Engineering Geology
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LECTURE – 17
Sampling and Non-Intensive Method for Subsurface Exploration

Hello everyone, welcome back. Today we are going to talk about sampling and non-intrusive testing for subsurface exploration. But before we get into the topic of discussion of today's presentation, we are going to look back to the question set of the previous lesson.

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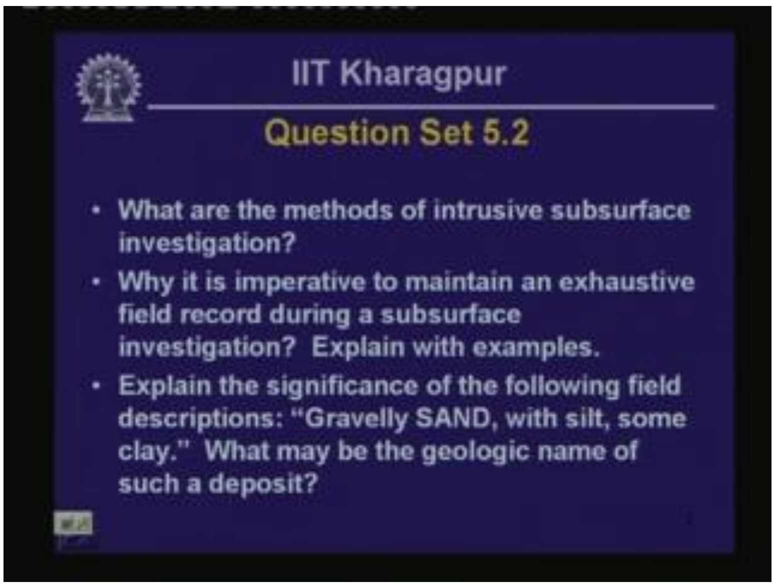

The first question that I have asked was what are methods of intrusive subsurface investigation? Basically in the discussion of this particular course, we just talked about two basic procedures; one is excavation of a pit or a trench in the ground for exploration of shallow layers underground and the second thing that we discussed, the second group of procedures that we discussed are based on drilling a circular hole in the ground and conducting some sampling exercise, we did not talk about sampling in the previous lesson, we are going to talk about the details of those procedures today. But basically we talked about two different procedures for subsurface investigation; one is the excavation of trenches or test pits and the other one is drilling and sampling.

Now, the second question that I asked was that why it is imperative to maintain an exhaustive field record during a subsurface investigation and I asked you to explain with examples. Now, the major problem that the designer faces is to get a clear picture of the layers that they are underground and for this, he or she needs to have an idea about what is the sequence of drilling, what kind of problems we are encountered during drilling and so on and so forth. And, some of these issues, I already have discussed in the previous lesson. And for example, we can talk about the coloration of a particular rock or soil sample and these colors typically change as the rock or soil sample, they get exposed to the weather.

Now, another thing that you could think about is in some cases because of exposure to weathering and because of the unloading, because of the loss of confinement, after sampling, some types of rock and soil samples they are notorious in changing their strength and structural characteristics. As an example we can think about the rock type called shale - clay stone in a sense. These rocks basically if they are kept exposed to the nature, then they actually ravel and the cracks develop, several sets of cracks develop at a very close spacing within the mass of the rock and if they are not identified or tested within a short period of time after sampling, they actually disintegrate almost completely in some situations and become like powder.

So, in these situations, it is extremely important actually for the field investigator or the field inspector to describe the strength and other behavioral characteristics of the sample so that the strength taken in the design of facility that is going to be constructed on the top of these layers or the these geologic units, they are not underestimated or over estimated.

Then the third question that was given for you to explain the significance of the following of a few field descriptions; say for example, the description that was given was gravelly sand, with silt, some clay. Now, as soon as that description is seen by a user of the drill log, then what he or she has in mind is that this particular sample contains a very large proportion of gravel and sand and it also has got some percentage of silt and some percentage of clay.

Now, the qualifiers that are used here, the qualifiers that were used here, with this qualifier and some or these two qualifiers we know what these qualifiers mean in the terminology of identification of hand samples obtained during a drilling operation.

Now, as we have noted, with means that particular component, slit in this case has got, it has got a percentage of approximately 20 to 30 and some - the type of constituent that is qualified with qualifier some that has got a percentage, I mean it has got a percentage of about 12 to 20 within the total soil mass. So, this particular soil has got almost a majority of gravel and sand, it is composed of majority for the main part by gravels and sands, gravel size particles and sands size particle and it has got 20 to 30% percent of slit and 12 to 20% of clay.

So, this essentially is a deposit which has got a very wide range of grain sizes within its volume and this type of deposit, one such deposit we talked about in one of the previous lessons is till deposit. Till deposit that is directly deposited from ice, glacial ice. So, that is in a sense the second part of the third question. And, what I asked is a possible name, possible geologic name of such a deposit and this deposit could indeed be a till deposit.

So, that takes care of the question set and now we move on the subject matter of today's lesson.

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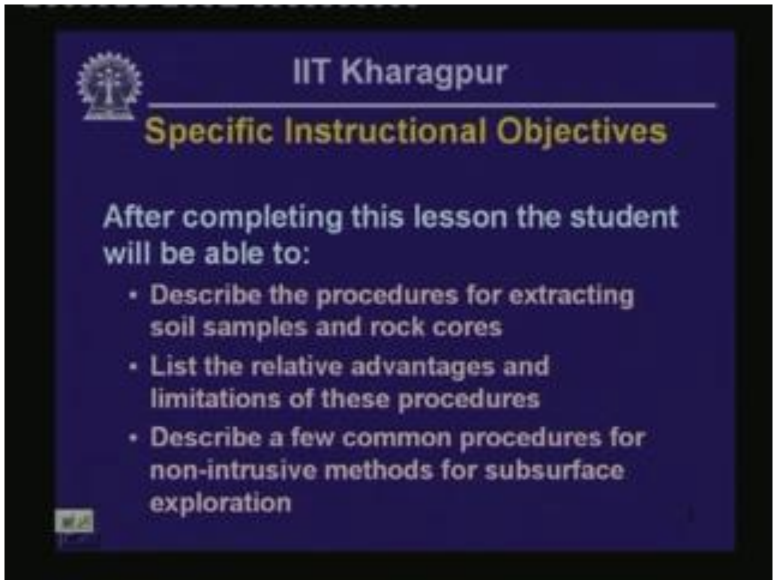

So, what we are going to try to do today is to describe a few common procedures for extracting soil samples and rock samples during or what is common during a subsurface exploration or drilling and sampling procedures that we discussed to some extend in the previous two lessons and then we are going to list the relative advantages and limitations of these procedures, we are also going to able to describe a few common procedures for non-intrusive methods for subsurface exploration and we should be able to also describe the limitations and advantages of these procedures.

So, those are the objective of this lesson and in the first part of this lesson, we are going to talk about soil sampling and then we are going to move on rock sampling and finally we are going to get into non-intrusive testing procedures.

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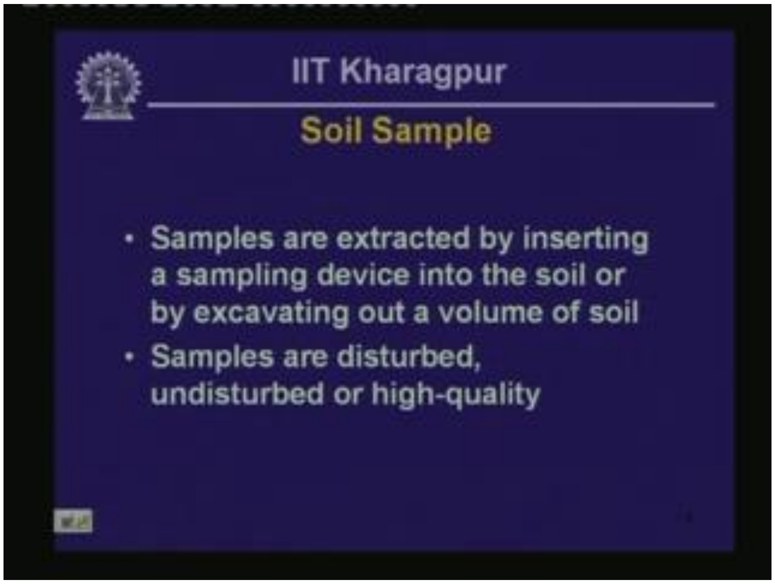

Now, soil samples are extracted basically, more usually they are extracted by inserting a sampling device into the soil or excavating out a volume of soil and we talked about some of these procedures of obtaining samples by excavating out a block in the previous lessons and also depending on what procedure is used during the sampling, the sampling could be disturbed or it could be undisturbed.

