

# SEISMIC SAFEGUARDS

Earthquakes do not have to destroy plumbing equipment and piping.

by Jim Sadler, PE



Figure 1 Thadd Street, Charleston, South Carolina, after the earthquake of 1886

**W**e all were shocked and saddened at the loss of life and devastation resulting from the tremendous earthquake and subsequent tsunami that hit Japan in March. Fortunately, excellent engineering and planning prevented further loss of life. However, the experience in Japan should make us question our own preparedness if such a large earthquake occurred in the United States.

Although the building codes have been studied and improved after many major earthquakes in this country, they still provide only theoretical seismic loads and exemptions. Design and construction teams must use this information as a start and then specify and install proper seismic restraints and anchorage. Quite understandably, many engineers do not feel comfortable providing seismic designs or details, and they may believe that they are limiting their liability by simply adding a note on the drawings that says something to the effect of "systems are to be installed in compliance with local seismic codes." This assumes that the building inspector will ensure that the proper seismic restraints are installed, but unfortunately in most areas of the country, inspectors are not well trained in seismic design. As dedicated as they may



Figure 2 USGS seismic risk map. Colors indicate predicted seismic loads in terms of G force.  
Source: U.S. Geological Survey

be, without this knowledge they cannot effectively inspect these systems.

General seismic notes also put contractors in a predicament: They don't know what to estimate for seismic restraint material and labor, which could cause them to lose the contract. The end result is that the public is often left unprotected.

However, with proper design and a reasonable investment, the potential damage to building systems and the risk of injury due to attachment failure can be reduced considerably. This article serves as a general guide to put us all on a common path toward proper seismic design and construction.

## SEISMIC RISK

We all are aware of the high seismic risk in California, but most of the United States has some seismic risk as well, with specific zones having potential seismic forces as high as those in California. In fact, the largest recorded earthquake to occur within the continental United States was not in California, but in New Madrid, Missouri in 1811. This earthquake was so powerful that it caused church bells in Boston to sway and ring, and it reversed the flow of the Mississippi River. The Richter scale did not exist back then, but by looking at historical

records of the damage, the New Madrid earthquake can be estimated to be close in magnitude to the recent disaster in Japan. Numerous quakes still occur along this fault line that lies just outside of Memphis, Tennessee.

Another very large quake struck South Carolina in 1886. This quake toppled 14,000 chimneys in Charleston and was felt in 30 states. Figure 1 is a photo from Charleston following the quake.

The International Building Code (IBC) prescribes higher design forces near known fault lines. Unfortunately, since no major earthquakes have occurred in some of these areas for many years, people tend to forget the danger. Let's not fall into this trap. Many have lived and worked in these areas for decades and have never felt a tremor, but a large quake could occur at any time. Haiti was hit by a massive earthquake in January 2010 that killed more than 300,000 people. The last major quake on the island was back in 1946.

Figure 2 is a U.S. Geological Survey map that approximates the seismic risk across the United States. It shows the potential lateral seismic accelerations, or G forces, that have a 2 percent probability of occurring in the next 50 years. Near the New Madrid seismic forces have the potential to be as

high as three times the force of gravity acting laterally on all structures and their contents. Thus, a 10,000-pound boiler could experience a seismic load as high as 30,000 pounds acting through its center of gravity. These forces are amplified at higher elevations within a building. (Keep in mind that only a small percentage of faults are known, so there are certainly high-risk areas of which we are completely unaware.)

## SEISMIC DESIGN CATEGORY

The intent of the seismic design requirements in the International Building Code is to prevent equipment and piping from breaking free of their attachments and hitting occupants or preventing people from getting out of the building. At essential facilities, including hospitals, police stations, fire stations, and in some cases schools, the code requires the equipment not only to stay in place, but also remain operational after an earthquake, with the purpose of keeping these emergency facilities going when they are needed most. Of course, as with any aspect of building design, good engineering judgment often demands surpassing the minimum seismic requirements spelled out in the code.

To determine if seismic restraints are required, you need to determine the project's Seismic Design Category. (This can be somewhat laborious, so in keeping with the objective to provide general information, the detailed procedure will not be discussed here. For more information regarding Seismic Design Categories, refer to IBC Chapter 16: Structural Design.)

