BASICS

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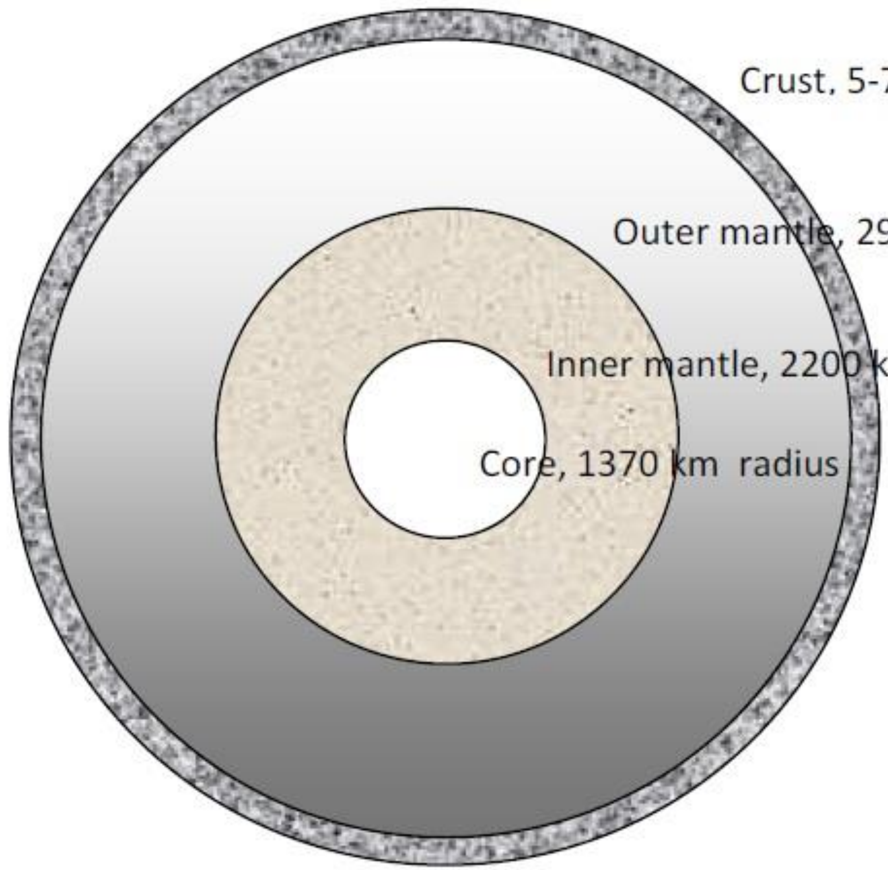
Introduction

- **Earthquakes** constitute one of the most unpredictable and natural hazards which often turn into disaster causing widespread destruction and loss to human life.
- Study of earthquake requires a good understanding of geophysical process which causes earthquake and various effects of earthquake.
- The effects of earthquake vary upon the magnitude and intensity.
- Earthquakes occur every now and then all round the world, except in some places where earthquakes occur rarely.
- The devastation of cities and towns is one of the effects of earthquake.

Internal Structure of Earth



Cross-section of interior of earth.

Interior of Earth can be classified into three major categories crust, mantle and core.

Shape - Oblate Spheroid
Dequator = 12740 km
Dpolar = 12700 km

EARTH'S INTERIOR

Crust (lithosphere)

Avg thickness 40 km below continents and decreases to 5 km beneath oceans.

Oceanic crust is constituted by basaltic rocks and continental part by granitic rocks overlying basaltic rocks.

Compared to layers below this layer has higher rigidity.

Mantle

Upper mantle - 400 km, olivine and pyroxene

Lower mantle – homogeneous mass of magnesium and iron oxide & quartz.

No earthquakes are recorded in lower mantle.

Sp gr on mantle - 5 , avg temp – 2200°C (material in viscous semi molten state)

The mantle act like fluid in response to slowly acting stresses and creeps under slow loads.

But it behaves like as solid in presence of rapidly acting stresses, e.g. that caused by earthquake waves.

Contd…

Core

- Radius of 3470 km and consists of an inner core of radius 1370 km and an outer core (1370 km < R < 3470 km).
- Composed of molten iron, probably mixed with small quantities of other elements such as nickel and sulphur or silicon.
- The inner solid core is very dense nickel-iron material and is subjected to very high pressures.
- The maximum temperature in the core is estimated to be about 3000 degree Celsius.
- The specific gravity of outer core is about 9-12 where as that of inner core is 15.

Continental Drift

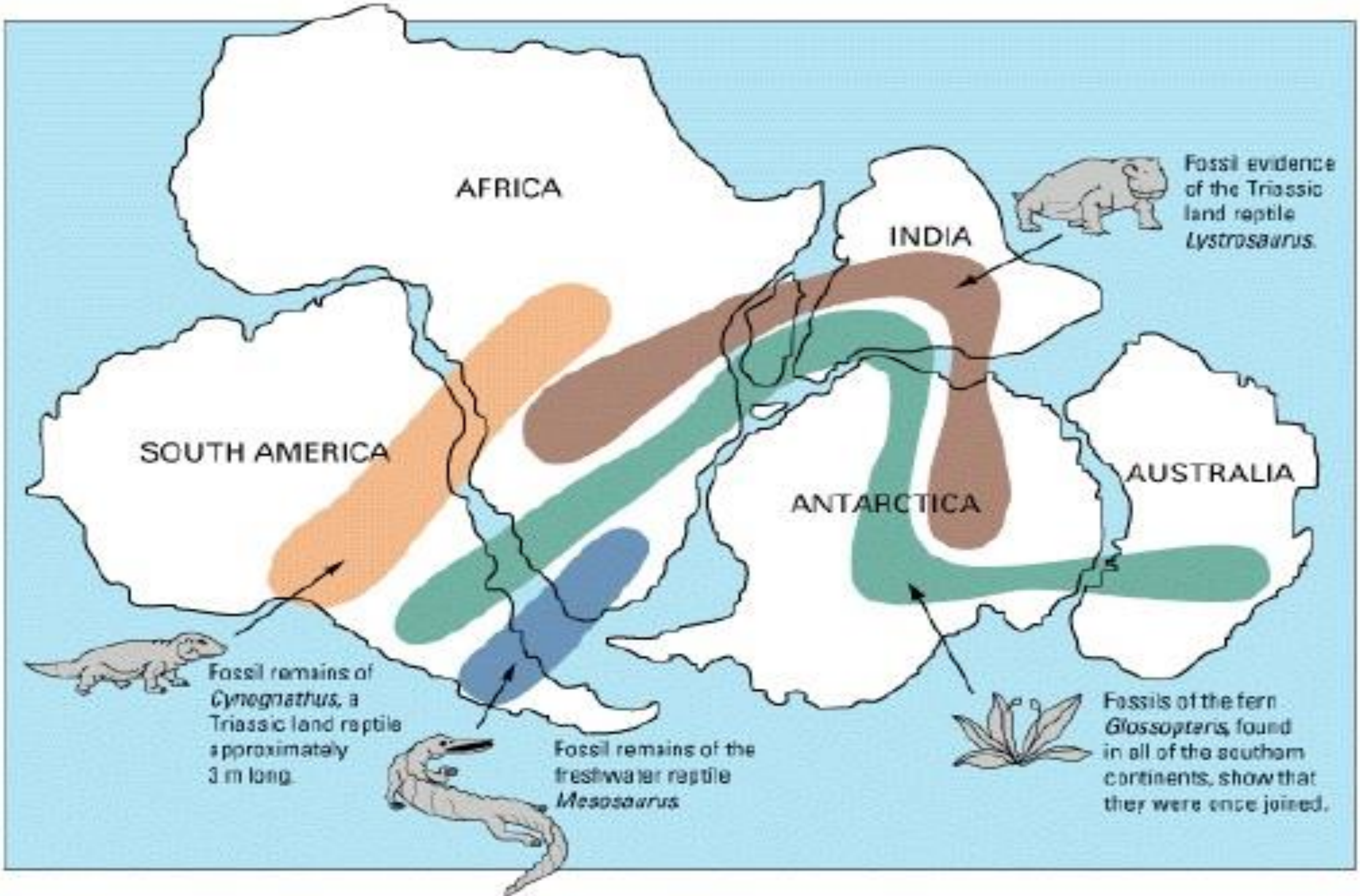
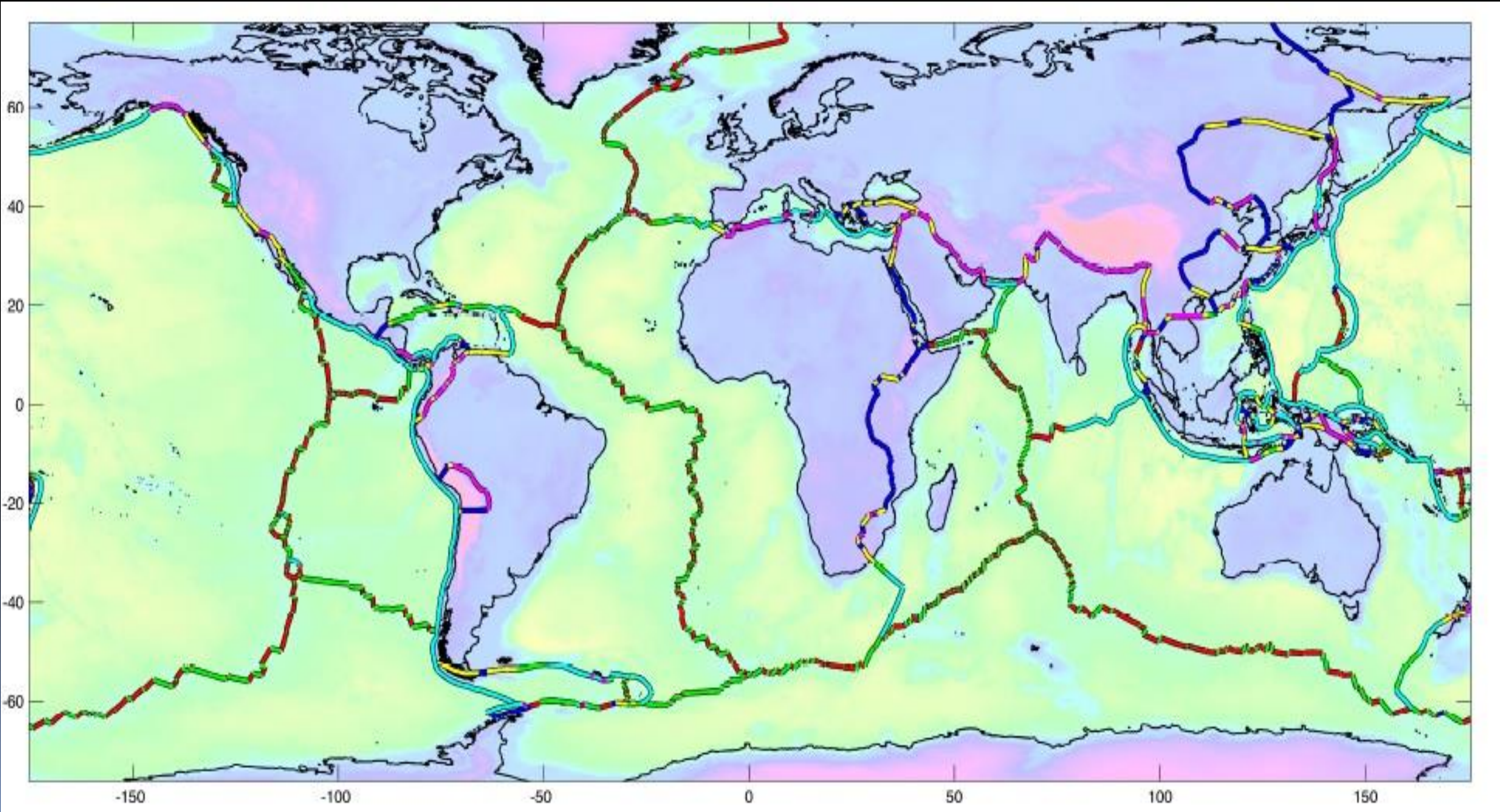


Plate Tectonics

- Theory of plate tectonics - presented in early 1960s
- Lithosphere is broken into seven large (and several smaller) segments called plates.



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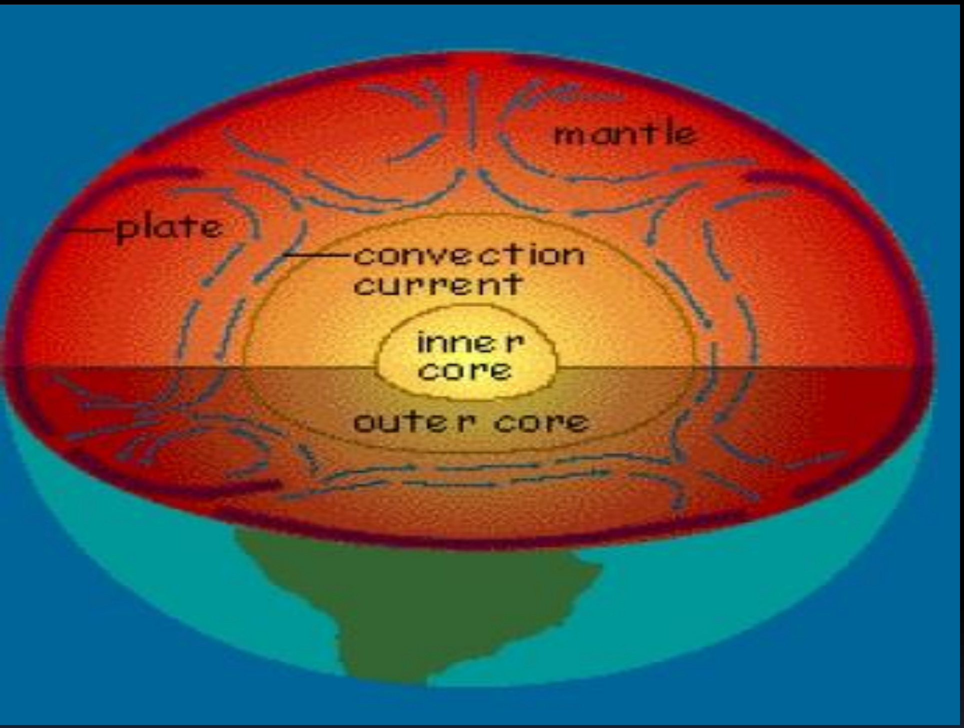
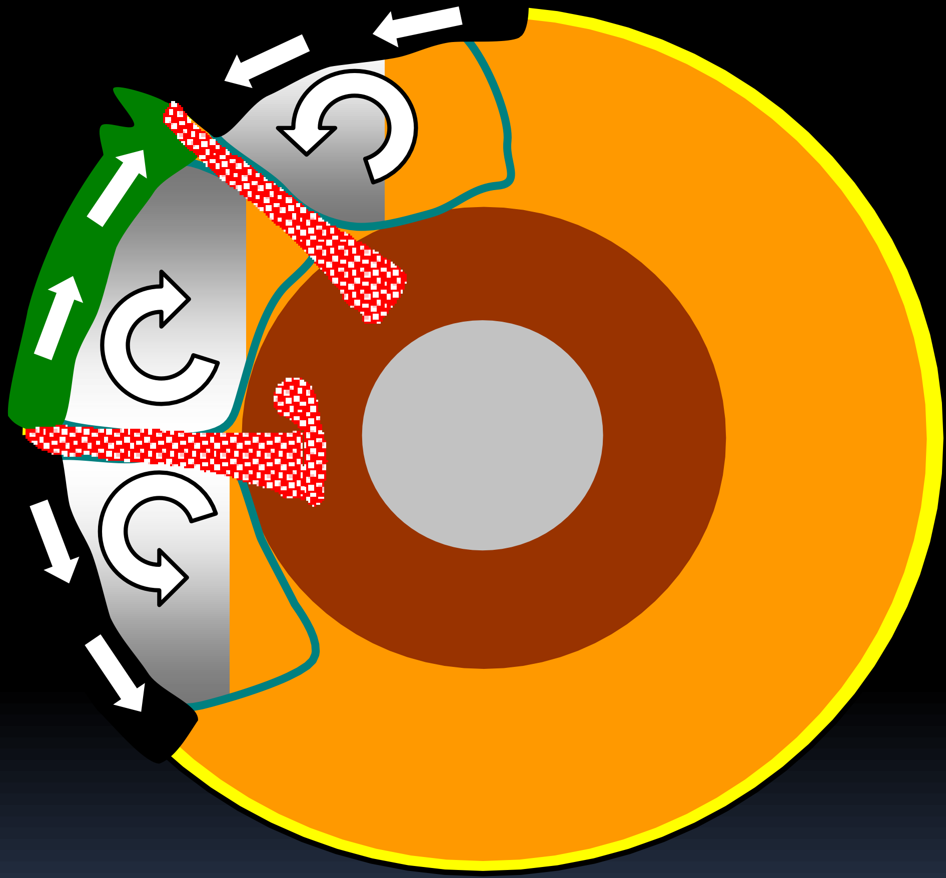
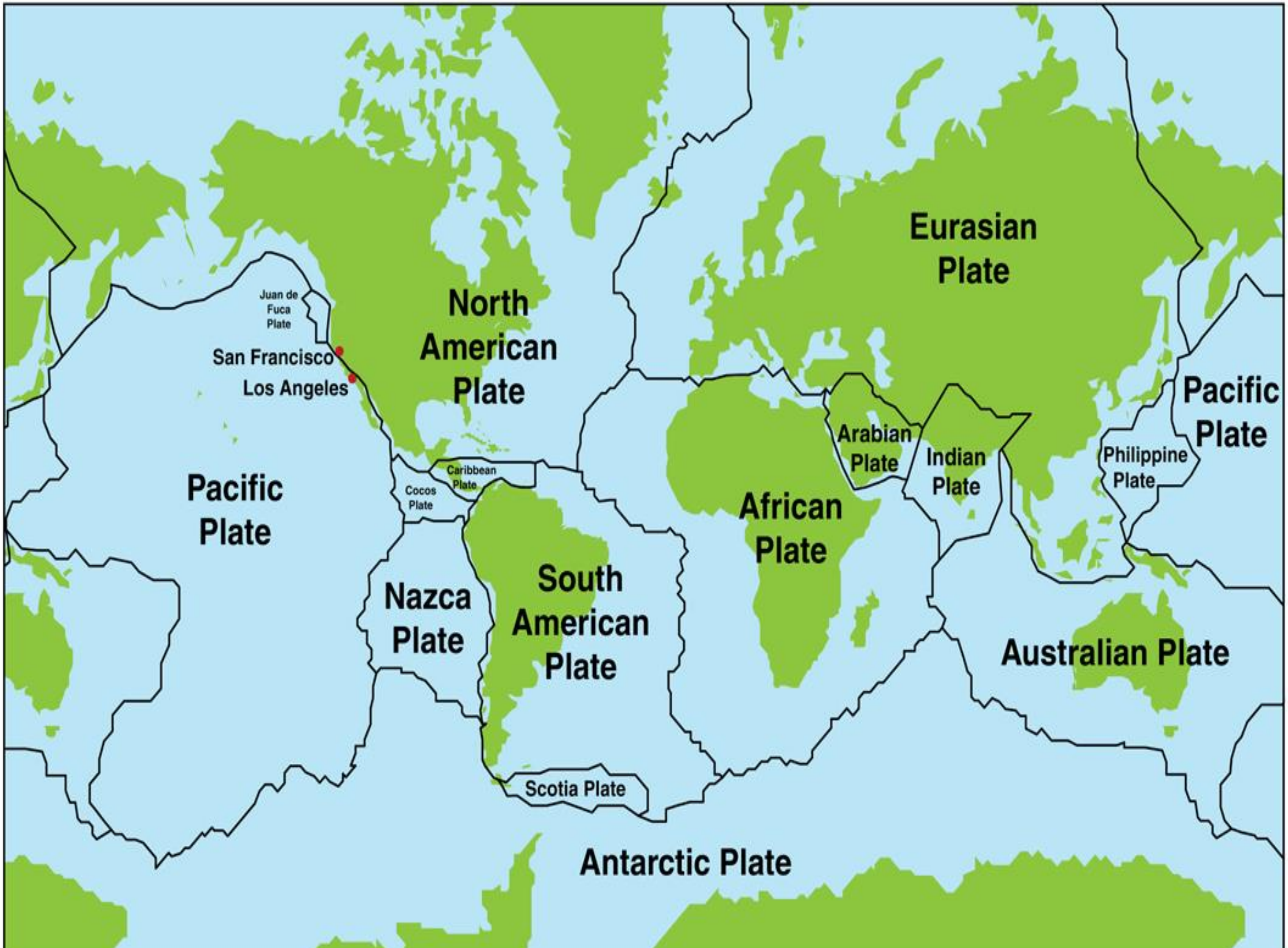
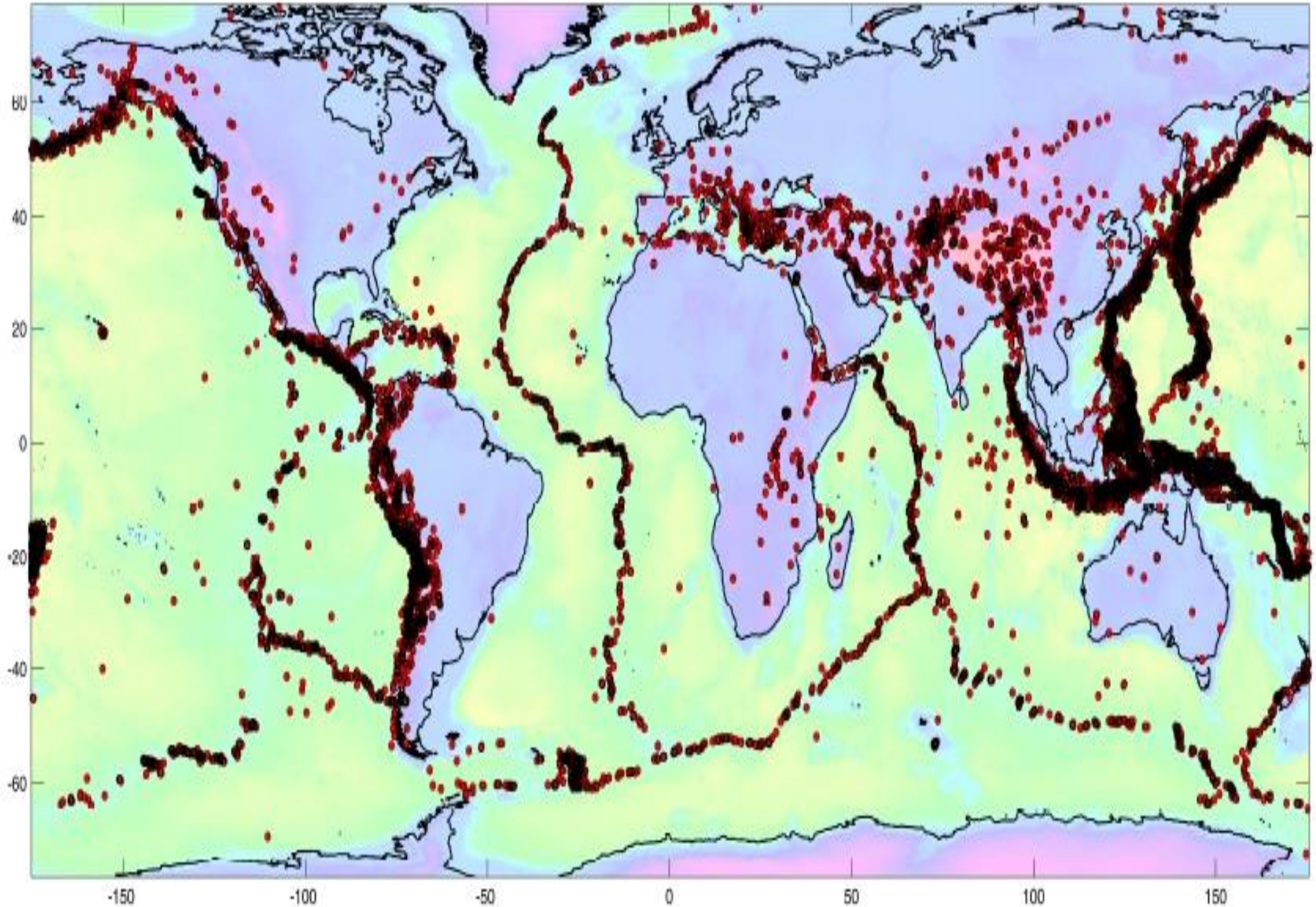
- This theory requires a source that can generate tremendous force is acting on the plates.
- The widely accepted explanation is based on the force offered by convection currents created by thermo-mechanical behaviour of the earth's subsurface.
- The variation of mantle density with temperature produces an unstable equilibrium.
- The colder and denser upper layer sinks under the action of gravity to the warmer bottom layer which is less dense.
- The lesser dense material rises upwards and the colder material as it sinks gets heated up and becomes less dense.
- These convection currents create shear stresses at the bottom of the plates which drags them along the surface of earth.


mantle
plate
convection
current
inner
core
outer core




Eurasian Plate
North American Plate
Juan de Fuca Plate
San Francisco
Los Angeles
Pacific Plate
Arabian Plate
Indian Plate
Philippine Plate
Pacific Plate
Caribbean Plate
Cocos Plate
African Plate
Nazca Plate
South American Plate
Australian Plate
Scotia Plate
Antarctic Plate

- The continental sized plates are African, American, Antarctic, Indo-Australian, Eurasian and pacific plate.
- Several smaller plates like Andaman, Philippine plate also exist.
- As plate glides over the asthenosphere, the continents and oceans move with it.
- Because the plates move in different directions, they knock against their neighbours at boundaries.
- The great forces thus generated at plate boundary build mountain ranges, cause volcanic eruptions and earthquakes.
- Most of the Earth's major geological activity occurs at plate boundaries, the zones where plates meet and interact.
- The earthquake that occurs at a plate boundary is known as inter-plate earthquake.
- Not all earthquakes occur at plate boundaries.
- These earthquakes are known as intra-plate earthquakes.
- The recurrence time for an intraplate earthquake is much longer than that of inter-plate earthquakes.



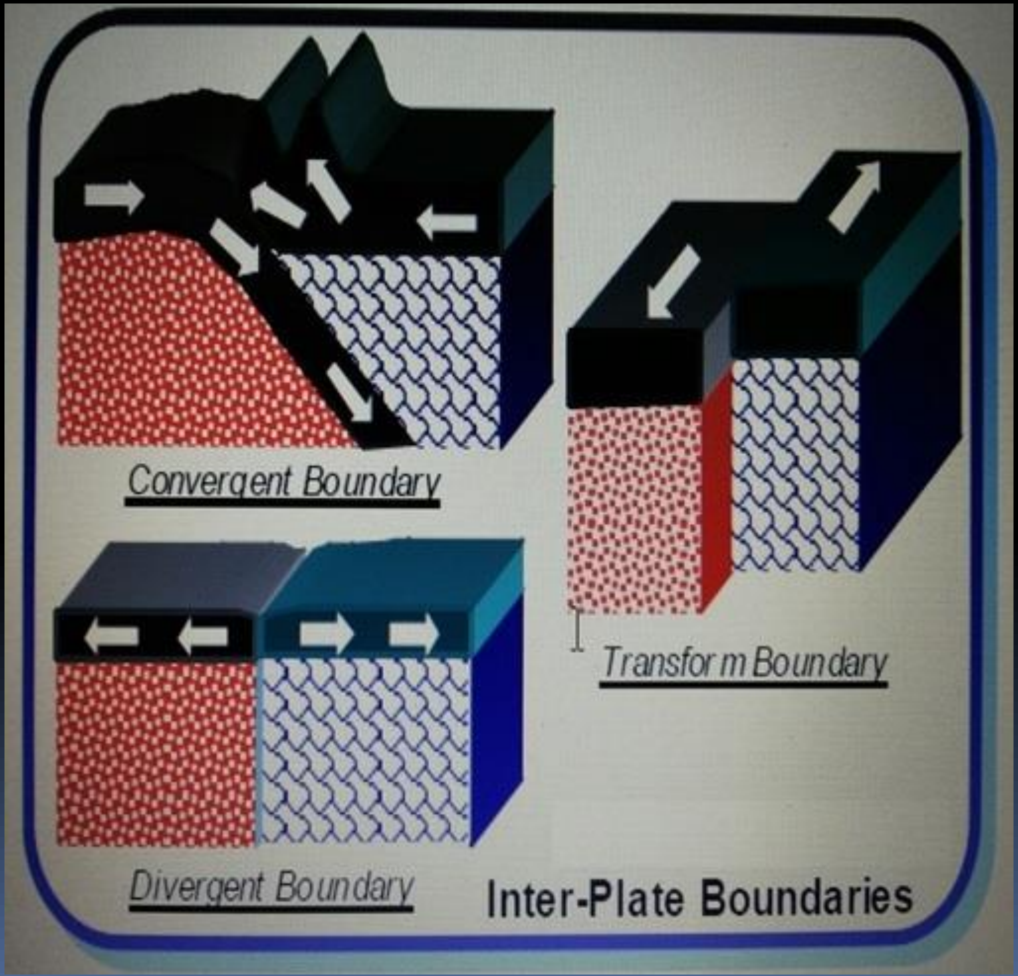
Map of distribution of epicenters around the world

Three types of inter-plate interactions are possible due to movement of plate boundaries:

1. Divergent Boundary

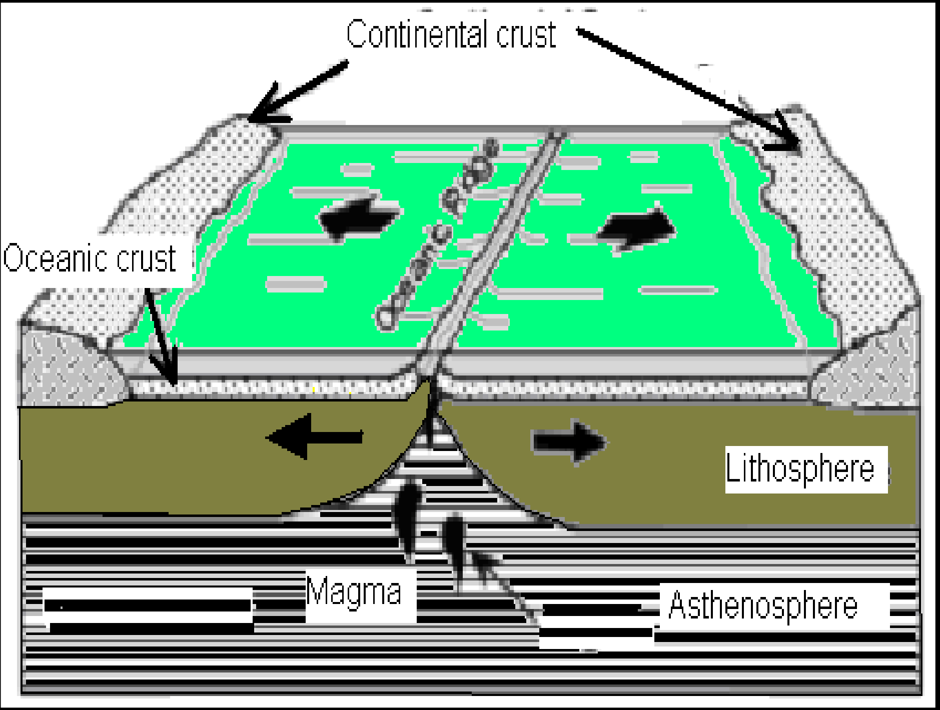
2. Convergent Boundary

3. Transform Boundary



1. Divergent Boundary

- Spreading ridges or divergent boundaries are areas along the edges of plates which move apart from each other.
- Location where the less dense molten rock from the mantle rises upwards and becomes part of crust after cooling.



c/s of the divergent plate boundary

- Generally, spreading ridges are located beneath the oceans.
- A few areas where the spreading occurs along the continental mass are East African rift valley and Iceland.

2. Convergent Boundary

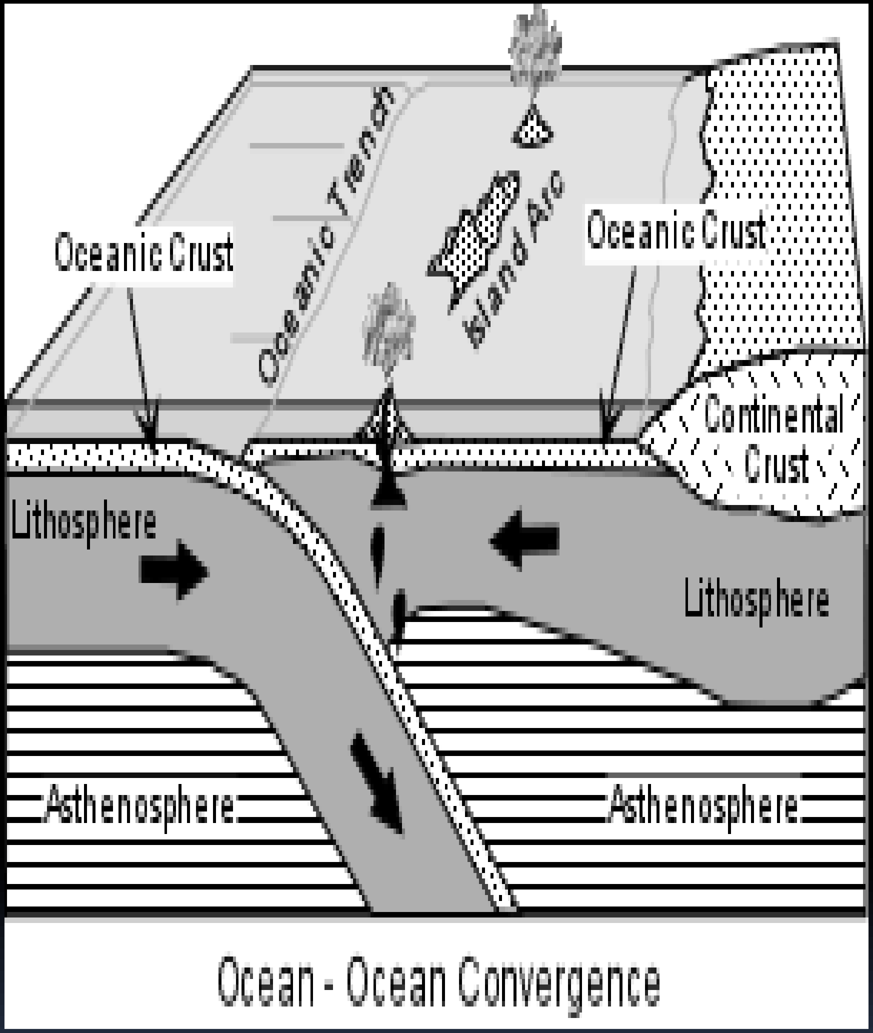
- The convergent boundaries are formed where the two plates moves towards each other.

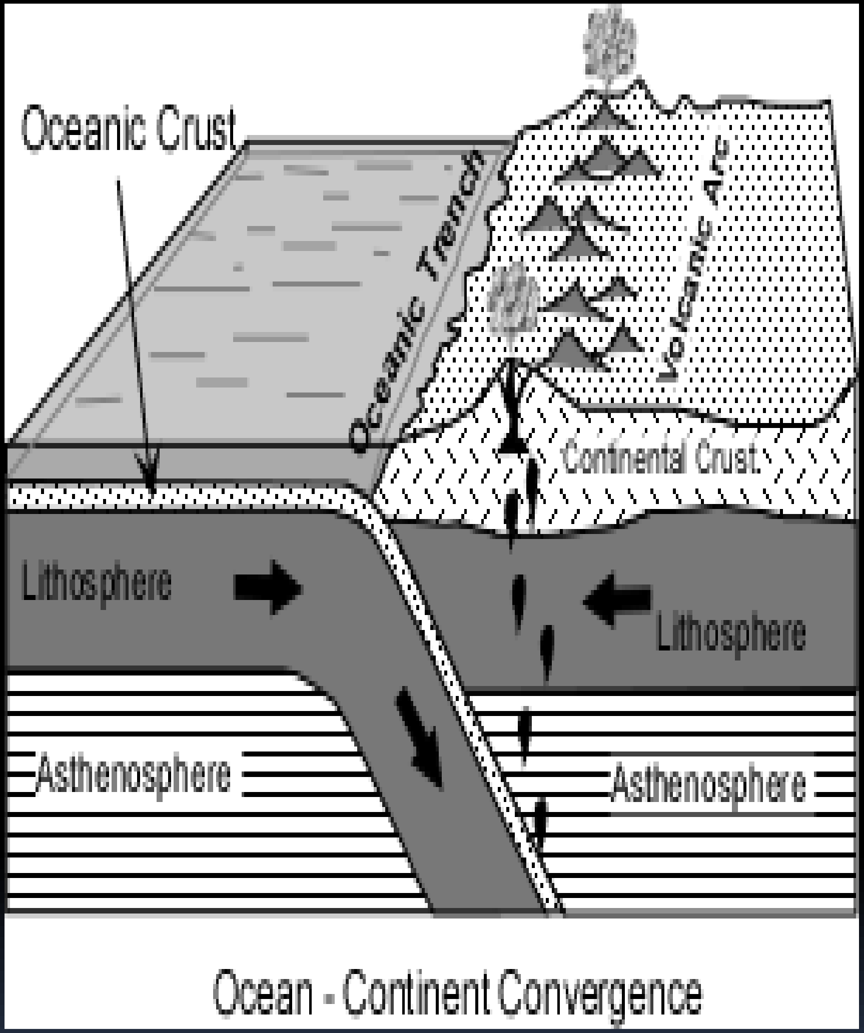
- In this process, one plate could slip below the other one or both could collide with each other.

a. Subduction boundaries

- These boundaries are created when either oceanic lithosphere subducts beneath oceanic lithosphere (ocean-ocean convergence), or when oceanic lithosphere subducts beneath continental lithosphere (ocean-continent convergence).

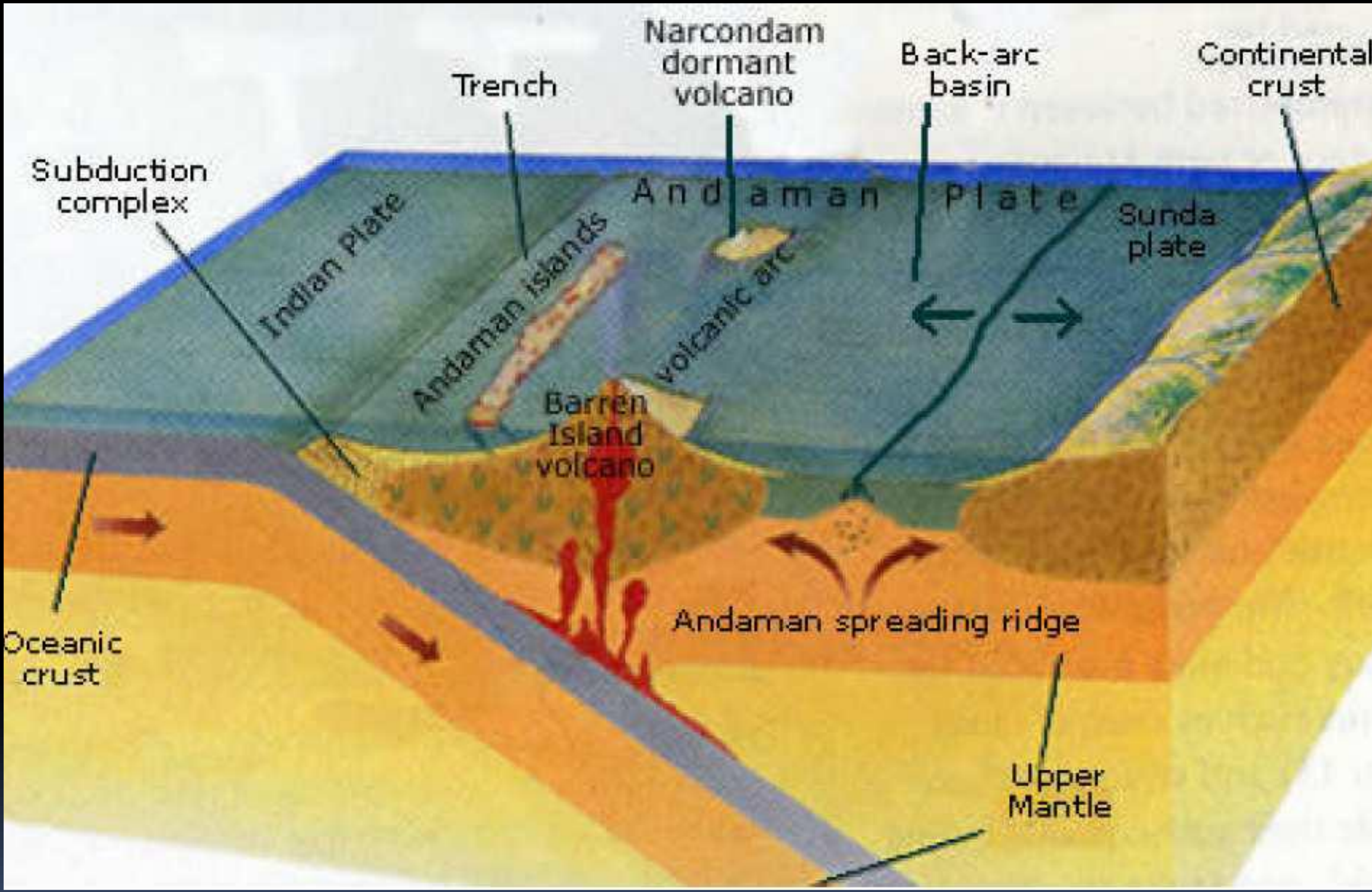
- The junction where the two plates meet, a trench known as *oceanic trench* is formed.





