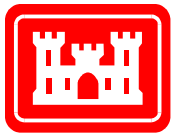

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Seismic Protection

For Mechanical Equipment

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What's Required?

- All architectural, mechanical, electrical, and other nonstructural components in structures shall be designed and constructed to resist the equivalent static forces and displacements determined in accordance with ASCE 7 Section 9.6. The design and evaluation of support structures and architectural components and equipment shall consider their flexibility as well as their strength.

ASCE 7

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Codes & Standards

- **IBC – International Building Code – International Code Council**
- **ASCE 7 – Minimum Design Loads for Buildings and other Structures - American Society of Civil Engineers**
- **NFPA 13 – Standard for the Installation of Sprinkler Systems – National Fire Protection Association**
- **UFC 3-310-04 – Seismic Design for Buildings (expected late FY)**
- **UFGS 15070 – Seismic Protection for Mechanical Eqiupment (expected late FY)**

How Do I Get There From Here?

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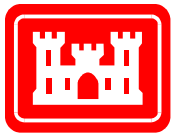
- Determine *Seismic Use Group* (IV, III, II, I) for the facility.
- Determine soil class (A, B, C, D, E, F). Use these and IBC Table(s) 16151.2 to select *Seismic Force Adjustment Factors* , F_s & F_v.
- Obtain *Maximum Considered Earthquake* seismic accelerations, % g for *Short* (0.2 sec) and long (*1* sec) accelerations, S_S & S_1, using "Shake Maps".
- Using *Site Coefficients,* F_s & F_v, calculate the *Adjusted (or Modified) Maximum Considered Earthquake*, which equals:

$$S_{MS} = S_S \times F_s \qquad \text{and} \qquad S_{M1} = S_1 \times F_v$$

- Calculate the *Design Earthquake* - S_{DS} & S_{D1}:

$$S_{DS} = 2/3\ S_{MS} \qquad \text{and} \qquad S_{D1} = 2/3\ S_{M1}$$

- Using these values, for S_{DS} and S_{D1}, refer to IBC 2003 Tables 1616.3(1) and 1616.3(2), and select a *Seismic Design Category* (A, B, C, D, or E and F) for each value, S_{DS} and S_{D1}, and the previously determined Seismic Use Group. The *WORST CASE* Seismic Design Category is to be used for the remainder of the design.



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Seismic Use Groups

- **Group III structures are those having essential facilities that are required for post-earthquake recovery and those containing substantial quantities of hazardous substances.**

- **Group II structures are those whose failure would result in substantial human loss due to structural failure because of occupancy density.**

- **Group I structures are those not assigned to either Seismic Use Groups II, III, or IV.**

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Seismic Use Groups

- ***Group IV structures are those considered to be mission-essential military assets which must function to support the strategic defense of the United States, or to prevent widespread catastrophic consequences due to release of nuclear, chemical, bioligical, or radiological materials.***