So, we are going to look at some of these procedures that give you disturbed samples and some of the procedures used for obtaining undisturbed soil samples. First of all, we look at disturbed soil samples.

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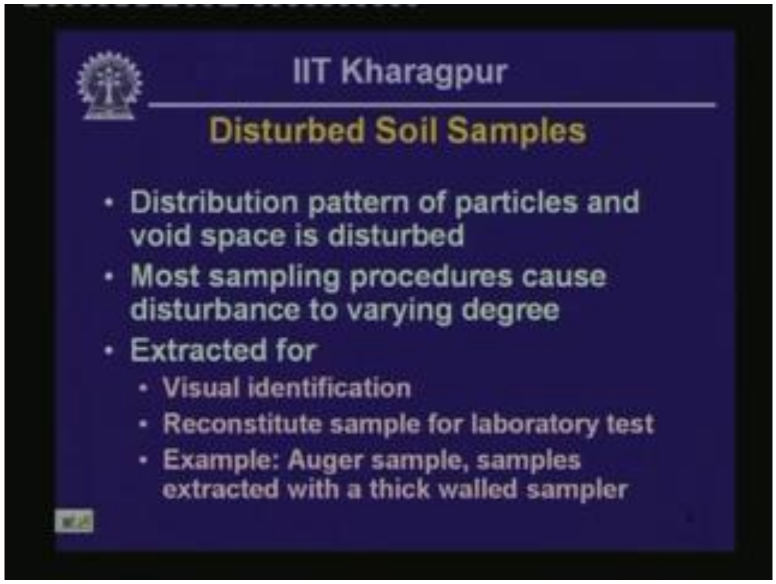

Now, what you mean by disturbance; that is the first question that comes into mind. Now, by disturbance what we mean is that the distribution of individual soil grains or the distribution of the void spaces, the pattern of distribution of the void space within a general volume of soil that gets changed during the sampling procedure.

So, that is disturbance and disturbance could be caused by the procedure of insertion of the sampler into the ground and it could also be caused because of the unloading that takes place during the drilling procedure itself or the confinement which vanishes as a result of the drilling procedure that itself is going to cause an unloading and that will translate into disturbance.

Then the third part of disturbance could be caused because of the circulation of the drilling slurry that is done normally in some of the drilling procedures that we have already discussed.

Then the second thing that you have to keep in mind is that the most of the sampling procedures will cause disturbance to or will introduce disturbance to the sample to some extent. Now, what is the purpose of obtaining disturbed soil samples? The purpose of obtaining disturbed soil samples is for visual identification of the sample in the field as well as in the laboratory later on. We could also use the samples obtained in this procedure to reconstitute a sample in the laboratory for further testing. Examples of disturbed soil samples include auger sample or samples extracted using a thick walled sampler. We are going to look at these procedures in the next little bit.

Now here, on the left there is a picture that shows a disturbed soil sample obtained by inserting a thick-walled sampler. In this case, the sampler is a split pool sampler; we are going to talk about spilt pool sampler later on, the details of construction of this type of sampler later on. So, this one is a spilt spoon sample.

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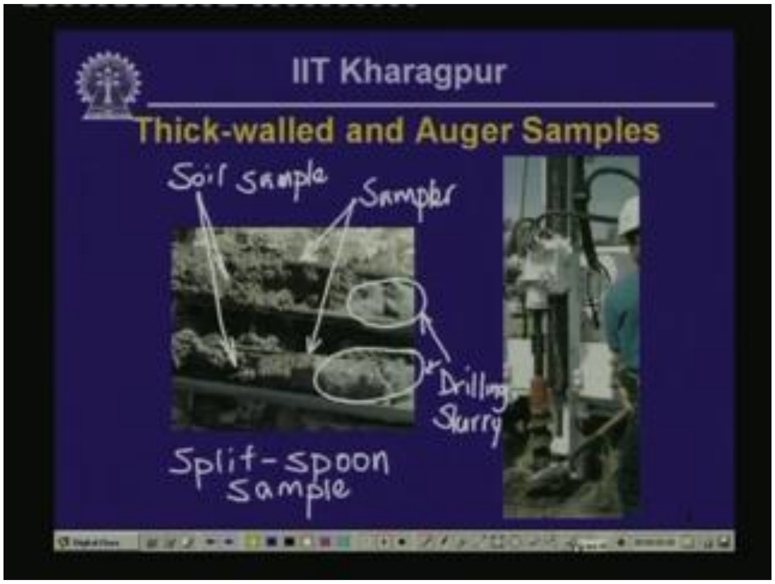

What you have got here? So, this one here is a sampler, this one and this one and this one here is the soil sample and you can probably if you can make out, if you look carefully, this particular sample is a sample containing, it is sand sample basically and it has got some gravel also in it.

You should notice the presence of drilling slurry near this particular portion of the sample. So the nature, disturbed nature of this particular sample is evident from the pattern that you see on the picture there. So, that is a spilt spoon sample, it is a disturbed sample, it is taken by a spilt spoon sampler and it has got a lot of disturbance inserted because of the fact that this particular sample is obtained using a very thick-walled, inserting a thick-walled sample into the soil and secondly because of the intermixing of the soil with the drilling slurry. That is the details of a spilt spoon sample and then the picture on your right shows an auger sample.

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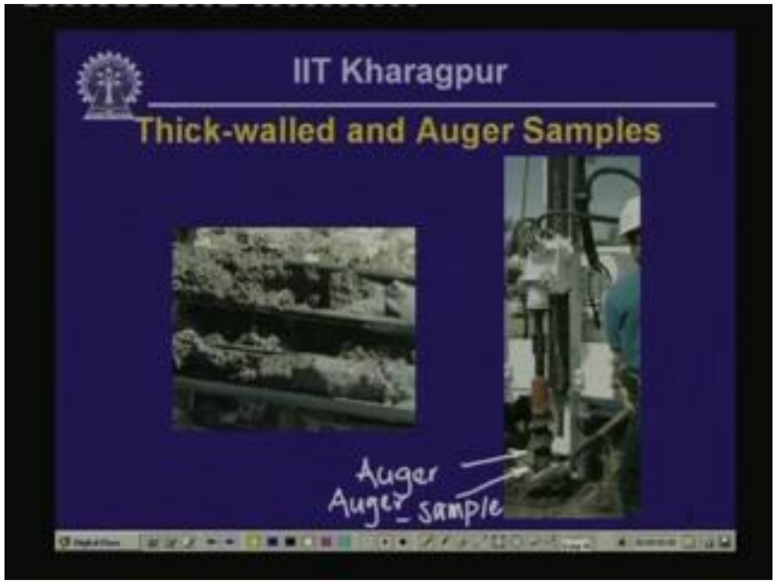

So, in this case, you saw a picture of an auger in one of the previous lessons and here what we got actually is an auger which is being used for drilling. So, this is our auger and this auger is bringing out the soil from the underground on the auger flights. So, this disturbed sample is called an auger sample. So, here the disturbances is even more in comparison with the spilt spoon sample in the sense that we do not exactly know from which depth the auger sample is actually coming exactly and they are totally altered interlayering within the different portion that might be existing in an underground structures, they are totally destroyed as the sample is brought to the ground surface by the screw action of these augers.

