Understanding the Hazard

Nisqually (Seattle, Wash., USA) Earthquake

Natural Hazards

Even moderate earthquake ground-shaking can cause damage to facilities when features intended to resist seismic forces or to accommodate earthquake-induced movement are absent or inadequate.

UTH topic categories:

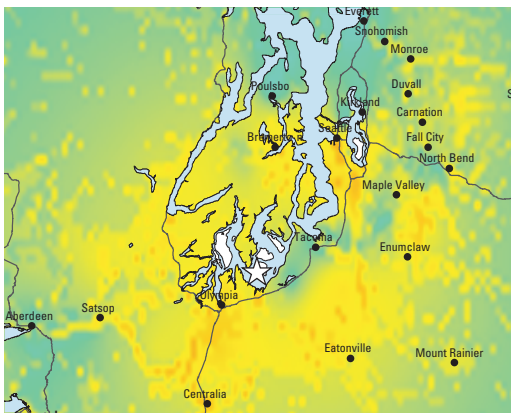
- Construction
- Equipment
- Fire Protection
- Human Element
- **Natural Hazards**
- Process Hazards

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 Earthquake

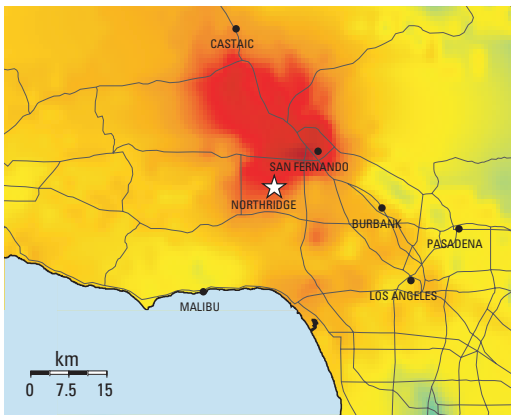
To longtime residents, the fact that this earthquake occurred was not a surprise. After all, this was an area where the ground had shaken before. A magnitude 7.1 earthquake on April 13, 1949, and a magnitude 6.5 shock on April 29, 1965, both occurred in the same general area.

To engineers and scientists, the surprise was that recorded ground motions and Modified Mercalli Intensity (MMI—see Modified Mercalli Index on page 4) estimates were generally lower than would be expected for an earthquake of this magnitude. An apt comparison would be the Jan. 17, 1994, Northridge, Calif., USA, earthquake.



Nisqually: Magnitude 6.8

MMI ≥ VI	2,800 square miles (7,300 square km)
MMI ≥ VII	200 square miles (520 square km)
MMI ≥ VIII	Small pockets
MMI ≥ IX	Essentially none



Northridge: Magnitude 6.7

MMI ≥ VI	2,500 square miles (6,500 square km)
MMI ≥ VII	1,100 square miles (2,800 square km)
MMI ≥ VIII	300 square miles (800 square km)
MMI ≥ IX	Small pockets

Top map courtesy of Pacific Northwest Seismic Network
Bottom map courtesy of TriNet

The Event

At 10:54 a.m. (PST), Wednesday, Feb. 28, 2001, the magnitude 6.8 Nisqually Earthquake shook the area surrounding Olympia, Wash., USA. The epicenter was located about 11 miles (18 km) northeast of Olympia, 15 miles (24 km) southwest of Tacoma and 36 miles (58 km) southwest of Seattle.

The earthquake occurred 32 miles (52 km) below the earth's surface as a result of tensional (normal) faulting in the subducting Juan de Fuca Plate. Due to the depth of the event, shaking was moderate and consequent earthquake damage was relatively light throughout the Seattle area.

A Wake-Up Call

There is a high probability that future deep Puget Sound earthquakes will occur. Such an event could have a magnitude of up to 7.5, about 11 times the energy release of Nisqually. In fact, five other magnitude 6.0 or greater earthquakes have occurred in the past 100 years at irregular intervals ranging from three to 30 years.

A larger earthquake, or one with a different epicenter, could result in stronger ground-shaking and more damage than the Nisqually event. Seismically vulnerable buildings (e.g., unreinforced masonry or poorly maintained structures), unrestrained equipment, and facilities founded on soft soil likely would be the most severely damaged.

