Rock Mechanics and Tunnelling
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Lecture 10
Geophysical Methods (Continued)

Welcome everyone to the fourth lecture of this module 2. So, we will continue our discussion with these geophysical methods.

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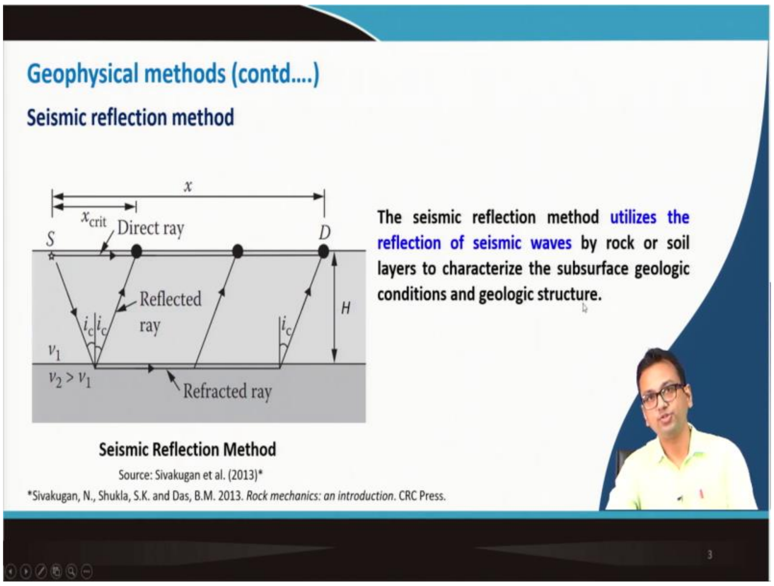

As discussed in the previous class, there are different methods like seismic reflection method, refraction method, cross-hole method etcetera. So, out of those things, today we will discuss about the seismic reflection method. In the diagram in slide 3, you can see that if there is some source from where seismic waves are generating, then if we place some receivers at certain distances, like receivers means mainly the geophones are used for that purpose.

If we do that, one wave will directly reach over there, so as the direct ray it will go there. Or, it may reflect from the boundary between upper layer and lower layer and it can reflect back to the receiver. Or, what may happen it may refract and then it may reach to a particular receiver or geophone. So, one is direct ray, one is reflected ray, one is refracted ray.

So, first we will focus on the this direct ray and reflected ray, how we can utilise the idea of this reflected ray and how we can find out the thickness of the layer or the velocity of the wave in a particular rock mass layer. The seismic reflection method utilises the reflection of seismic waves by rock or soil layers to characterise the subsurface geologic conditions and geologic structure.

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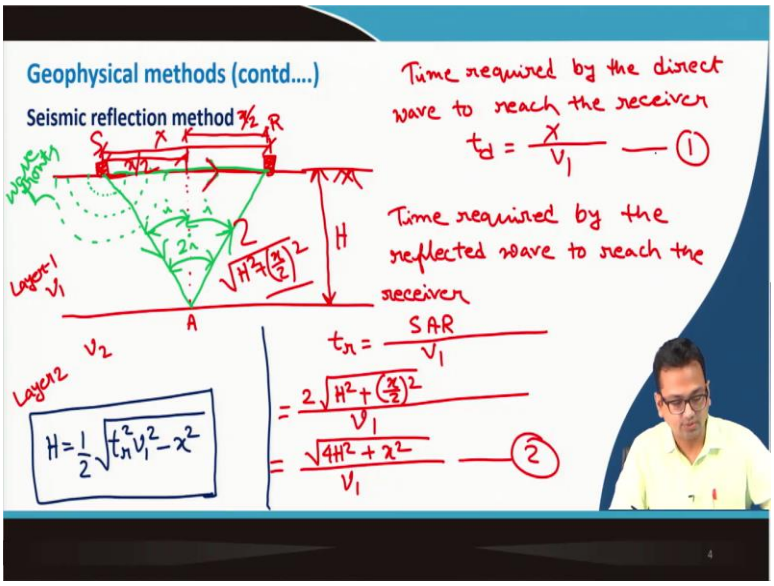

What is the idea behind this? Referring to slide 4, there is a source and at a distance X, your receiver, the geophone is present over there and there is the ground surface. There are two layers - layer 1 and layer 2. Suppose velocity of seismic wave at layer 1 is V_1, and at layer 2 it is V_2. Now, one thing what will happen? One is, directly this will go from source to receiver.

