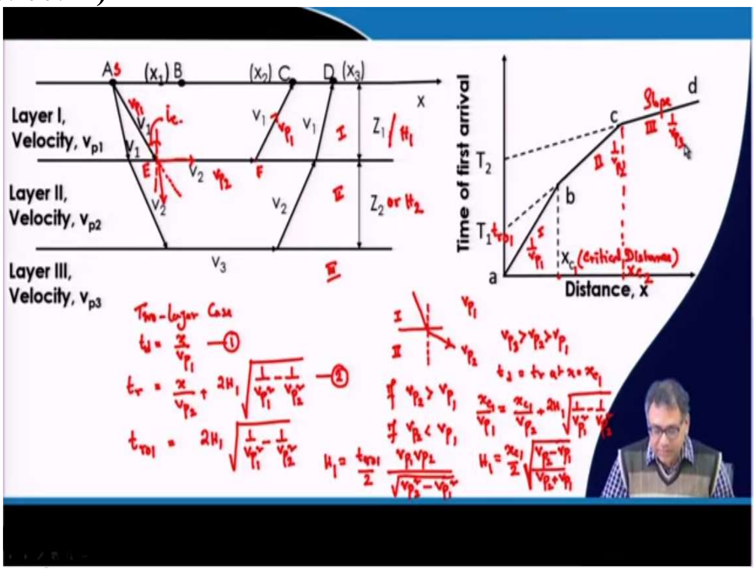
Advanced Foundation Engineering
Prof. Kousik Deb
Department of Civil Engineering
Indian Institute of Technology – Kharagpur

Lecture – 06
Soil Exploration – VI

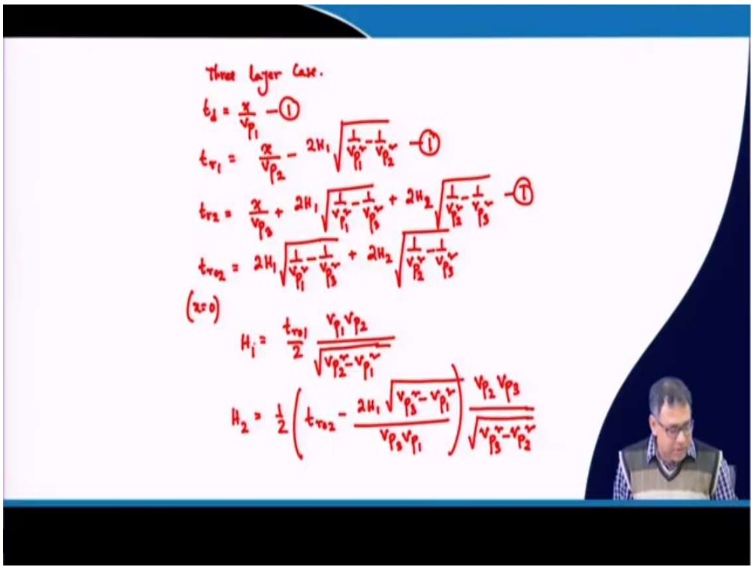
So, last class I have discussed about the seismic refraction test and I discussed about the 2 layer case. Now, this lecture, I will first discuss about the 3 layer case then I will solve 1 particular problem.

(Refer Slide Time: 00:44)



So, now this seismic refraction test as I was discussing that there will be a critical distance. So, if I put geophone within the distance X_{C1} then the direct ray will reach first if I put the geophone within the X_{C1} and X_{C2} the refracted rays passing through the interface of first and second layer will reach first and if I put a geophone beyond X_{C1} then the refracted rays passing to the interface between second and third layer will reach first and this is the expression and the 2 methodologies by which we can determine the thickness of the first layer.

(Refer Slide Time: 01:30)



