Geotechnical Measurements and Explorations

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Lecture No. # 24

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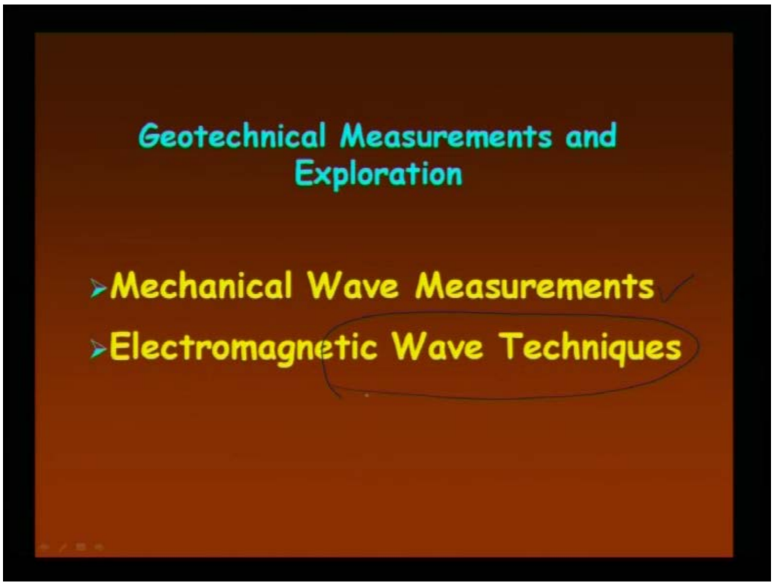

Next part is you are in geotechnical measurements and exploration. Two most important measurements, one is your mechanical wave measurement; other is your electromagnetic wave measurements.

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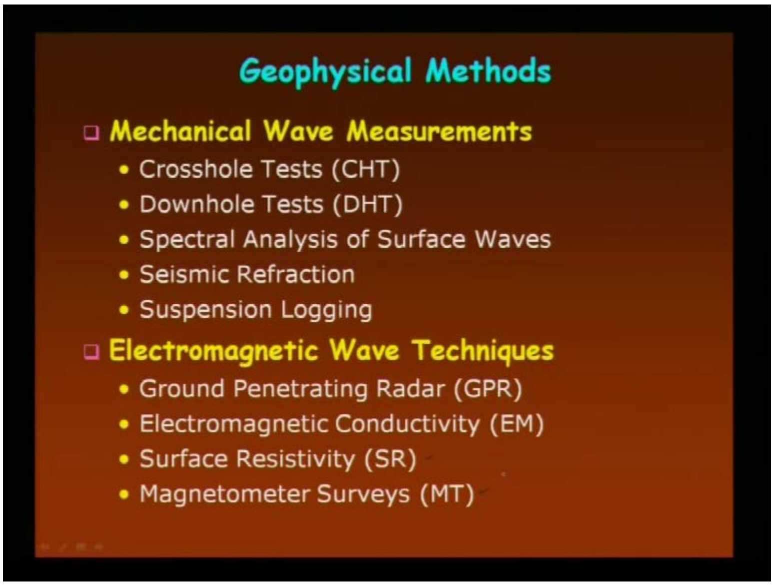

Geophysical methods: In mechanical wave measurements, these are the tests crosshole test, downhole test, spectral analysis of surface waves, seismic refraction, suspension logging. And electromagnetic wave techniques - ground penetrating radar, that is called GPR, electromagnetic conductivity that is called EM, surface resistivity - SR, and magnetometer surveys.

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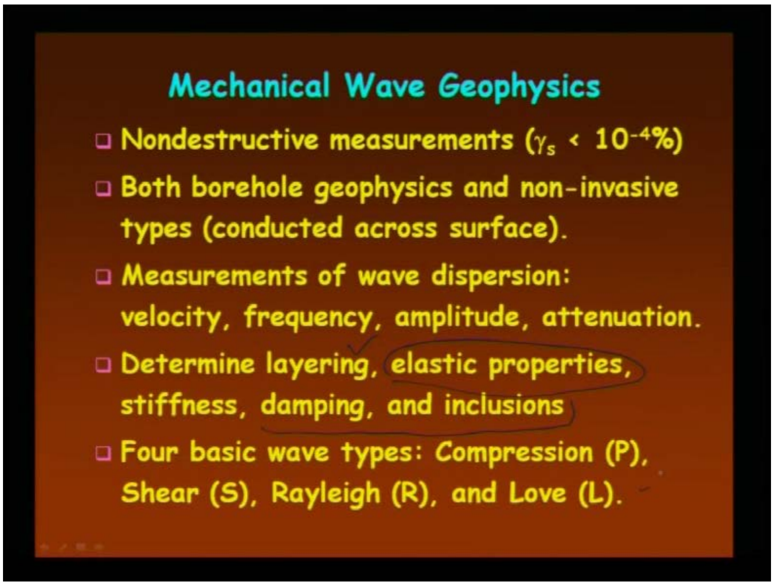

Mechanical wave geophysics: If you look at here, it is basically, why we are using this? What is the purpose? One is for non-destructive measurements; other is your measurement of shear wave or wave dispersions: velocity, frequency, amplitude and attenuation, and determination of layering, layers, and elastic properties elastic properties, stiffness, damping, and inclusions. These require particularly these called dynamic properties of soil how you can determine in in-situ conditions that means stiffness damping and inclusions. There are generally if you look at here there are generally four basic wave types classified - one is called compression, shear, Rayleigh and love.

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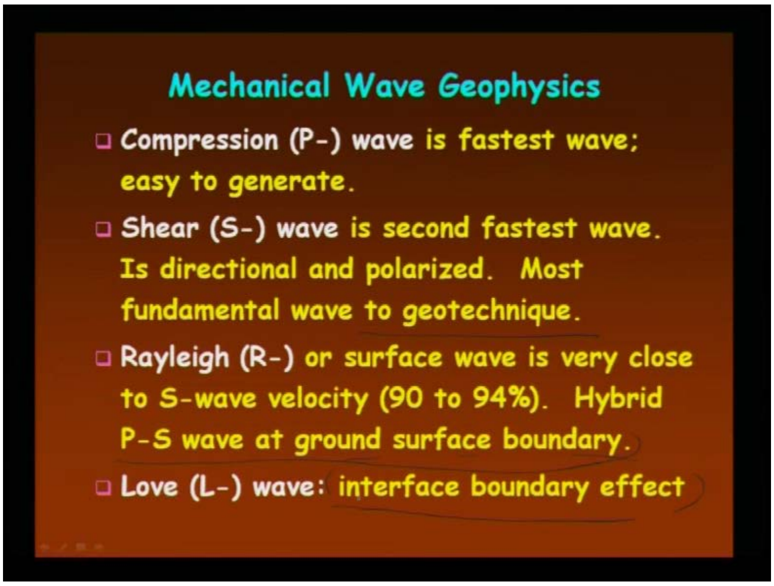

Now in compressional, it is called P-wave; it is a fastest wave to generate. And shear, it is called S-wave; this is second fastest, it is generally shear wave is more concerned for geotechnical engineers; this is called S-waves. Rayleigh wave R is a, it is a surface wave and very close to S, velocity of 90 to 94 percent and hybrid P and S wave are ground surface boundary; you can use also hybrid of P and S wave. Love wave – L-wave, this has been used for interface boundary effect to measure this, interface boundary effect.

