

**Geotechnical Engineering II / Foundation Engineering**  
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**Lecture – 26**  
**Geotechnical Investigation (Contd.)**

Good morning. So, let me continue with field investigation and that too by direct field investigation. So, the direct field testing and we have I have discussed about the SPT test; what is SPT test, how to utilize it and then if I carry out test in the field whether we can directly using in the calculation or you have to do something. So, I have mentioned that there are some corrections and most important correction perhaps is the overburden correction and how to apply overburden correction that also I have shown that through application.

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**Geotechnical Investigation**

**Cone Penetration Test**

- Newer method
- Good for developing profile (continuous) but do not get sample
- Faster and less expensive than drilling and SPT
- Use in conjunction with SPT
- Measures friction and cohesion, also can measure pore pressure and shear wave velocity (with piezocone).

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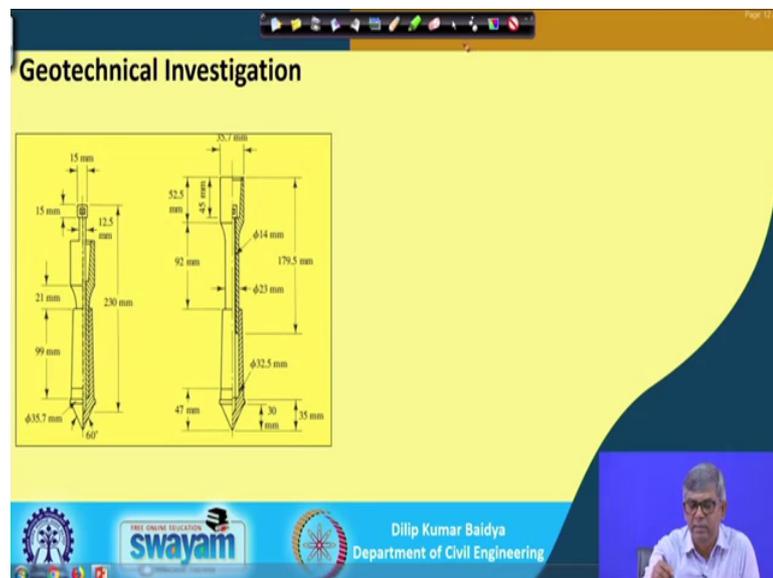
Now, I will discuss about some other technique that is actually your cone penetration test. This is becoming popular now actually in our country still it is not that popular, but it is still it is coming because of many foreign consultant here doing a lot of work. So, because of that this also becoming popular, and this is a comparatively new method and good for developing profile continuous profile; that means, you are when you are doing SPT actually suppose if there is a soil mark and SPT actually over depth, you do 1.5 meter or 3 meter or 4.5 like that discreet we are getting data at this point at this point at

this point whereas, cone penetration test continuously we will get some you know profile like this.

So, with each and every point whatever register is getting directly you are recording. So, continuous resistance profile we will get and that will be correlated to different soil properties and all that is there and it is very fast and less expensive and than drilling an SPT. When that means SPT actually the main part is you have to first of all you have to make a borehole and then at different depth, you have to conduct test and then go beyond like that. But here there is no point of bore making borehole you have to continually push the cone. So, that is why it is faster and is also economic and it can be used in conjunction SPT; SPT wherever SPT is done in this case can be done also this and measures friction and cohesion separately can be made.

And some time by using piezo cone. So, you can put pressure, you can measure you can shear wave velocity also you can measure. So, there are so many advancement in this, but we have very little information. So, information is there, but I do not want to burden you by giving too much of this.