Comparing the two earthquakes, it is clear that the Nisqually shaking was not as severe, even though both were similar magnitude (energy release) events. The reason for this is the depth of the fault rupture. The Nisqually earthquake occurred at a depth of about 32 miles (52 km) below the earth's surface. Northridge occurred much closer to the surface—about 12 miles (19 km) below. The greater depth of the Nisqually earthquake fault rupture led to greater attenuation of the seismic waves before they reached the earth's surface.

Damage to Facilities

In general, the damage was predictable and most severe at locations with significant seismic deficiencies.

Structural Damage

Structural damage was limited:

- Most significant structural damage was to unreinforced masonry (URM) buildings. Typically, brick walls had partially collapsed, cracked from in-plane shear and/or bulged out-of-plane. For example, about 600 ft.^{2} (56 m^2) of an exterior brick wall fell at the top floor in a six-story, 95-year-old URM building in Seattle.
- More often, structural damage was localized, such as the cracking observed in several exterior concrete wall panels and a concrete pilaster in a concrete tilt-up structure built in 1965, in Tukwila, Wash. Steel braces and columns also were damaged in several facilities.

Nonstructural building damage occurred throughout the shaking area:

- Cracking of nonstructural interior and exterior walls (including gypsum board, plaster and URM/URM infill) often was observed. Some of the most significant damage was cracking or failure of hollow clay tile infill walls, as observed in a seven-story cold storage warehouse and in several URM buildings.
- Exterior terra cotta or brick elements fell from some buildings. This was observed in two multi-story historic Seattle buildings where cornices and tile fell.
- Suspended ceiling systems occasionally failed, also resulting in sprinkler leakage at some locations.

Equipment and Storage System Damage

In general, damage to equipment and storage systems was localized:

- Equipment shifting (chillers, air-handling units, etc.) and toppling (e.g., leg-supported tanks) were observed at several facilities. In general, only a few items were affected. It appears that items located where ground motions were amplified through the structure (e.g., in penthouses) and items where conditions were unfavorable (full tanks as opposed to empty tanks, etc.) were more likely to shift or topple. In at least one case, a shifting tank broke an attached rigid pipe, releasing more than 1,000 lbs. (450 kg) of ammonia.
- In several locations, interior HVAC equipment or piping was damaged, resulting in water leakage.
- Some damage to pallet-rack storage was observed. In one facility in Renton,

The Pacific Northwest

There are numerous faults in the Pacific Northwest lying within the shallow crust of the North American plate that are potential sources of future earthquakes. The largest earthquake in Washington was a shallow magnitude 7.4 event in 1872 under the northern Cascades. The 1918 magnitude 7.0 and 1946 magnitude 7.3 Vancouver Island earthquakes also are considered crustal events. The precise seismicity of these faults is not completely understood, but crustal faults could produce 20-60 seconds of strong ground-shaking and MMIs of VIII to IX.

Many scientists believe earthquakes with magnitudes above 8.0 have occurred in the Cascadia Subduction zone (off the coast of Oregon, Washington and British Columbia, Canada). Geological evidence suggests there were at least eight large subduction earthquakes in the last 5,000 years; the last is thought to have occurred about 300 years ago.

The magnitude of a 475-year earthquake (the earthquake level used as the basis for structural design in modern building codes) on the offshore Cascadia Subduction zone is estimated at about 8.4. Ground motion produced by subduction events typically decays very slowly over distance, meaning the event can have a simultaneous impact throughout a very large area. In addition, the duration of strong ground-shaking could be one to three minutes, as opposed to the 15-30 second duration typical of deep earthquakes beneath Puget Sound (such as the Nisqually event). This allows much more time to cause damage. A subduction event could produce MMIs in excess of VIII over a large area in the Pacific Northwest.

Wash., all the racks had been anchored except one, which toppled during the earthquake. In a facility in Kent, Wash., heavily loaded pallet racks failed. The racks appeared to be marginally anchored, and prior forklift damage may have contributed to the failure.

- Elevator counterweights were damaged in at least three facilities. In one, the counterweight reportedly fell.

Fire-Protection System Impairments

Several hundred FM Global client facilities were contacted immediately after the earthquake. Of these facilities, only 8% reported sprinkler impairments as a result of the earthquake.

- Apparently, the lack of adequate bracing on sprinkler mains and drops to in-rack sprinklers were the main factors, contributing to impairment 75 percent of the time. Consequent damage to automatic sprinkler systems mainly involved broken small-diameter piping, such as test connections, and sprinkler head impact. Also, leakage at grooved pipe coupling joints on larger pipe occurred in a few locations.
- Partial collapse of ceiling systems, roofs, brick walls or pallet racks resulted in sprinkler system impairments in at least four locations.
- Breaks of lead-ins or underground mains impaired the automatic fire-protection system at six locations.

