The nature of seismicity: forms and causes
3.1.5.4 Hazards

What you need to know
The nature of seismicity and its relation to plate tectonics.
Forms of seismic hazard including earthquakes, shockwaves, tsunamis, liquefaction, landslides.
Spatial distribution, randomness, magnitude, frequency, regularity, predictability of hazard events.

Introduction
The crust of the Earth is made up of seven major plates and several minor ones. They are all on the move. At the plate margins, where plates are travelling in different directions, stress can build up. When the pressure - resulting from a build-up of friction - is released, a series of tremors or earthquakes can be felt.

Spatial distribution of earthquakes
The location of earthquakes is closely associated with plate margins.

- At destructive plate margins, earthquakes tend to occur at depth. They are associated with the subduction of one crust under another in a narrow area known as the Benioff zone, where compressional forces are greatest. Earthquakes occurring here can be very powerful and may take place under the sea close to heavily populated coastal zones; this makes the threat of dangerous tsunami much more likely.
- At constructive plate margins, earthquakes tend to be much shallower and less powerful. They are associated with tensional forces in the crust and occur along mid-ocean ridges away from land or large populations.
- At conservative plate margins, earthquakes tend to be shallow focused. Here the continental plates are dragging past each other and compressional forces are high. Earthquakes occurring here can be very powerful and damage can be severe if they occur in densely populated areas.

Magnitude of earthquakes
Most of the earthquakes that occur each year are too small to be felt. With increasing numbers of seismometers available to measure earthquakes and people living in more remote locations, we are reporting earthquakes more today than we have in the past. Earthquake magnitude can be measured on the **Richter scale**, a logarithmic scale 1-10, where 7 on the scale is ten times more powerful than a 6 and 100 times more powerful than a 5. Around 120 earthquakes of magnitude 6 and above occur each year, of these 20 measure 7 or above on the Richter scale (a major earthquake). Great earthquakes (measuring 8 or above) tend to occur once or twice a decade and for the people living at the epicentre it can completely destroy their community. Although the Richter scale is useful for measuring small-scale earthquakes, its accuracy decreases for larger earthquakes. The **Moment Magnitude scale** is a measure of the total distance a fault has moved and the force needed to generate it, known as the moment release of the earthquake, and is now used worldwide by seismologists. The **Modified Mercalli Intensity** (MMI) scale is more a measure of the effect on people and human infrastructure. The 12-point scale classifies the impact of the earthquake and indicates severity on humans rather than objective measurement of earthquake force. A moderate earthquake under a major city can register higher on the MMI than a strong earthquake in a largely unpopulated region.

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While 85 per cent of earthquakes occur near plate boundaries, some occur in intraplate locations. These earthquakes, internal to plates, can highlight undiscovered fault lines and areas of stress in crustal rocks, but they can also relate to other causes such as isostatic recoil, when the weight of glaciers is lifted as they melt and the crust lifts. Iceland's surface has lifted by 60m since the peak of the last ice age; with uplift comes stresses and strains in crustal rock and consequently earthquakes.

Earthquakes can also be a result of human activity. These quasi-natural earthquakes are most commonly associated with the crustal deformation caused by the weight of water stored in reservoirs. Some researchers have attributed the 7.9-magnitude Sichuan earthquake in May 2008, which killed an estimated 80,000 people, to the construction of the Zipingpu Dam in China and the resulting pressures imposed on the rocks underlying its reservoir once at full capacity.

Primary seismic hazards

- Earthquakes are the release of energy in the form of seismic waves from the point known as the **focus** where the pressure is released. Many earthquakes result from movements along fractures in rocks called faults. One of the most studied faults is the transform plate margin of California, USA. Years of research have found that this is not a single fault line, but a complex zone of faults. Once pressure is built up in a rock and released, seismic or shockwaves radiate out in all directions. The point on the surface of the Earth directly above the focus is known as the **epicentre** and can be the location of greatest damage. There are four types of seismic waves. **P waves** and **S waves** are body waves that travel through rock; P waves are the fastest and can also travel through liquids. When body waves arrive at the epicentre they cause people and property to rise and fall. This can sever water, gas and other infrastructure. Escaping gas frequently ignites and is difficult to extinguish, as ruptured water mains are unable to supply water to the emergency services.

  Surface waves (**Rayleigh** and **Love Waves**) travel out from the epicentre and they represent the most severe hazard to people and property. The rocking motion associated with these waves can shake and topple buildings like dominoes. Bedrock type can also affect the extent of damage to buildings. Soft clays and unconsolidated bedrock tend to wobble like jelly and amplify shaking. Solid bedrock tends to limit shaking. At Kobe, Japan, the port experienced severe damage as a result of the amplification of ground waves through the soft sands and muds it was built upon. Similarly, the Marina District of San Francisco, built on bay fill and muds was devastated as a result of the ground waves of the 1989 Loma Prieta earthquake. In general buildings constructed on solid bedrock are much less likely to suffer damage or collapse than those located on soft sediments.

