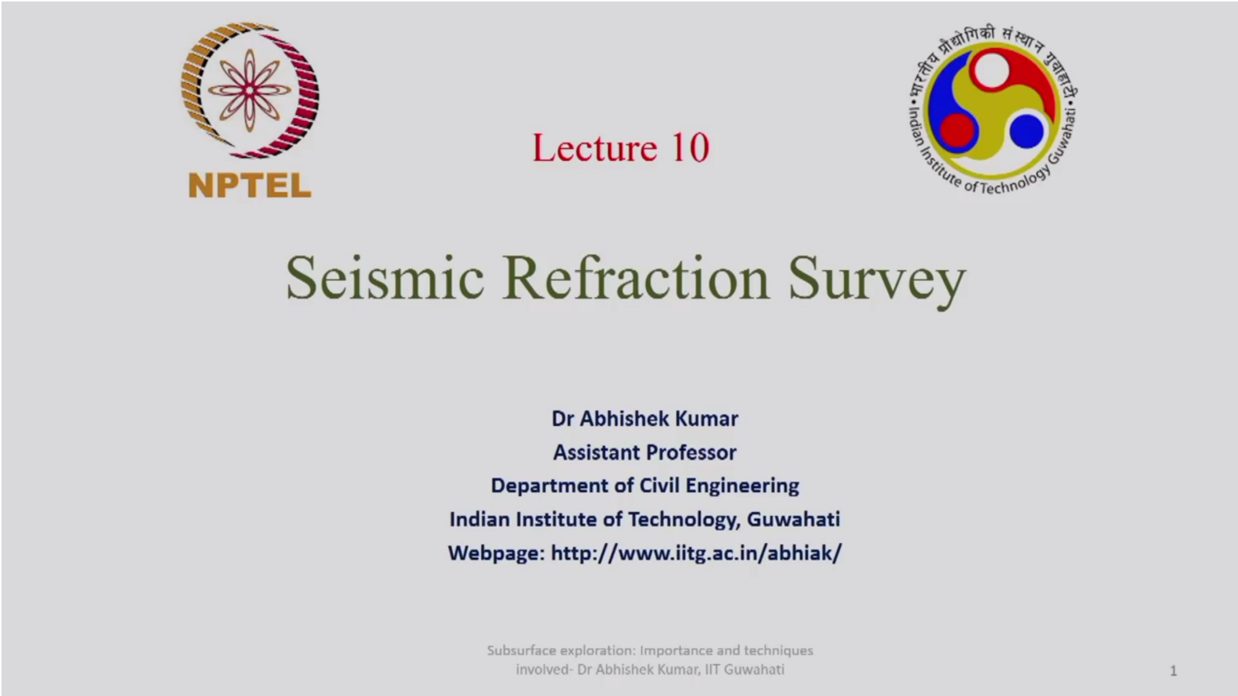


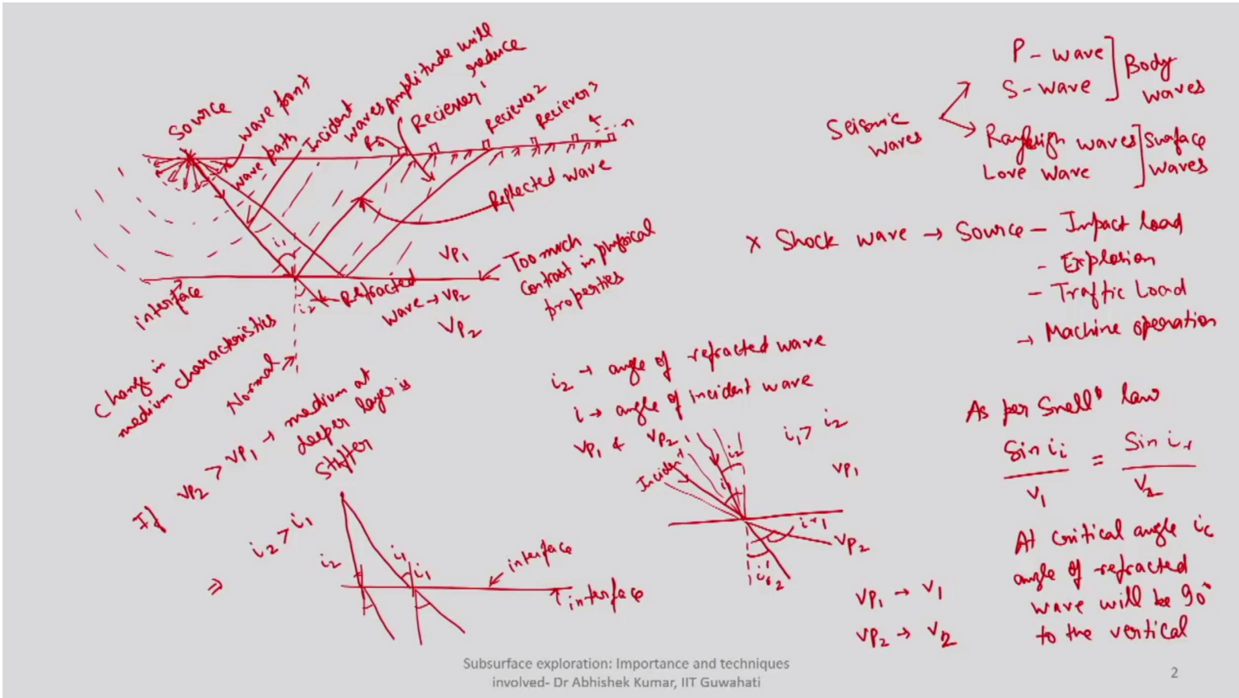
Dr. Abhishek Kumar: Welcome all to lecture 10 of Subsurface Exploration Importance and Techniques Involved. So in the last class, we had discussed why geophysical methods one should use, what are the advantages when we go for geophysical methods, particularly related to interpolation requirements. Whenever we are interested to find out how the different layers are varying, horizontally or laterally along the study area, and then particularly same way if you're interested to go for deeper exploration where routine geotechnical investigation cannot be done. Third is the findings from geotechnical investigation you want to extend to deeper layers, you can go for geotechnical as well as geotechnical investigation. So at shallower depth you can develop some kind of correlation between physical properties you are obtaining from geotechnical investigation, and similar properties you are getting from geophysical investigation. So then same way you will be able to understand the geotechnical properties at deeper depth based on geophysical test.