This is your suppose direct wave. Another thing can happen it will reflect at the layer 1. So, basically when you will hit at the source, or if you do some explosion with the help of hammer what will happen? Basically, the wavefronts will generate as I have stated you last previously.

Now, let us consider the angle between the reflected rays as 2i. Now, so this distance is nothing but $X/2$ and this is again $X/2$. Now, let us consider the thickness of the layer is H. So, this one will be what? $\sqrt{H^2 + \left(\frac{X}{2}\right)^2}$

Now, let us see what amount of time the direct wave will require to reach the receiver.

The time required by the direct wave to reach the receiver,

$$t_d = \frac{X}{V_1} \qquad \text{-------Eq 1}$$

Time required by the reflected wave, reflected wave to reach the receiver, t_r needs to be calculated. Referring the diagram in slide 4, the reflected wave needs to travel SA distance and AR distance with velocity V_1.

Now, SA = AR = $\sqrt{H^2 + \left(\frac{X}{2}\right)^2}$

So, this total distance of travel tr, will be,

$$t_r = \frac{SAR}{V_1}$$

$$= \frac{2\sqrt{H^2 + \left(\frac{X}{2}\right)^2}}{V_1}$$

On simplifying,

$$t_r = \frac{\sqrt{4H^2 + X^2}}{V_1} \qquad \text{-------Eq2}$$

Now, if the distance between source and receiver is known, and we will be able to measure what is the time required for reaching to this receiver direct wave, we can easily obtain our V_1. By using this, we can measure the time taken by the reflected wave to reach the receiver. Using this, X can be obtained. So, we can very easily find out our H from this one.

So the expression for the thickness of upper layer of rock mass, H is,

$$H = \frac{1}{2}\sqrt{t_r^2 V_1^2 - X^2}$$

Now with the help of equation 1 and equation 2, we can draw a distance time curve that will be quite useful.

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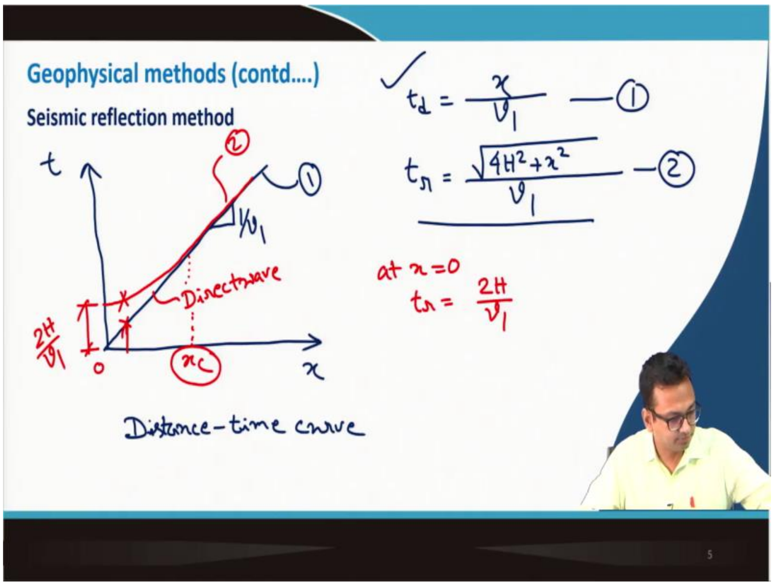

Referring to the diagram in slide 5, If I consider this direction it is x and this direction it is t, this is distance time curve we are trying to plot. So, if I plot this one, we will get a straight line passing through the origin. And, the slope of this plot will be 1 by v1.