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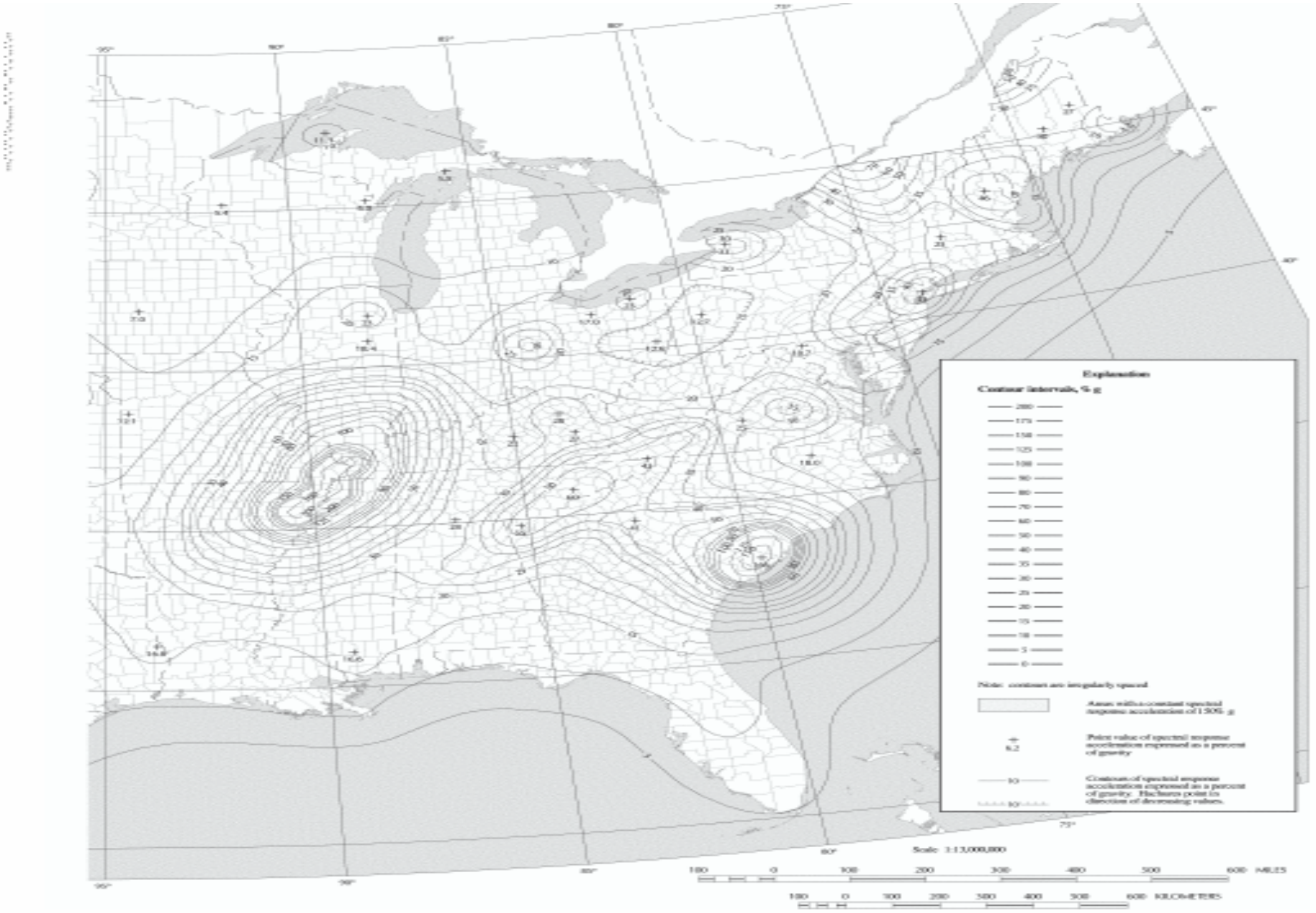
Site Class

TABLE 1615.1.1
SITE CLASS DEFINITIONS

SITE CLASS	SOIL PROFILE NAME	AVERAGE PROPERTIES IN TOP 100 feet, AS PER SECTION 1615.1.5		
		Soil shear wave velocity, $\overline{v}_s$, (ft/s)	Standard penetration resistance, $\overline{N}$	Soil undrained shear strength, $\overline{s}_u$, (psf)
A	Hard rock	$\overline{v}_s > 5{,}000$	N/A	N/A
B	Rock	$2{,}500 < \overline{v}_s \leq 5{,}000$	N/A	N/A
C	Very dense soil and soft rock	$1{,}200 < \overline{v}_s \leq 2{,}500$	$\overline{N} > 50$	$\overline{s}_u \geq 2{,}000$
D	Stiff soil profile	$600 \leq \overline{v}_s \leq 1{,}200$	$15 \leq \overline{N} \leq 50$	$1{,}000 \leq \overline{s}_u \leq 2{,}000$
E	Soft soil profile	$\overline{v}_s < 600$	$\overline{N} < 15$	$\overline{s}_u < 1{,}000$
E	—	Any profile with more than 10 feet of soil having the following characteristics: 1. Plasticity index $PI > 20$, 2. Moisture content $w \geq 40\%$, and 3. Undrained shear strength $\overline{s}_u < 500$ psf		
F	—	Any profile containing soils having one or more of the following characteristics: 1. Soils vulnerable to potential failure or collapse under seismic loading such as liquefiable soils, quick and highly sensitive clays, collapsible weakly cemented soils. 2. Peats and/or highly organic clays ($H >$ 10 feet of peat and/or highly organic clay where H = thickness of soil) 3. Very high plasticity clays ($H >$25 feet with plasticity index $PI >$75) 4. Very thick soft/medium stiff clays ($H >$120 feet)		