After that we started discussing like what are the different geophysical methods is primarily in use. Considering the number of topics which we will be covering under this module, I have selected few geophysical investigation techniques which are not commonly discussed. Two amongst those are seismic reflection survey, seismic refraction survey, and other methods as we discussed in the last class. Followed by in the last class, we discussed about what is seismic reflection survey, we also discussed like depending upon what kind of medium is there, depending upon which method we are using, each of these geophysical methods target to measure some variation in the physical properties of the medium, and we consider like this variation is happening whenever there’s significant change in the physical properties of the medium, actual physical properties of the medium.

So just by correlating the physical properties of the medium with the measurements of those physical properties by different geophysical methods, we can find out what are the different kind of mediums available at different depth, what are the physical properties available at different depth, and so on and so forth. So sometimes we go for shockwave, sometimes we go for gravitational properties of the medium, sometimes we got for magnetic properties of the medium, sometimes we go for electrical properties of the medium, and so on. So based on wherever there’s significant change in the medium characteristics, against each of those characteristics you will be able to detect those characteristics as an indication of possible change in soil type, geology type and so on and so forth.

So we discussed about seismic reflection survey in the last class. In today’s class, we will be discussing about seismic refraction survey, what is seismic refraction survey, how you can interpret the data, what is happening in seismic refraction survey, where the refraction is happening. In addition, before starting seismic refraction survey, I insisted last time, like depending upon the sources, which you are using for the development of shockwaves, your field record will be dominated by any particular kind of wave, whether it can be like different kinds of waves which we discussed like P waves, primary waves, S wave or shear waves. So depending upon the choice of sources, which you are using to generate shockwaves at the sources, sometime your ground record will be dominated by P waves, sometimes it will be dominated by S waves. This is more important because particularly when you are going for artificial sources, like you have to go for some subsurface investigation at the site of interest where you are interested to use some artificial source, so the choice of artificial sources, suppose if you’re interested to go for shear velocity measurements, but if you are going for vertical impact load, definitely vertical impact load will be more dominating P wave content. So in that case, your S wave content will be compromised.

So this understanding is very much important considering the choice of source which is going to be used for the generation of shockwaves, so the selection of source is very much important. That depends on what kind of medium characteristics you are interested to find out. So this understanding is particularly applicable when you are going for seismic methods. So in seismic refraction survey which we are going to start today, let’s discuss further how it works.



So last time we discussed like when we go for any kind of seismic methods, why it is called a seismic method, because generally during earthquakes so seismic activity, different kinds of waves, as we discussed like P wave or primary wave, which is causing compression, rarefaction, then S wave which is causing shearing in the material, depending upon the direction in which the waves are propagating, perpendicular, both perpendicular direction -- with respect to the direction of wave propagation, there will be a kind of shearing in the mediums.

So if it passing through the soils, so there will be some shearing in the material, perpendicular to the ground level if it is horizontal, and then another one be perpendicular again in horizontal plain, but it will be perpendicular to the direction of wave propagation. So both waves, it is causing some kind of shearing, some kind of relative motion between he particles as a result of which shear stresses will be developing in the material, and then considering the resistance offered by the material, which we call shear modular or shear strength of the material, that will govern how quickly that kind of wave will pass through that particular medium.

If it is able to provide more resistance, your S wave will be able to pass more quickly. And then we discussed about like when your body waves, collectively these are called as body waves, because these are mostly contained within the layer of the Earth. So I was discussing why these are called as seismic waves, because during an earthquake whenever we put ground motion recording sensors, so it will be detecting different kinds of waves, particularly P waves, S waves, then P waves sometimes. Again, there will be when this P wave interacts at the interface, there will be another component of P wave, so that will be called PP wave, SS wave, SPS and so on.

And then second thing, you will be having your Raleigh waves and Love Wave. So these are the permanent kinds of waves which are generally recorded at any ground motion recording instrument depending upon the relative position of your source or epicenter, because it is happening because of seismic activity, the waves generally classified as seismic waves or seismic wavs. So the first two are called as body waves, the second are called as surface waves. So depending upon relative distance between the source and your receivers, at times your record is dominated by body waves and sometimes it is dominated by surface waves as well, both are possible.

So when we discussed about seismic reflection survey, we discussed like there will be some kind of shockwaves, which are generated by means of a source. The source can be an impact load, it can be an explosion, like any kind of -- any source which is able to trigger some kind of vibrations in the medium, of course depending upon what is the range of frequency content you are interested in, those vibrations will be more interesting, and second thing the vibration you’re generating, it should have significant amplitude, so that it can be detected at wide range of -- I mean the receivers which are kept over varying range of distances. So it can be impact load, it can be explosion, it can be traffic load, it can be machine operation, and so no and so forth.

So explosion can be related to this particular method. I am going for some kind of exploration or sometimes when you are doing similar tests very near to your stone queries, there also people are using a lot of blasting, so that can also be detected and can be used as source of vibration. So this is when we discuss about seismic reflection survey. In case of seismic refraction survey also, though the objective is to detect the time of arrival of refracted waves as the name suggest, but more or less the setup will remains same. So there will be a source as you can see here, so there will be a source, there will be receiver, and generally when we are going for seismic refraction survey, we don’t go for single receiver, we go for an array of receivers, because the waves which are particular coming from deeper layers, mostly will be detected by receivers on some minimal distance. So you can call as receiver 1, receiver 2, receiver 3, 4 and so on, n number of receivers.

So again, whenever we generated some kind of vibrations at the source, what will happen, there will be wave path, the direction in which the wave is traveling, and then there will be wave front. So the size of the wave front will determine like what is the area in which, because of the propagation of a particular wave, the disturbance or any kind of particle movement is happening. Now same movement as it moves deeper and deeper, you can see it will be covering larger area and so on. So if you only consider these wave fronts, it will continue for ground distances also. The only thing like as you are going away from the source, the amplitude of those waves will be significant less, amplitude will reduce.

