Lecture 3: Introduction to Engineering Seismology; Terminologies and definitions; Earthquake types.

Topics

- Introduction
- Terminologies and Definitions
- Earthquake types
- Reservoir triggered earthquakes

Keywords: *Engineering Seismology, Earthquake types, Terminologies*

Topic 1

Introduction

- Seismology (the word is derived from the Greek word "seismos" which means Earthquake and logos means science) is the scientific study of Earthquakes and the movement of waves through the Earth. The field also includes studies of variants such as seaquakes, volcanoes and plate tectonics in general and consequential phenomena such as tsunamis.

- Engineering Seismology deals with the effects of Earthquakes on people and their environment and with methods of reducing those effects. It is a very young discipline, many of its most important developments having occurred in the past 30 to 40 years.

- Engineering Seismology requires first of all knowledge of the geologic causes of, and expected shaking, liquefaction, and other effects have on humankind, ranging from our buildings and other structures to the entire built and even social environment.

Topic 2

Terminologies and Definitions

- **Accelerometer:** a seismograph for measuring ground acceleration as a function of time.
- **Active fault:** a fault along which slip has occurred, either in historical or Holocene or quaternary time or Earthquake foci are located.
- **Active margin:** continental margin characterized by volcanic activity and Earthquakes (i.e., location of transform fault or subduction zone).
- **Aftershocks:** smaller Earthquakes following the largest Earthquake of a series concentrated near main shock rupture.
- **Amplitude (wave):** the height of a wave crest or depth of a trough.
- **Aseismic region:** one that is almost free of Earthquakes.

- **Asperities (fault):** roughness on the fault surface subject to slip.
- **Asthenosphere:** the layer below the lithosphere that is marked by low seismic-wave velocities and high seismic-wave attenuation. It is a soft layer, probably partially molten.
- **Attenuation:** the reduction in amplitude of a wave with time or distance traveled.
- **Auxiliary fault plane:** a plane orthogonal to the fault plane.
- **Basin depression:** depression in which sediments collect.
- **Barrier (fault):** an area of fault surface resistant to slip because of geometrical or structural changes.
- **Benioff zone:** a narrow zone, defined by Earthquake foci, that is tens of kilometers thick, dipping form the surface under the Earth's crust to depths of up to 700 kilometers.
- **Blind thrush:** a thrust fault deep in the crust with no or only indirect surface expression such as a fold structure.
- **Body wave:** a seismic wave that travels through the interior of an elastic material; P and S seismic waves.
- **Body-wave magnitude:** magnitude m_b of an Earthquake as estimated from the amplitude of initial P body wave.
- **Bore:** a single water wave with an almost vertical front.
- **B value:** a coefficient describing the ratio of small to large Earthquakes within a given area and time period, often shown to be the same over a wide range or magnitudes. It is the slope of the curve in the Gutenberg-Richter recurrence relationship.
- **Characteristic Earthquake:** an Earthquake with a size and generating mechanism typical for a particular fault source.
- **Coda:** the concluding train of seismic waves that follows the principal part of an Earthquake.
- **Continental shelf:** part of the continental margin between the coast and the continental slope; slopes about 0.1°.
- **Core (of Earth):** the central part of the Earth below a depth of 2900 kilometers. It is thought to be composed mainly of iron and silicates and to be molten on the outside with a solid central part.
- **Creep (slow fault slip):** slow slip occurring along a fault without producing Earthquakes. Sometimes called "silent Earthquakes".
- **Crust (of Earth):** the outermost rocky shell of the Earth.
- **Damping:** loss of energy in wave motion due to transfer into heat by frictional forces. damping is any effect that tends to reduce the amplitude of oscillations in an oscillatory system
- **Density:** the mass per unit volume of a substance, commonly expressed in grams per cubic centimeter.
- **Digital recording:** a series of discrete numerical digits. In digital recording, the analog signal of video or sound is converted into a stream of discrete numbers
- **Dilatancy (of rocks):** the increase in the volume of rocks mainly due to pervasive micro cracking.

