Understanding the Hazard

Earthquake Shake Damage to Facility Contents

Natural Hazards

Earthquake ground shaking can cause damage to inadequately anchored facility contents, especially tall, slender equipment that can easily overturn. FM Global can help you better understand the risk this hazard presents to your business, and provide solutions for mitigating that risk.

UTH topic categories:

- Construction
- Equipment
- Fire Protection
- Human Element
- **Natural Hazards**
- Process Hazards

This series of publications is designed to help you understand the everyday hazards present at your company's facilities. For more information on how you can better understand the risks your business and operations face every day, contact FM Global.

The Hazard

Shake damage, typically the largest component of an earthquake-related loss, varies significantly among sites depending on the intensity of the shaking and the particular characteristics of the facility. Total shake loss at a facility usually comprises minor to moderate damage to many items, but also can consist of—or even primarily result from—major damage to just a few items.

The most severe ground shaking occurs in the region nearest to the earthquake epicenter (and at sites with unfavorable local geologic conditions, such as soft soil). Visually striking structural failures in areas that have experienced severe ground shaking are often the subject of intense news coverage following an earthquake. Relatively few industrial and commercial buildings, however, actually fail from earthquake ground shaking. Even when located in severe ground-shaking zones, structures with reasonably good earthquake-force-resisting systems rarely collapse as a result of shake damage. If your facility is among the vast majority for which earthquake building damage is repairable, you can take practical, inexpensive preventive action to reduce shake damage to your facility's contents that will result in a quicker recovery.

Improving the earthquake resistance of buildings and other structures has received considerable—and well-deserved—attention in recent years. Less effort has been directed at improving the earthquake resistance of a building's contents. Fully mitigating shake damage to existing buildings and every piece of in-place equipment may require significant and expensive modifications. A substantial reduction in the risk of shake damage to a facility's contents, however, can be achieved cost effectively simply by restraining items that are both vulnerable to earthquake-induced damage and valuable or important to production. A logical starting point is to reduce the earthquake risk to objects that can topple during an earthquake. This is an important step, but only the first of many in mitigating earthquake shake damage.

Science of the Hazard

Most earthquake damage results from the sudden release of energy in the form of seismic waves (wave motion) and surface rupture (physical slippage) of the earth's crust. Of the two, seismic waves cause more widespread geographic damage because they radiate outward from the initial point of disturbance in all directions, like the ripples created when a pebble is dropped into a pond. Strength

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What You Can Do in Your Facility

Now:

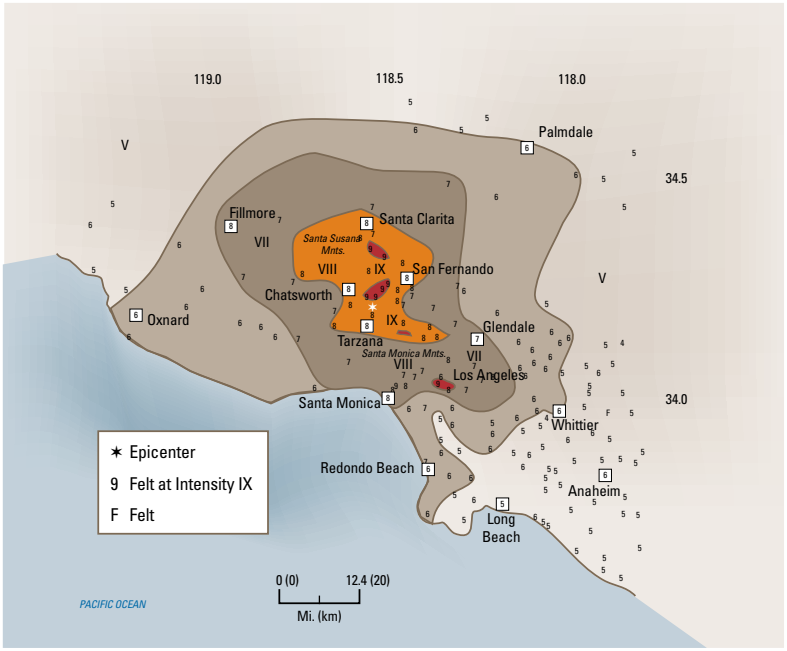
- Where possible restrain important, tall, slender objects by installing anchors through holes at the base of each object.
- Install automatic earthquake-actuated shutoff valves where flammable gas or ignitable liquid is piped into buildings.
- Incorporate earthquake response into emergency response team (ERT) activities.
- Involve FM Global in new construction projects, fire-protection system installations, and modifications and alterations to existing protection.
- Contact your FM Global client service team to find out about additional engineering services.

