Geotechnical Earthquake Engineering
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Module - 3
Lecture - 8
Engineering Seismology (Contd…)

Let us start our today's lecture on Geotechnical Earthquake Engineering. So, in this video course on geotechnical earthquake engineering, let us look at the slide, we were going through module number 3 which is Engineering Seismology, a quick recap what we have learned in the previous lecture, we discussed about the Plate Tectonics Theory.

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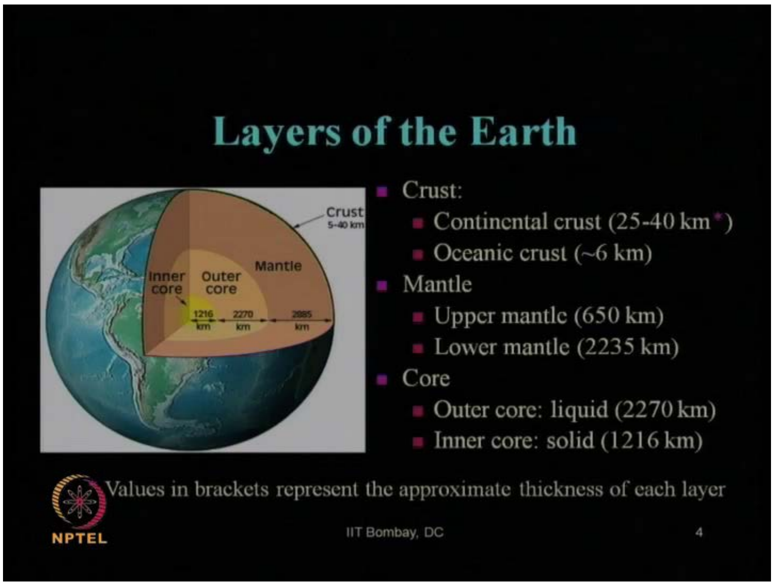

We talked about various layers of the earth and followed by the continental drift theory which was proposed by seismology's Alfred Wegener.

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And the evidence for that continental drift theory, we have shown or we have seen through this matching the coastlines, matching mountains, matching rock types and rock ages matching the glacier deposits and matching fossils.

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So, this was the example of matching the coastlines; this is matching the mountain ranges at different locations; this is through the matching of rock types and ages of the rocks at different locations, this shaded region all are having similar types of rocks which we have seen.

Then matching the glacier deposits 300 million years ago, and next we talked about the theory of plate tectonics and we have mentioned various tectonic plates on the earth surface, also we have seen the subduction zone at the boundary of this plates, also the ridge axis faults strike slip or transform type of faults, uncertain few uncertain plate boundaries through this dotted lines. And also it has been validated through this picture that most of our major earthquakes all around the worlds, those are occurring at those plate boundaries, where we have seen the plate boundaries, major plate boundaries all our historical major earthquakes are clustered or congested close to those points of plate boundaries.

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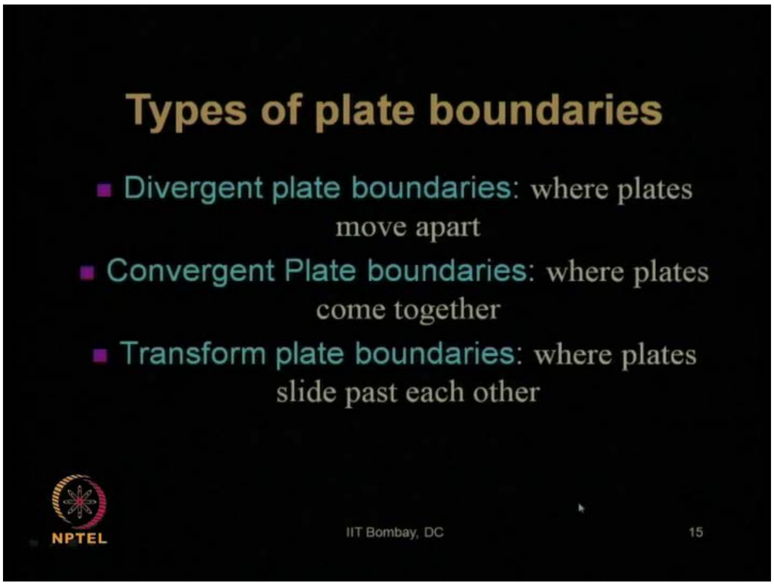

Then we have seen various types of plate boundaries, major 3 types of plate boundaries we have discussed like divergent plate boundary, where the plates move apart from each other subjected to tensile type of load.

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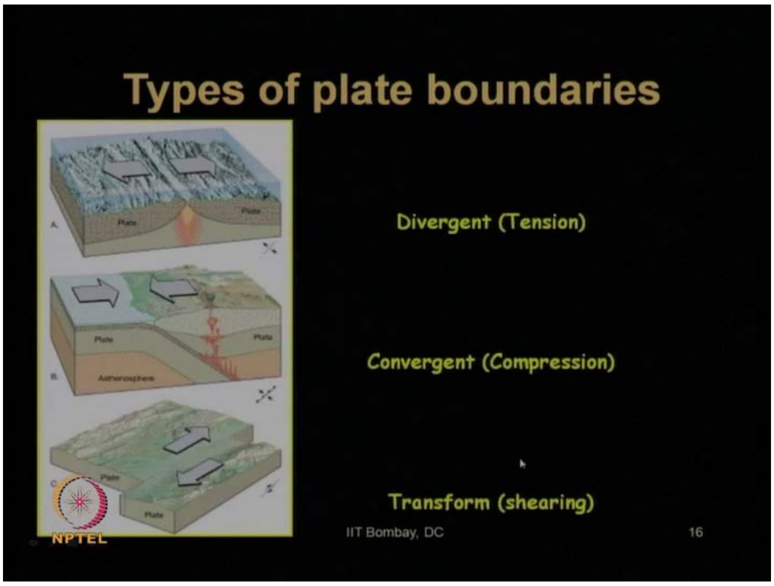

Convergent plate boundary where two plates comes together this is subjected to compressive type of load, and transform plate boundaries where two plates slide past each other this is shearing type of load.

So, through this picture we have seen what are the various types of plate boundaries; this is the picture of divergent plate boundary subjected to tensile forces; this is convergent type of plate boundary subjected to compressive forces and this is transform type of plate boundary movement where shearing takes place.

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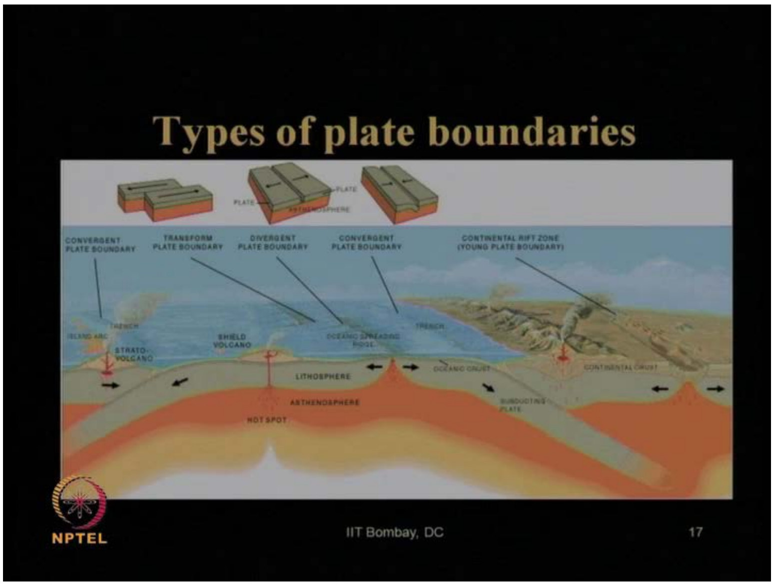

And over the earth at various locations, as we have seen some places can have the convergent plate boundary; obviously, the some other place will have the divergent plate boundary movement and some places can have transform type of plate boundary movement.

