Geotechnical Earthquake Engineering
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Module - 3
Lecture - 9
Engineering Seismology (Contd…)

Let us start our today's lecture on this video course of geotechnical earthquake engineering. Let us look at here, this course geotechnical earthquake engineering, we are going through our module three which is engineering seismology, and within that the sub topic which we are covering now, is types of faults and seismic waves.

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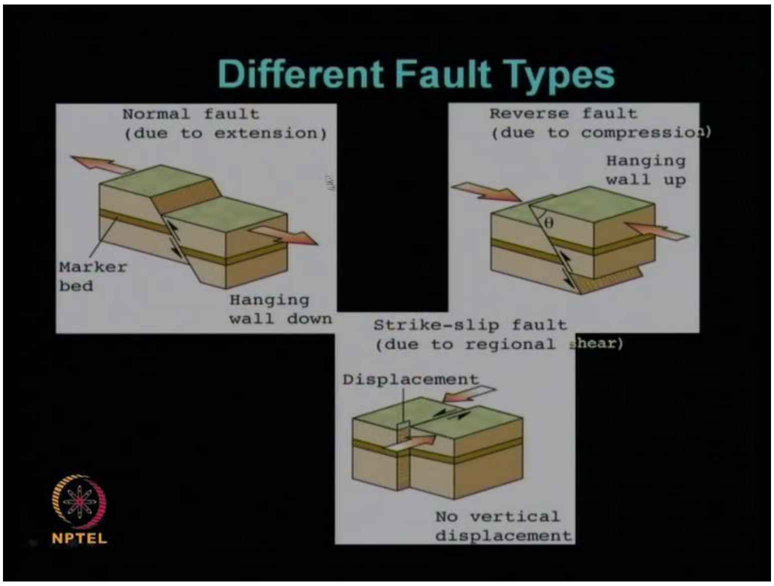

Let us quickly have a recap what we have learnt in the previous lecture, like what are the various types of faults we have seen. Mainly there are three types of faults; one is called normal fault, where the extensional force or tensile force will be acting between the two blocks. Reverse fault, where the compressive force will act between the two blocks and strike-slip fault, where shear force will act between the two blocks. And also, we have connected each one of this type of fault to corresponding plate boundary movement, like normal fault is nothing but connected to divergent type plate boundary movement, reverse fault is connected to convergent type plate boundary movement, whereas strike-slip fault is connected to transform type plate boundary movement.

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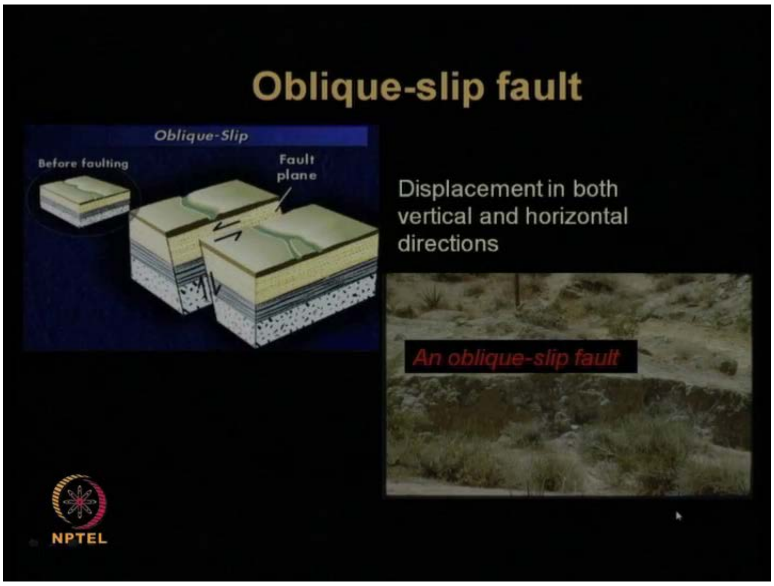

We have also seen another type of fault, which is a combination of two, like oblique-slip fault where we can have both vertical movement as well as the horizontal movement between the two blocks.

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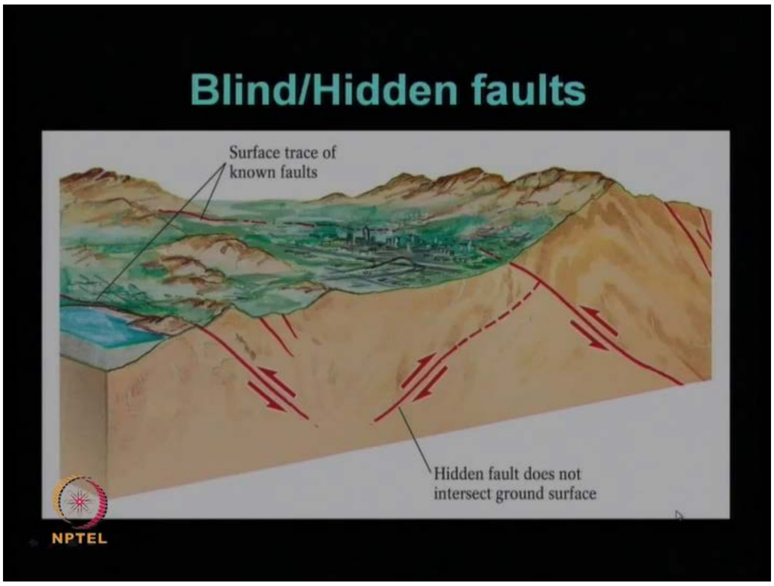

Also we have seen the concept of blind fault or hidden fault, those fault which will not make any trace on the ground surface are known as blind or hidden faults.

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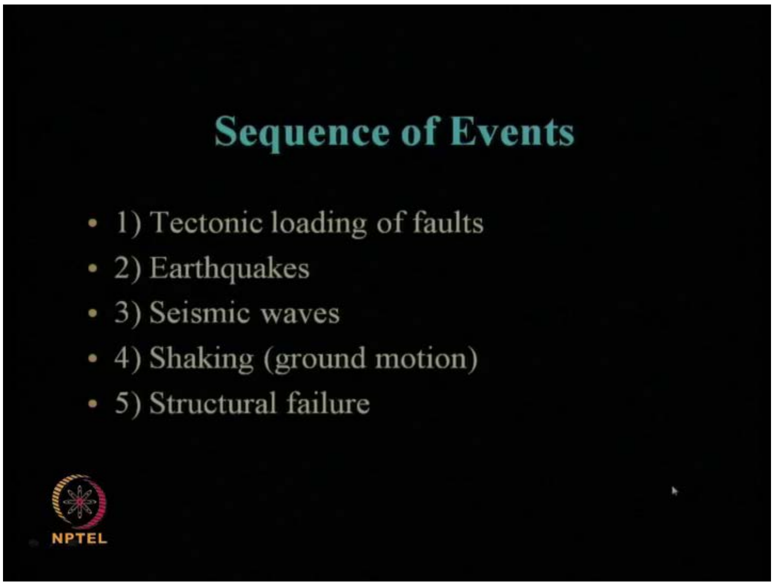

Then sequence of events before and after earthquake we have seen, first tectonic loading of the faults which will cause the earthquakes; once earthquake releases energy then seismic waves travels through the media, then shaking of the ground surface will take place, and finally that creates the structural failure.

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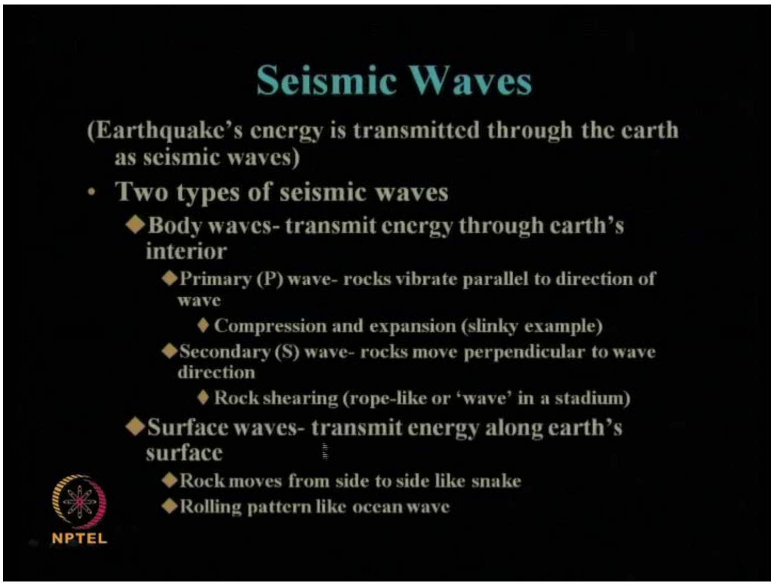

We have also seen that what are the various types of seismic waves, major two classifications of seismic waves are, two types of seismic wave one is called body wave, another is called surface wave. And body wave also can be sub classified into two categories, one is called primary or P wave, another is called secondary or shear wave or S wave. Whereas, surface wave also can be sub classified into two categories one is called love wave another is called Rayleigh wave. Next we have seen in the previous lecture, what is the basic characteristic of the body wave and mainly the primary wave and shear wave.

