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Seismic Design for Mechanical Systems

The forces exerted by an earthquake on a structure, or, more specifically, the mechanical systems within a building can be in any direction. However, since every building, and mechanical system support, is designed to take care of the vertical, or gravity, loads, the main emphasis for seismic design is in the control of horizontal forces exerted during a seismic event. The vertical load component for equipment is its operating weight. For ducts and pipes, the vertical load component includes the weight of the duct or pipe and the contained fluid.

The design of structural seismic restraints for mechanical systems assumes the building is designed to respond safely during earthquake events. The restraints' primary function is to insure the mechanical systems do not break away, but move with the building during an earthquake.

Because the direction of forces during an earthquake are unpredictable, and can be in any direction, it is important to provide restraint in the X, Y, and Z directions; vertically, laterally (transverse), and longitudinally. Together, transverse and longitudinal bracing with vertical (gravity) supports will resist seismic loads in all directions. The bracing that will be referenced in this guidance will provide for the additional members required to resist the horizontal forces during an earthquake.

Code references in this guidance are based on the policy established by Planning and Design Policy Statement 95-02, which adopted the International Mechanical Code (IMC) as NAVFAC's sole mechanical code. The IMC is published by three entities in the United States including: the Building Officials and Code Administrators International, Inc. (BOCA), the International Conference of Building Officials (ICBO), and the Southern Building Code Congress International, Inc. (SBCCI). Use of these U.S. Codes for projects outside the continental U.S. is contingent upon the engineer to determine it to be more strict than what the local requires; standard procedure requires the engineer to apply the strictest of U.S. and local codes in foreign countries.

- ## Seismic Bracing for Pipe and Duct

All building codes, including BOCA, require most structures to be designed for a horizontal seismic force. The formulas to determine the horizontal seismic force are in the form of:

$$Fp = Cs * Wp$$

where:	Fp	=	seismic force
	Cs	=	seismic coefficient
	Wp	=	weight of the ducts or pipes

Horizontal seismic forces may also is expressed as a percentage of the weight of the elements being braced. It is this percentage that correlates to a designation utilized by SMACNA called the "Seismic Hazard Level" (SHL) that will be addressed later and is fully explained in "Appendix A" of the <u>SMACNA Restraint Manual, Second Edition</u>. The codes have formulas for calculating the <u>percentage horizontal seismic force</u> based on the seismic zone, the importance factor, and the type construction.

The <u>percent horizontal seismic factor</u> is expressed as:

$$\%F = [Fp \div Wp] * 100$$

and: $$Cs = [Fp \div Wp]$$

$$= Cs * 100$$

More specifically, the formula in the IMC and used in the Building Officials and Code Administrators International, Inc. (BOCA), National Building Code, 1996, Chapter 16 to determine the seismic force is:

$$Fp = Av * Cc * P * Ac * Wc$$

where:	Av	=	Figure 1610.1.3(1)
	Cc	=	Figure 1610.6.4(1)
	P	=	Figure 1610.6.4(1); requires determination of "SHEG"
	SHEG	=	Seismic Hazard Exposure Group, Table 1610.1.5
	Ac	=	Figure 1610.6.4(2)

Conveniently, the percent horizontal seismic factor is expressed as:

$$\%F = [Fp \div Wc] * 100$$

$$= [Av * Cc * P * Ac] * 100$$

The "Seismic Hazard Level", SHL, designation was developed specifically for the SMACNA Restraint Manual, Second Edition. It is a designation of "A", "B", or "C" that combines s everal building codes, seismic zones, and other factors into a single system for determining appropriate restraints. SHL's are established by prescribed limits of resistive force as a percentage of weight of the ducts and pipes and correlate to the percent horizontal seismic factors, (%F), determined by building code formulas. The prescribed limits for the SHL's are with "A" being the most stringent, and "C" the least:

- Most stringent; covers buildings most vulnerable due to the strength of seismic events. The bracing for SHL "A" is designed to resist 48% of the weight of the ducts or pipes. If %F is = 48, then use SHL "A". If %F is > 48, the SMACNA Restraint Manual, Second Edition, cannot be used.

- The bracing for SHL "B" is designed to resist 30% of th e weight of the ducts or pipes. If %F is = 30, then use SHL "B".