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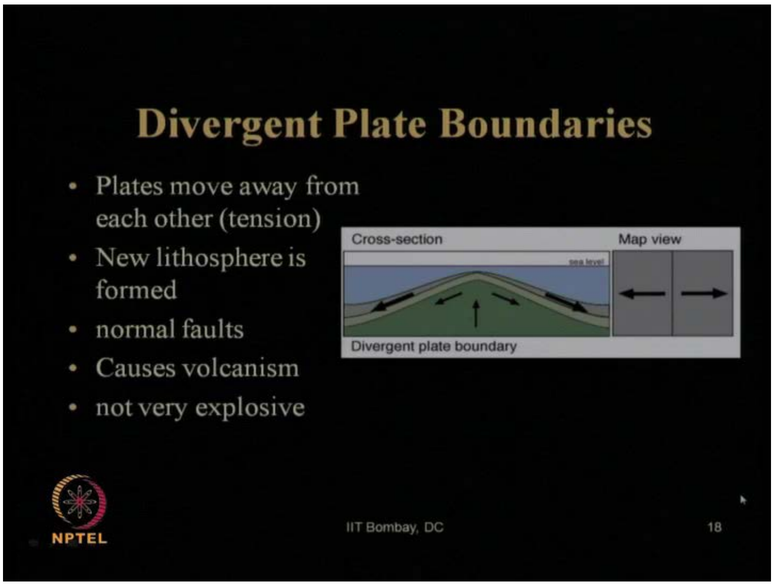

Then we have seen the basic characteristics of divergent plate boundary movement, where volcanisms can get formed and this type of fault which gets created in the map view of the earth surface is known as normal faults, and two plates move away from each other and this type of movement does not create much of an explosion.

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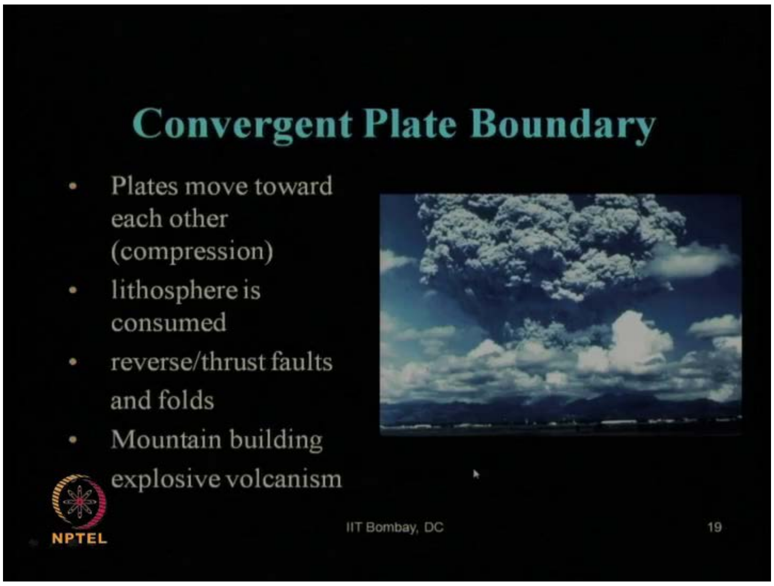

Whereas, convergent plate boundary the basic characteristics we have seen in this case the lithosphere or ground surface gets consumed, and this occurs in reverse or thrust faults and folds this creates mountains builds up and it creates huge explosive and volcanisms also in certain cases, like when ocean and continent two plates converge each other like this.

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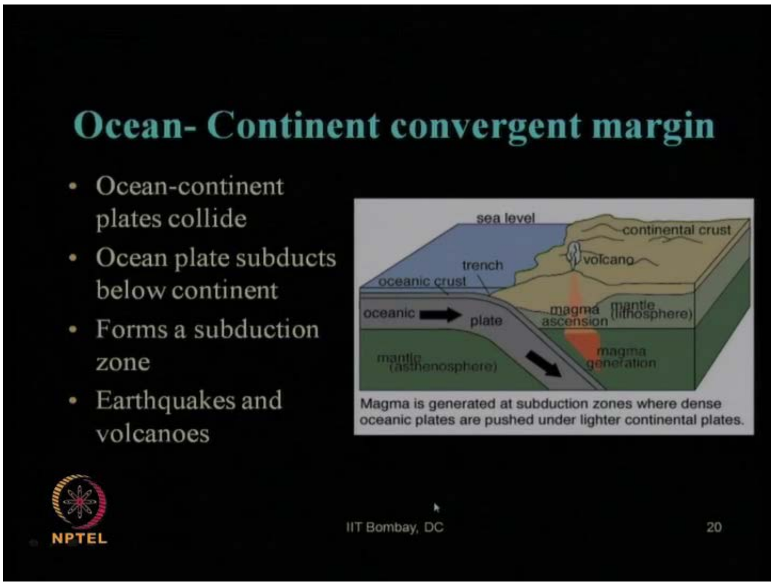

So, ocean continent plates collide each other, ocean plates subducts generally below the continent plate and forms a subduction zone. So, in this case both earthquake and volcanic eruption takes place.

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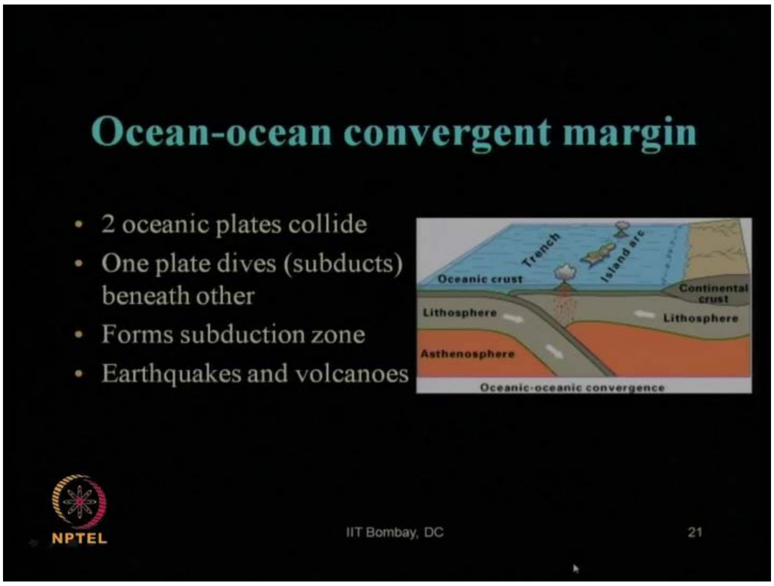

For ocean-ocean convergent movement two oceanic plate collide each other, in this case also earthquake and volcanic eruption takes place and the subduction zone is getting formed, because one plate dives beneath the other one that is gets subducted.

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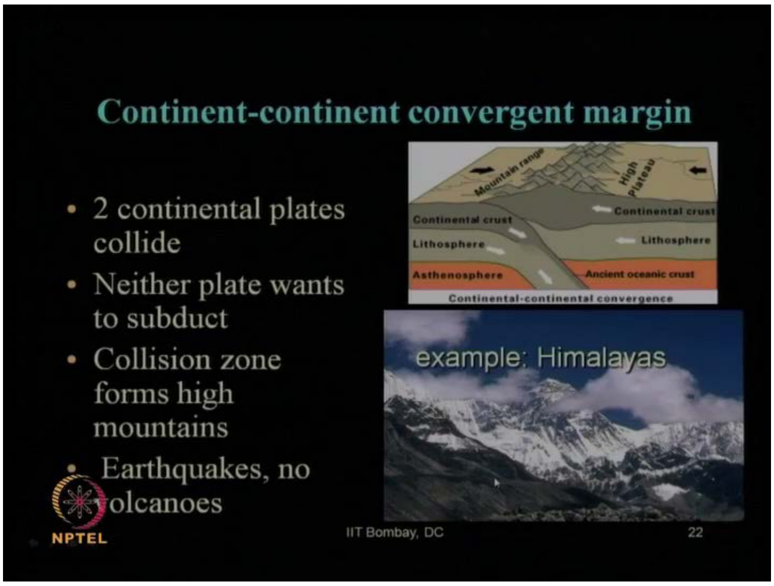

Whereas, continent-continent convergent plate movement we have seen two continent plates collide each other, neither of them tries to gets subducted it creates large mountains. And in this case mostly large earthquakes will occur, but no such volcanic eruptions, an example of two continental plate getting converging is the example of formation of mountain Himalaya.

