Advanced Foundation Engineering
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Lecture - 05
Soil Exploration - V

So, in the last lecture I have discussed that how we can determine the water table position for sandy soil and for the clay soil. Now, today I will first discuss about how we can determine the water table position for clay soil by using one example problem.

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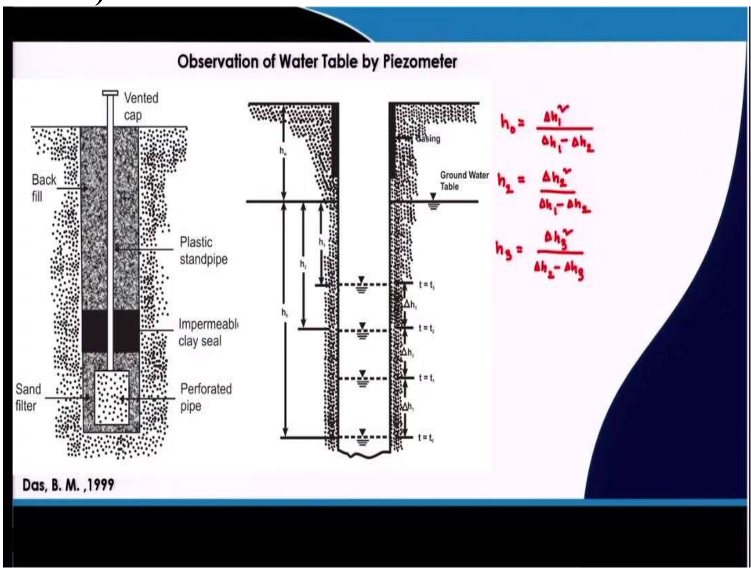

So, this is the expression by which we can determine the water table position of clay soil by using piezometer.

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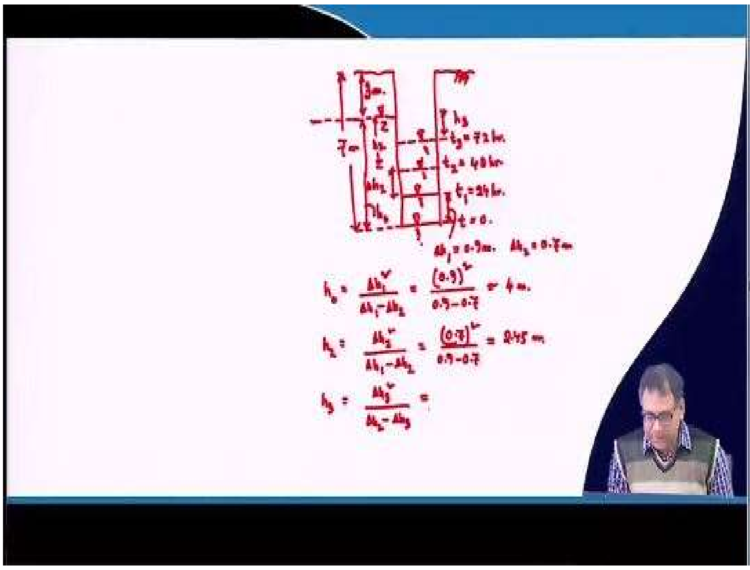

So, now, in example problem I want to show that suppose we have a ground this is the ground surface and this is the borehole. Now, at $t = 0$, this is the initial water table position at $t = 0$ and that distance from the top say 7 meter. So, that distance or initial water table position within the borehole is a $t = 0$ is 7 meter from the ground surface and then with time the distance of the water table from the ground surface is measured and the rise up of the water table within the borehole is measured.

So, this is at $t_1 = 24$ hours this is the position so, this is t with some time t_2 is say 48 hours and then this is the time t_3 for 72 hours and so on. And then these distances is say with some distance is Δh_1 which is say 0.9 meter and Δh_2 is another distance. So, now we will get h_0 which is from this to that water table position. Suppose this is now water table position so, this is a h_0 so, this is the h_0 which is water table position from the initial water position at the borehole.

So, h_0 expression we know that $\frac{\Delta h_1^2}{\Delta h_1 - \Delta h_2}$. So, we can put some values here this is Δh_2 is 0.7 meter. So, you can put that $\frac{0.9^2}{0.9-0.7}$. So, this will be roughly 4 meters. So, we know that this is the 7 meters so, this is roughly 4 meter. So, this distance will be roughly 3 meters. So, in this way we can determine the position of the water table from the ground surface. So, now for cross check that so, we can calculate again the h_2 which is $h_2 = \frac{\Delta h_2^2}{\Delta h_1 - \Delta h_2}$.

