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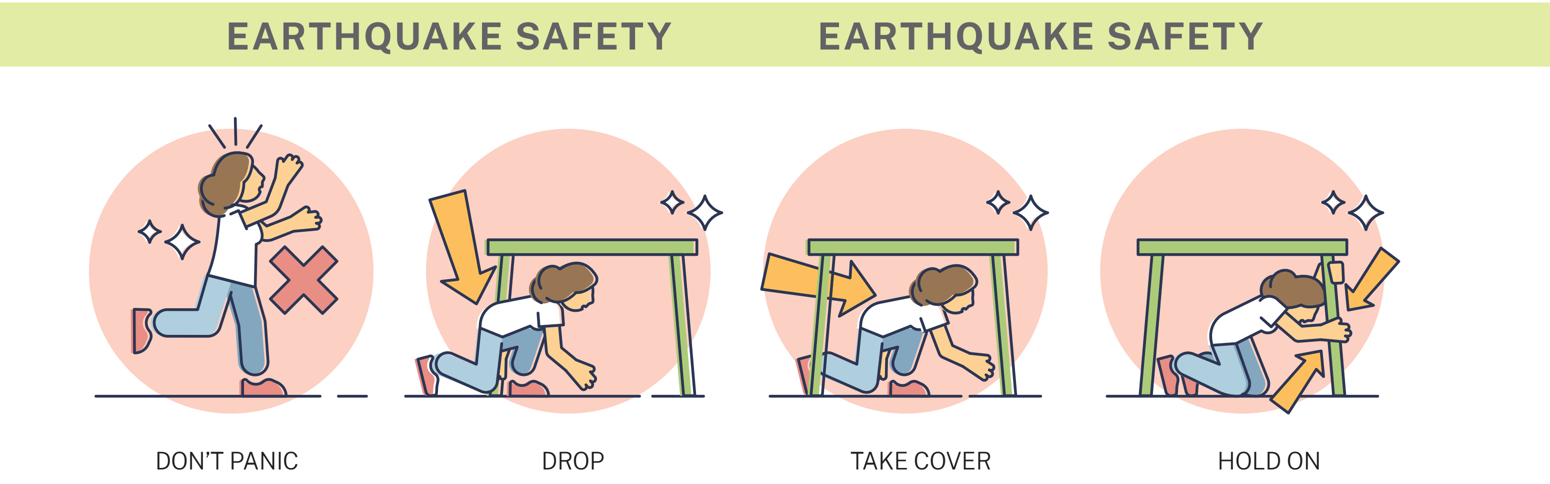

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DANGERS FROM THE DEPTHS

In populated regions, strong earthquakes are among the most devastating natural disasters. But minor tremors usually go unnoticed, as their existence is only detected with the aid of precise measuring instruments.

