Introduction to Engineering Seismology
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Lecture - 09
Introduction to Wave Propagation

So vanakkam. So we will continue our lecture on engineering seismology. So last few classes we talked about the earthquake. So how it is occurring, where it is occurring, what is the earthquake sources and how to classify the earthquake. So now, when earthquakes are occurring, we told that there was a vibration created. That vibration will be propagate throughout the earth.

So that we call it as a basically the earthquake vibration or the waves. So how these waves are propagating? What are the different type of waves caused by the earthquake. So that we are going to understand today class, okay which is called as a theory of wave propagation and seismic waves. So if we look at that the earthquake is basically originating at focus due to the breakage of the rock okay.

So this breakage of the rocks basically it releases a rupture okay. It releases a vibration, releases a some kind of the rupturing phenomena which try to transform throughout the region. So depends upon the rock type okay. So one side this will be propagating more, one side it will be propagating less from that. So the earthquake begins at the earth focus with crust rocks and then spread outward all the direction.

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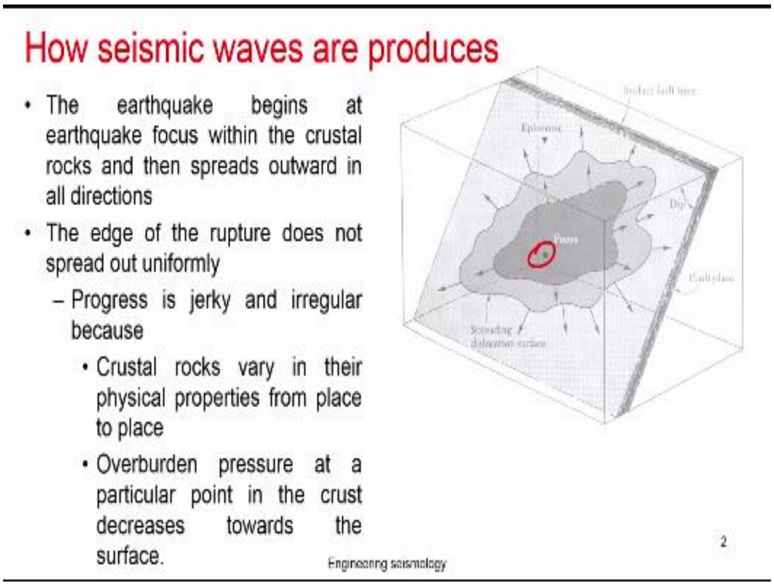

The edge of the rupture does not spread uniformly, it depends upon the rock. The progress is jerky and irregular because the crustal rocks vary their physical property from the place to place. So where it is weak, the propagation will take place larger. Where it is very hard the propagation will take place less. Similarly, there is a overburden pressure, so where that also controls this kind of rupture phenomena.

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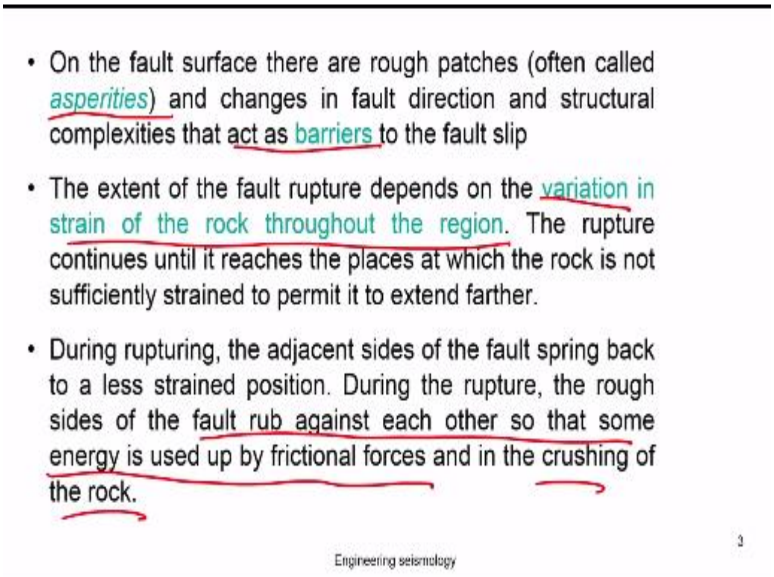

So this rupture phenomena basically okay so occurs on the rock where there is a rough patches which is called as a asperities, okay. So you should know what is. The change of the fault direction and structural complexity that act as a barrier for the fault to slip or stop the propagation of the rupture. That is called as a barriers. The extend of the fault rupture depends upon the variation of the strain on the rock throughout the region.

So the rupture continues until it reaches a place at which the rock is not sufficiently strained to permit extend. So the where the rock could able to stop that rupture up to that it ruptures. So during the rupture the adjacent side of the rock spring back less strained position. During the rupture the rock sides of the fault rub against each other so that some energy is used for the frictional forces and crushing of the rock and other energy can get passing through that particular material.

