ENVIRONMENTAL GEOSCIENCES

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Lecture-14

Geological Hazards - Earthquake

Welcome to the SWAYAM NPTEL course on Environmental Geosciences. We are covering the module three in which I have already discussed dip strike, folds and faults, its environmental interpretation in the lecture one. Today we will start the lecture two that is geological hazards and the hazard is the earthquake. In this lecture, the important concepts are Introduction to Earthquakes, Causes of Earthquakes, Earthquake Terminology, Types of Earthquakes, Seismic Waves and Ground Vibration, Earthquakes Measuring Instruments, Global Seismic Zones, Earthquake Zones in India, and Geological and Environmental Impacts.

So, one by one we will discuss. First of all, we should know about brief of the earthquakes. An earthquake is a ground movement from a slight to violent shaking that can damage buildings and create large cracks in the ground. It is a form of energy of wave motion transmitted through the surface layer of the Earth in widening circles from a point of sudden energy release and that point is called as focus. The ground beneath us seems solid.

Means Earth seems as solid but it is actually in constant motion. It is remaining in some motion. We can experience it by the earthquakes only. The earth surface seems stable but it is constantly vibrating due to the geological activities. Earth crust is broken up. into irregular pieces called tectonic plates.

We have learnt in the previous lecture also about the tectonic plates. So this earth crust is made up of several pieces of tectonic plates and these large pieces of crust were formed by the combination of gravity and rising heat from earth's core. There are seven major plates and many smaller ones all moving in relation to each other. These are the description about the major and minor tectonic plates. Generally, we are having major

tectonic plates like Pacific plate, North American plate, Eurasian plate, African plate, Antarctic plate, Indo-Australian plate, South American plate.

And few minor tectonic plates are also there. That is Arabian plate, Caribbean plate, Cocos plate, Juan de Fuca plate, Nazea plate, then Philippine sea plate, Scotia plate and Somali plate. So we are having major and minor tectonic plates. Lithosphere we have learned in the previous lecture. The lithosphere is nothing but it is the crust and upper part of the mantle.

And this lithosphere actually forms the earth tectonic plates. Tectonic plates can get stuck as they move along the fault zones. When pressure builds and plates slip, energy is released as seismic waves causing the ground to shake and this type of vibration or shaking is called as earthquake. The focus is the place inside Earth crust where an earthquake originates. The point on the Earth surface directly above the focus is generally called as an epicenter.

When energy is released at the focus the seismic waves traveling outward from that point in all direction. In the figure also you can see this is the focus inside the earth's surface and just from the focus you can see the seismic waves are traveling outward these are generating earthquake in the Earth surface. Now what are the causes of earthquakes. Generally the causes of earthquakes are of three types, tectonic earthquakes, then volcanic earthquakes and then surface causes. So one by one we will discuss these causes of earthquakes. First is the tectonic earthquakes.

It is caused by movement in the earth crust, that is by the movement of the tectonic plates. Stress accumulation leads to fracturing and displacement along fault lines. Earthquakes are produced by sudden movement along faults mostly because of tectonic origin. The concept of possible mode of origin of tectonic earthquake is known as elastic rebound theory, very important theory. Such earthquakes generally result from sudden yielding to strain produced on the rocks by accumulating stresses.

This causes the breaking of rocks and produces relative displacement of rocks. Such faulting causes shaking because displacement of rocks can only be possible by overcoming frictional resistance against the wall of the fault plane. The association of earthquakes with fault lines is an established fact. So this is about the tectonic earthquakes. Now second is the volcanic earthquakes ,result from volcanic eruptions though not all eruptions generate earthquakes. Severe examples include the 1883 Karakota eruption, typical local and less impactful compared to the tectonic earthquakes.

Usually earthquakes associated with volcanoes are more localized, both in extent of damage and in intensity of waves produced in comparison to the tectonic earthquakes due to faulting motions. A shock may be produced by any of the following mechanisms, like, explosion of the volcano upon the release and expansion of gases and lava, faulting within the volcano resulting from pressures in the chamber of the molten rock.

Collapse of the center of the volcano into the space formed by the extrusion of gases and molten matter. So these are some of the mechanisms through which shock may be produced. Besides the above, sometimes local regions may cause feeble earthquakes like failure of dams under the pressure of the impounding water. Third is the surface causes, mild tremors. Generally, we are getting wave action by wave action, vibration caused by dashing waves along seashores.

