المجلة العربية للعلوم الجيولوجية
Arabian Journal of Geosciences

جامعة الملك سعود
King Saud University

الجمعية السعودية لعلوم الأرض
Saudi Society for Geosciences

29

Al-Amri's Encyclopedia of Earth Sciences

موسوعة العمري في علوم الأرض

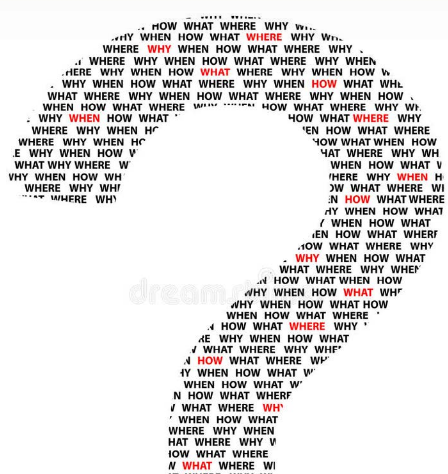
303 Q & A

سؤال جواب

In

Earthquakes & Engineering Seismology

الزلازل والزلزالية الهندسية



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1444 - 2023

www.alamrigeo.com

King Fahd National Library Cataloging-in-Publication Data

Alamri, Abdullah Mohammed
303 Questions & Answers In Earthquake & Engineering Seismology. / Abdullah Mohammed Alamri .- Riyadh , 2020

p.162 ; 20.5 x 27 cm

ISBN: 978-603-03-4784-1

1- Engineering I-Title

612.3 dc 1441/12784

L.D. no. 1441/12784
ISBN: 978-603-03-4784-1

Request your Free Paper Copy directly from the author at the following address:

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بسم الله الرحمن الرحيم

﴿ وَفِي ٱلْأَرْضِ ءَايَٰتٌ لِّلْمُوقِنِينَ ﴾

[سورة الذاريات : آية 20]

﴿And on the Earth are Signs for Those Whose Faith is Certain﴾

موسوعة العمودي في علوم الأرض

Preface

Praise and thanks to Allah who helped me accomplish this modest effort associated with writing the Scientific Encyclopedia. The comprehensive scientific encyclopedia in earth, environment and energy sciences aims to provide and serve researchers, school and university students and groups of society, due to the suffering of those interested in the problems of the scarcity of Arab references in this field. The encyclopedia is one of the largest in the world includes 30 scientific and cultural books documented and supported by pictures and simplified illustrations in approximately 6000 pages, covering five main parts:

The First Part consists of six books that discuss the age of the Earth, its shape, movements, internal structure, minerals and mining ores, gravity and its relationship to tides:

- Estimating Age of the Earth
- Earth's Shape & Movements
- Earth's Gravity & its Applications
- The Internal Structure of the Earth
- Minerals & Mining
- Tides

As for the Second Part of the encyclopedia, it included six books that link the Earth's relationship with the solar system, especially the moon, and the atmosphere, water, and vitality surrounding the Earth. As well as the role of earthquakes, explosions, volcanoes and tsunamis in affecting the structure of the earth and how to reduce its risks:

- Tsunami Waves
- Earthquakes & Explosions
- Seismic Hazard Assessment
- Volcanoes & Ways to Confront Them
- Geology of the Moon
- Spheres Surrounding the Earth

The Third Part consists of six books related to everything related to environmental problems and disasters and their solutions, climatic changes, the importance of afforestation and the treatment of global warming:

- Environmental Problems & Their Solutions
- Afforestation: Challenges & Solutions
- Climate Change & Global Warming
- Slips, Landslides & Floods
- Desertification & Drought
- Torrents & Water Dams

The Fourth Part of the encyclopedia consists of six books that discuss the relationship of Earth sciences with other sciences nuclear, and medically, as well as the role of clean, sustainable energy, economically and environmentally:

- Geothermal Energy
- Is the Age of Oil Over?
- Nuclear Geophysics
- Medical Geology
- The Future of Energy in our World
- Guide to Writing Theses & Scientific Publication

As for the Fifth Part, it consists of six books that contain 2020 Questions and Answers (Q & A) to help university students and researchers and prepare them for comprehensive and qualifying exams for postgraduate studies and practice the profession.

- 321 Questions & Answers in the Evolution of the Earth
- 358 Questions & Answers in Petrology, Geochemistry, Remote Sensing and GIS
- 358 Questions & Answers on Natural Resources
- 380 Questions & Answers in Geological Hazards
- 303 Questions & Answers in Seismology and Engineering Seismology
- 300 Questions & Answers in Applied Geophysics

Introduction

An **earthquake** is caused by slip on a fault. However, the slip motion is complex, reflecting the variation in basic physics that governs fault motion in different tectonic environmentsIt istheprimarymeansbywhichscientistlearnaboutEarth'sdeepinterior,wheredirectobservationsareimpossible,andhasprovidedmanyofthemostimportantdiscoveriesregardingthenatureofourplanet. Earthquakes frequently claim hundreds of lives and cause major damage to cities and infrastructures. Earthquakes can be disastrous over a large area in a short time, with casualties in a single earthquake sometimes amounting to hundreds of thousands. For this reason the first serious earthquake studies were primarily concerned with the macroseismic effects of earthquakes and the immediate reduction of hazards.

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236 Questions & Answers in Earthquake Seismology




1 What is Seismology ?

Seismology is the science of earthquakes and studies the causes and effects from minute pulsations to the most catastrophic natural phenomenon inside Earth. Seismology is the solid Earth geophysical discipline with the highest societal impact, both in assessing and reducing the danger from natural hazards and in revealing present Earth structure and buried resources. The methods are classified into two divisions based on energy source of the seismic waves. Earthquake seismology is caused by natural shock waves of earthquakes and derives information on physical properties, composition, and the gross internal structure of Earth.

Explosion seismology is the product of artificial blasts: (1) detonating a charge of dynamite (land) and (2) nonexplosive vibroseis or compressed air (marine) at selected sites to infer information about regional/local structures. This is extensively being applied to interpret the interfaces of rock boundaries, layered sedimentary sequences, location of water tables, and oil and gas exploration.

2 What is an earthquake?

An earthquake is the sudden release of strain energy in the Earth's crust resulting in waves of shaking that radiate outwards from the earthquake source. When stresses in the crust exceed the strength of the rock, it breaks along lines of weakness, either a pre-existing or new fault plane. The point where an earthquake starts is termed the focus or hypocenter and may be many kilometers deep within the earth. The point at the surface directly above the focus is called the earthquake epicenter.

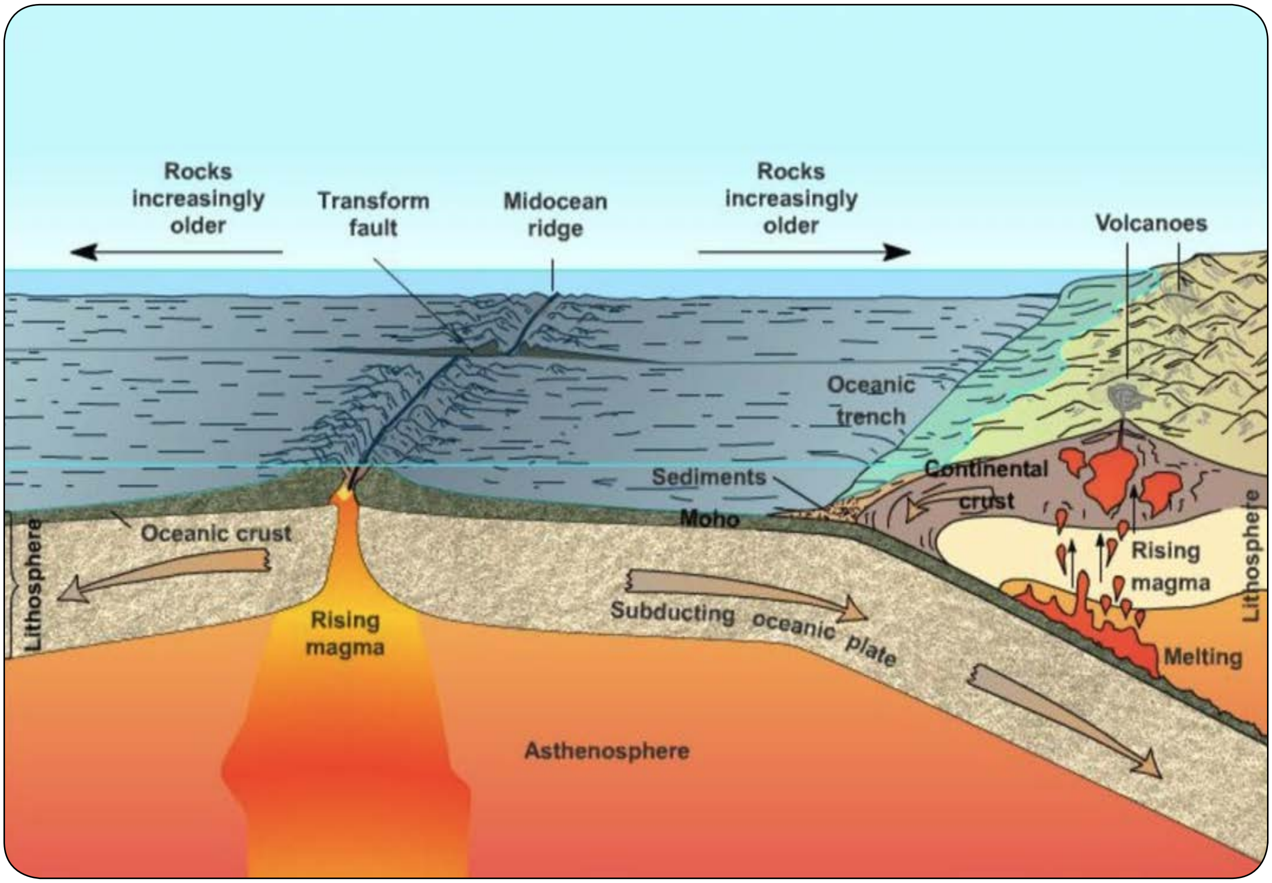
3 What are causes of an earthquake?

There are about 20 plates along the surface of the earth that move continuously and slowly past each other. When the plates squeeze or stretch, huge rocks form at their edges and the rocks shift with great force, causing an earthquake. As the plates move they put forces on themselves and each other. When the force is large enough, the crust is forced to break. When the break occurs, the stress is released as energy which moves through the Earth in the form of waves, which we feel and call an earthquake.

4 Discuss the theory of Plate Tectonics?

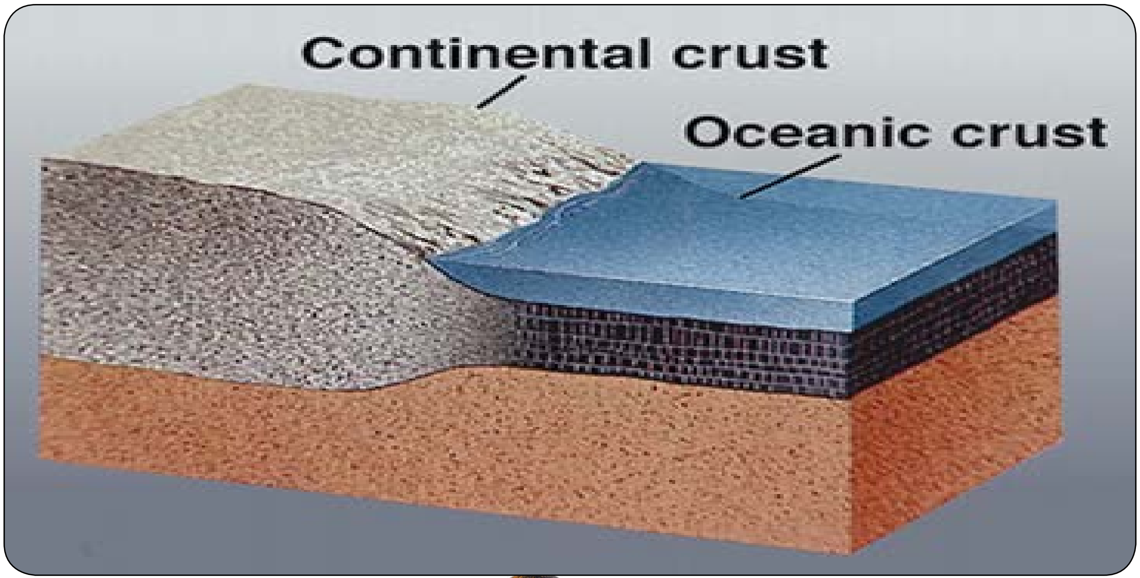
The theory of plate tectonics is mainly used to describe the structure of the outermost layers of the Earth and to explain the cause of earthquakes.The outermost part of the Earth is called the lithosphere, which is made up of cold, rigid and moveable rocks. The average thickness of the lithosphere is about 100 km. Below the lithosphere lies the asthenosphere, which is made up by liquefied materials with high viscosity. Under high temperature and high pressure, these liquefied materials develop plasticity and make the lithosphere flow above it.

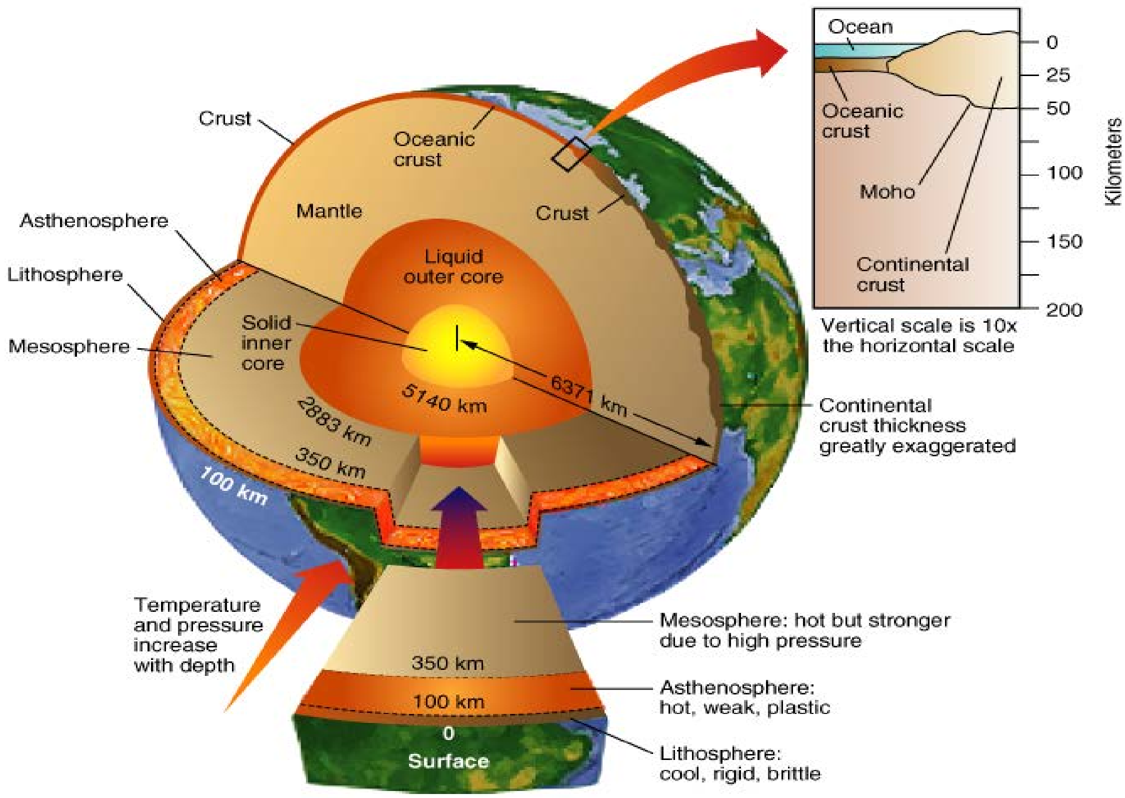
The basic concept of plate tectonics is that the lithosphere is divided into a few nearly 12 rigid plates. These plates are subjected to different tension, pressure, gravity, and convection in the mantle. Hence, these plates move slowly every year by several centimeters, with different speeds of movement. This results in the existence of differences in the relative velocities between neighboring plates. Most earthquakes, volcanoes, and orogenesis are the result of the interactions among the neighboring plates. Accordingly, there are three types of plate boundaries, 1. Divergent boundaries: A phenomenon of the Earth's crust extension, tension, and fracture movement. At the mid-ocean ridge location, neighboring tectonic plates mutually separate and produce the new lithosphere. 2. Convergent boundaries: When two plates mutually collide at their intersection, the heavy plate inserts itself underneath the light one (by approximately a 30°~ 45° inclination angle). As such, the old lithosphere vanishes into the mantle, and this insertion is called the subduction zone. Because of the friction between two plates, earthquakes frequently occur along the subduction zone, which forms a seismic zone. The depths of the hypocenters may vary from very shallow to about 700 kilometers. 3. Conservative boundaries: They neither produce the new lithosphere nor cause lithosphere vanishing. When any two neighboring tectonic plates act on each other with derailing friction, they produce earthquakes with shallow focal depths. The East Rift Valley Fault in Taitung is an examples of conservative boundaries between the Eurasian plate and the Philippine Sea plate.


Rocks
increasingly
older
Transform
fault
Midocean
ridge
Rocks
increasingly
older
Volcanoes
Oceanic
trench
Sediments
Continental
crust
Moho
Oceanic crust
Lithosphere
Rising
magma
Subducting oceanic plate
Rising
magma
Lithosphere
Melting
Asthenosphere

5 What is the composition and structure of the earth?

Crust. The outermost rock layer, divided into continental and oceanic crust. **Continental Crust** (averages about 35 km thick; 60 km in mountain ranges; diagram shows range of 20-70 km) Granitic composition. **Oceanic Crust** (5 - 12 km thick; diagram shows 7-10 km average) Basaltic composition. Oceanic crust has layered structure (ophiolite complex) Pillow basalts, sheeted dikes, Gabbro.
Mantle (2885 km thick). The mantle stretches from the below the crust to 2900 km below the surface. The upper part is partially molten and the lower part is very dense. The main mantle rock is peridotite.
Lithosphere = outermost 100 km of Earth . Consists of the crust plus the outermost part of the mantle. Divided into tectonic or lithospheric plates that cover surface of Earth.
Asthenosphere = low velocity zone at 100 - 250 km depth in Earth (seismic wave velocity decreases). Rocks are at or near melting point.
Outer core (2270 km thick). S-waves cannot pass through outer core, therefore we know the outer core is liquid (molten). Composition: Molten Fe (85%) with some Ni, based on studies of composition of meteorites. Core may also contain lighter elements such as Si, S, C, or O. Convection in liquid outer core plus spin of solid inner core generates Earth's magnetic field. Magnetic field is also evidence for a dominantly iron core. **Inner core** (1216 km radius). Solid Fe (85%) with some Ni- based on studies of meteorites.

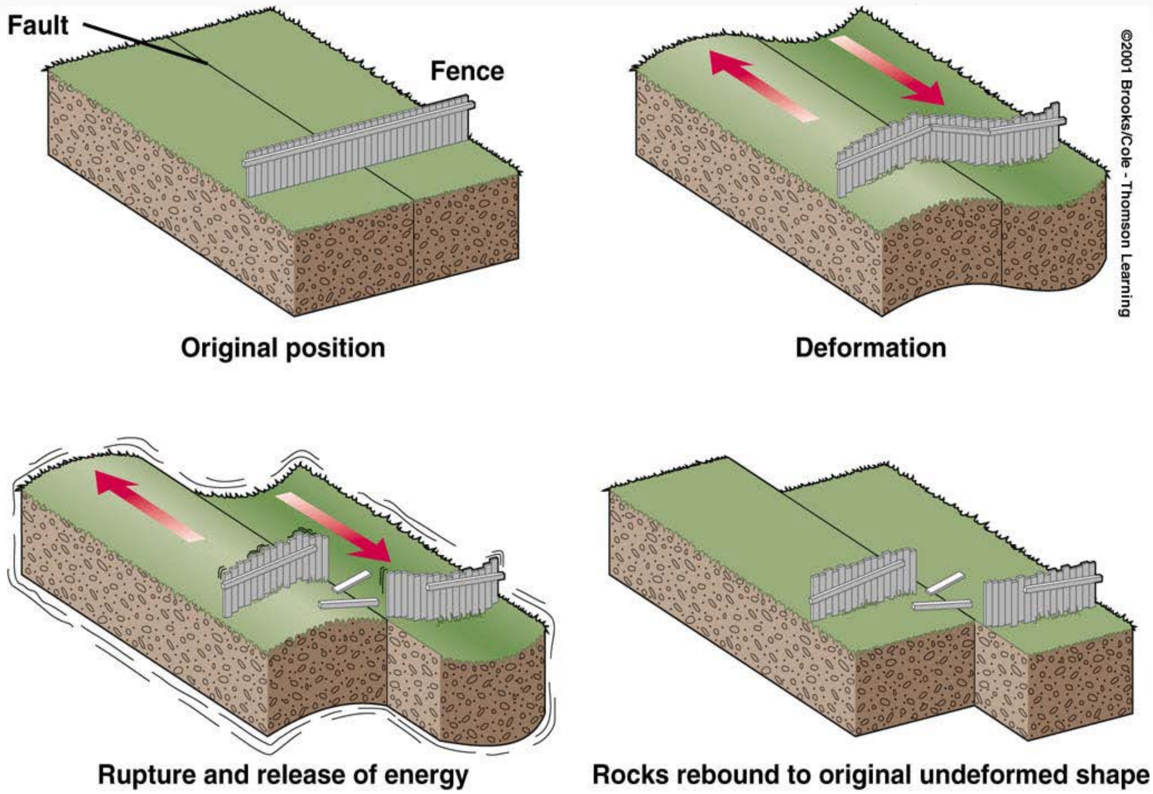




6 Define Elastic Rebound Theory?

Elastic rebound theory developed by Reid in 1911 demonstrates what happens to the crustal material on either side of a fault during an earthquake. The idea is that a fault is stuck until the strain accumulated in the rock on either side of the fault has overcome the friction making it stick. The rock becomes distorted, or bent, but holds its position until the earthquake occurs, and the rock snaps back into an unstrained position, releasing energy that produces seismic waves.

Because of friction, the blocks do not slide, but are deformed. When the stresses within rocks exceed friction, rupture occurs. Elastic energy, stored in the system, is released after rupture in waves that radiate outward from the fault.



7 **Identify different types of earthquakes?**

There are many different types of earthquakes: tectonic, volcanic, and explosion. The type of earthquake depends on the region where it occurs and the geological make-up of that region.

- tectonic earthquakes. These occur when rocks in the earth's crust break due to geological forces created by movement of tectonic plates.
- volcanic earthquakes, occur in conjunction with volcanic activity.
- Collapse earthquakes are small earthquakes in underground caverns and mines.
- Explosion earthquakes result from the explosion of nuclear and chemical devices.

8 **What are two major belts along which most of earthquakes occur?**

1. The Circum - Pacific belt : A large part (80 %) of the seismic energy released by all earthquakes is released along this belt. This includes the western coasts of South and North America , Japan, Philippines, and a strip through the East Indies and New Zealand.
2. The Alpide (Asiatic - European) belt : A high energy concentration (10 %) can also be seen along this belt. It extends from the Pacific belt in New Guinea through Summatra and Indonesia, the Himalayas, and mountains and faults of the Middle East , the Alps , and into the Atlantic Ocean far as the Azores.

9 **Nominate major plates of earth's lithosphere?**

The Earth's lithosphere is broken up into 6 major plates and about 14 minor ones. Oceanic plates are 50-100 km thick. Continental plates are 100-250 km thick. Tectonic plates can include both continental and oceanic areas. Six major plates are

1.Indian – Australian
2.Antarctic
3. Pacific
4. African
5. American (N. and S)
6. Eurasian.

10 **What are basic characteristics of Primary waves ?**

Primary or compressional (P) waves . The first kind of body wave is the P wave or primary wave. This is the fastest kind of seismic wave. The P wave can move through solid rock and fluids, like water or the liquid layers of the earth. It pushes and pulls the rock it moves through just like sound waves push and pull the air.Highest velocity (6 km/sec in the crust)

$$V_p = \sqrt{\frac{\Psi}{\rho}} = \sqrt{\frac{K + 4/3\,\mu}{\rho}} = \sqrt{\frac{\lambda + 2\mu}{\rho}}$$

11 **What are basic characteristics of Secondary waves ?**

Secondary or shear (S) waves. The second type of body wave is the S wave or secondary wave, which is the second wave you feel in an earthquake.An S wave is slower than a P wave and can only move through solid rock (3.6 km/sec in the crust). This wave moves rock up and down, or side to side.

$$V_P / V_S = (2(1-\alpha)/1-2\alpha))^{0.5} \quad \text{and So} \quad \alpha = V_P^2 - 2V_S^2 / 2(V_P^2 - V_S^2)$$

$\alpha = 0$ for a perfect fluid, so S-waves cannot propagate through fluids. Poisson's ratio is theoretically bounded between 0 and 0.5 and for most rocks lies around 0.25, so typically VP/VS is about 1.7

12 **What are basic characteristics of Surface waves (Love and Rayleigh waves)?**

Love Waves. The first kind of surface wave is called a Love wave, It's the fastest surface wave and moves the ground from side-to-side.

Rayleigh Waves rolls along the ground just like a wave rolls across a lake or an ocean. Because it rolls, it moves the ground up and down, and side-to-side in the same direction that the wave is moving. Most of the shaking felt from an earthquake is due to the Rayleigh wave, which can be much larger than the other waves.

13 **Classify earthquakes according to their focal depths?**

1. Shallow-focus earthquakes : have their foci at a depth between 0 and 70 Km. and take place at oceanic ridges and transform faults as well as at subduction zones.

2. Intermediate-focus earthquake : focal depth between 71 and 300 Km.

3. Deep-focus earthquakes : focal depth greater than 300 Km. Most earthquakes originate within the crust. At depth beneath the Moho (Crust-Mantle boundary), the number falls abruptly and dies away to zero at a depth of about 700 Km. Earthquakes along ridges usually occur at a depth of about 10 Km or less and are of moderate size. Transform faults generate large shocks at depth down to about 20 Km. The largest earthquakes occur along subduction zones.

14 **Classify earthquakes according to their epicentral distances?**

1. Local events : $\Delta < 1000$ km

2. Regional events : 1000 km $< \Delta <$ 3000 km

3. Teleseismic events : 3000 km $< \Delta <$ 12000 km. Shadow zone between (12000- 16000 km).

15 **What are seismic characteristic of events ($\Delta<10^{\circ}$)?**

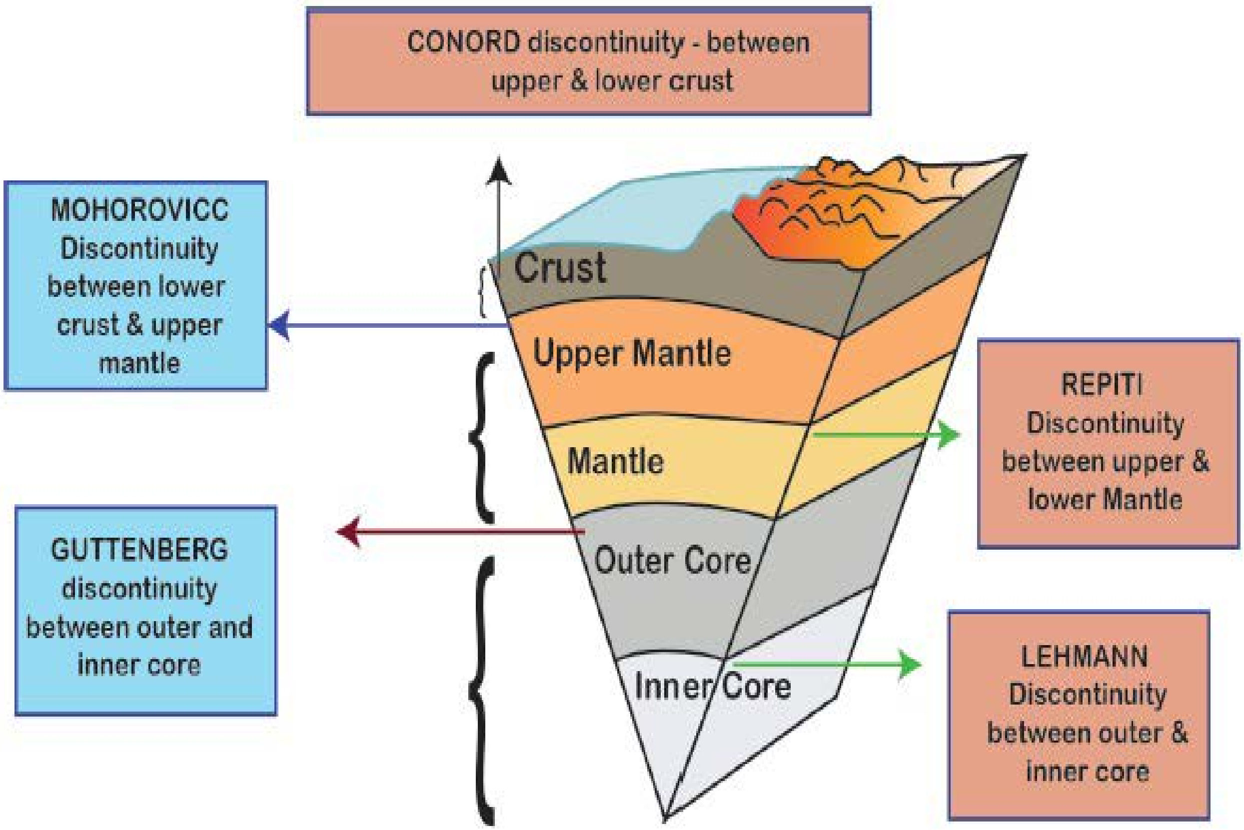
Duration < 5 min, seismogram complex (compared to 1 to 3 layers), dominant signal is Sg followed by waves with decreasing amplitude (Coda), Explosions may generate large Rayleigh waves, order of arrival: Pg, Pb, Pn for ts-p < 20s, and Pn, Pb, Pg for ts-p < 25s

16 **What are seismic characteristic of events ($\Delta>10^{\circ}$)**

Wave propagation mainly in mantel, mantel less heterogenous than the crust, large distances correspond with deeper penetration of waves into mantel, surface waves are dominating the seismogram depending on focal depth.

17 **List major Seismic Discontinuities of Earth's Interior?**

Seismic discontinuities are the regions in the earth where seismic waves behave a lot different compared to the surrounding regions due to a marked change in physical or chemical properties.The Conrad discontinuity is considered to be the border between the upper continental crust (granitic) and the lower one (basaltic) at depths range between 15-20 km. Mohorovicic (Moho) discontinuity forms the boundary between the crust and Upper mantle is abrupt increase in seismic velocity. Gutenberg discontinuity lies between the lower mantle and the outer core. The latter discontinuity exists at a depth of 2,900 kilometers. It is marked by a sudden increase in density, from about 5.7 at the base of the mantle to 9.7 at the top of outer core. Lehmann's discontinuity marks the boundary between the solid inner core the molten outer core to produce seismic waves that matched the measurements.

