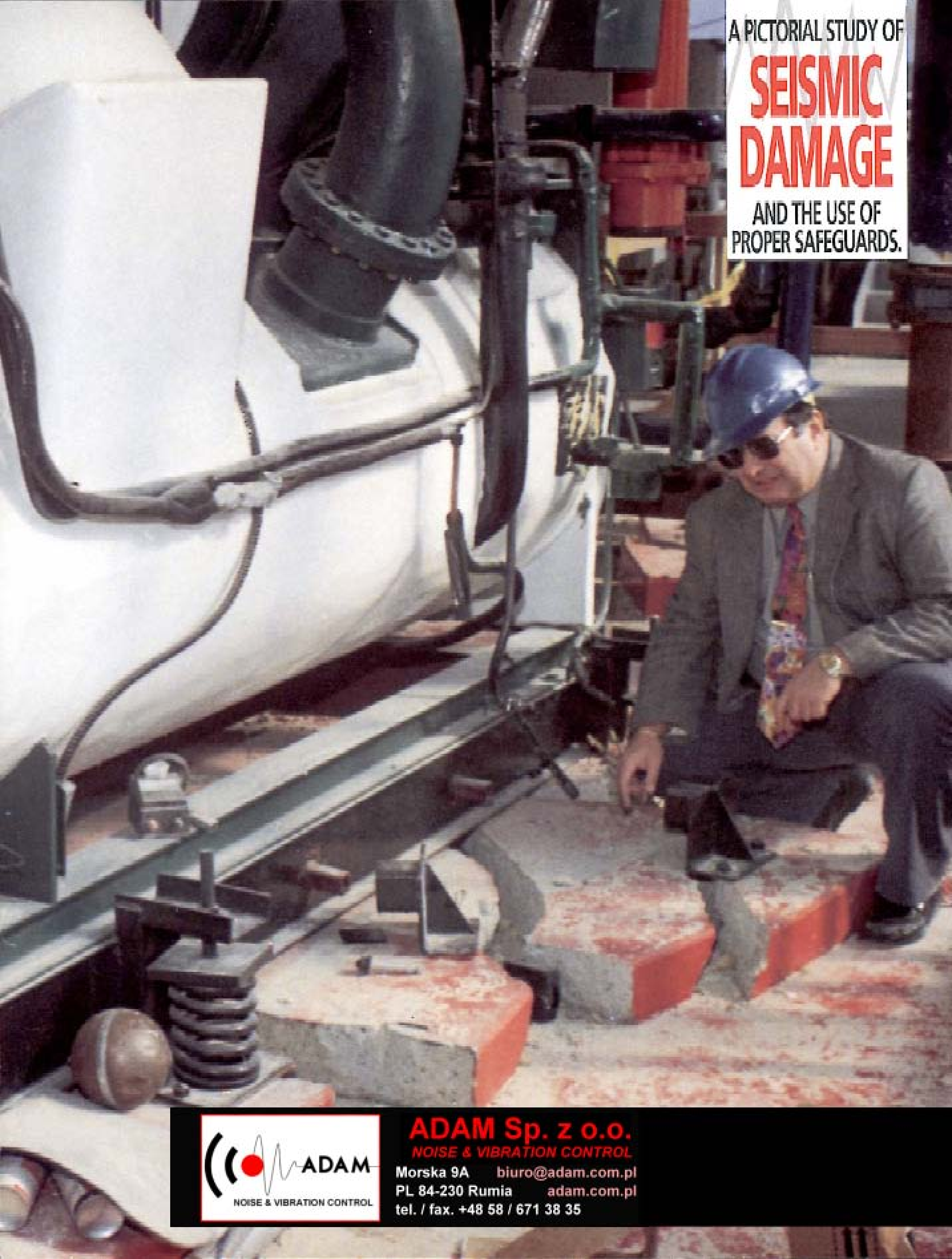
A PICTORIAL STUDY OF

SEISMIC DAMAGE

AND THE USE OF PROPER SAFEGUARDS.



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TRADITIONAL BUILDING CODES ARE STRUCTURED TO PROTECT LIVES.

When it comes to equipment within buildings, the responsibility lies with the engineer to provide the necessary safeguards during seismic activity.

On an early January morning in 1994, the Northridge area of Southern California was shaken by an earthquake that measured 6.6 on the Richter scale and lasted approximately 30 seconds. The repercussions are still being felt throughout the engineering community.