Another thing which comes into mind like here we're only targeting for waves, which are generated from the sources, but what will happen when these waves will interact, like particularly this wave front. Then it reaches this interface, interface means too much contrast in physical properties. To give you an example like VP1, VP2. The primary wave velocity of the resistance offered by the material in layer 1 and the material in layer 2. That will decide how much will be the VP1 and VP2 value. So this is like incident wave and depending upon the angle of incidence, this wave will be equally reflected. So this is called as reflected wave.

So up till this we had discussed last time when we were discussing about reflected wave, and same wave there will be another, I mean other frequency -- these wave fronts which will be reaching later state so you can put another receiver here which will be detecting. You can call it as R_0, because initially you had given from R1 onwards. So again, another wave front will be reaching some other distance, which will be detected maybe by this receiver and so on an and so forth. So because there will be -- like because of this wave, there will be wave fronts in all the direction. So you will be actually continuously recording these kinds of reflected wave all along the receiver lengths. Not only the receiver where you have put the waves but only in order to analyze you are putting the receiver at known distance. So you will be able to interpret based on the time of arrival of direct and reflected wave, what will be thickness and velocities of different medium.

Now in addition to this, right now we are targeting for reflected wave, but in addition to reflection there will be -- because there is change in medium characteristics, so what will happen, in addition to this reflection, you can call it as like when the wave reaches, some energy will start traveling toward the surface and some energy will be traveling downward. So what will happen, if you draw some, this thing, normal, so depending upon whether the medium characteristic are increasing, like medium is getting more and more stiffer with respect to you shockwave characteristics or shockwave stresses, the medium is getting more and more stiff, what will happen, once the wave reaches to the bottom direction, like the second layer, it will start deflecting away from the normal.

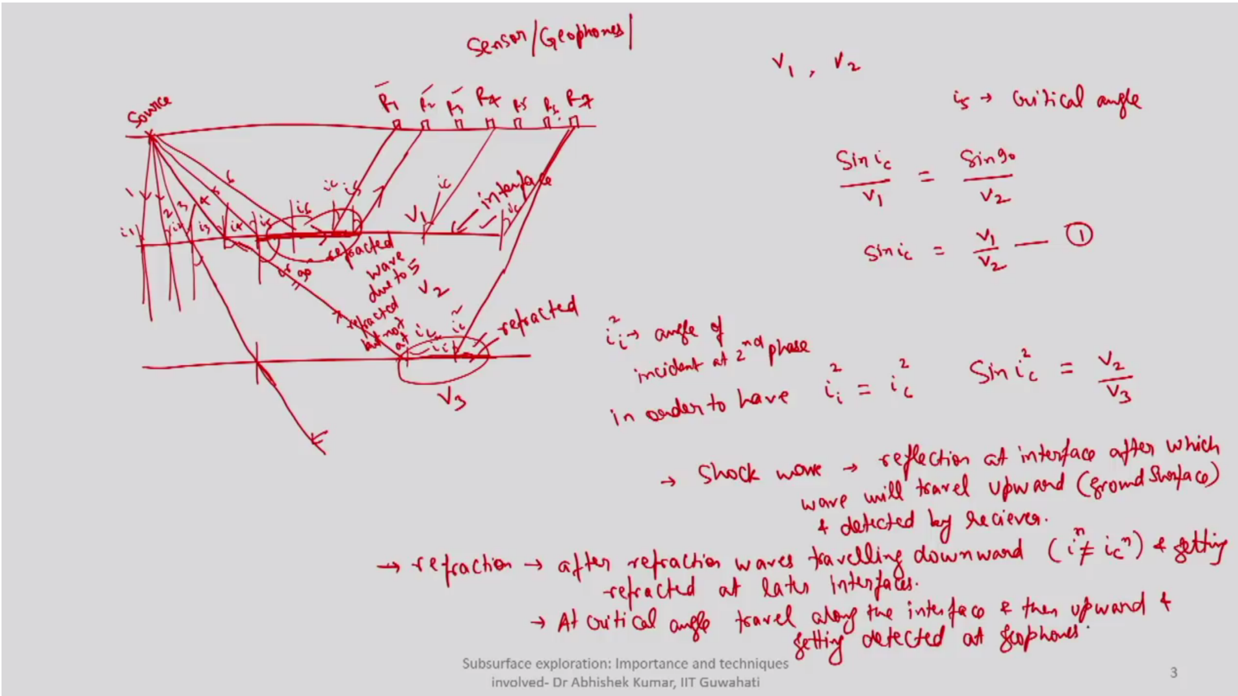
So if this is your i1, this will be i2. So if V2 is greater than VP1, that means indication like medium at deeper layer is stiffer. That will also indicate the value of i1 -- i2 will be greater than i1, and how much it will be greater than -- okay, so will be called as the refracted wave, which will actually travel in another medium with what velocity, so that will be corresponding to VP2 velocity, because this is now -- I mean once it crosses the interface, once the wave crosses the interface, it will go to the deeper medium, which is offering more resistance. As a result of which the wave propagation velocity will be significantly higher and because of this contrast between the medium characteristics, there will be some reflection which is from the interface start again traveling towards the surface and getting detected by the receiver.

Second will be the refracted wave, so depending upon if the medium is getting denser, the refracted wave will be moving away from the normal. Okay, so this angle i2 that is angle of refracted wave I can call it as, that will be function of three parameters. First i that is angle of incidence, ic I can call it as - okay let it be i, because ic will be very specific - angle of incident wave, which is undergoing reflection and refraction, VP1 and VP2 value. So depending upon the value of VP1, VP2 and i, the direction of VP if I draw it here again. So if you consider the value of VP1 and VP2 to be same for different cases which I am going to discuss now. So this is i1 that is incident wave.

Another incident wave at the same location if I am considering, which is significantly like this where it is i2. So if i1 is greater than i2, what will happen, considering same value -- so your wave will start traveling away from the -- I mean the value of -- like corresponding to i1 if this was ir1, as the value of ir2 increases, so this value will also increase. So this will become ir1. It will be like the angle of refraction wave, because of first incident wave. That will become ir2, because the angle is decreasing here, there also the angle of inclination of refracted wave also decrease.

So as per Snell’s law sin ii incident over V1, rather than VP1, I am calling it as V1, so VP1, I am calling it as V1, VP2, I am calling it as V2, so the sin i1 over this will be equal to sin of ir, so this is angle of inclination with respect to normal for incident wave and this is the angle of inclination of refraction wave with respect to normal. The same way if you consider multiple cases, like each incident wave at different, different angles because finally the angle of inclination, as you are considering the case, as you move away from the -- like this is your interface. What I am trying to say here like some refracted wave from the source, some incident wave at this location will reach maybe at angle i1, but some wave near this location will reach an angle which is lesser than i1.