Waterfalls and cascades, running water impact valley floors, produces vibrations. Human activity, heavy machinery, locomotives and vehicles generate feeble tremors. Landslides, rockfalls along hill slopes, they can trigger minor tremors. These causes are not intense enough to be destructive. So this is about the causes of earthquakes.

Now few terminologies are generally associated with the earthquakes. So first term is the focus. We have seen that it is the exact spot underneath the earth's surface at which an earthquake originates. It is also known as hypocenter. Second term is the epicenter.

It is the point on the surface of the earth above the focus of an earthquake. Third is the isosismal line or isoseists. It is a line joining all points at which the intensity of earthquake is the same. It is in fact an isodiastrophic line of equal damage. Fourth one is the homoseismal or coseismal or homseists.

These are lines joining the places where the shock wave arrives at the same time so in the figure also you can see the focus epicenter is given mentioned and isoseismal and homoseismal lines are also very clearly shown. Now types of earthquake. Generally natural earthquakes are of three types. According to their depth of origin, they are shallow focus earthquakes intermediate focus earthquakes and deep focus earthquakes. So, first one is the shallow focus earthquake. In this case the seismic shocks originate at a depth of about 30 miles that is 60 kilometer or less below the earth's surface. So when the focus will be near about 30 miles or 60 km. So, such type of earthquake is termed as shallow focus earthquake.

Second is the intermediate focus earthquake. In this case, the shock waves originate at a depth between thirty to 150 miles, that is 60 to 300 km. And deep focus earthquake, here the point of origin of the shock is at a depth between 150 to 450 miles, that is 300 to 700 km. So according to the origin of the earthquakes, they are again of three types. First is the tectonic, second is the volcanic and third is the submarine earthquakes.

The submarine shocks often generates very large waves on the surface of the seas and destroys the coastal tracts. These submarine earthquakes are termed as Tsunamis. See, when we are getting some shocks or large waves in the sea, then such type of submarine earthquakes are known as Tsunamis. Now we have seen that tectonic plates very very important role for the generation of earthquake on the Earth's surface. So here one theory is there and the name of the theory is the elastic rebound theory which was given by Professor H.F. Reid.

So just we will see what is theory and what is its interpretation. So the first point of this theory is that the materials of the Earth are elastic in nature. If it will remain elastic, definitely it can withstand a certain amount of stress without deforming matter permanently. But if the stress is continued for longer period of time or if it is raised in magnitude, definitely the rocks will first deform permanently and if it will continue, ultimately it will rupture. When the rupture occurs, rocks on either side of the fault tend to return to their original shape because of their elastic nature and an elastic rebound occurs.

So the rebound results in releasing the enormous amount of energy in the form of elastic waves and that sets up the seismic waves. Therefore the energy stored in the system through decades is released instantaneously causing underground dislocation of rocks and setting of vibrations which are either feeble or strong as the case may be. The rupture and movement of the blocks may take only a fraction of minute to be completed. This is the time of major shock. But the final adjustment of the rock block to its original position again may be completed over a longer period of time with number of minor shocks and such type of minor shocks are known as aftershocks.

So, in elastic rebound theory, the important point is stress is accumulating upon a deck bed. Second point is the bed has been deformed to some extent and a crack is developed. And third point is along the crack, the two fractured blocks rebound to their original position of no strain. So, in this way, this theory has been discussed. Now, next is the ground vibration.

Ground vibration refers to the shaking of oscillation of the ground due to the release of energy from a blast. For example, vibration caused by explosions, construction works, railway and road transport activities etc. This energy travels through the Earth as seismic waves. Ground vibrations are generated when explosive charges are detonated breaking the rock because of the detonation, breaking of the rock and displacement of the materials. The movement of any particles in ground can be described in three ways. that is displacement, velocity and acceleration.

Velocity are measured using transducers and geophones and the readings recorded can be converted to obtain displacement or oscillation. And for the purpose of geophones arranged orthogonally, one will be vertical and the others will too remain horizontal. Now, what are the different types of wave motion? Three main types of wave motion are generated by an earthquake. Primary waves, P waves, these are longitudinal waves, similar to sound wave and travel in solid, liquid and gaseous media.

They have short wavelength and a high frequency. This causes compression and rarefaction within the material, similar to the behavior of sound waves. P waves have a relatively small amplitude compared to surface wave which makes them less destructive. So it is less destructive than other waves. P waves are compressional waves meaning they cause the particles in the material move back and forth in the same direction as the wave is traveling.