So, h_2 will be $\frac{0.7^2}{0.9-0.7}$, which is also 2.45 meters similarly $h_3 = \frac{\Delta h_3^2}{\Delta h_2 - \Delta h_3}$. So, in this way, we will get another value. So, these value also Δh_2 is from here to the water table position and Δh_3 is from here. So, when you calculate the Δh_2 then the Δh_3 also all the position should be at this line. So, that means, the soil we can determine the position of the water table from the ground surface also. So, in this way we can determine the position of the water table from the ground surface.

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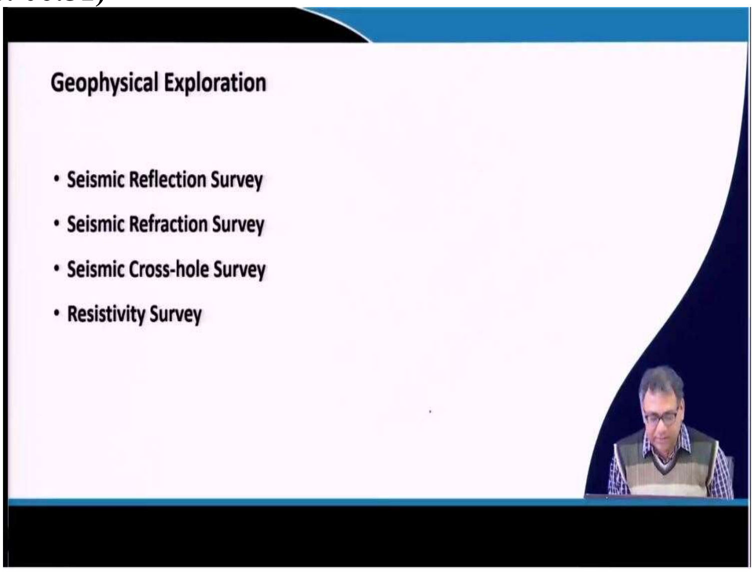

Now, in the next part that I will start about geophysical exploration, so, first I will discuss about the seismic reflection survey, then seismic refraction survey, then seismic cross-hole survey and then resistivity survey.

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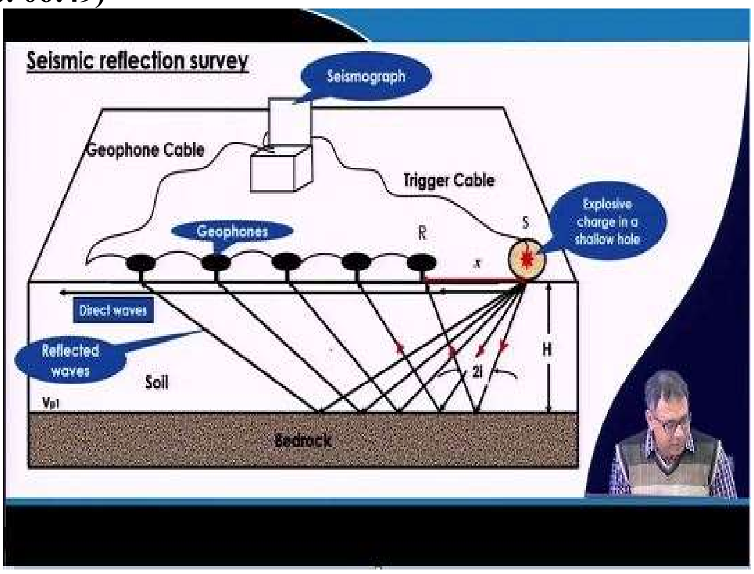

So, now, what is seismic reflection survey? So, in the seismic reflection survey, we have one source on the ground surface suppose this is the source on the ground surface and these are the geophones or these are called receivers. So, this is the source these are receivers and then we generate one source. So, that source will create a wave and this wave will reflect from the interface between 2 layers or our data and then it will go back to the receiver. So, that was formed here. So, this is the source it is coming in this direction then it is moving back.

Then also it is coming from this direction then it is going back. So, now, there will be n number of waves will generate but depending upon where you are placing the geophone these arrays are drawn. So, there if I put n number of geophones then these waves will be received by the geophones from the source. Now, there are two ways these waves can travel from the source to receiver, one is the direct wave which will travel from the source to the receiver disarrayed one is the direct wave.