So the same thing I am going to show here -- I mean because the refraction is happening all along the interface, because the medium contrast property is existing all along the interface. So even the refraction will be happening at the interface. So depending upon this, it will be like this, depending upon this, it might be like this. This is deciding how much will be your angle of refracted wave depending upon the angle of incident wave, keeping VP1 and VP2 as same value. So this is the same thing. At critical angle what will happen, at critical angle, I am calling it ic of incident wave, what will happen, your angle of refracted wave will be 90 degree to the vertical.



In order to see it further, let's go to next slide. So what I want to say here, it is like this. So this is your interface. This is your V1, this is your V2. Let's consider maybe some more cases here. So this is like V3. Now overall, if I am only targeting for refracted waves. I am putting a sensor here, R1, R2, this is like you can call it sensors. Sensors which are used for seismic refraction or even for ground motion records at times you can use. At times you can go for micro tremor records also for detecting these. So when you are going for geotechnical investigation -- geophysical investigation we generally for geophones. Some of you might have heard of geophones. You put those geophones at regular interval.

So what will happen here. I am putting geophones at regular interval for my ease. Now what will happen. So there was a wave, which is -- I mean there will be plenty of waves which are reaching here like this. All are incident waves. Again, this is having some angle. So all are like -- okay some incident angle will be there. This is with respect to vertical, yes. So if I number here 1, 2, 3, 4, 5, 6 and consider like the angle of inclination are i1, i2, i3, i4, i5, i6, depending upon V1, V2 and there might be an angle which might be called as critical angle. So suppose like i5 is critical angle, so as a result of waves, the refracted wave because of this critical angle will travel along this interface. I am showing you here a little thick link, so that you don't get confused with the interface.

So this is like refracted wave due to this fifth incident wave. So this is like refracted wave, not it is traveling surface again because it is traveling at the surface which is having too much contrast. What will happen? Again, some component of this will again start traveling back to the surface depending upon -- again this will be like critical angle i5 or maybe other angle. So I mean it will be traveling at different, different these things. So some might be -- no this will not be there. So this is at critical angle, it may be detected here. Some might be detected at the same critical angle at receiver 1, some might be detected at this critical angle after certain distance. So again, this will be called as ic and so on. So as you keep more and more number of receivers, each of these you can put more number of receivers also here, so that this refracted wave will be detected more number of receivers, so I can call it as R2, R3; you can call these as R4, R5, R6, R7

Now what will happen to other waves which were not ic or which are not at critical angle? First of all, we should write. So this angle ir becomes 90 degree. Now if you put this as 90 degree, what will happen. Your sin ic that is critical divided by V1 will be equal to sin 90/V2 or sin ic = V1/V2. So that’s how you can get to know -- that’s why I told you depending upon the angle of incident which is you can say here, it is again a function of -- so critical angle will be function of the ratio of primary velocities of both the mediums.

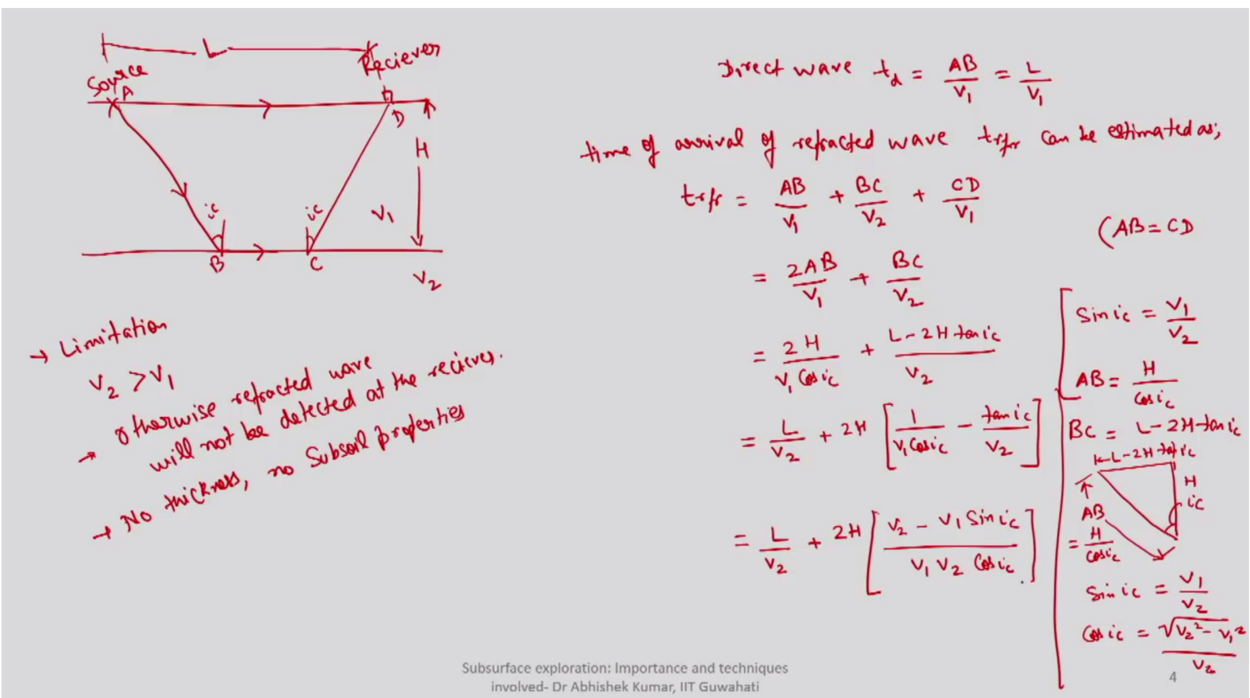
Now there are other waves also like i4 is there, i3 is there, what will happen, because the critical angle is less than this, so those will not be -- I mean not refraction, those waves will not travel along the interface, but will travel at slightly lesser inclination, like this. So depending upon how much is this inclination, this angle of inclination will also keep on -- like depending upon how much is this angle of inclination, this angle of inclination also keep on reducing, so that this ratio is maintained.