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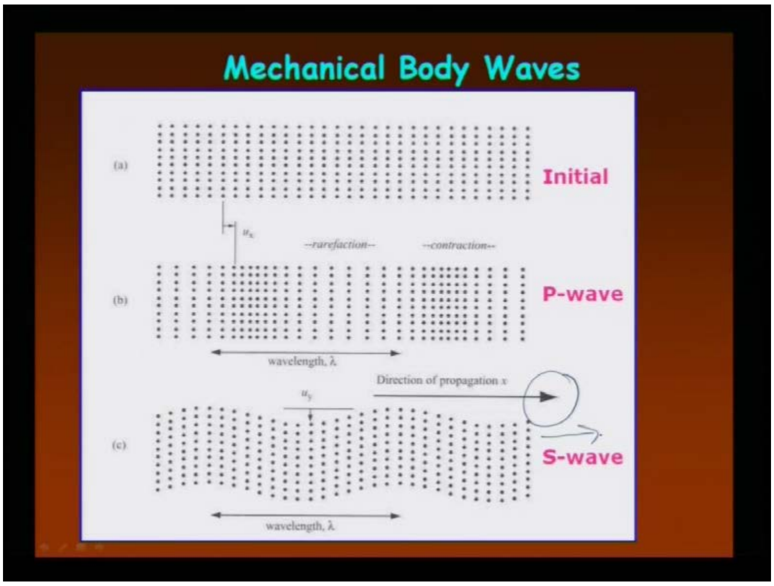

Look at this, how this P-wave will be there and it will be compressional wave. P-wave is nothing but, if you look at here. P-wave the moment I say P wave it means it is because of compressional wave. And then this is the wave length and and this is because of refraction as well as contraction this P-wave will be generated and in case of S-wave this will be a shear wave how it is travelling and direction of propagation in this direction - it is the direction of propagation.

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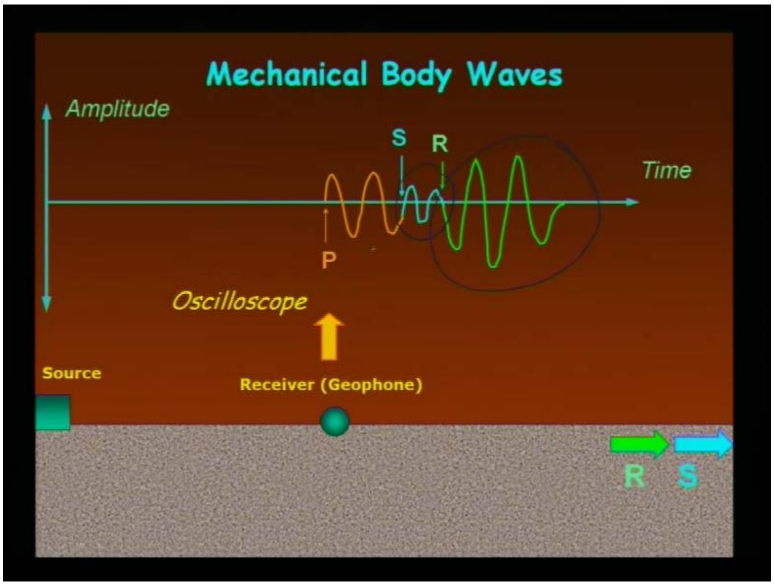

Now look at this if this is my source and this is the receiver of this geophone, how this P S and R waves or said P wave is your faster wave compared to S and R-wave. P for compressional; S for your, R for your Rayleigh. Oscilloscope by measuring this oscilloscope once this is the source you generate the source from this source you can generate P wave S wave or R wave then from this receiver geophone you can receive this wave by means of oscilloscope it will be a amplitude versus time how it how how you can know whether it is a P wave, S wave, and R wave. This kind of these things this is your P wave compressional wave, and this is S wave - it is a shearing shear wave, and the Rayleigh wave is the variation you see look at this Rayleigh wave variations, look at the S-wave look at this P-wave.

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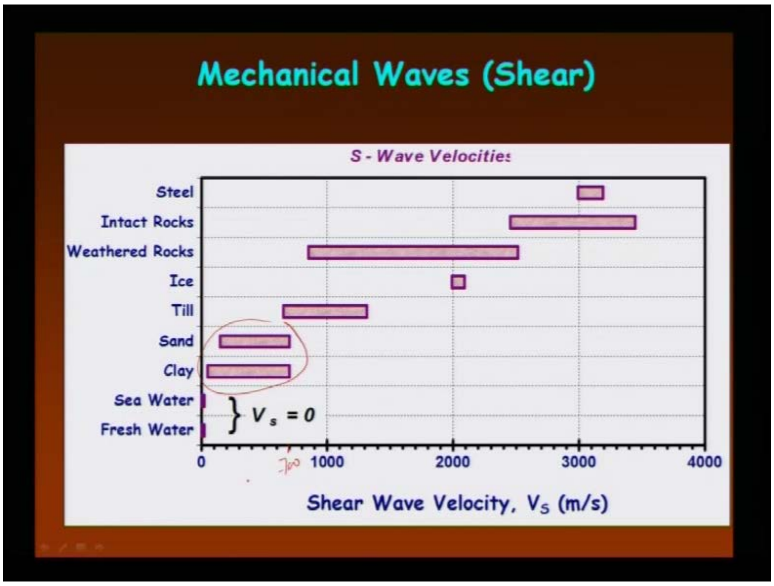

Now this range particularly compressional wave or P wave velocity - it varies from 1000 meter per second to 8000 meter per second; for particularly soil, sand and clay it ranges from 0 to not zero 500 to 2500 it ranges, and rock - particularly rock if you look at here the range is 2500 to 6000 6500; and steel, it is varying between 5500 to 7500. Similarly, S wave, S wave shear wave will it will give less very less value as compared to P wave. The range is for sand and clay, it is varying between 0 to 1000 or may be 700 you can say that 700 meter per second.

