Foundation Engineering
Prof. Kousik Deb
Department of Civil Engineering
Indian Institute of Technology, Kharagpur

Lecture - 10
Geophysical Exploration - II

So, in the last lecture I discussed about Seismic Reflection Test.

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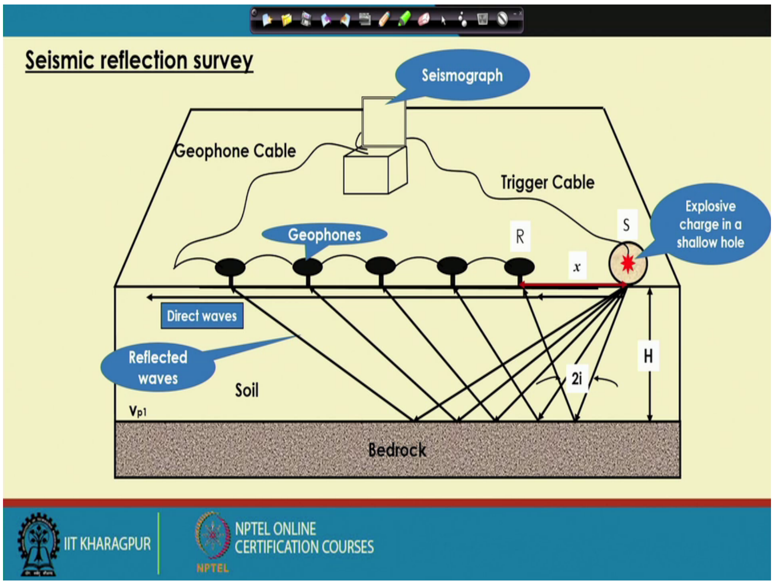

So, and this is the seismic reflection survey or test where the velocity of the soil layer is determined and the thickness of the soil layer is determined. And as I mentioned that this test, where we have to identify the travel time of 2 waves; one is the direct ray wave from the source to the receiver another is the reflected wave. So, this is the reflected waves so and. So, that is why identification of these 2 waves is sometimes difficult; so then we will go for the next test which is seismic reflection test.

Another one here we are measuring the velocity of the soil layer; layer I and the thickness of the layer I. So, this method is suitable if the soil is the homogeneous kind of soil, but if the soil is a layer kind of soil which is the common in most of the cases, then you have to go for the next technique which is seismic reflection survey.

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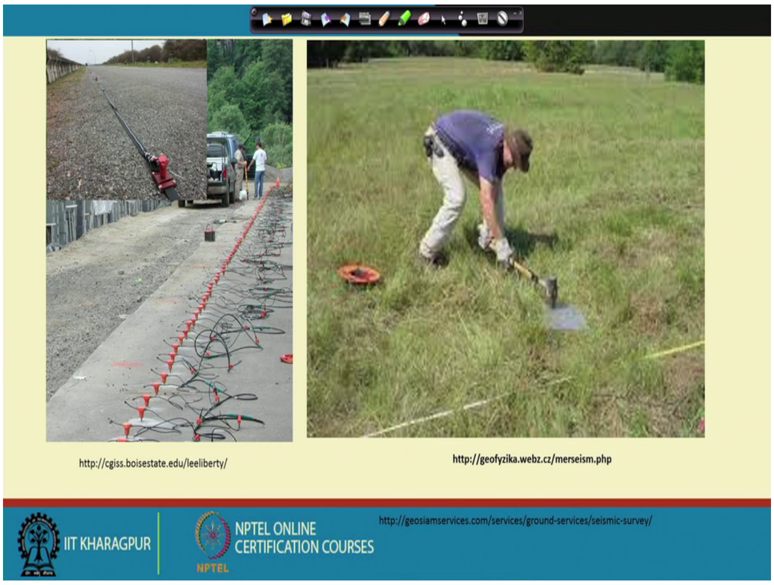

Now, as I have already discussed here we will apply the hammer blows; so, and these are the receivers. So, these will receive the wave and then it will identify the travel time of the wave from the source to the receiver either is this direct or the reflected. And then we can generate different wave depending upon how we are applying the hammer blow either it is p-wave, or the s-wave.