So this another wave, which though refracted but is not traveling at the -- like at V4 -- this is another waves, though refracted but not at ic, what will happen. This wave again will reach this interface. So this interface, if this is your angle i2, ii should say here. So I can take i2i which is angle of incidents at second interface. So same process which was happening at this interface will now happen at this interface. So in order to determine this value of -- in order to have ii2 to be equal to i critical at second interface, again, sin ic2 should be a ratio of V2/V3. So if this the case, again, there will be some kind of refracted wave which will travel at the interface, refracted wave.

Again, those refracted waves will have some component. This might be detected at the same receiver, which you had put there. So again, this is like ic2. So another refracted wave, which is not coming from the first interface, but it coming from the second interface will also be getting detected at the receiver, depending upon the relative position of those receivers with respect to different layer thicknesses from which refraction is happening. It may be possible the refracted wave from deeper layer may get detected by receivers which are kept closer to the source, and if the depth is more, it might be possible that the refracted wave before it reaches the ground surface, it may not be detected by the receiver, which are kept very close to the source.

But overall it will be like -- so you will be having refracted wave from first interface. You will be having refracted wave from second interface and so on and so forth. Like this one, if you consider one, if you consider one, it is not happening at critical angle for this interface. So this will again start traveling, so it will again start traveling. So what is happening? Overall, I can say like because shockwaves will have reflection at interface after which wave will travel upward or towards ground surface and detected by receiver. In addition, there will be a refraction which is happening. So there will be like two components. One after refraction waves traveling downward, because like angle of incidents was not equal to the critical angle of interface, angle of incident of any interface, and was not equal to the critical angle at that interface. So they will start traveling downward and getting refracted at later interfaces.

The next one is, again, there will be refracted wave at critical angle, which will be refracted. I mean travel along the interface and then upward and getting detected at geophones. So overall, all the geophones will detect.

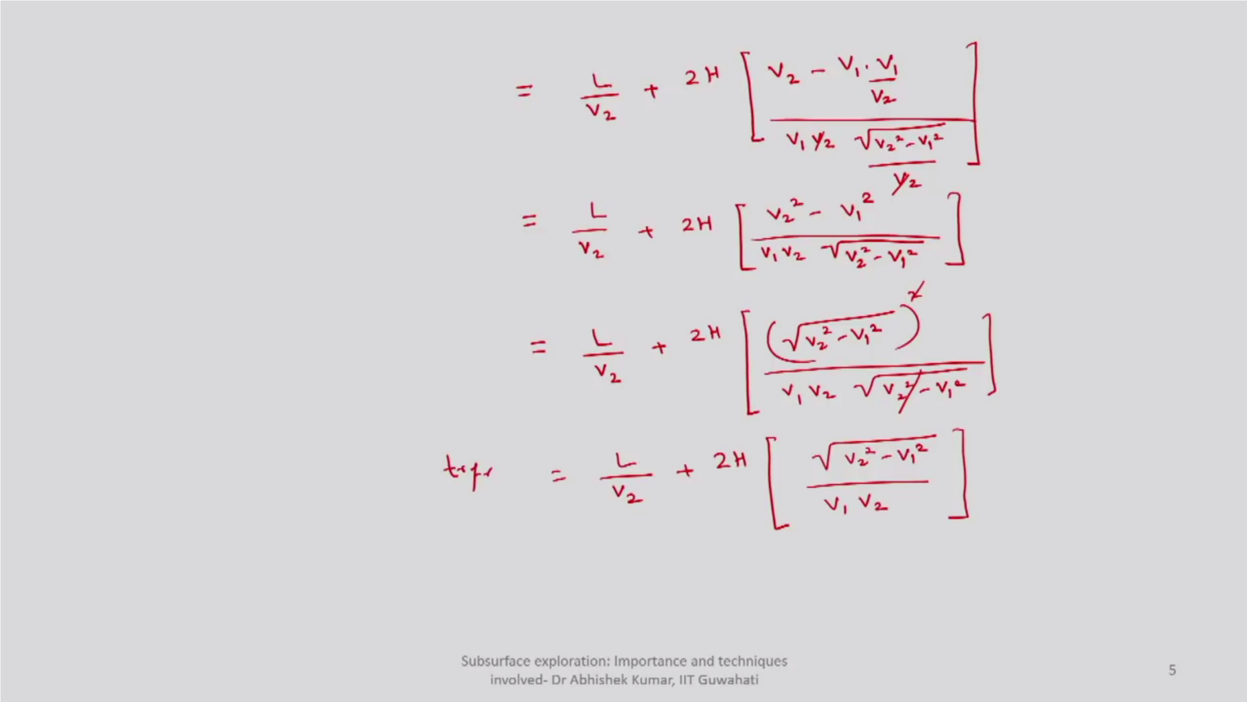


Now let’s see if you know like this is your source. This is some receiver, which is actually detecting your -- okay before going to this, I would like to highlight like seismic refraction limitation is, I can highlight here you understood. Like V2 value should be greater than V1 value, otherwise, though refraction will be there, but the refracted wave will never reach to the surface and thus will never be getting detected by the receiver. So that's why this is limitation. This V2 value should be greater than otherwise refracted wave will not be detected at the receiver. So if you're not detected, if you're not able to detect it, you will not be able to determine or quantify the physical properties, you will not be able to determine the thickness, so no thickness and subsoil properties. This has to be kept in mind, otherwise seismic refracted method will not work. So this is the limitation I would like to here. That's why I have written simply here.

