CHAPTER 49

SEISMIC RESTRAINT DESIGN

EARTHQUAKE damage to inadequately restrained heating, ventilating, air-conditioning, and refrigerating equipment can be extensive. High costs are incurred to replace or repair the damaged equipment, and the building cannot be occupied due to inadequate ventilation. The cost to restrain the equipment properly is relatively small compared to the possible damage that may occur.

This chapter covers restraint design to limit the movement of HVAC&R equipment during a seismic event (earthquake). Large or conservative safety factors are applied to reduce the complexity of earthquake response analysis and evaluation. However, the additional cost of higher capacity restraints is small.

Local building officials must be contacted for specific requirements that may be more stringent than presented in this chapter. Nearly all local codes in the United States are based on model building codes developed by three organizations: International Conference of Building Officials (ICBO), Building Officials and Code Administrators International (BOCAI), and Southern Building Code Conference, Inc. (SBCCI). Most seismic requirements adopted by local jurisdictions are based on the Uniform Building Code (UBC), which is developed by ICBO.

The Sheet Metal and Air Conditioning Contractors' National Association publishes HVAC *Systems—Duct Design* (SMACNA 1987), which includes seismic restraint guidelines for ductwork and piping. The National Fire Protection Association (NFPA) has developed standards on restraint design for fire protection systems. Restraint design for nuclear facilities, which is not discussed in this chapter, is covered in U.S. Department of Energy DOE 6430.1A and American Society of Mechanical Engineers publication ASME AG-1.

TERMINOLOGY

Base plate thickness. Thickness of the equipment bracket fastened to the floor.

Effective shear force (V_{eff}). Maximum shear force of one seismic restraint or tie-down bolt.

Effective tension force (T_{eff}). Maximum tension force or pullout force on one seismic restraint or tie-down bolt.

Equipment. Any component that must be restrained from movement during an earthquake.

Fragility level. Maximum lateral acceleration force that the equipment is able to withstand. This data may be available from the equipment manufacturer and is generally in the order of four times the force of gravity (4*g*) for mechanical equipment.

Liquefaction. Phenomenon of soil and sand behaving like a dense fluid during an earthquake.

Resilient support. Active seismic device (such as a spring with a bumper) to prevent equipment from moving beyond a specified amount.

Response spectra. Relationships 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 different soil conditions.

Rigid support. Passive seismic device used to restrict any movement.

Shear force (V). Force generated at the plane of the seismic restraints; it acts to cut the restraint at the base.

Seismic restraint. Device designed to withstand an earthquake.

Snubber. Device made of steel-housed, resilient bushings arranged to prevent equipment from moving beyond an established gap.

Tension force (T). Force generated by overturning moments at the plane of the seismic restraints, acting to pull out the bolt.

UBC 88 seismic zones. Identify the seismic zone factor by the geographical location of a facility, as listed in the Uniform Building Code (1988) (see Figure 1).

CALCULATIONS

Both static and dynamic analyses reduce the force generated by the earthquake to an equivalent static force, which acts in a horizontal 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 rigid-mounted and resilient-mounted equipment.

Dynamic Analysis

A dynamic analysis is based on site-specific ground motions developed by a geotechnical, or soils engineer. A common approach assumes an elastic response spectrum. The results of the dynamic analysis are then scaled up or down as a percentage of the total lateral force obtained from the static analysis performed on the building. The scaling coefficient is established by the UBC or by the governing building official. The scaled acceleration calculated by the structural engineer at any level in the structure can be determined and compared to the force calculated by Equation (1). The greater of the two should be used in the anchor design. The horizontal force factor C_p should be multiplied by a factor of two in either case, as shown in Table 2.

Static Analysis

Equation (1) is a basic formula used to establish the lateral force developed by an earthquake:

$$F_p = ZIC_pW_p \tag{1}$$

The preparation of this chapter is assigned to Task Group for Seismic Restraint Design.