So, it will travel from source to the receiver and then another will reflect from the layer interface then it will go back to the receiver. So, this is the direct wave red one and this black one is the reflected wave and then based on that we can determine what would be your thickness and properties of the soil layer.

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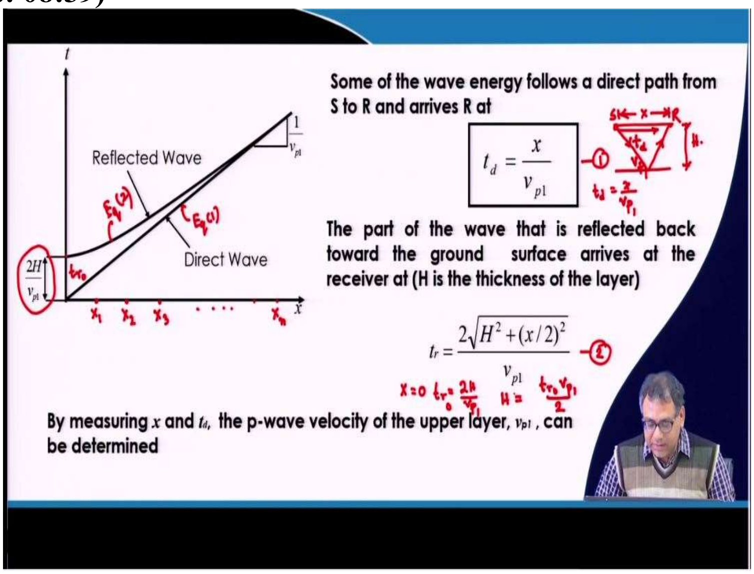

Now, so now, these are the 2 waves as discussed that 2 waves will be generated one is the directed wave and now is the reflected wave. So, the expression of the direct wave, so, suppose this is the direct wave or we can say this is my source and this is the receiver. So, the direct wave this is the t_d and this is the distance x. So, if the velocity of the wave in the first layer is v_{p1} then t_d will be $\frac{x}{v_{p1}}$.

So, this is the expression of the t_d and the t_r which is the reflected wave. So, that t_r expression also we can get by this expression this is $2\frac{\sqrt{H^2+(x/2)^2}}{v_{p1}}$. So, where h is the thickness of the layer. So, this is one particular case now, if I put n number of geophones say suppose this is the position of the first geophone which is x_1, this is the position of the second geophone this is the position of the third geophone and so, on there will be this is the position of n^{th} geophone so, all the geophones there will be one direct and one reflected wave.

So, now if I put the data of all the geophones in a graphical form that means, this x axis this the distance and y axis is the time. So, now, the 2 waves will be reached in each geophone. So, this is for every geophone the directory equation is $\frac{x}{v_{p1}}$ and v_{p1} will not change because it is the same soil layer only the distance will change and this is the straight-line equation is the equation 1 which is a straight line and it is passing through the origin.

So, this is the equation 1 which is the direct wave which is a straight line passing through the origin and equation 2 will give us equation which is not the straight one. So, it is a nonlinear type of equation, so, we will get one graph. So, that is the reflected wave graph. So, that means, what we will do we will plot that travel time for directly and distance travel time for the directory for different geophone and the corresponding distance that we will draw.

So, this will give us the equation number 1 and this will give us the equation number 2. So, again we will draw the travel time of the reflected wave and then the corresponding distance. So, this way we get these 2 curves. Now, that means in this survey, we have to measure the travel time of 2 waves one is the direct wave another is the reflected wave. Now, from here this equation 2 if I put $x = 0$ if then my t_r will be equal to $\frac{2H}{v_{p1}}$.

So, this is the value of $\frac{2H}{v_{p1}}$ at $x = 0$. So, this is the value $x = 0$, $t_r = \frac{2H}{v_{p1}}$. Now, from this equation number 1 the slope will give us $\frac{1}{v_{p1}}$ because this is the slope $\frac{1}{v_{p1}}$. So, from equation number 1, I will get the velocity of the layer and from equation number 2 put $x = 0$ I will get the t_r. So, that t_r or t_{r0} you can see so, this t_{r0} I will measure from here. So, I will extend this line and because it may not start from $x = 0$, it may start with some value of x but you have to extend that line and make it 0.