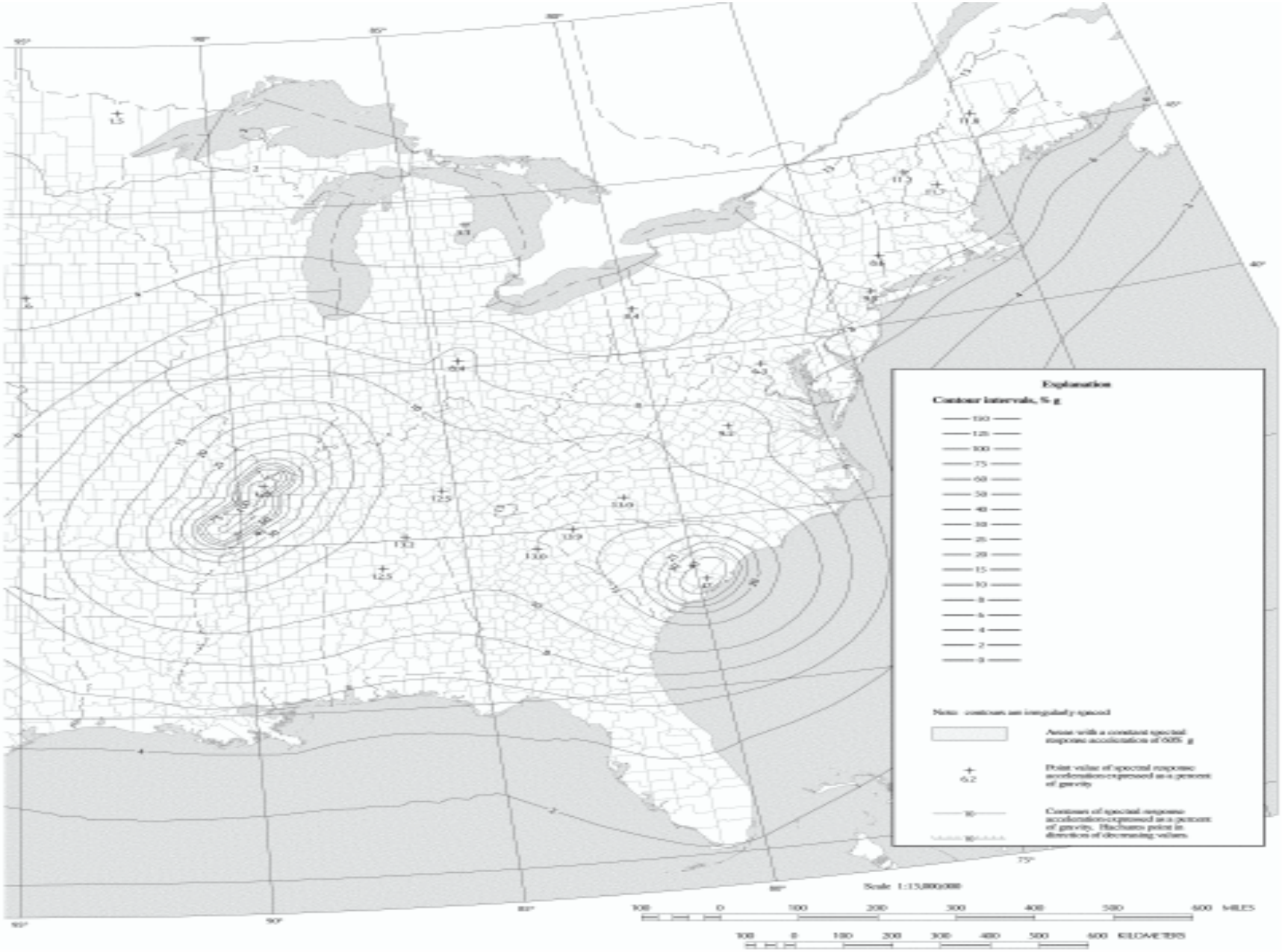
IBC 2003

Seismic Map - 0.2 Second Spectral Response



Seismic Map - 0.2 Second Spectral Response

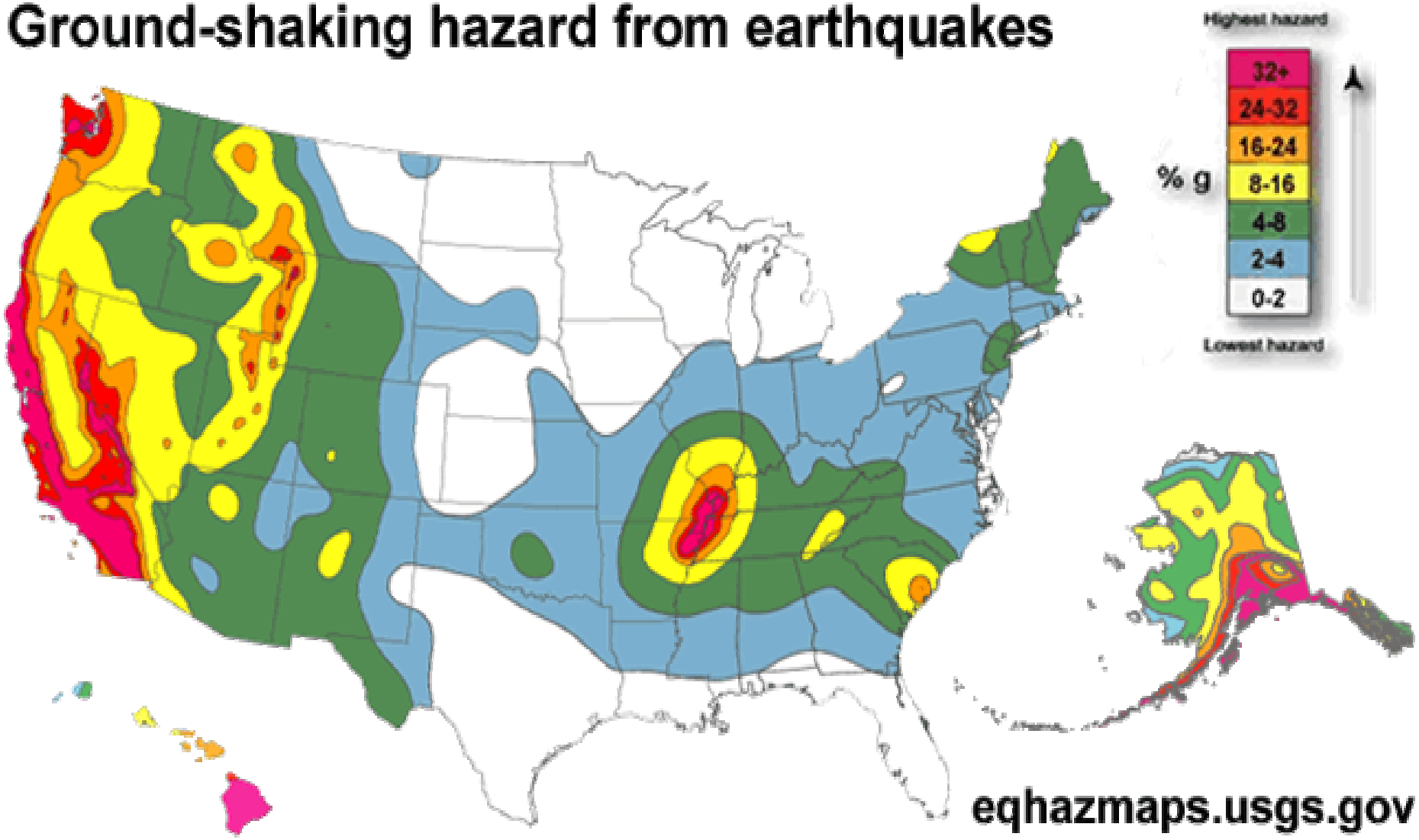
Seismic Map – 1.0 Second Spectral Response



Seismic Map – 1.0 Second Spectral Response

USGS
science for a changing world

Ground-shaking hazard from earthquakes



eqhazmaps.usgs.gov

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Site Coefficients

TABLE 1615.1.2(1)
VALUES OF SITE COEFFICIENT F_a AS A FUNCTION OF SITE CLASS AND MAPPED SPECTRAL RESPONSE ACCELERATION AT SHORT PERIODS (S_S)[a]