Seismic Design Categories range from A through F, with A having the lowest risk and F having the highest. The Seismic Design Category considers project location, occupancy, and the soil type at the site. Fortunately in most cases, this design information can be found on the structural drawings along with potential live wind and snow loads. Category A and B buildings have no seismic requirements for plumbing, HVAC, and electrical systems. For category C buildings, seismic bracing is required for life-safety systems such as sprinkler pipe or systems carrying hazardous materials like gas. All hospitals designated Seismic Design Category C require restraints for all systems, as do any buildings designated Seismic Design Categories D, E, and F.

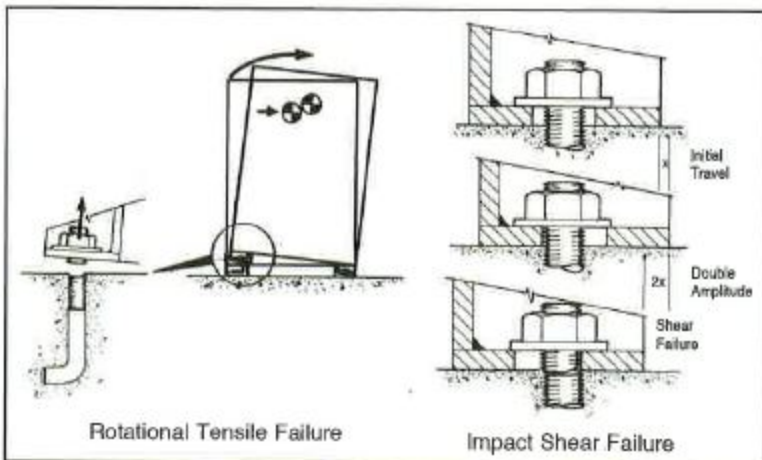
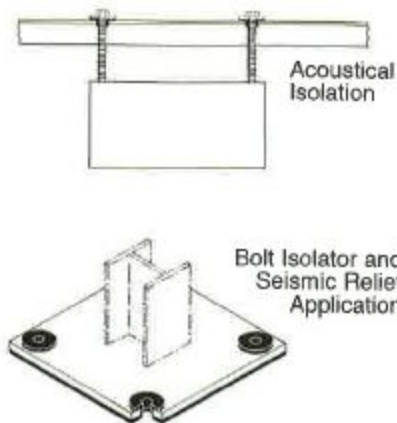
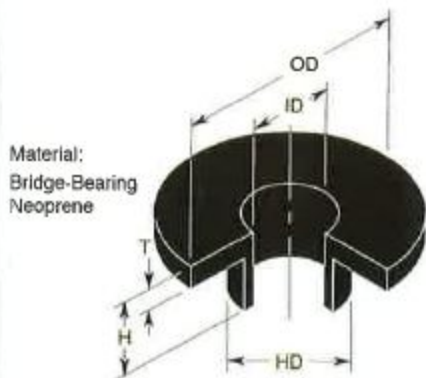


Figure 3 Potential shear failure during an earthquake

Figure 4 The use of elastomeric grommets can reduce the risk of bolt failure for rigidly mounted equipment.

Figure 5 Snubber installed on pump base

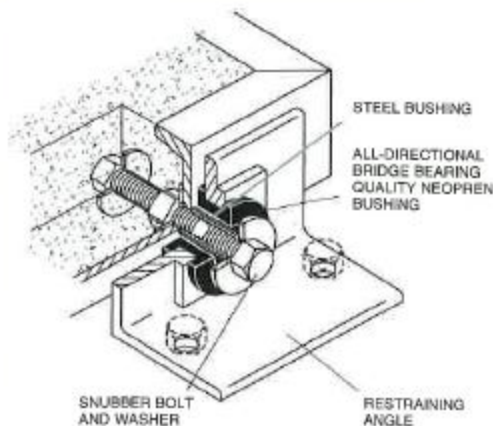
**TYPE HG**  
Bolt Isolation Washer Bushings



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. Installation of rubber collars between the equipment leg and bolt removes this problem.

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



The Seismic Design Category should be determined on a case-by-case basis, but by studying Figure 2 you can get a pretty good idea of the requirements for your area. Seismic restraints are required for all buildings within the brown, red, or tan regions (more than 0.48 G on the legend). For buildings in the light tan through green zones, seismic restraints are required for all essential facilities and most schools. However, even outside of these high-risk areas, requirements for essential facilities are often in place.