So, these samples are also retained for a very approximate identification, could be retained actually for a very approximate identification of the samples and finding out their relative distribution of grain sizes and so on and so forth. In comparison, the thick walled samplers, the amount of disturbance introduced by thick walled sampler is relatively less in the sense that in many of the thick walled samplers you could actually see the fine inter bedding that is present within the soil layers and those inter beddings are not identifiable in case of auger samples. So, these are basically two examples of the disturbed samples of varying degree, introducing a varying degree of disturbance to the sample.

Then we move on to the undisturbed soil samples. In this case, the distribution pattern of particles and void space is retained unlike disturbed soil samples. In undisturbed soil samples, we will have to lock in the pattern of distribution of individual soil particles and void spaces within a certain volume, within the sampled volume. Obviously, extraction of undisturbed soil sample is a more expensive proposition in comparison with that used for, with those used for disturbed soil samples.

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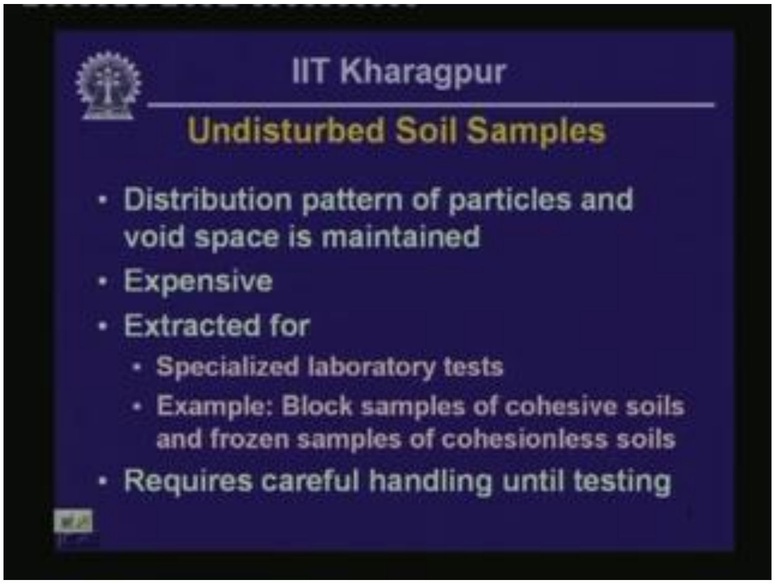

Now, these undisturbed soil samples are used for specialized laboratory test and these tests are those that are particularly affected by sample disturbance. Examples of undisturbed soil samples include block samples of cohesive soils and frozen samples of cohesion less soils. How to extract frozen samples? Actually in order to extract undisturbed samples of loose cohesion less soils, it is essential actually to, it is almost essential to freeze a certain volume of soil underground and using the procedure of rock coding that we are going to discuss in the next little bit to obtain a core of the frozen soil. So, that is the procedure used for extraction of undisturbed soil sample of cohesion less soils.

Now, undisturbed soil samples also required very careful handling after the samples are extracted and brought to the ground surface until they are taken to the laboratory and they are setup on a test stand and tested. So, between sampling and testing, the sample handling has to be carried out in a very careful manner so that disturbance is not introduced into the sample during the transportation of the samples.

Now, in between the disturbed and undisturbed soil samples, we also can talk about an intermediate state and that is high quality soil sample. So, in this case, the disturbance introduced into the soil sample is relatively less, is much less in fact in comparison with those imparted by procedures that we discussed for obtaining disturbed soil samples.

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Now, these procedures are much more economical in comparison with the procedures that are followed for obtaining, for extracting undisturbed soil samples, typically they are much more economical in comparison with the procedures for obtaining undisturbed soil samples and these soil samples are also extracted for laboratory tests provided that the test is targeted in obtaining a soil property that is not affected much by the sample disturbance introduced during the sampling procedure and also these particular type of sampling, they involve; there are two different examples that we consider here obtaining undisturbed soil samples and they are by using large diameter samplers and thin walled samplers, they also require careful handling and testing.

Now, why a large diameter and thin walled samplers are used for obtaining high quality samples; that becomes evident when I draw this particular sketch.

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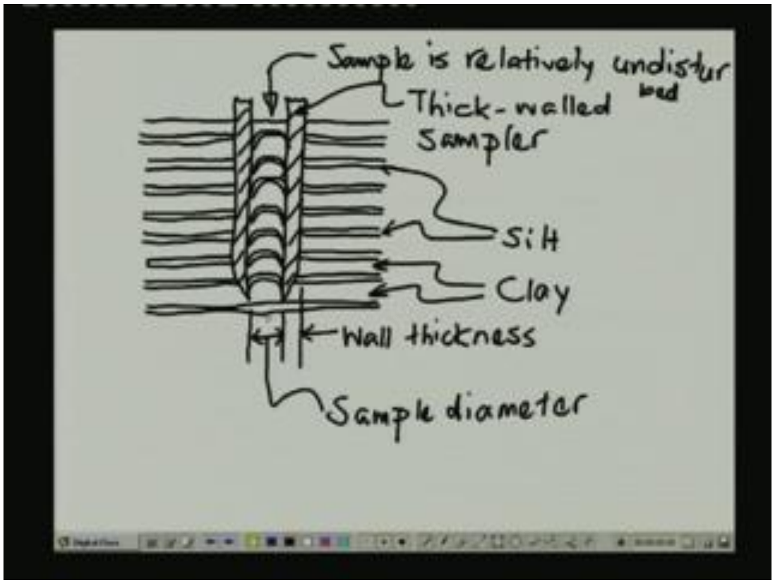

Let say, we try to introduce a thick walled sampler, cylindrical thick walled sampler into the ground, we are going to look at the definition of a thick walled sampler in the next little bit. Now, let say we are introducing a thick walled sampler like that. What is meant by thick walled sampler actually is that the proportion of the wall thickness, so this one is the wall thickness is quite large in comparison with the sample diameter.

So, let us imagine that we are inserting a thick walled sampler into the ground and for convenience, let us imagine that the ground, the soil underneath the ground surface is a walled deposit. Just giving you an example here; so if you recall, a walled deposit has got laminations of two different types of soils like that and in this case typically, one - it is alternating layering of clays and silts, so let us say the deposit is like that and in this case, these are the slit layers and the ones in between are clay layers. So, they are thin lamination really, a few millimeters thick.

So now, when the sampler is inserted, you can see within the sample, the laminations, they are curved down like this because of the friction that develops between the interface of the sampler and the soil inside it. So, you are going to have the laminations bent like this and that is an indication of the sample disturbance.

Now, you can see near the center of the sample, near the center of the sample, the sample is relatively undisturbed, sample is relatively undisturbed that is one thing you can see and the other thing is or the other thing is important is that this amount of distortion of the laminations inside the samples taken by the thick walled sampler, the amount of distortion or the amount of bending that is greatly minimized if the wall thickness of the sampler becomes smaller and smaller.

So, that is the reason why if we could device a sampler which is of relatively large diameter and the wall thickness is relatively small and if we can introduce some ways of reducing the friction inside the sampler, then we are going to improve the sample quality by a great extent. So, that is the reason why thin walled and large diameter samplers are used routinely to obtain high quality samples.

