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Lecture - 4
Soil Exploration: Geophysical Exploration

Hello. Today, I will start my fourth lecture in this series and that is related to soil exploration. And, this will be probably the last lecture on soil exploration. Now, in this lecture, I will be discussing about a technique: one is geophysical exploration. How to use this technique to determine the soil properties? What are the different types of geophysical exploration methods available? Those things I will discuss in this lecture.

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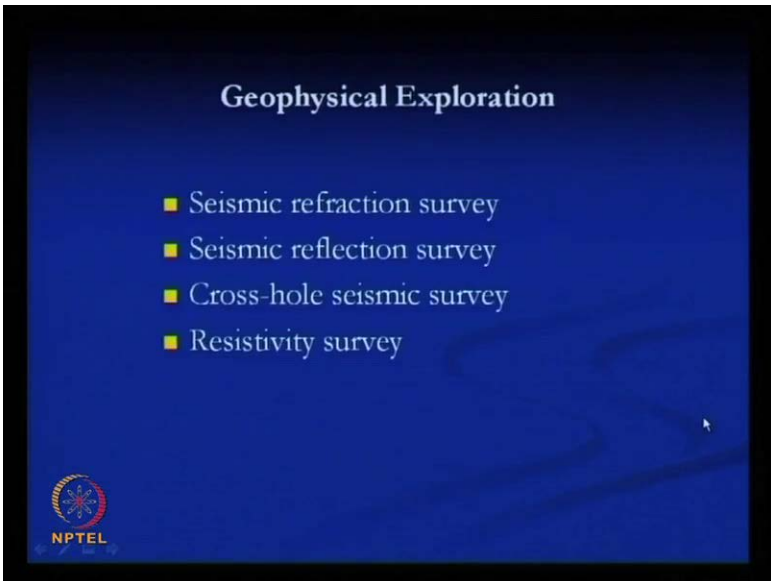

Now, first, these are the different types of geophysical exploration methods. One is seismic refraction survey; one is seismic reflection survey; then, cross-hole seismic survey; and then, resistivity survey. I will discuss one by one about the different type of this surveying methods and how to use this method to determine the soil properties.

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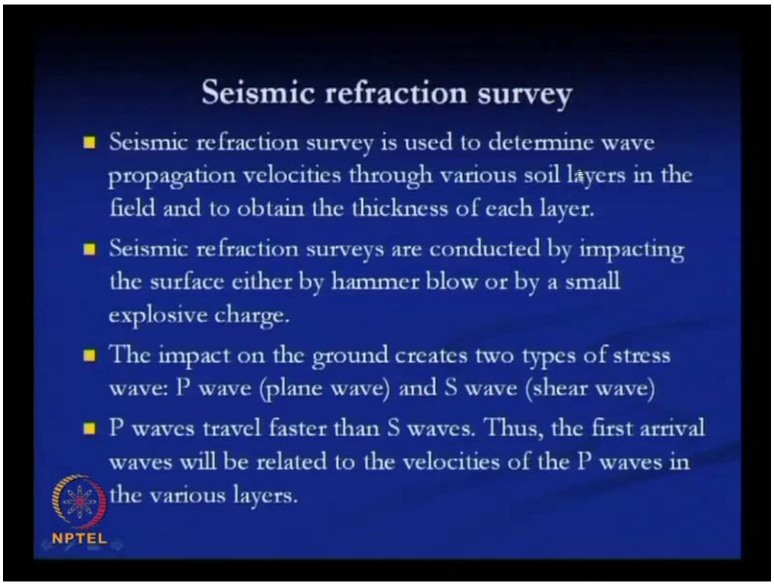

Now, first, I will start about this seismic refraction survey. Now, seismic refraction survey is used to determine the wave propagation velocities through various soil layers in the field and to obtain the thickness of each layer. Using of this surveying method, we can determine the velocity of the wave that is passing through that medium and the thickness of the each layers by which this velocity is passing. Next is the seismic refraction surveys are conductive by impacting the surface either by hammer blow or by a small explosive charge; that means we have to create waves and with the help of these waves, we have to determine the soil properties and the velocity of that wave and the respective thickness of the layers. Now, to how will generate these waves, so that we can generate either by the hammer blow or by small explosive charge.

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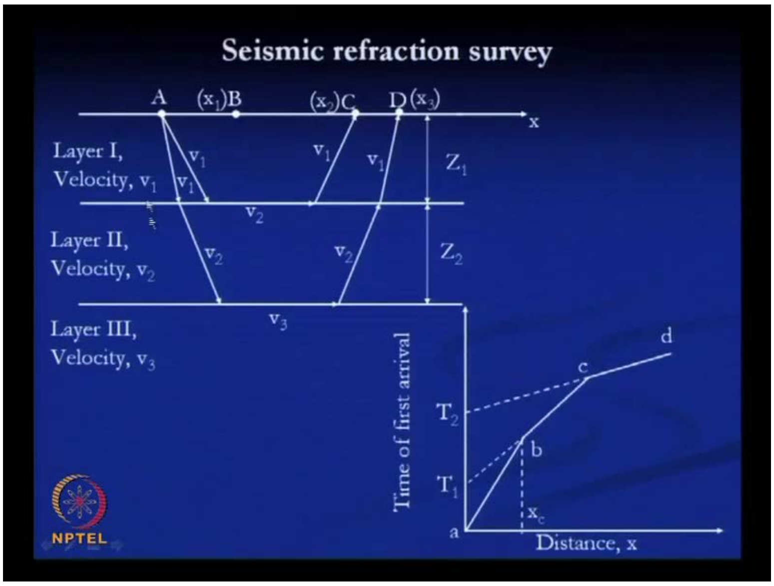