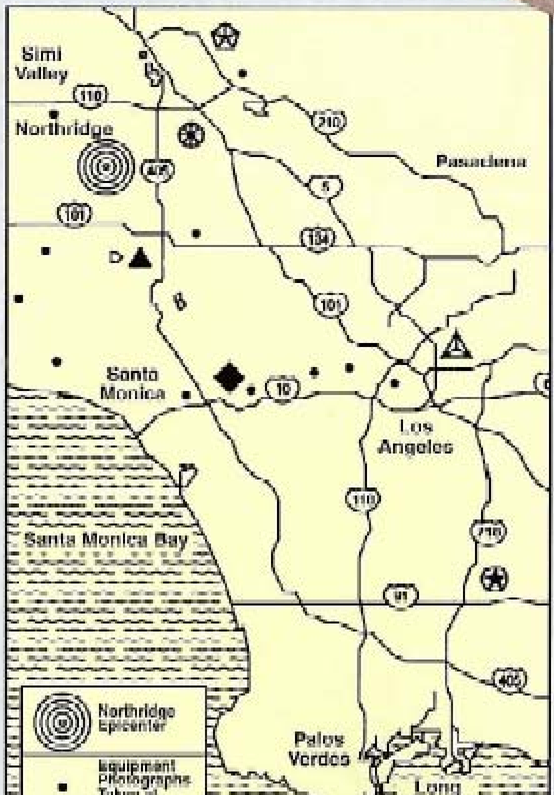
After billions of dollars in building and equipment damage, and an extensive investigation that measured the structural successes and failures of mounted machinery and electrical equipment, the conclusions are quite clear. Cushioning and restraint are the key factors and lack of it can cause earthquake-generated accelerations to amplify 30 to 50 times. Codes simply don't account for proper energy absorption when equipment is not hard mounted and braced, and the Northridge study bears this out.

The data for the study was accumulated by our structural and mechanical licensed engineers using professional photographers to document site damage.

The systems that were documented are specifically covered throughout these pages. We will examine nonisolated as well as isolated, mechanical and electrical, and floor mounted and suspended systems. The data offers excellent insights into which systems survived, which systems failed, and why.

In most cases, the seismic gV and gH next to the photos are ground level readings, depending on the locations of the seismic instrumentation. Since the damage is so extensive, the resonant amplification of these forces by the structural components is self-evident.

We have described the Mason mountings in the photographs wherever Mason was used. Out of courtesy to our competitors, we have not named the companies or products that did not do well. It would seem that we omitted the Mason failures, but that is not the case. If only one of our mountings had failed, we would have examined the failure in detail. Thankfully, we could not find one example.



Typical Input G							
Symbol	[symbol]	[symbol]	▲	◆	△	[symbol]
Max G Forces	.64V .65H	.6V .90H	1.8V 1.2H	.25V .93H	.1V .19H	.12V .16H

The map to the left highlights the structural sites chosen and demonstrates the variety of locations ringing the epicenter. Most of the mechanical equipment was located on upper floors where the structure itself further amplified ground level acceleration.

Because our seismic mountings are designed using ductile or steel housings rather than cast iron, we are not the successful bidders on every installation. For the most part we determine the strength of our products by testing and building them with the necessary safety factors to resist the indeterminate amplifications. All of these precautions increase cost. But, as you will see, these added safeguards can pay dividends in the long run.

WETSIDE

The independent rails rotated around their longitudinal axis, snapping anchor bolts and bending the cooling tower base. The problem could have been prevented by using a one piece structural base and double acting snubbers.

A properly mounted cooling tower must be supported by a complete structural steel frame, preferably with height saving brackets to lower the center of gravity. The free standing spring mountings need not be bolted down, as the blue all directional seismic snubbers next to each spring, limit the spring's motion. These all directional seismic snubbers are shown in Chapter 49 of the 1991 ASHRAE Guide Application Manual. Snubbers are double acting and selected for maximum calculated forces. Springs should be positioned within holders rather than welded to avoid cracking. Adequate edge distance to snubber anchor bolts is extremely important (Mason WF Base, SLF Spring Mountings, Z-1225 Snubbers).

COOLING TOWERS

The vertical snubber bolt could not prevent the rail rotation. The anchor bolt tore through the base plate and the support springs fell over.

