7 Geohazards

Indtroduction :

In Chapter I, we learned about dynamic processes of the Earth. All layers of the Earth (internal, surface and atmospheric) are continuously under the process of evolution, equilibration and interaction. Amongst these, the surface layer is of greatest concern to humans, especially when these natural processes act as hazards or geo-hazards. Geohazards are geological and environmental conditions that may lead to widespread damage or risk to life and infrastructure based on some long-term or short-term natural processes. Some of the most significant geohazards include: landslides, debris flows, snow/ rock avalanche, volcanoes, earthquakes, tsunami, cloud burst and flash floods, glacial lake outbursts and coastal erosion. Amongst these, earthquakes, volcanoes and landslides make the most common geological phenomena or happenings over the years as great disasters.

EARTHQUAKE

The 1755 Lisabon earthquake in Portugal that killed 32000 people was the benchmark for concerted efforts on earthquakes giving birth to the branch of seismology (seismos means ‘earthquake’ in Greek). Afterwards, some of the deadliest earthquakes like Shaanxi (China) in 1956 with a death toll of 8,30,000 and Tang-shan (China) in 1976 killing 7,00,000 lives encouraged funding, research and detailed studies in Seismology. The devastating earthquakes that shook India includes Assam (1897), Kangra (1905), Nepal-Bihar (1934), Assam (1950), Koyna (1967), Killari (1993), Kutch (2001) and Nepal (2015). Earthquakes are the indicators of the dynamic and unstable nature of the Earth’s interior apart from the expressions of plate interactions. On an average, more than a million earthquakes of varying intensities occur annually, resulting over 10,000 deaths all over the world. A detailed knowledge of the earthquakes is therefore required to understand these major geohazard activities.

Seismology deals with the behaviour of the seismic waves produced by earthquakes. The waves transfer energy (and not matter) from one place to another by vibration of particles. By anology, these waves are similar to the waves (/ripples) produced when a stone is dropped into a pond of calm water (fig. 7.1). Waves travel in all directions and their amplitude decrease with distance of travel from the point (/focus).

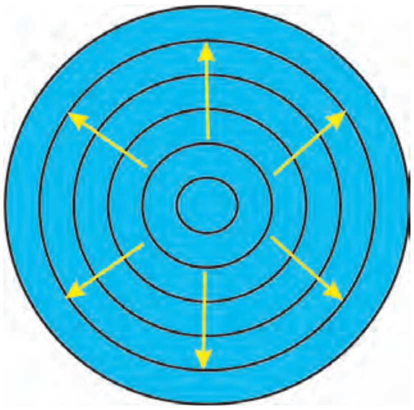


Fig. 7.1 : Visualization of ripples to understand the propogation of seismic waves due to an earthquake

Mainly two types of particle motion (oscillation) occur in this instance. When the particles oscillate perpendicular to the direction of propagation such waves are termed as transverse waves and when the oscillations are parallel to the propagation those are called longitudinal waves. An earthquake produces similar kind of waves in the Earth's crust with the transverse waves known as secondary or S waves and the longitudinal waves are primary or P waves.

Origin of the Earthquakes :

Earthquakes are explained by plate tectonics and the elastic rebound theory. The elastic rebound theory was proposed by H.F. Reid of Johns Hopkins University in 1906. It says that the constant motion of rocks along one side of a fault boundary causes the rocks on the opposite side to bend (fig. 7.2). The bending leads to a build-up of elastic energy which is created when a rock is deformed elastically, like a stretched rubber band. Rocks can also be deformed non-elastically, as a combination of the two. Frictional forces holding the rocks together are overcome and the rocks break at the weakest point along the fault plane, known as the focus of the earthquake (fig. 7.2). The deformed rock experiences slippage and then snaps back to its original position. The energy released by this slippage causes earthquake vibrations.

The energy released by the earthquake travels through the Earth in the form of waves classified as primary (P), secondary (S) and surface waves (L and R). The sudden breaking also called rupture usually results when the tectonic forces develop the strain beyond the limit of their strength (the elastic limit). When the shear (/frictional) forces are steadily increased between the two blocks of rocks separated by an existing fault, initially there is no movement. Finally, when the strain exceeds the strength of the fault, it results in rupture that extends rapidly along the fault plane. This allows the blocks on either side of it to return into less strained state. The energy that had been accumulating over time in the strained volume of rock is then suddenly released.

Science of seismology deals with the fundamental concepts of origin of the earthquake and its tectonic relationship, behaviour of rocks under different stress conditions, locating the earthquake, measuring the energy released by an earthquake, earthquake prediction and recurrence, building of earthquake resistant structures and long term behavior of faults.

Terminology used in Seismology :

The subject of seismology uses a universal terminology to describe the phenomenon. Following are the most common terms frequently used to explain the earthquakes.

i) **Focus :** It is a point within the Earth along the fault plane where the earthquake originates.

ii) **Epicentre :** This is the point on the Earth's surface, which is vertically above the focus.

iii) **Isoseismal lines :** Imaginary lines joining points on the Earth's surface, which have the same earthquake intensity.

iv) **Focal depth :** Vertical distance between focus and epicentre of an earthquake is called as focal depth or depth of focus.

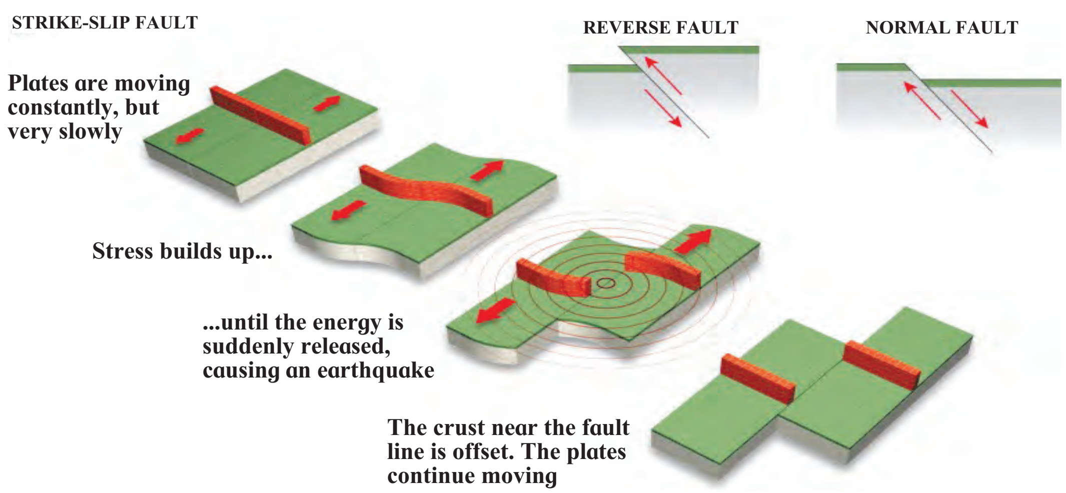


Fig. 7.2 : Diagrammatic representation of elastic rebound theory proposed by H. H. Reid to explain the origin of the earthquake

Depending upon the depth of focus three types of earthquakes are recognized :

a) **Shallow focus earthquakes :** Depth of focii within ~60 kms from the surface. These earthquakes are large in number and more disastrous.

b) **Intermediate focus earthquakes :** Depth of focii is between ~60 - 300 kms.

c) **Deep focus earthquakes :** Focal depth is more than 300 kms and upto 700 kms. These are recorded on a global scale and are less disastrous.