If I go this diagram, this is the diagram of this seismic refraction survey method and these are the three layer systems. This is the first layer, whose velocity of the wave is v 1; this is v 2, which is the velocity of wave; and, v 3 is the velocity of the wave in the three layers. And, suppose in the A, we have to create one wave here. So, by using the hammer blow or by small explosive charge, if we do the hammer blow here or by the small explosive charge, we can create that wave. So, here after this hammer blow, that wave will be generated and it will pass through this different direction. So, now, it will pass to this layer; it will come here. So, it will either reflect or it will refract. So, now, with the help of this methodology we can determine the Seismic properties or the velocity of that particular wave, which is generated; and then, the thickness of this each layer

Now, this impact of this ground creates two types of waves. Now, we are talking about the waves and we are talking about the velocities of these waves. Now, after this impact generally two types of waves are generated: one is called this P waves, that is, plane waves; or, another is called S wave, that is, shear wave So, these two types of stress wave will be generated after this impact. And, these two types of wave form these two types of waves: this P waves travels faster than S wave; so, that means, if we 1 2 record; that means, somewhere have to detect the or we have to place some geophones, which will receive those waves after this refraction; if we go for the first arrival of the receiving of these waves; so, that means, as P wave travels faster than the S wave, at first, the wave that will receive in the geophone, that is P wave; so, that means, in the plane wave that, the velocity we are talking of the velocity of the wave; that means, here the velocity of the wave will be the velocity of the P wave. So, we will generate two types of waves by using this hammer blow or this small explosive charge.

And, by using this hammer blow, we will generate two waves: P wave and S wave. But, as this P waves travel faster than this S wave, the first wave that we will receive by the geophone or by the receiver, which are placed at different distance from the A; this is the point of source; and, this B, C, D are the point of receivers or geophones, where we will receive first the P wave. So, the velocity that we will determine, that is basically the velocity of this P wave that is generated by this hammer blow or the explosive charge.

Now, how we will determine this velocity and how we will determine the thickness of each layer? Basically, by using this method, we will determine the velocity of this wave – P wave that is passing through the different soil layers; and, the thickness of each soil layer by which this wave is passing. And, this thickness will get… that means, we will get an idea that where the different types of soils are there; that the thickness of each soil layer; and, where the bedrocks are present. So, this idea we will get by this surveying method. Now, this velocity – we know that different soil layers have its own velocity range of this P wave velocity. So, we can determine the velocity of this wave. So, by using this range, we can get an idea which type of soil is it in this layer, what are the different types of soils presence. So, that idea also we will get.

Now, first, if I draw the methods… Suppose this is the ground surface or ground layer. Here this is the A, is the source, where will do this hammer blow. And, these are three layers. One is say this layer; this is two layer… This is layer number 1; this is layer number 2; and, this is layer number 3. Probably, first, we will go for this three layer system. Now, this technique can be used for any number of layers. As we are talking about that, we will calculate the velocity of this layer, that is, the velocity of this wave, that is, P wave. So, we will denote, this is velocity V P 1, is the velocity of the first layer; then, V P 2 is the velocity of P wave in the second layer; and, V P 3 is the velocity of the wave in the third layer. So, what will happen, after this hammer blow, this wave will generate and it will follow different directions.

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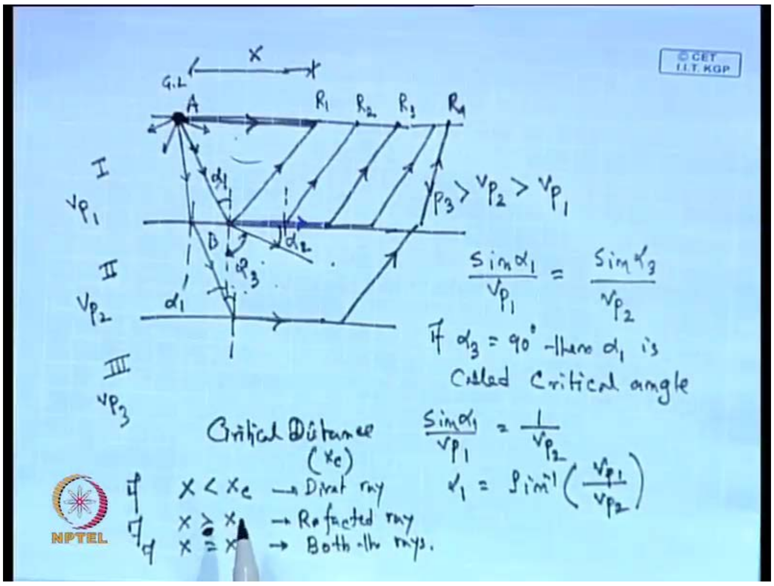

Now, one wave that will travel say suppose this is one wave that is traveling. This is the interface of the first and the second layer. First, it may reflect in this fashion. So, it will travel this… and some wave that will refract also. So, this wave will refract. We are now first talking about the seismic refraction survey. Now, we will consider only this refraction part. Now, this is the angle say alpha one by which this layer is making angle with this perpendicular line, that is, alpha. This ray is making that is angle alpha 1 with this perpendicular line. And, say another angle, which is alpha 2 – that is the angle by which this layer is passing; or, layer is refracting by this angle, which is the angle, which is making by this horizontal layer. And, this is another angle say alpha 3, which is also the angle. This refraction ray is making with this vertical line So, this is the first angle alpha 1; this is alpha 3.

