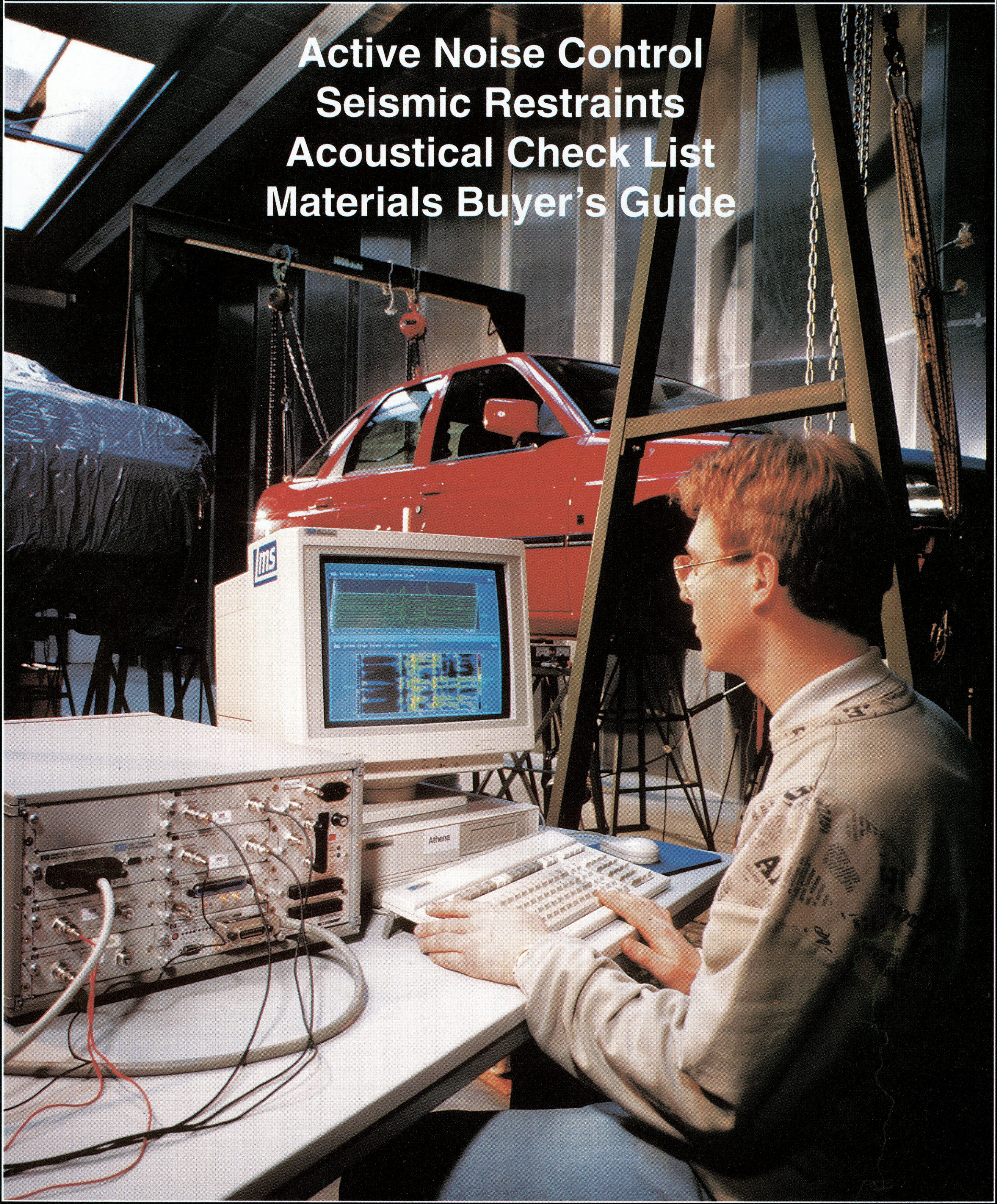
SOUND&VIBRATION

MATERIALS REFERENCE ISSUE JULY 1994

Active Noise Control
Seismic Restraints
Acoustical Check List
Materials Buyer's Guide



Effects of Seismic Inputs on Resiliently Mounted Mechanical Equipment

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Earthquake control of resiliently mounted systems is an area of primary concern for acoustical and mechanical engineers. The Northridge, CA earthquake of January 17th, 1994, provided several valuable lessons regarding protection of these systems. The lessons learned from this earthquake are highlighted with actual site photographs that are useful and dramatic. The photographs are combined with several tables and illustrations that provide practical guidelines for future mechanical system installations.

One function of an acoustician or a mechanical engineer is to decide what equipment requires vibration isolation, as well as what type of mountings and what static deflections to use. The picture gets more complicated, however, when this equipment also requires seismic protection. There is a conflict between what the acoustician or mechanical engineer is trying to accomplish and what the seismic engineer must accomplish. Although there is no question that an isolation system without any type of seismic device is superior acoustically, the engineer has to select the seismic systems to be used with his carefully planned vibration isolation system. Techniques that allow both disciplines to be somewhat satisfied have been developed based on information from the most recent earthquakes.

