Introduction to Engineering Seismology
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Lecture - 10
Seismic Wave Propagation

So vanakkam. So we will continue our engineering seismology course lectures. So last class we have discussed about the theory of wave propagation, so where we understood that the P wave basically controlled by the compression modulus and density. So if you assume a uniform rod with homogeneous material, so if you tap it then you can see that how the waves are propagating.

So you can also referred the theoretical basis of that. But you should also remember that all this equation, theoretical equation derivation with the assumption that its rod is uniformity material. And then it is homogeneous and infinite and all, which is practically not possible. So even in the earth surface even though it is very big diameter in nature, but the materials are not uniform.

So whenever there is a change in the material basically the property changes. It also affects the wave propagation. So we also seen that there are four type of wave propagation take place, so like reflection, refraction and then diffraction and then the attenuation and amplification we have seen. So these are all the character okay, wave character, so which you need to be understand, okay.

So this basically is very much important to further to estimate a earthquake size, understand the effect of earthquake or you want to design any structure against these waves this is very important. So the understanding of seismic wave propagation plays a major role in our entire subject. So but understanding means not that just you derive that equation or mug up that equation.

So I do not really believe on those kind of mugging up equation is necessary for the understanding that, okay. You have to understand how the each waves when it moves what happens to the medium, what happens to the particle motion. So as we have seen

that when the P wave moves basically the particles vibrate back and forth, okay. So similarly, when the S wave moves the particle vibrates vertically up and down.

So it is a perpendicular to the wave propagation. Similarly, when the surface wave moves basically it vibrates. So horizontally but the vibrations is larger at surface and when deeper it goes it reduces. So similarly, the Love wave when it moves. So it basically waves like a snake, the particles are moving, so perpendicular to the direction of the wave like a snake.

So all these waves basically say create a similar kind of motions in the material where it propagates. So when the waves are having the low amplitude, you may not notice this how the waves are propagating. When the waves are having the higher amplitude sometime you can even see this waves how it travels in the medium. For example soil itself will may undulate okay.

So it depends upon the material what you are using. You can see that the shape of the wave can be seen in the this kind of wave propagation. So there are several animation videos are available in online where you can see those videos and try to understand how these waves are really propagate.

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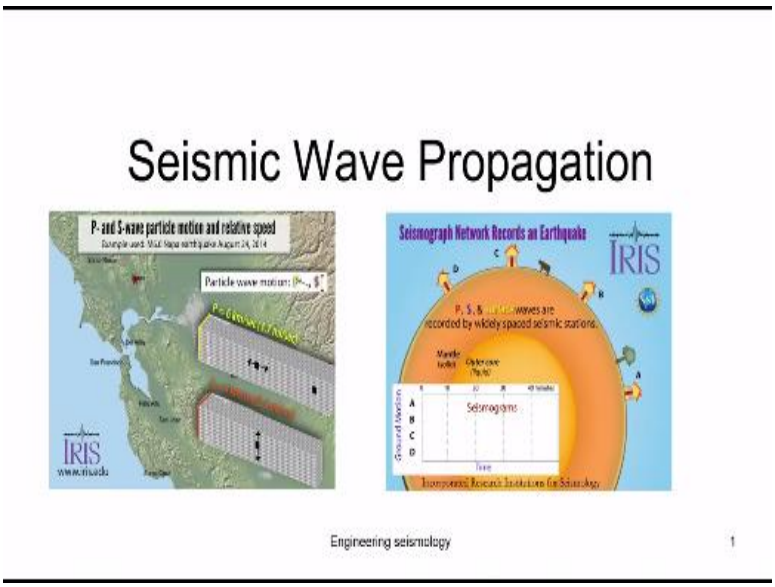

So I will show you some of the videos which is from IRIS website where you can see lots of other videos but I will only concentrate on the video where they S wave and P

wave travels and how the structure at different places respond, okay which is very important.

As I told you that the precipitation of the earthquake okay the origin of the earthquake and then the wave propagation need to be understand if you want to retrofit or prepared yourself to reduce a risk due to the earthquake. So in that angle we are going to see how this videos are animations are explaining us the wave propagation.

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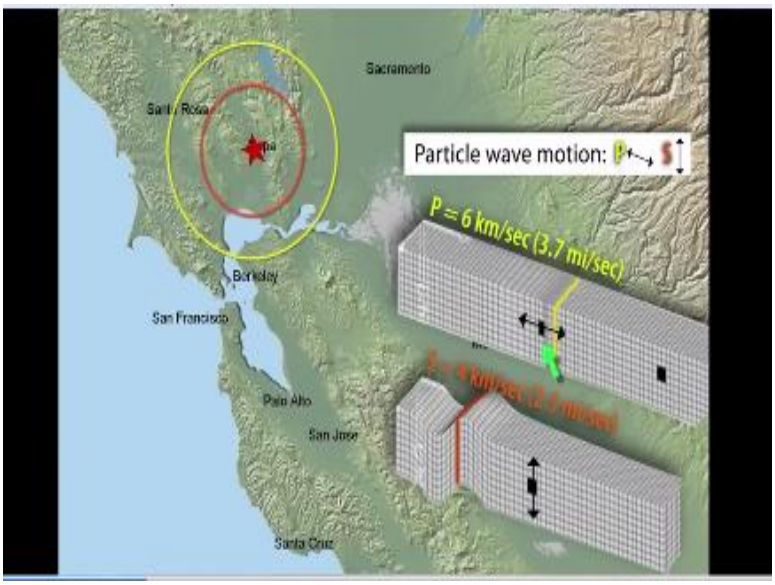

So if you look at this particular video, so you can see that basically okay so this is basically your earthquake. So when the earthquakes are occurring you can see immediately the yellow source. This is how the yellow wave is the P wave. You can see how this basically moves, okay. So the back one was the basically a the S wave, so where it as we have studied that the P wave has a higher velocity and the S wave has a lower velocity.

That is why it travels back from that. The similar way the particles in that area okay so try to respond. So when the P wave comes, so if you again see this animation carefully. So you can see that yellow wave starts okay. So the earthquake starts now. They yellow wave P wave basically starts. You can see this basically you can see the how the particle going to respond. See, see now very carefully you can see the video.

You see that the particle undergoes compression tension which we have seen in the wave amplitude. So the same time the followed by the next wave S wave is following.

So with velocity of basically 4 kilometer per second which we have seen in the wave character and P wave travels on the 6 kilometer per second. That is why the P waves are arrives in the faster manner when compared to S wave.

So you can see that the same particle in the S wave how it respond in the, the down portion of the red one. You can see here, see. So this velocities are slow. So it is coming less. You can see that how the particles are moving. So this is very important to interpret any seismic record, okay. To know that which wave we have received, what time we are received.