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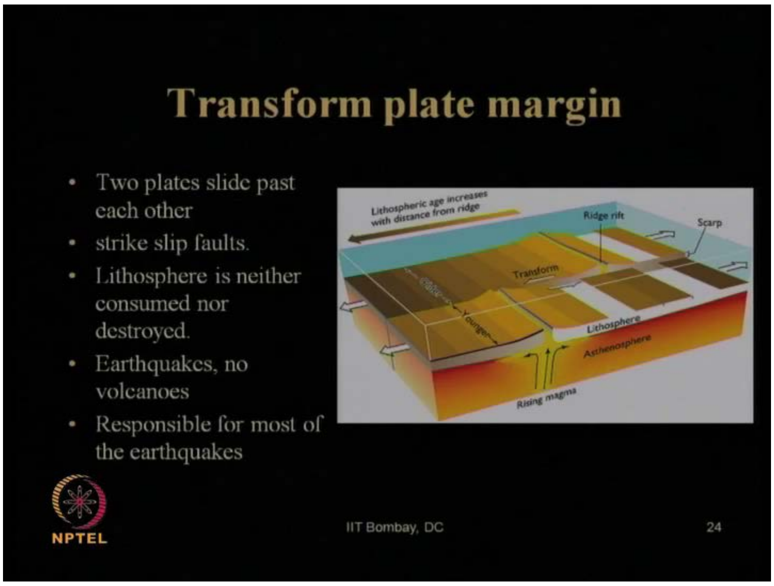

Then we talked about the plate tectonic within plate tectonic theory the transform plate margin that is the another type of or third type of plate movement where 2 plates slide past each other and it is responsible for most of the earthquakes in the world, here also earthquake occurs no significant volcanic eruption.

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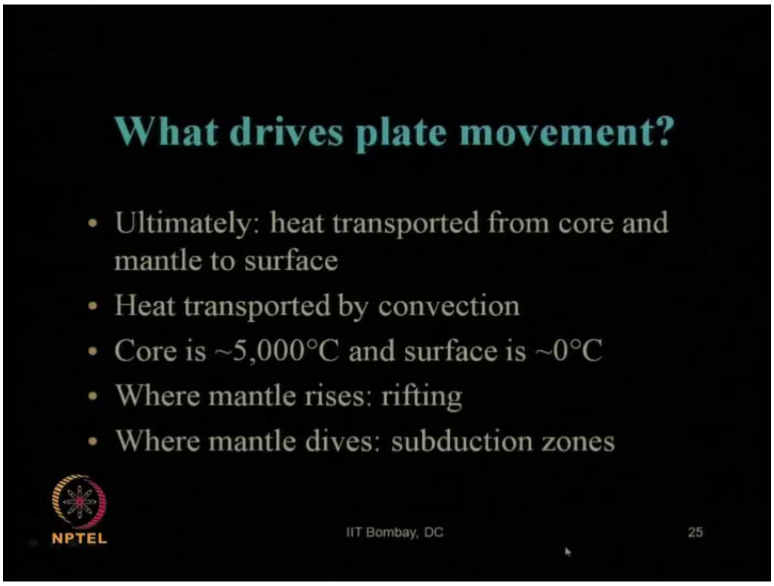

And what are the causes for that plate movement we have seen the huge temperature difference between the earth's core, and the surface which makes the heat to get transported by the convection process from the core through mantle to the surface.

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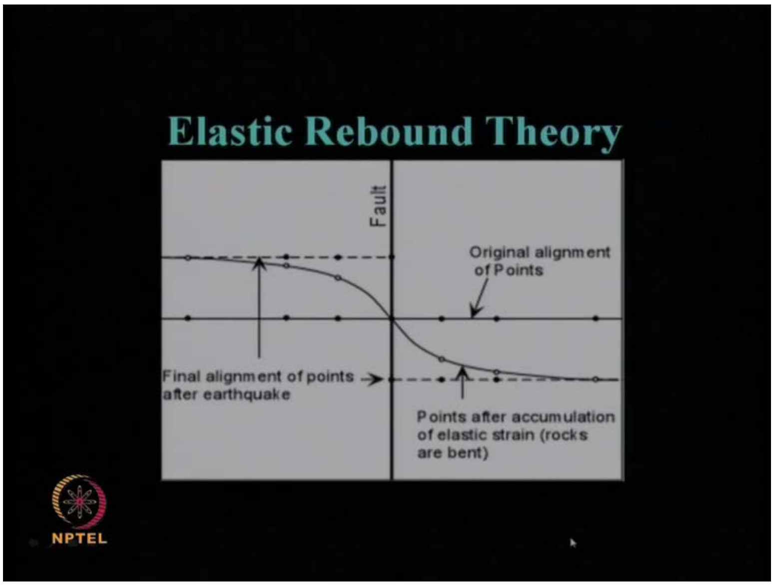

Then we have talked about types of faults, in this types of fault initially we have seen what is called elastic rebound theory.

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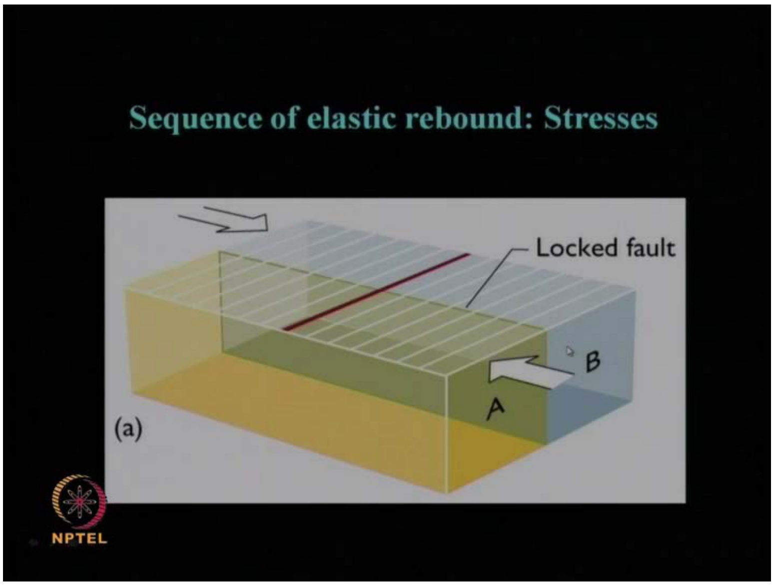

And what are the various steps or sequences of elastic rebound first the stresses are getting generated through the process the bending of the rock occurs, then rupture of the rock takes place, and finally it rebounds or there will be a certain amount of slip along the fault plate.

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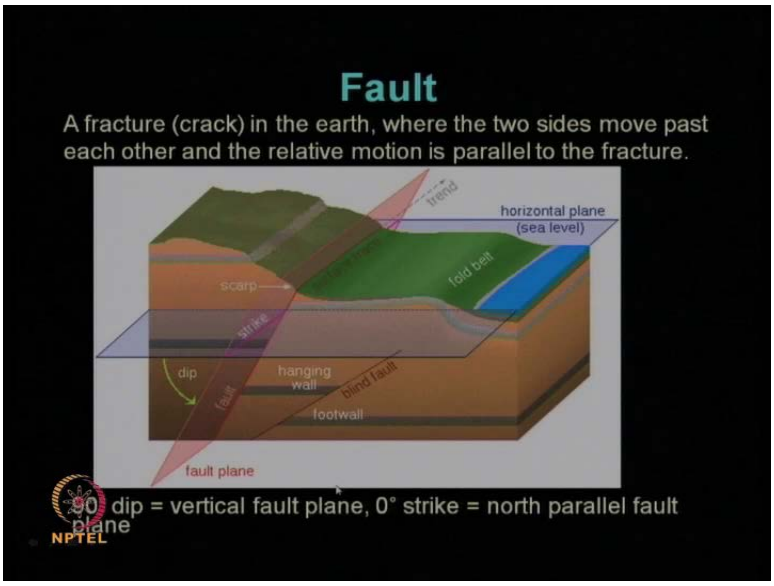

Then we have seen what is the fault it is a fracture or crack within the earth, where 2 sides move past each other relative and the relative motion is parallel to that fracture and we have seen the parameters, which define the position of a fault through angle of dip and angle of strike.