**RESTRAINT REQUIREMENTS**

Once you determine that a project has a seismic restraint requirement, the code prescribes the seismic forces that the equipment attachments must resist. The code dramatically simplifies the dynamic loading (shaking of equipment from 30 seconds to a minute) and models it statically. These theoretical static loads depend on the location of the project, soil stiffness at the project site, type of equipment, attachment type, and elevation of the system within the building. These force formulas can be found in ASCE/SBI 7: *Minimum Design Loads of Buildings and Other Structures* by the American Society of Civil Engineers and Structural Engineering Institute.

The design team must determine the best anchorage and bracing systems to resist the earthquake loads. This presents a design challenge for the engineer who wants to ensure that the anchorage is safe but does not know during the design stage exactly what equipment will be supplied on the project. (Specification advice is provided later in this article that the engineer can use to develop general specifications and details for the contractor.)

ASCE/SBI 7 Section 13.1.4 provides several exemptions for systems within a seismic project. These exemptions are based on equipment size, pipe diameter, and the system's distance from the support point. (Note: The following language is not verbatim from the code, and the author's commentary is included.)

- Restraints are not required for non-critical equipment (non-life-safety) that weigh less than 400 pounds and is mounted less than 4 feet off the ground. Flexible connections must be provided for all associated piping, ductwork, and conduit.

- Suspended equipment less than 75 pounds such as fans, heat exchangers, and humidifiers do not require bracing if they are installed in line with ductwork that is seismically braced.
- Suspended equipment (non-life-safety) less than 20 pounds does not require bracing. Flexible connections must be provided for all associated piping, ductwork, and conduit. (Note: Be careful with this exemption and number 2 above, as most people would not want to get hit by a 20-pound piece of equipment falling from 10 feet above, much less a 75-pound piece of equipment.)
- Piping that is supported by rods that are 12 inches or less in length as measured from the top of the pipe to the supporting structure does not require bracing. All supports must be designed to avoid bending of the hangers, and provisions must be made for piping to accommodate expected deflections. (Note that all supports in the run have to be 12 inches or less in length to meet this exemption, so a typical sloping waste line would not meet the criteria. Also, it often is easier and less expensive to simply brace the pipe at the standard elevation than to try to get the pipe within 12 inches of the structure.)
- If steel or copper pipe is used and provisions are made to avoid impact with larger pipes or mechanical components or to protect the piping in the event of such impact, the following systems do not require bracing:
  - Piping in high seismic risk areas that are 1 inch or less in diameter
  - Piping in moderate seismic risk areas that are 2 inches or less in diameter
  - Piping in low-risk areas that are 3 inches or less in diameter

When looking at piping exemptions, keep in mind that regardless of diameter, the pipe must be kept from swinging and impacting surrounding systems. As this requirement can be virtually impossible to meet in crowded ceiling spaces that have to accommodate duct, HVAC pipe, electrical, and communication lines as well as plumbing systems, sometimes it is safer and easier to brace everything.

As mentioned earlier, the IBC provides some potential forces and exemptions. It is difficult for the engineer to determine each and every anchorage and to detail them upfront as typically several brands of equipment may be acceptable. Each equipment brand will have different physical characteristics and therefore different seismic forces and anchorage requirements. Also, as we