FLOOR MOUNTED PIPE

Improperly restrained piping can damage the structure itself. Unlike duct work, piping has mass and rigidity. Electrical lines in walls can be destroyed when piping shifts. Columns can be distorted and the structural integrity of bearing walls can be compromised as well.

This damage was caused by the relatively minor forces of 0.15gV and 0.2gH.

WATER HEATER

Water heaters have high centers of gravity and tend to turn over easily. The forces on this particular installation were 0.15gV and 0.2gH, heaters should be bolted to the floor and strapped to the nearest wall or column.

WETSIDE

PUMPS

It is unacceptable to consider the horizontal and vertical stiffness of a spring to resist earthquake forces. With no snubbers to limit motion the springs resonate and bend if not break, their attachments. Anchor bolts can bend or shear off when the springs themselves do not fail or fall over. The attachment of proper snubbers to the steel frame would have averted this disaster.

Another example showing free standing springs cannot be used without snubbing devices. The anchor bolts under these spring mountings were too close to the edge, and broke the housekeeping pad. Forces were relatively low at 0.2gV and 0.25gH, but more than sufficient to create havoc on this unsnubbed, resonant system.

This is an excellent installation using all directional seismic snubbers to prevent the concrete bases going into resonance as would happen if the springs were used alone. There is no reason to bolt the springs to the floor as the snubbers restrict motion and the springs do not shift on their friction pads. Snubbers must always be anchored with proper anchor bolts. (Mason BMK Bases, SLF Spring Mountings, Z-1225 Snubbers)

Gray cast iron spring housings invariably shatter as shown. The shrapnel flies in areas that may be occupied by plant room personnel. The only acceptable castings are ductile iron or cast steel.

This pump system is mounted on a steel frame to minimize floor loading. The springs are inside a steel seismic housing with all directional elastomeric grommets to prevent hard surface impact. Anchor bolt edge distance was more than adequate and the system showed no sign of failure. (Mason MSL Base, SLRA Spring Mountings with extended base plates)

Mounting a pump directly on mountings without a supplementary steel or concrete base is bad practice because of pump coupling alignment problems when torque twists the bases. The mounting housings proved inadequate as the vertical restraining bolts failed. The restraining angles bent and either the anchor bolts were sized inadequately, of the wrong type or poorly installed as the anchorage broke free and the pump shifted out of position. Input was a low 0.2gV and 0.25gH.

Shatter resistant ductile iron housings are the correct choice in seismic areas. Inputs were very high at approximately 1.5gV and 1.4gH. The systems did not fail because the entire load path was properly designed. Notice that the anchor bolts are widely separated and edge distances are very conservative. Both the floating concrete base and the housekeeping pad were properly reinforced and the housekeeping pad securely attached to the structure. (Mason BMK Base and SSLFH Ductile Spring Mountings)

HOUSEKEEPING PADS

Housekeeping pad failures were common, because of improper doweling or fastening to the structural floor, and inadequate or no reinforcement in the pad itself. These pads, as the pads on the cover, had both problems. Inadequate fastening allows the pads to lift, chatter and shift. Poor reinforcement allows breakage. When the pads fail, the system must fail as nothing remains in place.

The anchor bolts were too close to the edge of the concrete housekeeping pad for the concrete to offer adequate resistance to the horizontal anchor bolt forces. The edges broke off so the anchor bolts were freed. This total failure of the restraint system occurred at only 0.15gV and 0.15gH. The mountings themselves showed considerable distortion as well.