Now, what will happen that, now, as this survey… One limitation is this survey is only applicable if this V P 2 is greater than V P 1. So, under this situation, we can able to this survey; that means V P how we can… Another thing V P 3 is greater than V P 2 is greater than V P 1; that means, as we will go further in the lower direction; that means to undertake this survey issued that the velocity of the wave should be greater than the velocity of the (( )) in the previous layer. So, velocity of this wave – that will increase as we will go in the deeper layer. As this V P 2 is greater than V P 1, this ray will travel away from this vertical line. By this law, we can write that sine alpha 1 divided by V P 1 is equal to sine alpha 3 divided by V P 2.

Now, another thing is that, depending on this alpha 1 angle, this alpha 3 angle – that will change. One particular situation if that we can see this alpha 3 is equal to 90 degree; that will happen when? If the alpha 1 angle is such that after this refraction, this alpha 3 angle is 90 degree, it means that after the refraction, this alpha 3 is 90 degree; that means, after the refraction, we will follow this path; that means, as this angle is 90 degree – alpha 3, it will follow this path. So, under this situation, if alpha 3 is 90 degree, then the corresponding alpha 1 is called the critical angle. So, if alpha is 90 degree, then alpha one is called the critical angle. So, this is called critical angle of incidence.

Now, if we put alpha three is equal to 90 degree, then we can write that sine alpha 1 divided by V P 1 will be equal to – sine ninety degree is – 1 by V P 2. So, alpha 1 will be equal to sine inverse V P 1 divided by V P 2. So, this alpha one angle is the critical angle under this situation. So, what will happen that, if we put receivers at different location… Suppose this is the position of point receiver say R 1; and, this is the position of another receiver R 2; and, this is the position of another receiver R 3. So, depending upon this receiver, that… So, every time, this ray now – after this thing, it will pass from A to say B; and then, it will follow this path; and then, it will again… So, as this… Here the velocity change means this V P 1 is less than V P 2. So, this ray we will go towards the vertical line. So, it will follow this path. So, it will receive one ray.

Here also if we put the receiver of geophone, it may follow this path and it may also follow this path. So, similar thing will happen for this… This is for the two layer system. So, I will go for the three layer systems further. Then, in three layer system, what will happen, it will follow this path; then, in this fashion, it will go; and then, it will follow this root here. Suppose, this angle is now the critical angle for this second layer and third layer. This alpha 1 is the critical angle with respect to first layer and second layer. And, this angle say alpha 1 dash is the critical angle with respect to second layer and third layer. So, it will follow this path; then again, it will follow this fashion. So, we can also receive if we put another geophone say R 4. And, we will receive this ray also. So, this is passing through first, second and this interface of the third layer. And, these rays are passing through the first and the interface of first and second layer.

Now, the question is that these rays are passing after the refraction. Now, in this, from A to this different receiver, this ray can travel directly from A to different receiver. So, there are two rays: one is passing through these different layers after the refraction of this total system; another is passing directly from A to different receivers. Now, we are talking about the first arrival time of the ray. Initially, it in the initial portion, if this distance is small, then this is the direct ray that is traveling directly from A to these receivers – that will arrive first faster compared to these refracted rays. But, after a certain distance, this refracted ray – that will travel or that will arrive in the receiver faster than the direct ray So, that distance is called critical distance. So, after the critical distance, the refracted ray will be received by this geophone faster than this direct ray.

Suppose this distance is critical say X c. Say X is any distance from the source. If X is less than X c, then the direct ray that will receive by the receiver before the refracted ray. And, if X is greater than equal to X c or greater than X c, then the refracted ray that will receive by the receiver before the direct ray. And, if X is equal to X c, then both the rays will be received at the same time. So, these are the three conditions… that means the travelled time for this direct ray and the travel time by this refracted ray will be same if X is equal to X c. So, this is the total system. Now, by using this total system, we will determine the velocity of the wave within different layers say layer 1, layer 2, layer 3; and, the thickness of each layer.