- **Dip:** the angle by which a rock layer or fault plane deviates from the horizontal. The angle is measured in a plane perpendicular to the strike.
- **Dip slip fault:** a fault in which the relative displacement is along the direction of dip of the fault plane; the offset is either normal or reverse.
- **Dispersion (wave):** the spreading out of a wave train due to each wave length traveling with its own velocity.
- **Duration (of strong shaking):** the time interval between the first and last peaks of strong ground motion above specified amplitude.
- **Earthquake:** the vibrations of the Earth caused by the passage of seismic waves radiating from some source of elastic energy.
- **Earthquake-recurrence interval:** the average interval of time between the occurrences of Earthquakes in a particular region.
- **Earthquake segment:** that part of a fault zone (or fault zones) that has ruptured during individual Earthquakes.
- **Elastic rebound theory:** the theory of Earthquake generation proposing that faults remain locked while strain energy slowly accumulates in the surrounding rock and then suddenly slip, releasing this energy in the form of heat and seismic waves.
- **Epicenter:** the point on the Earth's surface directly above the focus (or hypocenter) of an Earthquake.
- **Fault:** a fracture or zone of fractures in rock along which the two sides have been displaced relative to each other parallel to the fracture. The total fault offset may range from centimeters to kilometers.
- **Fault plane:** the plane that most closely coincides with the rupture surface of a fault.
- **First motion:** on a seismogram, the direction of motion at the beginning of the arrival of a P wave. Conventionally, upward motion indicates an initial compression of the ground; downward motion, a dilatation.
- **Flower structure:** more or less symmetrical splays into sub-faults near the intersection of the main fault with the ground surface.
- **Focal depth (of Earthquakes):** the depth of the focus below the surface of the Earth.
- **Focus (hypocenter):** the place at which rupture commences.
- **Footwall:** the underlying side of a nonvertical fault surface.
- **Foreshocks:** smaller Earthquakes preceding the largest Earthquake of a series concentrated in a restricted crustal volume.
- **Frequency:** number of oscillations per unit time; unit is hertz (Hz), i.e. cycles per second.
- **Geodimeter:** a surveying instrument to measure the distance between two points on the Earth's surface.
- **Global positioning system (GPS):** a geodetic surveying system in which multiple satellites are used to establish locations of ground stations.
- **Gouge:** crushed, sheared and powdered rock altered to clay in a fault zone.

- **Graben:** a crustal block of rock, generally long and narrow, that has dropped down along boundary faults relative to the adjacent rocks.
- **Gutenberg discontinuity:** discontinuity in seismic velocity that marks the boundary between the core and the mantle; named after seismologist Beno Gutenberg.
- **Hanging wall:** the overlying side of a non-vertical fault surface.
- **Hazard (seismic):** dangerous physical effects of Earthquakes, such as landslides, ground shaking, tsunamis.
- **Hertz:** the unit of frequency equal to 1 cycle per second, or 2π radians per second.
- **Holocene:** less than 10,000 years before the present.
- **Hypocenter:** same point as the focus.
- **Incompressibility:** an index of the resistance of an elastic body, such as a rock, to volume change.
- **Inner core (of Earth):** central solid region of the Earth's core, probably mostly iron; radius about 1221 kilometers.
- **Intensity (of Earthquakes):** a measure of ground shaking obtained from the damage done to structures built by humans, changes in the Earth's surface, and felt reports.
- **Interplate Earthquake:** Earthquake with its focus on plate boundary.
- **Intraplate Earthquake:** Earthquake with its focus well within a plate.
- **Island arc:** chain of islands above a subduction zone (e.g., Japan, Aleutians).
- **Isoseismal:** contour lines drawn to separate one level of seismic intensity from another.
- **Isostasy:** the balance in which the lithosphere "floats" on the athenosphere.
- **Lava:** magma, or molten rock that has reached the surface.
- **Left-lateral fault:** a strike- slip fault on which the displacement of the far block is to the left when viewed from either side.
- **Lehmann discontinuity:** boundary between outer and inner core of the Earth.
- **Liquefaction (of soil):** process of soil and sand behaving like a dense fluid rather than a wet solid mass during an Earthquake.
- **Lithology:** physical character of rocks.
- **Lithosphere (of Earth):** the outer, rigid shell of the Earth above the asthenosphere. It contains the crust, continents and uppermost mantle.
- **Love waves:** seismic surface waves with only horizontal shear motion transverse to the direction of propagation
- **Lurching of ground:** disruption of soil by lateral spreading under gravity.
- **Magma:** molten rock that forms igneous rocks upon cooling.
- **Magnitude (of Earthquake):** a measure of Earthquake size, determined by taking the common logarithm (base 10) of the largest ground motion recorded during the arrival of a seismic-wave type and applying a standard correction for distance to the epicenter. Three common types of magnitude are Richter (or local) (M_L), body (m_b), and surface wave (M_S). Calculated differently is moment magnitude (M_W).