WET SIDE

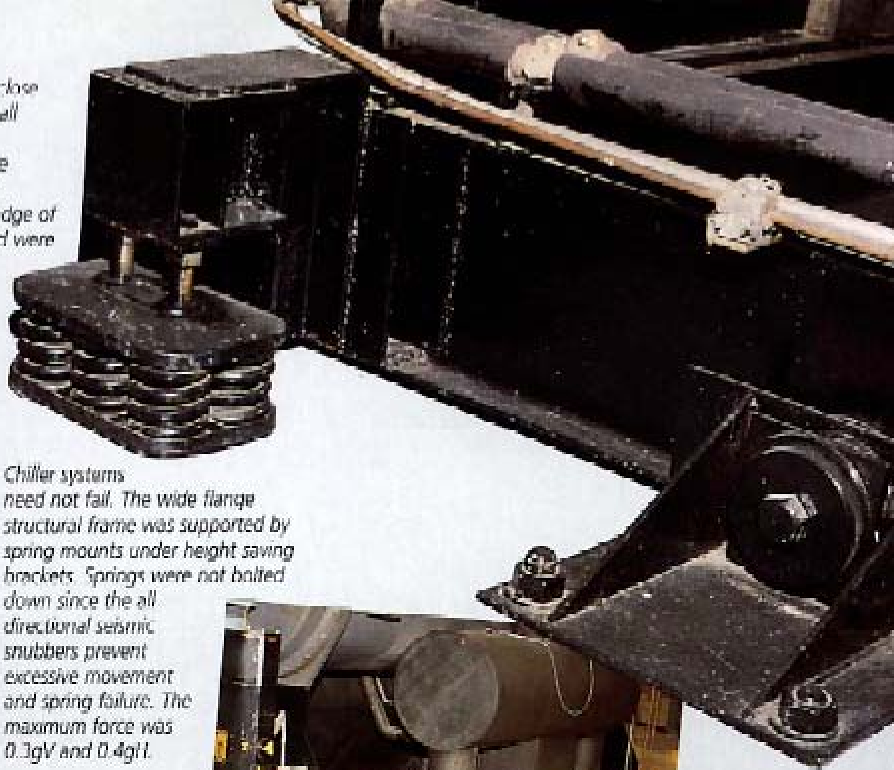
Rails rotated in virtually every application. In the upper photograph the rotation was initiated by the horizontal snubber pushing against the web of the beam. In both photographs the springs were secured by welding. Welding is always poor practice as the intense heat embrittles the spring so it tends to snap at the weld and scale inclusions produce welds that pop off. All systems failed with pipe breakage in addition to the other problems.

Another example of gray iron mounting failure. Fragments shown in the lower left and lower righthand corners can be dangerous to building personnel as well as equipment. Not only is the compressor out of service, but there is the additional worry of potential liability and damage.

Some chillers can be directly mounted on spring isolators, but not as shown in photographs above. Seismic forces were reasonably high at 0.3gV and 0.6gH. Not all the parts are shown in the photographs, but both the restraining bolts between the upper and lower housings and the anchor bolts failed. The top plates came free of the rest of the housing and may still be attached to the chiller. Base plates were weak and showed distortion. Mountings rated by test with OSHPD pre-approval would have been far safer. The chiller dropped some 14" in addition to shifting.

CHILLERS

This unusual photograph shows identical chillers side by side. One was mounted on rails with snubbers bearing against the webs of the beams. The other on a one piece structural steel frame supported by spring isolators with seismic restraints built into the steel housings. The base plates were enlarged to insure proper anchor bolt spacing. The rail installation failed completely, but there was no damage to the steel base system. (Mason WF Base with height saving brackets and SSLR Restrained Spring Mountings with enlarged base plates for anchorage.)



This photograph is a close up of the spring and all directional snubber installation below. The anchor bolts and the clearances from the edge of the housekeeping pad were all carefully calculated. (Mason WF Base, SLF Springs, Z-1011 Snubbers)

Here is another example of ragged, shattered pieces of cast iron. Cast iron should not be approved for seismic work regardless of the force levels. The systems were subjected to low inputs of 0.2gV and 0.25gH.

Chiller systems need not fail. The wide flange structural frame was supported by spring mounts under height saving brackets. Springs were not bolted down since the all directional seismic snubbers prevent excessive movement and spring failure. The maximum force was 0.3gV and 0.4gH.

AIR COOLED CHILLERS

This is an excellent installation using a structural steel frame with height saving brackets and spring mounts with their own built in seismic protection. These are not malleable or gray iron, but ductile castings that will not shatter. The air cooled chiller has very light sheet metal legs which did not buckle, because the steel frame tied the four legs together. This unit was almost at the epicenter of the earthquake and saw seismic inputs of 1.0gV and 1.4gH. These are some of the highest forces ever recorded by an instrument anywhere in the world, but the installation survived intact. (Mason WF Base. SSLFH Snubbed Spring Mountings)

WET SIDE PIPE

The clevis hanger in the center of the photograph fell apart and the rear hanger clevis is sufficiently displaced to have bent the ceiling bolt. There are chatter marks on the pipe in the front clevis, all indicating that this system went into resonance even though the accelerations were only 0.15gV and 0.2gH. Proper sway bracing, axial restraint and upper limit stops could have prevented this damage.

