PROTECTING YOUR FACILITY FROM THE DANGERS OF EARTHQUAKES

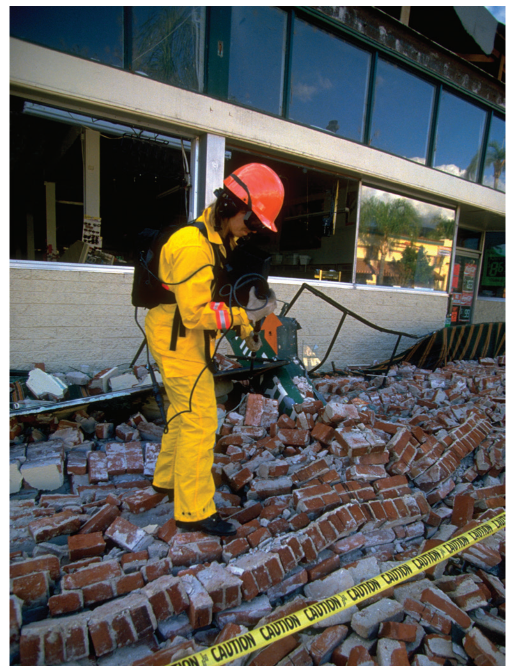
IDENTIFY EARTHQUAKE EXPOSURES

Earthquake is a rare natural hazard that cannot be prevented or predicted with any certainty. Fortunately, this reality does not preclude preventive action that can greatly reduce the amount of damage sustained in the event of major earth movement. This brochure offers guidelines to address key exposures in an effort to protect your facilities from earthquake-related damage.

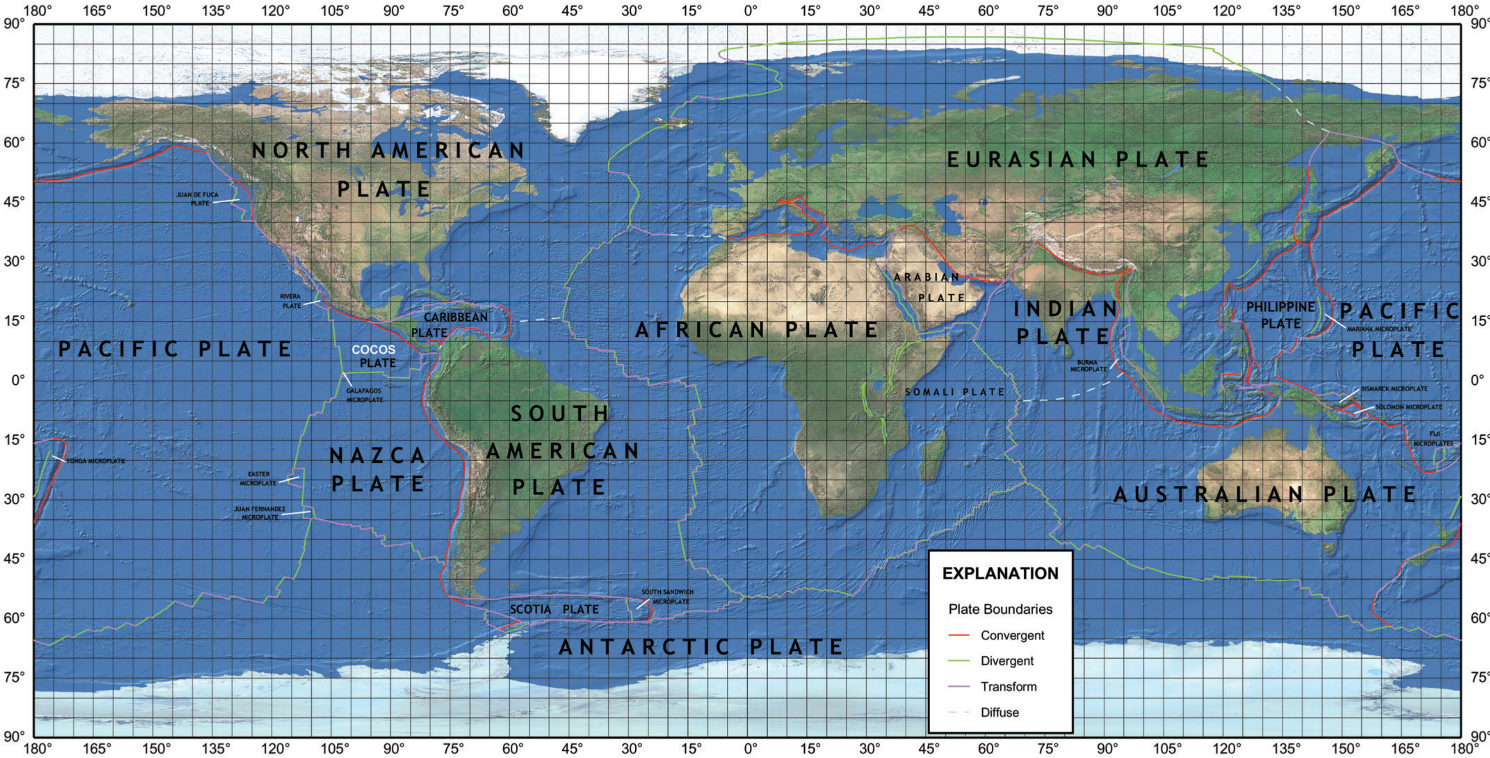
Scientists define an earthquake as a sudden and rapid shaking of the earth caused by breaking and shifting rock beneath the earth's surface. According to the U.S. Geological Survey, each year, about 1,500 earthquakes can be felt in the United States. Worldwide, there are more than 110,000 earthquakes each year that are strong enough to be felt (magnitude of 3.0 or more). The cost of earthquake-triggered damage to buildings and property can be astronomical.