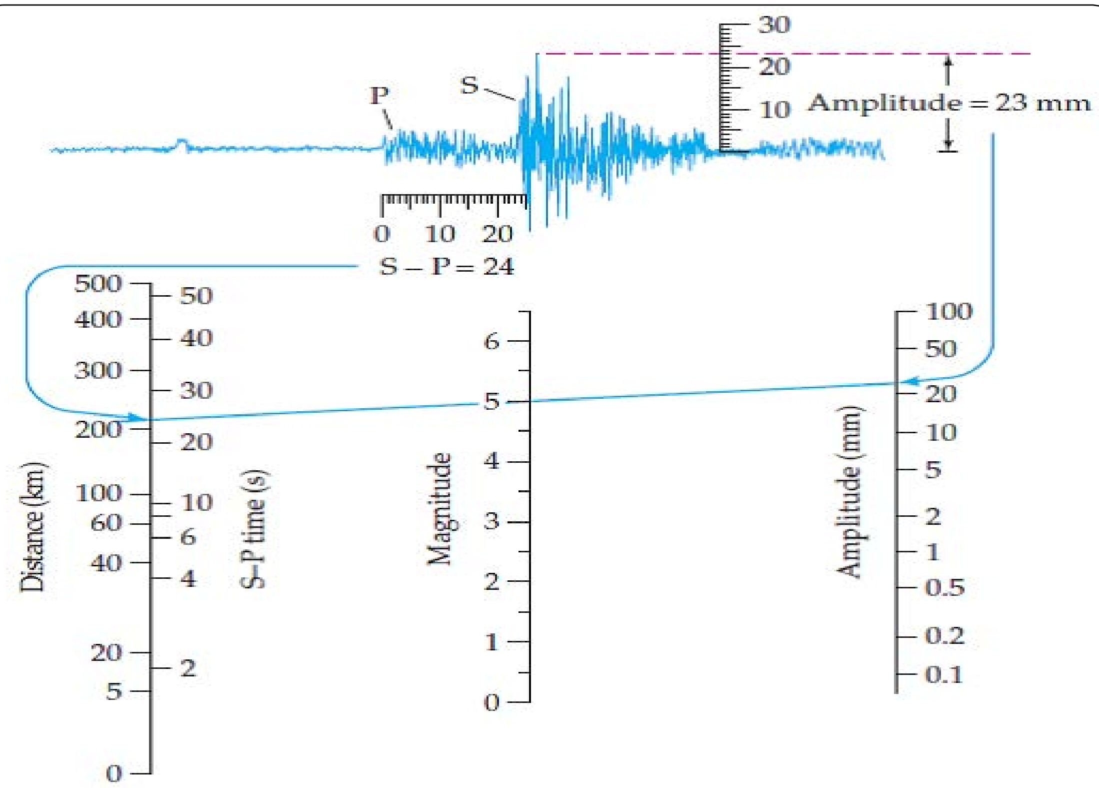


18	**What is a Richter scale?**

It is a magnitude scale designed by Richter in 1935 for California. It ranks the ground motion of the primary waves measured with a special seismograph (Wood Anderson seismograph) on a logarithmic scale. The Richter scale was originally defined for stations at a distance of a few hundred kilometers. In the following years further magnitude scales were developed to include stations at greater distances and sometimes analyze other wave types.

19 **What is "earthquake magnitude"?**

Magnitude is the logarithmic measure of the seismic energy released by an earthquake at its hypocenter. To determine the magnitude, the ground movements must be recorded as seismograms using seismometers. An increase in magnitude of one unit corresponds to an increase in ground movement by a factor of 10 and increase in energy roughly to the power of thirty. Whereas the magnitude is a measure of the energy released in the earthquake's hypocenter, the intensity classifies the vibrations at any given location on the Earth's surface.



Richter's earthquake nomogram

20 What is the intensity of an earthquake?

The intensity is a measure of degree of shaking and classifies the shocks/vibrations at any given location on the Earth's surface according to the type of vibration as perceived by people and the degree of earthquake damage. This intensity scale (MSK or MMS or EMS98) divides earthquakes into 12 classes. An intensity of 12 on this scale corresponds to total destruction. If the corresponding maximum vibrations do not apply for an indefinite distance from the quake's hypocenter but rather for the area directly above the hypocenter, at the so-called epicenter, then one speaks of the so-called I0 epicentral intensity.

21 How do seismometers record earthquakes?

Seismometers record ground motion and earthquakes. Attached to their base is a free mass, which is usually attached by a spring/string and allowed to move freely in one direction (up/down or side to side). When the earth moves the base of the seismometer moves as well, but the free swinging mass stays still. Originally a pen was attached to the mass and the base had a roll of paper to record the relative movement between the moving base and the stationary pen. Now systems tend to use magnet, which are free to move within a coil of wire, which creates an electrical current that is measured and converted into amount of ground movement.


LOW POWER
G. STRECKEISEN AG
SWITZERLAND
TYPE STS2
SERIAL NR 50903
X-AXIS
LOCKED


QUANTERRA Q330 PACKET BALER
POWER
Q330
EXT. GPS
CONSOLE
POWER
GPS ANT.

22 How do you deploy seismometers in a remote site?

Seismometers are deployed by digging a big hole up to 3 m depth and putting them in the ground, if possible onto a solid bit of rock (granitic or hard bedrock) so that they pick up vibrations and tiny movements well. They need to be completely level and kept dry. They need to be pointing towards the north to make it easier for us to tell what direction seismic energy is coming from. They need to be placed in really quiet locations so they don't record other things that could make the ground move a little, like people moving around, cars, rivers, high winds moving nearby tree roots etc. A mass can only move freely in one direction, so seismometers record in three different directions of motion (up/down, north/south and east/west) to describe the ground motion in 3D. In the remote site, a solar panels is required to generate electricity from the sun. The seismometers will record the tiny movements of the ground, sampling the motion up to 200 samples per second. This information will be sent directly to the recording center via VSAT or stored within the memory of data logger system in the site until we come back in the next visit and download it.

23 What are various Magnitude scales used in relation with Earthquakes?

Depending upon the range of magnitudes, epicentral distance and the characteristics of the seismographs, there are mainly five magnitude scales are in use with earthquakes, they are:

ML - "Local Magnitude" determined for local earthquakes (usually 600 km, or less from the recording station), originally developed by Charles Richter circa 1935 for classification of earthquakes in southern California. ML is defined asML = log(a) - log(ao) where a is the maximum trace amplitude recorded by a standard instrument (the Wood Anderson Torsion seismometer) at a given distance and ao is amplitude for an earthquake of zero magnitude at the same distance.

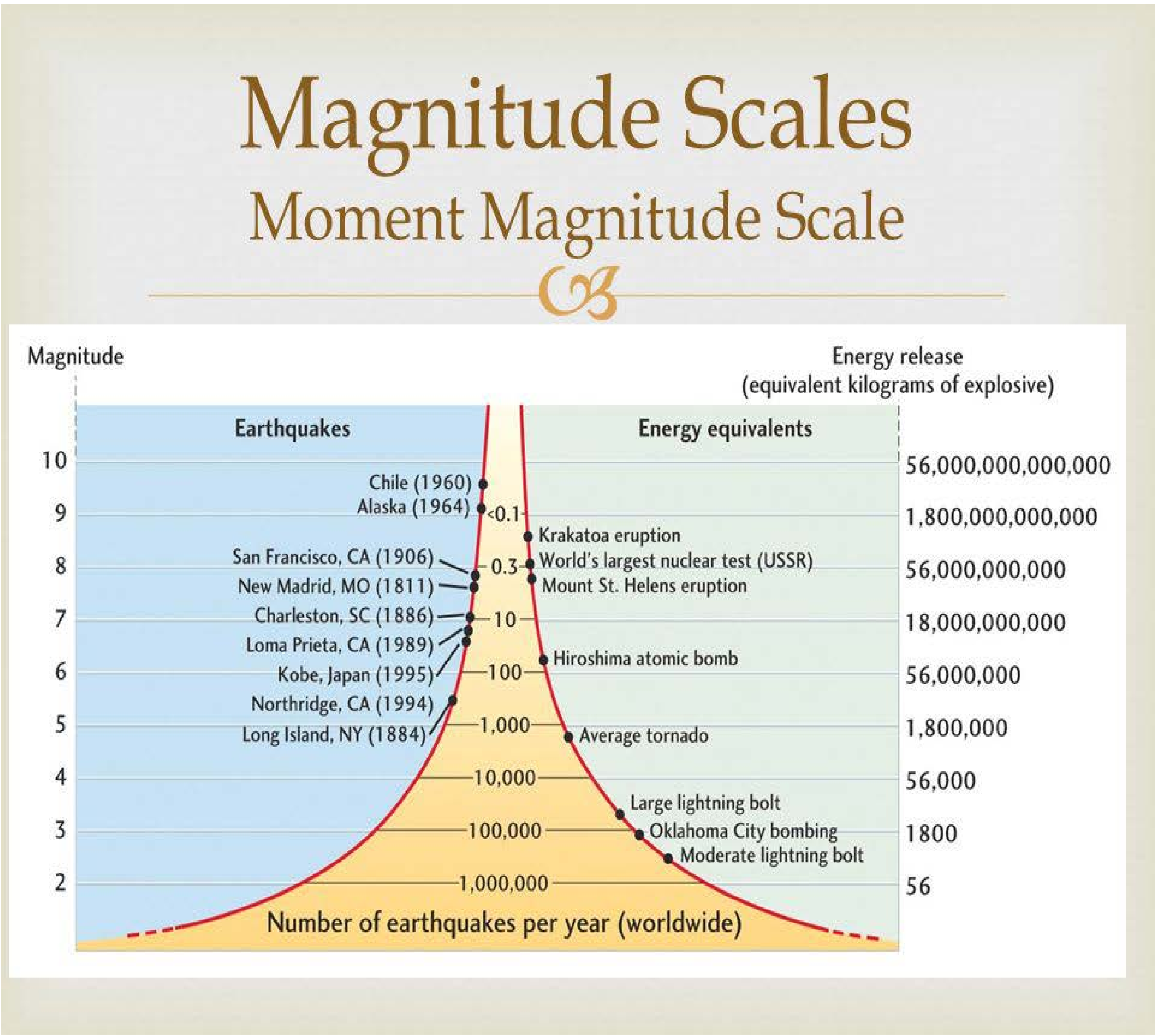
MD - "Duration Magnitude" is based on the length of time (starting from the initial P-wave arrival) the seismic wavetrain takes to diminish to 10% or less of its maximum recorded value. Md is mostly used for assigning magnitudes to small earthquakes of about magnitude 3.0 or less.

Ms - "Surface Wave Magnitude" used for shallow (depth < 70km) earthquakes at teleseismic distances (20-180 degrees) using the 20-second Rayleigh wave for the determination. Ms is defined:Ms = log(A/T) + s(distance,depth), where A is maximum displacement, T is the period of the displacement, and s is a correction term for the distance of the station and the depth of the earthquake.

mb - "Body Wave Magnitude" which uses the amplitude of the P-wave train, the first arriving body wave, in the magnitude calculation. It is used at teleseismic distances from 16 to about 100 degrees, where this waveform starts to graze and then enter the core of the earth, changing its character. mb is defined in analogous fashion to Ms, with different correction factors.

Mw - "Moment Magnitude"- To avoid the saturation effect and standardize the magnitude scales, a magnitude scale based on seismic moment (Mo) was proposed by Kanamori (1977). The moment magnitude (Mw) scale is estimated using Mw = (log Mo –16) /1.5where Mo, is the seismic moment in dyne-cm. The moment magnitude scale is the most preferred magnitude scale in case of large earthquakes.

24 **What is the equivalent amount of energy of large events released with magnitude scale?**



25 What is a fault ?

Fault is a fracture or zone of fractures between two blocks of rock. Faults allow the blocks to move relative to each other. This movement may occur rapidly, in the form of an earthquake- or may occur slowly, in the form of creep. Faults may range in length from a few millimeters to thousands of kilometers. Most faults produce repeated displacements over geologic time.During an earthquake, the rock on one side of the fault suddenly slips with respect to the other. The fault surface can be horizontal or vertical or some arbitrary angle in between. 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.

26 What are the different types of faults?

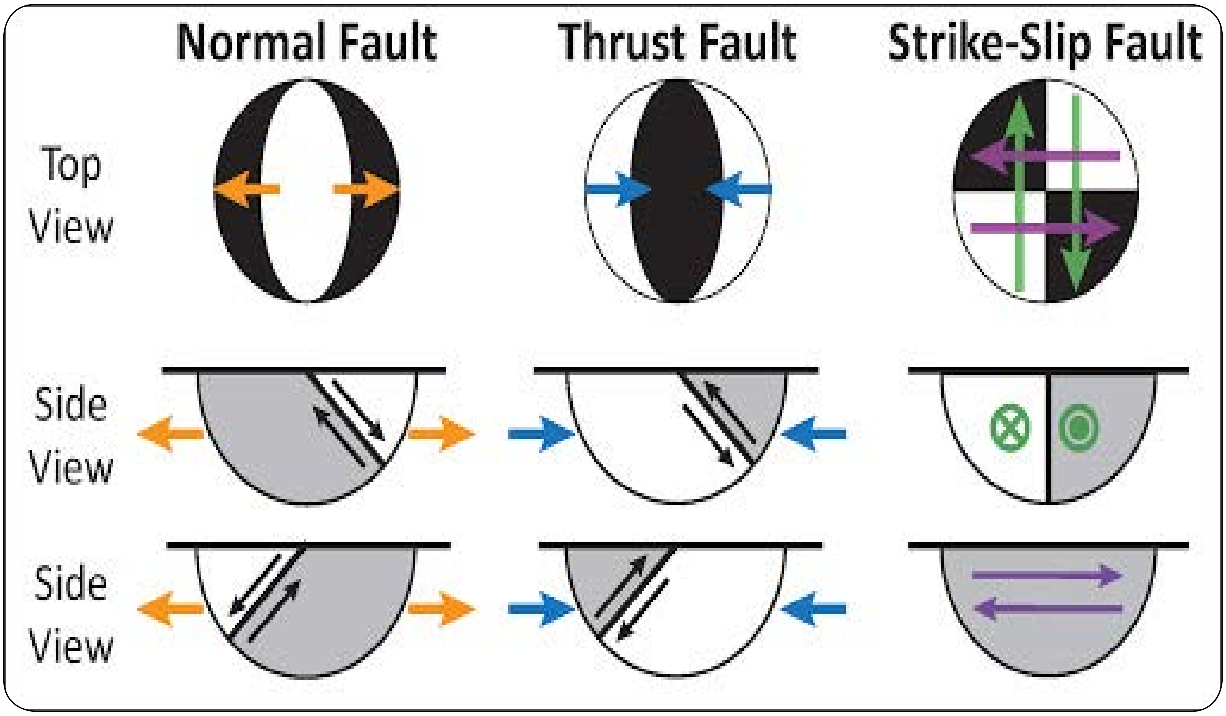
Normal Fault. A dip-slip fault in which the block above the fault has moved downward relative to the block below. This type of faulting occurs in response to extensionand is often observed along oceanic ridge systems.
Reverse Fault. A dip-slip fault in which the upper block, above the fault plane, moves up and over the lower block. This type of faulting is common in areas of compression, such as regions where one plate is being subducted under another as in Japan. When the dip angle is shallow, a reverse fault is often described as a thrust fault.
Left-Lateral Fault (Sinistral). A strike-slip fault on which the displacement of the far block is to the left when viewed from either side.
Right-Lateral Fault (Dextral). A strike-slip fault on which the displacement of the far block is to the right when viewed from either side. The San Andreas Fault is an example of a right lateral fault.Faults which show both dip-slip and strike-slip motion are known as oblique-slip faults.

27 What is meant by Focal Mechanism Solutions ?

The focal mechanism of an earthquake describes the deformation in the source region that generates the seismic waves. It refers to the orientation of the fault plane that slipped and the slip vector and is also known as a fault-plane solution. Focal mechanisms are derived from a solution of the moment tensor for the earthquake, which itself is estimated by an analysis of observed seismic waveforms. The focal mechanism can be derived from observing the pattern of «first motions», that is, whether the first arriving P waves break up or down.

28 Give some possible geometries of faulting for the three lower hemisphere earthquake focal mechanism solutions as shown below :

1. For normal fault : E dip 45 ^{o}, W dip 45 ^{o}
2. For thrust fault : E dip 45 ^{o}, W dip 45 ^{o}
3. For strike –slip : left lateral (Sinistral) E – W, right lateral (Dextral) N- S



29	**What is the different between First motion solution and Moment tensor solution ?**	

First motion solution. P wave polarity data. Initial rupture. Applicable to small events (M~1). Non—uniqueness. Difficulty in error estimation.
Moment tensor solution. Broadband waveform data. Averaged rupture. Not applicable to small events (M>3~4). Uniquely determined with variance reduction.

30 What was the first instrument that actually recorded an earthquake?

The earliest seismoscope was invented by the Chinese philosopher Chang Heng in A.D. 132. This was a large urn on the outside of which were eight dragon heads facing the eight principal directions of the compass. Below each dragon head was a toad with its mouth opened toward the dragon. When an earthquake occurred, one or more of the eight dragon-mouths would release a ball into the open mouth of the toad sitting below. The direction of the shaking determined which of the dragons released its ball. The instrument is reported to have detected an earthquake 400 miles away that was not felt at the location of the seismoscope. The inside of the seismoscope is unknown: most speculations assume that the motion of some kind of pendulum would activate the dragons

31 What are Forward and Inverse modelling in Earthquake Seismology ?

Forward modelling gives the distribution of velocity, density and attenuation coefficient with depth, and positions of all discontinuities, calculate travel times and amplitudes of some seismic phase (e.g. pP or SKS). This is relatively easy and always gives unique solution.
Inverse modelling gives the arrival times and amplitudes of several seismic phases on a number of stations, compute distribution of velocity, density and attenuation coefficient with depth, and positions of all discontinuities. This is very difficult and often does not give a unique solution. Instead, a range of solutions is offered, each with its own probability of being correct. The solution is better the more data we have. Seismic tomography Is an example of inverse modelling which gives us 3-D or 2-D images of shallow and deep structures in the Earth. They may be obtained using earthquake data, or explosions (controlled source seismology).

32 **What are Source Parameters for an earthquakes?**

Hypocenter (Latitude, Longitude, Depth); Origin Time (Start time of earthquake) ; Magnitude (Size of earthquake) ; Faulting Type (focal mechanism); Faulting Size (Length, Wide and Dislocation) ; Seismic moment (Size of earthquake); Stress Drop (Shear Stress Change) ; Source Process (Rupture Process).

33 **Define the relationships among elastic moduli?**

E : Young's Modulus, a measure of a material's resistance to uniaxial tensile or compressional longitudinal stresses $E = \mu(3\lambda + 2\mu) \div (\lambda + \mu)$

K : Bulk modulus, the modulus of incompressibility or bulk modulus, a material's resistance to volume change under stress $K = \lambda + 2/3\,\mu$

σ : Poisson's Ratio, a measure of the transverse to longitudinal strain under uniaxial longitudinal stresses. $\sigma = \lambda / 2(\lambda + \mu)$, material for which $\lambda = \mu$, giving $\sigma = 0.25$

λ: the Lamé modulus of incompressibility, another measure of a material's resistance to volume change under stress. For fluids, $\lambda = \kappa$. , $\lambda = E\sigma / (1+\sigma)(1-2\sigma)$

34 How do earthquakes cause damage?

Most earthquake damage is caused by ground shaking. The magnitude or size (energy release) of an earthquake, distance to the earthquake focus or source, focal depth, type of faulting, and type of material are important factors in determining the amount of ground shaking that might be produced at a particular site. Where there is an extensive history of earthquake activity, these parameters can often be estimated. In general, large earthquakes produce ground motions with large amplitudes and long durations. Large earthquakes also produce strong shaking over much larger areas than do smaller earthquakes. In addition, the amplitude of ground motion decreases with increasing distance from the focus of an earthquake. The frequency content of the shaking also changes with distance. Close to the epicenter, both high (rapid) and low (slow)-frequency motions are present. Farther away, low-frequency motions are dominant, a natural consequence of wave attenuation in rock. The frequency of ground motion is an important factor in determining the severity of damage to structures and which structures are affected.

35 What are Macroseismology and Microseismicity?

Macroseismology deals with effects of earthquakes on humans, animals, objects and surroundings. The data are collected by field trips into the shaken area. The effects are expressed as earthquake Intensity at each of the studied places. Intensity is graded according to macroseismic scales – (MCS), (MSK), (MMS), European Macroseismic Scale (EMS).Microseismicity describes the occurrence and frequency of small local earthquakes (micro quakes). These are normally so weak that they cannot be felt on the surface and can only be recorded with highly sensitive instruments. Many quakes are in fact so weak that they are hidden in the station-specific background noise and can thus not be distinguished as signals.

36 **Why is the liquid outer core through to be largely iron and nickel?**

Iron is a fairly abundant element in the universe, its density is just about right for an iron core to account for the total mass of the earth given the ferromagnetisian silicate composition of the mantle and iron is a good conductor electricity which is necessary in order to explain the origin of the earth's magnetic field.Meteorites that contain iron always contain a small proportion of nickel as well which suggest that these iron and nickel occur together in the solar system.

37 **Classify earthquakes according to their focal depths?**

1. **Shallow-focus earthquakes :** have their foci at a depth between 0 and 70 Km. and take place at oceanic ridges and transform faults as well as at subduction zones.
2. **Intermediate-focus earthquake :** focal depth between 71 and 300 Km.
3. **Deep-focus earthquakes :** focal depth greater than 300 Km. Most earthquakes originate within the crust. At depth beneath the Moho (Crust-Mantle boundary), the number falls abruptly and dies away to zero at a depth of about 700 Km. Earthquakes along ridges usually occur at a depth of about 10 Km or less and are of moderate size. Transform faults generate large shocks at depth down to about 20 Km. The largest earthquakes occur along subduction zones.

38 **Classify earthquakes according to their epicentral distances?**

1. Local events Δ <1000 km
2. Regional events1000 km < Δ <3000 km
3. Teleseismic events: 3000 km < Δ <12000 km.

Shadow zone between (12000- 16000 km).

39 **Can climate change or hot weather cause earthquakes?**

No, climate change or hot weather does not cause earthquakes. Earthquakes are caused by processes deep within the Earth while hot weather and climate change are related to the atmosphere.
No. Earthquakes can occur at any time of the year and at any time of the day or night. Earthquakes occur under all weather conditions, sunny, wet, hot, or cold–without special tendency.

40 **What are a seismometer, seismograph, and a seismogram?**

A seismometer is a sensor that measure vibrations of the Earth. A seismograph is an instrument that records these vibrations from a seismometer. A seismogram is the visual record of the Earth's vibrations produced by a seismograph

41 What are current seismic arrays worldwide?

YKA or Yellowknife Seismological Array is a medium size seismic array established in Canada, in 1962.YKA currently consists of 19 short period seismic sensors plus 4 broadband seismograph.
LASA or Large Aperture Seismic Array is the first large seismic array. It was built in Montana, USA, in 1965.
NORSAR or Norwegian Seismic Array was established at Kjeller, Norway in 1968 as part of the Norwegian-US agreement for the detection of earthquakes and nuclear explosions.
NORES and ARCES. NORES was the first regional seismic array constructed in southern Norway in 1984. A sister array ARCES was established in northern Norway in 1987. NORES and ARCES are small aperture arrays.
GERES is a small aperture array built in the Bavarian Forest near the border triangle of Germany, Austria and Czech, in 1988. It consists of 25 individual seismic stations arranged in 4 concentric rings with radius of 200m, 430m, 925m and 1988m.
SPITS is a very small aperture array at Spitsbergen, Norway. It was originally installed in 1992 and upgraded to International Monitoring System (|IMS) standard in 2007 by NORSAR.

42 What does a negative magnitude mean?

As magnitude calculations are based on a logarithmic scale, a ten-fold drop in amplitude decreases the magnitude by 1. At a station close to a magnitude 2 earthquake, the ground moves about 400 micrometers. So a ground movement of 40 micrometers would signify a magnitude 1 earthquake, 4 micrometers a magnitude 0 earthquake and 0.4 micrometers a magnitude -1 earthquake. Therefore, magnitude scales can be used to describe very small events expressed in negative numbers. These events are not felt by humans.

43 How is seismograph data interpreted?

In order to determine how big and where an earthquake has occurred, we must know exactly when our seismographs recorded it. By having data from many seismographs, we can determine the location by knowing how fast the seismic waves travel through the earth finding their common point of origin. The amplitude of the traces on the seismograms is used to determine its magnitude. Once we have this information, it is plotted on maps and passed on to emergency management agencies.

44 Foreshocks, aftershocks - what is the difference?

Foreshocks are earthquakes that precede larger earthquakes in the same location. An earthquake cannot be identified as a foreshock until after a larger earthquake in the same area occurs.

Aftershocks are smaller earthquakes that occur in the same general area during the days to years following a larger event or "mainshock." They occur within 12- fault lengths away and during the period of time before the background seismicity level has resumed. As a general rule, aftershocks represent minor readjustments along the portion of a fault that slipped at the time of the mainshock. The frequency of these aftershocks decreases with time. Historically, deep earthquakes (>30 km) are much less likely to be followed by aftershocks than shallow earthquakes.

45 What is the difference between aftershocks and swarms?

Aftershocks are a sequence of earthquakes that happen after a larger mainshock on a fault. Aftershocks occur near the fault zone where the mainshock rupture occurred and are part of the "readjustment process" after the main slip on the fault. Aftershocks become less frequent with time, although they can continue for days, weeks, months, or even years for a very large mainshock.

A swarm is a sequence of mostly small earthquakes with no identifiable mainshock. Swarms are usually short-lived, but they can continue for days, weeks, or sometimes even months. They often recur at the same locations. Most swarms are associated with geothermal activity.

46 Does a swarm mean the 'big one' is coming?

No. Although large earthquakes are sometimes preceded by smaller associated earthquake swarms (called foreshocks), swarms of seismic activity do not necessarily indicate that a large earthquake is to follow.

47 How long do earthquakes last?

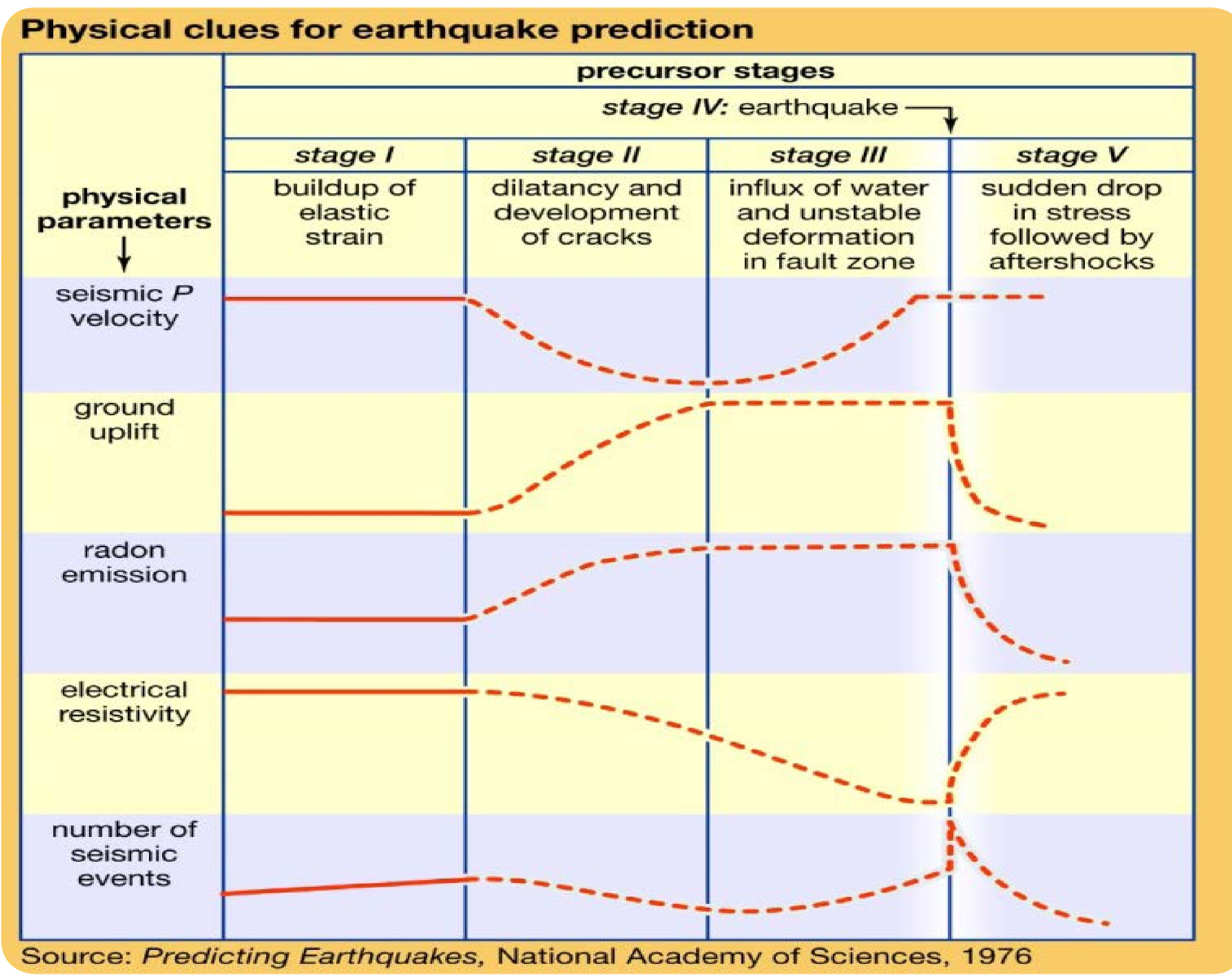
How long earthquakes last varies depending on the size of the earthquake. Earthquakes may last seconds to minutes. While the shaking of small earthquakes typically lasts only a few seconds, strong shaking during moderate to large earthquakescan lasts couple minutes.

48 Can earthquakes be predicted?

Although it is known that most global earthquakes will concentrate at the plate boundaries,Scientists are unable to predict the location, time and date of when an earthquake will occur, however, forecasts can be made based on past patterns of activity in a region. However, phenomena that could earthquakes are being monitored, including earthquake lights, earthquake clouds, elevated concentrations of radon, seismic quiet, electromagnetic signals, conspicuous animal behavior and foreshocks, which sometimes precede main quakes. But so far no patterns have been observed that could enable us to predict earthquakes reliably.

Most current research is concerned with minimizing the risk associated with earthquakes, by assessing the combination of seismic hazard and the vulnerability of a given area.

Generally, all attempts to predict earthquakes have, however, been generally considered as failures and it is unlikely that accurate prediction will occur in the near future. Efforts will, instead, be channeled into hazard mitigation. Earthquakes are difficult or impossible to predict because of their inherent random element and their near-chaotic behavior.


