MODULE 2

Syllabus:
Types of Natural Disasters I- Earth quakes, Landslides. Nature of impacts.

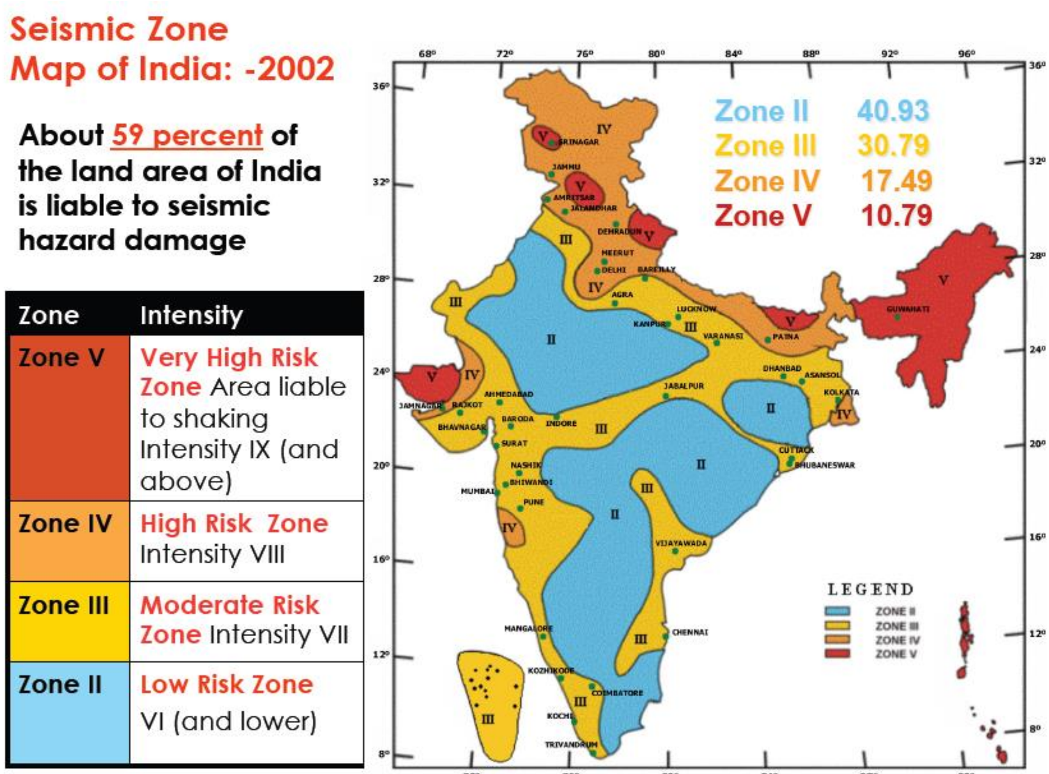
EARTHQUAKES

Earthquake is one of the most destructive natural hazard. They may occur at any time of the year, day or night, with sudden impact and little warning. They can destroy buildings and infrastructure in seconds, killing or injuring the inhabitants. Earthquakes not only destroy the entire habitation but may de-stabilize the government, economy and social structure of the country.

Definition: It is the sudden shaking of the earth crust. The impact of an earthquake is sudden and there is hardly any warning, making it impossible to predict.

Globally, earthquakes result in a loss of about 50,000 lives every year. Earthquakes over 5.5 magnitude on the Richter scale are progressively damaging to property and human life. However, there are many other factors that influences the damage pattern. Massive earthquakes generally occur near the junction of two tectonic plates, e.g., along the Himalayan range, where the Indian plate goes below Eurasian plate. The Indian sub- continent situated on the boundaries of two continental plates is very prone to earthquakes. Some of the most intense earthquakes of the world have occurred in India. Fortunately, none of these have occurred in any of the major cities. According to latest seismic zoning map brought out by the Bureau of Indian Standard (BIS), over 65 percent of the country is prone to earthquake of intensity Modified Mercalli Intensity Scale (MSK) VII or more.

India has been divided into four seismic zones according to the maximum intensity of earthquake expected (Figure below). Of these, zone V is the most active which comprises of whole of Northeast India, the northern portion of Bihar, Uttarakhand, Himachal Pradesh, J&K, Gujarat and Andaman & Nicobar Islands. India has highly populous cities and the constructions in these cities are not earthquake resistant. Regulatory mechanisms are weak, thus any earthquake striking in one of these cities would turn into a major disaster. Six major earthquakes have struck different parts of India over a span of the last 15 years.



The entire Himalayan Region is considered to be vulnerable to high intensity earthquakes of a magnitude exceeding 8.0 on the Richter scale, and in a relatively short span of about 50 years, four such major earthquakes have occurred in the region

Some significant earthquakes in India

Date	Epicenter		Location	Magnitude
	Lat (Deg. N)	Lat (Deg. E)		
16 June 1819	23.6	68.6	Kutch, Gujarat	8.0
10 June 1869	25	93	Near Cachar, Assam	7.5
30 May 1885	34.1	74.6	Sopor, J&K	7.0
12 June 1897	26	91	Shilong Plateau	8.7
04 April 1905	32.3	76.3	Kangra, HP	8.0
08 July 1918	24.5	91.0	Srimangal, Assam	7.6
02 July 1930	25.8	90.2	Dhubri, Assam	7.1
15 Jan 1934	26.6	86.8	Bihar- Nepal Border	8.3
26 June 1941	12.4	92.5	Andaman Island	8.1
23 Oct 1943	26.8	94.0	Assam	7.2
15 Aug 1950	28.5	96.7	Arunachal Pradesh- China Border	8.5
21 July 1956	23.3	70.0	Anjar, Gujarat	7.0
10 Dec 1967	17.37	73.75	Koyna, Maharastra	6.5
19 June 1975	32.38	78.49	Kinnuar, HP	6.2
06 Aug 1988	25.13	95.15	Manipur-Myanmar Border	6.6
21 Aug 1988	26.72	86.63	Bihar- Nepal Border	6.4
20 Oct 1991	30.75	78.86	Uttarkhashi, Uttarakhand	6.6
30 Sept 1993	18.07	76.62	Latur- Osmanabad, Maharshtra	6.3
22 May 1997	23.08	80.06	Jabalpur, MP	6.0
29 Mar 1999	30.41	79.42	Chamoli Dist, UK	6.8
26 Jan 2001	23.40	70.28	Bhuj, Gujarat	7.7
08 Oct 2005	34.49	73.15	Kashmir	7.6

THE CIRCULATIONS INSIDE EARTH

– **Convection currents develop in the viscous Mantle**, because of prevailing high temperature and pressure gradients between the Crust and the Core, like the convective flow of water when heated in a beaker.
– These convection currents **result in a circulation of the earth's mass**; hot molten lava comes out and the cold rock mass goes into the Earth. The mass absorbed eventually melts under high temperature and pressure and becomes a part of the Mantle
– Many such local circulations are taking place at different regions underneath the Earth's surface, leading to different portions of the Earth undergoing different directions of movements along the surface.