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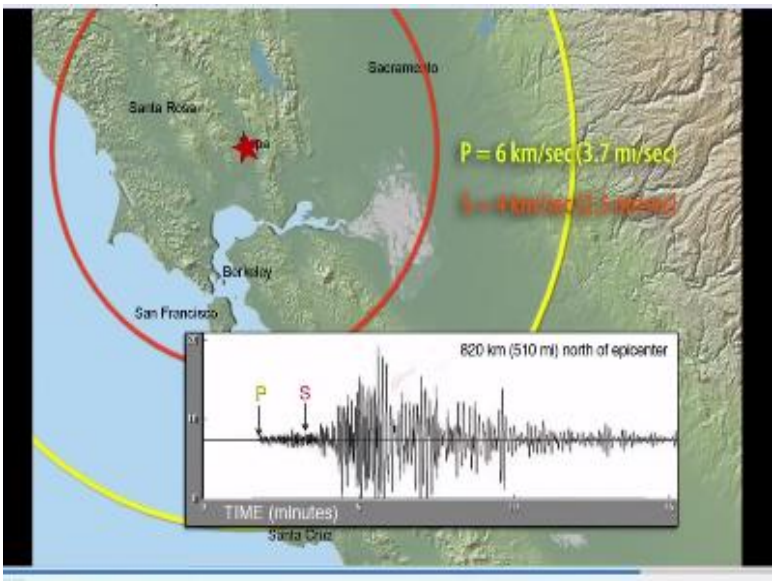

So based on this data only for example a typical earthquake record will look like this. So where you can see we have seen that the P waves arrives first. You can see the P wave then followed by the S wave arrive.

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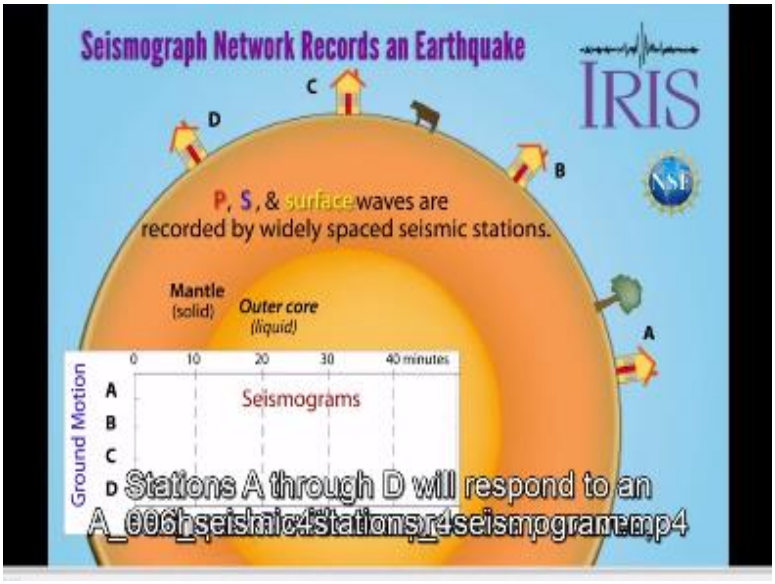

So these details will give you like from your point of measurement, how far the waves are originated okay which give you the. So you can also understand that this wave propagation basically decides the how your building is responding to that.

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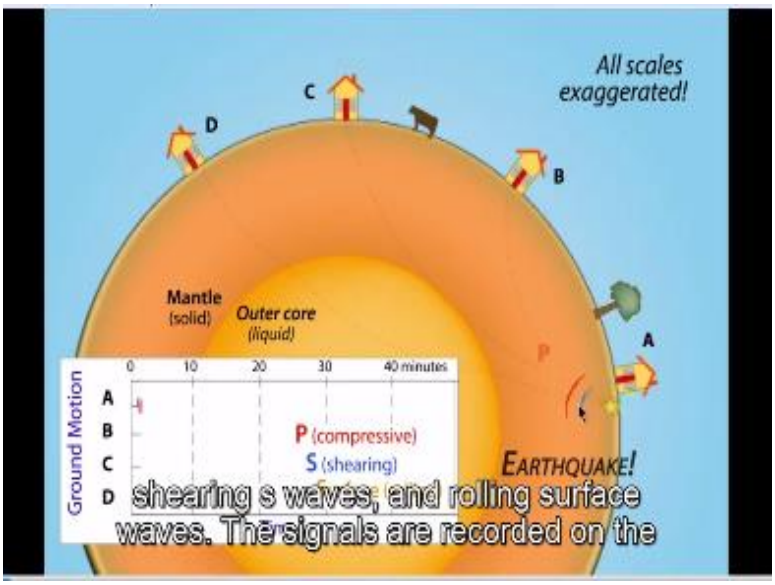

You can see carefully the four buildings in this video. So you can look at okay so the type of wave basically the first one which starts is the yellow wave so which is basically a P wave. Then followed by the, the red one is a S wave. Then the again yellow one is the surface wave. So you can see here very carefully, I will again once again, play very slowly.

See the look at the four building A, B, C, D. So it is located on the four spot. Basically these buildings are to show the animation of how it respond to the way, okay. That is

why the animation to the building is exaggerated. So basically when size of the earth the building vibrations are shown here very large to you to easily understand okay.

So if you clearly see the wave and earthquake, okay so now I now the earthquake started. You can see that when earthquake started there are two type of waves generated. So the first one basically your P wave, okay. This is the P wave. So this is the S wave. You can see that this is the place where it started. So where immediately if you notice very closer the building will undergo immediately that vibration the building A.

See that how it vibrates. So it indicates that you can also see how the buildings are located with respect to the earthquake location. For example, so your building, so this is the earthquake. This is the building which is very closer. The next three little away from the A building. Then the building B and then building C building D and then in between we also kept some animal for the easy understanding.

You can see the building which is very closer, the level of vibration which caused will be very large when compared to the building away. You can very carefully watch. So the first **S**P wave. Then S wave arrives. You can see the how it arrive. See how the buildings are responding.

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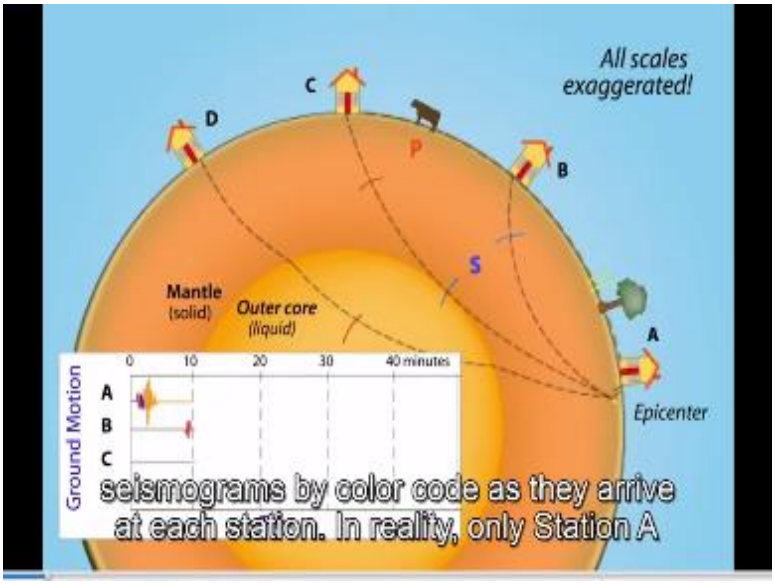

You can also see here when the P waves are hitting the building, I will again do this. So you can carefully watch the P wave basically now, so crossed two building but I

am just focusing on the building C and D to see how the P wave vibrates building. We can see here. See now the P wave going to hit C. You see that the building basically lifting the, building was lifted vertically and then come down.

That is why the compression wave does. Basically it pushes and pulls the particle okay. It pushes and pulls. So that is why the building because it is a buildings on the earth's surface the waves are coming. Since the waves are coming from very deep level so when it comes to the building base, basically this is the building. So this is the building. It comes and hitting like that.

So the building basically has to vibrate like this during the P wave, okay. The same when you do the S wave, okay. So you can carefully watch for the S wave. So this is the S is the S wave. So if you want even you can little bit go back so that the S wave you can watch from the building A, B, C, D what happens? So I start the animation. So quake started. The S wave hit this, you can see here.

