Foundation for Offshore Structures
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Module-1
Lecture-5
Basics of Soil Mechanics V

So we will continue with the soil investigation, I think yesterday we were looking at various sequence of activities involved, fieldwork + laboratory work + some set of you know analysis of the data to arrive at the design condition. So ultimately what we are trying to do is approximate to the real situation. So equipment I think depending on the type of strata expected you have to change it but then some amount of planning is required, especially for offshore. Onshore, not a big problem because you can mobilise any type of equipment at any time but if it is offshore, several thousand kilometres into the sea, you will not be able to bring back equipments, mostly you have to preplan it.

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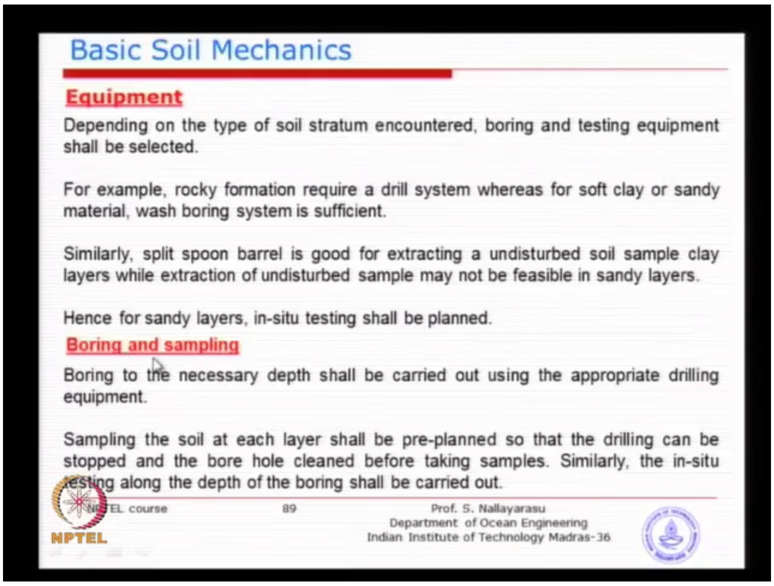

Boring and sampling is basically a very challenging activity because you need to take undisturbed samples and that might require some amount of you know critical work for drilling without disturbing and so on. Borehole location and numbers we discussed the other day, and I think I have summarised what is possible in terms of you know for offshore applications, onshore applications the different ideas as to be adapted. For most of the offshore projects, we use one borehole per structure but if you have time and money, some clients or some projects you may actually do 4 bore holes, each one at the corner so that you can indicate corresponding you know the pile that is going to be installed.

So as you know very well, most of the jackets we have piles at the corners, normally not in the middle. But several cases we use only one borehole and sometimes goes perfectly all right, sometimes you have localised boulders or localised strata change. Means, out of 3 piles, one pile becomes either under predicted capacity or overprotected capacity in different manner. In fact this season we had one problem, where you know the pile was expected to have refusal early stage, you know the soil was showing that hard layers, so they had asked my opinion of investigating whether can be driven.

So we did an analysis and found that it cannot be driven for the soil is provided to us. And we recommended that you go for a bigger hammer or reduce the penetration. But ultimately none of that happened at the contractor then mobilised the equipment and finally they could drive all 3 piles to the required penetration and only one pile they could drive but it was going very easy, means the resistance was so low. So then we back calculated the capacity is, 3 of them is sufficient capacity, one of them have only 60 to 70 percent of the capacity required. So the platform becomes unusable because that is the only pile carrying highest load.

So you could see the situation has come exactly opposite. We have soil borehole done, analysis and we are expected hard-driving and it happened in 3 piles, not hard-driving but at least sufficient effort is required, but one of the borehole, one of the pile has become potentially lesser capacity than what is expected. Because it was going very easy, that means the layer on that location or on that particular corner has degraded soil. So this also can happen, it is not always that soil is going to have higher strength than expected, it can have exactly opposite.