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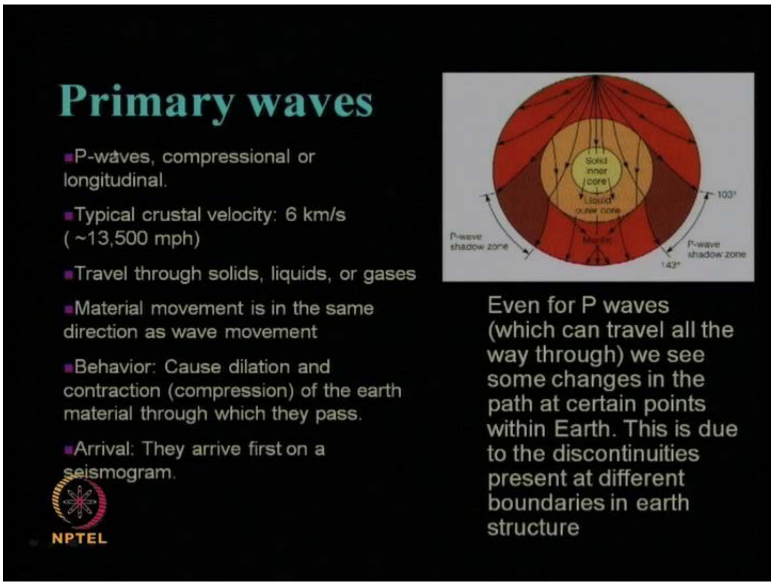

Let us look at the slide, the typical characteristics of primary wave or P wave or compressional wave or longitudinal wave, all are the names of the same type of this waves, which is having a typical crustal velocity of about 6 kilometer per second. And this P wave can travel through all various phases of the media- solid, liquid and gaseous. And behavior of the travel of P wave, we have seen that the particle movement or material movement occurs in the same direction of the wave propagation or wave movement; and behavior is, it causes dilation and contraction that is successive expansion and compression on the earth material through which they pass through, and because of their high crustal velocity they arrive first on any seismogram.

And, we have also seen, whatever be the hypo center or epicenter on an earth surface, during an earthquake the P waves can travel through all the various phases of the media of the earth surface, but still there will be a certain zone where the P wave cannot arrive which is called as P wave shadow zone, and it is typically between 103 to 143 degree from if we consider this point as 0 degree. So, on the both side 103 to 143 degree typically.

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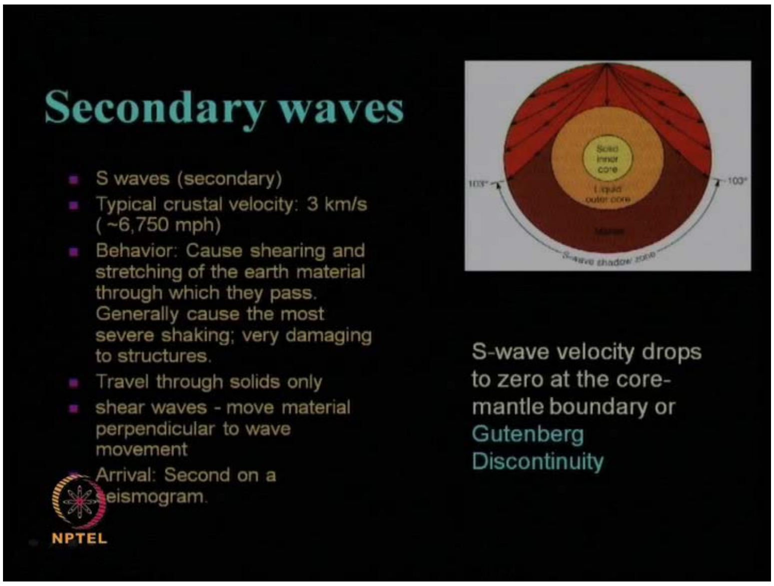

Then, we have seen the basic characteristics of the secondary wave or shear wave; there typical crustal velocity we have seen about 3 kilometer per second, and in this case it causes shearing and stretching of the earth material through which they pass; and one important characteristic of this secondary or shear wave is that they can travel only through solid media, they cannot travel through liquid or gaseous media; that means, as we know the outer core of the earth's interior is of liquid media, so it cannot travel through that media.

So, the boundary between the mantel and outer core is called Gutenberg boundary. Once this secondary wave touches that Gutenberg boundary or Gutenberg discontinuity immediately the velocity drops down to 0, because it cannot travel through the liquid media of the outer core; and their arrival in the seismograph is second because of their velocity which is almost half of the primary wave velocity in the crustal region; and their movement of the particle will be perpendicular to the direction of the movement of the wave.

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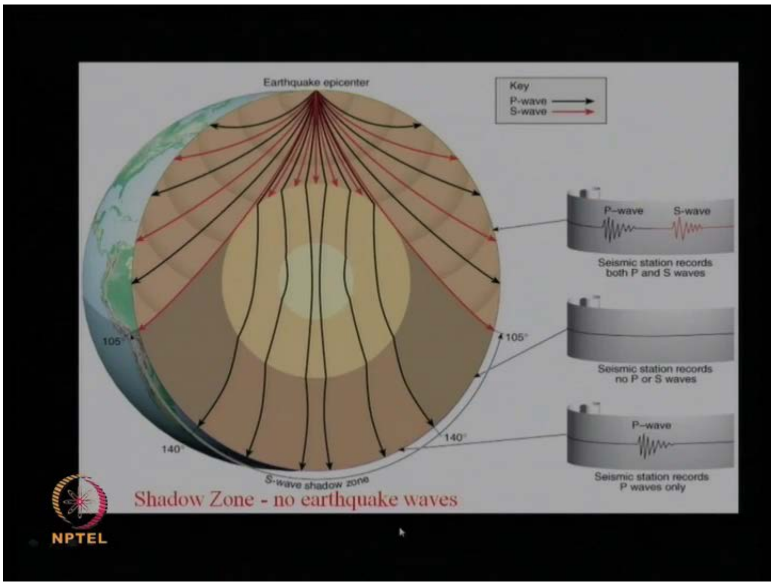

Then, we have seen through this slide that when any earthquake occurs at any point on earth, that earthquake may be recorded by several seismograph stations located all around the world except few zones which are called as shadow zone. So, for P wave we have seen the typical shadow zone about 103 to 143 degree, or 105 to 140 degree, typical ranges these are; whereas, for S wave we have seen the entire shadow zone is this from 103 or 105 degree to another side 103 or 105 degree, considering this as the 0 point.

So, only the seismographs which are located at the this part of the world, for this earthquake they will able to record both P wave and S wave; whereas, the seismographs located in this part of the world cannot record any wave of this earthquake; and the seismographs located at this part of the world will record only P wave, they cannot record S wave because they are in the S wave shadow zone. So, that way different seismographs located all around the world can record a particular type of earthquake wherever it is occurring, whether it is occurring in a deep ocean or in a desert, where human population is not present, still the travel of this seismic wave make us to characterize and find out, where this earthquake epicenter is occurring. So, we will see how to use this information for the determination of earthquake epicenter.

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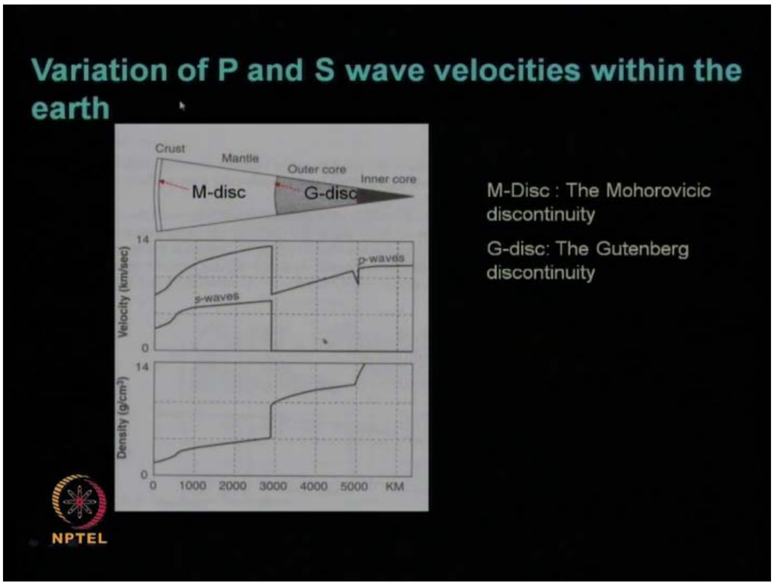

So, in today's lecture, let us see what are the further progresses, we can do in this topic. So, if you look at here, the variation of P wave and S wave velocities within the earth surface can be shown through this slide. In this slide, if you look at the earth's interior, section of earth's interior is taken over here, this very thin layer is nothing but earth's crust, followed by a mantle, followed by outer core, and then inner core.