The Northridge, Calif., USA, earthquake, a magnitude 6.7 event that struck in January 1994, is a vivid example, and it is considered the most destructive and costly earthquake to hit the United States since 1906. Though not categorized as "a major earthquake" by seismologists, energy released in Northridge is roughly equivalent to 2 billion kilograms of explosives.

Causing massive losses, the Northridge quake exceeded US$20 billion in direct damage-related costs, including US$12.5 billion in insured losses, according to the Insurance Information Institute. More devastating still was the Kobe earthquake, which struck Japan a year to the day later. The magnitude 6.9 quake produced total loss costs estimated at US$200 billion. With careful advance planning, proper design and protection of buildings and equipment, and training of employees, you can greatly reduce the potential physical damage and business interruption associated with the devastating forces of an earthquake.



Shown here, failure of an unreinforced masonry building in the 1994 Northridge, Calif., USA, earthquake. (Photo courtesy of FEMA)



Map of major plate boundaries courtesy of the U.S. Geological Survey National Earthquake Information Center

THE MOST OBVIOUS WAY TO SIGNIFICANTLY REDUCE OR ELIMINATE YOUR EXPOSURE TO EARTHQUAKE LOSS IS BY SELECTING LOCATIONS OUTSIDE SEISMIC AREAS OR IN LOW EARTHQUAKE HAZARD ZONES.

IDENTIFY SITE RISKS UP FRONT

Most earthquakes occur at the boundaries of adjacent crustal plates and within observable fault zones. The most obvious way to significantly reduce or eliminate your exposure to earthquake loss is by selecting locations outside seismic areas or in low earthquake hazard zones. Where this is not possible, avoid the most earthquake vulnerable sites, including sites that are located:

- on or very near (closer than 3 miles [5 km]) a known seismic fault
- on terrain subject to landslide
- in an area of poor soils or organic landfill subject to large settlement, liquefaction, lateral spreading, etc.
- too close to off-site exposures such as large natural gas transmission pipelines or adjacent hazardous sites
- in areas with unusual exposures due to off-site damage (e.g., served by a single, seismically deficient bridge)
- in a coastal area with shallow continental shelves and tsunami history

MEASURING AN EARTHQUAKE: MAGNITUDE VS. INTENSITY

The magnitude of an earthquake is a measure of the energy released, and often is expressed in terms of the Richter scale. A well-known measure, the Richter scale relates magnitude to the displacement of the ground surface as measured on a seismograph. Increasingly, the moment magnitude—which is directly calculated based on the area of the rupture surface, the displacement during the rupture and the strength of the ruptured rock—is used to measure earthquakes. Because they are derived in different ways, the moment magnitude often is slightly different from the Richter magnitude.