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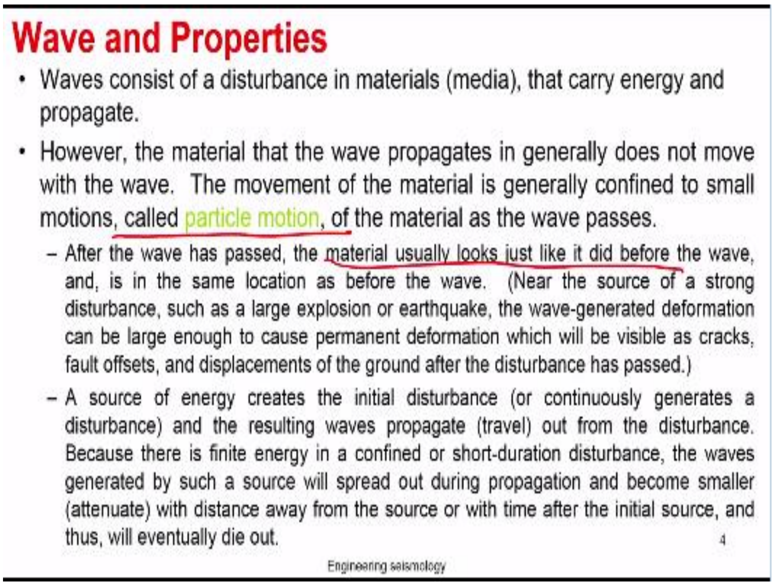

So that energy transformed in the form of waves, okay. The wave basically consist of the disturbance of material or media that carries energy and propagate. So when I speak actually I will basically create a vibration in the air. The air act as a medium to reach my voice to the person was sitting opposite to me. So that depends upon the medium the disturbance the okay the level will reach longer and shorter.

So the material that wave propagates generally does not move along with the wave. For example, when I speak the air is a medium so this medium does not move along with the wave. Only the waves are more. But the particles in the medium will vibrate to the vibration. So the movement of the material that generally confined a small motion is called as a particle motion. So the particle in the material will basically vibrate.

So after the wave passed the material usually looks like a did before the wave, okay. The wave the material does not change anything, but the particles in the medium will undergo a disturbance, but it comes back to original position. So near the source of the strong disturbance, large explosion or any other place, where if the particles are separatable, then you will get a displacement of the particle.

So that is why you see that surface displacement due to the earthquake. That happens when the particles are have a tendency to move due to the vibration which occurs generally on the very large vibration level. The source of energy created the initial disturbance or continuous generates disturbance and resulting waves propagate travel out from the disturbance.

Because of their finite energy confined a short duration of the disturbance, the wave generated by such source will spread out during the propagation became a smaller attenuate and distance away from the source with time after the source as vibration. So basically the waves will be created by the rupturing. That wave will move along the material. So the material in the particles in the material will respond to the this wave.

And it moves and then comes back to original position. So if there is a chance that the particle can permanently displace, you can see a ground displacement in the.

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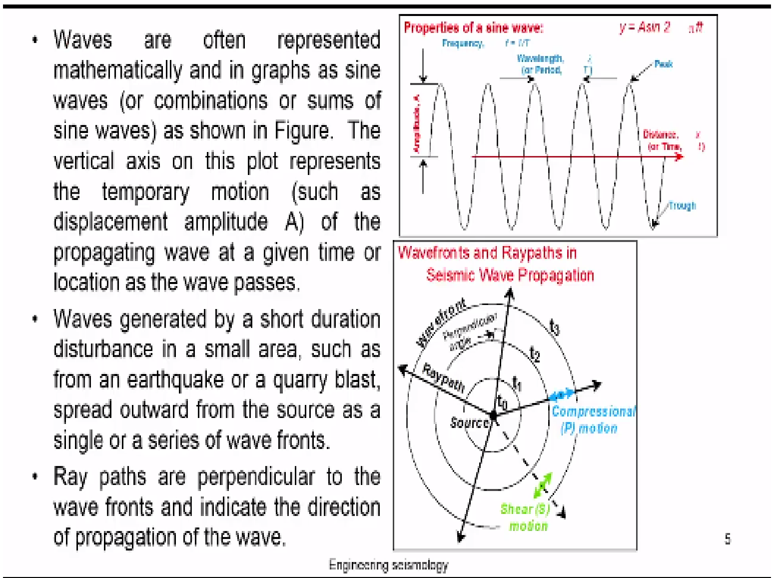

So these waves basically as a mathematically represented by the some kind of graph or a sine wave. For example, this is how the wave is mathematically represented. So you can see this part from initial to the this is the amplitude of the wave. So the from starting of this position to this position basically so is called as a wavelength. The frequency is basically the 1 by T or the period, okay.

So this basically implies the wave parameter. This is the peak, so this is the tough, okay. So this wave generally propagates on all the direction. So the ray path is basically the wave how the propagates. So the ray path with makes angle with a particular circle or particular position okay a perpendicular angle so that is called as a wave front okay.

So that depends upon the how the wave moves, how the particles respond to that particular wave the waves can be classified, okay. For example, this is the origin of the wave. It moves with distance with different time okay. So how this particles in the medium respond to the wave, based on that the wave can be classified as a different type of waves.