So, once I get make it 0 this maybe the intersection point of the curve to the t axis and that time is corresponding time is t_{r0}. So, that $t_{r0} = \frac{2H}{v_{p1}}$. So, now from here I can get $H = \frac{1}{2} t_{r0} v_{p1}$. So, from this equation, I know v_{p1} that I will get from the equation number 1 or the straight-line curve and then I will get t_{r0} from this curve intersection point and then I will get the thickness. So, I will get the thickness of the layer and I will get the velocity of the wave also.

So, now, why I am taking number of points because if I take one particular data then there is a possibility of error. So, to reduce that error or to minimize that error, we can take n number of geophones and then that data we can plot in a graphical form and then from that plot I can get the required properties that is the velocity of the wave and thickness of the layer.

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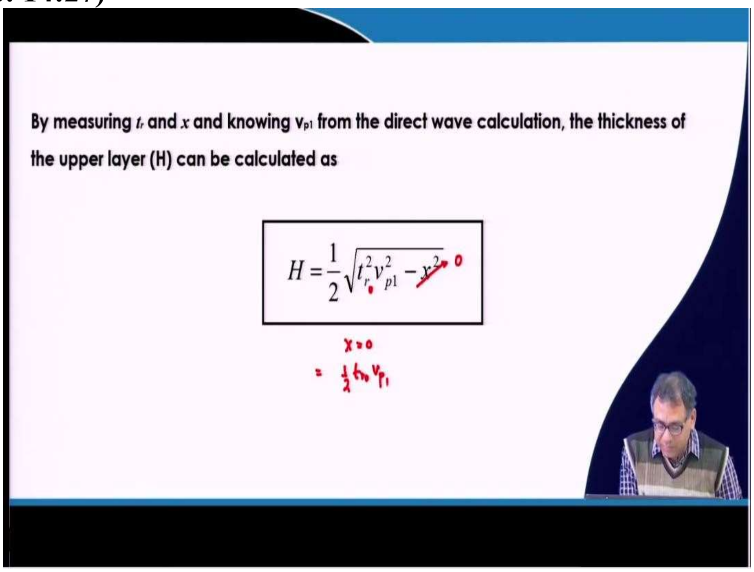

So, this is the H that I will get. So, now I am putting $H = x = 0$. So, that will give us this $x = 0$ this will give t_{r0} so which is nothing but $\frac{1}{2} t_{r0} v_{p1}$ which is the same expression that are given. So now one problem is that in this seismic reflection survey, we have to measure 2 waves and we have to measure the direct waves travel time and then we have to measure the reflected wave travel times. So, that means it is difficult to identify which one is the reflected wave and which one was the direct waves because it difficult to measure these 2 waves.

So, to remove that limitation, the seismic refraction survey can be conducted where we have to measure only the first arrival time of the wave that means, we will measure the travel time where the wave is received by the geophone first time. So, that means, we will measure the only one wave that will be received by the geophone first. So, that is the advantage of the refraction survey or the reflection survey and another issue is in the reflection survey, we are measuring the thickness of the top layer.

But in this seismic refraction survey, we can measure the thickness of *n* number of layers also. So, here your methodology is the same because here this is the source and these are the position of the geophones. So, again the power source there will be direct rays and refracted rays also if there is *n* number of layers, then there will be *n* number of refracted rays because these refracted rays, this is the interface between the top first layer and the second layer, these refracted rays, this is the interface between the second layer and the third layer.

So, that means, if there is a 2-layer system, then we will get one refracted ray and then one direct ray. So, but we will note down or required to measure only first arrival time of the wave. So, that means under for if there is a more than 2 number of layers, then there will be I mean more than one number of refracted rays.

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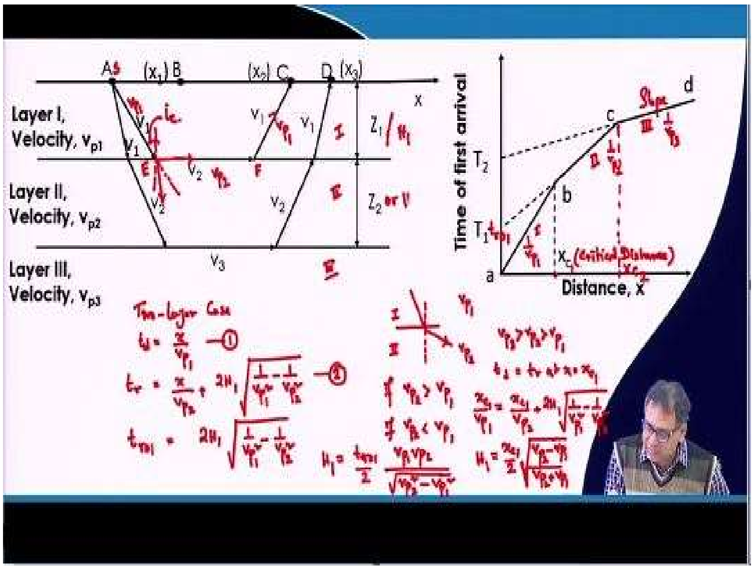