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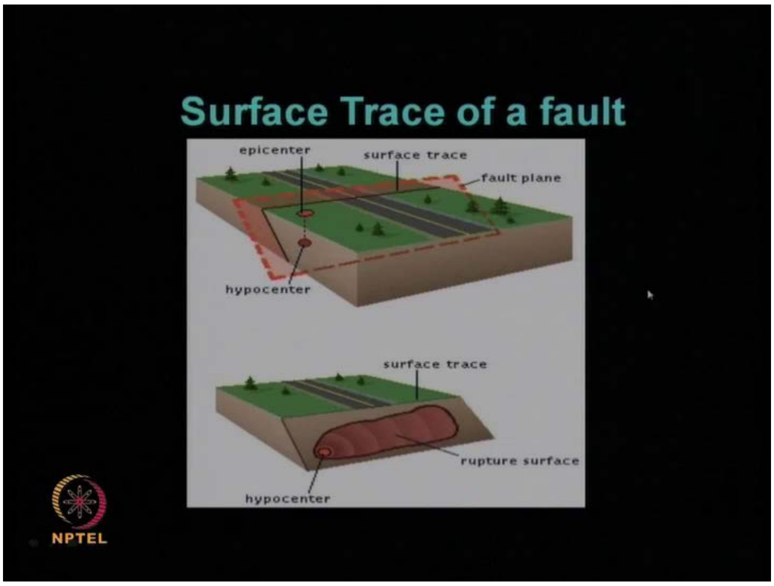

Now, in today's lecture we see the further portions of these types of fault and the seismic waves. So, if we look at this slide this is known as surface trace of a fault; that means, whenever there is a rupture surface; this is the hypo center; this one is the fault plane or the weaker plane, now if this plane make some mark on the ground or intersects the horizontal plane or the ground plane along this line. So, this is nothing but the intersection line will be called as that is these 2 planes where they are meeting each other at the ground surface is nothing but the surface trace of the fault, is it clear through this picture.

So, this is the location of our hypo center or focus of earthquake, the vertical projection is the epicenter on the ground and this is the surface trace of the fault. So, you can see very easily from this picture that it is not necessary that our epicenter should be located on the surface trace of the fault, is it clear? Because it depends on the dip and strike of this fault plane am I right. So, in case of 90 degree dip fault with 0 degree strike then we can expect that the epicenter may be falling on the surface trace of the fault, but not for non vertical fault plane; right, is that clear?

So, the fault plate can be far away from the epicenter also. So, this is one of the criteria we as an earthquake engineer should know, because layman common people they generally tried to believe that the fault of an earthquake will be very close or at the epicenter. So, it is not necessary that surface trace of the fault that is where you can see the fault or weakness on the ground surface need not be at the epicentral point that can occur only if it is a vertical fault plane otherwise for non vertical fault plane there can be huge distance on the ground surface between the epicenter, and the surface stress or the on the ground surface where we can see the fault plane there can be huge difference or distance is it clear from this picture.

So, this is new learning for us which is not in common belief of the layman or common people, they believe always that fault will be at the epicentral point need not be it can be far apart from each other.

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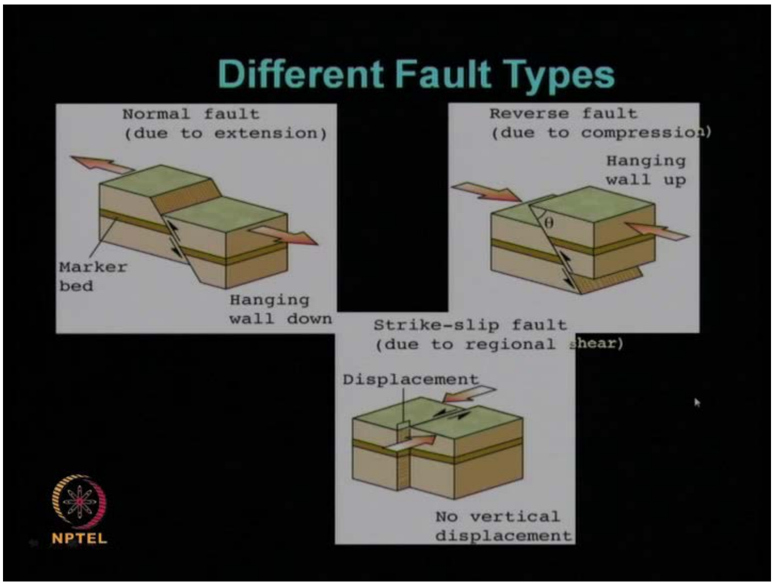

Let us look at the what are the different types of faults. So, this slide shows us there can be majorly 3 types of faults; one is called normal fault another one is called reverse fault and the other one is called strike slip fault; this normal fault as you can see from this picture; this 2 blocks are moving away from each other that is they are subjected to the extensional force or the tensile force. So, this type of situation occurs when when there is a divergent type of plate movement.

So, just we have seen the recap of our previous lecture. So, in the divergent type of plate movement, these normal faults are getting formed or the other way round we can say the divergent type of plate movement creates this normal fault. So, in this case if you make a marker for a particular bed you can see that hanging world down there is a force over this, you have on this point there is a movement both the vertical as well as horizontal right. So, this normal fault can make both vertical movement as well as horizontal movement of this 2 rock blocks fine.

In the case of reverse fault, what you can see over here 2 blocks are compressed with respect to each other. So, they are subjected to compressional load as shown in this picture and for what type of plate movement this condition can occur; for convergent type of plate movement. So, the convergent type of plate movement will create this type of reverse fault, in this case hanging wall up goes up and if you look again at the marker bed position change there is both vertical movement and horizontal movement and there is some subduction of the zone as you can see right.

So, that is the reverse fault whereas, strike slip fault is that fault where the regional shear or the shearing forces are acting between the 2 blocks. So, in this case the displacements between the two blocks occur, there is hardly any vertical displacement. So, no vertical displacement and this type of case we have seen in the case of transform type plate boundary movement. So, these 3 different types of faults can get created during 3 different types of plate boundary movement. So, the normal fault gets developed during divergent type of plate boundary movement reverse fault is getting developed during convergent type of plate boundary movement and the strike slip fault is getting developed during the transform plate boundary movement.

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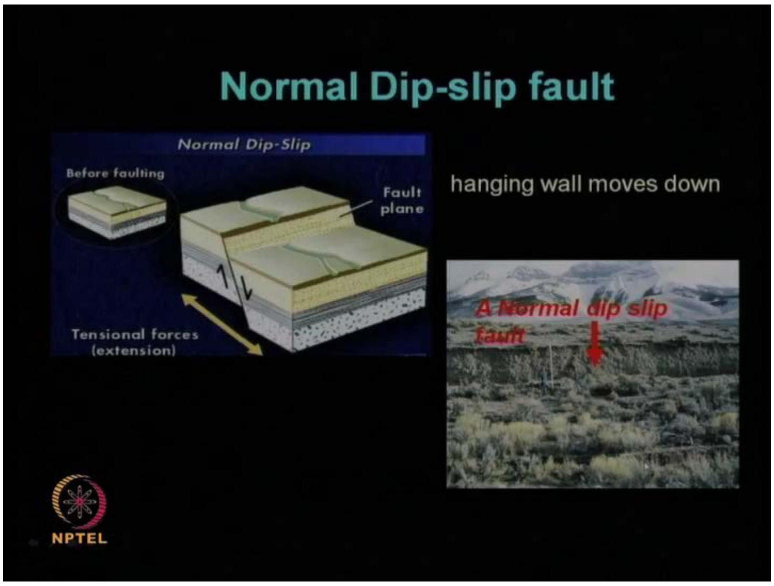

Let us discuss little bit about each of this fault. So, normal fault; normal dip-slip fault what is that? So, as we have mentioned before the faulting the rock block was a single one and then through the weak plane there is a movement and the movement is perpendicular to that weak plane. So, this is our fault plane and this gets separated out when the 2 blocks are subjected to this tensional force or extensional force there is a vertical as well as horizontal movement.