Then the S wave goes here. So you see the S wave movement. See the S wave how it vibrates. Basically the building vibrates on S wave like this, okay. So when the similar way the surface wave. See the building C carefully. Building C like this when the surface wave comes. So that is what the understanding of the wave propagation, how the building going to respond or particle responded plays a major role, okay.

This not only tell you that the building how respond, you can also get a information that when the earthquake started.

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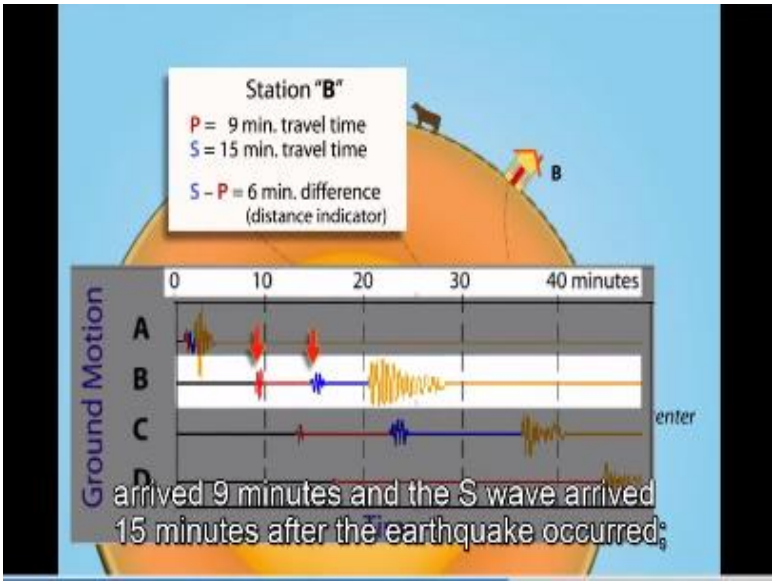

You know, what is the time of earthquake starting. Then at particular place, what type of wave it reaches first, okay.

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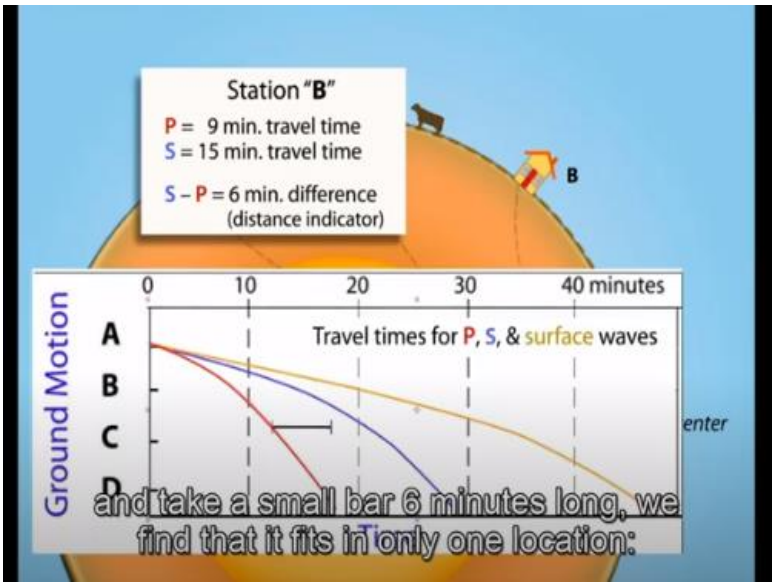

So if you watch very carefully this video okay. So once again you can see that some of the location okay where you can only see the S wave. Some of the location you can only see the surface wave. So not all the location will vary. Similarly, the time period between the P and S wave and surface wave are different which also is the one of the observation you can make.

So this makes us to understand how this wave propagation basically helps to identify the pose which is going to come in the structure or anything. So today class okay so with the continuation of the yesterday day class, today we are going to talk about

basically the application of wave propagation to interpret a earth interiors or to understand how the waves are propagating at different level.

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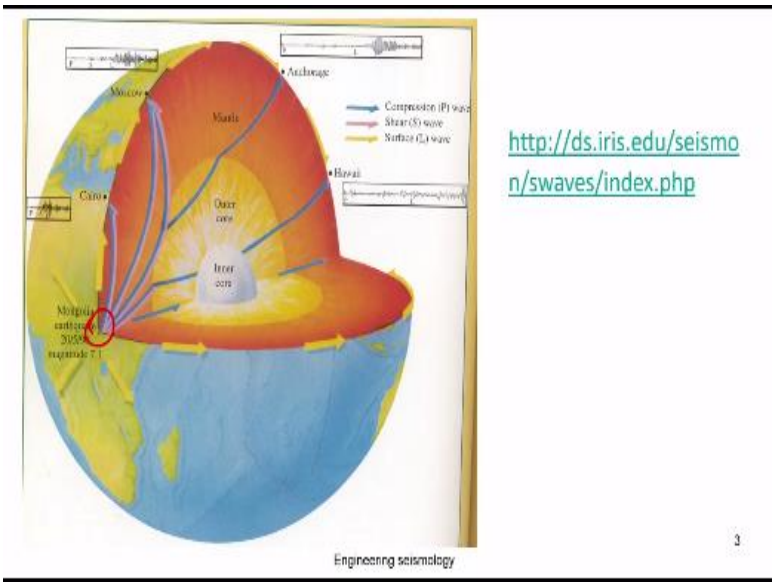

So if you look at the very carefully the typical earth cross section okay so where the earth is originating here. So you can see that the earthquake is originated here. Then you fix your seisometer at a different place. So place A, B and C, D, E and this is the interior to show you how clearly different type of waves you can expect. So when the earthquakes are occurring you can see that this place basically you get P and S wave, okay.

So similarly, when you go here basically you can get P, S, L wave. So when you go this place, so you do not you will get only slightly the P wave. There is no S wave record, okay. So why because the wave which crosses here has to cross this outer core. Since the outer core is liquid as we discussed yesterday that so the S wave does not travel on the liquid. So because of that, okay so the S waves are got diverted.

You do not find S wave at this component of the record. Then followed by you will have the surface wave which travels on the surface. Similarly, this place again you will find a P wave, okay then you do not find S wave, but you find L wave. So depends upon the place where you are located, where the earthquake is origin, you could able to see a particular type of wave is dominating.

So this is very important information. So not only for the to understand the seismic record what we have see to even to design your building in particular location. For example, there is a big earthquake going to occur at Himalaya boundary, okay, which is known for the very high seismic potential because it is a seismic boundary of the Indian plate. If that big earthquake occurs okay so how we are going to get a different type of wave at different places.

So the plate boundary earthquake occurs how a Tripura going to get what type of component of wave, how much amplitude? So how the Haryana okay so what type of wave and what amplitude you are going to get. So similarly Haryana, below that Delhi, then Madhya Pradesh, then Bangalore. So I can say that so we are sitting in the Bangalore, okay.

So we may get the P wave but since its distance is very far the P wave also the amplitude may reduce. Second we may get a S wave, surface wave. So S wave we may not get because it is very far. By refraction we may not get. We have to see the angle of the zone where the S wave basically divert which we will be discussing in the next slide. So then the surface wave.

But because of the distance if the surface wave amplitude reduced, we may not feel. If it is increased we may feel. So there are occasion where people reported that the Bhuj earthquake has been created vibration at Karnataka State at a particular location. So even some people even reported that during Sumatra earthquake there was a vibration felt in the Bangalore.