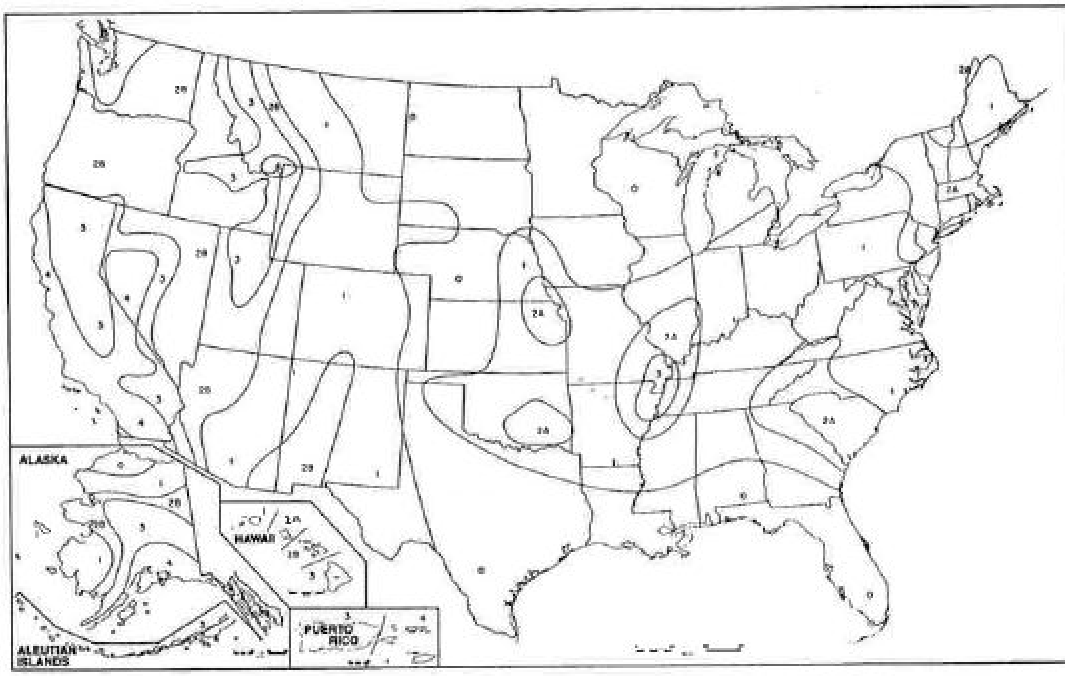

Fig. 1 Seismic Zone Factors for Contiguous 48 States of the United States

Figure 1 and Table 1 may be used to determine the seismic zone and seismic zone factor Z. The *Technical Manual—Seismic Design for Buildings* (Army, Navy, and Air Force 1982) can also be used to determine the seismic zone.

The importance factor I from the UBC (ICBO 1988) ranges from 1 to 1.25, depending on the building occupancy. For equipment, I should be conservatively set at 1.5.

The horizontal force factor C_p is determined from Table 2 based on the type of equipment, tie-down configuration, and type of base.

The mass W_p of the equipment should include all the items attached or contained in the equipment.

Table 1 Seismic Zone Factor Z

Zone	Z
1	0.075
2A	0.15
2B	0.20
3	0.30
4	0.40

Table 2 Horizontal Force Factor C_p

Equipment or nonstructural components	C_p
Mechanical equipment, plumbing, and electrical equipment and associated piping rigidly mounted	0.75
All equipment resiliently mounted (maximum 2.0)	$2C_p$

Note: Stacks and tanks should be evaluated to the applicable codes by a qualified engineer.

APPLYING STATIC ANALYSIS

The forces acting on the equipment are the lateral and vertical forces resulting from the earthquake, the mass of the equipment, and the forces of the restraint holding the equipment in place. Since the analysis assumes the equipment does not move during an earthquake, the sum of the forces and moments must be zero. When calculating the overturning moment, $F_p/3$ should be used as the vertical component at the center of gravity. This vertical component is generated by the seismic event simultaneous with the lateral force.

The forces of the restraint holding the equipment in position include shear and tension forces. It is important to determine the number of bolts that are affected by the earthquake forces. The direction of the lateral force should be evaluated in both horizontal directions as shown in Figure 2. All bolts or as few as a single bolt may be affected.

Figure 2 shows a typical rigid floor mount installation of a piece of equipment. To calculate the shear force, calculate F_p from Equation (1) and sum the forces in the horizontal plane as in Equation (2).

$$0 = F_p - V \tag{2}$$

The effective shear force (V_{eff}) is calculated by Equation (3).

$$V_{eff} = F_p / N_{bolt} \tag{3}$$

where

N_{bolt} = number of bolts in shear

The restraints shown in Figure 2 have two bolts on each side, so that four bolts are in shear. To calculate the tension force, sum the moments for overturning as follows:

$$F_p h_{cg} - (W_p - F_p/3)(D_o/2) - TD_o = 0$$

or,

$$T = [F_p h_{cg} - (W_p - F_p/3)(D_o/2)]/D_o \tag{4}$$

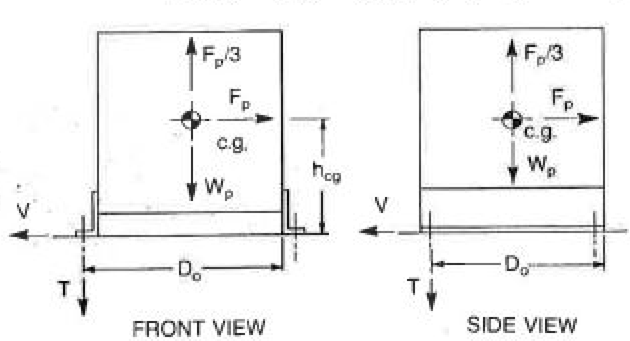

Fig. 2 Equipment with Rigidly Mounted Structural Bases

The effective tension force T_{eff}, where the overturning affects only one side, is calculated by Equation (5). In the example shown in Figure 2, two bolts are in tension.

$$T_{eff} = T/N_{bolt} \quad (5)$$

In the example in Figure 2, the evaluation of the shear and tension forces (T and V) should be independently calculated for both axes as shown in the front and side views. The worst case governs seismic restraint design; however, the direction of seismic loading that will govern the design is not always obvious. For example, if three bolts were installed on each side, the lateral force applied as shown in the side view of Figure 2 affects six bolts in shear and two in tension. The lateral force applied as shown on the front view results in six bolts affected in shear and three in tension. Also, D_o is different for each axis.