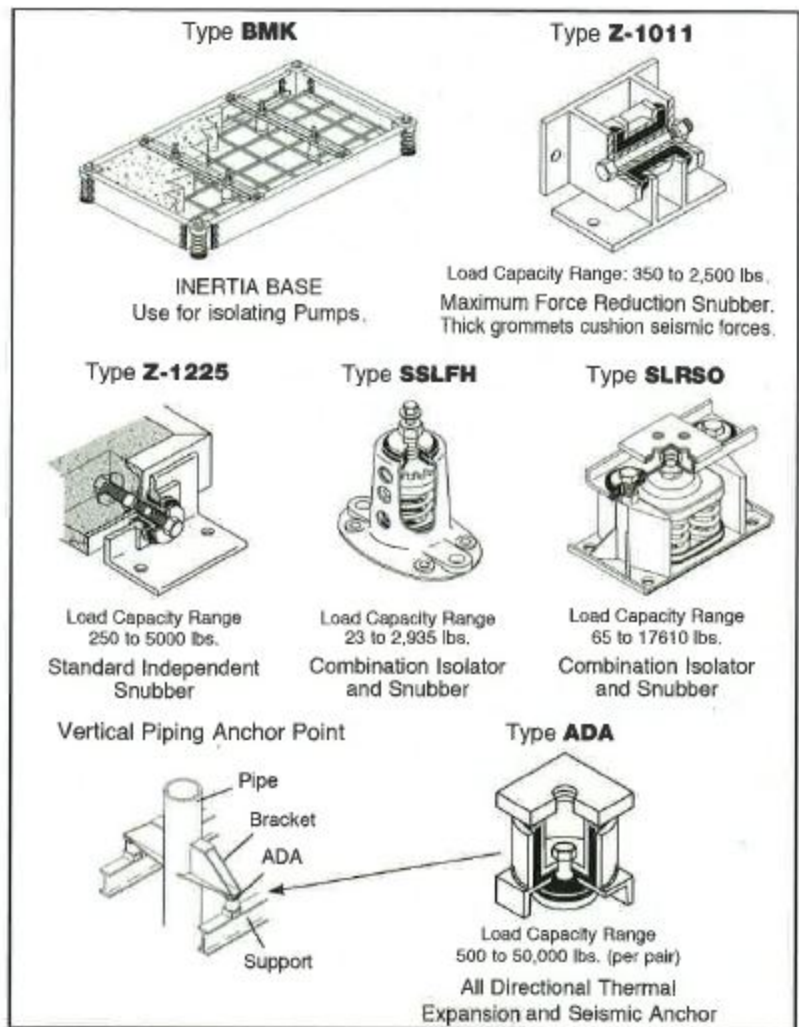
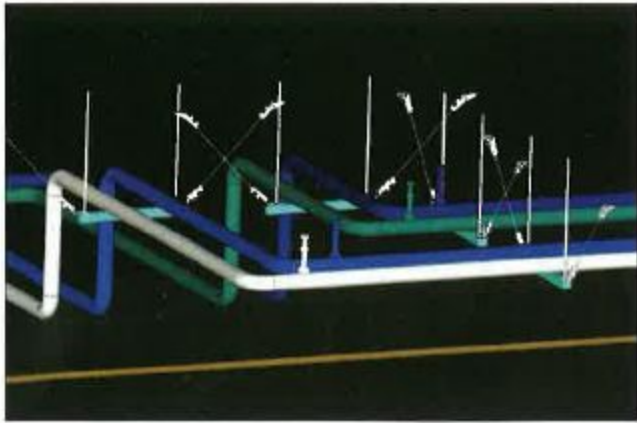


Figure 6 Details of seismic restraint products

Figure 7 Typical transverse cable brace restraint installed at Palomar Hospital in North San Diego. Brace has been painted green to indicate that it has been inspected and approved. Vertical formed channel rigidly locked to the hanger rod prevents buckling.

Figure 8 Solid transverse and longitudinal restraint installed at Palomar Hospital in North San Diego





all know, equipment and piping rarely are installed exactly where they are shown on the drawings. All of this makes it difficult for the design engineer to provide detailed information. However, it is important for the engineer to provide the contractor with general details and specifications for the type of attachment for which they are looking. This leads us to specifications.

## SPECIFICATIONS AND APPLICATIONS

### General Recommendations

Specifications should require seismic restraint calculations for all connections of equipment to the structure. These calculations should be stamped by a registered professional engineer with at least five years of seismic design experience and

licensed in the state of the job location. Seismic calculations should be submitted by the same company that is providing the seismic restraint material. Having the engineering and hardware coming from a single supplier provides a sole source of responsibility. Reputable suppliers of seismic restraint products can provide this engineering service.

The specification also should require all seismic restraints to be certified by a third party verifying their capacities. It is preferable that these certifications be based on testing versus calculations. Testing often reveals issues that cannot be predicted with pencil and paper.

The premier certifying agency for seismic restraints is the California Office of Statewide Health Planning and Develop-



Figure 9 Three-dimensional image of bracing locations

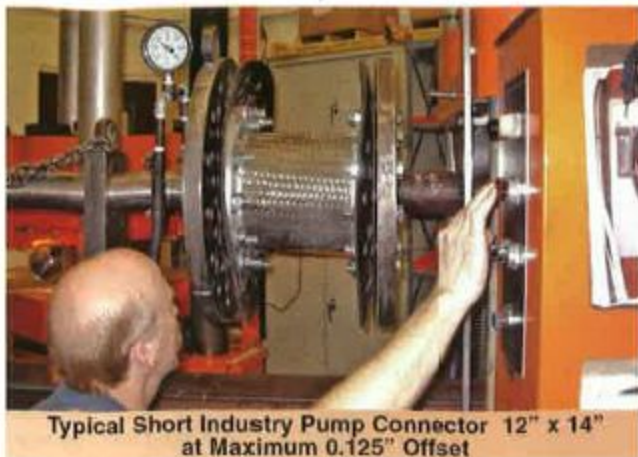
Figure 10 Damage at connection of piping to heat exchanger, Northridge, California earthquake, January 1994. A proper flexible connector may have prevented this failure.