So I come across some interesting case where somebody was referred one of my, one of our senior professor who was who is consultant for the insurance company. So after soon after 2004 Sumatra earthquake so he claimed that his house got crack, okay due to earthquake, so he want compensation for the insurance for that. So then that was referred because even though he is advisor for that, but he is not expert on those area.

So he asked me to help me on that. So then I took basically the location of the earthquake, where the Sumatra earthquake occurred, which is roughly more than 1500

kilometer from Bangalore city. And then I took a appropriate ground motion prediction equation which we will be discussing later stage of our class and tried to estimate how a different component of the wave can expected at Bangalore.

Can it cause a crack to the building or not? So finally, we found that it was a very negligible amount of the vibration you get. So that vibration does not cause any crack in the building. So whatever crack he had, maybe it was a previous one. He may be noticed after the earthquake. So that kind of suggestion and that kind of understanding so you need to know. So how this S wave and P wave propagates on this, okay.

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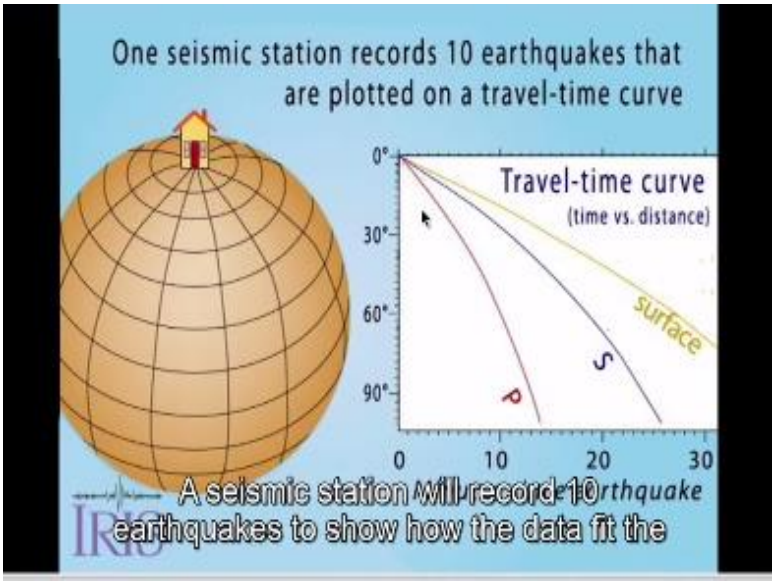

So this is a another example. So where you can see how this P and S wave get recorded at a particular location, okay. Depends upon the different place of earthquake. So I will open a another animation video. So you can see this very clearly. There are about so a P and S and surface wave. And this is actually the distance okay so in the. There are two ways you can look at this figure.

So one is that basically your station location. So the this is basically a station location. So the another one is the earthquake which is going to happen anywhere in the globe. So which wave you going to see on the particular location depends upon the speed of the wave and same time how this station also going to record a particular wave. So you can see basically there are several earthquake in this. We can see one by one.

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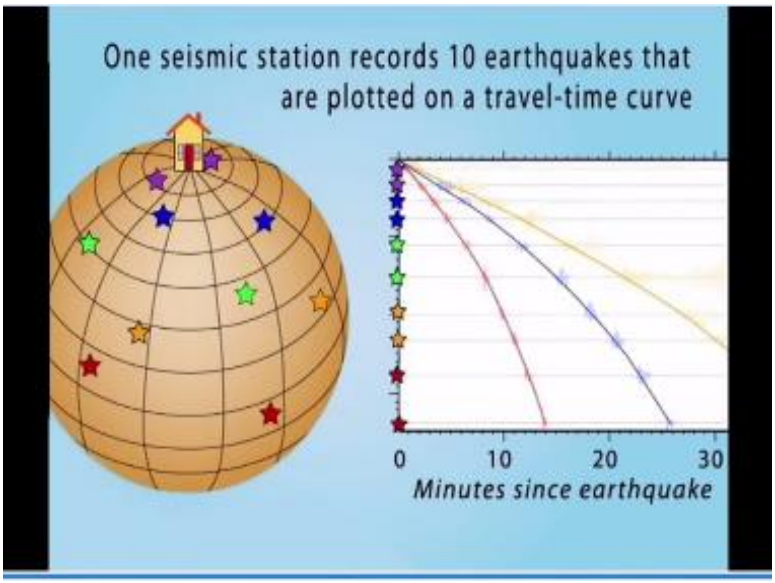

So there are 10 earthquakes are taken. So the first we will try to simulate this earthquake which is happened here. You can see here. So this is my station. So first I received the P wave. Then followed by S wave. Then I also received a surface wave, okay. So then the closer by you can see that I received the same thing with a very short time.

You can see there the distance where the location of the earthquake and the station plays a role when your waves are arriving. So this will indicate that if you have the seismic record okay at a particular location, if you know when this is arrived and this is arrived okay, based on this arrival time, you can know where is the earthquake origin okay.

So the understanding of the wave helps you to find out where from your earthquake origin when compared to your station location, you can see here. So this also will give you that if you get a so many data from the different location you can also see that what is the velocity pattern in your region, okay. How the S wave velocity, how the P wave velocity, how the surface wave velocity will takes to reach your region.

That is the average velocity one can expect in the particular region okay. So that is what you will get from this information. So you may be notice here that some of the waves are not recorded at a particular place. Why it is so? So as we told that the waves when it travels on the earth okay so it is undergoes a refraction and reflection okay.

So when the refraction is taking place, okay the reflection is taking place, a particular wave may not reach a opposite direction directly, okay. That will change its path. So that kind of change happens and create a zone okay where that absence of that particular earthquake that is called a yeah shadow zone.

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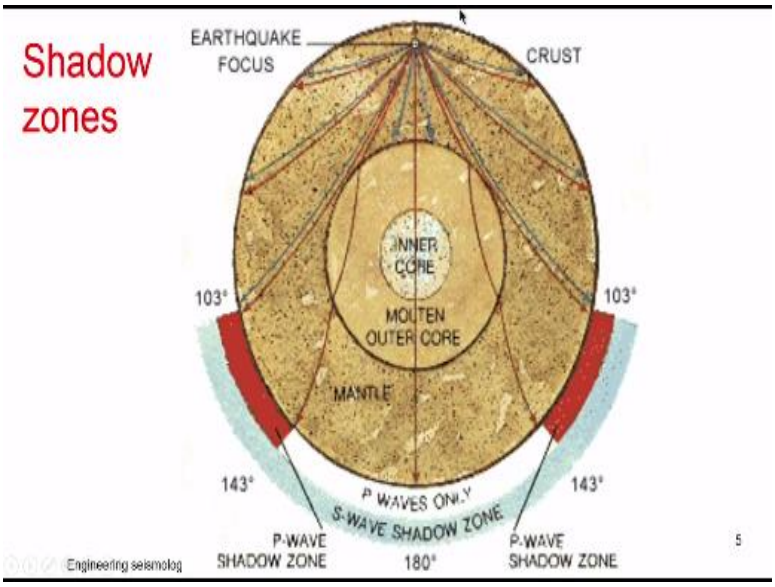

So for example, you can look at this figure very carefully. You can see this is the earthquake origin. So the energy is radiated, all the S wave, P wave, surface wave, everything radiates. So when it comes to here, because there is a boundary between the this layer and this layer. So this boundary basically reflects a wave and also refracts okay.