Equations (1), (2), and (3) may be applied to ceiling-mounted equipment. Equation (4) must be modified as in Equation (6), because the mass of the equipment adds to the overturning moment.

By summing the moments, Equation (6) may be used to determine the effective tension force.

$$T = [F_p h_{cg} + (W_p - F_p/3)(D_o/2)]/D_o \quad (6)$$

Interaction Formulas. To evaluate the combined effective forces (tension and shear) that act simultaneously on the bolt, the following equation applies:

$$(T_{eff}/T_{allow}) + (V_{eff}/V_{allow}) \leq 1.0 \quad (7)$$

For the allowable forces (T_{allow} and V_{allow}), refer to the generic allowable capacities given in Table 3 for wedge-type anchor bolts.

Table 3 Typical Allowable Loads for Wedge-Type Anchors

Diameter, in.	T_{allow}, lb	V_{allow}, lb
0.5	300	875
0.625	450	2200
0.75	675	3000

Notes:

1. The allowable tensile forces are for installations without special inspection (torque test) and may be doubled if the installation is inspected.
2. Additional tension and shear values may be obtained from published ICBO reports.

ANCHOR BOLTS

Several types of anchor bolts are manufactured. Wedge and sleeve anchors perform better than the self-drilling or drop-in types. Epoxy-type anchors are stronger than other anchors, but lose their strength at elevated temperatures, for example on rooftops and in areas damaged by fires.

Wedge-type anchors have a wedge on the end with a small clip around the wedge. After a hole is drilled, the bolt is inserted and the external nut tightened. The wedge expands the small clip which bites into the concrete.

A self-drilling anchor is basically a hollow drill bit. The anchor is used to drill the hole and is then removed. A wedge is then inserted on the end of the anchor, and the assembly is drilled back into place; the drill twists the assembly fully in place. The self-drilling anchor is weaker than other types, because it forms a rough hole.

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 recommended only for shallow installations since 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 the friction force will not develop the required holding force.

Adhesive anchors may be in glass capsules or installed with various tools. Pure epoxy, polyester, or vinylester 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 with heat. However, some adhesives have been tested without protection to 1100°F before failure—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.

Follow the manufacturer's installation instructions. Performance test data published by manufacturers should include shock, fatigue, and seismic resistance. For allowable forces used in the design, refer to the International Conference of Building Officials (ICBO) reports. Add a safety factor of two (2) if the installation is not inspected.

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 16,000 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:

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

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

The effective weld force is the sum of the vectors calculated in Equations (3) and (5). Since the vectors are perpendicular, they are added by the method of square root of sum of the squares (SRSS).

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

The length of weld required is given by Equation (8).

$$\text{Length} = (F_w)_{eff}/(F_w)_{allow} \quad (8)$$

SEISMIC SNUBBERS

Several types of snubbers are manufactured or field fabricated. All snubber assemblies should meet the following minimum requirements to avoid imparting excessive accelerations to the HVAC&R equipment. The impact surface should have a high quality elastomeric surface that is not cemented in place. The resilient material should be easy to inspect for damage and be replaceable if necessary. To ensure the stated load capacity and to avoid serious design flaws, snubbers should be tested by an independent test laboratory and should be analyzed by a registered engineer. The snubber types presently available are described as Types A through E.

Type A. All-directional with molded, replaceable neoprene element. Neoprene element of bridge-bearing quality is a minimum of 3/16 in. thick. Snubber must have a minimum of two anchor bolt holes (Figure 3).

Type B. All-directional with molded, replaceable neoprene element. Neoprene element of bridge-bearing quality is a minimum of 3/4 in. thick. Snubber must have a minimum of two anchor bolt holes (Figure 4).

Type C. Snubber built into a resilient mounting. All-directional, molded bridge-bearing quality neoprene element is a minimum of 1/8 in. thick. Mounting must have a minimum of two anchor bolt holes (Figure 5).

Type D. Neoprene mount capable of sustaining seismic loads in all directions. Mounting must have a minimum of two anchor bolt holes (Figure 6).

Type E. Aircraft wire rope with galvanized end connections that avoid bending the wire rope across sharp edges. This type of snubber must only be used with suspended pipe duct and equipment (Figure 7).