Now, if we look at the boundary between this crust and mantle, this boundary is called M discontinuity or the full name is Mohorovicic discontinuity. So, the discontinuity or the boundary between the crust and mantle is known as Mohorovicic discontinuity or M discontinuity; and the boundary between mantle and the outer core is known as G discontinuity or Gutenberg discontinuity, this we have discussed just few minutes back in the case of secondary wave or shear wave, when we were discussing the characteristics of S wave. So, this is G discontinuity and this is called M discontinuity.

Now, if we look at the typical velocity of this P wave and S wave in the various layers of the earth, you can see, this is the variation of the earth's interior from the ground surface, and this is the typical velocity in the unit of kilometer per second. So, if you look at here, this upper curve, upper line is showing the typical velocity of P wave in various earth's interior layer. So, where it is starting, if you look at here, it is typically staring in the range of about 6 kilometer per second. So, that is the typical crustal velocity of P wave, as we have already mentioned. So, this value that is P wave is having a typical velocity of 6 kilometer per second at crust level only. So, you should not consider that this is the velocity of P wave throughout any media. So, as the media changes, its velocity will also change. So, crustal velocity is about 6 kilometer per second, and this velocity of P wave keep on increasing as we go deeper and deeper, in the earth's layer.

And whenever there is a discontinuity here, there is a little jerk in this curve, as you can see after that again a smooth line, then again when it reaches this boundary of G discontinuity or Gutenberg discontinuity between mantle and outer core there is again a drop in the velocity of P wave, further it increases; and when it reaches another boundary of outer core and inner core there is again another jump in the P wave, and then again it continues. So, this is the typical range which varies from, if you see from here, about 6 kilometer per second to it reaches almost close to about 13.5 kilometer per second, highest value in this region of mantle, and in inner core it reaches about 11 kilometer per second, these are typical values of P waves in various media.

Now, if we look at the lower line, this lower curve, you will seem this is the curve for S wave velocity, S wave or shear wave velocity, at crustal level is almost half of that P wave velocity, as we have already mentioned. What is the typical value? Typical value is 3 kilometer per second for the S wave in crustal level, and it again increases as we go deeper, why it increases? Because the media from crust to mantle is becoming heavy; that means, its unit weight or density increases, we will talk about that very soon in the next figure. So, whenever it reaches the boundary there will be a jerk, then again it follows the smooth increase in the layer, particular layer, and if you look at here, that is when it reaches the boundary of mantle and outer core that is Gutenberg discontinuity, the velocity drops to 0, because further it cannot travel as this outer core is of liquid media, that is why it has to go to 0.

So, typical S wave velocity reaches from 3 kilometer per second to about 5 kilometer per second, this is the typical ranges of S wave within the earth's interior, that is crust and mantle level, remember this is not I am talking about the shallow soil layer that we will come later on, this is only the earth's interior velocity for the P wave and S wave. Now, if we look at the variation of the density of the earth's interior with this distance, we will see this density unit of gram per CC at ground surface or at crustal level, this is the earth's density; as we go deeper and deeper from crust to mantle, the density keeps on increasing, it reaches about close to value of 5 gram per CC over here, if you consider this as 14; and it further increases drastically, when it reaches this boundary of mantle and outer core. So, though this outer core is of liquid media, but it is a very thick or heavy liquid, which is having a very high density, you can see over here, but its state is, it is a molten state. So, all the heavy metal are in molten state in this region.

So, that is why though it is in the liquid form, but still its density is pretty high; and when it reaches the boundary of this outer core and inner core, again there is a sharp increase in the density, which reaches about this 14 gram per CC, that range. So, this value is automatically, we have seen earlier, the inner core is the heaviest part of the earth that is earth's entire weight is mostly concentrated at the earth's core which is known to us, which is justified through this variation of the density which we can see from this line. Clear.

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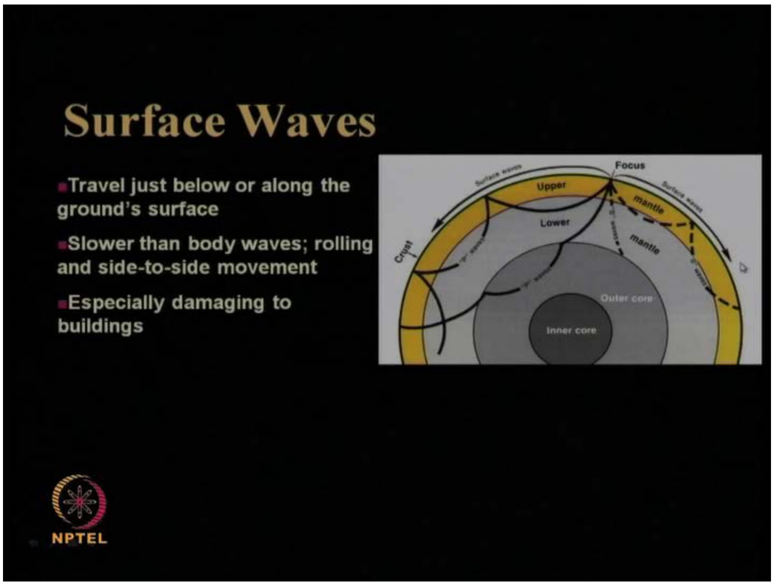

Now, let us come to surface waves, that is the next major classification of the seismic waves, after body waves we are now discussing about surface waves. As the name suggest, as I told earlier also, this surface waves travel just below or along the ground surface, that is the reason why they are called surface waves. Because they have to very close to the ground surface, and they are much slower than the body waves, but their behavior is rolling and side to side movement. And these surface waves are specially damaging to the buildings, because all our super structure those are constructed on or above ground surface they will be mostly affected by this surface wave. So, that is why surface wave because of their travel behavior they are most damaging to our civil engineering structures. And if we look at various layers over here, you can see, focus of the earthquake if it is very close to the ground surface, all the seismic wave travels through the various layers. So, whenever its starts travelling within the body of the earth that those are called body waves, like P wave, S wave, etcetera. And when they travel close to the ground surface they are nothing but the surface waves.

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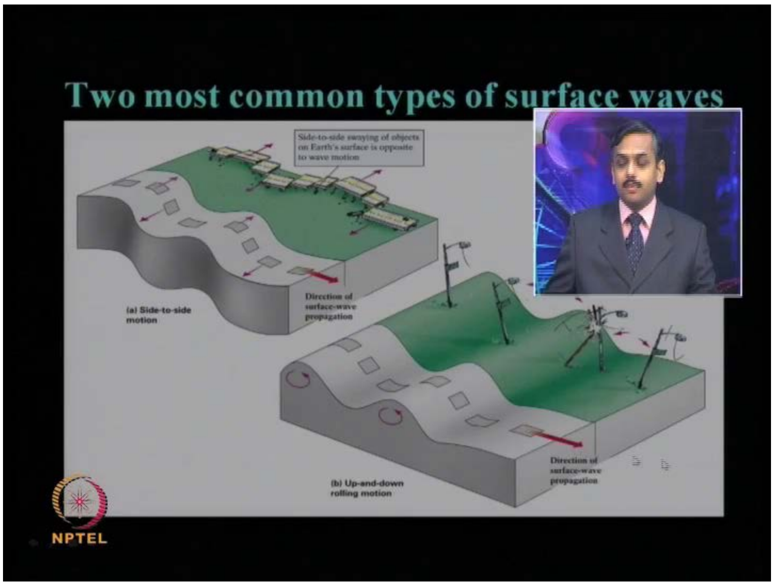

Now, two major or most common types of surface waves which we can see, that one type of motion will be side to side motion, that is if you look at this picture over here, this direction is showing the direction of surface wave propagation that is wave travels in this direction, but the movement of the particles if you look at it, it will be perpendicular to this direction, which is similar to the S wave movement. But in addition to that if you look at various buildings they are side to side motion can be observed over here. So, it is written that side to side showing of the objects on earth surface is opposite to the wave motion.