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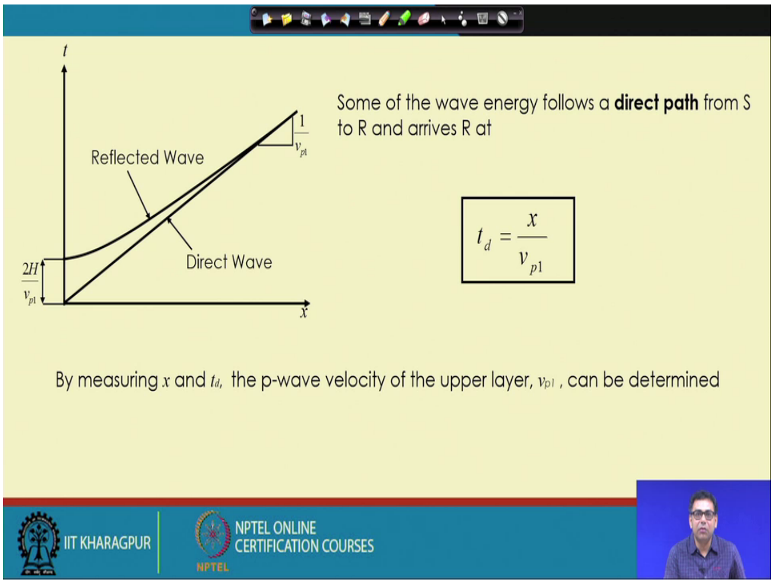

Now these are the 2 curves that I have discussed and instead of going one particular 2 curves, we can go for a single curve making a square X n square and t R; t R square and with that square curve will get that straight line. And from the straight line, we can get the vp 1 and the z value these are the expression.

So, next one that will go for the seismic refraction survey; now in the seismic refraction survey; so this is the source and you have to again put the n number of geophones and here we have say this the soil layer, it is also thus may be the soil layer. So, or the bedrock that initial it is the bedrock because if the seismic reflection we got a it is homogeneous case, but here it may not be the homogeneous it can be different layer soil also. So, here instead of bedrock we can go for a soil layer of different thicknesses different soil layers with different thicknesses.

So, what will happen? Here also we put the hammer blow and receiver. So, instead of these measuring 2 waves here; we will the receiver will measure the travel time of the first wave; the wave that will reach the receiver first; so, that we will call it the first arrival time of the wave. So, that can be the direct wave that can be the reflected wave that can be the reflected wave. Because when you are talking about reflection survey; there is a possibility there is can be a reflected waves also there is a possibility this can be a reflected wave this can be direct wave.

So, the receiver will indicate; so, the first arrival time of the wave. So, that is the advantage here we are not measuring 2 different waves whether one is direct one is reflected; here we are measuring the first wave arrival time it can be direct, or reflected, or refracted.

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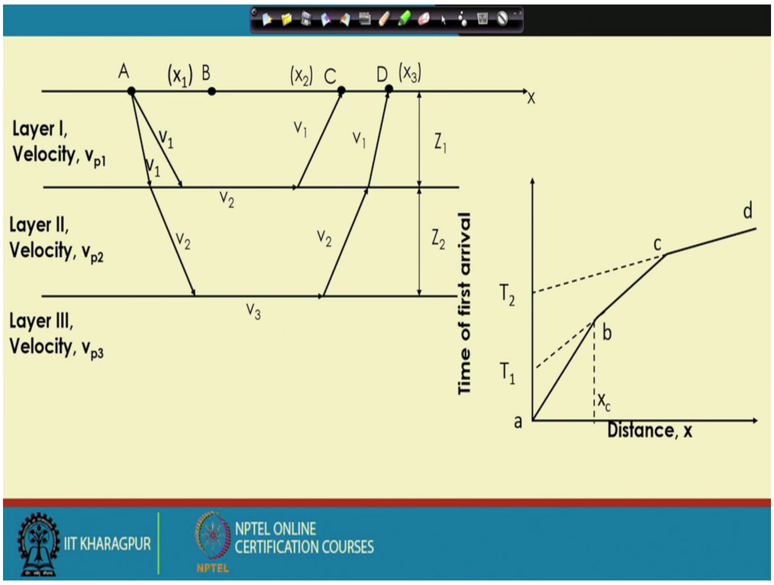

So, now so, so this is the way we are getting; so now how we will get the properties of different soil layer. So, here another advantage is there we can determine the thickness of different layers and the velocity of the different layers. So, let us again derive the equations; so how we will determine the properties here.