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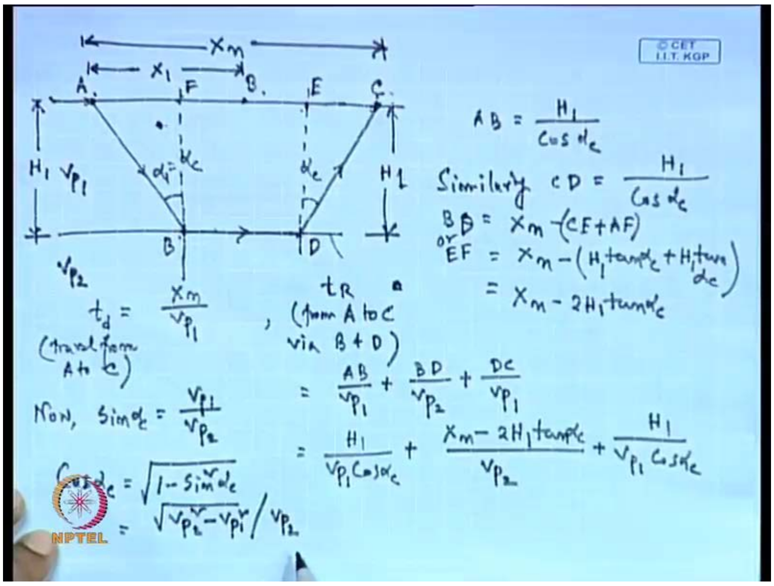

Again, if I draw this layer; suppose this is the source; this ray will travel in this fashion. This is say A; and then, this will travel in this fashion; and then, it will be received by the receiver at C. So, this angle is alpha 1 equal to alpha C; this angle will be also alpha C;

and, this thickness of the layer is H 1. And, this is the velocity of the layer 1 – V P 1; and, this is the velocity of the layer 2 – V P 2. Now, if I consider another point say B at a distance of say X 1; and, C distance is at a distance of say X n. Now, if X n is say the critical distance; that means the direct ray from A to C; and, this refracted ray is from A, B, then D to C. So, A B D C. And, from A to C, both the rays will be received by the geophone or receiver at C at the same time. Then, at the B point, the direct ray will be received before this refracted ray.

Now, we can write that for this C condition, the time required for the direct ray to travel from A to C – that distance required will be X m divided by V P 1; that means direct ray travel from A to C will be X m V to 1. Now, another time, that is, t R, which is travelled from A to C via B and D. So, this is another refracted ray that is travel from A to C also, but via this A, B, P, D and D, C. So, this time required… If this angle is alpha C and the thickness of this layer is H 1; or, we can write this thickness of this layer is H 1. And, V P 1 is the velocity of the first layer; V P 2 is the velocity of the second layer. And, this H 1 is the thickness of the first layer. So, this AB distance will be equal to H divided by cos alpha C.

Now, if this is H, this angle is alpha. So, we can determine AB that is equal to H divided by cos alpha C. Similarly, CD is also equal to H divided by cos alpha C. And, this distance BD that is equal to X n… because X n is the total distance minus this… So, X n minus CE plus AF. So, X n is the total distance minus CE plus AF. That will be equal to BD or EF. So, BD and EF will be X n minus EC minus AF. So, we can write that, this will be X n minus – EF and AF is – H tan alpha C plus H tan alpha C because… This CE will be equal to H or H 1; this is also H 1; H 1 alpha C. So, ultimately, we can write X n minus 2 H 1 tan alpha C. So, now, we know AB distance; we know CD distance; we know BD distance. So, if I want to write what is the time required t R, that will be equal to BD AB, that is, AB divided by V P 1, then plus BD divided by V P 2 and plus DC divided by V P 1. So, these are the three distance, because it is passing from AB, then BD and D to C. Here for this AB, it is passing through first layer; for CD, it is also passing through second layer, the first layer. But, for BD, it is passing through the second layer. So, we have to consider the second layer velocity and then calculate the time for this BD portion.

Now, if I put this value of AB, BD and DC, this expression will be H 1 divided by V P 1 cos alpha C plus X n minus 2 H 1 tan alpha C divided by V P 2 plus H 1 divided by V P 1 cos alpha C. Now, again, we know that, sine alpha c that is equal to V P 1 divided by V P 2 as previously, I have derived that sine alpha 1 is V P 1 by V P 2. So, alpha 1 is equal to alpha C. So, sin alpha c is equal to V P 1 by V P 2. So, cos alpha C that we can write, will be equal to root over 1 minus sine square alpha C. So, if we put this sine alpha C value here… So, cos alpha C will be finally, root over V P 2 square minus V P 1 square divided by V P 2; that means this one will be V P 1 square divided by V P 2 square. So, finally, we can write V P 2 square minus V P 1 square divided by V P 2.

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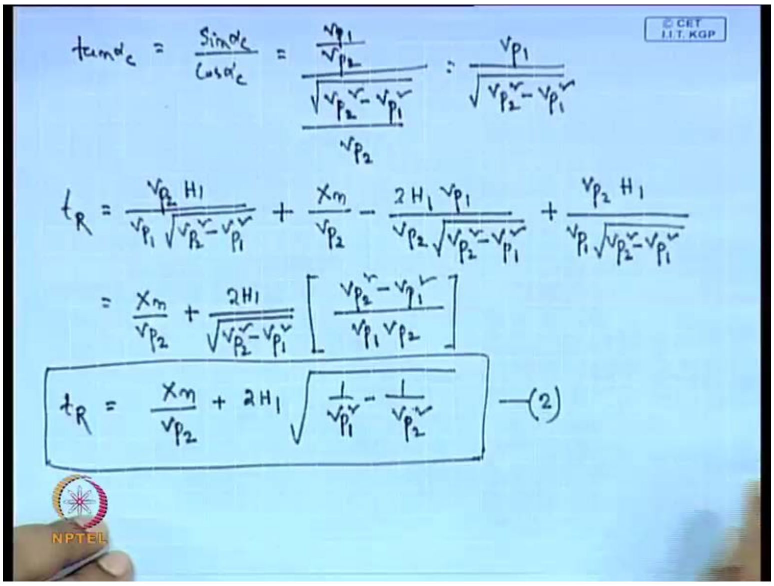