Soon:

- Implement corrective measures as soon as possible to resolve any seismic upgrade recommendations for fire following earthquake and fire-protection systems.
- Develop minimum seismic design standards and specifications for all construction and new equipment installations.
- Develop an earthquake recovery plan.
- Survey your facility contents to determine if sliding or swinging of objects during an earthquake would result in significant loss.
- Where justified by expected loss, engage a qualified engineer to design earthquake modifications for tall, slender objects that cannot be anchored through existing holes in their bases, and for other facility contents that can be damaged from sliding or swinging.

of shaking (intensity) is often expressed in terms of Modified Mercalli Intensity (MMI), on a 12-level scale (I to XII, from least to most severe). A review of the earthquake intensity map from the 1994 Northridge (Calif., USA) Earthquake (Figure 1) illustrates the strongest shaking typically is found near the earthquake epicenter, but also can occur farther from the earthquake source due to local geologic conditions. The map also shows another common characteristic of earthquake ground shaking: The most intense ground shaking affects a relatively small area, while lower intensity shaking affects a larger area. This is significant because structural collapse usually is concentrated in the smaller area of intense ground shaking, rather than the larger area of more moderate shaking.

Figure 1. Intensity Map of the 1994 Northridge (Calif., USA) Earthquake



U. S. Geological Survey Open File Report 95-92

Seismic events generate both vertical and horizontal motion, but the horizontal force usually governs earthquake performance of buildings and their contents. The actual shake damage sustained in an earthquake strongly depends on the specific characteristics of the building, equipment, storage system, piping, etc. Contents can be displaced if they are not anchored, in some cases, moving several feet (meters). For low-profile objects that slide, shake damage can be minimal, but loss can increase when equipment must be realigned or interconnections repaired. Some suspended items may swing without consequence, while others (e.g., piping) may sustain substantial damage from broken connections, impact with other objects or loss of vertical support. Objects with relatively high centers of gravity can topple. Because forces are amplified at higher points in a building, objects at the top of a structure are more likely to overturn than those at ground level.

Shake damage to buildings also strongly depends on construction material, building configuration and the earthquake-force-resisting system. Buildings constructed of extremely susceptible material—such as unreinforced masonry

Earthquake Design of New Facilities

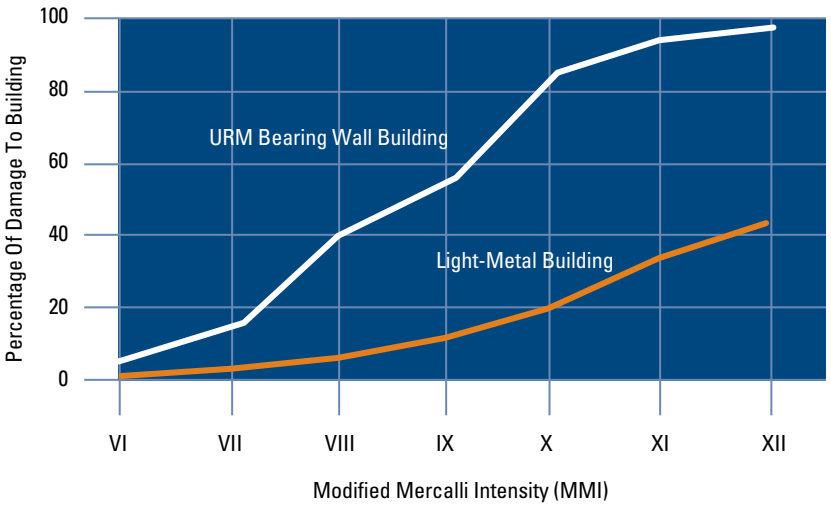
Modifying in-place contents and existing buildings can be costly or impractical. A substantial reduction in earthquake shake damage, however, is easily achieved by establishing and applying seismic design criteria for new equipment installation and building construction. Implementing measures to ensure better earthquake performance of new facilities does not necessarily translate into a significant increase in the cost of construction.

The type of building material and earthquake-resisting system used in a structure can have a significant effect on earthquake shake damage. For example, during a recent moderate earthquake, hollow clay-tile partitions and unreinforced masonry facade cracked in an FM Global client's office structure. Even though these elements were not close to actual failure, the cost of repair and removal was approximately 20 percent of the value of the entire building. Clearly, a cost-effective solution is to simply avoid using the types of building material and systems that are known to perform poorly in earthquakes.