And, another type of surface wave, we will come to the name, actually this type of surface wave is commonly known as love wave; and, this is another type of surface wave, which will create up and down type rolling motion, what does it mean? If we look at the ground profile over here, this is the direction of surface wave propagation, this is the direction of movement of the wave, but your particles moves in this rolling fashion up and down, as you can see over here. So, this creates like a wavy ground phenomena. So, if your structures are constructed on top of this ground they also will form a rolling motion like this. So, seismic rolling motion is that is why another important area of research for earthquake engineers, specially the structural engineers, they, those who are concerned not only about the translational accelerations, but also the rotational acceleration, this is the major reason; as you can see over here, rotational acceleration is also very significant or quiet damaging to the structures, which are mostly reflected by this type of surface wave, which is Rayleigh wave, Rayleigh type of surface wave.

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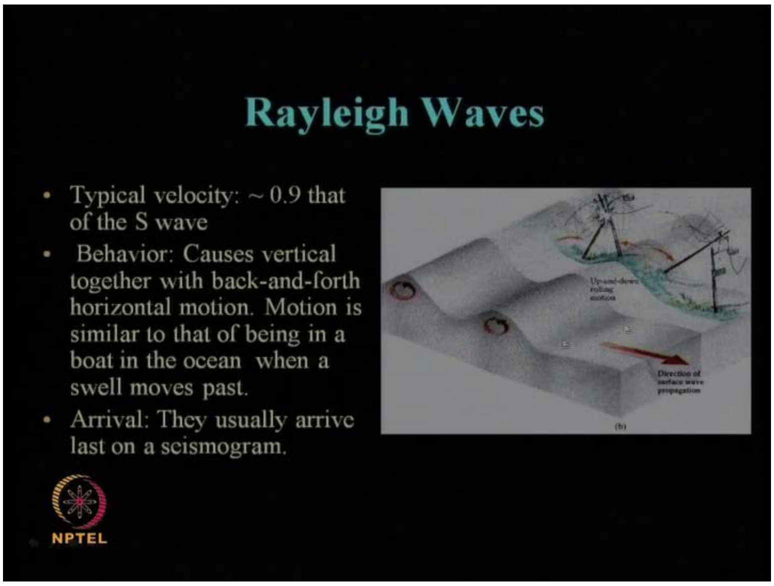

So, let us look at, about the characteristics of these various surface waves. First, we will talk here about Rayleigh waves. Just now we have seen in the picture, this is the behavior of the Rayleigh wave that is the rolling motion of the particles, up and down rolling motion; this is the direction of surface wave propagation. So, typical velocity of Rayleigh wave is considered to be about 90 percent of that shear wave or secondary wave. So, that is the typical relation of the Rayleigh wave, there can be exact relation be established, we will see that later if possible, that Rayleigh wave and surface wave, or a Rayleigh wave and shear wave, they are related by the Poisson's ratio of the material, that we will discuss in our chapter on wave motions and wave theory. So, from that relationship, one can easily say that a typical Rayleigh wave velocity will be about 0.9 times that of the shear wave or secondary wave.

And what is its behavior? We have seen just now, it causes particle together with back and forth horizontal motion, because of this rolling nature. So, motion is similar to that of being in a boat in the ocean when swell moves past. So, whenever there is a wavy motion in the ocean, if you travel that time in a boat, whatever will be the feeling at that situation, the same thing will be felt when an earthquake strikes and Rayleigh waves travels through your site, or where you are located, then you will feel almost the similar feeling, because of the travel of the Rayleigh wave. And their arrival is, they usually arrive last on the seismogram. So, their velocity is the lowest among all the four types of waves, that is P wave, S wave, love wave and Rayleigh wave, that is the reason, why they reach last in the seismogram, but if you look at the value of the velocity it is just 90 percent of the shear wave velocity or 0.9 times.

So, what we can say in the seismogram, what we are getting finally from the seismograph, there will be hardly any time lag between the occurrence or arrival of shear wave and this surface waves, that is love wave and Rayleigh wave, because you remember in between, there can be a love wave also.

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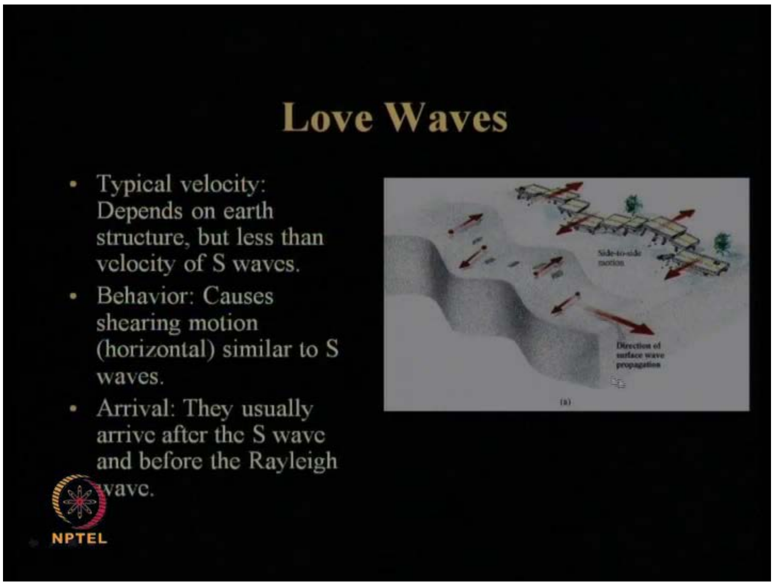

So, let us now look at the characteristics of love waves. We have seen, the movement or the behavior of the particles when the surface wave or love wave propagates through a media, its typical velocity, it depends on the earth’s structure, but it will be always less than the velocity of the S wave and more than that of Rayleigh wave. So, you can say, it is something in between the little less than the shear wave velocity, to little more than 0.9 times of share wave velocity, so that is the range. So, you can see, this velocity of shear wave, love wave and Rayleigh wave are pretty close to each other, and its behavior is causes shearing motion, that is horizontal, similar to the S wave, and their arrival is usually, they arrive in the seismograph after the shear wave, but before the Rayleigh wave.

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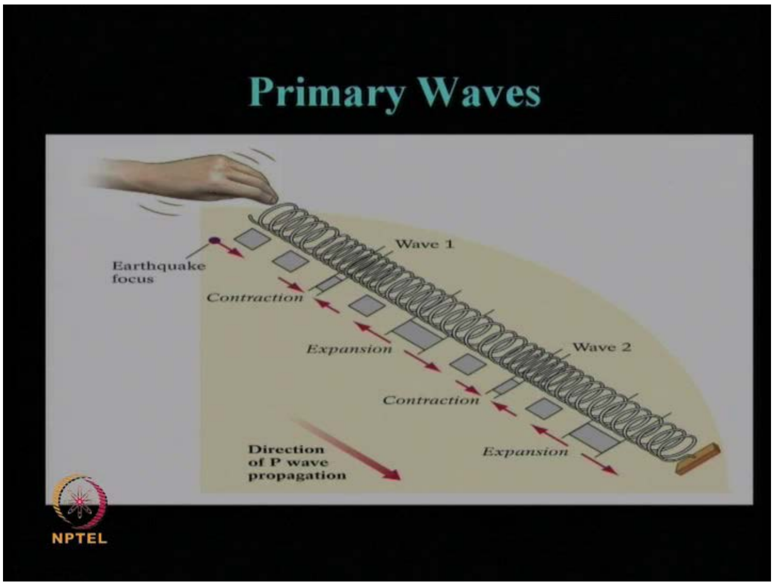

As we have already discussed about the body waves, the primary wave or compressional wave, we have mentioned already that it will pass through a successive contraction and expansion in the particles through which, or the media through which they travel through. So, this is the direction of P wave propagation, and you can see over here is this point is earthquake focus, subsequently we will have at some location contraction, some location expansion, again contraction, again expansion. So, that is the typical behavior of the media which it will subjected to when a P wave passes through that media, and this is the direction of the travel of the P wave, and particles also excite in the same direction or moves in same direction, in this fashion of successive contraction and expansion.