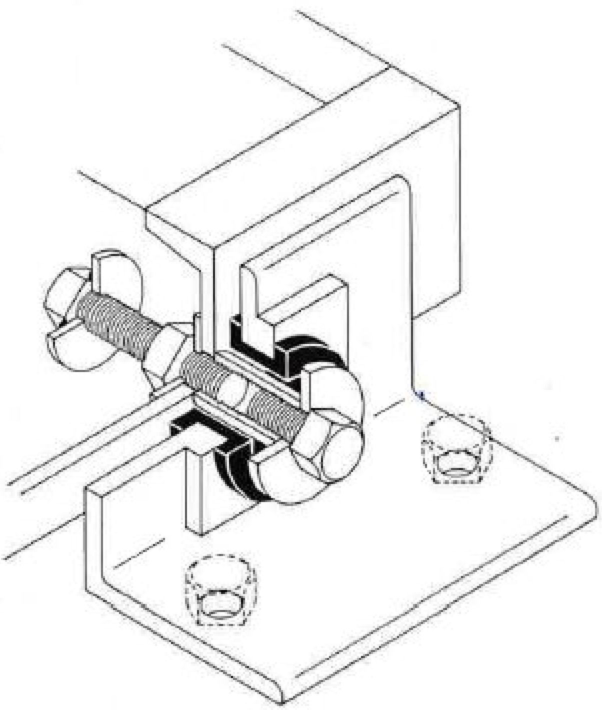

Fig. 3 Type A Snubber

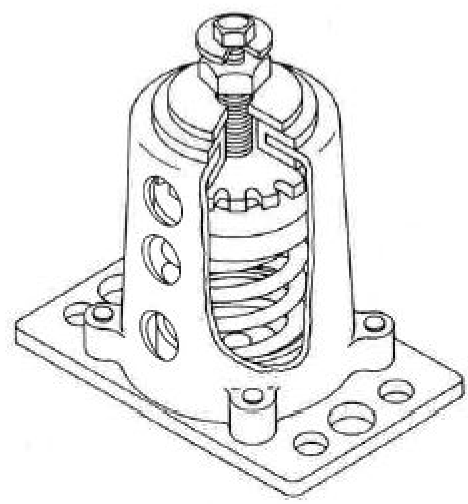

Fig. 5 Type C Snubber

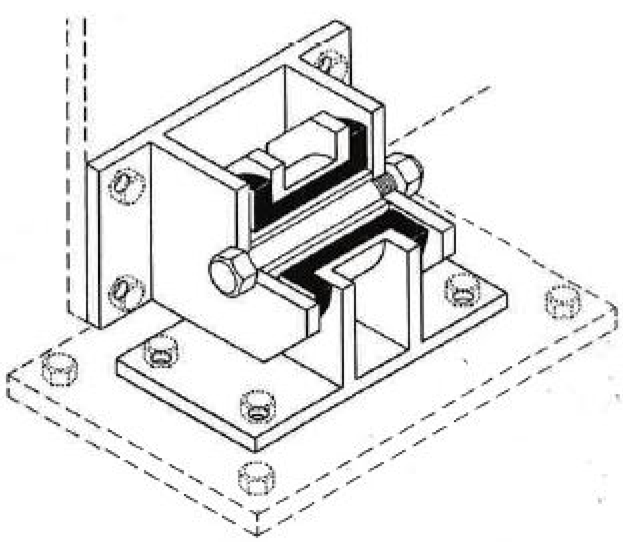

Fig. 4 Type B Snubber

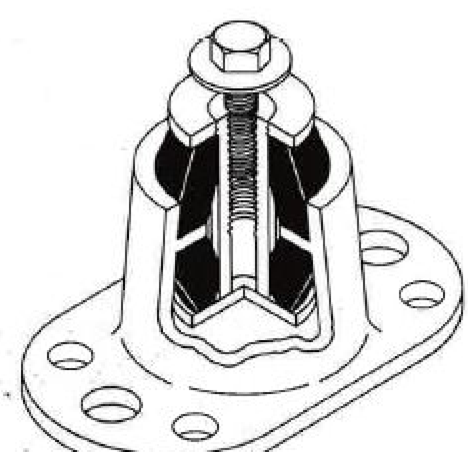

Fig. 6 Type D Snubber

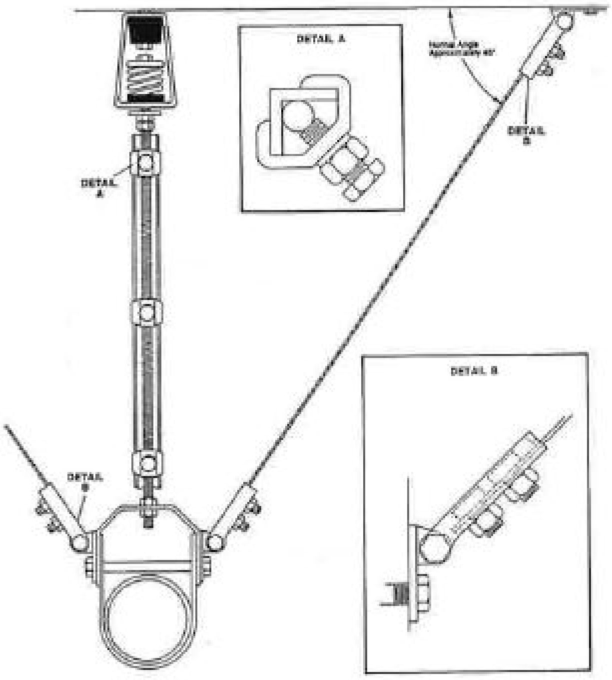

Fig. 7 Type E Snubber

Example 1

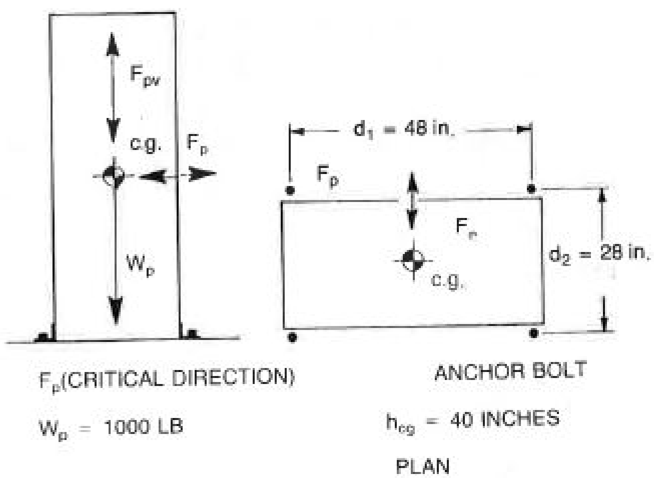

Fig. 8 Equipment Rigidly Mounted to Structure

EXAMPLES

The following examples are provided to assist in the design of equipment anchorage to resist seismic forces.

From Equation (1) (for Zone 4 areas):

$$F_p = 0.4 \times 1.5 \times 0.75 \times 1000 = 450 \text{ lb}$$

$$F_{pv} = F_p/3 = 150 \text{ lb}$$

Calculate the overturning moment (OTM):

$$\text{OTM} = F_p h_{cg} = (450 \times 40) = 18{,}000 \text{ in} \cdot \text{lb} \quad (9)$$

Calculate the resisting moment (RM):

$$\text{RM} = (W_p \pm F_{pv})\, d_{min}/2 = (1000 \pm 150)28/2 \quad (10)$$
$$= 16{,}100 \text{ or } 11{,}900 \text{ in} \cdot \text{lb}$$

Calculate the tension force T:

Use 11,900 in·lb to produce the maximum tension force for this case.

$$T = (\text{OTM} - \text{RM}_{min})/d_{min} = (18{,}000 - 11{,}900)/28 \quad (11)$$
$$= 218 \text{ lb}$$

This force is the same as that obtained by Equation (4).

Calculate T_{eff} per bolt from Equation (5):

$$T_{eff} = 218/2 = 109 \text{ lb/bolt}$$

Calculate shear force per bolt from Equation (3):

$$V_{eff} = 450/4 = 112.5 \text{ lb/bolt}$$

Case 1. Equipment attached to a timber structure.