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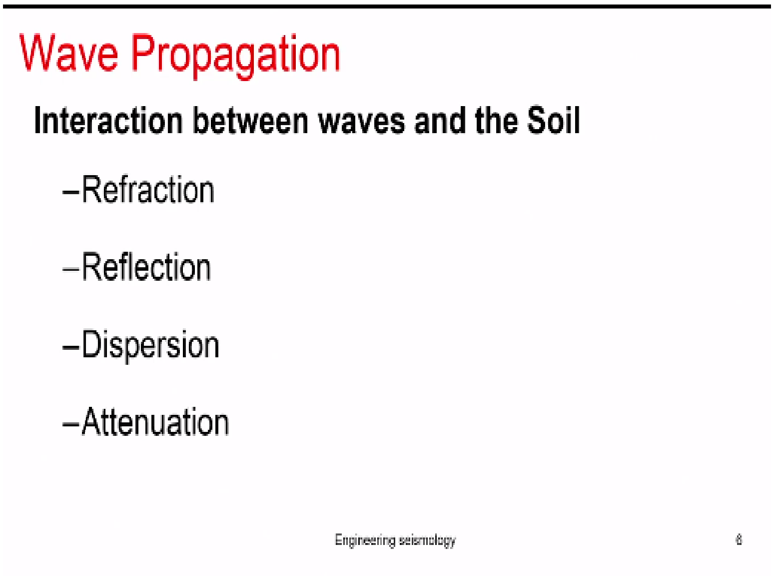

So in general the wave basically when it propagates from one position to other position, so it interacts with the medium where it travels or it interacts with the soil. So there where there are four phenomena how interaction happens. One is the refraction, reflection and dispersion and attenuation. So these are all the wave.

The wave will propagate from one medium okay when passes from one point to other point, where the medium will undergo this kind of transformation or a wave propagation.

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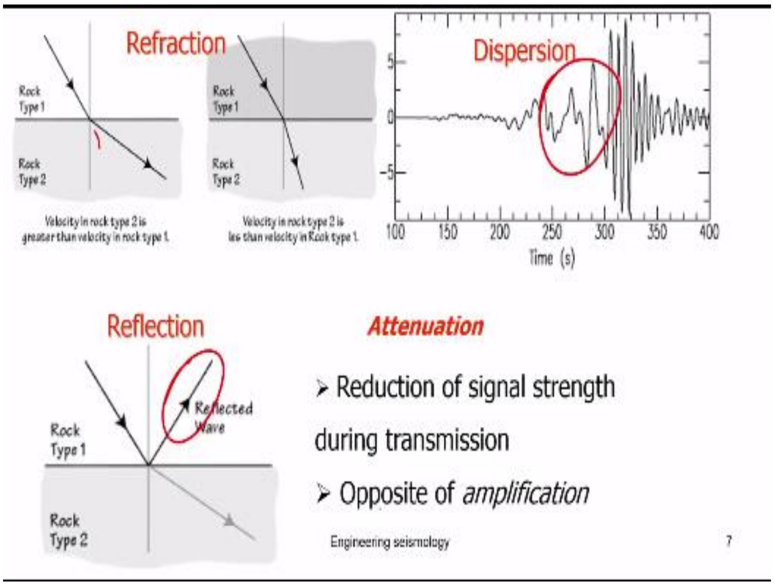

So the refraction is basically the wave travels from one medium to other medium. For simplicity we can assume that the seismic wave occurred at a rock which travels from one rock type to other rock type how the waves are get change in direction due to change in the material type that is called as a refraction.

So you can see that velocity in the rock 2 type is greater than the velocity in the rock 1 type where you can see that the wave angle changed from this position, original position to this level. So similarly the velocity of the rock type is less than the velocity rock type, you can see that wave changes like this okay. So then the reflection is basically the wave hit the surface and reflect.

So part of the wave part of the wave. This is called as a wave reflection. This you have seen in the Bursley and the light and then some physics experiment in the school days. The dispersion is wave get the frequency changes, a duration of the wave changes due to the medium changes. That is called as a dispersion or the separation of the waves like this is called as a dispersion.

So the attenuation is basically the reduction of the wave signal due to the medium property is called as a attenuation. The increase of the wave signal amplitude due to the medium property is called as a amplification. So the attenuation, amplifications are opposites, okay. Attenuation is less, amplification is more.

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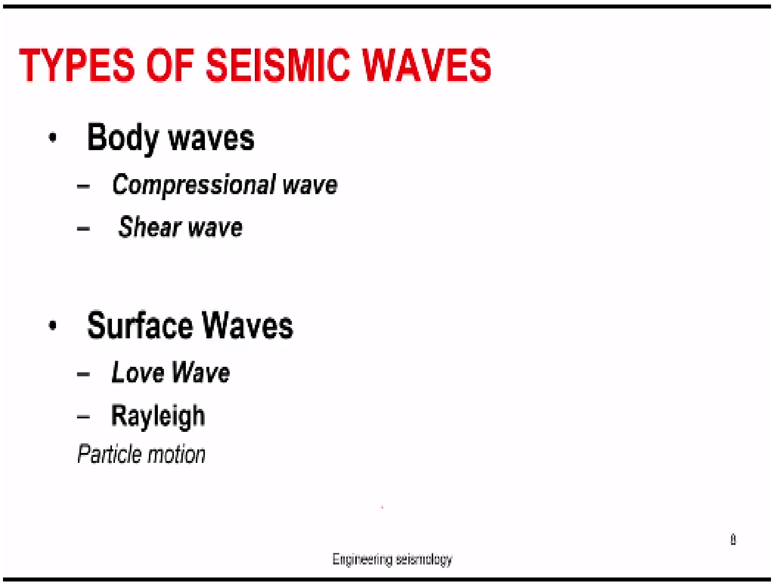

So this is how the wave propagates. So based on this propagation and how the particles in the medium respond to the waves, the wave can be categorized as a two major group. One is the body wave, another one is the surface wave. So the body wave again can be categorized as a two category. One is the compression wave, another the shear wave. The surface can be categorized as a two category.