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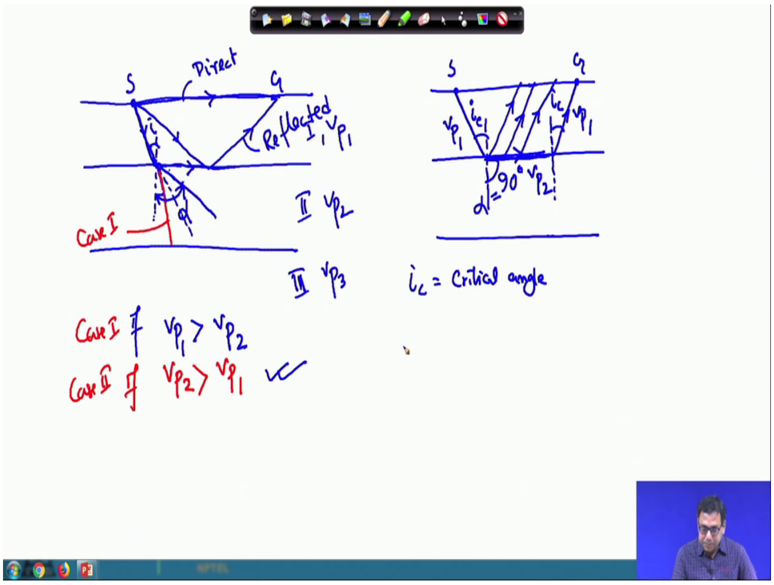

So, what will; so, suppose this is the ground surface where this is the source and this is different layer. So, suppose the layer I this is vp 1, this is layer II vp 2, and this is layer III say vp 3. So, now we are putting geophones so, this is our geophone and this is the source S and then again if this is the source there will be n number of waves. So, there will be one wave which will reach this geophone directly.

So, another way there is a possibility that it will reach by this reflected waves. So, this is the direct, this is the reflected and now there will be a refraction also that we did not consider in the previous case; so, how this is the refraction?

So, now suppose this is the wave; so, now depending upon this is the wave is coming here, depending upon the density of the soil the wave the reflected wave can move from the normal or towards the normal. Because these wave velocity is the function of density of the soil, now it is expected. Thus as the density of the soil increases, the wave velocity will also increase and if the density decreases the wave velocity will also decrease.

So, now if we can say that this is the direction of the wave. So, this is the direction of the wave now if the wave; so, suppose if that vp 1 is greater than vp 2 that mean this is the high speed material this is the low speed material. So, the wave will refracted towards the normal so; that means, if vp 1 is equal to vp 2 then these will be the possible or if I use the different color. So, this will be the possible path of the refracted wave if this is the case then this is case 1; so, this is case 1.

Now, if this is case 2 that vp 2 is greater than vp 1 then what will happen? This wave will refracted either from the normal; so, in that case. So, these if I take again different color; so this will be the travel path of the wave. So, this is I and this is another angle sorry this is the angle alpha alpha is this angle, so I can erase this line and now.

So, now, what does it mean? Ut means that that we have to receive this refracted ray by this receiver. So, this is only possible if these refracted rays follow this blue path because if it is follow a red path, then it will it will never reach to the surface. So, where the; we place the geophone? So; that means, we have to follow this blue path.

Now, if this has to be followed by this blue path then; that means, the one condition is that we have to always follow the case 2 where your velocity of the second layer must be greater than the velocity of the first layer. You have to remember this thing this is very important that you will get the good result or the better result if your velocity of the layer increases with depth; that means, if the velocity of the lower layer is greater than the velocity of the upper layer then only you will get the good results; otherwise and this is most of the cases it is common.

Because we have the velocity of the lower layer is greater than the velocity of the upper layer because of the overburden pressure. So, and because of that we will always get this type of layering where they will density increases with depth. So, the velocity will increase with depth and it will follow this path.

So, this is one thing so; that means, now there will be one particular. So, this is important now if sometimes we do not have this type of layering and we will get not good result. Then you have to go for the third option that is seismic cross hole survey. So, we will discuss this about the seismic cross hole survey.

So, now if we have we are placing geophone; so there is a particular wave where because of these angle instead of these wave following this path it will follow this path; so; that means, if I draw it in fresh. So, there is a particular; so this is the geophone this is the S, so this is the ray. So, it will follow this path; so this angle in such case is known as critical angle when this alpha value is equal to 90 degree.

So, if is follow this path then this angle is called the critical angle. So, i c is critical angle. So, alpha will be equal to 90 degree; so, when it to follow this path again in here it will follow this reverse option and it will follow the reverse path like this. So, it will again i c; so these total things will be completed, so it will reach into the ground.

So, now there is another question that why we have considered this path? Because when this is the point your reflected ray can go from this point onward, it can go like this also suppose this is the path it can go like this, it can go like this, it can go like this also, but we have considered this path because we have placed geophone here; if you place geophone here then we have to consider this wave or this path of the reflected rays. So, as we have considered this one; so this is the geophone.