Creation of subduction boundaries

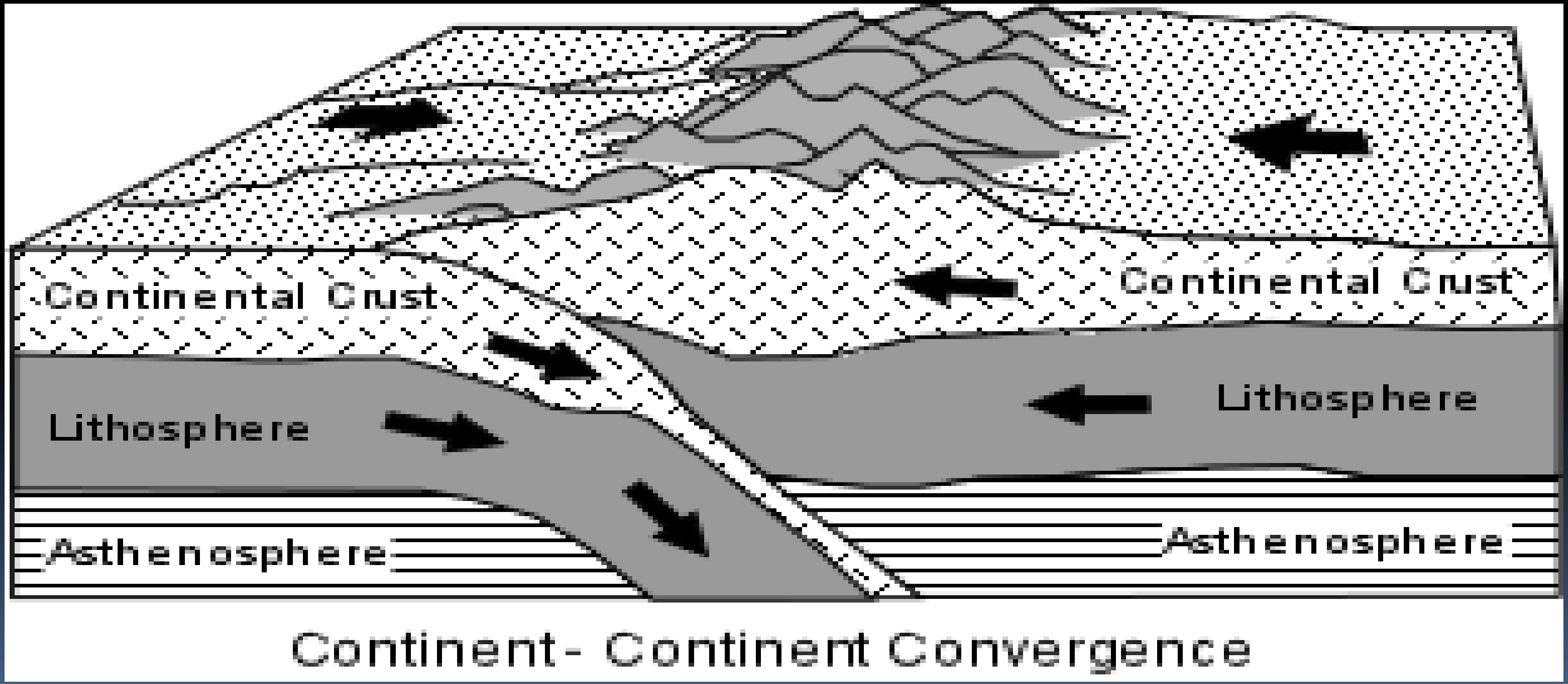
- When two plates of oceanic lithosphere run into one another, the subducting plate is pushed to depths where it causes melting to occur.
- When a plate made of oceanic lithosphere runs into a plate with continental lithosphere, the plate with oceanic lithosphere subducts because it has a higher density than continental lithosphere.
- The subducted plate melts as it encounters higher temperature regime inside earth melts and produces magma.
- This magma rises to the surface to produce chains of volcanos and islands known as island arcs.
- One of the areas around Indian peninsula where subduction process is in progress is near Andaman-Sumatra region, where the Indo-Australian plate is subducting below the Andaman and Sunda plates.



Subduction process along Andaman-Sumatra arc

b. Collision Boundaries

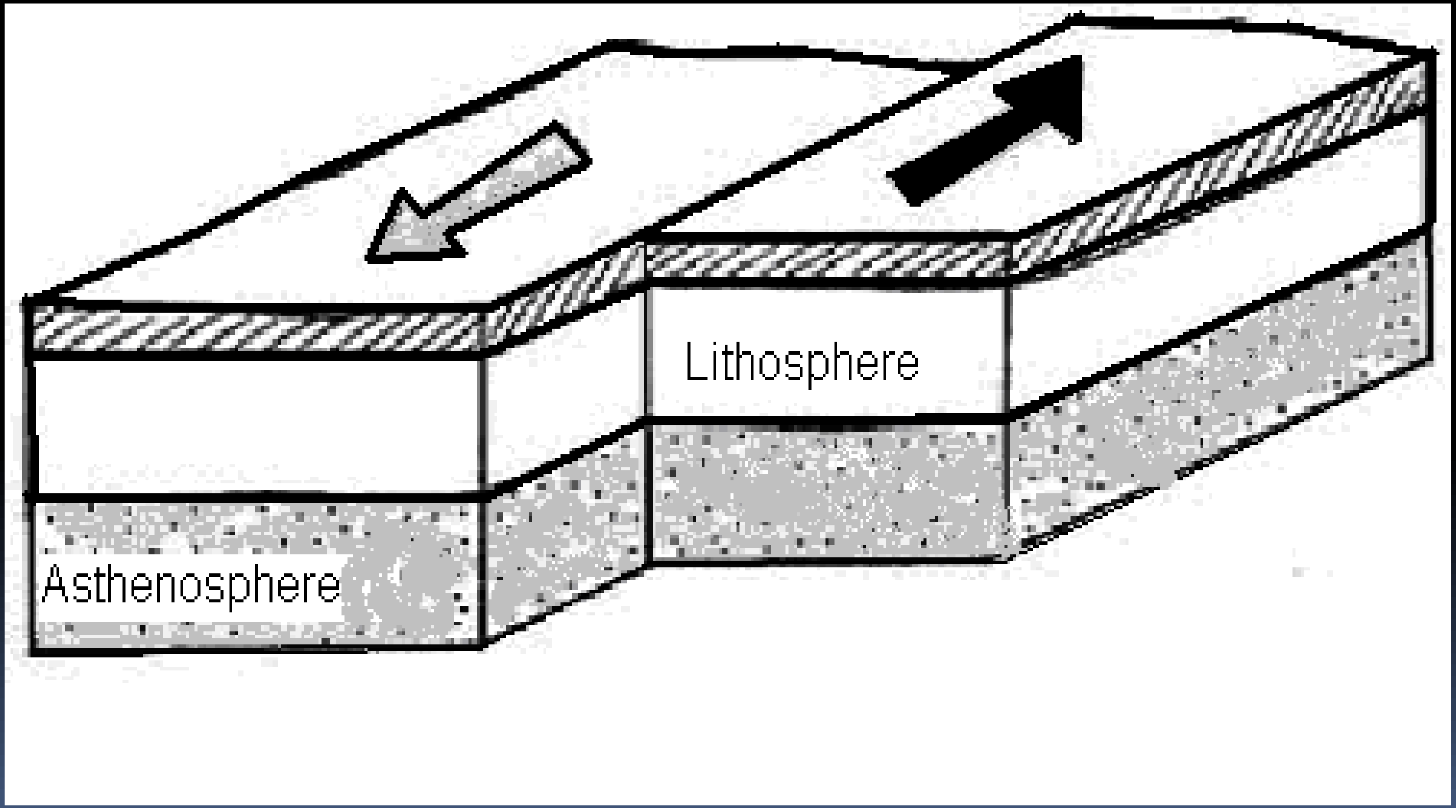
When two plates with continental lithosphere collide, subduction ceases and a mountain range is formed by squeezing together and uplifting the continental crust on both plates. The Himalayan Mountains between India and China were formed in this way.



Creation of collision boundaries

3. Transform Boundary

Transform boundaries occur along the plate margins where two plate moves past each other without destroying or creating new crust.



A typical profile of a transform plate boundary

Causes of Earthquake

The primary cause of an earthquake is **faults** on the crust of the earth.

“A Fault is a break or fracture b/w two blocks of rocks in response to stress.”

Plate boundary is also a type of fault.

Most faults produce repeated displacements over geological time.

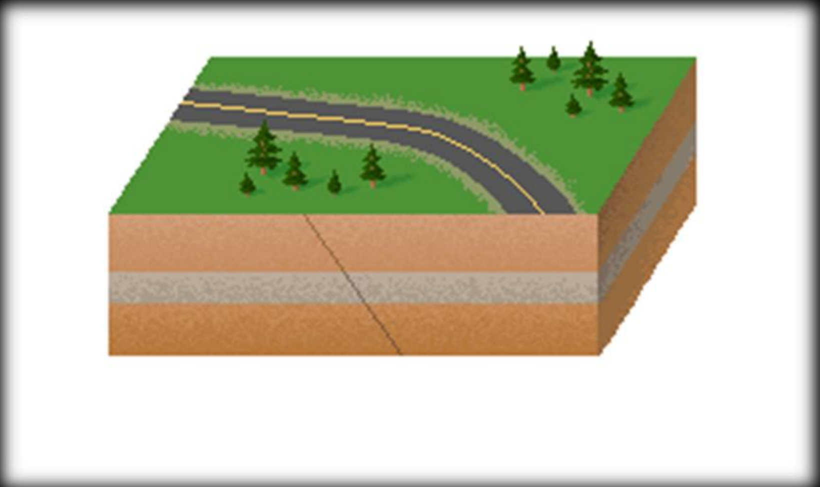
This movement may occur rapidly, in the form of an **earthquake** or may occur slowly, in the form of **creep.**

Earth scientists use the **angle of the fault** with respect to the surface (known as the dip) and the **direction of slip** along the fault to classify faults.

Classification of Faults

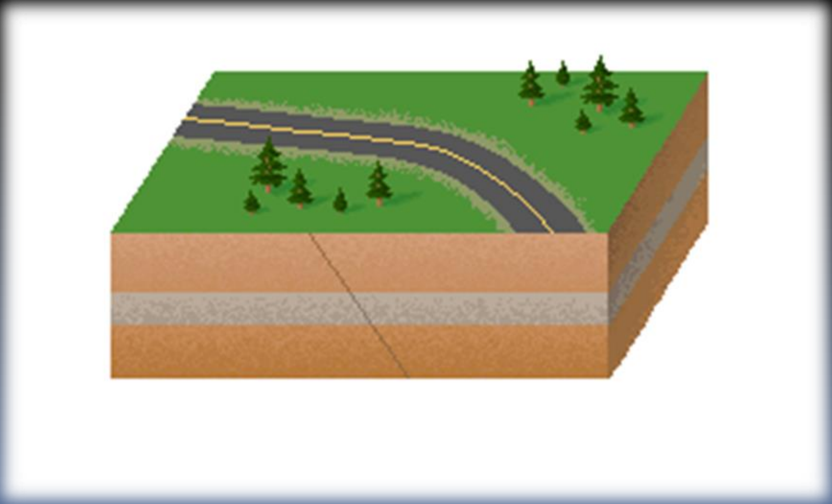
Normal fault:

a dip-slip fault in which the block above the fault has moved downward relative to the block below.



Thrust (Reverse) fault:

a dip-slip fault in which the upper block, above the fault plane, moves up and over the lower block.



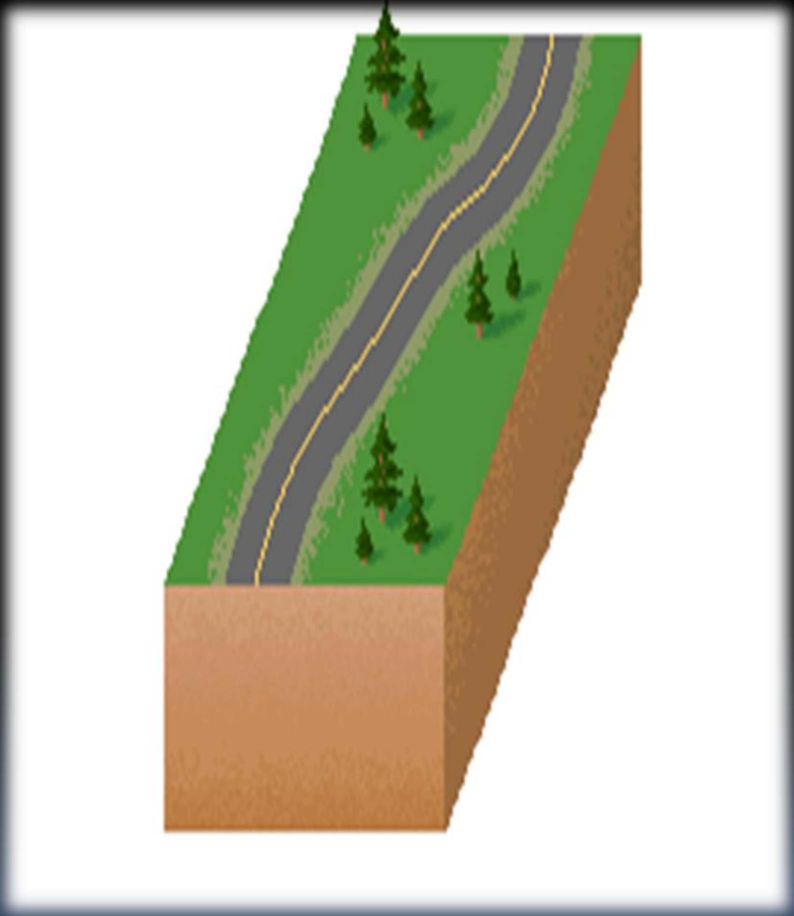
Strike-slip fault

A left-lateral strike-slip fault:

It is one on which the displacement of the far block is to the left when viewed from either side.

A right-lateral strike-slip fault:

It is one on which the displacement of the far block is to the right when viewed from either side.



Some major causes of earthquakes on basis of its causes are:

- Surface causes
- Volcanic causes
- Tectonic causes

Surface cause:

Great explosions, landslides, slips on steep coasts, dashing of sea waves, avalanches, railway trains, heavy trucks, some large engineering projects cause minor tremors. some of them are man made, other are natural.

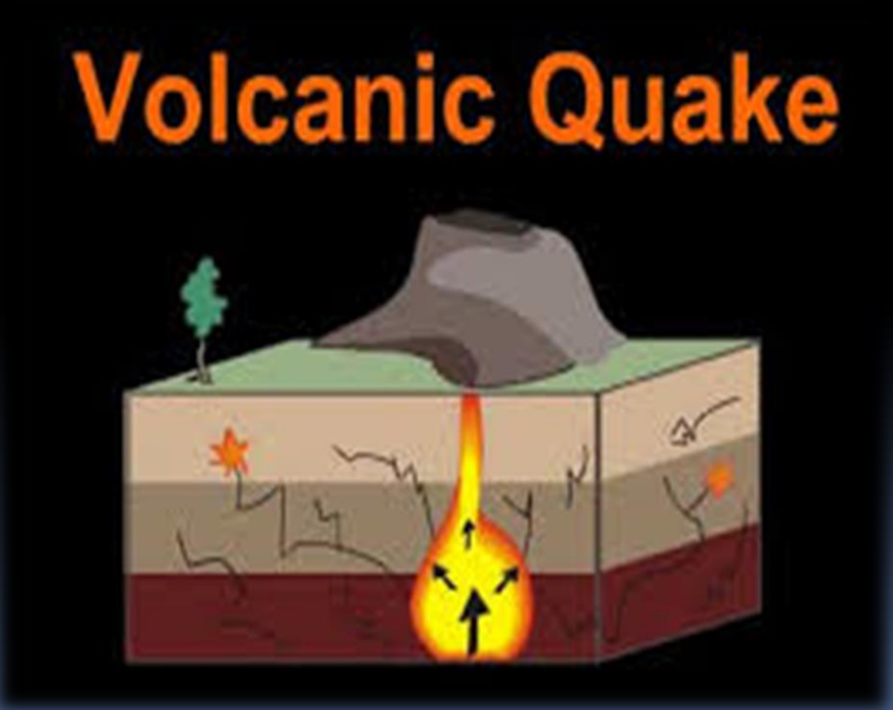
Volcanic cause:

Volcanic eruptions produce earthquakes. Earthquakes may precede, accompany and frequently follow volcanic eruptions.

They are caused by sudden displacements of lava within or beneath the earth crust.

There are two general categories of earthquakes that can occur at a volcano:

- Volcano-tectonic earthquakes
- Long period earthquakes

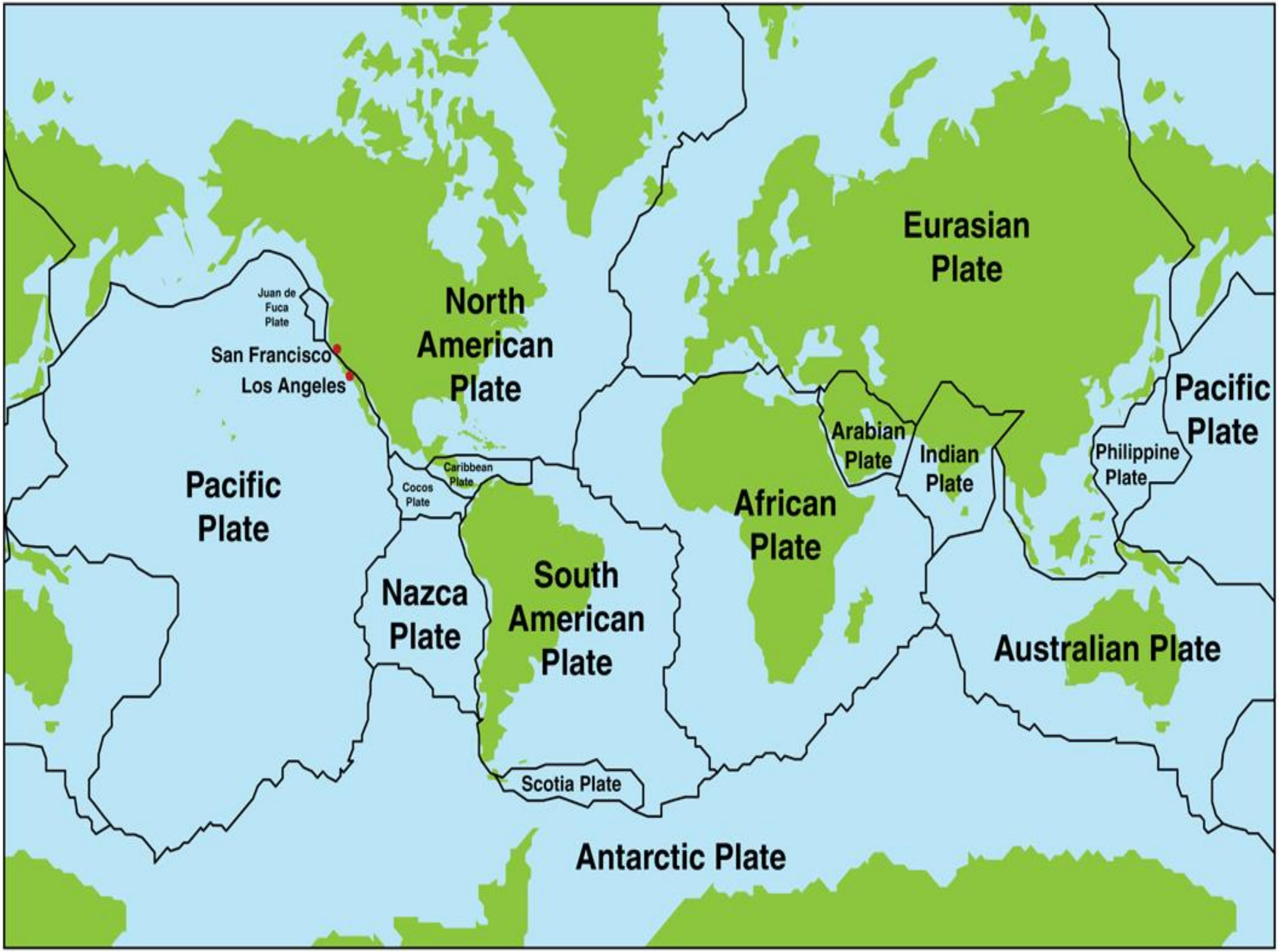


Tectonic cause:

Structural disturbances resulting in the parts of the lithosphere is the main cause of this type of earthquake.

Most of the disastrous earthquakes belong to this category and occur in areas of great faults and fractures.

Sudden yielding to strain produced on the rocks of accumulating stress causes displacements especially along old fault zones known as great transform faults.



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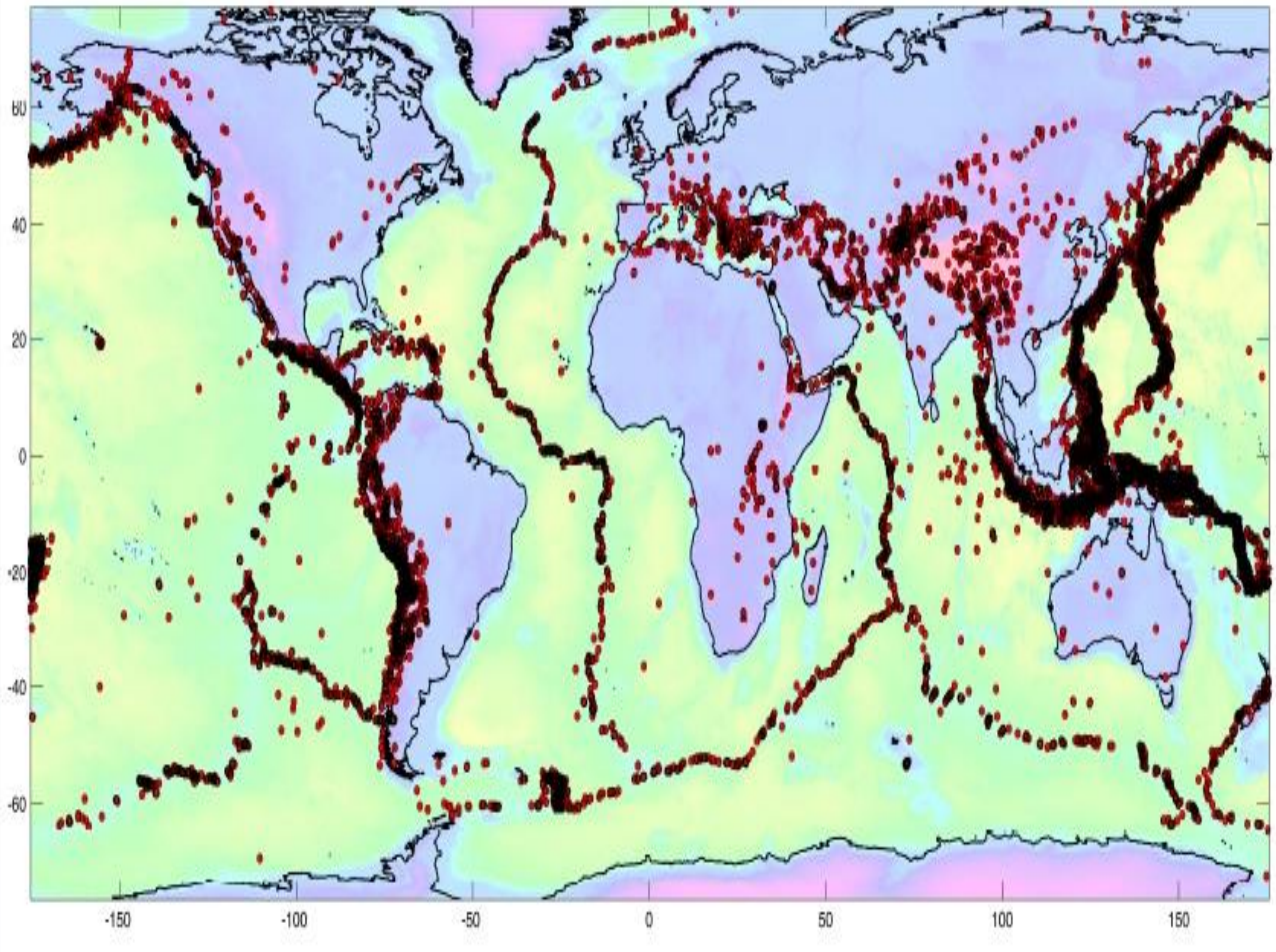


60
40
20
0
-20
-40
-60
-150
-100
-50
0
50
100
150

SEISMIC WAVES

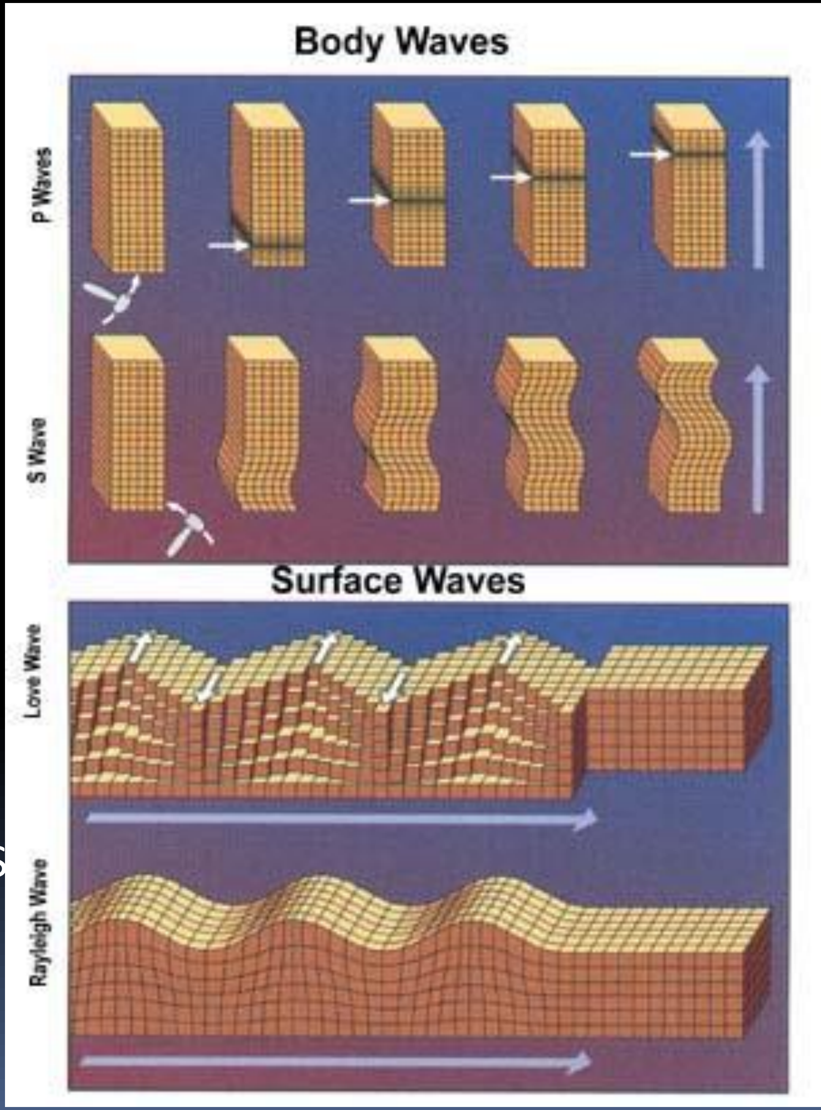
SEISMIC WAVES

BODY WAVES

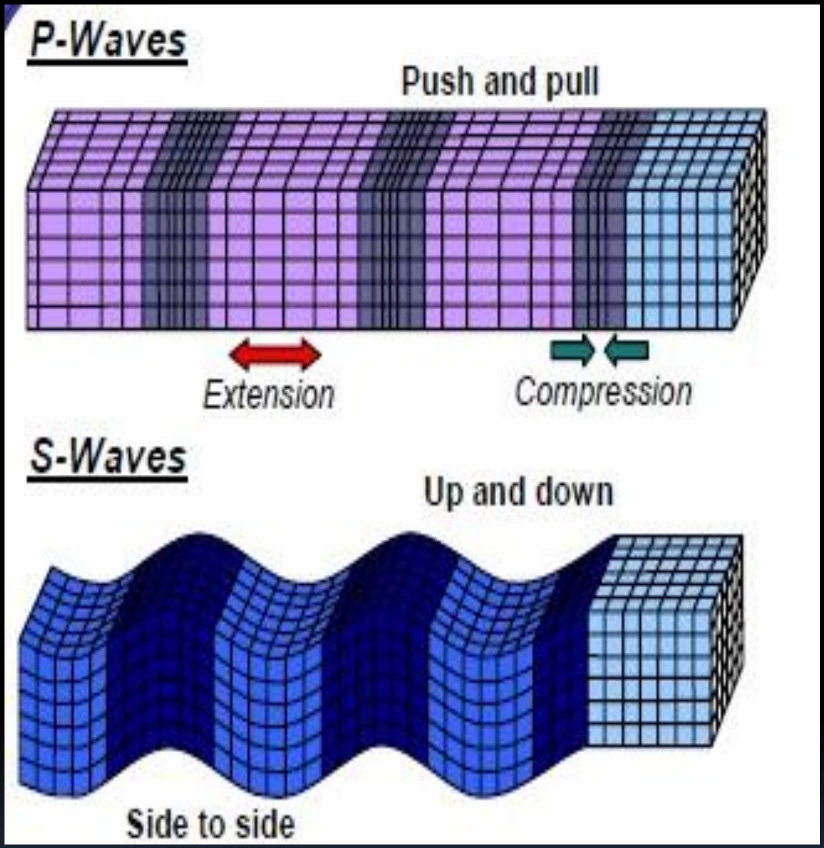
- P – WAVES
  Primary
- S – WAVES
  Secondary

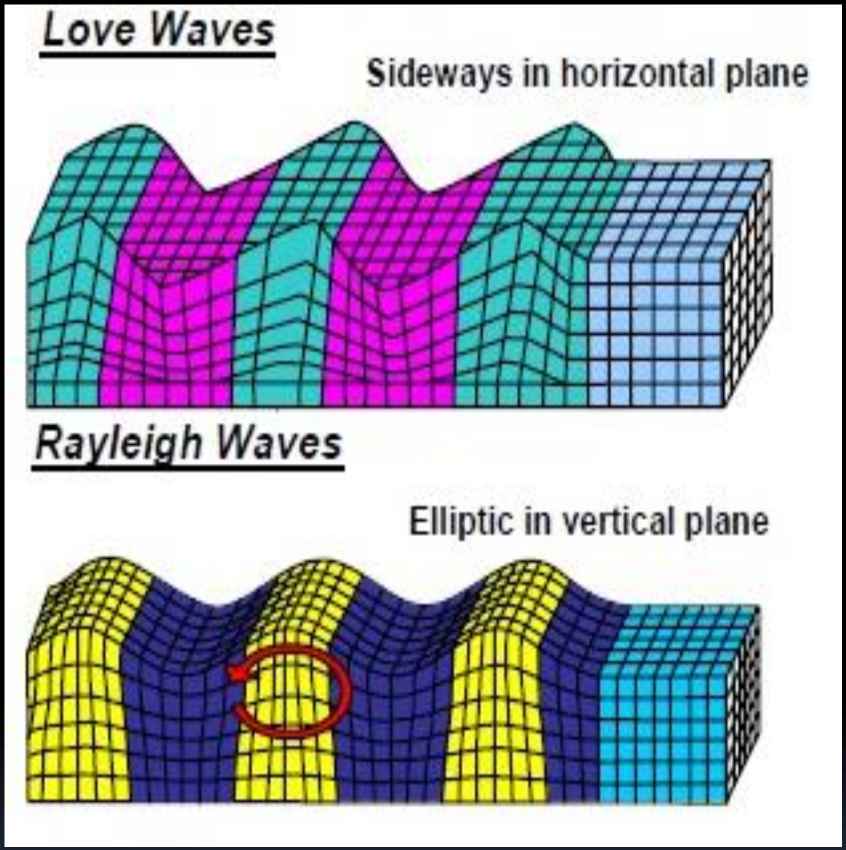
SURFACE WAVES

- LOVE WAVES
- RAYLEIGH WAVES



Earthquake Waves





Waves produced due to Earthquake

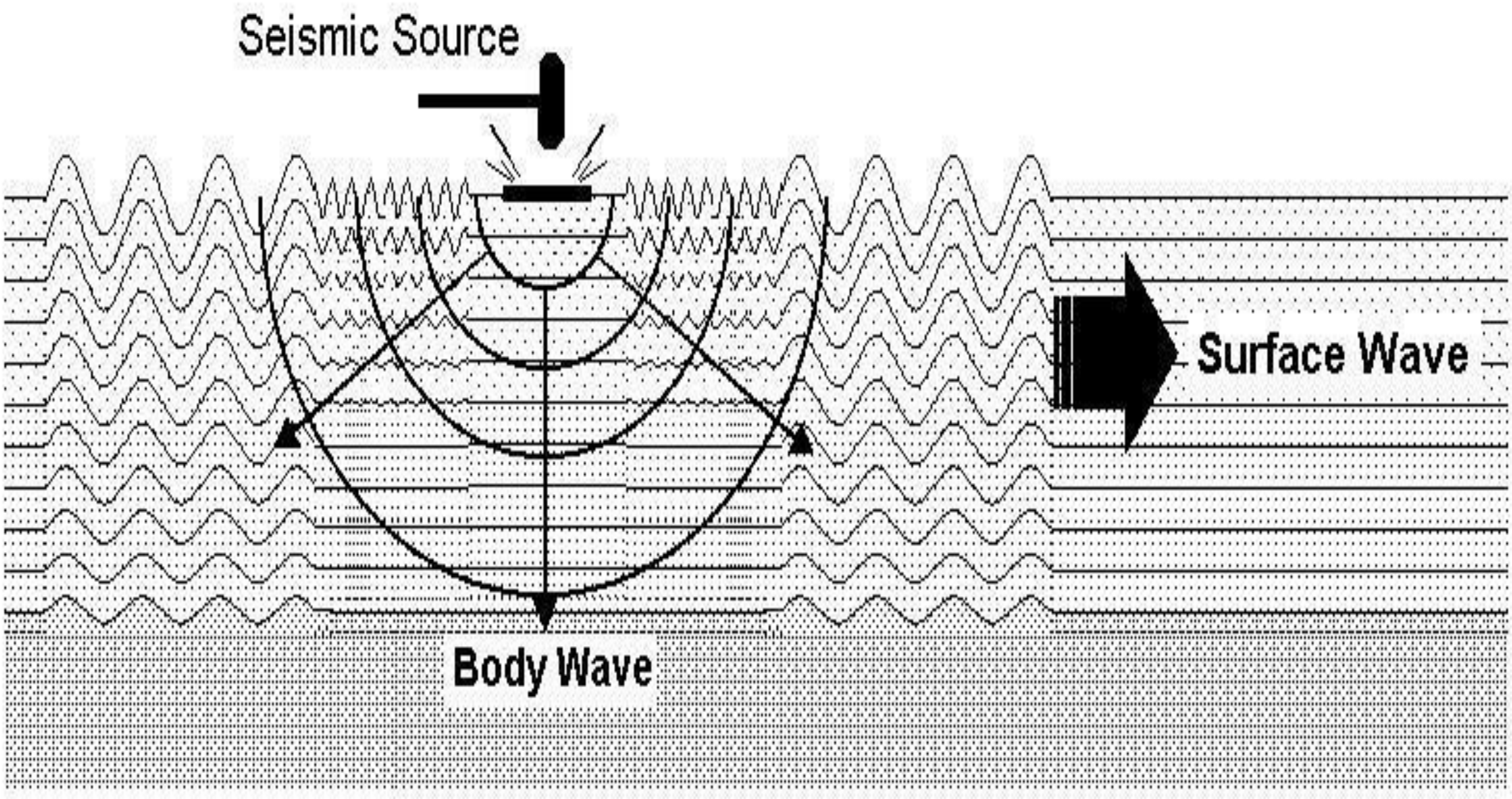
Body waves travel through the interior of the Earth.

Surface waves travel across the surface.

Surface waves decay more slowly with distance than do body waves, which travel in three dimensions.

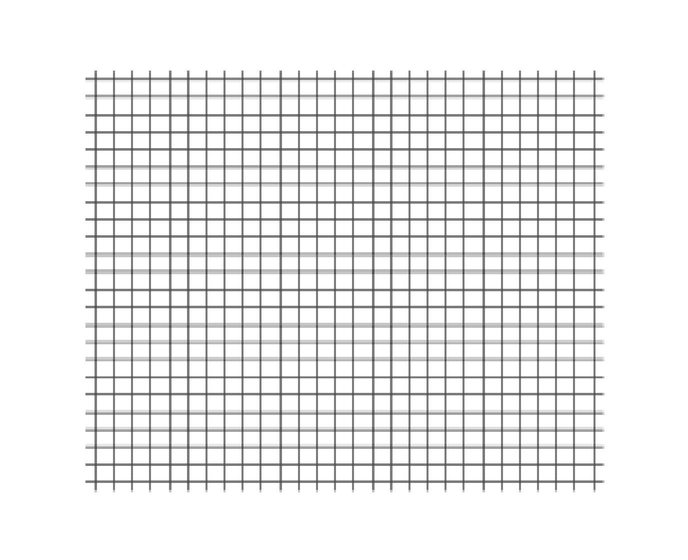
Particle motion of surface waves is larger than that of body waves, so surface waves tend to cause more damage.

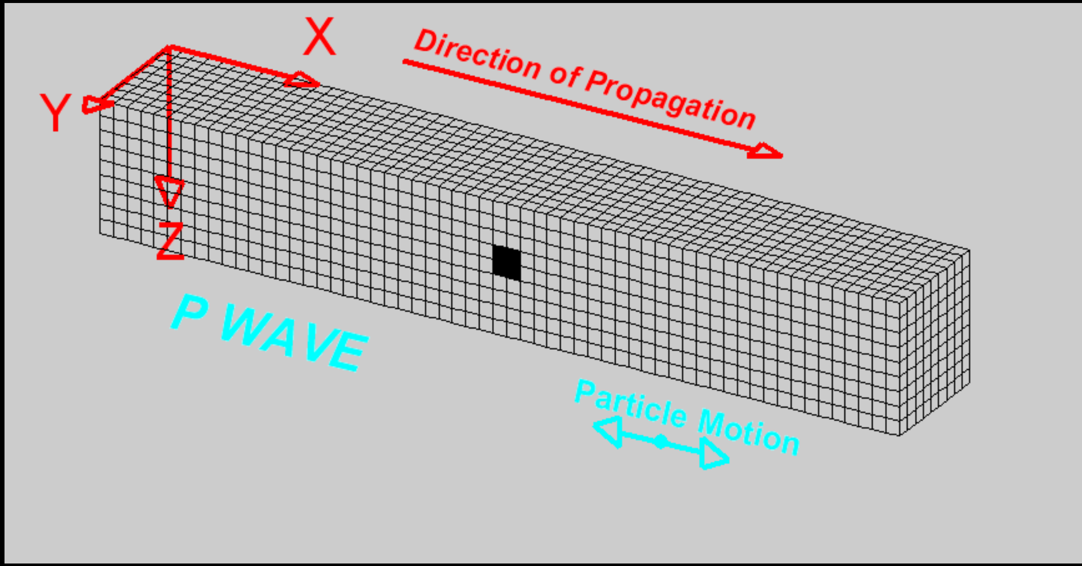
SEISMIC WAVES



Two major groups of seismic waves: body and surface waves. Body waves propagate through the body, whereas surface waves travel along the surface of the medium.

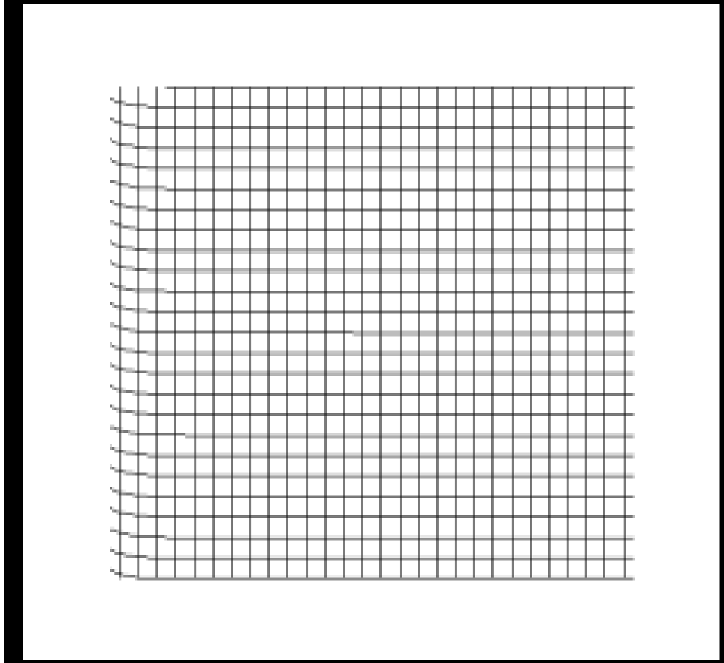
PRIMARY WAVES

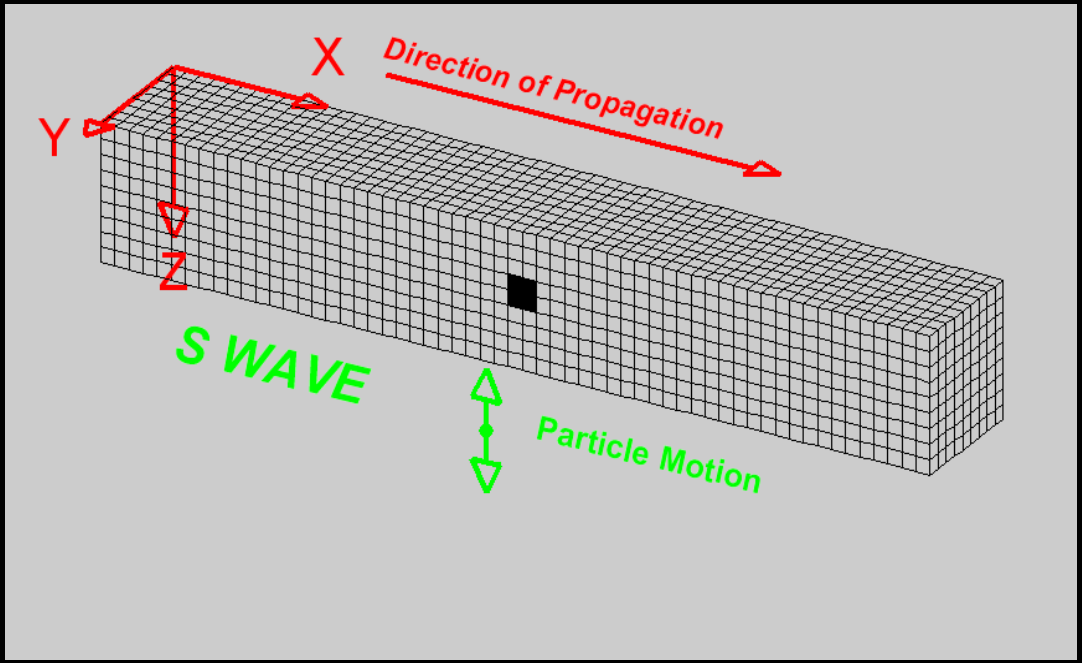




- They are also known as longitudinal or compressional waves.
- P waves are analogous to sound waves.
- They are fastest waves and are longitudinal in character.
- They can travel through all material like solid, liquid or air.
- Velocity of P waves is 4.8 km/sec as found in granite and 1.5 km/sec in water.

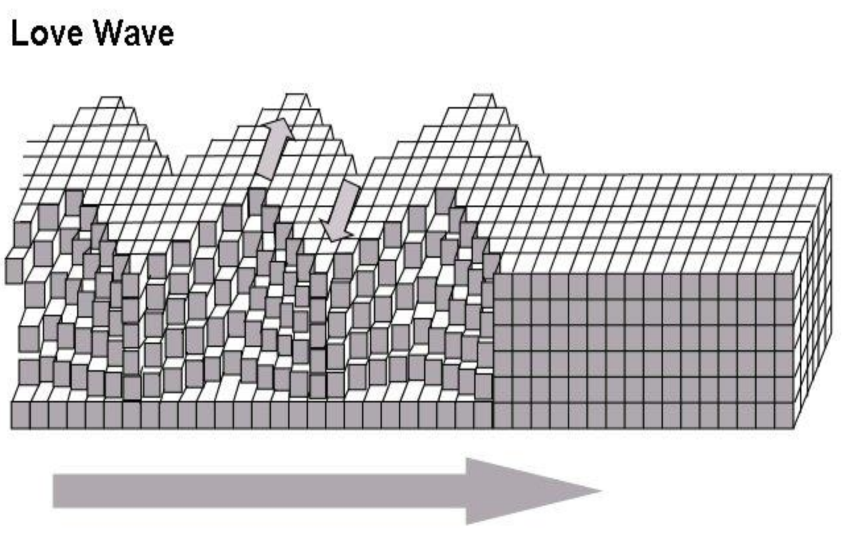
SECONDARY WAVES

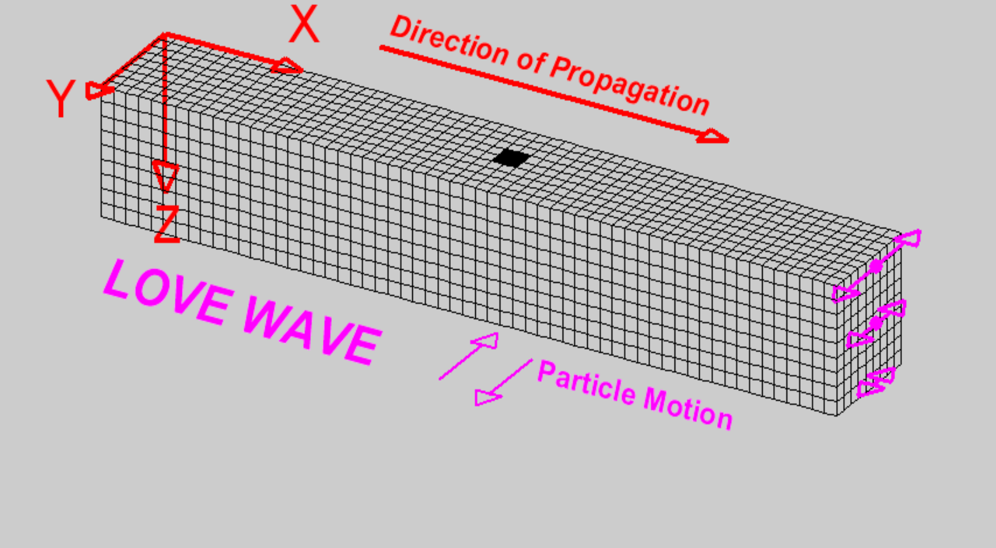




- They are also known as secondary waves.
- S waves are analogous to electromagnetic waves.
- S waves are slower then p waves.
- They can travel through solids but not through liquids.
- Their velocity in granite is 3 km/sec.