So since the material of this boundary also very important if it is a solid and water the P wave can travel without any issue, okay. Only thing the direction of the wave get changed. If the S wave if it is the liquid it will not travel, correct? That is what we understand from the wave propagation. So the surface wave only travels on the surface of the earth which we have seen and this one.

So we will talk about more P wave and S wave because the surface wave reaches very far and also the damage due to surface waves are considerably less than the S wave and P wave. So because of that it is not too much dealt in the engineering seismology. But the P wave and S wave understandings are more important for the civil engineering point of view.

So if we look at very carefully this okay. So you can see that the waves are traveling on the different part and when it reaches basically it get refracted. And again the another boundary refracted and reaches here. The same wave travels here. So when it travels here like this. So this is basically a P wave. You can see that the P wave together comes, one part basically reflected and goes like this, another part refracted and then again refracted and goes.

So in between there is no wave comes even though the initial path is same, okay. In between there is no. This zone is called as a P wave shadow zone. This zone is called as a P wave shadow zone. So similarly this side also. So this is your vertical zero okay. You can see that the P wave basically 103 to 140 degree you will not able to record P wave.

So if the earthquakes are occurring here, if you have the seismic station at this place you will not get record a P wave. But if you are having here you can record. If you are having here you can record. If you are having here you record. So depends upon the position of the station by understanding the refraction and reflection of the wave it has been found that this between you will not get a P wave signal.

So that region is called as a P wave shadow zone. Shadow zone means where you do not see the particular main component of the wave, okay. Shadow, it will actually shadow that particular wave, okay. So the another one basically the S wave shadow zone. As we have seen that the S waves also originate here. So you can see the S wave is basically a blue one, okay.

You can see all its propagates. Here you can see S wave. Here you can see S wave. Here you can see S wave. But when it comes to this interaction, the P wave basically refracted, but S wave does not travel on the liquid. So it does not travel at all, okay. It only travels up to this and end. It travels up to this, it end. It does not penetrate to this. Because this entire part is basically liquid.

So that means 103 degree to 103 degree okay you will not find any S wave record. That zone is called as a S wave shadow zone okay. So the people when they have the

instrument at different place, so they try to wonder why the particular wave is not coming. So then they understand that this shadow zone effect plays a major role.

So now, if you have the earthquake at one place, if you are sitting in the opposite of that particular location in the globe, you will not see some of the waves. So that means placing of instrument at one place may not be sufficient to record all the earthquake happening in the world. So you should place the instrument appropriately at several places. So we can see the animation for this again how this shadow zone is created.

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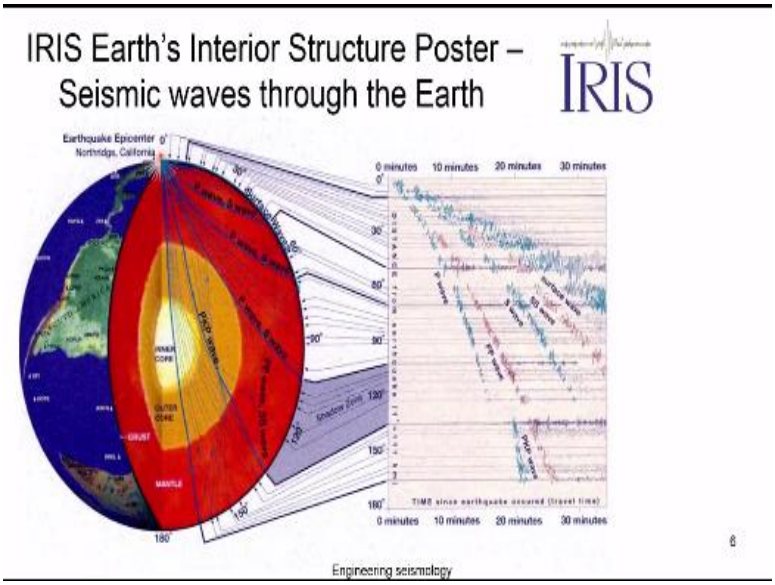

This is actually also observed by the when the number of seismic stations in the world. You can see this is actually the origin of the earth. You can see a different waves, the P wave okay, the S wave. Some places S wave is not there. Some places P wave is not there. So depends entirely you can see at different zone.

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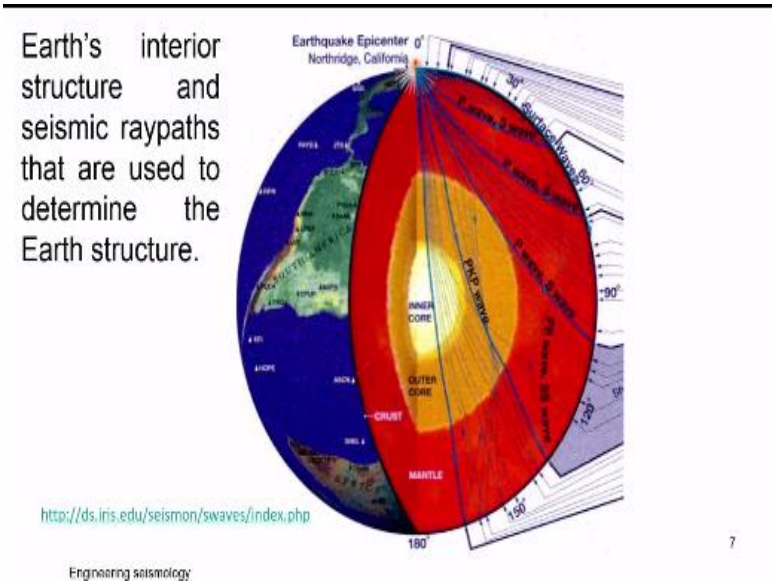

So this you can visualize well with some of the animations. So here we need to acknowledge so IRIS team where they created this kind of animation so helping basically the students to understand how the P wave and S wave zones are created, how the waves are basically transferring from one point of the medium to other point of the medium.

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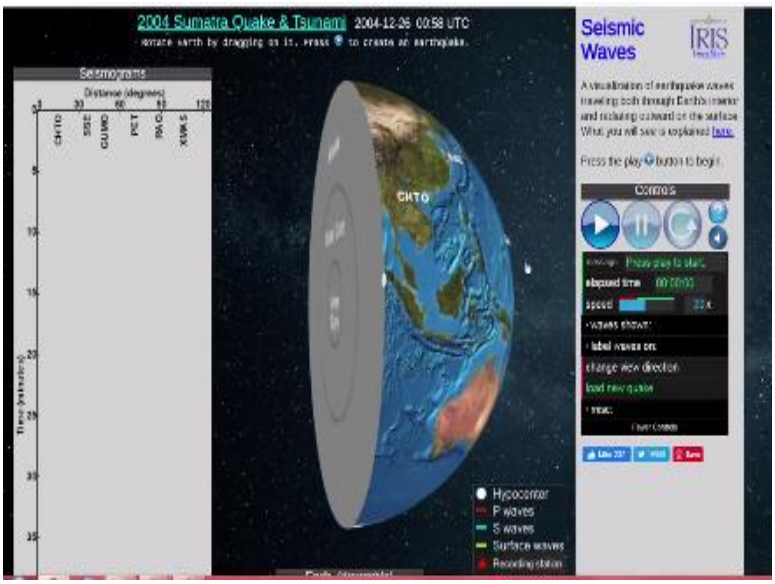

So this graph basically gives a this is actually the distance in degree from origin of the earthquake and this is actually the timescale where to show the earthquake and you can change a earthquake type and also you can see the globe on different position. So right now we take the Sumatra earthquake and I am concentrating on the right side of the earth so that you can see whichever point where you are recording the what type of wave.