So, now, so, this is one particular case that I was discussing, so, this is the source A when direct ray will go to C and D, where, C and D are the positions of the receiver then one refracted ray will go to the C point another refracted ray will go to the D point and this is the case for 3 layer system then this is the layer 1, this is layer 2 and this is layer 3. And one thing is that now, if I have 1 layer, this is a 2 layer now, then this is the ray that is coming for in the interface of the first layer and the second layer.

Now, suppose you have a velocity of v_{p1} for the first layer and v_{p2} for the second layer. Now, if your v_{p2} is greater than v_{p1}, then what will happen this refracted ray will go away from the normal but if v_{p2} is less than v_{p1} then refracted ray will travel towards the normal. So, now, under the second condition if refracted rays traveled to towards the normal then there is a no possibility that this ray will reach to the ground surface again and it will be measured by the geophone because, what I am saying that if this is the ray.

So, if this ray moves in this direction, then this will never reach to the ground surface. So, to reach to the ground surface these rays have to move away from the normal. So, and that is only possible if this first condition is satisfied that means v_{p2} is greater than v_{p1}. So, this is one of the limitations of this test is that these tests will give us the proper result.

If the velocity of the second wave is greater than the velocity of the third wave of first layer wave or if there is a 3-layer system then the v_{p3} should be greater than v_{p2} should be greater than v_{p1}. So, that means and when the velocity of the rays is function of the density that means if density increases then velocity of the wave will also increase. So, that will the velocity of the wave is more for a denser soil compared to the loose soil.

That means, which indicates that this survey will give us the proper result if the density of the soil layer increases as depth increases, that means, the density of the third layer should be more than the density of the second layer or and the density of the second layer should be more than the density of the first layer. So, then only I will get the good results. So, and in other ways that velocity of the third layer should be greater than the velocity of the second layer and velocity of the single layer should be greater than the velocity of the first layer.

Then only I will get the good result. So, that will as I am saying that now, there is a possibility that this ray will travel in this way and this is only possible if this angle is the critical angle. So, that means keep the angle at which these v_1 rays is intersecting the first layer and the second layer interface with an angle greater than the critical angle then only it will travel with parallel to the ground surface and then it will go to the second I mean geophone.

So, that means this angle is critical angle. So, this way here it will travel and this geophone will measure the first arrival time of the wave. And now, if I put again if I take *n* number of geophone data and if I draw them in *x* axis is the distance and *y* axis is the time then I will get at this type of plot. So, every change in slope indicates the change in soil layer. So, here in the given plot there is 3 slopes.

So, that means, which indicates that there are 3 layers, so, this is the layer 1 velocity this is the layer 2 velocity and this is the layer 3 velocity, slope of this curve will give us the velocity of each layer this is the slope is $\frac{1}{v_{p2}}$, this is $\frac{1}{v_{p3}}$,, so, this is the slope. So, this way I will get the velocity of wave in each layer. So, that means, if there is a change in slope that means the change in layers and we have to calculate the velocity of wave in each layer.

So, these slopes will give us the one by velocity of that layer. So, in this way I will get the velocity of each layer. Now, as I mentioned here the first arrival time we have to measure. So, now, if you look at this figure from A to C So, there is a possibility as I mentioned there will be direct rays and there will be a refracted ray and if there is a number of layers, then there are a number of refracted waves now, which ray will reach first now.

So, initially if you see definitely that from A to C if the distance between A to C is very small, then definitely direct ray will reach first because that will travel very small distance. But as the distance between A to C increases, then the refracted rays will reach first. Why? Because the travel distance will again increase whether your distance is small or large. But, as the distance increases between A and C, then this portion will also increase that means, the portion at which the wave will travel it is of velocity v_{p2}.