So, now, here that is them 3 cases are 3 rays are discussed one is the direct, another is the reflected another is the reflected. So, definitely direct ray we will always reach first compared to the reflected rays. So, that is because this reflected rays travel path is more than the direct rays travel path and we are talking about the first arrival time of the wave. And another option that when this reflected rays is travel with this path when it is travelling with this layer; it is vp 1, when its traveling here it is vp 2 and this is also v p 1. So, you can see when this length of this zone increases. So, there is a possibility that this wave may reach first compared to those direct rays because our vp 2 is greater than the vp 1.

Now so; that means, we are we are removing reflected wave, it will not reach first. Because reflect either the direct ray will reach first or the refracted ray will reach first because the reflected rays these velocity is greater than the vp 1. So, we are now removing the reflected rays because we are talking about the first arrival time of the wave. So, reflect ray will never reach first; so we are removing this reflect ray in this form here.

So, we are now considering direct ray and the refractor ray. So, if we if we increase the distance from source to the geophone, the possibility of the refracted rays to reach the geophone will increase. So, there is a one particular distance where the direct ray and the refractor ray will reach at the same time.

So, if you place geo from there that distance is called the critical distance. So, that is a critical angle similar to critical distance also; critical distance means where the direct ray and the reflected ray will reach at the same time to the geophone; so now that angle is called the critical distance.

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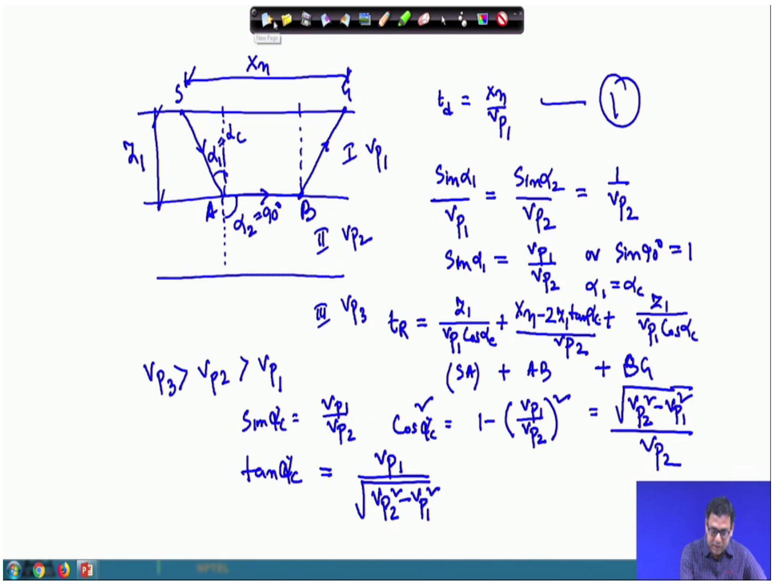

Now, next we are considering; so, finally, what we are doing? So, we are considering for the derivation purpose, we are considering this is the geophone this is S, and we have considered this ray because our geophone is placed here. So, this is vp 1 and this is v p 2 and this is vp 3 remember that vp 3 is greater than v p 2 is greater than v p 1.

So, now, we are quickly I will give you the expression of the derivation so; that means, here there is a direct ray. So, similarly I am doing the derivation for the 2 layer system only. So, this is the first layer and this is the second layer; so, that there is a direct ray td which is again X n divided by vp 1.

So, this is the X n and that is a; so, we can. So, we know that this is if this angle is alpha 1. So, sine alpha 1 divided by vp 1 and this angle if alpha 2. So, that will be equal to sine alpha 2 divided by vp 2 as alpha 2 is 90 degree. So, we can write this is 1 by vp 2 and so, our sine alpha 1 is equal to vp 1 divided by vp 2 as sin 90 degree is equal to 1.

So, if I now derive the expression of t R which is reflected rays; so, this will be suppose this thickness is z 1. So, this will be the z 1 divided by vp 1 cos alpha c because now this as alpha 2 is 90 degree. So, your alpha now alpha 1 is equal to alpha critical. So, and how we are getting the; so it is this path this value is z 1 and this angle is alpha C, this is alpha C. So, we can determine this will be the z 1 divided by alpha cos alpha C. So, if I divided by vp 1; so, this will give that time required to travel these distance S 2 say this is A and this is B..

So, this is basically the travel time of S A then plus the travel time of your A B, then plus travel time of B G. So, B G will be the same as z 1 divided by vp 1 cos alpha c and the A B will be plus A B will be X n; this is the X n minus this distance and this distance. So, this distance I can because this is known because z 1 I know; this is z 1 this is alpha c S. So, I can determine these distance; so, these distance minus 2 z 1 tan alpha c divided by as this is traveling with vp 2; so, this will be vp 2.