The earthquake of January 17th, 1994, (Northridge, CA earthquake) confirmed the lessons learned in the Loma Prieta earthquake of 1989, when properly designed and applied hardware protected mechanical systems from seismic shock. When the rules were not strictly followed, the result was often support failure. Figure 1 shows the overall map of the Los Angeles area, including the epicenter of the Northridge earthquake. Also indicated are some of the areas where the investigation teams studied the mechanical and electrical systems in modern structures. The examined systems cover a full gamut: non-isolated as well as isolated; mechanical and electrical; floor mounted and suspended systems. These systems showed dismal failures in some instances and no damage in others.

Seismic Protection

The object of seismic protection is to avoid amplification of the seismic input. For example, amplification occurs when the airgap of a bolt hole clearance to an anchor bolt is not cushioned, allowing a hard surface to strike a hard surface. This can cause an amplification of as much as 40 to 50 times[1] the input acceleration. Typical amplification can be demonstrated by relating the floor natural frequencies and the earthquake duration. Even in an earthquake with a 10 sec duration, the two hard surfaces could contact 60 or more times, resulting in a failure of the anchor bolt system as shown in Figure 2.

Suspended piping and duct work can also resonate with earthquake input. With limited "rattle space," they may impact on one another, causing amplifications and failures.

The same amplification problem can exist if a snubber is employed. Snubbers, by definition, have an airgap to avoid short circuiting the isolation system. This airgap would cause inertia effects to amplify the input accelerations by as much as 40 to 50 times if the hard surfaces are allowed to strike hard surfaces. This amplification factor can be reduced to approximately 3 or 4 with proper all-directional resilient collars on all contact surfaces. A compendium of proper seismic snubbers is shown in Figure 3.

It is not difficult to protect non-isolated systems from damage. Using a resilient grommet or molded epoxy grouting to eliminate the airgap and avoid hard surface contact is all that is

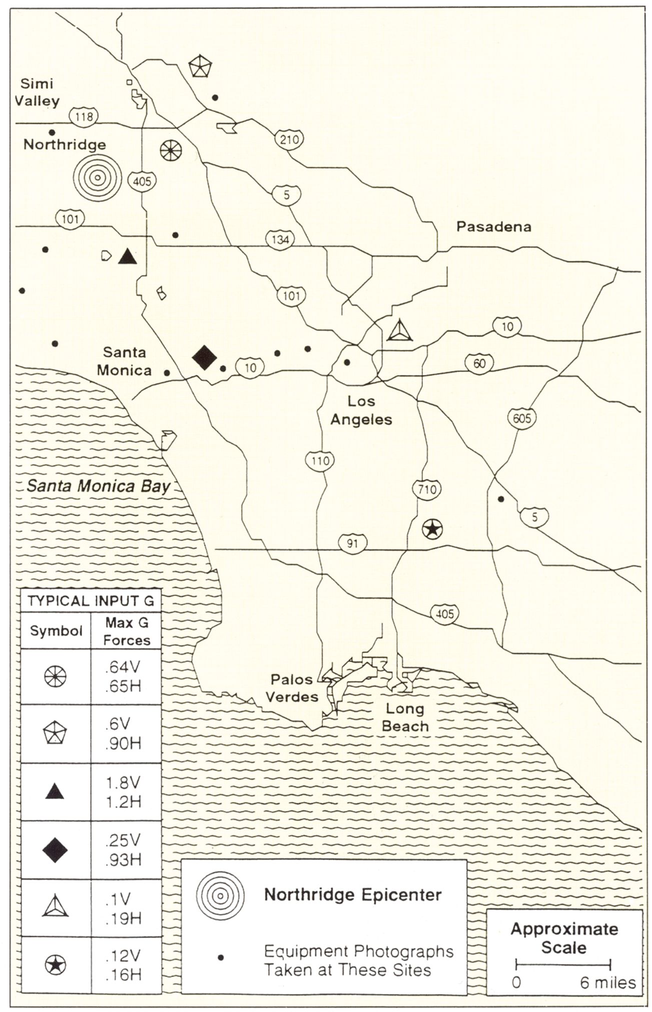


Figure 1. Map of the Los Angeles area showing the epicenter of the Northridge earthquake.

required (see Figure 4). The object of this article is to show how to protect isolated systems while preventing the vibration isolators from short circuiting.

There is no seismic snubbing device that does not have the potential to short circuit the isolation system. In a properly designed seismic snubbing system, the weak link is the isolation system. If shorted, the failure would be obvious and could be corrected in the field. Shorted isolation systems do not pose a threat to life or property. What must be avoided is a failure of the snubbing system during an earthquake. This potential failure is not obvious and there are no second chances. The risk to life or property in this case is very real.

The 1994 Northridge earthquake provides information as to what snubber system survived and why. These snubber systems can be designed to not interfere with the operation of the vibration isolation system that they are attached to.

The attachment of the snubber system is crucial. If there is a load path failure at any of its three component connections, the system simply fails. The component connections are the attachment of the snubber to the unit or the isolator frame, the structural integrity of the seismic snubber and the structural capability of the bolt down system for the snubber. The sim-

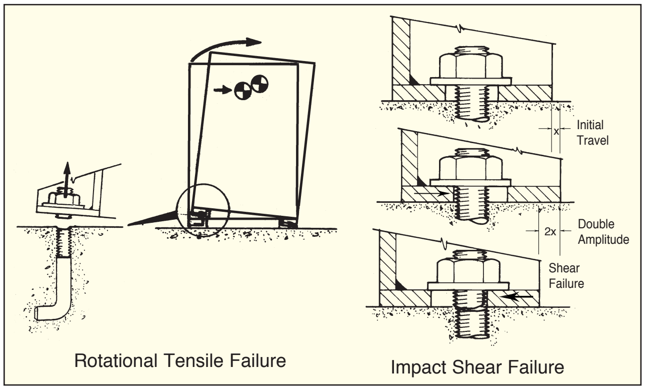


Figure 2. Anchor bolt failures caused by excessive bolt hole clearances.

