

ENCYCLOPEDIA ARTICLE

Seismic risk

The probability that social or economic consequences of earthquakes will equal or exceed specified values at a site, at several sites, or in an area, during a specified exposure time. Historically the term seismic risk has been used to describe an assortment of earthquake effects that range from ground shaking, surface faulting, and earthquake-induced landsliding to economic loss and casualties. As more quantitative methods for estimating the effects of earthquakes have been developed, terminology has become more precise. Although the term seismic risk is still sometimes used in a general sense to mean the potential for both the occurrence of natural phenomena and the economic and life loss associated with earthquakes, it is useful to differentiate between the concepts of seismic hazard and seismic risk. Seismic hazard may be defined as any physical phenomena (for example, ground shaking or ground failure) that are associated with an earthquake and that may produce adverse effects on human activities.

The exposure time is the time period of interest for seismic hazard or risk calculations. In practical applications, the exposure time may be considered to be the design lifetime of a building or the length of time over which it is of interest to estimate numbers of casualties. For example, the risk that a certain number of casualties will occur is the probability associated with all combinations of seismic hazards that may result from the earthquakes and all possible numbers of casualties resulting from those hazards. A general expression for the total risk is given by the equation below ,

$$P(R_i) = \sum_{\text{all } j} P(R_i|S_j)P(S_j)$$

in which $P(R_i)$ is the probability that the state of the system is i , S_j means that the seismic hazard is level j , $P(S_j)$ is the probability that seismic hazard is level j , and $P(R_i|S_j)$ is the probability that the behavior state of the system will be R_i , given that seismic input, S_j , takes place. Thus, evaluation of seismic risk requires that the seismic hazard be specified.

Seismic hazard analysis

A seismic hazard can be any one of various physical phenomena that result either from surface faulting during shallow earthquakes or from the ground shaking resulting from an earthquake.

Physical phenomena

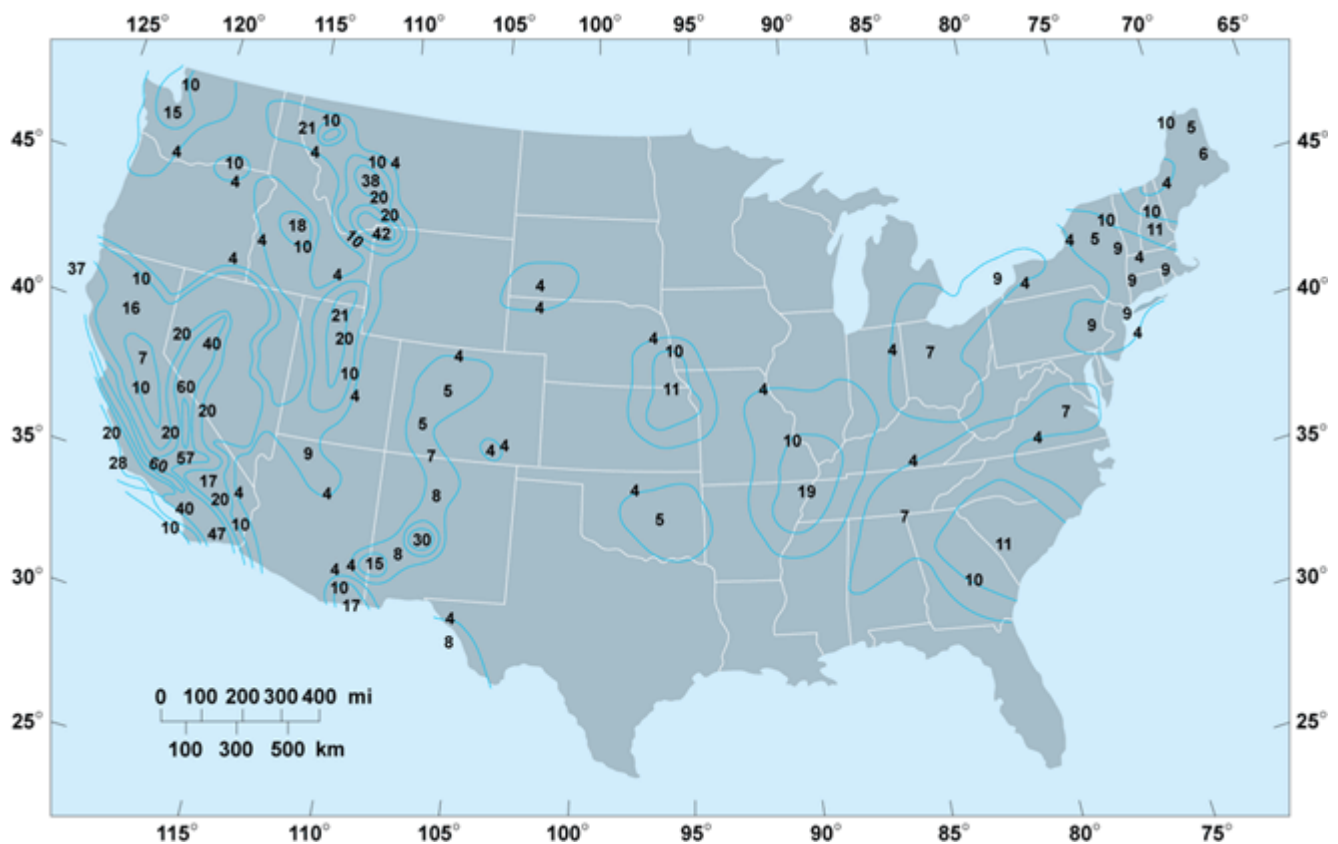
Surface faulting or rupturing of the Earth's surface usually occurs only in shallow earthquakes (12 mi or 20 km depth or less), but is not observed in all shallow earthquakes. The relative displacement of the two sides of a fault and the fault length both increase approximately exponentially with earthquake magnitude. The relative displacement between the two sides of a fault during great earthquakes may be as much as 40 to 90 ft (20 to 30 m), and the fault length in a single event may be 180 to 240 mi (300 to 400 km).