Piping without sway braces will shift position and change elevation. One hanger broke completely free and one pipe is displaced approximately 12" from its original location. On other jobsites, piping systems came down. Sway bracing and axial restraint is essential along with vertical limit stops at anchorage locations. Clevis bolts must be sleeved or braced as well.

SUSPENDED PIPE

Piping with cable sway bracing survives an earthquake with no damage and no distortion. Forces in this area were high at 0.9gV and 1.2gH.

A typical example showing the use of a cable sway brace with swivel fittings for the specific purpose. Fittings are adjustable and the installation simplified by their use (Mason Type SCB)

An unusual photograph showing both solid and cable braces. Both systems use swivel fittings specifically designed for the purpose to simplify installation and provide OSHPD approved attachment. Contractors often prefer cable to solid bracing even on non-isolated piping, because cables can be installed more quickly. (Cable Braces Mason Type SCB. Solid Braces Mason Type SSB)

The swivel sway brace fittings at the ends of the angle iron brace eliminate welding, fitting and fabrication time. Solid sway braces can only be used on equipment that is not isolated. When equipment is isolated, bracing must be by cable or isolated devices to prevent transmission of vibration. (Mason SSB)

FLEXIBLE JOINTS

Even with this extreme displacement of the flexible connector, the expensive cast iron gate valve was protected. This teflon connector was distorted beyond the manufacturer's movement limitations. A double sphere rubber joint would have had a much better chance of survival and it would only have been necessary to properly reposition the piping. (Recommendation: Mason Safeflex SFDEJ)

Metal flexible hose is designed to accept motion at right angles to the axis. The hoses prevented pump body failures, but after the system was back on line, the hoses leaked. Leakage was caused by metal fatigue, over travel transverse to the axis or compression and extension. Double sphere rubber connectors are all directional and can respond to motion in any direction without failure. (Recommendation: Mason Safeflex SFDEJ)

The metal flexible hose prevented pipe failure. However, the metal hose on the right was compressed. Braided metal hoses cannot accept compression and it had to be replaced. Flexible metal joints do not have the same movement capabilities as rubber joints, and tend to fail under seismic conditions. The seismic input was 0.15gV and 0.2gH. (Recommendation: Mason Safeflex SFDEJ)

Even a very fragile copper pipeline with sweat fittings will survive at the equipment interface if proper flexible joints are used. This system was subjected to approximately 0.2gV and 0.25gH, and showed no signs of failure because of the flexibility of the twin sphere rubber connectors. (Mason Twin Sphere Superflex shown. Current improved design is Mason Safeflex.)

PIPE CONNECTION TO CHILLER

An excellent example of equipment failure at the piping interface. Both the restrained equipment and piping move out of phase during an earthquake and the cast shells are not designed to accept the force necessary to drag the piping. Cast component failures are common. The solution is installation of a spherical twin sphere rubber expansion joint to allow for the motion.

FANS

AIRSIDE

This close up of the spring shows that the attachment bolt broke allowing the spring to shift and fly free. (The spring was moved back for the photograph.) This would be a dangerous missile anywhere, but particularly in an equipment room with electrical devices. Proper snubbing would have controlled the situation.

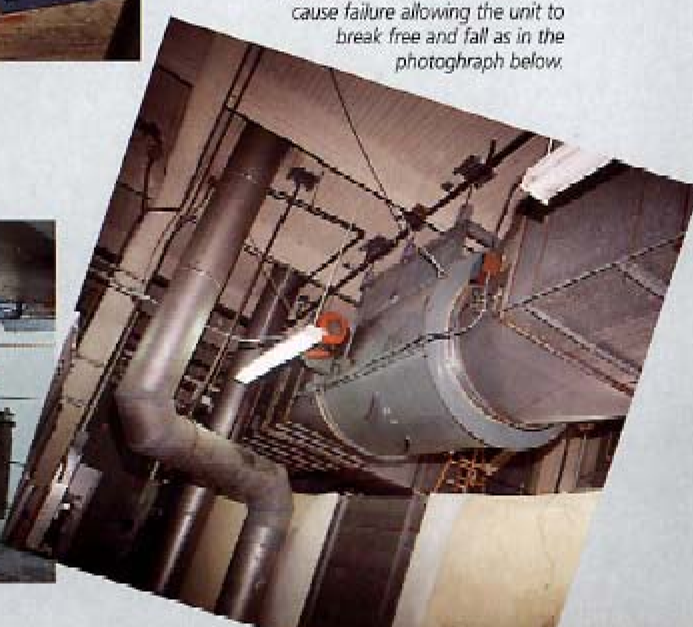
Spring isolators must be used with seismic snubbers to prevent resonance at seismic frequencies. When the horizontal amplitude became excessive, the whole system shifted releasing the springs while still compressed to 1,500 lb. This sudden release of energy can do damage to anything in the path of the flying springs. Unsnubbed systems not only fail, but they can be dangerous even at low input figures of 0.15gV and 0.12gH.