The slope obtained is related to equation 1. Now, for the second equation, this equation is hyperbolic in nature. So, obviously, the plot will also be hyperbolic. Please refer to the plot in slide 5.

So, t_r at $X = 0$ is,

$$t_r = 2H/V_1$$

If the distance between the receiver and source is very less, then the time taken by the direct wave to reach the receiver will be obviously less here whereas, the reflect reflected wave will take more time. It can be noted that, after a particular distance, X_c critical distance, what is happening?

This gap is reducing initially big gap then gradually this gap is reducing and then after certain time they are almost reaching at the same time. So, this is one of the important information which you can utilise to derive different things like the thickness of our layer. So, at what depth rock layer is present that also you can find out very easily using this seismic reflection method.

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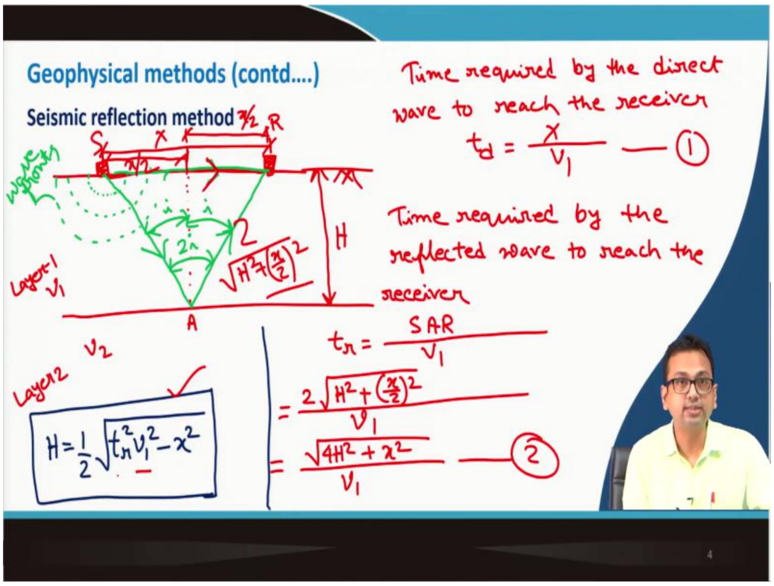

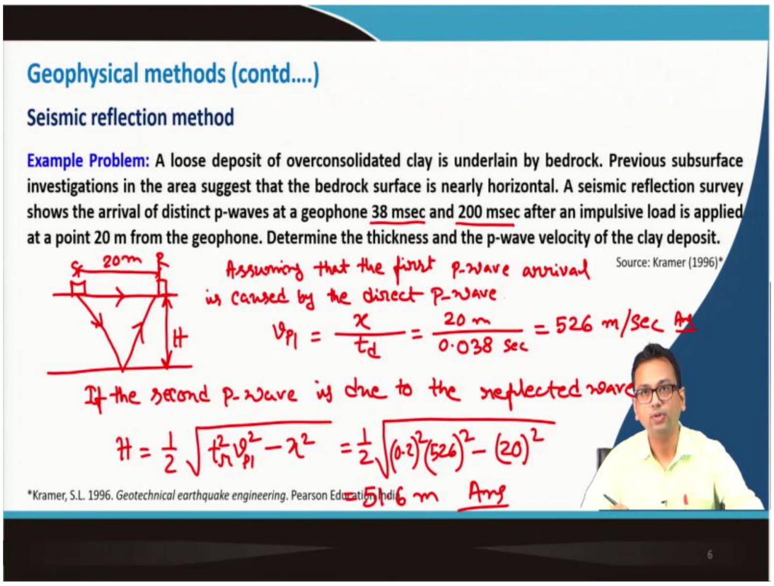

Now, let us take a simple small problem and let us clear our doubt even more. A loose deposit of over consolidated clay is underlain by bedrock. Previous subsurface investigations in the area suggests that the bedrock surface is nearly horizontal. A seismic reflection survey shows the arrival of this distinct p-waves at a geophone 38 milliseconds and 200 millisecond after an impulse load is applied at a point 20 metre from the geophone. Determine the thickness and the p-wave velocity of the clay deposit. So, idea is very simple that here is your source, here is your receiver, this distance is given as how much, 20 metre, now, 1 reflected wave and 1 direct wave.