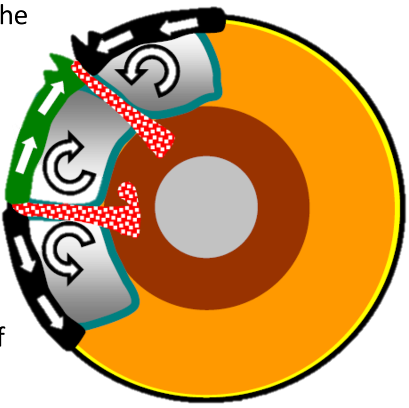
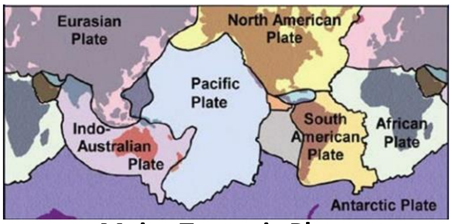


PLATE TECTONICS

– German scientist Alfred Wegener, in 1915 proposed that, 200 million years ago the earth had only one continent called Pangaea.
– Pangaea broke into pieces that slowly drifted into the present configuration of continents.
– The convective flows of Mantle material cause the Crust and some portion of the Mantle, to slide on the hot molten outer core.
– This sliding of Earth's mass takes place in pieces called **Tectonic Plates.**
– The surface of the Earth consists of seven major tectonic plates and many smaller ones

(a) Eurasian Plate
(b) Indo – Australian plate
(c) Pacific plate
(d) North – American Plate
(e) South – American Plate
(f) African Plate
(g) Antarctic Plate



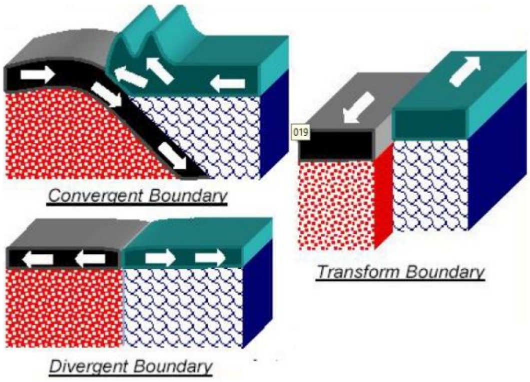
Major Tectonic Plates

– These plates move in different directions and at different speeds from those of the neighbouring ones.

(a) Convergent Boundaries: Sometimes, the plate in the front is slower; then, the plate behind it comes and collides (and *mountains* are formed).

(b) Divergent Boundaries: sometimes two plates move away from one another (and *rifts* are created).

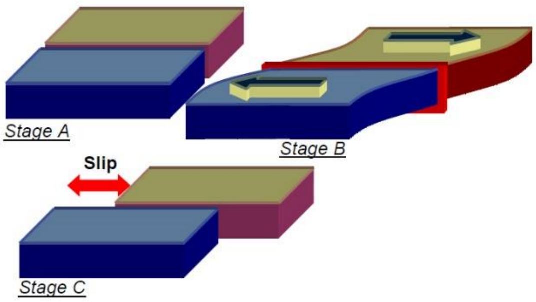
(c) Transform Boundaries: Two plates move side-by-side, along the same direction or in opposite directions.



– The convergent boundary has a peculiarity (like at the Himalayas) that sometimes neither of the colliding plates wants to sink.

ELASTIC REBOUND THEORY

– Tectonic plates are made of elastic but brittle rocky material.
– Hence, elastic strain energy is stored in them during the relative deformations that occur due to the gigantic tectonic plate actions taking place in the Earth.
– When the rocky material along the interface of the plates in the Earth's Crust reaches its strength, it fractures and a sudden movement takes place there



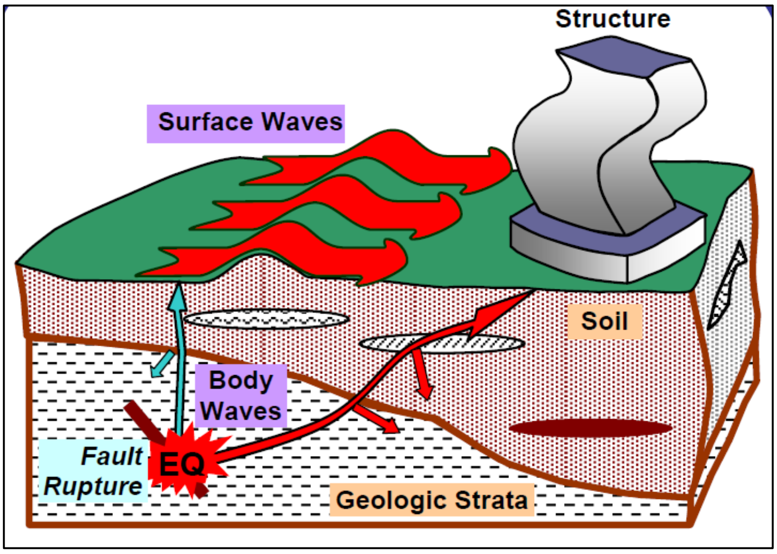
– The interface between the plates where the movement has taken place (called the **fault**) suddenly slips and releases the large elastic strain energy stored in the rocks at the interface.
– The sudden slip at the fault causes the earthquake - a violent shaking of the Earth during which large elastic strain energy released spreads out in the form of seismic waves that travel through the body and along the surface of the Earth.
– After the earthquake is over, the process of strain build-up at this modified interface between the tectonic plates starts all over again.
– Earth scientists know this as the **Elastic Rebound Theory**.

SEISMIC WAVES

Large strain energy released during an earthquake travels as seismic waves in all directions through the Earth's layers, reflecting and refracting at each interface.

These waves are of two types - **body waves and surface waves**

The surface waves are restricted to near the Earth's surface (See Fig. below). **Body waves consist of Primary Waves (P-waves) and Secondary Waves (S-waves)**, and **surface waves consist of Love waves (L-waves).**



Arrival of Seismic Waves at a Site

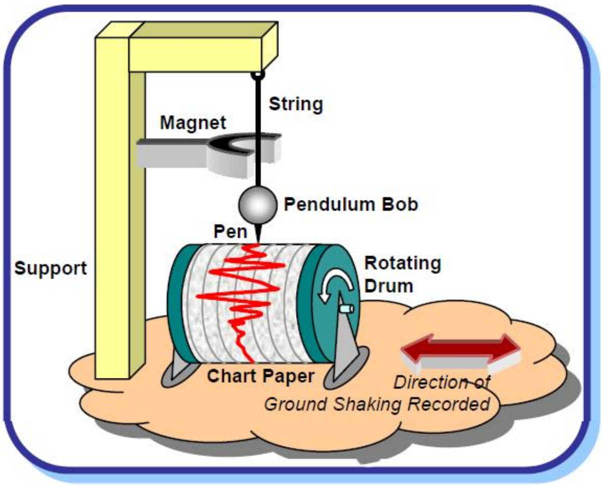
(a) The P-waves
- These are also called primary waves, push and pull waves.
- These are the fastest waves in which the particles vibrate in the direction of propagation.
- The velocity of P - wave is related to the rigidity of the medium and its density.

(b) The S- waves
- These are also called secondary waves.
- In these waves particles vibrate right angles to the direction of propagation of the wave.