- **Mantle (of Earth):** the main bulk of the Earth, between the crust and core, ranging from depths of about 40 to 3470 kilometers. It is composed of dense silicate rocks and divided into a number of concentric shells.
- **Mare:** a dark, low lying lunar plain, filled to an undetermined depth with volcanic rocks. (plural: Maria)
- **Meizoseismal region:** the area of strong shaking and significant damage in an Earthquake.
- **Meizoseisms:** weak, almost continuous back ground seismic waves or Earth "noise" that can be detected only by seismographs; often caused by surf, ocean waves, wind, or human activity.
- **Microzonation:** the division of a town or country into smaller areas according to the variation in seismic hazard.
- **Mohorovicic discontinuity (M-discontinuity):** the boundary between crust and mantle, marked by a rapid increase in seismic P-wave velocity to more than 7.6 kilometers per second; depth, 5 kilometers (under oceans) to 80 kilometers (under highest mountains).
- **Moment (of Earthquakes):** a measure of Earthquake size related to the leverage of the forces (couples) across the area of the fault slip; equal to the rigidity of the rock times the area of faulting times the amount of slip dimensions are dyne-cm (or Newton-meters).
- **Moment magnitude:** magnitude (M_W) of an Earthquake estimated from the seismic moment.
- **Normal fault:** a dip-slip fault in which the rock above the fault plan has moved downward relative to the rock below.
- **Oblique fault:** a fault that has slip components both along the dip and along the strike of the fault.
- **Origin time:** the time of initiation of the seismic waves at an Earthquake source (usually given in Universal Time, UT)
- **Outer core (of Earth):** outer liquid shell of the Earth's core, probably iron with some silicates; inner radius, 1221 kilometers; outer radius, 3480 kilometers.
- **Paleoseismology:** that part of Earthquake studies that deals with evidence for Earthquakes before instrumental recording of seismic waves or damage from felt reports.
- **Passive margin:** continental margin formed during initial rifting apart of continents to form an ocean; frequently has thick sedimentary deposits.
- **Period (wave):** the time interval between successive crests in a sinusoidal wave train; the period is the inverse of the frequency of a cyclic event.
- **Plate (tectonic):** a large, relatively rigid segment of the Earth's crust and uppermost mantle (the lithosphere) are divided into a number of more or less rigid segments (plates).
- **Prediction (of Earthquakes):** a change in the geological conditions that is a forerunner to Earthquake generation on a fault.
- **Probability:** the number of cases that actually occur divided by the total number of cases possible.