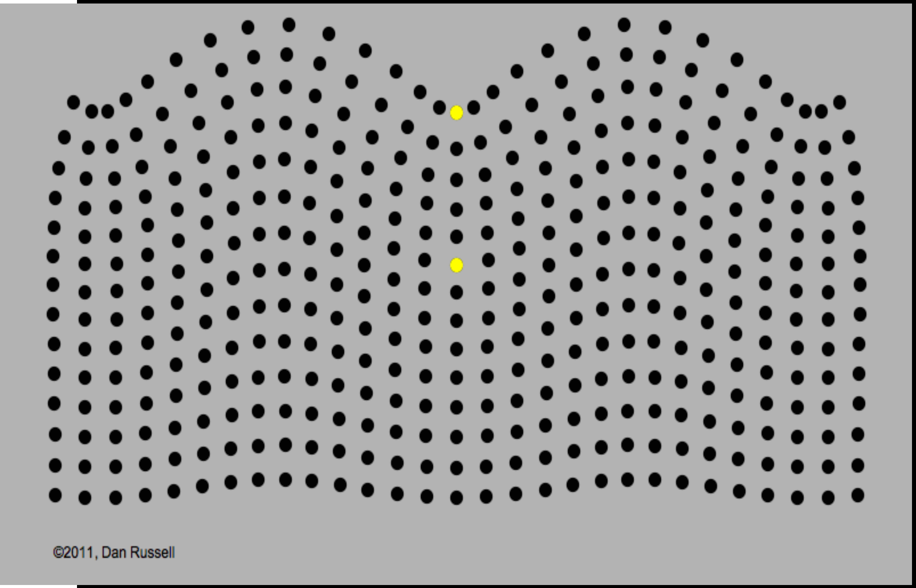
LOVE WAVES(L WAVES)

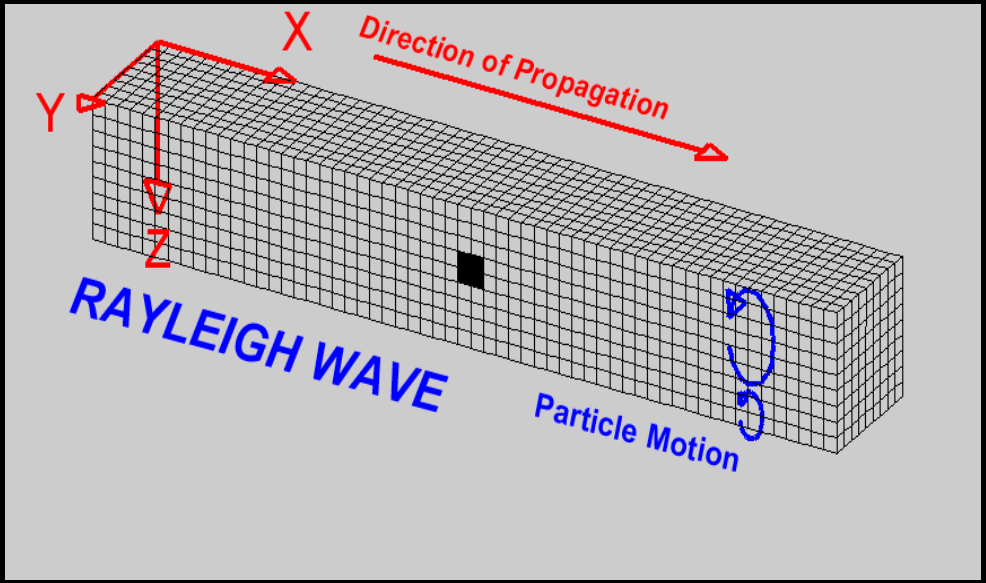




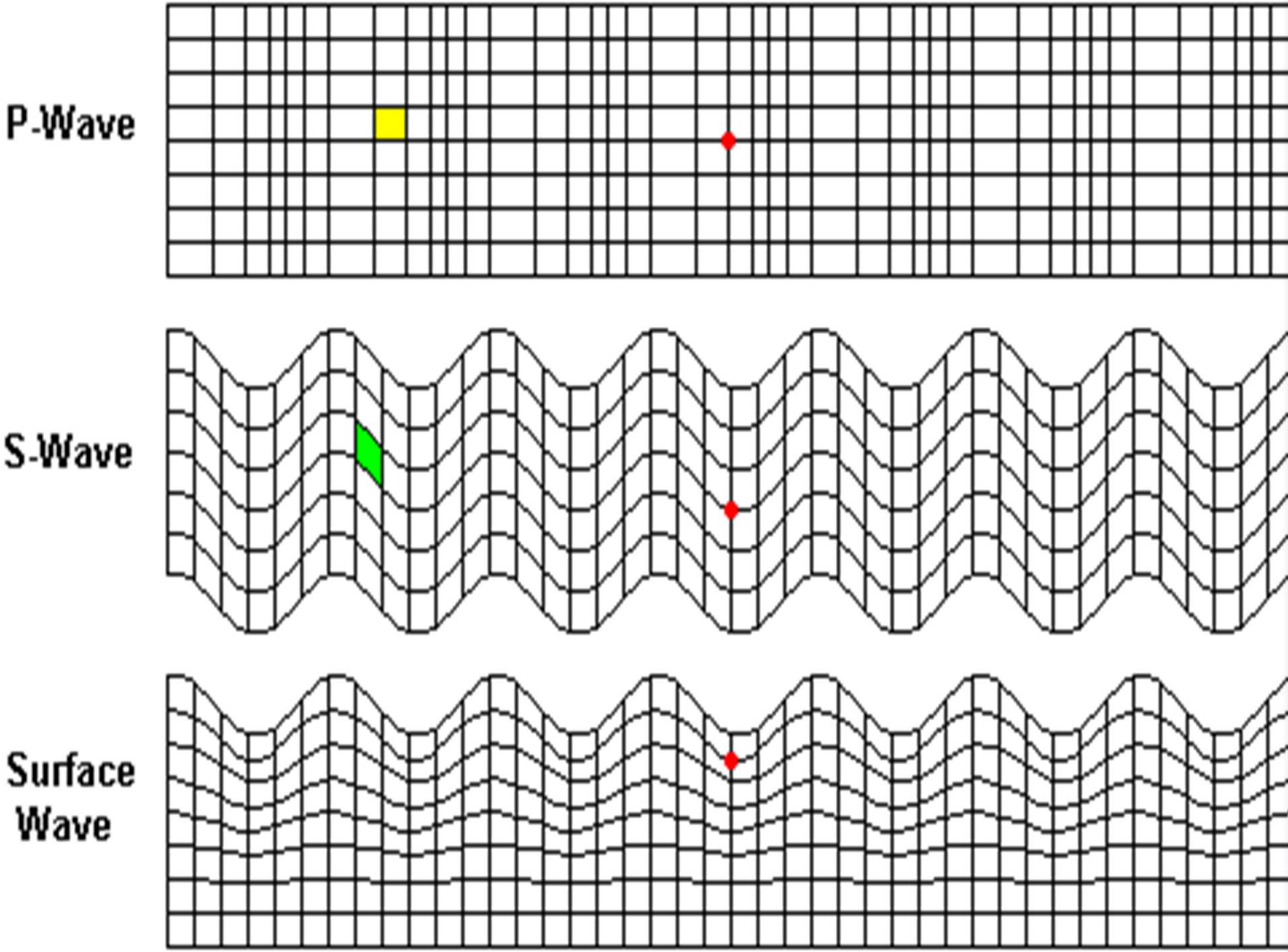
- L-wave named after A.E.H. Love, a British mathematician.
- They do not have vertical component of velocity.
- These waves generally tend to create shearing ruptures.
- Love waves are faster than Rayleigh waves but can not pass through water.
- In love waves particle motion is in horizontal plane and transverse to the direction of wave propagation.

RAYLEIGH WAVES





- Named for John William Strutt, Lord Rayleigh, who mathematically predicted the existence of this kind of wave in 1885.
- These waves are involved with both vertical and horizontal motion of earth.
- These waves are produced by interaction of P and S waves with earth surface.
- These waves are similar to waves produced when rock is thrown in a pond.
- These propagates at the surface of earth at low velocity and low frequency.


P-Wave
S-Wave
Surface Wave

Difference between P waves and S waves

Primary Waves (P-waves)	Secondary Waves(S-wave)
High frequency	High frequency
Short Wavelength	Short Wavelength
Longitudinal waves	Transverse waves
Passes through solids, liquids and gases	Can not move through liquids
Move forward and backwards as it is compressed and decompressed	Move in all direction from their source
P-wave is faster	S-wave is more slower than P-wave
First P-wave arrives	After P-wave, S-wave is arrives

Difference between Love waves and Rayleigh waves

Love Waves	Rayleigh wave
Guided waves	Guided waves
Displacement is parallel to the free surface	Displacement is perpendicular to love-wave displacement
Love wave is faster	Rayleigh wave is slower
Causes horizontal shifting of the earth surface.	Ground move in circular motion.

What is Earthquake?

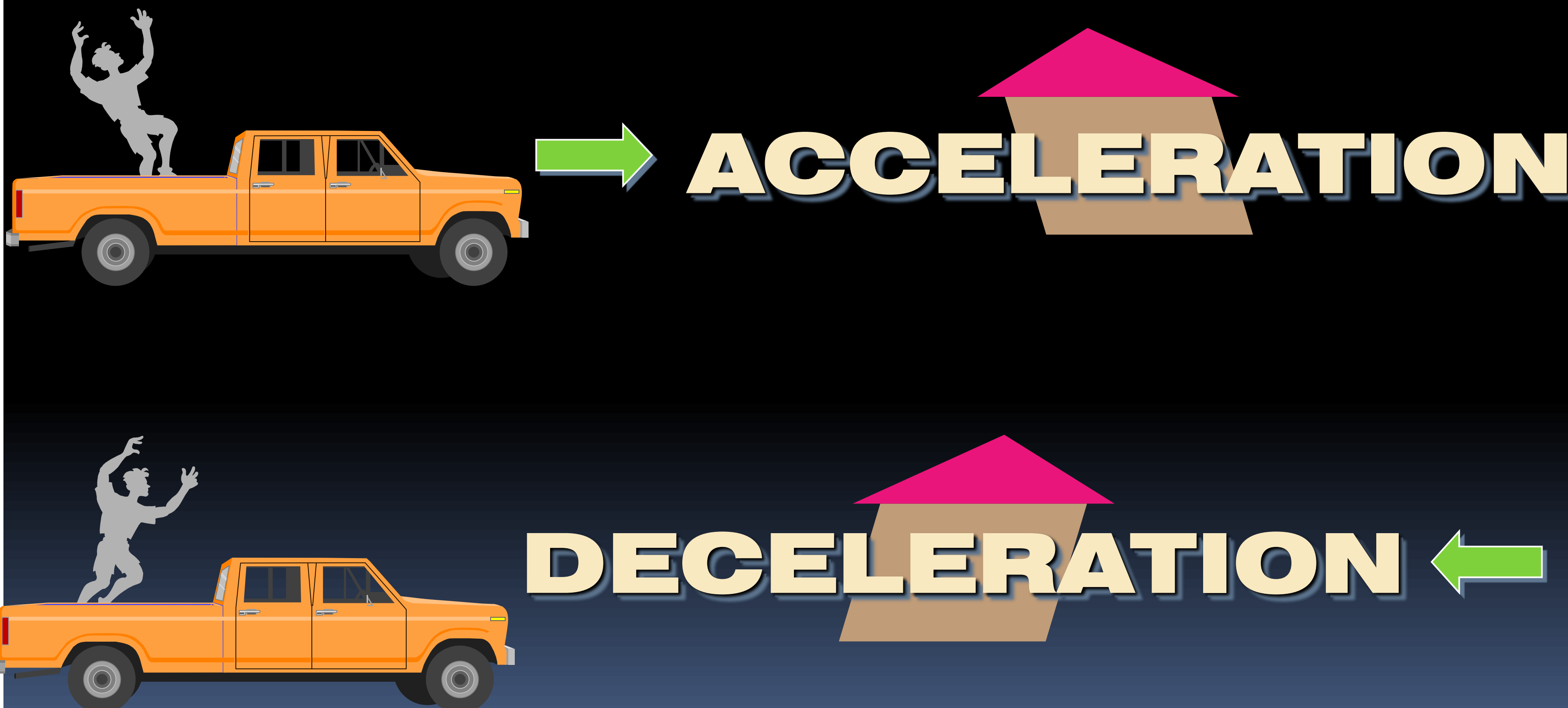
An Earthquake is the result of a sudden release of energy in the earth's crust that creates seismic waves.

OR

Earthquake is the vibration of earth's surface caused by waves coming from a source of disturbance inside the earth.

The seismic activity of an area refers to the frequency, type and size of earthquakes experienced over a period of time.

Earthquake/ Inertia Forces



For example:

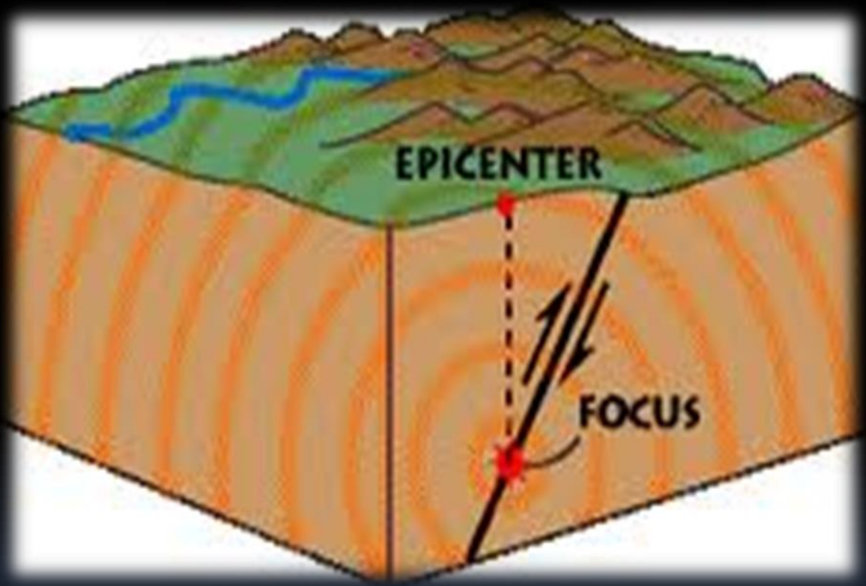
If you throw stone in a pond of still water, series of waves are produced on the surface of water, these waves spread out in all directions from the point where the stone strikes the water.

similarly, any sudden disturbances in the earth's crust may produce vibration in the crust which travel in all direction from point of disturbances.

Terms Related To Earthquake

Focus (Hypocenter):

Focus is the point/region on the fault where rupture occurs/initiates and the location from which seismic waves are released.



Epicenter:

Epicenter is the point on the earth's surface that is directly above the focus, the point where an earthquake or underground explosion originates.

Cont…

Fault Line:

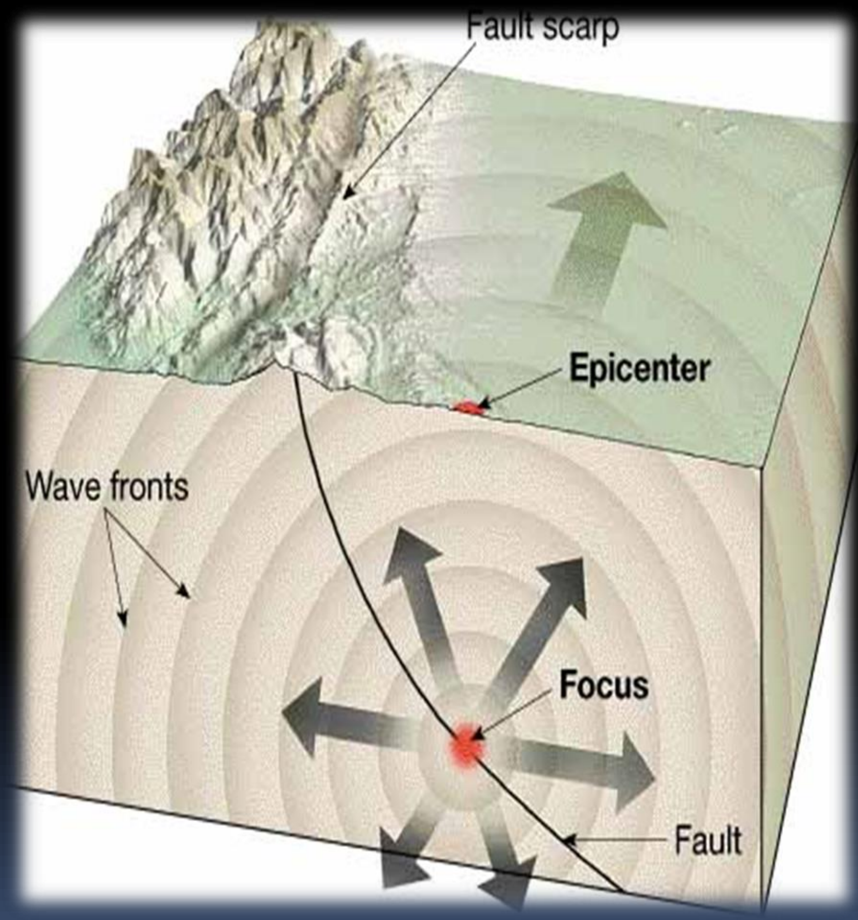
A Fault line is the surface trace of a fault, the line of intersection between the earth's surface.

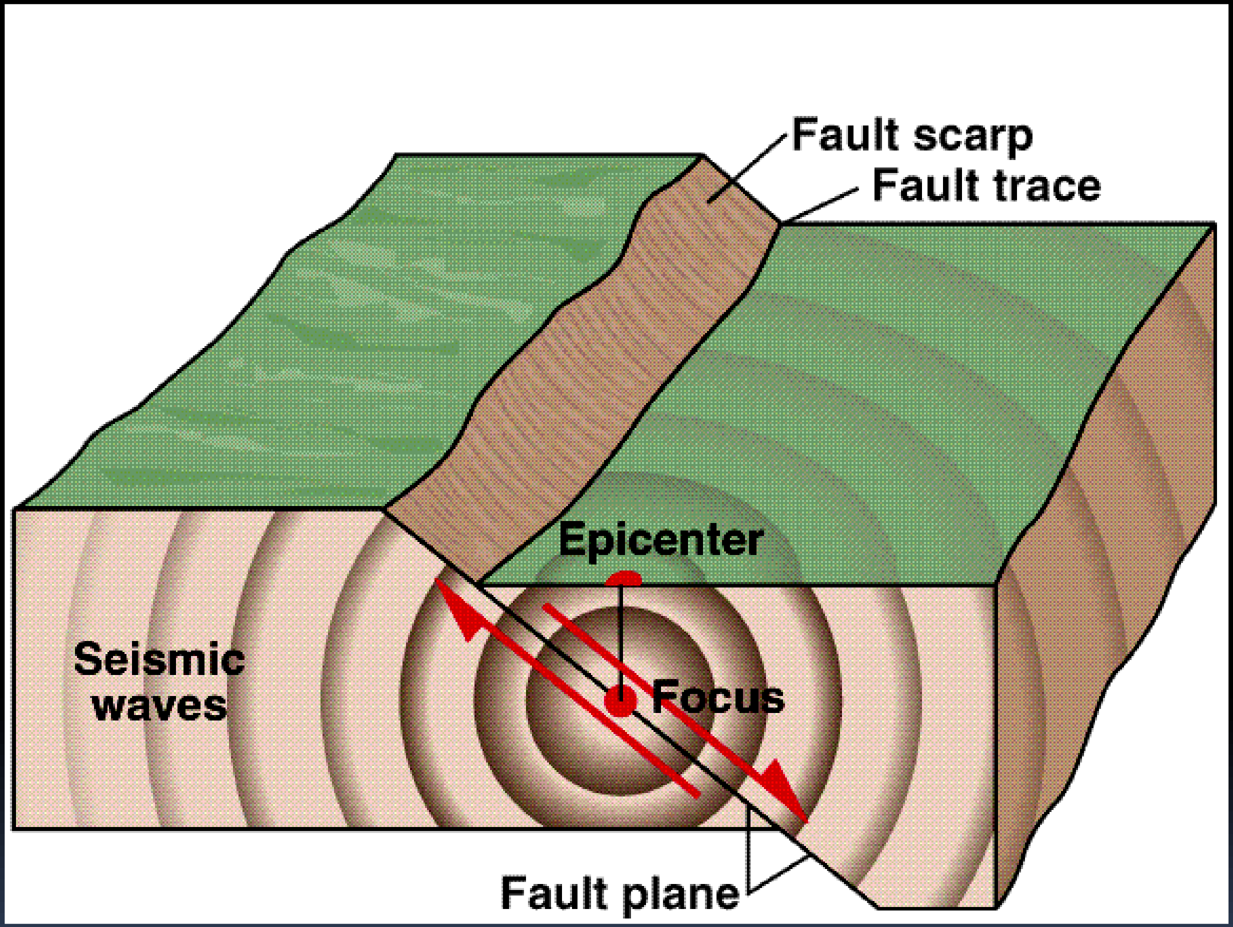
Fault plane:

Fault plane are the cracks or sudden slips of the land.

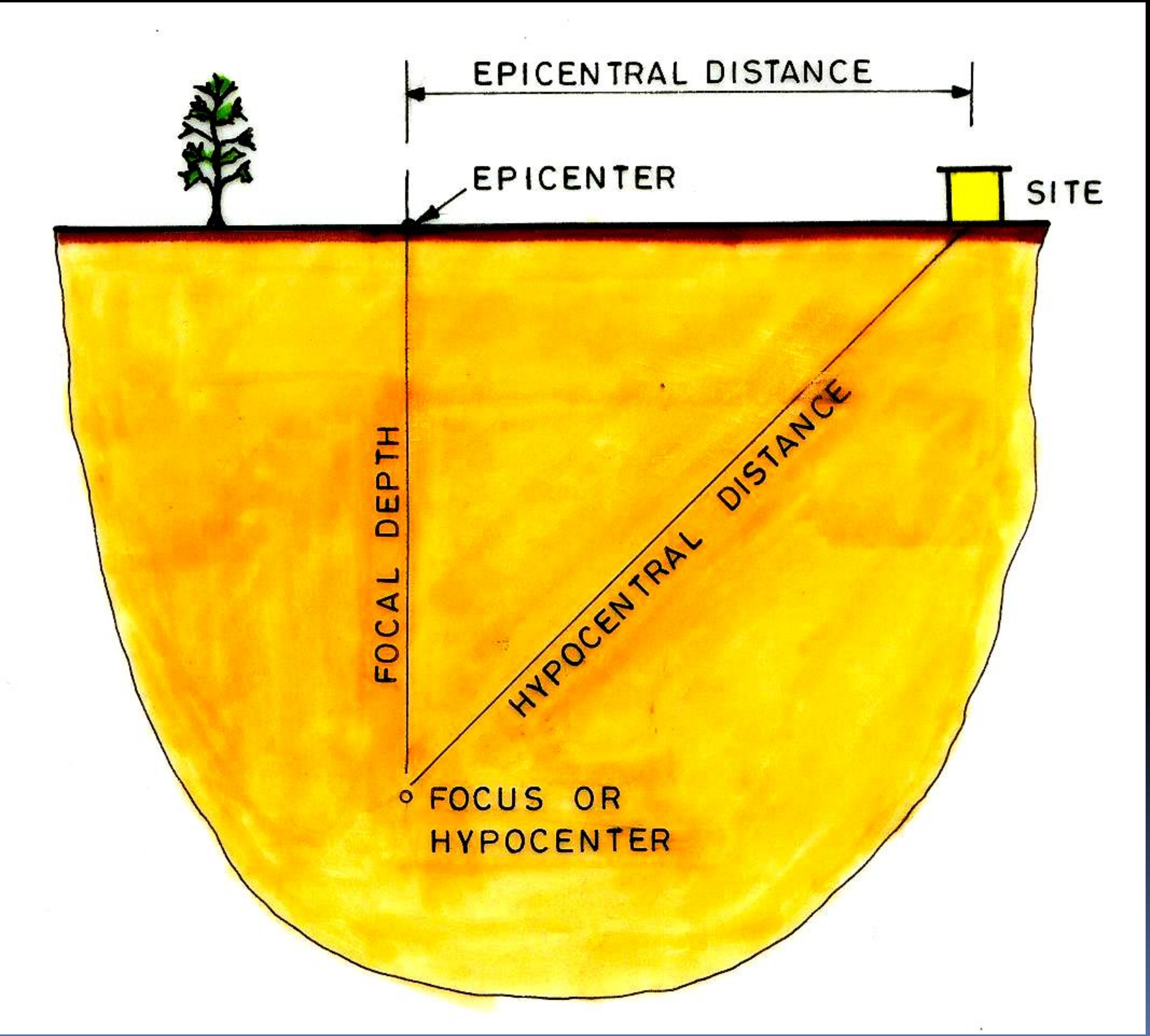
Fault Scrap:

A Fault scrap is the topographic expression of faulting attributed to the displacement of the land surface by movement along faults.




Fault scarp
Fault trace
Epicenter
Seismic
waves
Focus
Fault plane

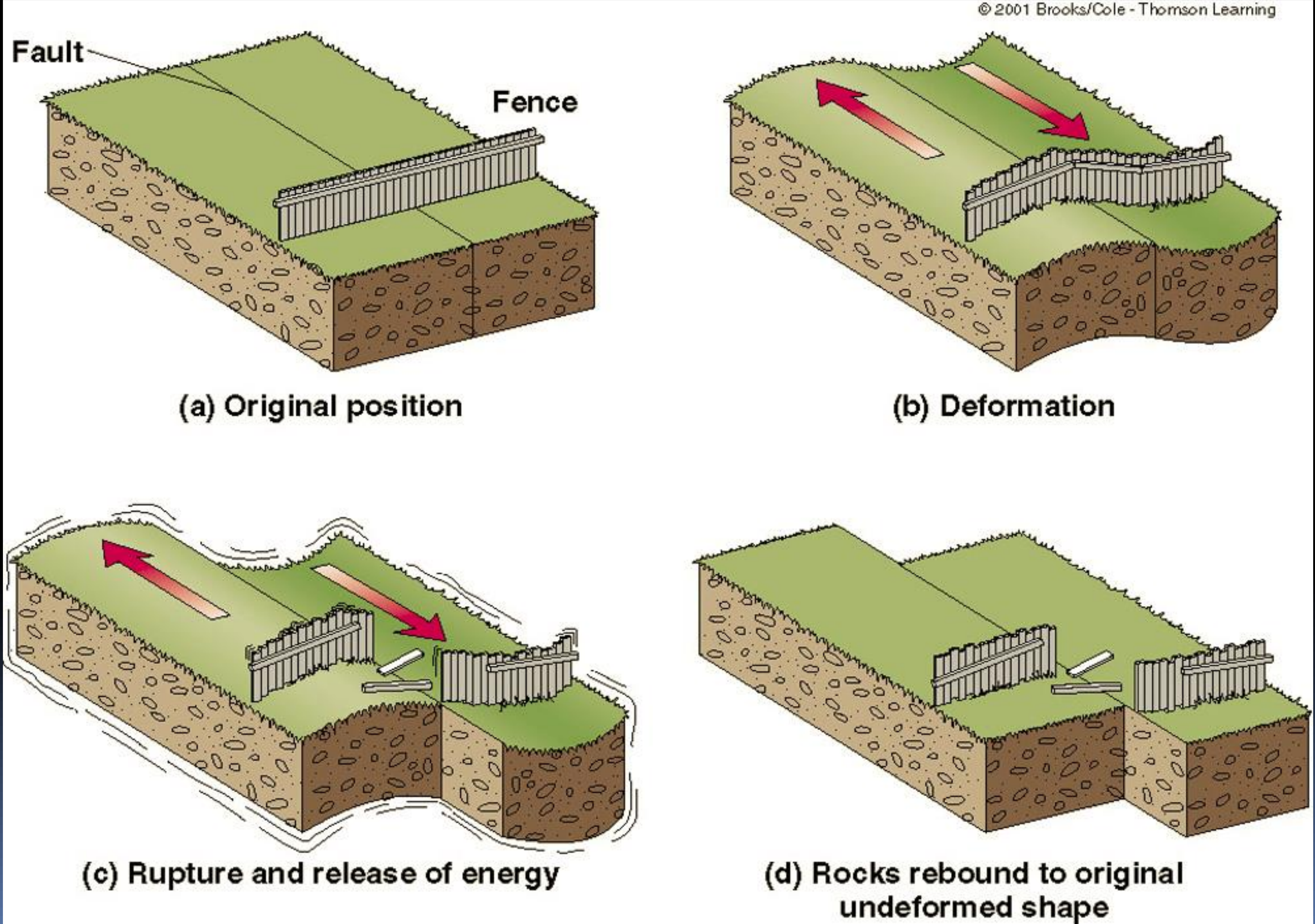
EARTHQUAKE PHENOMENON

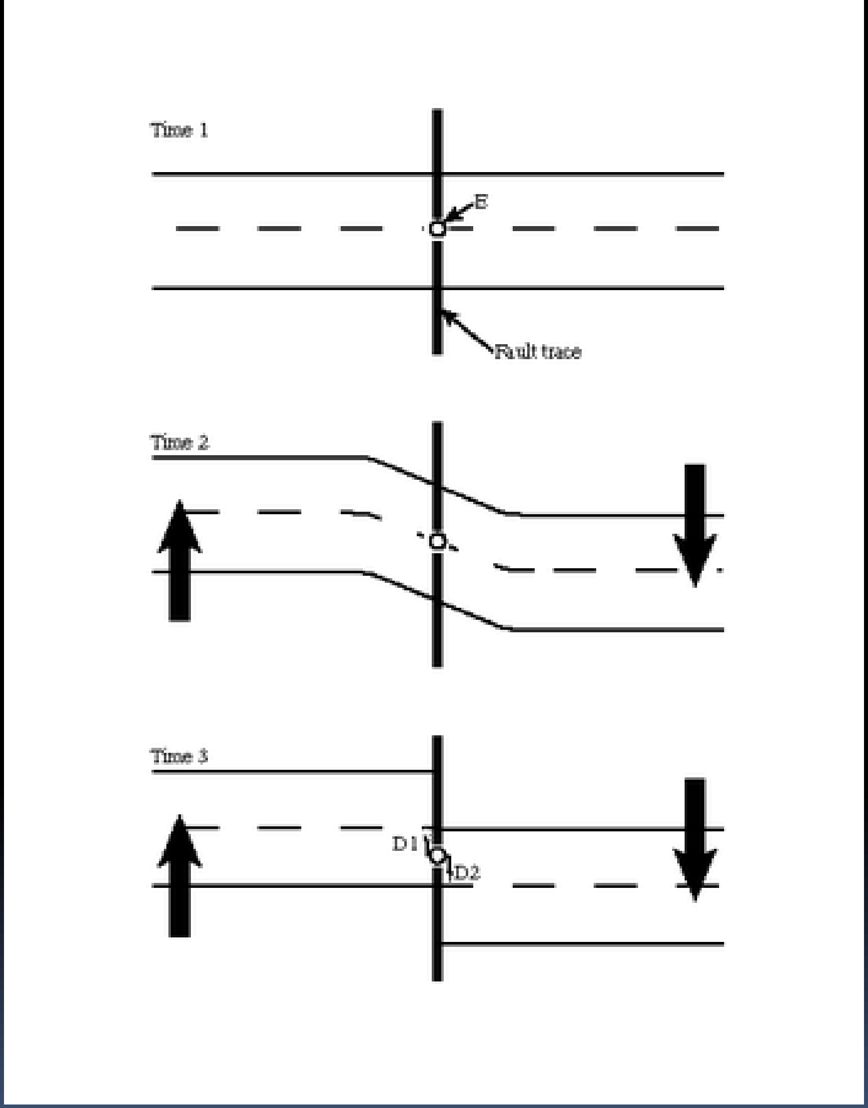


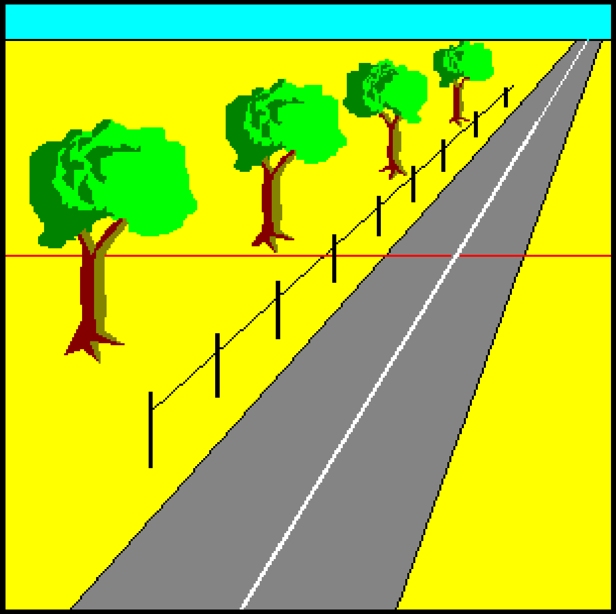
Elastic Rebound Theory

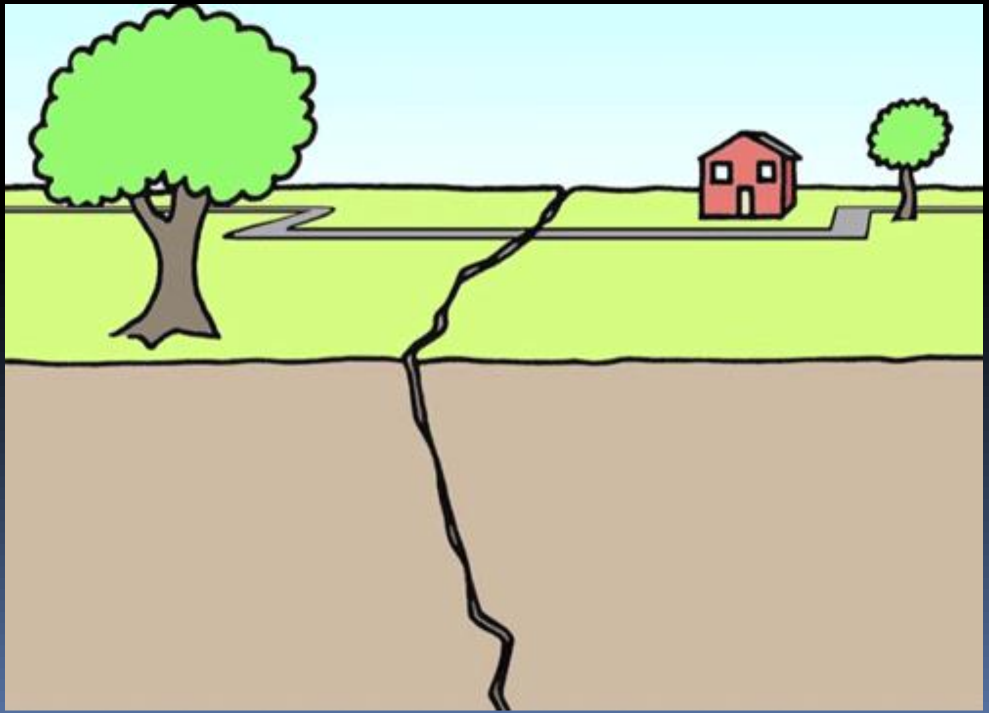
- After the devastating 1906 San Francisco, California earthquake, A fault trace was discovered that could be followed along the ground in a more or less straight line for **270 miles.**
- Earth on the one side of fault had slipped compared to the other side of the fault up to **21 feet!!**
- This fault trace drew curiosity of number of scientists, but nobody had yet been able explain what was happening within the earth to cause earthquakes.
- From an examination of the displacement of the ground surface which accompanied the 1906 earthquake, H. F. Reid, Professor of geology at Johns Hopkins University, concluded that the earthquake must have involved an "elastic rebound" of previous stored elastic stress.
- The gradual accumulation and release of stress and strain is now referred to as the "**Elastic Rebound Theory**" of earthquakes.

Elastic Rebound Theory




Time 1
E
Fault trace
Time 2
Time 3
D1
D2



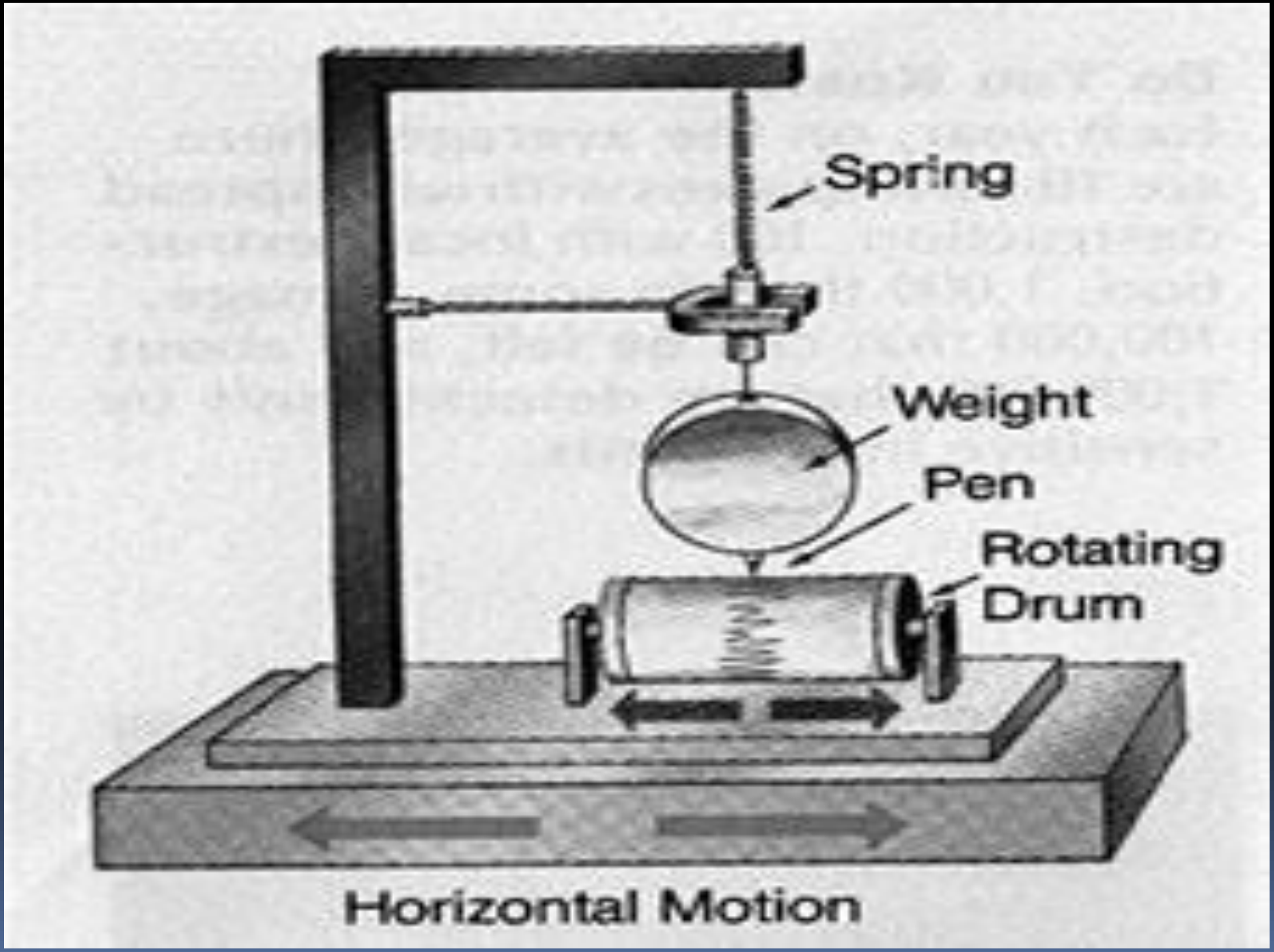


The typical characteristics of earthquake depends on following factors:

1. Stress drop during the slip
2. Total fault displacement
3. Size of slipped area
4. Roughness of the slipping process
5. Fault shape (Normal fault, Reverse fault, Strike slip fault)
6. Proximity of the slipped area to the ground surface
7. Soil condition

Measuring Instruments of Seismic waves

Seismograph



Seismograph

- It is a Measuring Instruments of Seismic waves.
- A Seismograph is an instrument used to measure the vibration of earth.
- It records earthquake ground motion in a particular direction as a function of time.
- The principle of the seismograph is that ground motion is measured by the vibration record of a simple pendulum hanging from a steady point.