So that mean C or from A to say E the wave will travel with a velocity of v_{p1} from E to F it will travel with the velocity of v_{p2} again from F to C it will travel with velocity v_{p1} because this is the interface between second layer and the first layer so it will travel with the velocity of v_{p2} and the v_{p2} is greater than the v_{p1}. So, the travel time will decrease as the distance between A to C will decrease, because as the distance between A to C will decrease, then the distance the wave will travel with a velocity of v_{p2} that will also decrease.

So, that means the travel time will decrease. So, there will be a point at which initially if we keep on increasing the distance between A to C that means, the source and the geophone initially that direct ray will reach fast, but after a certain time or certain distance your refracted ray will reach first compared to the direct ray because direct ray will always travel with the velocity of v_{p1}, but refracted ray will travel with the velocity of some portion is v_{p1} and some portion is v_{p2} and some portion is again v_{p1}.

Now, if the portion the wave is traveling with the velocity of v_{p2} increases and the travel time will decrease. So, ultimately there will be a point at which the direct ray and the refracted ray will reach at the same time. So, that distance from the source is called the critical distance. So, from the graph you will find the point where there will be a change in slope. So, corresponding that distance will give us the critical distance. So, this distance is called a critical distance. So, similarly, there will be another critical distance so, this I can say x_{c1} this is x_{c2}.

Now, what is the difference between x_{c1} this is x_{c2}? So, now, if you put any geophone within that distance of x_{c1} then your direct ray will reach fast if you put a geophone within the distance x_{c1} this is x_{c2} then the refracted rays passing through the interface of first and second layer will reach first now, if I put energy upon beyond the distance exceed 2 then the refracted rays traveled to the interface between second and third layer will reach first because again the third layer or velocity is greater than the second layer.

So, that means, every point this change of slope will give me a critical distance so, that which indicates that which refracted rays will reach fast. So, now, the equation that I am giving for 2-layer case your t_d expression is $\frac{x}{v_{p1}}$, x is the distance from the source to the geophone then t_r refracted rays that is $\frac{x}{v_{p1}} + 2H_1\sqrt{\frac{1}{v_{p1}^2} - \frac{1}{v_{p2}^2}}$. So, this is the second case. So, now, you can see that this is the equation of direct rays and refracted rays.

So, from this equation you can see the slope of these because if you put the geophone within the x_{c1} distance, so, definitely within that zone the equation 1 will be applied and between x_{c1} and x_{c2} equation 2 will be applied. So, that means you can see the slope will give $\frac{1}{v_{p1}}$ and the slope will give $\frac{1}{v_{p2}}$. So, now, how we can determine the distance x_1, so, again if I extend this line, so, these will give us t_{r01}.

So, now t_{r01} is that time at $x = 0$ if I put $x = 0$ so t_{r01} will be $2H_1\sqrt{\frac{1}{v_{p1}^2} - \frac{1}{v_{p2}^2}}$ or the H_1 I can calculate is equal to $\frac{t_{r01}}{2}\frac{v_{p1}v_{p2}}{\sqrt{v_{p2}^2 - v_{p1}^2}}$. So, this equation we can use and we can get the expression of H_1 so in this way I can get the thickness of the first layer. So, that means that the slope will give us the velocity of the corresponding layers and if I put the velocity and if I know this t_{r01} from the graph then I will get the H_1 thickness.

This is one way in another way also I can get the thickness H_1 that is that we know as I mentioned that at the critical distance the direct rays and the refracted rays will reach at the same time. So, this is the critical distance x_{c1}. So, at this critical distance my $t_d = t_r$ at $x = x_{c1}$. So, now if I put that one, I can write that $\frac{x_{c1}}{v_{p1}} = \frac{x_{c1}}{v_{p2}} + 2H_1\sqrt{\frac{1}{v_{p1}^2} - \frac{1}{v_{p2}^2}}$.

So, now here also that v_{p2} and v_{p1} are known and x_{c1} I will get from this plot the only unknown is H_1. So, again here H_1 expression will give us that $\frac{x_{c1}}{2}\sqrt{\frac{v_{p2}-v_{p1}}{v_{p2}+v_{p1}}}$. So, this is the whole route. So, either you can use this expression in terms of t_{r01} or you can use x_{c1}. So, both way you can determine the thickness of the first layer. So, this H_1 is the thickness of the first layer you can say Z_1 or H_1 you know so Z_1 or H_1 and Z_2 or H_2. So, next class I will discuss about the 3-layer case because this is a 2-layer case I have discussed. In the next class I will discuss about the 3-layer case. Thank you.