- **Probability of exceedence of a given Earthquake size:** the chance that the size of a future Earthquake will exceed some specified value.
- **P wave:** the primary or fastest wave traveling away from a seismic event through the rock and consisting of a train of compression and dilatations of the material.
- **Quaternary period:** about 2 million years before the present.
- **Rayleigh waves:** seismic surface waves with ground motion only in a vertical plane containing the direction of propagation of the waves.
- **Recurrence interval:** the average time interval between Earthquakes in a seismic region.
- **Resonance:** the largest vibration of a mechanical system (such as a soil layer) due to enhancement of the energy at a frequency special to that system.
- **Reverse fault:** the rock above the fault plane (the "hanging wall") moves and over the rock below (the "footwall").
- **Ridge (midoceanic):** a major linear elevated landform of the ocean floor, many hundreds of kilometers in extent. It resembles a mountain range with a central rift valley.
- **Rift:** region where the crust has split apart usually marked by a rift valley (e.g. East African Rift, Rhine Graben).
- **Right-lateral fault:** a strike-slip fault on which the displacement of the far block is to the right when viewed from either side.
- **Rigidity:** 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.
- **Risk (seismic):** the probability of life and property loss from an Earthquake hazard within a given time interval and region.
- **Run-up height:** the elevation of the water level above the immediate tide level when a tsunami runs up onto the coastal land.
- **Sag:** a narrow geological depression found in strike-slip fault zones. Those that contain water are called sag ponds.
- **Scarp (fault):** a cliff or steep slope formed by displacement of the ground surface.
- **Sea floor spreading:** the process by which adjacent plates along midoceanic ridges move apart to make room for new seafloor crust. This process may continue at 0.5 to 10 centimeters per year through many geological periods.
- **Seiche:** oscillations (standing waves) of the water in a bay or lake.
- **Seismic discontinuity:** a surface or thin layer within the Earth across which P-wave and/or S-wave velocities change rapidly.
- **Seismic gap:** an area in an Earthquake-prone region where there is a below-average release of seismic energy.
- **Seismicity:** the occurrence of Earthquakes in space and time.
- **Seismic wave:** an elastic wave in the Earth, usually generated by an Earthquake source or explosion.
- **Seismograph:** Instruments for recording as a function of time the motions of the Earth's surface that are caused by seismic waves.

- **Seismology:** the study of Earthquakes, seismic sources, and wave propagation through the Earth.
- **Seismometer:** the sensor part of the seismograph, usually a suspended pendulum
- **Seismoscope:** a simple seismograph recording on a plate without time marks.
- **Shadow zone:** the area on the Earth's surface protected from seismic –wave shaking by some blocking object in the Earth.
- **Slip (fault):** the relative motion of one face of a fault relative to the other.
- **Soil amplification:** growth in the wave amplitude when Earthquakes pass from rock into less rigid material such as soil.
- **Strain (elastic):** the geometrical deformation or change in shape of a body; the change in an angle, length, area, or volume divided by the original value.
- **Stress (elastic):** a measure of the forced acting on a body in units of force per unit area.
- **Stress drop:** the sudden reduction of stress across the fault plane during rupture.
- **Strike of fault:** the line intersection between the fault plane and the surface of the Earth. Its orientation is expressed as the angle west or east of true north.
- **Strike-slip fault:** a fault whose relative displacement is purely horizontal.
- **Strong ground motion:** the shaking of the ground near an Earthquake source made up of large-amplitude seismic waves of various types.
- **Subduction:** the process of one lithospheric plate descending beneath another.
- **Subduction zone:** a dipping ocean plate descending into the Earth beneath another plate. It is usually the locus of intermediate and deep Earthquakes defining the Wadati-Benioff zone.
- **Surface-wave magnitude:** magnitude M_S of an Earthquake estimated from measurements of the amplitude of 20-second surface waves.
- **Surface waves (of Earthquakes):** seismic waves that follow the Earth's surface only, with a speed less than that of S waves. There are two types of surface waves- Rayleigh waves and Love waves.
- **Swarm (of Earthquakes):** a series of Earthquakes in the same locality, no one Earthquake being of outstanding size.
- **S wave:** the secondary seismic wave, traveling more slowly than the P wave and consisting of elastic vibrations transverse to the direction of travel. It cannot propagate in a liquid.
- **Tectonic Earthquakes:** Earthquakes resulting from sudden release of energy stored by major deformation of the Earth.
- **Tectonics:** large-scale deformation of the outer part of the Earth resulting from forces in the Earth.
- **Teleseism:** an Earthquake that occurs at a distant place, usually overseas.
- **Thrust fault:** a reverse fault in which the upper rocks above the fault plane move up and over the lower rocks at an angle of 30° or less so that older strata are placed over younger.
- **Tomography:** construction of the image of an internal object or structure from measurements of seismic waves at the surface.