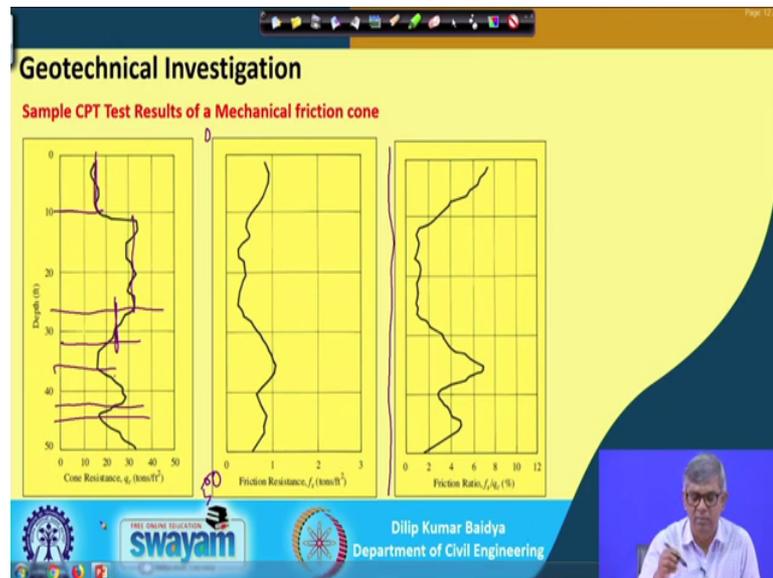
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So, just minimum I just mention here that typically a cone, cone penetration instrument looks like main part of this is the this one, they have these dimensions actually this is the one and when it is collapsed that we can we extend it.

So, this becomes the dimensions different parts, dimension or different parts are shown here. So, through this actually when you will be pushing, there will be arrangement for recording the value friction value and resistance values.

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So, that will be I will show you the next slide and you can see that you can see that this is the one this is a way actually get the resistance actually cone resistance  $q_c$  that is total resistance over depth. So, 0 to 50 meter the profile resistors profile is given and friction resistance if it is separated, then over depth same over depth 0 to 50 meter this is the distribution we get and here actually another can be separated  $f_s$  by  $q_c$  in percent actually that also can be obtained.

So, this is the way actually CPT data we get and once you get the data and you can see the this is that variation. So, it is continuously variation then how to find out every point the different soil will be treated like that no actually I can see that this is the average value. So, up to this there is one layer and you can see this is the layer, this is this must be the another layer. So, again from here that may be continuous change.

So, we can consider one layer somewhere here with some average value, they are also can be considered another layer, this can be considered another layer, this can be considered another layer, this can be considered another layer like that we can visualize by seeing these how many layers are there in this and accordingly we can correlate and with the different soil properties.

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**Geotechnical Investigation**

**Other methods:**

- Geophysical-seismic refraction, cross hole, down hole, up hole, electrical resistivity etc.
- Vane shear
- Pressure meter etc.

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Next actually other methods. Other geophysical method one is SPT that I have mentioned and this other methods are actually one is geophysical methods and you can see geophysical is the main then under that there will be seismic refraction, cross hole, down hole, up hole then electrical resistivity's, seismic deflection also can be there.

So, there are so, many then there can be vane shear test for some soil, then there may be pressure meter test there are several other test also there field test. So, will discuss by a large this 2 pressure meter will not be able to discuss here, but this 2 at least will try to discuss.

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**Geotechnical Investigation**

**Geophysical method :**

Boring and test pits is time consuming and expensive  
Gives subsurface conditions only at boring or test pit locations

Geophysical method is quick, less expensive, can cover greater area thoroughly. But results are more in qualitative nature.

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So, geophysical method actually before geophysical method what we were discussing that cone penetration or CPT whatever, generally SPT if you do then only you have to do boring and then you have to do the test speed and it will take time an expensive and give subsurface conditions only at boring or test points; that means, if I conduct the SPT test at a particular; suppose this is a site sorry.

So, this is the site suppose this is a site, and I have carried out SPT here, I have carried out SPT here, I carried out SPT somewhere here; that means, whatever information am getting related to this point, this point and this point and I am considering the average all three is a site condition sometime. So, that is what; that means, we are getting the information for a particular point.

So, that is the limitation of this type of SPT and CPT test whereas, geophysical method is quick and less expensive can cover greater area thoroughly; that means, if I started this one I can get the entire area how is it is and, but results are more in qualitative nature; that means, non exemption range will get not exact value will get. So, that is the limitation, but it is quite quick and to get the continuous information. So, for that geophysical method is also important and many times we use and very quickly it can be done it can be covered in large area.

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**Geotechnical Investigation**

**Geophysical Method**

**Seismic method:**

- Seismic Reflection ✓
- Seismic Refraction ✓
- Seismic Up Hole ✓
- Seismic Down Hole ✓
- Seismic cross Hole ✓

Electrical resistivity method

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So, will discuss one by one some geophysical method that is you can say first under these again you can see, there is a seismic reflection, seismic refraction, seismic up hole, seismic down hole, seismic cross hole and electrical resistivity.