The instrument has three components:

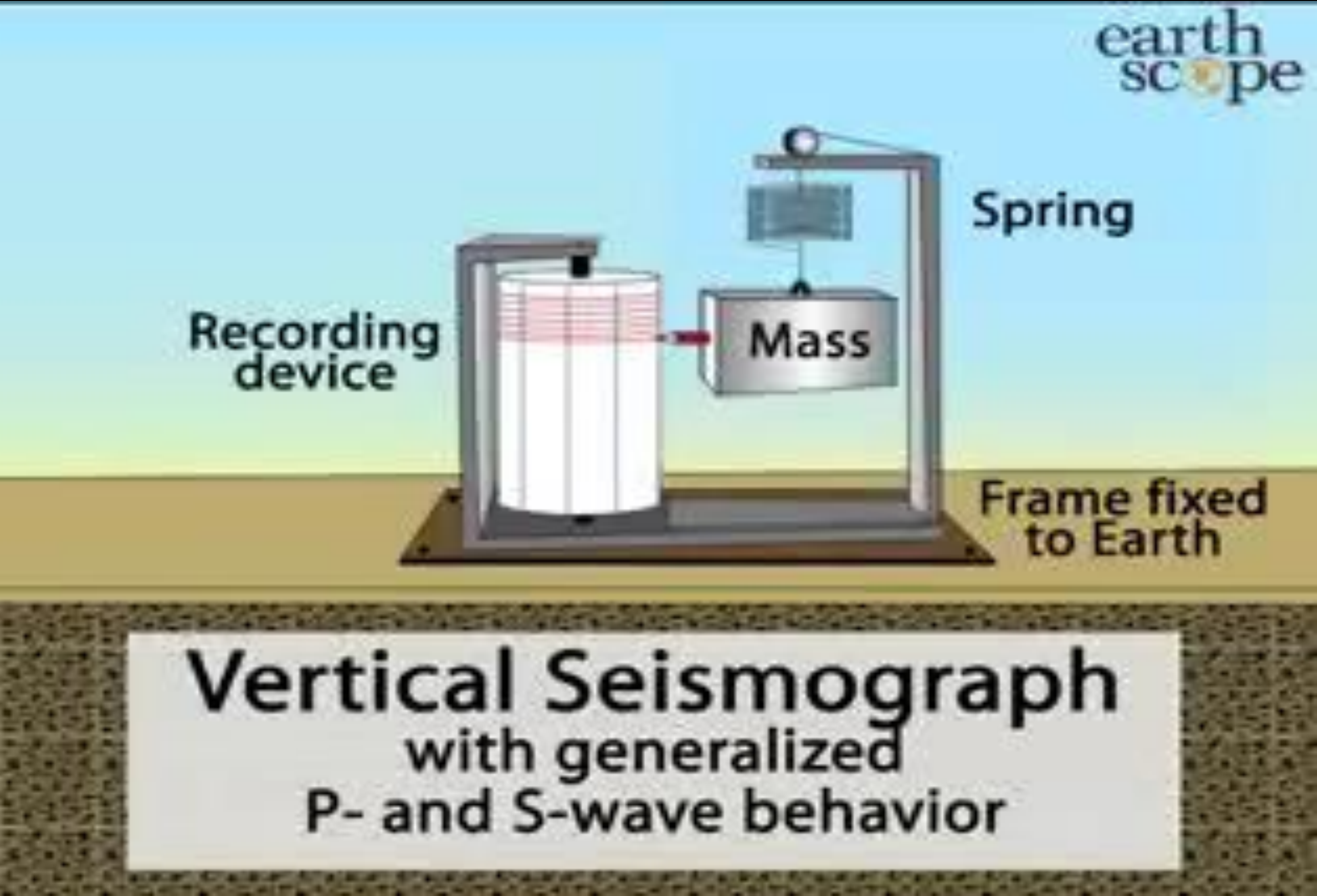
(1) The Sensor - Consisting of the pendulum mass, string, magnet and support.

(2) The Recorder - Consisting of the drum, pen and chart paper.

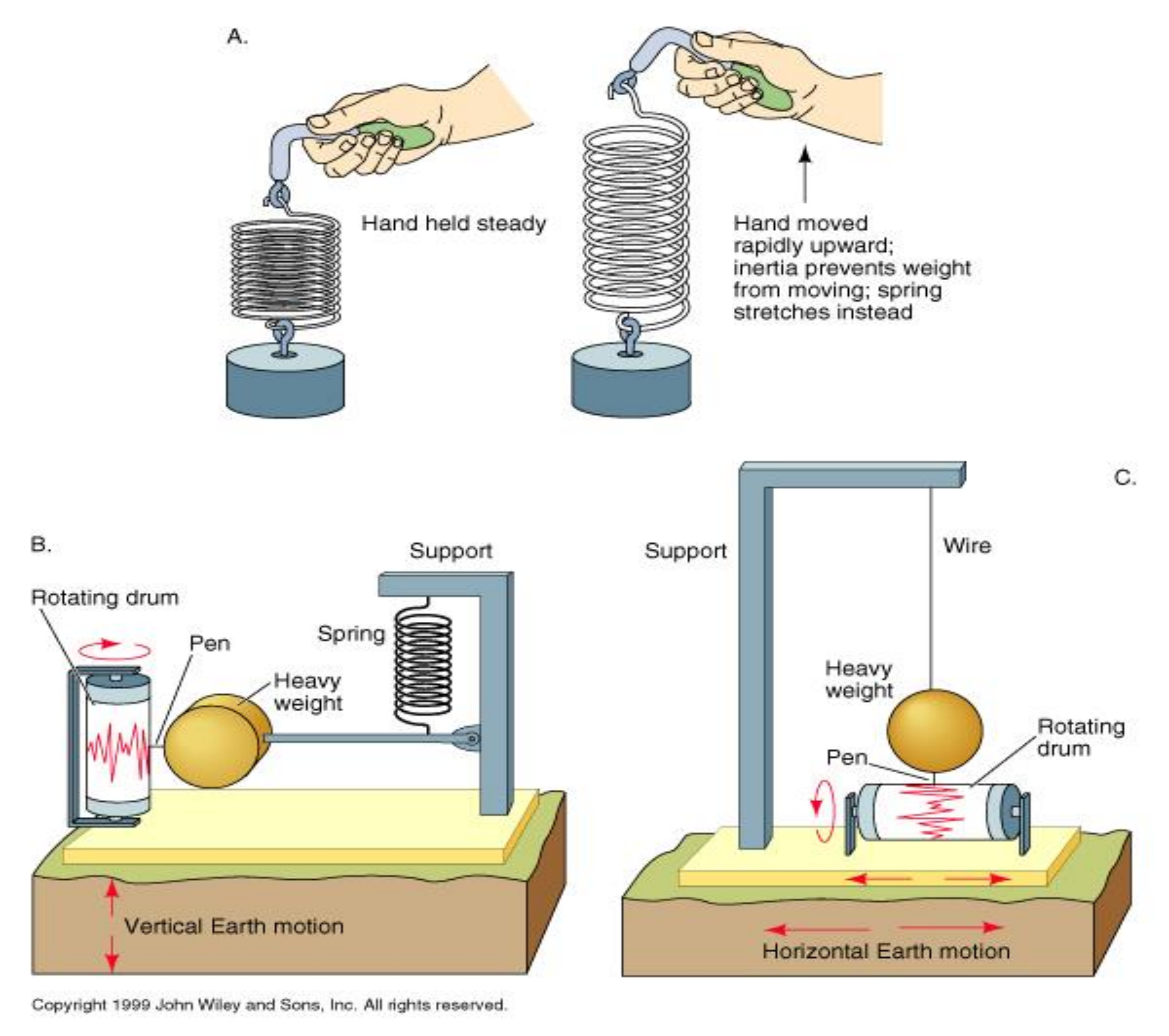
(3) **The Timer** - Consisting of motor that rotates the drum at constant speed.

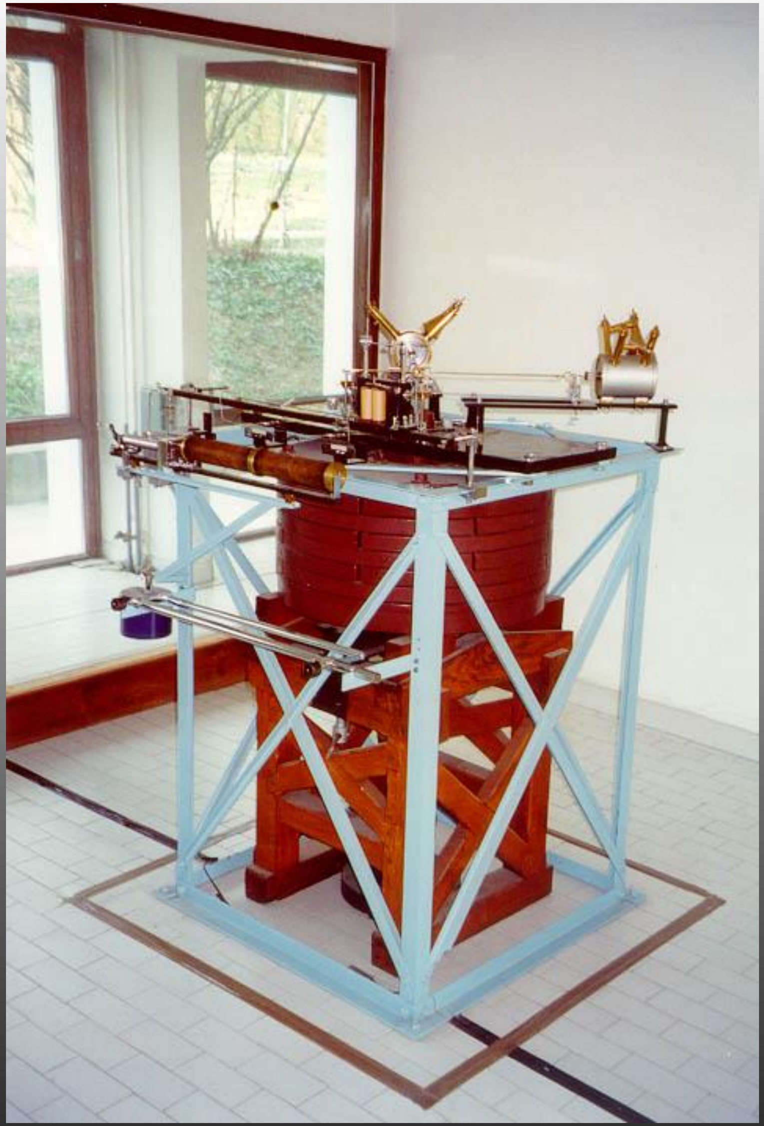
- **A magnet around the string provides required damping to control the amplitude of oscillations.**

Seismograph



Seismograph





Horizontal 1000 kg Wiechert seismograph in Zagreb (built in 1909)

MODERN DIGITAL BROADBAND SEISMOGRAPHS

The typical characteristics of earthquake depends on following factors:

1. Stress drop during the slip
2. Total fault displacement
3. Size of slipped area
4. Roughness of the slipping process
5. Fault shape(Normal fault, Reverse fault, Strike slip fault)
6. Proximity of the slipped area to the ground surface
7. Soil condition

SIZE OF EARTHQUAKES

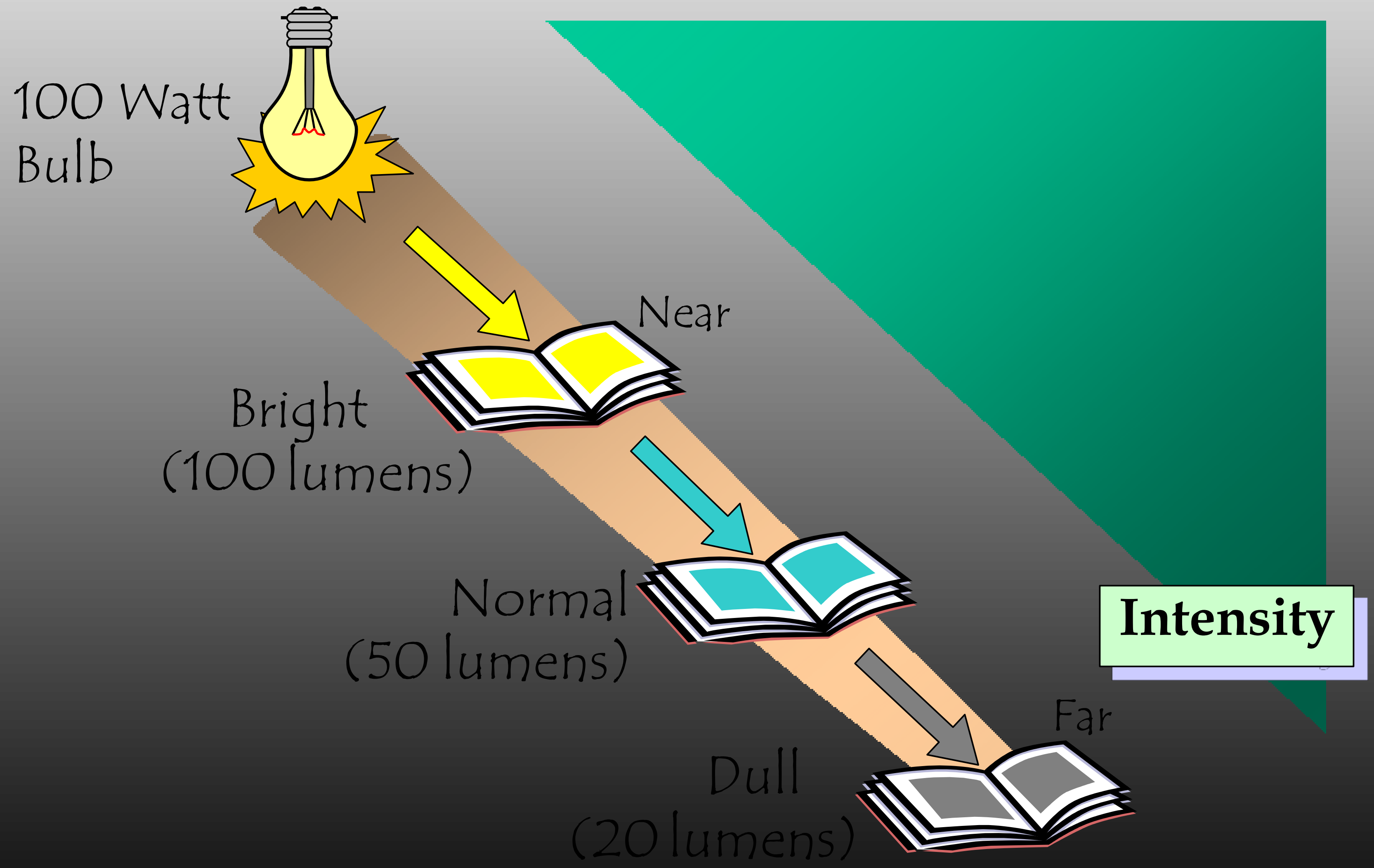
Intensity – A number describing the severity of an earthquake in terms of its effects on earth's surface and on humans and their structures.

- Intensity is a qualitative measure of the actual shaking at a location during an earthquake, and is assigned as Roman Capital Numerals.

Magnitude – A number that characterizes the relative size of an earthquake.

- It is based on measurement of the maximum motion recorded by a seismograph.
- Magnitude is a quantitative measure of the actual size of the earthquake.

Understanding of intensity



Intensity

- The intensity of an earthquake refers to the **degree of destruction** caused by it.
- This, of course is **empirical** to some extent because the extent of destruction or damage that takes place to a **construction at a given place depends on many factors.**
- Some of these factors are as follows:

(i) Distance from the epicentre

(ii) Compactness of the underlying ground

(iii) Type of construction

(iv) Magnitude of the earthquake

(v) Duration of the earthquake and

(vi) Depth of the focus

- Intensity is the oldest measure of earthquake.

Seismic Intensity Scale

- Seismic Intensity scale is the way of measuring or rating the effects of an earthquake at different sites.
- The assignment of intensity of an earthquake does not require any instrumental records.
- It depends very much on the **acuity of the observer**, and **is in principle subjective.**
- Intensity to different places of an affected area can be assigned **based on visual observations and interviews of residents or based on evaluation of questionnaires completed by residents of that area.**
- Intensity data are very useful for the development of seismic risk map of a region or country.
- Seismic risk maps are useful in planning safe sites for important structures like nuclear power plants or large dams.
- Risk maps are also valuable to insurance companies.
- Intensity data is also important in determination of historic seismicity of a region.

Continued…

- Rossi-Forel intensity scale, developed in the late 19th century, have **ten stages** to describe the earthquake effects in increasing order.
- **Mercalli (1902) proposed an intensity scale in which earthquake severity was classified in 12 stages.**
- The Mercalli intensity scale was **modified in 1931** to **suit the building conditions in the United States.**
- The modified version is widely known as **Modified Mercalli Intensity (MMI) Scale.**
- The **Medvedev-Spoonheuer-Karnik (MSK)** intensity scale introduced in 1964 also has twelve stages and differs from the MMI scale mainly in details.

Two commonly used scales are:-

1) **Modified Mercalli Intensity (MMI) Scale**

2) **MSK (Medvedev–Spoonheuer–Karnik) Scale**

- The distribution of intensity at different places during an earthquake is shown graphically using **isoseismals** (lines joining places with equal seismic intensity).

The intensity scales are based on three features of shaking:-

1) **Perception by people, animals**
2) **Performance of buildings**
3) **Changes to natural surroundings**

Medvedev-Sponheuer-Karnik (MSK) scale

- Macro seismic intensity scale used to evaluate the severity of ground shaking on the basis of observed effects in an area of the earthquake occurrence.

- The MSK scale has 12 intensity degrees expressed in **Roman numerals.**

- The scale was first proposed by **Sergei Medvedev (USSR).**

- In assigning the MSK intensity at a site due attention is paid to the type of structures, percentage of damage of each type of structure and grade of damage to different type of structures.

Modified Mercalli Intensity Scale (MMI)

- Values depend upon the distance to the earthquake, with the highest intensities being around the epicentral area.
- The lower degrees of the Modified Mercalli Intensity scale deal with the manner in which the earthquake is felt by people.
- The higher numbers of the scale are based on observed structural damage.

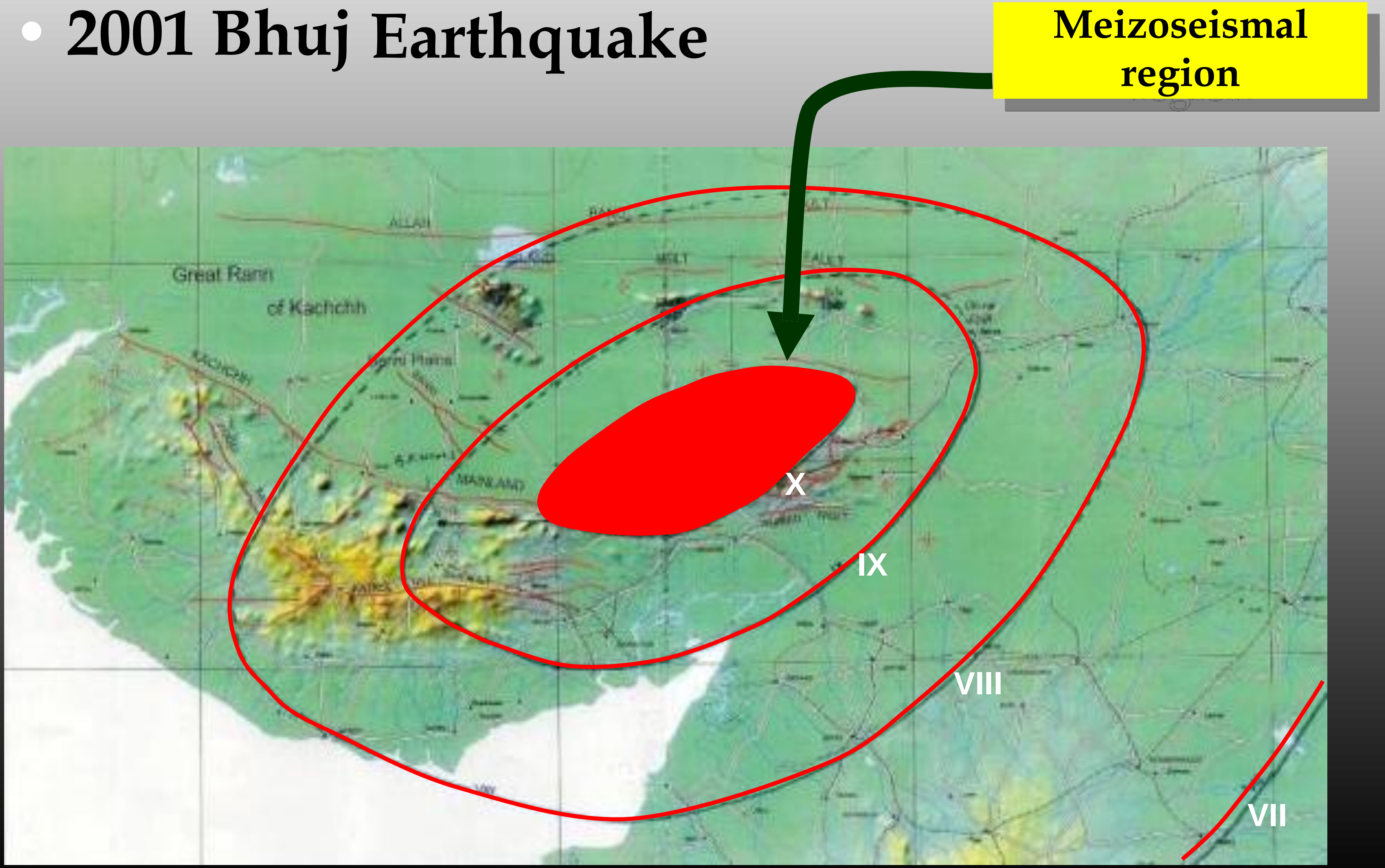
Modified Mercalli Intensity Scale

Degree	Force	Behavioural effects	Structural effects	Geologic effects
I	Imperceptible	Not felt		
II	Very light	felt sporadically		
III	Light	Felt only by people at rest		
IV	Moderate	Felt indoors, many awakened	Windows vibrate	
V	Fairly strong	Widely felt outdoors	Interior plaster cracks, hanging objects swing, tables shift	
VI	Strong	Fright	Damage to chimneys and masonry	Isolated cracks in soft ground
VII	Very strong	Many people flee their dwellings	Serious damage to buildings in poor condition, chimneys collapse	Isolated landslides on steep slopes
VIII	Damaging	General fright	Many old houses undergo partial collapse, breaks in canals	Changes in wells, rockfalls onto roads
X	Devastating	General panic	Brick buildings destroyed	Rails twisted, landslides on riverbanks, formation of new lakes
XI	Catastrophic	More panic	Few buildings remain standing, water thrown from canals	Widespread ground disturbances, tsunamis
XII	Very catastrophic	More Panic	Surface and underground structures completely destroyed	Upheaval of the landscape, tsunamis

Magnitude	Typical Maximum Modified Mercalli Intensity
Under 2.0	I
2.0 – 2.9	I – II
3.0 – 3.9	II – IV
4.0 – 4.9	IV – VI
5.0 – 5.9	VI – VIII
6.0 – 6.9	VII – X
7.0 – 9.9	VIII or higher
10.0 or higher	X or higher

Isoseismals

- 2001 Bhuj Earthquake



HOW MAGNITUDE AND INTENSITY DIFFERS?

Magnitude	Intensity
Measure of amount of energy released during an earthquake.	Measure of the actual ground shaking at a location during an earthquake.
Quantitative measure	Qualitative measure
For an earthquake, it is same at all places.	For an earthquake, it decreases with distance from epicenter.
More precise measure of an earthquake.	Less precise measure of an earthquake.
Based on direct measurement of an amplitude of seismic waves.	Subjective measure based on shaking perception by people , performance of building and changes to natural surroundings.

MAGNITUDE

- Magnitude of an earthquake is a measure of amount of energy released during an earthquake.
- Depending on size and nature of earthquake, seismologists use different methods to estimate magnitude.
- It is based on direct measurements of the size of seismic waves.
- Amount of ground shaking is related with magnitude.
- Since it is representative of the earthquake itself, thus there is **only one magnitude per earthquake.**
- But, magnitude values given by different seismological observatories for an event may vary.
- The uncertainty in an estimate of the magnitude is about ±0.3 unit.

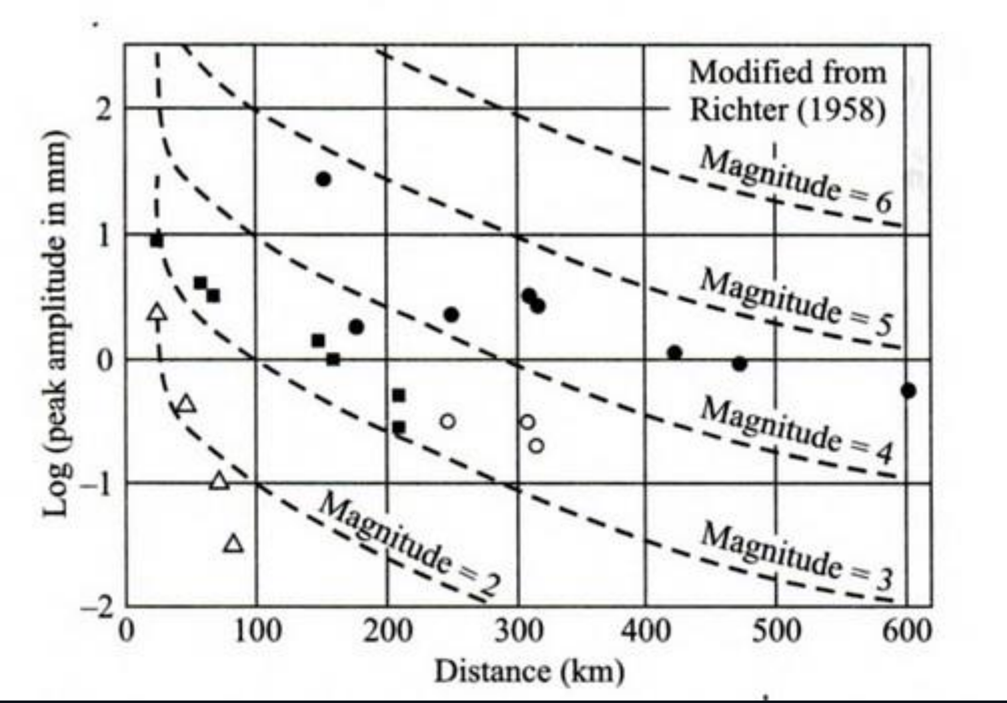
Group	Magnitude	Annual Average Number
Great	8 and higher	1
Major	7-7.9	18
Strong	6-6.9	120
Moderate	5-5.9	800
Light	4-4.9	6200
Minor	3-3.9	49000
Very Minor	< 3	M2-3 1000/day M1-2 8000/day

Various Magnitude Scales

- Richter Magnitude Scale
- Surface Wave Magnitude
- Body Wave Magnitude
- Duration Magnitude
- Moment Magnitude

Richter Magnitude Scale

- Richter (1935) collected the recordings of seismic waves from a large number of earthquake and constructed a diagram of peak ground motion versus distance.



- The logarithm of recorded amplitude was used due to enormous variability in amplitude.
- Richter inferred that the larger the intrinsic energy of earthquake, larger the amplitude of earthquake motion at a given distance.

Professor Charles Richter noticed that:-

1) At the same distance, seismograms of larger earthquakes have bigger wave amplitude than those of smaller earthquakes.

2) For a given earthquake, seismograms at farther distances have smaller wave amplitude than those at close distances.

- The idea of logarithmic earthquake magnitude scale struck into the mind of Richter after analysing the roughly parallel curves generated by different size earthquakes on the plot of log of the recorded amplitude at various epicentral distances.
- The **Richter Magnitude Scale** was developed to assign a single number to quantify the energy released during an earthquake.
- Scale is a base-10 logarithmic scale.
- The magnitude is defined as the logarithm of the ratio of the amplitude of waves measured by a seismograph to an arbitrary small amplitude.

- He proposed zero magnitude for an earthquake that would produce a record with amplitude of 1.0 μm at a distance of 100 km from the epicentre on WA (Wood Anderson) seismogram with 1.25 Hz natural frequency and 2800 magnification factor.

- The logarithmic form of **Richter Magnitude Scale (M_L)** is given as:

$$M_L = \log_{10} A - \log_{10} A_0$$

Where, A = recorded amplitude and

A_0 = amplitude for zero magnitude earthquake at different epicentral distances.

Limitations of Richter Magnitude Scale:

- Valid up to epicentral distance of 600 km.
- It depends only on the maximum amplitude of ground shaking.

SURFACE WAVE MAGNITUDE

- At large epicentral distances, body waves are usually attenuated and scattered so that the resulting motion is dominated by surface waves.
- On the other hand, the amplitude of earthquake waves is too small for deep focus earthquakes is too small.
- So, in order to take an advantage of the growing number of globally distributed seismograph stations, new magnitude scales that are an extension of Richter's original idea were developed.
- These include body-wave magnitude and surface wave magnitude.
- Each is valid for a particular period range and type of seismic wave.
- **It Records the magnitude for very large epicentral distance.**
- A commonly used equation for computing M_s of a shallow focus (<50km) earthquake from seismograph records between epicentral distances $20^o < \Delta < 160^o$ is the following one proposed by Bath (1966).

$$M_S = \log_{10} (A_S/T)_{max} + 1.66 \log_{10} \Delta + 3.3$$

Where, As = amplitude of horizontal ground motion in μm deduced from the surface wave with period T **(Rayleigh Wave Magnitude)**

T = period (around 20 ± 2 seconds) and

Δ = epicentral distance in degree

Body Wave Magnitude

- Gutenberg (1945) developed body wave magnitude (m_B) for teleseismic body waves such as P and S waves in the period range 0.5s to 12s.
- It is based on theoretical amplitude calculations corrected fro geometric spreading and attenuation and then adjusted to empirical observations from shallow and deep focus earthquakes.

$$M_B = \log_{10}(A/T)max + \sigma(\Delta,h)$$

Where, $\sigma(\Delta,h)$ = Distance correction factor at epicentral distance and focal depth

A = amplitude of horizontal ground motion and

T = Period

- Gutenberg and Richter (1956) published a table with distance correction factors $\sigma(\Delta,h)$ for body waves, which enable magnitude determinations.
- These distance corrections factors are used when ground motion trace amplitudes are in µm.

Duration Magnitude

- Analogue paper and tape recordings have a very limited dynamic range of only about 40dB and 60 dB, respectively.
- M_L cannot be determined since these records are often clipped in case of strong and near earthquakes.
- Therefore, alternative duration magnitude scale MD has been developed.
- Duration from the P-wave onset to the end of coda (back-scattered waves from numerous heterogeneities) is used in computations.
- Aki and Chouet (1975) reported that for a given local earthquake at epicentral distances lesser than 100 km the total duration of a signal is almost independent of distance, azimuth and property of materials along the path.
- This allowed development of duration magnitude scale without a distance term as follows:

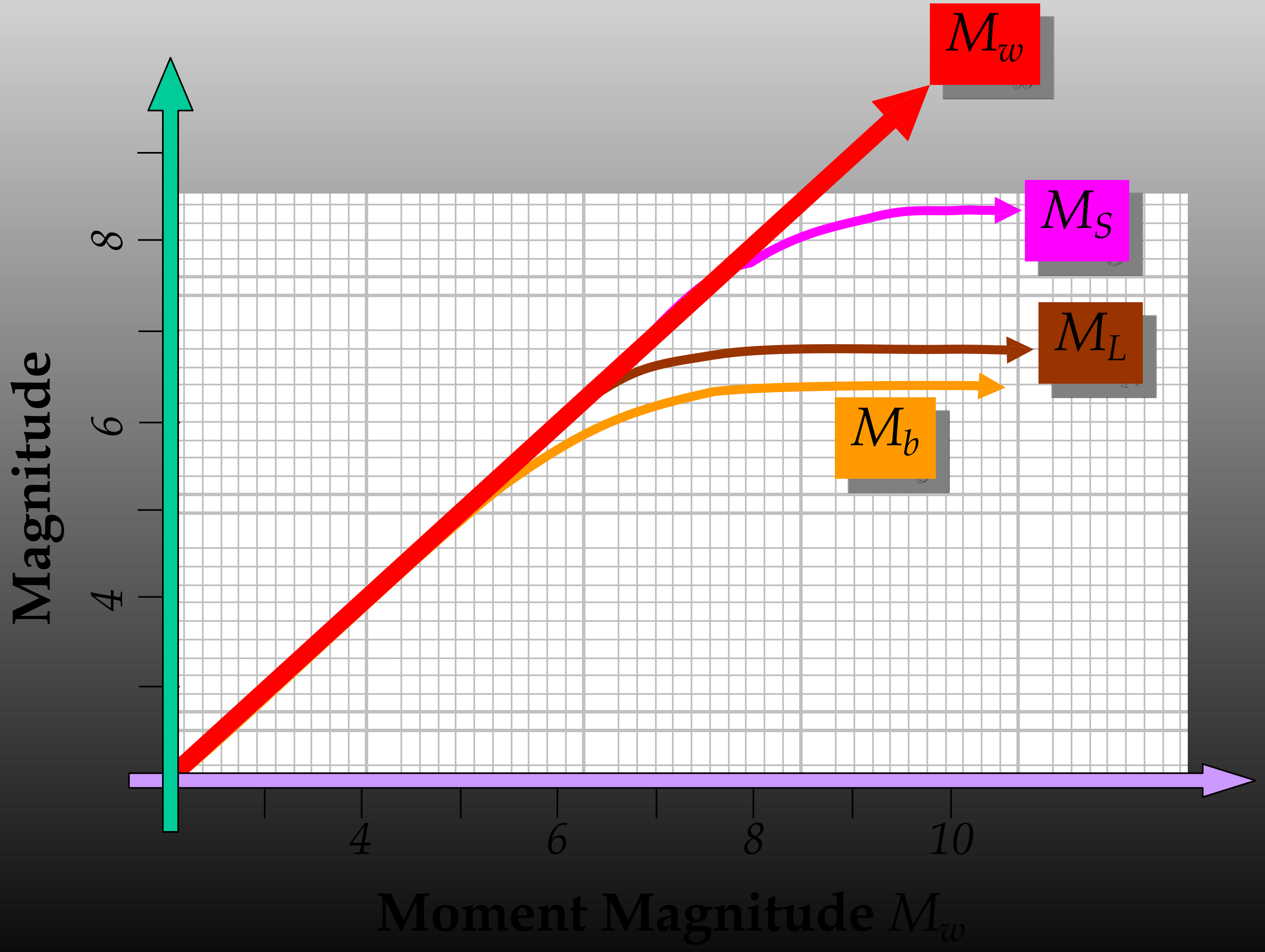
$$M_D = a_0 + a_1 \log D$$

Where, a_0 and a_1 are constants and

D = Duration in seconds

- The values of these constants vary region to region according to crustal structure, scattering and attenuation conditions.
- They have to be determined locally for a region with the help of available M_L.

Saturation of Magnitude Scales

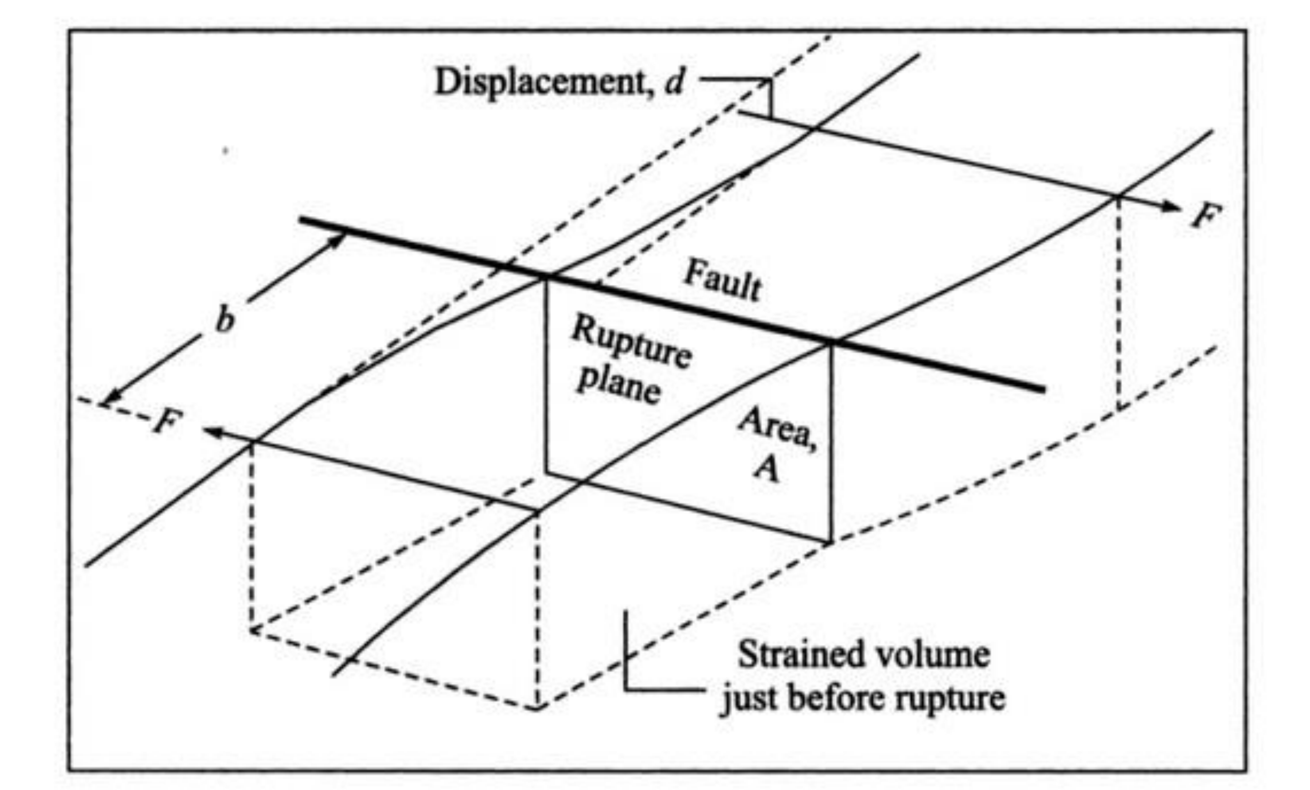


Moment Magnitude (M_W)

- Over the years, scientists observed that different magnitude scales had saturation points and the magnitudes estimated by different approaches did not point to a unique value of earthquake size The Richter magnitude saturates at about 6.8, and the surface wave magnitude at about 7.8.
- In addition, these magnitude estimates did not have a linear relation with the energy released due to earthquake rupture.
- To address these short falls, Hanks and Kanamori, in 1979 proposed a magnitude scale, termed as 'moment magnitude', based on the seismic moment due to earthquake rupture.
- The moment magnitude is given by

$$M_W = 2/3\ [\log_{10} M_o\ - 16]$$

Where, Mo = Moment in dyne.cm



MAGNITUDE AND INTENSITY IN SEISMIC DESIGN

Can my building withstand a magnitude 7.0 Earthquake?

- M7.0 earthquake causes different shaking intensities at different locations, and the damage induced in buildings at various locations is different.

- It is particular levels of intensity of shaking that buildings and structures are designed to resist.

- The **peak ground acceleration (PGA)**, i.e., maximum acceleration experienced by the ground during shaking, is one way of quantifying the severity of the ground shaking.

Amount of energy released during Earthquakes with different Intensities

Intensity of Earthquake on Richter Scale	Energy Release
1.0	170 Grams
2.0	6 Kilogram
3.0	179 Kilogram
4.0	5 Metric Tons
5.0	179 Metric Tons
6.0	5643 Metric Tons
7.0	179100 Metric Tons
7.5	1 Mega Tons
8.0	564300 Metric Tons

Earthquake Prediction

Earthquake prediction is usually defined as the ***specification of the time, location and magnitude of a future earthquake within stated limits.***

But some evidence of upcoming Earthquake are following:

- Unusual animal behavior
- Water level in wells
- Large scale of fluctuation of oil flow from oil wells
- Foreshocks or minor shocks before major earthquake
- Temperature change
- Uplifting of earth surface
- Change in seismic wave velocity

Effects of Earthquake

- Loss of life and property
- Damage to transport system i.e. roads, railways, highways, airports, marine
- Damage to infrastructure.
- Chances of Floods – Develop cracks in Dams
- Chances of fire short-circuit.
- Communications such as telephone wires are damaged.
- Water pipes, sewers are disrupted
- Economic activities like agriculture, industry, trade and transport are severely affected.

Earthquake Safety Rules

If you are in house;

- Don’t use lift for getting down from building.
- Be prepared to move with your family.

If you are in shop, school or office;

- Don’t run for an exit.
- Take cover under a disk/table.
- Move away from window glass.
- Do not go near electric point and cable. Keep away from weak portion of the building and false ceiling.

If you are outside;

- Avoid high buildings, walls, power lines and other objects that could fall and create block.
- Don’t run through streets.
- If possible, move on to an open area away from hazard including trees.

If you are in vehicle;

- Stop in a safe open place.
- Remain inside vehicle.
- Close window, doors and vents.

After An Earthquake

- Keep calm, switch on the transistor radio and obey instructions.
- Keep away from beaches and low banks of river. A huge wave may sweep in
- Do not re enter badly damaged buildings and do not go near damage structures.
- Turn off the water, gas and electricity.
- Do not smoke, light match or use a cigarette lighter
- Do not turn on switches there may be gas leak or short circuit
- If there is any fire, try to put it out or call fire brigade.

Continued

- Do not drink water from open containers without having examined it.
- If you aware of people have been buried, tell the rescue team. Do not rush and try not to worsen the situation.
- Avoid places where there are loose electric wires and do not come in contact with any metal object.
- Eat something. You will better and more capable of helping other.
- Do not walk around the streets to see what is happening. Keep the streets clear so rescue vehicles can access the roads easily.

Types of Zones

The earthquake zoning map of India divides India into 4 seismic zones Based on the observations of the affected area due to Earthquake in India:

Zone - II: This is said to be the least active seismic zone.

Zone - III: It is included in the moderate seismic zone.

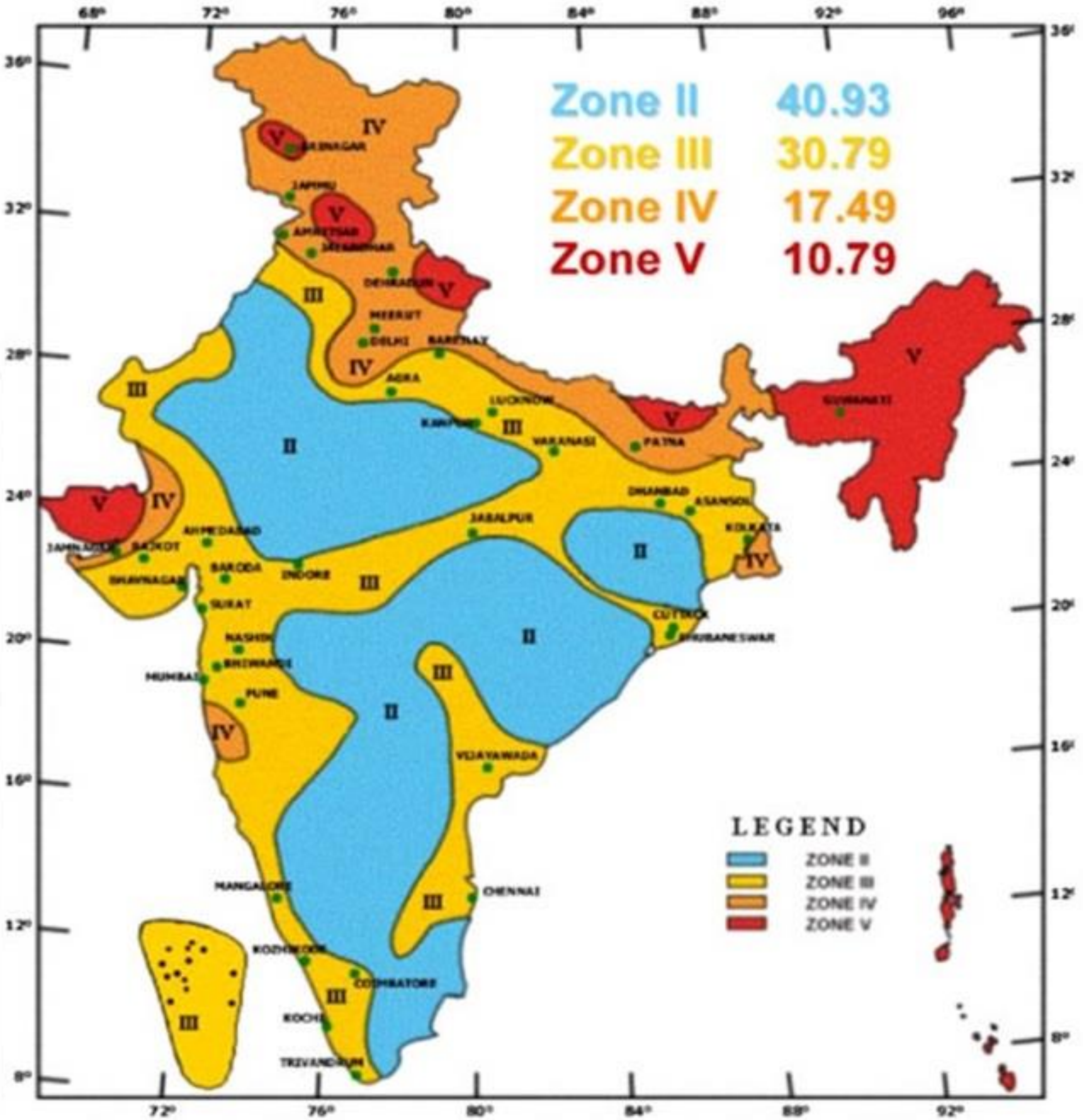
Zone - IV: This is considered to be the high seismic zone.