Physical clues for earthquake prediction
precursor stages
stage IV: earthquake
physical parameters
stage I
buildup of elastic strain
stage II
dilatancy and development of cracks
stage III
influx of water and unstable deformation in fault zone
stage V
sudden drop in stress followed by aftershocks
seismic P velocity
ground uplift
radon emission
electrical resistivity
number of seismic events
Source: Predicting Earthquakes, National Academy of Sciences, 1976

49 Can geothermal exploration cause earthquakes?

Yes, geothermal exploration does have the capacity to trigger earthquakes. Deep earthquakes occurring below geothermal exploration depths are unlikely to have been caused by geothermal exploration.

50 How you could determine 3-D structure of earth's interior?

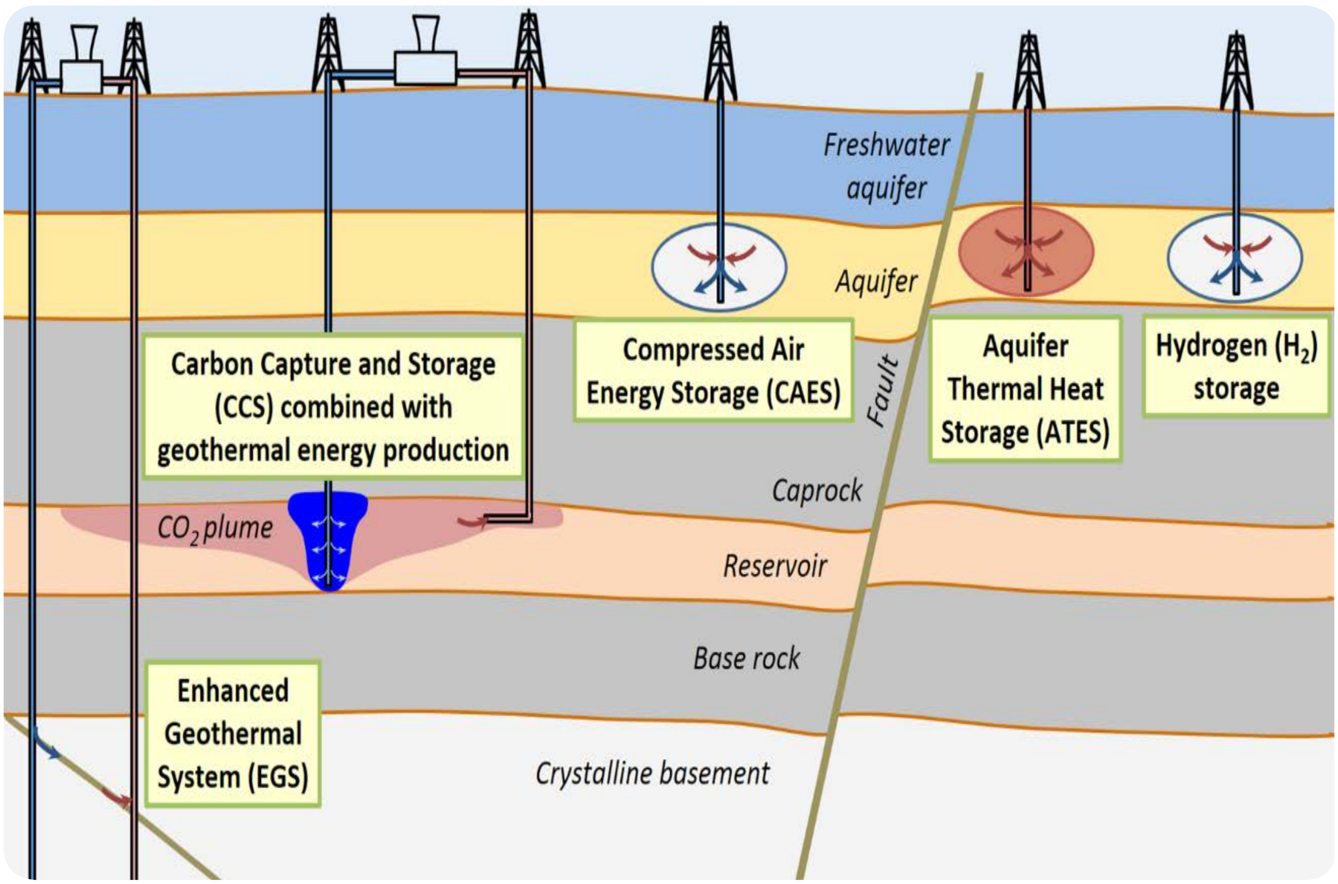
The 3-D structure of the Earth's interior can be determined by inverting the travel-time perturbations with respect to a spherically symmetric velocity model (e.g. PREM). The positiveand negativevelocity perturbations are thought to represent cold(dense) or hot (buoyant) regions, respectively.There is remarkable correlation between fast regions and subductin zones as well as slow regions with hot-spot (plume) activity.

51 What is Seismic Tomography?

Tomography can be defined as the analysis of lateral velocity variations fits this definition, if the travel time equation is perturbed about a reference velocity model. The field in this case is slowness perturbations, and the observations are travel time deviations.' Seismic tomography is used to map velocity- and density contrasts to find geological structures, caverns and stress anomalies. Repetition of tomographic imaging allows to identify regions of fast-changing stress conditions and to monitor the efficiency of stress release operations

52 **What is meant by induced seismicity?**

Induced seismicity refers to minor earthquakes and tremors that are caused by human activity that alters the stresses and strains on the Earth's crust. There are many different ways in which human activity can cause induced seismicity including geothermal operations, reservoir impoundment (water behind dams), waste water injections, and oil and gas operations such as hydraulic fracturing. Most induced seismicity is of a low magnitude. Earthquakes caused by human activity can be a significant hazard. A recent survey showed at least 10 earthquakes of magnitude 5 or greater could be attributed with some confidence to reservoir impoundment. These include the large events at Koyna, India (**M 6.5**) and Kremasta, Greece (**M 6.3**). Many smaller events have been shown to be caused by impoundment. Earthquakes with M greater than 5 are capable of causing significant loss to structures. Earthquakes may also be caused by the injection or withdrawal of fluids from underground reservoirs and in some cases these events have been felt in urban areas. The possibility of inducing significant earthquakes should be considered when reservoir impoundment, fluid withdrawal or fluid injection are contemplated in populated areas. Withdrawal of fluids may also cause a seismic faulting, that is slow fault movement unaccompanied by ground shaking.



Freshwater aquifer
Aquifer
Compressed Air Energy Storage (CAES)
Aquifer Thermal Heat Storage (ATES)
Hydrogen (H_2) storage
Carbon Capture and Storage (CCS) combined with geothermal energy production
Fault
Caprock
CO_2 plume
Reservoir
Base rock
Enhanced Geothermal System (EGS)
Crystalline basement

53 **What is Magnitude Saturation?**

As mb "body wave magnitude "above 6.2 and Ms "surface wave magnitude" above 8.3, there is an abrupt change in the rate at which frequency of occurrence decreases with magnitude. This change is not observed for moment-magnitude, $M_{W.}$

54 **What is Omori's Law?**

the rate of aftershocks decreases hyperbolically with time.Aftershock rate decays intime asR (t)=K / (t+c)p . It shows a relation between the numbers of aftershocks occurring and passing time t after the mainshock, which will be proportional to that time t taken to the negative power of p, a constant. This means that aftershock numbers will be rapidly decreased at first, but will gradually become less severe until it levels out.Aftershockscan follow Omori's law for hundreds ofyears. Omori's law is empirical. No one has been able toderive it.

55 **What is the Polarity?**

The polarity of initial P-wave pulse form an earthquake takes either of two opposite polarities: compressional (up or pushed) and dilatational (down or pulled). The first P-wave from an explosion to arrive at any seismic station, the polarity will be positive or up since radiation of seismic wave due to nuclear explosion is compressional.

56 How to determining Fault Plane Solution using polarity of P-wave?

To determine fault plane solution using P-wave polarity as follows: 1.Determining the polarity of P-wave first motion. 2.Calculating azimuth and take-off angle for each stations.3.Plotting the information of polarity of P-wave for each stations on the equal-area projection chart. 4.Selecting one nodal plane (A)5.Calculating pole of nodal plane (A) that is cross point between the another nodal plane (B) and the additional plane. 6.Selecting the another nodal plane (B).

57 Determine focal mechanism solution using polarity of first P-wave?

1. Many stations (depend on station coverage.
2. Using polarity and amplitude of first P-wave.
3. Five or more stations.
4. Using waveform of P-wave and S-wave.
5. Five or more . Components.
6. Using overall waveform.
7. One or more stations.

58 Determine focal mechanism solution using Composite P-first motion method?

In the case of a sparse local seismic network, P-first motion data may not be enough to determine reasonable solution. If we assume that the focal mechanisms for many earthquakes in close area are identical, the up-down information for each earthquake can be drown in same focal mechanism diagram. Using this focal mechanism diagram, we can determine the composite focal mechanism occurred in special area.

59 Define Frequency- Magnitude relation?

This relation is known as Gutenberg-Richter Law: logN (M) = a – bM. Relation- logN vs. M are typically modeled with a Gutenberg-Richter relation. M is the earthquake magnitude; N is the number of earthquake peryear of magnitude.a is called the "productivity" ; b is called the "b-value", and is typically in the range of 0.8-1.1. The b-value has served as a kind of tectonic parameter 1.8-1.0 oceanic ridge 1.0-0.7 interplate0.7-0.4 intraplate.

60 What is threshold magnitude?

Threshold means a value which must be exceeded to begin for earthquake statistics. It means that threshold value represents minimum magnitude which indicates the value for complete data. At least fifty numbers as suggested by USGS for earthquake calculations to give more precise information on b-value.

61 What is Double Couples of plane solution?

The radiation patterns of P and S waves due to motion ona fault plane is what would occur for a pair of forcecouples,which are pairs of forces in opposite directions but only asmall distance apart.However, due to the conservation of angular momentum,force couples do not exist in isolation. If one couple isoriented in the slip direction, then another must exist in theperpendicular auxiliary plane. This pair of force couplesare referred to asdouble couples.

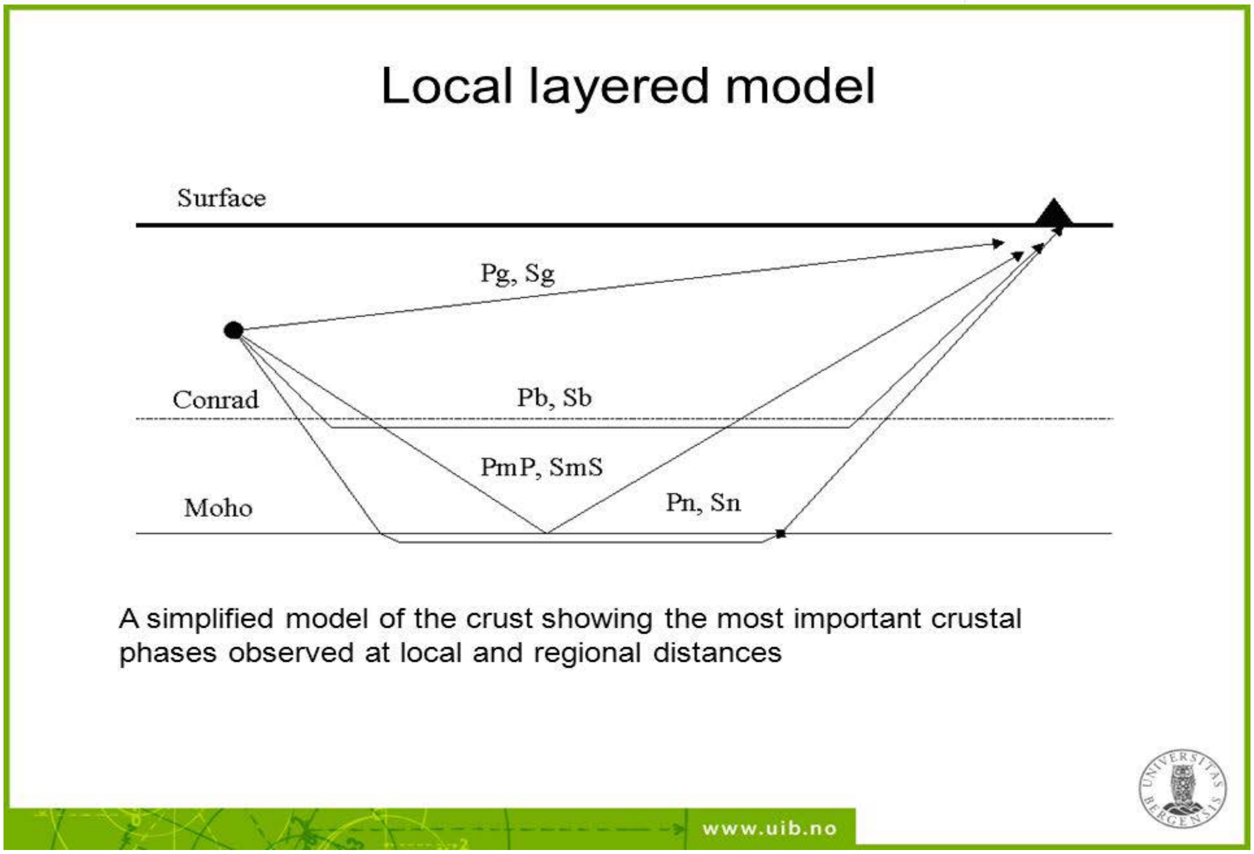
62 Define Lg and Rg waves?

Lg waves are one kind of guided waves in the continental crust. These are essentially high frequency Love waves at regional distances of thick continental crust. It travels over long continental paths with relatively little loss of energy. The subscript Lg refers to granitic layer. Lg waves being critically incident on Moho discontinuity propagate by multiple reflections within the crust with a typical velocity 3.5 km/s. Lgis usually recorded at epicentral distances of about 50 and larger.

Rg waves are high frequency fundamental mode of Rayleigh waves are labeled as Rg. The presence of short period Rg in the seismogram is a reliable indicator of very shallow event (like earthquake, nuclear explosion, mine burst etc.). In other words, absence of Rgindicatesdeeper natural event. The short period Rg waves travel as guided waves through continental crust with velocity 3 km/s; their range of propagation is limited to 600 km or less.

63 What are the characteristics of Pn and Sn waves?

In 1909, Mohorovičić identified refracted Pn and Sn arrivals from the interface between the crust and mantle, the layers of lower and higher velocity. He found that there is a critical distance, generally in the range 100-150 km, beyond which P and S waves are refracted, and arrive with small and long period motion. He designated these phases as Pnand Sn. respectively. These are also called head waves.



64 What are Pg, Sg and P*, S* waves?

Conrad observed a small sharp impulse between Pn and P which he named P*, and attributed it to refraction through an intermediate layer with a velocity of about 6.5 km/s. The upper boundary of this layer had been called Conrad discontinuity which separates predominantly granitic layer above it and basaltic layer below, within the crust, and given Pg, Sg and P*, S*. The Pg and Sg are practically the same as P and S.The conversion of seismic phases P to S (Ps) or S to P (Sp) at the Moho discontinuity is well established. The reflected rays from the Moho discontinuity are labeled as Pp (or PmP) and Ss or (SmS).

65 **Define PPn, SPn and T waves?**

PPn Depth phase that leaves the focus upward as P, is reflected as P at the free surface and continues further as Pn. **SPn** Depth phase that leaves the focus upward as S, is reflected and converted into P at the free surface and continues further as On.
T Compressional wave propagating through the ocean(Tertiary wave). T phases are occasionally observed even at larger teleseismic distances.

66 **What is meant by Wave Attenuation and Scattering?**

Seismic attenuation is caused by either intrinsic anelasticity or scattering effects. The intrinsic anelasticity is associated with small scale crystal dislocations, friction and movement of interstitial fluids. This effect is called intrinsic attenuation.
The scattering effect is an elastic process of redistributing wave energy by reflection, refraction and conversion that occur at discontinuities in the medium.
This scattering of energy at small scale heterogeneities along travel paths reduce amplitudes of the seismic waves. These effects are called scattering attenuation.

67 What is the Quality Factor (Q)?

The wave attenuation is usually expressed in terms of dimensionless quality factor Q, (Internal friction) where **$Q = 2\pi E/\Delta E$.** The ΔE is the dissipated energy per cycle. Large energy loss means low Q and vice versa, i.e. Q is inversely proportional to the attenuation. that for a constant value of Q a high frequency wave attenuate more rapidly than low frequency wave.Q is observed to be dependent on frequency.At higher frequency, in general, Q increases with frequency. In the Earth, Q is a function of depth, with the lowest Q values occurring in the upper mantle.

In general, Q increases with seismic impedance, i.e. with increased material density and velocity. The Q for P-waves in the Earth is systematically larger than Q for S-waves and thus refer to corresponding Qp and Qs respectively; $Q_p \sim 9/4\ Q_s$.

68 What is Seismic Diffraction?

Seismic Diffraction is defined as the transmission of energy by nongeometric ray paths. In seismology, diffraction occurs whenever the radius of curvature of a reflecting interface is less than the wavelengths of the propagating wave.

69 Can Origin time of an earthquake be determined?

The origin time of an earthquake can be determined with a very simple graphical technique, called Wadati plot (Wadati, 1933). The time separation of the P and S phase (ts-tp) is plotted against the arrival time of the P-wave. Since ts-tp = 0 at the hypocentre, a straight line fit on the Wadati diagram gives the origin time at the intercept with the P-arrival-time axis.

70 Does the earth open up during an earthquake?

No! A common misconception is that of a hole in the ground that opens during an earthquake to swallow up unfortunate victims. After a strong earthquake, some cracks may be seen on the ground or in basements. These are not faults, nor are they crevasses ready to close up again. Theses cracks are probably due to soil settlement caused by the ground shaking.

71 Where do earthquakes occur?

Earthquakes occur all over the world; however, most occur on active faults that define the major tectonic plates of the earth. Circum-Pacific seismic belt (Ring of Fire), is found along the rim of the Pacific Ocean, where about 81 percent of largest earthquakes occur. This belt exists along subducting boundaries of tectonic plates. Earthquakes in these subduction zones are caused by slip between plates and rupture within plates.

The Alpide earthquake belt extends from Java to Sumatra through the Himalayas, the Mediterranean, and out into the Atlantic. This belt accounts for about 17 percent of the world's largest earthquakes, including some of the most destructive earthquakes. The third prominent belt follows the submerged mid-Atlantic Ridge. The ridge marks where two tectonic plates are spreading apart (a divergent plate boundary). The remaining shocks are scattered in various areas of the world as an Intraplate earthquakes.

72 **Define briefly Earth’s free oscillations?**

Free Oscillation of the earth was considered to be transient phenomena occurring after large earthquakes. An analysis of records of strong motion earthquakes shows that Earth is freely oscillating at an observable level even in seismically inactive periods. The observed oscillations are the fundamental spheroidal modes at frequencies between 2 and 7 millihertz. It depends on broad averages of the Earth’s structural parameters - Not affected by limitations of data coverage due to uneven distribution of earthquakes and stations. It Provides a method for calculation of theoretical seismograms - Intrinsic low pass filters of Earth’s structure.Generally, these oscillations (normal modes) correspond to standing surface waves of the longest possible wavelength and lowest frequency (periods up to about 1 hour).The longest period oscillations are only excited in a measurable way by the largest earthquakes. The complete set of normal modes forms a basis for the description of any general elastic displacement that can occur within the Earth, and this property is used to calculate theoretical seismograms for long-period surface waves. Similar to the separation of Love and Rayleigh surface waves, the normal modes separate into two distinct types of oscillation: spheroidal, corresponding to standing Rayleigh waves, and toroidal, corresponding to standing Love waves.

73 **How to determine Earth structure from observed seismograms using travel times?**

1. Determine epicentral distance (from P and S or Rayleigh, then compare with travel time tables),
2. Get travel times for other phases PP, ScS, pP, sS, determine differential travel times (e.g. pP-P, sS-S) to estimate source depth.
3. Determine travel time perturbations from spherically symmetric model (e.g. iasp91, PREM).

74 What are functions of Receiver functions?

Receiver functions are time series, computed from three-component seismograms that show the response of Earth structure beneath a station. The waveform isolates P-to-S converted waves that reverberate in the structure beneath the seismometer.
Modeling the amplitude and timing of the reverberations can provide valuable constraints on the underlying geology (H, Vp/Vs). The main features of the structure can be approximated by a sequence of horizontal layers and the arrivals generated by each sharp boundary.

75 Provide seismic evidences of solid inner core?

Evidence for a solid inner core:
1. P–waves transmitted to depths of 5154 km, the depth to the inner core, are sharply refracted; these represent the phasePKIKP .
2. P–waves corresponding to reflections upwards off the inner core (the phase PKiKP) are also regularlyrecorded.
3. The sudden increase in P–wave velocity suggests a fluid–solid boundary.
4. There is some evidence that P–waves incident on the inner core generate mode–converted refracted S–waves within theinner core (the phase PKJKP).
5.Models of the periods of Earth oscillations employ a solid inner core.

76 Where is shadow zone is located?

The P– and S–wave shadow zones from the core. Because the P–wave velocity in the core is less than that in the lower mantle, the core casts a shadow. P–waves incident on the core are refracted towards the center of the Earth, leaving a gap in the P–wave travel time curve. The shadow appears at geocentric distances from the source between 103° and 143°. 103° is the distance at which the P–wave ray through the mantle just grazes the core; 143◦is the distance at which the first PKP wave emerges.

In practice some P–waves are diffracted a few degrees beyond 103◦and some PKP waves diffract to distances less than 143° Since the outer core cannot transmit S–waves, there is a complete shadow for S–waves. The only S–waves that are recorded in the shadow zone are waves that have bounced around between the core and surface and those that were mode converted to S on emerging from the outer core

77 Why can not earthquake occur at great depth in the earth?

The greater the depth, the greater the pressure and hence the greater the force needed to produce the sudden movement along a fault that causes an earthquake. At extreme depths it is impossible for the force needed to be generated.

78 **How does the radius of the earth's core compare with the radius of the earth as a whole?.**

How does the mass of the core compared with the mass of the earth as a whole?The core's radius is about 55% of the radius of the earth. The core's mass is about one-third the mass of the earth.

79 **What is meant by Dispersion?**

seismic surface waves of both Rayleigh and Love type, are dispersive; that is, their speed ofpropagation depends on their wavelength. Consequently surface wave trains spread out, or disperse, as they travel away fromtheir source, the faster waves arriving first and the slower waves becoming progressively delayed while body-wave arrivals with no or negligibly small dispersion only (due to intrinsic attenuation) appear in seismic records as rather impulsive onsets or short transient wavelets,the dispersion of surface waves forms long oscillating wave trains. Their duration increases with distance.

80 **Define D'' zone?**

A boundary layer called D" just above the core–mantle boundary that is of great interest since it isspeculated that mantle plumes may originate there and it may be the eventual "sink" for subducted slabs. The mid-mantle shows little lateral heterogeneity.

The lowermost mantle (D") hast strong (possibly >10%) lateral velocity perturbations. The may originate in a thermal boundary layer or from subducted lithosphere

81 What is seismic anisotropy?

Seismic anisotropy is the dependence of velocity on propagation direction or angle of the seismic signal within the geological medium.Shear wave splitting of the SKS phase indicates seismic anisotropy in the upper mantle. The alignment of the anisotropic symmetry system is thought to be correlated with tectonic plate motion. The Earth's inner core shows considerable anisotropy. Time-dependent differential travel times have led to the speculation that the Earth's inner core is rotating faster than the mantle.

82 Describe Earthquake Classification?

Earthquakes can be classified according to location, epicentral distance, focal depth and magnitude:

1. **Based on location** : (i) Interplate(ii) Intraplate
2. **Based on epicentral distance :** (i) Local earthquake < 1 degrees
   - (ii) Regional earthquake 1–10 degrees,
   - (iii) Teleseismic earthquake >10 degrees
3. Based on focal depth :
   - (i) Shallow depth 0–70 km
   - (ii) Intermediate depth 71–300 km
   - (iii) Deep earthquake > 300 km
4. Based on magnitude :
   - (i) Micro earthquake M < 3
   - (ii) Intermediate earthquake 3–4
   - (iii) Moderate earthquake 5–5.9
   - (iv) Strong earthquake 6–6.9
   - (v) Major earthquake 7–7.9
   - (vi) Great earthquake >8

83 Can people cause earthquakes?

Yes! Minor earthquakes have been triggered by human activities such as mining (rock bursts and cavity collapse), the filling of reservoirs behind large dams, and the injection of fluids into wells for oil recovery or waste disposal. Large dams hold back enormous quantities of water. Some of this water may penetrate into cracks in the underlying rock, and sometimes this may trigger small earthquakes under or very near the reservoir. Following an underground nuclear explosion, small earthquakes have often been recorded near the test site. These are due to the collapse of the cavity created by the explosion. Man-made earthquakes always occur close to the site of the activity. There is no link between human activities like these and earthquakes occurring hundreds or thousands of kilometers away.

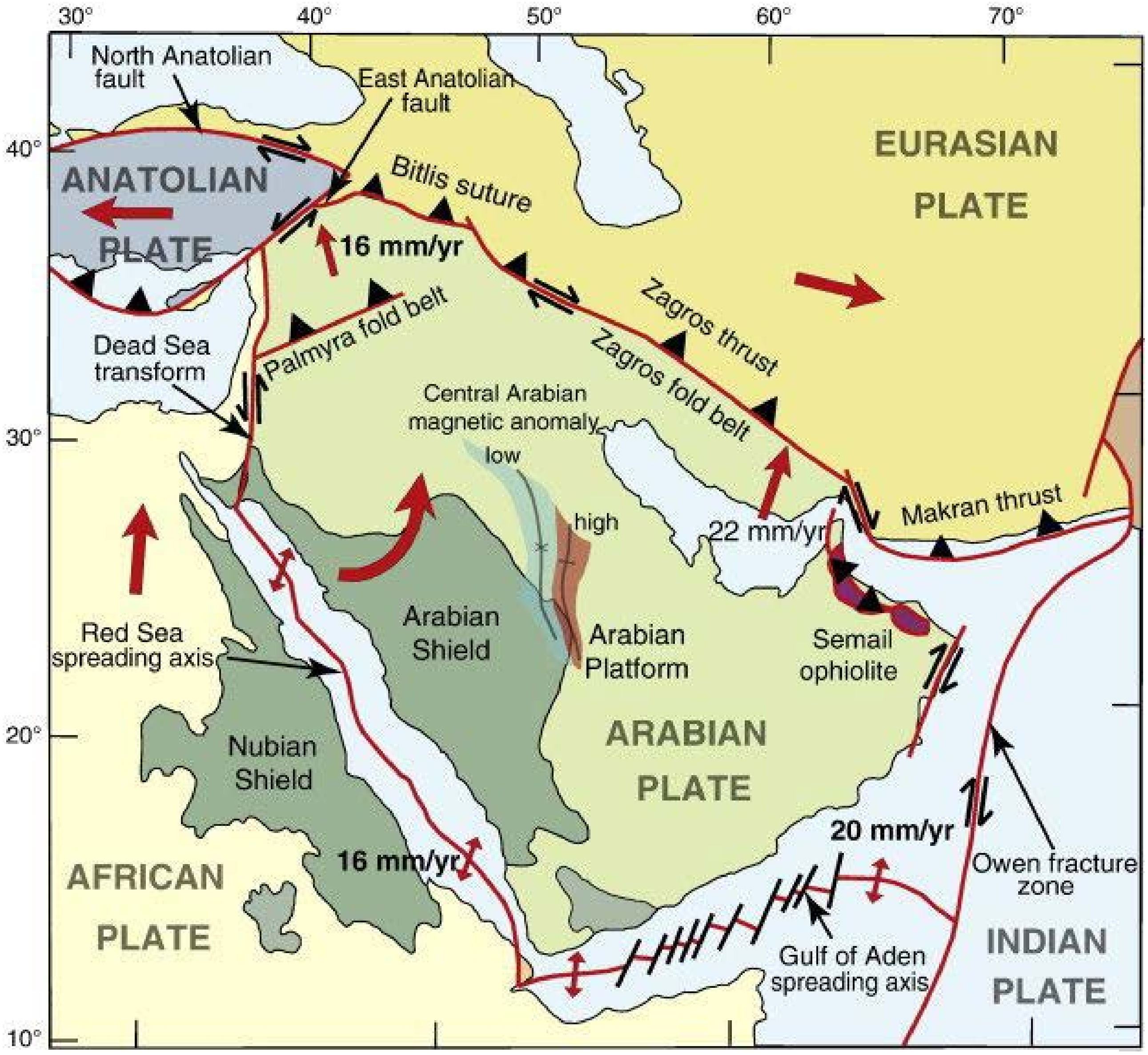
84 Is there a maximum magnitude for an earthquake?

Though theoretically there is no mathematical limit with the magnitude calculation, physically there is a limit. The magnitude is related to the surface area of the blocks of rock which rub together and in doing so give rise to seismic waves. Since the tectonic plates have finite dimensions, the magnitude must therefore also reach a maximum. It is believed that the greatest earthquakes can reach magnitude 9.5, which corresponds to the magnitude of the Chilean earthquake described below.

85 Discuss briefly Arabian plate boundaries?

The Arabian Plate is one of the tectonic plates that form the earth's crust. It moves northeastward as a result of the eruption of magmas along the Red Sea rift, which spreads annually at a rate of approximately 15 mm.

Arabian Peninsula is part of the so-called Arabian Plate. It is bordered by three types of tectonic boundaries: divergent, convergent, and transform fault boundaries. The plate is bounded from the west by the Red Sea floor spreading zone and from the south by the Gulf of Aden floor spreading zone, and in both regions, these parts of the Arabian Plate are larger. The Zagros and Makran Mountains in Iran and the Taurus Mountains in southern Turkey are, respectively, the eastern and northern boundaries of the Arabian Plate, which are classified as convergent plate boundaries that represent the zone of collision between the Arabian Plate and the Eurasian Plate. The Arabian Plate is bounded from the northwest by a left-lateral transform fault boundary, called the Dead Sea Rift, that extends from the northern end of the Red Sea to the Taurus Mountains in southern Turkey through the Dead Sea. The plate is bounded from the southeast by a right-lateral transform fault boundary that extends from the eastern end of the Gulf of Aden to the eastern end of the Makran Mountains, called the Owen Fault.


30°
40°
50°
60°
70°
40°
30°
20°
10°
North Anatolian fault
East Anatolian fault
ANATOLIAN PLATE
Bitlis suture
16 mm/yr
EURASIAN PLATE
Zagros thrust
Zagros fold belt
Palmyra fold belt
Dead Sea transform
Central Arabian magnetic anomaly
low
high
22 mm/yr
Makran thrust
Red Sea spreading axis
Arabian Shield
Arabian Platform
Semail ophiolite
Nubian Shield
ARABIAN PLATE
20 mm/yr
Owen fracture zone
AFRICAN PLATE
16 mm/yr
Gulf of Aden spreading axis
INDIAN PLATE

86 Why is it considered likely that the earth's outer core is liquid?

Transverse waves can not propagate through a liquid, and it is observed that S waves, which are transverse are unable to pass through the core although P waves which are pressure waves are able to. In support of the idea that the core is a liquid is the observation that the earth's magnetic field which originates in its interior, fluctuates in both magnitude and direction, which is hard to explain if the interior is solid but easy to explain if some of the interior is an electrically conducting liquid.