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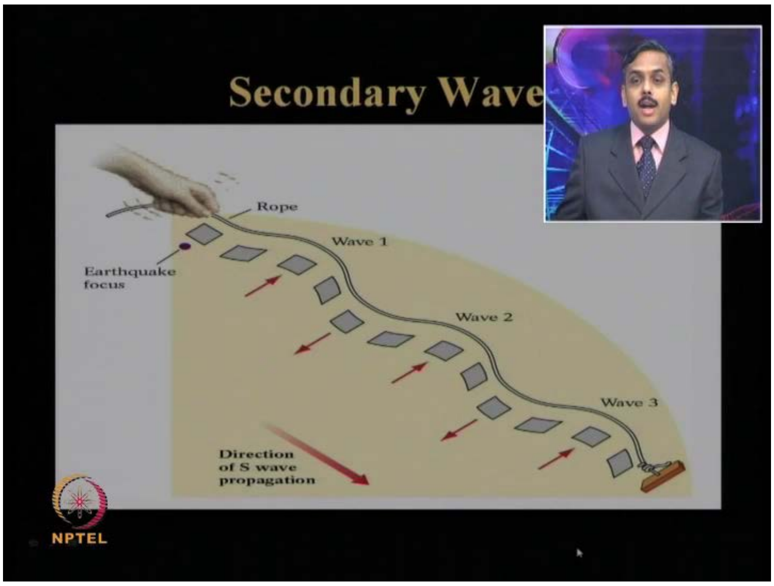

Whereas, for secondary wave, if this is the point of earthquake focus, and this is the direction of S wave propagation, it will be similar to behavior of like a, if you vibrate or shake a rope, the way the rope wave its getting propagated, the S wave also propagates in the same fashion. So, its direction of movement of S wave this direction, but the particles moves perpendicular to that. So, some particle goes in this direction, some particle comes in this direction. So, that way zigzag fashion, but perpendicular to the movement direction of the S wave, the particles move.

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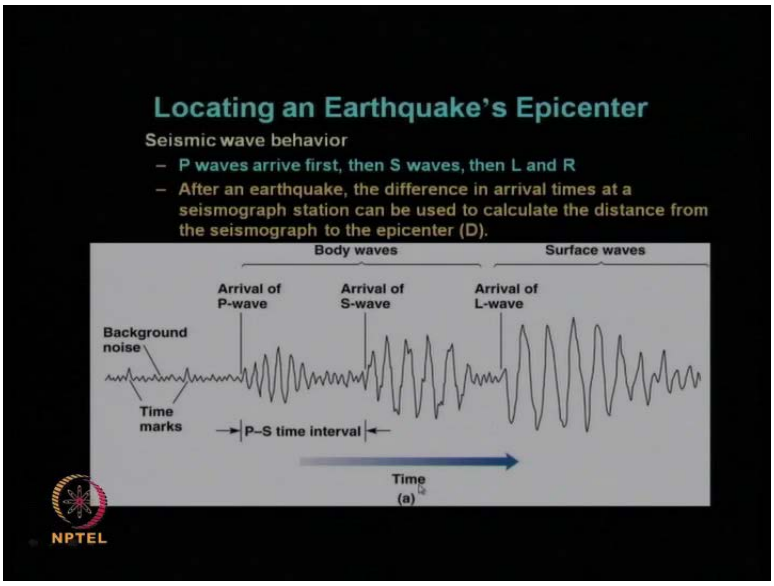

Now, our next important criteria is, how to locate the earthquakes epicenter? Because it is very important, as we have already learnt, that using the various numbers of seismographs, located all around the earth, we can locate the epicenter of an earthquake. So, how to locate that epicenter? Let us see here. So, seismic wave behavior, we have already seen, in the seismograph first P wave will arrive, because of their highest crustal velocity, next S wave will arrive, followed by the surface wave that is love way and Rayleigh wave, L and R. So, after an earthquake, the difference in arrival times, that is the first time when they arrive in your seismograph at a seismograph station, that can be used to calculate the distance from the seismograph station to the earthquake epicenter. So, that distance let us say it is D.

So, how to calculate the D from various seismograph stations located all around the world, we have to find out this various values of D, and through that we can find out the earthquake epicenter. So, this is the typical picture of a seismogram, we have already seen; initially there will be some small jerks like this, which is nothing but background noise.

Now, when there is a subsequent amount of displacement in your observation you record in your seismogram, that shows that some earthquake has occurred, and P wave has arrived. So, if some wave has arrived, it definitely shows in a seismograph station, that it has to be P wave right. We have already seen, it is not that only S wave can come first, there is no such shadow zone where P wave is not present, but S wave is present, right.

So, P wave must come if something is coming, otherwise nothing will come; if it is in the shadow zone of both P and S wave, nothing will come, but if they are not in a shadow zone, at least P wave will come; and after the P wave dies down, there will be again another large amount of pics will arrive in your seismogram, that will demark it that S wave has come; if no other movement comes in your seismogram that means it is in the shadow zone of S wave, and if it is shadow zone of S wave, definitely it automatically says no surface wave also will come, because we have seen both love wave and Rayleigh wave that is surface waves are nothing but derivatives of S wave, typically.

So, that is why if S wave is not coming, L and R wave also will not come. So, only in that case we can say it is in the shadow zone of S wave, so it recorded only P wave. But if this spikes comes, that means they are not in the shadow zone of either P or S wave.

Then we can have this, from the paper, which we get as an output from that seismograph recording station. From this seismogram we get, this time which is the starting or arrival time of the P wave, we also can obtain this staring time of S wave.

So, this time minus this time, gives us the difference of time between the arrival of S and P wave; and automatically later on you will find, arrival of love wave and arrival of Rayleigh wave. Truly speaking, this arrival time of S wave, love wave and Rayleigh wave, it is very difficult most of the time to separate out, or to observe distinctly, why? Because as I have mentioned, their velocities are very close to the S wave velocity, so it will keep on jerking over here. So, it will be difficult in many cases, unless it travels a much longer distance, so that at least we can identify this difference of time, between arrival of love wave and S wave.

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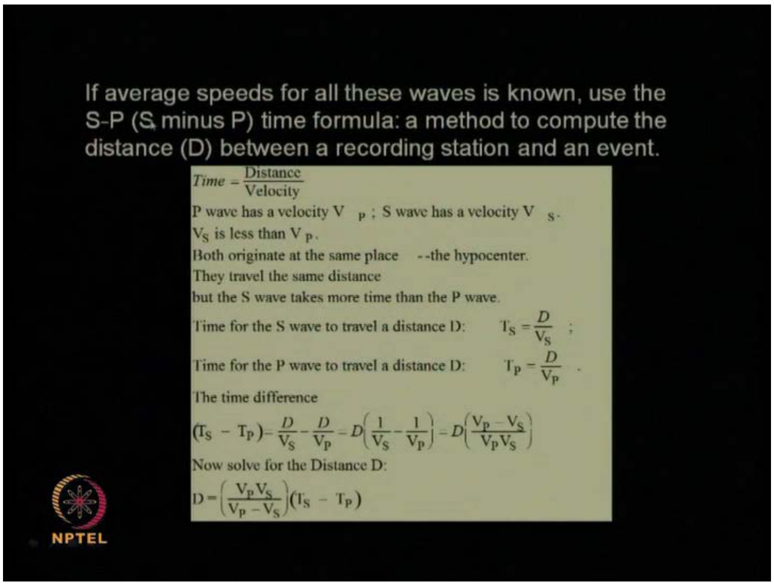

Next, how to calculate the distance from the seismograph station to an possible epicenter. So, if the average speed for all these waves are known, then use this formula of S minus P, that is arrival time of shear wave minus arrival time of P wave, that time formula method. This is the method to compute the distance between a recording station to that event where the earthquake has occurred.

So, the time is nothing but distance by velocity, as we all know. So, P wave is having a velocity say V P, in the crustal region; S wave is having a velocity V S, in the crustal region; and obviously this V S is less than V P, as we already know; and both originate at the same place that is the hypocenter, and they travel the same distance d, but the S wave will take more time than P wave, because of their lower velocity than V P. So, the time required for the S wave to travel a distance D can be calculated as T S, which is nothing but the distance by the velocity of shear wave V S.

And, the time for P wave to travel at a distance D, is nothing but T P, is D by that velocity of primary wave or P wave V P, right. So, what is the time difference, which we have observed in the seismograph station, that is T S minus T P, T S will be larger time, because it take it comes later. So, T S minus T P is nothing but if we put these two expressions D by V S minus D by V P, so D V if we take common 1 by V S minus 1 by V P, so now if we solve for this D, which needs to be obtained. So, that distance D can be calculated as after solving V P V S by V P minus V S into the T S minus T P.

Now, in this case, what are the things known to us? On the right hand side, every parameter is known to us, because T S is known from our seismograph record, T P is known from that seismograph record, V P and V S in the crustal level are known, so we can compute the value of D. So, this is the way you can find out the typical epicentral distance from a particular seismograph station.