So, this is the expression; so, some as I know that sin ic is vp 1 vp 2. So, similarly cos ic will be 1 minus vp vp 1 by vp 2 whole square. So, this will be equal to root over vp 2 square minus c square minus vp 1 square divided by vp 2.

Similarly I can write tan ic will be equal to vp 1 divided by root over vp 2 square minus vp 1 square. So, sorry this is not ic this is alpha c all are alpha c because we are using alpha here; so, this is alpha c.

So, now we put this tan alpha c value here we put cos alpha c value here; now if I put these value and then simplify these equation. So, if I put; so this is our equation number 1 and now if in this t R equation; if I put all this tan alpha c tan alpha c cos alpha c in these equation and simplify it.

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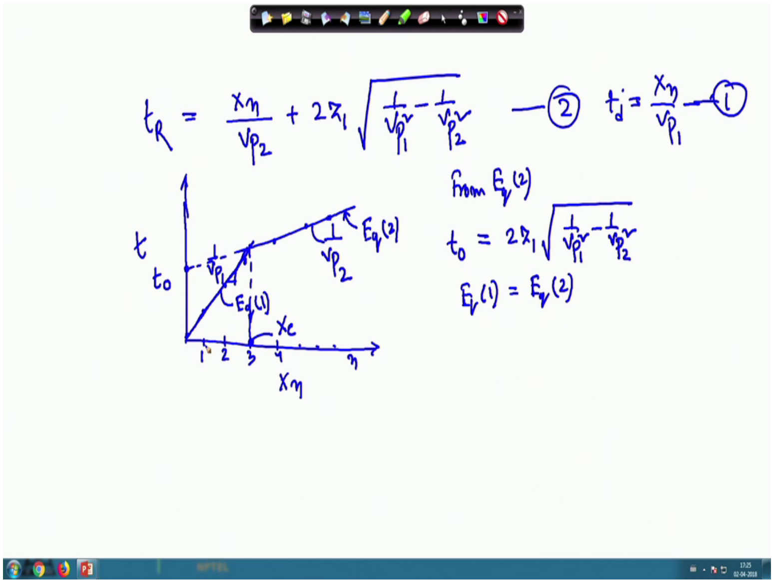

So, I will get the final expression of t R will be equal to X n divided by vp 2 plus 2 z 1 root over 1 minus vp 1 square minus 1 by vp 2 square. So, this is our equation number 2. So, our equation number 1 was that this is the direct ray's equation. So, that is td equal to X n by vp 1; so, this is the equation number 1.

So, we have this is the refracted rays equation travel time this is the direct rays travel time and we are measuring the first travel time. So, instead of again taking one particular geophone here also we will take n number of geophone and then we will draw the graph. So, here; so we will draw the graph; so, this is our X n and this is the t remember that this t is the first arrival time of the wave.

So, now, so as I mentioned if we increase the distance from the geophone to the source; then the possibility of the refracted wave will reach first. So, the when the distance is very less; then the direct ray will reach first to the geophone.

If distance increases the refracted ray will reach first to the geophone; so, and we are measuring the first arrival time. So, what will get? For suppose this is the first position of the first, second, third, fourth and so on n number of geophone. So, we will get this type of point; so if I join these points.

So, we will get this type of curve; so, which indicates that that this path will follow equation number 1, and this curve will follow equation number 2, and if I extend these line. So, these will give the critical distance X c where both the curves or both the rays is reach at the same time.

So, we can say the slope of these curve the slope of these curve will they give vp 1. This is the slope of this curve equation number vp 1, and slope of this curve will give vp 2. So, this is vp 2 sorry 1 by vp 2, this is 1 by vp 1. So, this is slope of this curve will give 1 by vp 2 slope of this curve will give 1 by vp; vp 1.

And if I extend this curve so these will give t 0; now as we are extending the equation number 2, so is t 0 corresponding to X n equal to 0. So, if I put this value in equation number 2 from equation number 2; so, this is t 0 will equal to this is 0 2 z 1 root over 1 by vp 1 square minus 1 by vp 2 square. So, 1 by vp 1 I will get from slope of this curve 1 by vp 2; I will get slope of this curve and t 0; I will get from the curve, this is the t 0 value and then only unknown is the z 1; so, I will get the z 1 value.

So, now this is the one way we can calculate the z 1 another way that we get the X c. Now X c is the point where both the rays will reach first. So, we have we have equate the equation number 1 will be equal to equation number 2. So, we equate these 2 equations instead of X c, X, X n we will put X c. So, X c we will get from the curve vp 1, vp 2 we will get from this slope and only unknown is the is z 2.