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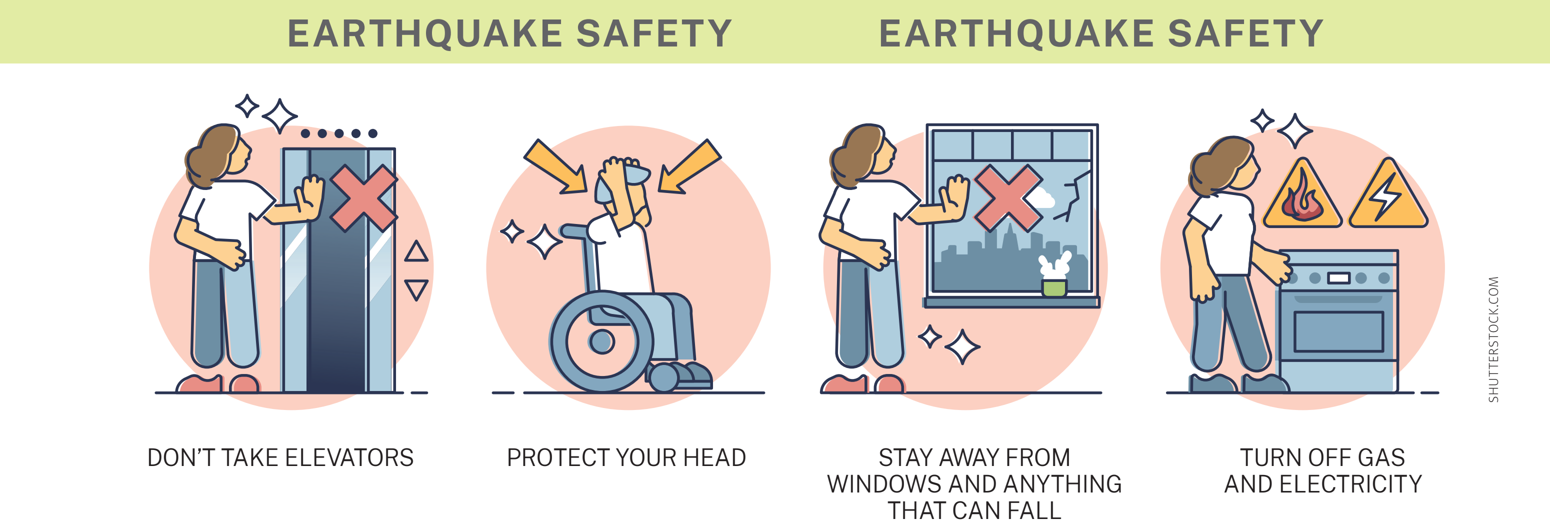
Earthquakes are caused by natural processes taking place deep within our planet, more specifically the movement of the tectonic plates of the lithosphere, the Earth's outermost layer. These processes lead to the formation of mountains and changes in the distribution of continents. An earthquake is typically seen as a natural catastrophe and may have disastrous consequences. Humans have experienced earthquakes since the beginning of time, but their impacts became more dangerous in tandem with the rise of cities, which became more densely populated as civilizations developed. Earthquakes damage buildings and infrastructure and therefore pose a deadly threat to people, but they rarely kill wild animals and other living organisms in their natural environment.

Strong earthquakes, which may have catastrophic consequences, occur only along active fault lines, near the boundaries between tectonic plates. The Earth's crust is made of plates that move relative to one another at an average rate of 10–40 mm a year – the movement of these plates is decribed by plate tectonics. There are three types of plate movements. The first of these occurs when plates collide, and one plate sinks



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under another. The second occurs when plates move apart, and the space between them is filled with material flowing out of the Earth's interior. Thirdly, the plates can slide horizontally past one another. The corresponding three types of plate boundaries are known as subduction zones, rift zones, and transform boundaries, respectively. Earthquakes occur because the movement of tectonic plates relative to one another is not continuous or constant. Friction prevents tectonic plates from sliding smoothly, leading to the buildup of pressure and stress along the boundary between them. Eventually, the plates press against each other so strongly that the resultant stress exceeds the friction along a smaller or larger section of the boundary between the plates, leading to a sudden fracture and one-time displacement of the rock masses, which causes an earthquake. The most powerful earthquakes occur in two regions: the Circum-Pacific Belt (also called the Pacific Ring of Fire) and the Asian-Mediterranean zone, which stretches from the Philippines, through the Himalayas and Asia Minor, to the Mediterranean basin. More than 100,000 earthquakes are recorded worldwide each year, and the number of small quakes recorded grows every year as a result of the growing number of seismic stations and increased sensitivity of the seismographic network.

Measurements

Most earthquakes are detectable only by sensitive measurement instruments. Only some of them are sizeable enough to be felt by people, and the catastrophic ones occur very rarely. Assessing the severity of seismic events has posed a key challenge since the early days of seismology. The concept of "magnitude" was introduced by Charles Richter in 1935 as an absolute measure of the size of an earthquake. At the time, it was a measure based on empirical data, in particular the observed maximum wave amplitude recorded by the Wood-Anderson seismograph, and called the Richter scale. In 1979, Hanks and Kanamori linked magnitude to the "seismic moment," which is the result of the multiplication of the average displacement of rock material during an earthquake, the area of the fault where the displacement occurred, and the rigidity of the rock fault. The seismic moment can be computed from modern seismic records. Magnitude is proportional to the logarithm of the seismic moment and is a dimensionless quantity. Each increase in magnitude by one unit means an approximately 30-fold rise in the energy released by the tremors, including a 10-fold rise in the movement during the earthquake, occurring over an area that is three times larger. An earthquake can have any magnitude, and it can even be represented by a negative number. The largest earthquake recorded instrumentally had a magnitude of 9.5; the smallest ones, recorded in laboratories, have negative values.

