Rock Mechanics and Tunnelling
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Lecture 11
Geophysical Methods (Continued)

Hello everyone, I welcome all of you to the course Rock Mechanics and Tunnelling and it is our fifth lecture of second module. So, we were discussing about geophysical methods.

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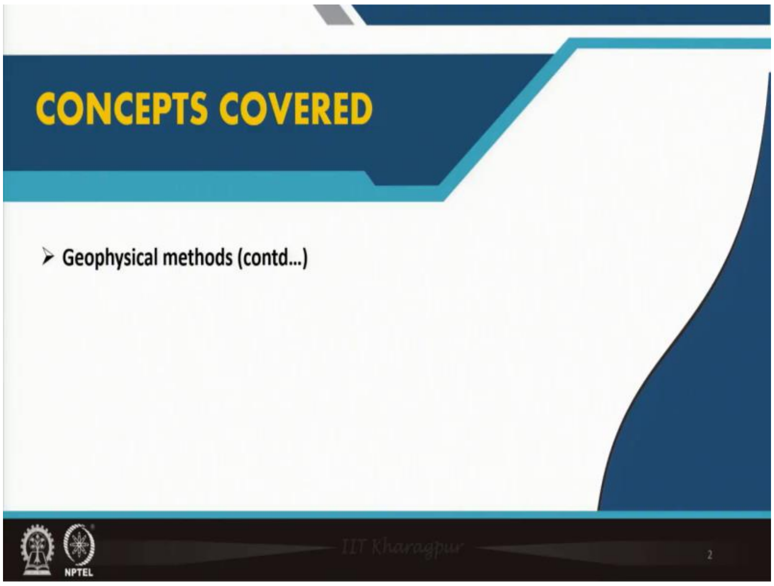

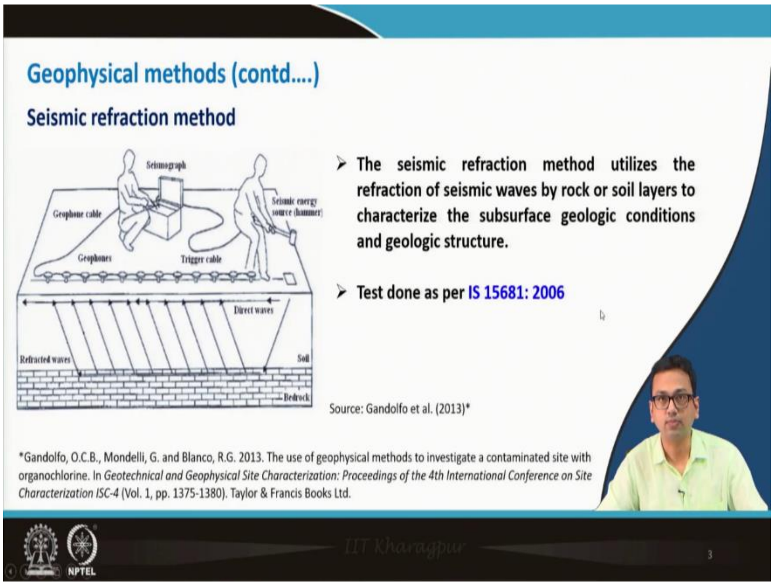

In our previous class, we started discussing our seismic refraction method, before that, we have completed seismic reflection method in detail and solved a example problem also. So now, we will continue our discussion related to seismic refraction method.

So, this is a schematic diagram (slide 3) as you can see the person is hitting on the ground with the help of a hammer and then the ray is going then getting refracted and coming out here, these are the geophones or receivers. They will receive the signals and these are the direct waves. So, we have to notice direct wave as well as look into these refracted waves.

So, this is the instrument where the details are getting recorded. We have seen that the seismic refraction method utilises the refraction of seismic waves by rock or soil layers to characterise the subsurface geologic conditions and geologic structure. So, for conducting the seismic refraction test, we can get some guideline from IS 15681: 2006.

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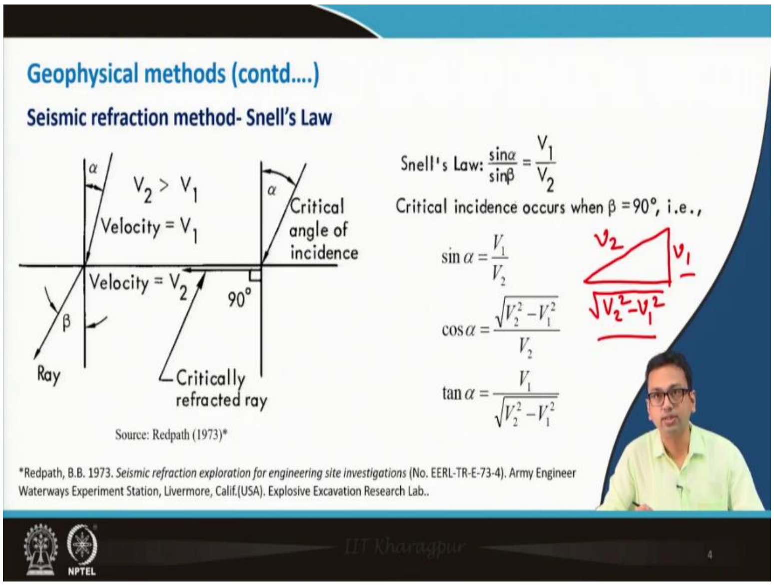

So now, I hope you remember that in our previous class we have discussed about the Snell's law also.

As you can see, that Snell's law says

$$\frac{\sin\alpha}{\sin\beta} = \frac{V_1}{V_2}$$

where V_1 is the velocity of seismic wave in our upper layer, layer 1. Suppose, we are signalling this one and this is our layer 2, where velocity of seismic wave is V_2.

Now, this α and β what are they? So, it is the ray making an angle with the normal that is nothing but my α and this is the refracted ray, which is making angle β. Now, if this β angle becomes 90 degree that critical refracted ray if it develops then this angle α is nothing but the critical angle of incidence. So, critical angle of incidence occurs when our β is equal to 90 degree.

So, sin90° is 1.

So, that means, $\sin\alpha = \frac{V_1}{V_2}$

$$\cos\alpha = \frac{\sqrt{V_2^2 - V_1^2}}{V_2}$$

$$\tan\alpha = \frac{V_1}{\sqrt{V_2^2 - V_1^2}}$$

Just quickly to better understand let me just draw this small diagram.

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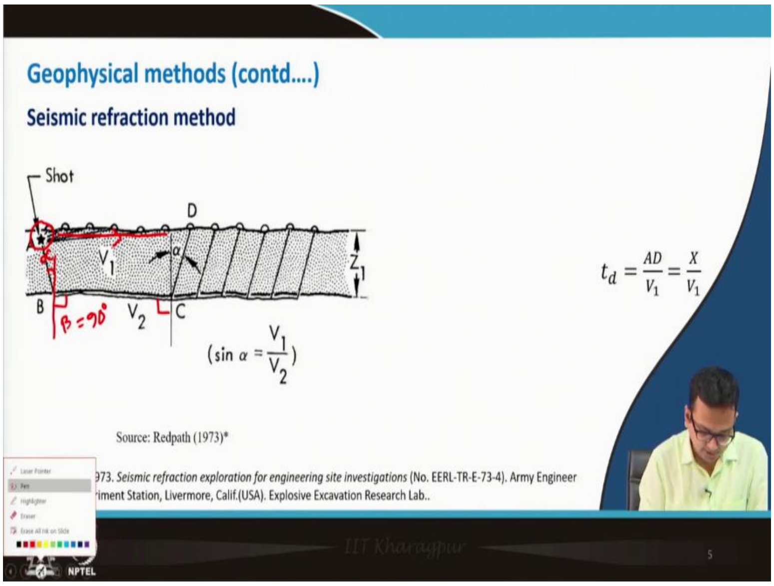

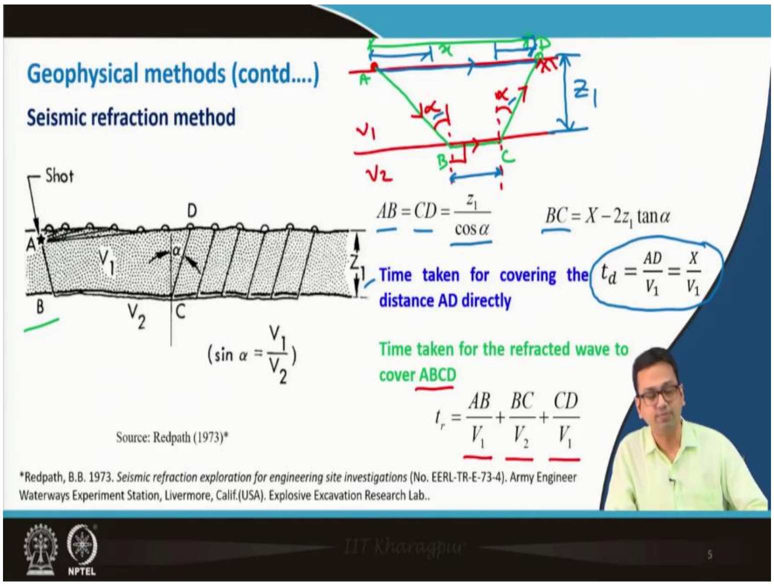

So, let us go to our next slide. So, here you see this is the initial diagram as we have seen in our previous class also. The source is point A and from there this ray is getting reflected in layer 2 and this $\beta = 90°$, here, this is our α and here also $\beta = 90°$ then again α and it is reaching at D. On the other hand, direct waves are also there, so, direct wave is going like this.