Figure 11 Elastomeric connectors came through the 1994 Northridge earthquake unscathed. Properly constructed elastomeric connectors are the best choice for attachments to equipment in seismic zones.

ment (OSHPD). This agency is charged with reviewing designs for all hospitals in the state of California. Any restraint device to be installed at a California hospital must be structurally tested to failure. OSHPD then applies a 2-to-1 safety factor to determine the safe working capacity of the device. Although you may never work on a hospital in California, requiring OSHPD certification ensures that you are getting restraints that have the capacity advertised by the supplier. Many reputable vendors have OSHPD approval for their materials, so asking for the certification will not lock in any one supplier.

### Equipment

The two types of equipment connections are hard mounting, where the equipment



**Typical Short Industry Pump Connector 12" x 14"  
at Maximum 0.125" Offset**

Figure 12 Testing shows that short pump connectors are stiffer than the piping to which they are attached. Flexibility between equipment and piping is critical to limit seismic damage. When stainless hoses are necessary, specifications should require longer hoses with a high number of internal corrugations per foot.

**TABLE 1 ISOLATION AND SEISMIC RESTRAINT  
RECOMMENDATIONS FOR EQUIPMENT**

Floor-mounted pumps	Use an inertia base supported on springs. Use 1-inch deflection springs for ground floor applications and 3-inch deflection springs for installations on upper floors. Use at least four all-directional seismic snubbers.
Suspended pumps	Use spring isolation hangers and cable bracing for acoustically sensitive installations and rigid or cable bracing where no isolation is required.
Water heaters	Bolt equipment to the structure. Use rubber grommets at connections. Smaller heaters without provisions for bolting often can be strapped to an adjacent wall.
Boilers	In acoustically sensitive applications, isolate boilers with combination isolation and snubbing devices. Use 1-inch deflection for boilers located on grade and 2-inch deflection for boilers located on upper stories. In non-acoustical applications, bolt boilers to the structure using rubber grommets at connections. Smaller boilers without substructures suitable for bolting may require supplementary steel angles around the perimeter.
Vacuum pumps	Vacuum pumps typically are supplied with large steel frames. Isolate with combination isolation and snubbing devices. Use 1-inch deflection for units installed on grade and 3-inch deflection for units installed on upper floors.
Compressors	Use an inertia base supported on springs. Use 1-inch deflection springs for ground floor applications and 3-inch deflection springs for installations on upper floors. Use at least four all-directional snubbers.
Domestic water boosters	These units typically are supplied with steel frames that can be supported directly on combination isolation and snubbing devices. Use 1-inch deflection for units installed on grade and 3-inch deflection for units installed on upper floors.
Floor-supported tanks	Bolt directly to structure. Use rubber grommets at connections.
Ceiling-supported tanks	Use cable or rigid bracing to prevent sway.
Piping	Use cable or rigid bracing for non-isolated piping. Use cable bracing on isolated systems. Flexible connections should be used to attach the piping to the equipment.

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Figure 13 The Northridge quake lifted this chiller and housekeeping pad off the ground and slammed it into the structure.



Figure 14 The proper housekeeping pad footprint is important to ensure the proper distance from the anchor bolt to the edge of the pad. A wider pad would have prevented this failure.

is attached directly to the structure, and flexible mounting, which involves supporting equipment on springs or rubber mounts to prevent noise and vibration from being transmitted from the equipment to the structure.

As mentioned earlier, the code approach is a static simplification of a dynamic event. Although an attachment may look good statically, in the dynamic shaking of an earthquake the attachment bolt may be impacted by the equipment leg dozens of times. These shocks can result in a shear failure as shown in Figure 3. Elastomeric neoprene collars placed between the bolt and mounting hole in the equipment can drastically reduce the impact on the bolt and help prevent failure (see Figure 4).