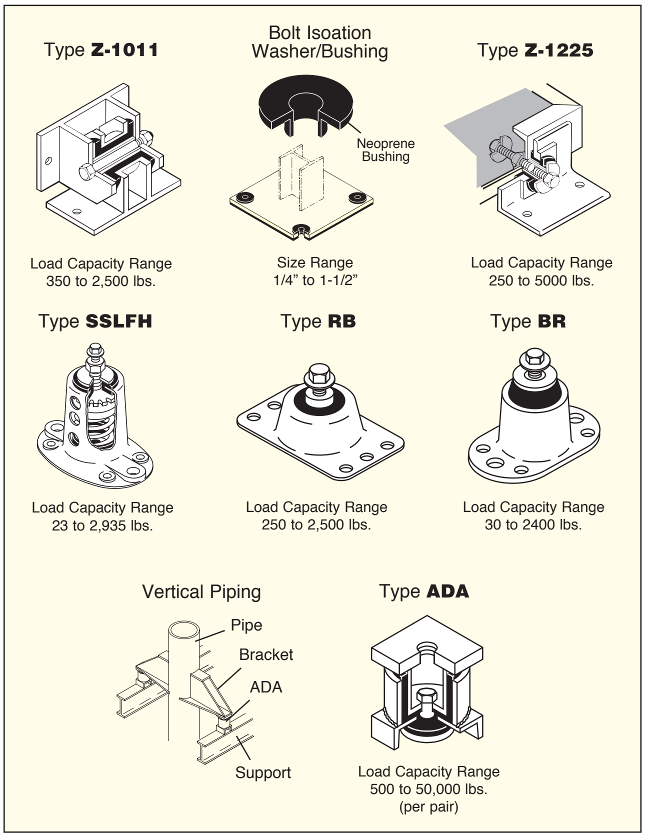
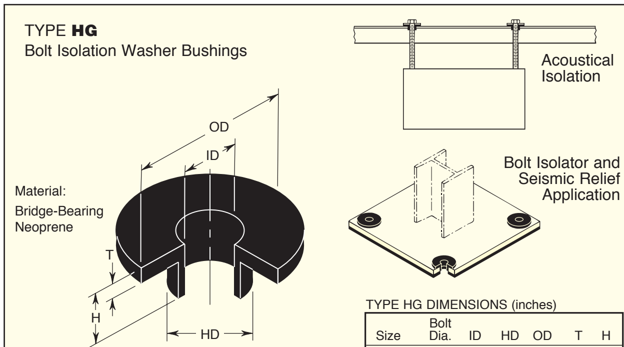


Figure 3. Compendium of seismic snubbers.



TYPE HG DIMENSIONS (inches)

Size	Bolt Dia.	ID	HD	OD	T	H
HG-25	1/4	1/4	1/2	1	1/8	3/8
HG-38	3/8	3/8	5/8	1 1/4	1/8	1/2
HG-50	1/2	1/2	3/4	1 5/8	1/8	1/2
HG-63	5/8	5/8	7/8	2	3/16	5/8
HG-75	3/4	3/4	1	2 1/4	3/16	5/8
HG-100	1	1	1 1/4	2 3/4	1/4	7/8
HG-125	1 1/4	1 1/4	1 1/2	3 1/4	1/4	7/8
HG-150	1 1/2	1 1/2	1 3/4	3 3/4	1/4	1

Equipment rigidly attached to foundations have been known to break free in moderate earthquakes and blasts, even with low (0.2 g) ground level accelerations. This has been attributed to the motion and subsequent high g impact occurring due to the clearance between the anchor bolts and the equipment bolt holes. What is initially thought to be a static system may in reality become dynamic.

To eliminate this problem where you have loose-fitting, off-center bolts or odd-shaped bolt holes, use Type HCF Hole Clearance Filler to fill the area around the anchor bolts.

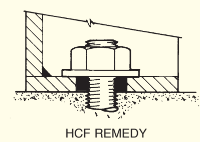


Figure 4. Use of resilient grommets in bolt holes to avoid metal-to-metal contact.

Figure 5. Direct mounting of vibration isolators can result in failure if the machinery frame is not adequate and local buckling occurs (roof location, 2 stories, approximate maximum seismic excitation – 0.42 g horizontal, 0.3 g vertical).

plest connection to look at is the connection of the seismic snubber to the isolated equipment or equipment frame. This connection is the easiest to deal with since the structural integrity of the equipment leg or frame is not complex to investigate. When in doubt, use a structural frame (steel or concrete). Do not use rails, since recent studies indicate rails fail. Figures 5 and 6 show improper systems and Figure 7 shows a system that is proper at this interface connection.

The design of the snubber itself is more complex. Some acoustical or mechanical consultants dislike or refuse to use seismic snubbers that are built into the isolation mounts. This objection may be justified, since this is the most difficult system to adjust properly to insure no short circuiting of the vibration isolation system. There are occasions, however, when there is no other choice. These units can be properly adjusted to not interfere with the isolating characteristics of the resilient element if properly designed.