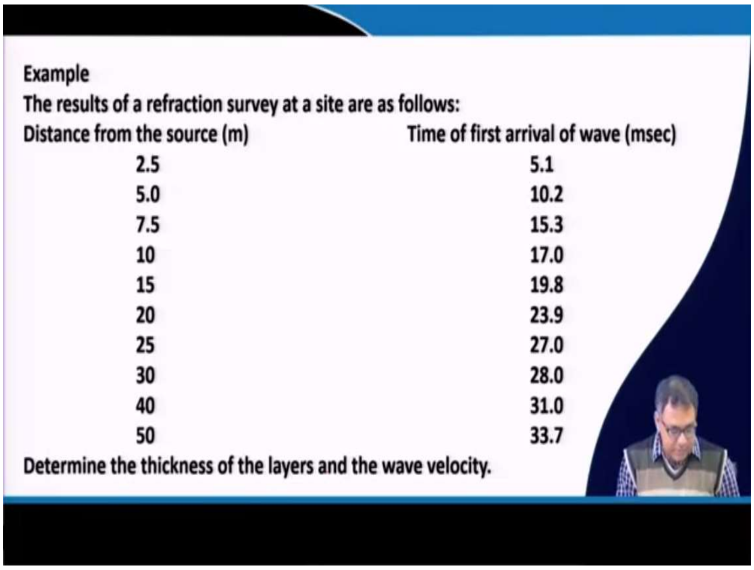
Now, I will discuss about the 3 layer case. So, the 3-layer case a similar type of expression I will give, so, $t_d = \frac{x}{v_{p1}}$, this is expression 1 and $t_{r1} = \frac{x}{v_{p2}} + 2H_1\sqrt{\frac{1}{v_{p1}^2} - \frac{1}{v_{p2}^2}}$. So, this is the t_{r1} that means the refracted rays travelling through the interface of first and second layer. Now for the second- and third-layer refracted rays t_{r2} that expression is $\frac{x}{v_{p3}} + 2H_1\sqrt{\frac{1}{v_{p1}^2} - \frac{1}{v_{p3}^2}} + 2H_1\sqrt{\frac{1}{v_{p2}^2} - \frac{1}{v_{p3}^2}}$.

So, similar to the first case or 2-layer case in the 3-layer case also we have to extend these because this line and then this will give us t_{r02}. Now if I put this value the t_{r02} here, so, I will get this is the t_{r02} at $x = 0$. So, I will get $2H_1\sqrt{\frac{1}{v_{p1}^2} - \frac{1}{v_{p3}^2}} + 2H_1\sqrt{\frac{1}{v_{p2}^2} - \frac{1}{v_{p3}^2}}$. So here I have already discussed how I will get the H_1.

So H_1 expression is given only in terms of time so $\frac{t_{r01}}{2}\frac{v_{p1}v_{p2}}{\sqrt{v_{p2}^2 - v_{p1}^2}}$ so this is the expression of H_1. So by using v_{p1}, v_{p2}, v_{p3} , I will get from the slope of the curve then I will get the H_1 from this expression and t_{r01} I will get from the curve this is and so I will get the H_1 all the velocities the only unknown is H_2 .So, I will get the thickness of the second layer also.

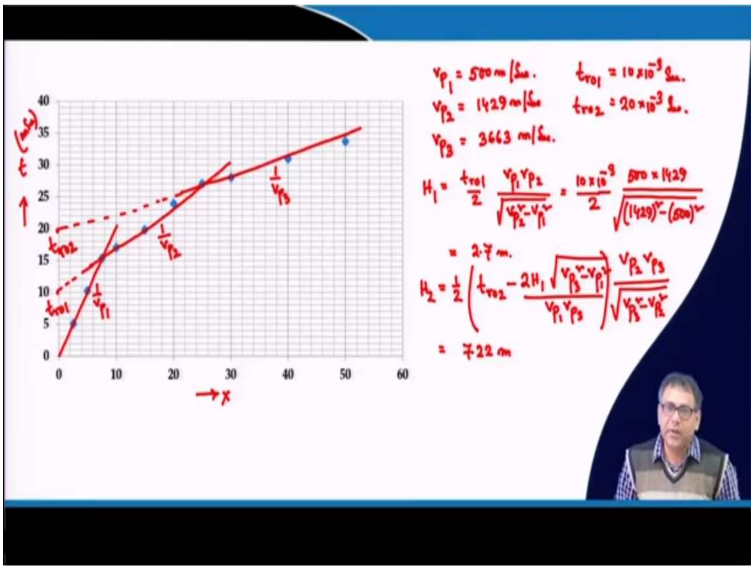
The H_2 is in that way $\frac{1}{2}\left(t_{r02}-\frac{2H_1\sqrt{v_{p3}^2-v_{p1}^2}}{v_{p3}v_{p1}}\right)\frac{v_{p2}v_{p3}}{\sqrt{v_{p3}^2-v_{p2}^2}}$. So this is the expression of H_1 and H_2 and I will discuss how I will get the H_1 and H_2.

(Refer Slide Time: 05:51)



So now I will solve one example problem that this is the example problem that we have done a refraction test at a site. And these are the distance from source to the geophone or the receiver and the distance from the source and this is the time of first arrival of wave. In the fast arrival of the wave and that is in milliseconds and we have determined the thickness of the layers and the wave velocity.