Aftermath

Most tremors, recorded only by measurement instruments, are so small that they essentially have no impact. To pose a threat, a seismic event has to be medium-sized or large. However, such events are quite rare and account for a negligible share of all earthquakes. The damage caused by an earthquake is not directly related to its size. Sometimes medium-sized quakes cause a catastrophe, while much larger ones cause no damage. The location of the earthquake is the most important factor here: densely populated areas sustain more damage than less populated ones.

An earthquake may have catastrophic consequences, which include ground shaking, landslides, ground liquefaction, and tsunamis. Shaking is the first and usually the most spectacular consequence: it destroys buildings, and the falling debris may kill people. Those who are unaccustomed to earthquakes often panic and want to get out of a shaking building as fast as possible. But being outside is typically even more dangerous due to falling pieces of façade and fragments of glass. In addition, a building is more likely to collapse in an outward direction than into itself. When the tremors stop, the danger does not go away: the most significant threat is then posed by damaged electrical, water, and gas installations. Rescue operations are hindered by damaged roads and secondary earthquake-induced phenomena such as aftershocks and landslides.

Aftershocks are smaller earthquakes that occur in an area recently affected by a more powerful one. A strong earthquake causes a shift in rock masses and releases built-up stress, but never brings it down to zero. A rock mass torn apart by a large earthquake must have time to adjust to the new situation, which proceeds in part through smaller earthquakes. After extremely large earthquakes, aftershocks can continue for years, but their number and strength dwindle over time. After the 9.5 magnitude earthquake in Japan in March 2011, aftershocks continued to be recorded for the following 10 years.

The consequences may also include tsunamis. These occur in the aftermath of earthquakes whose hypocenter is situated not too deeply under the seafloor. The vertical movement of the seabed uplifts the water above it, giving rise to major waves. Out in the deep ocean, a tsunami can move at a speed of 300 km to 850 km per hour. In the open sea, it is a relatively harmless, very long wave. But when it reaches the coast, it slows down significantly and the water surges. The devastating power of tsunamis made themselves evident following the Sumatra earthquake in 2004 and the earthquake in Japan in 2011. In both cases, the tsunamis were the direct cause of most of the 200,000 and 20,000 deaths, respectively, and the tsunami following the earthquake in Japan moreover led to the failure of the Fukushima nuclear power plant.

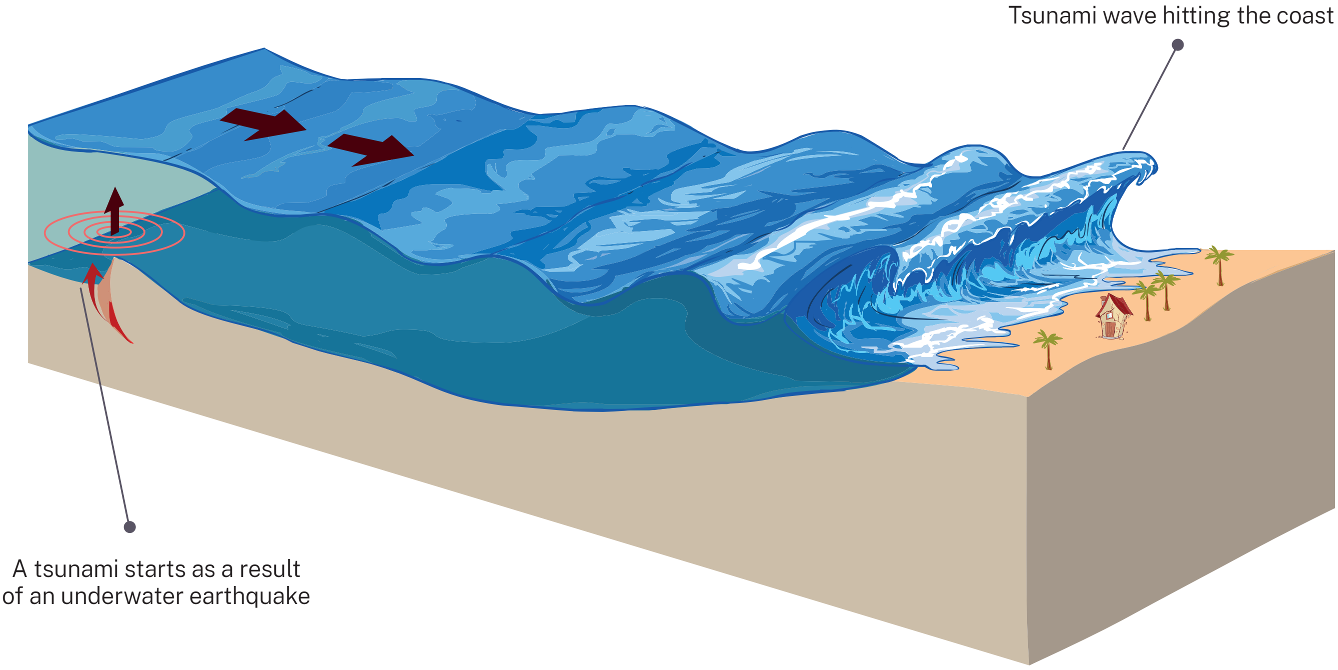
The final stage of a seismic disaster involves further delayed effects, mainly famine and disease. Famine can result from the destruction of food supplies, agricultural fields, irrigation systems, and the food processing industry, as well as the infrastructure needed to transport goods. Diseases, on the other hand, result from the contamination of water sources and the decomposition of animal and plant remains.

