EARTHQUAKES

- **Nature of Earthquakes**
- **Causes of Earthquake**
- **Basic Features of Earthquakes (Mechanism)**
- **Distribution of Earthquakes (Earthquake zones)**
- **Some Historic Earthquakes**
- **Basic definitions**
- **Earthquake energy**
    - **Magnitude**
    - **Seismograph**
- **Seismic waves**
- **Forecasting and predicting earthquakes**

DEFINITION

Earthquake is a phenomenon during the occurrence of which the earth's crust is set shaking for a period of time.

The shaking is caused by the passage through the earth of seismic waves - low frequency sound waves that are emanated from a point in the earth's interior where a sudden rapid motion has taken place.

The earth is not a static body but is changing, moving, and full of energy. When parts of the earth move, rocks are deformed.

The changes in shape or volume which result from deformation are known as strain.

When accumulated strain is suddenly released, it creates kinetic energy which travels through the earth as *seismic waves.*

According to modern geophysics: Earthquakes, are trains of energetic seismic waves.

The earth is continually undergoing deformation due to stresses that are set up within it. If the stresses continue to build up over a long time fracture may take place, resulting in an earthquake.

This involves a sudden release of energy, part of which takes the form of elastic waves which travel through the earth.

The Nature of Earthquakes

When a stone is thrown into a pool, a series of waves spreads through the water in all directions.
Similarly, when rocks are suddenly disturbed, vibrations spread out in all direction from the source of the disturbance, e.g. when hammering a large boulder of rock.

An earthquake is the passage of these vibrations. In the neighborhood of the disturbance itself the shaking of the ground can be felt and the effects may be catastrophic but farther away the tremors die away.

Greek meaning **Seio- shake**
Seismos- an earthquake
Seismology: It is the study of earthquakes.

It is more proper today to use the term earthquake to refer to the source of seismic waves, rather than the shaking phenomenon, which is an effect of the earthquake.

CAUSES OF EARTHQUAKES

Japanese :
They thought that earthquakes were the result of sudden movement of giant spider that carried the earth on its back.

Mongolian Mythology:
Recorded that the huge, but occasionally unbalanced supporter of the earth was a giant mole (a fur animal living underground or tunnel)

Hindus: Fish, Tortoise.
Greek and Roman: Ascribed earthquakes to air escaping from underground caverns or for the collapse of vast subterranean cavities.

European scholars began a more scientific treatment of earthquakes after the great tremor that devastated Lisbon, Portugal in 1755.

The systematic study of earthquakes in the United States was given its impetus by the 1906 San Francisco earthquake. The city was reduced to the ruins.

As ordinary vibrations are set up in solid bodies by:

- a. **A sudden blow or rupture or**
- b. **By scraping together of two rough surfaces**

Natural causes:

Volcanic explosions
Tectonic earthquakes
(Related to movements along faults)

- i. **The initiation of faults and**
- ii. **The movements of the rocks along fault planes**

Artificial causes are:

- a. **Perceptible tremors are set up by the passage of trains, heavy load vehicles etc.**
- b. **Explosions of all kinds**

Other causes are:

- a. **By Avalanches and landslides**
- b. **By rock falls in mines and caverns**

The majority of natural earthquakes, however, including all the most disastrous examples, are due to sudden earth movements, generally along faults.

These are distinguished as *Tectonic earthquakes.*
Tectonics (Greek tecton - a builder): Means any structural change in rocks brought about by their deformation or displacement.

The causes of earthquakes may also be divided as:

- a. **Surface causes -landslides, sea waves, underground roof collapse**
- b. **Volcanic causes - Krakatoa(1883) Sumatra.**
- c. **Tectonic causes**

The cause of *Tectonic Earthquake* is thus the building up of stresses in rocks until they are strained to breaking point, when they suddenly rupture and move.

MECHANISM
ELASTIC REBOUND THEORY
(Reid, 1911)

The cause of *Tectonic Earthquake* is thus the building up of stresses in rocks until they are strained to breaking point, when they suddenly rupture and move.