Several of these systems are shown in Figure 8. These units have fared very well during the Northridge earthquake and withstood input accelerations over 2 g horizontal. This is the highest input magnitude ever recorded anywhere in the world.

The problem with this type of built-in snubber system occurs when it is used on fan or air handling units that have medium to high static pressure. The adjusting bolt tends to move horizontally and lock out on the resilient collar. This can be prevented by the use of properly installed and adjusted thrust restraints that have been commercially available for years.

Snubbing systems that engineers tend to favor over the built-in snubber systems are shown in Figure 9. These are the molded all-directional neoprene collar type that are installed separately from the vibration isolators themselves. It is easier to control short circuiting with these units since inspection and adjustment is simplified. If the collar is shorted, it is easy to re-adjust the isolators and eliminate the short circuit.

Snubbing System Ratings

All snubbing systems should have capacities certified by some independent agency. Since there are no U.S. or international standards in place governing seismic snubbers, the engineer has one of two choices. He can personally look over

Figure 6. The attachment of the stand to the pipe and to the top of the machinery mount is not proper. This allowed the stand to shift off the mounting (basement location, 6 stories, approximate seismic excitation – 0.3 g horizontal, 0.25 g vertical).

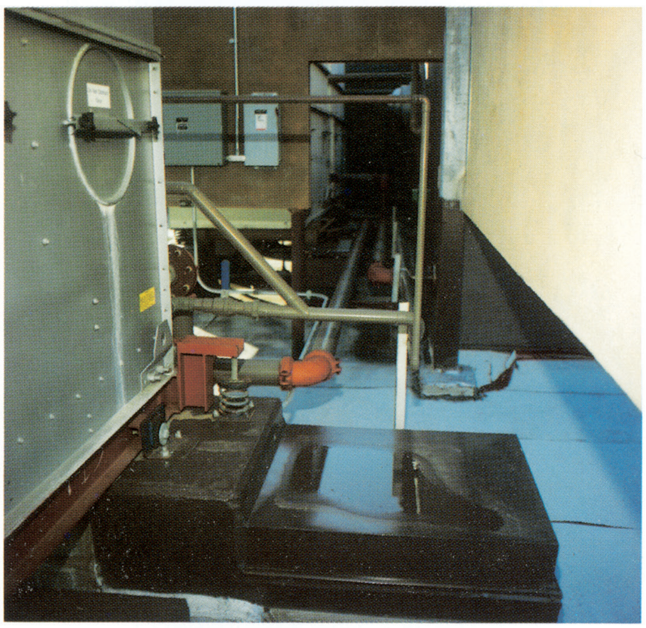


Figure 7. The cooling tower is mounted on a proper structural frame with all-directional Z-1011 seismic snubbers. The result is no failure with the cooling tower remaining operational (roof location, 8 stories, approximate maximum seismic excitation – 0.45 g horizontal, 0.32 g vertical.

Figure 8. The seismic snubbers are built into the vibration isolators. The system was properly adjusted and withstood the effects of over 2 g input and remained operational. The mounting type is Mason SSLFH (roof location, 7 stories, approximate maximum seismic excitation – 2.3 g horizontal, vertical n/a).

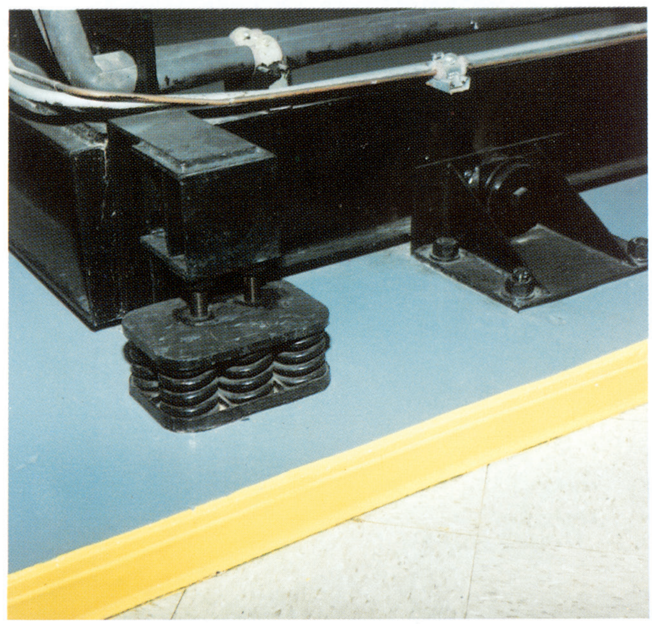


Figure 9. Separate all-directional Mason Type Z-1011 snubbers were as effective as built-in snubbers. The snubbers can be adjusted for clearance by using the spring mounted adjusting bolts (31st floor location, 32 stories, approximate maximum seismic excitation – 0.28 g horizontal, 0.2 g vertical.

the testing and analysis data of these systems and determine that the ratings based on these submitted documents are correct. Or he can accept the seismic ratings assigned by an independent governmental agency. The one governmental agency that rates these snubbing systems' seismic capacity is called OSHPD (The Office of Statewide Health, Planning & Development) from the State of California.