This A, B, C, D this path let me draw in a separate diagram (slide 5). So, suppose this is my ground surface. A is the source, so then maybe this is coming like this then moving like this and then you end like this. So, it is A this is my B, then C then D, D is my receiver here they are source.

So, let us consider this distance is my X and so, this is the ray here $\alpha = 90°$. Again this, α the ray is here velocity V_1 here V_2 it is going like this and then this and on the other hand another ray is there that is the direct wave that is going like this. So, along AD it is going and the refracted ray means first travelling through layer 1, A to B then B to C with velocity V_2 and then again in C to D it is taking velocity V_1 and the thickness of the layer suppose it is Z_1.

So now, the total travel path for our direct wave is simply AD which is nothing but my X and on the other hand the travel path for that refracted wave is first in layer 1 AB then BC with velocity V_2 and CD with velocity again V_1.

So, $AB = CD = \dfrac{z_1}{\cos\alpha}$

Similarly, A to D the source to receiver this distance total distance is suppose *X*. So, then this distance B to C is $BC = X_c - 2z_1 \tan\alpha$

What is t_d? t_d is nothing but the time taken for covering the distance AD directly. So, that is nothing but AD/V_1, V_1 is because it is in layer 1 only and the velocity of seismic wave is V_1 there, so *X* by V_1 simply. Now, what about the time taken for the refracted wave to cover ABCD path.

So, ABCD path as you can see in the diagram also. So now, what we can see as just I have stated that AB along this path AB, its velocities, when it was travelling taking the path AB its velocity was V_1, then it got refracted, and so, in BC path its velocity was V_2 and again in layer one that is CD path, this velocity was V_1. So, this is nothing but the time taken for the refracted wave to cover ABCD.

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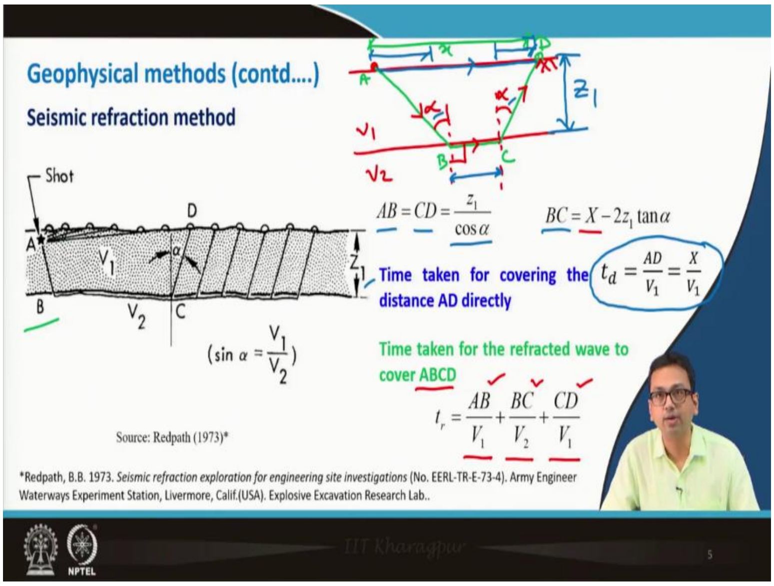

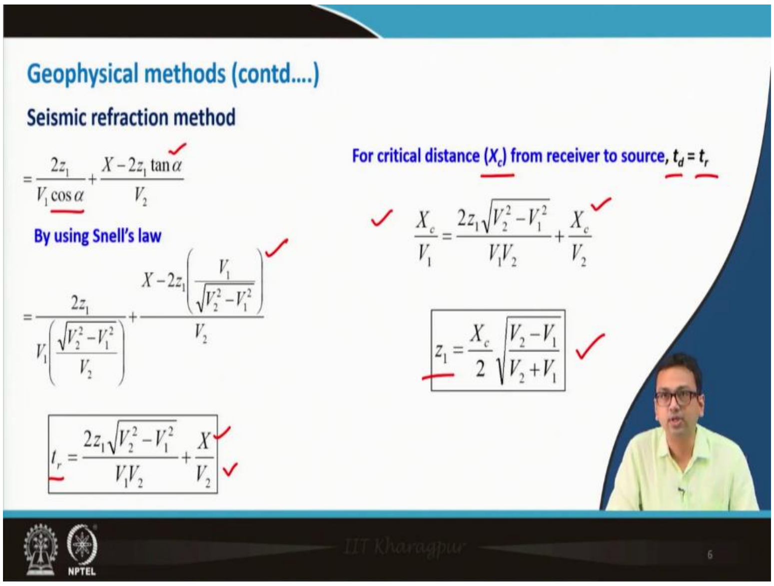

$$AB = CD = \frac{z_1}{\cos\alpha}$$

$$t_r = \frac{2z_1}{V_1 \cos\alpha} + \frac{X_c - 2z_1 \tan\alpha}{V_2}$$

So,

$$t_r = \frac{2z_1}{V_1\left(\frac{\sqrt{V_2^2 - V_1^2}}{V_2}\right)} + \frac{X_c - 2z_1\left(\frac{V_1}{\sqrt{V_2^2 - V_1^2}}\right)}{V_2}$$

On simplifying,

$$t_r = \frac{2z_1\sqrt{V_2^2 - V_1^2}}{V_1 V_2} + \frac{X}{V_2}$$

So, time taken by the refracted wave to travel the path ABCD. Now, this is very important as we have seen in case of seismic reflection survey also we have found out a critical distance where if the geophone is placed at that location then our reflected wave and direct wave reach at same time.

Similarly, in case of refraction survey it is very important because with the help of it we can do a lot of things. So, we need to find out the critical distance X_c between the receiver and source so that my td becomes equal to tr. td is nothing but the time required for the direct wave to reach or travel the path A to D and t_r is this one.

(Refer slide 6) So, if we equate them t_d was X/V_1, so, X I am replacing with X_c which is critical distance and here also this X what was here that one here we are replacing it X_c, critical distance. So, now, if we simplify it gives a simple small nice expression this.

$$\frac{X_c}{V_1} = \frac{2z_1\sqrt{V_2^2 - V_1^2}}{V_1V_2} + \frac{X_c}{V_2}$$

$$z_1 = \frac{X_c}{2}\sqrt{\frac{\sqrt{V_2^2 - V_1^2}}{V_1 + V_2}}$$

So, if we can identify this X_c then our job becomes extremely easy without going for detail rock exploration we can get the thickness of the layer.

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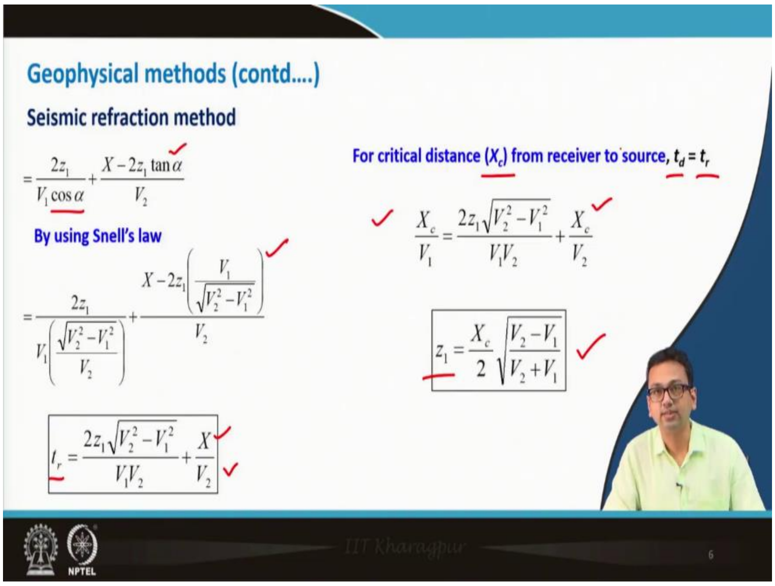

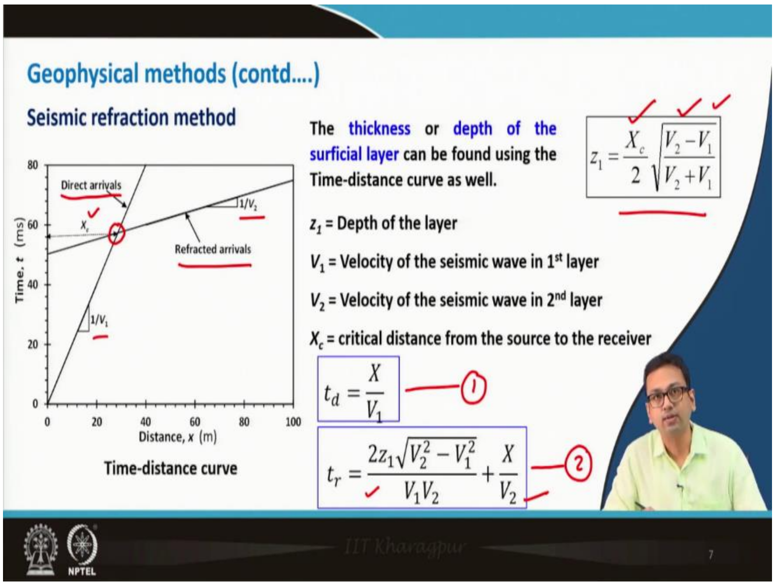

Now, you see another thing I will show you, this thickness or the depth of the surficial layer can be found using the time distance curves as well. So, time distance curve is nothing but in *Y* axis will show time, *X* will show distance. Now, distance is nothing but the distance between the source and the receiver and then the same expression shown Slide 6.