Many but, by no means, all earthquakes are related to motion along faults.

At times, the opposite sides of a fault become locked together and both bend as further motion takes place.

Eventually, the fault becomes unlocked and snaps out of its bend position. Such motion creates a large earthquake. Small gradual motion create tremors. It is called elastic rebound theory.

The fault movements themselves may be:
Vertical
Horizontal or
Oblique.

During the Alaskan earthquake of 1899, the uplift was exceptionally high- around 14m

Crustal blocks often move obliquely, both vertical and sideways movements being observed .

When the rocks are nearly at their breaking point, an earthquake may be triggered off by some extraneous agents such as:

a. high tides
b. heavy rainfall or flood
c. rapid change of barometric pressure
d. the tremors from an independent earthquake originating far away
e. shock waves from an exploding H-bomb.

Foreshock-The principal shock -Aftershocks

Considering the whole earth, earthquakes of one kind or another are known to take place every few seconds. But many of them are too slight to be felt by men.

Really severe earthquakes take place every two or three weeks. On average most of these originate beneath the continental slopes and cause little damage from human point of view.

Strike-slip friction and elastic rebound

As the plates move past each other, the motion at their boundaries does not occur by continuous slippage but in a series of rapid Jerks. Each jerk is an earthquake.

Nomotion-Sticking

The periods between major earthquakes is thus during which strain slowly builds up near the plate boundary in response to the continuous movement of the plates. The strain is ultimately released by an earthquake when the frictional strength of the plate boundary is exceeded.

This form of strain build up and release was discovered by H. F. Reid in his study of the 1906 San Francisco earthquake. From this he deduced his theory of Elastic rebound.

Seismic waves are also called

1. **Tremors - if gentle**
2. **Shocks - if powerful**

Fore shocks : Principal shock
After shocks: Follows the principal shock

Focus: The place where the energy is first released.
Epicenter: The place on the surface of the earth directly above the focus.

The depth of focus of an earthquakes can vary from approximately 5 to 100 km.

Tectonic earthquakes are classified as:

Shallow	**(<60 km or 70 km,**
Intermediate	**(60-300 km)**
Deep	**(>300 up to 720 km)**

Coseismal lines
Lines joining the places where the shocks arrive at the same time.

If a focus is at a point, the coseismals will be circles. But as the focus is a tract rather than a point, the coseismals are generally elliptical.Lines:

Isoseismal lines
Lines joining the places where earthquake is of equal intensity is called the isoseismal lines

DISTRIBUTION OF EARTHQUAKES

1. **Circum pacific belt**
2. **Alpine-Himalayan belt**
3. **Mid oceanic ridges**

SOME HISTORIC EARTHQUAKES

1. **Lisbon, Portugal (1st Nov. 1755)**
   This was the first great earthquake to strike Europe in hundreds of years. It killed 30,000 (some estimate 60,000) people. The earthquake came as series of three great shocks.
   Tsunami roared up the river and one km inland and divastated. it reached 5,600 km on the opposite of the Atlantic.
2. **The Naples earthquake, Italy (1857): in which 12,000 people died.**

3. The shillong earthquake, Assam (July 1897): A great loss of life and property was caused.
4. Alaska (1899): Great Alaskan earthquake.
5. The Kangra earthquake, India: 19,000 people died.
6. The San Francisco earthquake, California (1906): 700 persons were killed. It had a mgnitude of 8.3

7. The Tokyo- Yokohama earthquake, Japan (Sept 1, 1923): 1,40,000 (some estimate 250,000) lives were lost and lot of damage. The whole Tokyo was destroyed.
8. The Kansu earthquake, China (1920): 180,000 (some estimate 200,000) people died.
9. The north Bihar-Nepal earthquake (Jan 15,1934): More than 12,000 persons died.