In the same process, we can write that tan alpha C is equal to sine alpha C divided by cos alpha C. So, that is equal to – sin alpha C is – V P 1 divided by V P 2 then divided by root over V P 2 square minus V P 1 square divided by V P 2. So, finally, the expression of tan – we will get V P 1 root over V P 2 square minus V P 1 square. So, this is the expression of this tan. Now, if I put the expression of this sine alpha C, cos alpha C, tan alpha C in the main expression, that is, this expression, we can write that t R will be equal to V P 2 into H 1 divided by V P 1 root over V P 2 square minus V P 1 square. We have to put cos value here; cos is root over V P 2 square minus V P 1 square divided by V P 2; then, plus X n divided by V P 2 minus 2 H 1 – we have to write the tan value – that is, V P 1; then V P 2 root over V P 2 square minus V P 1 square. Then, the next part – again, this V P 2 into H 1 divided by V P 1 root over V P 2 square minus V P 1 square.

Now, if we simplify this expression, we will get X n divided by V P 2 plus 2 H 1 divided by V P 2 square minus V P 1 square. We take this thing common. Then, we will get V P 2 square minus V P 1 square divided by V P 1 and V P 2. So, we are taking common this V P 1; then, V P 2. Now, finally, if we further simplify this expression, we will get finally, t R will be x n divided by V P 2 plus 2 H 1 into root over 1 by V P 1 square minus 1 by V P 2 square. So, this will be the final expression of the time required to travel by this refracted ray from A to C. Now, the next step that as we have assume that… Suppose this is our equation number 2; and, the direct ray equation that we have solved this t d 1 – this is equation number 1.

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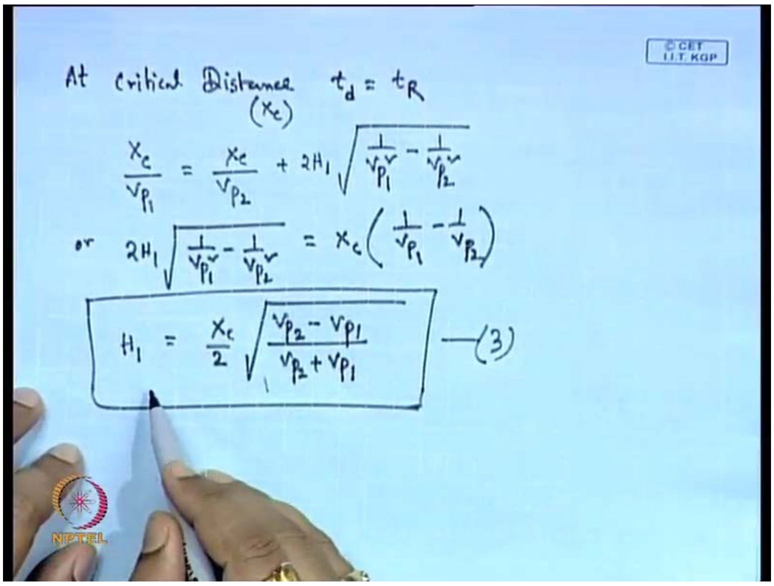

As we have mentioned, this is the critical distance. At critical distance, suppose the C point is the critical… At critical distance or t d that, will be equal to t R; that means time required to travel by the direct ray and the refracted ray both are same. Now, if we put this expression, then at the critical distance – that we can write this is X c – at X c distance, X c divided by V P 1; that will be equal to X c divided by V P 2 plus 2 H 1 root over 1 by V P 1 square minus root over 1 by V P 2 square. So, root over 1 by V P 1 square minus 1 by V P 2 square.

If I further simplify this expression, we can write that, 2 H 1 root over 1 by V P 1 square minus 1 by V P 2 square; that is equal to X c 1 by V P 1 minus 1 by V P 2. See if we further simplify this expression, we can finally get that H 1 will be equal to X c divided by 2 into root over V P 2 minus V P 1 divided by V P 2 plus V P 1. So, this will give you the expression of the layer. Here we have written H 1, because this is the first layer we have taken. In general, we can write that H or the thickness of the layer will be equal to the critical distance divided by 2 into root over the velocity of the wave in the second layer minus velocity of the wave in the first layer by velocity of the wave in the second layer plus velocity of the wave in the first layer. So, now, we have this. This is say expression number 3. So, we have three expressions; that is, for the direct ray expression; and then, the second one is the refracted ray time required expression. And, this one is the third one, is the expression for the thickness of the layer.