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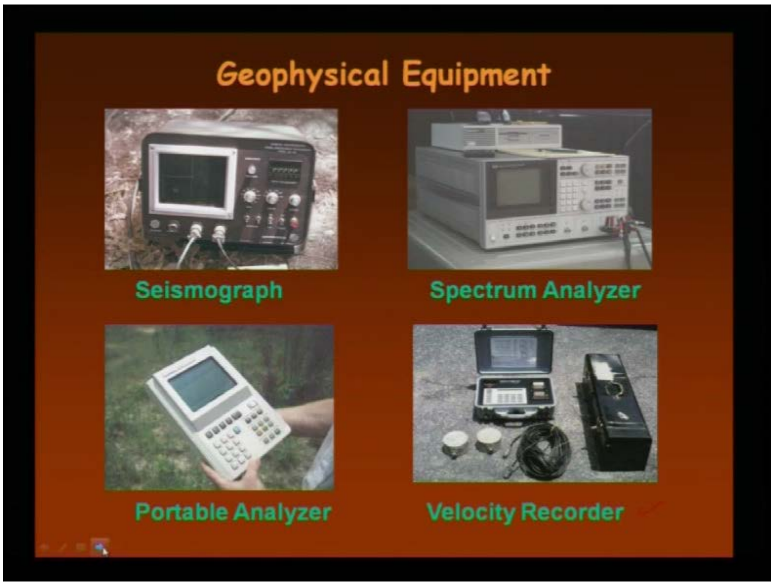

What are the different equipments used to measure this; one is your seismograph, then spectrum analyzer, portable analyzer, and last one is your velocity recorder.

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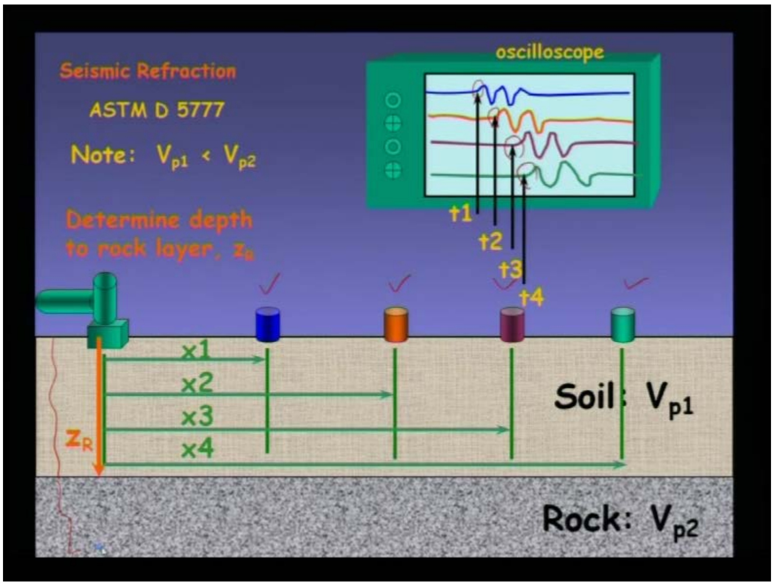

Let us start with this seismic refraction, it has already been explained it is as per this ASTM D 5777. I am showing this by means of animation. How the oscilloscope reads? How the reading in the oscilloscope? How you are getting it? Look at here, this is oscilloscope; this is your source; these are all your geophones or receivers.

Now from the source, you can start with these P wave or S wave by then. Next step if I go, yes vertical geophones - this is your source plate, now see it generate the source how it starts and how it has been received in oscilloscope. These are the receiver -1; receiver 1 receiver 2 receiver 3 by means of receiver 4 geophone how much time it takes by means of oscilloscope, you can record. If you look at this plus 1 plus 2 plus t 1, t 2, t 3, t 1, t 2, t 3, and t 4 and it has been received time required to receive in the first receiver geophone -1; this is your t 1 this is your t 2 this is your 3 and this is your t 4 and initially it will travel where it will receive this reflection or refraction it the curve will come like this.

The moment it receives, so these are the recording in the oscilloscope how you are measuring t 1, t 2, t 3, and t 4; t 1, t 2, t 3, t 4 is your time to receive this wave from in the in this geophones that means in this receivers. Then why this seismic refraction has been used, it basically used to determine the depth - that means determine the layer thickness, layer thickness layer 1 and layer 2. Suppose layer 1 is soil; layer 2 is rock then you can find it out what is the depth of the layer 1.

Now once again I am showing this animation. Source plate, these are all vertical geophones, now hammering has been done; waves has been generated how it is receiving two, three then four by means of reflection and refraction. It will come measured by means of oscilloscope then plot this graph then this is the distance measured the distance from source, what is your means from this source receiver - what is the distance you measure it. This is a z R this is a distance x 1, x 2, x 3, and x 4 with respect to with respect to source these are receiver 1, receiver 2, receiver 3, receiver 4. Receiver 1 at distance x 1, receiver 2 at distance x 2, receiver 3 at distance x 3, receiver 4 at distance x 4.

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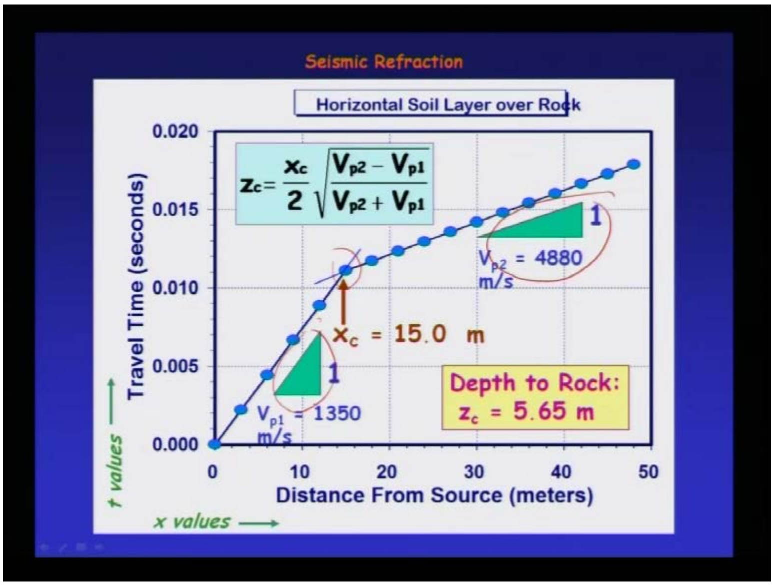

Now travel time versus, I explained earlier travel time versus this distance from the source with this. This is by means of either reflection or refraction and of with this slope we can find it out measuring the slope you can find it out what is the distance z, and also you can find it out how much the shear wave velocity. The velocity is nothing but the slope of this and the slope of this; this is your velocity v 1 and this is your velocity v 2.