10. The Quetta earthquake, Baluchistan, Pakistan (March 31, 1935): 20,000 people died.
11. Chile (May, 1960): Three main shocks received. 10,000 people died.
12. Alaska, Anchorage city (1964): 114 people died. It is considered to be one of the greatest earthquake of modern time. The magnitude was 8.6 (between 8.3 and 8.75) probably largest of the century and one of the largest in history (130,000 sq km affected. The seismic activity took place along the *Denali fault zone.* West of the fault the land was lowered by 2 m and covered by sea. To the east the land rose by 10 m. It also caused tsunami (tsu- harbor, nami-waves). The earthquake lasted for about3 to 4 minutes.

14. Peru (May 31, 1970): It had a magnitude of 7.8 and claimed the lives of 50,000 people, it was the deadliest earthquake in Latin American history

13. The Tangshan earthquake, China (July 28, 1976): 750,000 people died.

This is perhaps the second most devastating earthquake in history. (The most destructive also occurred in China in 1556). The enormous shock registered 8.2 on the Richte scale.

14. The Mexico earthquake (1985):

Effects of Earthquake

Earthquakes do not kill people, it is the man made structures that kill people

EFFECTS OF EARTHQUAKES

1. Damage to buildings, rail roads, highways, etc. (Damage done by quake itself).
2. Slope failures
3. Tsunami
4. Fires

Effects of earthquake depends upon factors other than energy released given by Richter magnitude. e.g.

a. Closeness of the epicenter
b. Nature of the subsurface material

Magnitude and Intensity of Earthquake

MEASUREMENT OF MAGNITUDE OF EARTHQUAKE

Seismograph and seismogram

The energy released during a great earthquake (such as 1906 California earthquake) has been compared to the force of 100,000 atomic bombs.

However, to seismologists the most meaningful way to describe earthquake is not in terms of atomic bombs or tons of TNT, but in terms of ground motion and energy released.

Earthquake Energy

Interpretation of seismograms has made possible a calculation of the quantities of energy released as wave motion by earthquake of various magnitude.

In 1935 a leading seismologist Charles F. Richter brought forth a scale of earthquake magnitudes describing the quantity of energy released at the earthquake focus.

This scale consists of numbers ranging from

0 to 8.6

The scale is logarithmic, i.e. the energy of the shocks increase by powers of 10 in relation to magnitude numbers.

The relationship between the magnitude M and the energy released E is given by the equation:

$$\log E = 11.8 + 1.5M$$

Where, E in ergs

Magnitude

About 100 Joules of energy is released from each cubic meter of rock at the time of an earthquake. 1000 km (length) x 100 km (depth) x 50 km (width) on either side of the fault (1016 cubic meters) will produce 1018 Joules equivalent to thousand nuclear explosion of 1 megaton TNT

Magnitude
measures the amount of energy released from an earthquake. Measured in Richter Scale (0-8.6).

Richter Magnitude:

1 to 2 means 30 times the energy
1 to 3 means 900 times energy

Two or three earthquakes of the last century have Richter magnitude of 8.9.

1906 San Francisco	**8.25**
1960 22 may, Chile	**8.5**

For example when a stone is dropped in a pond, bigger the stone stronger the waves and higher the amplitude and wave length of waves. Similarly waves in ground depends upon energy released.
The first crude instrument for recording ground motion caused by seismic waves was used in Italy in 1841.

Modern descendants of this instruments, called seismographs are still being refined, but principles remains the same.

The record of seismic waves made by seismograph is a seismogram.

Perhaps the earliest seismograph (seismoscope) was invented in China A.D. 136 (132) by a man named Choko.

SEISMOGRAPH

In recording earthquake we need to know:

1. **The direction and**
2. **The amount of earth motion**

The mechanical problem is that the instrument itself must be resting on the ground and will therefore also move with the ground.

Because the instrument can not be physically separated from the earth, the seismograph designer must make use of the principle of inertia to overcome the effect of the attachment.