So, dip-slip fault that creates hanging wall moves down. So, this hanging wall it moves down. So, a normal dip-slip fault this picture shows clearly you can see this portion is much above than this portion of the ground, a person is standing over there you can easily make out what magnitude of movement can occur looking at the height of this person and height of this cars and vehicles etcetera, it can be much more than the height of a person even double the height of a person. So, that type of movement can occur during this normal dip-slip fault where one block is hanging over the other one through this development of the tensional forces between the 2 blocks.

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In case of reverse fault, so reverse dip-slip fault; this is the picture before faulting now when these blocks are subjected to the compressive forces, that is their lengths are shortening or one get subducted over the other, that is the convergent type of movement or plate boundary movement occurs. So, along this fault plane what happens hanging wall moves up. So, this hanging wall it moves up and this is also called a thrust fault.

So, another name of this reverse dip-slip fault is thrust fault. So, if somebody says thrust fault that is indicate it is nothing but a reverse fault, why the name thrust fault because in this case of this convergent type of plate boundary movement a thrust or a compressional load is acting. So, that is why one block is providing thrust with respect to the other one. So, that is the reason why the name of thrust fault is used over here. So, you can see in this picture as well a reverse dip-slip fault is occurring. So, through that thrust fault; this portion of the earth or ground is moving up and this remains at the previous location. So, this hanging wall moves up, you can again see over here; this is the height of a typical person and the amount of vertical movement is almost double of the height of a human being. So, that type of movement can easily occur through this fault during this reverse dip-slip fault or thrust fault.

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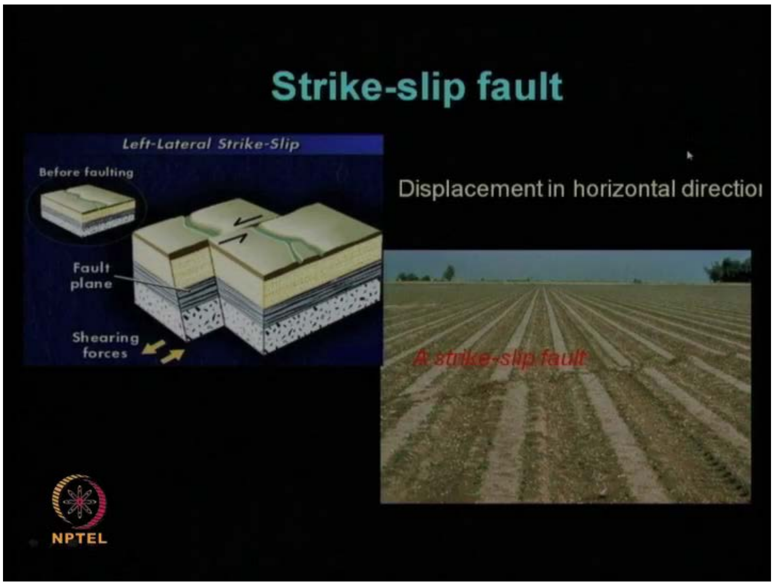

The third one that is the strike-slip fault what we can discuss about this you see over here. So, this is before faulting. So, before the fault gets opened up; this is the picture now when the 2 blocks shear with respect to each other. So, this shearing force takes place you can see over here. So, through this fault plane there is a shear force and sliding movement along this plane.

So, this displacement is in the horizontal direction this displacement is in the horizontal direction. So, you can see this marking point or if it is a river anything they got displaced totally from one place to another place. So, a good example pictorial representation of actual strike slip-fault you can see over here initially probably it was matching with this line and after the amount of strike slip-fault this 2 blocks as moved with respect to each other laterally in this direction. So, there is now no continuity like we have seen this similar picture in San Andreas fault earlier in one of our lecture. So, a strike-slip fault displacement has occurred in the horizontal direction.

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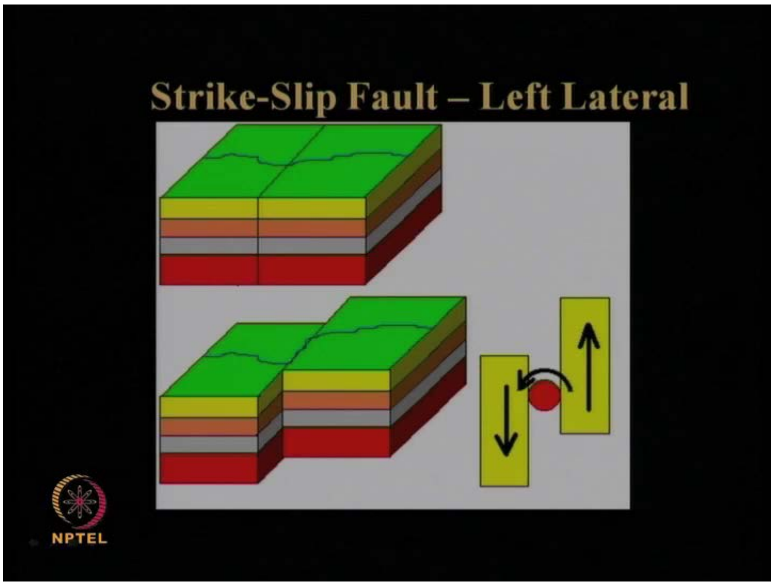

Now, this strike-slip fault there is a sub classes within that fault; one is called left lateral; what is that meaning of left lateral? if you see this 2 blocks; this the fault plane or the fault surface, now if 2 blocks are moving with respect to each other like this which we can show pictorially through this process that is the shearing takes place like this with respect to the central point, if we see the shearing forces it is developing and anti clockwise movement about that center point.

Then we call it as left lateral that is laterally the left block has moved like this subjected to an anti clockwise force getting generated due to this shearing action of between the two blocks, and the another classification sub classification of this strike slip fault is right lateral, that is 2 blocks with respect to each other this block remains stationery the right one has sheared off or moved laterally like this. So, in this case if you look at the shear force like this about the central point if you see the movement it is causing a clock wise movement. So, that case the right block has moved laterally. So, this is called right lateral type strike-slip fault.

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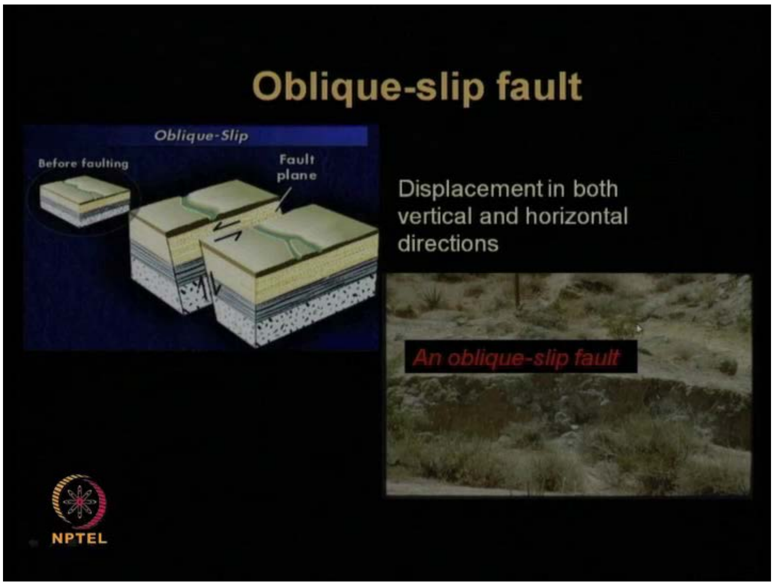

Now, coming to another type of special fault which is known as oblique-slip fault, so this is I should say this is a combination of the previous fault. So, you can see over here, in this case this was the before faulting picture and after faulting this is the exposed fault plane there is both shearing force as well as there is some divergent or the convergent force which is creating this type of vertical movement. So, in this case of oblique-slip fault displacement occurs both in vertical and horizontal direction, that is there will be a horizontal direction as you can see the movement between this 2 points as well as there will be a vertical movement.