Reference: *National Design Specification for Wood Construction* (NDS)(NFPA 1986).

Note: Selected fasteners must be secured to solid lumber, not to plywood or other similar material. Check whether a 1/2-in. diameter, 4-in. long lag screw will hold the required load.

From Table 8.1A in the NDS, for Group IV (redwood) $G = 0.37$

From Table 8.6A of the NDS:

$$T_{allow} = (241 \text{ lb/in} \times 3.5\text{-in. penetration})2/3 = 562 \text{ lb}$$

From Table 8.6C, V_{all} = 180 lb

Note: The factor 2/3 accounts for the fact that about one-third of the length of a lag screw or bolt has no threads on the shank.

Other types of wood may be used with appropriate factors from Table 8 and/or other reductions as specified in Part II of NDS.

In timber construction, the interaction formula, Equation (7), does not apply per Section 8.6.8 of the NDS. The ratio of the calculated shear and tension values to the allowable values should each be less than 1.0.

$$T/T_{allow} = 218/562 = 0.39 < 1.0$$

$$V/V_{allow} = 112.5/180 = 0.63 < 1.0$$

Therefore, use a 1/2-in. diameter, 4-in. long lag screw at each corner of the equipment.

Case 2. Equipment attached to concrete with drill-in bolts.

Note: Good design practice is to specify a minimum of 1/2-in. diameter bolts to attach roof or floor-mounted equipment to the structure.

Try 1/2-in. wedge anchors with special inspection provisions:

From Table 3: T_{allow} = 600 lb V_{allow} = 875 lb

From Equation (7) 109/600 + 112.5/875 = 0.31 < 1.0

Therefore, use 1/2-in. diameter, 4-in. long lag screws.