Landslides may be triggered by earthquake ground shaking, and under certain conditions can be catastrophic. The magnitude 7.4 earthquake that occurred off the coast of Peru in 1970 triggered a landslide above the village of Yungay in the Peruvian Andes, which resulted in the death of more than 15,000 people. Ground shaking also may cause a complex type of ground failure known as liquefaction, that is, the transformation of a granular material from a solid state into a liquefied state as a consequence of increased pore-water pressure. Liquefaction is known to cause widespread damage when concomitant to large earthquakes, as has been exemplified at Puerto Montt, Chile (1960), Niigata, Japan (1964), Anchorage,

Alaska (1964), San Fernando, California (1971), and Cauçete, Argentina (1977). Even moderate levels of ground shaking may result in liquefaction and subsequent ground failure. See also: Landslide

Earthquakes may also result in tsunamis, which are water waves with periods of about 5 to 60 min that are believed to be caused by underwater tectonic displacements. Tsunamis may also be caused by landslides and subaqueous slides that may or may not have been triggered by an earthquake. Tsunamis have caused extensive property damage and life loss, particularly on Pacific islands and in coastal areas on the periphery of the Pacific Ocean, for example, those associated with the May 23, 1960, Chilean earthquake and the March 27, 1964, Alaskan earthquakes. See also: Tsunami

Acceleration hazard map of the United States. The numbers represent the horizontal acceleration in rock with a 90% probability of not being exceeded in 50 years. The acceleration is expressed as a percentage of the acceleration of gravity ($\approx 10 \text{ m/s}^2$ or 32 ft/s^2). Therefore the numbers represent units of 10 cm/s^2 (4 in./s^2). Other numbers represent the highest acceleration attained within the contours. (After S. T. Algermissen and D. M. Perkins, *A Probabilistic Estimate of Maximum Acceleration in Rock in the Contiguous United States*, U. S. Geol. Surv. Open-File Rep. 76-416, 1976)



Maps

Until about 1965, seismic hazards were estimated almost exclusively by use of deterministic methods. A number of seismic zoning maps have been prepared for the United States which provide estimates of earthquake effects. These have been compiled on the basis of a consideration of the regional geologic structure and its relationship to the size and spatial distribution of historic earthquake activity and of the resulting earthquake effects, described in degrees of intensity.