While the energy released (magnitude) remains constant, the effect of an earthquake (intensity) varies from site to site. The Modified Mercalli Intensity (MMI) is a measurement of the intensity or severity of an earthquake. The 12-level scale (from least to most severe) measures not only the degree of damage caused to structures, but also human reaction to shaking at a given location. Little damage occurs below MMI VI. Damage at MMI VI is usually slight. At levels above MMI VI, sprinkler systems often fail unless properly braced. According to FM Global research, nearly 80% of improperly braced sprinkler systems leaked as a result of shaking where the MMI was VIII or above in the Northridge temblor. Yet, adequately braced sprinkler systems performed almost flawlessly.

ROUGH EARTHQUAKE MAGNITUDE/INTENSITY COMPARISON (AT EPICENTER)

		Modified Mercalli Intensity (MMI)	
Earthquake Descriptor (Average Number/Year)	Magnitude	MMI	MMI Description
Micro (Millions)	Less than 3.0	I	I. Not felt.
Minor (100,000)	3.0-3.9	II-III	II. Felt by some under favorable conditions. III. Felt indoors especially on upper floors of buildings. Vibration similar to light trucks passing by the building.
Light (10,000)	4.0-4.9	IV-V	IV. Felt indoors by many, outdoors by few. Sensation like a heavy truck passing by the building. V. Felt by nearly everyone. Small unstable objects shifted or upset.
Moderate (1,500)	5.0-5.9	VI-VII	VI. Felt by all, many are frightened and run outdoors. A few instances of fallen plaster or damaged chimneys. Damage slight. VII. Damage negligible in buildings of good design and construction; slight to moderate in well-built ordinary structures; considerable in poorly built or badly designed structures.
Strong (140)	6.0-6.9	VII-IX	VIII. Damage slight in specially designed structures; considerable in ordinary substantial buildings with partial collapse. Damage great in poorly built structures. IX. Damage considerable in specially designed structures; well-designed frame structures thrown out of plumb. Damage great in substantial buildings. Buildings shifted off foundations.
Major (15)	7.0-7.9	VIII and higher	X. Most masonry and frame structures and some well-built wooden structures destroyed. Rails bent. XI. Few masonry structures remain standing. Rails bent greatly. XII. Damage nearly total.
Great (1)	8.0 or greater		

Note: While magnitude and intensity are interdependent to some degree, there is no exact correlation between them. For example, an earthquake might have a low magnitude, but because of poor soil conditions or building construction, it might cause a great deal of damage, and thus exhibit relatively high intensity.

This photo, from the 1994 Northridge, Calif., USA, earthquake, illustrates that, while adequately designed buildings seldom collapse, earthquake damage to structural and architectural systems, and content damage, can result in significant losses. (Photo courtesy of FEMA)

CHOOSING PROPER DESIGN CRITERIA FOR EARTHQUAKE PROTECTION

If you do choose to locate your facility in a seismic area, it can be made safer with proper design and earthquake protection.

Earthquake damage is widely thought to be associated with collapsing buildings. Design of the building's structural systems to resist earthquake forces is obviously important; past experience has shown that adequately designed industrial buildings seldom collapse from earthquakes. However, research by FM Global has found the following key exposures account for the bulk of earthquake losses:

- leakage from poorly braced sprinkler systems
- fires involving leaking gas lines
- direct shake damage to building nonstructural systems, equipment and stock due to shifting, falling or toppling

In existing buildings, virtually all sprinkler leakage and gas line ruptures can be prevented; content losses can be greatly reduced through strengthening selected critical systems; and, in some buildings, damage to structural and nonstructural systems can be significantly lowered. In new facilities, proper site selection and cost-effective engineering/construction practices can essentially eliminate significant contents losses and limit building structural and nonstructural system damage to merely superficial or cosmetic damage. FM Global recommends establishing minimum design criteria for all new construction, and reviewing earthquake vulnerability of properties you are considering for acquisition. Favorable features, such as the following, can reduce the potential for damage and downtime:

- a symmetric, regular building configuration
- properly braced sprinkler systems
- equipment anchored to prevent overturning, sliding and excessive swinging
- flexible connections attaching equipment to utilities

For a new construction project, in particular, you should be aware of the following advice:

- Do not build in known fault zones or areas with poor soil without proper design considerations.
- Establish criteria beyond the minimum provisions contained in building codes (which are designed primarily to safeguard against major structural failures, not to limit damage or maintain function).
- Design buildings to be symmetrical and regular.
- Do not use extremely susceptible systems (such as unreinforced walls or nonductile or precast concrete moment-resisting frames) to resist earthquake forces, even if allowed by local code or common practice.
- Avoid poor building features, such as unreinforced masonry infill or partitions and tall cantilevered walls (e.g., MFL walls).
- Establish equipment procurement specifications that include provisions for anchoring the equipment to resist earthquake forces.
- To the extent possible, avoid routing liquid piping over areas that are extremely susceptible to liquid damage.

Inadequately designed or installed equipment anchorage may not prevent movement in very severe ground shaking.

Hollow clay tile partitions (e.g. surrounding stairwells) always perform poorly in earthquakes and should be avoided, even in low seismicity areas.

- Be sure to properly design sprinkler systems for seismic areas, and lay out sprinkler systems to limit the need to accommodate differential movement (e.g., short drops from roofs to mezzanines).
- Install earthquake-actuated shutoff valves where flammable gas or ignitable liquid is piped into buildings.
- Require engineering consultants to perform construction observations at critical stages of construction, and strongly consider requiring a second engineer to conduct a peer review of the earthquake design of critical facilities.
- Follow the steps outlined in FM Global's Ten Qualities of a Well-Protected Facility (P8114).

If you are considering acquisition of property, or when retrofitting earthquake protection of equipment, contents and piping, you will need to evaluate exposures for toppling, swinging and sliding before determining the necessary steps (e.g., utilizing sway bracing, swing joints, flexible couplings, and anchorage as appropriate). In many cases—adding protection to sprinkler systems, for example—it is no more difficult or expensive than it would have been to install bracing in the original system. Costs to retrofit buildings to resist earthquake can vary widely.

SEISMIC PROTECTION AT MAJOR LOCATIONS		
Bracing	Flexibility	Clearance
• On risers at the top and at elevated floors in multistory buildings • On major piping (usually mains) » Where it changes directions » At regular intervals along its length » At ends	• On risers at the top and bottom, and at elevated floors in multistory buildings • On piping that spans seismic or expansion joints or between buildings • At drops to in-rack sprinklers or mezzanines • Near fire pumps and tanks	• Where piping passes through nonfrangible walls or floors • Between sprinkler system components (especially sprinklers) and structural or nonstructural elements

PROTECT YOUR FIRE PROTECTION SYSTEMS

During earthquake shaking, automatic sprinkler systems inadequately protected to withstand seismic loads often leak, potentially leading to the catastrophic failure of major system components. Major leaks not only expose the building and its contents to severe water damage, but also impair the sprinkler system at a time when the facility may be most vulnerable to fire.

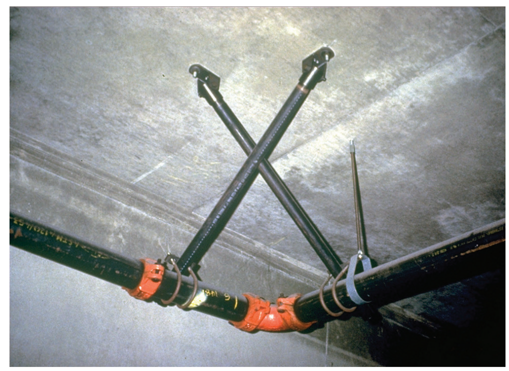
Seismic protection can be achieved through the proper balance of *bracing, flexibility and clearance.* Nearly all sprinkler leakage can be prevented by determining:

- where it is best for the sprinkler system to remain firmly braced to the structure
- where flexibility is required to allow movement of one part of the sprinkler system relative to the remainder of the system
- where clearance is necessary to allow movement between sprinkler system components and building floors/walls or equipment that can move differently