Whereas, in normal fault, pure normal fault and pure reverse fault; what we have seen there will be only vertical movement right, there is hardly any horizontal movement and whereas, in pure strike-slip fault what we have seen there is only horizontal movement there is no vertical movement. So, that is why this oblique-slip fault is nothing but a combination of this vertical as well as horizontal movement. So, among this types of fault which faults can create tsunami in the ocean.

So, during the earthquake process, when there is say if normal fault or reverse fault or oblique slip fault where there is a vertical component of the movement between the two plates those can create tsunami whereas, the strike-slip fault where only the horizontal movement takes place between two blocks that cannot create tsunami as already seen from this pictures because in that case strike-slip fault we do not have any vertical movement.

So, we need some amount of vertical movement in the ocean plate between the 2 oceanic plate to get tsunami generated. So, that is the reason you can see only oblique-slip reverse fault and normal fault can create the tsunami during an earthquake process.

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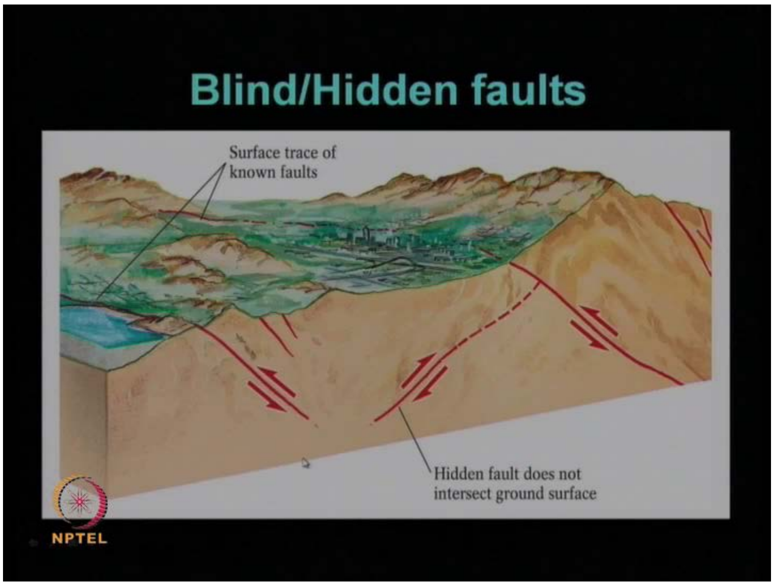

Now, let us see another parameter or another title which is known as blind faults or hidden faults. So, what are these hidden faults or blind faults, that is as the name suggest these faults are not easily identifiable or not visible on the ground surface that is the meaning of hidden faults. So, you can see on this picture; this line, dotted line on the ground surface is the surface trace of known fault, because this is the fault plane as you can see over here this solid red line this fault plane when it intersects the horizontal plane of the ground that it creates a mark on the ground that is the surface trace of the fault as we have seen just few minutes back. So, that is the surface trace of this known fault also you can see another fault over here this fault plane makes a surface trace like this. So, this is the surface trace of another known fault, but look at this fault; this is the fault of course, weak region within this mass of rock, but this fault plane is not able to make any surface trace on the ground why because they got intersected by this another fault.

So, what happens; this fault plane is not creating any surface trace on the ground surface so; obviously, people in general from the ground surface will not be able to identify this fault at the surface level. So, that is known as hidden fault because it does not intersect the ground surface or another name is called as blind faults. So, these hidden and blind faults are more dangerous, because these are not identifiable easily and these faults may create earthquake at some locations which may be till date people considered as a stable zone in terms of earthquake that is not much of an earthquake can occur. So, we can give a very good example of this like for our peninsular India, earlier people are used to think that is the stable plate where no much earthquake incident can occur, but after the Jabalpur earthquake Cohen earthquake etcetera.

That wrong perception of people got changed which was before 1990s, that peninsular India plate is stable plate, but after those earthquakes Jabalpur, Cohen etcetera, later people identified that even a peninsular India plate can have major earthquake and many times reason can be given that there were probably many hidden faults earlier which were not discovered by the seismologist or geologist, but through this earthquake processes they were now known to us.

So, that is why various parts of the world you may have this type of hidden fault or blind fault which may create earthquake in future which is not yet known. So, to identify these blind and hidden faults is another very big topic of research for the seismologist or geologist.

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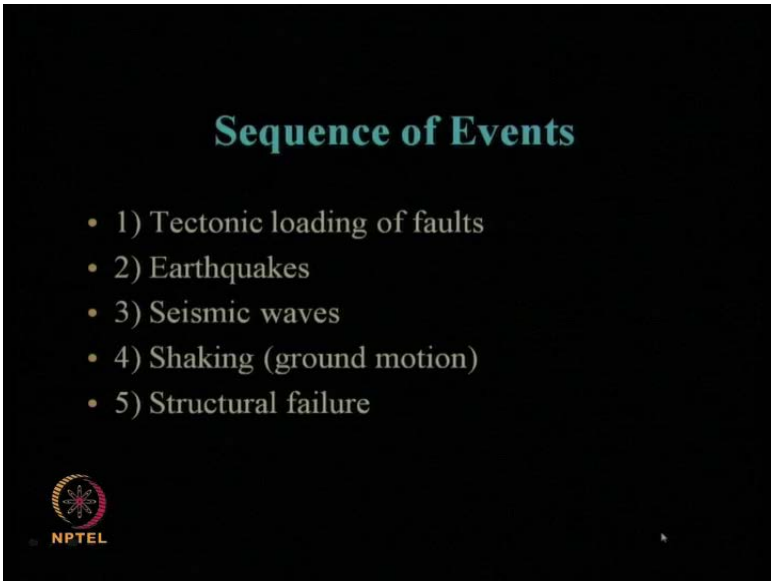

So, what are the various sequences of an earthquake event let us see at the sequence. So, first the tectonic loading of the faults will take place, that creates the earthquake and during that earthquake process various seismic waves gets generated and those seismic waves creates a shaking on the ground, that creates a ground motion and finally, that shaking creates all the structural failure for our civil engineering structures. So, these are the various steps which are occurring during an earthquake process, during and after earthquake process. Let us look at here tectonic loading of faults, earthquakes, seismic waves, shaking and structural failure; five major sequence of the event before during and after earthquake.

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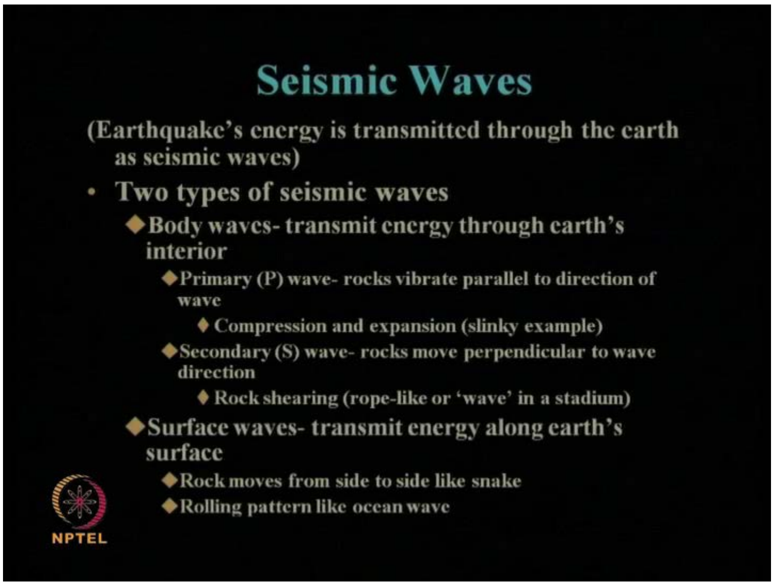

So, now, let us come to our sub topic on seismic waves. So, earth's through this process of earthquake the earthquakes energy is getting transmitted through earth as the seismic waves. Waves are getting generated they travel and those are those waves are known as seismic waves. So, these waves are of basically two types. So, basic classification of that seismic wave is one is called body wave another is called surface wave. So, these two are the major two types of waves.