One is a Love wave another one is a Rayleigh wave. So all this depends upon the particle's motion in the medium.

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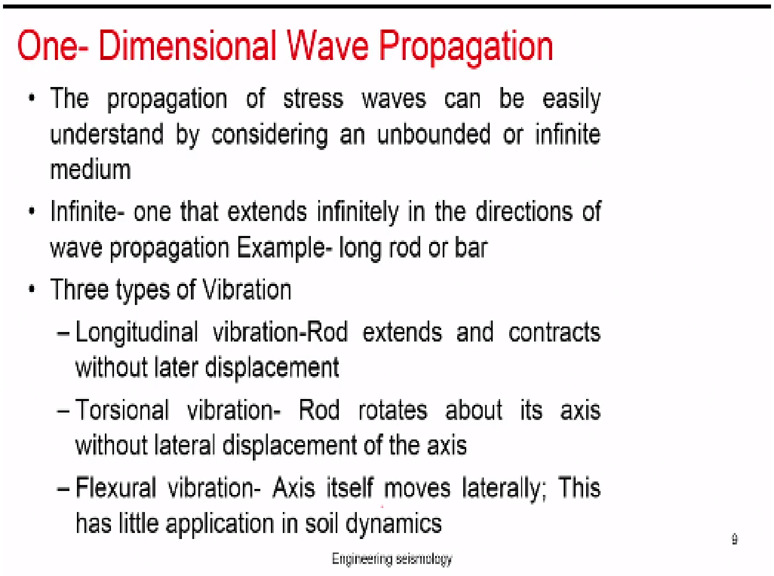

So the one dimensional wave propagation basically explains okay how the this wave can be theoretically propagation can be theoretically understood. So the wave propagation stress waves can be easily understand by considering the unbounded infinite medium. So the infinite one is extend infinitely in the direction of the wave propagation. Example, a long rod or a bar.

There are three type of vibration we can create in that. One is a longitudinal vibration. So rod extend and contract without later displacement, lateral displacement. The torsional vibration rod rotates about its axis without lateral displacement of the axis. The flexural vibration axis itself move laterally. This little application in the soil dynamics. So we will be talking more of longitudinal and torsional vibration.

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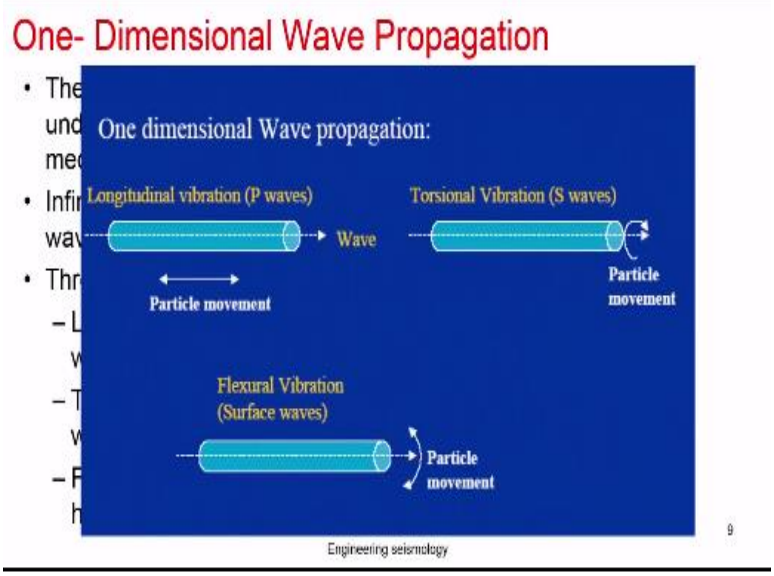

So for example, this is a very long rod. So where the waves are propagating in that. So the particles in the rod will vibrate back and forth for the wave. That kind of motion is called as a longitudinal waves or a P waves okay, a primary wave. So if the same waves when it goes if you apply a rotation the particles will basically vibrate perpendicular to the direction of the wave.

That is called as a S wave or P wave. So that we can create by rotating the rod, okay. This is by pushing the rod and pressing and releasing. So then the particle movements which happen plus the flexural that is called as a surface wave, which we will understand in detail in the coming.

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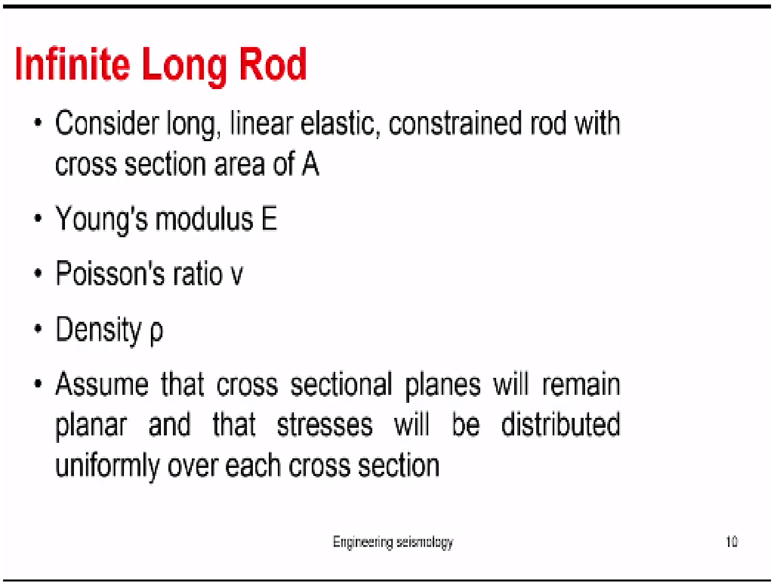

So this can be explained by considering the long, linear elastic, constrained rod with cross section A, Young's modulus E, Poisson ratio v and density rho. Assume that the cross sectional plane will be remains planar, the stress will be distributed uniformly over each section, okay.