So, how much time the direct wave has taken that is given and also how much time the reflected wave has taken that is also given to us. So, as we know we already have obtained equation 1. So, using that, we can very easily obtain the velocity of the wave because 38 millisecond is the arrival time of the direct wave and 200 millisecond is the arrival time of the reflected wave.

So, assuming that the first p-wave arrives. First p-wave arrival is caused by the direct p-wave, is caused by the direct p-wave, let us assume that. So, accordingly we can obtain our V_{p1} as,

$$V_{p1} = X/t_d$$

Now, x is given as 20 metre and td is 38 milliseconds so, 0.038 second. So, if we simplify it you should get it as 526 metre per second.

Now, the second part is to determine the thickness of the p-wave thickness of the layer and the p-wave velocity. So, suppose this is my H. So, what are the things provided here V_1 just now we have obtained x is given and t_r is 200 milliseconds. So, t_r is nothing but the time taken by the reflected wave to reach the receiver. If the second p-wave is due to the reflected wave, we can write H as,

$$H = \frac{1}{2}\sqrt{t_r^2 V_{p1}^2 - X^2}$$

So, $H = \frac{1}{2}\sqrt{(0.2)^2(526)^2 - (20)^2} = 51.6\text{m}$

So, basically using our simple knowledge of geometry or trigonometry, and we could get the thickness of the layer as well as the velocity at which the seismic wave is travelling.

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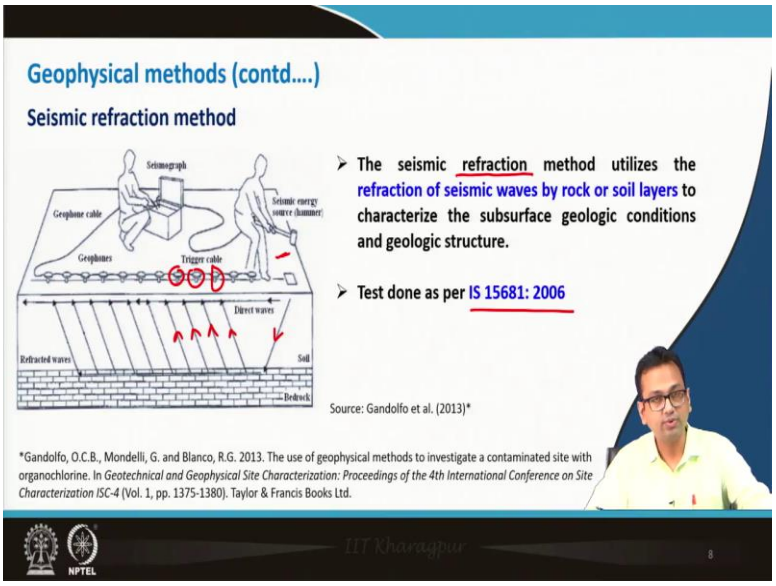

Now, the second one which is extremely useful and for this instrumentation, the curve is a little bit more sophisticated, but it is very useful in determining the thickness of maybe see with the help of the reflection survey in general you will get the thickness of only the upper layer. Now, there maybe you may be interested in knowing maybe thickness of 5 layers or 10 layers.

So, in that case your seismic reflection survey can become extremely useful. So, it is again without doing any borehole, means it is non-invasive technique and with the help of this technique very easily you can find out the thickness of different layers and also you will be able to know the velocity of travel at different layers.

So, seismic refraction method utilises the refraction of seismic waves by rock or soil layers to characterise the subsurface geologic conditions and geologic structure. In India, we follow this IS code, IS 15681: 2006, for conducting the seismic refraction test.