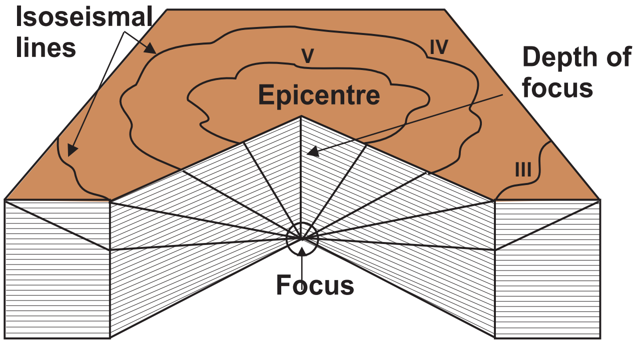


Fig. 7.3 : Focus, Epicentre and Isoseismal lines

Seismogram :

The seismogram is the record that consists of various types of zig-zag lines, that are intermittently recorded in between almost straight lines. The zig-zag lines represent the seismic waves generated by the earthquake, while straight lines are characteristic of the quiet time span, when there is no seismicity (fig. 7.4).

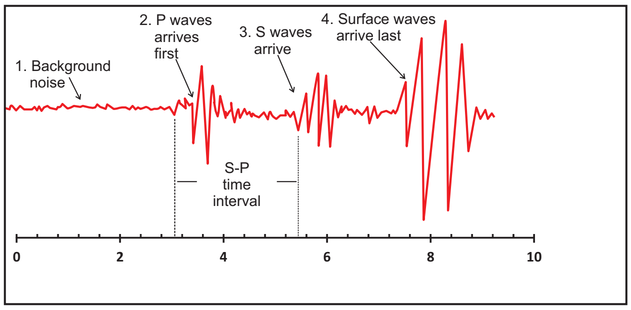


Fig. 7.4 : A typical seismogram

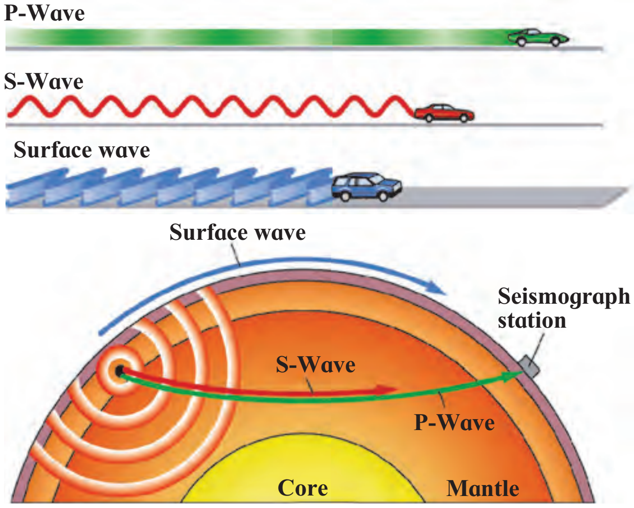
Seismic Waves :

The energy released by an earthquake can be traced in the form of seismic waves. Seismic waves travel through various layers of the Earth to reach a detector instrument.

Seismic waves are of two types (fig. 7.5), i.e., body waves and surface waves. The body waves are further divided into :

1) P waves also called compressional/ longitudinal/primary waves are the first to generate and travel fastest at velocities between 1.5 and 8 km/sec in the Earth's crust.

2) S waves also called shear/ translational/ secondary waves travel at 60% to 70% of the velocity of P waves. This can be reasoned as P waves shake the ground in the direction of propagation, while S waves shake perpendicularly or transverse to the direction of propagation.



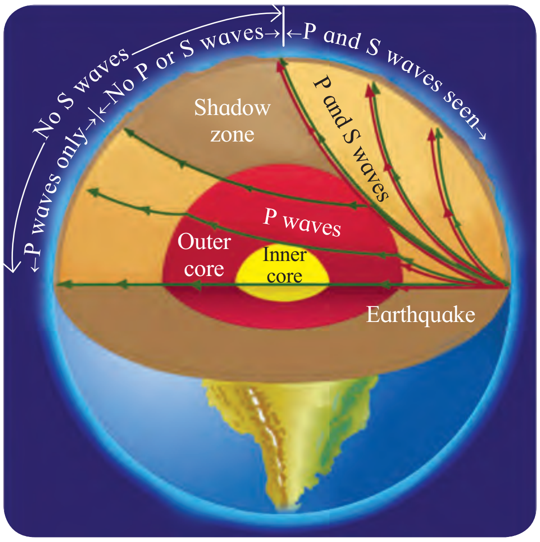
(**Source:**https://prezi.com/ctor9n6ebotf/lesson-11-cat-events/)

Fig. 7.5 : Types of seismic waves and their relative velocities

The second type of waves called surface waves travel along the surface of the Earth are divided into L waves and R waves. The L waves moves ground from side to side like a snake moves whereas the R waves roll the ground apparently up and down. The surface waves are most damaging to property and infrastructure.

Although wave speeds vary by a factor of ten or more in the Earth, the ratio between the average speeds of a P wave and of its following S wave (Vp/Vs) is quite constant. This fact enables to simply time the delay between the arrival of the P wave and the arrival of the S wave. This helps to get a quick and reasonably accurate estimate of the distance of the earthquake from the observation station (fig. 7.6).

For a quick examination the seismologists multiply the S minus P (S-P) time, by a factor of 8 km/s to get the approximate distance of an earthquake epicentre from the earthquake.



(**Source:**https://multimediascienceleahaviscounte.weebly.com/seismic-waves.html).

Fig 7.6 : Distribution pattern of the body waves from the focus resulting from the reflection/refraction of the waves due to internal structure of the Earth

Do you know?

How Secret Nuclear Tests are detected by seismology?

Nuclear explosion generates similar kind of energy to that of an earthquake. Seismologist sitting in distant countries can differentiate an explosion from an earthquake by looking at the ratio of P to S wave velocities. Earthquakes generate weak P waves and strong S waves. Explosions, on the other hand, generate strong P waves and weak S waves. A powerful explosions have higher P:S ratio than earthquakes. Further, the earthquakes will be detected very deep compared to nuclear explosion. The duration of the wave and its frequency is also characteristic of the explosion and earthquakes.

Both types of surface wave are slower than P- and S waves and so are rarely used for measuring travel-times, but they are important to understand the geohazards due to greater damages on the surface caused by them. Surface waves are generated by most seismic sources and often have the largest amplitude responsible for damage on the surface.

Earthquakes as geohazards :

1) **In developed or urbanised areas :** During an earthquake, the land surface mechanically responds to the waves. It results in partial to complete damage or collapse of buildings, walls, bridges, dams and other man-made structures. It often destroys power supply, water, oil and gas pipe lines. Railway lines and fences get twisted and the roads may crack open or get displaced. Loss of life may result from the collapse of structures or from fire caused due to leakage of gas, friction, electric current and other inflammable objects.