This agency of the California State government has competent structural engineers who very carefully analyze submitted structural calculations and tests of all snubbing devices and decide if they meet published rated capacities. When this independent group is satisfied, it issues an Approved 'R' Number which must be renewed every three years for that particular item. The engineer can feel secure that these snubbers, manufactured by various companies worldwide, meet their stated design capacities. The fastening of these snubbers to the structure, however, is not part of the OSHPD rating system. Hold-down anchor bolt capacity is a function of the grade of concrete used, which can vary from 3000 psi up to 9000 psi or greater. The OSHPD rating system does not address this and each case must be reviewed.

The snubber manufacturer must provide the proper analysis and select the anchor bolt size, type and imbedment. These calculations should be signed by a Registered Engineer in the State where the project is located and this engineer should be in the employ of the snubber manufacturer. The anchor bolt type that is recommended is a wedge anchor. The wedge anchor has reserve capacity to prevent pull-out when the slab is cracked from the seismic input. Figure 10 is a quick reference for the various types of drill-in anchors currently available. Poured-in-place anchors are not economically feasible and are not practical for snubber tie-down. This is due to the lack of

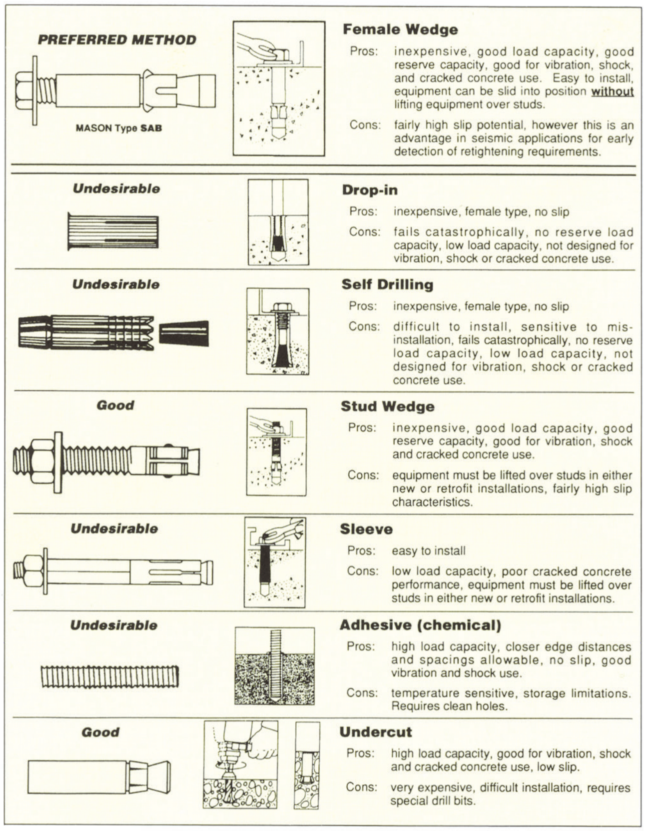


Figure 10. Drill-in bolt anchors currently available.

information on equipment location at the time the structural slab is poured.

Snubber Selection

Important points concerning the selection of snubbers are:

1. Snubbers should be all-directional, since seismic inputs do not come in at a particular direction.
2. All contact surfaces shall have resilient collars of bridge bearing neoprene, a minimum of 3/8″ thick.
3. All snubber ratings shall be verified by the State of California (OSHPD).
4. A minimum of four snubbers per system is required.
5. The snubber selection shall be based on *overturning* calculations by a Registered Engineer in the State that the system is to be installed. See Figure 3 for typical snubber types currently available. This discussion has been limited to floor supported equipment. Suspended equipment constitutes a large portion of the HVAC system. This equipment must be protected from seismic damage as well.

Suspended equipment such as piping, ducts and miscellaneous HVAC equipment must be sway braced. Suspended equipment does not react to seismic shock input the same as floor mounted equipment. The pendulum action of the supports has a much lower natural frequency and cushions shock force relatively well. Equipment will sway, however, and this will cause collisions between pipes and ducts or other suspended units.

Table 1. Minimum reinforcing and doweling required on housekeeping pads.

Max. Housekeeping Pad Area, ft^2	Min. Dowel Size & Embedment, in.	Max. Dowel Spacing Both Ways, in.	Min. Reinforcing
Up to 40	1/2 × 3	18	6×6×10 Ga Mesh
40 to 100	1/2 × 3	16	#2 Rebar, 8 in. O.C.
100 to 200	5/8 × 4	12	#4 Rebar, 8 in. O.C.
200 to 400	3/4 × 4	12	#5 Rebar, 8 in. O.C.

Notes: 1. Minimum housekeeping pad thickness – 3 in.
2. Minimum concrete compressive strength – 3000 PSI.