So, using this expression and by utilising the plot we can very easily obtain the thickness of the surficial layer. Z_1 is the depth of the layer, V_1 is the velocity of seismic wave in first layer, V_2 is the velocity of seismic wave in second layer, X_c is the critical distance from the source to the receiver, means when t_r is becoming equal to t_d.

The equation or the time taken by the direct wave to reach the receiver from the sources,

$t_d = \frac{AD}{V_1}$ and another one is equation for t_r ,

$$t_r = \frac{2z_1\sqrt{V_2^2 - V_1^2}}{V_1 V_2} + \frac{X}{V_2}$$

Now, if you plot these two equations in this way, so, what we will see? Let us first consider on equation 1.

It must pass through the origin and it is a straight line because it is a linear equation. The slope of these equations is, $1/V_1$. V_1 is velocity of seismic wave in first layer. So, from there you can get V_1.

Now, for equation 2 also, if it is a linear equation on the straight line, the slope of this line is nothing but $1/V_2$ and this is nothing but the where it is intersecting the t axis.

First plot is for direct arrival and second plot is for refracted arrivals. From here already I have seen we can easily get $1/V_1$ from there V_1 and $1/V_1$ is the slope of this line from there V_2 we can get.

Another important information we are getting that, the location at which the plots are crossing each other is X_c. X_c means, the critical distance. If you place your receiver at this X_c distance then both your direct wave and refracted wave will reach together.

So, this is very important. Now, suppose you are given with some data and that travel time versus distance, data is provided to you then if you plot them or those data in a excel sheet you will get something like this and so, from there you can very easily find out X_c. Now, if you place X_c here in this equation and V_2 by V_2 and V_1 from also these 2 plots, just by seeing the slope you can get your corresponding, the velocity of the seismic waves in corresponding layer.

So, V_2, V_1 you can very easily get and finally, with the help of this plot, you can get the thickness of your layer.

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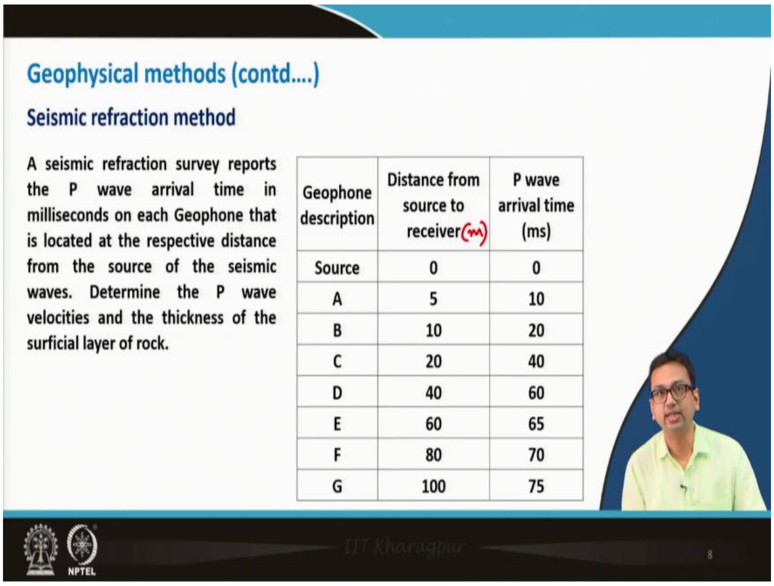

Geophone description	Distance from source to receiver(m)	P wave arrival time (ms)
Source	0	0
A	5	10
B	10	20
C	20	40
D	40	60
E	60	65
F	80	70
G	100	75

Now, this is a small problem. A seismic refraction survey reports the p-wave arrival time in milliseconds on each geophone that is located at the respective distance from the source of the seismic waves. Determine the p-wave velocities and the thickness of the surficial layer of rock. After conducting the seismic refraction test these are the data we will get. So, geophone descriptions like source A, B, C, D, E, F, G and corresponding distance from source to the receiver.

So, obviously at source it is 2 then 5, 10, 20 likewise up to 100 metre it has gone. So, these are in metres and this is the p-wave arrival time. So, 0 as expected at source and then these are the 10, 20, 40 likewise. So, this is the data you have. Now, you have to find out the p-wave velocity and the thickness of the surficial layer of the rock.

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Geophysical methods (contd....)

Seismic refraction method

A seismic refraction survey reports the P wave arrival time in milliseconds on each Geophone that is located at the respective distance from the source of the seismic waves. Determine the P wave velocities and the thickness of the surficial layer of rock.

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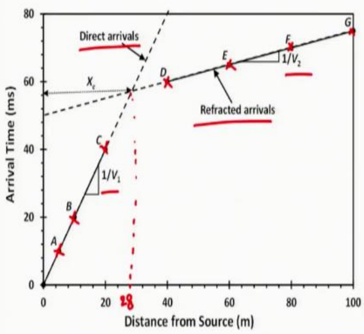
Geophysical methods (contd....)

Seismic refraction method



Distance-time curve

$v_1 = \frac{5}{0.010} = 500\ m/s$

$v_2 = \frac{20}{0.005} = 4000\ m/s$

$X_c = 28$ m; $V_1 = 500$ m/s; $V_2 = 4000$ m/s

The thickness of the surficial layer is,

$$z_1 = \frac{X_c}{2}\sqrt{\frac{V_2 - V_1}{V_2 + V_1}}$$

Hence, $Z_1 = 12.35$ m

First you have to plot this. So, either a on a graph paper manually or using excel you can plot this and then after plotting it like A location, location A, location B, location C, then location D, E, F you can plot then A, B, C you can clearly see that this is a straight line going like this and this is another straight line going like this. So, now, obviously, this A, B, C line is passing through the origin.

So, this is for the direct arrivals and this E, D, E, F, G this line if we extend it, it will not pass through the origin. So, this must be the refracted because of the refracted wave. So, this is the refracted arrivals. So, now, from here what we can very easily get X_c , what is X_c ? So, if you now check over here, so it is your X_c so, here the divisions are like 5 division each are 4 so, it must be 28 and then in order to get V_1 and V_2 you have these slopes you have to see.

So, let us see what is the solution. So, first as I have written this is the X_c is 28 metre. Now, what about our V_1? So, V_1 is nothing but we will get it from the slope. Slope is $1/V_1$. So, this is we have to get this V_1. So, this is 500 metre per second, how it is coming you see the data we have we know what is the what was the this let us just quickly show this. So, A, 5 metre corresponding arrival time is 10 millisecond and B 10 metre this is 20 millisecond.

So, A, B, C it is in the same line so, we can find out the slope very easily from here. So, what we can do, that V_1 is nothing but that 5 /10 milliseconds. So, it is giving us 500 metre per second. Now, similarly, V_2 means, we have to see the data for D, E, F either DE or DF or FG that will give us.

So, if you look at here, so D and E if you see over here, so 40, 60 is a difference is 20 and here it is 5, so we can very easily we can write it like V_2 is nothing but your 20 by 5 seconds, so, 5 milliseconds So, 0.005 so this is nothing but equal to 4000 metre per second and that is what it is shown over there. Now, if we have V_1, V_2, X_c the thickness of the layer we can get using this equation as I have mentioned.

So now, if you place it you will get your thickness as 12.35 metre. It is very quick technique and extremely useful. So, that is why we are learning this without going for invasive techniques. So, we know we can get our record information.

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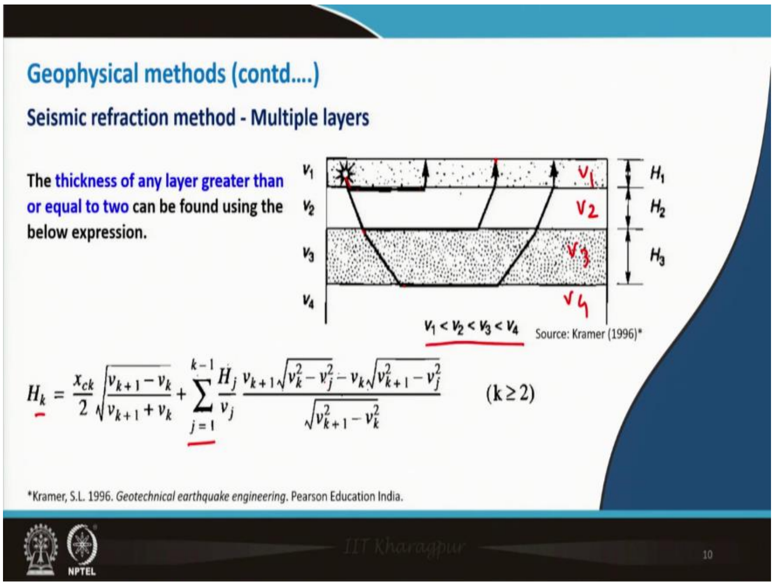

Now, if this is the case, for the seismic refraction method for multiple layers. So, the beauty of this method is that you can obtain the thickness of any layer using this philosophy, that seismic refraction this refraction, because if you see if a from the source if the wave start generating, what may happen, this will reflect refract here fine then, it will further if some portion of ray will go here and they will refract, a receiver it will get the signal likewise another ray, refracting here and going like this.