   Fire was a major cause of damage in the 1906 San Francisco earthquake and in the Kobe earthquake in Japan in 1995. It is therefore essential to evaluate every building as measure to damage and safety in the event of an earthquake. Earthquake resistant structures and buildings sustain the damage to a large extent.

Fig. 7.7: Effects of an earthquake in urbanized area example from 2015 Nepal earthquake (source: https://www.preventionweb.net/news/view/51350)

2) **Morphological changes :** Rivers and streams may change their course and cause floods or blocking. Groundwater circulation gets disturbed. The water from

lakes and wells may drain off through cracks and fractures. New lakes may come into existence. Old springs may dry out and new ones may arise elsewhere.

3) **Damage in coastal areas :** Loose sediments on the continental shelf may slide down to the sea floor. Some coastal land may get submerged, while new land may emerge from the sea.

4) **Tsunamis :** These are huge sea waves that strike the coastal regions, resulting from a strong submarine earthquake. The waves generated by these shocks reach coastal areas with very large amplitudes and cause inundation of land. Tsunamis are generated when a mass of water is abruptly displaced by movement of the sea floor, often by an earthquake, volcanic eruptions and landslides. The tsunami waves travel across the deep oceans with a wavelength of perhaps 100 km and an amplitude of about a meter. When the waves reach the shallow water near a coast they 'break' and surf landwards. Tsunamis may reach a height of 30 m or more, and historical evidences are found carrying ships to improbable places and devastating towns. Though the waves travel at ~800 km/hr, they still take several hours to cross an ocean.

5) **Damage in mountainous regions :** Landslides and avalanches may be set off and where glaciers enter the sea, they may break off to form icebergs.

Locating an Earthquake :

When an earthquake occurs the most urgent information needed is about location of earthquake i.e. the epicentre. Since the earthquake is a sudden phenomenon, the immediate information about its location is vital to any rescue agency. The location of earthquake can be immediately established by finding the epicenter, by using triangulation method. The recorded data from a minimum of three stations can be shared to find the radius of an imaginary circle drawn around each station. The intersection of at least three such circles would enable to know the location of an earthquake (fig. 7.8).

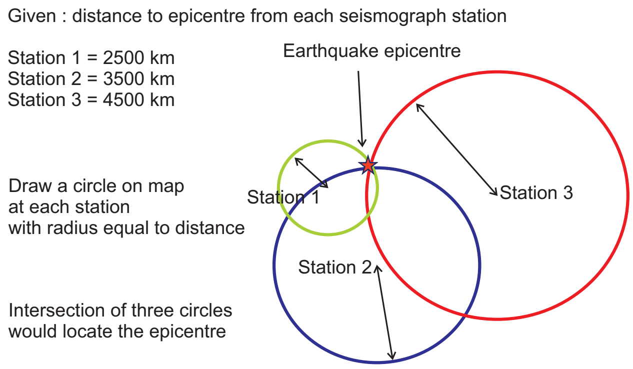


Fig. 7.8 : Triangulation method of locating epicentre of an Earthquake

The traces of an earthquake recorded at number of seismic stations in the form of arrival time of P and S waves are converted into distance. As S-waves travel more slowly than P-waves, the more distant the earthquake from the receiver, greater is the time lag between arrivals of S after the P waves. By matching this delay to standard P and S travel-time curves, the distance of the earthquake from a given station can be located (fig. 7.9).

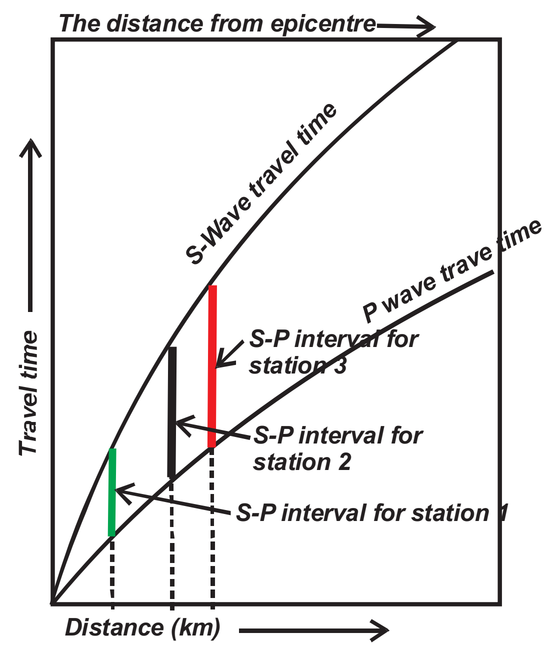


Fig. 7.9 : The concept of using standard travel-time graph to calculate the distance from station to epicentre using P-S time lag

Table. 1: Modified Mercalli Intensity Scale

Zone	Intensity	Abbreviated Description of Effects
I	Not felt	Not felt except by a very few under especially favorable conditions.
II	Feeble	Felt only by a few persons at rest, especially on upper floors of buildings.
III	Slight	Felt quite noticeably by persons indoors, especially on upper floors of buildings. Many people do not recognize it as an earthquake. Standing motor cars may rock slightly. Vibrations similar to the passing of a truck. Duration estimated.
IV	Moderate	Felt indoors by many, outdoors by few during the day. At night, some awakened. Dishes, windows, doors disturbed; walls make cracking sound. Sensation like heavy truck striking building. Standing motor cars rocked noticeably.
V	Reasona-bly strong	Felt by nearly everyone; many awakened. Some dishes, windows broken. Unstable objects overturned. Pendulum clocks may stop.
VI	Strong	Felt by all, many frightened. Some heavy furniture moved; a few instances of fallen plaster. Damage slight.
VII	Very strong	Damage negligible in buildings of good design and construction; slight to moderate in well-built ordinary structures; considerable damage in poorly built or badly designed structures; some chimneys broken.
VIII	Destruc-tive	Damage slight in specially designed structures; considerable damage in ordinary substantial buildings with partial collapse. Damage great in poorly built structures. Fall of chimneys, factory stacks, columns, monuments, walls. Heavy furniture overturned.
IX	Ruinous	Damage considerable in specially designed structures; well-designed frame structures thrown out of plumb. Damage great in substantial buildings, with partial collapse. Buildings shifted off foundations.
X	Disastrous	Some well-built wooden structures destroyed; most masonary and frame structures destroyed with foundations. Rails bent.
XI	Very disastrous	Few, if any (masonary) structures remain standing. Bridges destroyed. Rails bent greatly.
XII	Cata-strophic	Damage total. Lines of sight and level are distorted. Objects thrown into the air.

Earthquake Intensity : An earthquake is expressed by its intensity and magnitude. Intensity is the severity of damage by an earthquake at a given locality or region. Size of an earthquake is proportionate to the effects at the locality or of the disturbance at the source. The scale most commonly used to measure the intensity is Modified Mercalli (MM) Scale of 1931, with twelve categories, I to XII (See table 1). It allows the intensity at each locality to be estimated after the earthquake, by observing and defining the damages with the recording done immediately after the earthquake.

Earthquake Magnitude :

The most widely used Richter scale measures the total amount of energy released by an earthquake as magnitude of the earthquake. In this scale, the amplitude of the largest wave produced by an earthquake is corrected for distance and assigned a value on an open-ended logarithmic scale (fig. 7.10). One order increase in magnitude of Richter scale corresponds to tenfold increase in amplitude.