Zone - V: It is the highest seismic zone.

Seismic Zone Map of India: -2002

About <u>59 percent</u> of the land area of India is liable to seismic hazard damage

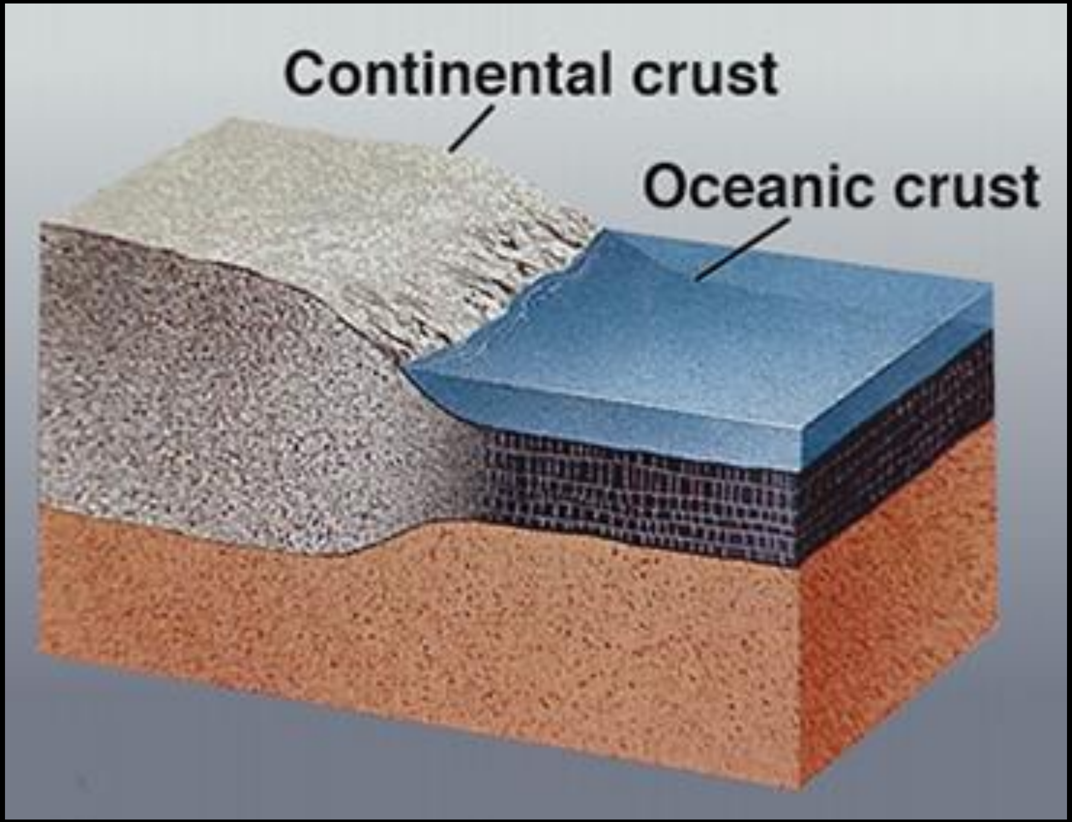
Zone	Intensity
Zone V	**Very High Risk Zone** Area liable to shaking Intensity IX (and above)
Zone IV	**High Risk Zone** Intensity VIII
Zone III	**Moderate Risk Zone** Intensity VII
Zone II	**Low Risk Zone** VI (and lower)

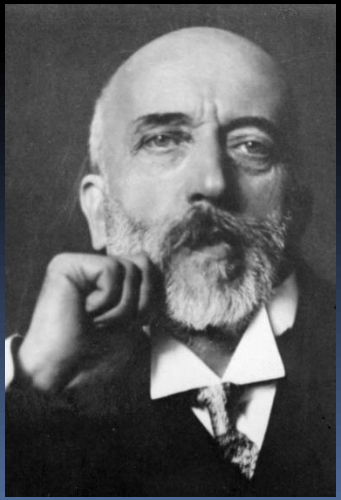


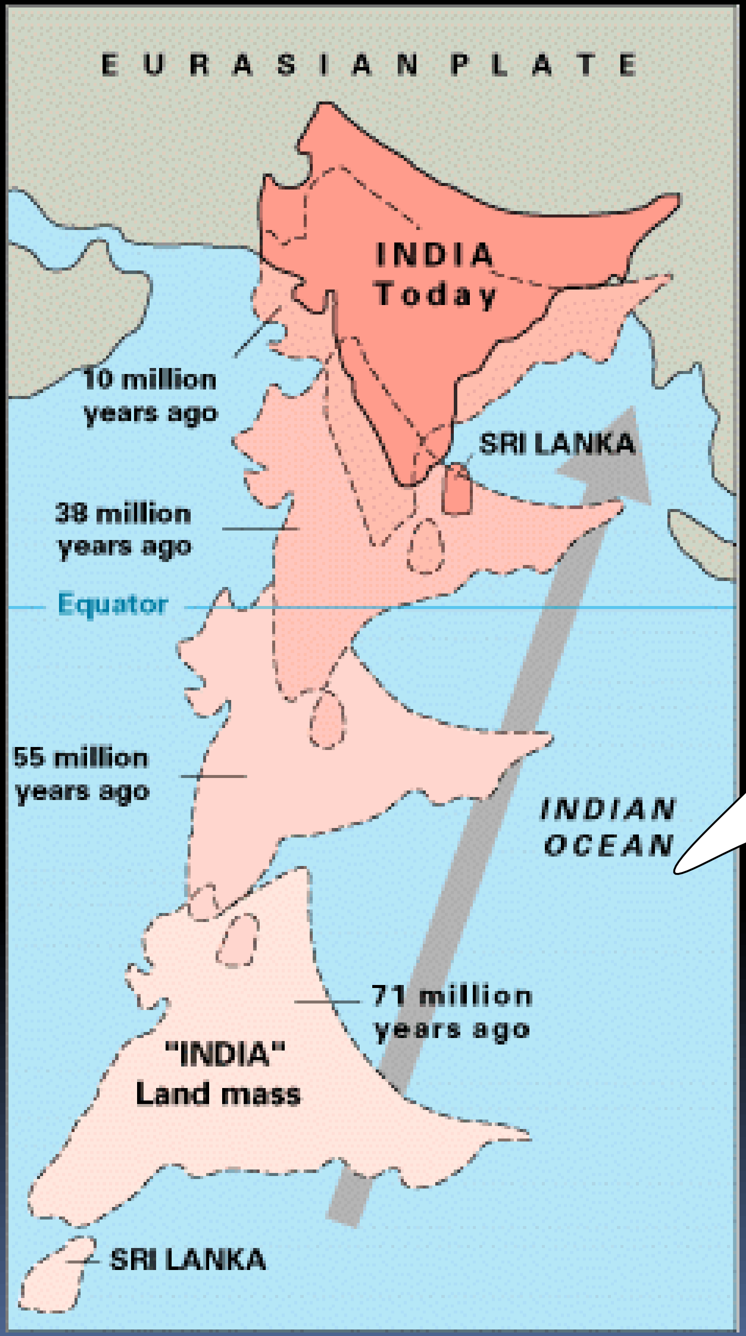
Seismic zonation and intensity map of India

Crust- lithosphere

- The crust is the most heterogeneous layer in the Earth.
- Average thickness 33 km below continents and decreases to 5 km beneath oceans.
- Oceanic crust is constituted by basaltic rocks and continental part by granitic rocks overlying basaltic rocks.
- Compared to layers below this layer has higher rigidity.
- The boundary between the crust and the mantle is mostly chemical.
- The crust and mantle have different compositions.
- This boundary is referred to as the **Mohorovičić discontinuity or "Moho"**.
- It was discovered in 1910 by the Croatian seismologist Andrija Mohorovičić.





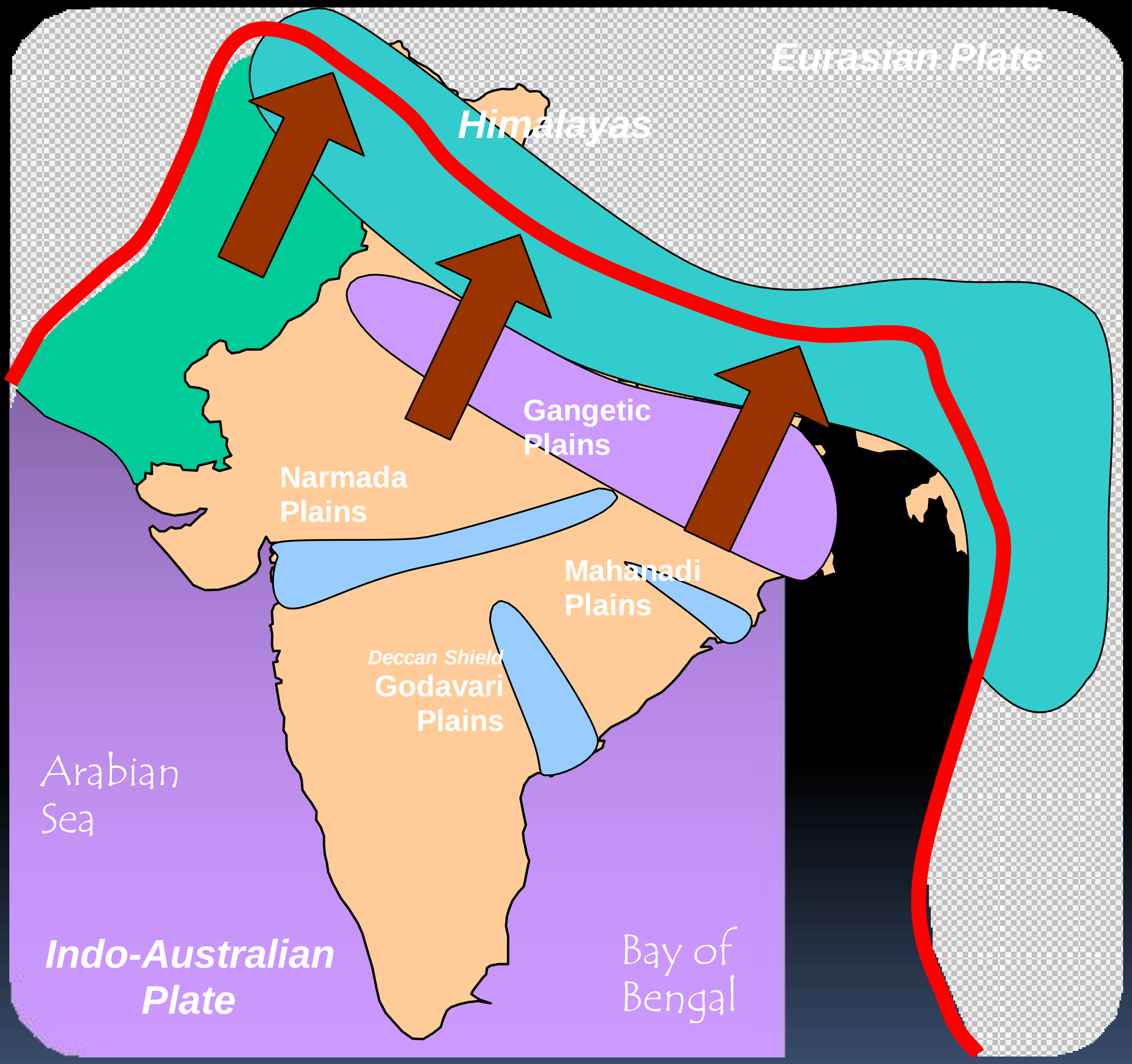


6400 km journey

>2900 km wide collision

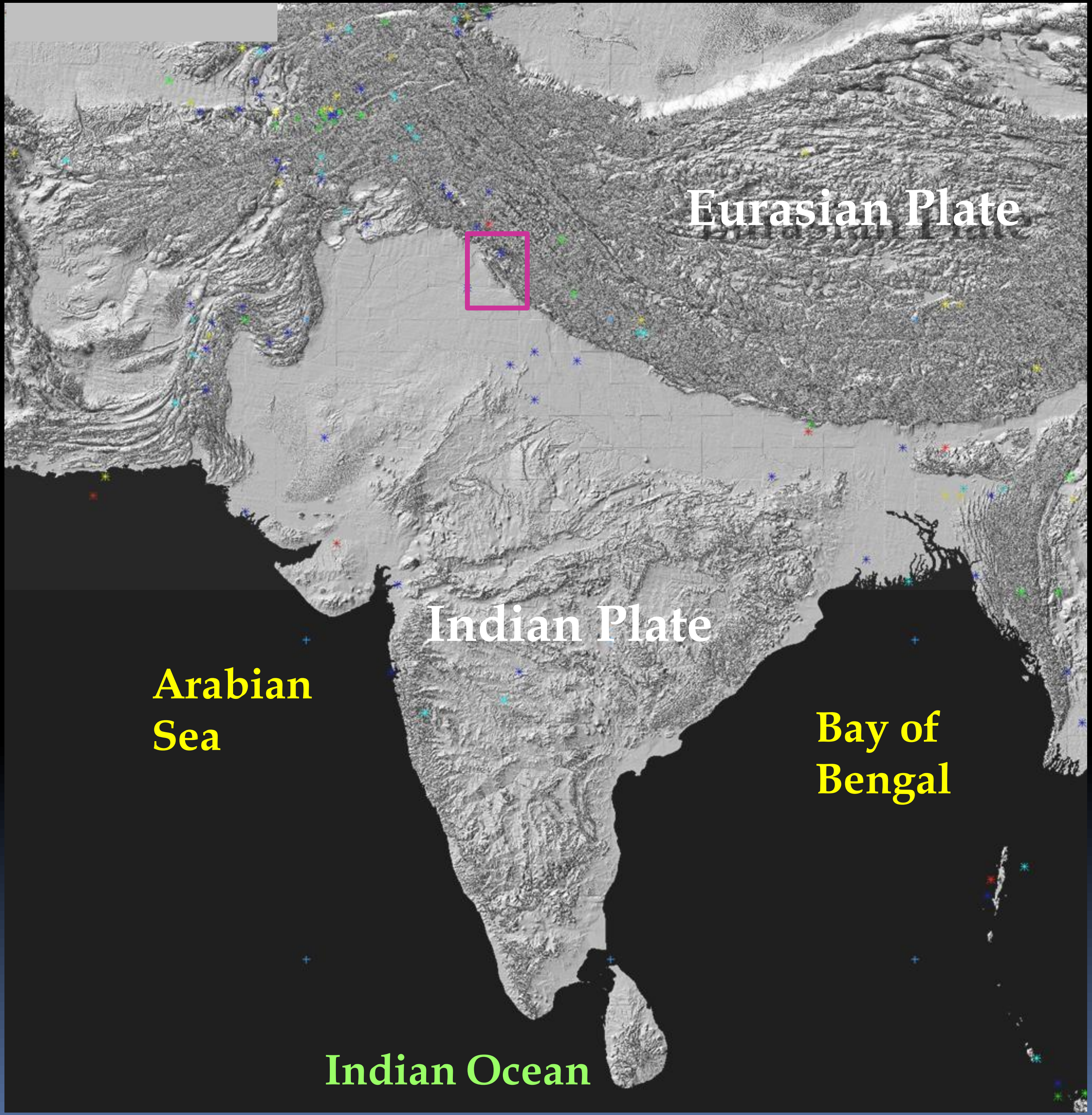
2000 km shortening

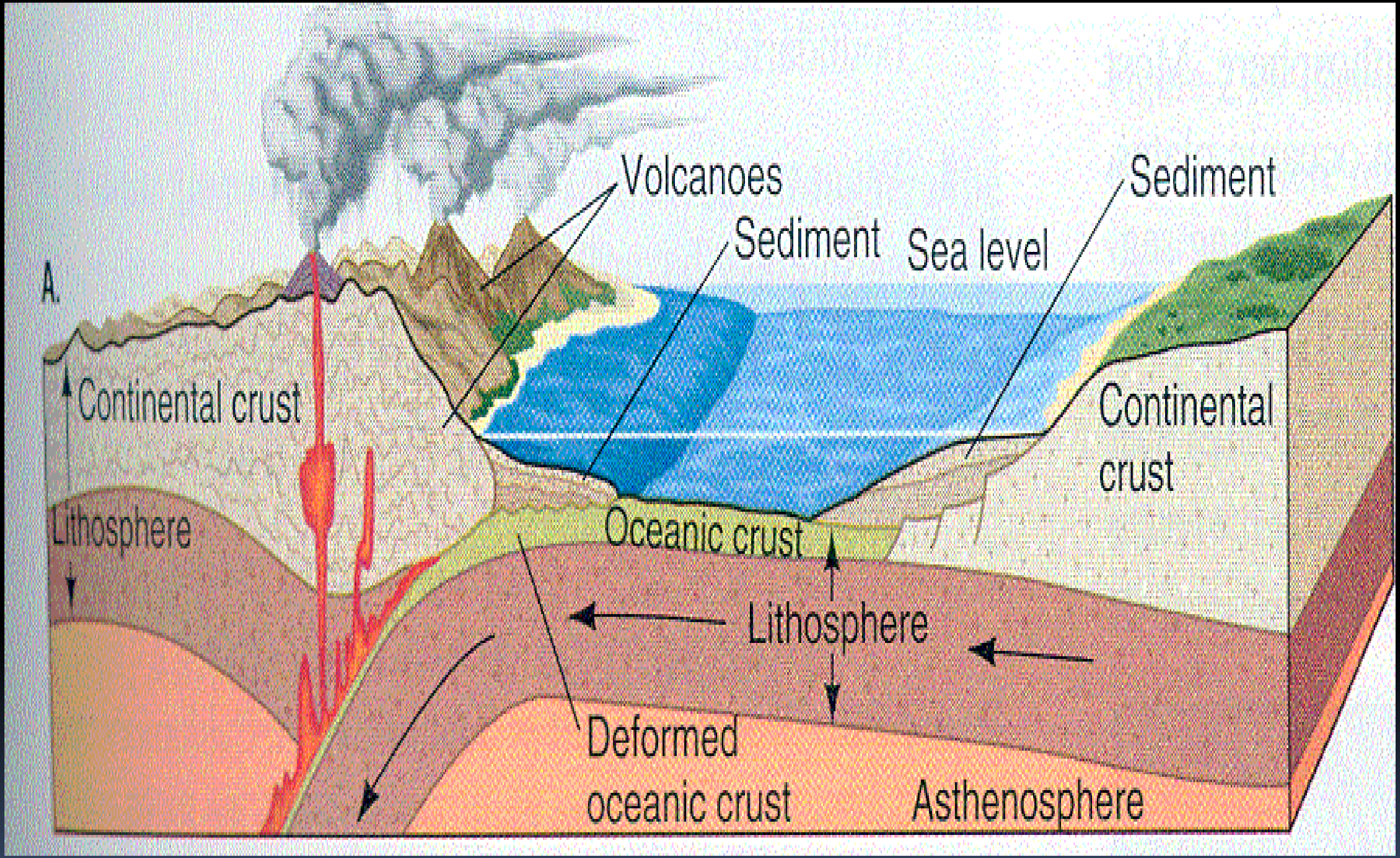
~300 km compression in the making of Himalayas itself



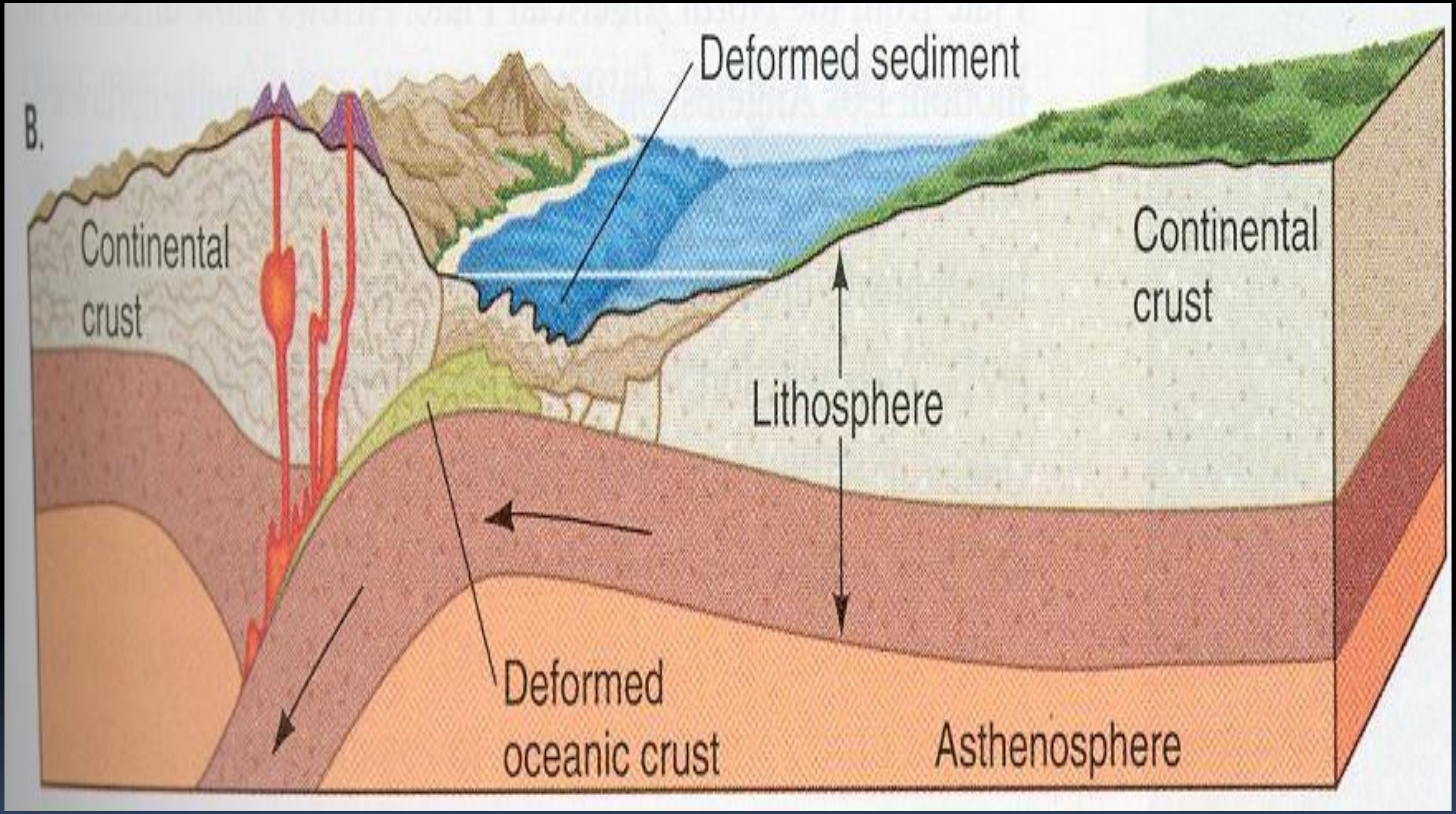
Eurasian Plate
Himalayas
Gangetic Plains
Narmada Plains
Mahanadi Plains
Deccan Shield
Godavari Plains
Arabian Sea
Indo-Australian Plate
Bay of Bengal

One of the most seismically active regions of the world

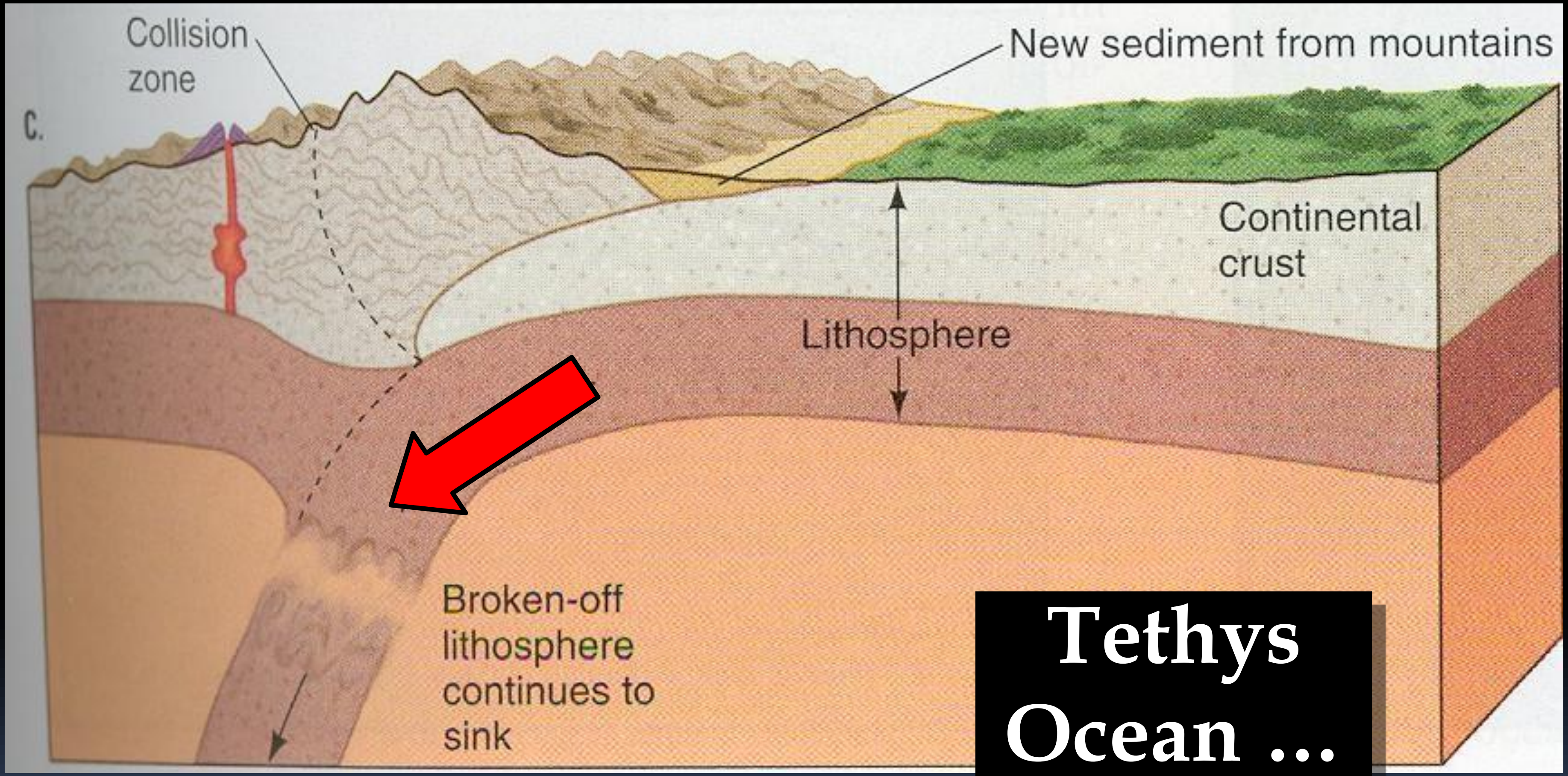




Tethys Ocean

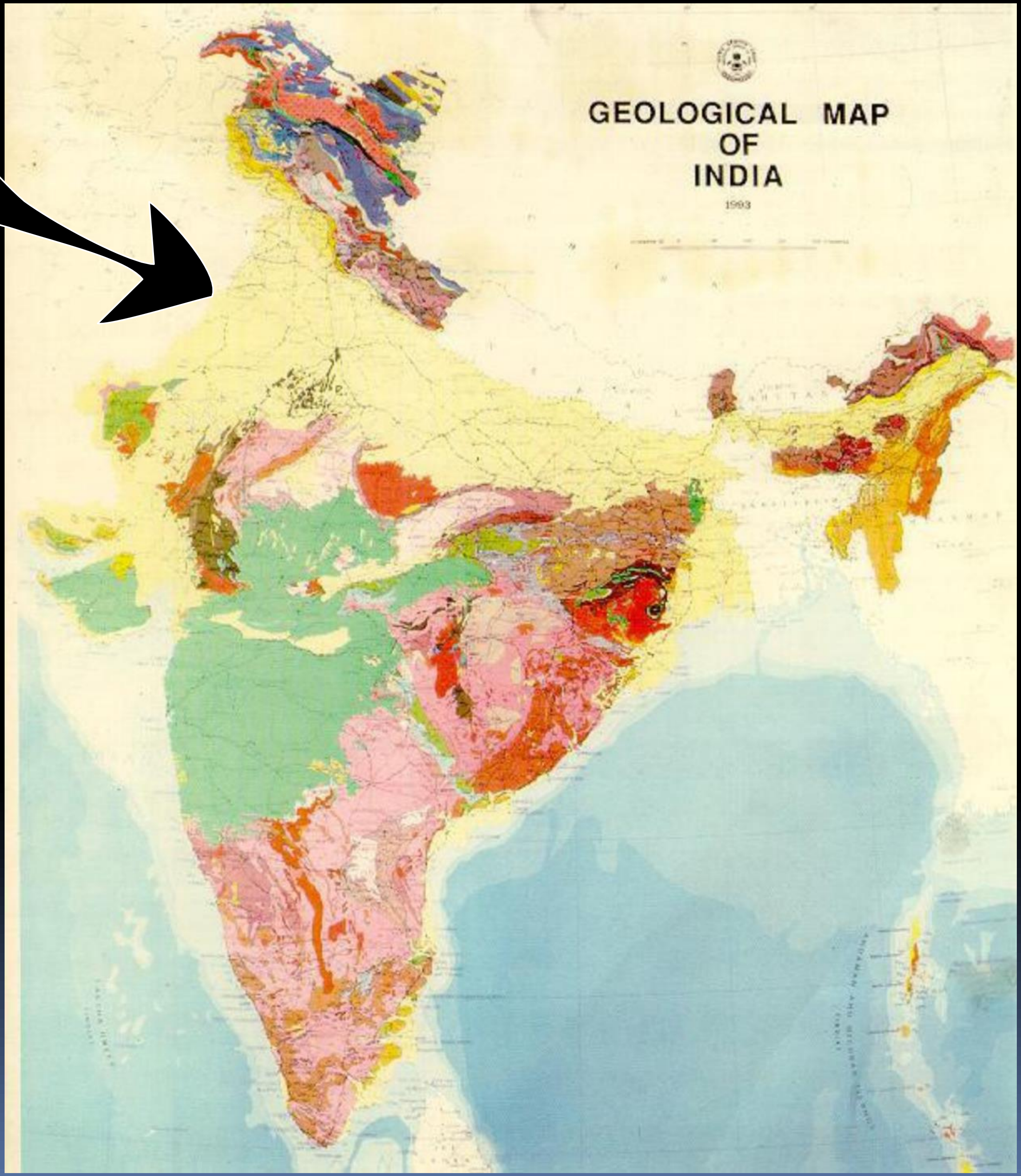


Tethys Ocean … reduced



Tethys Ocean … removed

Remains of
the Tethys Sea



Determination of Moment Magnitude

Ex: An earthquake causes an average of 2.5 m strike – slip displacement over a 70 km long, 24 km deep portion of transformed fault. Assuming the average rupture strength along the fault as 185 kPa, estimate the seismic moment and moment magnitude of the earthquake.

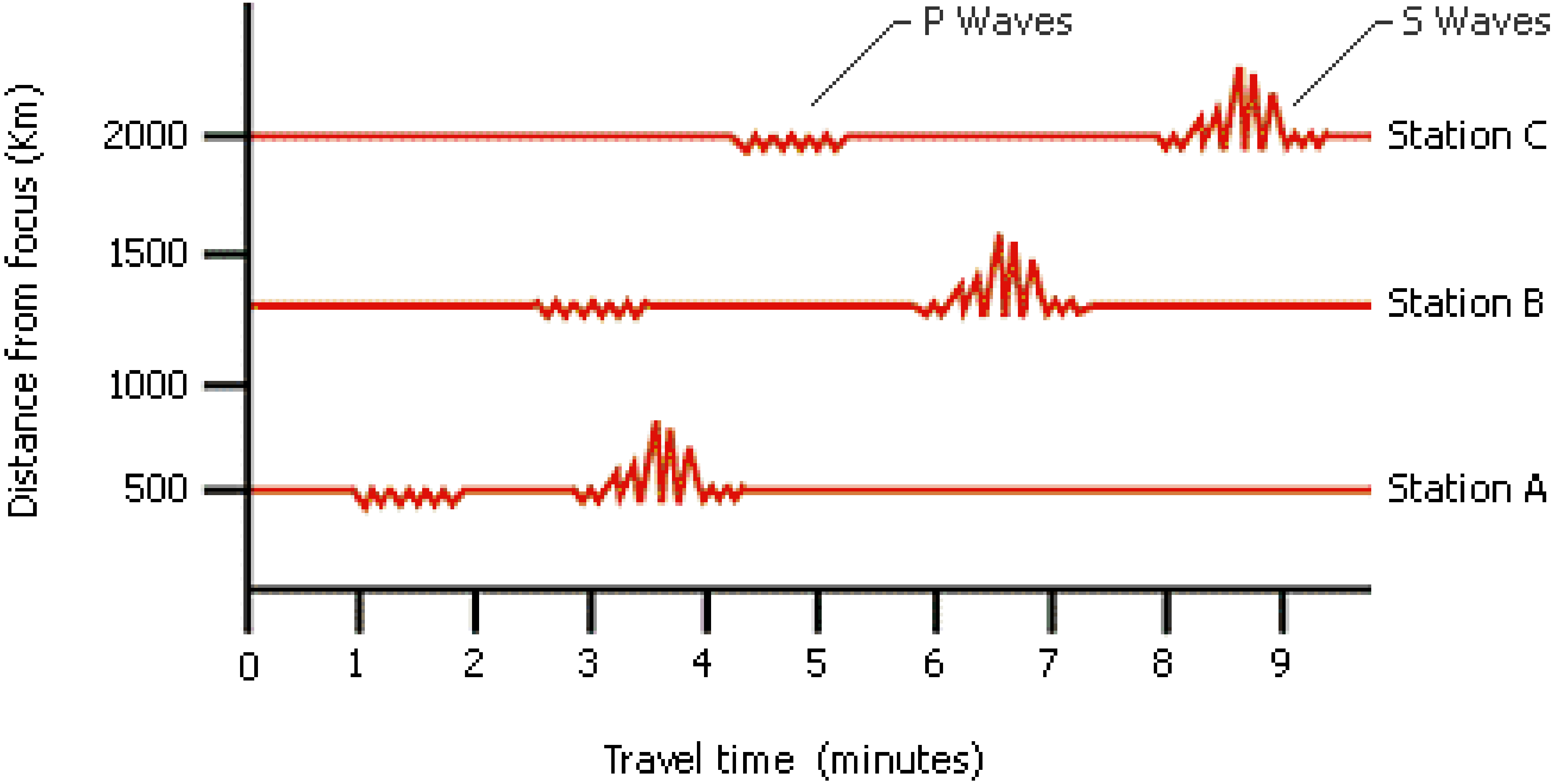
A = Area of Rupture = 70 x 24 = 1680 km^2 = 1680 x 10^{10} cm^2

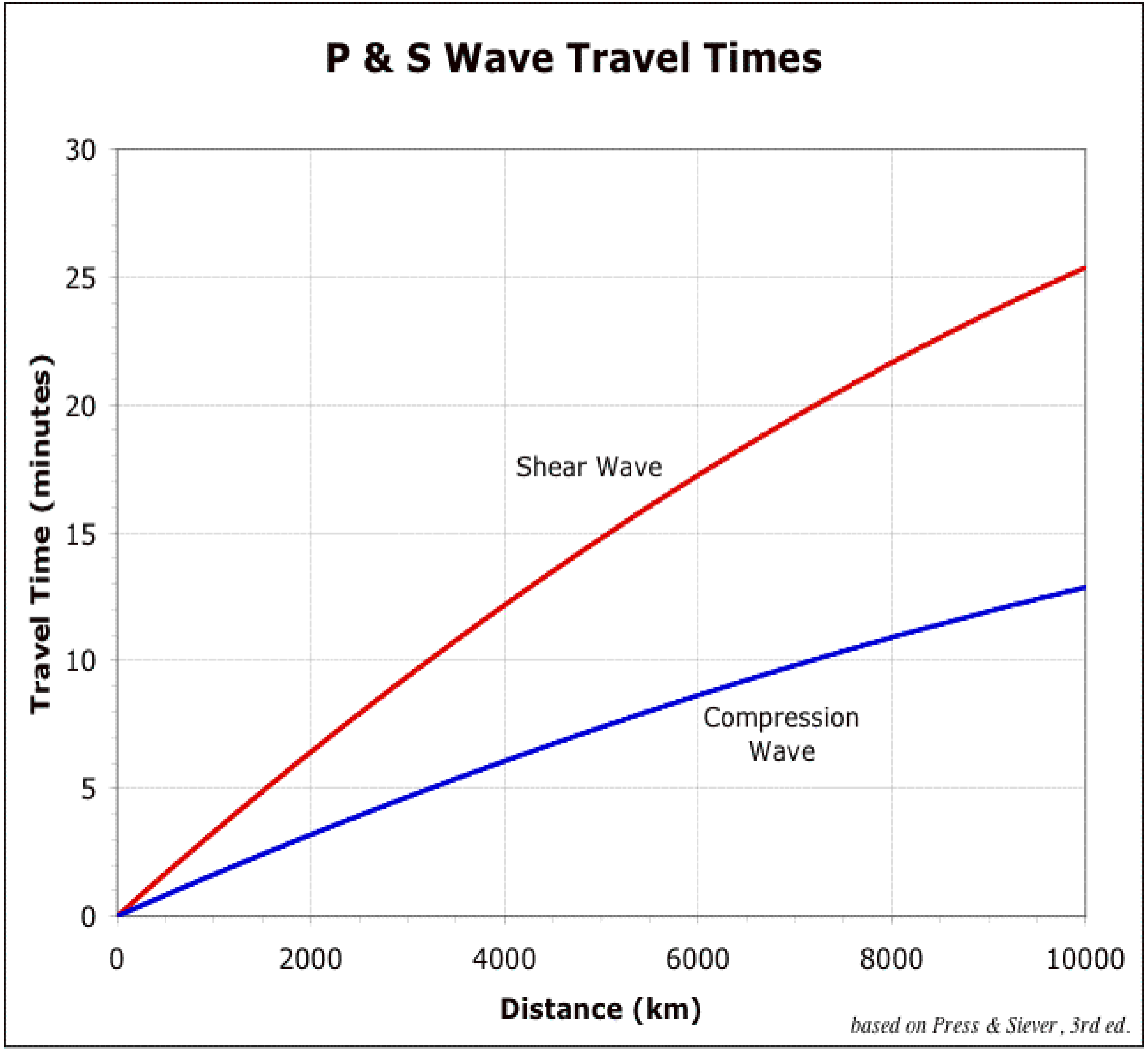
d = Displacement = 2.5 m = 250 cm

μ =Rupture strength = 185 kN/m^2 = 185 x 10^4 dyne / cm^2

Mo = Seismic Moment = μ A d = 7.77 x 10^{21} dyne-cm

Moment Magnitude, $M_W = 2/3 [\log_{10} M_o - 16] = 3.94$


P Waves
S Waves
Distance from focus (Km)
2000
1500
1000
500
Station C
Station B
Station A
0
1
2
3
4
5
6
7
8
9
Travel time (minutes)



Velocity of P wave,

$$V_p = \sqrt{\frac{(1-\mu)}{(1-2\mu)(1+\mu)}\frac{E}{\rho}}$$

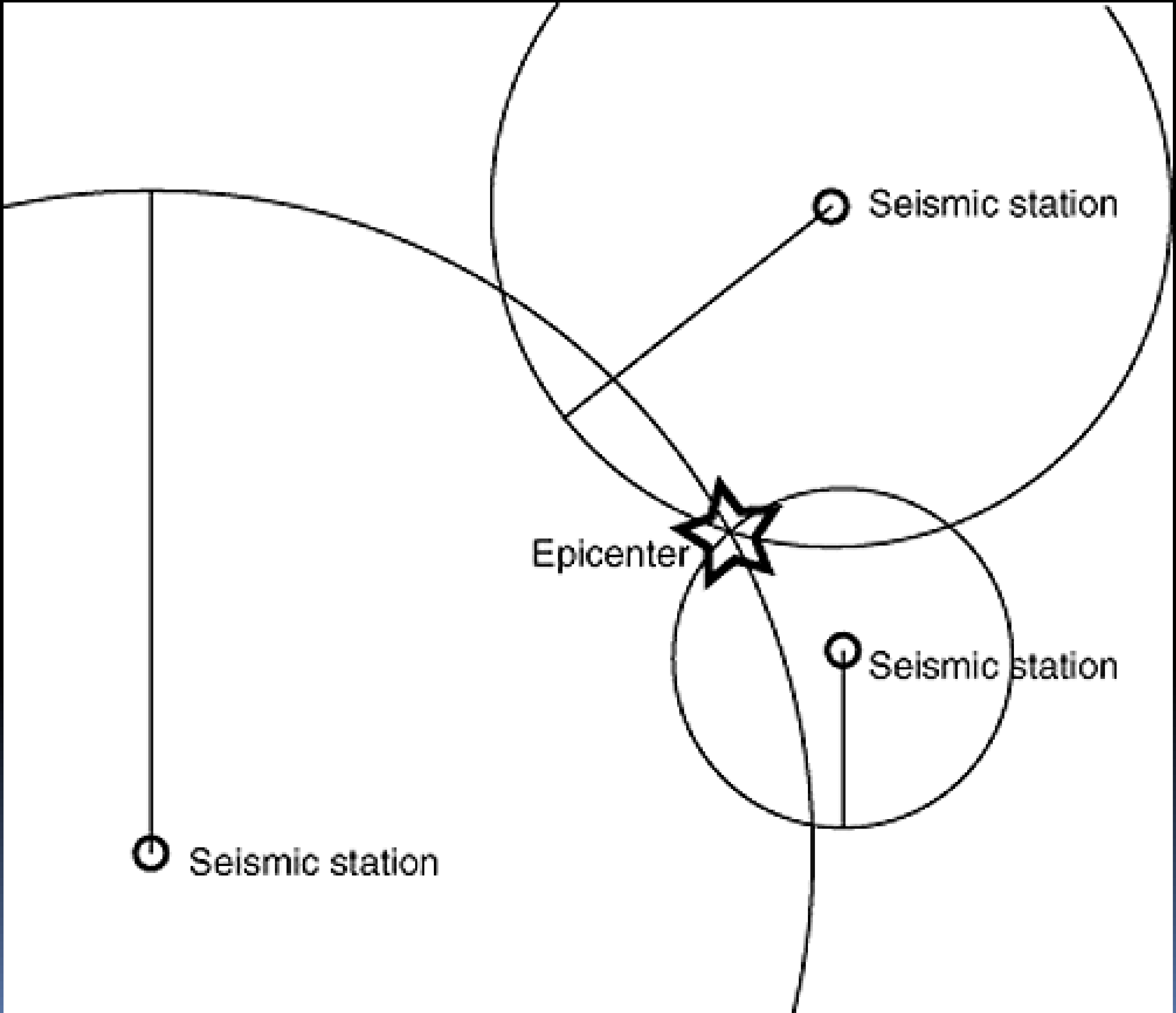
Velocity of S wave,

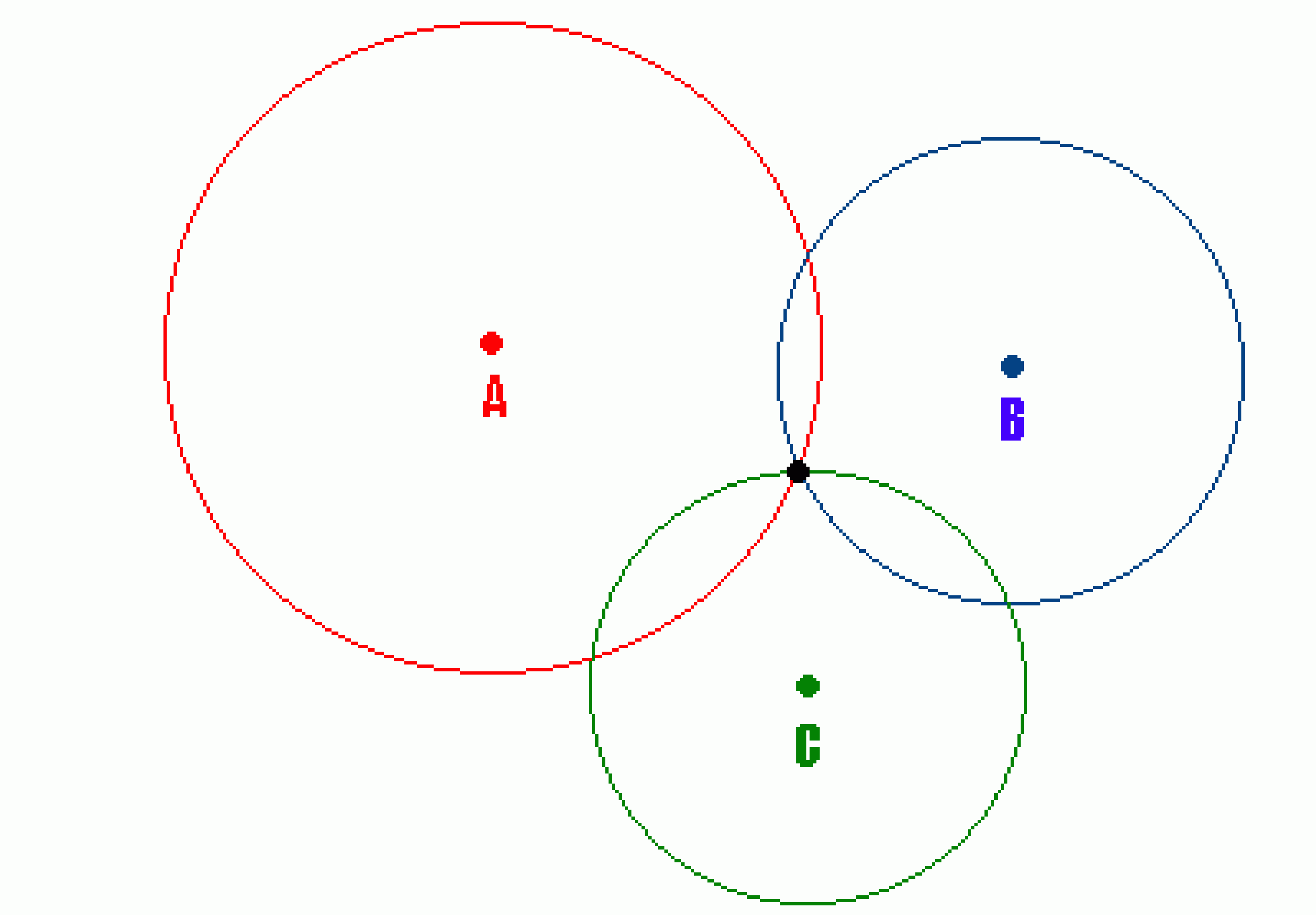
$$V_s = \sqrt{\frac{1}{(1+\mu)}\frac{E}{2\rho}} = \sqrt{\frac{G}{\rho}}$$

Where,
E = Modulus of Elasticity,
G = Shear modulus,
P = Density of strata and
μ = Poisson's ratio

RELATION BETWEEN Vp and Vs??