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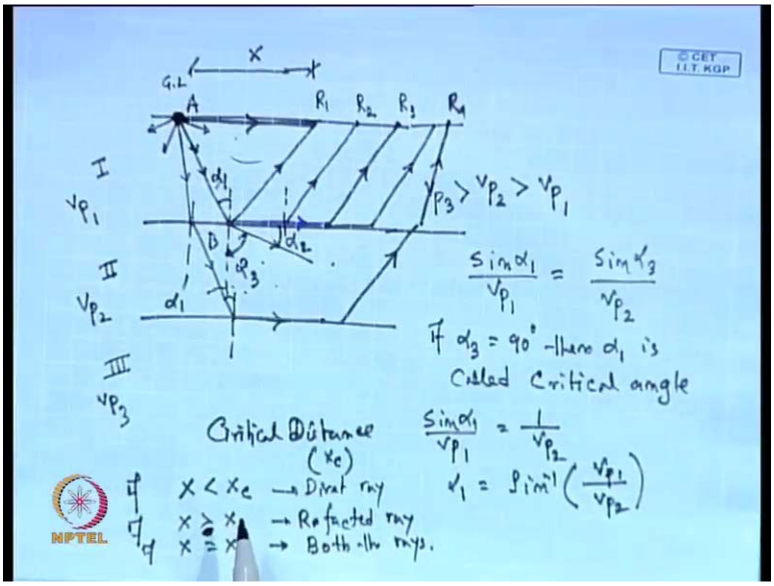

Now, using this expression… Now, in the first figure, where as explained that, we can put this receiver at different distance, because now, if…; that means, the beyond the critical distance we can put the receivers where we will get first the refracted ray. So, beyond the critical distance and in the critical distance, if we put the receiver, wave that will receive first, that is the refracted wave. So, if we put this receiver beyond this critical distance at different points, we can receive the time required for this refracted ray, because this is the first arrival of the refracted ray and the time require.

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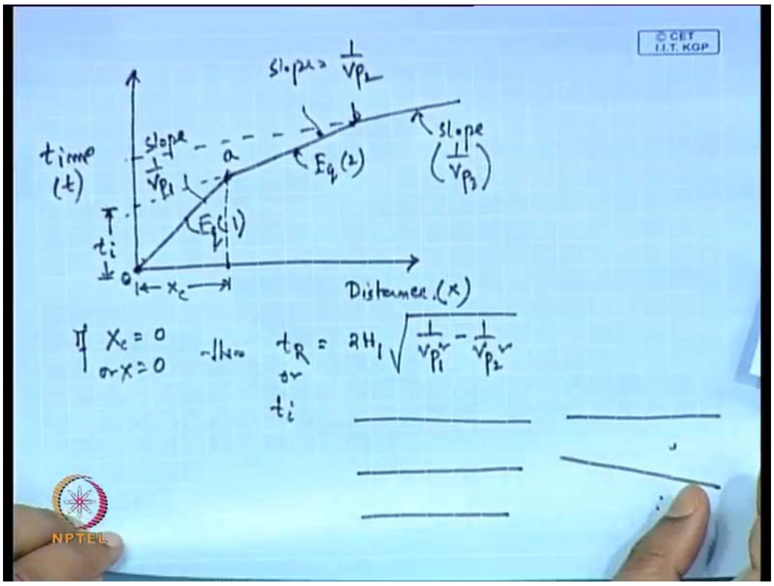

Then, we can draw a graph. In this (( )) this is the distance X and this is the time t. This time is the first arrival time of the rays. So, if we put the receiver beyond the critical distance at different points, then we will get the first arrival time, that is, the refracted ray. And, if we put the receivers within the critical distance at different distance from the source, point from the source, that ray will give you the first arrival time or the first arrival ray, that is, the direct ray.

Now, if I plot the expression of different expression, the time (( )). First, up to the critical distance, the time required – that will follow this expression number 1. So, that will follow… And, this is will be the linear graph. So, it will follow this fashion. Next, it will follow this expression number 2 for the next one. So, this will follow this fashion. This will follow this expression 2. So, this will follow this one; that means there are two graphs, where the slopes are different. So, we can point out the point of intersection of these two straight lines. So, this straight line. From initial point to this point – this will give us the critical distance, because at this critical distance, it will follow the expression 1. So, that is the first arrival time for the direct ray. And, this graph represents the time versus distance of the refracted ray.

Now, if we exchange this line, this is the time t i, where X is 0. Now, the slope of this… This is for the equation 1; this is for the equation 2. Now, slope of this first say suppose 0 to a and say b. So, slope of 0 to a line will give us 1 by V P 1, because from this expression, we can see the slope is 1 by V P 1. So, this is t versus X m graph, so that the slope is 1 by V P 1. Similarly, the slope of this graph – that will give us 1 by V P 1. Similarly, the slope of this second graph, that means, the expression 2 – this is the slope – that will give us 1 by V P 2; that means, the slope of this second graph – that is equal to 1 by V P 2. So, slope of this first 0 to a – that will give us 1 by V P 1; and, slope of this second graph – second portion – that will give us 1 by V P 2.

Now, if there is three layer system, then will get another straight line. And, the slope of this curve will give us 1 by V P 3. And then, we can extend this line also. So, similarly, we will get the slope of different state portion; and, that slope will give you 1 by V P or 1 by… of the different layers. Now, from this, if you know the slope, then we will easily determine the velocity of the each layer. Here we will determine the velocity of the first layer. By this graph, we will determine the velocity of the second layer; by this graph, we will determine the velocity of the third layer. If we draw this graph, we can determine this slope. Now, from this graph, we know the velocities of the each layer.