(Refer Slide Time: 06:25)



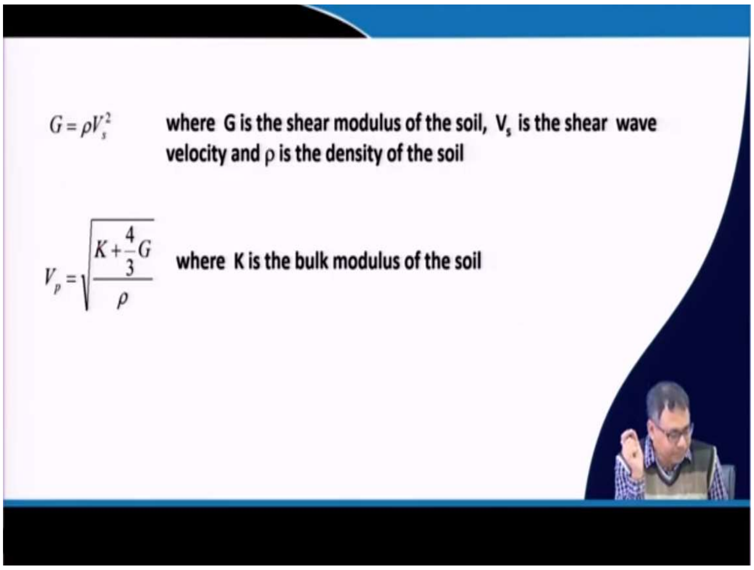
So, I have drawn the graph here. So, I plot all the values in a excel sheet and then this is the distance x and this is t time. So, from this graph, I can see that this is one slope and this is another slope and this is another slope. So, I plotted all the points corresponding to x and t because I know that this is the time and distance. So, this time and distance are plotted in this graph and this time is the first arrival time of the wave.

So, I will get 3 slopes that means the 3-layer case, so, it is the 3-layer case and this will give us the v_{p1} the slope of this straight portion 1 / v_{p1}, this is 1 / v_{p2}, this is 1 / v_{p3}. So, from here I can write that v_{p1} is coming out to be 500 metre per second, then v_{p2} is coming out to be 1429 metre per second, and v_{p3} is 3663 metre per second. Now, if I extend this line and this one also if I extend this line I will get this value this is t_{r01} this is t_{r02}.

Now, t_{r01} from the plot it is 10 and it is in milliseconds. So, in second I can write 10×10^{-3} second and t_{r02} it is 20 milliseconds. So this is 20×10^{-3} seconds. So, now if I put I know the velocity if I put the H_1, so, H_1 expression I know this is $\frac{t_{r01}}{2}\frac{v_{p1}v_{p2}}{\sqrt{v_{p2}^2-v_{p1}^2}}$. So, if I put these values that mean $\frac{10 \times 10^{-3}}{2}\frac{500 \times 1429}{\sqrt{1429^2-500^2}}$. So, I will get the thickness 2.7 metre.

Similarly for the H_2 the expression is given that is $\frac{1}{2}\left(t_{r02} - \frac{2H_1\sqrt{v_{p3}^2 - v_{p1}^2}}{v_{p3}v_{p1}}\right)\frac{v_{p2}v_{p3}}{\sqrt{v_{p3}^2 - v_{p2}^2}}$. So, if I know all this value I know each one I will see if I put these values I will get 7.22 metre. So, the soil I can determine the thickness of the layer as well as the velocity of different soil layers. Now, this velocity we can use for soil properties calculation because these velocities are used for soil properties calculation.

(Refer Slide Time: 11:12)