Case 3. Equipment attached to steel.

For the case where equipment is attached directly to a steel member, the analysis is the same as that shown in Case 1 above. The allowable values for the attaching bolts are given in the *Manual of Steel Construction* (AISC 1980).

The following values can be used for A307 bolts:

Table 4 Allowable Loads for A307 Bolts

Diameter, in.	T_{allow}, lb	V_{allow}, lb	A_b, in^2
1/2	3900	1950	0.196
5/8	6100	3100	0.307
3/4	8800	4400	0.442
1	15700	7900	0.785

The interaction formula, Equation (7), does not apply to steel-to-steel connections. The allowable tension load is modified by the following formula:

$$(T_{allow})_{mod} = F_t A_b$$

where

$$F_t = 26 - 1.8(V/N_{bolt}A_b) \leq 20(4/3) = 26.67$$

V/N_{bolt} is in kips (1 kip = 1000 lb) and F_t is in kip/in² (ksi). If F_t is less than 20 ksi, multiply the calculated $(T_{all})_{mod}$ by 1000 for equivalent values to those shown in Table 4. The 33% (4/3) stress increase is allowed for short-term loads such as wind or earthquakes.

Example 2

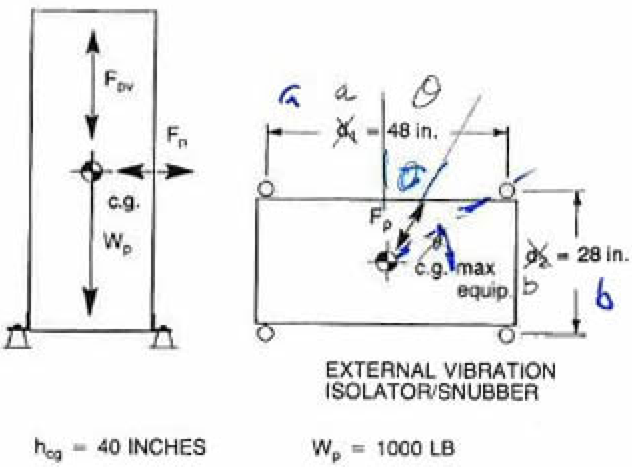

Fig. 9 Equipment Supported by External Spring Mounts

Note: A mechanical or acoustical consultant should choose the type of isolator/snubber or combination of the two. Then the product vendor should select the actual spring snubber.

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

T = maximum tension on isolator
C = maximum compression on isolator
$F_{pv} = F_p/3$

$$T = (-W_p + F_{pv})/4 + F_p h_{cg}\cos\theta/2b + F_p h_{cg}\sin\theta/2a$$

$$T = (-W_p + F_{pv})/4 + (F_p h_{cg}/2)(\cos\theta/b + \sin\theta/a)$$

To find maximum T or C, find $dt/d\theta = 0$

$$dt/d\theta = (F_p h_{cg}/2)(-\sin\theta/b + \cos\theta/a) = 0$$

Therefore, $\theta_{max} = \tan^{-1}(b/a)$ (12)

$$T = (-W_p + F_{pv})/4 + (F_p h_{cg}/2)(\cos\theta_{max}/b + \sin\theta_{max}/a) \quad (13)$$

$$C = (-W_p - F_{pv})/4 - (F_p h_{cg}/2)(\cos\theta_{max}/b + \sin\theta_{max}/a) \quad (14)$$

From Equation (1):

$F_p = 0.4 \times 1.5 \times 2 \times 0.75 \times 1000 = 900$ lb
$F_{pv} = 900/3 = 300$ lb

From Equation (12):

$\theta = \tan^{-1}(28/48) = 30.26°$

From Equations (13) and (14):

$T = -175 + 744 = 569$ lb
$C = -175 - 744 = -919$ lb
−325 −1069

Calculate the shear force per isolator:

$$V = F_p/N_{iso} = 900/4 = 225 \text{ lb} \quad (15)$$

This shear force is applied at the operating height of the isolator. Uplift T on the vibration isolator provides 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 (Figure 10).

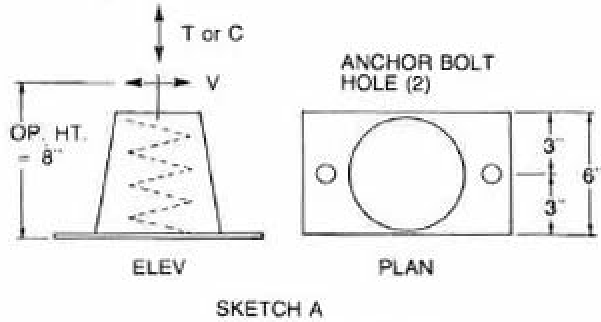

Fig. 10 Spring Mount Detail

$$(T_1)_{eff} \text{ per bolt} = T/2 = 569/2 = 284 \text{ lb}$$

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

$$(T_2)_{eff} = V_{op\ ht}/0.85dN_{bolt}$$

where

d = distance from edge of isolator base plate to center of bolt hole

$$(T_2)_{eff} = 225 \times 8/(0.85 \times 3 \times 2) = 353 \text{ lb}$$

$$(T_{max})_{eff} = (T_1)_{eff} + (T_2)_{eff} = 284 + 353 = 637 \text{ lb}$$

$$V_{eff} = 225/2 = 113 \text{ lb}$$

Check if 5/8-in. drill-in bolts will handle this load. From Equation (7):

$$637/900 + 113/2200 = 0.76 < 1.0$$

Therefore, 5/8-in. bolts will carry the load.