- **Transform fault:** a strike-slip fault connecting the ends of an offset in a midoceanic ridge, an island arc, or an arc ridge chain. Pairs of plates slide past along transform faults.
- **Travel-time curve:** a graph of travel time of seismic waves versus distance to a seismic source. Each type of seismic wave has its own curve.
- **Trench:** long, narrow arcuate depression in the seabed that results from the bending of the lithospheric plate as it descends into the mantle at a subduction zone.
- **Triple junction:** point where three plates meet.
- **Tsunami:** a long ocean wave usually caused by sea floor displacement in an Earthquake or landslide.
- **Turbidite:** a sedimentary deposit resulting from a turbulent current along the sea bottom.
- **Viscoelastic material:** a material that behaves as an elastic solid on a short time scale and as a viscous fluid on a long one.
- **Volcanic Earthquakes:** Earthquakes associated with volcanic activity.
- **Volcanic rock:** igneous rock that involves the eruption of molten rock.
- **Volcanic tremor:** the more or less continuous vibration of the ground near an active volcano.
- **Volcanism:** geological process that involves the eruption of molten rock.
- **Volcano:** an opening in the crust that has allowed magma to reach the surface.
- **Wadati-**Benioff zone: See Benioff zone.
- **Wave front:** the farthest geometrical surface reached by a wave in a given time.
- **Wave length:** the distance between two successive crests or troughs.

Topic 3

Earthquake Types

- The most common type of earthquakes is the **Tectonic earthquakes**. These are produced when rocks break suddenly in response to various geological forces. Tectonic earthquakes are scientifically important to the study of the earth's interior and of tremendous social significance because they pose the greatest hazard.
    - 95% of worldwide seismic energy release by plate tectonic and causes Tectonic earthquakes

- A second well-known type of earthquake accompanies volcanic eruptions. A **volcanic earthquake** is still defined as one that occurs in conjunction with volcanic activity, but it is believed that while eruptions and earthquakes both result from tectonic forces in the rocks, they need not occur together. The actual mechanism of wave production in volcanic earthquakes is probably the same as that in tectonic earthquakes.

- **Collapse earthquakes** are small earthquakes occurring in regions of underground caverns and mines. The immediate cause of ground shaking is the collapse of the roof of the mine or cave. An often observed variation of this phenomenon is the so-called mine burst.

- Earthquakes are also sometimes produced by massive land-sliding. The landslide is not triggered by a nearby tectonic earthquake, but part of the gravitation energy is lost in the rapid downward movement of the soil and rock and is converted to seismic waves.

- Humans cause explosion earthquakes, or ground shaking produced by the detonation of chemicals or nuclear devices. Underground nuclear explosions during the past several decades at a number of test sites around the world have produced substantial earthquakes.

- Impact earthquakes are an interesting separate class of earthquake. Meteorite (bolide) strikes are such a powerful force that the massive 1908 meteorite impact in Siberia gave distant seismic wave recordings.

- People and animals sometimes produce earthquakes (usually small) in other ways. A shocking example was the terrorist jet plane attacks on the World trade center on September 11, 2001.

Types of earthquake based on depth

- The point from which the seismic waves first emanate is called the earthquake focus or the hypocenter. The foci of natural earthquakes are at some depth below the ground surface.

- **Shallow focus Earthquake** – Those with foci less than 70 kilometers deep are called shallow focus. Shallow earthquakes wreak the most devastation, and they contribute more than three-quarters of the total energy released in earthquakes throughout the world.