They are the fastest seismic waves and are the first to be detected by the seismic instruments following an event travelling at speeds of about five to eight km per second in the Earth's crust. P waves can move through both solids and liquids which allows them to travel through the Earth's outer core where materials are in a liquid state. This property is critical for understanding the Earth's internal structure. The particle motion in P waves is parallel to the direction of wave propagation resulting in the alternating regions of compression and rarefaction. You can see the calculation of the velocity of P waves also.

One equation is given in which young modulus of the material, density of the material and Poisson's ratio of the material are also there. Through this equation we can able to calculate the velocity of the primary waves. Next is the secondary waves or S waves. These are transverse waves, also known as shear waves, travel only in solid media. In comparison to primary waves, they are slow in motion.

They travel at varying velocity through the solid parts, proportional to the density of the materials. They are also having short wavelength and high frequency. S waves are shear

waves, meaning they cause particles to move perpendicular to the direction of wave propagation, creating a side-to-side motion. S-waves are slower than P-waves traveling at speeds of about 3-5 kilometers. They arrive after P-waves in a seismic event.

Unlike P-waves, S-wave can only move through the solids and cannot pass through the liquids. These characteristics help geologists to understand the composition of the Earth's inner layer. As S-waves do not travel through the liquid outer core, the particle motion in S waves is perpendicular to the wave direction which creates a shearing effect that can cause more intense shaking compared to P waves. Calculations for S waves are also mentioned here through the equation in which the Young modulus density and Poisson ratio has been discussed. Now based on those equations, one numerical is here.

A geological survey is being conducted in a region where the rock has a density of 2500 kg/m^3. The Young modulus of the rock is found to be 40 GPa or $40x10^9$ Pascal and the Poisson ratio is near about 0.25. Now question is calculate the velocity of the P waves in the rock using the relationship between Young modulus, Poisson ratio and intensity. Second, calculate the velocity of S waves in the rock using the same parameters. Now solution is, calculation of P wave with the formula which has been mentioned.

Just putting the value in the formula, you can see it is coming near about 1562.5 and if we will continue the calculation, we can get the velocity of P waves is near about 4386.45 m/s. Again for calculating the velocity of S waves using the S wave velocity formula. If we will substitute the value, then we are getting the value of S wave is near about 2538.61 m/s. Third type of waves is known as L waves. These are transverse vibration and are confined to the outer part of the crust.

They are also known as surface waves or Rayleigh waves. They have low velocity, low frequency and low wavelength. These are responsible for most of the destructive force of the earthquake. Now, scale of intensity. Various scales have been proposed to estimate the intensity of earthquake from the amount of damage caused.

These scales are Rossi-Forel, Mercalli scale and Richter scale. Rossi-Forel scale, in this scale the intensity has been classified into three types, severe, catastrophic and disastrous. Mercalli scale, the Mercalli intensity scale has devised 12 numbers with the increase of intensity. In this case, number one is detected only by seismograph. Gradually the number increases when the earthquake intensity becomes feeble, slight, moderate, strong etc. At number eight it is destructive and becomes disastrous. At 10 and 12 the effect is totally catastrophic where there is total destruction and objects thrown into the air.

Here you can see the different values magnitude is being given left side and what is the feeling is also mentioned here in Richter scale. Generally in Richter scale the number ranges from 0 to 9. Here it is particularly important to note that a magnitude 8 earthquake is 10 times larger than a magnitude 7 earthquake and 100 times larger than a magnitude 6 earthquake and 1000 times larger than a magnitude 5 earthquake. So this is very important concept. Every time the magnitude value is enhancing,

Now how we are recording the earthquakes. The instrument used for recording of seismic shock is known as seismograph. The records of seismic shocks prepared and presented by seismographs are known as seismograms. So just opposite, in other cases, the instrument is known as gram and the graph is known as graph, but here the instrument is known as seismograph and the records of seismic shocks presented in the form of graph is known as seismograms. Now distribution of earthquakes.

Generally, the destructive earthquakes are concentrated in this ring surrounding the Pacific Ocean. This ring coincides with the circum pacific ring of fire. The second chain is termed as East Indian which extends from Indonesia and Andaman Nicobar Islands and Burma. The third belt extends from Himalayas, Kun-Lun, Tien Shan and Altai Range up to the Lake Baikal. Another belt extends from the Pamir Knot to Afghanistan, Iran, Turkey, Greece, Romania, Atlas Mountains, Gibraltar and the Azores Islands.