Seismic Restraints

1. All floor mounted equipment whether isolated or not shall be anchored, bolted or welded to the structure to comply with the required acceleration. Bolt locations, diameter of inserts, embedment depth and weld length as shown on the approved submittal drawings shall be installed as approved.
2. All suspended equipment including, but not limited to fans, tanks, stacks, VAV boxes, unit heaters, fan powered boxes, cabinet unit heaters shall be two or four point independently braced with Type III(a) restraints, installed taut for non-isolated equipment, such as piping or ductwork, and slack with 1/2″ cable deflection for isolated equipment. A minimum of four (4) cables must be used. Support rod compressive stresses resulting from seismic accelerations shall be included in the calculations and addressed accordingly. Non-isolated equipment may be restrained with rigid bracing to structure using Type III(b) restraints.
3. All suspended pipe, duct, cable trays and conduit not excluded by diameter or attachment distance from structure allowances shall use restraint Type III or V. Support rod compressive stresses resulting from seismic accelerations shall be included in the calculations and addressed accordingly. Spacing of seismic bracing shall be as follows: (a) all ducts requiring seismic bracing must be transversely braced on a maximum of 30′ centers and within 48″ of each change of direction and longitudinally braced on a maximum of 60′ centers; (b) all threaded, flanged, welded, soldered or grooved connection pipe requiring seismic bracing must be braced in accordance with the following:
   1. Standard pipe less than 2-1/2″ diameter in equipment rooms must be transversely braced on a maximum of 30′ centers. Fire protection piping less than 2-1/2″ diameter requiring bracing under NFPA 13 must be braced on a maximum of 25′ centers; longitudinally braced on a maximum of 80′ centers.
   2. Pipe 16″ diameter or less must be transversely braced on a maximum of 40′ centers or within 10′ or fifteen pipe diameters (whichever is less) of each change of direction; longitudinally braced on a maximum of 80′ centers.
   3. Pipe 18″ diameter or larger but less than 30″ diameter must be transversely braced on a maximum of 30′ centers or within 10′ or fifteen pipe diameters (whichever is less) of each change of direction; longitudinally braced on a maximum of 60′ centers.
   4. Pipe 30″ diameter or larger but less than 42″ diameter must be transversely braced on a maximum of 20′ centers or within 10′ or fifteen pipe diameters (whichever is less) of each change of direction; longitudinally braced on a maximum of 60′ centers.
   5. Pipe 42″ diameter or larger must be transversely braced on a maximum of 10′ centers or within 10′ or fifteen pipe diameters (whichever is less); longitudinally braced on a maximum of 30′ centers.

To control this “rattle space,” cable sway braces are used. Cables will not interfere with the isolation hangers and are simple to select, locate and install. Information on required cable spacing for pipe is shown in the sidebar. Completed tables preapproved by OSHPD are available from Mason Industries or other referenced sources generally free of charge. Figures 11 and 12 show typical damage when sway braces are omitted. Figure 13 shows a typical sway brace system that survived the Northridge earthquake with no damage. Rigid braces are not recommended for vibration isolated pipes, ducts or HVAC equipment since they will short circuit the isolation sys-

Figure 11. Pipe support rods were displaced which caused the piping to distort. The pipe distortion is expensive to repair (8th floor location, 8 stories, approximate maximum seismic excitation - 0.36 g horizontal, 0.22 g vertical.

Figure 12. Duct failure resulted when sway braces were omitted (4th floor location, 4 stories, approximate maximum seismic excitation - 0.4 g horizontal, 0.28 g vertical).

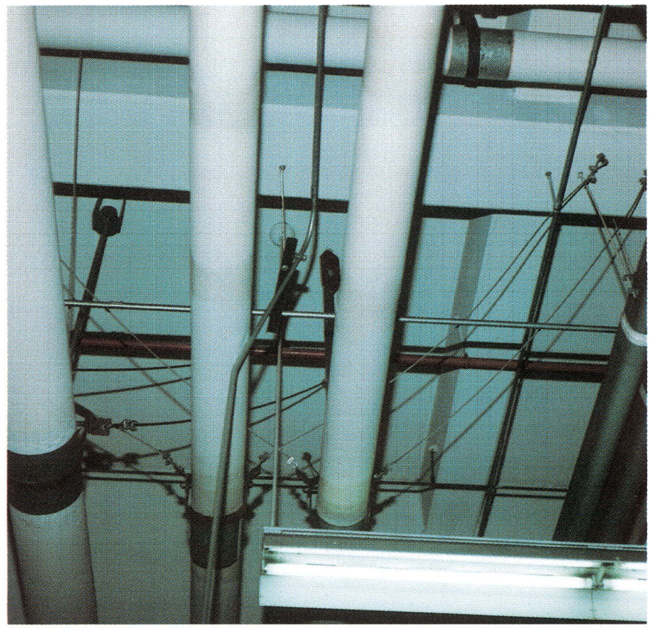


Figure 13. The cable sway brace system prevented pipe damage (5th floor location, 5 stories, approximate maximum seismic excitation - 0.45 g horizontal, 0.32 g vertical).

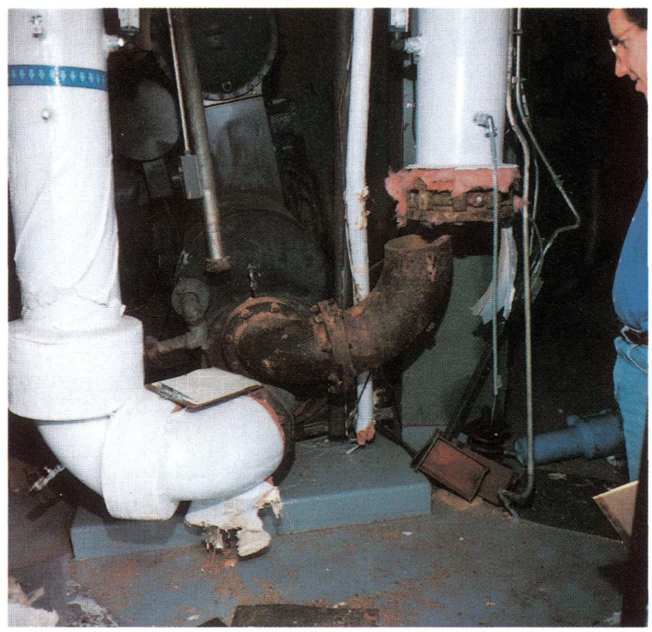


Figure 14. Piping failures at interface connections can be prevented with the use of elastomeric joints (15th floor location, 15 stories, approximate maximum seismic excitation - 0.4 g horizontal, 0.28 g vertical).

tem and are expensive and difficult to install.