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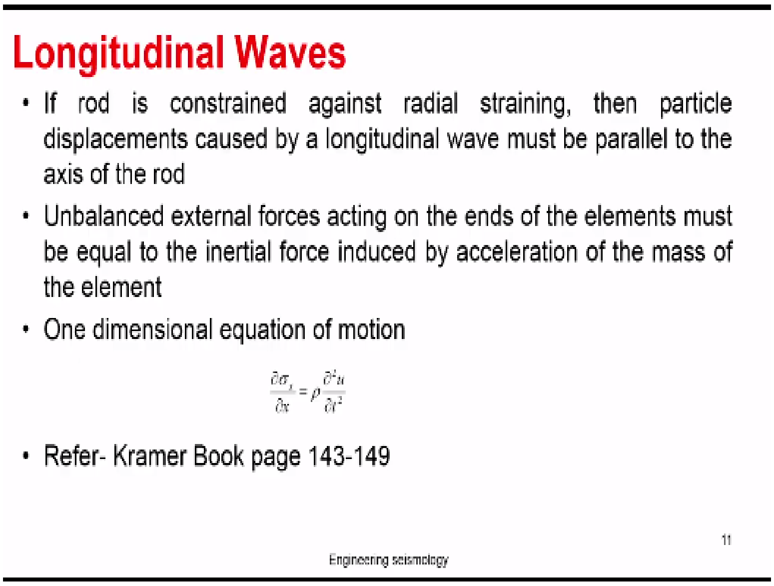

So then the wave propagation is controlled by the equation. So it is proved from the explanation, theoretical explanation is the material property okay which controls a wave propagation is actually a modulus okay, and then the density. These two materials are basically. So I ask the the Kramer, my TS to derive this and upload a derivation for the wave propagation which is also available in the most of the standard textbooks which is used for the earthquake engineering.

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- The wave propagation velocity depends only on the properties of the rod material (stiffness and density) and is independent of the amplitude of the stress wave
- The wave propagation velocity increases with increasing stiffness and with decreasing density.
- The wave propagation velocity is an extremely important material properties and relied upon heavily in soil dynamics and Geotechnical Earthquake Engineering
- The wave propagation velocity is the velocity at which a stress wave should travel along the rod. It is not the same the particle velocity
- Particle velocity is the velocity at which a single point within the rod would move as the wave passes through it
- Particle velocity is proportional to the axial stress in the rod. The coefficient of proportionality ρv_p is called the specific impedance of the material

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So the longitudinal waves basically makes the particles to vibrate back and forth and which is controlled by the constrained modulus and density of the material, okay.

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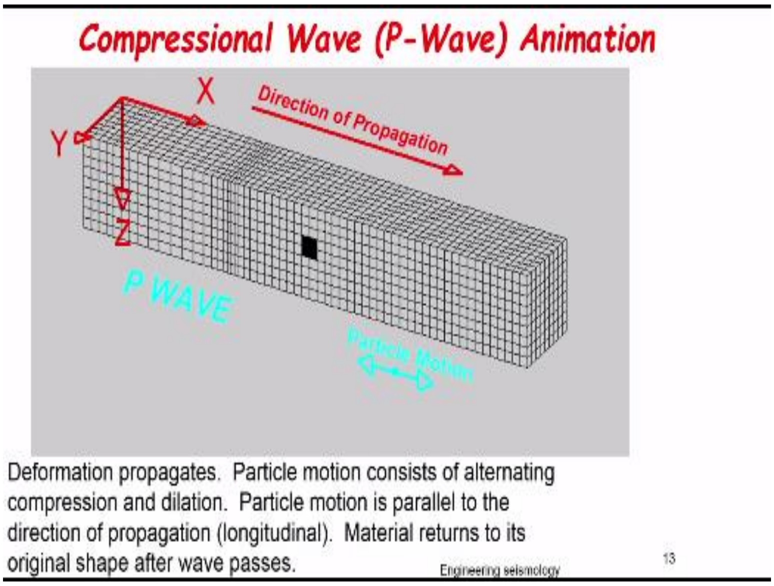

So this is how it taking place. You can see very closely this is the medium which travels. So when the waves coming you can see this is a particle. So this is basically a wave. When wave comes you can see that the particle motions are contract and extend. So this kind of phenomena happens, that wave is called as a P wave okay. So where the particles of the motion, so along the direction of the wave, where it expand as well as contrast. This kind of waves is called as a P wave.