So, this is the critical distance approach and the first one is the t 0 is that time intercept approach. So, any 2 approach you can choose to determine z 1 so, but again there is a condition that your velocity of the wave should be increases with depth. Now I will; I will solve one example then you will see that if I take.

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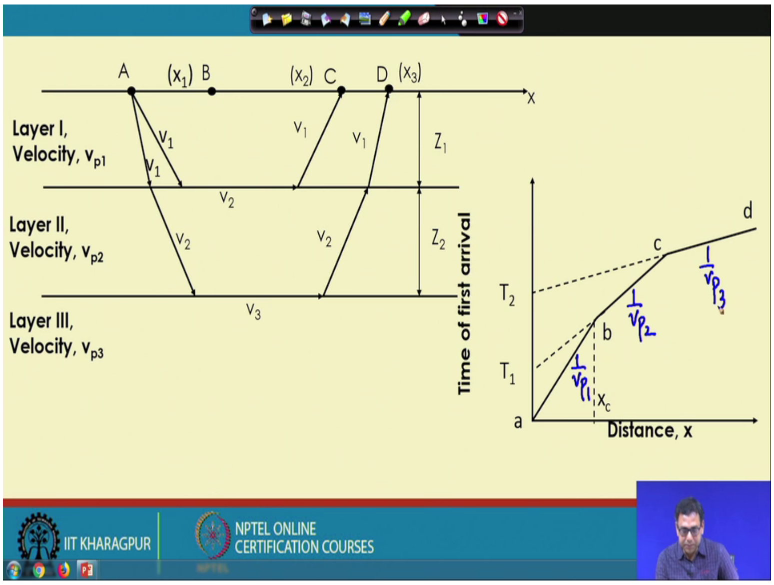

So, this is the curve we can see not only one layer, we can calculate with this change of slope, we can determine the velocity of. So, this is this will give us the 1 by vp 1, this will be 1 by vp 2 and this is give 1 by v p 3 and so, on. Similarly we can determine the thickness of the Z 1, Z 2 like that.

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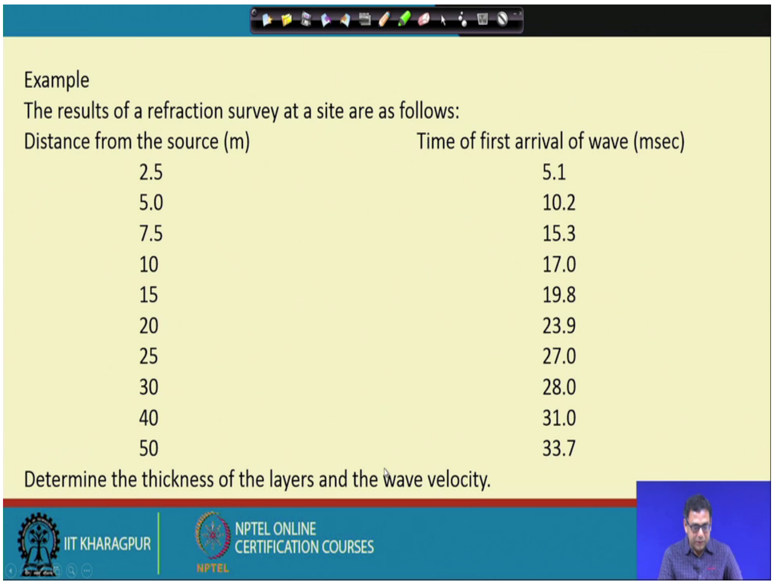

Now so, if I solve one particular problem so this is the example problem where we have done some refraction survey at the side and you are getting the we are used 1, 2, 3, 4, 5, 6, 7, 8, 9, 10; 10, 10 geophone. And the distance of the geophone from the source is this one; 2.5, 5, 7.5, 10 to 50 meter and the time of the first arrival of the wave which is millisecond remember that; this is in millisecond; so, these are the values. So, these are the values and these are the distance; so, what we have done? We have done, we have drawn it in a in a X n versus the first arrival time of the wave.