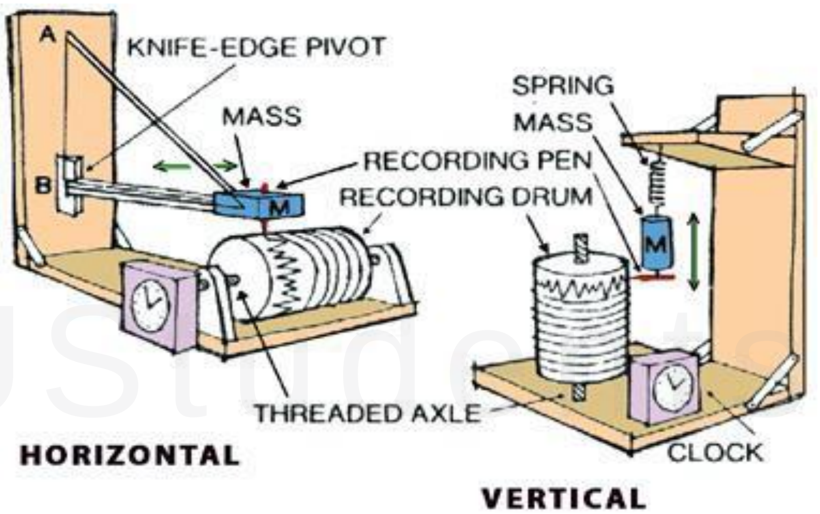
(c) The L-waves
- These waves also called Long waves or surface waves.
- These waves are sluggish and recorded only after the arrival of the P and S waves.
- S-waves do not travel through liquids.
- S-waves in association with effects of Love waves cause maximum damage to structures

RECORDING OF EARTHQUAKES

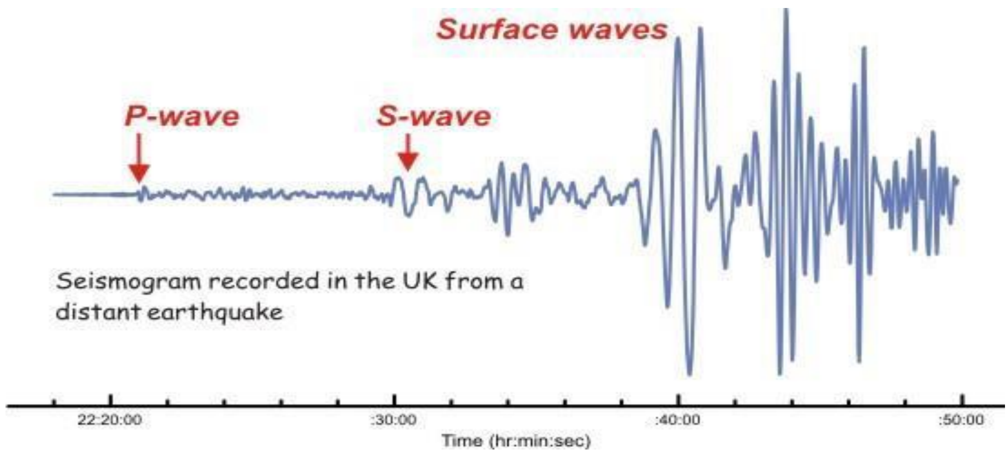
- The instrument used to record the motion of seismic waves is called **seismograph**
- The record produced by the instrument is called **Seismogram**
- A seismograph is designed **for recording either the horizontal or the vertical component of ground motion**
- A seismograph, has three components – **the sensor, the recorder and the timer.**
  (a) ***The Sensor:*** The pendulum mass, string, magnet and support
  (b) ***The Recorder:*** The drum, pen and chart paper constitute the recorder; and
  (c) ***The Timer:*** the motor that rotates the drum at constant speed forms the timer.
- Pendulum type seismographs are generally used.
- **Principle of Seismograph**
  - A pen attached at the tip of an oscillating simple pendulum (a mass hung by a string from a support) marks on a chart paper that is held on a drum rotating at a constant speed.
  - A magnet around the string provides required damping to control the amplitude of oscillations.



- One such instrument is required in each of the two orthogonal horizontal directions.
- For measuring vertical oscillations, the *string* pendulum is replaced with a *spring* pendulum oscillating about a fulcrum.

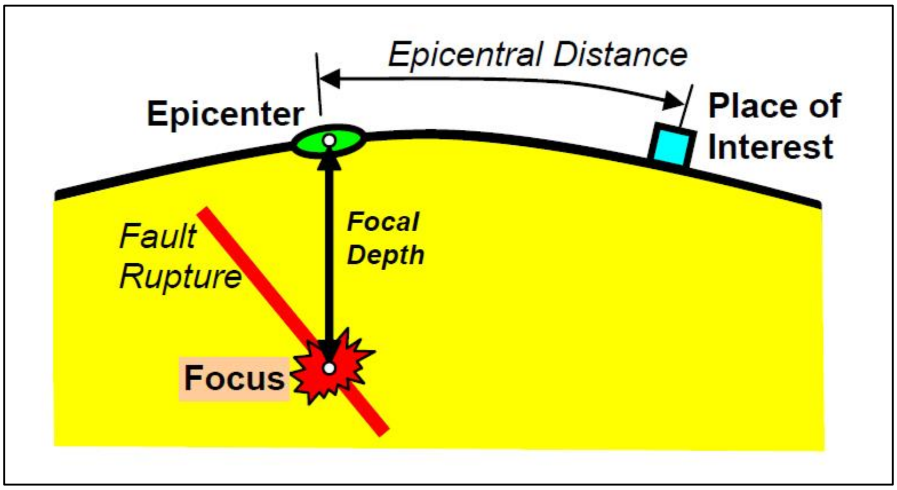


- Today, ***digital instruments*** using modern computer technology are more commonly used.
- The digital instrument records the ground motion on the memory of the microprocessor that is in-built in the instrument.



TERMINOLOGY

The point on the fault where slip starts is the **Focus or Hypocenter**, and the point vertically above this on the surface of the Earth is the **Epicenter** (See fig. below). The depth of focus from the epicenter, called as **Focal Depth**. Most of the damaging earthquakes have shallow focus with focal depths less than about 70km. Distance from epicenter to any point of interest is called **epicentral distance.**



MAGNITUDE OF EARTHQUAKE

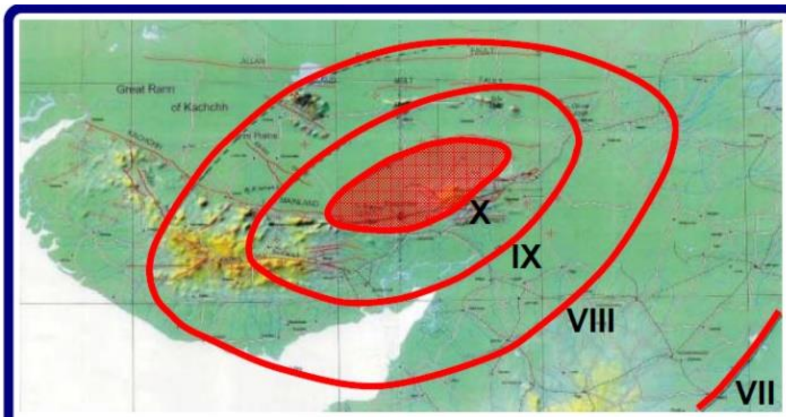
- Magnitude is a **quantitative measure** of the actual Size of the earthquake.
- Magnitude of an earthquake is a **measure of its size**
- *Professor Charles Richter noticed that,*
  - (a) At the same distance, seismograms of larger earthquakes have bigger wave amplitude than those of smaller earthquakes; and
  - (b) For a given earthquake, seismograms at farther distances have smaller wave amplitude than those at close distances.
- These prompted him to propose the now commonly used magnitude scale, **the Richter scale.**
- It is obtained from the seismograms and accounts for the dependence of waveform amplitude on epicentral distance. This scale is **also called Local Magnitude scale**.
- Earthquakes are classified based on magnitude as

Group	Magnitude
Great	8 and higher
Major	7 – 7.9
Strong	6 – 6.6
Moderate	5 – 5.9
Light	4 – 4.9
Minor	3 – 3.9
Very Minor	< 3.0