Resiliently mounted equipment is more prone to failure during an earthquake because the isolators can resonate and amplify the seismic forces. The code recognizes this by calling for higher static design loads for isolated equipment. Seismic snubbing devices for isolated equipment that don't short-circuit the function of the isolators but will limit movement in the event of an earthquake are preferred. Separate, stand-alone snubbers are best, but snubbers also can be built into the isolator. A stand-alone snubber applied to an isolated pump base is shown in Figure 5.

A proper snubber should have the following characteristics:

- Snubbers should be all-directional. In other words, whether the earthquake shifts the equipment east, west, north, south, up, or down, the snubber should be engaged. Bumper-type snubbers that resist seismic forces in only one or two directions should be avoided.
- Snubbers should have preapproval from OSHPD or some other third party confirming their capacity.
- Snubbers should incorporate neoprene cushions that will absorb the seismic forces. Remember, earthquakes are dynamic events. Attachments will endure multiple impacts, and these loads are transmitted to the equipment. Cushions should be at least ¼ inch thick, and the allowable pressure on the bushing should be limited to 1,000 pounds per square inch (psi).

Each project's equipment should be examined to determine the appropriate isolation and seismic requirements, and these general requirements should be shown on the equipment schedule. Table 1 shows some general recommendations for standard equipment. See Figure 6 for details on some of the seismic restraint products mentioned.

### Piping

Piping must be braced to the structure above to prevent it from swaying and pos-

sibly breaking free or impacting surrounding systems. Specifications should call for the maximum spacing between braces. The spacing for transverse braces (those that prevent piping from swaying side to side, see Figure 7) for ductile pipe (steel or copper) is 40 feet. The maximum spacing between longitudinal braces (those that prevent the pipe from moving along its length, see Figure 8) is 80 feet. Brace spacing for gas, cast iron, and non-metallic pipe is 20 feet for transverse braces and 40 feet for longitudinal braces.

Care must be taken when designing a seismic bracing system for piping. Specifications should include a plan view drawing showing all brace locations. Attachment details also should be included. As with equipment calculations, all seismic piping drawings should be stamped by a registered professional engineer.

Three-dimensional drawings can be provided by many seismic vendors. 3D drawings allow the contractor to see conflicts before systems are installed. (See Figure 9 for a typical three-dimensional image of brace location.) 3D drawings allow the contractor to install brace attachments as the structure is going up rather than drilling and setting anchors later.

A proper design also takes into account any potential thermal growth of the system.

## Connections Between Equipment and Piping

After the equipment and piping are properly braced to the structure, the next challenge is selecting the appropriate connection to attach the pipe to the equipment. The problem is that the piping is braced to the ceiling, and the equipment is braced to the floor. These structural elements may move relative to one another during a quake. To prevent breakage where the pipe connects to the equipment, flex connectors must be used (see Figure 10).

Elastomeric connectors are the best answer, as they allow movement in all directions and are resistant to fatigue (see Figure 11). These connectors have the added benefit of preventing noise and vibration created by the equipment from travelling through the piping. Elastomeric connectors can be made fail-safe with the proper compounds and reinforcing. Peroxide-cured EPDM elastomer and Kevlar reinforcing are recommended.

Sometimes the system's pressure or temperature exceeds the capability of elastomeric connectors, so braided stainless steel

hoses must be used. The length and number of corrugations per length are critical for adequate flexibility. Standard industry pump connectors are not flexible at all, and testing indicates that they often are stiffer than the lengths of piping to which they are attached (see Figure 12). As an example, a standard 4-inch-diameter pump connector is 9 inches long. Under a pressure of 150 psi, it takes 620 pounds to displace this connector  $\frac{1}{8}$  inch laterally. Under the same pressure, it takes 155 pounds to displace an 18-inch-long model the same  $\frac{1}{8}$  inch and only 105 pounds to displace a 24-inch version. Thus, with a relatively small increase in length, you can reduce the connector's spring rate dramatically.

Specifying the number of internal corrugations is equally important. For 4-inch diameters, a minimum of 32 corrugations per foot is recommended. Since this connector style can only accept movement perpendicular to its length, it is good practice to install two connectors 90 degrees to each other or a V loop to ensure flexibility in all directions.

## Housekeeping Pads

Following the Northridge, California earthquake in 1994, it was discovered that while many systems had the proper seismic restraints, the housekeeping pads they were attached to were destroyed (see Figures 13 and 14). Housekeeping pads must be reinforced and doweled to the structure to prevent damage. A typical design is shown in Figure 15. Housekeeping pad anchor locations and minimum dimensions are included on the drawing.