87 What are Microseisms and Microearthquakes?

A microseism is defined as a faint earth tremor caused by natural phenomena. The term is most commonly used to refer to the dominant background seismic noise signal on Earth, which are mostly composed of Rayleigh waves and caused by water waves in the oceans and lakes. Thus a microseism is a small and long-continuing oscillation of the ground.

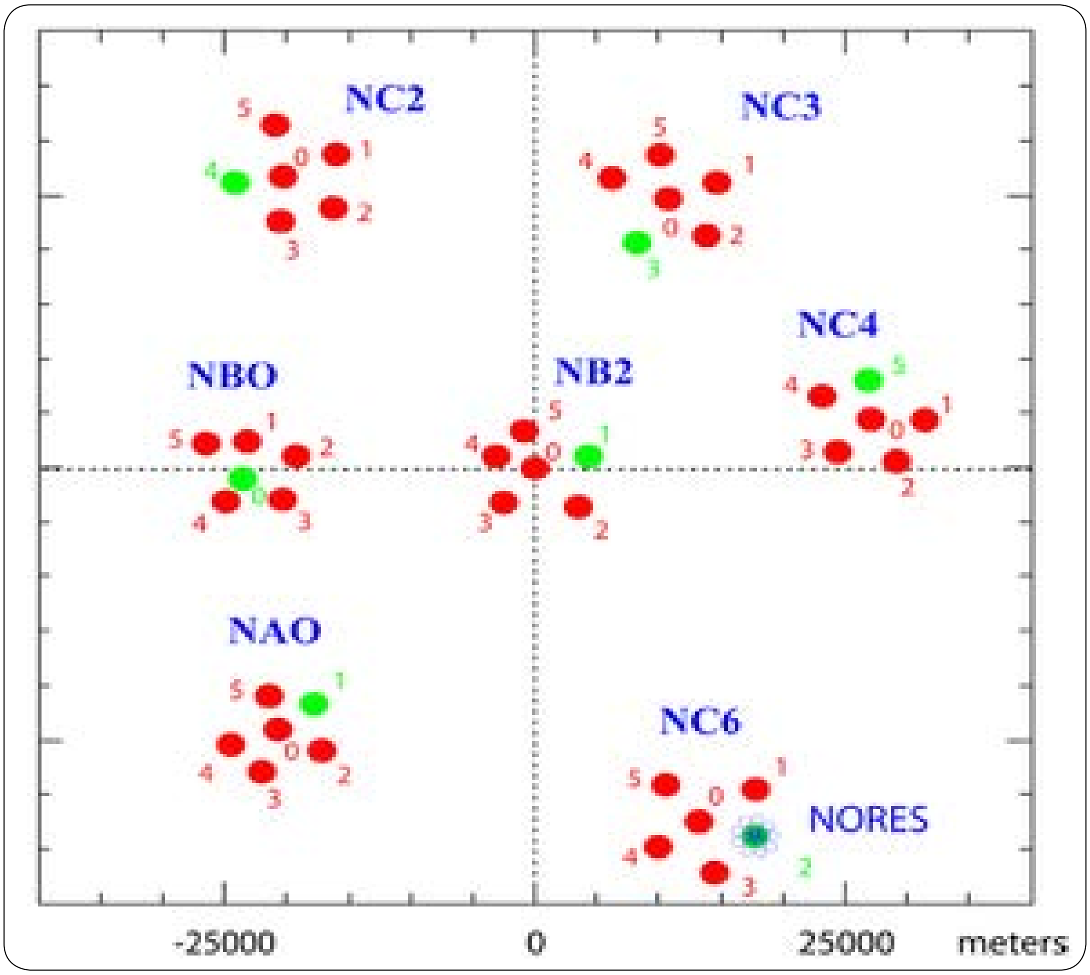
A microearthquake is a very low intensity earthquake which is 2.0 or less in magnitude. They are very rarely felt beyond 8 km from their epicenter. They may also be seen as a result of underground nuclear testing or even large detonations of conventional explosives for producing excavations. They normally cause no damage to life or property, and are very rarely felt by people. Microquakes occur often near volcanoes as they approach an eruption, and frequently in certain regions exploited for geothermal energy.

88 **What is a seismic array ?**

A seismic array is a system of linked seismometers arranged in a regular geometric pattern (cross, circle, rectangular etc.) to increase sensitivity to earthquake and explosion detection.

A seismic array differs from a local network of seismic stations mainly by the techniques used for data analysis. The data from a seismic array is obtained using special digital signal processing techniques such as beamforming, which suppress noises and thus enhance the signal-to-noise ratio (SNR). The earliest seismic arrays were built in the 1950s in order to improve the detection of nuclear tests worldwide. Many of these deployed arrays were classified until the 1990s.

Today they become part of the IMS as primary or auxiliary stations. Seismic arrays are not only used to monitor earthquakes and nuclear tests, but also used as a tool for investigating nature and source regions of microseisms as well as locating and tracking volcanic tremor and analyzing complex seismic wave-field properties in volcanic areas.

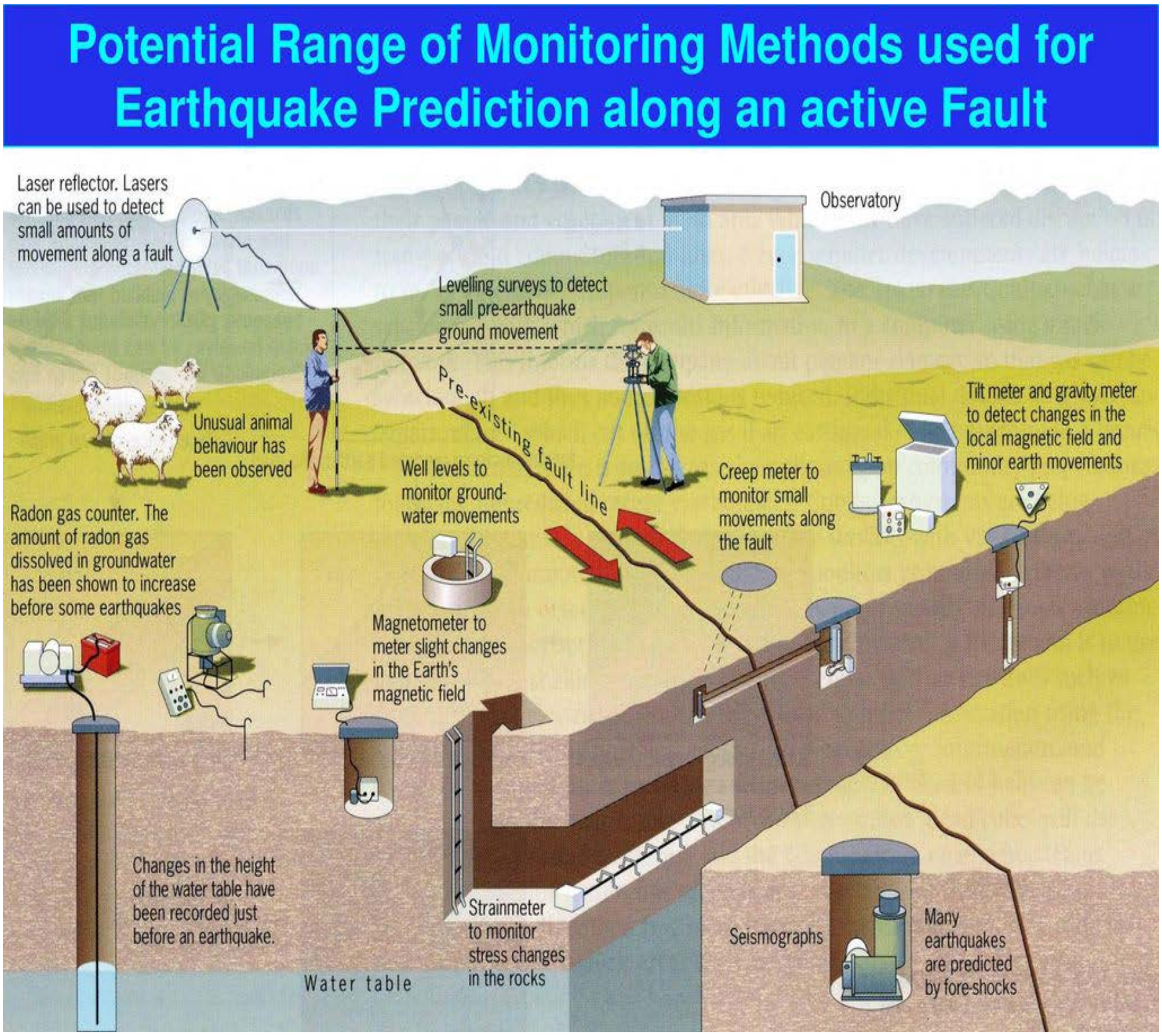

NC2
NC3
NC4
NBO
NB2
NAO
NC6
NORES
-25000
0
25000
meters

89 What is the viscosity of the earth's mantle?

Viscosity is the resistance to flow of a fluid. It is defined as the ratio of shear stress (Tangential Force/Area) to shear rate (velocity/gap). The viscosity of most fluids decreases as its temperature increases and vice verse. This occurs because as the liquid is heated, the force of attraction between the molecules, the cohesive forces, is reduced. The viscosity of the mantle is important to theories of convection and continental drift and also to the understanding of the earth's external gravity field.Higher SiO_2 (silica) content magmas have higher viscosity than lower SiO_2 content magmas (viscosity increases with increasing SiO_2 concentration in the magma).

90 Can animals predict earthquakes?

So far, there has been no conclusive evidence that animals can predict earthquakes or sense that they are about to occur. Changes in animal behavior cannot be used to predict earthquakes. Even though there have been some cases of unusual animal behavior prior to earthquakes, a reproducible connection between a specific behavior and the occurrence of an earthquake has not been made. But animals also change their behavior for many reasons, and given that an earthquake can shake millions of people, it is likely that a few of their pets will, by chance, be acting strangely before an earthquake

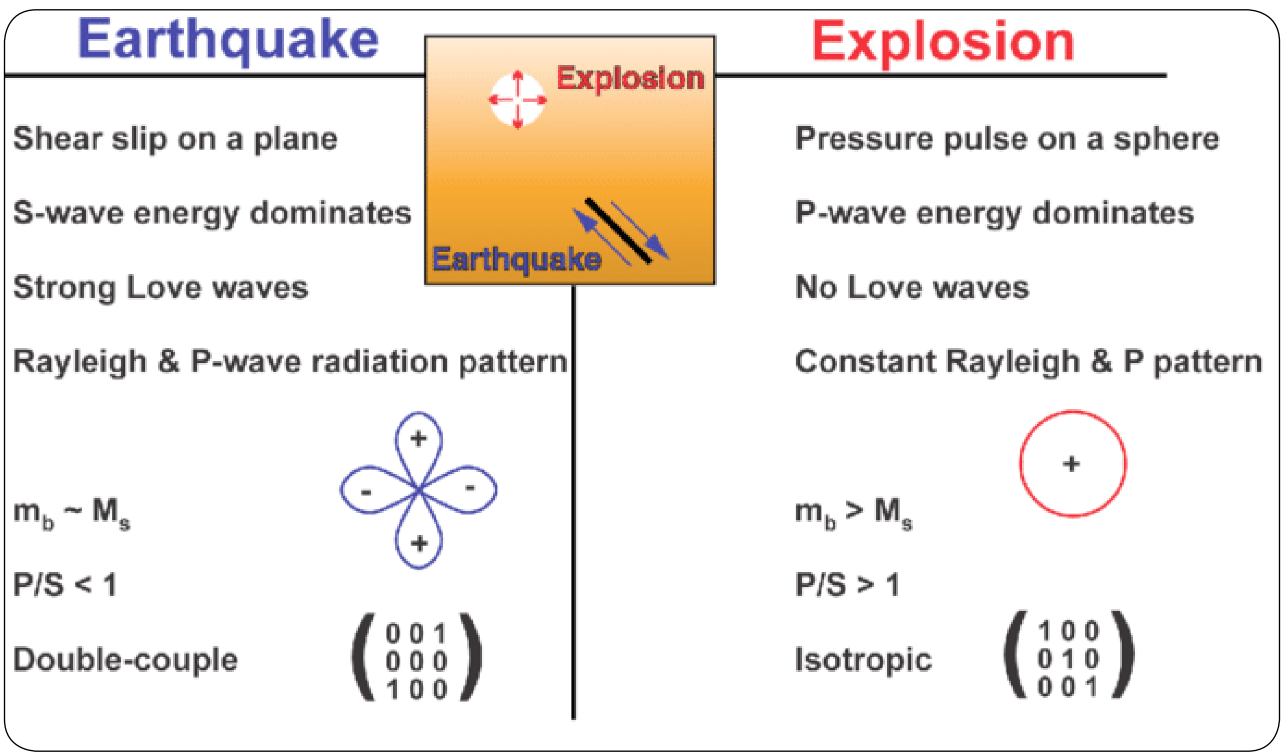

Potential Range of Monitoring Methods used for Earthquake Prediction along an active Fault
Laser reflector. Lasers can be used to detect small amounts of movement along a fault
Observatory
Levelling surveys to detect small pre-earthquake ground movement
Pre-existing fault line
Unusual animal behaviour has been observed
Tilt meter and gravity meter to detect changes in the local magnetic field and minor earth movements
Well levels to monitor ground-water movements
Creep meter to monitor small movements along the fault
Radon gas counter. The amount of radon gas dissolved in groundwater has been shown to increase before some earthquakes
Magnetometer to meter slight changes in the Earth's magnetic field
Changes in the height of the water table have been recorded just before an earthquake.
Strainmeter to monitor stress changes in the rocks
Seismographs
Many earthquakes are predicted by fore-shocks
Water table

91 What are the differences between explosions and earthquakes?

Explosions and earthquakes both release a large amount of energy very quickly, and both can be recorded by seismic instruments. However, because the forces involved in each are very different, the waveforms that each creates look different.

Nuclear tests are very near the surface of the earth; all of the energy is released from a small volume surrounding the device. Earthquakes are typically several to many kilometers beneath the surface of the Earth; the energy is released from the fault surface, which can be several to many kilometers long, depending on the size of the fault. The differences in the depth and extent of the energy source produces differences in the waveforms that are recorded on a seismogram.if seismic waves are generated very deep within the Earth then they can only be caused by an earthquake.

Also explosions do not generate very strong seismic surface waves, therefore strong surface waves (the ones that cause the most damage to buildings) must come from an earthquake.Lastly, nuclear explosions typically release energy between 2-50 kilotons of yield, compared to, for example, the M6.5 Afghanistan earthquake in May of 1998 that had an equivalent yield of 2,000 kilotons.


Earthquake
Explosion
Explosion
Earthquake
Shear slip on a plane
S-wave energy dominates
Strong Love waves
Rayleigh & P-wave radiation pattern
+
-
-
+
$m_b \sim M_s$
P/S < 1
Double-couple
0 0 1
0 0 0
1 0 0
Pressure pulse on a sphere
P-wave energy dominates
No Love waves
Constant Rayleigh & P pattern
+
$m_b > M_s$
P/S > 1
Isotropic
1 0 0
0 1 0
0 0 1

92 How many earthquakes occur annually worldwide?

Very strong earthquakes with magnitudes of 8 and higher occur once a year on a global average. On average, 15 quakes ranging in magnitude between 7 and 8 strike on an annual basis. Quakes with magnitudes greater than 7 can have devastating effects on people and the environment. Up to 1,300 moderate quakes on a scale of 5 to 6 take place worldwide every year, smaller quakes with magnitudes of 3 to 4 occur, roughly speaking, 130,000 times a year.

93 Can the position of the moon or the planets affect seismicity?

Several recent studieshave found a correlation between earth tides (caused by the position of the moon relative to the earth) and some types of earthquakes. During times of higher earth and ocean tides, such as during times of full or new moon, earthquakes are more likely on shallow thrust faults near the edges of continents and in (underwater) subduction zones. Lunar or solar eclipses represent, of course, special cases of full and new moon, but do not cause any special or different tidal effects from full and new moon.

Earth tides (Earth's surface going up and down by a couple of centimeters) and especially ocean tides (surface of the ocean going up and down by a meter or more) raise and lower the confining pressure on shallow, dipping faults near continental edges and in subduction zones.

When the confining pressure is lessened, the faults are unclamped and more likely to slip. The increased probability is a factor of ~3 during high tides.

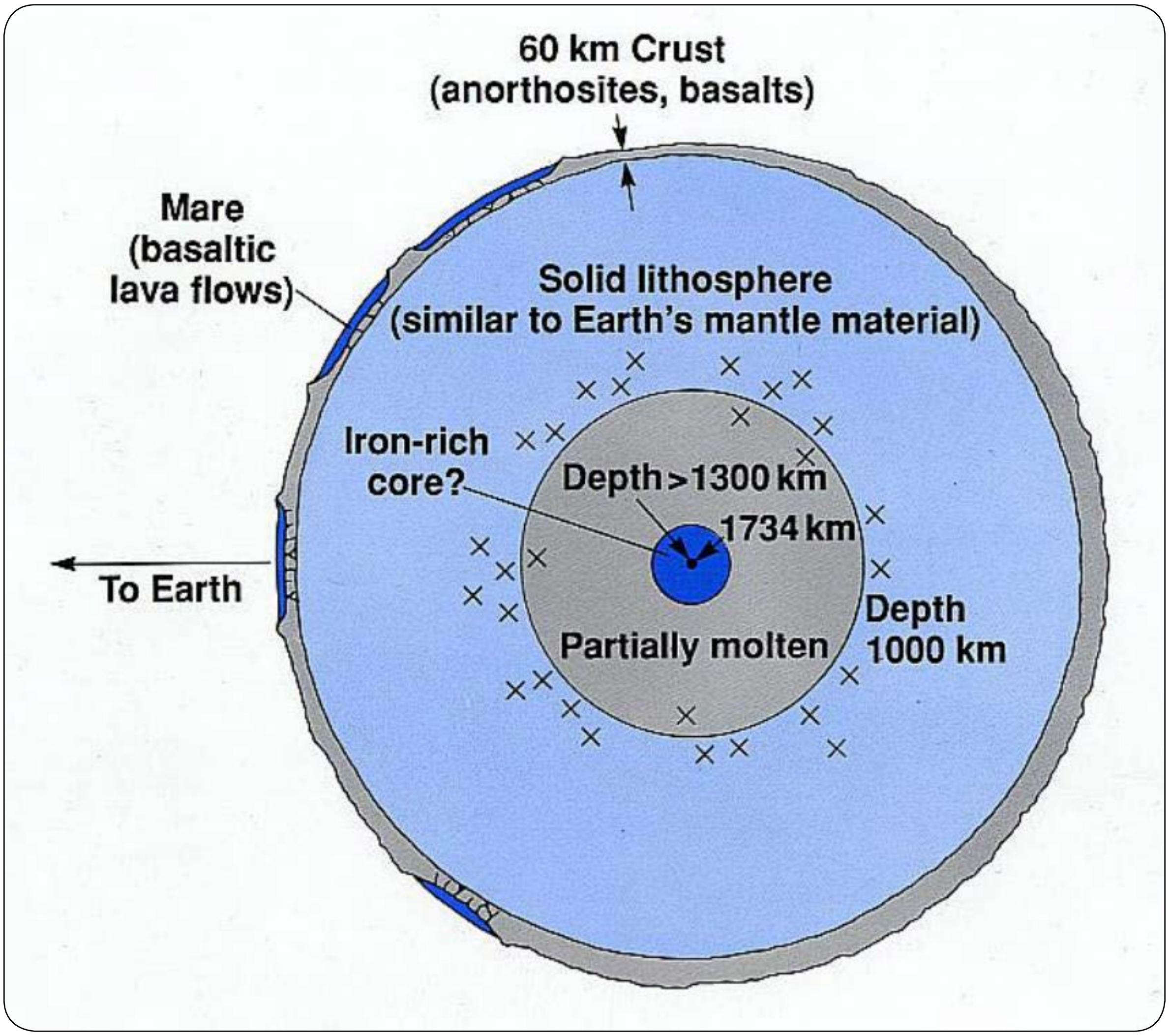
The moon, sun, and other planets have an influence on the earth in the form of perturbations (small changes) to the gravitational field. The relative amount of influence is proportional to the objects mass, and inversely proportional to the third power of its distance from the earth.

94 Which types of moonquakes are most common?

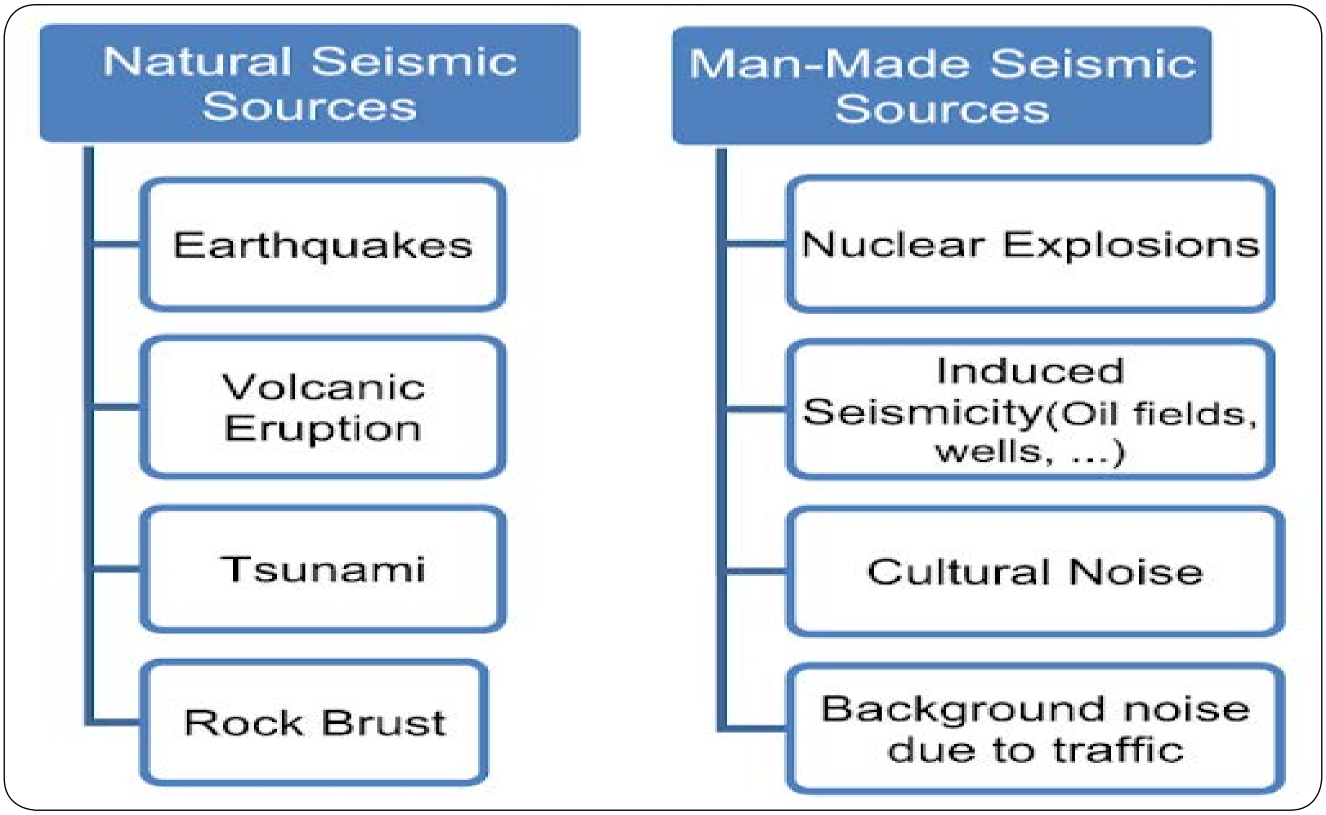
There are at least four different kinds of moonquakes: (1) deep moonquakes about 700 km below the surface, probably caused by tides; (2) vibrations from the impact of meteorites; (3) thermal quakes caused by the expansion of the frigid crust when first illuminated by the morning sun after two weeks of deep-freeze lunar night; and (4) shallow moonquakes only 20 or 30 kilometers below the surface.The first three were generally mild and harmless. Shallow moonquakes on the other hand were doozies. Between 1972 and 1977, the Apollo seismic network saw twenty-eight of them; a few “registered up to 5.5 on the Richter scale.

95 How much activity is there currently in the Moon’s interior?

Seismographic stations of moon as provided by Apollo 12, 14, 15, and 16 (1969-1977). They detected over 12,500 “moonquakes”: 1) 3,000 deep moonquakes (700 to 1,000 km below the surface); 2) 1,700 meteorite impacts; 3) 28 shallow moonquakes (20 to 30 km below the surface); and 4) other small quakes. The deep quakes are directly related to the interaction of the Moon with the Earth and the suntides. The timing of the quakes themselves shows that most of them were the result of tidal stresses, but that a few of them may have been due to the tidal effects triggering weak areas within the Moon (the core-mantle boundary). The impacts were due to objects ranging in size from 1 kg up to over 1,000 kg. The shallow quakes were as strong as magnitude 5.5 and are thought to be related to landslides in the interior of craters. The majority of the quakes are weak and seem to be related to thermal stress near the surface as the Moon warms up and cools off as it is heated and cooled by the daylight to non-daylight cycle. When there are large shallow quakes, the Moon actually rings like a bell. On Earth, earthquakes dampen out in a minute or two . For the Moon, these quakes can last for 10 minutes or more because the rock is drier and does not dampen the shaking as much.


60 km Crust
(anorthosites, basalts)
Mare
(basaltic
lava flows)
Solid lithosphere
(similar to Earth's mantle material)
Iron-rich
core?
Depth>1300 km
1734 km
To Earth
Depth
1000 km
Partially molten

96 **List major Natural and Induced Seismic Sources?**



97 **Mention some old myths and legends on earthquake causes and occurrences?**

Earthquakes occur :

When one of the eight elephants that carry the Earth gets tired (Hindu)
When a frog that carries the world moves (Mongolia)
When the giant on whose head we all live,sneezes or scratches (Africa)
When the attention of the god Kashima (who looks after the giant catfish Namazu that supports the Earth and prevents it to sink into the ocean) weakens and Namazu moves (Japan)
When the god Maimas decides to count the population in Peru his footsteps shake the Earth. Then natives run out of their huts and yell: “I’m here, I’m here

98 **Provide two kinds of evidence that support the theory of plate tectonics?**

1. The shapes of continents fit together like a puzzle. The matching coastlines show where the continents broke apart. Identical rocks that formed over 200 million years ago have been found on different continents.

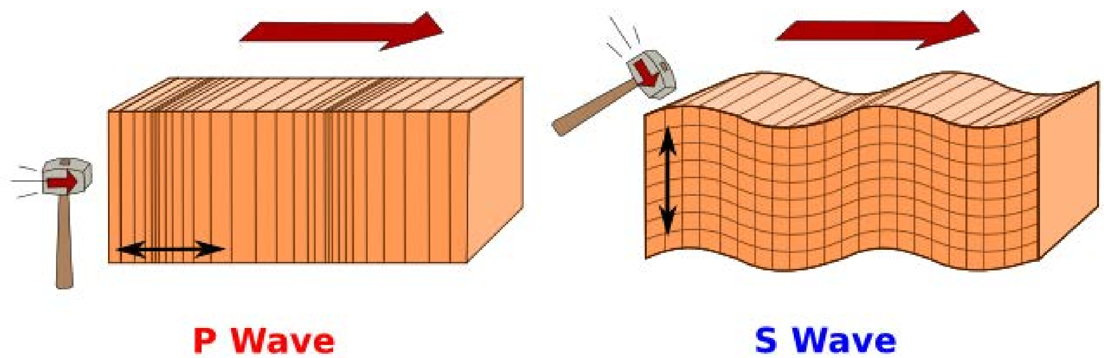
2. The minerals and textures of the rocks indicate that they formed in the same place before the continents separated. Identical fossils have been found in South America and Africa. This supports the explanation that these animals lived on the same continent before it separated.

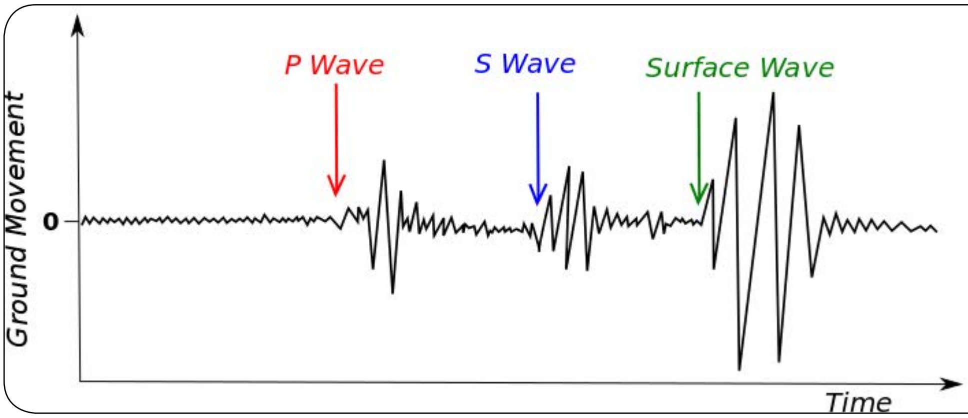
99 How do you locate earthquakes?

When an earthquake happens energy travels outwards as waves in all directions, like a ripple spreading across the surface of a pond. There are two main types of earthquake (seismic) waves: P waves which have a squashing together (longitudinal) motion and are faster, and S waves which have a side to side (transverse) motion and are slower.

As the wave moves outwards when they pass a seismometer the ground will shake a bit and the seismometer will record the ground motion. Since the P wave is faster, the seismometer will first detect a little wobble of the ground when the P waves goes past and a bit later another wobble of the ground when the S wave goes past. Next, you figure out how far apart these waves arrive, called the S-P time.

You can then go to a table of distance as a function of S-P time and work out how far away the earthquake was from your station. If you have three or more stations, you can draw circles on a map, and where the circles meet is the location of your earthquake. Essentially, you are triangulating the earthquake's location.


P Wave
S Wave


Ground Movement
0
P Wave
S Wave
Surface Wave
Time


Seismometer

100 How Do I Read a Seismogram?

When you look at a seismogram, there will be wiggly lines all across it. These are all the seismic waves that the seismograph has recorded. Most of these waves were so small that nobody felt them. These tiny microseisms can be caused by heavy traffic near the seismograph, waves hitting a beach, the wind, and any number of other ordinary things that cause some shaking of the seismograph. The P wave will be the first wiggle that is bigger than the rest of the little ones (the microseisms). Because P waves are the fastest seismic waves, they will usually be the first ones that your seismograph records. The next set of seismic waves on your seismogram will be the S waves. These are usually bigger than the P waves.The surface waves (Love and Rayleigh waves) are the other, often larger, waves marked on the seismogram. They have a lower frequency, which means that waves (the lines; the ups-and-downs) are more spread out. Surface waves travel a little slower than S waves (which, in turn, are slower than P waves) so they tend to arrive at the seismograph just after the S waves. For shallow earthquakes (earthquakes with a focus near the surface of the earth), the surface waves may be the largest waves recorded by the seismograph. Often they are the only waves recorded a long distance from medium-sized earthquakes.