- Least stringent; covers buildings least vulnerable due to the strength of seismic events. The bracing for SHL "C" is designed to resist 15% of the weight of the ducts or pipes. If %F is = 15, then use SHL "C".

Determination of the SHL for a specific project is fundamental, and indeed the first step in the use of the SMACNA Restraint Manual, Second Edition. The bracing detailed in the SMACNA Restraint Manual, Second Edition provides for the additional members needed to resist horizontal forces in pipe and duct systems. It does not cover seismic restraints for equipment. All in-line equipment must be braced independently of all the ducts or pipes and in conformance with all applicable buildi ng codes. Additionally, SMACNA does not consider forces due to thermal expansion; seismic bracing referenced here is not intended to handle forces imposed by thermal expansion.

<u>Steps in the Use of SMACNA Sizing Tables</u>:

Step 1. Determine the Seismic Hazard Level (SHL). *The determination of the SHL requires familiarity with the earthquake design portion of the building codes, and **<u>shall not</u>** be left up to a contactor to establish; the design engineer **<u>must</u>** specify the SHL in the contract documents.*

The SHL for each Seismic Hazard Exposure Group (see Table 1610.1.5, <u>National Building Code</u>, 1996, Chapter 16) within a specific geographic location in the LANTNAVFACENGCOM jurisdiction are presented in Table 1, entitled "SHL Factors".

Table 1

Seismic Hazard Level (SHL) Factors

Geographic Location	Seismic Hazard Exposure Group (SHEG) (Note 1)	Factors					Seismic Hazard Level (SHL)	
		Av	Cc		P	Ac	Duct & Non-Hazardous Pipe	Gas & Hazardous Pipe
			Duct & Non-Haz Pipe	Gas & Haz Pipe Boilers (Note 2)				
Tidewater Virginia	I	0.05	0.67	2.0	0.5	1.0	C	B
	II	0.05	0.67	2.0	1.0	1.0	C	B
	III	0.05	0.67	2.0	1.5	1.0	C	B
MCAS Cherry Point	I	0.10	0.67	2.0	0.5	1.0	C	B
MCB Camp Lejeune	II	0.10	0.67	2.0	1.0	1.0	C	B
MCAS New River	III	0.10	0.67	2.0	1.5	1.0	C	B
Sugar Grove, WVA	I	0.05	0.67	2.0	0.5	1.0	C	B
	II	0.05	0.67	2.0	1.0	1.0	C	B
	III	0.05	0.67	2.0	1.5	1.0	C	B
Puerto Rico	I	0.20	0.67	2.0	0.5	1.0	C	(Note 3)
	II	0.20	0.67	2.0	1.0	1.0	C	(Note 3)
	III	0.20	0.67	2.0	1.5	1.0	B	(Note 3)
Naples, Italy	I	0.15	0.67	2.0	0.5	1.0	C	A
	II	0.15	0.67	2.0	1.0	1.0	C	A
	III	0.15	0.67	2.0	1.5	1.0	B	A
Sigonella, Italy	I	0.40	0.67	2.0	0.5	1.0	C	(Note 3)
	II	0.40	0.67	2.0	1.0	1.0	B	(Note 3)
	III	0.40	0.67	2.0	1.5	1.0	A	(Note 3)
Aviano AFB, Italy	I	0.15	0.67	2.0	0.5	1.0	C	A
	II	0.15	0.67	2.0	1.0	1.0	C	A
	III	0.15	0.67	2.0	1.5	1.0	B	A
Iceland	I	0.40	0.67	2.0	0.5	1.0	C	(Note 3)
	II	0.40	0.67	2.0	1.0	1.0	B	(Note 3)
	III	0.40	0.67	2.0	1.5	1.0	A	(Note 3)

Notes:

(1) See Table 1610.1.5, the BOCA National Building Code f or Seismic Hazard Exposure Group classifications
(2) Includes boilers, furnaces, incinerators, water heaters, and other equipment utilizing combustible energy sources
(3) The horizontal seismic factor percentage exceeds 50%; SMACNA Restraint Manual, Second Edition, cannot be used.

Step 2. Check the structural system to determine the type structure from which ducts and pipes are supported. If SHL "A" has been specified, determine the connection level.