There are so, many methods and let us discuss one by one. Suppose seismic reflection is nothing actually seismic reflection is just if I know this and I can find out the from here to here travel time if you know, then I can find out the velocity actually if I know other details. This distance if I know and all and these depth you know then I can find out the velocity. So, this is some time to find out the depth of the sea and other thing this is used, but otherwise in soil most of the time we do seismic refractions is up hole down hole and cross hole.

So, I will discuss that actually in detail.

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**Geotechnical Investigation**

**Seismic refraction method:** First arrival time of P waves are recorded through a seismogram, then travel time vs travel distance plot. From the plot one can obtain Thickness of the layers and velocity of waves through each layer which is related to the shear modulus/elastic modulus of the soils.

$$v_s = \frac{v_p}{\sqrt{3}}$$

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So, seismic refraction method. So, in these actually there are a number of waves will be coming and that first arrival time of the P waves are recorded. That is most important in the instrument that is the arrangement will be there. The P waves first arrived that will be recorded in the seismogram and then travel time verses travel distance plot will be done and from the plot one can obtain thickness of the layers and velocity of waves through each layer and which is related to the shear modulus and elastic modulus of the soil.

So; that means, if I know the velocity, and velocity of the particular layer actually if I know the velocity that is what to be actually rho vs square actually. So, from here actually we can get the shear wave velocity if I know the velocity.

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The slide is titled "Geotechnical Investigation" and features two diagrams illustrating seismic refraction. The left diagram shows a cross-section of the ground with an "Explosion" source, "Wires" connecting to a "Seismograph", and "Detectors" placed at various "Distances in Solid Rock". It also labels "Soil" and "Shear Strength Soil". The right diagram is a graph of "Time of Wave Travel" versus "Distance from the Shock Source", showing two lines: "Line 1" and "Line 2". Handwritten notes on the graph include  $y = mx + c$ ,  $y = mx$ , and  $v = \frac{L}{t}$ . Below the graph, it states: "Note:  $v_1 = \text{Reciprocal of the Slope of Line 1}$ " and " $v_2 = \text{Reciprocal of the Slope of Line 2}$ ". At the bottom of the slide, there are logos for "swayam" and "Dilip Kumar Baidya, Department of Civil Engineering". A small video inset shows a man speaking.

So, that seismic refraction shall be as our test as I have mentioned that I want to discuss and we can see the testing method is like there will be a explosion or source were actually we generate waves.

And when the waves generates the waves will be moving in different direction of course, and we can see there will be a number of receivers are kept and the soil maybe stratified and then what will happen? When waves can go in a number of ways waves can go directly to this to this like this, and sometimes waves can strike here and then move with this and then again reflect back at least to some somewhere like this. So, partly reflected and partly refracted.

So, this way that travel waves can move this way or waves can move this way like that and traveling by these 2 ways which one is faster actually that will be recorded. So, you can see that there may be few pickups were straight path because this test actually will be applicable when  $v_1$  is less than  $v_2$  that mean this layer actually shear of velocity higher so, because of that though this is going this way, but when straightaway the lower velocity. So, still if it goes by this way still it may reach faster here this way because the velocity here is less. So, that is the way actually. So, number of this there will be explosion or source point and there will be receiver that when there are a number of points where wave actually we are recording the arrival time.

So; that means, from this point to this point, waves are arriving at what time how much time it is taking and will not be able to identify initially whether it has come from this way or it has come from this way, if you plot only then only we will be able to find out. So, this actually what actually happen? So, if it travel these way direct path then it will be same material. So, velocity will be distance or  $L$  divided by  $t$  will be velocity and it will be for everyone it will be applicable. So, it will be linear so; that means, up to the (Refer Time: 12:24) directly it direct path it has it has come faster; that means, they will be representing these points and when there may be some points where the this path its coming faster they are also they will also follow linear why it is so?

Because you can see when the waves are coming from here to here and then traveling this way and then reflecting here. So, these and this and there are three parts ok. So, these and these one part that is traveling with the first material and this is actually traveling with the second material similarly if I if it goes from here and then move this way and then this way and you can see, these and this part again traveling through first material and this part is traveling through second material.

Now these and these and these and these are same why it is same? Because this reflection angle and refraction angle depends on the material actually by snells formula or the snells law. So, this and this angle and this angle will be same so; that means, this distance and this distance will be same at this 2 distance will be same and together and similarly these and these also will be same. So, because of that when the particular wave is traveling from here to this way and this, here to this way and these.