Inertia is the tendency of any mass to resist a change in a state of rest or of uniform motion in a straight line. The greater the mass of the object, the greater its inertia.

To record an earthquake, then a very heavy mass, such as an iron ball, might be suspended from a very thin wire or from a flexible coil spring.

When the earth moves back and forth or up and down in earthquake wave motion, the large mass will stay almost motionless because the supporting wire or spring flexes easily and does not transmit the motion through to the weight (e.g. shock absorber in vehicles or cars).

If a pen is now attached to the mass, so that the point is just touching a sheet of paper wrapped around a moving drum, the pen will provide a wavy line on the paper.

More than a million earthquake occur around the world each year, 50 are large enough to cause property damage and loss of lives. Most earthquakes are small, and each year 800,000 small tremors recorded by instruments are not felt by human beings.

Generally shallow earthquakes have to reach a Richter magnitude of more than 5.5 before significant damage occurs near the source.

Every year, more than 150,000 earthquakes are recorded by the worldwide network of seismic stations and are analyzed with the aid of computers at the earthquake data center in Boulder, Colorado. With this network, the exact location, depth, and magnitude of all detectable earthquakes are plotted on regional maps.

Great earthquakes with magnitudes exceeding 8.0 occur about once every five to ten years.

Earthquake Intensity

Early seismologists used a scale developed in 1880’s which defines earthquake by subjective assessment of damage and other observable effects.

The scale was revised in 1902 by Italian seismologist Mercalli (1850-1914) and then modified again in 1931.

The modern version, the Modified Mercalli Scale runs from Roman numeral I through XII and is still used combined with Richter Scale.

Intensity

it is a measure of damage at a particular locality due to an earthquake. Measured in Modified Mecarlli or MMI Scale (I-XII)

Modified Mercalli Scale Intensity map

Seismic waves

Seismic waves

Seismic waves are also called elastic waves because the waves are related to the elastic properties of matter.

Classification of seismic waves

Classification depends upon:

1. **Where they travel**
2. **How they look on the seismogram, and**
3. **Relationship between direction of waves traveling and the direction of motion of the material**

1. Where they travel:

a. Within the earth: Body waves
b. Moving along the surface: Surface waves

In an earthquake only body waves leave the focus. After the body waves have reached the surface, they create the motions that give rise to the surface waves.

2. How they look on the seismogram:

a. Primary or Push (P) waves First group of waves to be recorded
b. Secondary (S) waves Recorded a little later
c. Large (L) waves The wave traces become very confused due to these large waves.

3. Relationship between the directions the waves are traveling and the directions of motion of the materials as the waves travel

a. Longitudinal waves (P waves) Motion of particles along the direction of travel

b. Transverse waves (S waves) Motion of particles at right angles to the direction of travel

Nature of waves

P-Waves
The seismic P-waves are mechanically equivalent to sound waves i.e. they pass through solid, liquid and gases, by setting up back and forth movement of compression and dilation in the direction of travel.

The effect resembles the motion of an accordion. Therefore P-waves are also called Push-Pull waves or Primary waves.

P-waves travel approximately 1.7 times as rapidly as S waves.

S-Waves
Seismic S-waves cause material through which they pass to be sheared back and forth along lines at right angles to the direction of travel. Thus they are named Shear waves.

Shear waves can pass through solid only. Fluids lack the shearing resistance necessary to transmit S-waves.

L-waves

They consist of two important kinds and both are surface waves

Love waves: Transverse motion in the horizontal plane characterizes Love waves (named after A.E.H. Love, a British mathematician). Love wave can be visualized a shear waves in the horizontal plane.
During an earthquake, Love waves are felt as gentle side to side swaying. It is a surface motion where only horizontal motion is present.

Rayleigh waves:

The second kind of seismic L waves cause the land surface to roll up and down , as water waves on the sea. In this case both vertical and horizontal motion is present.