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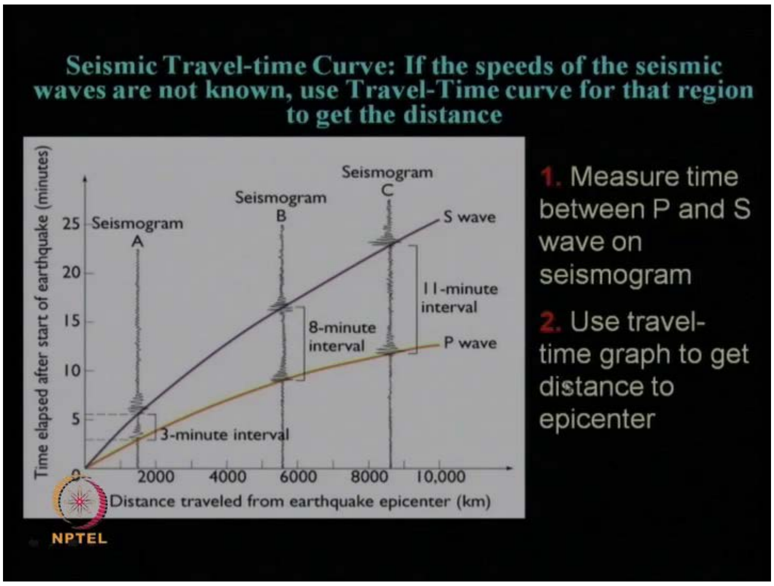

Now, another method is there, which is called seismic travel time curve method. If the speeds of the seismic waves are not known, see in the earlier case we have assumed that seismic wave velocity of shear and primary wave are known to us, but if it is not known.

So, where this method will be applicable? If I ask you, what we have mentioned, that V P is about 6 kilometer per second for crustal velocity, V S is crustal velocity is 3 kilometer per second, that means if we have a shallow earthquake, which occurs within few kilometers from the ground surface, that is within the crustal plate or crustal region of the ground or earth's interior, then we can use this formula of, or then we can use the values of V P and V S as 6 and 3 kilometer per second, the typical values of crustal velocity.

But, if the earthquake is a deep earthquake, as per its depth, the hypocenter, or even intermediate one, then it has to travel not only through the crust, but also through the mantle, and we have seen, there is a certain change or jerk and the velocity in mantle changes, so we do not know how far it has traveled in the thickness of mantle and crust. So, in that case, where we do not know about the velocity of this V P and V S, in that case the seismic travel time curve method, which I am showing here, will be applicable.

So, use this travel time curve for that region to get a particular distance, so this is the graphical method, as the name suggest. As you can see over here, this is the distance travelled from earthquake epicenter, and time elapsed after the start of the earthquake in the unit of minutes. Now let us say, all over the world there are various seismogram data which we have collected for a particular earthquake, now look at their values of arrival time between P wave and S wave.

You will find, that some station the arrival time differences say for example, as it is shown over here say 3 minute, in some station say it is 8 minute, some station it is 11 minute, what does it mean? It means, the 3 minute seismogram is located nearest to the epicenter, 8 minute interval where we got that is located intermediately, and the 11 minute interval where we got, that is located farthest from the earthquake hypocenter or epicenter. So, try to put those seismogram data in this graph by proper orientation and distance, so that they will form a band like this, that gives you a proper estimation of the distance. So, it is a shifting or trial and error procedure by which shifting this different lines on this curve, you can get the typical distance.

So, what it says? You have to measure the time between P and S wave on the seismogram, various seismograms, recorded all over the world, and use this travel time graph method to get the distance of the epicenter like this, fine. So, this is another way how to find out the typical distance, and once you put it, you will get definitely from the curve, what are the typical distance of the epicentral point, from that seismogram station.

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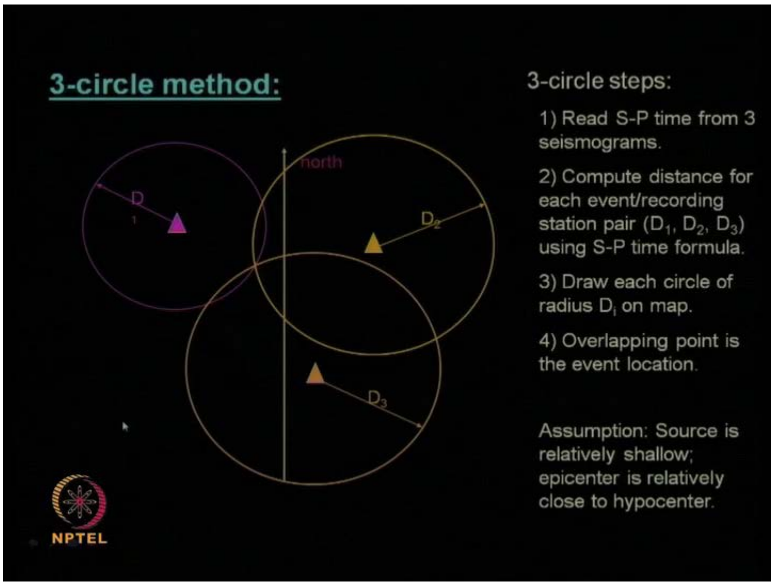

Let us come to another method, this is the most popular method to find out the earthquake epicenter, which is called three circle method. What is three circle method? The three circle method, the steps are like this, first you have to read the S wave arrival and P wave arrival time, at minimum 3 seismograms, which are located say far apart from each other; that means, all over the world, you have to select minimum 3 seismograph stations, where reliable data has been recorded for both P wave as well as for S wave, and get the time difference of arrival of that P and S wave from those 3 minimum seismogram stations.

Now, once you get that data, compute the distance for each of the event or recording station pair, using the S minus P time formula, what we have seen two slides back, that is using the typical crustal velocity if it is a shallow earthquake, and most of our earthquake, as we have mentioned, is shallow earthquake.

So, use that S minus P time formula to get the distance D 1, D 2, D 3; what are this D 1, D 2, D 3 corresponds to? D 1 corresponds to the distance calculated from the seismograph station number 1, D 2 is the distance calculated using the data from seismograph station number 2, and D 3 is the distance calculated the seismograph station number 3. Now once you get this distance, what you can do? Draw each circle of the radius of this D I, on the map. You take a map, now on this map, the location of your seismogram stations are known; that means, the latitudes and longitudes are known to you, you know where you have located your seismogram stations, so plot those latitude longitude, put a north direction in the map, whatever wave we plot.

So, plot it in, in that fashion and then draw a circle of that individual D I from corresponding seismogram station, that means from seismogram station 1, you have to draw a circle with the radius of D 1, why? because this seismogram station whatever earthquake excitations it has recorded in its seismograph, it shows that epicenter is at a distance of D 1 from this point, now in which direction we do not know, that is the reason why we have drawn a circle; but we know the distance, but in which direction whether it is in the west, in the east, in the north, in the south, we do not know. So, that is the reason, you have draw a circle at a distance of D 1. So, on any point that earthquake epicenter is possible, as for as this distance D 1 is concerned.

Similarly, for the station 2, you have already calculated that epicenter is located at a distance of D 2. So, draw a circle of radius D 2 from that seismograph station point number 2. So, the epicenter is located at a distance D 2, but again we do not know in which direction. So, that is the reason we have drawn the circle. Similarly, for seismograph station number 3, the distance we have calculated D 3, but we do not know where it is occurring. So, we have drawn a circle with a radius of that distance D 3. Now wherever this 3 circle meets at a point, that is nothing but the earthquake's epicenter, right am I right. So, you will find it out, means if the measuring centers are closely spaced and very well recorded data you can obtain, and if it is a very shallow earthquake. this three circle method will give you a single point like this.

But, if the seismograph stations are located little far apart, and also say, earthquake is, may not be a shallow earthquake, it may be intermediate earthquake, or if there is a problem in recording seismic station data, you may not converge to a single point, you may have converge to a small area. So, then what you need to do. So, your epicenter it will say, it is falling in that small area, probably you can use another one or two seismograph data, putting another two three circles, where they will meet, that can you give the exact epicenter location. So, it is quite obvious, if you use more number of circles, you will better converge to a more accurate position of the earthquake's epicenter.

Now, one question. So, limitation you have understood about this method, like it has to be a shallow earthquake; if it is an intermediate or deep earthquake, the three circle method has to be used very cautiously, because that calculation of this D using V S or V P of 3 kilometer per second and 6 kilometer per second may not be valid in that case, and also, if it is not converging to a particular point, we can use number of, more number of circles. So, minimum is 3, but more number of circle will, may give us a better result.

And, why it is called earthquake epicenter? Look at here, we have plotted everything, as if it is representing the earth's surface on a two dimensional graph paper or sheet, page of paper. So, on that ground surface you are locating this point so that is why we are mentioning it is earth's epicenter, so it is the epicentral location, not the hypo central one.