So, thickness of any layer greater than equal to 2 can be found using another one expression I will show you using that we can get it the, but the thing is we can get it using this idea. Now, the only thing is your that seismic wave velocity should be in this order means the velocity of seismic wave in the upper layer should be lesser than the this lower layer. So, if it is V_1 it is V_2, V_3, V_4 then V_1 should be less than V_2 should be less than V_3 should be less than V_4 otherwise you will not get the correct result.

So now, let us see that directly I am showing you this expression, this is the thickness of k_{th} layer actually, for that this expression you can use. So, you can use it for n number of layers. So, k must be greater than or equal to 2 as we can understand. For 2-layer case already we have seen a separate expression, but if we do multi-layer, we can simply use this equation. So, j is varying from 1 from 1 to k minus 1 and these are the v the seismic wave velocities nothing but these v's are they.

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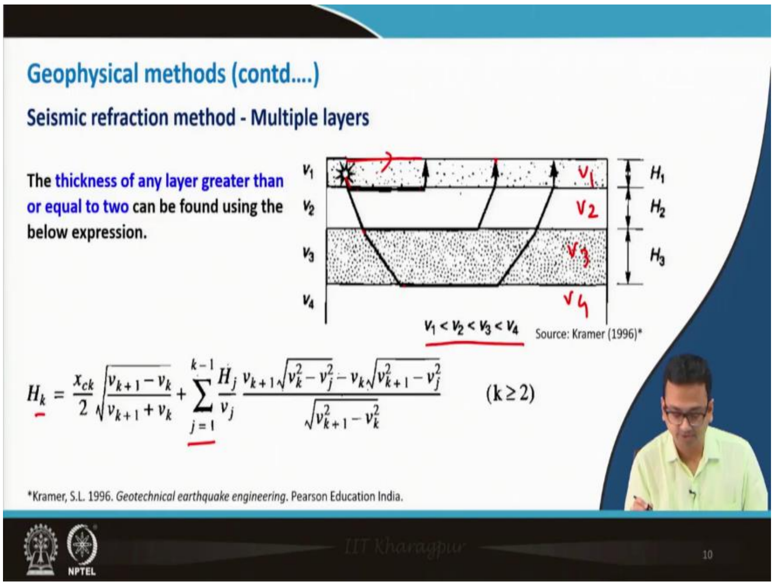

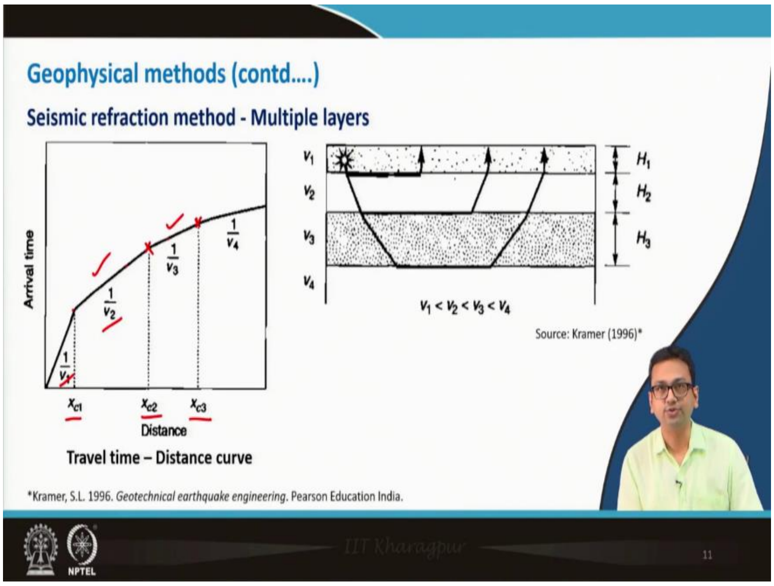

Now, this one if we plot on this travel time distance curve, it will look like this. So, for this case, you see you will have a direct wave also. So, this one now, refraction in this second layer means between first and second layer that in second layer, this is because of refraction this line will come and the slope of this line is nothing but $1/V_2$ likewise slope of this line will give us $1/V_3$ likewise $1/V_4$ and X_{c1}, X_{c2}, X_{c3} are nothing but the corresponding critical distances.

So, you see here this and this are crossing, so it is my X_{c1} likewise this line and this line is intersecting. This is my X_{c2}, this is my X_{c3}. So, very useful actually this test is.

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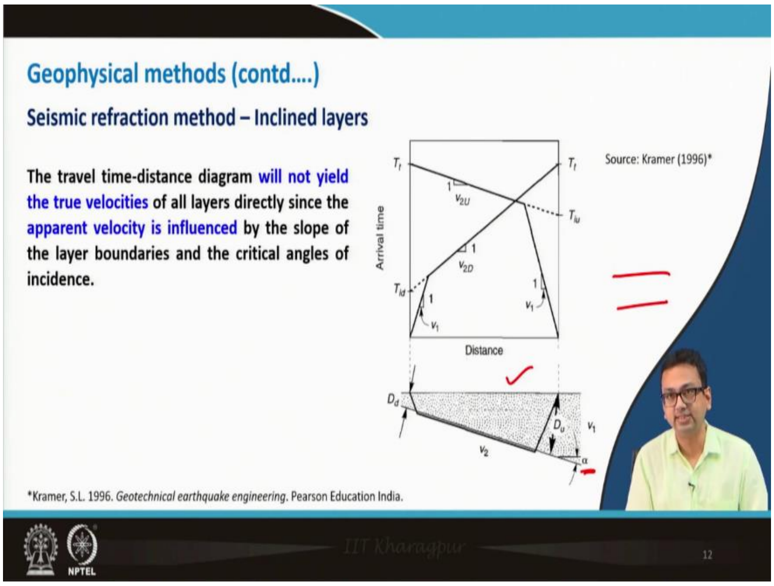

Now, another thing we should also know now, we have discussed about only the upper layer and lower layer both are parallel to each other now, you may obviously, it is very natural that you may in natural formation there will not be always in this layer and the second layer will not be always parallel to each other.

So, you may encounter this situation. So, for that your expressions changes little bit you see this is nothing but your that travel time and distance plot and but if the slope it is like the this layer and this layer, they are not parallel to each other, then you will directly not get the your those information from this plot. So, that is only it is stated here, the travel time distance diagram will not yield the true velocities of all layers directly since the apparent velocity is influenced by the slope of the layer boundaries and the critical angle of incidence.

So, this is since it this slope is there you see α, because of that, that your apparent velocity actually that is influenced by this presence of the slope and the critical angle of incidence on this it will depend.

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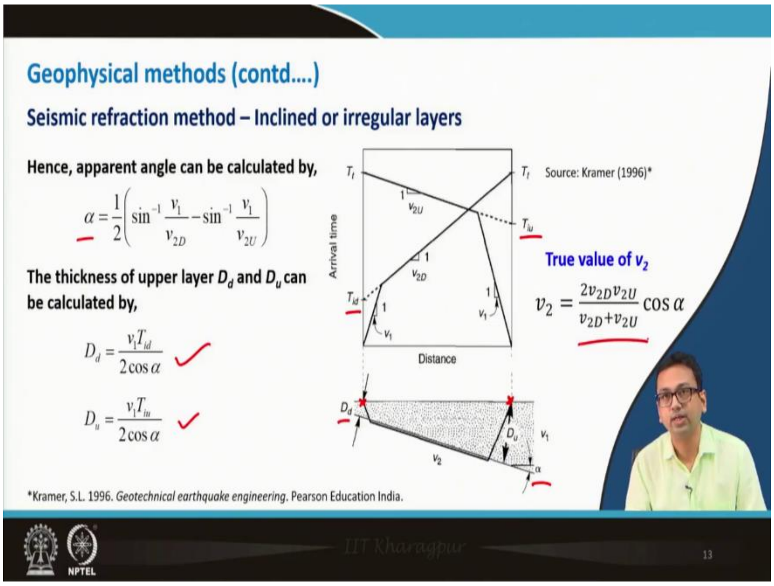

So now, for that some expressions are available. So, obviously, different researchers have developed this I am not going to those derivations. So, first one is the opponent angle. So, apparent angle can be calculated by this equation this. So, alpha is my apparent angle as it is shown over here. So, this is half sine inverse V_1 by V_{1D} minus sine inverse V_1 by V_{2U}. Now, what are they?

They are nothing but corresponding to this this is D this is U. So, and one thing I must say that in this kind of test, what you have to do? Once you have to keep your source here, receiver here and you find out what is the, this travel time and then you have to place your source here and receiver over here and you have to repeat the same procedure and you have to find out the travel time.

So, both here one source here, here receiver again reverse thing means opposite thing here source, here receiver. So, in this you will get your apparent angle as this then the thickness of upper this D_d if I say and if it is this side if this perpendicular distance from here if it is D_d and if this is D_u what are the expressions for that? D_d can be obtained using this equation and D_u can be obtained using this expression.