101 What about earthquake early warning?

Although no one can predict earthquakes, today's technology is advanced to the point that automatic systems can detect an earthquake, calculate the maximum expected shaking, and send alerts to other areas before the damaging shaking arrives; this is Earthquake Early Warning (EEW). Warning times range from a few seconds to several minutes in favorable cases. Even a few seconds is enough time to take protective action such as taking cover, moving away from hazardous items, stopping trains and elevators, and automatically stopping critical processes to prevent damage and injury. The USGS along with university, state, and private partners has developed such a system called ShakeAlert for the west coast of the United States where the earthquake risk is greatest.

102 Which is more dangerous, Shallow or Deep earthquakes?

Seismic waves are of two types, Body waves and Surface waves . The main difference between the two is that body waves travel deep inside the earth's crust while the surface waves travel on earth's surface, possessing major threat to both life and property.

Surface waves are more dangerous than the body waves. That is why shallow earthquakes are a greater threat; most of the seismic energy travels as surface waves.

103 What do the terms frequency and natural frequency mean?

The frequency of an object is its number of vibrations per second as measured in Hertz (Hz), whereby 1 Hz = 1 wave per second.The natural frequency of a physical object is the frequency at which it vibrates after excitation.

The natural frequency of a building will depend, among other things, on its method of construction, the materials used in it and its height.

104 What are the period, wavelength and amplitude?

A period is the duration of a single oscillation and is measured in seconds.

A wavelength is the spatial equivalent to a period and is the length of a single oscillation.

In the case of seismic waves, the wavelength value is typically in the region of between several dozen meters and several kilometers.The amplitude is the force or deflection of a single oscillation. Modern seismometers are able to record amplitudes of less than one nanometer (one millionth of a millimeter).

105 **What is UTC time?**

Coordinated Universal Time (UTC) is the internationally applicable world time standard. In seismology, it is used to make international earthquake data easier to compare and utilize by eliminating the complications associated with different time zones and hemispheres.

Coordinated Universal Time was introduced in 1972 and corresponds to Greenwich Mean Time. UTC follows the highly precise second-based International Atomic Time (TAI). Since the Earth's rotation can fluctuate and a day can therefore last longer than 24 x 3,600 seconds, from time to time a leap second is added.

106 **What is meant by anearthquake sequence'?**

A significant magnitude earthquake with which is associated, in time and space, smaller magnitude earthquakes (the lower the magnitudes, the higher the numbers of events), possibly preceding, but certainly following, is described as an earthquake sequence.

107 **What is the difference between volcanic earthquakes and tectonic earthquakes?**

As magma makes its way through the crust to the surface of the earth, it breaks apart surrounding rock thereby generating volcanic earthquakes. Volcanic earthquakes are one of the main signs that a volcano is restless.Tectonic earthquakes are caused by the movement of plates when energy accumulated within plate boundary zones is released. Tectonic earthquakes are usually larger than volcanic earthquakes.

108 What are types of Seismological Networks?

Seismological networks are divided to : global seismological network ; regional or national networks ; explosion monitoring networks ; local networks for seismicity study; local networks for induced seismicity; array processing networks and portable seismological network .

109 Why we need high dynamics and resolution in monitoring Seismic events?

To resolve : large span of earthquakes' magnitude, differences in amplitudes of different phases, low or high frequency content of event spectra (sensors' and events' dependent), contemporary events of different types and magnitudes, arithmetical processing of data (e.g. filtering or displacement, velocity, acceleration calculations).

110 How to resolve the problem in depth determination of earthquakes?

Earthquakes depth is of prime interest because of its important seismic risk and tectonic implications. An average distance among stations in a network should not be larger than the double average expected depth of events for reliable depth determinations.

111 **Numerically, what is the is the importance of seismic stations?**

Three stations to give a theoretical minimum for epicenter determination, deterministic approach , known depth known structure and known weave velocity .
Four stations to give a theoretical minimum for hypocenter determination, deterministic approach known structure and known wave velocity.
Five – Six stations to know a minimum for hypocenter determination with confidence limits, known structure and known wave velocity.
Six to Eight stations is the minimum for hypocenter and structure study.

112 **Discuss possible frequency ranges from seismological point of view?**

Studies of the dynamic process in earthquake foci (**3 - 0.005 Hz**), energy calculation of earthquakes (**10 - 0.01 Hz**), studies of the crust properties (**1- 0.02 Hz**), scattering and diffraction on the core boundary **(2 - 0.02 Hz**), frequency dependence of absorption (**20 - 0.01 Hz**), dispersion of surface waves (**0.2 - 0.003 Hz**), free oscillations of the earth (**0.01 - 0.0005 Hz**), strong motion (**0.1 – 25 Hz**), local events (**0.1 - 20 Hz**), very weak and local events (**2 - 100 Hz**).

113 **What are frequencies of interest for different seismic sensors?**

Short period sensors (SP)- (**0.5 - 20 Hz**),
Long period sensors (LP)- **(0.003 - 0.1 Hz**)
Broad band sensors (BB)- **(0.003 – 20 Hz**),
Very broad band sensors (VBB)- (**0.0005 – 5 Hz**)

114 **What is the Kinematic concepts of seismic data analysis?**

1. source of information is travel times of different phases
2. results: location of events, velocity structure of the earth, travel time tomography

115 **What is the Dynamic concepts of seismic data analysis?**

1. source of information is signal amplitudes
2. results: magnitude determination, moment determination , source mechanism determination , where, how deep, how strong , how often

116 **What you will get from analyzing a complete seismogram?**

1. source of information is signal waveforms
2. results: inversion. of waveform data sets, spatial heterogeneity, spatial anisotropy , free oscillations studies. synthetic seismograms. ray tracing methods, mode representation of wavefields , coherent signals analysis

117 **What are the reasons of uncertainty in hypocentral determination?**

Limited precision of on-set time readings of phases, uncertain interpretation of the type of phases, unknown velocity structure of the ground, computational problems and human errors.

118 **What is meant by seismic triplication?**

It is known that The velocities of both P and S waves increase gradually with depth in the mantle. At CMB, the velocity of P waves drops sharply when they enter the core and then increase with depth toward the earth's center. Hence, triplication is resulting from a steep velocity increases and is known as The transition from prograde to retrograde and back to prograde motions when taking the relation of T- X. Caustics are the endpoints on the triplication.

119 **What is seismic anisotropy?**

$$\sigma_{ij} = c_{ijkl} e_{kl}$$

Seismic wave propagation in anisotropic media is quite different from isotropic media.There are in general 21 independent elastic constants (instead of 2in the isotropic case there is shear wave splitting (analogous to optical birefringence) . Waves travel at different speeds depending on the direction ofpropagation. The polarization of compressional and shear waves may not be perpendicular or parallel to the wavefront, respectively.

120 **What is WWSSN?**

Worldwide during the late 1950s, there were only about 700 seismographic stations, which were equipped with seismographs of various types and frequency responses. The World-Wide Standardized Seismographic Network (WWSSN), the first modern worldwide standardized system. Each station of the WWSSN had six seismographs—three short-period and three long-period seismographs. By 1967 the WWSSN consisted of about 120 stations distributed over 60 countries. By the 1980s a further upgrading of permanent seismographic stations began with the installation of digital equipment by a number of organizations. Among the global networks of digital seismographic stations now in operation are the Seismic Research Observatories in boreholes 100 meters deep and modified high-gain, long-period surface observatories.

121 **What does Mw in the following equation represent?**

Mw = 2/3 log10 (Mo) - 10.7 . Mw is the seismic moment magnitude or simply the moment magnitude.
Mo = μSd, m is the shear strength, S is the surface area of rupture along the fault, and d is the average displacement along the fault.

122 **Does the rate of earthquakes increase during the cold weather?**

Although cold temperatures greatly affect the ground near the surface, it has no effect at greater depths. Near the surface, freeze and thaw cycles can weaken and break rock due to high water pressure. The hypocenter of an earthquake is generally located several km below the surface where the surface temperature would have no influence.

123 **How Does the Mantle Convect?**

The mantle is, in general, solid. It turns out that rocks, along with most other solids, flow by a solid-state, creeping motion, especially when they are hot and given enough time. This is what happens in the mantle.
Based on observations of the rates at which the surface of Earth moves, geologists estimate the mantle convectively flows at rates of several centimeters a year.
The heat driving mantle convection has three sources. “Primordial” heat (left over from the accretion and differentiation that led to the formation of Earth’s core) contributes 20 to 50% of the heat. Heating due to the decay of radioactive isotopes (mainly potassium, thorium, and uranium) contributes 50 to 80%. Thirdly, tidal friction from the Moon’s pull on the Earth contributes perhaps 10%. Mantle convection is the main mechanism by which this heat escapes from the interior of Earth.The mantle’s convective motions break the lithosphere into plates and move them around the surface of the planet. These plates may move away from, move by, or collide with each other. This process forms ocean basins, shifts continents, and pushes up mountains.

124 Why is Earth's outer-core liquid?

As we move out from the solid inner core, temperature drops, and pressure also decreases. The drop in pressure must be quite significant compared to the drop in temperature as radius increases from the core.Towards center of the Earth, temperature, pressure and density gradients are positive, as we move from surface to the center. Despite that there are discontinuities, on the average, all these increase with depth. The core temperature 5500+oC matches the Sun's surface temperature. The structure of matter is transitional, without marked demarcation. So, the classification of layers ought to change up om further research on data, from seismographs. As of now, the outer core is bearing low-viscous liquid and is visualized. from the depth of about 2800 km to 5100 km. Beyond nearly this depth, It is a spherical inner core. It is surmised that matter reverts to very high density (13.1 g.cc) solid form, near the center, under very extreme conditions of temperature and pressure.

125 What should you do during an earthquake?

Falling objects pose the greatest danger during a major earthquake. Of prime concern, therefore, is protection from falling objects such as framed pictures, light fixtures, plaster from ceilings or the upper part of walls, or chimneys which may fall outside or through the roof into the house.Here is what to do:

- Stay calm- don't panic.
- If you are indoors, stay there. Do not run outside: you could be hit by flying debris or bits of glass. Take cover under, and hold on to a sturdy desk, a table, or a bed- or stand in a doorframe. Never use the elevators (they may have been damaged and/or the power may fail).
- If you are outdoors, stay there. Keep away from power lines and buildings. (House chimneys are likely to topple during a strong earthquake).
- If you are in a vehicle, stop and park away from buildings, bridges and overpasses.

126 What should you do after a strong earthquake?

- Stay calm.
- Help the injured, if any. Speak calmly with family members, especially children about what has just happened, in order to relieve stress.
- Stay tuned to the radio and follow instructions.
- Use the telephone only in an emergency.
- Do not enter damaged buildings.
- To prevent fire, check the chimneys or have them checked before using the furnace or fireplace. Check all gas lines.
- Earthquakes can trigger huge ocean waves called tsunamis. The best warning is the earthquake itself and residents in tsunami risk areas should be prepared to evacuate to higher ground immediately (at least 10 meters above sea level) in the case of a large undersea earthquake. Stay tuned to your radio during a disaster.

127 **Compute the deepest point reached in the earth by a P- wave which enters the top of the mantle at an angle of 60O from the normal. Assuming the velocities of the lower crust and the upper mantle are 7.8 and 8.2 km/s respectively.**

Sin R = V2 / V1 Sin ic = 8.2 / 7.8 Sin 60 = 65.57^{o}

R = Radius of the earth = 6371 km

Rb = (6371 – 50) Sin 65.57 / Sin 90 = 6321/ Sin 90 = Rb / Sin 65.57

Rb = 5754.87 Km.

Deepest Point = 6371 – 5754.87 = = 616.13 Km

128 **Consider a spherical earth with a mantle of constant velocity 9 km / sec. A P-wave enters the mantle and propagates into the mantle at an incident angle of 25 o. at what angle does this ray encounters the core-mantle boundary.**

R sin i / V1 = R2 Sin i2 / V2

R = Radius of the earth = 6371 km.

(6371 – 50) Sin 25 / 9 = (6371 – 2900) Sin i2 / 9

i2 = 50.3^{o}

129 **The young's modulus of the material of a wire is 6X1012N/m2 and there is no transverse strain in it. Find its modulus of rigidity?**

Modulus of rigidity is given by

$\mu = Y / 2 (1 + \sigma)$ where σ is strain, **Here $\sigma = 0$**

$\mu = Y / 2 = 6 \times 10^{12} / 2 = 3 \times 10^{12}$ N m^{2}

130 **The breaking stress of aluminum is 8.1X107Nm-2. Find the greatest length of aluminum wire that can hang vertically without breaking. Density of aluminum is 2.7X103 kgm-3. Let a = area of cross section and l = length of wire which can be suspended Mass of the wire, m=volume X densit**

$m = (a\,l) \times \rho$

Breaking Stress $= mg/a = a\,l\,\rho g/a = \rho g\,l = 8.1 \times 10^7$

$l = 8.1 \times 10^7 / 2.7 \times 10^3 \times 10 = 3 \times 10^3$ m

131 **Two wires A and B of the same material have radii in the ratio 2:1 and lengths in the ratio 4:1. Find the ratio of the normal forces required to produce the same change in the lengths of the two wires?**

Given radii are 2:1 and lengths are 4:1

$Y = F_l / A\Delta l$ Then $F = Y A \Delta l / l$

$F_1/F_2 = A_1/A_2 \times l_2/l_1 = r_1^2/r_2^2 \times l_2/l_1$

$F_1/F_2 = 4/1 \times 1/4 = 1/1$

132 **Find the maximum length of steel wire that can hang without breaking. Breaking stress=7.9X1012dyne/cm2. Density of steel =7.9g/cc**

Breaking Stress = Weight of wire / Area $= (A\,l)\rho g/A = l\rho g$

OR l = Breaking Stress / $\rho g = 7.9 \times 10^{12} / 7.9 \times 980 = 1.02 \times 10^9$ cm.

133 **A long spring is stretched by 2 cm and its potential energy is V. Find the potential energy of the spring if it is stretched by 10 cm?**

Potential energy of the stretched spring

$V = 0.5\ KX^2$ Where **K** is Spring Constant

$V = 0.5\ K \times 2^2$ OR $K = V / 2$

New Potential Energy $V'' = 0.5\ K \times 10^2$

$V'' = 0.5\ (V / 2) \times 100 = 25\ V$

134 **An earthquake occurs 10,000 km from a seismographic station. How many minutes later do the P, S and L waves arrive there ?**

The P waves will arrive after about 13 min, the S waves after about 24 min, and the L waves after about 43 min.

135 **The S waves of an earthquake arrive at a station 5 min after the P waves. How far away did the earthquake occur?.**

Approxiately 4000 km away.

136 **The young's modulus of the material of a wire is 6X1012N/m2 and there is no transverse strain in it. Find its modulus of rigidity?**

Modulus of rigidity is given by

$\mu = Y / 2(1 + \sigma)$ where σ is strain, **Here $\sigma = 0$**

$\mu = Y / 2 = 6 \times 10^{12} / 2 = \underline{3 \times 10^{12} \text{ N m}^2}$

137 **Earthquakes are produced during:**

(a) plastic failure within the mantle,
(b) brittle failure during faulting,
(c) mushrooming during folding
(d) none of the above

138 **Seismic waves are waves of energy that:**

(a) plastically distort the material that they pass through,
(b) permanently distort the material that they pass through,
(c) break the material that they pass through
(d) elastically distort the material that they pass through

139 **The region of initiation of seismic energy within the Earth is called the:**

(a) epicenter,
(b) hypocenter,
(c) area of greatest building damage
(d) area of least building damage

140 **As rupture along a fault initiates, waves of energy travel outward from the hypocenter (a)**

linear fashion,
(b) a straight line path,
(c) a spherical fashion,
(d) none of the above

141 **Body waves emanate spherically from the focus traveling:**

(a) entirely within the interior of the Earth,
(b) along the surface of the Earth,
(c) within the worlds oceans
(d) into space dude!

142 **P-waves produce a series of:**

(a) shearing motions that are at right angles to the direction of wave propagation,
(b) contractions and expansions that are in the direction of wave propagation,
(c) circular motions like an ocean wave
(d) snake-like motions parallel to the Earth's surface

143 **S-waves produce a series of:**

(a) contractions and expansions that are in the direction of wave propagation,
(b) snake-like motions parallel to the Earth's surface,
(c) circular motions like an ocean wave
(d) shearing motions that are at right angles to the direction of wave propagation

144 **Rayleigh waves move along the surface of the Earth forming a wave that is much like:**

(a) a skier moving down a mountain hill,
(b) a car traveling through the sand dunes,
(c) an ocean wave
(d) a whale gliding along the ocean's surface

145 **At 400 km discontinuity, Olivine changes to:**

A.	Spinel	C.	Perovskite
B.	Post- SpinelL	D.	Magnesium Oxides

146 **P-wave velocity drops sharply from 13.6 to 8 km/s at :**

A.	Moho Disc..	C.	400 Km Disc.
B.	Guttenburg Disc.	D.	670 Km Disc.

147 **Magnitude determination for microearthquakes from**

A.	Signal Duration	C.	Acceleration
B.	A / T	D.	None of the above

148 **Mb & Ms are coincided at magnitude**

A.	6.0	C.	5.5
B.	6.5	D.	Never Coincided

149 **Seismic waves transmitted outer core are :**

A.	SKS	C.	PPP
B.	PKP	D.	PcP

150 **Seismic record is known as**

A.	Seismometer	C.	Seismograph
B.	Seismoscope	D.	Seismogram

151 **Seismograph is a device used to:**

(a) sound an alarm,
(b)prevent earthquakes from occurring,
(c) record the vibrations produced during an earthquake
(d) calm the seismologist during an earthquake

152 **Which of the following classes represent earthquakes with magnitudes between 6 and 6.9?**

A.	moderate	C.	strong
B.	great	D.	light

153 **On a global scale, on average, over 900,000 earthquakes a year occur with magnitudes below**

A.	6.0	C.	2.5
B.	7.0	D.	5.0

154 **Great earthquakes, on average, occur**

A.	30,000 times annually	C.	100 times annually
B.	500 times annually	D.	once every 5 years

155 **Mercalli indices of VII or higher measure the effects of an earthquake on**

A.	cows	C.	horses	E.	buildings
B.	dogs	D.	people		

156 **Quality factor values are highest in**

A.	Inner Core	C.	Upper Mantle
B.	Lithosphere	D.	Outer Core

157 **Maximums energy released from earthquakes are highest in**

A.	Surface Eqs.	C.	Deep Eqs.
B.	Intermediate Eqs.	D.	Eq. Swarms

158 **No. of aftershocks per day decreases with increasing**

A.	Time	C.	Epicentral distance
B.	Depth	D.	Intensity

159 **Energy travels with**

A.	Group velocity	C.	Group & Phase
B.	Phase velocity	D.	None of them

160 **When the waves are dispersive in deep water , this means**

A.	Vp > Vs	C.	Vp = Vs
B.	Vp < Vs	D.	No relation

161 **Which of these is NOT a scale for measuring earthquakes?**

A.	Mercalli Intensity Scale	C.	Rossi-Forel scale
B.	Richter Scale	D.	Anatolia Rift Scale

162 **The angle between the fault plane and the horizontal is**

A.	Strike	C.	Azimuth
B.	Dip	D.	Slip vector

163 occur whenever the radius of curvature of a reflecting interface is less than a few wavelengths of the propagating wave.

A. <u>Diffraction</u>
B. Refraction
C. Reflection
D. Transmission

164 Not associated with an earthquake, as in aseismic slip. Also used to indicate an area with no record of earthquakes: an aseismic zone.

A. <u>Aseismic</u>
B. Volcanic
C. Tsunami
D. Plates

165 A plane orthogonal to the fault plane.

A. <u>Auxiliary</u>
B. Normal
C. Reverse
D. Fold

166 The plane that most closely coincides with the rupture surface of a fault.

A. Normal
B. Auxiliary
C. <u>Fault</u>
D. Fold

167 **Step like linear landform coincident with a fault trace and caused by geologically recent slip on the fault.**

A.	Reverse	C.	Thrust
B.	Strike Slip	D.	<u>Fault Scarp</u>

168 **Intersection of a fault with the ground surface; also, the line commonly plotted on geologic maps to represent a fault.**

A.	<u>Fault Trace</u>	C.	Nodal Plane
B.	Fault Plane	D.	Thrust

169 **An earthquake whose focus is located between 70 to 300 kilometers from the earth's surface.**

A.	Shallow	C.	<u>Intermediate</u>
B.	Deep	D.	very deep

170 **Earthquake with its focus on a plate boundary. Offshore earthquakes of Red Sea are of this type.**

A.	<u>Interplate</u>	C.	middle plate
B.	Intraplate	D.	internal plate

171 **Earthquake with its focus within a tectonic plate. Arabian Shield earthquakes are of this type.**

A.	Interplate	C.	external plate
B.	Intraplate	D.	Hypocenter

172 **Chain of islands above a subduction zone (e.g., Japan, Aleutians).**

A.	Mid ocean	C.	island arc
B.	lithosphere	D.	Benioff

173 **A line connecting points on the Earth's surface at which earthquake intensity is the same. It is usually a closed curve around the epicenter.**

A.	Contour line	C.	Latitude
B.	isoseismal	D.	Longitude

174 **The way in which the lithosphere 'floats' on the asthenosphere.**

A.	Gravity	C.	Geodesy
B.	Faulting	D.	Isostasy

175 **A fault that is not slipping because frictional resistance on the fault is greater than the shear stress across the fault.**

A.	Reverse	C.	Normal
B.	Locked	D.	Sinistral

176 **A narrow zone, defined by earthquake foci, that is tens of kilometers thick dipping from the surface under the Earth's crust to depths of up to 700 kilometers.**

A.	Moho	C.	Island arc
B.	Guttenberg	D.	Benioff

177 **A fault that does not extend upward to the Earth's surface. It usually terminates upward in the axial region of an anticline. If is dip is less than 45 degrees, it is a blind thrust.**

A.	Oblique	C.	Normal
B.	Blind	D.	Reverse

178 **The concluding train of seismic waves that follows the principal waves from an earthquake.**

A.	Coda	C.	Surface
B.	Moment	D.	Secondary

179 **The theory, first advanced by Alfred Wegener, that Earth's continents were originally one land mass. Pieces of the land mass split off and migrated to form the continents.**

A.	Plate tectonics	C.	Wadatti
B.	Continental Drift	D.	Benioff zone

180 **Slow, continuous movement occurring on faults because of ongoing tectonic deformation, with no tendency for large earthquakes.**

A.	Graben	C.	Creep
B.	Horst	D.	Faulting

181 **Loss of energy in wave motion due to transfer into heat by frictional forces.**

A.	Absorption	C.	Damping
B.	Elasticity	D.	Amplitude

182 **The increase in the volume of rocks mainly due to pervasive micro cracking.**

A.	Rigidity	C.	Compressibility
B.	Poisson Ratio	D.	Dilatancy

183 **A fault in which the relative displacement is along the direction of dip of the fault plane; the offset is either normal or reverse.**

A.	Rigidity	C.	Compressibility
B.	Poisson Ratio	D.	Dilatancy

184 **An event that causes major disruption on the economy, society and the environment. Its origin or causes may be directly derived from natural phenomena.**

A.	Natural Hazard	C.	Risk
B.	Tsunami	D.	Disaster

185 **The spreading out of a wave train due to each wavelength travelling with its own velocity.**

A.	Velocity	C.	Amplitude
B.	Dispersion	D.	Depth

186 **Time interval between the first and last peaks of strong ground motion above a specified amplitude.**

A.	Period	C.	Duration
B.	Wave length	D.	Average

187 **The study of ancient (prehistoric) earthquakes from their geological evidences.**

A.	Paleoseismicity	C.	Historical
B.	Macroseismicity	D.	Induced

188 **The time interval between successive crests in a sinusoidal wave train; the period is the inverse of the frequency of a cyclic event.**

A.	Wave length	C.	Period
B.	Average time	D.	Least time

189 **The onset of a displacement or oscillation on a seismogram, indicating the arrival of a different type of seismic wave.**

A.	Phase	C.	Origin time
B.	Period	D.	Least time

190 **A strike-slip fault on which the displacement of the far block is to the right when viewed from either side. The Queen Charlotte fault is one of this type of fault**

A.	Right lateral	C.	Left lateral
B.	Sinistral	D.	Reverse

191 **A strike-slip fault on which the displacement of the far block is to the left when viewed from either side.**

A.	Dextral	C.	Thrust
B.	Right lateral	D.	Left lateral

192 **An index of the resistance of an elastic body to shear. The ratio of the shearing stress to the amount of angular rotation it produces in a rock sample.**

A.	Rigidity	C.	Poisson ratio
B.	Young module	D.	Compressibility

193 **A free or standing wave oscillation of the surface of water in an enclosed basin, that is initiated by local atmospheric changes, tidal currents, or earthquakes. Similar to water sloshing in a bathtub.**

A.	Love	C.	Seiche
B.	Rayleigh	D.	Shear

194 **An area in an earthquake-prone region where there is a below-average release of seismic energy.**

A.	Low seismicity	C.	Seismic gap
B.	Aseismic	D.	Creep

195 **The comparison between the amplitude of the seismic signal and the amplitude of noise caused by seismic unrest and (or) the seismic instruments.**

A.	<u>S / N</u>	C.	Noise level
B.	NMO	D.	CMB

196 **Is the ratio of applied force F to the area across which it is acts.**

A.	<u>Stress</u>	C.	Rigidity
B.	Strain	D.	Poisson ratio

197 **Essentially states that stress is proportional to strain.**

A.	Young	C.	Compressibility
B.	Shear modulus	D.	<u>Hooke's</u>

198 **Longitudinal strain proportional to longitudinal stress.**

A.	<u>Young</u>	C.	Lame coefficient
B.	Rigidity	D.	Bulk modulus

199 **Motion of particles in the solid is in direction of wave propagation**

A.	Primary waves	C.	Love waves
B.	Shear waves	D.	Rayleigh waves

200 **The change in velocity with frequency is known as**

A.	Dispersion	C.	wave front
B.	wave length	D.	Ray path

201 **Every point on a wavefront can be considered a secondary source of spherical waves**

A.	Fermat	C.	Huygen
B.	Snell	D.	Faust

202 **Relates the angles of incidence, reflection and refraction to the velocities of a medium.**

A.	Faust	C.	Fermat
B.	Snell	D.	Huygen

203 **Low velocity zone between 100 - 250 km depth in Earth is known as**

A.	Moho	C.	Asthenosphere
B.	Lithosphere	D.	Crust

204 **S-waves can not pass through it, therefore we know its composition is liquid (molten).**

A.	Inner core	C.	mantle
B.	Outer core	D.	Crust

205 **Is a fault on which the two blocks slide past one another**

A.	Normal	C.	Strike Slip
B.	Thrust	D.	Reverse

206 **The vertical projection of the hypocenter onto the earth's surface is called**

A.	Focus	C.	Depth
B.	Epicenter	D.	Magnitude

207 **A large part (80 %) of the seismic energy released by all earthquakes is released along**

A.	Pacific belt	C.	Atlantic
B.	Alpide belt	D.	Intraplate

208 **Is defined as the logarithm to the base 10 of the amplitude of the largest ground motion.**

A.	Intensity	C.	Energy
B.	Magnitude	D.	Richter

209 **The Richter magnitude scale is determined by the amplitudes of the P- and S-waves at a distance of**

A.	100 km	C.	300 km
B.	200 km	D.	400 km

210 **The Richter magnitude scale is logarithmic with commonly reported magnitudes scaling to**

A.	9 degrees	C.	12
B.	10	D.	No upper or lower limit

211 **Each unit increase in magnitude on the Richter scale corresponds to an increase in seismic wave amplitude of**

A.	<u>10-fold</u>	C.	60
B.	30	D.	100

212 **How big an increase in energy is released in going from one Richter magnitude unit to the next?**

A.	<u>32</u>	C.	60
B.	10	D.	100

213 **A Richter magnitude 3 earthquake releases how many times the energy of a magnitude 1 earthquake?**

A.	<u>1024</u>	C.	33
B.	900	D.	66

214 **On what type of plate boundary would you expect mostly light to minor earthquakes?**

A.	<u>Divergent</u>	C.	Strike – slip
B.	Convergent	D.	Subduction

215 **On what type of plate boundary would you expect a great earthquake?**

A.	<u>Convergent</u>	C.	strike slip
B.	Divergent	D.	Transform

216 **Most of very large earthquake are located in trenches at.............km?**

A.	30	C.	<u>700</u>
B.	300	D.	140

217 **Local earthquakes are occurring at epicentral distance between less than............?**

A.	<u>1000 km</u>	C.	6000 km
B.	3000 km	D.	12000 km

218 **is a measure of the degree of shaking at a particular site.**

A.	<u>Intensity</u>	C.	Moment
B.	Magnitude	D.	Energy

219 Converted waves are mostly

A.	SV.	C.	ScS
B.	SH	D.	PKP

220 Rayleigh Wave speed is slightly less than velocity of shear waves with:

A.	10%	C.	50%
B.	30%	D.	92%

221 is the energy loss per cycle (wave length) Δ E/E

A.	Absorption	C.	Q factor
B.	Attenuation	D.	Elasticity

222 At deep-focus earthquakes, focal depths are

A.	< 70 km	C.	< 300 km
B.	> 300 km	D.	150 km

223 **The abrupt decrease in Vp at the core/mantle boundary is known as………**

A.	<u>Guttenberg</u>	C.	Lehmann
B.	Moho	D.	Conrad

224 **At CMB, P-wave can not reach the earth between 103-143O**

A.	<u>Shadow zone</u>	C.	D’’
B.	Transition	D.	Convection

225 **The existence of the liquid outer core is important in earth’s magnetic field and the solid inner core is important in…………..?**

A.	<u>Convection</u>	C.	Reflection
B.	Diffraction	D.	Refraction

226 **Occurs everywhere under the continents and oceans at depths vary between 20 -70 km beneath Continents and 5 – 10 km beneath Oceans and it can be recognized by the abrupt increase of Vp & Vs.**

A.	Lehmann	C.	Conrad
B.	Guttenberg	D.	<u>Moho</u>

227 The................. discontinuity is attributed to Mineral phase change to Perovskite.

- A. 400 km
- B. 650 km
- C. Moho
- D. Conrad

228 ....is located at lower most part of the Mantle at 2880 km. and this region can be indicated by less homogeneity, scattering of seismic waves due to thermal energy at CMB.

- A. D'' region
- B. Outer core
- C. Lower mantle
- D. Transition zone

229 . ...is any instrument which measures the time dependence of the ground displacement.

- A. Seismogram
- B. Seismograph
- C. Accelerometer
- D. Seismoscope

230 ....defined as displacement of mass / Amplitude of ground acceleration.