Structural Failures

Earthquakes do cause structural building elements such as floors, walls and ceilings to move out of phase. This poses a problem at the pipe and equipment interface. To prevent pull-out failure as shown in Figure 14, an elastomeric expansion joint must be used. It is recommended that a fail safe design with a flat ring instead of a wire at the flange and hose body interface be used to prevent body pull-out.

Minor details such as anchor bolt edge clearance and housekeeping pad reinforcement and doweling are handled using basic engineering data. Edge distance is defined by ICBO (International Conference of Building Officials) code data. This same information is available in BOCA and SSBCI code publications. Table 1 defines the minimum reinforcing and doweling required on housekeeping pads to prevent damage as shown in Figure 15.

Two other types of systems that had high failure rates were isolated aluminum roof curbs and internal isolation systems. The main cause of failure of isolated curbs was the lack of structural strength of the aluminum itself. Figure 16 illustrates the type of collapse the aluminum curbs experienced. This type of failure is difficult to fix. The unit must be lifted off the roof in many cases by a crane with a large boom. In some cases a helicopter lift is necessary. The aluminum frame is replaced and this unit re-rigged into place. The electrical, plumbing and duct connections are then re-connected. This is an involved process that can be avoided by using isolated steel roof curbs Mason type RSC. There were no roof curb failures using this type of unit.

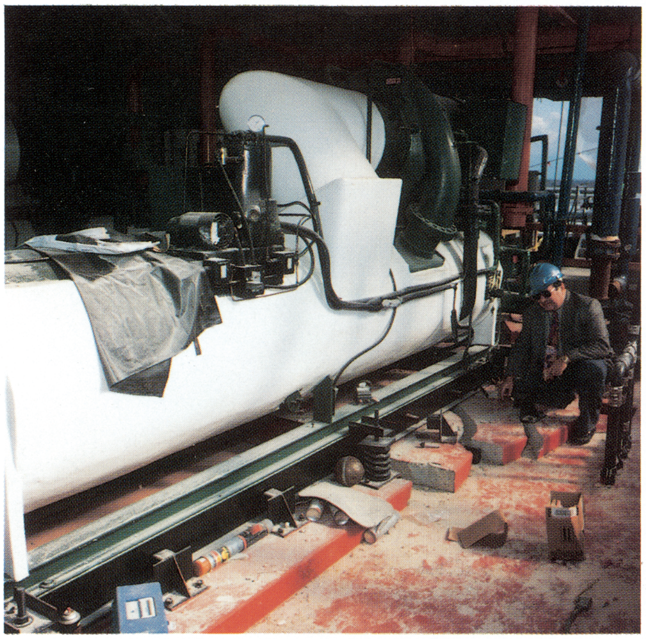


Figure 15. Housekeeping pads that are not doweled to the structural slab and not reinforced failed (8th floor location, 8 stories, approximate maximum seismic excitation – 0.45 g horizontal, 0.32 g vertical).

Figure 16. Isolated aluminum roof curbs failed because of the lack of structural strength of the aluminum sections (roof location, 4 stories, approximate maximum seismic excitation – 0.3 g horizontal, 0.22 g vertical).

Internal isolators do not have to meet codes since these isolators are considered part of the internal components of the unit. The code treats the unit as a black box and does not address the inside components. The internal isolators failed if they did not follow the standard guidelines used for external isolators and seismic snubbers. The engineer must insist that the OEM meet the same criteria for internal seismic snubbers as for the external snubbers. This would be the case for rated capacity, test data, seismic calculations and anchor bolts. Failure to do so will only cause internal failures as devastating as external failures.

Summary

Following the basic rules outlined here will help prevent seismic failure of isolated systems and help avoid short circuiting these systems. As the engineering community is exposed to additional seismic events, the analysis, design and application of seismic snubbers will continue to improve. S/V