So, here T_{id}, T_{ud} are are nothing but you see you can see in these plots. So, from here where it is intersecting that you need to find out. So now, another thing is true value of V_2 that also you can get using this expression.

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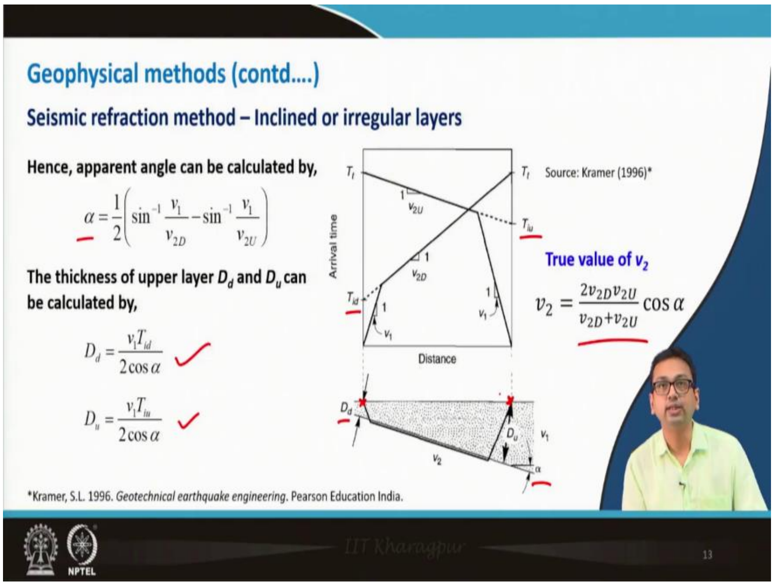

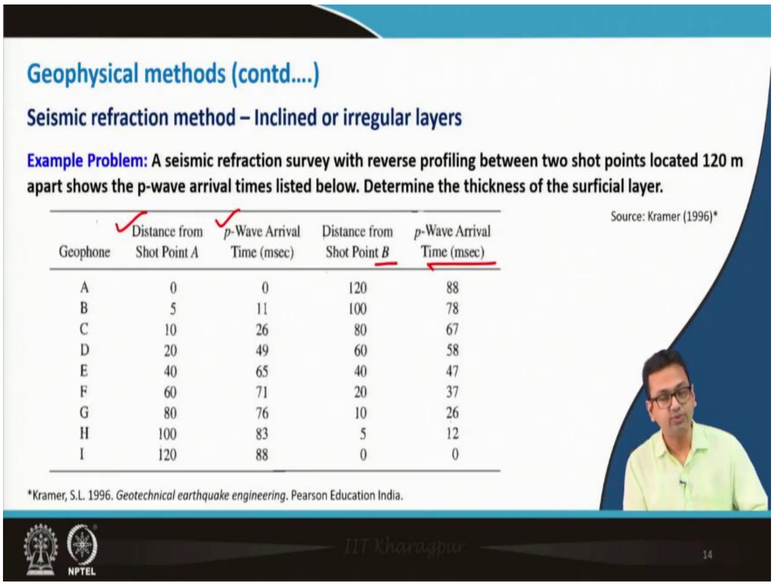

So now, let us take a small problem and make our concept clear. So, a seismic refraction survey with reverse profiling. So, this is called reverse profiling. So, once you will, first you will keep your source at a location and at geophone or receiver at one location and then at those locations only again you will just interchange the position means your first source here, receiver here then source here, receiver here.

So, that is only here stated a seismic refraction survey with reverse profiling it is called reverse profiling, reverse profiling between 2 shot points located 120 metre apart shows the p-wave arrival times listed below. So, determine the thickness of the surficial layer. So, this is you see the distance from shot point A and corresponding p-wave arrival times and then this is nothing but the distance from shot point B and corresponding p-wave travel time.

So, these are there. So, first job is you need to take a graphs paper, normal graph paper and manually plot it or with the help of excel you plot this one.

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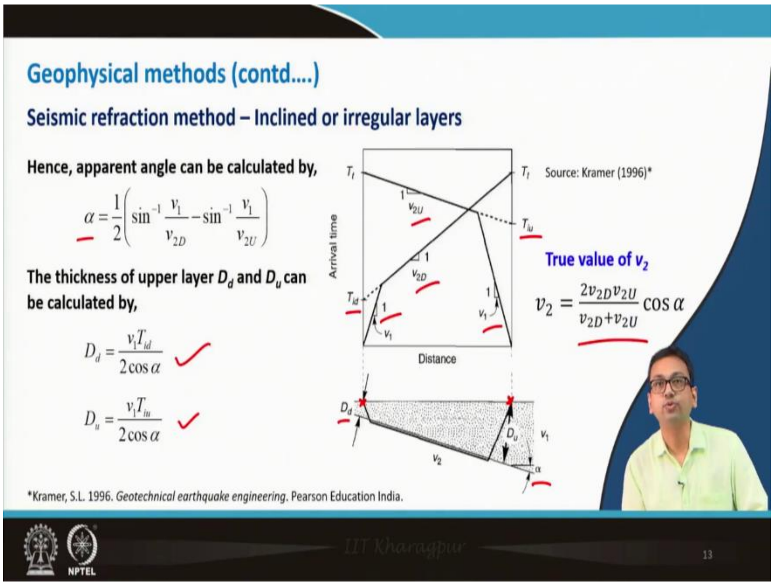

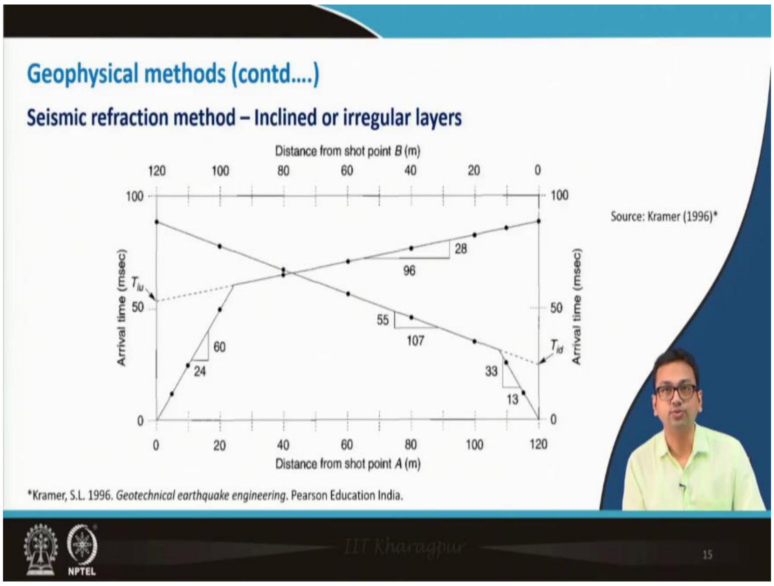

So, we have plotted this for the direct wave and these are for refracted wave and these are nothing but the slope some numbers are provided here. So, for quick reference these are given. So, from here as we know this is nothing but as we have seen over here in this diagram. So, this one is $1/V_1$, this is 1/2, $1/V_{2D}$. This is again $1/V_1$ this is $1/V_{2U}$. So, those are the values are provided here for our quick reference now.

Now, if I have to solve this problem, so what I will do for the question asked is you need to find out the thickness.

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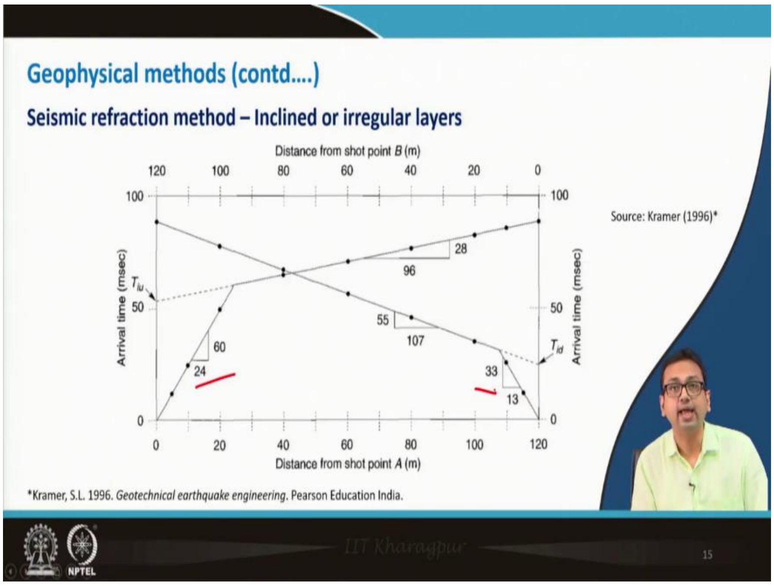
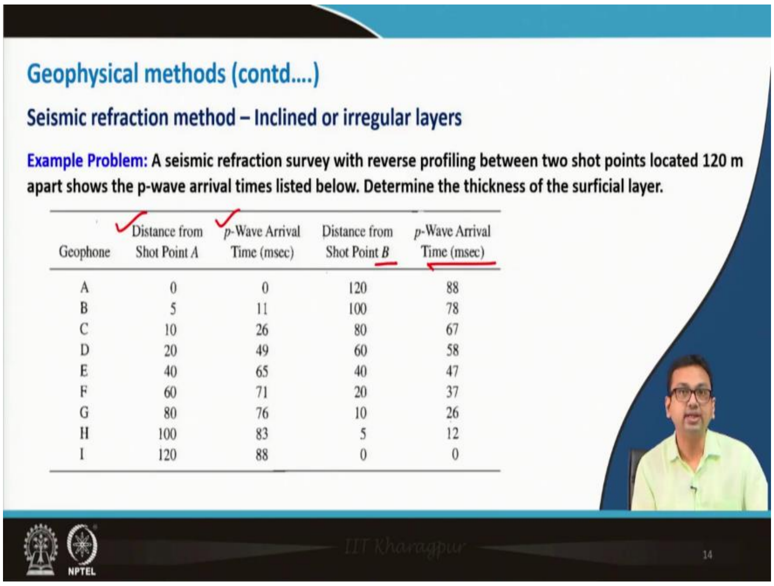




Geophysical methods (contd….)