Now, within body waves what are body waves; these are the seismic waves which transmit the energy through earth's interior. So, that is the name why the body came these waves travel within earth's interior or earth's body. So, that is the reason why they are called body waves now if we see the sub classification of the body waves, there can be again 2 types of body waves; one is called primary wave or P wave another is called secondary wave or S wave or shear wave. So, primary wave is nothing but when the rocks vibrate parallel to the direction of the wave that case is called the primary wave, these are compressional in nature and the successive compression and expansion will take place when this wave travels through a medium. So, the slinky type of example can be given for this P wave movement we will see soon through pictures. Secondary wave in this case rocks move perpendicular to the wave direction.

So, in P wave the rocks moves parallel to the direction of the wave whereas, in S wave or shear wave or secondary wave the movement of the particles or the rocks that takes place perpendicular at 90 degree to the wave direction, in this case rock shearing takes place and the behavior can be called as rope like or wavy motion in a stadium we will see through pictures soon; whereas, the another major type of seismic wave as we have mentioned surface wave as the name suggest these are the waves which transmit energy along the earth surface.

So, they are very close to the ground surface. So, that is the reason why the name surface has been used. So, this body means, these waves transmit through the earth's interior or earths body whereas, the surface waves transmit the energy or travels through the earth surface or ground surface, there also can be two subdivisions of this surface wave, there can be two types of surface wave one is called Rayleigh wave another is called love wave. So, their behavior will be rock moves from side to side like a snake. So, this is for love wave and rolling pattern like ocean wave this is for Rayleigh wave we will see their characteristics etcetera soon in the sub sequent slides.

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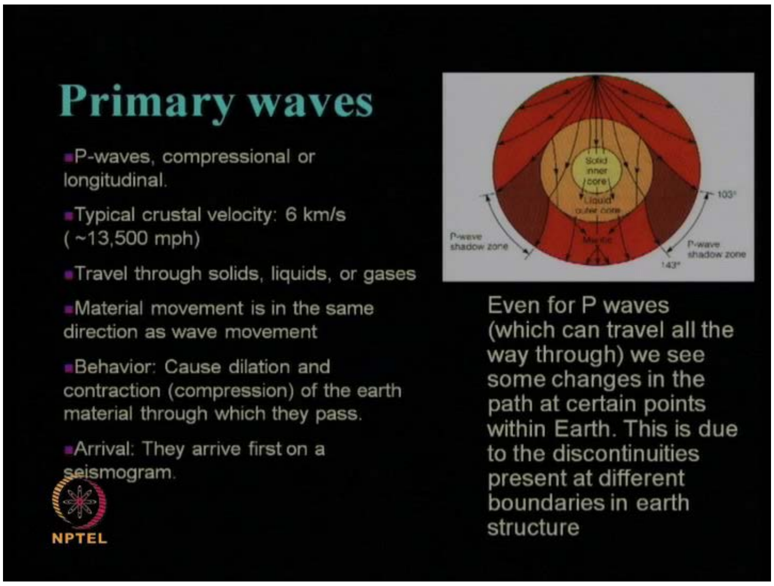

So, let us talk about the first type of body wave which is the primary wave or P wave. So, the another names for this primary waves are P waves, compressional waves or longitudinal waves. So, these are the common names which are alternatively used for primary waves and what is the typical crustal velocity of these primary waves typically its velocity will be crustal velocity that is at the earth's crust.

That is at rock level 6 kilometer per second. So, it travels so fast, you can see the velocity 6 kilometer per second which is about 13500 miles per hour huge amount of velocity that is its speed is very fast the P wave in the earth's crust and what are the characteristics of this P waves, they travel through all the medium that is through solids through liquids or gaseous, that is this P wave or compressional wave or longitudinal wave they can travel through any type of media whether it is solid media or liquid media or gaseous media and in this case material movement is in the same direction as the wave movement as I had mentioned in this case the particles which are getting shaked through the movement of the waves, they move in the same direction as the wave also moves or propagates its behavior is it causes dilation and contraction, that is in some places it creates the dilation or expansion in some cases it creates compression.

So, this is the subsequent cases of dilation, compression, dilation, compression; that is expansion, compression, expansion, compression along the length of the movement of the particles in the direction of the wave propagation of the earth's material through which they pass through and arrival about the arrival they arrive first on any seismogram, that is where your recording your earthquake waves arrival time and their behavior in that case P wave, because of their very high value of the crustal velocity they arrive first in those seismogram.

Now, let us look here in this picture; this explains many things I will discuss now. So, even for P waves if you see at this picture which can travel through all the media that is solid liquid and gases we can see that some changes in the path at certain points within earth can occur and this is due to the discontinuities which are present at different boundaries in earth's structure; what does it means, suppose the earthquake epicenter is here and hypocenter we can say closed to that point. So, from hypocenter; this will be a vertical projection epicenter is here, now the seismic waves gets generated and travels in all the directions. So, they are travelling like this as it is mentioned, but when it comes to a boundary of two layers.

So, the outer layer is the crustal layer which is very thin layer as we have seen next part is this layer red portion is nothing but the mantle; this is the thickness of mantle. So, when this waves comes and hit this boundary between the mantle and the outer core, we have seen the earth's interior; this one is outer core and then inner core; inner core is a solid material whereas, outer core is a liquid or fluidized state right. So, when this wave intersects between this mantle and outer core boundary due to the change of material property as well as the state of the material there will be some reflection, refraction of this waves will takes place.

So, finally, some waves will get transmitted through this because these waves can travels through all the media. So, from solid to liquid it can travel easily similarly, when it hits over here another boundary that is from liquid outer layer to the solid inner core there is again some transmission of the wave through this media, is it clear. So, it can travels in all the directions finally, when this waves comes out from the other side of the earth that is from this part to another part of the earth, that is 180 degree opposite part even some waves will further gets transmitted through from this outer core to mantle now, our seismograms are located all around the earth.

So, you can see from this picture clearly that earthquake occurred at this point of the earth can get recorded by the seismograms located at this point; this point; this point; this point; this point; this point all over the earth. So, that is the reason why I was mentioning that during an earthquake when this seismic waves travels through various layers of the earth it gets recorded at different parts of the world that is the reason why you will see after an earthquake say in Japan or in India even the US which is almost on the other side of the globe even they can record the arrival of this wave at certain locations using the seismograph located at various points.

Even that is the reason why, an earthquake which is having an epicenter or hypocenter within the deep portion can get recorded in other seismograph locations on various continents say Japan, US, India and various parts of the world. So, the P waves what we have seen on this picture is getting observed their arrival is getting measured at different seismogram located at various parts of the world, only thing is that the P wave which is getting recorded at this part of the world, their arrival time will be less than the arrival time at this point which is quite obvious because it takes certain time to travel through this distance, because it is having some velocity 6 kilometer per second.

So, according to your distance from this epicenter to your seismograph location it will take required amount of time to reach that particular seismograph located at various points. Now, if you look very carefully on this picture, between a typical angular point of 100 and 3 degree to 143 degree; this is the typical range considering this as your 0 degree point.

So, from this point if you measure; this is 100 and 3 degree and this is 143 degree on both the sides of the earth. So, this portion is called P wave shadow zone, what does it mean if you see at the waves travelling; this wave is coming over here directly, but this wave is coming here it get transmitted to another media. So, there will be a change in the angle of its incident and then refraction then finally, when it comes out from this area its again there will be a change in its angle of refraction or the transmission.