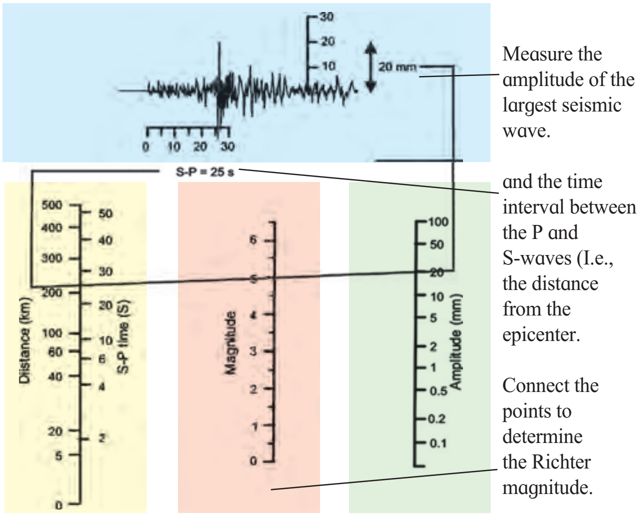


Fig. 7.10 : Description and example of Richter Scale for assigning the magnitude of an earthquake (Source: http://earthquakes.bgs.ac.uk/education/eq_guide/eq_booklet_measuring_size_eqs.htm)

Earthquake belts :

A survey of the Earth's seismic activity over the years reveals that majority of earthquakes are restricted to narrow and elongated zones on the Earth's surface, which are called earthquake belts. These belts are;

1) Circum-Pacific belt
2) Mediterranean-Asiatic belt
3) Mid-oceanic ridge belt

Fig. 7.11, defines the plate boundaries along with the earthquake belts.

1) **Circum-Pacific belt :** This belt runs along the margin of Pacific ocean and passes through Japan, Philippines, Chile, New Guinea, New Zealand, Alaska and the west coasts of North and South America. The San Andreas fault in United States falls under this belt. Almost 70% of the deep focus earthquakes occur in this belt.

2) **Trans-Mediterranean belt :** This belt runs between Gibraltar and south-east Asia. It passes through the Mediterranean Sea, Iran, Himalayas and Myanmar. About 21% of the past deep focus earthquakes have occurred in this belt.

3) **Mid-Oceanic Ridge belt :** This belt passes through most of the ocean floors of the Earth.

Global seismic centres in 1975-99
earthquakes of magnitude 5.5 and greater

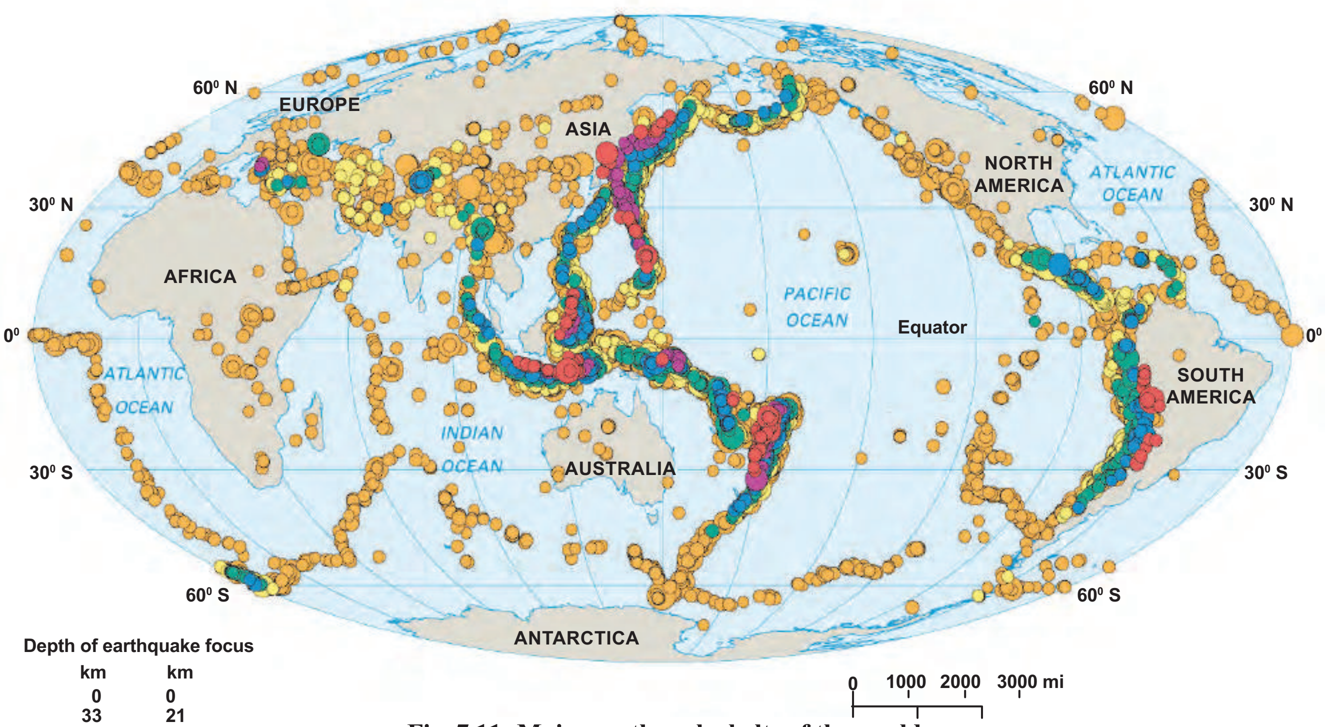


Fig. 7.11: Major earthquake belts of the world

Prediction and mitigation of the earthquake :

Earthquakes are caused by tectonic forces that are beyond our control. Precise prediction of the size, location and time of an earthquake is essential. Despite of all the developments in earthquake science and technology, till date there is no reliable method for such accurate prediction. However, a number of possible precursors warn us of an impending earthquake. These include changes in seismicity; variation in electrical and other properties of ground; variation in the water level in wells and its radon content. Efforts are needed to reduce the severity of damage due to an earthquake and is called the mitigation of the earthquakes adopting precautionary measures. Earthquake prone areas have been identified from.

a) Detailed geology (seismo tectonics),

b) Study of geomorphology (active tectonics),

c) Paleo seismicity signatures and historical records.