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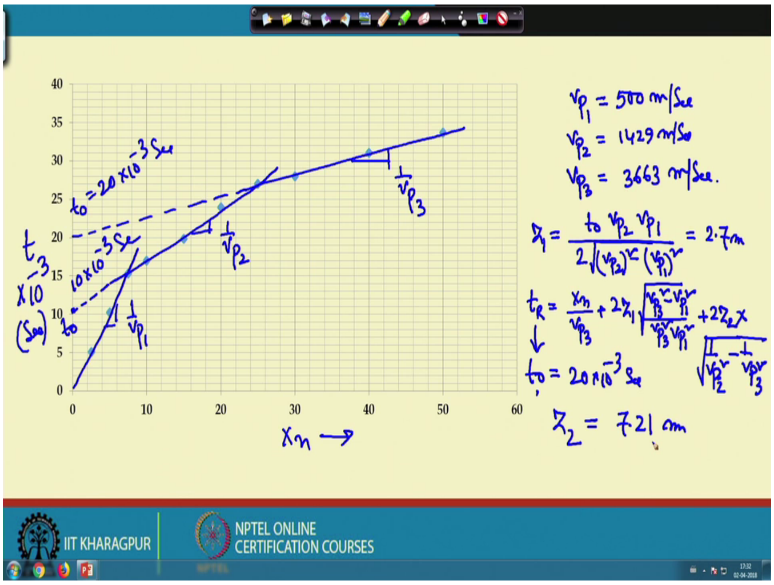

So, this is the curve; so we have drawn this curve. So, this is the X n and this is the time which is millisecond into 10 to the power minus 3 in second. So, it is in second 10 to the power minus 3 because these values are in millisecond.

So, now if I look at this curve that there is a different slope you know you can see that. So, what is this slope? We can identify these slopes; so, this is one slope the next one is this one and the third one is this one. So, from these curve; from these test data we can determine this slope will give 1 by vp 1, this slope will give 1 by vp 2 and this slope will give 1 by vp 3.

So, now we have done the calculation and from the slope what we are getting? We are getting that vp 1 is equal to 500 meter per second, vp 2 is equal to 1429 meter per second and vp 3 is equal to 3663 meter per second.

So, we are you may get some different slightly different values because that depends on how you are drawing these curve because you are joining these curve, but these are the 3 slope there is no that there is no doubt, but you may get slightly different values what I have received, but that should be close to these values. Now this is we will get the velocity of the each layer; now thickness I will get if I extend these line.

So, here if I extend this line it is 10 and if I extend these line. So, what I am getting this is another 10. So, here the T 0 value here 20 into 10 to the power minus 3 second, here 10 into 10 to the power minus 3 second this is the t 0.

So, now from here we will get the value that our Z 1 is equal to t 0; if I write in a simplified form of this equation v p 2 into vp 1 divided by 2 root over vp 2 square minus vp 1 square. Now if I put these values you will get Z 1 is 2.7; so, t 0 is 10 into 10 to the power minus 3. So, if I put t 0 is equal to 10 into 10 to the minus 3 and vp is these values the these value what we have received; so we will get Z 1 is 2.7 meter.

Similarly we can get Z 2 also the expression of that t R in terms of Z 2 and just given which is X n v P 3 plus 2 z 1 root over vp 3 square minus vp 1 square divided by vp 3 square vp 1 square plus 2 Z 2 then into root over 1 by vp; vp 2 square minus 1 by vp 3 square. So, this is also 1 by vp 1 square minus 2 by vp 3 square; so similar value here.

So, here also if I extend these curves so here this is the t 0 we are getting. So, t R will be the t 0 and this t 0 we are getting here 20 into 10 to the power minus 3; and we put this value X n is equal to 0 and we z 1 will get from here and vp 1, v p 2, v P 3 will put from here. So, only unknown is Z 2 and Z 2 value is coming out to be 7.21 meter.

So, this derivation I have not done; so, this is for 3 layer system. So, here we can do for the n number of layer system also. So, I have done the derivation for 2 layer system, but you can extend it for 3 layer system, you will get this type of expression of t R. So, here these are the 3 velocity of the wave and these are the thickness of each layer II 2.7 meter and 7.21 meter; so, these are the example.

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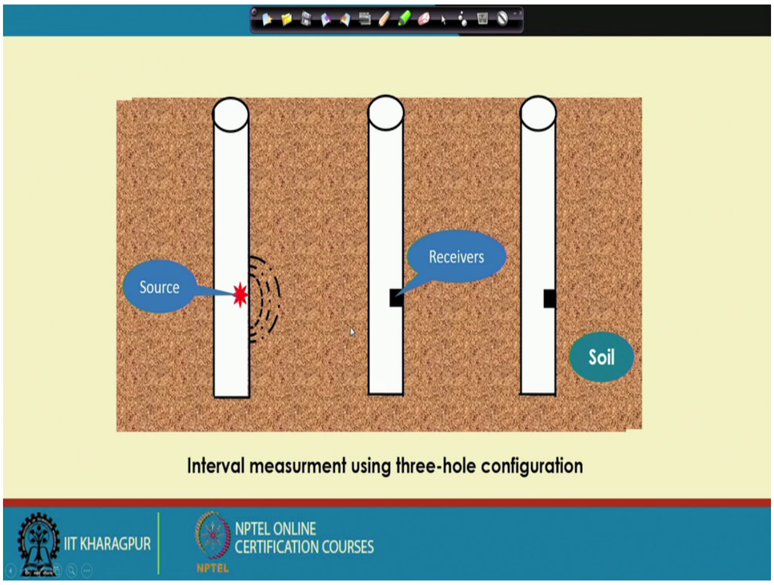