INTENSITY OF EARTHQUAKE

- Intensity is an **indicator of the severity of shaking** generated at a given location
- Intensity is a **qualitative measure** of the actual shaking at a location during an earthquake, and is assigned as Roman Capital Numerals.
- There are many intensity scales. Two commonly used ones are **the Modified Mercalli Intensity (MMI) Scale and the Medvedev–Sponheuer–Karnik (MSK) Scale.**
- Both scales are quite similar and **range from I (least perceptive) to XII (most severe).**

- The intensity scales are based on three features of shaking,
  - (a) Perception by people and animals,
  - (b) performance of buildings, and
  - (c) Changes to natural surroundings.
- The distribution of intensity at different places during an earthquake is shown graphically using **isoseismals**, lines joining places with equal seismic intensity



Isoseismal Map of the 2001 Bhuj (India) Earthquake (MSK Intensity)

MODIFIED MERCALLI SCALE		RICHTER SCALE	
I. II.	Felt by almost no one. Felt by very few people.	2.5	Generally not felt, but recorded on seismometers.
III. IV. V.	Tremor noticed by many, but they often do not realize it is an earthquake. Felt indoors by many. Feels like a truck has struck the building. Felt by nearly everyone; many people awakened. Swaying trees and poles may be observed.	3.5	Felt by many people.
VI. VII.	Felt by all; many people run outdoors. Furniture moved, slight damage occurs. Everyone runs outdoors. Poorly built structures considerably damaged; slight damage elsewhere.	4.5	Some local damage may occur.
VIII. IX.	Specially designed structures damaged slightly, others collapse. All buildings considerably damaged, many shift off foundations. Noticeable cracks in ground.	6.0	A destructive earthquake.
X.	Many structures destroyed. Ground is badly cracked.	7.0	A major earthquake.
XI. XII.	Almost all structures fall. Very wide cracks in ground. Total destruction. Waves seen on ground surfaces, objects are tumbled and tossed.	8.0 and up	Great earthquakes.

CLASSIFICATION OF EARTHQUAKES

(a) Depth of focus as basis:

i. ***Shallow*** : Depth of focus lies up to 60km below the surface

ii. ***Intermediate*** : Depth of focus lies between 60-300km below the surface

iii. ***Deep seated*** : Depth of focus lies between 300-700km below the surface

(b) Magnitude as basis (See classification above in Magnitude)

(c) Cause of origin as basis:

i. ***Tectonic earthquakes:*** Caused due to relative displacements of blocks of the crust of the earth along the rupture planes

ii. ***Non-tectonic earthquake:*** Caused due to volcanic eruptions, atomic explosions landslides and subsidence.

SEISMIC HAZARDS

Damage occurs to human settlement, buildings, structures and infrastructure, especially bridges, elevated roads, railways, water towers, pipelines, electrical generating facilities. Aftershocks of an earthquake can cause much greater damage to already weakened structures.

Secondary effects include fires, dam failure and landslides which may block water ways and also cause flooding. Damage may occur to facilities using or manufacturing dangerous materials resulting in possible chemical spills. There may also be a breakdown of communication facilities. The effect of an earthquake is diverse. There are large number of casualties because of the poor engineering design of the buildings and close proximity of the people. About 95 percent of the people who are killed or who are affected by the earthquake is because of the building collapse. There is also a huge loss to the public health system, transport and communication and water supply in the affected areas.

The hazards associated with earthquakes are as follows

1. **Ground Shaking**
   Ground surface may shift during an earthquake (especially if focus is shallow). Vertical displacements of surface produce faults

2. **Structural Hazards**
   Frequency of shaking differs for different seismic wave. High frequency body waves shake low buildings more. Low frequency surface waves shake high buildings more. Intensity of shaking also depends on type of subsurface material
3. **Liquefaction**
   - During earthquake, the strength of the soil is reduced drastically to a point where it is unable to support structures.
4. **Lateral Spreading**
   - It is a phenomenon characterized by incremental displacements that range from negligible to quite large during earthquake shaking.
5. **Landslides**
6. **Lifeline Hazards**
   - The network of facilities like electrical power and telecommunications, transportation, water and sewage, oil and gas distribution, and waste storage system have collectively come to known as lifelines.
   - Lifeline failures not only have severe economic consequences but can also adversely affect the environment and quality of life following an earthquake.
7. **Tsunami and Seiche Hazards**
   - Rapid vertical sea floor movements caused by fault rupture during earthquake can produce long period sea waves called tsunamis. In open sea, Tsunami travel great distances at high speeds.
   - Earthquake induced waves in enclosed water bodies (in a lake or reservoir) are called Seiche.

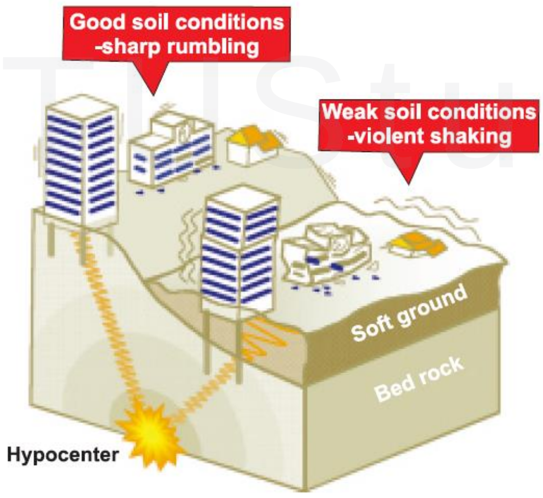
POSSIBLE RISK REDUCTION MEASURES:

Community preparedness: Community preparedness is vital for mitigating earthquake impact. The most effective way to save you even in a slightest shaking is 'DROP, COVER and HOLD'.

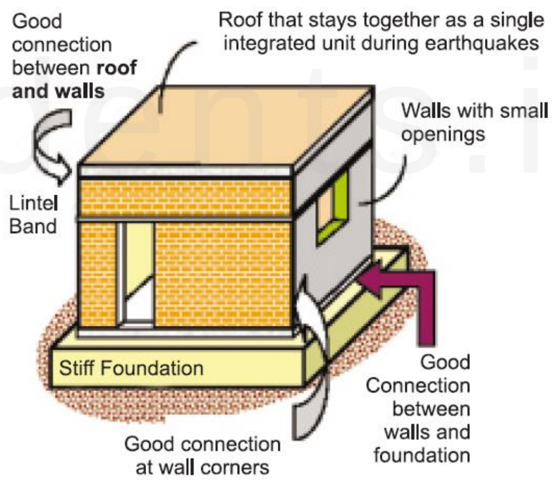
Planning: The Bureau of Indian Standards has published building codes and guidelines for safe construction of buildings against earthquakes. Before the buildings are constructed the building plans have to be checked by the Municipality, according to the laid down bylaws. Many existing lifeline buildings such as hospitals, schools and fire stations may not be built with earthquake safety measures. Their earthquake safety needs to be upgraded by retrofitting techniques.

Public education is educating the public on causes and characteristics of an earthquake and preparedness measures. It can be created through sensitization and training programme for community, architects, engineers, builders, masons, teachers, government functionaries teachers and students.

Engineered structures: Buildings need to be designed and constructed as per the building by laws to withstand ground shaking. Architectural and engineering inputs need to be put together to improve building design and construction practices. The soil type needs to be analyzed before construction. Building structures on soft soil should be avoided. Buildings on soft soil are more likely to get damaged even if the magnitude of the earthquake is not strong as shown in Figure below. Similar problems persist in the buildings constructed on the river banks which have alluvial soil.