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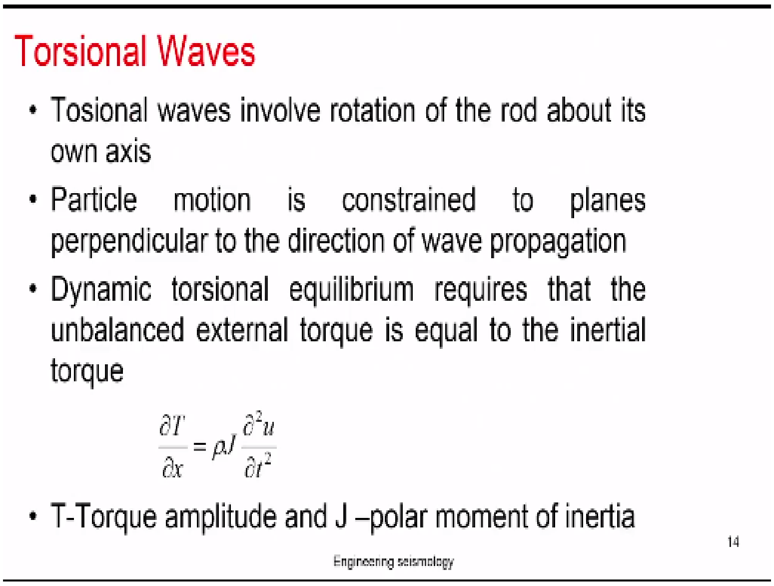

So the torsional wave where you rotate and create a torsional wave. The particle motion of the constraint to the plane perpendicular to the direction of the wave. The dynamic torsional equilibrium requires to make the this unbalanced force to bring to the equal. So where the torque applied and polar moment of inertia plays a role.

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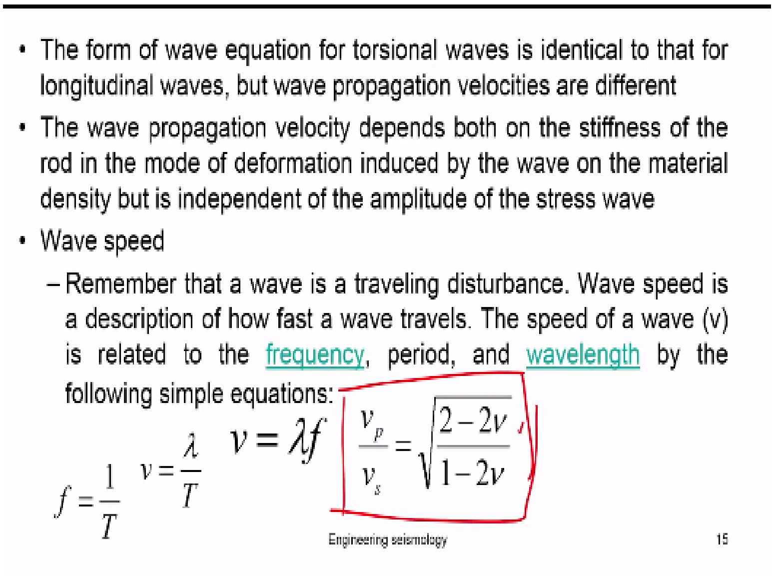

So which is basically constrained to the shear modulus and density of the material plays a role. So there is a change in the shear modulus and density you will get a change in the wave propagation of this particular type of wave which is called as a S wave. Basically the S wave is called as a v s. The P wave is called as a v p which is again interlinked with the Poisson ratio. So this is how you can see.

This is the standard relations used for express the ratio between the v p and v s.

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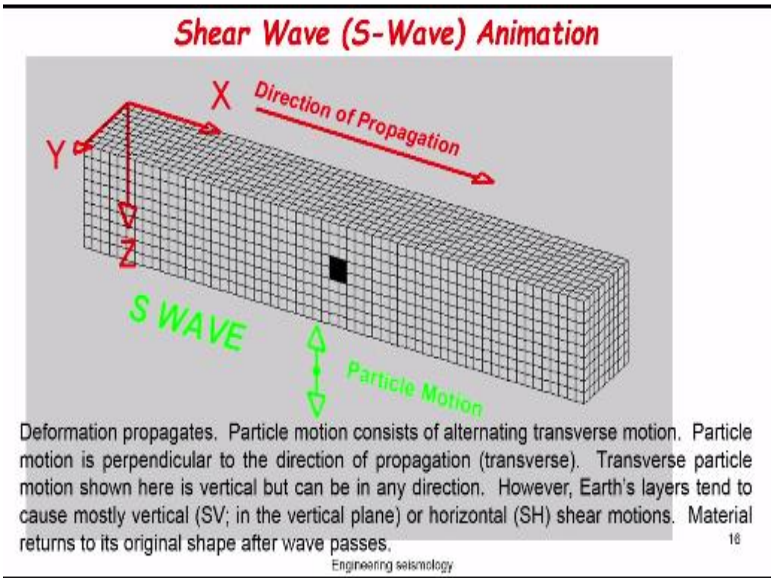

How the v s basically occurs. So the v s waves are occurring like that. The particle in the direction of the wave move perpendicular to the wave direction. You can very carefully watch the particle. You can see how this moves basically. See it goes up and down. So these kind of waves are called as a surface wave, okay. So sorry these kind of waves are called as a shear wave.

So where it where the particles are moving up and down along the direction of the wave.