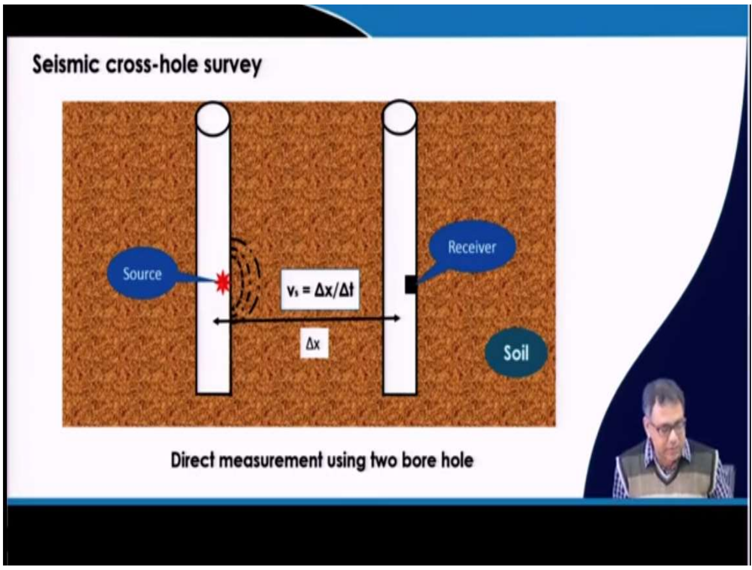
Now, we can calculate the shear modulus, G which is ρV_s^2 and $V_s = \sqrt{\frac{K+\frac{4}{3}G}{\rho}}$, where, K is the bulk modulus of the soil. Now, what are V_s and V_p, this V_p is the velocity of the primary wave and V_s is the velocity of the shear wave. So, these are all body waves that we will generate during the impact. So, the V_p is the velocity of the primary wave and V_s is the velocity of the shear wave. Now, this depending upon how you are generating the wave you can generate V_s or V_p.

So, now, which way we are generating suppose, if you are generating V_s then you will measure the velocity of the shear wave and because I have derived all the equations by considering V_p velocity of your primary wave, but you can generate the shear wave also if you generate the shear wave then you will measure the velocity of the shear wave or velocity of the P wave or the primary wave.

So, that means if you are using the velocity of the shear wave then you know the velocity of the wave, ρ is the density of the soil then you can determine the shear modulus and if you know the velocity of the P wave and then you can determine the bulk modulus of the soil also. So, but as I mentioned in the refraction wave it will give you the proper result if the velocity of the third layer is greater than the velocity of the second layer is greater than the velocity of the first layer.

And most of the cases this is the normal trend of the soil velocity that means, that your density of the soil increases as depth increases because of the overburden, but sometimes if it is not the case that means the density is not increasing with the depth or there is a very soft layer between 2 dense layers.

(Refer Slide Time: 13:44)

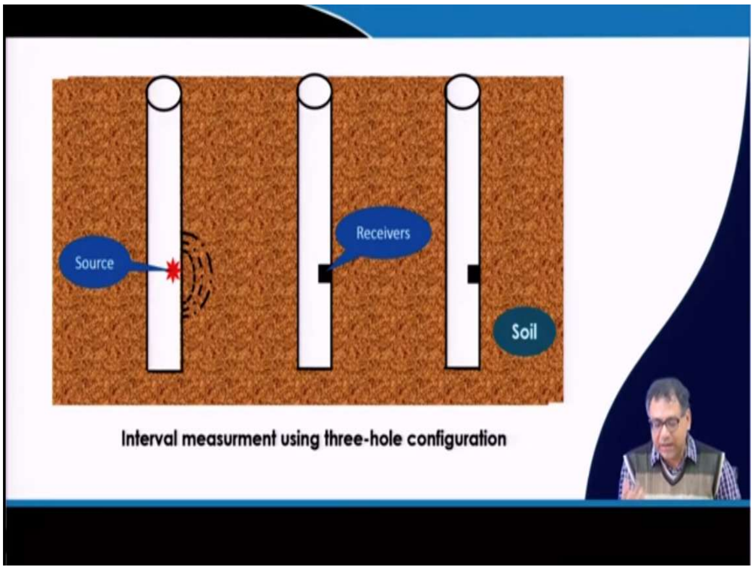


In such case this refraction wave will not give you the proper result. So, in such case you have to go for the seismic cross-hole survey where to construct a borehole and then we put the source inside the borehole and then another borehole you put the receiver we know the distance and we measure the travel time then we will get the velocity, but with the previous test that when the refraction test I mean time requirement is less because we do not need to construct the borehole.

But in the Seismic cross-hole survey, we have to go for the borehole, so it will take more time. So here we can identify the change of the layer also as we are going for the borehole. So we have the borehole data and we have the soil profile we can identify and at required point we can measure the velocity also. But it is time consuming. But sometimes a single borehole is also used. In that case the source, either source or the receiver is placed within the borehole or the receiver is placed at the ground surface.