So, you see here this person, with the help of a hammer he or she is hitting over this plate and because of that seismic waves are generating. Now, those seismic waves are, what can happen one thing is, it can there are several geophones are provided they are working as the receivers. Now, one thing as we know through simple reflection it can reach there that is fine.

Other than that, but with the help of that we will only be able to know the thickness of the one layer, one thing. But if you are interested in knowing this thickness multiple layers, we have, as I have stated, we need to have seismic refraction method. So, here though this picture is showing for one layer only, we will learn about the multiple layer case also.

Now, what is happening, one is direct wave reaching to this geophone, another is you see the this is coming over here then it is moving through this second layer and then again it is coming back here and at this geophone you will get some signals. Similarly, you are getting signals at different geophones.

Based on the travel time of those direct wave and the refracted wave, we will be able to find out different things such as the thickness of the different layers.

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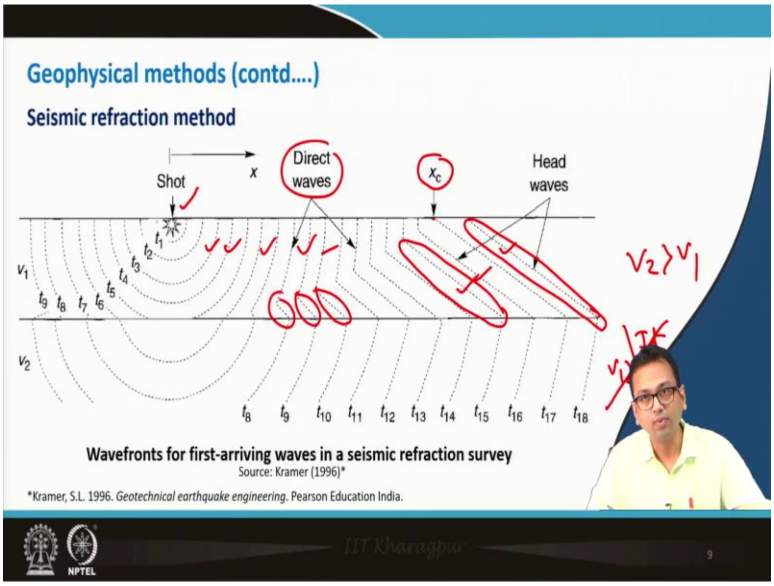

So, let us see how to do that. Suppose this is the source, now after hitting, seismic waves are generated. So now, these are nothing but the wave fronts as I have stated. So, this is layer 1, layer 2, now, at layer here this is going like this, but then when it is reaching at the layer 2 you see these portions have started developing and ultimately these are becoming very much predominant.

Now, what is written over here you see these are nothing but the direct waves and these are called as the head waves, which is generating because of this refraction phenomena actually and what you can see over here that up to this X_c, your direct waves are reaching before this head waves.

Then, after X_c what is happening? At X_c, actually both are reaching together and beyond that you see your head waves are reaching to the ground surface before the direct wave. Now, this will happen only if your V_2 is greater than V_1 that is one condition. So, you can consider this as one of the limitation. This refraction method will work when you will have a medium like the lower medium when it will be strong means we will have the bit higher velocity than the upper layer. So, in that case, this one will be useful. If v1 is greater than v2 then this will not work.

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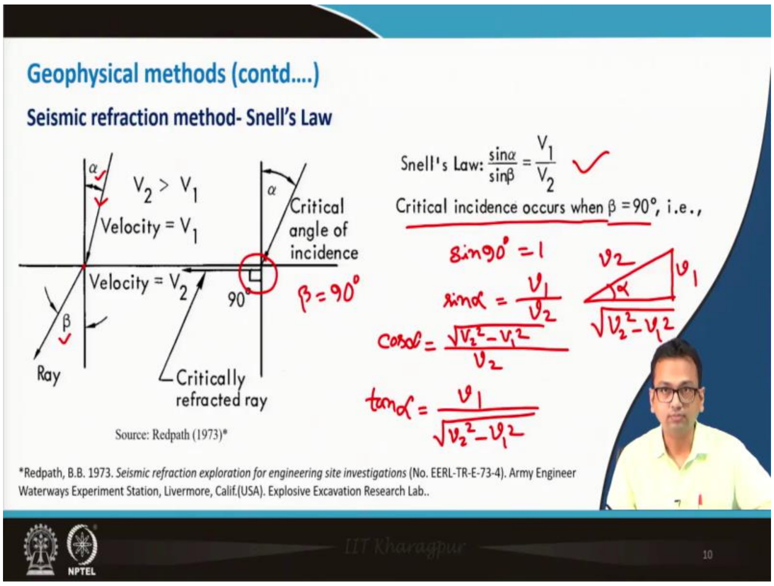