So, finally, you will see there is certain location on the earth where P wave will never arrive, that is called as the shadow zone, shadow zone means at in that zone no P wave will arrive that is P wave shadow zone. So, if your seismograph is located here that seismograph will record nothing, because no P wave because of this earthquake can reach here. So, they will feel that as if no earthquake has occurred at any part of the world, but the other parts of the world they will record this incident they will say no it has occurred at some part of the world probably your seismograph could not record because you may be located in the shadow zone of that P wave that is why the P wave could not arrive at your seismograph provided of course, the seismograph is in working condition right. So, this is the observation you can see why an earthquake occurring at any part of the world is getting recorded all over the world except those shadow zone clear.

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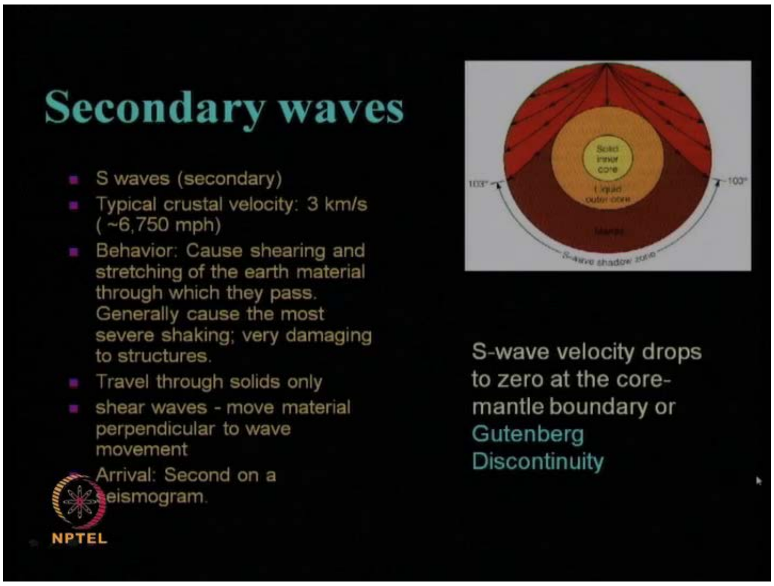

Let us come to the next slide which shows the behavior or characteristics of the secondary wave or S wave or shear wave. So, let us look at the slide over here; secondary waves, S waves or shear wave, what these are the different names commonly used for the secondary waves, the typical crustal velocity of this secondary wave is about 3 kilometers per second.

So, in the crust, earth's crust their typical velocity is about half of the primary wave, as we can see primary wave is having typical crustal velocity of about 6 kilometers per second and this secondary wave is having typical crustal velocity of about 3 kilometer per second, and its behavior is it causes shearing and stretching of the earth's material through which they pass. And generally it causes the most severe shaking which is very damaging to the structures and it shear wave travels through only solid media it cannot travel through fluid media that is it cannot travel through liquid, and gaseous media, because they are shear wave as we know the shear load cannot act on fluid media the same reason why this shearing waves or shear waves or secondary waves cannot travel through liquid or gaseous media it can travel only through the solid media.

So, shear waves they move material perpendicular to the wave movement that is if this is the direction of the movement of the wave the particles move perpendicular to that 90 degree to that and their arrival in the seismograph is secondary. So, when you are recording on a seismogram, seismogram will show this will arrive second after P wave. So, P wave because of its highest velocity among all the seismic wave will arrive first then second one will be the secondary wave.

Now, if you see at this picture we can say the S wave velocity drops to 0 at the core and mantle boundary, core mantle boundary which is known as Gutenberg discontinuity. So, what is that mantle and core boundary because outer core is a liquid state, so obviously if any shear wave is coming from this epicentral or hypo central point to this point automatically they cannot travel further to another because it is in liquid state and it can travel only in solid media. So, that velocity drops to 0 at this boundary; this boundary is known as Gutenberg discontinuity, that is the boundary between the this mantle and outer core is called Gutenberg discontinuity where shear wave drops to 0 shear wave velocity.

So; obviously, as nothing is going in here, nothing comes out from this side, no shear wave comes out from this side because there is no existence of the shear waves in this liquid outer core region. So, only the shear wave can travel directly to all this points and if you look at the picture if we consider this point as 0 degree than 103 degree to 103 degree between that entire area is called S wave shadow zone; that means, if your seismographs are located anywhere on this part of this globe, none of them will record in their seismograph any arrival of the S wave.

But if seismographs are located at these locations, they will record the arrival of s waves in their seismograph. So, what does it mean some stations, seismograph stations which are between 103 degree and 143 degree; this seismograph will neither record P wave nor record S wave. So, they will feel that no earthquake has occurred anywhere in the world and this portion that is between this angle of 143 degree to another this part of 143 degree; this seismographs on the other side of the earth where the earthquake occurs. So, they will record the arrival of P wave, but they will not record arrival of S wave.

So, what they will conclude they will automatically conclude that; obviously, we are staying at the other side of the occurrence of earthquake point. So, can you see how worldwide the earthquake records in this seismographs give us the information whereas, seismographs located at this points will record both arrival of primary wave as well as arrival of shear wave or secondary waves.

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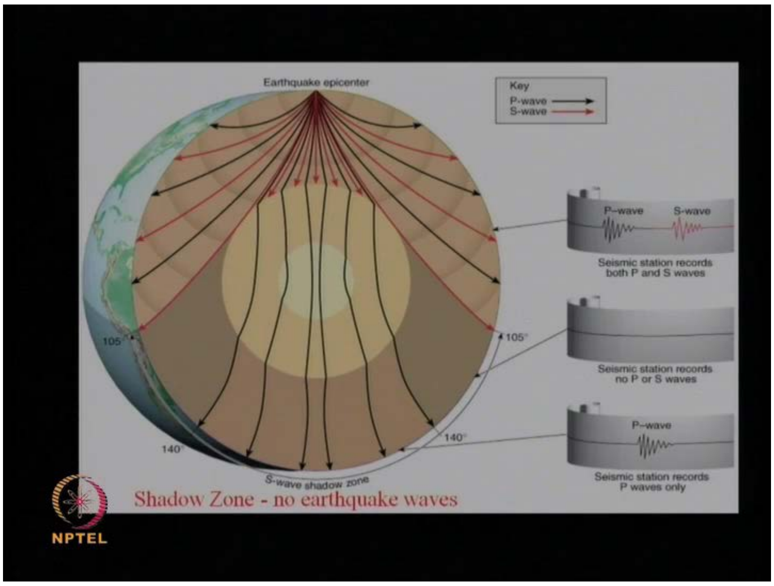

So, through this picture it clearly shows the black arrows shows the P wave, the red arrows shows the S waves. So, earthquake epicenter waves are travelling in all directions, these are body waves, because they are transmitting through earth's interior or earth's body; that is the reason why these two are body waves.

So, seismograph located at this location seismic station they record both P wave they will arrive first in that seismogram, and after certain time because there is a difference of velocity between these 2 waves. So, it will take certain time then the S wave will come. Whereas, in this location typically about we said 103 degree to 143 degree or some people say 105 degree to 140 degree. So, this is a typical angles, if any seismic station is placed at this location, they will record no P wave and no S wave, because they are lying in the shadow zone of both P wave and S wave; whereas, some seismic stations which are located at this point they will record only P wave.

But after some time they will keep on waiting, but no another wave will come; that means, they can automatically understand that they are probably staying in the S wave shadow zone, but not in P wave shadow zone of course, provided the recording instrument is working after recording this P wave; that is the obviously the basic fundamental assumption.

So, you can see all over the world any earthquake occurring at any point, whether it is in deep ocean or in a continent or in a desert everything can get recorded at various locations of seismic stations located across the world, and the shadow zones means no earthquake waves. So, S wave shadow zone means no S wave, and P wave and S wave shadow zone means no P wave and no S wave; that is why no black color arrows, no red color arrows in this region whereas, here it is only s wave shadow zone. So, there is no red color arrows, but P waves can arrive pass through this all the various phases of the earth’s interior solid, liquid, solid and again liquid and then solid. So, P waves arrive, but no S wave arrives here. So, with this we have come to the end of today’s lecture, we will continue further in the next lecture.