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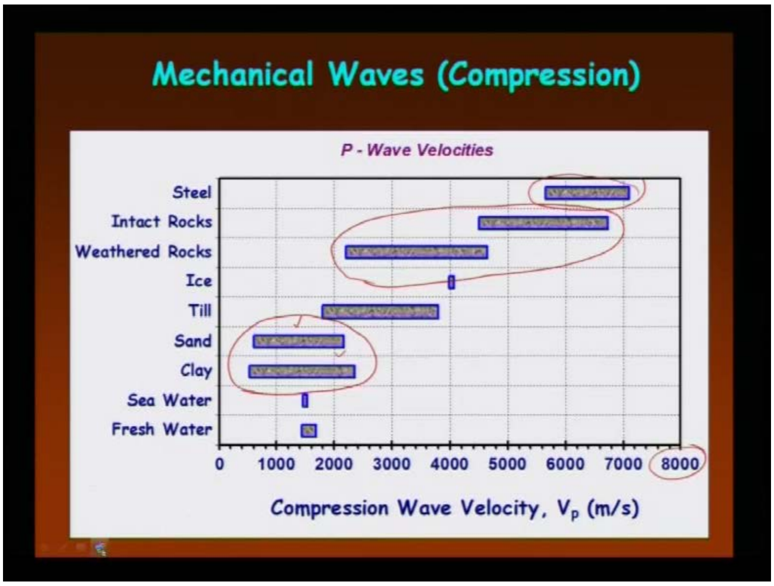

Based on that v 1 and v 2 you can classify whether what kind of wave you generate. If you generate P wave that means compressional wave, whatever velocity you are getting from there from the source you are generating this wave, and receiver you are receiving this wave and at what time interval distance by time you can measure the velocity. Once you get the velocity then you can classify what kind of soil or what is the rock is there. Then also at the same time you can find it out, what is that distance? This distance or may be depth or may be the thickness of soil or rock. This slope is nothing but, your velocity; this slope is nothing but, your velocity.

In this case particularly, if you look at in this case the wave generate wave generate this hammering has been done in vertical direction that means the wave generate will be your compressional wave compressional wave. So you can say that in seismic refraction method compressional wave has been generated to measure the thickness as well as velocity of the soil profile.

Now next part is your, next example is your shear wave velocity. This is most important in case of measuring the dynamic properties of soil

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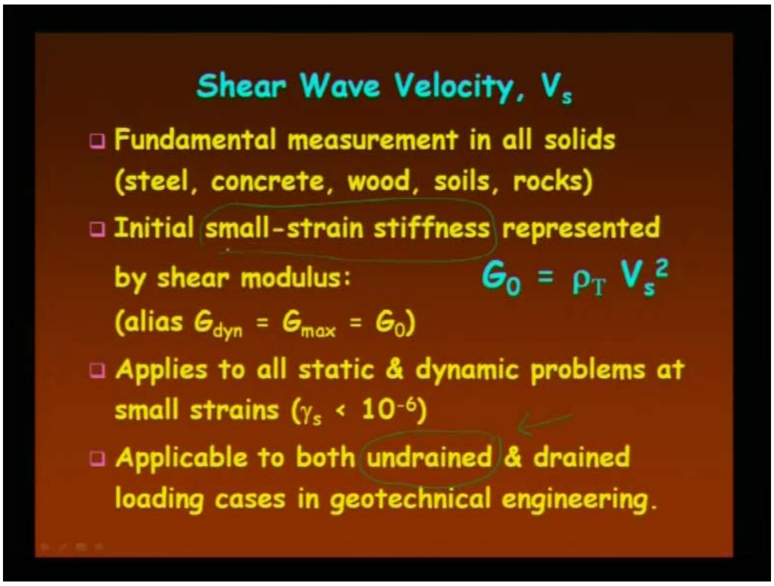

if you look at here initial stress, strain stiffness represented by shear modulus. Any soil parameter, any soil with respect to so earth quake loading what are the parameter required for your design. Your parameters require is your G maximum or G dynamics - that is called shear modulus. That shear modulus you can get it from this shear wave velocity, you can find it out shear modulus G 0 - that is your basic input parameter for design of soils with respect to dynamic loading. Then you can also find all static and dynamic problems at small strain. Strain rate of less than 10 to the power minus 6 - small strain rate it is useful, particularly this shear wave velocity technique is useful. Applicable to both undrained and drained loading cases in geotechnical engineering. If you look at there it is applicable to both undrained and drained loading - that means during loading during loading there will be a drainage valve will be there that means there will be a volume change because of your water. During loading there you will not be any volume change in both the cases this shear wave velocity component will give you value of G or G 0.

In undrained conditions, what will happen? So this shear wave velocity has many applications measuring this shear wave velocity particularly in soil. In undrained condition as I said in undrained condition you can predict by if you know the, what is the value of G and G maximum these are the input parameters for liquefaction analysis or seismic analysis or ground response analysis of soil. Then you can say that whether if there is a liquefaction peak ground oscillation you can find it out from ground response analysis. G and G maximum is required also all static and dynamic problems are small strains, generally soil spell are small strains less than 10 to the power minus 6. So that you can get it also also small-strain-stiffness; this also required parameter. Basically if I conclude what is the use of measuring shear wave velocity, the conclusion says measuring shear wave velocity - you can measure dynamic properties of soil and that can be useful any seismic analysis, any kind of seismic analysis that is an input parameter.

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Now look at these. Now these are there are different techniques as I said there are different techniques you can measure shear wave velocity - one of these crosshole seismic testing equipment. so in this why this is called crosshole? Crosshole meaning is that means there are definitely bore holes made side by side so that at one side your source other is your receiver from there you can measure the travel time based on the distance you can measure your shear wave velocity.