- A. Dynamic magnification
- B. Period
- C. Attenuation
- D. Frequency

231 **The basic characteristics of any........................ are natural period, damping factor and magnification.**

A.	Seismoscope	**C.**	Seismograph
B.	Seismogram	**D.**	Seismometer

232 **..............................is the precise time the earthquake occurred.**

A.	Arrival time	**C.**	S-P time
B.	Origin time	**D.**	Period

233 **Local earthquakes are occurring at epicentral distance less than ………………...**

A.	30 degrees	**C.**	103 degrees
B.	10 degrees	**D.**	60 degrees

234 **The ....parameters specifying the location of an Earthquake are longitude, latitude, origin time and depth.**

A.	Epicentral	**C.**	Focal mechanism
B.	Hypocentral	**D.**	Elastic

235 The accuracy of ………………………………. is very dependent on arrival picks, depth of event, No. of stations and velocity model.

A.	Geiger method	C.	Diffraction
B.	Reflection	D.	Delay time

236 ………………………..Magnitude is used mostly in case of : shallow focus (h < 50 km), teleseismic Eq. (20 < epicentral distance < 160 o) and T = 20 sec.

A.	MB	C.	ML
B.	MS	D.	MW

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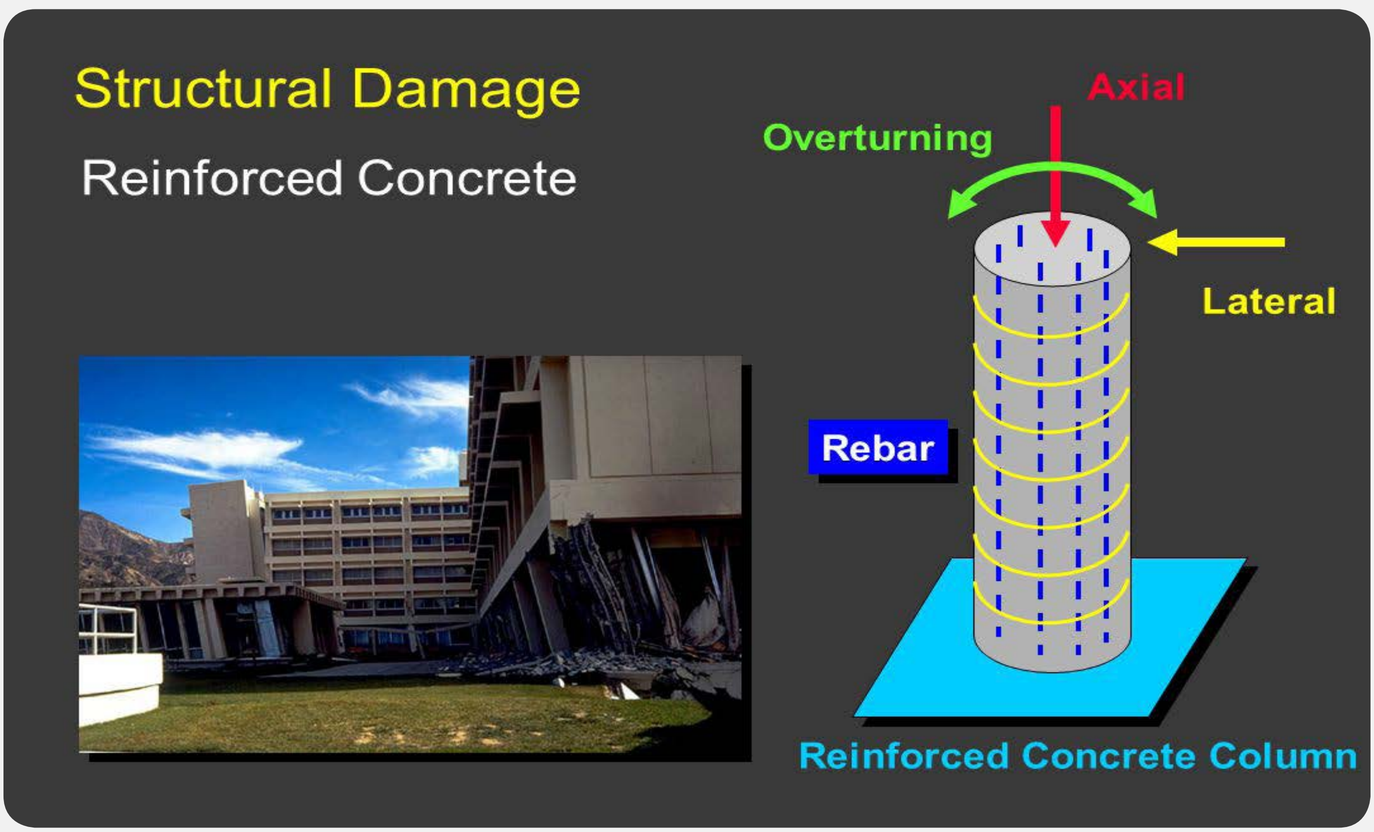
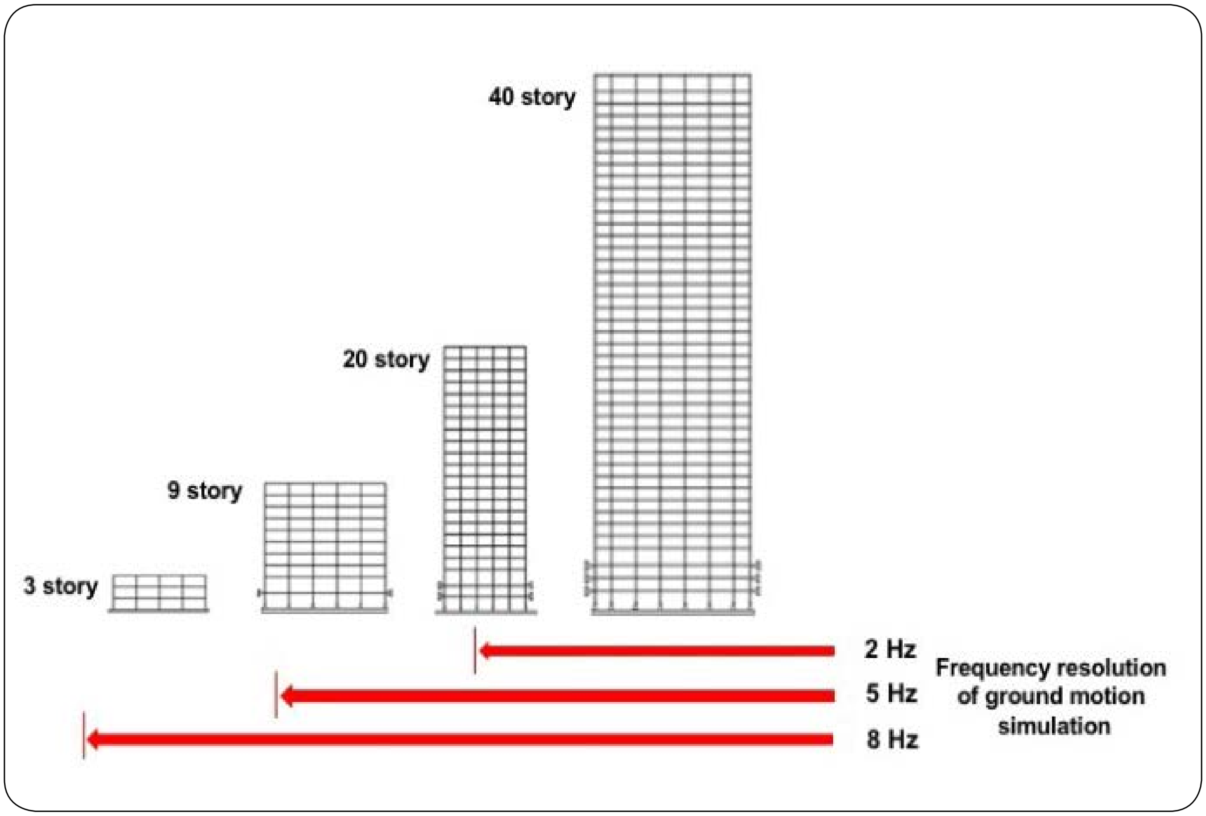
Questions & Answers in Engineering Seismology



Intruduction

Development of earthquake engineering technologies will never eliminate earthquake disasters. Humans will never be able to conquer nature and can only live in it with a better relationship. Earthquake engineering specialists have achieved only a limited understanding of global crustal behavior. While predicting the magnitude, epicenter, and precise time of large earthquakes is very difficult and beyond our scientific knowledge, earthquakes are certain to occur within a long enough time period. The currently existing seismic design methods allow structures to undergo plastic deformations under large earthquakes, while remaining elastic under small or moderate earthquakes. The plastic deformation dissipates earthquake energy and is intended to prevent structural collapse.


40 story
20 story
9 story
3 story
2 Hz
5 Hz
8 Hz
Frequency resolution of ground motion simulation

1 What is Engineering Seismology ?

Is the study of Seismology as related to Engineering. This involves understanding the source, the size and the mechanisms of earthquakes, how the ground motion propagates from the source to the site of engineering importance, the characteristics of ground motion at the site and how the ground motion is evaluated for engineering design. This subject is therefore related to the hazard of earthquakes. The seismic hazard at a site cannot be controlled. It can only be assessed.

2 What is Earthquake Engineering ?

Is the subject of analysis and design of structures to resist stresses caused by the earthquake ground motion. Resisting the stresses imply either resisting without failure or yielding to the stresses gracefully without collapse. This subject is related to the vulnerability of built structures to seismic ground motion. The vulnerability is controlled by design. The decision to control the vulnerability of a structure is based on the economics of the situation and on the judgement about the acceptable risk to the community.

3 What are most common input parameters of Engineering Seismology?

- maximal expected horizontal ground acceleration (PGA)
- maximal expected horizontal ground velocity (PGV)
- maximal expected horizontal ground displacement (PGD)
- response spectra (SA)
- maximal expected intensity (Imax)
- duration of significant shaking
- dominant period of shaking

4 What is seismic hazard?

Seismic hazard is a physical phenomenon, such as surface faulting, ground shaking, landslides, liquefaction, tectonic deformation, tsunamis, or seiches, that is associated with an earthquake and that may produce adverse effects on the normal activities of the people.

Hazard Assessment- An estimate of the range of the threat (i.e., magnitude, frequency, duration, areal extent, speed of onset spatial dispersion, and temporal spacing) to humans and their welfare from natural and technological hazards.

Seismic hazards can be assessed either by probabilistic seismic hazard analysis (PSHA) or deterministic seismic hazard analysis (DSHA). The fundamental difference between PSHA and DSHA is in how the uncertainties are treated: either implicitly (PSHA) or explicitly (DSHA). Although PSHA has been more widely used.

5 What is Seismic Risk?

Conceptually, **seismic risk**, has been defined as

Risk = Hazard (H) *Exposure (E) *Vulnerability (V) *Location (L).

The seismic risk at a given location (L) of ground / built environment in a seismotectonic domain is defined as function of likelihood or probability of occurrence of ground motion (PGA, PGV, PGD and duration) and accompanied manifestation in ground shaking in linear / non linear deformation. High seismic hazard does not necessarily mean high seismic risk, and vice versa. On the other hand, the seismic risk could be high in some areas, such as Pakistan and Iran, because of high exposures, even though the hazards are moderate.

6 What controls the level of shaking ?

- Magnitude—More energy released
- Distance—Shaking decays with distance
- Geology—Local soils amplify the shaking
- Building style—Construction, not height
- Duration of shaking

7 What is meant by Ground shaking?

Ground shaking refers to the dynamic, elastic, vibratory movement of the ground in response to the arrival and propagation of the elastic P, S, Love, and Rayleigh seismic waves. Ground shaking is characterized In terms of amplitude, frequency composition, duration, and energy, and is indicated in terms of Modified Mercalli Intensity, ground acceleration, ground velocity, ground displacement, and spectral response.

Ground shaking can be Increased by soil amplification, source directivity, topography, anomalously shallow focal depths, surface fault rupture, and the fling of the fault. The "killer pulse" is a longduration acceleration pulse that is generated close to the causative fault and is thought to be related to the fling of the fault as It ruptures. All structures are vulnerable at some level of amplitude, frequency, and duration of ground shaking.

8 What is the Ground failure?

Ground failure A-term referring to the permanent, Inelastic deformation of the soil and/or rock triggered by ground shaking. Landslides, the most common and wide spread type of ground failure, consists of falls, topples, slides, spreads, and flows of soil and/or rock on unstable slopes. Liquefaction, which results in a temporary loss of bearing strength, occurs mainly In young, shallow, loosely compacted, water saturated sand and gravel deposits when subjected to ground shaking.

Surface fault rupture occurs in some earthquakes when the fault breaks the surface. Regional tectonic deformation, changes in elevation over regional distances, Is a feature of earthquakes having magnitudes of 8 or greater. Tsunami run up results when the long period ocean waves generated by the sudden, Impulsive, vertical displacement of a submarine earthquake, reaches low lying areas along the coast.

Seiches are standing waves induced in lakes and harbors by earthquake ground shaking. Aftershocks refer to the long, exponentially decaying, sequence of smaller earthquakes that follow a large magnitude earthquake for months to years, exacerbating the damage. Earthquake Hazards-The physical effects generated in an earthquake (e.g., ground shaking, ground failure, surface fault rupture, regional tectonic deformation, tsunami run up, seiches, and aftershocks).

9 What are major geological hazards caused by earthquakes ?

Ground Shaking, Surface Faulting, Tsunamis, Landslides and Liquefaction (Rock Avalanches, Rapid Soil Flows, Rock Falls, Mud Flows, Flow Failure, Loss of Bearing Strength, Lateral Spreads)

10 What is the Intensity of an earthquake.Intensity

A numerical index denoted by Roman numerals from **I** to **XII** describing the physical effects of an earthquake on the earth's surface, man, or on structures built by man. These values are determined subjectively by individuals performing post earthquake investigations to determine the nature and spatial extent of the damage distribution, not by Instrumental readings. The most commonly used scales throughout the word are Modified Mercalli Intensity (MMI), developed fn the 1930's by an Italian, and the MSK scale, developed in the 1960's by scientists in the former Soviet Union, which are essentially equivalent for intensities **VII** to **X**. Intensity **VI** denotes the threshold for potential ground failure such as liquefaction. Intensity **VII** denotes the threshold for architectural damage. Intensity **VIII** denotes the threshold for structural damage. Intensity **IX** denotes intense structural damage. Intensities **X** to **XII** denote various levels of total destruction.

11 What causes damage?

Most earthquake damage is caused by ground shaking. The magnitude or size of an earthquake, distance to the earthquake focus or source, type of faulting, depth, and type of material are important factors in determining the amount of ground shaking that might be produced at a particular site. Where there is an extensive history of earthquake activity, these parameters can often be estimated. The magnitude of an earthquake, for instance, influences ground shaking in several ways. Large earthquakes usually produce ground motions with large amplitudes and long durations. Large earthquakes also produce strong shaking over much larger areas than do smaller earthquakes. In addition, the amplitude of ground motion decreases with increasing distance from the focus of an earthquake. The frequency content of the shaking also changes with distance. Close to the epicenter, both high (rapid)and low (slow)-frequency motions are present. Farther away, low-frequency motions are dominant, a natural consequence of wave attenuation in rock. The frequency of ground motion is an important factor in determining the severity of damage to structures and which structures are affected.

12 What is Acceleration and Accelerogram?

Acceleration is a force having the units of gravity that denotes the rate of change of the back and forth movement of the ground during an earthquake. Velocity (the rate of the ground motion at a given instant of time with units of cm/s) and displacement (the distance the ground has moved from it's rest position with units of cm) are derived from an accelerogram.

Accelerogram-Therecord or time history obtained from an instrument called an accelerometer showing acceleration of a point on the ground or a point in a building as a function of time. The peak acceleration, the largest value of acceleration on the record is typically used in design criteria. The velocity and displacement time histories and the response spectrum are derived analytically from the time history of acceleration.

13 Define Attenuation?

Seismic attenuation is an intrinsic property of rocks causing dissipation of energy as seismic waves propagate through the subsurface. It results in the decay of amplitude of the seismic waves. Attenuation is related to velocity dispersion. The energy of seismic wave is conserved if it travels through a perfectly elastic medium. Propagating seismic waves loose energy due to 1. Geometrical spreading
2. Absorption (anelastic attenuation)
3. Scattering (elastic attenuation).The higher-frequency components of propagating seismic waves are more attenuated than the lower-frequency components.

$I(R) = I0 + a + bR + C \log10 R$

R : Radius of the Circle from Epicenter

I(R) : Intensity from distance R, a,b,c : Constants

$I(R) = I0 + 6.453 – 0.00121 R - 2.15 \ln (R+20)$

$I0 = 0.95 Ms + 1.99$

Ignore 0.00121 R

$I = 8.443 + 0.95 Ms - 2.15 \ln (R+20)$

14 **How can we calculate the probability of an EQ to happen?**

Probability is simply inversely related to earthquake frequency.

Frequency-Magnitude relation as "**Log N= a – b M**". Then, you can estimate recurrence of earthquake (Period) which is inverse of N for any value of M (say M=6). Then, you can find the recurrence time (T) for M=6 from the frequency value of N(M=6). The inverse of T (1/N) might provide you a probability for per year.

15 **What are types of Strong Motion Networks?**

Strong motion networks are divided to :

national – free field networks , **permanent** local networks; **very dense** networks; **portable** local networks; **soil**- structure interaction study networks; civil engineering objects monitoring.

16 What are PGA and PGV ?

The key factor in determining peak ground acceleration (PGA) and peak ground velocity (PGV) is the horizontal ground movement caused by an earthquake. Both peak ground acceleration and peak ground velocity can be depicted on a ShakeMap. Both peak ground acceleration and peak ground velocity depend on several factors: the length and direction of the fault, magnitude, the distance between the measuring station and the epicenter, and the geology of the subsoil.

PGA (Peak ground acceleration) is the largest increase in velocity recorded by a particular station during an earthquake." PGA is most typically "expressed in g (the acceleration due to gravity) or m/s^2. Peak ground acceleration is a measure of earthquake acceleration. Unlike the Richter magnitude scale, it is not a measure of the total size of the earthquake, but rather how hard the earth shakes in a given geographic area.

Building and infrastructure damage from earthquakes is more closely related to ground motion, which PGA and PGV. PGA has been more commonly used in earthquake engineering and seismic hazard maps used for building codes.PGA is a good index in determining seismic hazard for shorter buildings (7 stories or less).

$\text{Log (PGA) h} = 0.57 + 0.5\ mb - 0.83\ \log(R^2 + h^2_m)^{1/2} - 0.00069R$

R: Hypocentral Distance

h_m : Minimum Focal depth

$Hm = -1.73 + 0.456\ mb \qquad mb > 4.5$

PGV (Peak ground velocity) is the greatest speed of shaking recorded at particular point during an earthquake.

$\text{Log (PGV)}_h = -3.6 + 1.0\ mb - 0.83\ \text{Log}(R^2 + h^2_m)^{1/2} - 0.00033R$

PGV is the better index in determining seismic hazard for taller buildings. It can help estimate macroseismic intensity and is often applied in determining liquefaction potential and in the seismic design and assessment of buried pipelines

17 Can buildings collapse during aftershocks?

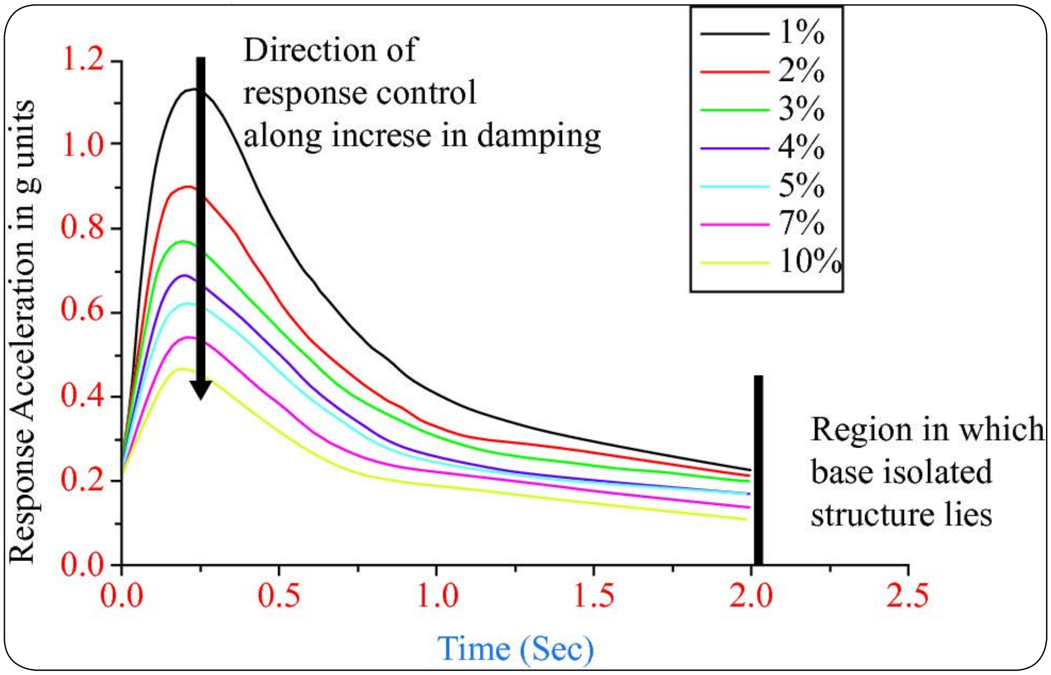
Yes, if a building has been sufficiently weakened during the main earthquake it could collapse during an aftershock.

18 What is the safest type of structure?

The safest type of structure is a modern, well-designed, and well-constructed building. Generally, wood-frame houses perform very well during an earthquake. However, even these structures are prone to damage from soil failure, chimneys may be damaged or collapse, windows may break, interior walls may crack, and those houses not securely bolted to their foundation may fail at or near ground level. Unreinforced masonry structures (those not seismically upgraded) are generally more vulnerable to earthquake damage

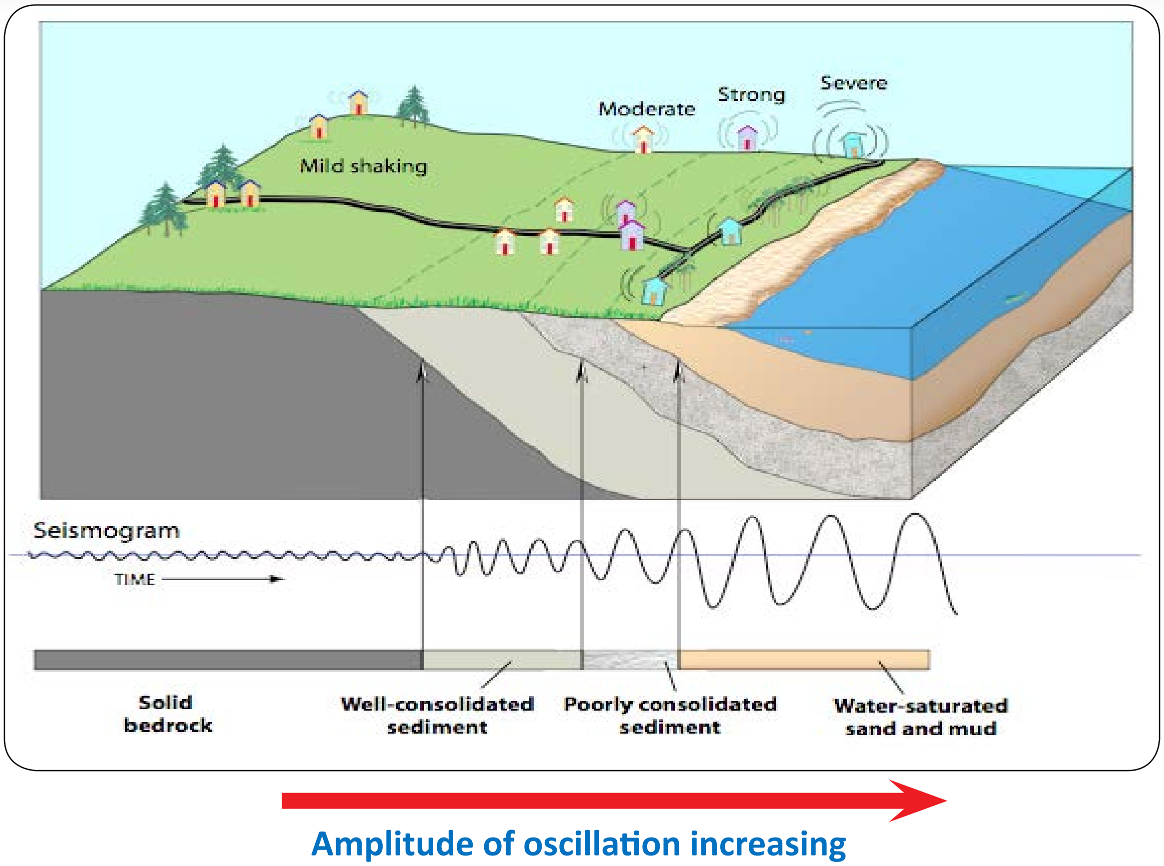
19 What is Response Spectrum?

A response spectrum is a function of frequency or period, showing the peak response of a simple harmonic oscillator that is subjected to a transient event. The response spectrum is a function of the natural frequency of the oscillator and of its damping. Thus, it is not a direct representation of the frequency content of the excitation (as in a Fourier transform), but rather of the effect that the signal has on a postulated system with a single degree of freedom (SDOF). The accelerogram Is used to excite them into vibration in the 0,05, 10 seconds period range, the range of Interest to engineers. The concept of the response spectrum is used in building codes and the design of essential and critical structures.All response quantities are positive, therefore RSA is not suitable for torsional irregularity.The method is only approximate, but it is often a useful, inexpensive method for preliminary design studies.



20 What Factors controlling Seismic Intensity?

Seismic Intensity is affected by rock type. The figure shows how the seismic wave oscillates as it enters different materials. The least damage occurs where buildings are constructed on bedrock. Note that the seismogram signal through "solid bedrock" is a high-frequency, low-amplitude. By the time the seismic wave reaches the "well-consolidated sediment" it begins to wobble with more amplitude but less frequently. The "poorly consolidated" sediment is even worse. As the wave enters the "water-saturated sand and mud" the wave records a low-frequency, high-amplitude signal. It really gets rolling and can cause liquefaction (during ground shaking, some sandy, water-saturated soils can behave like liquids rather than solids).



21 What is the meaning of seismic risk assessment?

Seismic risk assessment is defined as the evaluation of potential economic losses, loss of function, loss of confidence, fatalities, and injuries from earthquake hazards. Given the current state of knowledge of seismic phenomena, little can be done to modify the hazard by controlling tectonic processes, but there are a variety of ways to control the risk or exposure to seismic hazards. There are four steps involved in conducting a seismic risk assessment:

(1) an evaluation of earthquake hazards and prepare hazard zonation maps;
(2) an inventory of elements at risk, e.g., structures and population;
(3) a vulnerability assessment; and
(4) determination of levels of acceptable risk.

22 What is the acceptable risk , Risk and risk assessment?

Acceptable risk is the probability of occurrences of physical, social, or economic consequences of an earthquake that is considered by authorities to be sufficiently low in comparison with the risks from other natural or technological hazards that these occurrences are accepted as realistic reference points for determining design requirements for structures, or for taking social, political, legal, and economic actions In the community to protect people and property.
Risk is the probability of loss to the elements at risk as the result of the occurrence, physical and societal consequences of a natural or technological hazard, and the mitigation and preparedness measures in place in the community.
Risk Assessment is an objective scientific assessment of the chance of loss or adverse consequences when physical and social elements are exposed to potentially harmful natural and technological hazards. The endpoints or consequences depend on the hazard and include: damage, loss of economic value, loss of function, loss of natural resources, loss of ecological systems, environmental impact, deterioration of health, mortality, and morbidity. Risk assessments Integrate hazard assessments with the vulnerability of the exposed elements at risk to seek reliable answers to the following questions:

1. What can happen?
2. How likely are each of the possible outcomes?
3. When the possible outcomes happen, what are the likely consequences and losses?

23 What is Vulnerability?

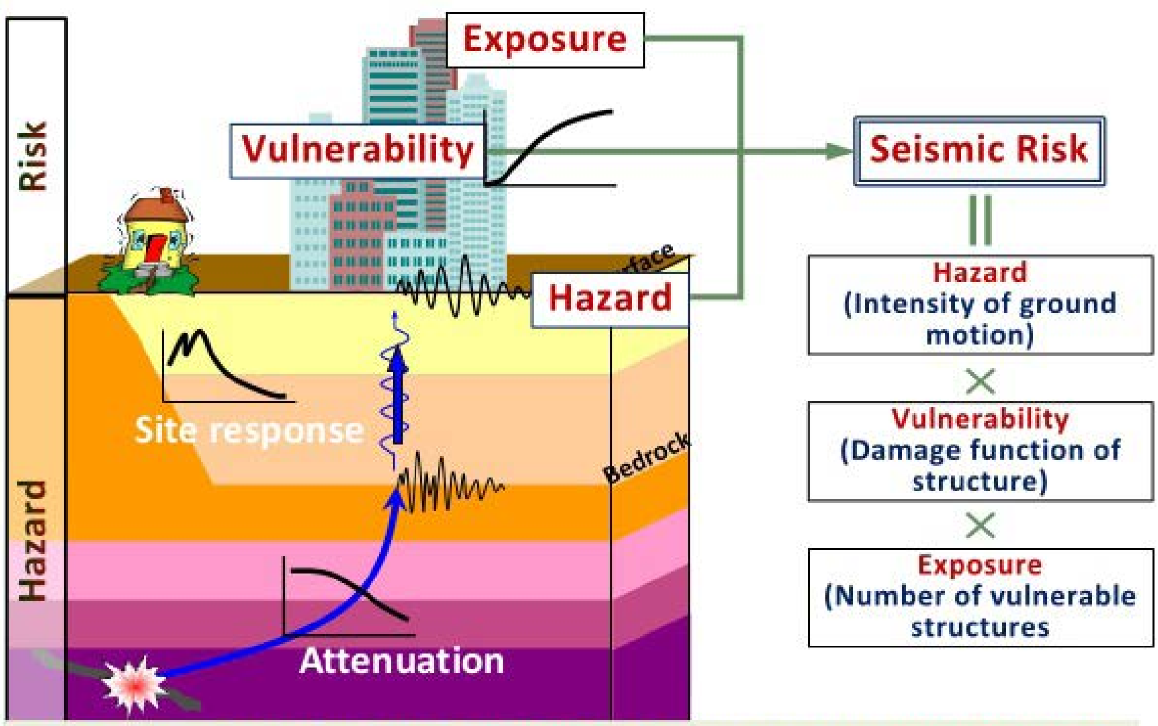
Vulnerability is the degree of damage caused by various levels of loading. The vulnerability may be calculated in a probabilistic or deterministic way for a single structure or groups of structures. Vulnerability-The potential loss in value of each element at risk from the occurrence and consequences of natural and technological hazards. The factors that influence vulnerability include: demographics, the age and resilience of the built environment, technology, social differentiation and diversity, regional and global economies, and political arrangements. Vulnerability is a result of flaws in planning, sitting, design, and construction.