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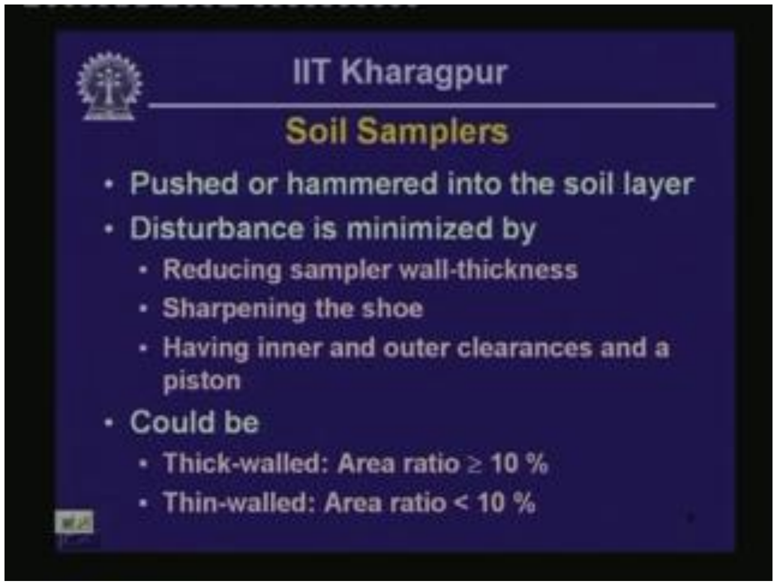

Now, as I mentioned also earlier that these samples also require careful handling until they are tested in the laboratory. So, soil samplers; we need to look at typical soil sampler then, so these soil samplers are typically pushed into the soil layer or they are hammered into the soil layer. Now, as I indicated in the previous sketch that the disturbance introduced into the sample because of the insertion of the soil sampler is reduced by decreasing the wall thickness, it can also be decreased, the disturbance also be decreased by sharpening the shoe and also by having an inner and outer clearance and a piston. So, what is meant by it; let us look at it in a little bit more detail.

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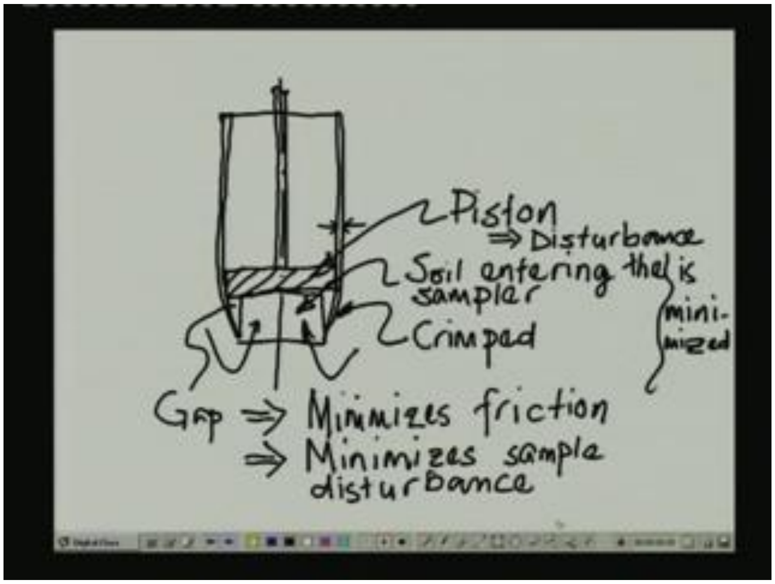

So, what we want to have is a sampler which has a small wall thickness in comparison with the diameter of the sample that is taken in. So, this is the sampler that we are talking about and in this case you can realize that the wall thickness is a very very small proportion of the diameter of the sample. Then the end of the sampler is crimped in this case and what this crimping does is that when the soil enters into the sample; so this is the soil sample, soil entering the sampler, soil entering the sampler; so what happens actually is there is a gap, there is a very small minute gap in between the soil that is entering the sampler and the sampler wall and this gap actually minimizes the friction, sample to soil friction and that itself minimizes the soil disturbance. So, that is how the disturbance is minimized by having a thin walled sampler and also by having a little bit of inner clearance.

Then the second thing that is important is to have a piston on top of the sampler, on top of the soil sample and this particular piston prevents the soil from outside, soil from outside, the cross section of the sampler to get inside of the sampler during the insertion process and that actually minimizes the disturbance more. So, this is a piston that precludes, that actually prevents the soil from outside of the sampler cross section to get within the sampler during the insertion process of the sampler and that in turn minimizes the disturbance. So, disturbance is minimized by this particular, disturbance is minimized by having a piston as well.

So, what are the measures then? We have to have a thin walled sampler, we have to have a relatively large diameter in comparison with the wall thickness of the sampler, we need to have an inner clearance, a little bit a minute inner clearance so that the friction between the soil getting into the soil sampler and the sampler wall is minimized and we want to have a piston inside the sampler which actually prevents soils from outside the cross sectional area, outside the outer diameter area of the sampler to get into the sampler; these all measures actually minimize the disturbance imparted into the soil sampler.

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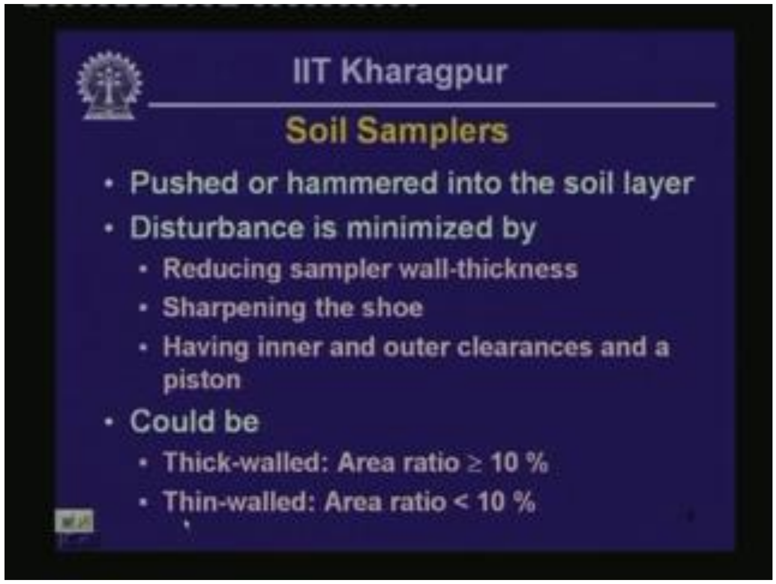

Now, what is a thick walled sampler and what is a thin walled sampler? Now, thick walled sampler are those samplers which has got an area ratio of greater than or equal to 10%, whereas thin walled sampler has got an area ratio of less than 10%. So, what is an area ration? Area ratio is the ratio of the area underneath the wall of the sampler to the cross sectional area of the soil sample that has been taken within the sampler during the sampling process. So, let me explain what I mean by that.

Let say, let us look at a cross section of a sampler, the sampler looks like this and this is the cross section of the tube, sampling tube. So, in case, there is no or so this thickness of the sampler wall, this is the wall thickness and then inside of it is the soil sample. Let us for simplicity consider that there is no inner clearance. So, let us assume that the diameter of the soil sample is d and let us assume that the wall thickness in this case is t.

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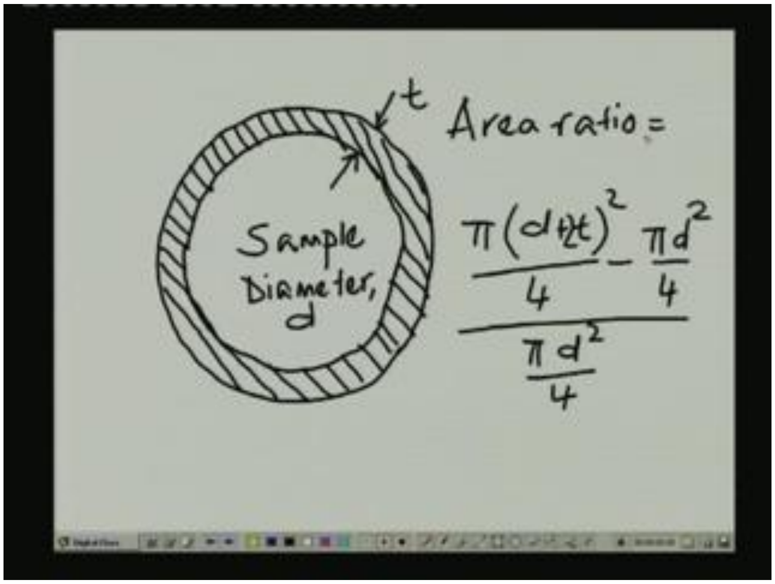

So, the area which is shown by cross hatching, that area is going to be pie times d plus t square divided by, d plus 2 t square divided by 4 minus 5 d square divided by 4. So, that is the area of the cross section of the tube itself and this, we divide by the sample cross section and then what we get is the area ratio. So, this is the definition of an area ratio of a sampler. Now, as we have seen that area ratio; what we want actually in order to minimize sample disturbance is we want to have an area ratio of less than or equal to 10% or less than 10%.