So, with this, now we can have one example problem, about how to find out the earthquake's epicenter using this simple 3 circle method, which is used worldwide very commonly. So, let us look at the problem statement over here.

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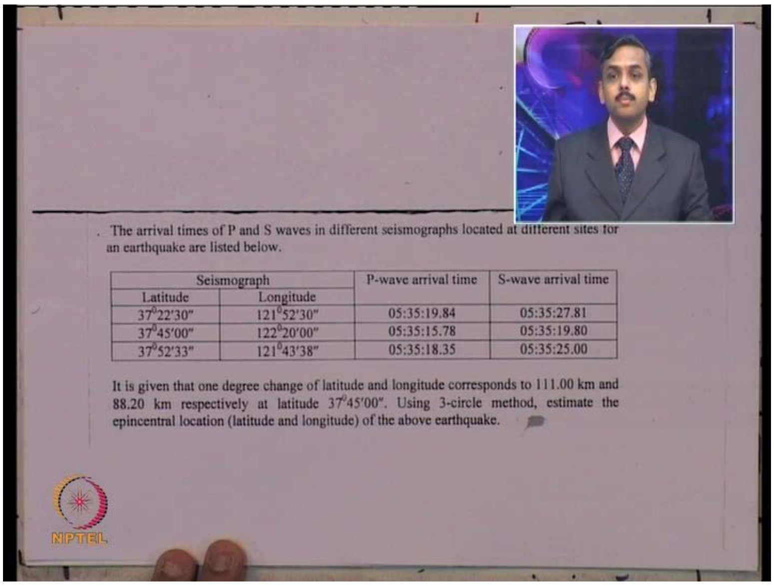

The arrival times of P and S waves in different seismographs located at different sites for an earthquake are listed below.

Seismograph		P-wave arrival time	S-wave arrival time
Latitude	Longitude		
$37^0 22'30''$	$121^0 52'30''$	05:35:19.84	05:35:27.81
$37^0 45'00''$	$122^0 20'00''$	05:35:15.78	05:35:19.80
$37^0 52'33''$	$121^0 43'38''$	05:35:18.35	05:35:25.00

It is given that one degree change of latitude and longitude corresponds to 111.00 km and 88.20 km respectively at latitude $37^0 45'00''$. Using 3-circle method, estimate the epincentral location (latitude and longitude) of the above earthquake.

So, the problem says, the arrival times of P and S waves in different seismographs located at different sites for an earthquake are given below, like these are the seismograph stations, 3 stations have been given with their latitude and longitude. This column is showing P wave arrival time, in individual seismograph stations; and this column gives us the S wave arrival time in these three seismograph stations. So, what it is asked? That it is given that, 1 degree of change of latitude and 1 degree change of longitude, corresponds to 111 kilometer and 88.20 kilometer respectively, at the latitude location of 37 degree 45 minute 00 second; that means, at the latitude location where seismograph number 2 is located.

Why this information is necessary? Because we need to plot the distances on a graph sheet or on a sheet of paper, so we have to find out the distance. And as you know, as the latitudes are changing, the distance between two longitudes are different, like the distance between adjacent longitudes at the central location of earth or close to the pole will be different. So, that is the reason why this information is requires to be provided, and it is known one can easily calculate from simple geography, and that data has to be given corresponding to a particular latitude, that is at which latitude location that 1 degree change corresponds to how much kilometer, is it right.

So, using the 3 circle method, estimate the epicentral location; that means the latitude and longitude of the epicenters, like we have talked about the various earthquake data, their magnitude, occurrence time, and the latitude and longitude, in one of our previous lecture, at the initial lecture. So, this information we get about the epicentral latitude and longitude, using this method.

So, for the above earthquake, we have to find out using this information, where that earthquake epicenter is located, which has been recorded by this three seismograph station, station number 1, 2 and 3, from the given P wave and S wave arrival time. So, what will be our initial first basic assumption? Let us assume, it is a shallow earthquake so that the crustal velocity of P and S wave can be considered for the calculation of the distance from the seismograph. So, let us do the calculation now, how to solve this problem.

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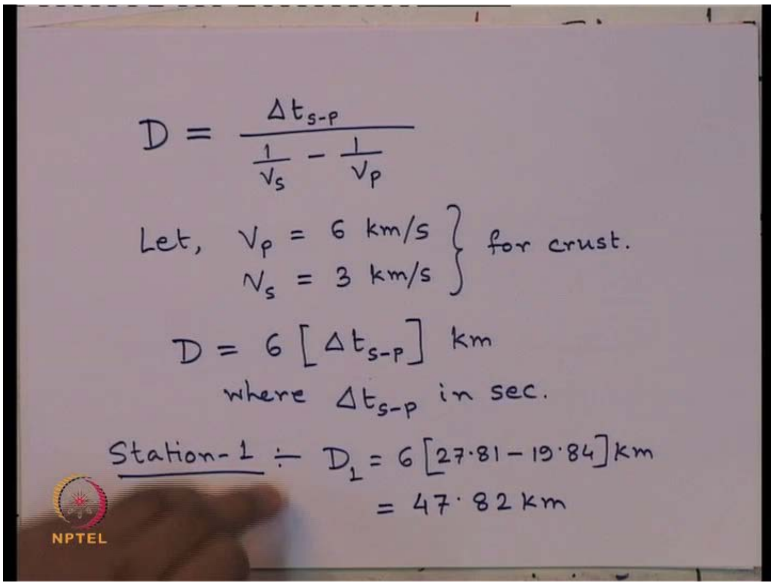

So, the distance D, as we have seen just now, is calculated like delta t, time difference between S and P by 1 by V S minus 1 by V P. So, this is the formula we have already seen. Now, as I have mentioned about the assumption, let the value of V P is 6 kilometer per second, and value of V S is 3 kilometer per second. So, that is at crust, so for crustal level. Now, this, if you simplify this after putting this values over here, what it comes, D comes out to be 6 times this value of delta t S minus P, so much of kilometer, where this delta t S minus P as in the unit of second, then this is valid, because we have taken this as second.

So, we have to estimate this delta t S minus P for the 3 stations. So, for seismograph station number 1, what is the value of this delta t S minus P, let us calculate the D, say D 1, D 1 will be 6 times this time difference, let us look at over here, the time difference will be, this arrival time is 5 hour 35 minute 27.81 second, this is 5 hour 35 minute 19.84 second. So, in the second unit the difference is 27.81 minus 19.84, so 27.81 minus 19.84 so much of kilometer, which works out to be 47.82 kilometer.

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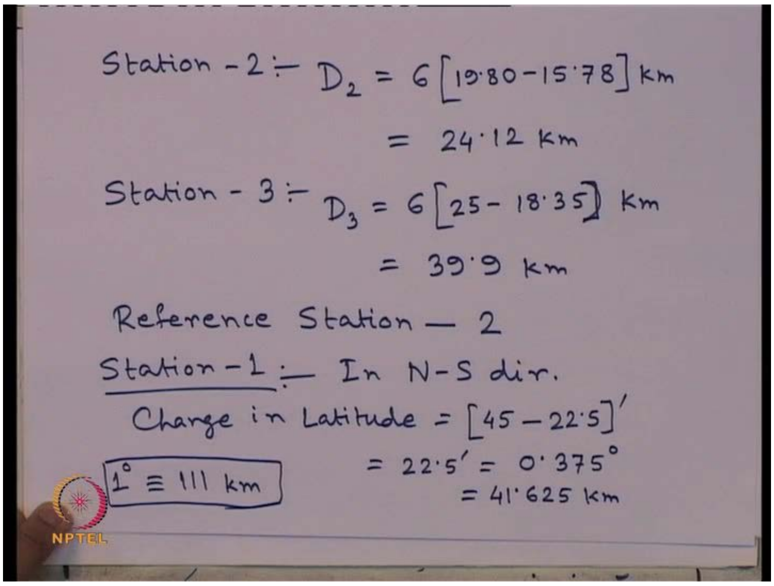

Similarly, for next station two, the value of D 2 can be 6 times, let us now look for station 2, it arrives 5 hour 35 minute 19.80 second and 5 hour 35 minute 15.78 seconds. So, there is a change in second only. So, we can put that 19.80 minus 15.78 so much of kilometer, which comes out to be 24.12 kilometer. If we talk about next station, station number 3, the value of D 3 comes out to be 6 times, let us see the difference of time, it is 25 seconds, same hour and minute, same hour and minute, second only changes, 18.35 seconds. So, it will be 25 minus 18.35 kilometer, which gives us 39.9 kilometer.