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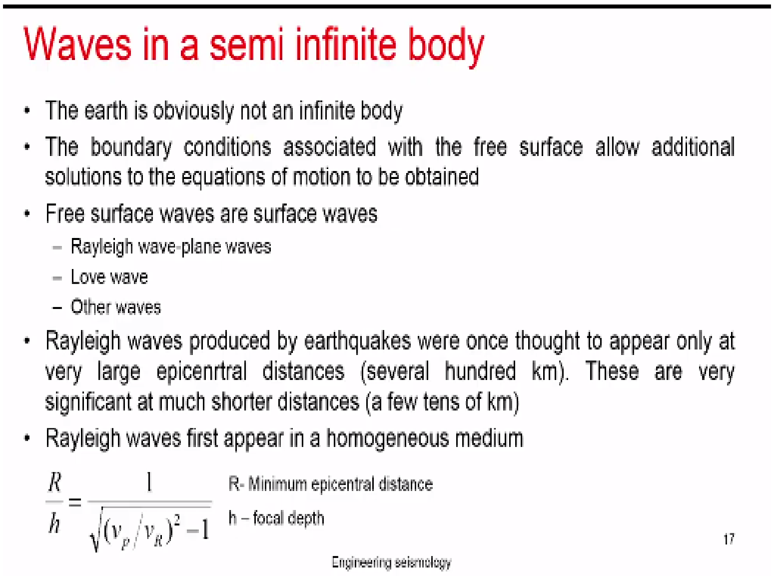

So the another wave is a basically a Love wave, which is basically defined and explained by using the semi infinite rock. So this two type of surface wave you can see. One is a Rayleigh wave, which is the plane wave. Another one is a Love wave. So this was actually invented by the scientists Rayleigh and Love. So where they found these waves are occurring at the different than the P and S wave which is occurs at the surface of the material rather than the stiffness of the material.

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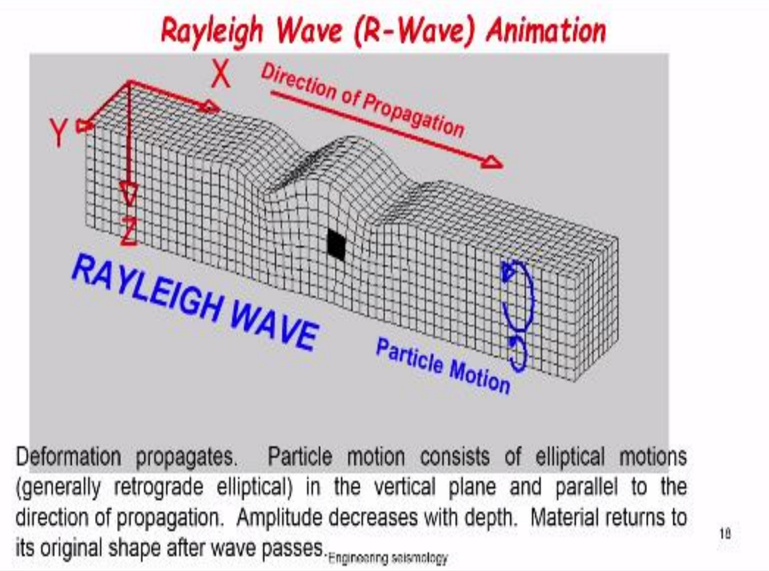

So basically this waves we can see here. So this surface the waves this is similar to S wave. But it is not occurring at whole body. It occurs at only surface. You can see the particle motion. The particle basically rotates. You can see how it rotates. So these rotations are larger in the surface of the material and lower at bottom of the material. This kind of waves are called as a Rayleigh waves.

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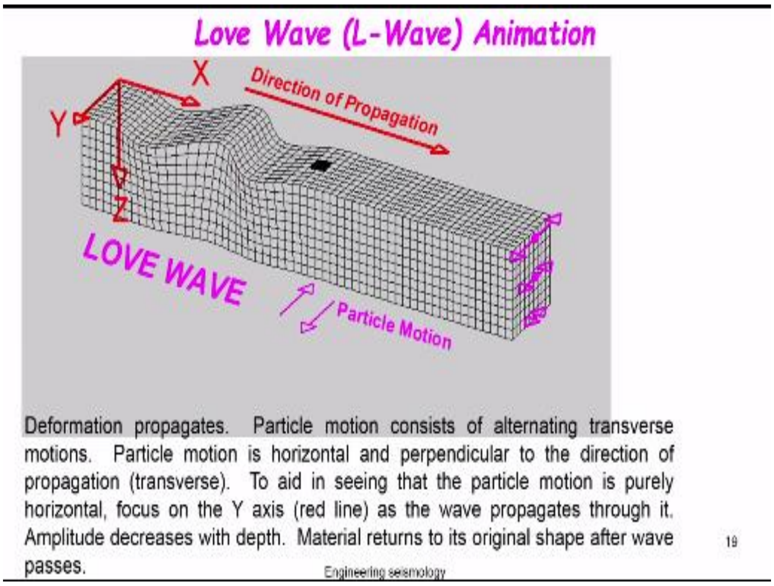

So similarly the Love wave which is like a snake. So where the particles are move perpendicular, but its movements are large at surface and less at this one. So wave propagation, it is horizontal direction. It is perpendicular to the horizontal direction, not on the vertical direction. This kind of waves are called as a Love wave which is invented by the scientist called Love.

So when earthquakes are occurring, all this four type of waves will be generated. So depends upon the location you can experience a particular wave dominant this particular wave negligible okay that we are going to see in the part of our course.