- When working in SHL "A", one of two con nection levels to the supporting structure must be selected.
    - Connection Level "2" is the most strict condition.
        - Must be used in the State of California within the jurisdiction of OSHPD (California hospitals) and the Office of the State Architect (OSA)(California schools).
        - Conservatively, use this connection level for any area of structural concrete.
    - Use of Connection Level "1" may be used if it is substantiated. May be used anywhere except when connecting into concrete within the jurisdiction of OSHOD (California hospitals) and the Office of the State Architect (OSA)(California schools).

Step 3. Find the detail in the SMACNA Restraint Manual, Second Edition (Chapter 4), which corresponds to the type duct or pipe restraint required. Notes in the detail will refer to the table where member sizes and connections can be found.

Step 4. Determine which chapter of the SMACNA Restraint Manual, Second Edition provides the table for the SHL for your specific project.

- For SHL "A", use Chapter 5.
- For SHL "B", use Chapter 6.
- For SHL "C", use Chapter 7.

Step 5. In the chapter determined by Step 4, find the table referred to in the detail from Chapter 4 of the SMACNA Restraint Manual, Second Edition by Step 3.

Step 6. In the first column, find the duct or pipe size. If the exact size is not liste d, use the next larger size. Ducts are assumed to be of SMACNA standard construction and pipes are assumed to be Schedule 40 water pipes. If pipes are insulated or of heavy construction, the weight of the duct or pipe must be determined and the "weight column" in the tables must be used to select the proper braces.

Step 7. Once the appropriate row in the table has been found, move to the right to read the size requirements for the hangers, braces and bolts.

Step 8. In the same row, under the column "Connection Type to Structural Member", find the connection type designated by a capital letter (A through H). For SHL "A", use the connection level determined in Step 2 to find the connection type.

Step 9. Find the connection type in the first column in Table 8-1 in Chapter 8 of the SMACNA Restraint Manual, Second Edition. Move to the right in the same row to find sizes for the expansion anchors, bolts, spreader sizes, and angle connectors for connecting to the supporting structure.

Step 10. Find a detail in Chapter 8 of the SMACNA Restraint Manual, Second Edition that corresponds to your connection type and to your type of supporting structural system. Install transverse and longitudinal seismic braces at the intervals specified in the general requirements for ducts in Chapter 3 or the tables for pipes in Chapters 5, 6, or 7 of the SMACNA Restraint Manual.

• Seismic Bracing for HVAC Equipment

As with the design of seismic bracing of pipe and duct, the initial step to design restraints for HVAC equipment is to consult the appropriate code. Here, the same code references apply, specifically, Chapter 16 of the Building Officials and Code Administrators International, Inc. (BOCA), National Building Code, 1996.

The BOCA Code provides a seismic force formula to determine the horizontal seismic static force acting at the center of gravity of HVAC equipment. That formula takes the form of:

$$Fp = Av * Cc * P * Ac * Wc$$

where:	Av	=	Figure 1610.1.3(1)
	Cc	=	Figure 1610.6.4(1)
	P	=	Figure 1610.6.4(1); requires determination of "SHEG"
	SHEG	=	Seismic Hazard Exposure Group, Table 1610.1.5
	Ac	=	Figure 1610.6.4(2)

Once the seismic force (Fp) is determined, the seismic loads at the connection between the equipment and the building must be resolved. Static load calculations will be required and examples showing how to compute the loads may be found in the ASHRAE Handbook, HVAC Applications and the ASHRAE, A Practical Guide to Seismic Restraint.

Seismic restraint of HVAC equipment will depend on how the equipment is isolated and whether it is supported on the floor, or from the wall, or overhead.

• Seismic Design Requirements

- **General Requirements:**

  Use either cable or solid bracing for all situations. Do not mix bracing types.

  All runs must have a minimum of two transverse braces and on longitudinal brace. A run is defined as a length of duct or pipe without any change in direction except as allowed by offsets (see Chapter 4 of the SMACNA Restraint Manual, Second Edition).

- **Duct Bracing:**

Brace all ducts with a cross-sectional area of 0.56 sm (6 ft^2), or greater; Rectangular ductwork less than 0.56 sm (6 ft^2) in cross-section does not require seismic restraint.

Round duct less than 710 mm (28") diameter does not require seismic restraint.

Brace flat oval ducts in the same manner as rectangular ducts.

No bracing is required if the duct is suspended by hangers 305 mm (12"), or less, in length, as measured from the top of the duct to the bottom of the support where the hanger is attached.