SITE CLASS	MAPPED SPECTRAL RESPONSE ACCELERATION AT SHORT PERIODS				
	$S_S \le 0.25$	$S_S = 0.50$	$S_S = 0.75$	$S_S = 1.00$	$S_S \ge 1.25$
A	0.8	0.8	0.8	0.8	0.8
B	1.0	1.0	1.0	1.0	1.0
C	1.2	1.2	1.1	1.0	1.0
D	1.6	1.4	1.2	1.1	1.0
E	2.5	1.7	1.2	0.9	0.9
F	Note b	Note b	Note b	Note b	Note b

a. Use straight-line interpolation for intermediate values of mapped spectral response acceleration at short period, S_S.
b. Site-specific geotechnical investigation and dynamic site response analyses shall be performed to determine appropriate values, except that for structures with periods of vibration equal to or less than 0.5 second, values of F_a for liquefiable soils are permitted to be taken equal to the values for the site class determined without regard to liquefaction in Section 1615.1.5.1.

TABLE 1615.1.2(2)
VALUES OF SITE COEFFICIENT F_V AS A FUNCTION OF SITE CLASS AND MAPPED SPECTRAL RESPONSE ACCELERATION AT 1-SECOND PERIOD (S_1)[a]

SITE CLASS	MAPPED SPECTRAL RESPONSE ACCELERATION AT SHORT PERIODS				
	$S_1 \le 0.1$	$S_1 = 0.2$	$S_1 = 0.3$	$S_1 = 0.4$	$S_1 \ge 0.5$
A	0.8	0.8	0.8	0.8	0.8
B	1.0	1.0	1.0	1.0	1.0
C	1.7	1.6	1.5	1.4	1.3
D	2.4	2.0	1.8	1.6	1.5
E	3.5	3.2	2.8	2.4	2.4
F	Note b	Note b	Note b	Note b	Note b

a. Use straight-line interpolation for intermediate values of mapped spectral response acceleration at 1-second period, S_1.
b. Site-specific geotechnical investigation and dynamic site response analyses shall be performed to determine appropriate values, except that for structures with periods of vibration equal to or less than 0.5 second, values of F_v for liquefiable soils are permitted to be taken equal to the values for the site class determined without regard to liquefaction in Section 1615.1.5.1.

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Adjusted Maximum Considered Earthquake

The site class *Adjusted Maximum Considered Earthquake* spectral response accelerations for short periods, S_{MS}, and at 1-second period, S_{M1} are:

$$S_{MS} = F_a S_s$$
$$S_{M1} = F_v S_1$$

where:

F_a = Site coefficient defined in Table 1615.1.2(1).

F_v = Site coefficient defined in Table 1615.1.2(2).

S_S = The mapped spectral accelerations for short periods as determined in Section 1615.1.

S_1 = The mapped spectral accelerations for a one second period as determined in Section 1615.1.

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Design Earthquake

Five-percent damped, *Design* spectral response accelerations are:

$S_{DS} = 2/3\ S_{MS}$ **(Equation 16-40)**
$S_{D1} = 2/3\ S_{M1}$ **(Equation 16-41)**

IBC 2003

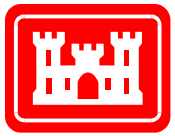
Seismic Design Category (1)

TABLE 1616.3(1)
SEISMIC DESIGN CATEGORY BASED ON
SHORT-PERIOD RESPONSE ACCELERATIONS

VALUE OF S_{DS}	SEISMIC USE GROUP		
	I	II	III
$S_{DS} < 0.167g$	A	A	A
$0.167g \le S_{DS} < 0.33g$	B	B	C
$0.33g \le S_{DS} < 0.50g$	C	C	D
$0.50g \le S_{DS}$	D[a]	D[a]	D[a]

a. Seismic Use Group I and II structures located on sites with mapped maximum considered earthquake spectral response acceleration at 1-second period, S_1, equal to or greater than 0.75g, shall be assigned to Seismic Design Category E, and Seismic Use Group III structures located on such sites shall be assigned to Seismic Design Category F.

IBC 2003



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Seismic Design Category (2)

TABLE 1616.3(2)
SEISMIC DESIGN CATEGORY BASED ON 1-SECOND PERIOD RESPONSE ACCELERATION

VALUE OF S_{DI}	SEISMIC USE GROUP		
	I	II	III
$S_{DI} < 0.067g$	A	A	A
$0.067g \leq S_{DI} < 0.133g$	B	B	C
$0.133g \leq S_{DI} < 0.20g$	C	C	D
$0.20g \leq S_{DI}$	D[a]	D[a]	D[a]

a. Seismic Use Group I and II structures located on sites with mapped maximum considered earthquake spectral response acceleration at 1-second period, S_1, equal to or greater than 0.75g, shall be assigned to Seismic Design Category E, and Seismic Use Group III structures located on such sites shall be assigned to Seismic Design Category F.