So, these 2 points if I plot travel time versus distance then also will be linear. Here actually directly linear means here it was  $y$  equal to  $mx$  form and this part actually this plus these actually traveling through the first material. So, that will again these plus these traveling with the first material that then it will be constant part.

So, second line will be equation will be  $y$  equal to  $mx$  plus  $c$ . So,  $mx$  plus  $c$ ; that means, travel this distance by this distance divided by velocity whatever time that is actually becoming the constant. So, this is  $c$ . So, so that is why this line if I extend, this line if I extend you can see this equation of this line is nothing, but  $y$  equal to  $mx$  plus  $c$  whereas, this line is  $ma$   $y$  equal to  $mx$ . So, that means, if there is a stratification and if I generate waves, and keep number of receiver in front then some of the waves will be reaching

directly to the receiver, some of the waves will go to the second layer and then some of the partly it will be reflected and partly it will be refracted.

So, reflection part will reach to the receiver little away and like their subsequent other receiver also received this path also. But while we plot we will see that your distance versus travel time this plot will be linear, initial few records maybe linear that represents that they are coming directly. In another few records maybe again linear, but it is linear with a form  $y$  equals  $mx$  plus  $c$ ; that means, there is a constant part with  $mx$  so; that means, that is again representing another layer. Like that if a get a subsequently another slope then that will represent third layer. Like that distance versus travel time if you plot simply in a graph paper, then by I express estimation we can think you can imagine you can visualize that the a bunch of datas representing a straight line; that means, those portion is actually through the particular layer like that.

So, that represent slope of this line represents actually inverse of velocity of first layer, similarly slope of this line is giving a inverse of velocity of the second layer. So, that is the way actually you have to utilize the refraction method for finding out shear wave velocity. So, next is so; that means, we will have the source here and we will keep number of receiver in line, and then the wave actually will try to move different ways actually that and our condition is fast arrival time to be recorded and fast arrival when they are going directly maybe in few records.

So, they will represent one straight line and next subsequently there may be few records coming through this way faster than direct path, that will represent also another straight line. So, slope of this line will be inverse of velocity of second line second layer, slope of that line will be inverse of velocity of the first layer and this intersecting point of this 2 straight line will give you the thickness of actually some calculation will see that is actually to be recorded actually some number  $L_1$  suppose and that  $L_1$  will be used to calculate the thickness of the layer.

So, I will come to that subsequently.

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**Geotechnical Investigation**

$v_1 = \frac{L_2 - L_1}{t_2 - t_1}$   
 $v_2 = \frac{1}{2} \sqrt{\frac{v_2 - v_1}{v_1 + v_2}}$

$H_1 = \frac{1}{2} \sqrt{\frac{v_2 - v_1}{v_1 + v_2}}$

$L = \frac{t}{L}$

**v1 is the wave velocity of the layer 1, inverse of the slope of the distance versus travel time plot**

**v2 is the wave velocity in the second layer, inverse of the slope of the second part of the distance versus travel time plot**

**H1 is the thickness of the top layer**

**L is the distance taken from the distance versus travel time plot where the two slopes intersect**

The slide features a yellow background with handwritten annotations in red and black. It includes two graphs: one showing a single line with a slope and a point (t, L), and another showing two lines with different slopes intersecting at a point. The Swamyam logo and the name of the presenter, Dilip Kumar Baidya, are visible at the bottom.

You can see here that  $v_1$  is the wave velocity of the layer one inverse of the slope of the. So, I can if I know 2 points if I suppose if I this is actually if I know these points. So, this is  $L_1$  and this is  $L_2$ . So,  $L_2 - L_1$  is distance and  $t_2 - t_1$  is the  $v_1$ . So, here distance by time is actually  $v_1$ , that actually we can find out; but if I want to find out slope of this line. So, this is  $t$  and this is  $t$  and this is  $L$  if I find out the slope of this line, it is becoming  $t$  over  $L$ . So, that is why inverse of slope will be velocity.

So, inverse of slope inverse of slope of the distance versus travel time plot will be velocity one. Directly otherwise on the line we can fix 2 points and to read the velocity, and those 2 points you find read the time. So, difference of velocity divide by I sorry difference of time divided by difference of difference of length divided by difference of time, gives you velocity 1 or we directly if you plot a graph paper you just measure the slope and then inverse it that will give you also directly the velocity of the of that particular layer. And similarly if the second part of the line suppose if there is the another line something like this, then again you can fix one or 2 points and they are also you can find out  $L_1$   $L_2$  or whatever number and  $t_2 - t_1$  and then you can do there also you can get the velocity.