Effect of Soil type on ground shaking



Essential requirements in a Masonry building

QUAKE RESISTANT BUILDINGS

Consider the following parts of building:

1. The foundations
2. The body
3. The roof

1. The foundations

- Structure on Loose sediments weak rocks is subjected to greater risk as compared to structures on hard rocks
- Soil particles undergo settlement during earthquake
- Foundations should be excavated to the same level
- The superstructure should be thoroughly tied with the foundations by introducing reinforcements to prevent sliding

2. **The body**
   - Walls should be properly designed for resisting lateral forces
   - Walls should be light in weight and made up of wood or light weight as possible
   - Use reinforcements in the walls
3. **The roof**
   - Flat roofs gives better resistance as compared to sloping roofs
   - Care should be taken to minimize the lateral stresses when tiles and corrugated sheets are used in flat roofs
   - Projections beyond roof like chimneys should be avoided

Generally speaking:

- Entire structure should acts as a unit
- Uniform height should be given to the structure
- Parapets ,Cantilevers, arches and domes should be avoided

EARTHQUAKE HAZARD MITIGATION

Unlike other disasters, the damages caused by earthquakes are more devastating. Since it also destroys most of the transport and communication links, providing timely relief to the victims becomes difficult. It is not possible to prevent the occurrence of an earthquake; hence, the next best option is to emphasis on disaster preparedness and mitigation rather than curative measures such as:

(i) Establishing earthquake monitoring centres (seismological centres) for regular monitoring and fast dissemination of information among the people in the vulnerable areas. Use of Geographical Positioning System (GPS) can be of great help in monitoring the movement of tectonic plates.

(ii) Preparing a vulnerability map of the country and dissemination of vulnerability risk information among the people and educating them about the ways and means minimising the adverse impacts of disasters.

(iii) Modifying the house types and building designs in the vulnerable areas and discouraging construction of high-rise buildings, large industrial establishments and big urban centres in such areas.

(iv) Finally, making it mandatory to adopt earthquake-resistant designs and use light materials in major construction activities in the vulnerable areas.

MASS MOVEMENT

In many regions of the world a temporary instability of superficial mass of soil and rock has always been an acute problem. These superficial mass may leave their original position **abruptly** or **extremely slowly** and start their downgrade movement or vertically downward sinking.

This Movement of the ground may entail loss to property and life, especially when they happen to occur in or near the populated areas, along highways, railway lines, dams and reservoirs, tunnels or under heavy structures.

Such **movements of the superficial masses** have been termed in common language as **landslides or landslips**, technically termed as **Mass Movement.**

CLASSIFICATION

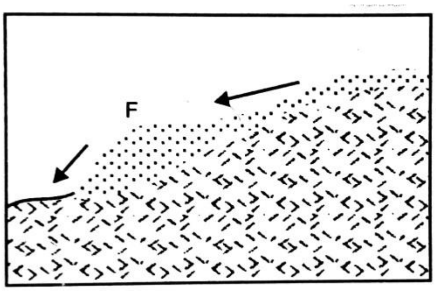
Many classification has been suggested for Mass movements attributed to a number of factors such as variety of geological situations, nature of surface, speed with which failure occurs etc.

On the basis of type of failure, mass movements are divided into **3 types,**

1. **Flowage**
2. **Sliding**
3. **Subsidence**

1. Flowage

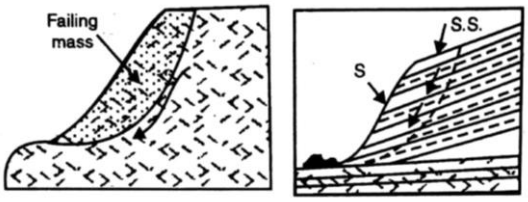
- By flowage is understood a downgrade movement of mass along **no definite surface of failure.**
- Mass involved in this type of failure is primarily **unconsolidated or loosely packed** or rendered so by natural processes of decay and disintegration.
- The result is that the movement is distributed throughout the mass and in a highly irregular manner



- Flowage is further distinguished into **slow and rapid flowage.**
- In the **slow flowage**, failure is not easily perceptible. The ground may be moving downslope at as such low rates as few centimeters a year or even less.
- In **rapid flowage**, however, the movement of failing mass may be easily visible and the mass may travel a few meters or more a day.

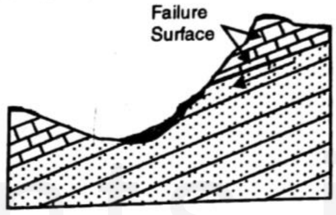
2. <u>Sliding</u>

- True landslide is a type of mass failure in which a superficial mass fails by moving as a whole along a definite surface of failure.
- The surface of failure may be planar or semicircular in outline.
- It is often characteristic of a landslide that the mass above the failure surface is unstable whereas the material lying below this surface is generally stable.
- In unconsolidated deposits, loose inherently weak rock masses, sliding commonly takes place along curved shear surfaces.



(A & B) Sliding in a Mass Along a Circular Failure Surface; S = Slope, SS = Sliding surface.

- But when the mass involved is hard, brittle and coherent, such as massive rocks, shear surfaces are broadly planar in nature. In such cases, a set of joint planes or bedding planes or fault planes may be the most convenient natural planes of failure.



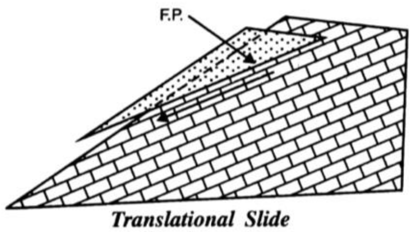
Slide Along a Planar Surface (A Bedding Plane

- **Types of Landslide**

  On the basis of the type of movement involved in the failure:

  (a) <u>Translational slides</u>

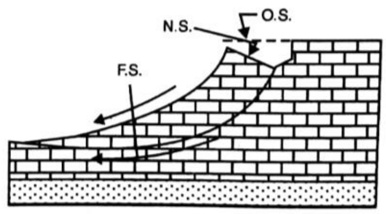
  - The **surface of failure is generally planar in character, speed of failure is quite rapid**
  - The nature of mass involved in failing may be rock blocks, rock slabs, debris and soil cover or even a mixture of all of them.
  - These slides are quite frequent in slopes made up of rocks and cohesive soil.



Translational Slide
F.P. = Plane of failure

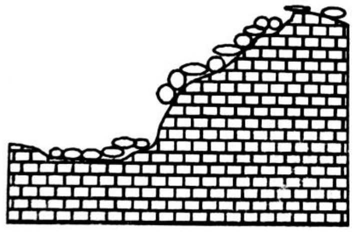
  (b) <u>Rotational slides</u>

  - In such slides, the **failing surface is generally curved in character and the speed of failure is also quite rapid**
  - Because of the nature of the failing surface, the movement of the mass takes the form of a sort of **rotation, rather than translation**.
  - The material involved in failure tilts downwards at the rear end and heaves up at the front or toe.



Rotational Slide
Note tilting back at the top of sliding block
O.S. = Original Surface N.S. = New Surface
F.S. = Failure Surface.

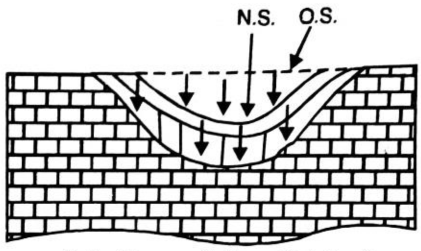
(c) Rock toppling and falls



- These are grouped along with slides although there may be little or no sliding involved in their failure (since they are commonly associated or accompanied with landslides)
- They are essentially a slope-failure phenomenon.
- In the falls, there is almost a free, sudden and fast decent from a steep slope.
- These conditions are favored for this type of failure is weathering of rocks on the slopes due to climatic changes e.g. frost action, expansion and contraction, leaching of natural binders etc.