Soil

Localized ground shifting occurred at a number of facilities founded on loose, saturated soil, including port areas adjacent to the Duwamish Waterway and several other sites in Seattle, Renton and Aberdeen, Wash. Most often, slabs and asphalt on grade were cracked or had minor settlement. At several sites, underground utilities were damaged. At least one site reported damage in a building under construction and to the foundation under an existing main building column.

Protect Yourself Against Future Events

In a future earthquake with stronger ground-shaking, damage could be much more severe. You can, however, safeguard your business.

- **Brace the sprinkler systems:** It is not uncommon for fire sprinkler systems to be inadequately braced in Pacific Northwest facilities. Although the weak ground-shaking resulted in few leaks this time, in stronger ground-shaking, leakage is more likely.
- **Protect against gas fire and explosion:** The Seattle Fire Department responded to gas leaks at 49 locations; six were interior leaks. The potential for gas leaks in a stronger earthquake is significant for many facilities. Installing earthquake-actuated gas shutoff valves, restraining natural gas-fired equipment and providing appropriate flexibility in piping can mitigate this risk.
- **Avoid spills and fire:** In the city of Kent, three chemical spills and one fire resulted from sloshing of contents from open-topped tanks. In more severe or longer duration ground-shaking, the potential for spills would be magnified.

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 Earthquake* (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)

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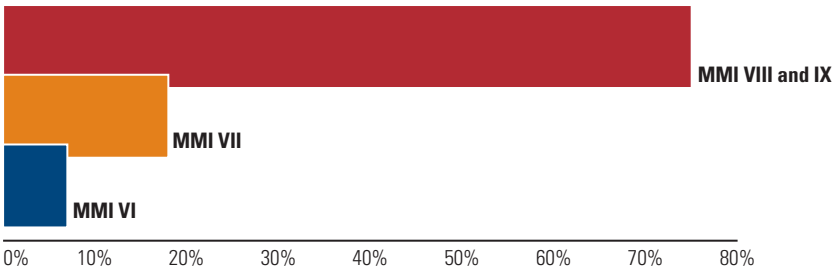
Percentage of Buildings with Sprinkler Leakage, Northridge, Calif., USA



As illustrated here, the Northridge earthquake demonstrated that sprinkler systems can fail at earthquake intensity levels above MMI VI when not braced as recommended by FM Global.

- **Retrofit older, more vulnerable buildings:** The number of older buildings in the Puget Sound area is significant. Some of these were observed to have unfavorable features (soft stories, URM construction, etc.) that may lead to very significant damage, and possibly total loss or collapse in stronger ground-shaking. Even if repairable, restoration costs could be very high, particularly where buildings have been designated as historic, contain asbestos material or have other additional cost factors. In more severe ground-shaking, hollow clay tile and URM walls could be extensively cracked, requiring major repairs.
- **Understand your soil:** Although soil failures were relatively limited, soft soil sites exist in many locations. The potential for damage to underground fire protection mains and utilities, and to items supported directly on grade (slabs, asphalt, equipment, etc.), could be high even if foundations are designed for soil instability.
- **Implement low-cost bracing solutions:** Damage to equipment, suspended ceilings, etc., modest in this earthquake, could be very significant in stronger shaking.

Protect Your Business Now

The minimal damage was more the result of low levels of ground-shaking than an indication that all buildings were adequately protected. While many facilities undoubtedly were well-designed, vulnerabilities often exist that can lead to more extensive damage in severe ground-shaking.

Modified Mercalli Intensity (MMI)
The MMI scale consists of 12 levels from I (not felt) to XII (total damage). Little damage occurs below MMI VI. Intensity above MMI X is uncommon. Some MMI descriptions:

VI	Felt by all. Some heavy furniture moved; a few instances of fallen plaster. Damage slight.
VII	Damage negligible in buildings of good design and construction; slight to moderate in well-built ordinary structures; considerable in poorly built structures.
VIII	Damage slight in specially designed structures; considerable in ordinary, substantial buildings with partial collapse; and great in poorly built structures.
IX	Damage considerable in specially designed structures; great in substantial buildings with partial collapse.