Seismic refraction method – Inclined or irregular layers

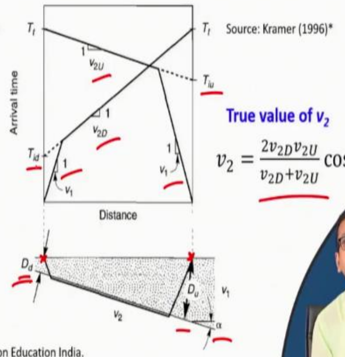
Hence, apparent angle can be calculated by,

$$\alpha = \frac{1}{2}\left(\sin^{-1}\frac{v_1}{v_{2D}} - \sin^{-1}\frac{v_1}{v_{2U}}\right)$$

The thickness of upper layer D_d and D_u can be calculated by,

$$D_d = \frac{v_1 T_{id}}{2\cos\alpha}$$

$$D_u = \frac{v_1 T_{iu}}{2\cos\alpha}$$



True value of v_2

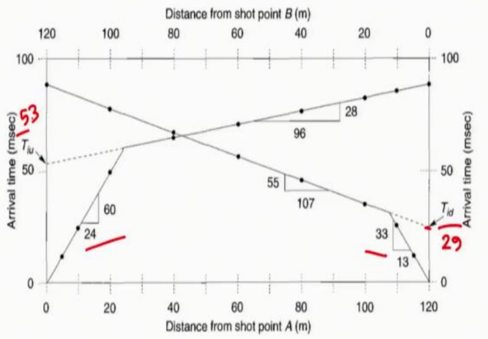
$$v_2 = \frac{2v_{2D}v_{2U}}{v_{2D}+v_{2U}}\cos\alpha$$

*Kramer, S.L. 1996. *Geotechnical earthquake engineering*. Pearson Education India.

Geophysical methods (contd….)

Seismic refraction method – Inclined or irregular layers

Solution:



Source: Kramer (1996)*

*Kramer, S.L. 1996. *Geotechnical earthquake engineering*. Pearson Education India.

Geophysical methods (contd….)

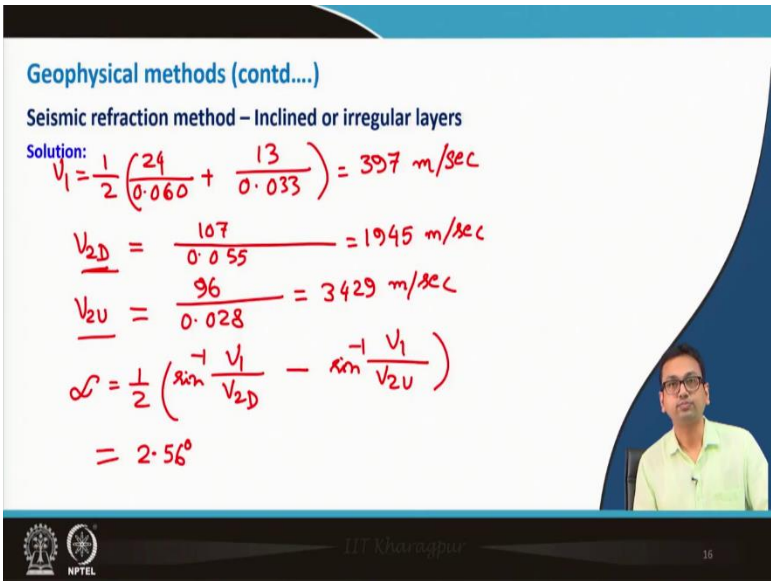
Seismic refraction method – Inclined or irregular layers

Example Problem: A seismic refraction survey with reverse profiling between two shot points located 120 m apart shows the p-wave arrival times listed below. Determine the thickness of the surficial layer.

Source: Kramer (1996)*

Geophone	Distance from Shot Point *A*	*p*-Wave Arrival Time (msec)	Distance from Shot Point *B*	*p*-Wave Arrival Time (msec)
A	0	0	120	88
B	5	11	100	78
C	10	26	80	67
D	20	49	60	58
E	40	65	40	47
F	60	71	20	37
G	80	76	10	26
H	100	83	5	12
I	120	88	0	0

*Kramer, S.L. 1996. *Geotechnical earthquake engineering*. Pearson Education India.



So, we already know all the expressions. So quickly if we solve it, first what we have to get? we have to obtain V_1 as the average of these two lines. So, we have $1/V_1$ we will get once from here, here and one V_1 from here, so we will take the average. So, that we will do so, 1 by 2 and they are nothing but just see 60 here 24 or 33, 13. So, V_1 will be 24 by 60, 60 milliseconds, so we will convert it into second likewise 13 by 33 millisecond will convert into second so 24 by 0.060 plus 13 by 0.033. So, it is giving us 397 metre per second.

Then what we have to obtain? We will obtain V_{2D} apparent velocity in down dip, this is called the down dip direction velocity and this is called the up-dip direction velocity. So, you know dip, what is dip and dip is known to you. So, dip direction, dip strike, we have discussed a lot. So, it is the apparent these are the apparent velocities in down dip direction. This is down dip and it is up dip direction.

Down dip for D capital D of D, up-dip for U. So, these expressions are these values are what we can again go back to the diagram quickly. So, this is 107 by 55 millisecond. So, and this is your 96 by 28 millisecond. So, we convert everything into seconds. So, 107 by 0.055 it is giving us 1945 metre per second and this one is 96 by 0.028 so, it is giving us 3429 metre per second.

Now, if we get this then what we can get? We can very easily obtain our alpha that expression I have provided so, half this expression, half sine inverse V_1 by V_{2D} minus sine inverse V_1 by V_{2U}. So, if you replace V_1, V_{2U}, V_{2D} all these things you should get it as 2.56 degree, fine, that is done.

So, if that is done then I can very easily obtain what was our question just you see the question was to determine the thickness of the surficial layers. So, basically, if I see this diagram means I need to find out this and this and what are the expressions for them, this one and this one. So, I require alpha I have obtained and I need v1 that I have obtained the average one and also I need T_{id}, T_{iu}. So, T_{iu} is this and T_{id} is this.

So now, from the diagram if I carefully examine because we have the excel sheet I have means we have plotted in an excel sheet or manually we have done it. So, T_{id} what is the value we can get it from the graph paper or the actual plot and this one also you can get very easily. So, basically if we check it these T_{iu} is becoming basically around 53 milliseconds and this is becoming around 29 milliseconds.

So, this is 29 and this is 53. So, let us use these values in in our expression for our DA and DB maybe or you can say yeah DA because A and B we have marked them actually, if you remember here the A means if we consider the first source point A and here, source point B. So, DA and DB if I want to find out.

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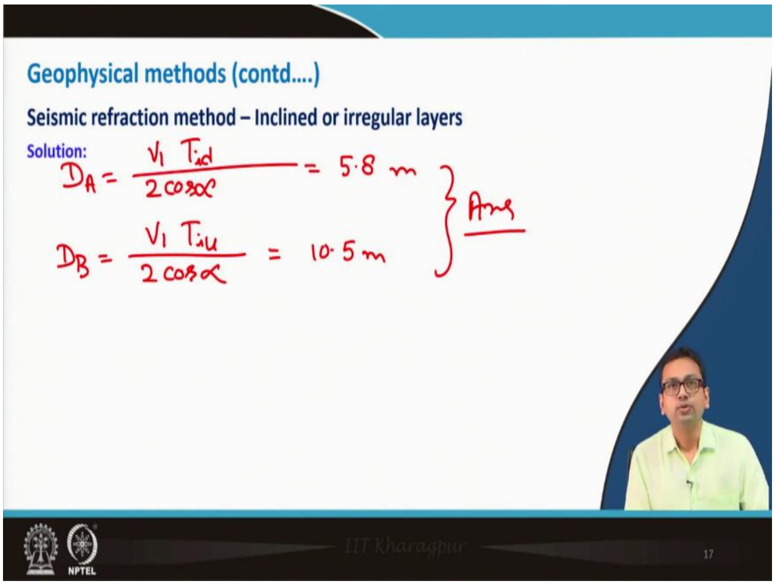

So, my DA will be $V_1T_{id}/2\cos\alpha$ and DB is equal to $V_1T_{iu}/2\cos\alpha$. So, if you place these values you should get it a 5.8 metre and this one is 10.5 metre. So, these are your answers. So, you see even for incline ground also you could able to get it very easily.