So, this particular sketch actually shows two different samplers used for soil sampling and the one on the top is a picture of a thick walled sampler. So, this one is a thick walled sampler and the sampler in this case is a split spoon sampler which is the same sampler which was shown in one of the pictures earlier.

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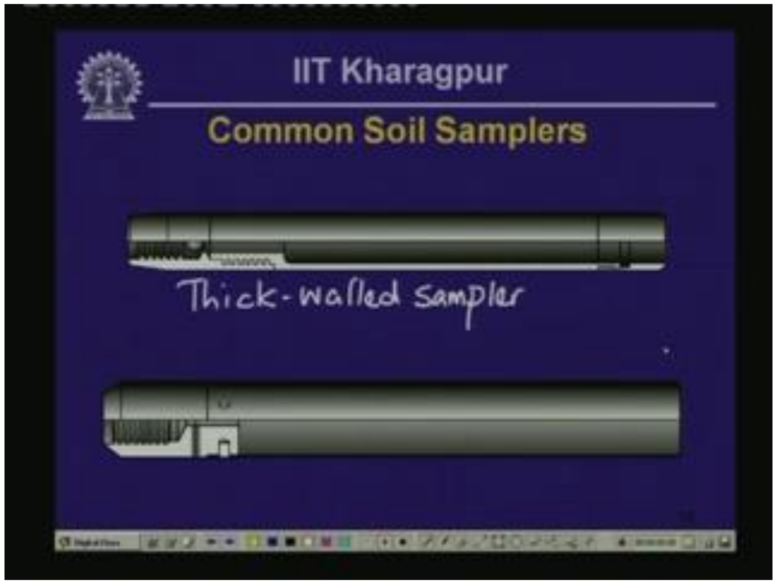

In this case, what we have is a shoe. So, this one here is the shoe and this one is the split spoon. Actually, this particular part has got two different or it is composed of two different segments. So, if we take a section there, then it is going to look like this. So, it is composed of two hemispherical segments; this is the cross section that I am trying to draw and then you can see that the bottom end, so this one enters the soil first, this end enters the soil first and this is the top end.

So, this is the top of the sampler and this is the bottom of the sampler to the right and what is there at the bottom end is the shoe has got a threading and these two hemispherical halves of the split spoon, they actually screw on to the shoe and they are tightened and once the shoe - the shoe is a single piece construction - and once the shoe goes on to the bottom end of the split spoon of the two hemispherical portions of the split spoon, then the split spoon behaves in or they cannot separate from each other.

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Then at the top end of the sampler also there is a threaded portion and this is the thread, you can see a threaded portion near the top end through which the split spoons are attached to an adopter and this adopter itself has got another set of threads, so these threads that I am talking about in this case; these threads, they screw on to the drilling rods such as aw rods or bw rods and also is of interest in this case that there is a ball, you can that there is a ball inside of the sampler.

By the way, this particular view is a cut view of the sampler; so the top half of this picture shows the outer appearance of the sampler and the bottom half of the sampler actually gives you a cut section. So, you can see the ball there, near the top and this ball allows the air and water to escape as the sampler is inserted into the ground.

So, that is basically the construction of a thick walled split spoon sampler and once this sampler is taken out of the ground, it comes out of the ground with the soil sample inside, then the shoe and the top adopter is unscrewed and then the two halves of the split spoon can be disassembled and this disassembled configuration was shown in the picture that was shown before. So, that is the construction of a thick walled split spoon sampler, this sampler we are going look at again when we talk about a testing procedure called standard penetration test later on.

Then the bottom sketch shows a thin walled sampler and in this case, the sampler does not have a piston in it. So, this particular sampler is called a Shelby tube.

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So, what is there actually like in the top sketch there, this particular picture also shows a partially cut view. So, the upper half of this picture actually it shows the outer appearance of this sampler and the bottom part shows the cut view or the section of the sampler. So, here obviously, this is your wall thickness; whereas in the previous in the thick walled sampler, you can see that that was the wall thickness. So, it is obvious that the wall thickness is quite small here.

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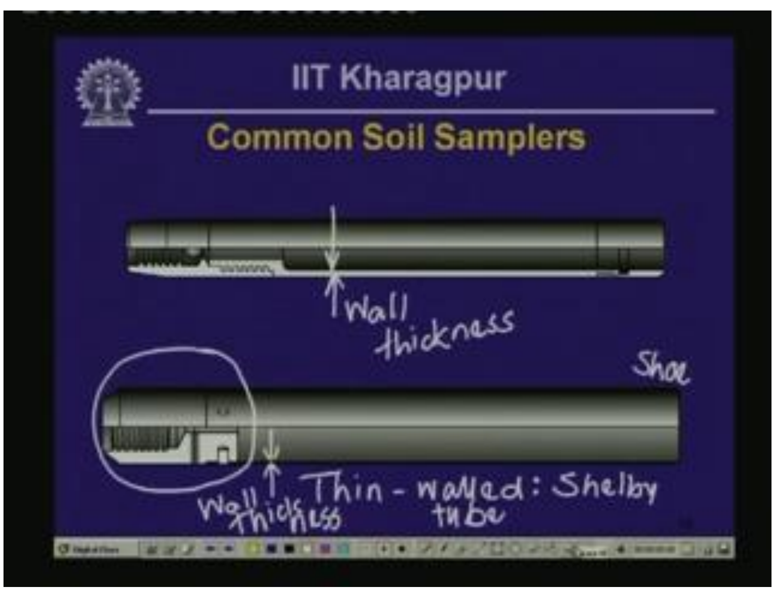

Actually, both these pictures, both these sketches are drawn to the same scale approximately. So, you can see that relative to the diameter of the sample itself, the wall thickness is quite small in case of a thick walled Shelby tube sampler and here the adopter near the top is shown on the left just like before and this is the shoe that cuts into the soil as the sampler is inserted into the ground. So, in this case, the sampler is not hammered in but is simply pushed into the soil gently. So, Shelby tube is a pushed in type of sampler; whereas the split spoon thick walled sampler is typically hammered into the soil. So, that is the construction essentially of a thick walled and a thin walled sampler.

Now, we try to look at a little bit of piston sampling. So in this case, what is shown here is the schematic of a piston sampling procedure and this type of sampler is called a stationary piston sampler.