While adequate bracing, flexibility and clearance will prevent most damage to fire protection systems, remedying other deficiencies will further reduce the risk. Some of the other more important provisions include:

- Splay-wire bracing and compression struts on suspended ceiling systems
- Modification or replacement of marginal hanger attachments (e.g., provide retaining straps on C-clamps or replace powder-driven fasteners)
- Anchorage of water supply equipment, including suction tanks, fire pumps and drivers, controllers, starter batteries, fuel tanks, and emergency generators for electric fire pumps
- Anchorage of storage racks with in-rack sprinklers, and immediate repair of rack damage

We recommend you survey existing fire protection systems to ensure they meet the recommended minimum bracing, flexibility and clearance safeguards (consult FM Global Property Loss Prevention Data Sheet 2-8, *Earthquake Protection for Water- Based Fire Protection Systems*, for more information on protecting your facility against seismic forces).



Proper earthquake bracing is essential, for example, where piping changes directions.

PREVENT FIRE AFTER EARTHQUAKE

Controlling post-earthquake fires can be much more difficult than fire control under normal conditions. Multiple simultaneous ignitions can be expected immediately after the event, and, because alarm equipment is likely to be damaged and communications systems overtaxed, these fires are allowed to grow. Delayed ignitions are another potential threat, as fires often occur as a result of restoration of electrical and gas service in damaged buildings.

FLAMMABLE GAS AND IGNITABLE LIQUID LEAKS

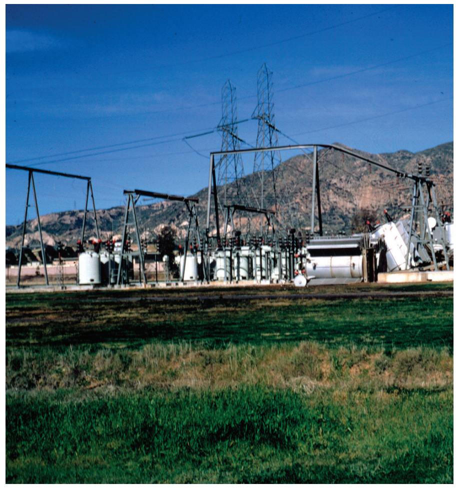
Preventing release of flammable gas and ignitable liquid is the most practical way to reduce the risk of fire following earthquake. Industry data shows that, after the Northridge earthquake, more than 14,000 leaks occurred in natural gas lines, and at least 110 fires were reported in the shaken area. For both Northridge and the 2001 Nisqually earthquake, a magnitude 6.8 event in Washington State, USA, unrestrained natural gas-fired equipment and rigid connections were the primary causes of leaks. In the United States, natural gas (methane) historically has been a factor in 15 to 50% of fires following earthquakes.

The fire risk can be mitigated by installing affordable, earthquake-actuated shutoff valves that stop the flow of flammable gas or ignitable liquid; restraining equipment and piping; and providing appropriate flexibility in piping. The cost of adding the protections (see below) is typically very small during initial construction, and can vary widely when retrofitting, depending on circumstances.

Earthquake-actuated shutoff valves stop the flow until it is safe to restart, and should be installed wherever flammable gas or ignitable liquid is piped into a building. They often are installed directly on small flammable gas lines. In other designs, flow from a pipe can be stopped, or other processes shutdown, by a signal sent by a separate seismic indicator to a control panel or valve. Modern earthquake-actuated shut-off valves operate (i.e., close) at MMI shaking of VII or above. When properly installed, these valves should not operate due to vibrations from passing trains, trucks or similar non-seismic sources.

CONTROLLING POST-EARTHQUAKE FIRES CAN BE MUCH MORE DIFFICULT THAN FIRE CONTROL UNDER NORMAL CONDITIONS.

For fuel gas (e.g., natural gas), one piece in-line earthquake-actuated shutoff valves (left and middle) are available. For other flammable gas and ignitable liquid, or for high-pressure or large-diameter fuel gas lines, remote seismic sensors (right) can be linked to appropriate valves or control panels to shut off flow.