Hangers must be attached to the duct within 50 mm (2") of the top of the duct with a minimum of two M5 x 0.8 (#10) sheet metal screws.

Transverse bracing must occur at intervals specified in tables in Chapters 5, 6, and 7, of the SMACNA Restraint Manual, Second Edition or at both ends if the duct run is less than the specified interval. Transverse bracing will be installed at each duct turn and at each end of the duct run, with a minimum of one brace at each end.

Longitudinal bracing must occur at the interval specified in tables in Chapters 5, 6, and 7 of the SMACNA Restraint Manual, Second Edition, with at least one brace per duct run. Transverse bracing for one duct section may also act as a longitudinal brace for a duct section at 90° turns if the bracing is installed within two times the duct width of the intersection of both ducts and the bracing is sized for the larger duct (see Figure 4-1, Chapter 4 of the SMACNA Restraint Manual, Second Edition).

A group of ducts may be combined in a larger frame so that the combined weights and dimensions of the ducts are less than or equal to the maximum weight and dimensions of the duct for which bracing details are selected.

Example: To brace a 760 mm x 760 mm (30"x30") duct adjacent to a 1370 mm x 710 mm (54"x28") duct, select bracing for an 2134 mm x 1067mm (84"x42") duct. The horizontal dimension of the 2134 mm x 1067 mm (84"x42") duct is equal to that of the combined ducts and its weight is greater than their combined weights.

Walls, including gypsum board non-load bearing partitions that have ducts running through them, may replace a typical transverse brace. Provide solid blocking around duct penetrations at all stud wall construction.

Unbraced ducts must be installed with a 150 mm (6") minimum clearance to vertical ceiling hanger wires.

- **Pipe Bracing:**

Brace all fuel oil, natural gas, medical gas, and compressed air piping in accordance with local codes.

Brace all piping located in boiler, mechanical equipment, and refrigeration mechanical rooms that is 32 mm (1¼") nominal diameter and greater.

Brace all pipes 65 mm (2½") nominal diameter and greater.

Piping suspended by individual hangers 305 mm (12"), or le ss, in length (as measured from the top of the pipe to the bottom of the support where the hanger is attached) need not be braced. For pipes on a trapeze, the 305 mm (12") exception is measured from the upper face of the horizontal structure member (or th e bottom of the pipe).

Transverse bracing must be at 12-meter (40 ft) minimum intervals, except where a lesser spacing is indicated in the tables for pipe bracing.

Longitudinal bracing must be at 24-meter (80 ft) minimum intervals, except where a lesser spacing is indicated in the tables.

For gas piping, the bracing details, schedules, and notes may be used, except that transverse and longitudinal bracing will be at one -half the spacing shown in the tables in Chapter 5 of the SMACNA Restraint Manual, Second Edition. Provide seismic automatic shut-off valves where required by NAVFAC Specifications 15195N, Natural Gas Piping, and 02556a, Gas Distribution Systems.

Transverse bracing for one pipe section may also act as the longitudinal brace for a pipe section of the same size at a 90° turn if the bracing is installed within 610 mm (24") of the elbow as long as the brace is sized as a longitudinal brace (see Figure 4 - 1 of the SMACNA Restraint Manual, Second Edition).

Provide joints capable of accommodating seismic movements where pipes pass through building seismic or expansion joints or where rigidly supported pipes connect to equipment with vibration isolators. The joints must allow movement in all directions.

Branch lines may not be used to brace main lines.

Cast iron pipe of all types, glass pipe, and any other pipe joined with a shield and clamp assembly, where the top of the pipe is 610 mm (24"), or more, from the supported structure, must be braced on each side of the change in direction of 90° or more. Riser joints must be braced or stabilized between floors.

Vertical risers not specifically engineered must be laterally supported with a riser clamp at each floor. For buildings greater than six floors, all risers must be engineered individually. For risers in hubless piping systems where the riser joints are unsupported between floors, see Figure 9 -10 of the SMACNA Restraint Manual, Second Edition for brace.

- **HVAC Equipment Bracing:**

  Mechanical equipment less than 181 kg (400 lbs) does not requir e seismic restraint.