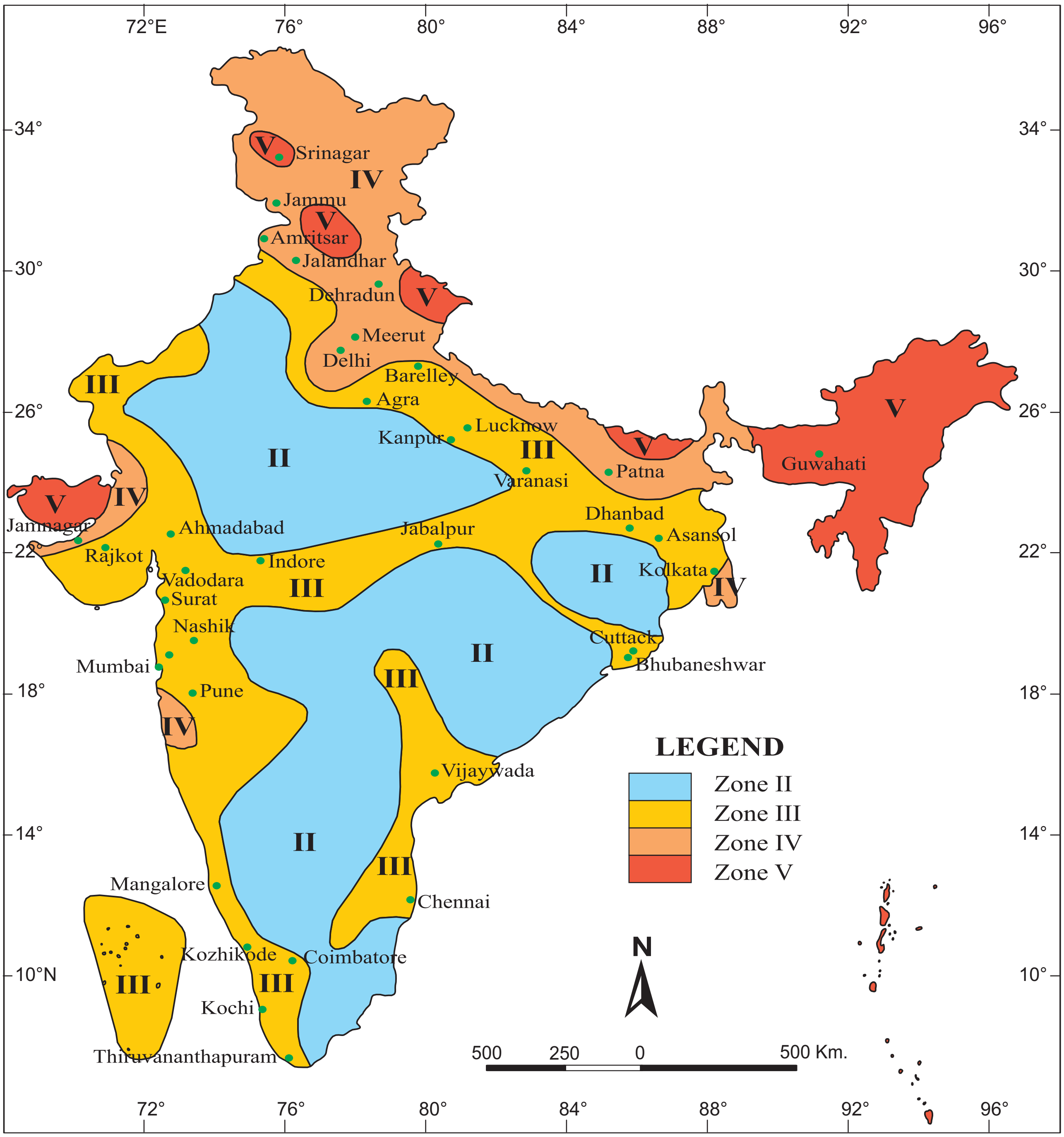


Fig. 7.12 : Seismic Hazard Zonation map of India

(Source : National Institute of Disaster Management: https://nidm.gov.in/safety_earthquake.asp)

Such information is used to develop hazard zonation maps and draw appropriate building codes to reduce the damage. Currently a hazard zonation map of India is available for such activity

Seismic Hazard Zonation :

The government agencies and research institutes classified the country into different zones based on the intensity of damage or frequency of earthquake occurrences. Such zonation provides guidelines and regulations to adopt norms for design of buildings in these zones (fig. 7.12).

Do you know?

Mohorovicic discontinuity, usually referred to as the Moho. It is the boundary between Earth's crust and the mantle. Named after pioneering Croatian seismologist Andrija Mohorovicic, Moho separates both oceanic crust and continental crust from underlying mantle. It defines the lithosphere – asthenosphere boundary. Mohorovicic discontinuity was first identified in 1909 by Mohorovicic, when he observed that seismograms from shallow-focus earthquakes had two sets of P- waves and S-waves, one that followed a direct path near Earth's surface and the other refracted by a high velocity medium.

Mohorovicic discontinuity is 5 to 10 km below the ocean floor and 20 to 90 km beneath typical continents, with an average depth of 35 km.

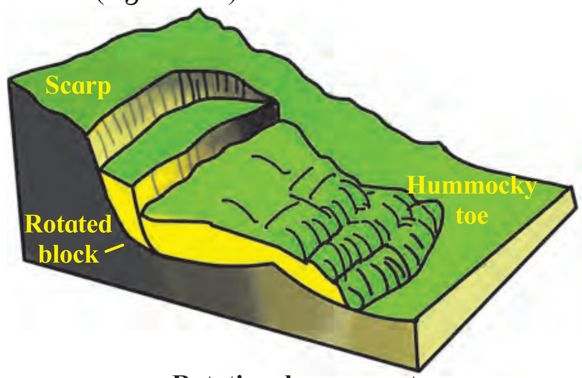
LANDSLIDES

Landslide is a naturally occurring phenomenon. As a geologist, one must know the processes, make predictions, and assess the risk of this threat in order to acclimatize to the potential hazards.

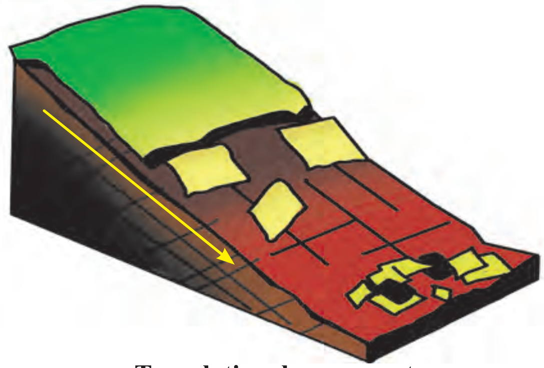
The downslope movement of rock debris/ regolith (loose unconsolidated mixture of soil and rock particles that cover the Earth's Surface) and soil in response to gravitational stresses is referred to as Land slide/ Slope failure or mass wasting. Three major types of mass wasting are classified by the type of downslope movement; they are falls, slides and flows.

Types of Landslides :

Earth materials may fail and move or deform in several ways. Rotational slumps involve sliding along a curved slip plain producing slump blocks (fig. 7.13a). Translational sliding is downslope movement of Earth materials along a planar slip plane such as a bedding plane or fracture (fig. 7.13b).



Rotational movement



Translational movement

Fig. 7.13 a, b: Types of movements due to landslides

Landslides are commonly complex combination of sliding and flowage. Such complex landslides may form when water-saturated Earth materials flow from the lower part of the slope, undermining the upper part and causing slumping of blocks of Earth materials. Important variables in classifying downslope movements are the type of movement (slide, fall, flow, slump, or complex movement), slope material type, amount of water present and rate of movement. In general, the movement is considered rapid if it can be discerned with the naked eye; otherwise, it is classified as slow (fig. 7.14 a-l). Actual rates vary from a slow creep of a few millimeters or centimeters per year to very rapid, at 1.5 m (5 ft) per day, to extremely rapid, at 30 m (98 ft) or more per second.