When anchorage requirements are specified at the time equipment is ordered and installed, it is typically inexpensive to restrain these items. Similarly, bracing sprinkler system piping and flammable gas and ignitable liquid systems when they are originally installed is the most cost-effective way to avoid shake damage and consequent loss from water leakage, fire-protection-system impairment and fire following earthquake.

(bricks or concrete blocks without reinforcing steel), with structural irregularities (e.g., a weak first story) or fragile architectural features—will sustain more shake damage than buildings without those characteristics. The graph below (Figure 2) shows the relative shake damage for two low-rise structures: a building with unreinforced masonry (URM) load-bearing walls (a poor earthquake construction type), and a light-metal building (one of the best earthquake construction types). The graph illustrates two points. First, construction type can make a big difference in the amount of shake damage a building sustains. Second, even very poor earthquake construction types can survive moderate (MMI VII) to high (MMI VIII) shaking, experiencing damage that does not necessarily lead to collapse. Thus, it makes sense for all facilities, even those of poor construction located in areas likely to experience very strong ground shaking, to have the risk of earthquake shake damage to their contents reduced.

Figure 2. Comparison of Predicted Shake Loss Expectancies (90-Percent Confidence of Non-Exceedence) for Low-Rise Buildings



Source: Applied Technology Council reports ATC-13 and ATC-13-1

Loss Experience

During a recent 10-year period, roughly 75 percent of the earthquake loss at FM Global client facilities was attributable to shake damage.

Mitigating damage to sprinkler systems by providing bracing, flexibility and clearance is a relatively straightforward and cost-effective process. Similarly, significant reduction in fire-following-earthquake risk can be achieved by installing automatic seismic shutoff valves on selected flammable gas and ignitable liquid lines, and anchoring a few pieces of equipment.

Mitigating all possible shake damage at a facility, however, is a much more complex task. For some facilities, the cost of anchoring every piece of in-place equipment can be very high. In such cases, it is usually best to prioritize the need for anchoring based on whether movement would result in significant damage. Objects with a high priority for anchorage are those vulnerable to earthquake damage and also high in value, important to production continuity, or hazardous if damaged.

Need more information?

Ask your FM Global engineer or client service team about the following:

- *Earthquake Checklist* (P9807)
- *Protecting Your Facility from the Dangers of Earthquakes* (P9505)
- Understanding the Hazard: *Fire Following Earthquake* (P0181)
- Understanding the Hazard: *Lack of Earthquake Bracing on Sprinkler Systems* (P0042)
- Understanding the Hazard: *Lack of Seismic Gas Shutoff Valves* (P0290)
- Understanding the Hazard: *Nisqually (Seattle, Wash., USA) Earthquake* (P0112)

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A reasonable starting point for the mitigation of shake damage to a facility's contents is to anchor tall, slender objects, such as electrical and telecommunication cabinets and pallet racks. Experience shows these items, if unanchored, can overturn during strong ground shaking and sustain heavy damage; however, they typically perform well if restrained. For example, at one facility visited by FM Global engineers after the 2001 Nisqually (Seattle, Wash., USA) Earthquake, all anchored steel storage racks survived the earthquake undamaged; the one unanchored rack overturned. A 2005 report generated for the U.S. Federal Emergency Management Agency (FEMA) also found anchored racks performed well in moderate-to-strong ground shaking, unless they were significantly overloaded or had been damaged (e.g., by forklifts) prior to the event.

But What About...

…building code requirements? Will anchorage alone meet the code provisions?

In some cases, simply adding anchorage to objects through existing holes in their bases is adequate to meet building code provisions and protect the objects from the strongest shaking likely to occur at the site. Sometimes, though, the configuration of already in-place equipment limits the size or number of anchors that can easily be installed. This modification may then protect the equipment only from moderate shaking (still likely to be adequate for most sites during most earthquakes because, as previously noted, the vast majority of facilities are not in severe ground-shaking zones during any given earthquake). If you must be absolutely certain that you have adequate protection in place, the only way to provide complete earthquake protection to a facility's contents is to have a qualified engineer perform an analysis and recommend custom solutions. These custom solutions may require modifications beyond anchorage and likely will be more expensive. While it may not prevent all loss, targeting an achievable level of improvement (e.g., installing bolts through existing holes) will substantially reduce overall loss, while limiting your investment.

Don't Let This Happen to You

A high percentage of Turkey's industry is located in the northwestern part of the country near Izmit, the location of a magnitude 7.4 earthquake in August 1999. Toppling of storage racks in this pharmaceutical plant is one example of the substantial damage to industrial facilities that can result from ground shaking.

Photo Courtesy of ABS Consulting