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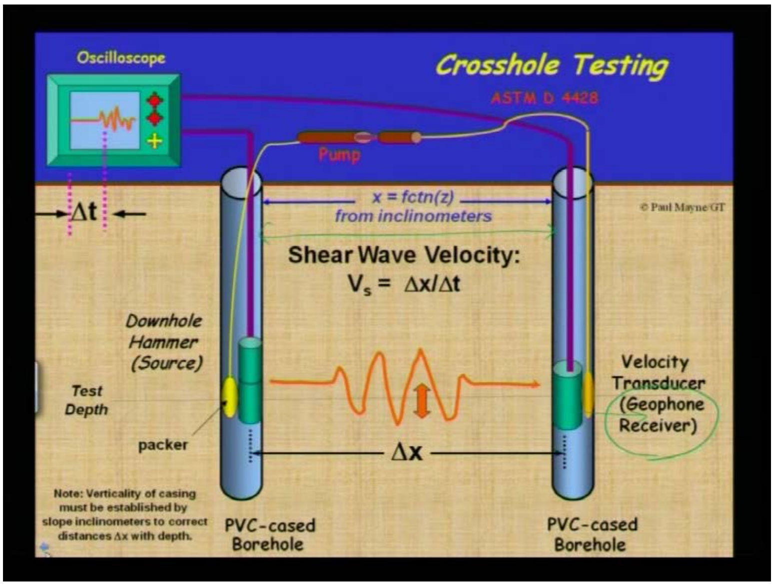

Look at this. This is a crosshole testing as per ASTM D 4424. This slope inclinometer by means of this you can put it inside. There are two boreholes - one is your PVC case borehole, this is your PVC case borehole, and this distance from inclinometer. This is your distance, basic distance from inclinometer, so let it finish. If you look at here now down hole hammer, this is a source this is a source you can generate, generate shear wave. You can generate the shear wave in the soil, so once it has been generated shear wave it will travel and this shear wave will be received this is geophone this is geophone receiver. Look at here this is geophone receiver.

The geophone properties it will receive this wave then it will convert then in this oscilloscope. Oscilloscope it will convert you can find it out what is the travel time? what is the travel time The moment it will travel the moment you receive this is the difference you can get the travel time then vertical verticality of guessing must be established by slope inclinometer to correct distance between delta x with depth x by means of slope inclinometer you can measure whether the distance x can be measured or not. And pump with this a packer has to be arranged you see this packers why it has been provided. I can hang the source and the receiver, it cannot hang; the moment you generate if it is hang the moment you generate your shear wave then there is a chance of resonance or that might be chance proper wave cannot be generated.

Once it has been packed - packed means intact tight - that means the source with this packer and geophone as a receiver with this packer it will be intact inside the borehole, there should not be any gap. The moment you generate your source wave or your shear wave, so it will be intact in this borehole smooth travel of share wave you can generate. At the same time, if the geophone receiver is intact, similarly the receiver it can receive this wave properly.

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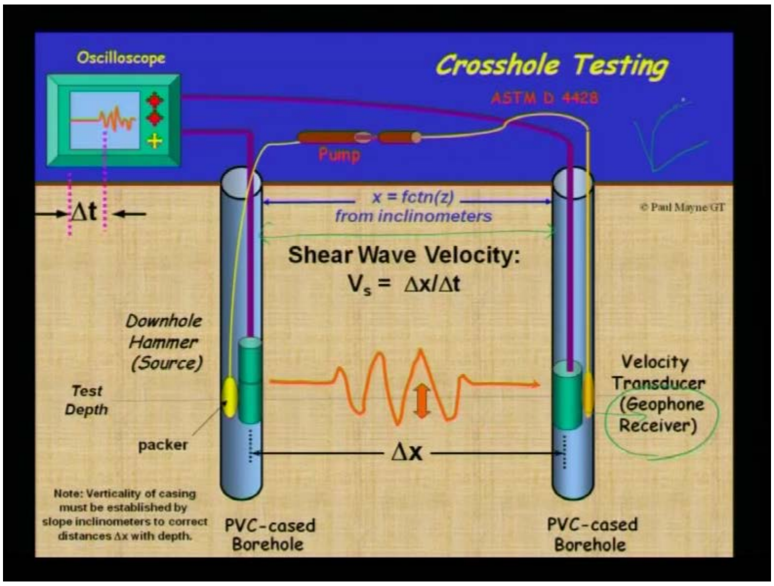

Now once again showing this animation; slope inclinometer it has to be done so that this perfect distance can be delta x with the depth can be made it. Then down hole hammer that is a source then geophone receiver then these packers. These packers are like this it is filled up by air or may be water. What happen this packers has been inserted outside by pump; we can this packers should be filled off by air or water. So slowly, slowly by air once you packer you fill it off, it will make so that being this that there is there is some arrangement where you can change the find it out the increase in volume change.

The volume change will increase at certain distance it remains constant, so that means what the moment it remains constant that means it is intact that means it is tight.

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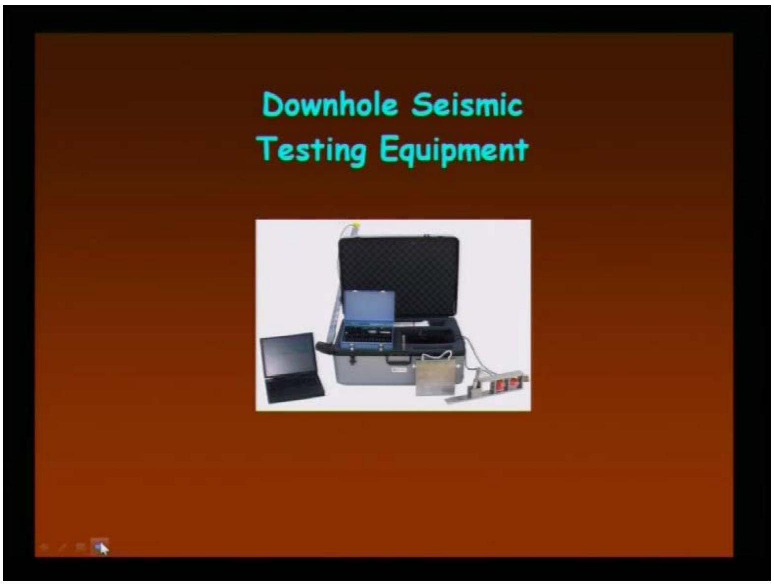

Then go to the next one. There are two types of shear wave velocity particularly downhole- one is your crosshole; other is your downhole seismic testing equipment