Impact of Geological structures on landslides:

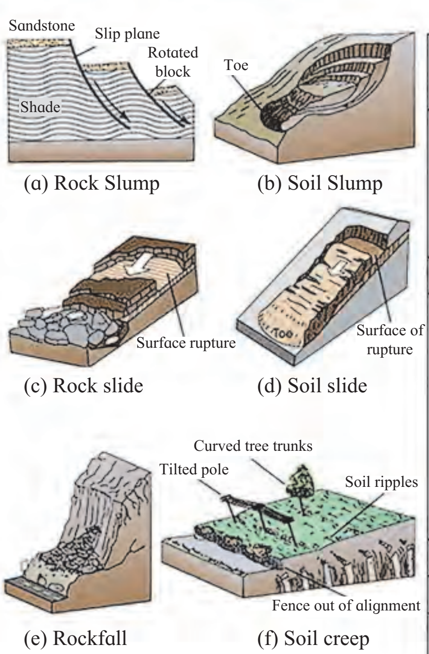
Geology is a critical component in the study of landslides. Specific factors related to the cause of a landslide that can be identified and attributed to geology are low strength rock or soil, faults, joints, bedding planes, etc.

- **Bedding Planes :** This is the plane of least cohesion in the layered rock masses. Bedding plane may be horizontal, inclined or even vertical. Horizontal beds tend to be most stable as compared to the inclined ones.
- **Schistosity and foliation :** They behave as planes of weakness. Failure is most common when they are inclined towards the free slope.
- **Joints :** Very few rocks are free from joints. Joints occur in sets, thereby reducing the strength. While studying the joints, their inclination must be carefully studied. A set of joints inclined towards the free side of the slope reduces the stability of the slope. Joints may be more vulnerable to failure when lubricated with water.

Monitoring and prevention of landslides :

The effect of human use on the magnitude and frequency of landslides varies from nearly insignificant to very significant. In cases where human use has increased the number and severity of landslides, we need to learn how to recognize, control, and minimize their occurrence wherever possible.

Identifying areas with high potential for landslides is the first step in developing a plan to avoid landslide hazards. Slide tendency can be recognized by examining both geologic conditions in the field and aerial photographs to identify previous slides. This information can



Type of Movement	Materials	
	Rock	Soil
Landslides with variable water content and rate of movement	Rotational	
	Slump(a)	Slump(b)
	Translational	
	Rock slide(c)	Soil slide (slip)(d)
Falls	Rock fall(e)	Soil fall
Flows: Slow	Rock creep	Soil creep(f)
	Unconsolidated rock and soil (saturated)	
Rapid	Earth flow(g)	
	Debris flow / mud flow(h)	
Very rapid	Debris avalanche(i)	
Lateral spread	Rock(j)	Soil
Subsidence	Rock(k)	Soil
Complex	Combination of slides, slumps, and flows(l)	

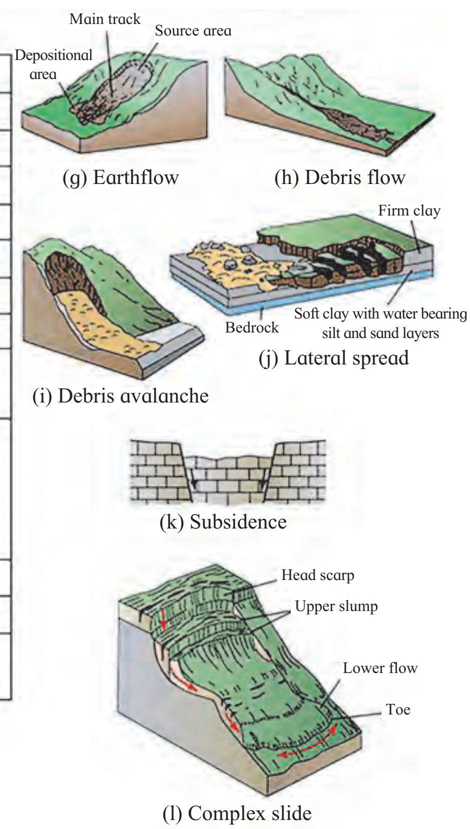


Fig 7.14 (a-l): Types of landslides

then be used to evaluate the risk and produce slope stability maps.

Preventing large, natural landslides is difficult, but common sense and good engineering practices can help to minimize the hazard. Common engineering techniques for landslide prevention include provisions for surface and subsurface drainage, removal of unstable slope materials, construction of retaining walls or other supporting structures, or combination of these.

The amount of water infiltrating a slope can be controlled by covering the slope with an impermeable layer such as soil-cement, asphalt, or even plastic. Groundwater may be inhibited from entering a slope by constructing subsurface drains. Cut-and-fill can be practiced where the material from the upper part of a slope is removed and placed near the base. The overall gradient is thus reduced. However, this method is not practical on very steep slopes. As an alternative, the slope may be cut into a series of benches or steps. The benches are designed with surface drains to divert runoff. The benches reduce the overall slope of the land and are good collection sites for falling rock and small slides. Slope Supports, retaining walls constructed from concrete, stone-filled wire baskets, bolting, or piles (long concrete, steel, or wooden beams driven into the ground are some of the methods for prevention of landslides).

VOLCANOES

The word volcano comes from the little island of Vulcano in the Mediterranean Sea, off Sicily. A volcano is simply a vent at the surface of the Earth through which lava and other volcanic materials are ejected from the Earth`s interior. Lava is the term used for magma that has reached the surface because of a volcanic eruption. Magma is the molten material below the Earth's surface.

Types of Volcanoes :

There are three primary types of volcanoes: i) Shield ii) Composite and iii) Dome.

i) **Shield volcano :** They are the largest of the three types, are gently sloping and built almost entirely of low viscosity basaltic lava flows (fig. 7.15). The eruptions are generally non-explosive due to the low silica content. Shield volcanoes are typified by those on the Hawaiian and Galapagos Islands and on Iceland. Numerous small shield volcanoes are typical throughout the eastern Snake River Plain in Idaho, USA. Examples include the Wapi lava field and Hells Half Acre U.S.A.

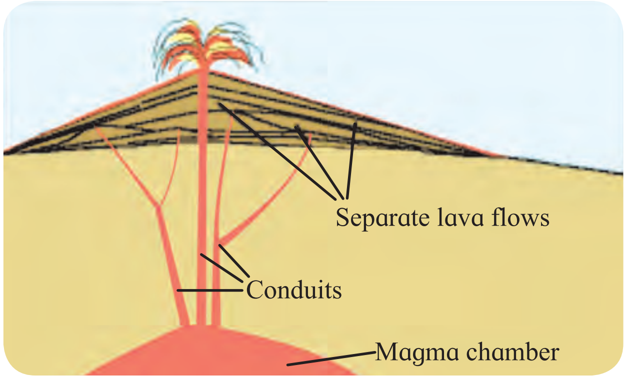


Fig 7.15 : Shield volcano in cross section

ii) **Composite volcanoes :** They are also called as strato-volcanoes and are the most beautiful and most deadly of the volcano types (fig. 7.16). They are steep-sided, symmetrical cones built up by eruptions of intermediate viscosity andesitic lava and explosive tephra, giving rise to crude stratification and hence the name. Examples of composite volcanoes, are Mount Shasta in California, Mount St. Helens and Mount Rainier in Washington state, and Mount Fuji in Japan.