Example 3

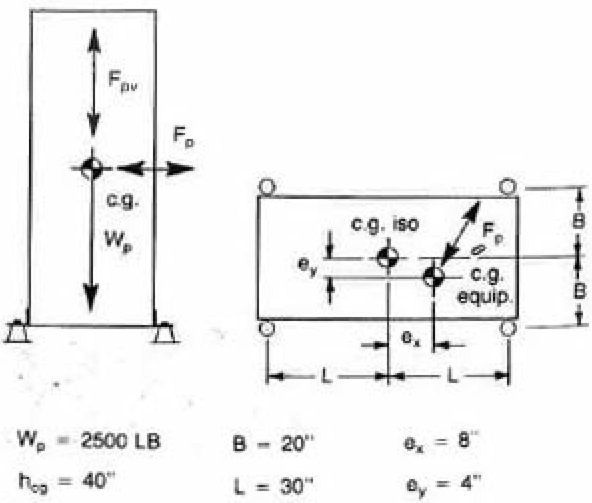

Fig. 11 Equipment with Different Center of Gravity than Isolator Group

Anchor properties: $I_x = 4B^2$ $I_y = 4L^2$

Angles:

$$\theta = \tan^{-1}(B/L) \quad (16)$$

$$\alpha = \tan^{-1}(e_x/e_y) \quad (17)$$

$$\beta = 180 - |\alpha - \theta| \quad (18)$$

$$\phi = \tan^{-1}(LI_x)/BI_y) \quad (19)$$

Vertical reactions:

$$(W_n)_{max/min} = W_p \pm F_{pv} \quad (20)$$

Vertical reaction due to overturning moment:

$$T_m = F_p h_{cg}[(B/I_x)\cos\phi + (L/I_y)\sin\phi] \quad (21)$$

Vertical reaction due to eccentricity:

$$(T_e)_{max/min} = (W_n)_{max/min}(Be_y/I_x + Le_x/I_y) \quad (22)$$

Vertical reaction due to W_p:

$$(T_w)_{max/min} = (W_n)_{max/min}/4 \quad (23)$$

$$T_{max} = T_m + (T_e)_{max} + (T_w)_{max} \quad (24)$$

$$T_{min} = T_m + (T_e)_{min} + (T_w)_{min} \text{ (tension if positive)} \quad (25)$$

Horizontal reactions:

Due to rotation: $V_{rot} = F_p[(e_x^2 + e_y^2)/16(B^2 + L^2)]^{0.5}$ (26)

$$V_{dir} = F_p/4 \quad (27)$$

$$V_{max} = (V_{rot}^2 + V_{dir}^2 - 2V_{rot}V_{dir}\cos\beta)^{0.5} \quad (28)$$

From Equation (1):

$F_p = 0.4 \times 1.5 \times 2 \times 0.75 \times 2500 = 2250$ lb

$F_{pv} = 2250/3 = 750$ lb

$I_x = 4(20)^2 = 1600$ $I_y = 4(30)^2 = 3600$

From Equations (16) through (19):

$\theta = 33.69°$ $\alpha = 63.43°$

$\beta = 150.26°$ $\phi = 33.69°$

From Equation (20):

$(W_n)_{max/min} = 3000$ lb or 1500 lb

From Equation (21): $T_m = 90{,}000(0.01 + 0.005) = 1352$ lb

From Equation (22):

$(T_e)_{max/min} = 0.1167(W_n)_{max/min} = 350$ lb or 175 lb

From Equation (23): $(T_w)_{max/min} = 750$ lb or 375 lb

$T_{max} = 1352 + 350 + 750 = 2452$ lb

$T_{min} = 1352 + 175 - 375 = 1152$ lb (tension)