An intensity scale is a descriptive scale of earthquake effects arranged in degrees of increasing severity. The intensity scale most commonly used in the United States is the Modified Mercalli Intensity Scale (1931). This scale has 12 degrees, with I signifying earthquakes not felt or felt only rarely, under especially favorable

circumstances, and XII signifying total destruction. Degrees I–V of the scale are based mostly on human reaction and perception of ground shaking; degrees VI–IX are based principally on the severity of damage to structures; and degrees X–XII are based mainly on geologic effects.

Deterministic hazard maps, which outline areas of potential fault rupture, landsliding, and liquefaction, have also been prepared.

Probabilistic models

Since 1965, interest in the probabilistic treatment of seismic hazard has increased. The most widely used (and perhaps the simplest) model assumes that earthquakes are exponentially distributed with regard to magnitude and that they follow a Poisson arrival process in time. The Poisson assumption is not in accord with concepts of the nature of earthquake occurrence, but it is suitable for the engineering evaluation of earthquake hazards. The occurrence of moderate to large earthquakes can closely approximate a Poisson process, and these earthquakes are the most important events in hazard and risk analyses. In addition, a suitable time-dependent model for large-earthquake occurrence is difficult to specify because of insufficient data. Bayesian statistics have been used with some success to model the earthquake process, but specification of prior probabilities will present difficulties until the earthquake mechanism is more clearly understood. A time history of ground motion resulting from an earthquake at any particular location of interest completely describes the ground-shaking hazard, but this information is rarely available. Seismic intensity has been used frequently as a mapping parameter for seismic hazard, but because of its descriptive nature, it is somewhat unsuitable for formulating engineering specifications for the design of earthquake-resistant structures. The seismic ground-shaking hazard has been specified also by using peak ground acceleration, velocity, or displacement as a mapping parameter. Single-parameter descriptions of ground motion are not entirely satisfactory for the earthquake-resistant design of buildings, because the properties of ground motion that cause building damage cannot be described entirely by a single parameter. A probabilistic acceleration map of the United States is shown in the **illustration**. It has been used by the Applied Technology Council in the construction of two maps of the United States: one for effective peak acceleration and another for effective peak velocity. These two maps are used in constructing generalized spectra for ground motion on different kinds of superficial materials. These spectral shapes are considered to be the descriptions of ground motion for the determination of suitable earthquake-resistant designs for structures. The ground motions specified have an approximately 10% probability of being exceeded at least once in 50 years.

Risk studies

Seismic-risk analysis has been defined here as it involves probability, but risk studies can be deterministic or probabilistic, depending upon the requirements of the particular study. Practical techniques for probabilistic risk analysis in the earthquake-resistant design of structures have become highly developed. Seismic-risk estimates conducted on a regional or national basis for disaster preparedness and for economic studies have been largely deterministic in nature. Risk studies provide the framework for the evaluation of acceptable risks, those judged appropriate for determination of structure design or development of social or economic policy. Such analyses on a regional and national scale have yielded significant results. Studies have predicted that about 70% of the earthquake damage in the United States will occur in the western regions, even though this area contains only about 50% of the construction in the country.

While large earthquakes cause serious losses, the potential for cumulative losses from moderate earthquakes as least as great as those from individual large earthquakes exists because of their much more frequent occurrence. The Richter magnitudes for moderate earthquakes range from 5.5 to 6.5.

Earthquake losses in the United States are expected to become progressively larger with time because of the increase in population and the dispersion of the population. The difficulties in estimating seismic risk on a regional and national level are great because of the problem in estimating the construction characteristics, spatial distribution and value of structures, and their probable resistance to earthquake ground shaking. Seismic risk also is involved with the nature and importance of secondary economic losses resulting from an earthquake, such as those associated with suspension of business activities during building repair or restoration of utilities, increases in repair costs because of material shortages, and lack of skilled workers. The difficulty of evaluating total earthquake loss has prevented accurate and complete estimates of earthquake tolls. See also: Earthquake; Risk assessment and management

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