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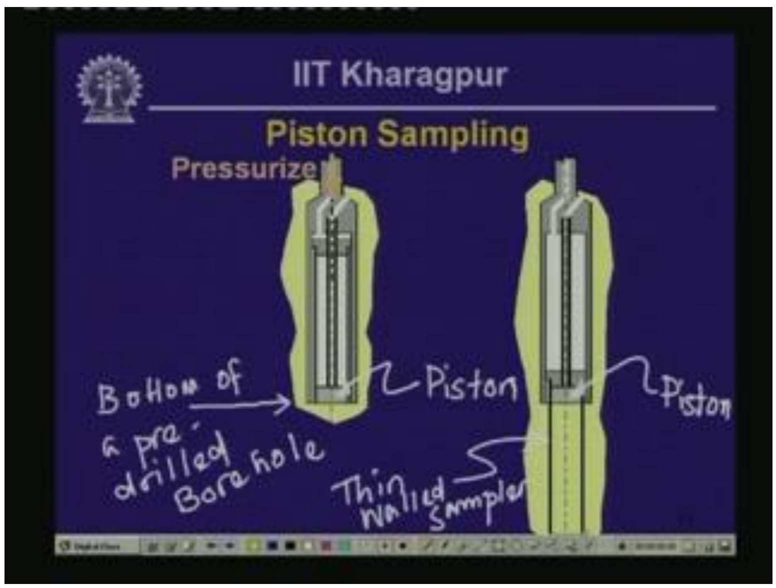

So, the sketch on your left actually shows the piston sampler placed at the bottom of the bore hole. So, this one here is placed at the bottom of the bore hole. So, this one is the bottom of the bore hole, bottom of a predrilled bore hole and then what happens is the piston is kept stationary - you can see that on the sketch to the right - piston is kept stationary and what is done is to insert the thin walled sampler into the soil underneath.

At the end of the stroke, this has gone into the ground into the soil underneath and the piston which was originally at this particular location, it remains at the same elevation. So, this is the location of the piston after the sampler has been inserted and you can compare it with the original elevation of the piston. Both these sketches are constructed at the same vertical elevation and they show the section of the sampler basically.

So, that is how a piston sampler, a stationary piston sampler operates and because the piston is at the bottom of the bore hole; when the sampler enters the soil, it actually prevents the soil from getting into the sampler when the sampler tries to displace the soil. So, that is the reason why piston samplers are used in order to obtain soil samples with minimal disturbance. Now, we get into rock sampling.

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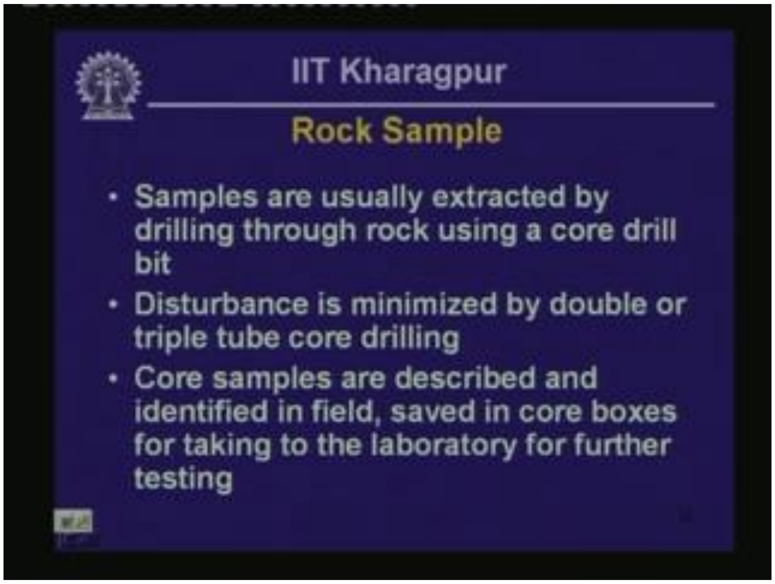

So here, the samples are extracted by drilling through rock layers, drilling through rock layers using a core drill. We have seen in the previous lessons, examples of core drill bit. Now, disturbance in this case is minimized by introducing a double or triple tube core drilling, core samples are described and identified in the field that are save in core boxes before taking to the laboratory for further testing.

Now, we look at the core drilling procedures in the sketches shown here. So, one on the left actually is showing you a double tube core drilling. So in this case, what is happening is the sampler, so this is the rock core getting into the tube. So, this one is the core and this is the drill bit and you can see here that the drilling slurry, this is the slurry end and yellow arrow there shows the slurry out.

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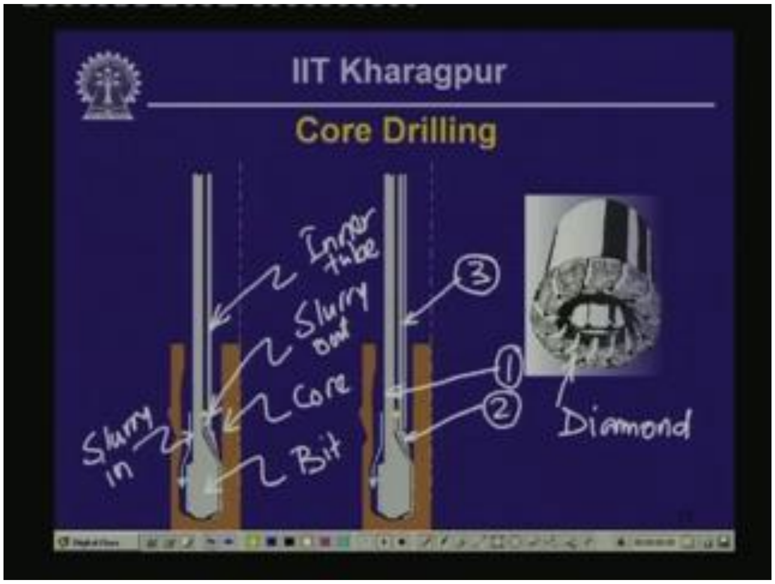

So, by introducing an inner tube we are not allowing the slurry that is getting flushed upward, this particular slurry to come in direct contact with the core that is taken within the sampling tube and because of the fact that there is no direct contact between the slurry and the sample that is getting into the tube, the sampling disturbance is going to be minimized, it is hoped.

Then you could also have a triple tube sampling and that is shown on the sketch to the right. Here, you can see that this one is the first tube, then you have got the second tube and finally you have got an inner tube which is also called the liner. So here, you have got a double protection in between the core that is getting into the tube and the slurry that is being circulated and one of the drill bits that is used in core drilling, an example of it is shown on the picture on the right of this particular slide. And, in this case, the drill bit is a diamond drill bit; so these tip here, they are diamond tips. You could also instead have a tungsten carbide tips in relatively softer rocks.

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This is an example of a core sample, core sample of basalt. You can see that the discontinuities and joints, they are clearly visible on the sample itself. We are going to talk about it later how to describe the discontinuities and the joint sets within such core samples and this core sample is ready for transportation to the laboratory.

Now, we get into nonintrusive methods. Nonintrusive methods involve no intrusion into the formation. So, this particular technique is useful if exploration has to be carried out underneath an existing structure or the site is underlained by a number of underground utilities or exploration requires to penetrate contaminated sites which should not come into contact of the devices that are going to be otherwise inserted into the formation because then those devices will have to cleaned up properly and that could be is some situations very expensive.

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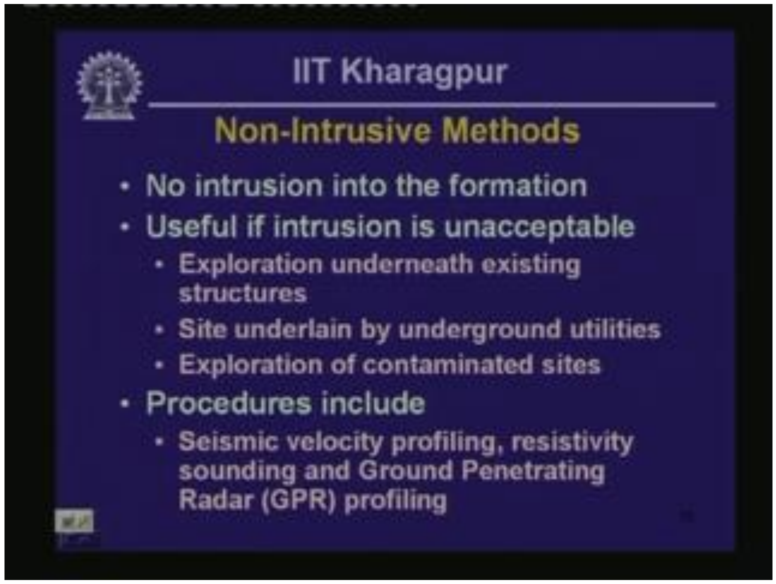

So, these procedures include seismic velocity profiling, resistivity sounding and ground penetrating radar profiling. We look at now the details of these things.