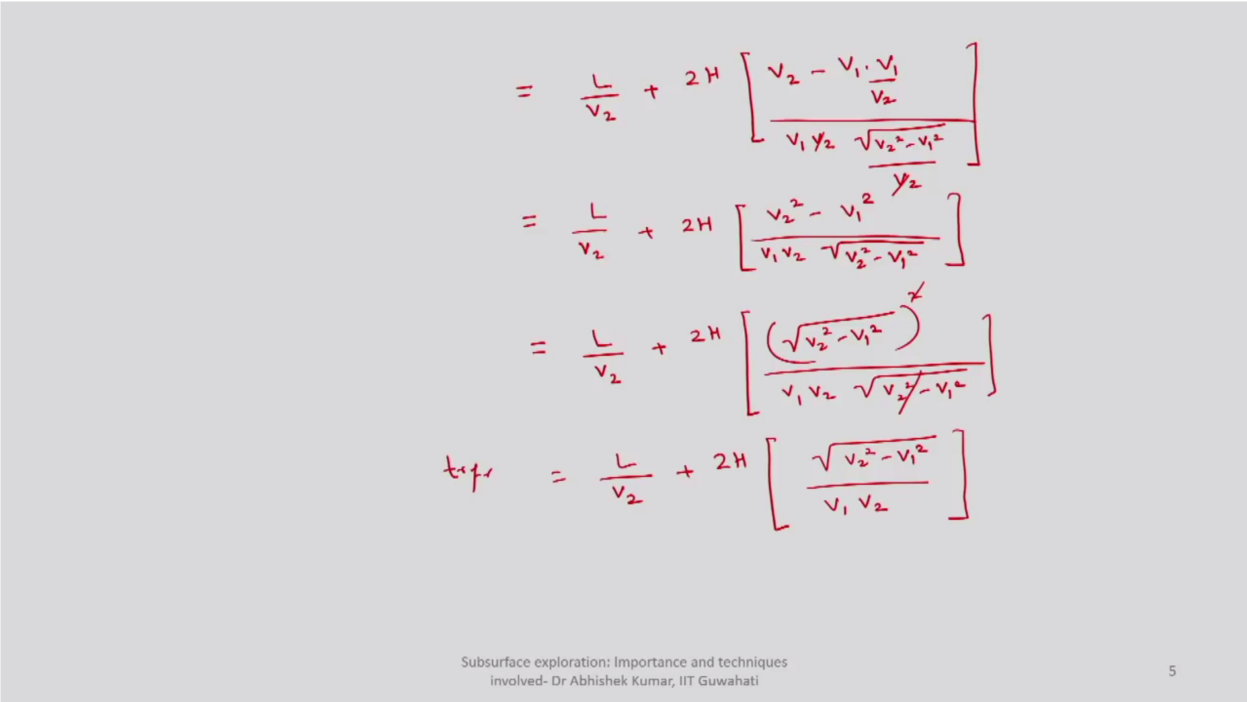
Now I am considering one wave, I am considering a case where the wave is there, which is traveling at critical angle, traveling along the interface, and then getting detected at the receiver 1. So if I number like A, B, C, D, you consider the thickness of the medium, the layer is H, this is V2, this is V1 and you have kept both the source and the receive at the known distance L. Now the time of arrival, so again there will be two waves, one is called as direct wave, which will be t_d, so that will be equal to AB/V1 that is L/V1. Then for time of arrival of refracted wave that is t_{rfr} can be quantified, can be estimated as t_{rfr} = AB in which the wave is traveling with V1 + BC in which the wave is traveling with V2 + CD in which the wave is traveling again with V1.

Now we know the value of AB will be equal to value of CD considering the interface is horizontal, so you can call it as 2AB/V1 + BC/V2. Now again, we consider sin ic = V1/V2. In that case, AB will be equal to how much, AB = H/cos ic and BC = L-2H tan ic, like this is the thing. This is ic, this is H, so this will be equal to AB, which will be equal to H/cos ic, and this will be equal to L-2H tan ic. Okay, so this is like this. Again, I can put it here, 2AB that is H/V1 cos ic + BC = l-2H tan ic/V2. Okay, so just take L as common here, I can call it as L/V2 + 2H [1/V1 cos ic - tan ic/V2]. Okay, so that's how if you solve it, you will be able to understand here, L/V2 + 2H that will be equal to V2.

So again, I wanted to highlight here, if sin ic = V1/V2, cos ic = $\sqrt{V2^2 - V1^2}/V2$. So I can put it here and so on will be about tan ic. So that will be equal to V2 - V1 sin ic/V1 V2 cos ic.



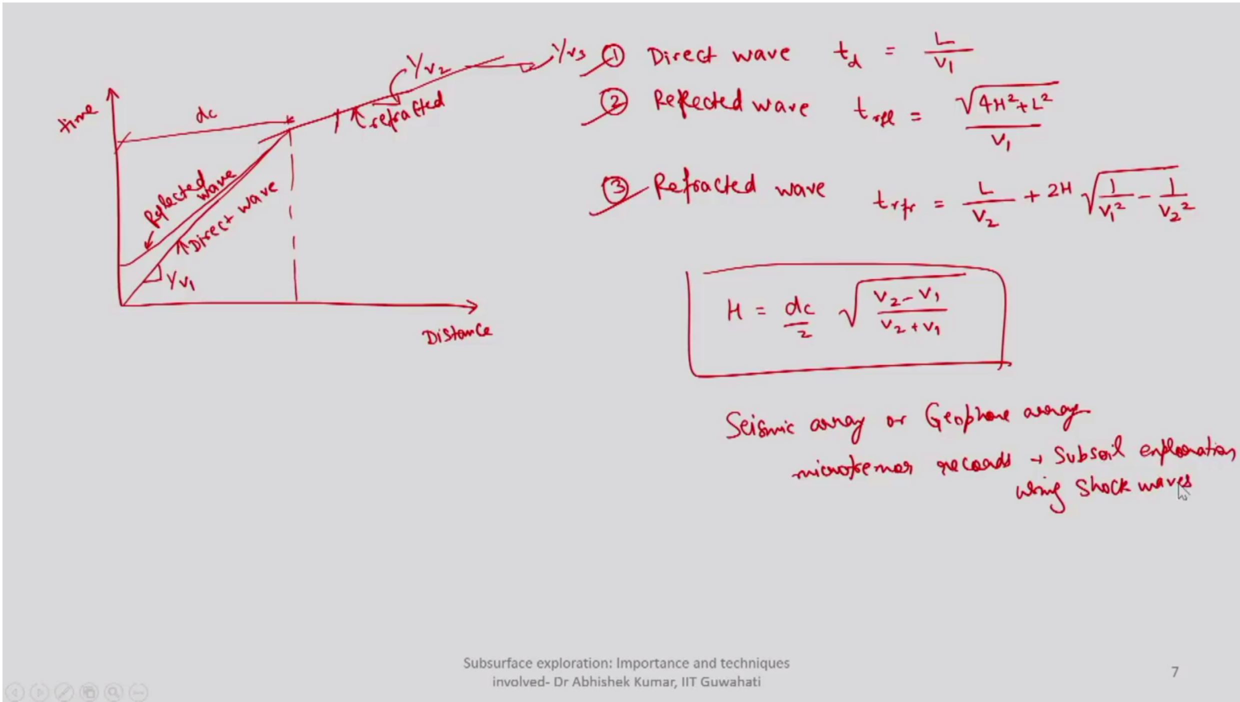
So I can put the value of sin ic and cos ic, I will get here L/V2 + 2H [V2 - V1 V1/V2/V1 V2 $\sqrt{V2^2 - V1^2}$/V2]. So this get cancelled. You'll get here L/V2 + 2H [$V2^2 - V1^2$/V1 V2 $\sqrt{V2^2 - V1^2}$], which can further be solved as L/V2 + 2H [$(\sqrt{V2^2 - V1^2})^2$/V1 V2 $\sqrt{V2^2 - V1^2}$], so this gets cancelled. You'll get L/V2 = 2H [$\sqrt{V2^2 - V1^2}$/V1 V2]. Okay, now this is again referring to t_{rfr} that is time of arrival of refracted wave.