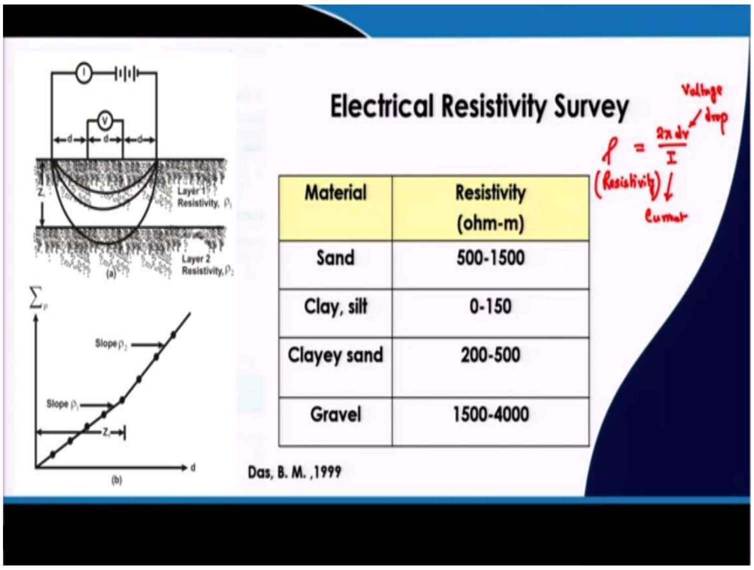
Now, if the receiver is placed at the ground surface and source is within the borehole below the ground surface then this is called seismic or full survey and if the receiver is below the ground surface within the borehole and the source is at the ground surface, then it is called seismic down hole survey or down hole test. So, that means, either you go for the seismic cross-hole survey or seismic half hole survey or seismic down hole survey.

(Refer Slide Time: 15:38)



Now this is you can go for the 3 borehole case also that means source and 2 receivers. So, here you can 1 borehole there is a possibility of the error so, that we can reduce also and then we will get the soil property.

(Refer Slide Time: 15:59)



Now, the last type of seismic refraction geophysical exploration is the electrical resistivity survey. So, in this electrical resistivity survey, we basically pass the current through the soil and then we measure the voltage drop and then finally, based on that we measure the resistivity of the soil. Now, this resistivity when you get the resistivity of the soil and from this chart also I can give the different range of the resistivity for different soil. So, for sand clay, clay, sand gravel, so, these are the different range.

So, from this chart I can identify which type of soil it is based on the resistivity value that I will obtain. In addition to that I can determine the thickness of each layer also suppose for homogeneous soil, what we will do for homogeneous soil in all the cases the 4 electrodes are used. These 4 electrodes, this is 1,2,3,4 and they are driven into the soil at the ground surface and the outer 2 electrodes are used to send the electrical current and the inner 2 electrodes are used to measure the voltage drop.

And I can calculate the resistivity ρ by this expression this is $\frac{2\pi dv}{I}$. So, I is the current and v is the voltage drop and d is the distance between the electrodes. So, these distances are generally equal. So, that means these electrodes are equally spaced and these distances d, so, for the homogeneous case we know what the resistivity is and we will get the value.

So, we will pass the current and then we will measure the voltage drop and then by using this equations we will get the resistivity of the soil. And by using this chart I can identify which type of soil it is, but if it is a layered soil, then also we can measure the resistivity for each layer and the thickness of the layer in such case what do we do that we change this distance between the electrodes.

So, we change them and we take the measurement for different d values. So, measure this resistivity for different d values and then I will put them in this way. So, I will plot them. So, this is the x axis is that d is the different distance and y axis is the summation of the resistivity, the summation of the ρ. So, this is the d_1 and then the resistivity and next one d_2 and the summation of the resistivity and every time you have to sum the resistivity.

And then I will get this type of plot and then the slope of each plot will give us the resistivity for each layer, and where the slope is changing that distance from the origin will be along the distance axis will give us the thickness of layer. So, this way we can determine the different soil properties or the resistivity of the soil and then different type of soil and the thickness of the soil layer. So, that means we can perform it for homogenous soil as well as the layered soil.

So, this way I have covered the soil exploration part. So, I have covered almost the major or the important tests that in-situ tests those are conducted in site to determine the define soil properties. So, some are directly we can determine the soil properties in some case we have to measure the something else then we can correlate those things with the soil properties, those are required for design purpose and sometimes we can identify the type of soil also by using these types of tests.

So, in the next class I will start the design part that means, the shallow foundation part how I can use these soil properties that we have measured or we measure from the soil exploration then how we can use them to design the foundation. So, initial part I will discuss the shallow foundation then I will go for the deep foundation. So, in the next class, I will start the bearing capacity of the shallow foundation. Thank you.