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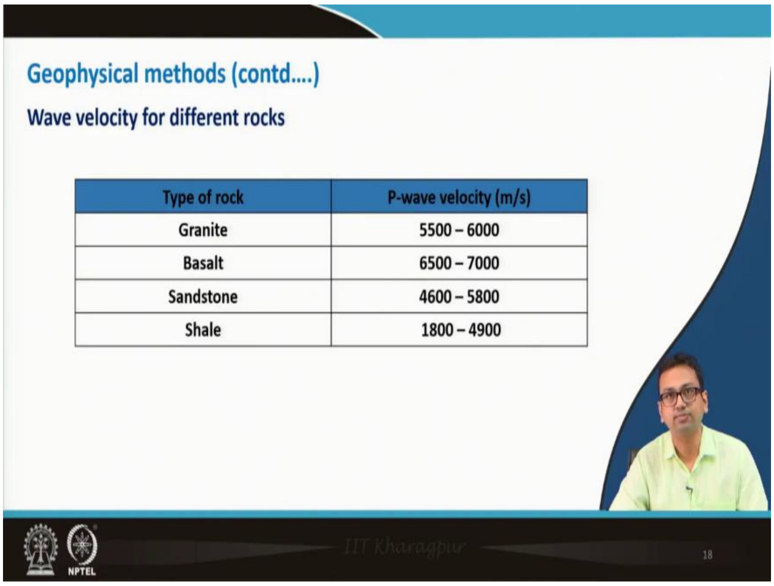

Type of rock	P-wave velocity (m/s)
Granite	5500 – 6000
Basalt	6500 – 7000
Sandstone	4600 – 5800
Shale	1800 – 4900

Now, these are some of the means typical velocities, means p-wave velocity in different type of rocks. So, just for our reference so, we can get based on the refractions or we can also means mix some idea about what type of rock it is roughly you can say that.

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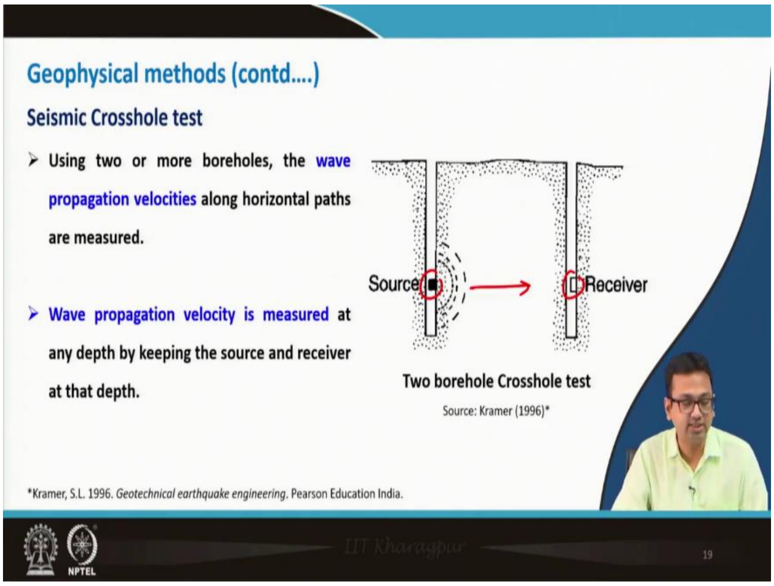

Now, seismic crosshole test, quickly we will discuss about this. In means, there maybe we can using two or more boreholes, wave propagation velocities along horizontal path you see this path it can be obtained, measured. So, here it is shown for a 2-borehole cross hole test. So, here as you can see source is here, receiver is here and the wave propagation velocity is measured at any depth by keeping the source and receiver at the same depth actually.

So, it is very simple idea is very simple, and you can find out the seismic wave velocity and from there again by using those charts also you can get some idea that what type of rock it is.

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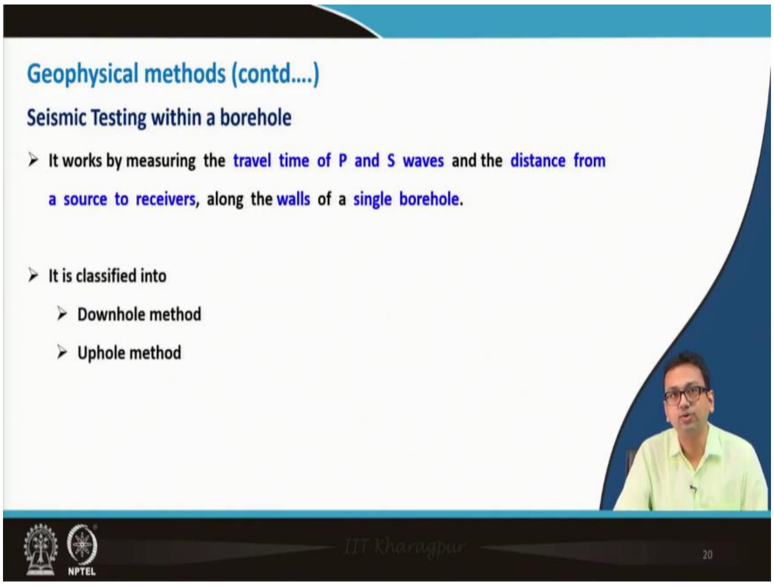

Basic idea you can get. Likewise, there is another type of test which is means within a borehole it is done actually. So, source and receiver means, it works by measuring the travel time of P and S waves and the distance from a source to receiver along the wall of the single borehole. So, both are there in the single borehole, you can do it. So, classified into categories downhole method, uphole method

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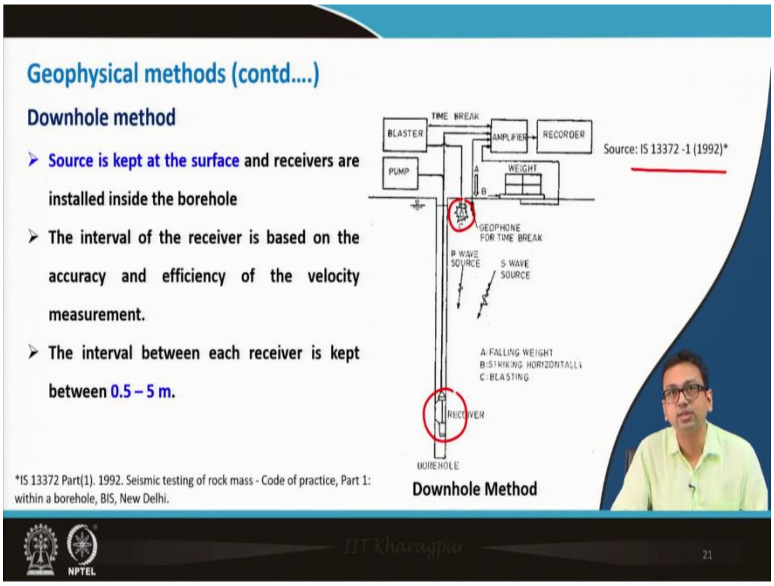

And downhole method is very simple, this is the arrangement. See for this I am we can get the guideline from the IS 13372 Part 1 1992. So, this is for downhole method. So, source is kept at the surface and receiver are installed inside the borehole. So, you see there is the source at the ground surface and receivers like here. So, the interval of the receiver is based on the accuracy and efficiency of the velocity measurement.

So, depends on that how many receivers you will use the interval between each receiver is kept between 0.5 and 5 metre depends on different cases.

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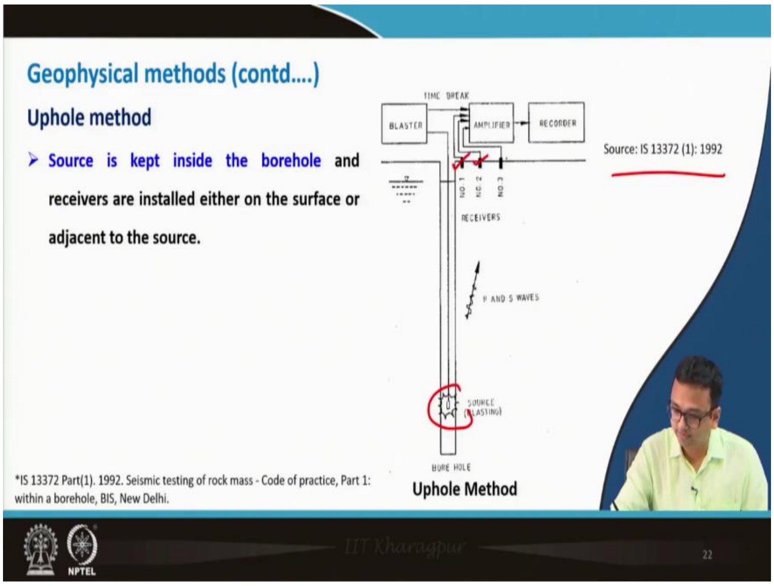

So, on the other hand uphole test, what uphole method what we do? The as again this also you will get in same IS code so, source is kept inside, you see? The source is here and inside the borehole and receivers are installed either on the surface or adjacent to source. So, this is the, here the receivers are placed.