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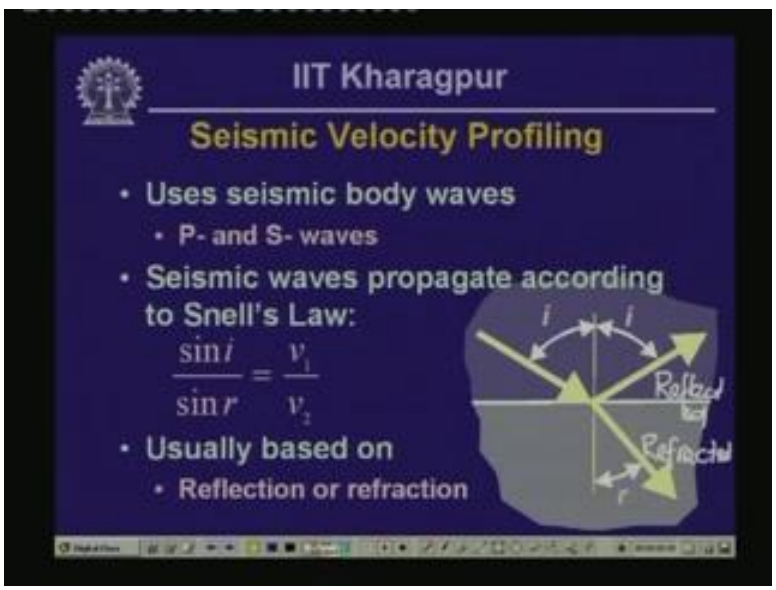

So, seismic velocity profiling use seismic body waves and the body waves are in a sense P waves or S waves. So, P waves are similar to the sound waves in a sense. In this case, the particle motion is in the same direction as the propagation direction. S waves on the other hand, the particle motion is in a direction transverse to the direction of propagation.

Now, seismic waves, both these body waves during propagation, they follow Snell's law. That means sin of the incident angle divided by the sin of the reflected angle, refracted angle rather; they are in the ration, the ratio is equal to the ration of the velocity of the propagation of the waves in these two medium. So, that is actually indicated on the sketch to the right.

So here, we have got an interlayer; above the interlayer, the velocity of propagation of seismic wave is v_1 and at the bottom it is v_2. So, in that case, sin i over sin r will be equal to v_1 over v_2 as seen on the equation there. Now this is, the seismic velocity profiling is usually based on reflection of seismic waves and the reflected wave in this case, this is the reflected wave is the one that is shown there and the wave below is the refracted wave, this is known to you from the preliminary physics courses. So basically, we make use of reflected waves and refracted waves and how do we do that is going to be explained in the next little bit.

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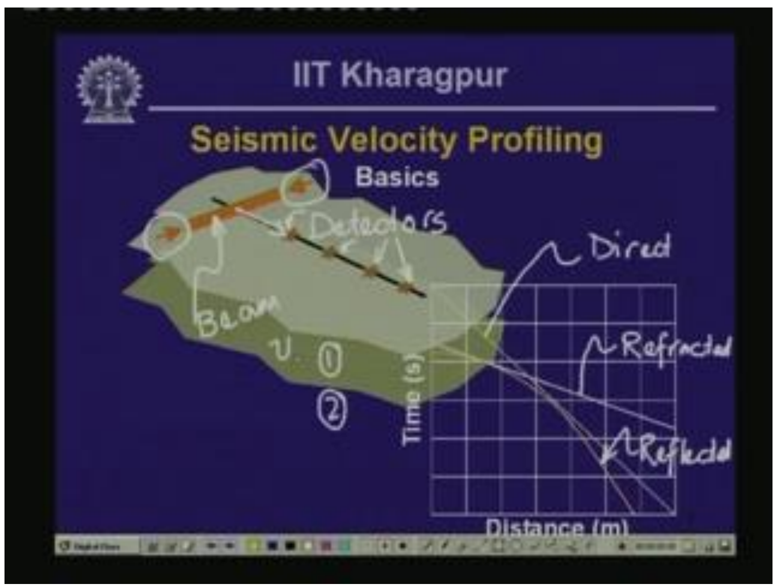

So here, what we have got is we have a got a very heavy beam say; so we have got a heavy beam and we hit this particular beam, first say to the right and then we hit this beam from the left. Now, because of the disturbance caused by this particular thing, seismic waves, they are going to start propagating and this case, we have got layered structure. So, this beam is at the surface of the earth and what we do is we place a series of detectors of seismic waves. So these are detectors; this one, this one and this one, as well as this one.

So, these detectors, they pick up the signals as they reflect from the inter layer boundary and come back and also they refract and travel along the interlayer boundary and come back and because of that, we can get different arrival times. So, from those arrival times, the pattern of those arrival times, we can construct the layered structure underneath the location which is being surveyed by seismic velocity profiling. So here, the waves that arrive in sequences are shown on the sketch on the plot to the bottom right of this particular slide.

So, in this case, this one is the direct arrival that means the waves that originate there and travel along the surface and arrive at a given detector. This one here is refraction, refracted wave; so that go down and start travelling along the interface of layer 1 and layer 2 and arrive at detectors. Then you have got reflected waves; their arrival is as shown in the particular plot. So, using these patterns actually, you can construct the velocity structure, you can find out what is the velocity of v_1, what is thickness of v_1, so what is the thickness h_1 and also you could get velocity of v_2 and so on and so forth; that in a sense is the seismic velocity profiling.

Then resistivity sounding; it attends to detect resistivity contrast of different layers; all different types of geologic mediums has got different resistivity values. For instance, clays exhibit low resistivity whereas granular soils, coarse grain soils have got larger resistivity values. Then the governing equation in this case is shown there, is shown below that is essentially rho is equal to 2 pie times d times e over i.

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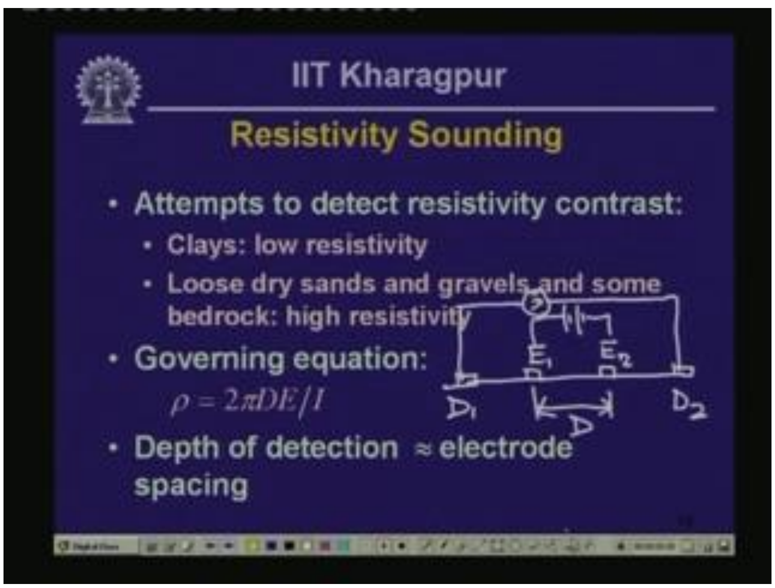

So, rho is the resistivity in this case, d is the distance between the electrodes that are used in order to circulate the current and these electrodes are placed at the ground surface where e is the voltage drop between the detectors and i is the current generated at the detectors.