Critical facility equipment should be anchored to prevent damage and business interruption. Damage to utility transformers and substations may result in loss of power; your emergency plan should address this exposure.

BUILDING CONTENTS ARE OFTEN DESIGNED TO WITHSTAND ONLY GRAVITY LOADS, BUT BECAUSE EARTHQUAKES PRODUCE VERTICAL AND HORIZONTAL FORCES, THEY CAN AFFECT EVEN THE STRONGEST STRUCTURE IF SIDE-TO-SIDE FORCES HAVE NOT BEEN CONSIDERED.

Restraint can make a considerable difference in loss potential. It has been estimated that approximately 80% of gas leaks occur at the point of use (i.e., the equipment). Because restraint is easily accomplished by bracing or bolting equipment to the floor, restraint of equipment supplied with flammable gas or ignitable liquid is strongly encouraged even when earthquake-actuated valves are provided. Equipment restraint prevents sliding, overturning and swinging. Flammable gas or ignitable liquid pipe may need to be braced to withstand earthquake motions as well, so that the pipes move with the building as one unit, not as individual parts.

Flexibility should be provided to allow for movement where piping connects to equipment (even equipment that is restrained). This can be achieved by, for example, providing flexible metal piping or loops rated for the flammable gas or ignitable liquid being conveyed. In other instances, rigid pipe can be reconfigured to allow some movement.

In addition to minimizing the risk of continuous flammable gas and ignitable liquid releases, several other steps can be taken to reduce the risk of post-earthquake fire. These include:

- Engineered restraint for tanks, storage cabinets and equipment using smaller amounts of ignitable liquid
- Proper storage and restraint of small containers of ignitable liquid
- Upper and lower restraint of high-pressure flammable and oxidizing gas cylinders to prevent toppling
- Avoiding buildup of combustible wastes and deposits (e.g., lint) that could serve as fuel for an electrically ignited fire

PROTECT YOUR EQUIPMENT AND CONTENTS

Earthquake requirements in building codes typically focus on the design of the structure to resist lateral forces. Consulting engineers generally have a similar focus. Although building codes usually contain provisions for the earthquake design of contents (equipment, storage racks, etc.), contents earthquake protection often is an afterthought; and, at times, is not enforced or is left to the discretion of the building owner.

Building contents usually are designed as though gravity were the only force on them. Racks and individual pieces of equipment often can withstand gravitational pull that is many times their own weight. These objects, however, can sometimes withstand very little force in other directions; and because earthquakes produce vertical and horizontal forces, they can affect even the strongest structure if side-to-side forces have not been considered.

For new construction, the best course of action is to include requirements to anchor equipment in design criteria and procurement specifications.

The cost of anchoring equipment is minimal if restraint is installed during construction.

For existing facilities, the cost of anchoring all equipment can be very expensive. It is usually best to prioritize the need for restraint based on whether movement would result in fire, other hazardous conditions or significant loss.