One of the proper ways to mount a fan and motor is to bolt the equipment to a rigid rectangular steel base. The spring mountings friction pads eliminate the need for bolting as the snubbers will limit motion. All directional thick Neoprene snubber bushings both restrain and cushion shock. (Mason WF Base, SLF Springs, Z-1225 Snubbers)

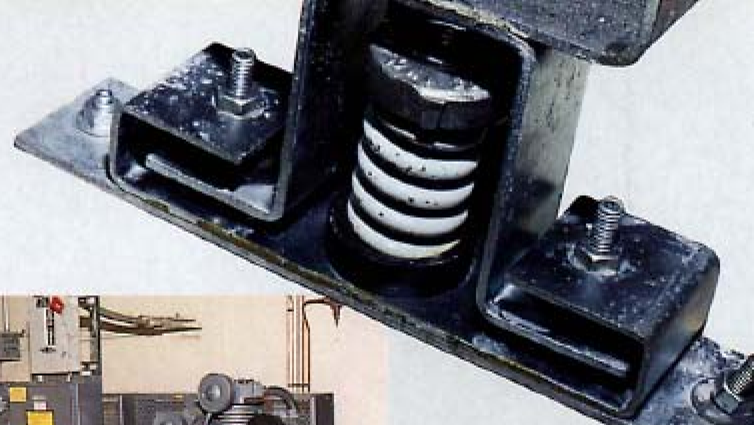
This large fan did not come down because there were control cables to prevent pendulum motion. Unchecked swaying bends suspension rods and can ultimately cause failure allowing the unit to break free and fall as in the photoghraph below.

SUSPENDED FANS

This small tubular fan broke free of the ceiling and landed on the mechanical room floor. It could have caused severe injury or equipment damage. Electrical lines and control panels are particularly sensitive. This swinging almost always takes place when seismic energy is applied to suspended systems. Proper cable sway bracing would have limited the pendulum action.



TANK MOUNTED AIR COMPRESSORS



The spring mountings under this air compressor failed, because the snubbers were not all directional. Single bolted restraints can rotate. This angle had a simple pad cemented to one face. The arrangement could only contain the system transversely rather than in all directions. As is typical, the equipment resonated and the springs fell over. Forces were about 0.25g Vertical and 0.35g Horizontal. Proper all directional snubbers would have solved the problem.

This is a simple isolation method for a horizontal tank mounted compressor (if the base legs are sturdy enough) without the use of a supplementary steel base. Mountings have built in seismic snubbers with ratings from OSHPD in the State of California. Not only these mountings, but similar designs were successful in every reviewed location. Forces were approximately 0.2gV and 9.25gH. (Mason SLRA Mountings)

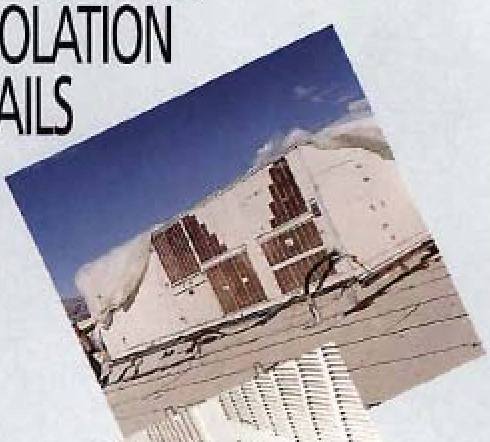
This close up of the SLRA seismic mounting shows that the righthand anchor bolt was distorted at installation and not by the quake. Were it a seismic shift, the other bolt would have been bent as well. The all directional Neoprene collars reduce the impact of steel on steel. (Mason SLRA with extended base plate for anchorage)

ROOFTOP AIR HANDLING UNIT

Using a poor copy of a good snubber can result in disaster. Rather than a snubber made with a one-piece double acting, all directional Neoprene sleeve with washer faces, this hard rubber washer was cemented to the angle. The rubber bushing does not appear to be thick enough. The minor cost saving, if any, resulted in a dramatic, costly failure and major equipment displacement.