So, now, if we take our reference station, so reference station will be station number 2, because for station number two the latitude is given corresponding to, that the change of latitude corresponds to how much kilometer and longitude how much kilometer is given. So, that is why we have to identify which is your reference station. So, the station number 1, how it is located? We have to find out. So, in north south direction, we have to find out the change in latitude; change in latitude is, if we look at the value, change of latitude between this station 2 to station 1, there is same degree, minute is changing 45 minute 0 0 seconds this is 22 minutes 30 seconds. So, this is the difference between the latitudes, between 2 stations. So, it is 45 minus 22.5 so much of minute, because 22 minute 30 seconds means nothing but 22.5 minute right. So, it gives us 22.5 minute, which corresponds to, if we convert it to degree 0.375 degree.

Now, it is given to us that 1 degree corresponds to, how much kilometer of variation in the latitude? 1 degree corresponds to 111 kilometer. So, 1 degree means 111 kilometer. So, we can say, this is equal to or equivalent to 41.625 kilometer, this 0.375 degree corresponds to this kilometer, because this data is given to us.

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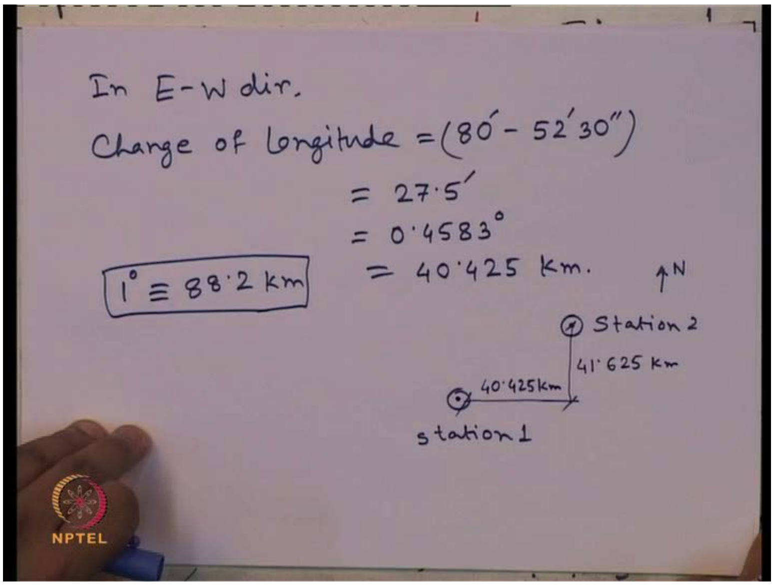

Next, we have to see the longitude change. So, now, in East West direction that is in the longitudinal change direction, we have to find out what is the change. So, change of longitude is, let us see how much is the change in the longitude, there is a change in the degree also, it is 122 degree 20 minute 0 0 second, it is 120 degree 52 minute 30 seconds. So, 80 minute minus 52 minute 30 seconds that is the change of longitude.

What I have done? Why I have written 80 minutes? Just I have taken this degree equal, I have converted this 20 minutes to 80 minutes, I have added 60 over here, clear. So, it gives me the difference 27.5 minute which is equals to 0.4583 degree. Now, what is given? 1 degree is equivalent to, how much kilometer change in the case of longitude? It is 88.20 kilometer, so 1 degree equivalent to 88.2 kilometer. So, with that given information, we can write this 0.4583 degree corresponds to 40.425 kilometer.

So, if our station one is station 2 is located here, if it is station 2, station 1 will be somewhere here, why it is so? Because if we talk about this as the north direction from the values of the latitude and longitude, we can see the seismograph station number 1 is on the higher latitude, that is to the towards the north of the seismograph station 1, and we can see its longitude is on the eastern side of the seismogram station 1. So, one should be at the west of seismograph station 2. So, you have to see this very carefully and then you can put the distance.

So, this distance is now known, and this distance is known, this already we have computed, this already we have. So, longitude distance corresponds to this 40.425 kilometer, and this one corresponds to 41.625 kilometer. Similarly, we can do the same calculation for seismograph station number 3.

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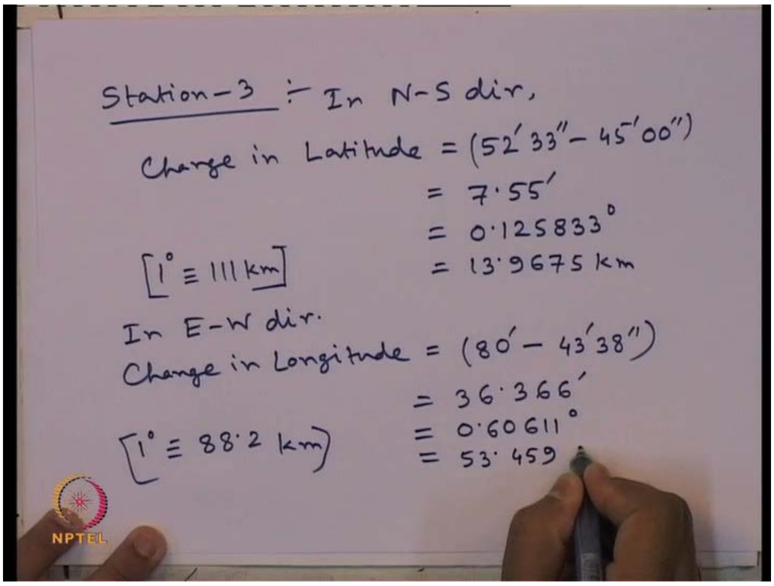

So, for station number 3, in North South direction, change in latitude is 52 minute 33 seconds minus 45 minute 00 second, which comes out to be 7.55 minute, which is 0.125833 degree. Now, 1 degree corresponds to 111 kilometer, so knowing that we can say this is equals to 13.9675 kilometer. And in East West direction change in longitude with respect to station number 2, is again I am converting it to 80 minus 43 minute 38 seconds, if you convert minute to seconds it comes to 36.366 minute, which corresponds to 0.60611 degree. Now, 1 degree equivalent to 88.2 kilometer, so that gives us this corresponds to 53.459 kilometer.

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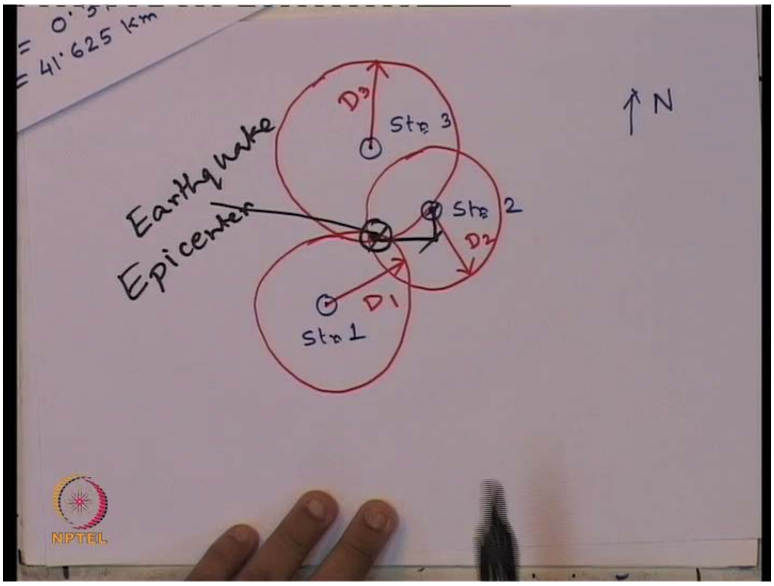

That means, if we look at the value of the station 3, so station 2 is here, station 2, station 1 is here, we have already identified, with respect to that station 3 will be somewhere here. So, this is the location of station 3, why? Because if we look at the value, compared to station 2 and 3, 3 is located still further north to the station 2, as per as latitude is concerned and longitude is station 3 is on the west side of the station 2. So, it is in the northwest direction of station 2 that is why north west. So, this is our north direction.

Now, all the distances D 1, D 2, D 3, we have calculated. So, what we can do? Using station 1, D 1 we have to draw a circle with D 1. So, let us say, it comes out to be like this with D 1, we have to draw it on a graph sheet using a compass so that it comes nicely. For station 2, say D 2 is something like this, this is D 2; and for station 3, let us say the value goes like this, this is D 3. So, wherever these 3 circles meet, that common point that point will be our epicenter, this is our earthquake epicenter.

Now, how to locate its latitude and longitude? Now station 2 is our reference point, corresponding to that you find out what is the distance, this direction and this direction that corresponds to how much degree and minute, will give you the latitude and longitude position of earthquake epicenter. So, that is the answer of this problem, how one can find it out. So, with this we have come to the end of this lecture, we will continue further in the next class.