$V_p = \sqrt{3}\,V_s$


Seismic station
Epicenter
Seismic station
Seismic station



Earthquake epicenter requires at least 3 recording stations to localize.

Having known epicenter of earthquake.

Now we need to determine focus/hypocentre of an earthquake

So, What about depth?

For this we need Seismic phases

Earthquakes occur anywhere between earth's surface and about 700 km below the surface.

Classification of earthquakes based on depth of focus:

Shallow (0-70 km)

Intermediate (70-300 km)

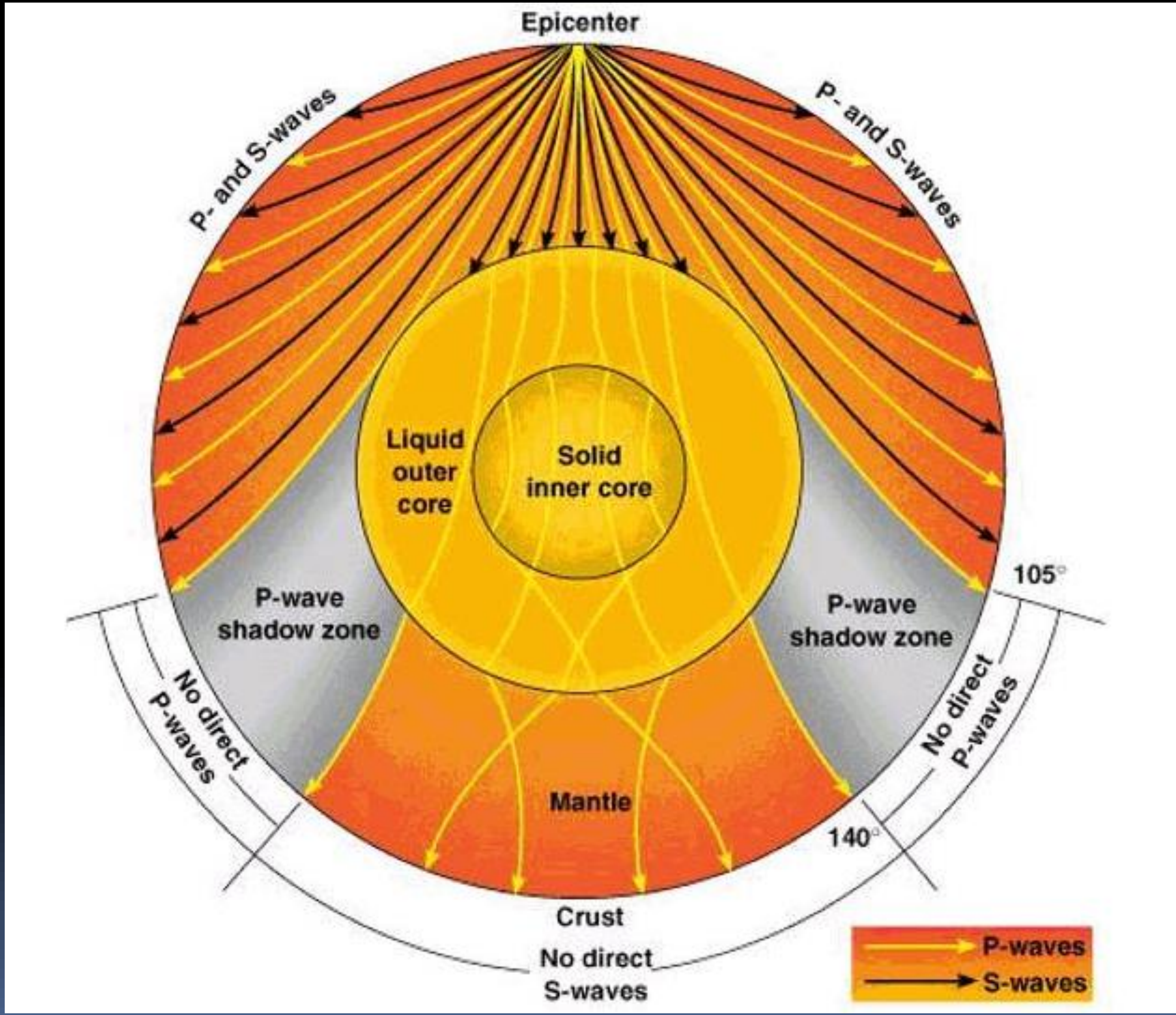
and Deep (300-700 km)

Classification of Earthquakes

- Classification of Earthquakes
  - Based on depth of Focal Depth
    - - Shallow (0 – 70 km)
    - - Intermediate (70 – 300 km)
    - - Deep (>300 km)
  - Based on Location
    - - Interplate Earthquake
    - - Intraplate Earthquake
  - Based on Epicentral Distance
    - - Local Earthquake (<1°)
    - - Regional Earthquake (1°-10°)
    - - Teleseismic Earthquake (>10°)
  - Based on Magnitude

Group	Magnitude
Great	8 and higher
Major	7-7.9
Strong	6-6.9
Moderate	5-5.9
Light	4-4.9
Minor	3-3.9
Very Minor	< 3

Earthquake Shadow Zone



BEHAVIOUR OF BRICK MASONRY STRUCTURES DURING EARTHQUAKE

Behaviour of Wall

- Masonry buildings are most vulnerable during earthquakes. (Brittle Structures)
- Wall is most vulnerable component of such buildings against earthquake. (Horizontal Forces)
- Walls offer great resistance, if pushed along its length. (Strong Direction)
- Walls topples easily, if pushed perpendicular to its length. (Weak Direction)

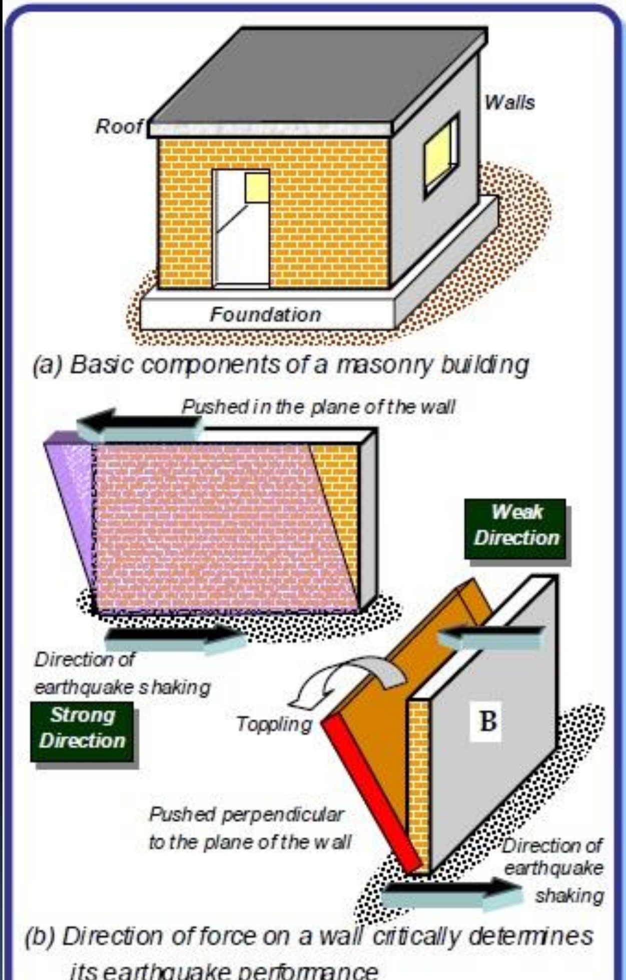


Figure 1: Basic components of a masonry building – walls are sensitive to direction of earthquake forces.

BEHAVIOUR OF BRICK MASONRY STRUCTURES DURING EARTHQUAKE

Behaviour of Wall

- Masonry buildings are most vulnerable during earthquakes. (Brittle Structures)

BASIC COMPONENTS OF A MASONRY BUILDING

- Wall is most vulnerable component of such buildings against earthquake. (Horizontal Forces)

- Walls offer great resistance, if pushed along its length. (Strong Direction)

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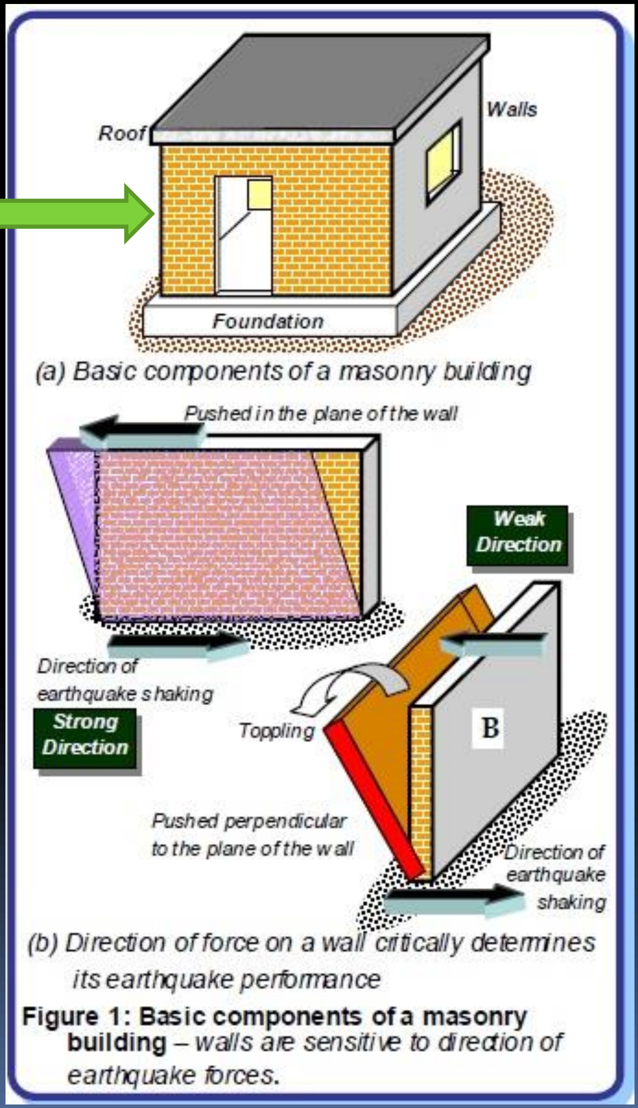
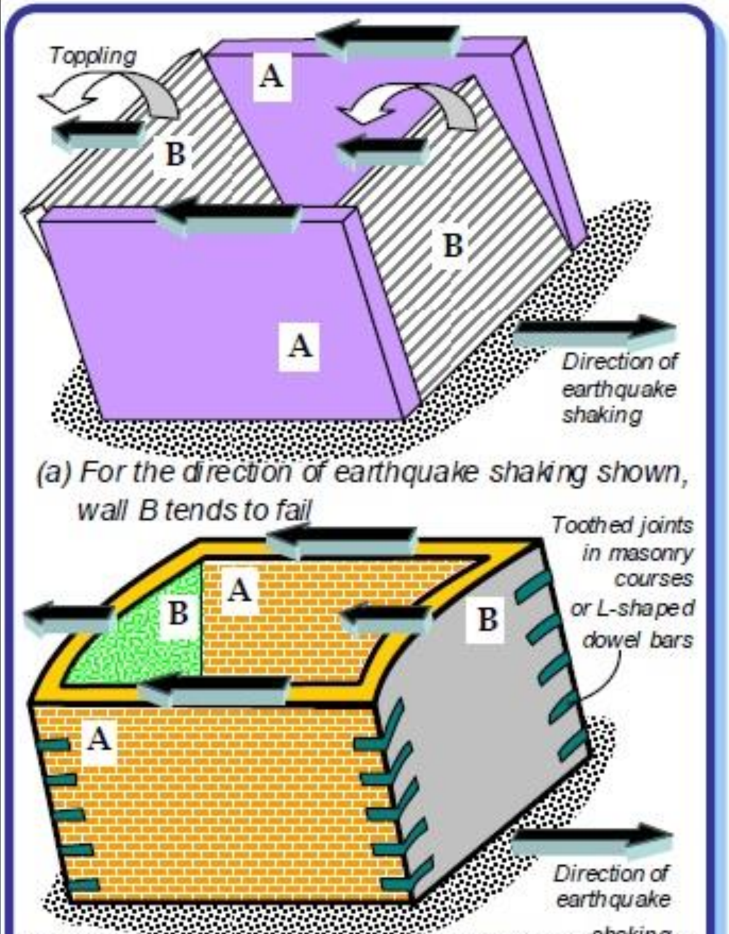


Figure 1: Basic components of a masonry building – *walls are sensitive to direction of earthquake forces.*

CONTD.....

- All walls, if joined properly to the adjacent walls gives good seismic performance.
- Walls loaded in weak direction take advantage of the good lateral resistance offered in strong direction.
- Walls need to be tied to the roof and foundation to reserve their overall integrity.



(a) For the direction of earthquake shaking shown, wall B tends to fail

(b) Wall B properly connected to Wall A (Note: roof is not shown): Walls A (loaded in strong direction) support Walls B (loaded in weak direction)

Figure 2: Advantage sharing between walls – *only possible if walls are well connected.*

- The tendency of a wall to topple when pushed in the weak direction can be reduced by limiting its length-to-thickness and height to-thickness ratios.

- Design codes specify limits for these ratios.

- A wall that is too tall or too long in comparison to its thickness, is particularly vulnerable to shaking in its weak direction

- Long wall are also susceptable to earthquake as there is large portion of wall that is not supported by cross walls.

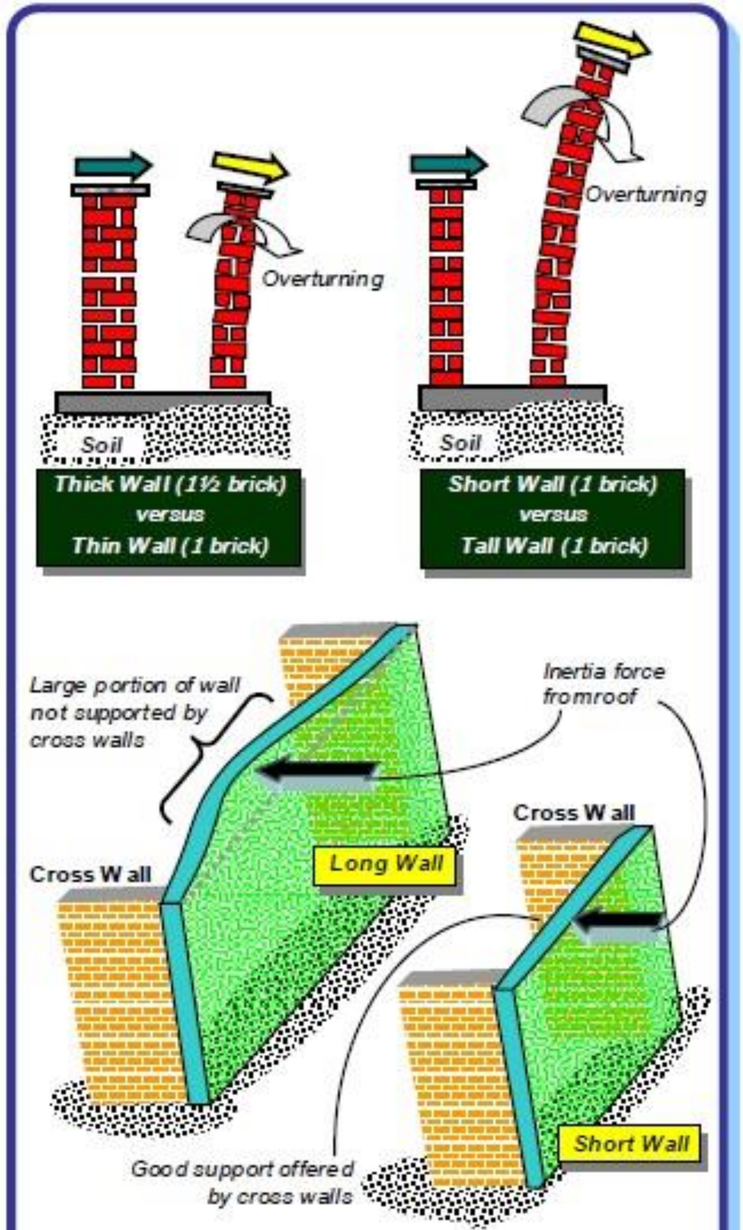


Figure 3: Slender walls are vulnerable – *height and length to be kept within limits. Note: In this figure, the effect of roof on walls is not shown.*

SIMPLE STRUCTURAL CONFIGURATION REQUIRED FOR MASONRY BUILDINGS

BOX ACTION IN MASONRY BUILDING

- Separate block can oscillate independently and even hammer each other. (If too close during Earthquake)
- Adequate gap is required between such blocks.
- Gap not necessary, if horizontal projections in the buildings are small.
- An integrally connected inclined staircase slab acts like a cross brace between floors.
- It transfers large horizontal forces at the roof and the lower level. (Area of potential damage)

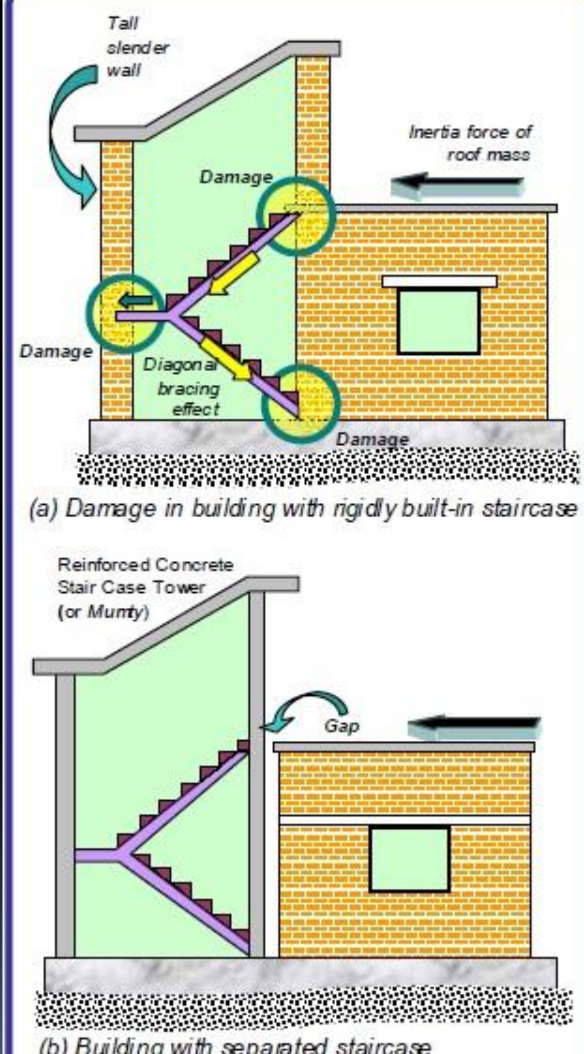


Figure 4: Earthquake-resistant detailing of staircase in masonry building – must be carefully designed and constructed.

- Box action of structure is required in case of masonry building.
- So horizontal bands are introduced in building.
- As shown in fig for given direction of earthquake A1 and A2 are stronger walls and B1 and B2 are weaker walls is earthquake direction is changed A1 and A2 becomes weaker walls and B1 and B2 becomes stronger walls.
- This shows maximum amount of earthquake force is resisted at joint of structure.
- So for any earthquake openings should be kept away from earthquake.
- If openings are provided near joints weakens the structure.

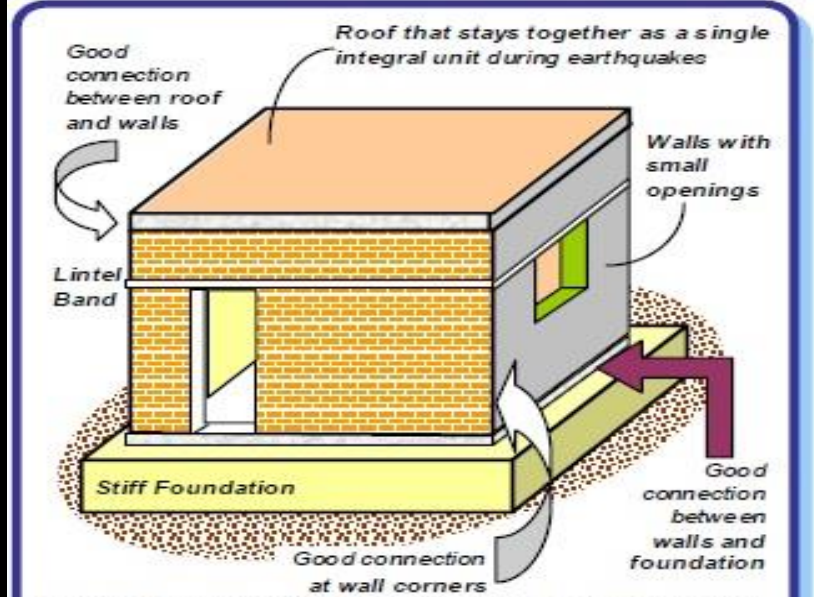


Figure 1: Essential requirements to ensure *box action* in a masonry building.

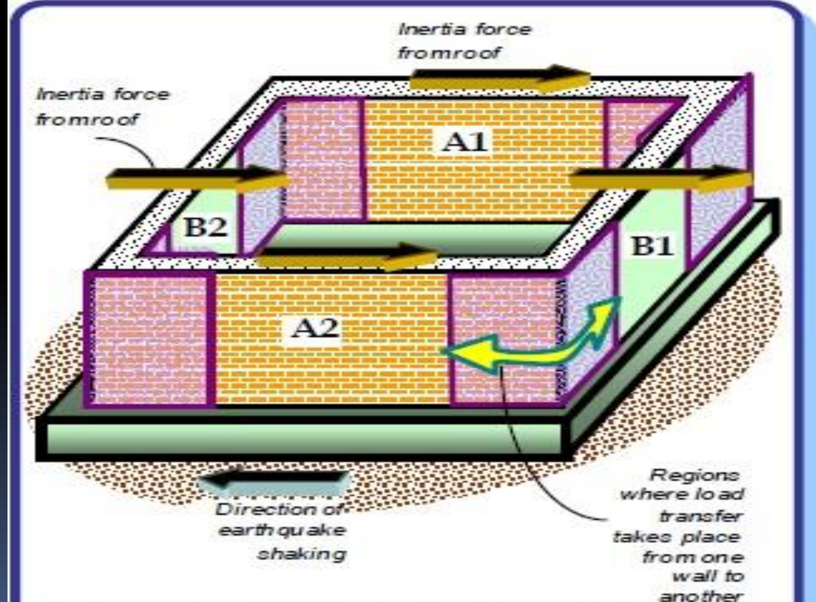


Figure 2: Regions of force transfer from weak walls to strong walls in a masonry building – *wall B1 pulls walls A1 and A2, while wall B2 pushes walls A1 and A2.*

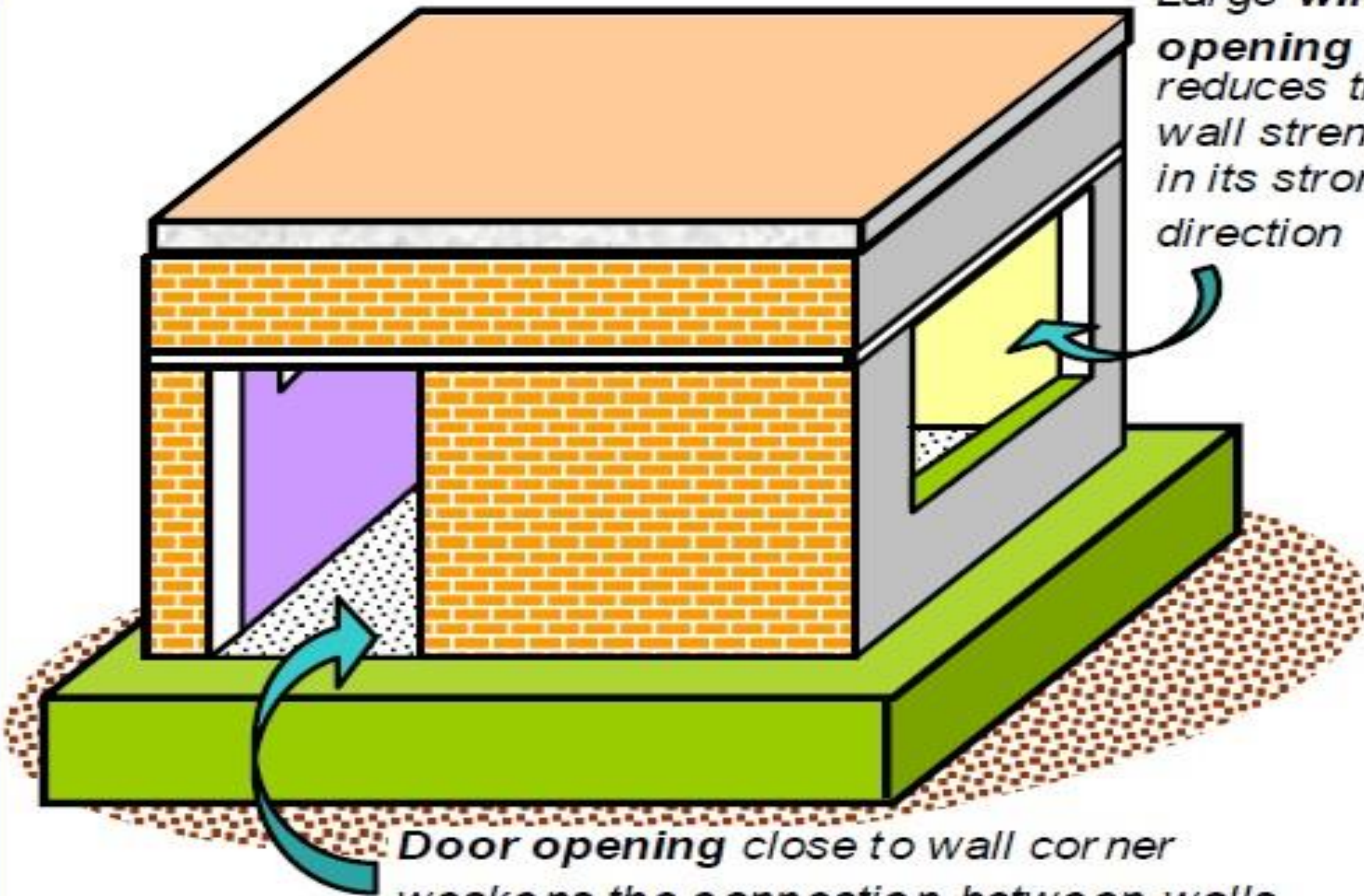


Figure 3: Openings weaken walls in a masonry building *–a single closed horizontal band must be provided above all of them.*

HORIZONTAL BANDS IN MASONRY STRUCTURE

- Main purpose of horizontal bands is to hold masonry building as a single unit by tying all walls together.
- There are four types of horizontal bands
  1. Lintel band
  2. Plinth band
  3. Roof band
  4. Gable band

LINTEL BAND

The lintel band ties the walls together and creates a support for walls loaded along weak direction from walls loaded in strong direction. This band also reduces the unsupported height of the walls and thereby improves their stability in the weak direction.

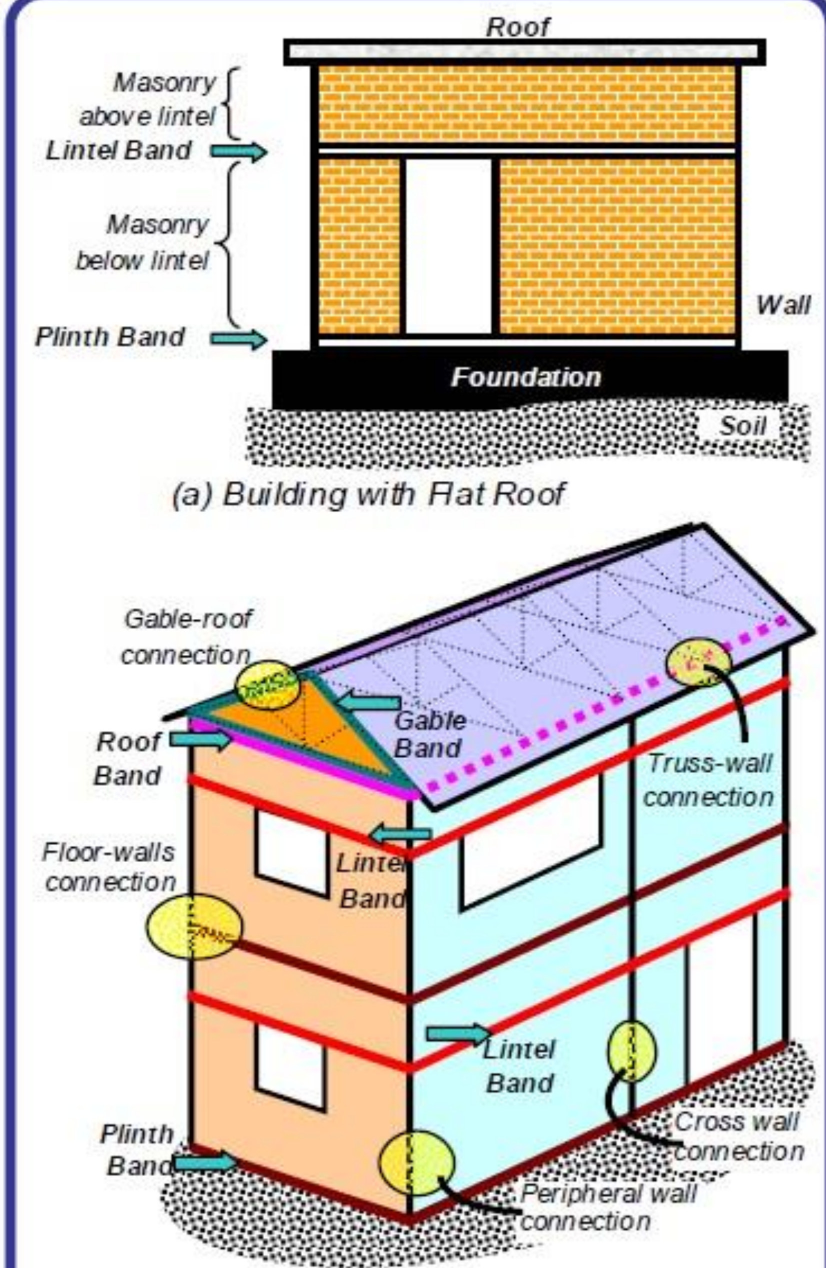


Figure 1: Horizontal Bands in masonry building – Improve earthquake-resistance.

GABLE BAND

- gable band is employed only in buildings with pitched or sloped roofs.

ROOF BAND

- In buildings with flat ***reinforced concrete*** or ***reinforced brick roofs***, the roof band is not required, because the roof slab also plays the role of a band.
- However, in buildings with flat timber or CGI sheet roof, roof band needs to be provided.
- In buildings with pitched or sloped roof, the roof band is very important.

PLINTH BAND

- Plinth bands are primarily used when there is concern about uneven settlement of foundation soil.

- Horizontal bands are provided in masonry buildings to improve their earthquake performance. These bands include **plinth band, lintel band** and **roof band.**
- Even if horizontal bands are provided, masonry buildings are weakened by the openings in their walls.
- During earthquake shaking, the masonry walls get grouped into three sub-units, namely **spandrel masonry, wall pier masonry** and **sill masonry.**

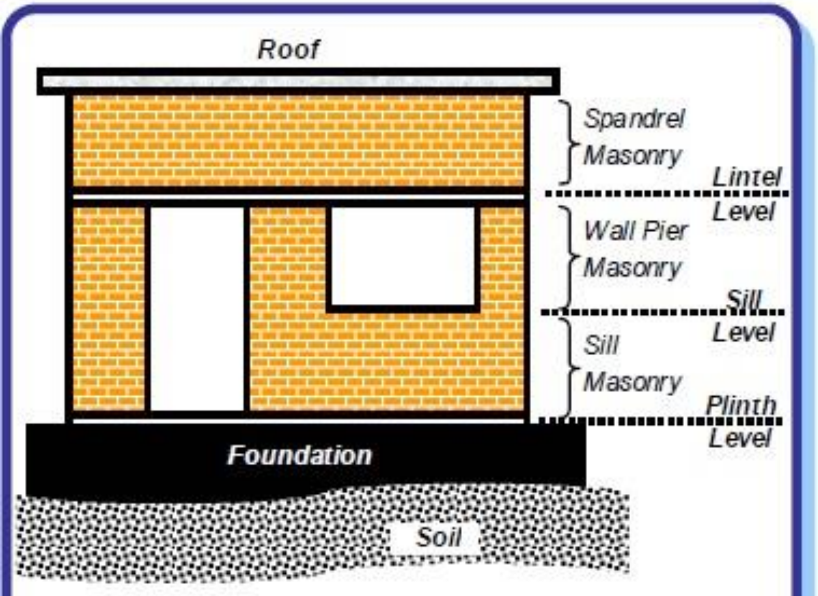


Figure 1: Sub-units in masonry building – *walls behave as discrete units during earthquakes.*

- When the ground shakes, the inertia force causes the small-sized masonry **wall piers** to disconnect from the masonry above and below.
- These masonry sub-units rock back and forth, developing contact only at the opposite diagonals . The rocking of a masonry pier can crush the masonry at the corners.
- Rocking is possible when masonry piers are slender, and when weight of the structure above is small.
- Otherwise, the piers are more likely to develop diagonal shear cracking; this is the most common failure type in masonry buildings.

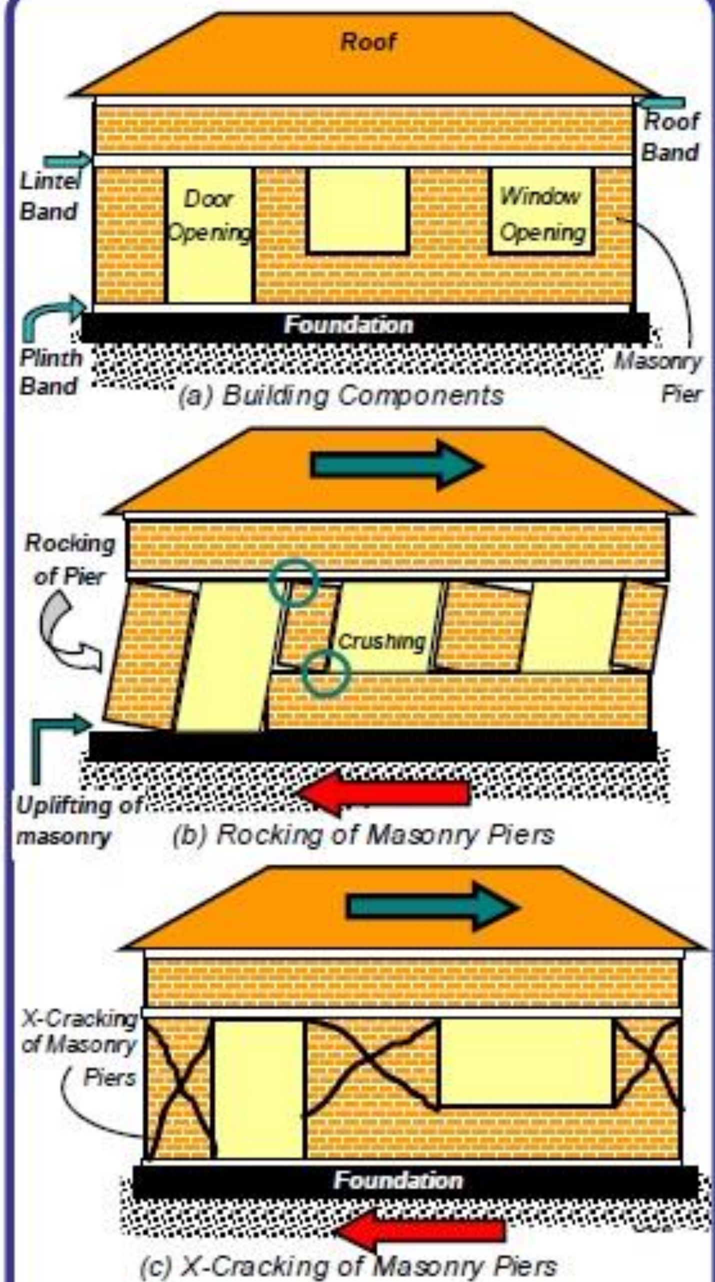


Figure 2: Earthquake response of a hipped roof masonry building – *no vertical reinforcement is provided in walls.*

- In un-reinforced masonry buildings , the cross-section area of the masonry wall reduces at the opening.

- During strong earthquake shaking, the building may **slide** just under the roof, below the lintel band or at the sill level.

- Sometimes, the building may also slide at the plinth level.

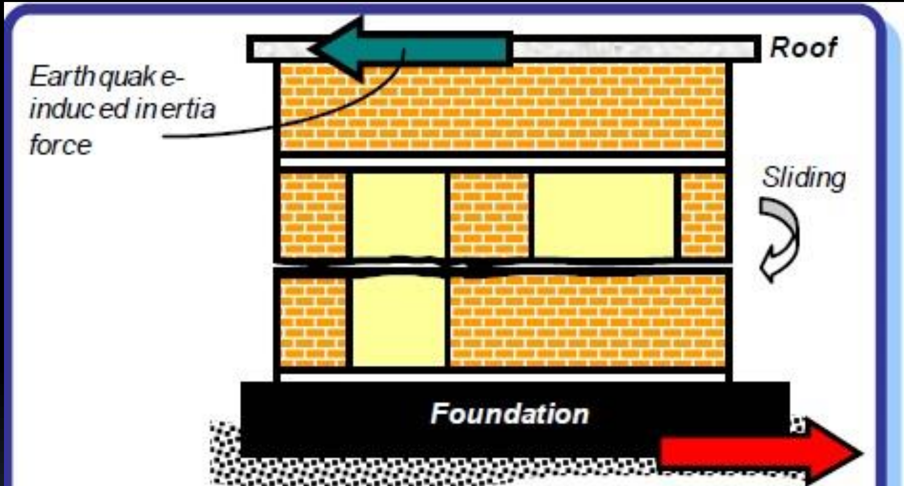


Figure 3: Horizontal sliding at sill level in a masonry building – *no vertical reinforcement.*

- The exact location of sliding depends on numerous factors including building weight, the earthquake-induced inertia force, the area of openings, and type of doorframes used.

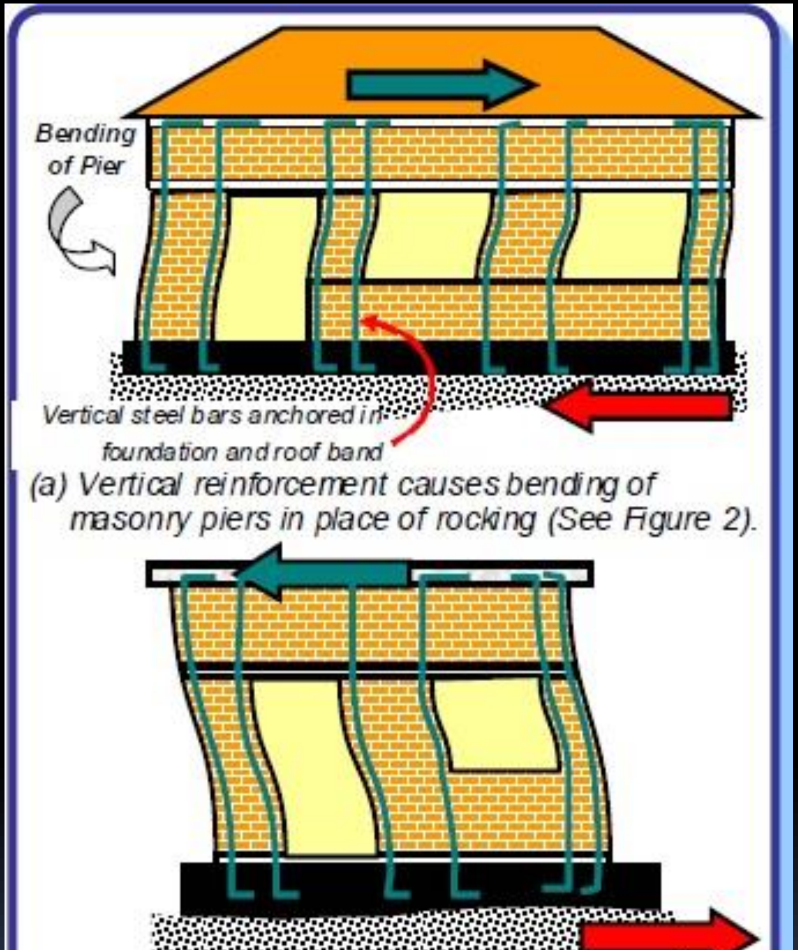
VERTICAL REINFORCEMENT

- Embedding vertical reinforcement bars in the edges of the wall piers and anchoring them in the foundation at the bottom and in the roof band at the top, forces the slender masonry piers to undergo **bending** instead of **rocking.**

- In wider wall piers, the vertical bars enhance their capability to resist horizontal earthquake forces and delay the X-cracking.

