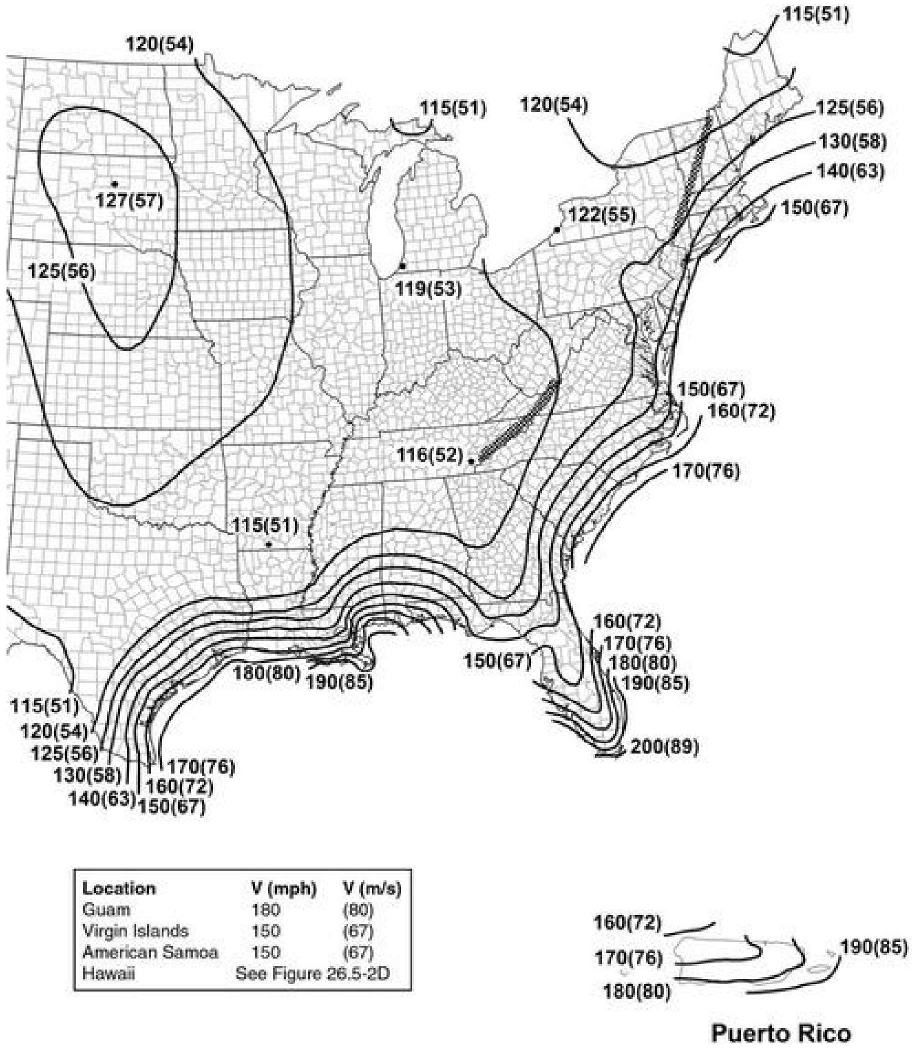


Figure 12H. Basic Wind Speeds for Risk Category IV Buildings and Other Structures

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