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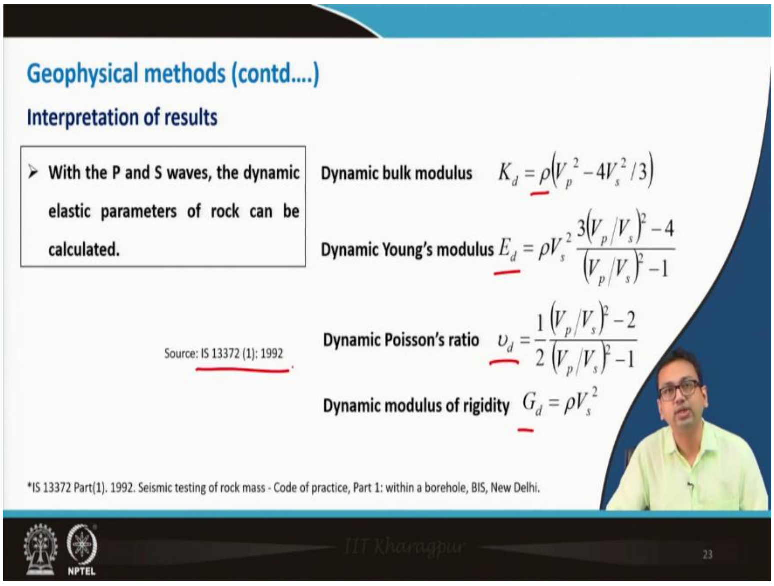

Now, these data of P and S wave, with the help of this P wave and S wave velocities the dynamic elastic parameters of rock can be calculated using these equations actually. So, you see for bulk modulus this one here it is nothing but the density of rock. Then V_p, V_s are nothing but P wave velocity, S wave velocity. Then dynamic Young's modulus you can get, the dynamic Poisson's ratio you can get using this simple data and also the dynamic modulus of rigidity you can get. So, this is also available in the same IS code one can see this.

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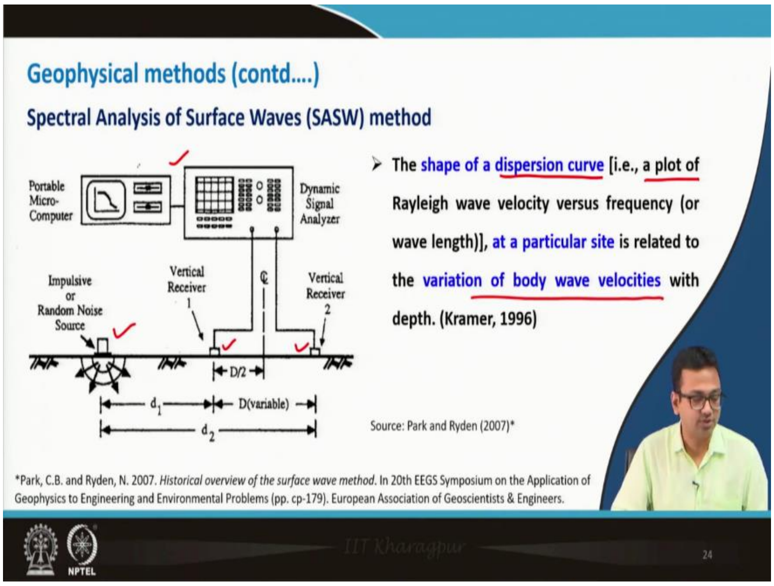

Now, just last 1, 2 things, they are nothing but I just have told you. Another instrument is, method is called as Spectral Analysis of Surface Wave method. So, here surface wave is utilized for this purpose, measurement. So, you see there is a source, then, 2 receivers are used, vertical receivers are there and this is my data acquisition system, it is a delicate instrument means relatively little more costly but very useful, nowadays very popular.

So, it is and I will not go into the details so, only just I will tell you that the shape of the dispersion curve at a particular site is related to the variation of the body wave velocities with depth. So, based on this idea it works actually and what is dispersion curve? That is also written here, a plot of Rayleigh wave velocity versus frequency or the wavelength.

So, a plot of Rayleigh wave velocity versus frequency or the wavelength that is called the dispersion curve and the shape of the dispersion curve at a particular site is related to the variation of body wave velocities with depth. So, based on this idea, principle it works and it is as I have stated little more delicate instrument, so, little costly, but very useful.

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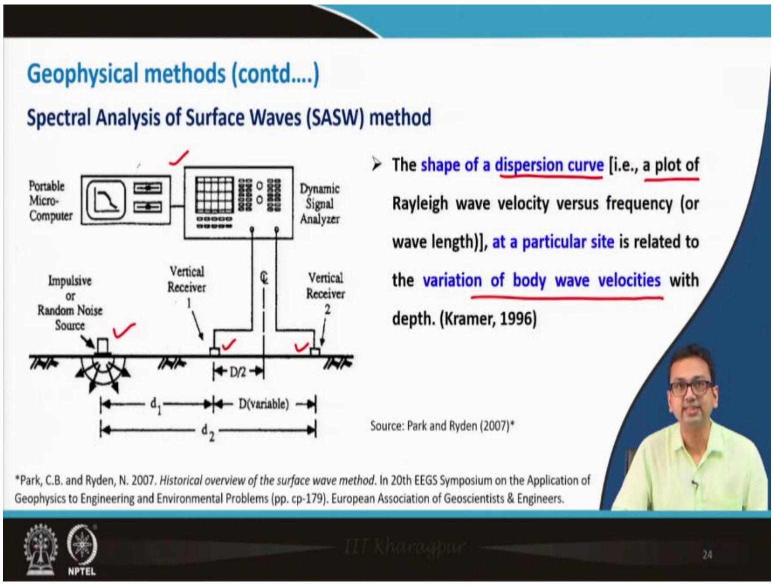

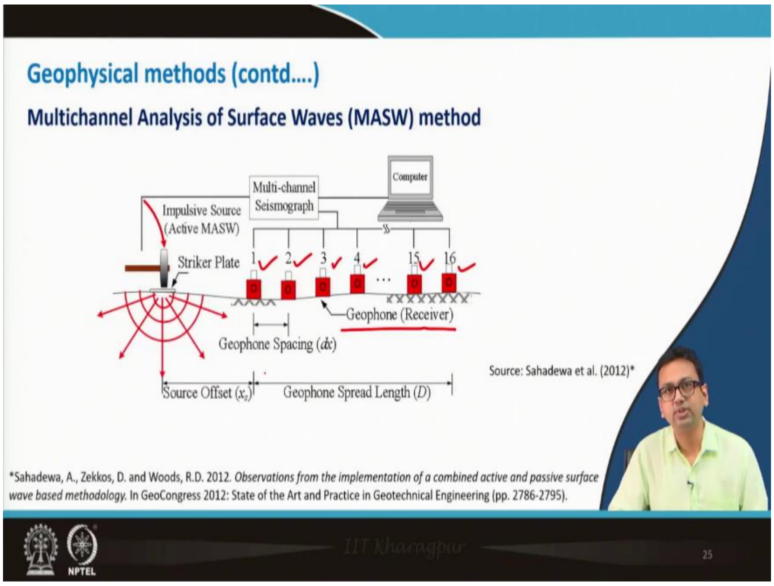

Similarly, that was Spectral Analysis of Surface Wave, SASW, another one is Multichannel Analysis of Surface Waves MASW. This is also based on that surface wave principle means using that we tried to get the other seismic velocities and we tried to finally find out the profile of that particular area, what type of profile is there that we can get.

Only thing you see there are multiple receivers are used, so these are all the geophones, multiple receivers are there, geophones are there. Whereas, in SASW, only two receivers.

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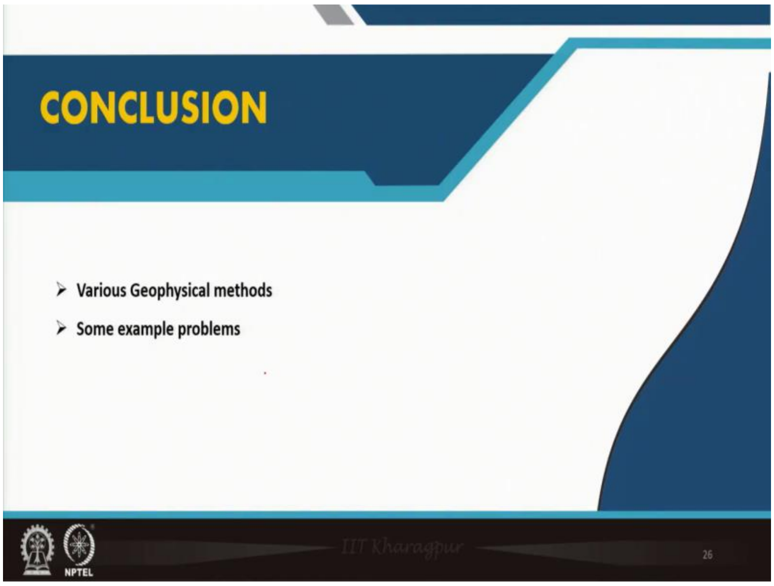

So, I think with this we have discussed a good amount, spared, spent good amount time, good amount of time on understanding various geophysical methods and also, we have solved some example problems. So, I hope this will be useful for your these example problems can also be useful for your different exams as well as overall theory what you have learned also I hope will be useful for you. So, thank you.