Now if again at critical distance just like critical angle, at critical distance we call at dc, what will happen, the direct wave which is coming along the surface as well as refracted wave which is coming from deeper layers, first layer or first interface will reach the receiver simultaneously. That is time of arrival of direct wave will be equal to time of arrival of refracted wave. Now the time of arrival of direct wave we know it will be equal to how much, L/V1. So the equation which we have calculated here, we can call it ass number 2. So equate equation 1 and 2, equations 1 and 2 should be equal at L = dc. So put that, so you will get dc/V1 = dc/V2 + 2H. That further equation can be solved at as $\sqrt{1/V1^2 - 1/V2^2}$. So you can take this dc [1/V1 - 1/V2] = 2H $\sqrt{1/V1^2 - 1/V2^2}$.

Okay, so that's how you can get the value of -- if you solve this equation further, you will be get the value of dc that is 2H = dc (√V2 - V1)/√V2 - V1 √V2 + V1, so that will give you the value as dc/2 √V2 - V1/V2 + V1, that is the value of H. So this is -- you can call this is where H is thickness of first layer. Same way you can determine the approach dimension, but you will be able to determine the value of second layer, third layer, and so on and forth.

So the value of dc, you can -- how you get the value of dc, you will be able to get the value of dc based on your distance time, because I mentioned like when you go for field recording, this derivation I showed for one wave front, one wave -- if you put more number of receivers, so each of those receivers will be detecting different wave coming from different interface, but because the value of V1 and V2 are constant for each wave, so overall the wave which is coming from first interface will give you the characteristics of first interface whether it is detected by 1, 2, and more; and second -- I mean similarly, the waves which are refracted and coming from second interface will give you the value of V2 whether it is from R1, R2 or overall from R1, R2 and so on.



So this is -- now one question which comes to our mind is once we have the number of receivers which are detecting the wave, how you will be distinguish whether the wave detected by the receiver will be a direct wave, reflected wave or a refracted wave. So in order to understand that, we have to understand like in terms of physical parameters and the variation of these parameters, you can call it as direct wave, time of arrival that is td, that will be called as L/V1. So it is simply as you keep on increasing the distance, it will be linearly dependent. Then you have reflected wave. So if you remember last time we have retained also trfr, that is equal to $\sqrt{4H^2} + L^2/V1$, third one is refracted wave, which we discussed today, that will be trfr = L/V2 with the same thing. Once you know the value of H, you put it back so you will get the value of rfr for any distance. I mean if your receiver is at any distance other than critical distance. So you will get the value like this, $\sqrt{1/V1^2} - 1/V2^2$.

So you can see here the time of arrival of direct wave. Reflected wave and refracted wave are different. So if you put more number of receivers over a range of distance, and this is time, what you are going to get is, it will be like direct wave, based on the time of arrival, which is picked up by the geophone you can get, like this will be direct wave, then there will be reflected wave, you can call it as direct wave. After certain distance, reflected wave and direct wave will reach at same time. At the same time, this is reflected wave, and then you will be having, completed different way you will be having refracted wave. It is observed like after certain distance, you have refracted wave, because some component of refracted wave is traveling through stiffer medium.

So refracted wave will reach like at this distance, the refracted wave will reach much earlier than your direct wave. Again, you see here like this is the location at which direct wave and refracted wave both are reaching at same time. So this distance will be called as dc, you can get it if you know from distance time curve obtained from number of geophones or same geophones kept over different distances and excited for same source. So that's how you can get the value of dc. This will give you the value of 1/V1, this is going to give you a value of 1/V2, and so when more number of sources are there, you will get more and more like this. This will be 1/V3 and so on.

Why, I told you, because if you remember the equation, $dc/2 \sqrt{V2 - V1/V2 + V1}$, so the value of dc you can get from time distance curve where refracted and direct wave are meeting, and one value you can get as the inverse of the slope of, first phase of field record which is coming from direct wave, starting from origin, V2 you can get from the inverse of the slope of second wave, that is refracted wave. So once you know the value of V1, V2 and dc from you field record, that's how you can put in this equation and get the value of your thickness.