Now, the next step – how to determine the thickness each layer of this. So, if I go for this third expression, that the H 1 is equal to X c divided by 2. Now, from this expression, from this graph, we can determine this. This is the intersection point corresponding distance that will give us the X c. So, now, if we can determine this X c value… Now, we know this velocity of this different layer. So, we can put this X c, will determine the thickness of the first layer. And, another way we can determine the thickness of the… This is for the thickness of the first layer.

What we will get the thickness of the others layers also? In general term, we can determine the thickness of this layer. Now, if in expression 2, that is, in this expression if X is 0, which is because this second state portion represent the equation 2. So, here if X is 0, if X c is 0 or X is equal to 0, then t R will be equal to 2 H 1 root over 1 by V P 1 square minus 1 by V P 2 square; or, here we can write t R in terms of t i. t i is the kind, where X is equal to 0. So, we will get this value. Now, from this graph, we can determine what will be the value of t i. If we extend this graph in this direction, we will get the t i value. Now, if I put this t i value here and we know the velocity of the each layer from this slope, then we can easily determine the thickness of the first layer.

Similarly, for the second layer also, if we extend the third straight line; and then, we will get the time at 0 distance; then, by using the general expression, we can also determine the thickness of this second layer also if we know the thickness of the first layer and the velocity of the first, second and the third layer, because here we will get the velocity of the first, second and third layer; and, here we will get the thickness of the first layer. So, by extending this line, we will get the thickness of the second layer also. So, in this fashion, we can determine the velocity of the each layer and the thickness of this each layer. And, this is for this horizontal slope.

Now, this technique we can use for inclined layer also. Suppose here the layer is horizontal in this way. Here also, we can use this technique. Now, if any layer is inclined – this is for the inclined layer, there also, we can use this technique and determine this angle, inclination of the layer, velocity of the wave between these two layers and the thickness at any particular point from the source of this layer; that also we can determine. So, this is seismic refraction surveying.

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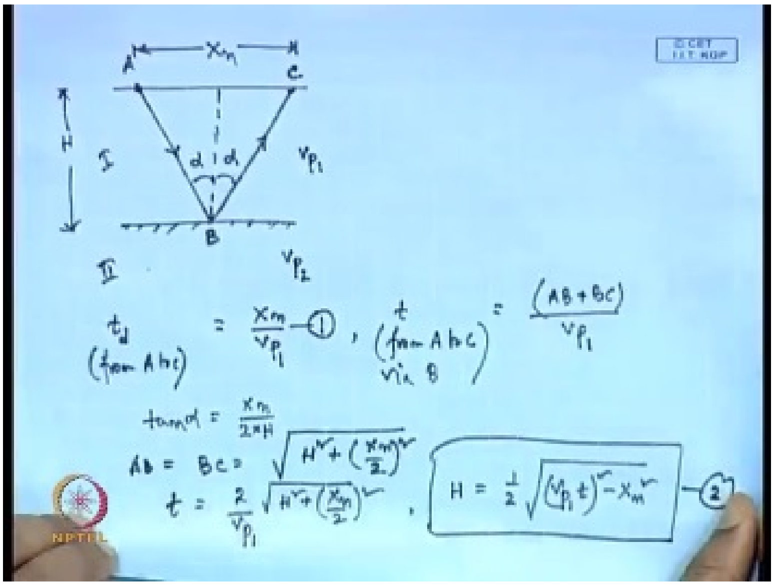

Now, next one that I will explain, that is, seismic reflection survey; first one is the refraction survey; this is reflection survey. Now, in this surveying, because this is… These are the refraction… the first one – the refraction… Then, in this surveying also, we will create one impact. Suppose this is the source A. Now, it will create one impact and the ray will travel in this direction; then, it will reflect. And then, it will be received by this receiver at C. This B is the intersection point between the layer. So, this is first layer; this is second layer; where, velocity is V P 1 for the first layer; and V P 2 is the velocity of the second layer. Suppose this angle is alpha; this angle is also alpha. Now, here also, this wave can travel from A to C directly and via this root A B C.

Now, the time required for the direct travel from A to C – again, we can write if this distance is again X n; we can write this – X n divided by V P 1. Another time required – travel from A to C via B – we will get that AB plus BC divided by V P 1. So, now, we can write that tan alpha – that will be equal to X n divided by 2 into H; suppose this thickness of this layer is H. So, this is for the second layer, because here we will not be able to determine this velocity of the second layer; we will only determine the velocity of the first layer. And, we can determine this is… If there is any bedrock here, then we can use this technique, because then in that case also… But, here we are not able to determine this velocity of the second layer.

Now, this is alpha 1. Now, we can write AB will be equal to BC; that is equal to H square plus X n divided by 2 whole square. Now, we can write this t, that is, the time required for this ray via BC from A to C. That will be equal to 2 into root over H square plus X n divided by 2 whole square divided by V P 1. Now, further simplifying; if we simplify this expression, then we will get the expression of H in this form; that is, 1 divided by 2 root over V P 1 t square minus X n square. So, this will give us the expression of H in this form. So, this is first equation and this is second equation.