So, in this case, typically what is done is on the ground surface, you place two electrodes; let us call them e_1 and e_2 and then you have got detectors, so let us call that d_1 and d_2. So, here basically, this is the value of d in the equation and this is driven by actually a voltage supplied across the electrodes and then you are going to measure the voltage drop and the current in between the detectors. So, those things are used in the equation on the left there.

Now, depth of detection in this case is approximately equal to the electrode spacing in this case. So basically, the depth of sampling of different layers is going to be equal to d in this case.

The GPR profiling; this is also very similar to the seismic velocity profiling. But in this case, typically we make use of reflection only; not refraction. So, in this case, what we have got?

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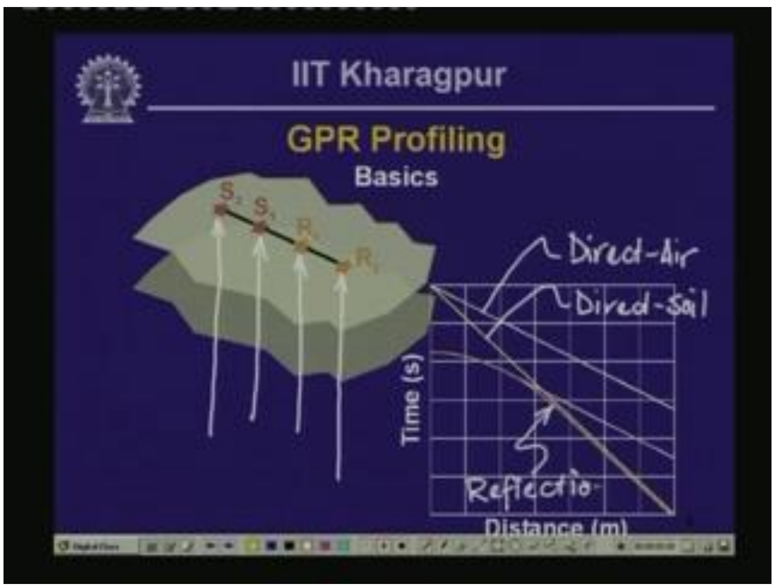

We have got a source of RADAR waves s_1 and then we have got a detector called r_1. So, this is what we do basically; we use a source and we use a detector to find out what is the radar signature of the subsurface layers and in sense and then we alter the location, we take the source to a different location and we take the detector to a different location and by looking at signature for different detection signals or signals detected, we construct the profile of the subsurface layers.

And in this case, what we have got? We have got an arrival which arrives directly from source to receiver through air, then we have got direct arrival but this is from soil to the surface of the soil and then we also have got reflected signal arrival in this case, arrival of reflection and that is shown by that line there and by looking at these patterns, we also just like before we can find out what is the interlayer structure.

Here we make use of RADAR waves between 200 to 900 megahertz and we use reflection signature as we have indicated, then the antennas are shielded to eliminate reflection from above ground objects and typically the depth sample is less than or equal to 10 meter. The resolution is not very great in this case and it does not work well for many absorbing material, absorbing soil types such as clays.

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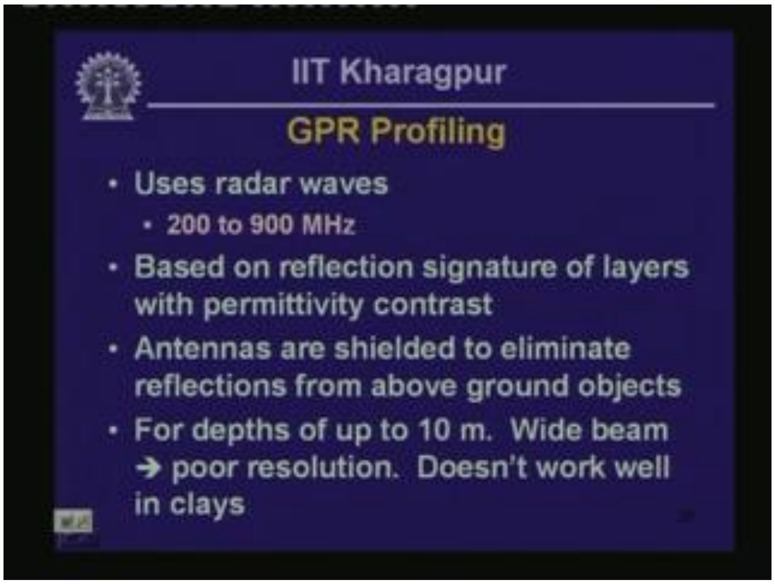

To summarize this particular lesson, what we learnt here are different types of procedures for drilling and sampling, we looked at a few common procedures for non-intrusive methods of subsurface exploration and then we looked at the list of relative advantages and limitations of these procedures.

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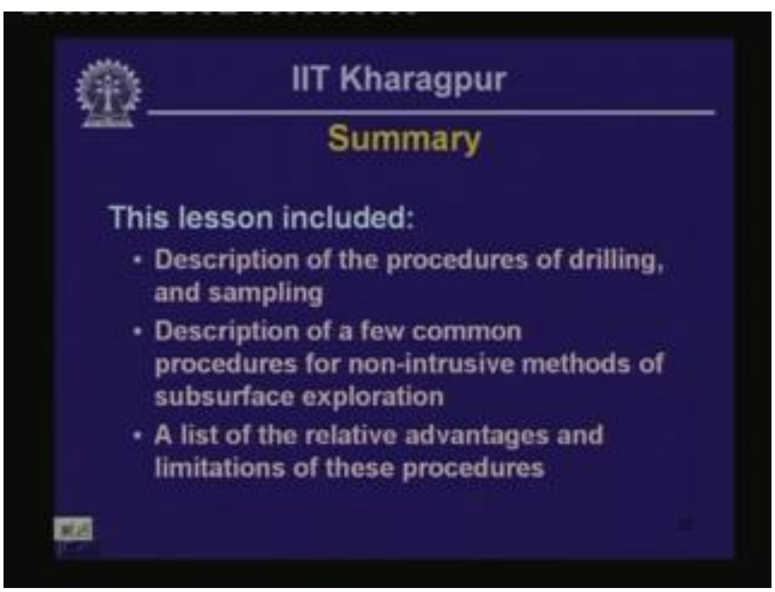

We end with the question set.

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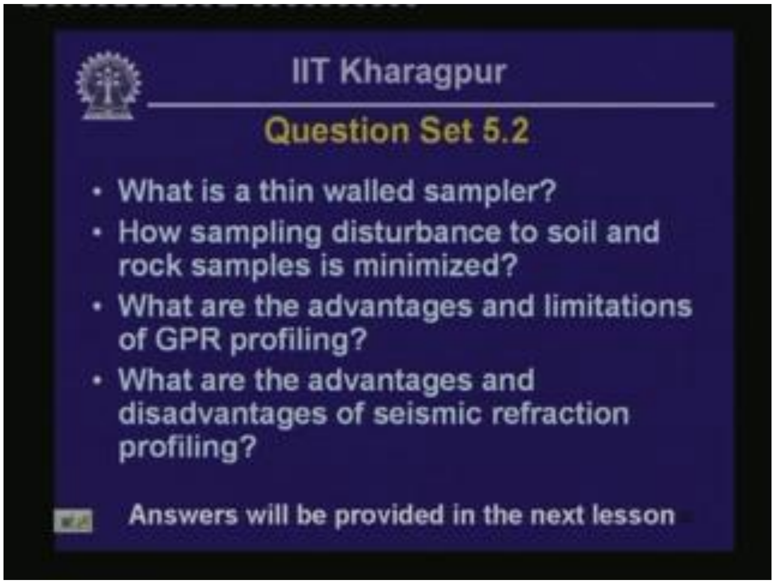

The first question is what is the thin walled sampler? Then, how sampling disturbance to soil and rock sample is minimized? What are the advantages and limitations of GPR profiling? And, what are the advantages and disadvantages of seismic refraction profiling? Try to find out answers to these questions at your leisure and when we meet again, we are going to talk about the answers.

Thank you very much.