- **Intermediate focus Earthquake** – Those with foci from 70 to 300 kilometers deep are arbitrarily called intermediate focus.

- **Deep focus Earthquake** - Those below the depth of 300 kilometers are termed deep focus. Many foci are situated hundreds of kilometers deep, such regions include South American Andes, the Tonga islands, Somoa, The New Hebrides chain, the Japan Sea, Indonesia, and the Caribbean Antilles.

Types of earthquake based on location

- Earthquakes occurring along the edges of the interacting plates are called **interplate earthquakes**. Most (over 90%) earthquakes are of this type of earthquakes. Some areas of the world that are particularly prone to such events include the west coast of North America (especially California and Alaska), the northeastern Mediterranean region (Greece, Italy, and Turkey in particular), Iran, New Zealand, Indonesia, Japan, and parts of China.

- Earthquakes occurring within the plate boundaries are called **intraplate earthquakes**. Intraplate earthquakes are rare compared to earthquakes at plate boundaries. Nonetheless, very large intraplate earthquakes can inflict heavy damage. Notable examples of damaging intraplate earthquake are the 1811-1812 earthquakes in New Madrid, Missouri, and the 1886 earthquake in Charleston, South Carolina. In 2001, a large intraplate earthquake devastated the region of Gujarat, India.

Types of earthquake based on size

- The size of an earthquake is obviously a very important parameter, and it has been described in different ways. Prior to the development of modern instruments, methods for characterizing the size of earthquakes were based on crude and qualitative descriptions of the effects of the earthquakes. More recently, modern seismographs have allowed the development of a number of quantitative measures of earthquake size. Classification of earthquake based on magnitude is given in Table 3.1.

Table 3.1: Approximate categorization of earthquakes

Earthquake Magnitude	Classification
Not felt	Micro Earthquake
Small	<5
Moderate	5~6.5
Large	6.5~8
Great	>8

Topic 4

Reservoir triggered earthquakes

- The earth or concrete dam is an expensive structure; it directly affects the economy of the region through power generation, flood control, and irrigation. As the population grows, structural failure of a large dam poses increasingly greater danger for residents exposed to the sudden inundation of the flood plains. Indeed

in many countries major dams are located in areas that have suffered large earthquakes.

- We must take into account a curious connection between large reservoirs and earthquakes. There have been at least 13 incidents in different countries in which swarms of earthquakes have occurred very near a large reservoir soon after it has been filled.

- The effect of the added weight due to water in the reservoir on the rocks below stimulates earthquakes. A more plausible trigger mechanism is that extra water pressure produced by the reservoir loading spreads out as a pressure wave or pulse through the pores of the crustal rocks.

- Because of its slow spreading, it may take months or years to travel a distance of 5 kilometers, depending on the permeability and amount of fracturing of the rock. But when the pressure pulse finally reaches a zone of micro cracks, it forces water into them and so decreases the forces that are preventing the already present tectonic strain from initiating sudden sliding.

The effect of water on rocks beneath the surface

- The slow straining of the crust under the local tectonic forces produces many micro-cracks throughout the rock. Particularly in fault zones, these changes to the rock first weaken them; then the presence of water in the cracks reduces the restraining forces so that a major crack extends along the fault. In this way the elastic rebound of the strained crustal rocks may begin and spread.

- Water acts in a way that allows a sudden slip to take place, perhaps by providing a kind of lubrication along slide planes, but more effectively by increasing the local pore pressure and hence, weakening the rock.

- The typical geological section in fault zones shows a succession of gouge, crushed and sheared rock and clays, hydrological conditions in the fault zone commonly produce hydrous, or water containing, rocks such as serpentinite. At least near the surface, the gouge and clays often show direct evidence of shear slip associated with wet conditions, with successive smooth striated layers called slickenside.

End of Lecture 3 in Introduction to Engineering Seismology, Terminologies and definitions and Earthquake types.