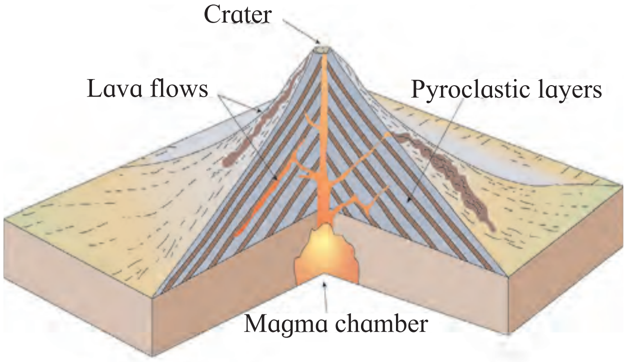


Fig 7.16 : Cross-section of a composite volcano

iii) Volcanic Domes : These comprise the third primary type of volcano. They are formed by highly viscous rhyolitic magma (approximately 70% silica) (fig. 7.17). Volcanic domes are typically small. Some are subject to explosive blowouts during dome building processes. Domes commonly occur adjacent to or within craters of composite volcanoes. Other domes begin as shallow laccolithic intrusions that grow and expand beyond subsurface confinement.

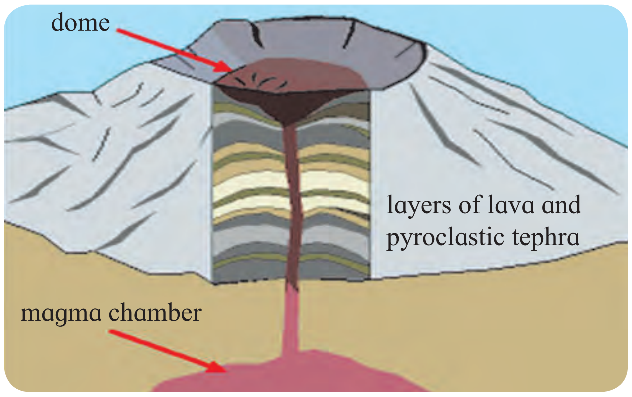


Fig 7.17 : Cross-section of a volcanic dome

Volcanic hazards :

The effects of volcanoes are studied as they cause a lot of human concern. Lava flows, ash-flows, lateral blasts, ash-falls, gases, lahars/ mudflows, floods, fires, and tsunamis are the various types of volcanic hazards (fig. 7.18) that disrupt normal human activities.

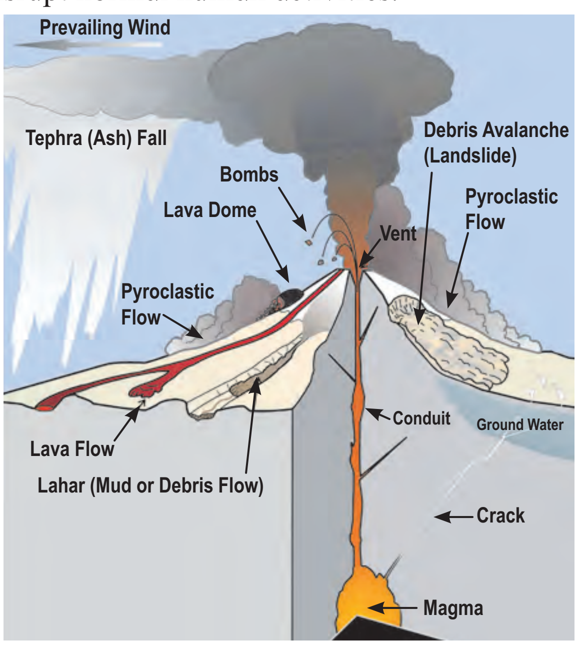


Fig 7.18 : Visualization of volcanic hazards

Volcanic hazard refers to any potentially dangerous volcanic process. It may lead to potential loss or damage. It may negatively impact the productive capacity/ sustainability of a population.

Many eruptions are explosive in nature. They produce fragmental rocks from erupting lava and the surrounding country rock. Some eruptions are highly explosive and produce fine volcanic ash that rises many kilometers into the atmosphere. Explosive activity also causes widespread ash fall, pyroclastic flows, debris avalanches, landslides, pyroclastic surges and lahars.

Types of volcanic hazards :

i) **Lava flows :** These are less dangerous to human life than to property, traffic and communication. Highly viscous lava generally does not advance far but commonly piles up above an active vent as a Lava dome. Such domes collapse repeatedly and generate hot block and ash flows, hot surges and blasts.

ii) **Ash Falls :** A volcanic eruption generally does not directly endanger life, although the collapse of roof and houses under the ash load are most common.

iii) **Pyroclastic flows :** Low density surges that are frequently associated with blasts are extremely hazardous types of volcanic eruptions. Pyroclastic flows are a mixture of volcanic gases and ash are generated during many volcanic eruptions.

iv) **Volcanic Debris/ Avalanches :** They are commonly generated by sliding of larger portions of volcanic cones. These avalanches are highly mobile and may bury large tracts of land and block streams to form lakes that can drain catastrophically and generate lahars and floods.

v) **Lahars (volcanic mud and debris flow) :** These are common major volcanic hazard to life and property. Lahars proceed very quickly and possess great destructive power. They develop either as a direct consequence of a volcanic eruption, or as a secondary event resulting due to heavy rainfall or sometimes as an after effect of eruption.

Effects of Volcanic hazards :

Damage to human life, social structure and property may not always be induced only by direct effects of volcanic eruption. Some of the most dangerous secondary phenomena are tsunamis, contaminated ashes or long-lasting aerosol clouds that can orbit the Earth for years after large volcanic eruption (e.g., Toba volcano). Aerosol clouds are composed of condensed volcanic gases, mainly sulphuric acid. The emission of large quantities of SO_2 and also possibly halogens into the stratosphere may lead to a temperature decrease on the Earth's surface by increasing the global albedo.

Prediction of Volcanic activity :

Prediction of a volcanic eruption is extremely important to provide early evacuation of densely populated regions. Prediction based on statistics of previous eruptions is too vague for specific and short term prediction of an eruption. A forecast is a general announcement that a volcano will probably erupt in the near future. A prediction is a relatively precise statement that describes the future volcanic event, its time and type of eruption.

Volcanic eruptions are often announced years, months, days or hours in advance. The relatively slow ascent of viscous magma to the upper crust generates a surface expansion that can be measured with modern geodetic instruments.

Prevention and mitigation of volcanic hazard :

In order to reduce the after effects of a volcanic hazard, a series of measures must be taken before, during and after a volcanic eruption. Preparation of hazard maps help to determine whether a volcano is potentially hazardous and to assess the risk. Monitoring of volcanoes by satellite must be increased in order to detect possible changes. Public must be informed and educated using brochures, placards, lectures, advertisements on the television etc.

A volcanic eruption cannot be potentially controlled by man. However limited possibilities to control its effects such as barriers against lava flows, cooling lava flow with sea water, channeling small lahars by artificial dams and artificially draining the lahar crater lakes can be practiced.