Otherwise you can again find out the slope of this line, an inverse of that will be velocity of that line and  $H_1$  can be calculated that is actually; that means, thickness of the layer will be the half multiplied by  $v_2 - v_1$  by  $v_1 + v_2$ . So, by this formula. So, so.

So, no here actually there is something missing this formula may be wrong I have to correct there will be L should be there actually this L should be coming into this equation, I will correct it later on. So, L is the distance taking from the first distance; that means, as I have told you that there is a one part is these and this line and another line is suppose these, so, intersecting point of these 2 lines that is actually L. So, that L should come in this calculation H 1 calculation.

So, that I will may be correct later on. So, this is the way actually we do the correction for we do the by seismic refraction method we find out the velocity of the layers, and if you know the velocity of the layer then actually you can find out the shear of velocity there is related shear of velocity is related to velocity of the this velocity.

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Distance from the shot point (m)	2.5	5	7.5	10	15	20	25	30
Time of first arrival (ms)	11.2	23.3	33.5	42.4	50.9	57.2	64.4	68.6

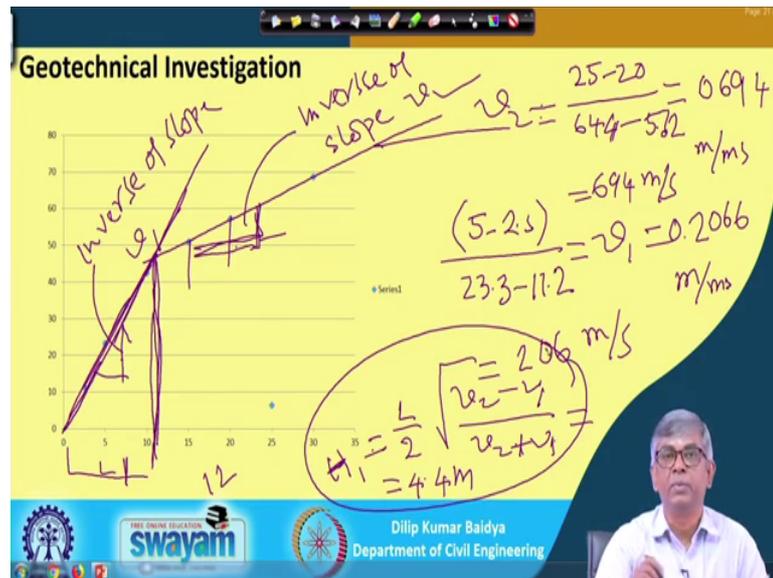
So, this is the problem actually suppose if the data is like this.

So, one set of data is given, that distance from the short point; that means, as I have mentioned that you have the source somewhere here and we have explored and some velocity waves are generated and then it will move like this ok. So, the receivers and if there is a layer, then it will go like these, it will go like this then if it is like this then it will go like this like that.

So, number of receivers are there and the distance from the short point 2.5 7.5 10 15 20 25 30 like that is given and time of fast arrival suppose it is millisecond 11.2 23.3 these

are the things are given. So, by using this you have to find out the velocity of the shear of velocity in the 2 layers of the soil and you have to possibly you have to find out the thickness of the layer. So, this one if you plot now, if I have attempted to plot this one in the excel and I can show you how it is coming.

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We can see that the excel came like this 2 point and you can see that these are the four points by a large straight line you can see and another thing actually these three points and again by a large straight line ok. So, now, from here actually; that means, for calculation of thickness this will be give you a L 1 and you can find out the slope of this line; either slope of this line or I can find out L 2 minus L 1 by t 2 minus t 1 and if I do that, then you will get like this velocity will be something if you do this one for this one.

So, the if I consider these are all in line then it will be 5 minus 2.5 that is L 2 minus L 1 divided by t 2 minus t 1; that means, 23.3 minus 11.2 and that supposed to v 1. So, if I calculate this will be 5 minus. So, it will be 2.5 divided by 23.3 minus 11.2 that gives you 0.2066, it gives you 0.2066 meter per millisecond. So, if I make if I make meter per second. So, it will be 206 meter per second ok.