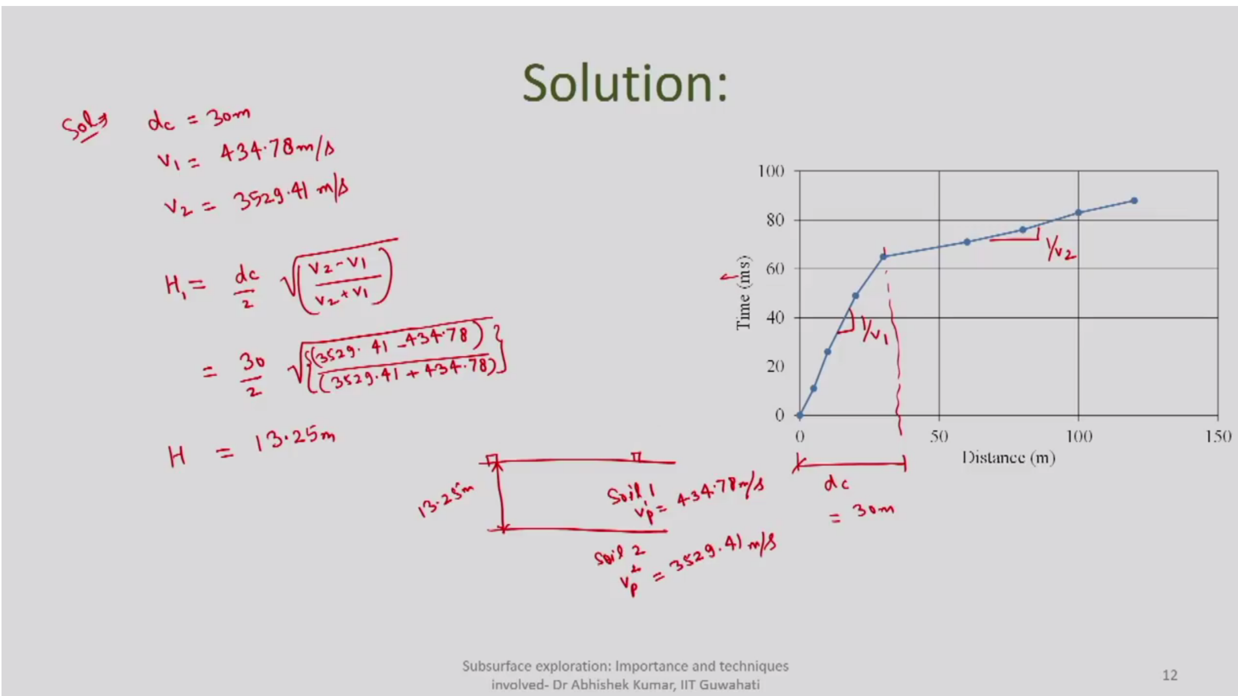
Now based on this, let's -- so you can got for seismic array or you for geophone array or even you can go for microtremor records once you are interested to find out for subsoil exploration using shockwaves. You can got with any of this.

Problem: A seismic refraction survey yields following times of arrival of P waves at geophones kept over given range of distance. Estimate the P wave velocities as well as the layer thickness.

Distance to geophone from source (m)	P wave arrival time (ms)
0	0
5	11
10	26
20	49
40	65
60	71
80	76
100	83
120	88

Now let’s see one example before going into detail. I mentioned here, so that you can see here how the seismic refraction survey, we can do the interpretation. So the problem is like a seismic refraction survey yields following times of arrival of P waves, so you have put the sensors at different, different locations that you can understand from first column, and corresponding to each of the sensors, the time of arrival of P waves is detected. Based on this record, you are interested to find out the thickness and P wave velocities of the medium.

Now based on this time distance first of all, in order to interpret where is the direct wave, where is the refracted wave, first of all we have to develop the distance time curve here. So you see that I have just taken those values, you can simply take those values.



The value of time is giving in milliseconds, so be careful while giving the final values, and then distance is given in meters. So you can simply put those values in Excel and you can get the value of distance time curve.

Now the first, as I mentioned here, because it is starting from origin, this is going to give you the value of 1/V1, this is going to give you the value of 1/V2. You know the values, you can direct get from the Excel sheet. Another thing you will be able to understand here, this is the value of dc, which is if I remember, I got the value corresponding to 30-meter in this particular. You yourself can determine the value. Like in this case, the time of this critical distance is matching with the geophone location. It may be possible like there is no geophone, but based on the intersection of these two slopes, you will be able to determine the value of dc. So if I put here, if I know the value -- so based on this, I’ve got to know the value of dc, which is coming out as 30 meter. The value of V1 from this, I have estimated that is coming out to be 434.78 meter. You can put it in Excel, you can determine how much is the value of V1 meter per second.

When you converting, just make sure like this is given in milliseconds, so you have to convert it into seconds in order to determine the value of V1. Similarly, the value of V2, which is the inverse of the slope of second part of the curve, which is given as 3529.41 meter per second. Now you know the value of dc, you know the value of V1 and V2, you can determine simply how much will be the thickness of this layer, that is layer 1, that is called as dc/2 √V2 - V1/V2 + V1. So I am just putting the values here 30/2 times √{(3529.41 - 434.78)/(3529.41 + 434.78)}. If you put those values here, if you solve it, you will be able to understand the value is 13.25 meter.

So the stratification is like this and something. So this is like soil 1, having V1 or VP1 value equals to 434.78 meter per second, and this is soil 2 having VP2 or primary wave velocity as 3529.41 meter per second, and this is your layer thickness, which you have estimated as 13.25 meter. There was a source here and there was a geophone which is kept at 30 meter, which is at critical distance I am telling. This is varying, so you need not put it, I am just going to give you what is the overall geometry of the site as obtained from seismic refraction survey.

So same way, we can go for incline method, I mean the base bedrock or the interface which is inclined. Same way we can got for interpretation with respect to number of layers, but only thing which has to be mentioned here, the graph which I have shown here, it is showing very simplest case where you are having the refraction coming from the first interface, but if you put number of interfaces like from between soil layer 2, and 3, 3 and 4, and so on, there will be more sources for refraction, there will be -- similarly those sources attach sources for reflection. Same way if you have some local pockets of denser material, that will again induce some more refraction and reflection form within the layers, which will be also getting detected at the same receivers.

Another thing, if you have another source of vibration rather than this source like some machine operation is happening just in the region, because of which some shocks are generating and getting detected by the geophone, that will add more and more complexity to your field record. So generally, if you consider any typical field record, it may not look very streamlined like this, the field record I have shown here. So you have to have more and more expertise whenever you are going for interpretation of field record for seismic methods.

But I hope, I tried, though it is giving you simplest case where you will be distinguish very clearly between direct wave and reflected or refracted wave. That will give you an understanding about how this method works, how this method is able to give you the subsurface investigation or subsurface properties, because this is objective. When we go for subsurface investigation, we have to find out different material. And depending upon, again, these properties, you will be able to determine whether this soil is soft, whether this soil is stiff, whether the soil is of the order of limestone or granite like this.

Initially, I had given you some ranges of VP value of for different materials, so comparing those values with this value will also get an idea what kind of soil medium is there existing below the ground surface, which you have probably explored based on seismic reflection survey.

So thank you, thank you so much.