Summary :

Amongst the natural hazards, earthquakes are the most disastrous, as these cannot be predicted by time and exact location. Earthquake release an enormous energy, and their prevention is impossible. However the risk of damage to property and life can be reduced by acquiring detailed knowledge on seismology and adopting methods such as construction of earthquake resistant structures.

The landslides present one of the most common relatively small scale disasters. The damage due to landslides can be reduced by mapping of the landslide prone area and retrofitting the causes for landslide occurrence. For this purpose the fundamental knowledge on the origin, occurrence and types of landslide is essential.

The volcanoes are the disasters with well-known occurrences of active volcanoes in the given region. The volcanic eruption cause primary as well as secondary disasters. Primary disasters are associated with direct contact of volcanic material to property or life causing loss. Proper study of the given volcano and correct monitoring can produce warning of a volcanic activity with sufficient time of evacuation.

EXERCISE

Q. 1. Fill In the blanks :

1) Downslope movement of rock debris in response to gravitational stresses is called ....
   a) faulting b) slip
   c) thrusting d) landslide
2) Debris avalanche is a ....
   a) Very rapid to extremely rapid debris flow
   b) Slow to extremely slow debris flow
   c) Very rapid to slow debris flow
   d) Very rapid to extremely rapid rock fall
3) Landslides are a complex combination of …..... and …............
   a) Sliding and slippage
   b) Thrusting and flowage
   c) Sliding and flowage
   d) Slipping and flowage
4) Water contributes to …............ when sediment pores are partially filled with water.
   a) Gravitational forces
   b) Resisting forces
   c) Driving forces
   d) Centrifugal forces
5) ....….. are the most beautiful but deadliest volcanoes
   a) Composite b) Shield
   c) Fissure d) Dome
6) ………. slumps involve sliding along a curved slip plain producing slump blocks
   a) Translational b) motional
   c) rotational d) gravitational
7) For a quick estimation of the distance of an earthquake epicentre from the seismic station, seismologists use a multiplication factor of ………. to the S minus P (S-P) time.
8) The most common scale to measure the intensity of an earthquake is ……….
9) Globally the earthquake occurrence belt coincides with ……….
10) In Richter scale the ………. of the largest wave produced by an earthquake is corrected for distance and assigned a value on an open-ended logarithmic scale.

Q. 2. Choose the correct alternative :

1) The Geohazards can originate
   a) Only from the surface processes,
   b) Surface to atmospheric interaction,
   c) Only from the interior of the Earth,
   d) All of the above
2) The seismic waves can be correlated with the analogy of ripples in pond for
   a) Their travel away from the source
   b) Their velocities inside the Earth
   c) Distribution of body and surface waves
   d) Origin of fault
3) The elastic rebound theory of H H Reid explains
   a) The origin of earthquake
   b) The origin of body waves
   c) The distribution of earthquakes
   d) Rheology of material
4) The contours of imaginary lines on maps joining points of the same earthquake intensity are called.
   a) Isoquake lines b) Isoseismal lines
   c) Isotropic lines d) Richter lines
5) The record of zig-zag lines representing the seismic waves generated by an earthquake is called:
   a) Seismograph b) Seismogram
   c) Seismic train d) Velocity graph
6) Shield volcanoes are:
   i) largest of the three types,
   ii) gently sloping
   iii) highly viscous basaltic lava flows
   iv) eruptions are generally non-explosive
   a) all statements are true
   b) statements i, ii and iv are true
   c) statements ii, iii and iv are true
   d) statements i, iii and iv are true

Q. 3. Short answers :

1) Why do earthquakes not occur deeper than 700 km.
2) Velocities of P waves are greater than S waves. Explain.
3) Why are surface waves more damaging as geohazards than the body waves.

4) In how many seismic zones is India divided and which area of the country is the most susceptible to seismic hazards?
5) What are the major types of mass movements?
6) Discuss the role of joints on occurrence of landslides.
7) What is the difference between intensity and magnitude of earthquake?
8) What is the standard method to find the distance between an earthquake and the recording station?
9) How can volcanic hazards be mitigated?
10) Discuss the importance of monitoring and prevention of landslides.

Q. 4. Long answers

1) Explain the role of geology in occurrence of a landslide.
2) Compare amongst the three major geohazards (Earthquake, Volcano and landslides) for their scale, predictability and mitigation.
3) Describe why the earthquakes cannot be predicted precisely.
4) Describe the different types of seismic waves and how they are produced.
5) Which conditions of volcano are the most significant in prevention of hazards?
6) Discuss the effects of landslides during planning and execution of developmental projects in a region.
7) Which type of volcanic hazard generally does not directly endanger life

Practical exercise

Locating the epicenter of an Earthquake

The different types of seismic waves travel at different speeds. P-waves travel faster relative to S-waves, and the surface waves are still slower. These different travel times of seismic waves after an earthquake occur is the basis of locating the epicenters of earthquakes (refer figures 7.5, 7.6, 7.8 and 7.9).

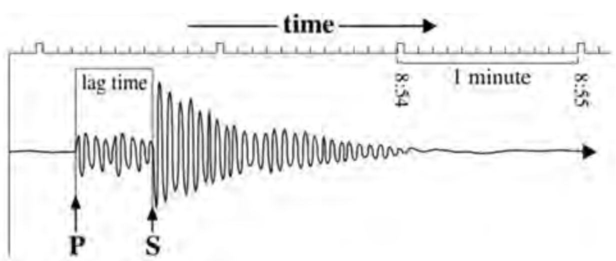


Figure: Seiemogram showing the first arrival times for the P-waves and S-waves. The lag time is the interval between P- and S- wave arrivals.

This exercise is to learn the key concept of seismic wave travel time and to understand how seismograms are used to find the distance to an earthquake epicenter. Imagine that car A and car B depart together at same starting point and same time. However the car A travels at a speed of 100 km per hour (kph), and the car B travels at 85 kph. An observer anywhere along the cars' route can calculate exactly how far they had traveled simply by measuring the arrival time difference between the cars at given location. Now consider that the car A passes a given spot at 2:30 pm, and car B passes the same spot at 2:45 pm, then find the distance between that spot and the cars' point of departure.

We know that the distance travelled (d) is the product of rate (r) and time (t):

d = r * t ………………………..(1.1)

Because the distance travelled is the same for both cars, the following must be true:

d = rA * tA = rB * tB………………… (1.2)

Given the speed of the two cars (rA and rB) and that car B passed the spot 15 minutes after car A (tB = tA + 0.25 hrs), Equation 1.2 becomes:

100 km/hr * tA = 85 km/hr * (tA + 0.25 hrs)………… (1.3)

Simplifying and solving for

tA = 1.42 hr………..(1.4)

Combining Equations 1.4 and 1.2:

d = rA * tA………………… (1.5)

d = 100 km/hr * 1.42 hr……………….. (1.6)

d = 142 km…………….. (1.7)

Explanations : In case of the earthquake data, a seismogram at given station is used to find the time lag as shown in the figure. Then this time (lag) for P and S wave is plotted along the Y- axis of a tabulation diagram like Figure 7.9 and on X- axis the distance from the epicenter is obtained. Such data from minimum three stations is required to get the epicenter as shown in figure 7.8. In practice however, the seismologists plot the data from more number of stations to reduce the error and get the exact location of the epicenter of an earthquake.