HOW CAN WE REDUCE RISK?

RISK = HAZARD x EXPOSURE x VULNERABILITY

- **HAZARD**: We can improve our abilities to monitor and forecast hazards
- **EXPOSURE**: Increased awareness of the hazards faced by communities and their exposure to them
- **VULNERABILITY**: The greatest benefits can be achieved by reducing the vulnerability to natural hazards

Seismic Risk Assessment



Total risk is determined by the intensity of ground motion, vulnerability of structure and the number of vulnerable structures

5

24 What is Exceedance Probability and Exposure Time?

The probability (for example, 10 %) that an earthquake will generate a level of ground motion that exceeds a specified reference level during a given exposure time.Exposure Time-The period of tine (for example, 50 years) that a structure or a community is exposed to potential earthquake ground shaking, ground failure, and other earthquake hazards.

25 What are ShakeMaps?

ShakeMaps provide near-real-time maps of ground motion and shaking intensity following significant earthquakes. These maps are used by federal, state, and local organizations, both public and private, for post-earthquake response and recovery, public and scientific information, as well as for preparedness exercises and disaster planning.

ShakeMaps supply considerably more information than standard earthquake maps, which typically show only the epicentre and magnitude. ShakeMaps' additional details are useful to those affected by ground shaking as well as to rescue workers, who can use them as a basis for further action.In addition to ShakeMaps depicting earthquake intensity, there are also some that show peak ground acceleration (PGA) and peak ground velocity (PGV).

26 What is Seismic Zonation?

Seismic Zonation is the division of a geographic region into smaller areas or zones based on an integrated assessment of the hazard, built, and policy environments of the Nation, a region, or a community . Seismic zonation maps, which can be constructed on scales ranging from national to urban, provide decision makers with a scientific and technical basis for selecting prevention, mitigation, and preparedness options to cope with the physical phenomena generated in an earthquake (i.e., ground shaking, ground failure, surface fault rupture, regional tectonic deformation, tsunami run up, and aftershocks). Seismic zonation contributes to risk reduction and sustainability of new development. Seismic zonation maps are the result of a process that integrates data, results of research and post earthquake Investigations, and experiences on the hazard, built, and policy environments. The maps are used to answer questions decision makers and end users are asking about their communities, such as:

* Which part(s) of the geographic area under consideration is (are) safest for a single-family dwelling? A high-rise building? A government building? Commercial buildings? A school? A hospital? A dam? Short bridges? Long span bridges? Utility pipeline systems? A port?

* Which part(s) of the geographic area Is best for avoiding ground shaking above a certain threshold (such as 20 % of gravity, or 20 cm/sec, or 100 cm)? Soil amplification that enhances a particular period band of the ground motion (e.g., 0.2 second, 1.0 second, or 2.0 seconds)? Liquefaction? Lateral Spreads? Large volume landslides? Surface fault rupture? The “killer pulse” generated by the fling of the fault? Source directivity? Regional uplift or subsidence? Tsunami wave run up? Seich? Aftershocks?

* Which part(s) of the geographic area is(are) most vulnerable in a damaging earthquake? Which element(s) at risk is (are) most vulnerable?

27 What are Applications of Seismic Zonation?

- **To stop Increasing the Risk**

a. Building Codes
b. Land Use Ordinances
c. Urban / Regional Development Plans

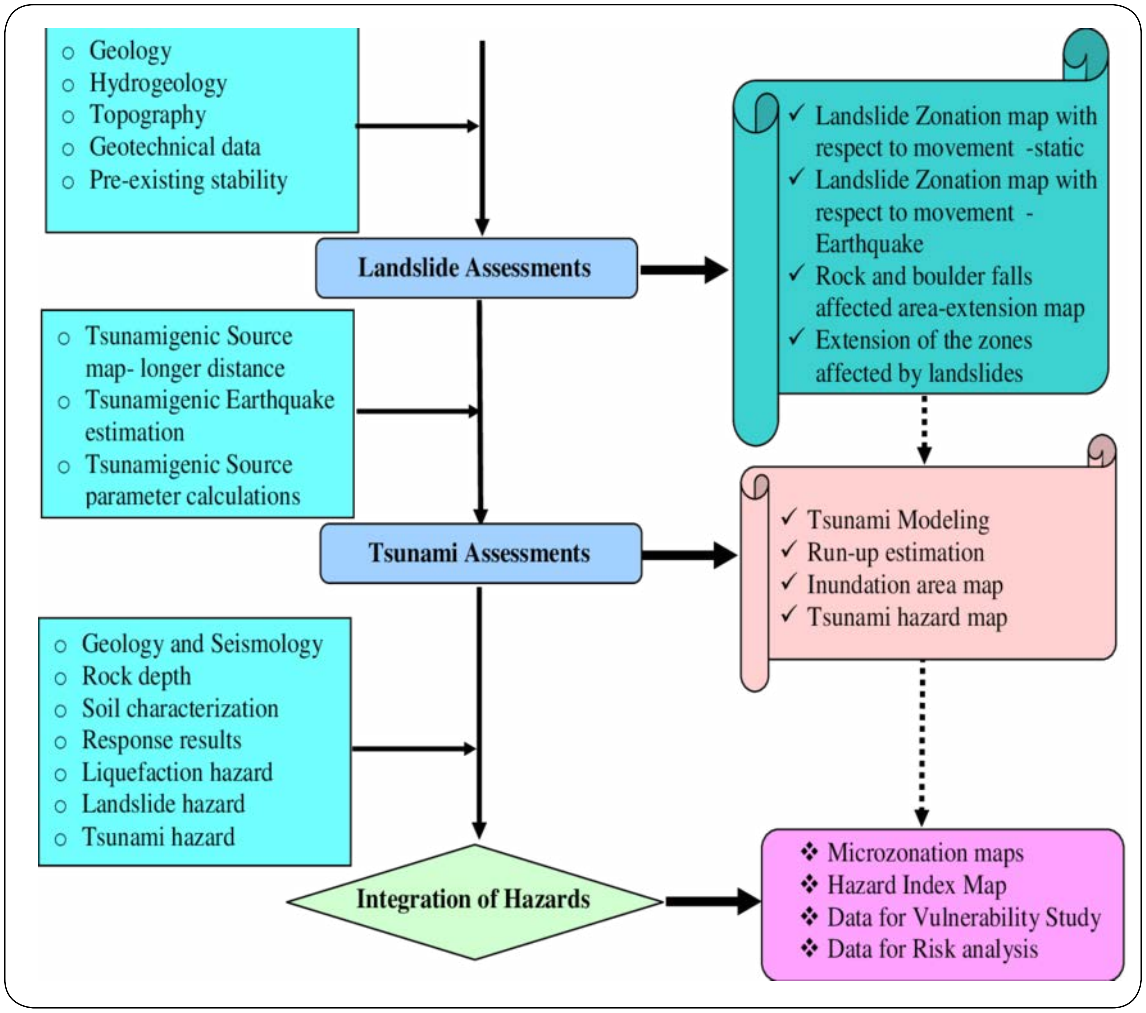
- **To start Decreasing the Risk**

a. Structural Strengthening
b. Non – structural detailing

- **To Continue Planning for the Inevitable**
  - Scenarios for Emergency Response
  - Scenarios for Recovery and construction

28 What is Seismic Microzonation?

The Seismic Hazard and Risk Microzonation" (SHRM) is a process of classifying the given geographic domain into small unitsof likely uniform Hazard (H) level (Peak Ground Acceleration-PGA, Spectral Acceleration-Sa), nature of hazard (susceptibility to liquefaction and slope failure) and Risk. The objective of Seismic Microzonation is to provide (a) probabilistic estimate of the hazard for each microzone due to earthquake shaking, (b) extent of likely damage to the built environment (dwellings, community structures, lifelines, industrial structures, monuments, heritage structures, etc.) and define damage ratio and people living in structures susceptible to damage, (c) retrofitting measures for the existing structures to render them safe and (d) specific guidelines for designing and construction of earthquake resistant structures belonging to microzones.



Geology
Hydrogeology
Topography
Geotechnical data
Pre-existing stability
Landslide Assessments
Landslide Zonation map with respect to movement -static
Landslide Zonation map with respect to movement - Earthquake
Rock and boulder falls affected area-extension map
Extension of the zones affected by landslides
Tsunamigenic Source map- longer distance
Tsunamigenic Earthquake estimation
Tsunamigenic Source parameter calculations
Tsunami Assessments
Tsunami Modeling
Run-up estimation
Inundation area map
Tsunami hazard map
Geology and Seismology
Rock depth
Soil characterization
Response results
Liquefaction hazard
Landslide hazard
Tsunami hazard
Integration of Hazards
Microzonation maps
Hazard Index Map
Data for Vulnerability Study
Data for Risk analysis

29 What is the significance important of Liquefaction?

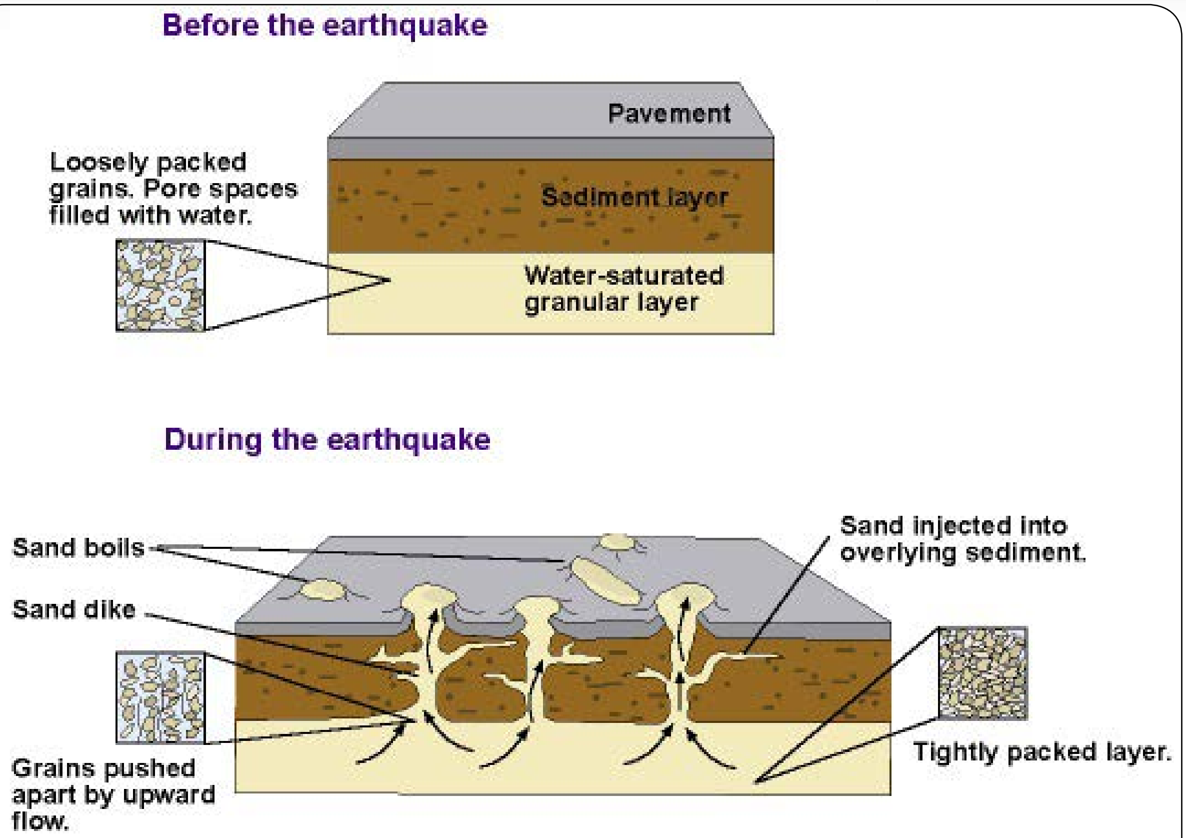
Liquefaction is a phenomenon in which the strength and stiffness of a soil is reduced by earthquake shaking or other rapid loading. Liquefaction and related phenomena have been responsible for tremendous amounts of damage in historical earthquakes around the world. Liquefaction occurs in saturated soils, that is, soils in which the space between individual particles is completely filled with water. This water exerts a pressure on the soil particles that influences how tightly the particles themselves are pressed together. Prior to an earthquake, the water pressure is relatively low. However, earthquake shaking can cause the water pressure to increase to the point where the soil particles can readily move with respect to each other.

Because liquefaction only occurs in saturated soil, its effects are most commonly observed in low-lying areas near bodies of water such as rivers, lakes, bays, and oceans. The effects of liquefaction may include major sliding of soil toward the body slumping.

Liquefaction also frequently causes damage to bridges that cross rivers and other bodies of water. Such damage can have drastic consequences, impeding emergency response and rescue operations in the short term and causing significant economic loss from business disruption in the longer term

30 Why can the ground liquefy due to an earthquake?

Soil liquefaction is a physical phenomenon related to a complete loss of shear resistance. Granular loose material like sand undergoes a rapid compaction when shaken. If this material is saturated, in the compaction leads to a rapid pore pressure increase. As a result the water attempts to flow out from the soil towards the ground surface. The deformation associated with liquefaction goes from being very limited to huge lateral displacements and vertical disruptions. Liquefaction mainly affects young geological formations, poorly consolidated deposits such as alluvial and littoral formations and also man-made landfills. The effect of liquefaction can be reproduced, for example, by kicking a couple of times the sand close to the shoreline making this mechanically stressed area flabby. Experts call this liquefaction, thixotropy.



EARTHQUAKE-INDUCED LIQUEFACTION

31 What is Soil Amplification and Structure Resonance?

Soils have a period-dependent effect on the ground motion, increasing the level of shaking for certain periods of vibration and decreasing It for others as a function of the “softness” and thickness of the soil relative to the underlying rock and the three-dimensional properties of the soil/rock column. Soil/Structure Resonance is a physical phenomenon Increasing the potential for destructiveness that results when the input seismic waves causes the underlying soil and the structure to resonate, or vibrate at the same period.

32 Define Earthquake Resilient Buildings and Infrastructure?

Buildings that are sited, designed and constructed in such a way that they are able to resist the ground shaking from large magnitude earthquakes without collapsing and from moderate-magnitude earthquakes without significant loss of function and with damage that is repairable.

Infrastructure-Thesestructures and facilities provide the essential functions of supply, disposal, communication, and transportation in a community. They are also called Community Lifelines.

33 How large of an earthquake does it take to make an earthen dam fail?

The amplitude and other characteristics of shaking required to cause a dam to fail are really an engineering issue. The shaking will be determined not only by the size of the earthquake, but also by it's proximity to the dam (e.g., a closer smaller earthquake may cause greater shaking than a larger more distant one).

34 Earthquake-Resistant Construction?

Earthquake-resistant construction offers the best protection against the consequences of serious seismic activity. Its prime objective is to prevent buildings from collapsing and thereby avoid injuries and fatalities. Furthermore, it seeks to help keep buildings working in the event of an earthquake and limit subsequent damage, caused by fire for example.

'Strong' earthquakes, with an intensity of around VI and above on the Mercalli scale can be expected to cause damage.

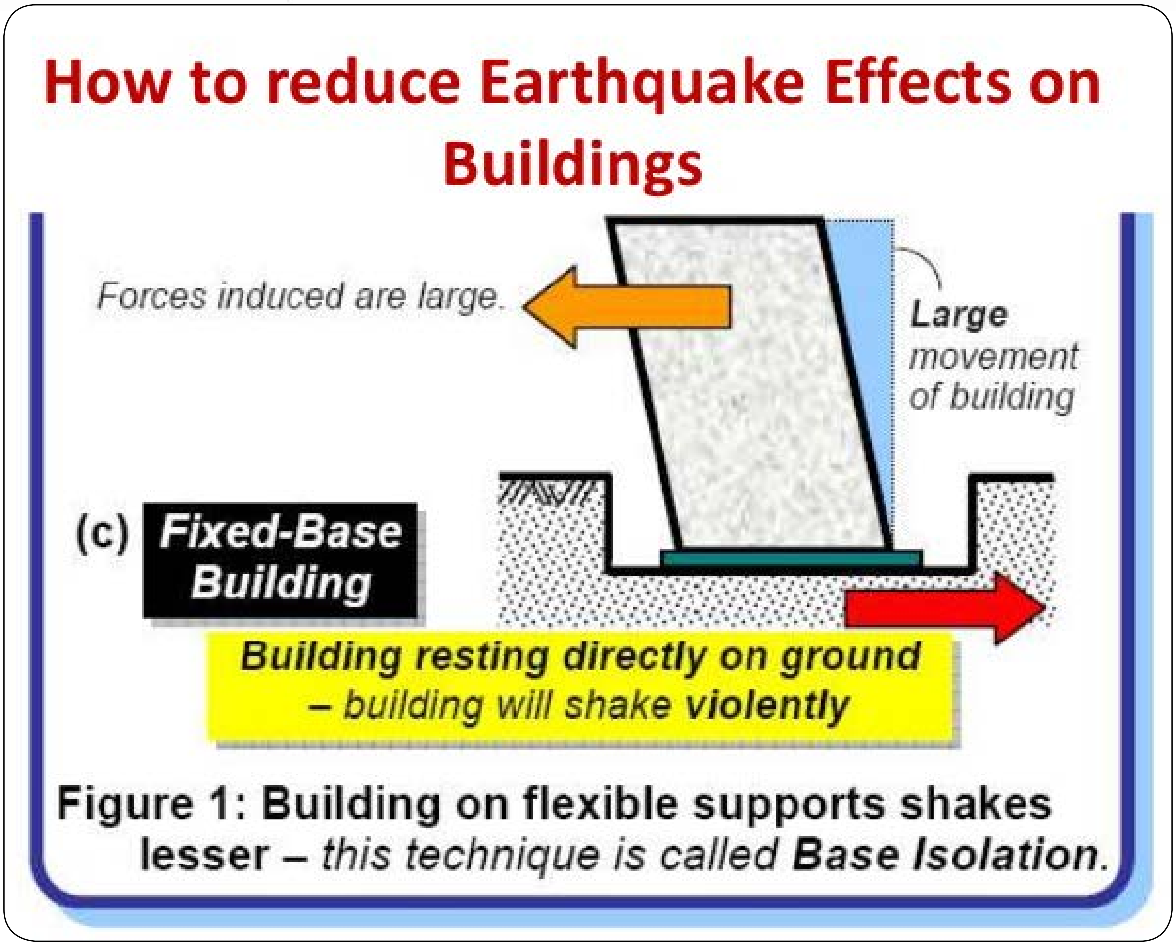
35 Earthquake-Resistant Design?

Close cooperation between architects and structural engineers in the early stages of a construction project is extremely important when planning an earthquake-resistant building, because it ensures an optimal combination of architectural considerations and seismic safety features. If a building is to withstand an earthquake, it must have a robust supporting framework to reduce horizontal earthquake loads. To this end, reinforcing structural components (such as walls or trusses) must extend over the full height of the building right down to the foundations, be as symmetrical as possible and be frictionally connected to its ceilings.

In addition to taking account of the building's load-bearing structure, an earthquake-resistant design must also consider the seismic safety of non-load-bearing components, installations and fittings like facades, partition walls, suspended ceilings, raised floors, heavy appliances and pipework.

36 How does earthquake effect buildings?

Earthquakes are caused due to movements of 'plates' under ground. In an earthquake, the ground shakes and suddenly starts to move backward and forward. This movement may be in any direction. Near the epicenter of the earthquake, there is also an upward and downward movement; because of which the foundation of the buildings move with the ground, but the interia of the rest of the building relays movement of upper part of the building. It is this delay which comes stresses in the buildings and cracking which is a typical of earthquake damage.



37 **Is it possible to build "Earthquake proof" houses?**

It is a misconception commonly shared that, houses could be made earthquake proof. The reality however is that by taking precautions, the earthquake resistance of the house can be increased finitely, making them capable to resist quakes of specific magnitudes. These houses, too, may fail once they face quakes of higher intensity than they are designed for.

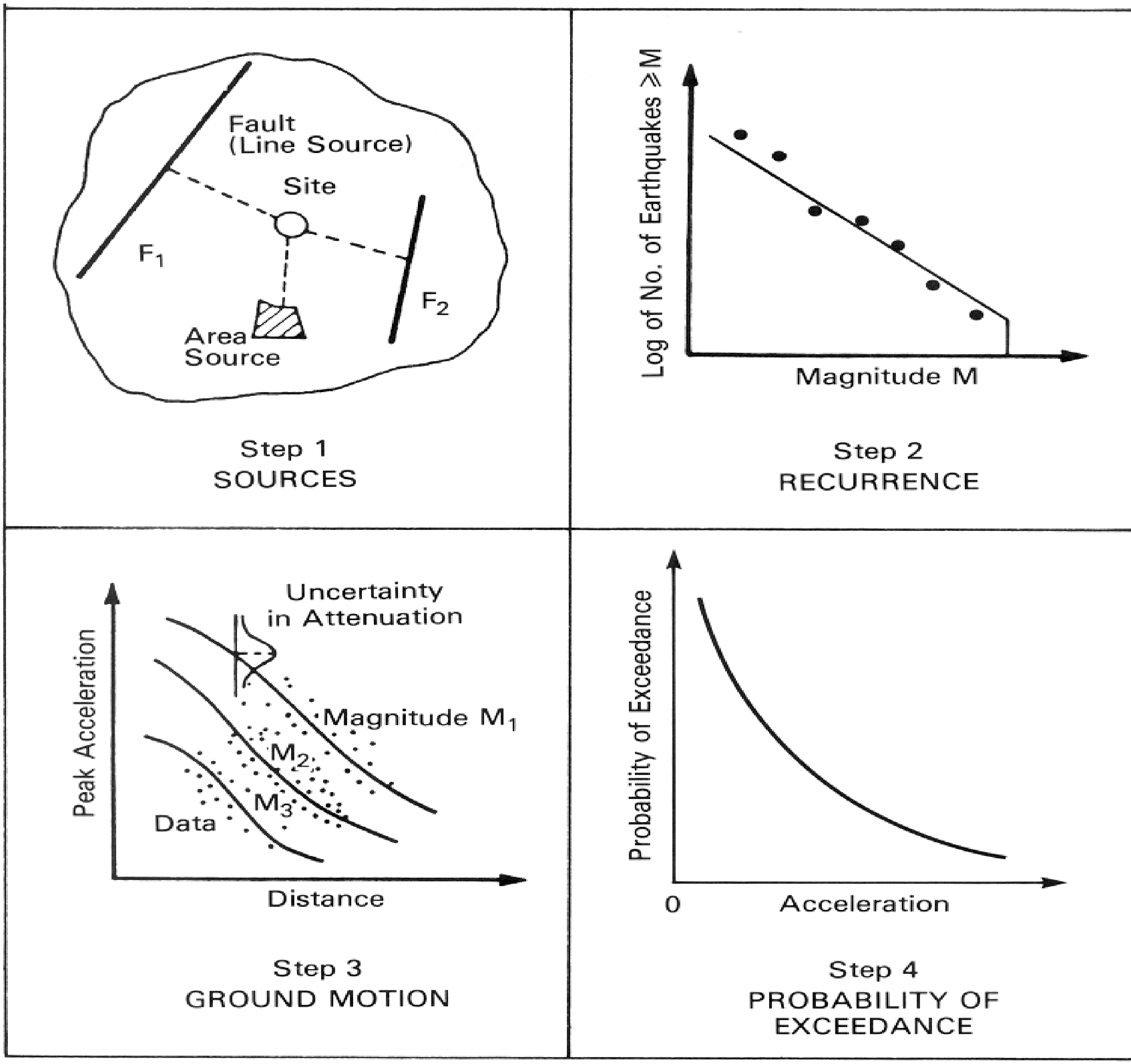
38 How strong should buildings be made?

The purpose of earthquake resistant design is not to prevent all damage by a severe earthquake, for such an objective would result in unreasonably expensive structures. The first aim is to ensure against the loss of life or injury. Second step is to balance the cost of additional design strength against the probable cost of repair of damage over the expected life of the structure. The main objective should be to prevent collapse of building with consequent loss of life. One must expect buildings to crack and to need repair if there is a major earthquake.Community buildings like schools, hospitals, power stations are more important than individual houses. Hence these buildings should be built more strongly than ordinary houses.

39 What is meant by PSHA and DSHA?

Probabilistic seismic hazard analysis (PSHA) is a methodology that estimates the likelihood that various levels of earthquake-caused ground motions will be exceeded at a given location in a given future time period. The results of such an analysis are expressed as estimated probabilities per year or estimated annual frequenciesThe PSHA method comprises five analysis steps 1.Identify the possible earthquake source zones. 2.Quantify the distribution of the earthquake magnitudes in these source zones. 3. Quantify the location uncertainty. 4. Formulate a prediction for the ground motion arriving at the site from events with different magnitudes, distances, etc. 5.Combine the uncertainties of all the above predictions using the total probability theorem and obtain yearly probability of exceedance for the ground motion.

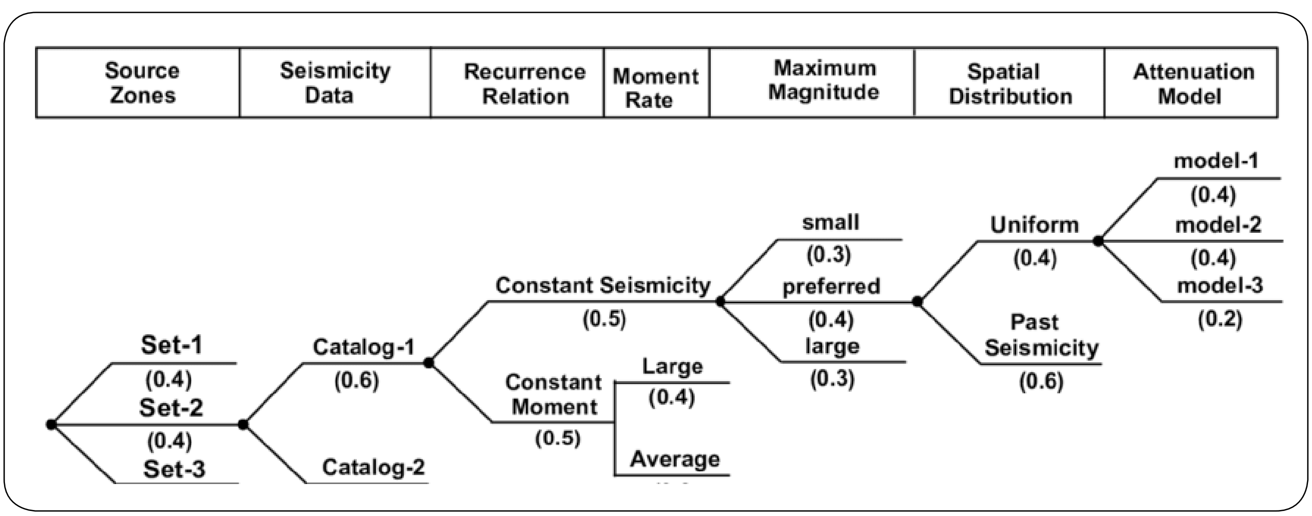
Deterministic seismic hazard analysis (DSHA) is an approach for evaluating site-specific seismic hazard that is influenced by the maximum hazard from the controlling sources affecting the specific study site. DSHA does not consider sources other than the largest "controlling" source and it does not account for the time factors owing to the uncertainty of earthquakes occurrences in time. Under certain condition, ignoring these factors can lower the conservatism of the hazard estimate, especially when other non-controlling sources generate hazards nearly equivalent to that of the controlling source or when the structure's design life is longer than the controlling source earthquake's return period


Fault
(Line Source)
Site
F1
F2
Area
Source
Step 1
SOURCES
Log of No. of Earthquakes ≥M
Magnitude M
Step 2
RECURRENCE
Uncertainty
in Attenuation
Magnitude M1
M2
M3
Data
Peak Acceleration
Distance
Step 3
GROUND MOTION
Probability of Exceedance
0
Acceleration
Step 4
PROBABILITY OF
EXCEEDANCE

40 Explain Logic Tree for Probabilistic Seismic Hazard Analysis (PSHA)?

Logic trees have become a standard feature of probabilistic seismic hazard analyses (PSHA) for determining design ground motions. A logic tree's purpose is to capture and quantify the epistemic uncertainty associated with the inputs to PSHA and thus enable estimation of the resulting uncertainty in the hazard. \A logic tree in PSHA is described as that all steps in which there are uncertainties to calculate the seismic hazard analysis are separated branches ,each branches are added for each of the choices that the analyst considers feasible, and a normalized weight is assigned to reflect the analyst's Confidence in choice of the most correct model or best estimation. The hazard calculation are then performed following all the possible branches. The logic tree is used in PSHA to estimate the epistemic uncertainty. A simple mixture of models (probability distributions). Weighting factors based on expert opinions or special approaches.

The hazard calculations are followed all the possible branches through the logic tree, each analysis producing a single hazard curve showing ground motion against annual frequency of exceedance. The weighting of each hazard curve is determined by multiplying the weights along all the component branches.



41 **What will happen if the building shakes too much?**

If the building shakes too much, structural elements, including beams, columns, walls and braces, can be damaged, rendering the building nonfunctional.Base isolators are like shock absorbers between the building and the ground motion, letting a building slide back and forth while remaining upright during a quake. Buildings that use base isolation are more likely to survive a strong earthquake and be functional afterward.

42 **What is meant by Base isolation and dampers?**

Base isolation is a technique where a building is built away (isolated) from the ground, resting on flexible bearings or pads known as base isolators. Base isolation technology can make medium-rise masonry (stone or brick) or reinforced concrete structures capable of withstanding earthquakes, protecting them and their occupants from major damage or injury. It is not suitable for all types of structures such as taller buildings.Seismic dampers are a method for dissipating the energy of an earthquake. Dampers are incorporated at beam-column joins. They are made of materials that disperse an earth-quake's energy, reducing the chance of breakage.

43 How Do Earthquakes Cause Damage?

Most earthquake damage is caused by ground shaking. The magnitude or size (energy release) of an earthquake, distance to the earthquake focus or source, focal depth, type of faulting, and type of material is important factors in determining the amount of ground shaking that might be produced at a particular site. Where there is an extensive history of earthquake activity, these parameters can often be estimated. In general, large earthquakes produce ground motions with large amplitudes and long durations. Large earthquakes also produce strong shaking over much larger areas than do smaller earthquakes. In addition, the amplitude of ground motion decreases with increasing distance from the focus of an earthquake. The frequency content of the shaking also changes with distance. Close to the epicenter, both high (rapid) and low (slow)-frequency motions are present. Farther away, low-frequency motions are dominant, a natural consequence of wave attenuation in rock. The frequency of ground motion is an important factor in determining the severity of damage to structures and which structures are affected.