So, similarly if I have taken first 2 similarly I can take 2 and 3 between that also we can calculate and similarly I want to find out the slope of this line a velocity of these then I can take this 2 reading. So, that is actually if I do that. So, I want to find out v 2 suppose. For v 2 calculation I will take suppose these and these 2 points. So, these 2 points

basically I have these 2 points your velocity is 25 minus 20 25 minus 20 that way 5 divided by your 57 64.4 minus 57.2 that gives you point that gives you it will be 25 minus 20 divided by 64.4 minus 57.2 this is actually sorry 57.2 this gives you 0.694 meter per millisecond and if I convert in to meter per second, then it will be 694 meters per second.

So, and this is actually by I have assuming this three point exactly to straight line and based on that I have calculated the similar like assume that this all four lines are exactly the straight line, then I have taken that one and using those I calculate otherwise. If you take a plane paper of graph sheet and plot this one and then you find out the slope of this, find out slope of this sorry slope of this line slope of these line. So, inverse of this slope inverse of the slope an inverse of this slope this is inverse of this slope this is  $v_1$  and this is inverse of this slope become  $v_2$  and this will be  $L_1$ .

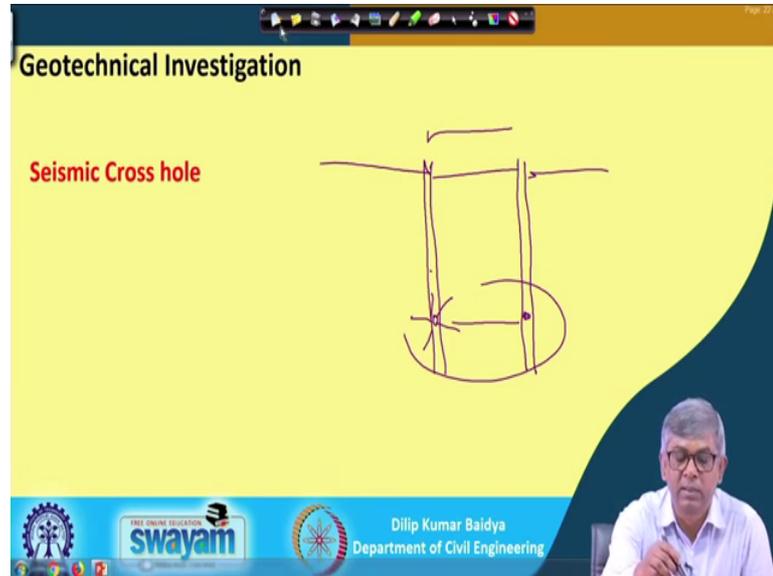
And  $L_1$  will be used to calculate  $H_1$  by that formula and that formula it will be basically it will be  $L$  by 2 that is actually  $L$  instead of  $L$  by 2 multiplied by  $v_2$  minus  $v_1$ ,  $v_2$  minus  $v_1$  by  $v_2$  plus  $v_1$  so; that means, it will be that is 200 this is 206 and 694. So, it will be 694 minus 206 that divided by 694 plus 206 that. So, it become 0.54 under root 0.54, that we have 0.73 multiplied by this distance will be coming something around 11 or.

So, 11 or 12 it will come. So, your this distance will be multiplied by if I take 12 and divided by 2 so; that means, 4.4. So, this gives you the  $H_1$  that means, the thickness of the first layer is around 4.4 meters so; that means, this is the way actually one has to do the calculations; that means, if you get if you generate a disturbance at a particular source point and if you keep a number of the receiver in the same line, then we get the first arrival time recorded and then you find out the time to first arrival a distance, then plot distance versus travel time and then we will see the data then will see that a bunch of data will be in a straight lines.

So, that bunch initial bunch of straight line we connected by one straightline, subsequently other bunch of secondary data can be can be connected by straight line and then slope inverse of slope of this line will be velocity 1 inverse of slope of this line will be velocity 2 if I get another line also inverse of slope velocity will be 3 also. So, that I have not discussed, but if a then 2 straight line is intersecting at a particular point that

intersecting point to be measured from here and that to be used for calculation of thickness of the first layer. So, that is the way one can do the calculation ok.