- Adequate cross-sectional area of these vertical bars prevents the bar from yielding in tension.

- Further, the vertical bars also help protect the wall from sliding as well as from collapsing in the weak direction.



(a) Vertical reinforcement causes bending of masonry piers in place of rocking (See Figure 2).

(b) Vertical reinforcement prevents sliding in walls (See Figure 3).

Figure 4: Vertical reinforcement in masonry walls – *wall behaviour is modified.*

- The most common damage, observed after an earthquake, is diagonal X-cracking of wall piers, and also inclined cracks at the corners of door and window openings.
- When a wall with an opening deforms during earthquake shaking, the shape of the opening distorts and becomes more like a **rhombus** - **two opposite corners move away and the other two come closer.**
- Under this type of deformation, the corners that come closer develop cracks.
- The cracks are bigger when the opening sizes are larger.
- Steel bars provided in the wall masonry all around the openings restrict these cracks at the corners. In summary, lintel and sill bands above and below openings, and vertical reinforcement adjacent to vertical edges, provide protection against this type of damage.

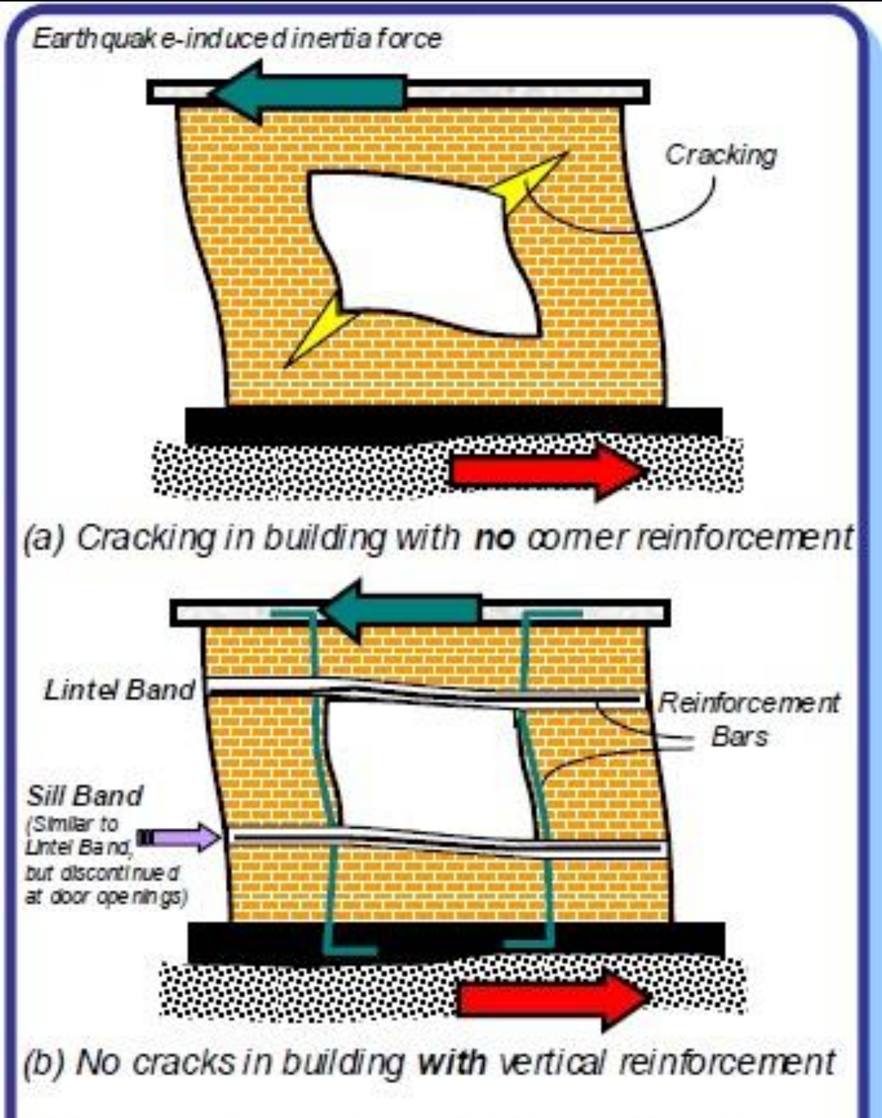


Figure 5: Cracks at corners of openings in a masonry building – *reinforcement around them helps.*

- Bands can be made of wood (including bamboo splits) or of reinforced concrete(RC); the RC bands are the best.
- The straight lengths of the band must be properly connected at the wall corners.
- This will allow the band to support walls loaded in their weak direction by walls loaded in their strong direction.
- Small lengths of wood spacers (in wooden bands) or steel links (in RC bands) are used to make the straight lengths of wood runners or steel bars act together.
- In wooden bands, proper nailing of straight lengths with spacers is important.
- Likewise, in RC bands, adequate anchoring of steel links with steel bars is necessary.

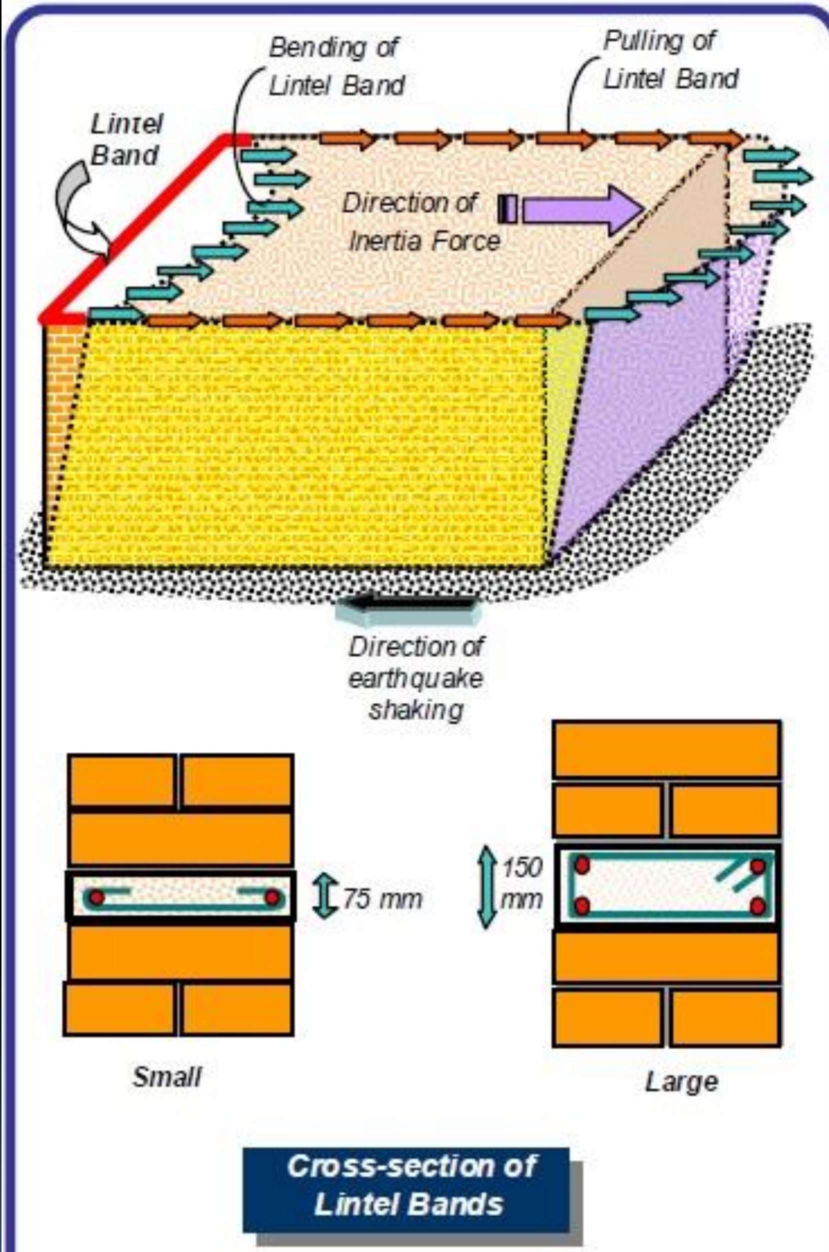


Figure 3: Bending and pulling in lintel bands – *Bands must be capable of resisting these.*

- The Indian Standards IS:4326-1993 and IS:13828 (1993) provide sizes and details of the bands.
- When wooden bands are used, the cross-section of **runners** is to be at least 75mm x 38mm and of **spacers** at least 50mm x 30mm.
- When RC bands are used, the minimum thickness is 75mm, and at least two bars of 8mm diameter are required, tied across with steel links of at least 6mm diameter at a spacing of 150mm centers.

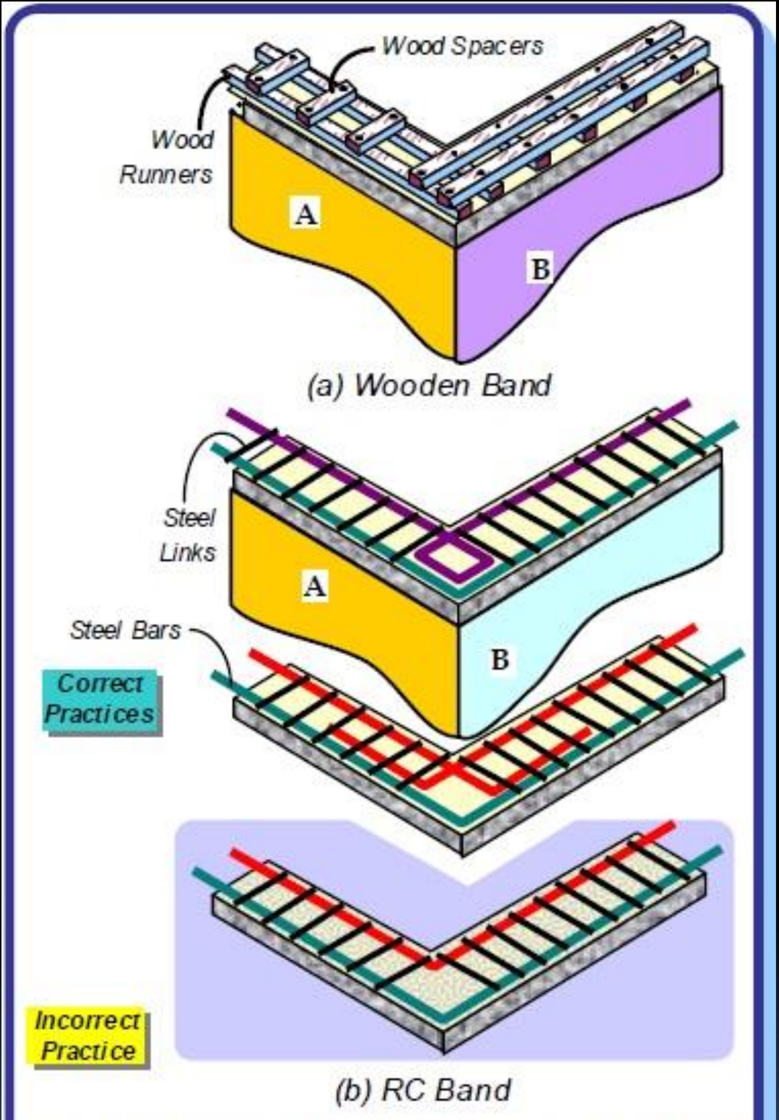


Figure 4: Horizontal Bands in masonry buildings – *RC bands are the best.*

Inertia Forces in Structures

- Earthquake causes shaking of the ground. So a building resting on it will experience motion at its base.

- From **Newton's First Law of Motion**, even though the base of the building moves with the ground, the roof has a tendency to stay in its original position.

- But since the walls and columns are connected to it, they drag the roof along with them.

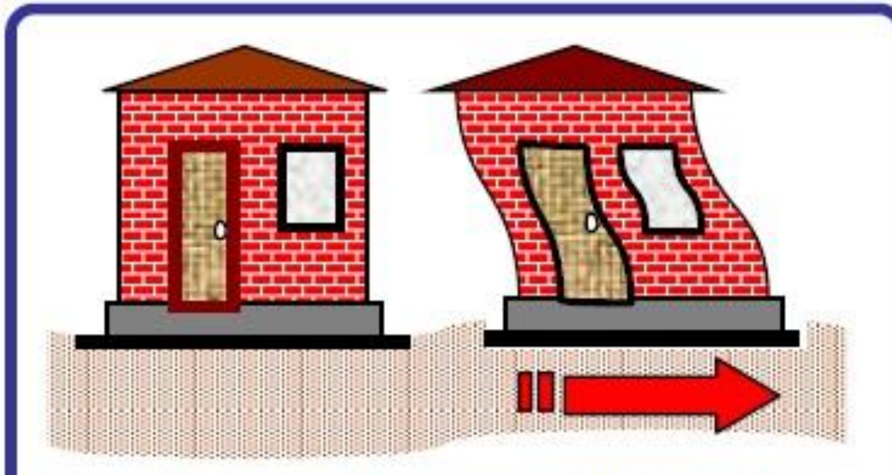


Figure 1: Effect of Inertia in a building when shaken at its base

- This tendency to continue to remain in the previous position is known as **Inertia.**

- In the building, since the walls or columns are flexible, the motion of the roof is different from that of the ground

- The inertia force experienced by the roof is transferred to the ground via the columns, causing forces in columns.

- During earthquake shaking, the columns undergo relative movement between their ends.

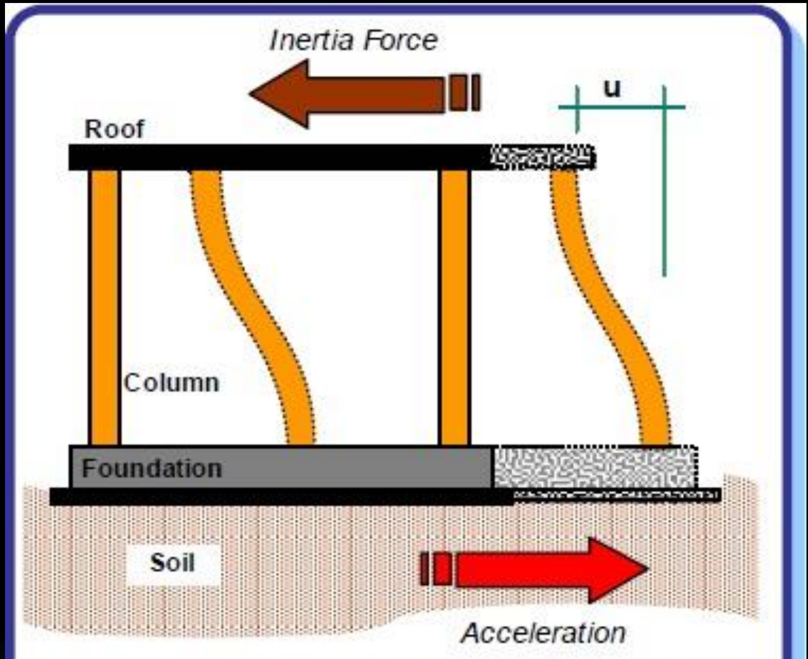


Figure 2: Inertia force and relative motion within a building

- The inertia force experienced by the roof is transferred to the ground via the columns, causing forces in columns.
- During earthquake shaking, the columns undergo relative movement between their ends this movement is shown as quantity u between the roof and the ground.
- The larger is the relative horizontal displacement u between the top and bottom of the column, the larger this internal force in columns.
- Also, the stiffer the columns are **(i.e.** bigger is the column size), larger is this force.
- For this reason, these internal forces in the columns are called **stiffness forces.**

- Earthquake causes shaking of the ground in all three directions - along the two horizontal directions (X **and Y, say),** and the vertical direction (Z, **say).**

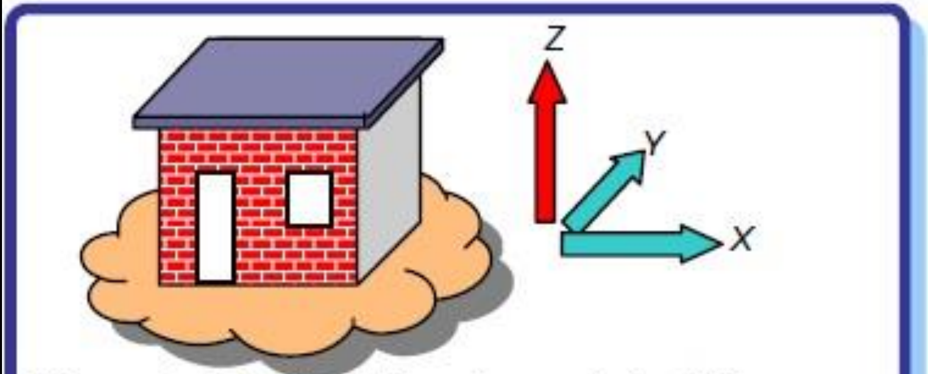


Figure 3: Principal directions of a building

- All structures are primarily designed to carry the gravity loads.

- Since factors of safety are used in the design of structures to resist the gravity loads, usually most structures tend to be adequate against vertical shaking.

- However, horizontal shaking along X and Y directions (both + and - directions of each) remains a concern. Structures designed for gravity loads, in general, may not be able to safely sustain the effects of horizontal earthquake shaking.

- Hence, it is necessary to ensure adequacy of the structures against horizontal earthquake effects.

Adjacency of Buildings

- When two buildings are too close to each other, they may pound on each other during strong shaking.

- With increase in building height, this collision can be a greater problem.

- When building heights do not match , the roof of the shorter building may pound at the mid-height of the column of the taller one; this can be very dangerous.

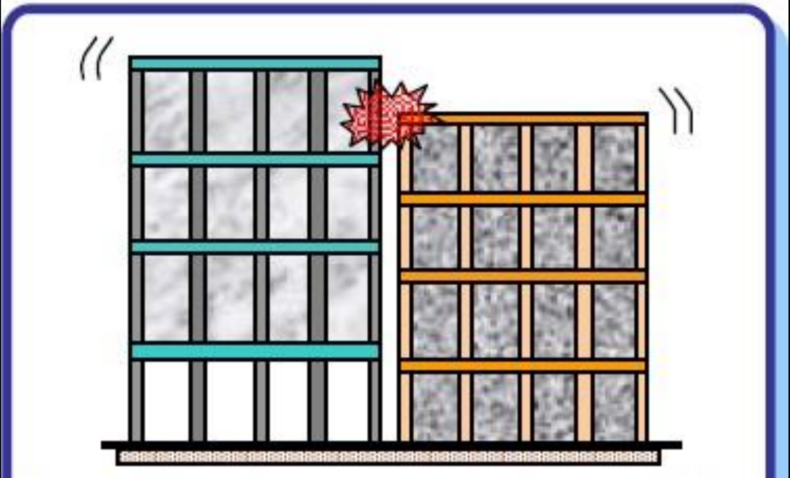


Figure 4: Pounding can occur between adjoining buildings due to horizontal vibrations of the two buildings.

- In case of masonry structure bricks are good in case of compressive load but can hardly take tensile load.
- Concrete is also used widely. It also has greater compressive strength but less amount of tensile strength
- Steel is used in masonry and concrete buildings as reinforcement bars of diameter ranging from 6mm to 40mm.
- Reinforcing steel can carry both tensile and compressive loads. Moreover, steel is a **ductile material.**
- This important property of ductility enables steel bars to undergo large elongation before breaking.

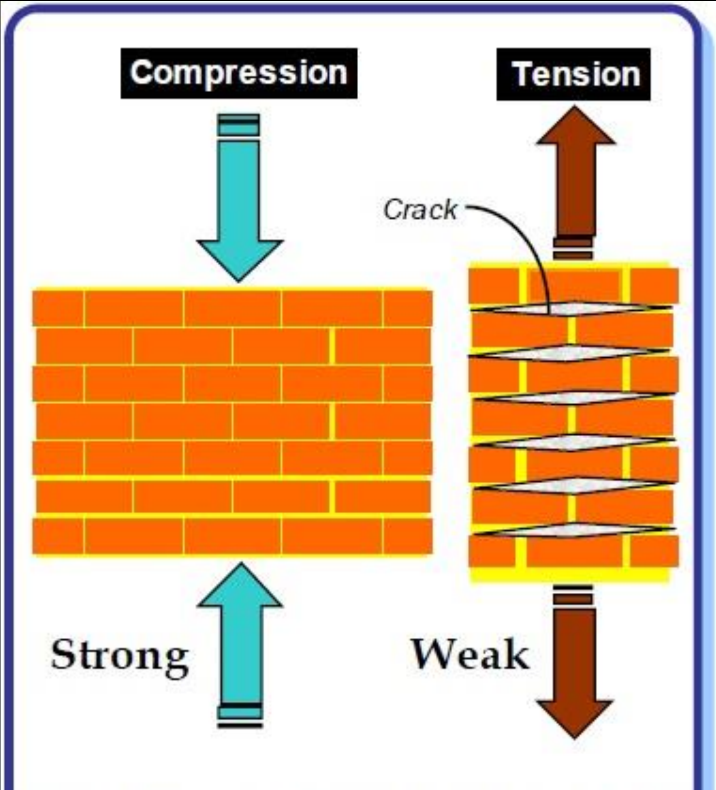


Figure 1: Masonry is strong in compression but weak in tension.

- Concrete is used in buildings along with steel reinforcement bars. This composite material is called **reinforced cement concrete (RCC)** or simply **reinforced concrete (RC).**

- The amount and location of steel in a member should be such that the failure of the member is by steel reaching its strength in tension before concrete reaches its strength in compression.

- This type of failure is **ductile failure,** and hence is preferred over a failure where concrete fails first in compression. Therefore, contrary to common thinking, providing too much steel in RC buildings can be harmful even!!

- Let us take two bars of same length and cross sectional area - one made of a ductile material and another of a brittle material. Now, pull these two bars until they break!!

- You will notice that the ductile bar elongates by a large amount before it breaks, while the brittle bar breaks suddenly on reaching its maximum strength at a relatively small elongation .

- Amongst the materials used in building construction, steel is **ductile,** while masonry and concrete are **brittle.**

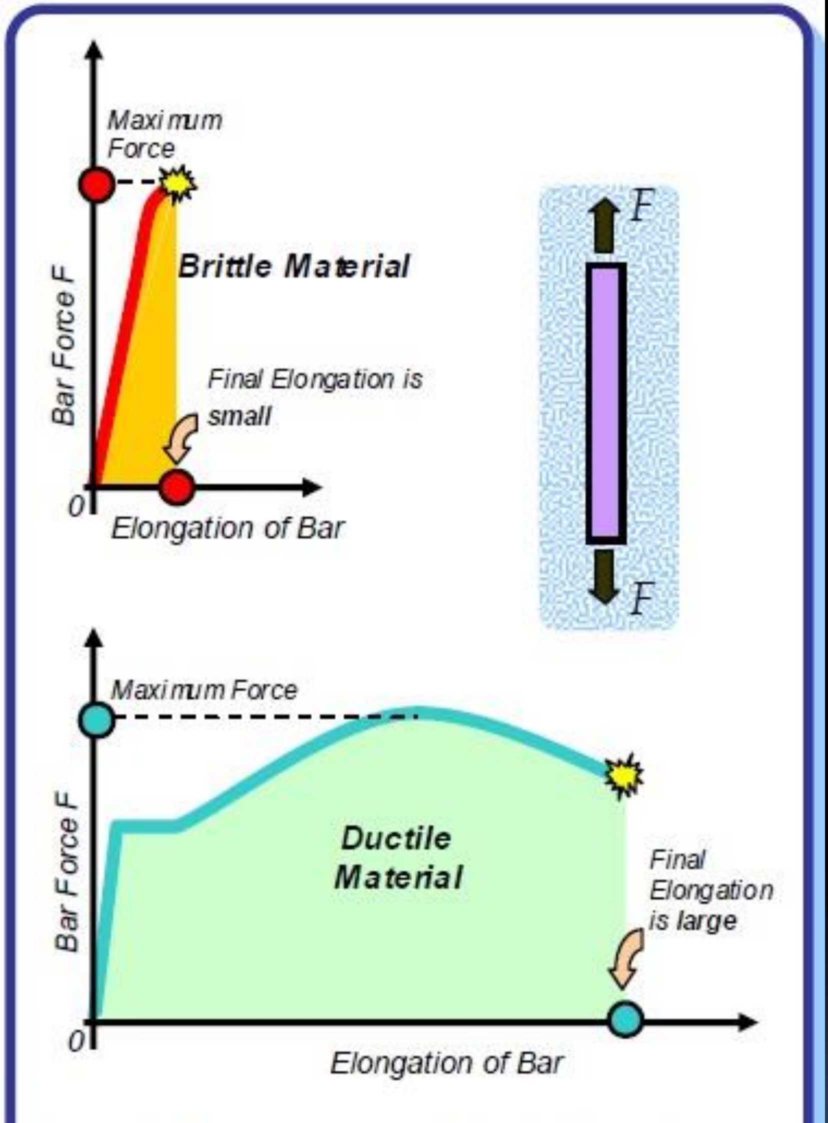


Figure 2: Tension Test on Materials – *ductile versus brittle materials.*

Capacity Design Concept

- Now, let us make a chain with links made of **brittle** and **ductile** materials.

- Now, hold the last link at either end of the chain and apply a force F.

- Since the same force F is being transferred through all the links, the force in each link is the same, **i.e.,** F.

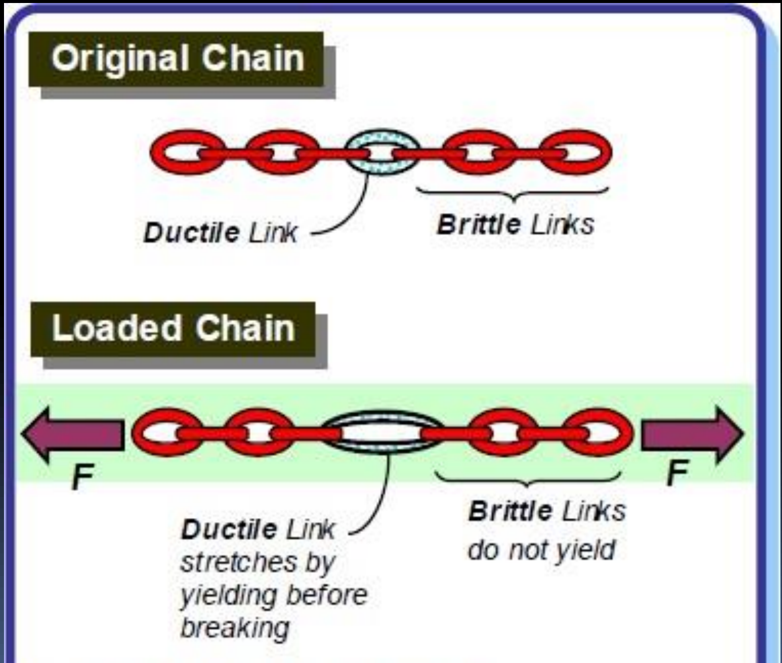
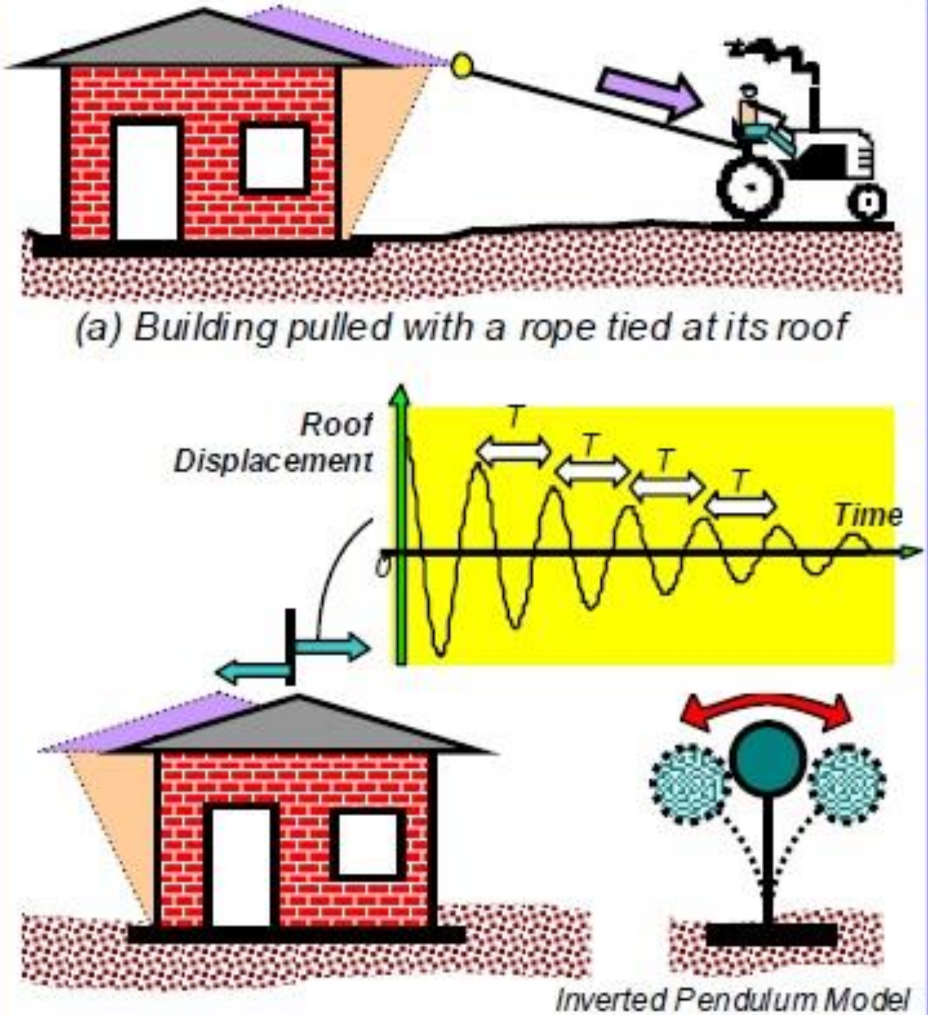


Figure 3: Ductile chain design.

- As more and more force is applied, eventually the chain will break when the **weakest link** in it breaks.

- If the ductile link is the **weak** one **(i.e.,** its capacity to take load is less), then the chain will show large final elongation.

- Instead, if the brittle link is the weak one, then the chain will fail suddenly and show small final elongation. Therefore, if we want to have such a **ductile** chain, we have to make the ductile link to be the **weakest** link.



(a) Building pulled with a rope tied at its roof

(b) Oscillation of building on cutting the rope

Figure 1: Free vibration response of a building:
the back-and-forth motion is periodic.

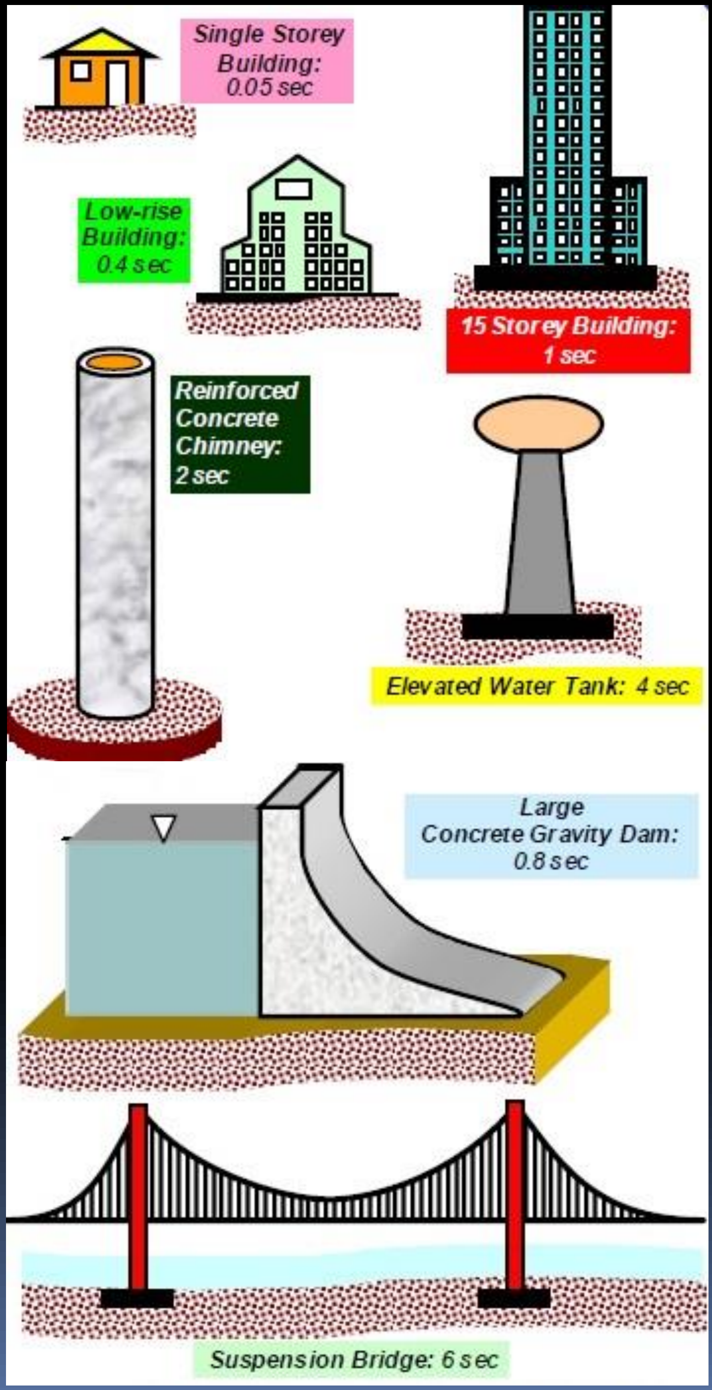
- Take a fat coir rope and tie one end of it to the roof of a building and its other end to a motorized vehicle Next, start the tractor and pull the building; it will move in the direction of pull For the same amount of pull force, the movement is larger for a more flexible building.

- Now, cut the rope! The building will oscillate back-and-forth horizontally and after some time come back to the original position (Figure l(b)); these oscillations are periodic.

- The time taken **(in seconds)** for each complete cycle of oscillation **(i.e.,** one complete **back-and-forth** motion) is the same and is called **Fundamental Natural Period T** of the building. Value of **T** depends on the building flexibility and mass; more the flexibility, the longer is the T, and more the mass, the longer is the **T.**

- In general, taller buildings are more flexible and have larger mass, and therefore have a longer T. On the contrary, low- to medium-rise buildings generally have shorter T (less than 0.4 sec).

- Fundamental natural period T is an inherent property of a building.
- Any alterations made to the building will change its T. Fundamental natural periods **T** of normal single Storey to **20** Storey buildings are usually in the range **0.05-2.00 sec.**
- Some examples of natural periods of different structures are shown in Figure.



IMPORTANCE OF FLEXIBILITY IN BUILDING

- The ground shaking during an earthquake contains a mixture of many sinusoidal waves of different frequencies, ranging from short to long periods .
- The time taken by the wave to complete one cycle of motion is called **period of the earthquake wave.**
- In general, earthquake shaking of the ground has waves whose periods vary in the range **0.03-33sec.** Even within this range, some earthquake waves are stronger than the others.
- Intensity of earthquake waves at a particular building location depends on a number of factors, including the **magnitude** of the earthquake, the **epicentral distance,** and the type of ground that the earthquake waves travelled through before reaching the location of interest.

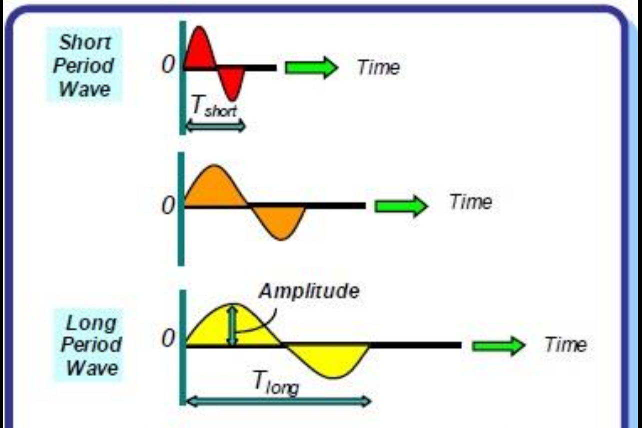


Figure 3: Strong Earthquake Ground Motion is transmitted by waves of different periods.

- In a typical city, there are buildings of many different sizes and shapes.
- One way of categorizing them is by their **fundamental natural period T.** The ground motion under these buildings varies across the city.
- If the ground is shaken back-and-forth by earthquake waves that have short periods, then **short period buildings** will have large response.
- Similarly, if the earthquake ground motion has long period waves, then **long period buildings** will have larger response.
- Thus, depending on the value of T of the buildings and on the characteristics of earthquake ground motion (i.e., the periods and amplitude of the earthquake waves), some buildings will be shaken more than the others.
- Flexible buildings undergo larger relative horizontal displacements, which may result in damage to various nonstructural building components and the contents.

- For example, some items in buildings, like glass windows, cannot take large lateral movements, and are therefore damaged severely or crushed.

- Unsecured shelves might topple, especially at upper stories of multi-storied buildings. These damages may not affect safety of buildings, but may cause economic losses, injuries and panic among its residents.

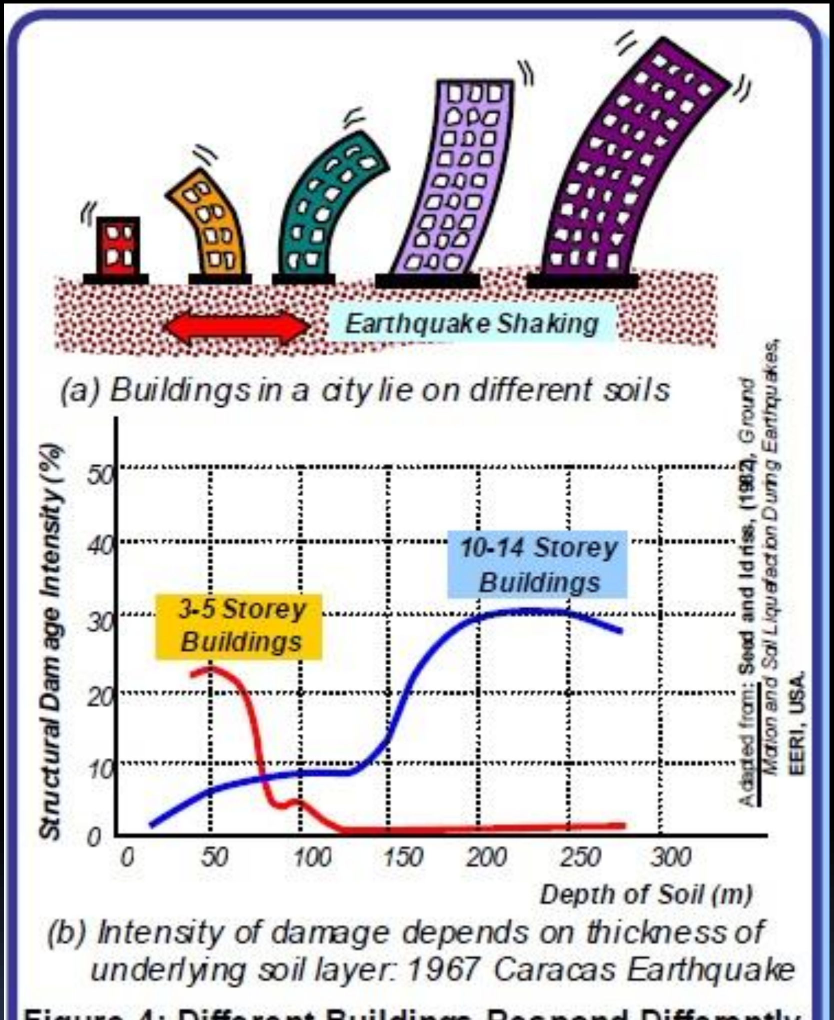


Figure 4: Different Buildings Respond Differently to Same Ground Vibration.

CONFINED MASONARY CONSTRUCTION

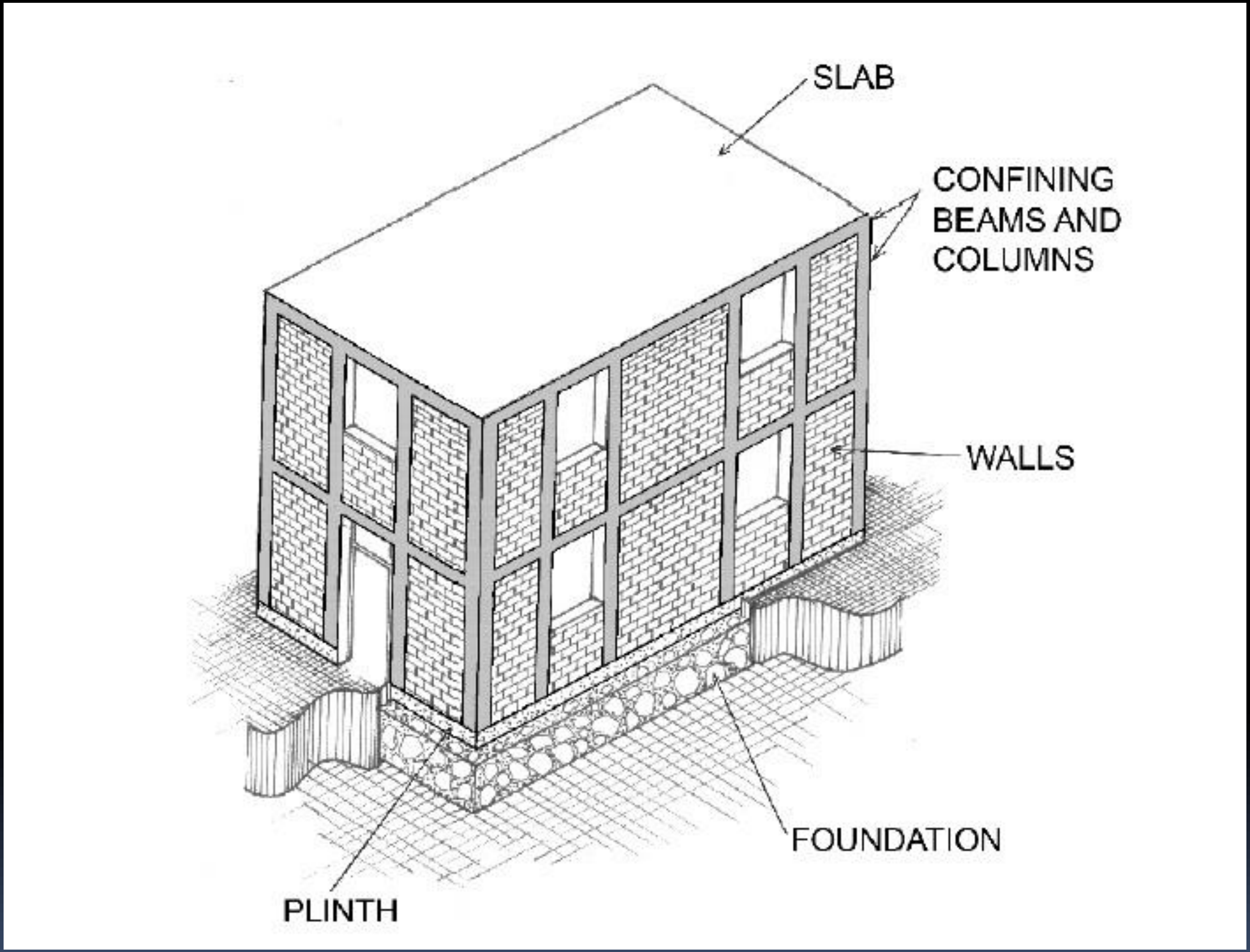
- Confined masonry construction consists of unreinforced masonry walls confined with reinforced concrete (RC) tie-columns and RC tie-beams.