Named after Lord Rayleigh, British physicist.
The motion is in the vertical plane. The motion is an ellipse whose vertical axis is 1.2 times it s horizontal axis.

The short, choppy Rayleigh waves cause extensive damages to buildings during an earthquake.

DETERMINING STATE OF MATTER

P-waves can pass through solid, liquid and gases whereas S-waves can pass only through solids.

If P-waves from an earthquake, but not S-waves, are recorded, at a given station, we know that a gas-filled or liquid-filled space lies between the focus and the seismograph.

DETERMINING DENSITIES OF MATERIAL

The speed of both P and S waves are determined by the kind of material through which they travel. The speed of body waves increase with the density of the material.

LOCATING THE EARTHQUAKE EPICENTRE

FORECASTING AND PREDICTING EARTHQUAKES

WHAT TO DO WHEN AN EARTHQUAKE STRIKES

Earthquake in Nepal

The Himalaya

Seismically one of the most active parts on earth

It has experienced many mega-earthquakes

Himalaya

Its birth and rise

The trenching done so far in east, central and west Nepal have shown the following dates:

Eastern Nepal

1. Bering Khola MFT Active Fault:

(Nakata et al, 1998, Upreti et al, 2000)

At least 4 m of displacement and age of most recent surface rupture is about **1200 AD**

2. Tokla Tea Garden near Kakarbhitta (Ganges-Bengal Fault)

(Nakata et al, 1998, Upreti et al, 2000):

Time of the most recent surface rupture is not well-defined and appears to be between **1000 and 1200 AD**

Central east Nepal

3. Kemalipur (Aurahi River, N of Janakpur)

(present authors**)**

The latest faulting event occurred between **896 BC and 1439 AD**. Thus no evidence of faulting with surface rupture at least during the last 560 years.

4. Mahara Khola:

(Yule et al, 2006, Lave et al. 2005)

vertical offset 7.2 m and displacement 17 m: dated as **1120-1160 AD**

Western Nepal

5. Badel Pokhari, Butwal

(Upreti et a., present work)

•The latest event (or multiple events) was occurred between **1640 AD and 800 BC.**

•During the latest event (or multiple events) vertical slip is 4 m, net slip is 9.2 m.

Far western Nepal

6. Mohana Khola

(Yule et al.., 2006)

Apparent vertical throw ~ 8 m and estimated displacement ~20 m

Analysis of the organic content of the deformed soil, with charcoal and roots removed, yields an age of **1410 Ad.**

Nepal-Bihar Earthquake of 1934 (1990 BS)

Deaths in Kathmandu Valley due to 1934 earthquake

Place	Men	Women	Total
Kathmandu	254	225	479
Outskirts of Kathmandu	79	166	245
Patan	250	297	547
Outskirts of Patan	871	826	1697
Bhaktapur	433	739	1172
Outskirts of Bhaktapur	65	91	156
Totals for the Kathmandu Valley	1952	2344	4296

Deaths due to 1934 earthquake in out of Valley

Place	Men	Women	Total
Eastern Mountain region	1792	2182	3974
Western Mountain region	29	36	65
Terai	77	107	184
	1898	2325	4223

Total Deaths by 1934 earthquake			
Kathmandu Valley	1952	2344	4296
Rest of Nepal	1898	2325	4223
Total	3850	4669	**8519**

Total Deaths by 1934 earthquake			
Kathmandu Valley	1,952	2,344	4,296
Rest of Nepal	1,898	2,325	4,223
Total	3,850	4,669	**8,519**

The future great central Himalayan earthquake

Potential Impact due to scenario EQ in KV
(KVERMP estimates for IX MMI)

Impact	Extent
Death	>40,000
Injuries	>95,000
Buildings destroyed/collapsed	>60%
Homeless population	>700,000
Bridges impassable	>50%
Road length damaged	>10%
Water supply pipes damaged	>95%
Telephone exchange buildings	most
Telephone lines	>60%
Electric substations	most
Electric lines	40%