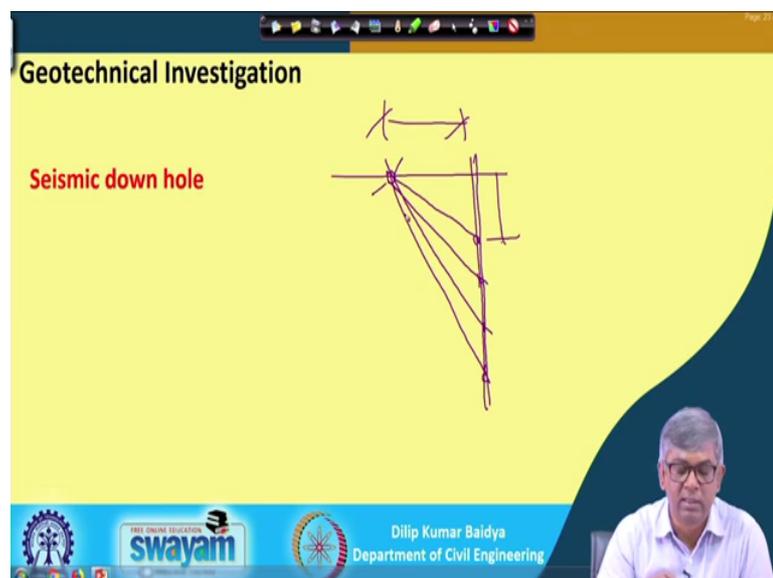
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So, maybe then seismic cross hole this is a method actually I will just quickly I will show this is the ground surface and there will be one bore hole will be made and this will be another borehole will be made, and there will be source here; that means, some disturbance will be kept and receiver will be here.

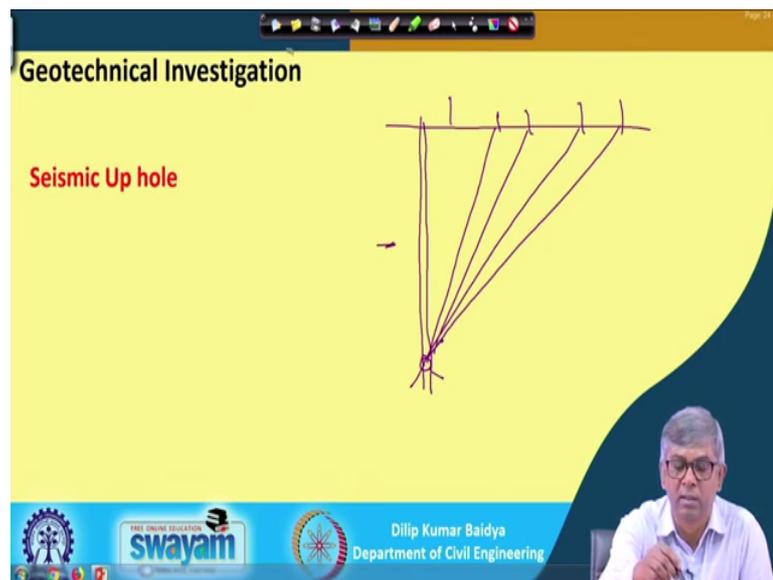
So, the if I know the distance by recording a different depth, we can find out the velocity.

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Similar to these, there is a seismic down hole; that means, you we make a sorry we make a disturbance, we make a disturbance on a surface suppose this is down hole and in the borehole actually from different location we can receive. So, this will be the receiver this is the different distance we can find out, at how what distance from if you know that this distance and if you know this distance then and if I record a travel time from here actually we get the velocity.

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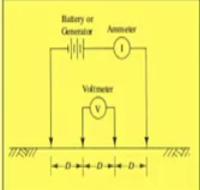


Similar to these we have half hole; actually half hole is just reverse; that means, in the borehole itself will put disturbance.

And on the surface will keep receivers. So, it will go this way, this way, this way, this way and if I know these distance and if I know this distance that we can find out the velocity.

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**Geotechnical Investigation**  
**Electrical Resistivity Method**



A soil's resistivity generally varies inversely with its water content and dissolved ion concentration. Because clayey soils exhibit high dissolved ion concentrations, wet clayey soils have the lowest resistivities of all soil materials—as low as 1.5 ohm · m. Coarse, dry sand and gravel deposits and massive bedded and hard bedrocks have the highest resistivities 2400 ohm · m.

**Resistance to movement of an electrical current through soil is determined in the electrical resistivity method.**



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So, like that there are several seismic methods are available, and then afterwards sorry and of course, geophysical another geophysical method is resistivity method perhaps I will take this one next class I will stop here.

Thank you.