- This type of construction is used both in urban and rural areas, either for single-family residential construction or for multifamily construction up to four or five stories in height.

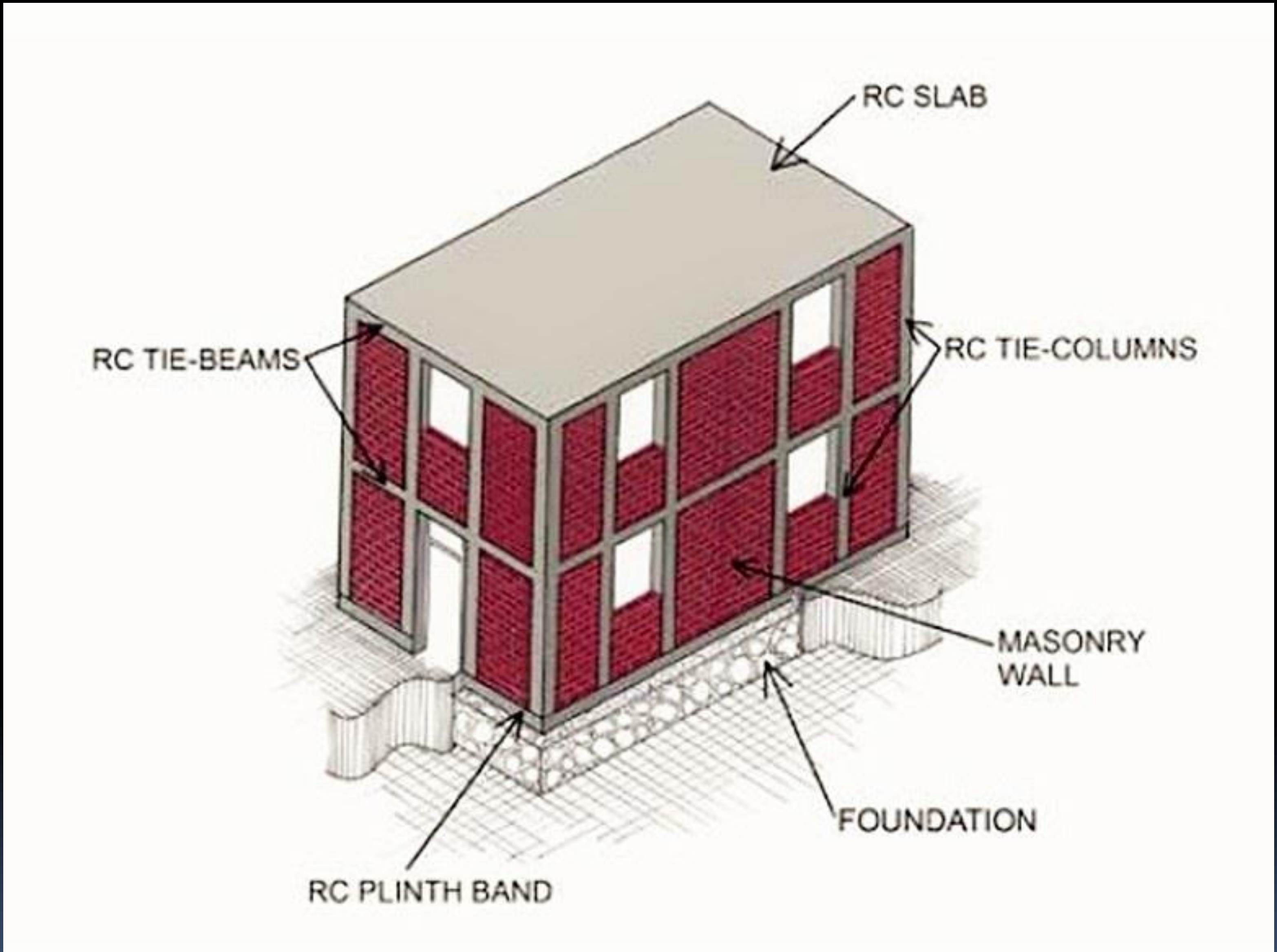
- In Mexico, in addition to low rise construction for single-family units, this type of construction is also used for buildings up to seven stories high.

- In this case, the first two floors are constructed with reinforced concrete structural walls as the lateral load-resisting system; the upper floors are constructed only with confined masonry walls.


Confined masonry housing in Chile (left) and solvenia (right)



Typical Confined Masonry Building



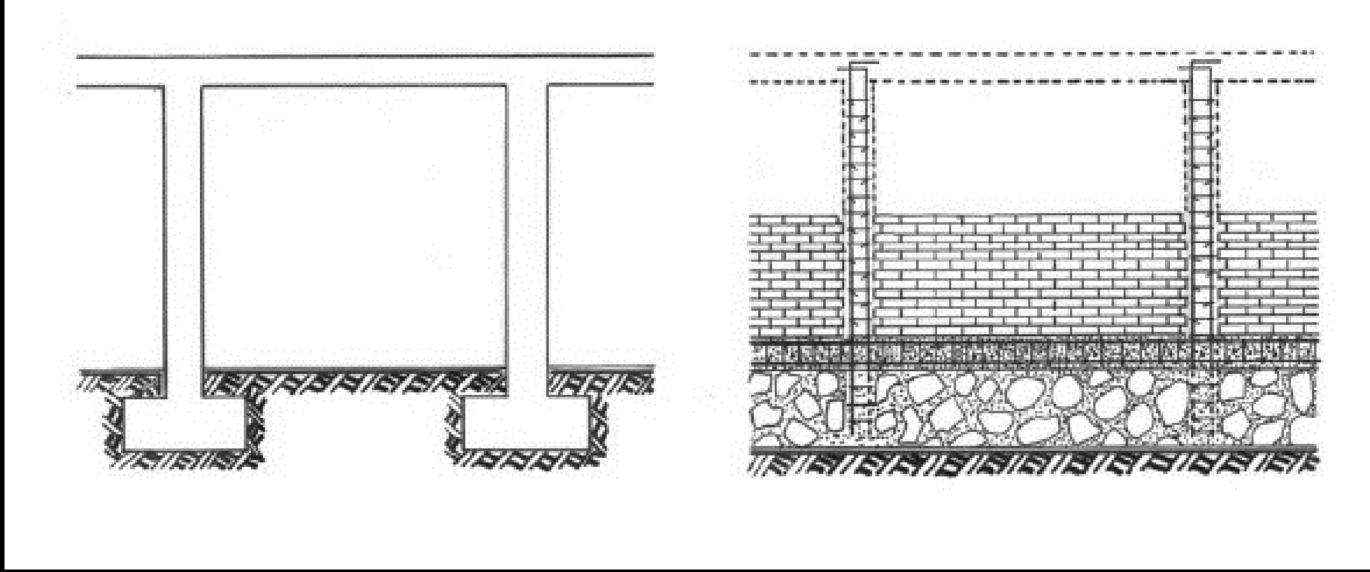
Key components of a confined masonry building

Structural component of confined masonry buildings are as following:

1. **Masonry walls:** They transmit the gravity load from slabs above down to foundation. The walls acts as bracing panels, which resist horizontal earthquake forces. The walls must be confined by concrete tie-beams and tie-columns to ensure satisfactory earthquake performance.
2. **Confining Elements (Tie-columns and Tie-beams):** They restrain to masonry walls and they protect them from complete disintegration even in major earthquakes. These elements resist gravity loads and have important role in ensuring vertical stability of a building in earthquake.
3. **Floor and Roof Slabs:** They transmit both gravity and lateral loads to the walls. In an earthquake, slabs behave like horizontal beams and are called diaphragms.
4. **Plinth band:** They transmit the load from the walls to the foundation. They also protects the ground floor walls from excessive settlements in soft soil conditions.
5. **Foundation:** They transmit the load from structure to the ground.

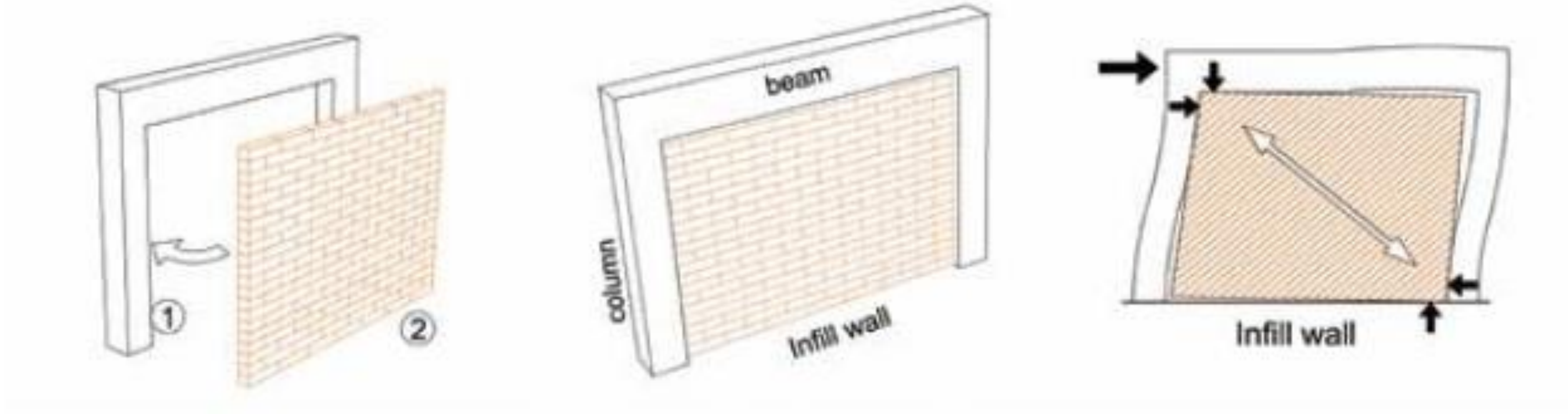
How is confined masonry different from RC frame construction?

	Confined Masonry Construction	RC frame Construction
Gravity and lateral load resisting system	Masonry walls are the main load bearing elements and are expected to resist both gravity and lateral loads. Confining elements are significantly smaller in size than RC beams and columns.	RC frames resist both gravity and lateral loads through their relatively large beams, columns and their connections. Masonry infills are not load bearing walls.
Foundation Construction	Strip footing beneath the wall and the RC plinth band	Isolated footing beneath each column
Super-structure Construction Sequence	1. Masonry walls are constructed first. 2. Subsequently, tie-columns and are cast in place. 3. Finally, tie beams are constructed on top of the walls, simultaneously with the floor/roof slab construction.	1. The frame is constructed first. 2. Masonry walls are constructed at later stage and are not bonded to the frae members; these walls are non-structural, that is, non-load bearing walls.

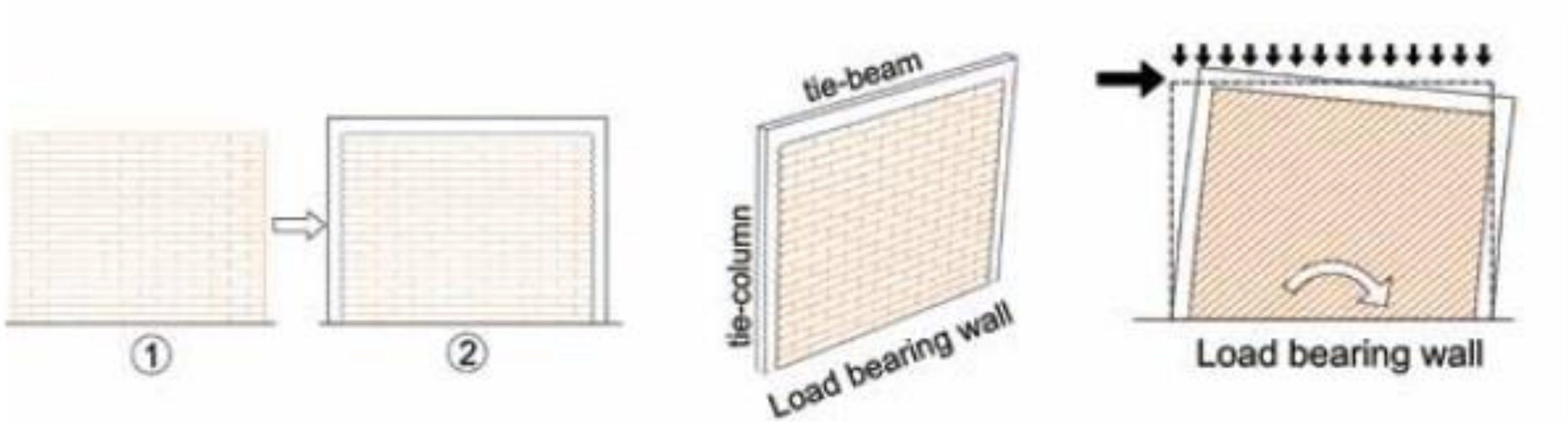


RC frame construction (left) and confined masonry construction (right)

RC frame construction in Cambodia (left) and confined masonry construction in Mexico (right)



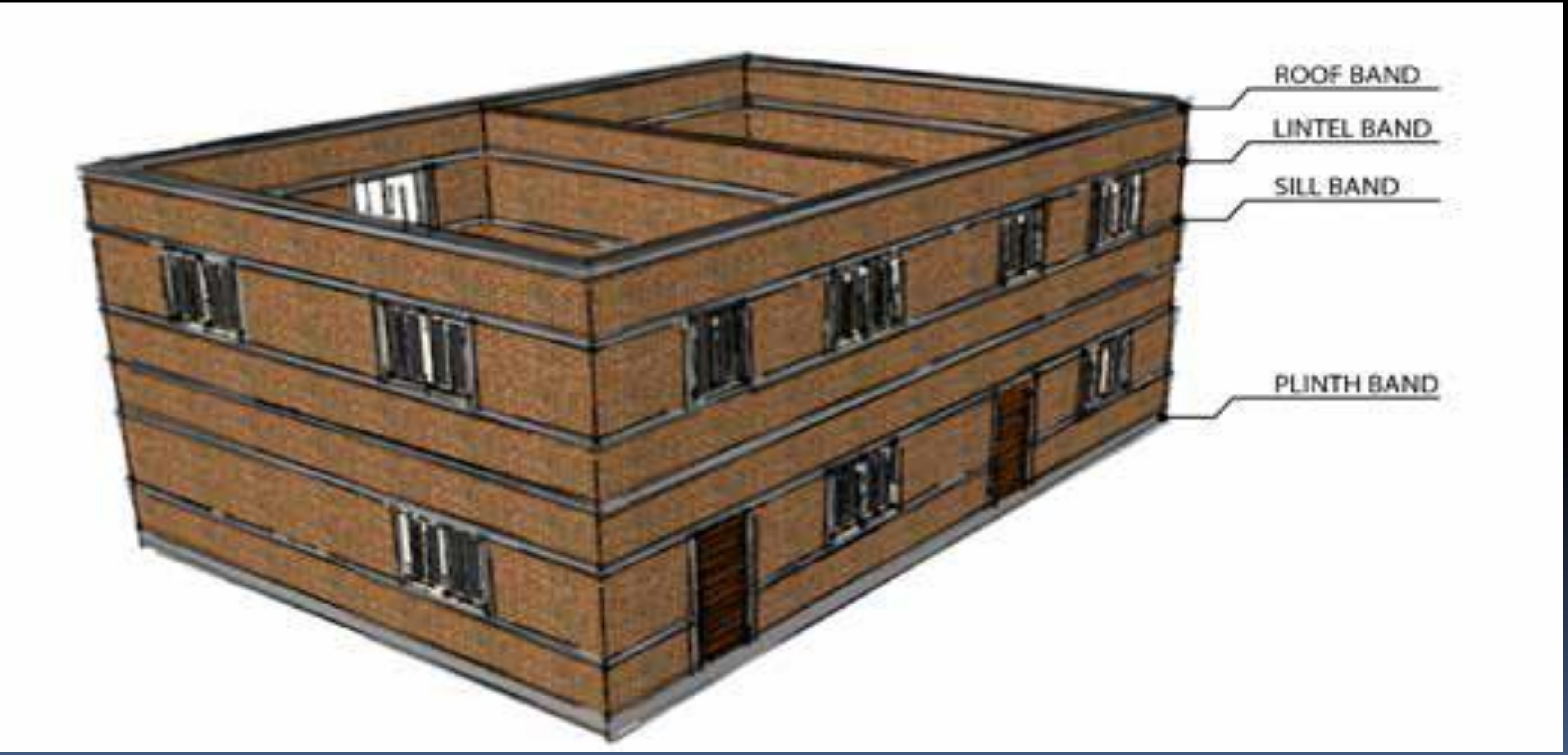
RC frame with masonry infills



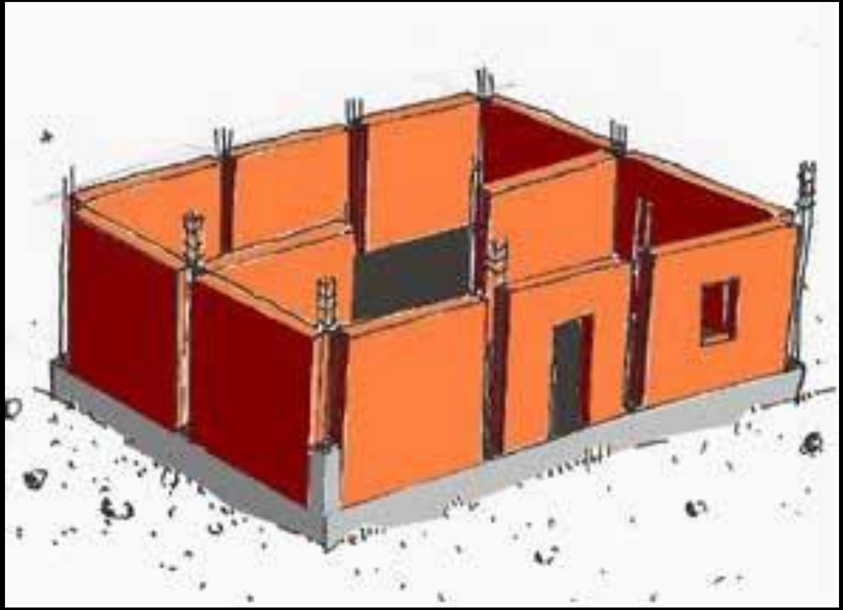
Confined masonry wall

Comparison of RC frame with masonry infills and a confined masonry wall

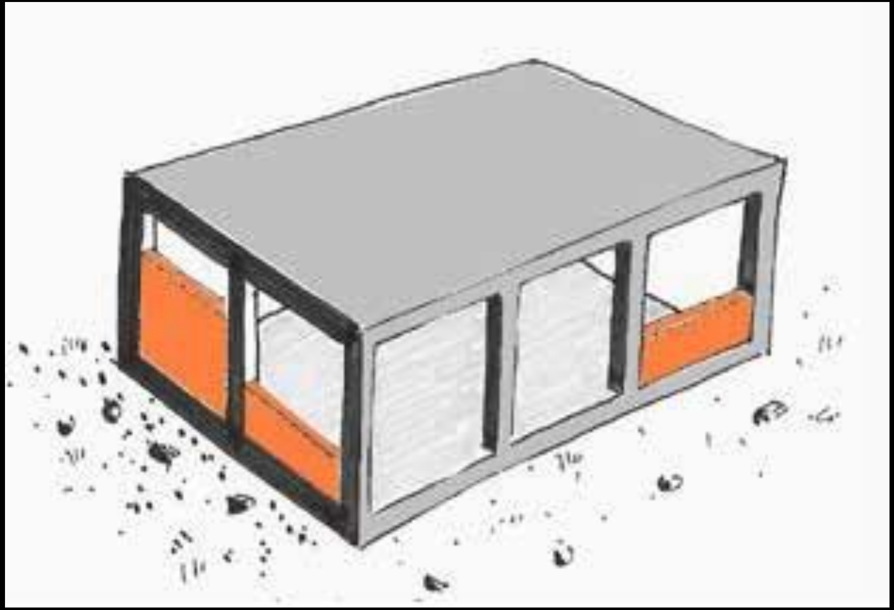
- The effectiveness of RC lintel bands in improving the seismic performance of masonry buildings was confirmed in past earthquakes in India, including the 1993 Killari, Maharashtra earthquake (Magnitude 6.2) and the 2001 Bhuj, Gujarat earthquake (Magnitude 7.7).



Required seismic bands for masonry buildings in Seismic Zone V in India according to IS:4326



Confined masonry building under construction



RC frame building with masonry infills

Masonry wall between adjacent tie-columns (construction in progress)

Toothing at the wall-to-tie-column interface

Concrete construction completed at lower portion of a RC tie-column

Formwork in place at upper portion of a RC tie-column

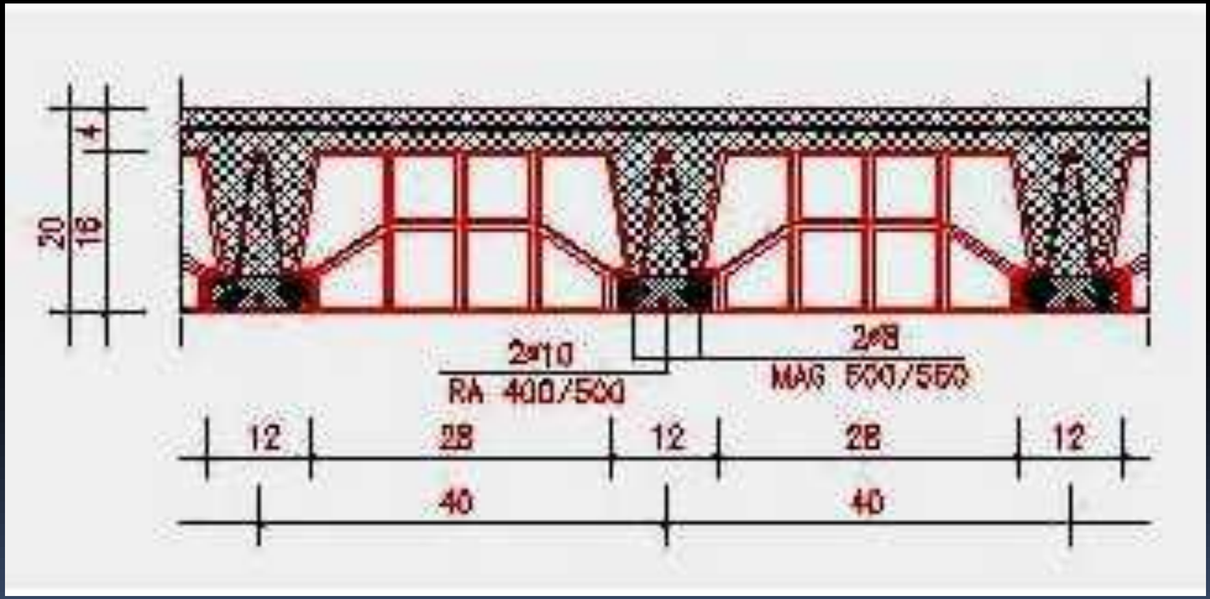
STRUCTURAL FEATURES

- Confined masonry construction consists of unreinforced masonry walls confined with reinforced concrete (RC) tie-columns and RC tie-beams.
- The tie-columns and tie-beams provide confinement in the plane of the walls and also reduce out-of-plane bending effects in the walls. The walls are made of different masonry units, ranging from hollow clay or hollow concrete blocks to solid masonry units of either clay or concrete.

Confining members are effective in:

- Enhancing the stability and integrity of masonry walls for in plane and out of plane earthquake loads. **(confining members can effectively contain effectively damaged masonry walls).**
- Enhancing the strength (resistance) of masonry walls under lateral earthquake loads and
- Reducing the brittleness of masonry walls under earthquake loads and hence improving their earthquake performance.

Confined masonry housing during construction in Solvenia



Masonry units used in confined masonry structure (left) detail of floor construction (right)

- A very important feature of confined masonry is that tie-columns are cast-in-place after the masonry wall construction has been completed.
- Alternatively, tie-columns are constructed using hollow masonry blocks to allow for placement of vertical reinforcement and cement-based grout. Figure 2 shows an example of the use of both types of tie-columns in residential construction in Slovenia.
- Typically, tie-columns consist of a rectangular section, with cross-sectional dimensions corresponding to the wall thickness, usually within the range of 150 to 200 mm.
- However, in Slovenia and Serbia, the minimum wall thickness is specified as 190 mm.
- Figure 3 shows an example of the masonry units used in Slovenia. The spacing of tie-columns is limited to 3 m in Mexico.
- In Chile, RC structural walls of a minimum 1 m in length are required in buildings in which a plan dimension exceeds 20 m.
- These walls need to be placed at the building perimeter.

Performances in Past Earthquakes

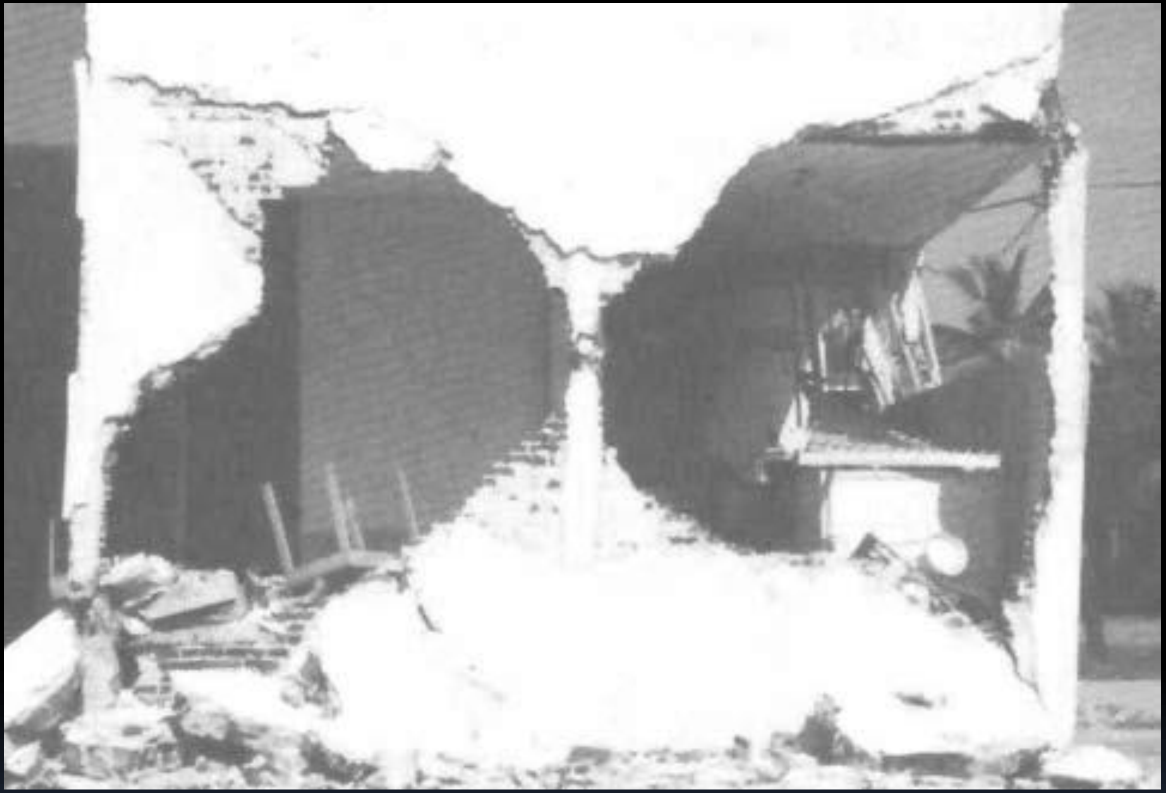
- If properly constructed, confined masonry construction is expected to show satisfactory performance in earthquakes.

- The behavior observed in past earthquakes involved houses that were built without tie-columns and/or tie-beams, with inadequate roof-to-wall connection, or with poor-quality materials and construction.

- Major earthquakes that have affected confined masonry construction include the 1985 Llolleo, Chile, earthquake (M 7.8) and the 1990 Manjil, Iran, earthquake (M 7.6).

- Confined masonry buildings suffered light damage in the 1985 Lloleo earthquake and collapse was not reported.

- In most of the damaged buildings, tie-columns were missing and the following characteristic damage patterns were observed.
- Shear cracks in walls that propagate into the tie-columns; most cracks passed through mortar joints.
- Also, crushing of masonry units has been observed in the middle portion of the walls subjected to maximum stresses Horizontal cracks at the joints between masonry walls and reinforced concrete floors or foundations.
- Cracks in window piers and walls due to out-of-plane action in inadequately confined walls.
- Crushing of concrete at the joints between vertical tie-columns and horizontal tie beams when the reinforcement was not properly anchored.



Damage to confined masonry construction in the 1985 Llolleo, Chile

UNIT – 2

SEISMIC DESIGN OF MASONRY BUILDINGS

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METHOD FOR CALCULATING THE RIGIDITY OF WALL WITH OPENING

Assumptions

- The masonry shear wall may be assumed to behave like a cantilever.

The deflection Δ_c, of the pier (or) wall, fixed at bottom and free at top is given by:

$$\Delta_c = \frac{P}{E_m t}\left[4\left(\frac{h}{d}\right)^3 + 3\left(\frac{h}{d}\right)\right] --- \text{For cantilever}$$

& Rigidity of cantilever,

$$R_c = \frac{1}{\Delta_c}$$

METHOD FOR CALCULATING THE RIGIDITY OF WALL WITH OPENING

Assumptions

- The segments of the wall between adjacent openings (door, windows, ventilators) called piers may be assumed to be fixed at their top & bottom.
- However, both of these may be considered as cantilever (or) fixed depending on the relative rigidities of walls & door diaphragms.

The deflection of pier or wall, fixed at top and bottom is given by:

$$\Delta_f = \frac{P}{E_m t}\left[\left(\frac{h}{d}\right)^3 + 3\left(\frac{h}{d}\right)\right] --- \text{For fixed at both ends}$$

$$\text{\& Rigidity } R_f = \frac{1}{\Delta_f}$$

METHOD FOR CALCULATING THE RIGIDITY OF WALL WITH OPENING

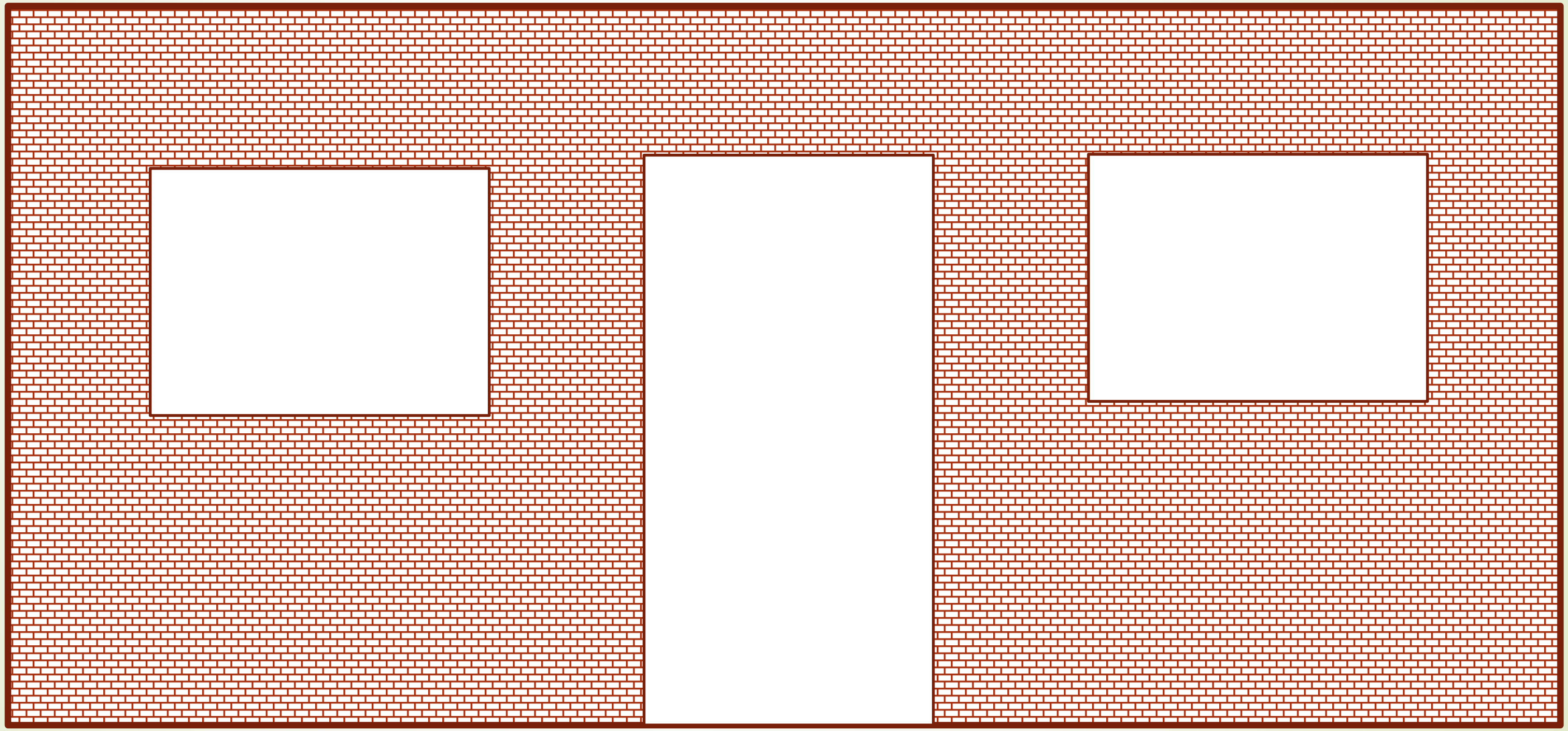
- **If the masonry wall segments are combined horizontally, the combined rigidity is given by,**

$$R_c = R_{c1} + R_{c2} + R_{c3} + ...$$

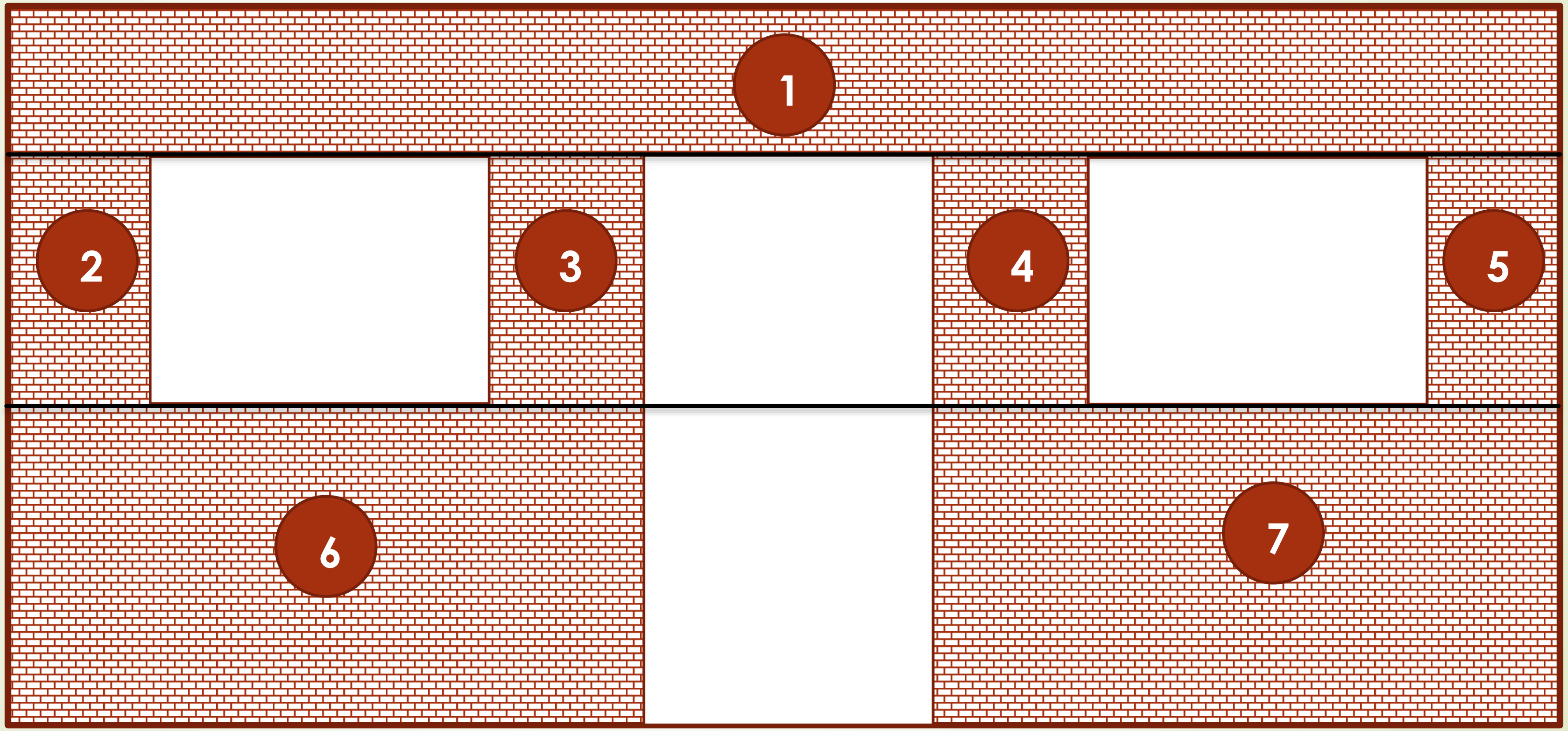
- **If the masonry wall segments are combined vertically, the combined rigidity is given by,**

$$\frac{1}{R_c} = \frac{1}{R_{c1}} + \frac{1}{R_{c2}} + \frac{1}{R_{c3}} + ...$$

METHOD FOR CALCULATING THE RIGIDITY OF WALL WITH OPENING



METHOD FOR CALCULATING THE RIGIDITY OF WALL WITH OPENING

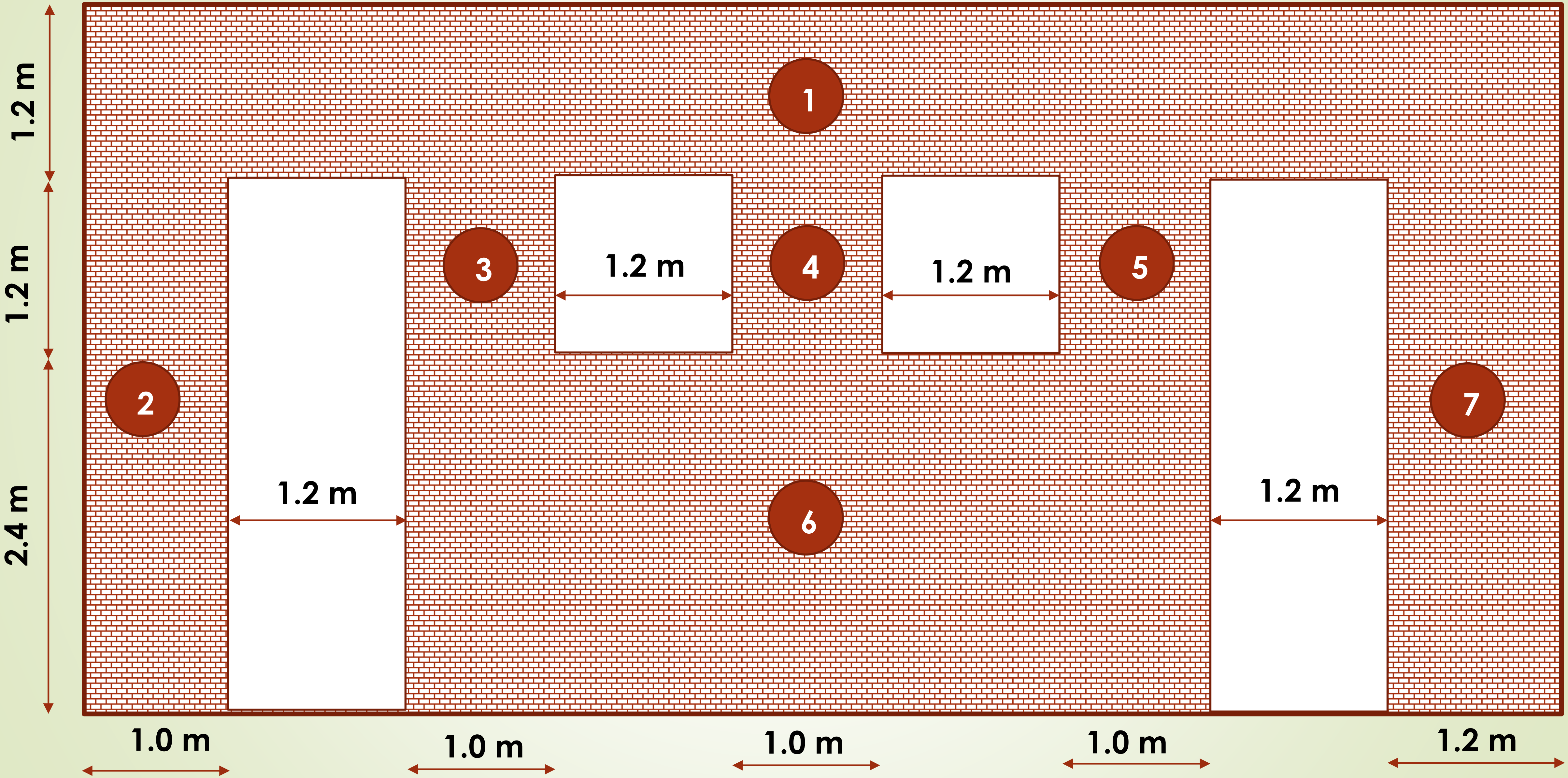


METHOD FOR CALCULATING THE RIGIDITY OF WALL WITH OPENING

Steps:

- Calculate the deflection of solid wall as a cantilever, Δ_{solid}. (for one or two storey building)
- An opening having a height equal to that of the largest opening is selected.
- ✓ The deflection of this strip (strip A) of wall is calculated as $\Delta_{\text{strip of highest opening}}$.
- Deflection of all the piers numbered 2,3,4,5,6,7 is worked out as Δ_{pier}.
- The Total deflection of wall, $\Delta = \Delta_{solid} - \Delta_{strip} + \Delta_{pier}$

Example: Determine the rigidity of masonry shear wall of thickness 't' in terms of Et.



SOLUTION

Delta solid wall = 1.882/Et

Delta strip A = 1.266/Et

$R_3 = R_4 = R_{5(f)} = 0.187/Et$

$\Delta_{3456}(f) = 2.311/Et$

$\Delta B_{(f)} = 0.671/Et$

$R_{3456} = 0.292Et$, $R_{34567} = 0.337Et$

$R_{wall} = 0.279Et$, $\Delta_{wall} = 3.583/Et$