



# Improving the Safety of Schools and Other Buildings in Earthquakes

An Online Continuing Education Course for Engineers

**Course Number: S-3009**

**Credit: 3 Hours / 3 PDH / 3 CPD**

## Introduction

**T**his course outlines the earthquake risk to schools and the processes and methods that can be used to reduce it. An explanation of the nature and probability of earthquakes is provided, together with procedures for determining the earthquake threat to specific locations and for evaluating the vulnerability of a school building. An assessment of the scope and effectiveness of seismic building codes is followed by a description of current methods of designing for seismic resistance in new buildings and upgrading existing buildings. Lastly, this course presents guidance on determining acceptable risk and the use of performance-based design.

---

## The Nature and Probability of Earthquakes

**A**lthough earthquakes cannot be prevented, modern science and engineering provide tools that can be used to reduce their effects. Science can now identify, with considerable accuracy, where earthquakes are likely to occur and what forces they will generate. This information is readily available and can be obtained for local geographic regions.

### Earthquakes and Other Geologic Hazards

Earthquakes have long been feared as one of nature's most terrifying phenomena. Early in human history, the sudden shaking of the earth and the death and destruction that resulted were seen as mysterious and uncontrollable. We now understand the origin of earthquakes and know that they must be accepted as a natural environmental process. Scientific explanations, however, have not lessened the terrifying nature of the earthquake experience. Other types of phenomena sometimes accompany seismic ground shaking and are generally identified as geologic hazards:

- **Liquefaction** occurs when loose granular soils and sand in the presence of water change temporarily from a solid to a liquid state when subjected to ground shaking. Soils that are loose, not well graded, and saturated with water are prone to liquefaction. These conditions often occur near waterways such as rivers, lakes, and bays, but not always. In addition to the soil type, the probability of liquefaction also depends on the depth from the surface to the vulnerable soil layer, and the intensity of ground motion. Further, the results of liquefaction can vary from a small, uniform ground settlement across a site, to loss of foundation bearing, resulting in extreme ground settlement and horizontal movement of tens of feet (called lateral spreading). Lastly, the risk of liquefaction is directly dependent on the earthquake risk. Due to this complex set of conditions, damage potential from liquefaction is difficult to map. For all but the smallest projects, many building jurisdictions in seismic areas require that the liquefaction potential be assessed in a site-specific geotechnical report, particularly in areas of known potential vulnerability. On sites where liquefaction is more than a remote possibility, the likely results of liquefaction at the ground surface or at the building foundations is also estimated. Small settlements may be tolerated without mitigation. Larger potential settlements can be prevented by site remediation measures, if economically justified. Building on sites with potential massive liquefaction and lateral spreading may not be cost effective. Officials in some regions of high seismicity have developed maps of local areas that are potentially susceptible to liquefaction and require site-specific investigation before building/permitting begins.

- 
- **Landslides**, which involve the slipping of soil and rock on sloping ground, can be triggered by earthquake ground motion (see Figure 1). The shaking from earthquakes can cause landslides, depending on the slope, type, and configuration of soil stratum. Landslides can cause damage to improvements built within the slide area or near the top of the slide, ranging from complete destruction to distortion from relatively small vertical or lateral movements. Sites can also be threatened by landslides occurring uphill, sometimes completely offsite and quite a distance away.

Similar to liquefaction, accurate probability of land sliding is difficult to map on a regional or national scale, and this threat is normally identified in site-specific geologic hazard studies. Also similar to liquefaction, the largest portion of the risk may be a triggering event. In some cases, stabilizing small areas at risk of potential landslides may be possible and cost effective. Stabilizing larger areas at risk of landslides may not be feasible. Some regions of high seismicity have developed maps of the areas susceptible to landslides based on average slopes, geologic soil types, and the past history of sliding. Building jurisdictions require site-specific investigations for sites within these susceptible zones.



**Figure 1:**  
**School in Anchorage, AK,**  
**1964, severely damaged**  
**by earthquake-induced**  
**landslide**

SOURCE: NATIONAL  
INFORMATION SERVICE FOR  
EARTHQUAKE ENGINEERING,  
UNIVERSITY OF CALIFORNIA,  
BERKELEY

- **Tsunamis** are seismic wave movements in the ocean that travel at high speed and may result in large coastal waves of 30 feet or more. They are sometimes, and incorrectly, called tidal waves. Researchers have studied tsunamis for many years. Sites near large bodies of

---

water at elevations 50 feet or less above the water surface are susceptible. Although similar to storm surge, the height and the potential velocity of a tsunami wave represent a separate hazard and must be mapped separately. In addition to dependence on local conditions, quantification of the risk from tsunamis is difficult because not every earthquake generates such a wave. Studies considering the individual characteristics of the site and the facility are required to establish the risk and identify possible mitigating measures.