3. Subsidence

It is defined as **sinking or settling of the ground in almost vertically downward** direction which may occur because of removal of natural support from the underground or due to compaction of the weaker rocks under the load from overlying mass.



Subsidence O.S = Original Surface, N.S. = New Surface

Definitions

Landslide Hazard refers to the potential of occurrence of a damaging landslide within a given area; such damage could include loss of life or injury, property damage, social and economic disruption, or environmental degradation.

Landslide Vulnerability reflects the extent of potential loss to given elements (or set of elements) within the area affected by the hazard, expressed on a scale of 0 (no loss) to 1 (total loss); vulnerability is shaped by physical, social, economic and environmental conditions.

Landslide Risk refers to the probability of harmful consequences-the expected number of lives lost, persons injured, extent of damage to property or ecological systems, or disruption of economic activity –within a landslide prone area. The risk may be individual or societal in scope, resulting from an interaction between the hazard and individual or societal vulnerability.

Landslide Risk Evaluation is the application of analyses and judgments (encompassing physical, social, and economic dimensions of landslide vulnerability) to determine risk management alternatives, which may include determination that the landslide risk is acceptable or tolerable.

CAUSES OF MASS MOVEMENT

There are many factors involved in causing mass movement. Some of them have direct role and some are indirectly responsible for the instability of land mass. All such factors can be grouped into two, **Internal factors & External factors.**

A. Internal Factors

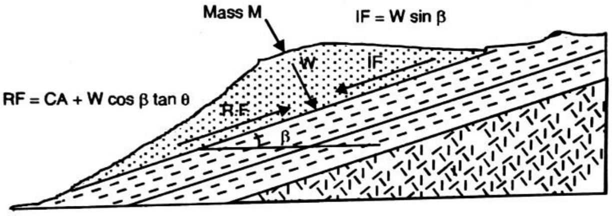
These include such causes, which **tend to reduce the shearing strength of soil or rock mass**.

(i) Nature of Slope

- A great majority of mass failures are confined to slopes only, it is reasonable to conclude that nature of a slope may be a deciding factor in defining the stability of a land mass.
- By nature of slope it is meant here, the **type of material** of which the land mass is made up (soil or rock) and the **angle at which this particular mass is inclined** with the horizontal (the slope angle).
- Any mass forming a slope is subject to two types of forces:

First, those forces or strength by virtue of which it can **retain the soil mass** in stable position (i.e. shear strength of soil) and ***second***, those forces which **tend to induce failure** into it.

- Shear strength of soil is given by: $\boxed{\tau = c + \sigma tan\emptyset}$
- Where **τ** – shear strength, **c** – cohesion, **σ** – normal stress and **ϕ** – angle of internal friction of mass
- Among the forces that tend to induce failure in a mass, the most important is the pull due to gravity which acts through the weight of the material.
- When Forces tending to induce failure is greater than shear strength of soil, the mass becomes unstable.
- This may be explained in a simple case assuming a mass M forming a slope angle β and resting over a possible surface of planar failure.



Forces Effecting Stability of a Mass on Planar Surface
IF = Forces inducing failure, RF = Forces resisting failure

– Forces **resisting failure,** RF = cA + W cosβ tanϕ
– Forces **Inducing failure,** IF = W sinβ
– Where **c** – Cohesion of mass, **W** – Force of mass acting through it, **β** – Angle of slope,
– **ϕ** – Angle of internal friction and **A** – Area of block at contact
– The condition of limiting equilibrium is satisfied when **IF = RF**
– In the analysis of stability conditions for slopes, a factor of safety, FS is expressed as

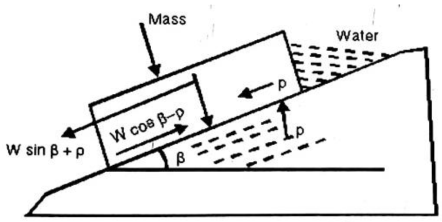
$$\boxed{\mathbf{FS} = \frac{\mathbf{\Sigma RF}}{\mathbf{\Sigma IF}}}$$

Angle of Repose

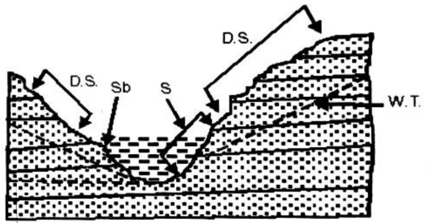
– It has been observed that most materials are stable up to a certain angle of slope.
– This is called the critical angle of slope (sometimes called angle of repose) and varies from 35° for unconsolidated sediments to 90° for perfectly crystalline un-jointed rocks.
– For partially jointed rocks it may range from 60° -90°.

(ii) *Role of Water*

- Both surface and subsurface water have important role in causing mass movement.
- Water may to reduce the shearing strength of a rock or soil mass in a number of ways.
- Some general cases of role of water is discussed below under 4 ways:



Influence of Water on Stability Conditions



Different types of Environment for a Slope
D.S. = dry; Sb = submerged; W.T. = water table.

(a) Water that **penetrates the soil and rocks through seepage and moves into the pores of the mass** may be the cause of development of an uplift or pore-pressure within the mass under consideration.
This pore pressure, "p", ***reduce the normal stress of the mass and thereby reduce shear strength of soil.***

(b) **Water accumulates at the back of a mass may exert a pressure**, in the opposite direction of shear strength thereby reduce the net resisting forces against failure and thus cause instability. Such water pressure cause great reduction in the factor of safety of a mass.

(c) A still different way in which water may weaken the soil or rock mass is through its **repeated change of state with climate changes.**
Water freezing within the pores and other open spaces during extremely cold weather expands and exerts considerable pressure. This may be followed by melting or thawing of ice crystal in following summers.
The water so produced may saturate the mass. This process of **frost action may be repeated again and again in cold humid regions resulting in disintegration of layers of soils and rocks.** As a consequence stable slopes of massive nature may change gradually into unstable slopes.
Flowage, whether slow or rapid, invariably involves presence of water. In cold regions, frost action has been found to be the primary cause of frequent rock falls from high steep slopes.

(d) Water also **facilitates mass failure through its lubricating action.**
Thus, when groundwater happens to move along a plane of weakness (e.g. a joint set, a fault pane, shear zone and a bedding plane etc.) within a mass, that plane gets lubricated, thereby decreasing the friction forces and it affects the stability.

(iii) <u>Composition of Mass</u>

- Materials are stable in a given set of conditions of slope and water content
- By composition of the mass is meant in the present study:
  (a) Whether the mass is in the form of soil or a rock**; rock formation is stable as compared to soil formation**
  (b) If soil, whether it is cohesive or non-cohesive, and also, if it is sandy, silty or clayey or a mixture of two or more of these components; **Cohesive soil is stable compared to non-cohesive soil**
  (c) If rock, whether it is an igneous or sedimentary or metamorphic rock, and also, within each group, to which particular class it belongs. **Igneous rock is stronger rock**
- The role of composition of mass in its stability becomes important because a broad assessment can be made about the stability of a mass if its exact composition (in both physical and chemical sense) is known.