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Wave Character

Wave Type	Particle Motion	Typical Velocity	Other Characteristics
P, Compressional, Primary, Longitudinal	Alternating compressions same direction as the wave is propagating	$V_P \sim 5 - 7$ km/s in typical Earth's crust; ~1.5 km/s in water; ~0.3 km/s in air.	Generally smaller and higher frequency than the S and Surface-waves. P waves in a liquid or gas are pressure waves, including sound waves.
S, Shear, Secondary, Transverse	Alternating transverse motions, particle motion is in vertical or horizontal planes.	$V_S \sim 3 - 4$ km/s in typical Earth's crust;	S-waves do not travel through fluids, S waves travel slower than P waves in a solid and, therefore, arrive after the P wave.

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So this wave characters are very important to understand the earthquake. So the basically the P wave or compressional wave or primary wave is the first wave which comes due to the earthquake. So where the alternating of compression same direction as the wave propagates. So it has a 5 to 7 kilometer per second speed in the earth crust. 1.5 kilometer in the water. 0.3 kilometer per second in the air.

The speed of the typical velocity range of this compression wave. So generally smaller and higher frequency than the S wave, surface wave and then the P wave is liquid or gas, the pressure waves including the sound waves. So as I told you that yesterday people felt vibration because of the this P wave and sound wave. So secondary wave or the shear wave is called as a S wave.

So this is actually alternating the transverse motion, particle motion is in the vertical or horizontal plane. It has a velocity range of 3 to 4 kilometer in a typical earth crust. So the S wave do not travel through a fluid. So this property is very important, S wave do not travel through a fluid. You try to understand why S wave do not travel in the fluid by goggling in yourself in the Google.

You can get a nice video explanation for that. So S wave travels slower than the P wave in a solid. And therefore, arrives after the P wave. This informations are very important for interpreting the wave type in the seismogram.

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Wave Type (and names)	Particle Motion	Typical Velocity	Other Characteristics
L, **Love**, Surface waves, Long waves	Transverse horizontal motion, perpendicular to the direction of propagation and generally parallel to the Earth's surface.	V_L ~ 2.0 - 4.4 km/s in the Earth depending on frequency, faster than the Rayleigh waves.	Decrease in amplitude with depth. dispersive, velocity is dependent on frequency, low frequencies - propagating at higher velocity. Lower frequencies penetrating to greater depth.
R, **Rayleigh**, Surface waves, Long waves, Ground roll	Motion is both in the direction of propagation and perpendicular	V_R ~ 2.0 - 4.2 km/s in the Earth waves.	Dispersive, amplitudes decrease with depth, Appearance like water waves. Depth of penetration dependent on frequency, lower frequencies penetrating to greater depth.

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So the Love wave, the surface wave or long waves travels horizontal motion perpendicular to the direction of the propagation, generally parallel to the earth surface. It has a velocity 2 to 4.4 kilometer in the earth depending upon the frequency. Faster than the Rayleigh wave. Decrease in amplitude with depth. Dispersive velocity depend upon the frequency.

And low frequency propagating higher velocity. Lower frequencies penetrating to the greater depth. Rayleigh wave, surface wave or long wave, ground roll motion is both in direction of propagation and perpendicular to the propagation. It ranges from 2 to 4.2. So dispersive and amplitude decrease with the depth. Appearance like a water waves.

So when you throw a stone on the water body you will get a waves know, that kind of waves basically a Rayleigh wave. So the depth of penetrating depends upon the frequency. Low frequencies penetrating to the greater depth. So high frequency penetrate to the shallow depth. So this is the type of the wave which you generally experience in the from the earthquake.

So basically the earthquake can causes a two type of wave. One is that a body wave which is again a two component P wave and S wave. So which travels body of the earth, okay. That is called as a body wave okay. So the another one is the surface wave which travels surface of the earth, okay. So which basically called as a surface wave. So the particle motion at surface is very large when the deeper level it reduces.

So and the wave speed also depends upon the frequency. So the highest fast wave is a P wave which travel very fast. So the slowest wave will be the surface wave, which reaches very late okay. So in between is a S wave. So if any vibrations are occurring all this wave will be generated. Depends upon the location where you are located you can find a particular wave.

You can feel or particular wave you can record, okay. So this plays a very important role in understanding the earthquake waves and earthquake distance and where the earthquake are occurring, okay. Basically the interior of the earth we seen that plate tectonics. We told that earth as a four major category like inner core, outer core, mantle and crust. We told that the outer core is basically a liquid.

So how they done basically? They created a vibration and tried to record a different place. They found that a particular zone there is no propagation of the S wave which we have seen that S wave does not travel on the liquid part. Then they categorized that zone as a liquid, okay. That is what is happened in the when categorizing these waves.

This plays a very important role to characterize a materials in the earth and also to classify the materials to understand the geological explorations and find out a material types, okay, the mining materials in the ground using the seismic survey. So these seismic surveys are predominantly used by the mining people for getting the mining materials identification and excavation and all those things.

So with this we will close today lecture. So we talked about the wave type and wave character. You should now remember all this wave behavior and wave character so that when you are going for the interpretation of the seismic record this datas will be useful. So part of today class one is that you should go through the derivation for how the material property affect a wave propagation.

As we have seen that the P wave is affected by the constrained modulus and density. And S wave affected by the density and shear modulus, okay or polar movement of inertia. And then the Love wave and other wave affected by the so the shear properties of the material. So that will help you to model parameter selection for the seismic wave propagation of P wave propagation in the later stage.

So with that, with this I close this lecture. Thank you. So we will see you in the next class, how this wave propagation, theory of wave propagation can be useful to interpret a earth interior material type using this, okay. How you can identify a earth signals or vibration signals from this wave propagation theory.