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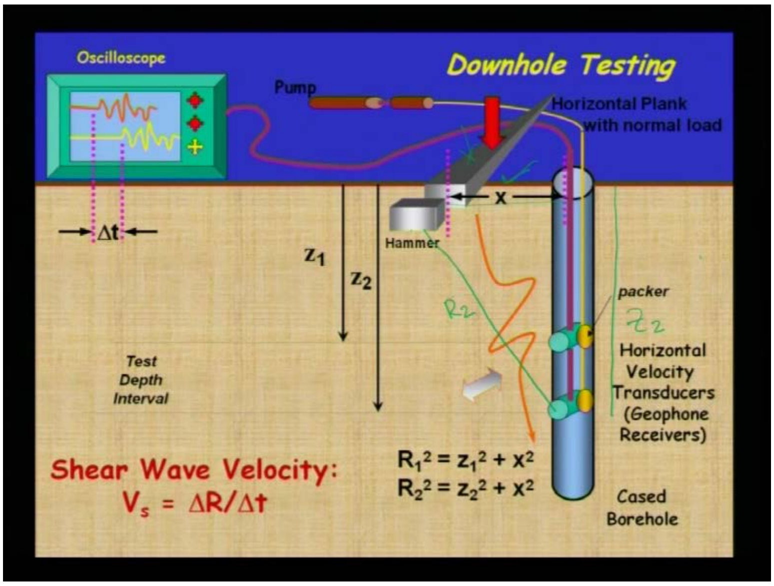

Downhole technique equipment if you look at here let it complete the animation. In downhole testing, only one borehole is required. in downhole testing one borehole is required. This borehole is there inside the borehole with a proof you place horizontal velocity transducers that is called geophone receivers - receiver 1, receiver 2. Then with this receiver 1 and receiver 2, you put it where this your depth where you required to find it out. This is my this is the soil layer where we are interested to find it out shear wave velocity - that means depth test depth interval; it will give how much test depth interval you can go; generally it will be 1 to 2 meter. This you can vary it starts with 1 meter, you can go for 2 meter, 3 meter, 4 meter this you can vary.

Then wooden plank, generally wooden plank these dimensions also clearly mentions in ASTM code; there is a wooden plank, thick wooden plank you take it and by means of hammer. If I hammer at the top, if I hammer at the top, it will generate compressional wave or P wave. If I hammer at the side, if I hammer at the side it will generate shear wave. Then what will happen the moment it will generate the shear wave, the generation of shear wave it try to it will travel through this ground. Once it travel, it will pass through the soil layer where you are interested to find it out shear wave velocity. Once it passes then this by means of geophone receiver, you can measure this you can receive this shear wave velocity. Then the distance travel, this is your distance travel - if I put it there this distance travel this distance is known and this distance also known to us, this distance you can calculate the distance travel then how much time it take this can be recorded by means of oscilloscope.

Then shear wave velocity you can find it out by means of delta R by delta t. And delta R you can find it out, R 1 square as I said z 1 square plus x square; z 1 square is your... This is, this is your this is your R 1, this is for R 1 that means look at here if the shear wave has been generated from here this is the first receiver this will be my R 1. And this distance x is known and this is nothing but, your z 1; this is also known. So z 1 square plus x square root over is your R 1, similarly, by shear wave travel to receive by transducer geophone receiver at two - R 2, this distance is known this is nothing but, your z 2, so R 2 is equal to z 2 square plus x square from there you can find it out R 2.

Now this time, delta t delta R by delta t it is nothing but, your shear wave velocity you can find it out. Remember there are two techniques in in-situ - one is downhole testing; other is your crosshole testing. In downhole testing in downhole first identify the difference look at the difference in this technique the wave has been generated at the surface. The shear wave has been generated at the surface by means of a wooden plank with a hammer if you hammer it here you will get shear wave .

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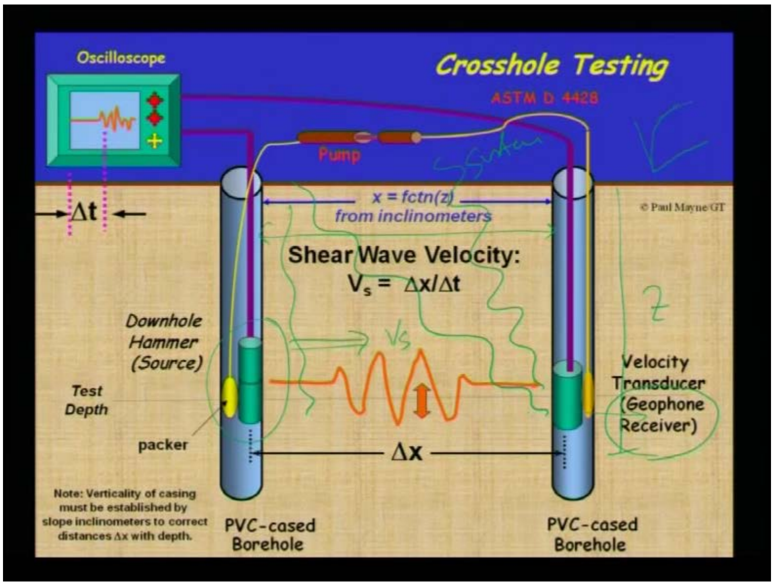

if you come back to earlier one, if you look at here, this wave the source has been inserted inside the surface at this depth. Suppose at this depth at this depth, we want to find it out shear wave velocity - V s; that this means hammering at the source we insert this source inside another borehole; it will be at the same depth. Mark these difference in case of crosshole test, there are two boreholes at an distance x and source it will be inserted inside the borehole, and it will be generated at the same depth of z d of the distance say z at the same depth of the z, you can generate your shear wave velocity. At distance x, you can measure your shear wave velocity by means of geophone receiver.

While if you go back to this is called crosshole, if you go back to crosshole, look at this. The source particularly it has been generated at the surface not inside the ground; it has been generated at the surface by means of hammer and a wooden plank. This has been well defined by means of ASTM (American society for testing material) ASTM - it is well defined there. And from there we can measure your delta R and delta t both has advantage and disadvantage also limitations. This has also disadvantage; this is a quick test instead of going for two boreholes. You can go for a one borehole cost saving is there and less man power, but the disadvantage is there source particularly wave has been generated at the surface and shear wave travel. It has a limitation, you cannot go certain depth beyond if you go beyond a certain depth this shear wave velocity may not receive properly. But, the advantage of this other technique crosshole test, in this advantage at any depth, you can put it inside - you can generate your source particularly so that this shear wave velocity can travel you can directly measure. So there is no problem; particularly down wave seismic down wave this shear wave travelled from the surface, if this is my surface surface shear wave travelled from the surface, so here this shear wave at that depth has been generated and it travelled at that depth it has been received.