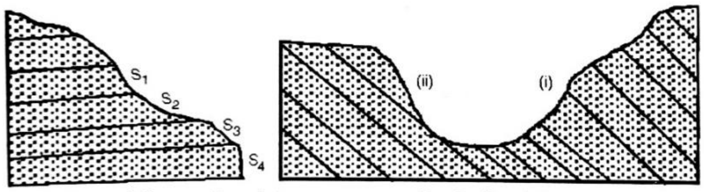
(iv) <u>Geological Structures</u>

- Geological structures are of great significance in defining the stability of mass, especially in rocks.
- Relationship of geological structures with the stability of mass has been discussed below under 3 headings:

  (a) Bedding planes

  – Many sedimentary rocks are layered or stratified and thickness of layers may range from few centimeters to many meters. The bedding plane (the surface between any two adjacent layers) is a plane, with least cohesion in a layered mass. These layers may be horizontal, inclined at various angles with the horizontal (dipping) or even vertical. The dip or inclination of the stratified rocks exerts very important influence on the stability of slopes.
  – This may be explained in different cases as follows:
  <u>CASE I:</u> The layers are horizontal (Dip = 0°). Such rocks forming the slopes of the natural valleys and artificial cuts are stable at all the angles up to 90°. When they fail, it may be due to presence of secondary jointing or related fractures.
  <u>CASE II:</u>
  The layers are Inclined. In such a situation, assuming that the rock is free from any other types of discontinuities (joints, shear and fault zones), the stability of a slope (natural

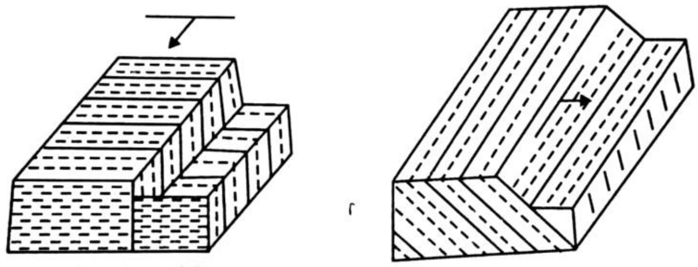
the artificial) will depend primarily on the condition whether the layers are dipping backwards into the mountain or forward into the valley or the cut.



A = Horizontal Layers (nearly) B = Inclined Layers

Inclination of Layers Vs Stability

- # When dipping into the mountain, the tendency of layers to slide along the bedding planes is resisted by enormous weight of the mountain resting against them. Hence, in such a situation, even a nearly vertical slope should be stable.
- # When dipping into the valley, there will be tendency of the layers to slide and sliding may take place where the dip of the layers is greater than angle of internal friction, $\phi = 30$ and the slope angle β exceeds the dip angle α .
- # Cuts parallel to the dip of the rocks are more safe and stable compared to those parallel to the strike of the layers.



A. Cut Parallel to Dip of Strata B. Cut Parallel to strike of Strata

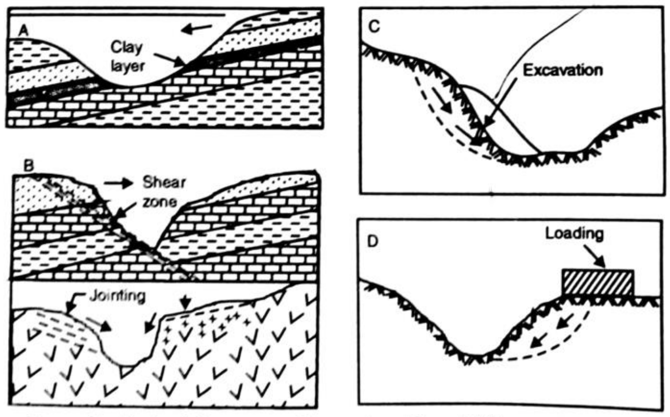
Dip Factors Versus Cuts (See Text for Explanation)

(b) The Metamorphic Structures

– Schistosity, foliation and cleavage structures as found in metamorphic rocks like schists, gneisses and slates respectively and thus all behave as surfaces of weakness and promote the failure.

(c) The Jointing Structures

– Joints reduce the shear strength of soil and rock formations



Some Geological Structures Favouring Slope Failures (See Text)

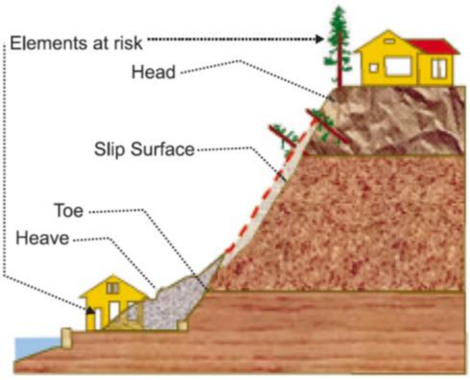
B. <u>External factors</u>

- An analysis of many slope failure makes it clear that in some cases an external factor might have triggered the slide
- External factors include **vibrations from artificial and natural phenomenon.**
  Vibrations due to artificial causes - **Heavy blasting and heavy traffic on hill roads**
  Vibrations due to natural causes – **Earthquakes**

- Another important external factor is the **removal of the support at the foot of the slope**, during excavation for road widening.
- **Removal of trees** is another is another external cause for mass movement

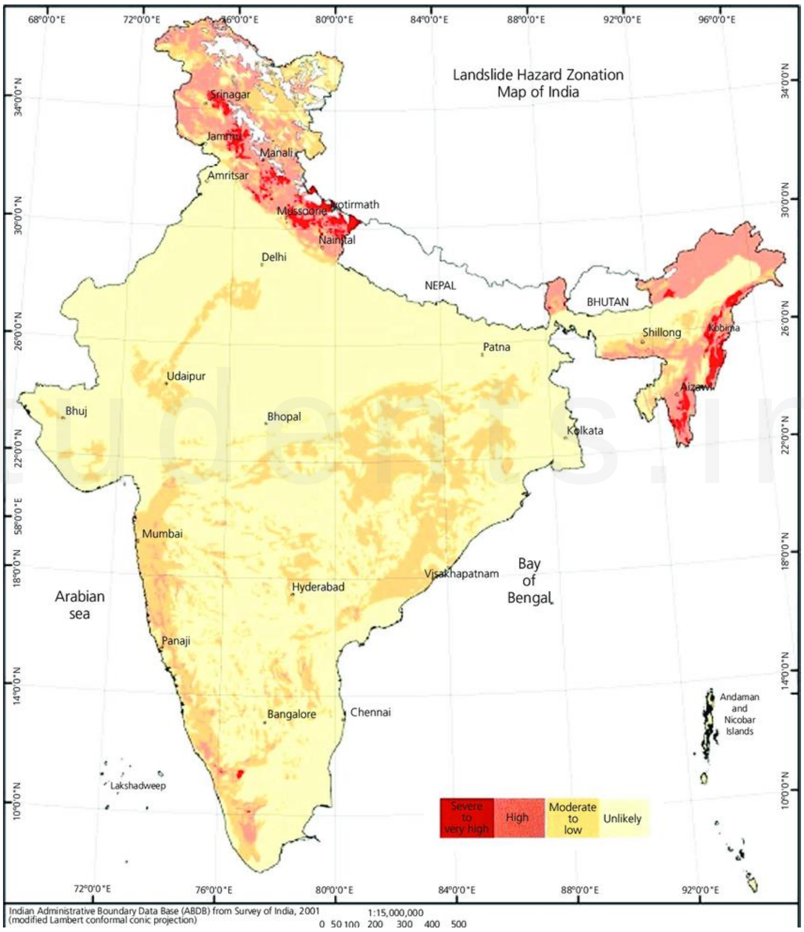
ADVERSE EFFECTS

The most common elements at risk are the settlements built on the steep slopes, built at the toe and those built at the mouth of the streams emerging from the mountain valley. All those buildings constructed without appropriate foundation for a given soil and in sloppy areas are also at risk. Roads, communication lines are vulnerable.