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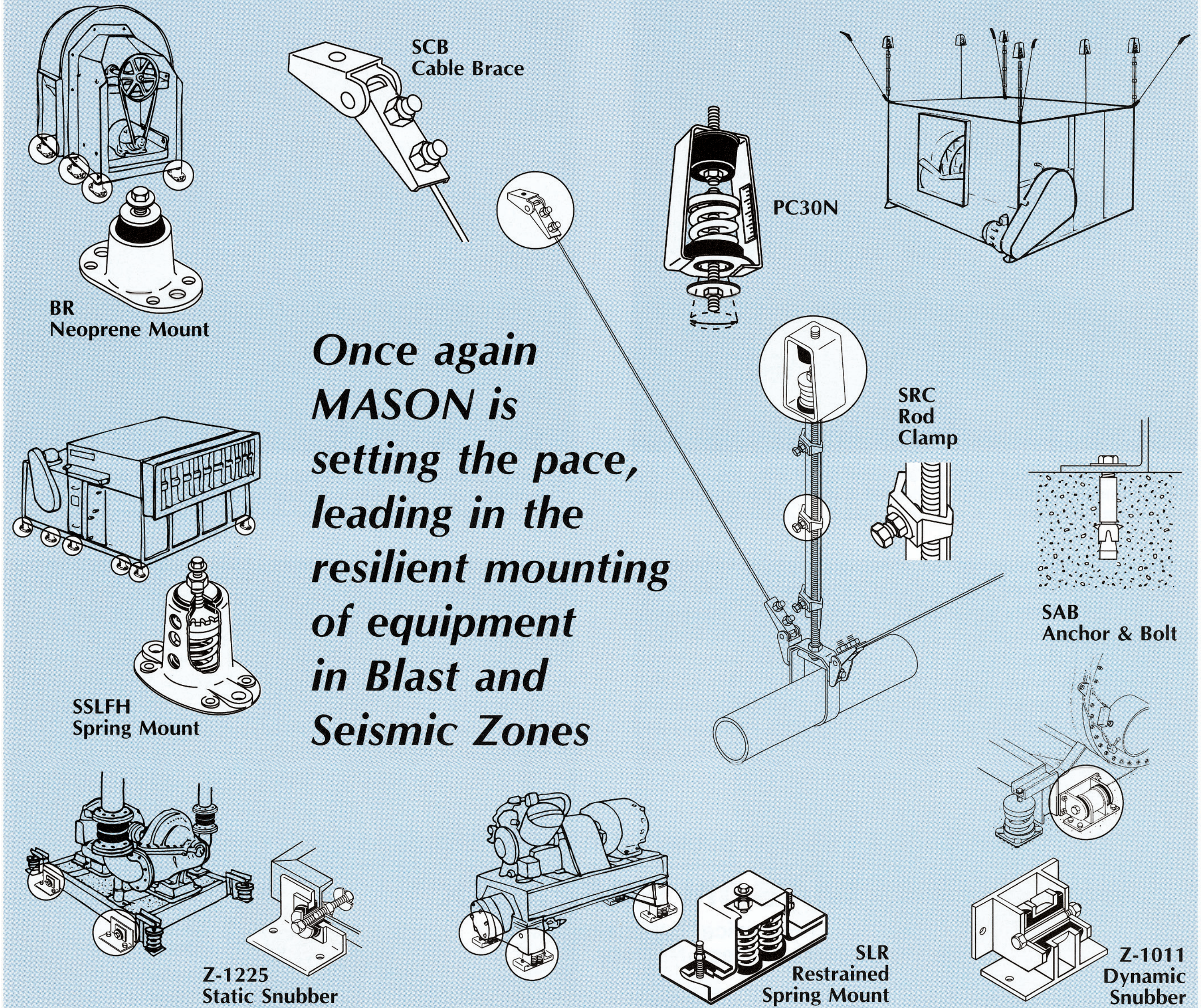
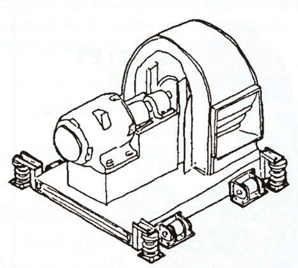
MASON Certified Seismic Restraints

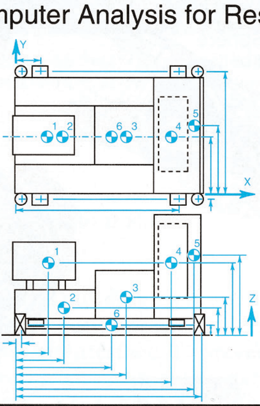


Once again MASON is setting the pace, leading in the resilient mounting of equipment in Blast and Seismic Zones

CERTIFIED CALCULATIONS BY PROFESSIONAL ENGINEERS

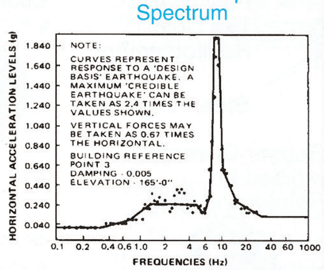
Dynamic Response Computer Analysis for Resiliently Mounted Equipment





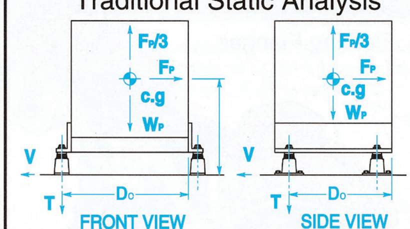
1 - CG MOTOR
2 - CG MOTOR PEDESTAL
3 - CG BEARING PEDESTAL
4 - CG FAN WHEEL
5 - CG FAN HOUSING
6 - CG BASE

Acceleration Response Spectrum



Computer Modeling for Proper Mount Design

Traditional Static Analysis



Equipment with Resiliently Mounted Structural Bases

(1) $F_p = ZIC_pW_p$

(2) $0 = F_p - V$

(3) $V_{eff} = F_p/N_{bolt}$

(4) $T = [F_p h_{cg} - (W_p - F_p/3)(D_0/2)]/D_0$

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

(6) $T = [F_p h_{cg} + (W_p - F_p/3)(D_0/2)]/D_0$

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

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