Now the next thing is that if your you are not good result because of the your condition is not satisfying that you your velocity is not increasing with depth and there is a hidden layer where it is giving the opposite trend, then you have to go for the seismic cross hole survey which is simple that you construct 2 or more bore holes, then this is your source and you put the receiver here, you know the distance, measure the time simple you will get V s or V p that is distance divided by time which is simple.

Here you are you can collect the soil sample also because you have the bore holes. So, here whether it is a increasing or decreasing does not matter, but the problem here yet is time consuming you have to construct bore holes, but the other method seismic refraction test where you do not need to go for any bore hole. So, which is very I mean time saving and very less time you can get the properties, but here we have to we have to go for the bore hole which is time consuming.

But if the soil layer is not satisfying; the condition of seismic refraction test then you have to go for the seismic cross hole survey. And then the, but among these 3 tests if your soil has satisfying the condition; seismic refraction survey is most acceptable and we use that.

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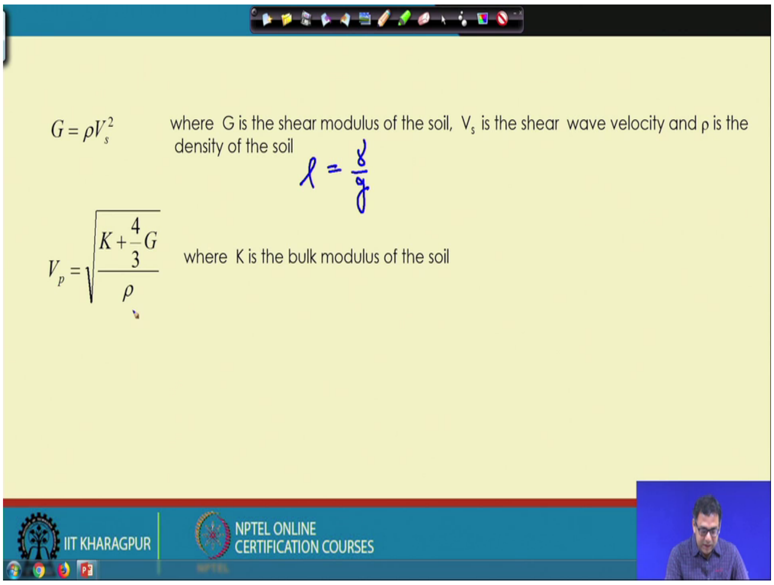

Now, once we get the velocity then what we will do? We will then, so this is if we have different this is this is for I mean 2 one receiver, this is for the multiple receiver as to minimize the error. And now once you get the velocity either the V p or V s these are the expressions. So, you will get the soil properties; so this is the G is the shear layer, rho is the rho is the density of the soil.

So, remember that density means rho is equal to unit weight divided by the g. So, this is; so, if I know the rho all unit weight and G is the G we can take 10 um 10 meter per this second square. So, that we can use for the G and this is the velocity V s that you are getting.

So, if you know the velocity, if you know the density then we can determine what is the shear modulus of the soil? Similarly K is the bulk modulus of the soil if I know the V p if I know the G, if I know the rho G get from these expression then we can calculate the bulk modulus of the soil.

So, these are the modulus that we are getting from this velocity. So, from the so; that means, ultimately from the velocity we are getting the soil properties as well as the thickness of the soil layer. But the one last things I want to mention before I finish this lecture; today's lecture that from here as I mentioned that your velocity.

So, if I take the V s; V s is equal to G by rho. So, I mentioned that as the density increases velocity increases, but here your density from these expression if I say G is constant then density increases means velocity will decrease. So, it is not satisfying actually is not true because when your density your increases your G is not constant G is also increases.

So, so G is also increased; so that is why overall the velocity of the soil increases. So, if your density increases, shear modulus is also increased and the velocity of the wave is also increased.

So, this with this and note I am finishing this today's lecture. So, this is the last lecture of soil exploration. So, next class I will discuss about the shallow foundation and then there I will discuss how these properties will use to design our foundation.

Thank you.