Distributional Pattern:

Landslides constitute a major natural hazard in our country, which accounts for considerable loss of life and damage to communication routes, human settlements, agricultural fields and forest lands. The Indian subcontinent, with diverse physiographic, seismic, tectonic and climatological conditions is subjected to varying degree of landslide hazards; the Himalayas including Northeastern mountains ranges being the worst affected, followed by a section of Western Ghats and the Vindhyas. Removal of vegetation and toe erosion have also triggered slides. Torrential rainfall on the deforested slopes is the main factor in the Peninsular India namely in Western Ghat and Nilgiris. Human intervention by way of slope modification has added to this effect. Figure shows landslide hazard zonation map of India.



MONITORING OF MASS MOVEMENTS

- Detection of possibility of failure before its occurrence by noting the present conditions is called Monitoring.
- Monitoring of slopes may be achieved by using conventional surveying techniques.
- Land or mass movement can be ascertained using electronic equipment, laser equipment, settlement gauges and extensometers.
- Pore water pressure can be measured using the Piezometers and thus possibility of failure by pore water pressure can be understood.

TECHNIQUES TO REDUCE LANDSLIDE HAZARDS

Following are some of the techniques used to reduce landslide hazards. These may be used in a variety of combinations to help to solve both existing and potential landslide problems. The techniques are generally applicable to all types of surface ground failure, including flows, slides and falls. The effectiveness of each hazard reduction varies with time, place and persons involved in the planning and implementing of the Programme for reducing the hazard.

Discouraging new developments in hazardous areas by:
Disclosing the hazard to real-estate buyers
Posting warnings of potential hazards
Adopting utility and public facility service area policies
Informing and educating the public
Making a public record of hazards

Removing or converting existing development through:
Acquiring or exchanging hazardous properties
Discontinuing non-conforming uses
Reconstructing damaged areas after landslides
Removing unsafe structures
Clearing and redeveloping blighted areas before landslides

Providing financial incentives or disincentives by:
Conditioning federal and state financial assistance
Clarifying the legal liability of property owners
Adopting lending policies that reflect risk of loss
Requiring insurance related to level of hazard
Providing tax credits or lower assessments to property owners

Regulating new development in hazardous areas by:
Enacting grading ordinances
Adopting hillside development regulations
Amending land-use zoning districts and regulations
Enacting sanitary ordinances
Creating special hazard reduction zones and regulations
Enacting subdivision ordinances
Placing moratoriums on rebuilding

Protecting existing development by:
Controlling landslides and slumps
Controlling mudflows and debris flows
Controlling rockfalls
Creating improvement districts that assess costs to beneficiaries
Operating monitoring, warning, and evacuating systems

CONTROL OF MASS MOVEMENTS

1. Drainage

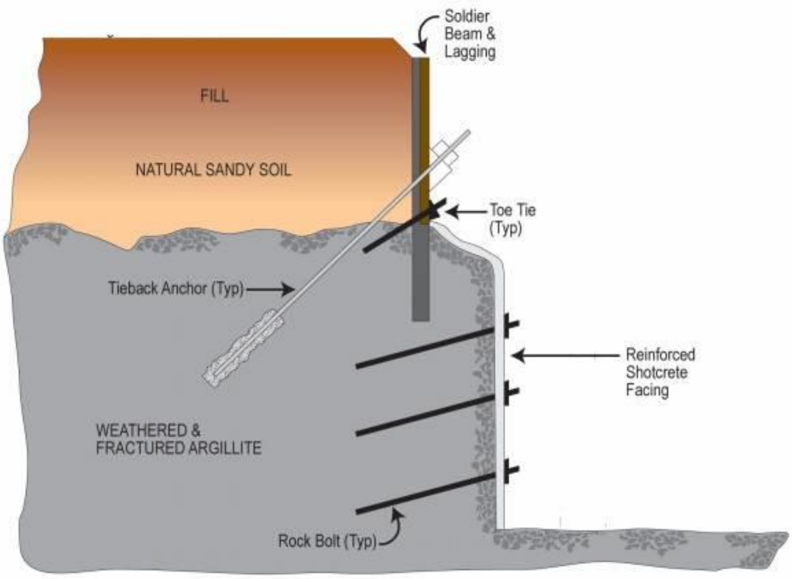
- Water presence is the one of the factor that leads to the mass movement.
- Avoid water content either by surface or sub-surface methods.
  - Construct series of ditches
  - Backfill the pits on the soil surface with concrete or asphalt to prevent the water impounding.
  - Cover the slope surface with granular material to remove excess rainfall.
  - Remove the cracks and fissures in the surface by filling with cement, bitumen or clay mixture.
  - Construct interception drains (To reduce pore water pressure)
  - Oiling of slope surfaces
  - Electro- osmosis
  - Heating the slope surface to avoid water content

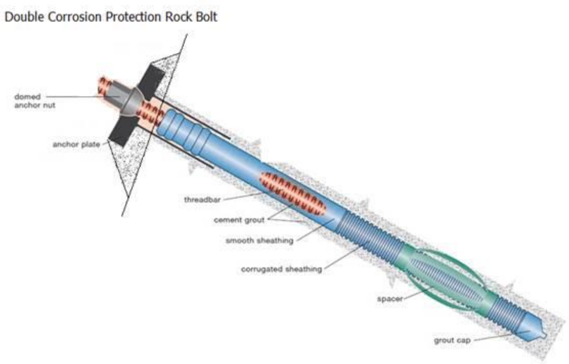
2. **Retaining structures**
   - **Construct Retaining walls and buttresses**
   - These are suitable where:
     (a) The ground is neither too fine nor too plastic.
     (b) The sliding mass is likely to remain dry
     (c) The movement is of a shallow nature and limited extent

3. **Slope reinforcement by rock bolting**

   Rock Bolts

   - Rock bolts are used to tie up different rock blocks together thereby improving the stability of rock mass.
   - A rock bolt is a steel bar of suitable dia (2-25mm) and length (60cm- 5m) one end of which is designed for expanding and other end is threaded to take a nut and washer.
   - Such a bolt is inserted into a hole drilled in the rock at a proper angle with the plane of weakness and its end within the rock is made to expand whereby it fits tightly into the rock.
   - The other end is tied on a plate with the help of a nut and washer. The rod is generally pre-stressed and is always placed in tension.
   - When placed in the above fashion, the rock bolt held up within the two ends of the bolt gets compressed and hence stabilized against falling.





Rock Anchors

- Rock anchors are structural elements made up of cables, bars. Like bolts, it is also placed in previously drilled holes and then whole or part of them is bonded to the rock using a proper technique.
- They may be tensioned after placing in the hole before or after grouting which is an integral part of anchorage system.
- Anchor system may exceed 20-30m in length and once installed they modify the original stress field of the rock to a considerable extent.
- Use corrosion resistant materials for rock anchors

4. Slope treatment

- Treat the top layers of formation
- Apply concrete or mortar on the top surface.
- The mixture of cement and sand (1:3) with little water is applied on the face under pressure and thus the slopes gains sufficient strength on hardening.
- Flatten the slope to ensure stability.
- Decreasing the load on slopes (For example on hill roads, reduce the traffic)
- Provide benches at the foot of the slope
- Promote afforestation (Vegetation cover reduces the infiltration of water)

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