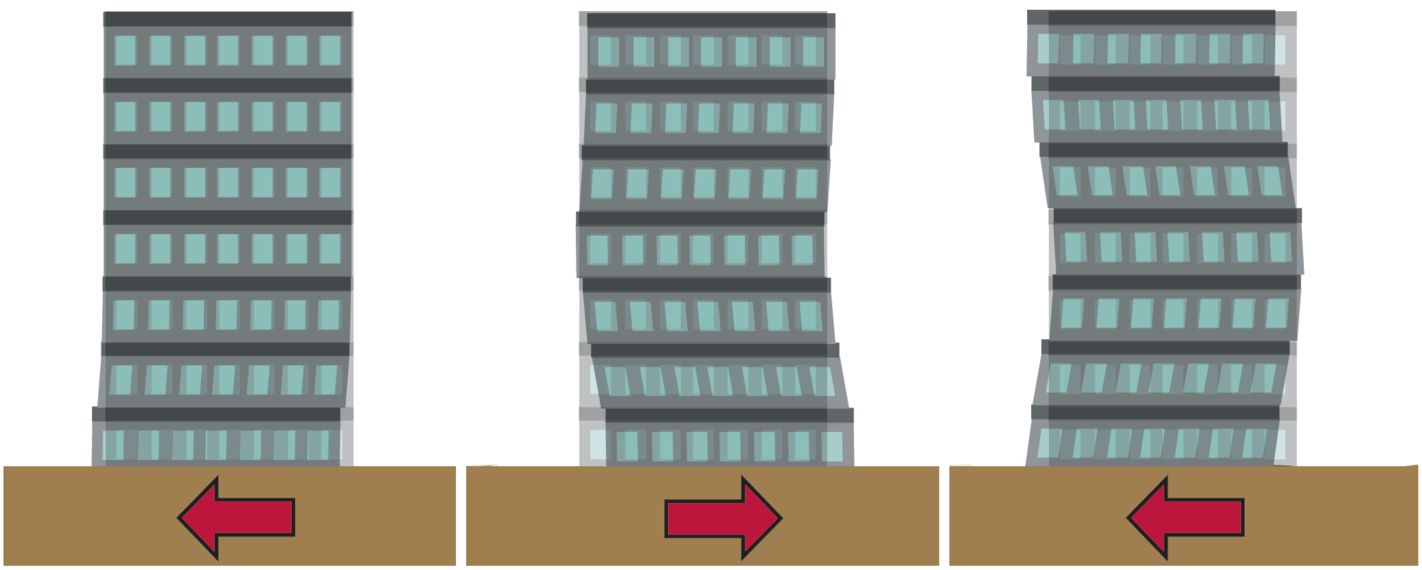
Items that should be a high priority for anchorage typically are those that are vulnerable to earthquake damage (fragile) and also high in value, important to production continuity, or hazardous if damaged.

Contents can be subject to:

- **toppling**, which is prevalent when items are tall in comparison to their bases, or carry a disproportionate amount of weight at their tops. Because forces are amplified at higher points in a building, items at the top of a structure are more likely to overturn than items at the ground.
- **sliding**, arguably the most common earthquake effect, is the horizontal displacement of normally stable objects. In many cases, damage is minimal, but losses can mount when equipment must be realigned, or interconnections repaired. Items that could fall from supports as a result of sliding may be of particular concern.
- **swinging**, which will, in some cases, result in minimal damage. However, when a swinging item can impact adjacent items, or when damage is possible due to the swinging itself (e.g., piping), losses can increase. Consequent damage can result if piping carrying ignitable or non-ignitable liquids, or flammable or corrosive gas, ruptures or leaks.

For both new construction and existing facilities, consideration should be given in some cases to installing a seismic protection system (e.g., seismic sensor[s] and control panel) that will shut down major equipment automatically in an earthquake.

EXAMPLE OF DIFFERENTIAL MOVEMENT (IN ONE DIMENSION)



Earthquake force = earthquake ground shaking + building inertia = the effect of a seismic wave

ASSURE TIMELY RESPONSE AND RAPID RESTORATION OF OPERATIONS

Timely response and rapid recovery from an earthquake require careful planning and speedy action immediately following the event. With knowledge of your seismic risk, it's important that you incorporate earthquake response into emergency response team (ERT) activities, and conduct appropriate earthquake specific training.

Effective emergency response is essential in the event of an earthquake because it is impossible to identify all ignition sources; and, ignition can be delayed because fires often occur as a result of restoration of electrical and gas service in damaged buildings.

Also, sprinkler system damage, and damage to buildings and contents, may require immediate action.

Prior to an earthquake, you can:

- Establish a comprehensive emergency action plan to control hazards; ensure the integrity of fire protection; conduct salvage and repair operations; and minimize business interruption.
- Train emergency personnel covering all shifts to implement the emergency action plan and stockpile emergency supplies that may be needed to support ERT efforts.
- Ensure emergency gear—such as tools, firefighting equipment and electrical generators—is accessible and adequate.

Keep in mind that an effective emergency plan includes contingency plans that address external loss factors. During an earthquake, disruption of public water sources is likely, as is a lack of (or extremely delayed) response by the public fire service, gas company and other key public service personnel. That means it is up to you to ensure an adequate water supply, backup electrical power, independent fire-suppression methods, and other measures to protect your facility during an emergency.