So if you want to see the same way how it propagates interior we have to see like this, okay. So let us start the video.

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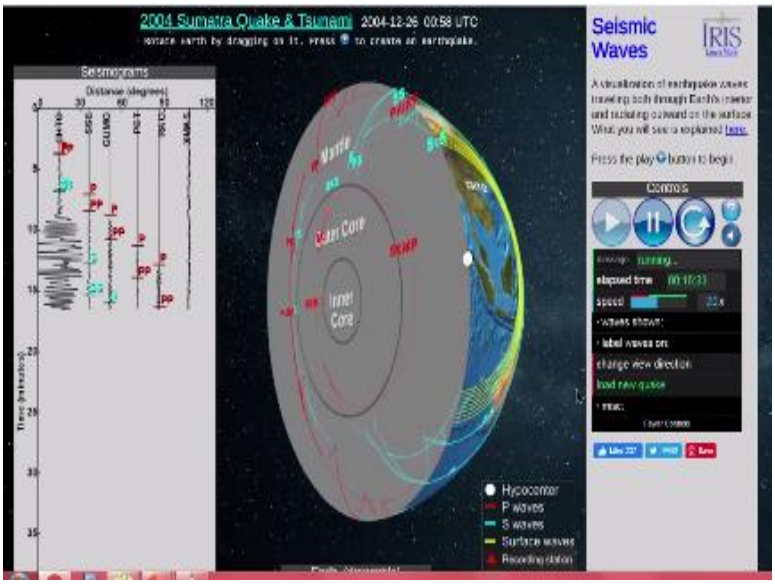

You can see now okay, the earthquake originated, Sumatra earthquake basically this one. You can see that the earthquake originated, the P wave started okay. So now it is going to reach a station. So the P wave is recorded. You can see the P wave recorded. So once depends upon the medium in the particular place it get reflected refracted. So you can see the S wave reached the station CHTO.

Similarly, the other place. So when the reflection and refraction happens basically the combination of the waves like P, PP wave; S, SS wave; PS wave. So like that a different combination of the wave will happen. That also it is very clearly specified. You can see here. So here it can you can see very clearly see how the S wave generated in the this one. I will again go back to show you how the S wave propagates.

You clearly see the when what happens to the S wave when the. So now the earthquake origin. So you can see that the mantle with the crust, so crust P and S wave are going. You can concentrate on interior of the earth okay, you can see that. So when outer core the P wave goes, it gets reflected and refracted, you can see that. But the S wave, main S wave going to hit the boundary.

You can see it hit the boundary okay. It get reflected there is no refraction is taking place. You can see that there is no a light green waves are passing through outer core. You can see very clearly. So that is what this kind of reflection and refraction creates a shadow zone for a particular earthquake okay. So this video actually available in the website, so IRIS website it is available.

So where you can go through and try to understand how this wave propagates and which will help you to understand further on using this wave whatever we are going to discuss further, okay. How to record this wave? How to understand getting the engineering properties or design parameters from this wave? How to know the location of the earthquake? How to know the strength of the earthquake?

All these things are depends upon the wave what we are going to record. So we should know that what wave we have recorded and how far that wave? What are the type of wave it consists of? And where that earthquake was origined? Everything is known from this waves. So understanding of this wave propagation is very important. You should also do the similar situations.

So okay simulations on different earthquake. For example, if you want to change the other earthquake, you can put a Nepal earthquake. If you want you can change the Nepal earthquake. So change view direction. So I can go to the Nepal earthquake, load the quake.

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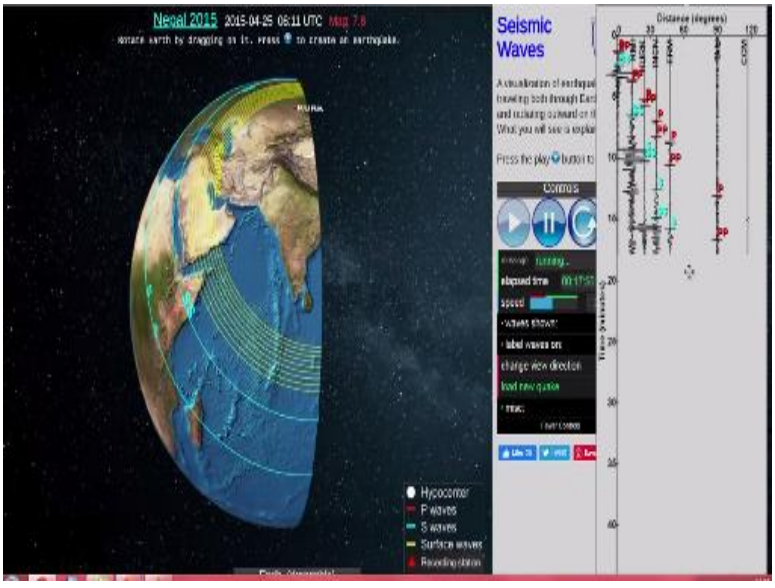

So I will go to the other direction because we want to see what happens in India. As I told you that when the plate boundary earthquakes are occurring how it going to affect, okay. So this you can keep it this side, you can zoom it here. So let us start playing. You can see the Nepal earthquake which is happened at boundary, okay. So you can also keep watching the seismic signal which arrives.

You can see when it middle like Bangalore, you can get a P wave, but the amplitude of P wave is very small. When the earthquake comes you can see how the amplitude, okay. So you have to visually see how much the amplitude is occurring. Since there is no seismic station created by them because they created some standard location with respect to the origin they created in the degree like 30 okay.

So 90 and 120 kind of things you can see. So you can see that the wave arrival and amplitude depends upon the where that particular station is located. That is the message you can get and also you can see that if you are in shadow zone you do not get P wave shadow if you are in the P wave shadow zone. You do not get S wave if you are in the S wave shadow zone.

So the S wave shadow zone is bigger in size, 103 degree left to 103 degree right. So the P wave shadow zone is basically 103 to 148 left. Similarly, 103 to 148 right. But in between 143 to 143 you can get a P wave. So these are all the information you can get.

You can also look at this link and try to understand how the different earthquake, they have given 10 earthquake simulation to see how the earthquake waves are getting generated okay, how it propagates using this link. So the understanding of shadow zone will help us to basically identify this one.

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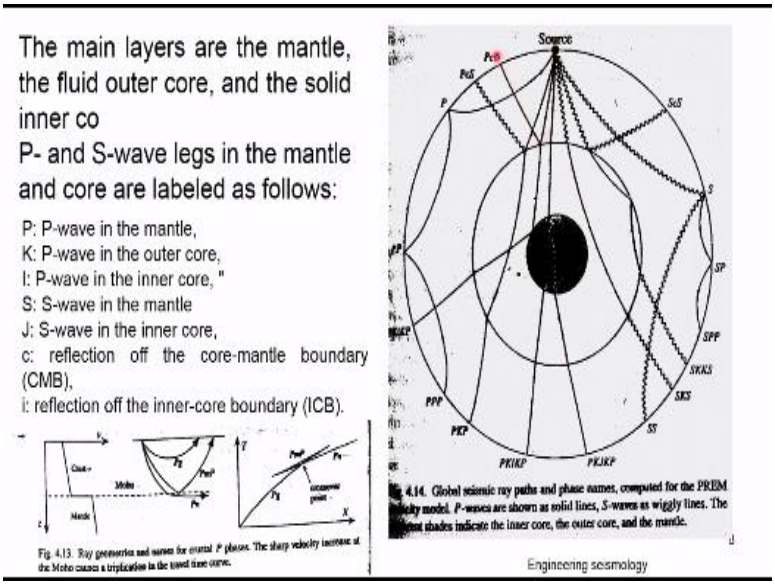

So as we have discussed that when the waves are transferring from one medium to other medium so a particular wave get reflected. So there is a combination of waves, okay. It is not that only P wave and S wave we will get. So the P wave is when you measure directly with P wave. So when you see the P wave origin here, basically this P wave propagates like this and reflected.