So the advantage in this case is at any depth you can measure shear wave. Only disadvantage is this cost technique. At the same time, you can go for two boreholes with this two bore holes then you can go for boring and push the casing pipe inside put the pipe, PVC pipe inside and do this and insert also your source then generate your shear wave velocity, but despite that both methods has been widely used depending upon what is the depth, this cost will be definitely higher in crosshole because and as compare to your downhole.

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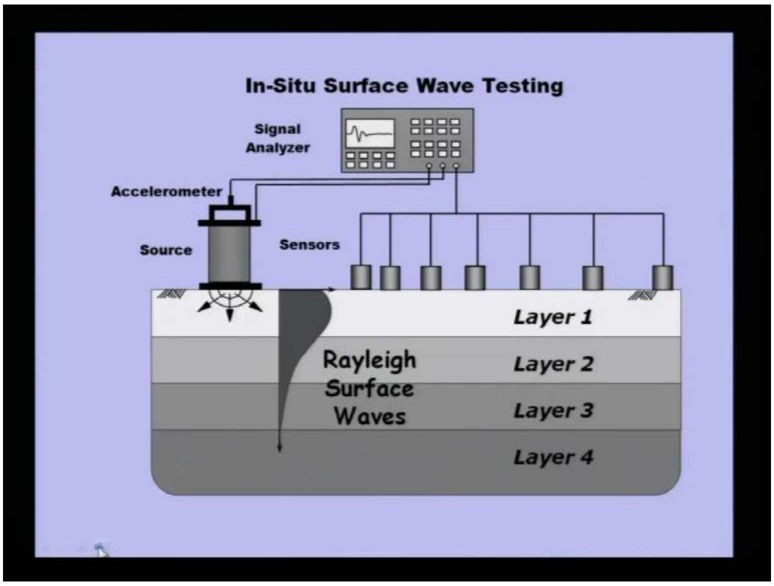

Another one is your in-situ surface wave analyser. This has been generated by Rayleigh shear waves. If you look at earlier that is only shear wave, earlier one seismic refraction that is your compressional wave.

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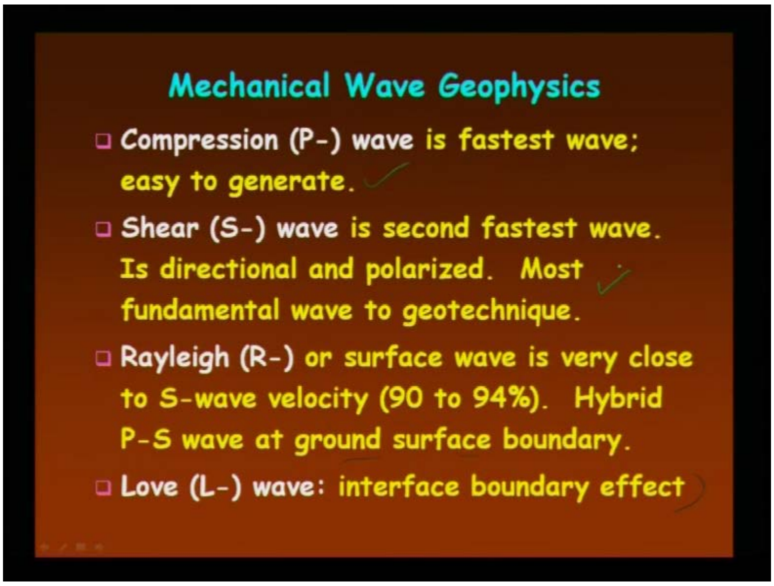

Now if you if I come back to beginning, I have finish this compressional wave - P wave, and example we have shown that seismic refraction, and also shear wave. We have shown that two techniques by crosshole as well as downhole; another one is your Rayleigh wave, and this is called surface wave it started from the surface.

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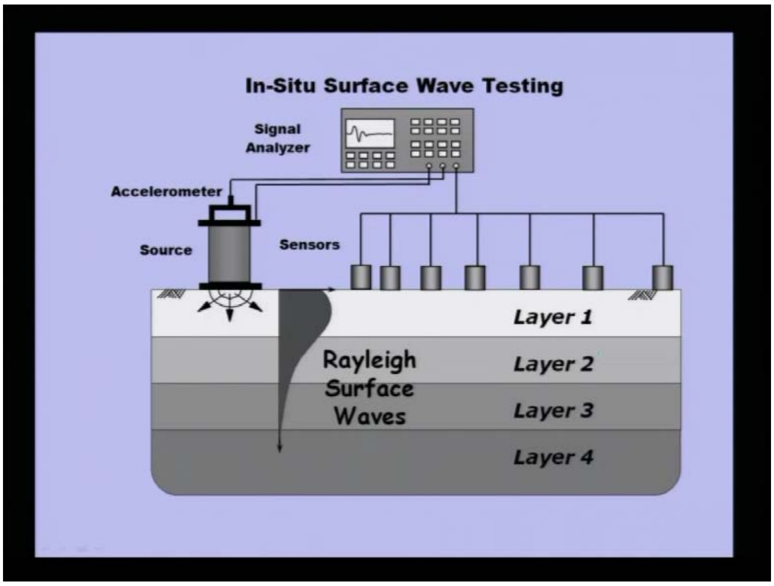

These we are going to at the surface this source by means of accelerometer, accelerometer and the sensors. Sensors has been put it at different distance and Rayleigh surface wave has been generated from the source and by means of Rayleigh surface wave again this is a surface wave. It started with this from layer 1, layer 2, layer 3, layer 4 you can measure. These velocities in-situ surface wave velocities also based on that you can do the classifications of this soil layer. Again it has also disadvantage because this wave generated at the surface.

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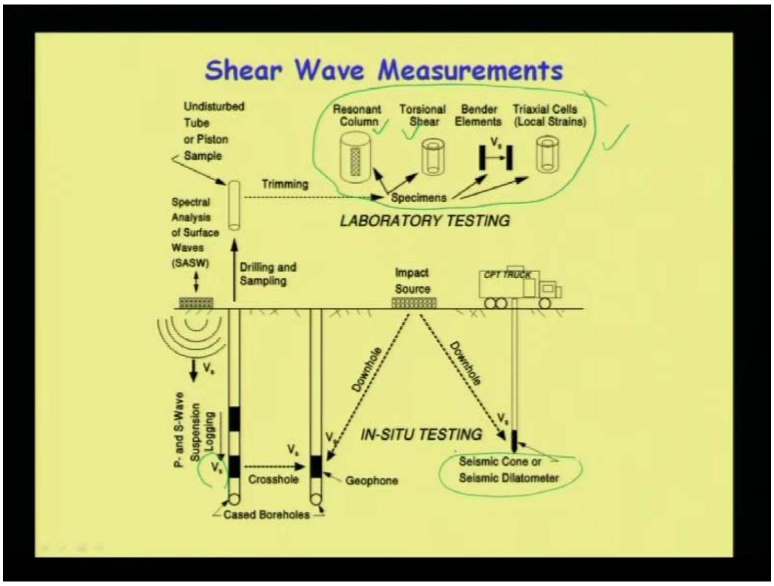