Secondary seismic hazards

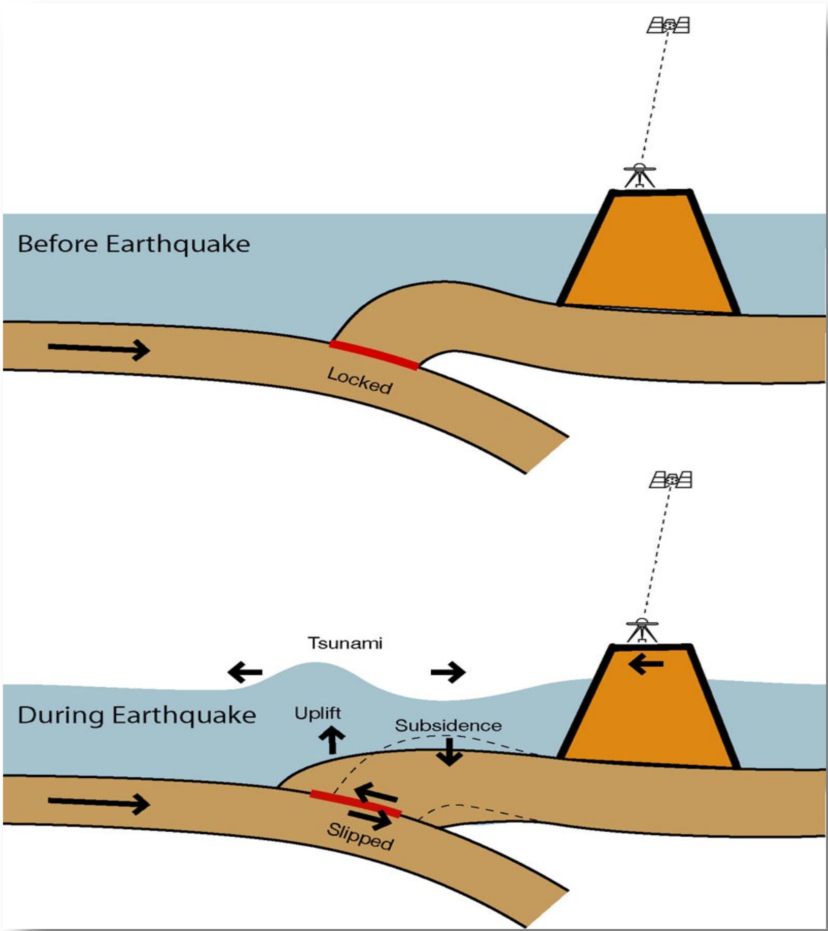
- ***Soil liquefaction***

When seismic waves travel through soft sediments, they cause it to behave as if it were a liquid, due to an increase in pore water pressure. It affects unconsolidated sediments at depths of less than ten metres, which are saturated with water. As a result of soil liquefaction, the foundations of buildings become unsupported and consequently they sink or topple over. During the Christchurch earthquakes that struck New Zealand in 2011, liquefaction was largely responsible for the extensive damage to residential properties. Soil liquefaction is most dangerous when it causes the collapse of road and rail supporting structures, as happened to the San Francisco–Oakland Bay Bridge and the Cypress Street Viaduct (Nimitz Freeway) during the Loma Prieta earthquake in 1989.

- ***Tsunami***

When a submarine earthquake occurs it can generate seismic waves that, if large enough, can generate a tsunami in the ocean. The rapid deformation of the sea bed can uplift a column of water as the oceanic crust is thrust upwards. The resulting collapsing column of water acts like ripples in a pond and radiates energy outwards from the focus.

Some 90 per cent of damaging tsunami occur in the Pacific Basin as they are generated at subduction-convergent plate margins, particularly those bordering Japan, the Aleutians and South America. The magnitude 9.0 Tōhoku Earthquake which hit Japan in 2011, triggered a powerful tsunami with waves that reached up to 40 metres in height. The effects of the tsunami were felt around the world, but were most severe in north-east Japan where 130 000 homes collapsed, 4.4 million households were left without electricity and over 16,000 people died.



Source NASA (public domain).

- ***Landslides***

  Sudden ground shaking can cause slope failure on even gentle-slopes. In many earthquakes, particularly in mountainous zones, landslides can be more dangerous that the primary ground shaking. Between 200 and 300 million cubic metres of landslides occurred as a result of the Gorkha earthquake that struck Nepal in April 2015. They blocked some of the key routes to Kathmandu along the Langtang valley and obstructed the entire valley along the Trisuli River. An avalanche triggered by the quake swept through a Mount Everest base camp, killing 17 and injuring 61, making it the deadliest day in Everest history.

The predictability of hazard events

We know much about where earthquakes are likely to occur, due to their association with plate margins. However, predicting when earthquakes will occur is almost impossible. Seismologists are specialist scientists that study earthquakes. Hazard mapping can help to predict where the next earthquakes might occur. Each time an earthquake strikes, it is mapped. Places on plate margins that have not recently experienced an earthquake have a higher strain building up in the crustal rocks and a higher probability of experiencing an earthquake. This 'gap theory' can be used to provide earthquake probabilities and help authorities plan for possible hazard events. The 2015 Gorkha earthquake in Nepal was predicted back in 2013, as measurements suggested that there was sufficient accumulated energy to produce a great earthquake (magnitude 8). The precise moment of occurrence was more difficult to define, however. If inhabitants don't have faith in earthquake predictions made by scientists, or forecasts have proved to be inaccurate in the past, they are less likely to heed warnings of impending seismic activity.

Attempts to predict earthquakes involve monitoring pre-existing fault lines. This can be expensive as the precise time and location of earthquakes is unknown. The Hayward fault along the eastern side of San Francisco Bay is arguably one of the most hazardous faults in the world and also the most studied.

Monitoring methods include the following:

- Tiltmeters and magnetometers are used to detect changes in the ground height and local magnetic field.
- Seismographs can detect foreshocks prior to the main seismic event.
- Water can be measured for radon gas and changes in the height of the water table.
- Strainmeters can monitor the increase in stress experienced in crustal rocks.
- Unusual animal behaviour can indicate an imminent earthquake. Horses, dogs, birds and other animals seem to sense electromagnetic disturbance as rock friction increases. Immediately prior to the devastating Boxing Day earthquake in the Indian Ocean and resultant tsunami affecting much of the coast of south east Asia, working elephants were seen to become extremely anxious and break their leg chains before running inland into the forest.