Now, this is based on a simple law that is known to you that is Snell's law. As per Snell's law, you see it is the ray what is coming over this layer the boundary of these 2 layers, then, because of refraction what will happen this ray will change its path and then if this is alpha angle this will be beta angle. Now, if this angle is such that the refraction what is happening that is 90 degree means your beta is becoming here 90 degree then this angle is called as the critical angle of incidence.

So, as per Snell's law as it is shown over here,

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

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

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

Now, for critical incidents, beta is equal to 90 degree. Now, the sin 90 is nothing but 1. So, from these what we can write as,

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

Now, if it is the case, then what will be the cos alpha?

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

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

Fine, now maybe pictorially also I can show it to you like since this is your V_1, this is your V_2, this is your α. So, this is nothing but V_2 square minus V_1 square.

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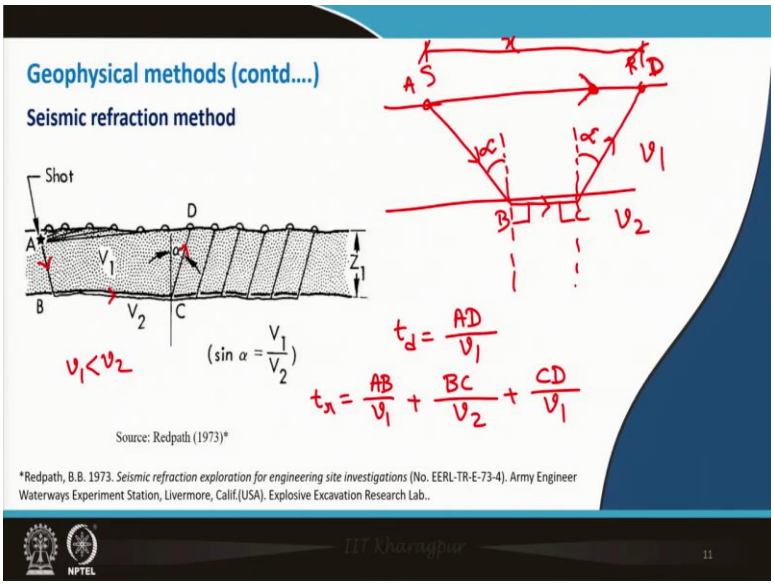

Now, you see the seismic refraction is happening over here. The condition is here V_1 is less than V_2. So, V_2 is always greater than V_1. Now, suppose this is the source. So, rays are coming like these then this is refracted, then again going back and this is reaching to this receiver. So, this diagram maybe I can draw once again a little bit in detail over here maybe the this is your A, this is your maybe another layer this is coming like this, the system then again then again take it at this location not this one.

So, this is the ray refracted then this is going so, let me give an A, B, C and D. Now, one thing is this direct wave is going like this and another is refracted wave going like this. So, suppose this angle or this angle is nothing but my α, and they are the critical angles and because of that, this angle has become 90 degree. So, what we can say from here that this is your source and this is your receiver.

So, for the direct wave, if this distance is X, then the direct travel time of direct wave is t_d.

t_d = AD/V_1

Whereas, travel time for your refracted wave is,

$$t_r = \frac{AB}{V_1} + \frac{BC}{V_2} + \frac{CD}{V_1}$$

We will continue our derivation in our next class. Thank you.