It is become a PcP waves, okay. So here the P wave reflected and then the S waves also combines, it is a PcS wave. So the S wave comes here and then reflected ScS waves. When S wave directly comes is the S wave, okay. So like this a combination of several type of waves are taking place. This is the combinations given. P wave in mantle. So the K is the P wave in outer core.

I is a P wave in inner core. S is the S wave in mantle. J is the S wave inner core. Like that a different combination happens. So you can see how this basically the crust okay then followed by mantle. Moho we have seen the definition. It is the interface between the two crust and mantle portion. You can see how the waves are get travelled.

So based on this you can know where is the origin of the earthquake and distance of the earthquake occurred, okay.

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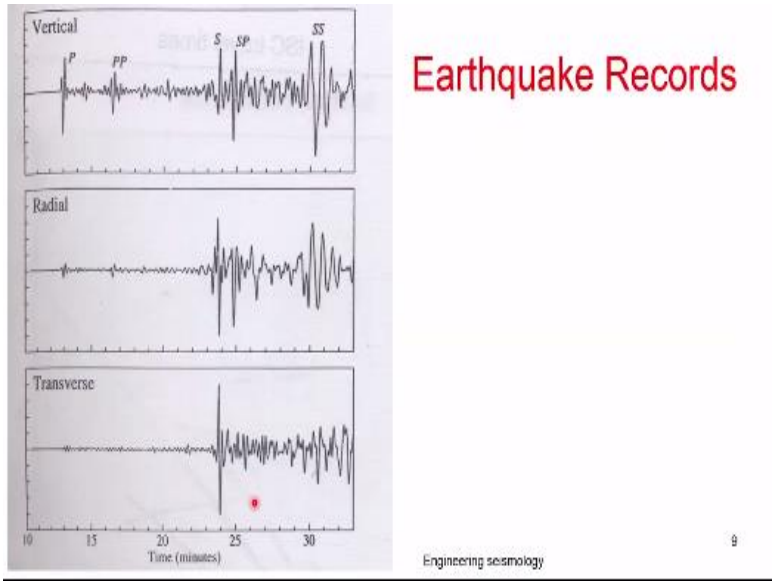

So this is the typical plot at different wave record. For example, the P wave at one particular place. So then the P wave which is reflected. Then S wave, the SP wave and SS wave. Similarly, the other components, the vertical component, the radial component, transfer component. You can see that in this vertical component you can see the P wave very dominantly.

But the radial and transfer component you are not able to see this wave dominantly. Because in this location the waves are get attenuated. You can see that it is attenuated because the station may be located on the such place where the P waves are not properly done.

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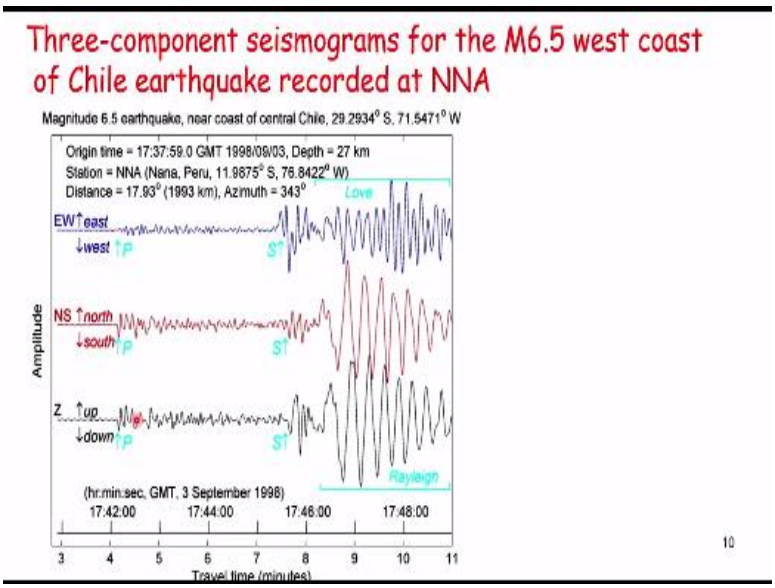

So these are all the very important aspect to understand how the mediums at okay where you are located when compared to the earthquake. So this is again a typical 6.5 magnitude of the near coast of Central Chile, where it has been recorded at a particular location, where you can see that the amplitude of the S and P waves are considerably lower than the surface wave amplitude, you can see here.

So these are all the cases where you can see that sometime you will get a dominated surface wave at particular location depends upon the earthquake origin and where your stations are located or building is located.

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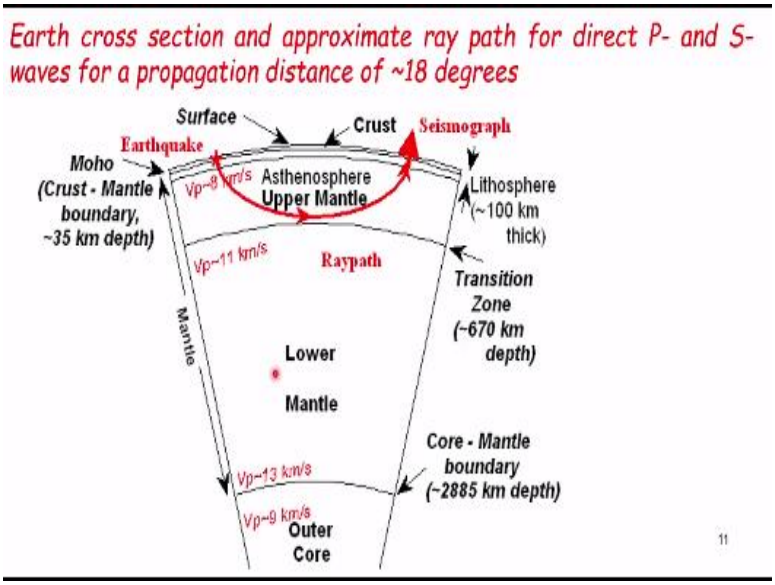

So this will help basically to understand how the interior of the earth, okay. If you know the velocity of this then you can know that what is the V p velocity in your region. Similarly V p velocity at other part. So this helped people to map a interior of the earth, okay and tried to understand what material it is. As you know that most of the material is the function of its stiffness and density, okay. The density plays a major role.

So if the coal or gold it depends upon the density of the materials okay. So by measuring like this you geophysical survey, the understanding of the seismic signal and geophysical survey to understand this kind of wave velocities and arrival time and all will help you to understand the resource okay in the particular location and mining activity, okay.