  - **Seismic Restraint of Equipment without Vibration Isolators:**

    Seismic restraint of floor -mounted equipment without vibration isolation is most straightforward and easiest to address. Such equipment, like tube heat exchangers and stora ge tanks, without moving parts are simply bolted to the floor. Equipment, such as exhaust fans and small pumps, mounted in non - vibration sensitive locations may also be simply bolted to the floor or slab. The calculated seismic force determines the specific means of anchorage. The engineered anchorage must address the type and size of the anchor bolts, with particular attention given to the clearance around the bolt. Excessive clearances between bolts and equipment may lead to anchor failure due to shea r during earthquakes. Neoprene grommets or epoxy fillers should be used fill the clearances. Anchorage to steel, wood and concrete requires additional considerations:

- Anchorage to steel: Consult the "American Institute of Steel Construction Manual" for the actual strength of the anchor bolts.

- Anchorage to wood: The strength of an anchor to wood depends on the type and grade of wood as well as the embedment. Generally, a 15 mm (1/2") to 20 mm (3/4") diameter lag bolt with a depth of 50 mm (2") to 75 m m (3") provides adequate anchorage.

- Anchorage to concrete: Set-in-concrete anchor bolts are not practical. Use post drill anchors where practical. ASHRAE, A Practical Guide to Seismic Restraint provides specific information on their use. Anchorage for large equipment (>11 metric tons) in high seismic zones may make the use of numerous post drill anchors impractical. Other solutions may include the connection of embedment plates to structural elements of a reinforced slab.

Bracing of non-vibration isolated, suspended equipment such as small in-line pumps, fan coils, mixing boxes, water source heat pumps and the like, involves nothing more than to keep the equipment from swaying into adjacent equipment, pipes, ducts or structure. Anti-sway bracing may be accomplished by use of slack cables or steel struts. ASHRAE recommends use of prestretched aircraft quality cable. Additional information can be found in ASHRAE, A Practical Guide to Seismic Restraint.

- **Seismic Restraint of Equipment with Vibration Isolators:**

Seismic restraint for equipment mounted on vibration isolators is more complex since the isolators tend to amplify seismic forces. Amplification occurs because vibration isolators usually have the same natural resonant frequency as an earthquake energy peak. To quell the amplified movement of equipment on vibration isolators, snubbing devices or sway braces are employed. Considerations on the use of snubbers and sway braces include:

- Clearances around snubbers should be about 6 mm (1/4"). Larger gaps will permit high inertia forces that will increase load on equipment. Smaller gaps could hinder the effectiveness of vibration isolators.

- Chillers and boilers, etc. can be directly mounted on seismic snubbers with built-in vibration isolators.

- Floor mounted, lightweight equipment not having adequate stiffness may require supplemental structural bases to prevent buckling at snubbers. Most airside equipment falls in this category.

- Floor mounted pumps may require concrete bases to control distortion to bearings, couplings and seals when point mounted on vibration isolators.

- For adequate stiffness, concrete base thickness should be 1/12th of the maximum span between isolators, but no less than 150 mm (6"). The depth of structural members in steel bases should be 1/10th of the maximum span between isolators, but no less than 100 mm (4").

- Many manufacturers employ internal isolators in their equipment. Because the unit casings are commonly lightweight sheet metal, they are not structurally adequate to incorporate snubbing devices, or there is not adequate clearance within the case to prevent contact between components. ASHRAE recommends cautious use of internal seismic mountings and snubbers and only with written guarantees from the equipment ma nufacturer or from an independent certified test.

- Use snubber devices on wall-mounted equipment such as propeller fans, some air handling units and exhaust fans, if equipped with vibration isolators.

- Sway bracing consisting of slack cable is required for suspended HVAC equipment to prevent the pendulum effect; a rigid sway brace of channel or angle steel would cause transfer of vibration to the structure.

  Sway bracing cable may be attached to the top of bottom of the unit and at least for cables per unit will be required for proper seismic restraint.

  When employing the sway bracing cable system, particular attention must be paid to the cable connection to the building structure. Consult ASHRAE, A Practical Guide to Seismic Restraint for specific guidanc e.

- **Drawing Requirements**

Seismic restraint detailing for mechanical and plumbing systems, complete and appropriate for the project location and seismic hazard exposure group, shall be provided on the contract drawings. It shall be incumbent upon the A& E to determine the Seismic Hazard Level (SHL) factor and to clearly indicate the determination on the mechanical and plumbing contract drawings.