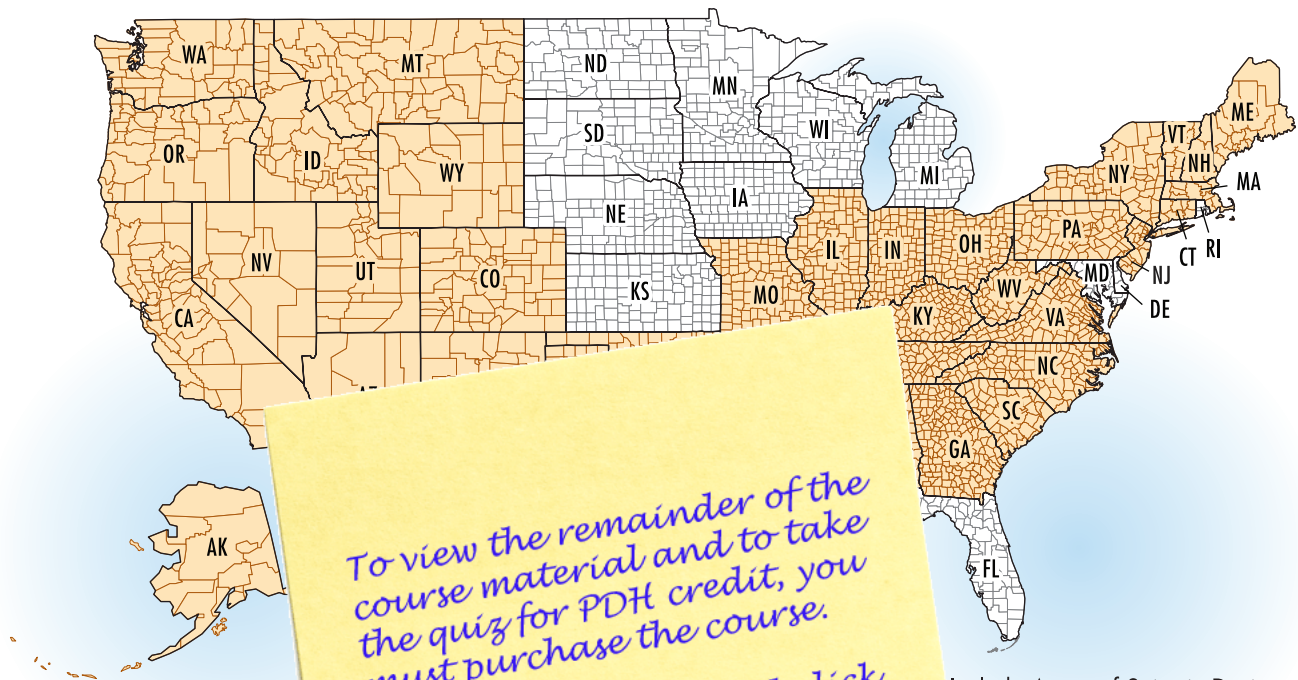
- **Seiches** are similar to tsunamis, but take the form of sloshing in closed lakes or bays; they have the potential to cause serious damage, although such occurrences have been very rare.

For all of the above geologic hazards, the only truly effective defense is the application of good land-use practices that limit development in hazard-prone locations. Seismic design and construction is aimed at reducing the consequences of seismic ground shaking, which is the primary cause of damage and casualties from an earthquake.

### Earthquakes: A National Problem

The U.S. Congress recognized earthquakes as a national problem in 1977 when it passed legislation authorizing the National Earthquake Hazards Reduction Program (NEHRP) to reduce risks to life and property in the United States that result from earthquakes. NEHRP has supported considerable research and hazard mitigation efforts since that time.

Most people now know that, although most frequent in California and Alaska, earthquakes are not restricted to just a few areas in the United States. In fact, two of the greatest earthquakes in U.S. history occurred not in California, but near New Madrid, Missouri, in 1811 and 1812. In the International Building Code (IBC) (ICC, 2009), the most common model building code in use in the United States and its territories, buildings on sites with a low enough seismic risk that specific design for seismic forces is not required are classified as Seismic Design Category (SDC) A. As shown in Figure 2, 37 of 50 States have regions with sufficient seismic risk to require designs more stringent than SDC A. The likelihood of a damaging earthquake occurring west of the Rocky Mountains, and particularly in California, Oregon, Washington, Alaska, and Utah, is much greater than it is in the East, Midwest, or South. However, the New Madrid, MO, and Charleston, SC, regions are subject to potentially more severe earthquakes with a lesser probability. According to the IBC design maps, and the USGS hazard maps, on which they are based, other locations should also plan for intermediate ground motions.



Include Areas of Seismic Design in Seismic Design Category A

Figure 2: States with

Records show that moderate to major earthquakes in other areas have “re- about 200 to 400 year return period” seismic probabilities and shorter than average return periods. Schools to be located in earthquake-prone areas should be designed assuming that a large earthquake is likely to occur at any time.

Moderate and even very large earthquakes may occur in areas of normally low seismicity. Even buildings in these regions are vulnerable to seismic damages if not constructed in accordance with building code requirements for seismic resistance. In high seismic regions, however, the earthquake threat is quite familiar. Schools in many areas of California and Alaska will be shaken by an earthquake perhaps two or three times a year and, since the early 20th century, have been built to incorporate some level of earthquake-resistant design. While the areas where earthquakes are likely to occur and the potential size or magnitude of these earthquakes are well identified, predicting the near-term occurrence of a damaging earthquake is not yet possible. Lacking useful predictions, it makes sense in any seismic region to take at least the minimum affordable prudent actions to save lives. Because most lives are lost in earthquakes when buildings collapse, U.S. seismic building code provisions require the minimum measures necessary to prevent building collapse.