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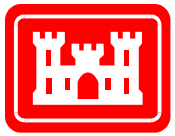
Amplification & Response Modification Factors

MECHANICAL AND ELECTRICAL COMPONENTS SEISMIC COEFFICIENTS

Mechanical and Electrical Component or Element[b]	a_p[a]	R_p
General Mechanical Equipment		
Boilers and furnaces	1.0	2.5
Pressure vessels on skirts and free-standing	2.5	2.5
stacks	2.5	2.5
Cantilevered chimneys	2.5	2.5
Other	1.0	2.5
Manufacturing and Process Machinery		
General	1.0	2.5
Conveyors (non-personnel)	2.5	2.5
Piping Systems		
High deformability elements and attachments	1.0	3.5
Limited deformability elements and attachments	1.0	2.5
Low deformability elements and attachments	1.0	1.5
HVAC Systems		
Vibration isolated	2.5	2.5
Nonvibration isolated	1.0	2.5
Mounted in-line with ductwork	1.0	2.5
Other	1.0	2.5
Elevator Components	1.0	2.5
Escalator Components	1.0	2.5

ASCE 7



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Seismic Force

Seismic forces shall be determined by:

$$F_P = \frac{0.4\, a_p S_{DS} W_p\, (1+2z/h)}{R_p/I_p} \qquad \text{(Equation 9.6.1.3-1)}$$

F_p is not required to be taken as greater than:

$$F_p = 1.6 S_{DS} I_p W_p \qquad \text{(Equation 9.6.1.3-2)}$$

F_p shall not be taken as less :

$$F_p = 0.3 S_{DS} I_p W_p \qquad \text{(Equation 9.6.1.3-3)}$$

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Seismic Force

Where:

F_P = seismic design force
a_p = component amplification factor (from ASCE Table 9.6.3.2)
S_{DS} = seismic acceleration (determined previously)
W_p = component operating weight
R_p = component response modification factor (from ASCE Table 9.6.3.2)
I_p = component importance factor (user selected, either 1.0 or 1.5)
z = height in structure of point of attachment of component w.r.t.b.
h = average roof height of structure w.r.t.b.

ASCE 7

Effect of Amplification & Response Factors

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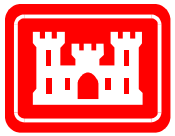
Seismic forces are:

$$F_P = \frac{I_p \; 0.4 \; a_p \, S_{DS} W_p \; (1+2z/h)}{R_p}$$

MECHANICAL AND ELECTRICAL COMPONENTS SEISMIC COEFFICIENTS

Mechanical and Electrical Component or Element[b]	a_p[a]	R_p
General Mechanical Equipment		
Boilers and furnaces	1.0	2.5
Pressure vessels on skirts and free-standing	2.5	2.5
stacks	2.5	2.5
Cantilevered chimneys	2.5	2.5
Other	1.0	2.5
Manufacturing and Process Machinery		
General	1.0	2.5
Conveyors (non-personnel)	2.5	2.5
Piping Systems		
High deformability elements and attachments	1.0	3.5
Limited deformability elements and attachments	1.0	2.5
Low deformability elements and attachments	1.0	1.5
HVAC Systems		
Vibration isolated	2.5	2.5
Nonvibration isolated	1.0	2.5
Mounted in-line with ductwork	1.0	2.5
Other	1.0	2.5
Elevator Components	1.0	2.5
Escalator Components	1.0	2.5



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Amplification & Response Modification Factors

- Lower values for a_p shall not be used unless justified by detailed dynamic analyses. The value for a_p shall not be less than 1.0. The value of a_p=1 is for equipment generally regarded as rigid or rigidly attached. The value of a_p=2.5 is for equipment generally regarded as flexible or flexibly attached.

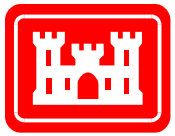
- Components mounted on vibration isolation systems shall have a bumper restraint or snubber in each horizontal direction. The design force shall be taken as ***2***F_p if the maximum clearance (air gap) between the equipment support frame and restraint is greater than 1/4 in. If the maximum clearance is specified on the construction documents to be not greater than 1/4 in., the design force may be taken as F_p.