AIRSIDE

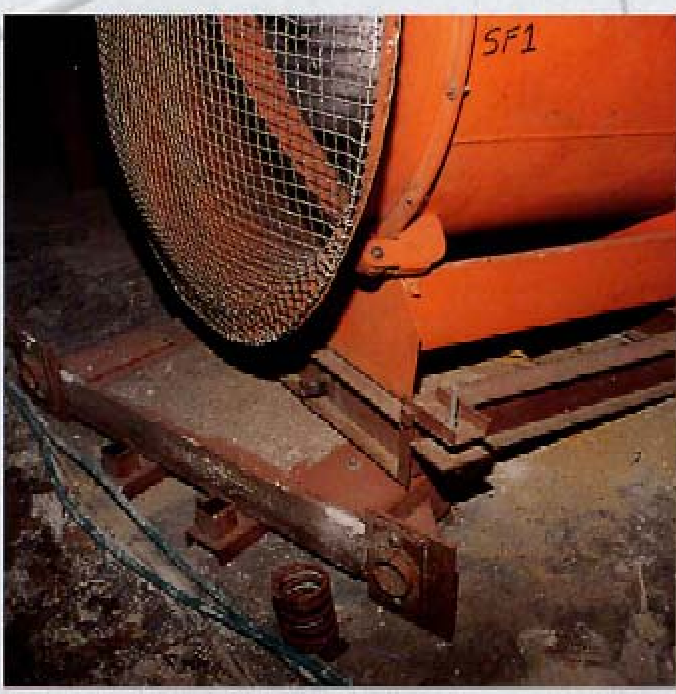
ALUMINUM ISOLATION RAILS



Curb top aluminum isolation bases have very little structural capability and generally fail. These failures are difficult to repair as the roof seldom allows for rigging, and the unit has to be lifted by helicopter or crane before bases can be replaced. Forces were small at 0.1gV and 0.15gH. The problem could have been prevented by using a seismically OSHPD approved complete isolation curb for the same application.

AIR HANDLING UNIT

The self contained restrained mountings held up. However, the formed channel base deformed badly and the mounting anchors let go. All of the isolators either rotated or shifted. Part of this problem was the use of slots in the base plates rather than holes. Slotted holes simplify installation, but they are single acting and minor shifts allow one end to escape the anchor bolts and the other to follow. The system would have survived had it been mounted on a steel frame with adequate anchor bolts through base plate holes. Forces were not high at 0.15gV and 0.2gH.



CONCRETE PIERS

This axial fan was mounted on two concrete piers. The piers fell over sideways because of inadequate anchorage to the structural floor and the axial fan fell about 3 feet. This could have been prevented by pouring the piers with a concrete web between them. The entire load path should always be studied from the structural slab right up to and including the equipment mountings. Forces were 0.2gV and 0.25gH.

INTERNAL ISOLATION ROOFTOP UNIT

Building codes are not concerned with internal mounting systems as the codes are meant for life safety rather than contained equipment disruption. Internal components are subjected to severe damage as are external systems if they do not have proper seismic snubbing devices. Internal damage can be more expensive and harder to repair than external. Typical problems are torn up bearings, couplings, fittings, coil damage, etc.