A belt also extends from the Gulf of Aden between Seychelles and Maldives Islands, turns to the West-South of Africa and goes up to the Falkland Islands. Another belt also runs along the Great Rift Valley of East Africa. It is noticed that the present earthquake regions are associated with the younger fold mountain regions and the present earthquake activity is a phase of the end of the alpine orogeny. Earthquake monitoring in India, you can see the National Centre for Seismology, Ministry of Earth Sciences and Nodal Agency of the Government of India dealing with the various activities in the field of seismology and allied sciences. National Center for Seismology under MOES monitors earthquake activity in real-time basis, twenty four into seven.

It maintains a countrywide seismological network to detect and locate earthquakes occurring in and around the country. The network also includes a seventeen-stations real-time seismic monitoring system to monitor and report large magnitude earthquakes. A Tsunami early warning system is also in place at Indian National Centre for Ocean Information Services, Hyderabad, to provide early warning on Tsunamis. Earthquake Zones of India, Bureau of Indian Standards, IS one eight nine three Part one of two

thousand two, based on the past seismic history, grouped the country into four seismic zones, that is Zone two, Zone three, Zone four and Zone five. Of these zone five is the most seismically active region while zone two is the least.

The modified Mercalli intensity scale which measures the impact of the earthquake on the surface of the earth broadly classified with various zones and these zones are seismic zone two that is the low intensity zone if the intensity on modified Mercalli scale will be 6 or less. Zone three is the moderately intensity zone. It is the intensity remains near about 7. Zone four, severity zone, intensity or modified Mercalli scale remains at 8. And zone five, very severe intensity zone, when the intensity or modified Mercalli scale remains nine and above.

Since the current division of India into earthquake hazard zones does not use zone one, so no area of India is classified as zone one. Now, one by one, we will see the zone five. It comprises of entire northeastern India, parts of Jammu and Kashmir, Himachal Pradesh, Uttaranchal, Rann of Kutch in Gujarat, parts of North Bihar and Andaman in Kaur Islands. Zone four, it covers remaining parts of Jammu and Kashmir and Himachal Pradesh, Union Territory of Delhi, Sikkim, northern parts of Uttar Pradesh, Bihar and West Bengal, parts of Gujarat and small portion of Maharashtra near the west coast and Rajasthan. Zone three, it comprises Kerala, Goa, Lakshadweep Islands, remaining parts of Uttar Pradesh, Gujarat and West Bengal, parts of Punjab, Rajasthan, Madhya Pradesh, Bihar, Jharkhand, Chhattisgarh, Maharashtra, Odisha, Andhra Pradesh, Tamil Nadu and Karnataka.

And zone two, it covers remaining parts of the country. Geological and environmental impacts of earthquake, generally because of the earthquake, the disruption of normal life takes place. Earthquake affects a large number of people. It loses to lives, livelihoods and property, loss of housing and damage to infrastructure. Disruption of transport and communication system, disruption of marketing systems, breakdown of social order, loss of business and loss of industrial output.

Because of this we are seeing in the nature. Preparedness and mitigation. Preparedness and mitigation are essential to minimize earthquake risks and impacts. Preparedness involves creating awareness, conducting drills, and establishing emergency response plans to ensure public safety during the earthquakes. It also includes retrofitting buildings, maintaining emergency supplies, and designing evacuation routes.

Mitigation focuses on reducing the long-term effects through resilient infrastructure, land use planning, and enforcing strict construction roads in the high-risk zones. Technologies such as early warning systems plays a vital role in saving lives by providing critical alerts. Community education, disaster management policies, and international cooperation further enhance readiness, helping societies adapt to and recover swiftly from earthquake disasters. So this is the brief summary about the lecture. We have already discussed the causes of earthquakes.

Generally it arise due to the shifting of the tectonic plates volcanic activity or anthropogenic factors like explosion of mining and minerals and reservoir induced seismicity. Seismic waves, seismic waves include P waves S waves and surface waves and each varying in varying speed and behavior. They provide crucial information about earth's interior. Measuring earthquake is generally, It is measured by the Richter scale, while the Mercalli intensity scale also measured the earthquake. Geological impacts we have seen, earthquake caused ground rupture, landslides, tsunamis and soil liquefaction, reshaping landscape and significantly affecting the ecosystems and human settlements. And mitigation is that preparedness and mitigation minimize the earthquake leaks through awareness. emergency plans, resilient infrastructure and strict construction codes. Early warning system, community education and disaster policy, ensure readiness, reducing impacts and aiding swift recovery. Thank you very much to all.