ASCE 7

What's Required?

- All architectural, mechanical, electrical, and other nonstructural components in structures shall be designed and constructed to resist the equivalent static forces and displacements determined in accordance with ASCE 7 Section 9.6. The design and evaluation of support structures and architectural components and equipment shall consider their flexibility as well as their strength.

ASCE 7



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Seismic Protection Exemptions

Exemptions are:

All components in Seismic Design Category A.

Mechanical components in Seismic Design Category B.

Mechanical components in structures assigned to Seismic Design Category C provided that the importance factor ***(I_p)*** is equal to 1.0.

Exemptions, cont'd

- Mechanical components in Seismic Design Categories D, E, and F where I_p = 1.0 and flexible connections between the components and associated ductwork, piping, and conduit are provided and that are mounted at 4 ft or less above a floor level and weigh 400 lb or less.

- Mechanical components in Seismic Design Categories D, E, and F weighing 20 lb or less where I_p = 1.0 and flexible connections between the components and associated ductwork, piping, and conduit are provided, or for distribution systems, weighing 5 lb/ft or less.

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Supports & Restraints

- Support & restraint types include foundation and housekeeping pads, anchor bolts, structural members, braces, frames, skirts, legs, saddles, pedestals, cables, guys, stays, snubbers, and tethers, as well as elements forged or cast as a part of the mechanical equipment. If standard or proprietary supports are used, they shall be designed by either load testing or for the calculated seismic forces.

- Three analyses must be performed:
  - Attachment of the equipment to the restraint
  - Restraint design
  - Attachment of the restraint to the substructure

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Piping

- *When forces and displacements from ASCE 7 are used:*

- Piping and support systems designed & installed in accordance with ASME B31 or NFPA 13 are deemed to meet the requirements of the Code.

- Piping not designed as above but with an I_p *of 1.5* has restrictions based upon material ductility and construction techniques, and must be investigated to ensure adequate flexibility, and to ensure that harmful interactions do not exist with it and any other piping, conduit, ductwork, equipment, or structure.

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Pipe Supports

- **Piping not designed as above shall have supports constructed suitable for the application and in accordance with a nationally recognized structural code.**
- **Attachments embedded in concrete shall be suitable for cyclic loads.**
- **Rod hangers cannot be used as seismic supports unless 12” or less, and must not be subject to bending moments.**
- **Seismic supports shall be constructed so that support engagement is maintained.**

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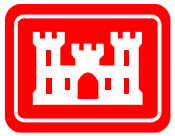
Pipe Supports, cont'd

- **Seismic supports are not required for:**
  - **Ductile piping in Seismic Design Categories D, E, or F with an I_p=1.5 and 1" or smaller when protected from interactions with other piping, conduit, ductwork, equipment, or structure.**
  - **Ductile piping in Seismic Design Category C with an I_p=1.5 and 2" or smaller when protected from interactions with other piping, conduit, ductwork, equipment, or structure.**
  - **Ductile piping in Seismic Design Category D, E, or F designated as having an I_p= 1.0 and a nominal pipe size of 3" or smaller.**
  - **Ductile piping in Seismic Design Category A, B, or C designated as having an I_p= 1.0 and a nominal pipe size of 6" or less.**



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Ductwork

- **In addition to their attachments and supports, ductwork systems designated as having an I_p = 1.5 themselves shall be designed to meet the force and displacement provisions of ASCE 7.**

- **Where HVAC ductwork runs between structures that could displace relative to one another and for seismically isolated structures where the HVAC ductwork crosses the seismic isolation interface, the HVAC ductwork shall be designed to accommodate the seismic relative displacements.**

- **Seismic restraints are not required for HVAC ducts with I_p of 1.0 if either of the following conditions are met:**

  - **HVAC ducts are suspended from hangers 12” or less in length from the top of the duct to the supporting structure. The hangers shall be detailed to avoid significant bending of the hangers and their attachments,**

    or

  - **HVAC ducts have a cross-sectional area of less than 6 square feet.**

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Ductwork

- **HVAC duct systems fabricated and installed in accordance with standards approved by the authority having jurisdiction shall be deemed to meet the lateral bracing requirements.**