Risk assessment

Despite decades of scientific advances, it is currently not technologically possible to accurately predict the location and time of strong earthquakes. However, a probability-based forecast can be made based on information about the locations, frequency, and magnitude of known earthquakes. We can compare such forecasting to weather forecasting, which is also not perfectly predictive but generally regarded as functional and useful.

One major difference is that seismology deals with a much larger time scale. For example, large earthquakes may occur in the same area every several hundred years. Seismologists continually generate statistical forecasts called seismic hazard assessments. This enables them to calculate the probability that an earth-

Earthquake causing a tsunami



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A devastating magnitude 7.8 earthquake hit the Turkish province of Kahramanmaraş in 2023

quake of an assumed magnitude will occur at a specific location over a specific timeframe. Right now, the occurrence of a large earthquake in a given place in the next 30 years can be predicted with roughly the same level of accuracy as a daily rain forecast. Unfortunately, such a prediction is worthless from the point of view of everyday life. A vast earthquake-prone region cannot be simply evacuated for an entire generation. Were this to be done, the economic and social losses would be many times greater than the damage caused by the quake.

Statistical forecasts are more likely to be used to determine the probability that tremors of certain intensity will occur at a specific place and within a specific period of time. Such forecasts are used by civil engineers to design buildings that should withstand specific conditions, including ground shaking caused by earthquakes. Such forecasts exist for many regions of the world – the larger the statistical database (the more earthquakes that occurred and were recorded in a specific area), the more accurate such forecasts are. Assessing the hazards related to the phenomena caused by an earthquake is the first step towards estimating the seismic risk, or determining the probability of harmful effects, including human casualties. This risk depends on the seismic hazard and such factors as the age and type of buildings and infrastructure, population density, the type of land and land use, and the time of day when an earthquake may occur. To put it in simple terms, a large earthquake in an uninhibited area poses a high seismic hazard but a low seismic risk.

Minimizing the effects of earthquakes requires that seismic hazards and geological conditions be taken into account during the design and construction of infrastructure in earthquake-prone areas. This is particularly true for strategic facilities like nuclear power plants, dams, toxic waste tanks, and so on. Such goals are often accomplished by complying with construction standards that conform to guidelines based on seismological and engineering knowledge. Examples include the EU standard called Eurocode 8, which is used for the design of structures for earthquake resistance. Sometimes such standards are ignored, as demonstrated by what happened in Türkiye this year. Buildings outside the city of Gaziantep did not meet the stricter building standards despite the 90% probability that a strong earthquake would occur in the region in the following 20 years. In Türkiye's case, the construction standards could be legally ignored following the payment of an additional fee during the process of obtaining relevant permits. This probably resulted in the faster and less expensive construction of houses and office buildings, but also to thousands of deaths in the February 2023 earthquakes. ■

Further reading:

U.S. Geological Survey on the science of earthquakes: https://www.usgs.gov/programs/earthquake-hazards/science-earthquakes

Stanford University research on earthquakes: https://earth.stanford.edu/news/science-behind-earthquakes

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