## A WHOLE TEAM APPROACH

I hope the general guidelines discussed here are helpful to engineers in designing and specifying seismic restraints for plumbing systems. Of course, the best design involves coordination between the architect, plumbing system designer, code official, and contractor. Inviting input from everyone on the construction team right from the start will help create the safest, most effective seismic restraint systems.

## PSD

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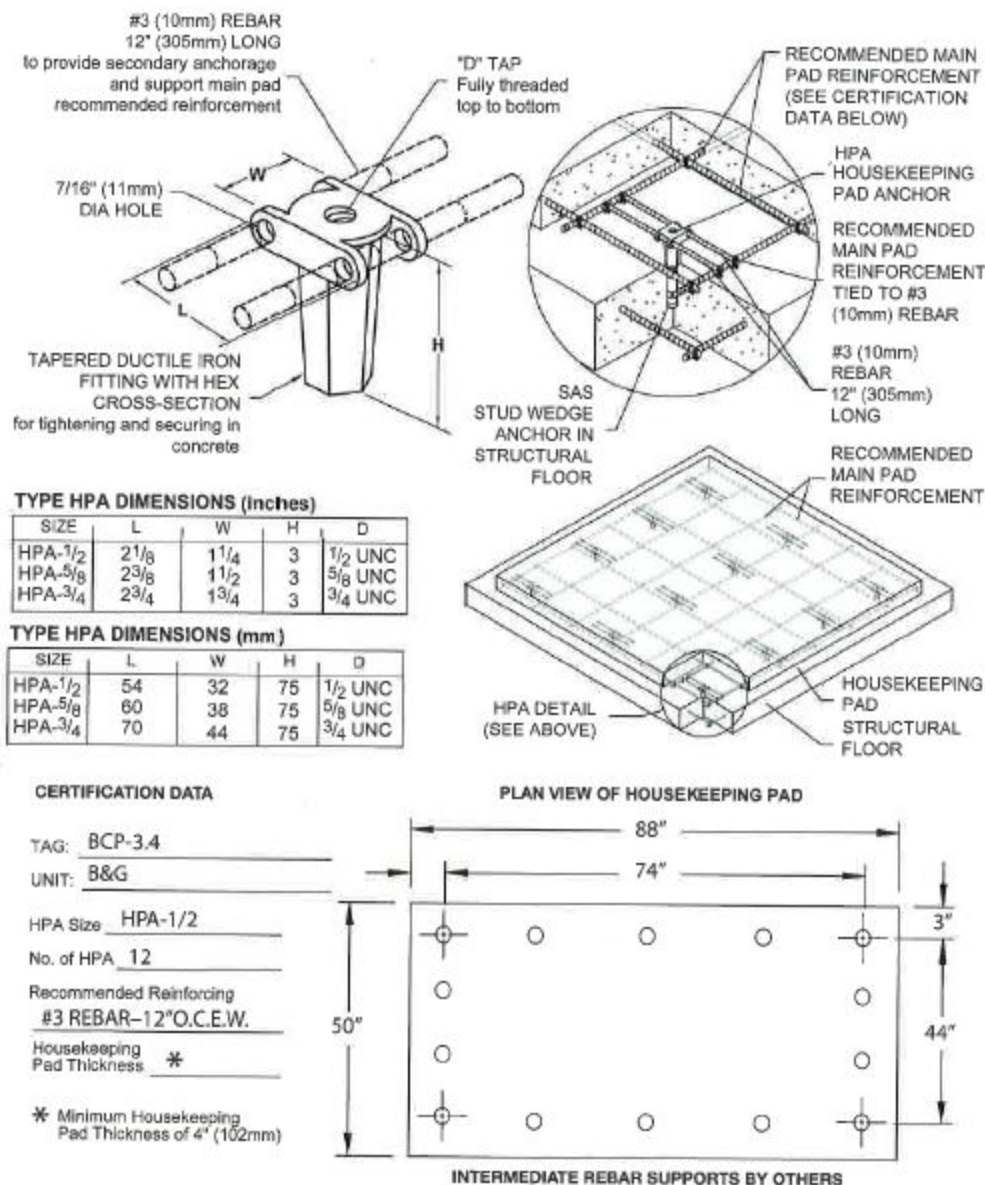


Figure 15 A proper seismic design includes housekeeping pad details. In this case, the engineer is utilizing cast iron housekeeping pad anchors that are installed after structural floor is in place. Design includes reinforcement selection.