44 What Are Earthquake Hazards?

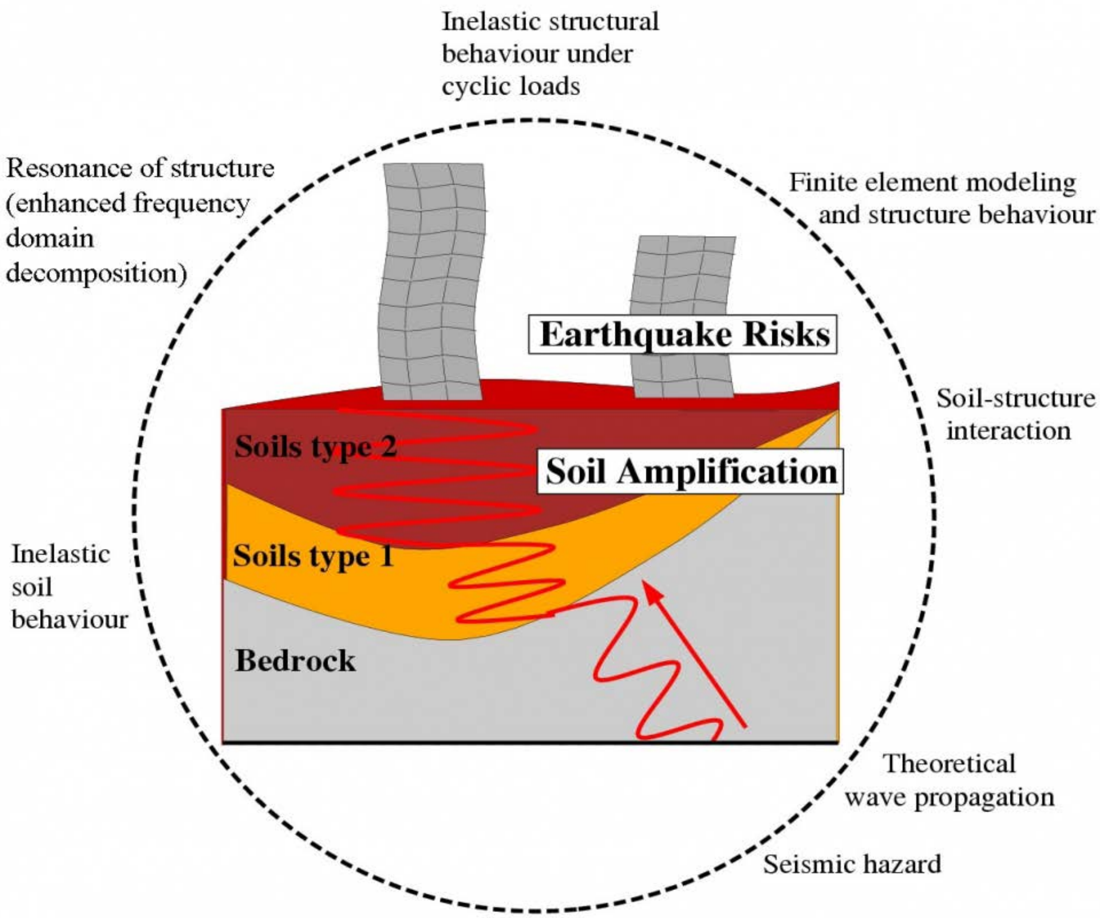
Earthquakes really pose little direct danger to a person. People can›t be shaken to death by an earthquake. Some movies show scenes with the ground suddenly opening up and people falling into fiery pits, but this just doesn›t happen in real life.

A. **The Effect of Ground Shaking.** Buildings can be damaged by the shaking itself or by the ground beneath them settling to a different level than it was before the earthquake (subsidence).Buildings can even sink into the ground if soil liquefaction occurs. If liquefaction occurs under a building, it may start to lean, tip over, or sink several feet. Liquefaction is a hazard in areas that have groundwater near the surface and sandy soil. Buildings can also be damaged by strong surface waves making the ground heave and lurch. Any buildings in the path of these surface waves can lean or tip over from all the movement. The ground shaking may also cause landslides, mudslides, and avalanches on steeper hills or mountains, all of which can damage buildings and hurt people.

B. **Ground Displacement**. Ground displacement (ground movement) along a fault. If a structure (a building, road, etc.) is built across a fault, the ground displacement during an earthquake could seriously damage or rip apart that structure.

C. **Flooding**. An earthquake can rupture (break) dams or levees along a river. The water from the river or the reservoir would then flood the area, damaging buildings and maybe sweeping away or drowning people. Tsunamis and seiches can also cause a great deal of damage. A tsunami is a huge wave caused by an earthquake under the ocean. Seiches are like small tsunamis. They occur on lakes that are shaken by the earthquake..

D. **Fire.** These fires can be started by broken gas lines and power lines, or tipped over wood or coal stoves. They can be a serious problem, especially if the water lines that feed the fire hydrants are broken, too.



45 Is my house safe?

There are two categories of seismic effects on a home; cosmetic and catastrophic . The seismic design principles incorporated into current building codes are specifically designed to prevent catastrophic failures of the structure. Cosmetic failures include cracking of drywall and finish work, cracks in concrete and masonry elements, and sticking of doors and windows. These types of seismic effects are expected even for designs under the current building code. If you own an older home, you should consider checking your seismic zone, to see if your home is located in a particularly at-risk area.

46 Do I need a seismic retrofit?

If your home has never received a seismic retrofit, then there is a good chance that it needs one—particularly if you live in an at-risk seismic zone. You should schedule a structural inspection and evaluation to determine whether a seismic retrofit is required.

47 Why is my drywall cracking?

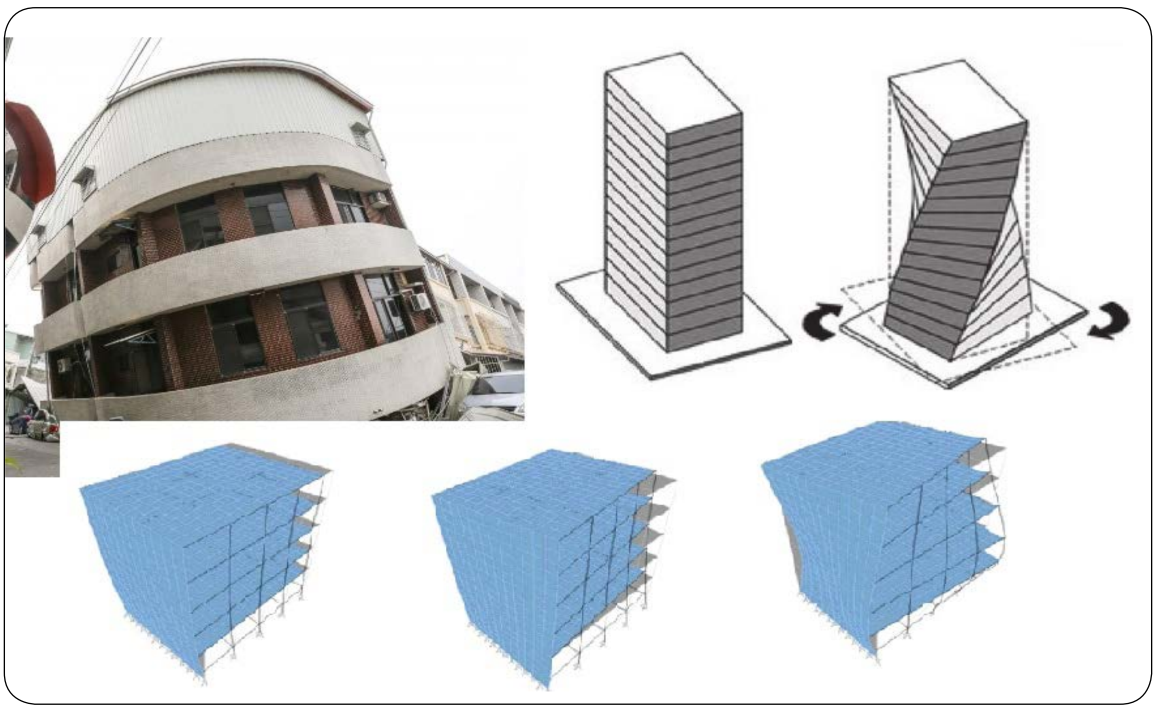
It's important to recognize that earthquakes and other seismic activity are not the only causes of drywall cracks. On the contrary, everything from soil characteristics, to moisture and foundation settling (the downward movement into the soil below) can cause cracks in the drywall. Drywall, paint and other wall materials are more brittle and less flexible than your home's framing. As such, while the frame of your house might be well equipped to handle settling or even seismic activity, the drywall doesn't have the same luxury. The brittleness of drywall explains why drywall will often crack during or following earthquakes—even in structurally sound homes.

48 What are Redundancy factors?

Redundancy factors are those factors in a home's original construction that protect it during an earthquake. These factors are unique to each home, so they can be are difficult to measure. Therefore engineers, contractors and building codes simply ignore them, and assume there is NO earthquake resistance in the original construction. There are three types of redundancy: load path redundancy, structural redundancy, and internal redundancy.

49 What are causes Twisting of Buildings During Earthquakes?

Twisting of buildings is one of the factors that cause severe damages during earthquakes. This commonly occurs in buildings due to stiffness irregularities in plan and elevation of buildings, and mass irregularity in plan and elevations of buildings.So, when an earthquake occurs, the seismic forces would cause greater movement at the side of a building in which the mass of the floor is greater or the vertical members are not distributed with the same concentration compare with the other side. Irregularity in stiffness in the plan occurs due to the use of columns of different sizes, presence of structural wall on one side of buildings, or presence of staircase or elevator core at one corner of buildings.



50 What are the effects of Twisting of Buildings During Earthquakes?

Twisting in buildings, called torsion by engineers, makes different portions at the same floor level to move horizontally by different amounts. This induces more damage in the columns and walls on the side that moves more. Many buildings have been severely affected by this excessive torsional behavior during past earthquakes. It is best to minimize (if not completely avoid) this twist by ensuring that buildings have symmetry in plan (i.e., uniformly distributed mass and uniformly placed vertical members).If this twist cannot be avoided, special calculations need to be done to account for this additional shear forces in the design of buildings. But, for sure, buildings with a twist would perform poorly during strong earthquake shaking.

51 What are causes of Earthquake Damages in Unreinforced Masonry Buildings?

There are several weaknesses that may cause the failure of unreinforced masonry structure during earthquakes. These weaknesses are design and construction errors which should be considered and addressed during the design and construction of such structure.

The main weaknesses in unreinforced masonry design and construction that lead to extensive seismic damage are inadequate brick unit, poor mortar, irregularities in plane and vertical directions, weak load bearing walls, lack of vertical confining elements, weak first story, wall openings, long; slender; and unsupported walls, insufficient shear base, heavy and stiff structure.

52 **Define briefly earthquake resistance structures?**

The earthquake resistance structure is differ from the earthquake proof structure. The earthquake proof structure completely safe without any damages, .but the cost of earthquake proof structure is too high whereas the earthquake resistance structure protect the structure from failure.34.

53 **Does the ground always shake?**

Yes, there are a lot of elements on the Earth that create seismic energy (human activity, headrest explosion, winds, sea waves, etc. traveling waves on the Earth and tremors on its surface. We call these movements background noise. With this exception only, there are always very weak earthquakes that are felt only by using a seismometer.

54 **What Are Building Codes?**

Building codes are sets of regulations governing the design, construction, alteration and maintenance of structures. They specify the minimum requirements to adequately safeguard the health, safety and welfare of building occupants. There is no more important factor in reducing a community's risk from an earthquake than the adoption and enforcement of up-to-date building codes. Evaluating older buildings and retrofitting structural and non-structural components also are critical steps. To survive and remain resilient, communities should also strengthen their core infrastructure and critical facilities so that these can withstand an earthquake or other disaster and continue to provide essential services.

55 What is the Seismic Code?

Some provisions within the IBC, IRC and IEBC are intended to ensure that structures can adequately resist seismic forces during earthquakes. These seismic provisions represent the best available guidance on how structures should be designed and constructed to limit seismic risk.The equations used to determine Seismic Design Forces are based on historical data that has been collected during past earthquakes. As the level of knowledge and data collected increases, these equations are modified to better represent these forces. Codes must also be effectively enforced to ensure that buildings and their occupants benefit from advances in seismic provisions in the model codes. For the most part, code enforcement is the responsibility of local government building officials who review design plans, inspect construction work and issue building and occupancy permits.

56 How Important Is Seismic Retrofitting?

Seismic retrofitting of vulnerable structures is critical to reducing risk. It is important for protecting the lives and assets of building occupants and the continuity of their work. On the whole, communities with more retrofitted structures can recover from earthquakes more rapidly.If you live or work in retrofitted structures, you’re less likely to be injured during an earthquake. Businesses that use retrofitted buildings are more likely to survive damaging earthquakes and to sustain shorter business interruptions and fewer inventory losses.Seismic retrofitting of a building must also include steps to better protect non-structural components (suspended ceilings, non-load-bearing walls and utility systems) and building contents (furnishings, supplies, inventory and equipment).

57 Can We Make Old Buildings Safe?

It's possible to make these buildings more resistant to earthquakes through seismic retrofitting. When dealing with a population of buildings, the first step is to perform a quick survey using Rapid Visual Screening of Buildings for Potential Seismic Hazards (FEMA 154). The next step is to evaluate the building. FEMA's QuakeSmart program helps businesses identify and address their seismic risks through retrofitting and other earthquake mitigation activities.

58 What is the effects of earthquakes on buildings?

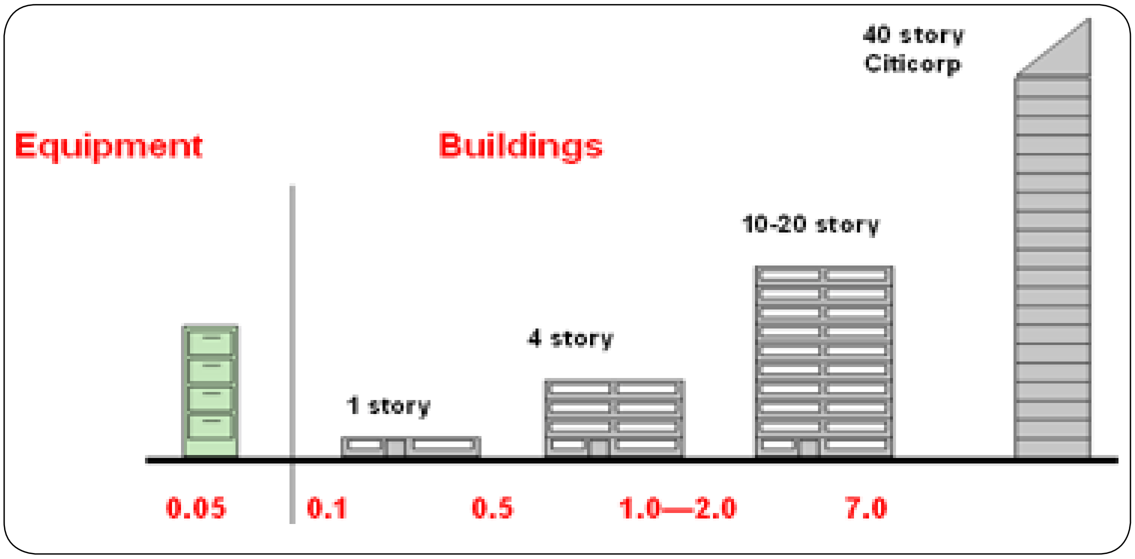
Seismic measures are used to calculate forces that earthquakes impose on buildings. Ground shaking (pushing back and forth, sideways, up and down) generates internal forces within buildings called the Inertial Force ($F_{Inertial}$), which in turn causes most seismic damage.

$F_{Inertial}$ = Mass (M) X Acceleration (A).

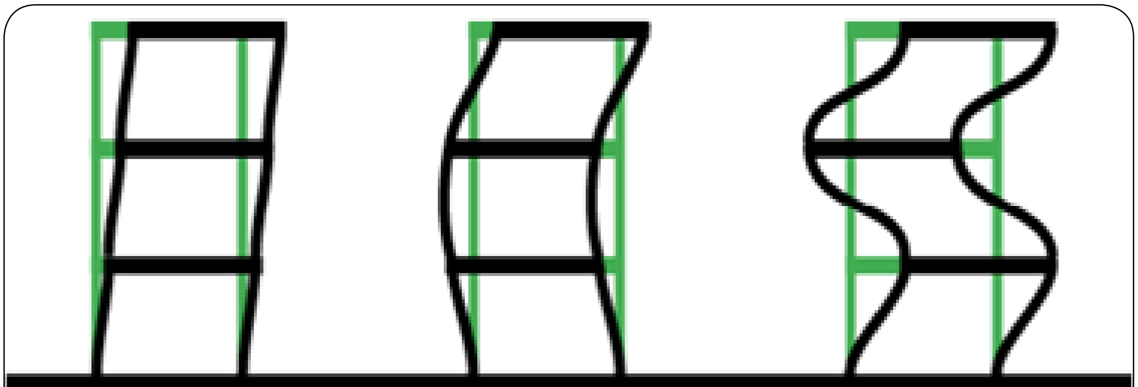
The greater the mass (weight of the building), the greater the internal inertial forces generated. Lightweight construction with less mass is typically an advantage in seismic design. Greater mass generates greater lateral forces, thereby increasing the possibility of columns being displaced, out of plumb, and/or buckling under vertical load (P delta Effect).

Earthquakes generate waves that may be slow and long, or short and abrupt. The length of a full cycle in seconds is the Period of the wave and is the inverse of the Frequency. All objects, including buildings, have a natural or fundamental period at which they vibrate if jolted by a shock.

The natural period is a primary consideration for seismic design, although other aspects of the building design may also contribute to a lesser degree to the mitigation measures. If the period of the shock wave and the natural period of the building coincide, then the building will «resonate» and its vibration will increase or «amplify» several times.



Height is the main determinant of fundamental period—each object has its own fundamental period at which it will vibrate. The period is proportionate to the height of the building.
The soil also has a period varying between 0.4 and 1.5 sec., very soft soil being 2.0 sec. Soft soils generally have a tendency to increase shaking as much as 2 to 6 times as compared to rock. Also, the period of the soil coinciding with the natural period of the building can greatly amplify acceleration of the building and is therefore a design consideration.



First mode   Second mode   Third mode

Tall buildings will undergo several modes of vibration, but for seismic purposes (except for very tall buildings) the fundamental period, or first mode is usually the most significant.

59 **What are factors controlling seismic design?**

The following factors affect and are affected by the design of the building.

Torsion: Objects and buildings have a center of mass, a point by which the object (building) can be balanced without rotation occurring. If the mass is uniformly distributed then the geometric center of the floor and the center of mass may coincide. Uneven mass distribution will position the center of mass outside of the geometric center causing "torsion" generating stress concentrations. A certain amount of torsion is unavoidable in every building design. Symmetrical arrangement of masses, however, will result in balanced stiffness against either direction and keep torsion within a manageable range.

Damping: Buildings in general are poor resonators to dynamic shock and dissipate vibration by absorbing it. Damping is a rate at which natural vibration is absorbed.

Ductility: Ductility is the characteristic of a material (such as steel) to bend, flex, or move, but fails only after considerable deformation has occurred. Non-ductile materials (such as poorly reinforced concrete) fail abruptly by crumbling. Good ductility can be achieved with carefully detailed joints.

Strength and Stiffness: Strength is a property of a material to resist and bear applied forces within a safe limit. Stiffness of a material is a degree of resistance to deflection or drift (drift being a horizontal story-to-story relative displacement).

Building Configuration (regular and irregular): This term defines a building's size and shape, and structural and nonstructural elements. Building configuration determines the way seismic forces are distributed within the structure, their relative magnitude, and problematic design concerns.

60 **What are the most important aspects of seismic design?**

A number of strategies are important to the design of structures that will behave adequately in strong earthquakes. These include 1. provision of continuity 2. adequate stiffness and strength 3. Regularity 4. Redundancy 5. defined yield mechanism.

61 **What is the relation between Intensity and Peak Ground Acceleration.**

Modified Mercalli Intensity	Peak Ground Acceleration (g)
VI	0.05–0.10
VII	0.10–0.20
VIII	0.20–0.30
IX	0.30–0.60
X	> 0.60

62 According to the building codes, what are defined site classes of soil?

The building codes and SEI/ASCE 7 adopted the concept of Site Class as a means of categorizing the tendency of a site to amplify or attenuate motion in different period ranges, in a relatively simple manner. Since the characteristics of soil within the upper 100 meters relative to the ground surface have the most significant effect on the shaking that is significant to buildings and building-like structures, Site Class is determined based on the average properties of soil within this zone. Six different site classes are designated in the code and are labeled A, B, C, D, E and F.Site Class A corresponds to very hard and competent rock including granites, quartz and similar stones. Site Class B corresponds to soft sedimentary rocks including sandstone, claystone, siltstone and similar materials.Site Class C corresponds to firm site conditions typified by dense sand and gravels and very stiff clays.Site Class D corresponds to average site conditions containing moderately dense granular soils and stiff clays.Site Class E corresponds to soils having high plasticity and compressibility, notably including weak clays, loose saturated silts and similar materials.Site Class F corresponds to soils that are unstable and which could experience such effects as liquefaction.

63 What is Site Class, and why is it important ?

When an earthquake occurs, the primary factors that affect the intensity of shaking that is experienced at a building site, and the destructive potential of this shaking, are: 1. The magnitude of the earthquake 2. The distance of the site from the fault 3. The direction of fault rupture 4. The characteristics of the rock through which the earthquake shaking propagates as it approaches the site 5. The nature of soils at the site.

64 Why does the code impose drift limits on buildings?

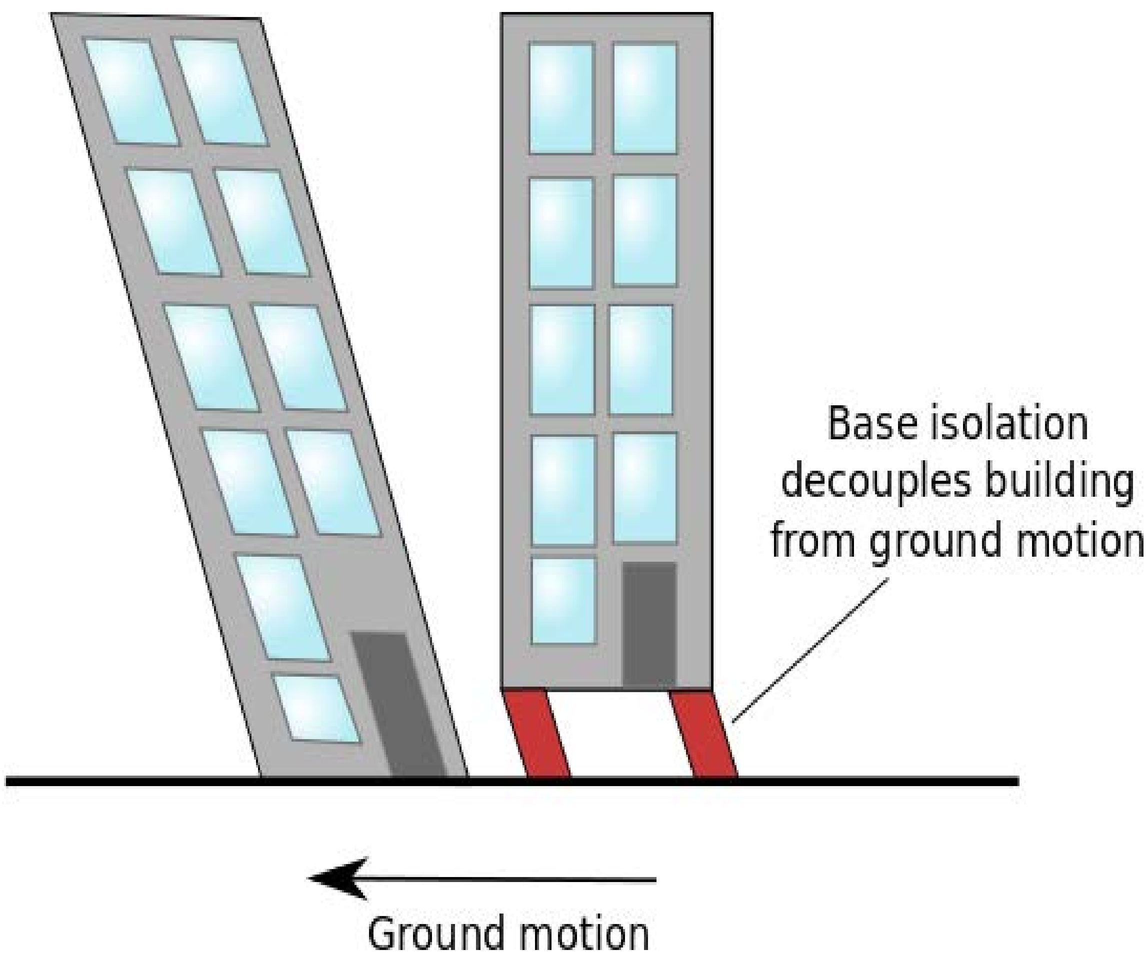
There are two basic reasons that the code places limits on the design drift for a building. The first of these relates to a lack of confidence in our ability to reliably predict structural response and behavior under very large deformations. In effect, the drift limits force the design of structures that should respond within our zone of comfort. A second reason the code limits drift is to protect nonstructural components, including exterior curtain walls, interior partitions and similar items, against damage during moderate intensity ground shaking.

65 What is an irregularity, and why is it important?

The structures that perform best in response to earthquakes, in addition to having adequate strength, stiffness, ductility and redundancy, also have distributions of stiffness, mass and strength that enable them to respond to earthquake shaking with deformations well distributed throughout the structure, rather than concentrated in one or a few locations. The reason these characteristics are important is that if in-elastic deformation is concentrated in a few locations within a structure, the inelastic capacity of the elements in these areas of large deformation demand can easily be exceeded, and instability can develop.SEI/ASCE 7 defines several types of irregularities, which are generally classified as horizontal irregularities or vertical irregularities, depending on the nature of the irregularity. Most of these irregularities relate to the geometric configuration of the structure and in particular, its seismic load resisting system

66 How do you make tall buildings earthquake-proof?

Tall buildings feel the effects of earthquakes much more so than short buildings since the vibrations are amplified over their height. So engineers have come up with many clever tricks to try and protect skyscrapers from earthquakes. Base isolation can be used, so buildings do not sit directly on the ground, and thus are decoupled from ground movement. Instead buildings sit on top of systems of ball bearings or springs which act as shock absorbers. Other systems attempt to balance out the swaying at the base of tall buildings by putting in a free swinging mass at the top, like a giant pendulum.



67 **Problem:**

The seismicity of a particular region is described by the Gutenberg-Richter recurrence law: **Ln N(m) = 9 – 1.6 m**

(a) What is the probability that at least one earthquake of magnitude greater than 7.0 will occur in a 10-year period? In a 50-year period? In a 250-year period?

(b) What is the probability that exactly one earthquake of magnitude greater than 7.0 will occur in a 10-year period? In a 50-year period? In a 250-year period?

(c) Determine the earthquake magnitude that would have a 10% probability of being exceeded at least once in a 50-year period.

Solution :

(a) $\lambda_m = N(m) = \exp(\alpha - \beta m) = \exp(9 - 1.6\ m)$

$\lambda_7 = \exp(9 - 1.6 * 7) = 0.111$ events/year

P(at least one M > 7 in 10 yrs) = 1 - exp(-0.111 * 10) = 67%

The corresponding probabilities in 50 yrs and 250 yrs are 99.6% and 100%, respectively.

(b) $P_n(t) = \frac{(\lambda_m t)^n \exp(-\lambda_m t)}{n!}$

$P_1(10) = 0.111 * 10 \exp(-0.111 * 10) = 36.6\%$

$P_1(50) = 0.111 * 50 \exp(-0.111*50) = 2.2\%$

$P_1(250) = 0.111 * 250 \exp(-0.111 *250) = \%$

(c) P(at least one M > m in 50 yrs) = 0.1

$= 1 - \exp(-\lambda_m *50)$

$\lambda_m = \text{Ln}(1 - 0.1) / 50 = 0.00211$

$\lambda_m = 0.00211 = \exp(9 - 1.6\ m)$

$M = [9 - \text{Ln}(0.00211)] / 1.6 = 9.5$

REFERENCES

Beiser, A (1975). Earth Sciences. Schaum's Outline Series. Mc Graw-Hill Book Company. 129 P.

CIDER (2018). Lectures collection.

https://seismo.berkeley.edu/wiki/cider/index.

El-Kammar A. (2018). Principles of Geochemistry (PPT). Cairo Univ. Egypt.

Mussett, A. and Khan, M. (2000). Looking into the Earth. Cambridge University Press. 470 P.

Passbook Series (1991). Earth Science (Q-46). National Learning Corporation. New York.

Passbook Series (1979). Geophysicist (C-302). National Learning Corporation. New York.

Passbook Series (1998). Earth Sciences & General Science (T-14). National Learning Corporation. New York.

Passbook Series (1992). General Geophysics (DANTES-17). National Learning Corporation. New York.

Passbook Series (1991). Geophysics (Q-64). National Learning Corporation. New York.

Passbook Series (2002). Geology. National Learning Corporation. New York.

QUORA. (2020). www.quora.com.

Rawlinson, N. (2015). Lecture 13: Earthquake magnitudes and moment. Australian National University.

Rudman, J. (1987). Graduate Record Examination Series (Geology 8). National Learning Corporation. New York.

Tufty, B. (1969). 1001 Questions Answered About Earthquakes, Avalanches, Floods and Other Natural Disasters. Dover Publications, Inc. New York. 341 P.

Wilcock, W (2012). Lecture notes on PPT. OCEAN/ESS 410. University of Washington, USA.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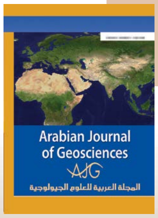
Scientific Publication	• Published more than **200** scientific papers in peer-reviewed journals • Authored **35** scientific books • issued a digital encyclopedia of earth sciences of **14** volumes and **107** scientific files.
Projects	• Completed **40** local projects, **16** international projects and **74** technical reports.
Conferences	• Participated in more than **125** local and international conferences & **75** specialized seminars and workshops
International Cooperation	• Principal researcher in **13** American and German working groups.
Prizes	• Received Almarai Prize for Scientific Creativity in 2005. • Received the Golden Excellence Award from KACST in 2006. • Received Abha Appreciation Award for Scientific Contributions in 2007. • Received King Saud University Award for Scientific Excellence in 2013. • Received the American Geophysical Union Award for International Cooperation and Research Activities in 2013. • Received the Sultan Qaboos University Award for Scientific Contributions in 2013. • Received the King Saud Prize for inclusion of the Arab Journal of Geological Sciences in the ISI list. • Received the award for the best editor-in-chief of the scientific journal of the year 2017 & 2018 from the German publisher Springer. • Recipient of the 2018 Albert Nelson Marquis Lifetime Achievement Award from Who's Who • Received **85** honorary shields and certificates of appreciation from Saudi Arabia, Oman, Kuwait, UAE, Jordan, Egypt, Tunisia Algeria, Germany and America



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