FORMULA FOR AN EFFECTIVE EARTHQUAKE PLAN

- Empower emergency response team (ERT) members to maintain as much fire protection in service as possible when sprinkler piping is damaged.
- Where fire protection systems are intact, check that all sprinkler water supply valves are open and water supply is in service.
- Check process systems, as well as gas, water and electrical services for damage, and institute procedures for shutting off systems as necessary.
- Repair damaged fire protection systems as soon as possible, following FM Global's Red Tag Permit System kit (P7427) if systems are impaired.
- Survey the site for damage and combustibles in contact with ignition sources. Inspect systems (e.g., flammable gas and ignitable liquid piping and equipment) protected by earthquake-actuated shutoff valves for damage before resetting the shutoff.
- Prohibit hot work until fire protection is restored. For repairs requiring hot work, follow instructions outlined in FM Global's Hot Work Permit System kit (P9311).
- Begin salvage operations with awareness that fire danger is greatest shortly after an earthquake (research by FM Global indicates that 50 to 75% of earthquake-initiated fires start immediately after the event).
- Monitor equipment that continues operation.
- Plan to conduct business in the face of structural damage or lack of power (e.g., identifying an alternative site beyond the earthquake area where you can continue operations).
- Maintain an inventory of key spare parts for major production and utility equipment, with particular attention to components susceptible to seismic damage.
- Have an agreement with contractors for priority treatment if your repair and salvage plan depends on outside help.

With a clear understanding of hazards present at your facility and the risks they represent, you can confidently follow FM Global's formula for developing an effective emergency response plan (below).

1. Incorporate property protection into your emergency response plan.
2. Form a planning committee that includes police and fire services. Refer to FM Global's *Pocket Guide to Prefire Planning* (P9809) for more information.
3. List the hazards and associated risks. And, examine all processes that could lead to fire, explosion, hazardous materials spill or other detrimental events.
4. Learn from the past by reviewing previous emergencies at your facility, studying their causes.
5. Define action steps. In other words, plan your response to likely emergencies based on what you have learned about your facility's hazards and associated risks and past experience.
6. Publicize your plan.
7. List assets to protect, including equipment, raw materials, finished goods, storage and personal property.
8. Define ERT procedures. More information is available from FM Global's The Emergency Response Team (P8116).
9. Validate and maintain the plan. Review and update it at least once a year, as well as when significant facility or ERT member changes are made.
10. Practice your plan through drills, such as computer-assisted simulations, communications exercises or real-life simulation.

FM GLOBAL HELPS YOU AVOID DISASTER

While earthquakes can't be prevented, their impact on your organization can be mitigated through careful preplanning, employee training and management commitment. FM Global offers resources and expertise to guide you in effectively protecting your facilities from earthquake-related damage. Don't let earthquake-related loss imperil your organization.

Be sure to contact your FM Global engineer or client service team for further information and details about the topics that appear in this brochure and any questions concerning potential earthquake exposures at your facilities, including:

- Additional engineering service opportunities for review of your fire protection systems.
- Information specific to your site regarding reduction of the fire following earthquake potential, including additional information about the different types of earthquake-actuated shutoff valves available.
- Consultation with one of our earthquake specialists who can provide you with other earthquake information or suggest who to contact for additional engineering service.

RELATED FM GLOBAL PUBLICATIONS:

- *Earthquake Checklist* (P9807)
- *Ten Qualities of a Well-Protected Facility* (P8114)
- *The Emergency Response Team* (P8116)
- *Pocket Guide to Prefire Planning* (P9809)
- *Red Tag Permit System Kit* (P7427)
- *Hot Work Permit System Kit* (P9311)

RELATED UNDERSTANDING THE HAZARD TITLES:

- *Lack of Emergency Response* (P0034)
- *Fire Following Earthquake* (P0181)
- *Lack of Contingency Planning* (P0179)
- *Lack of Earthquake Bracing on Sprinkler Systems* (P0042)
- *Lack of Pre-Incident Planning* (P0033)
- *Lack of Seismic Gas Shutoff Valves* (P0290)
- *Nisqually Earthquake* (P0112)
- *Service Interruption* (P0229)

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