Now if I summarize shear wave measurements, if you look at if I summarize shear wave measurements, there are four types. If you look at their one is your laboratory testing; other is your in-situ testing. If I take into laboratory testing, I have not come yet this laboratory testing, I am just doing right now this in-situ testing. In laboratory testing by means of resonant column, by means of torsional shear, by means of bender element - bender element is nothing but, in a triaxial cell you provide the bender element that means source and receiver with this travel time shear wave velocity you can measure, and by means of triaxial cell, by means of cyclic, by means of cyclic or dynamic triaxial cell you can measure. These are the techniques where you can measure your shear wave velocity.

Once you measure the shear wave velocity, you can find it out G maximum or G 0, shear wave velocity with this from this shear wave velocity you can measure G - which is a input parameter shear modulus is an input parameter for seismic analysis. In in-situ in in-situ there are one is seismic, one method is if you look at here one method is seismic downhole, seismic cone or seismic dilatometer; other is your seismic downhole or seismic cross hole. In case of seismic downhole, as I said only one downhole, and with the source at the surface you can measure by means of geophone you can measure shear wave velocity. In case of crosshole by means of again source inside the ground surface you can measure shear wave velocity. Another third one is your by means of rayleigh wave spectral analysis of surface wave this is called S a S w.

By this method, you can generate P and S wave also you can measure your shear wave velocity, so drilling and sampling has been done undisruptive and piston sampling. Once it has been done then you can go for soil classifications. Once you make the borehole, you can take the drilling and sampling, you can go for a soil. In this case in-situ case you can go for soil classification, you can find it out what kind of soil. Once drilling has been made then either you decide what technique you are going to use to measure your shear wave velocity. This shear wave measurement basically if I classified into two parts - one is your laboratory testing as well as in-situ. In in-situ in the inside this soil in in-situ condition we can measure shear wave velocity with your either undisturbed or in concentrated samples you can measure also your laboratory testing's.

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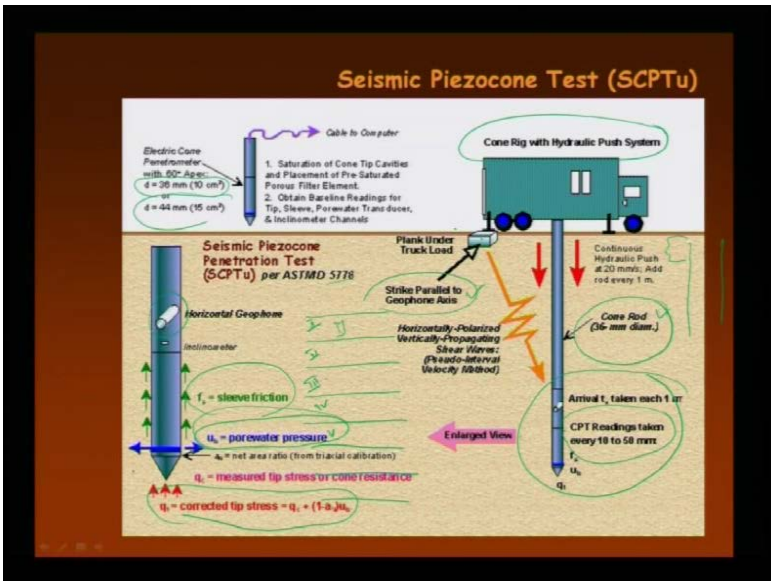

Then as I said first when you is your seismic cone or seismic dilatometer with the help of seismic cone or seismic dilatometer, you can start. If you look at here, this is called, I said earlier - one is your cone test; another is your seismic piezocone test. This is called SCPTu and in this seismic piezocone test this you can measure there are three in one. As

I explained earlier three in one - one is your deep resistance, soft resistance, bore water pressure from there you can directly find it out also liquefaction potential. This is as per ASTM D 5778 you can measure this.

Now why it is called piezocone? This is an electric cone piezometer with 60 degree apex cone diameter is 36 to 36 mm to 44 mm saturation of cone tip cone tipcavities and placement of pre saturated porous filter cement. If you look at here, this is my cone and there are horizontal geophones also there and there are arrangements above the cone conetip where you can measure your bore water pressure at regular depth. So I have taken particularly here if you take these, this is the enlarged view of this. How it looks? This part how it looks?

Now what will happen at the surface by means of this, you can hammer, you can generate your wave. Then this wave should be generated lateral direction parallel to your geophone axis. The geophones are there, the receivers are there, these axis you rotate, this axis you rotate so that this axis what will happen this axis should be parallel to this, this axis should be parallel to this, so that the moment you generate the wave here you generate the wave here, it should be parallel to this. So that the receiving you can receive it very easily. This arrangement in this three in one as I said once you generate it will automatically horizontally polarised vertical propagating shear waves.

Pseudo interval velocity methods generally the cone rod diameter is 36 mm, and there is a truck or it is called cone rig cone rig this has been mounted in a truck. So this is called cone rig with hydraulic push system this has been mounted in a truck, so it is a continuous hydraulic push that means what happen if I start with the procedure at the same time at the same time you start hammering parallel. Once you hammer this shear wave will be generated and it will travel; at the same time with this hydraulic push system hydraulic push system the cone rod cone rod has been pushed inside continuously.

So by means of receiver here by means of geophone, you are receiving this shear wave velocity. Suppose let us say this is a layer of soils say layer 1, layer 2, layer 3, layer 4, layer 5. By means of cone rig with hydraulic push system, you push this cone rod continuously. Then once you push this cone rod inside the ground surface at the same time strike parallel to your geophone axis, geophone axis make in such a way that it should be parallel to this your source you strike it.

So once you push it, this part will simultaneously it will it will record tip resistance, bore water pressure, side resistance also record your travel shear wave velocity. Once it record your travel shear wave velocity by means of oscilloscope you can measure your travel time. That means all measurement layer by layer, I can do. Once you reach layer 1, strike it record your all data, then got to layer 2 - strike it record your data, go to layer 3 - strike it strike the source record your data. It is a continuous phenomenon - that means you will get at the same time continuously cone resistance, bore water pressure as well as your shear wave velocity at each layer.