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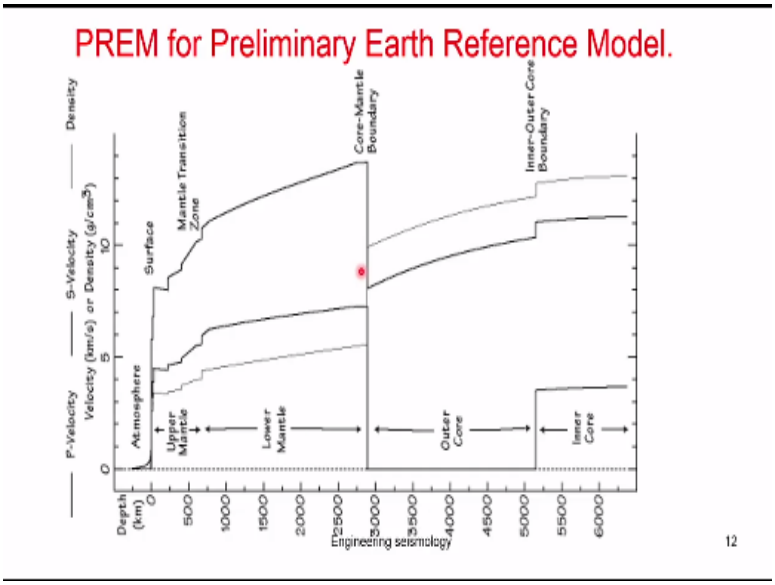

So that is what the geophysical studies, deep geophysical studies are well established to do all this kind of things. So this is the typically people have measured at different seismic stations by created a natural one and then they tried to map the average velocity of the different layer of the earth like the P wave average, S wave average and density.

You can see that from zero is the surface of the earth and this is the middle of the earth you can see how these value are varies. The P wave and S wave you can see. And some portions where you can see that there is no S wave at all. Here you can see three of them as present, when the crust and upper mantle, I mean mantle and crust. And then when you come to outer core there is no P wave.

When again when inner core comes, so there also there is no P wave. Then followed by opposite side if you go you will get the this recordings once again. So this help like average velocity at that particular location. These velocities are again changes with the place to place. If I measure this velocity at Bangalore region it will be different.

If I measure the same thing at Delhi region it will be different because of the composition of the material as the wave properties are controlled by the constrained modulus density, shear modulus and density. So this material changes basically your velocity speed also changes.

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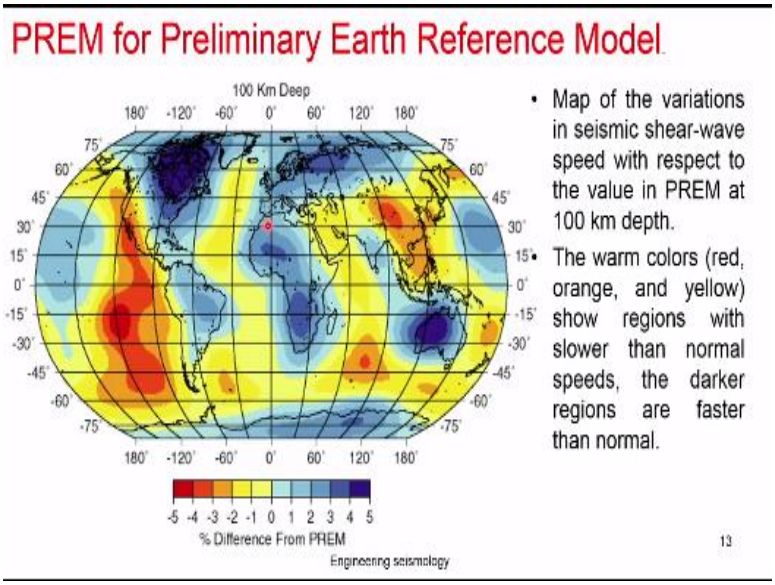

So that one has to remember. So what the scientists did actually they collected large amount of the seismic record placed throughout the world and tried to understand how the interior of the earth at different depth. So that is called as a preliminary earth reference model, a development of preliminary earth reference model. For this basically, they used a earthquake or they created a vibrations on recorder, okay.

So this is the typical earth preliminary model at depth of 100 kilometer from that. If earth is you feel it is a orange okay if you peal the orange skin 100 kilometer okay so then you will get a this 100 kilometer inside this is what you can see. You can see that basically the difference of the variation okay you can take zero is yellow and then you can see that increase and decrease.

So the minus red is basically decrease and then the dark blue increases. So with respect to the average value in the yellow. You can see how the stiffness and density of the material changes. So the assuming the uniform P and S wave velocity is not appropriate. You have to basically measure or estimate using the your own regional data okay that is what the message you can get.

Here also you can see that the Himalayan belt and also South India and further Central India you will find a different in 100 kilometer depth. The similar things they have done basically to the deeper level too.

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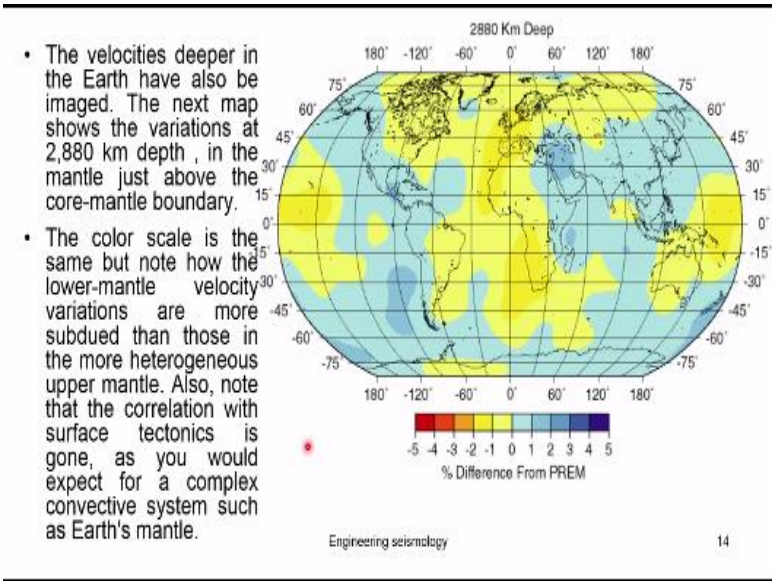

So this is basically 2880 kilometer depth how the again difference. You can see that when it goes interior okay the variations are negligible okay. You can see that -2 to basically +2 or maximum +3 okay. So not too much difference from -5 to +5. So that variation also you can see. So when you go inner and inner you get a uniform material more or less but at particular location.

But entire globe there is a change, you can see that. And this is a completely yellow. This is completely a light green kind of things okay. So the entire India at the depth of 2880 kilometer you will have the same material below the India region. But it is not same at other place. For example, if you go to the Saudi Arabia, you can see you can the variation in the different place, here one, here one.

Again if you go to the Africa the same thing. In US, particularly South America, you can see there is a contrast, particularly there is a two type of material you can find. So Australia also similar. So this is are important to understand how the particular wave arrives as this material controls its speed okay. So this is the application side of the wave propagation.

So if you know the wave propagation basically, you will try to understand like these materials, how the variations are there, how the speed varies, and you can know where is that event is occurred. So with this actually, we will close this lecture. So thank you for watching this lecture. So next class we are going to talk about continuation of this subject, how this waves can be measured, okay.

So right now we have seen the wave character and how these waves are useful. So next class we are going to see how this wave can be measured. How this scientific development happen towards a measurement of the earthquake or measurement of the seismic waves, okay. So thank you.