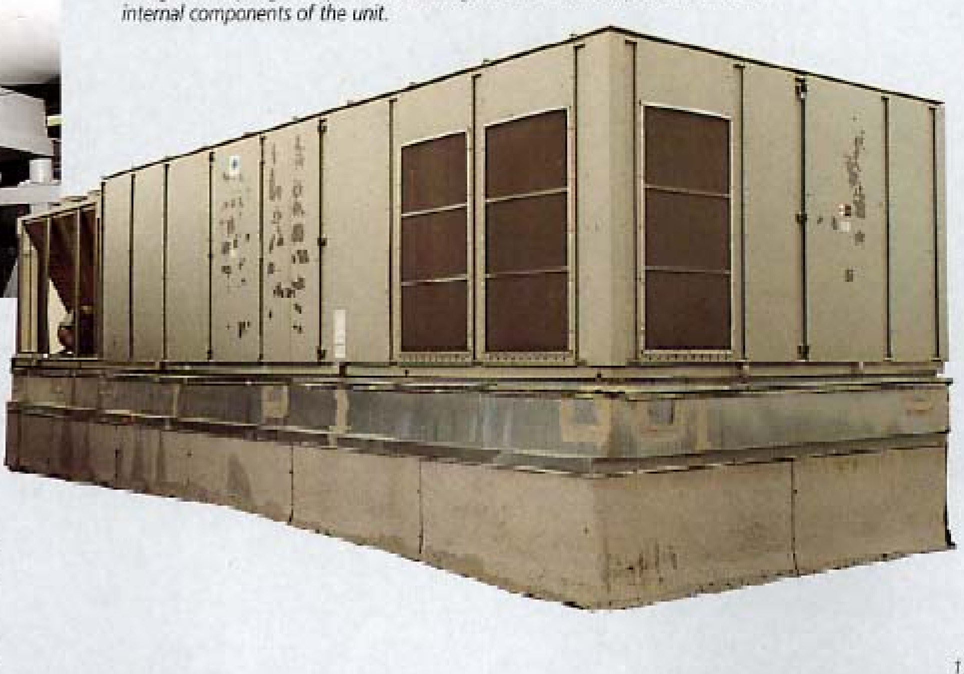
The cable system is an emergency measure to try to keep the compressor in place in anticipation of after shock. Forces were small at approximately 0.15gV and 0.2gH. Equipment with hard mounted internal components and external cushioned seismic isolation systems have a better chance of remaining operative.

STEEL SUPPORT FRAME

This excellent design uses square steel tubing as the support columns, cross braced by steel angles. The frame was securely fastened to the structure and the isolation positioned on top. Self-contained ductile iron, seismic mountings supported a supplementary steel base under the blower. The system was subjected to very high forces of 1.4gV and 1.2gH with no failure to the system. (Mason Industries' MS Lower Base, SSLFH Ductile Iron Seismic Mountings, MSL Steel Base)

COMPLETE ROOF CURB

This properly designed seismically rated spring curb had resistances based on testing to allow for seismic input. The input forces were approximately 0.2gV and 0.25gH. The spring curb prevented damage to the lower support curb and the internal components of the unit.



The duct work and piping in this photograph is almost all supported by spring hangers. However, the cable sway bracing kept everything in place and there were no failures in this area.

AIRSIDE DUCTS

The roof mounted ducts were supported by the steel columns. The four columns were not interconnected, because the loading was so light. However, horizontal forces were large enough to cause failure as the supports were not cross braced to form one integral unit.

SUSPENDED DUCT WORK

Duct work is very susceptible to seismic damage. Notice the straps that held the ducting that is now on the floor shown in Photograph to the left. This can be prevented by the use of sway bracing to limit sway and keep the duct work in place. Input was 0.15gV and 0.2gH.

MISCELLANEOUS

LAY IN SUSPENDED CEILINGS

Suspended ceilings sustained damage in many installations, because sway wires were not used at all or installed improperly. Damage was extensive and very dangerous to people in the spaces below. Fortunately, the earthquake occurred when most offices were not occupied. Forces in this location were 0.2gV and 0.25gH.

EMERGENCY GENERATOR

This is a common but unacceptable method of mounting an emergency generator. The generator was bolted to a concrete floating base and supported on springs within gray iron castings. As in other applications, these castings failed to restrain the generator because both the corner rubber inserts and the springs flew out. This design has no upward restraint either. Of all the equipment, every precaution should be taken so the emergency generator remains operational. Failure was total at the very low levels of 0.1gV and 0.15gH. The steel framed reinforced concrete base looks satisfactory, but the supports should have been spring mountings protected by proper snubbers or springs within all directional ductile housings.

At Mason, our vibration control products exceed acceptable seismic code guidelines.

For nearly four decades Mason Industries has created its own standard for developing and building vibration control products for the HVAC industry. "Acceptable" has never been part of our vocabulary. Starting with engineering, and continuing through assembly and quality control testing, Mason products are built to provide the ultimate in seismic vibration isolation.

Our successes have been documented throughout this booklet. Mason springs, mountings, snubbers, anchor bolts, and cable restraints have all responded under severe seismic trauma. Our expansion joint technology has a worldwide reputation for top-notch performance and durability. For all types of seismic vibration control, you can count on Mason to protect lives, and keep equipment securely attached to the structure without interfering with vibration isolation.

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