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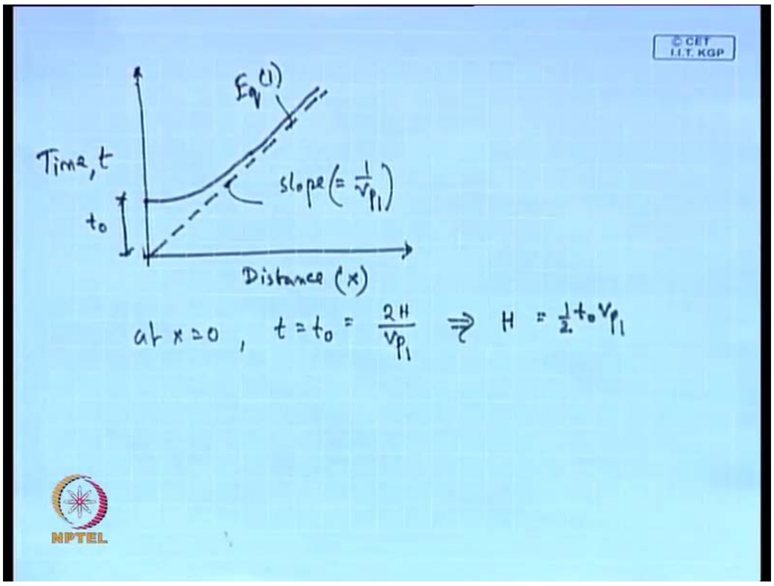

Here also, if I put the receiver at different distance from the source and then if we draw the graph… Again, this is distance X and this is the time t. So, for the first expression for the first equation, that is, this equation t d – x n divided by V P I; and, if we put at different distance of the receiver, and this X n will change; similarly, the t d will also change; and, it will follow a linear fashion. And, the slope of that linear graph will give you 1 by V P 1. So, we can draw that linear graph. This is for equation 1. And, slope of this graph that will give us 1 by V P 1.

Now again, if I draw the slope or the graph of this second equation, it will follow this path. So, this is parabolic in nature of this second expression – this t. For this second expression, if x n equal to 0, then we will get a time t. So, if I draw the second expression – time versus X n, that will follow a parabolic nature graph. And, if the X n is 0, then we will get a time say t 0. So, this time say t 0 is the time. So, it is for this… So, we will get this… If we draw this first equation curve, the different distance though, we will get the velocity of this layer. Now, we have to determine the thickness of that first layer or that particular layer. So, at X equal to 0, t will be equal to t 0; that is equal to 2 H root over V P 1, because in this expression, if I put X n equal to 0, then t will be equal to t 0, will be 2 H divided by V P 1. So, that is 2 H V P 1.

Now, from this expression, if I know this t 0, now, using this expression also, we can write H is equal to half t 0 V P 1. So, from this graph, we have to use the two graphs.

From the first graph, the slope, we will get 1 by V P 1; from that, we will get the velocity of this layer. And, from this second graph, where it is intersecting the time axis, here we will get the t 0. If we know this t 0, we will put this t 0 here and the velocity. And then, by using this expression, we will get the thickness of this layer. So, in this two surveying methods that I have discussed, for this surveying, we will get the thickness of these different layers and the velocity of the wave that is passing through this layer at different layers.

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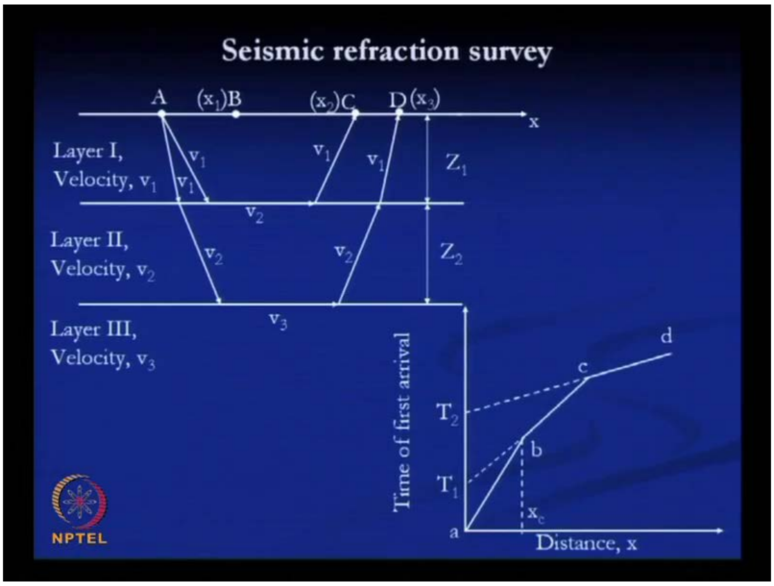

So by this first seismic refraction surveying, if we use the seismic refraction surveying that is where we can determine that, thickness of different layers and the velocity of the waves at different layers. But, the condition is that under this situation, where this V P or the velocity of the wave will be greater or that will increase if I go in the further depth. That is one condition; but, where will get the thickness and velocity of the each layer; and, for the seismic reflection survey, where we will get the thickness and the velocity of one particular layer.

In the next class, I will discuss the other two geophysical surveying methods and then I will start this shallow foundation part.

Thank you.