- **Equipment items installed in-line with the duct system (e.g., fans, heat exchangers, and humidifiers) weighing more than 75 lb (344 N) shall be supported and laterally braced independent of the duct system and shall meet the force requirements ASCE 7.**

- **Appurtenances such as dampers, louvers, and diffusers shall be positively attached with mechanical fasteners.**

- **Unbraced piping attached to in-line equipment shall be provided with adequate flexibility to accommodate differential displacements.**

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Boilers

- **In addition to their attachments and supports, boilers and pressure vessels designated as having an I_p = 1.5 shall be designed to meet the force and displacement provisions of ASCE 7.**

- **The seismic design of a boiler or pressure vessel shall include analysis of the following: the dynamic effects of the boiler or pressure vessel, its contents, and its supports; sloshing of liquid contents; loads from attached components such as piping; and the interaction between the boiler or pressure vessel and its support.**

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Boilers

- **<u>When forces and displacements from ASCE 7 are used:</u>**
- **Boilers or pressure vessels designed in accordance with the ASME Boiler and Pressure Vessel Code shall be deemed to meet the force, displacement, and other requirements of ASCE 7.**
- **Boilers or pressure vessels not designed as above but with an I_p of 1.5 have restrictions based upon material ductility and construction techniques, and must be investigated to ensure adequate flexibility, and to ensure that harmful interactions do not exist with it and any other piping, conduit, ductwork, equipment, or structure.**

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Other Equipment

- **<u>Forces and displacements from ASCE 7 must be used in the design and installation.</u>**

- **Equipment Manufacturers must certify that their equipment is designed to withstand the design earthquake forces.**

Other Code Requirements

Depending on Seismic Design Category:

Increasing severity of *Seismic Design Categories* requires all design documents to be stamped by a Registered Design Professional.

- **Increasing severity of Seismic Design Categories requires ongoing inspections by a Registered Design Professional or otherwise qualified inspector during and after construction of the project.**

- **Increasing severity of Seismic Design Categories requires periodic inspections by a qualified inspector after construction.**

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Design Resources Available

- **ASHRAE - American Society of Heating, Refrigerating and Air-Conditioning Engineers - Handbook, 2003 General Applications, Chapter 54 - Seismic and Wind Restraint Design**
- **MSS – Manufacturers Standardization Society – Bracing for Piping Systems – Seismic – Wind – Dynamic Design, Selection, Application**
- **SMACNA - Sheet Metal and Air Conditioning Contractors National Association - Seismic Restraint Manual Guidelines for Mechanical Systems - Second Edition**
- **VISCMA – Vibration Isolation and Seismic Control Manufacturers Association – FEMA 412 – Installing Seismic Restraints for Mechanical Equipment & FEMA 414 - Installing Seismic Restraints for Duct and Pipe**

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ASHRAE Handbook

- **Summary and discussion of seismic design requirements**
- **Example calculations**
- **Discussion on proper application of different seismic restraint types**

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MSS Seismic Restraint Manual

- **Good piping support reference**
- **Standard hanger and bracing details and their load capacities**
- **Load ratings for bolting, expansion bolts, concrete embedded bolts, wire rope and other bracing members**

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SMACNA Seismic Restraint Manual

- **Good ductwork *and* piping support reference**
- **Standard hanger and bracing details and their load capacities**
- **Load ratings for bolting, expansion bolts, concrete embedded bolts, wire rope and other bracing members**

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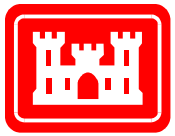
VISCMA – Equipment, Duct, & Piping Restraints

FEMA 412 – Installing Seismic Restraints for Mechanical Equipment
FEMA 414 - Installing Seismic Restraints for Duct and Pipe

- **Cookbook approach as a designer's guide, as well as, installation manual with graphical illustrations and installation instructions.**

- **Covers all types of Mechanical Equipment installations, as well as all types of piping and ductwork hangers.**



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Useful References

- ASHRAE – American Society of Heating, Refrigeration, Air-Conditioning Engineers – www.ashrae.org
- EERI – Earthquake Engineering Research Institute – www.eeri.org
- FEMA – Federal Emergency Management Agency – www.fema.gov/hazards/earthquakes
- NFPA – National Fire Protection Association – www.nfpa.org

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QUESTIONS?

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Background

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