From Equation (26): $V_{rot} = 2250 \times 0.062 = 140$ lb

From Equation (27): $V_{dir} = 2250/4 = 563$ lb

From Equation (28): $V_{max} = 687$ lb

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

Example 4

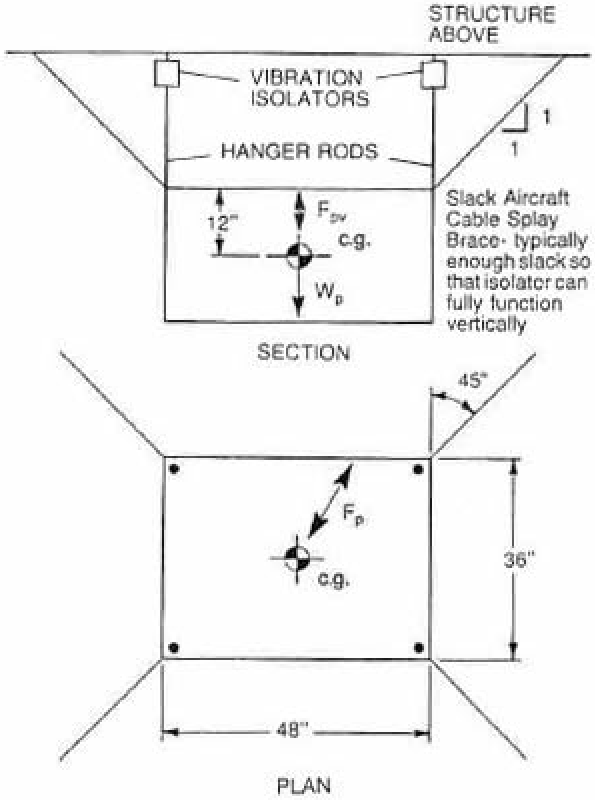

Fig. 12 Supports and Bracing for Suspended Equipment

Note: Vibration isolators should be used between the equipment and the structure to dampen out vibrations generated by the equipment, since drill-in bolts may not withstand published allowable static loads when subjected to vibratory loads.

$$W_p = 500 \text{ lb}$$

From Equation (1):

$F_p = 0.4 \times 1.5 \times 2 \times 0.75 \times 500 = 450$ lb

$F_{pv} = 450/3 = 150$ lb

From Equation (9):

$$\text{OTM} = 450 \times 12 = 5400 \text{ in·lb}$$

From Equation (10):

$$\text{RM} = (500 \pm 150)36/2 = 11700 \text{ or } 6300 \text{ in·lb}$$

Since RM > OTM, overturning is not critical.

Force to the hanger rods:

$$T_{eff} = (W_p + F_{pv})/4 = (500 + 150)/4 = 163 \text{ lb}$$

Force in the splay brace $= \sqrt{2}F_p = 636$ lb

Due to the force being applied at the critical angle, similar to Example 2, only 1 splay brace is effective in resisting the lateral load F_p. If eccentricities occur, as in Example 3, a similar method of analysis must be done to obtain the design forces.

Design of hanger rod/vibration isolator and connection to structure.

Note: When installing drill-in anchors into the underside of a concrete beam or slab, the allowable tension loads on the anchors must be reduced to account for the cracking of the concrete. A general rule is to use half the allowable load.

Using a 1/2-in. wedge anchor with special inspection provisions:

$$T_{allow} = 600 \times 0.5 = 300 \text{ lb} > T_{eff} = 163 \text{ lb}$$

Use a 1/2-in. rod and drill-in bolt at each corner of the unit.

Design of splay brace and connection to structure.

Force in the slack cable = 636 lb

Force in the connection to the structure:

$$V_{max} = 636/\sqrt{2} = 450 \text{ lb} \qquad T_{max} = F_p = 450 \text{ lb}$$

Check a 3/4-in. wedge-type anchor with special inspection provisions. From Table (3):

$$T_{allow} = 1350/2 = 675 \text{ lb} \qquad V_{allow} = 3000 \text{ lb}$$

From Equation (7): $450/675 + 450/3000 = 0.82 < 1.0$

A 3/4-in. anchor or multiple anchors of a smaller size bolted through a clip and to the structure is permissible.

Since 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 to the equipment.

INSTALLATION PROBLEMS

The following problems with seismic restraint have been recognized.

- Anchor location affects the required strengths. Locate concrete anchors away from edges, stress joints, or existing fractures. Follow ASTM *Standard* E-488-90 as a guide for edge distances and center-to-center spacing.
- Concrete anchors too close together. Spacing of epoxy-type anchors can be closer together than expansion type anchors. Expansion-type anchors (self-drilling and drop-in anchors) can crush the concrete where they expand and impose internal stresses in the concrete. Carefully review spacing of all anchor bolts. (See manufacturer's recommendations.)
- Supplementary steel bases and frames, concrete bases, or equipment modifications may void some manufacturer's warranties. Snubbers, for example, should be properly attached to a subbase. Bumpers may be used with springs.
- 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.
- Equipment must be strong enough to withstand the high deceleration forces developed by resilient restraints.
- Bumpers installed to limit horizontal motion should be outfitted with resilient neoprene pads to soften the potential impact loads of the equipment.
- Inspect the anchor installation; in many cases, damage occurs because bolts were not properly installed. To develop the rated restraint, bolts should be installed according to manufacturers' recommendations.
- Brackets in structural steel attachments should be matched to reduce bending and internal stresses at the joint. Rigid seismic restraints should not have slotted holes.

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