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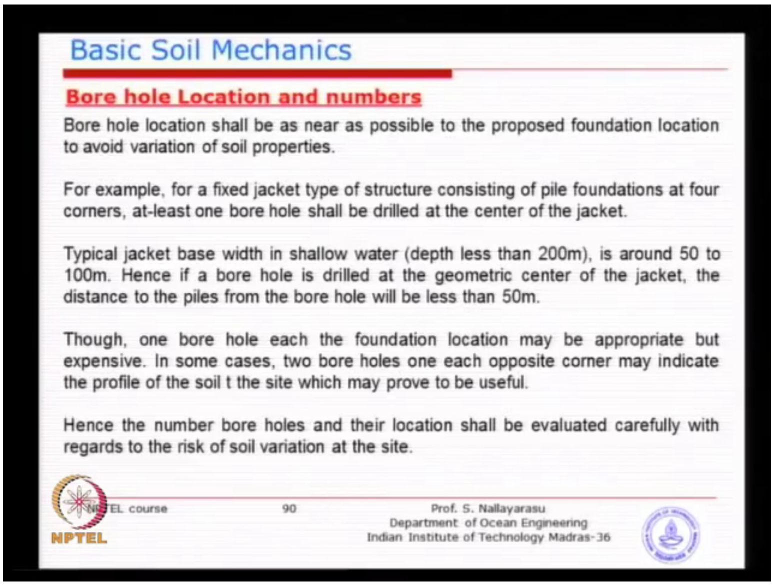

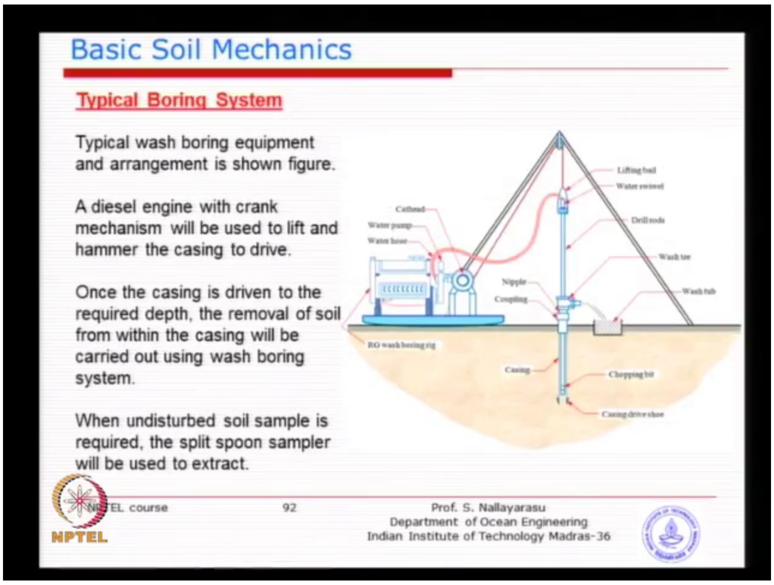

Now we have been planning to do some remedial action by adding additional pile there. So you can see how much money and effort you have to spend to get another pile installed there is, it is a very big difference. So that is why though we do all these kind of borehole, due diligence is still required. Typical boring system onshore, I just wanted to show you which is easy to understand, you will have a tripod, you may have diesel engine or you may have hydraulic engine, but most of the time you have diesel engine to do the rotation of the cam so that you know you can try.

And you may have a wash boring system by which you know the smallbore, the soil will come out to a depth where did you want to actually drill. Or you can have agar Boring depending on the type of material. You know, if you cannot use your wash boring system, wash boring is very simple, very smallbore, basically the soil is washed away as you go through drilling and stop the boring when you want to do a testing in situ. You know basically a 5 metre I want to do a testing and stop the testing, cleanup the whole, put your testing equipment, it could be any of the equipments which we are going to discuss, it could be standard penetration test or it can be tar vane test.

And you can actually pick up a undisturbed sample using a sample of, you know you just send one split pool sampler. Take a sample, bring it up to the surface and put it in a container and bring to the laboratory. So all these activities will be planned after certain depth, it is not going to be continuous, you drill through, you remove the, remove or cleanup either by Agar boring or by wash boring and if it is rock, then you use actually drill bit, bring out the core so all these activities is to do some kind of understanding of the soil and testing of the soil or testing at laboratory.

So this is simple tripod but imagine if you have to do this one in offshore, this tripod will need to be supported on a structure. For example, we want to do a testing borehole in 10 metre water depths, like coastal areas, you still can employ this. What normally people do is, they construct a temporary platform using either timber posts or steel planks or some kind of temporary structures, on top of which this bound, this tripod can be mounted with a platform. If it is 10 metre, 15 metre, maybe 20 metre but beyond which this temporary platform becomes difficult to install, difficult to operate because the sea conditions will not permit.

So that is the time you will move away from the fixed type of arrangement to a floating type of arrangement. So we will see that most of the coastal area people still try to do this tripod, somehow they build very temporary I would say, will not be even stable for a few days because they do not use a construction equipment, they use whatever they have not just put some poles and platforms. So this wash boring system is still commonly used in onshore projects but normally not in offshore because it is quite difficult in underwater condition.

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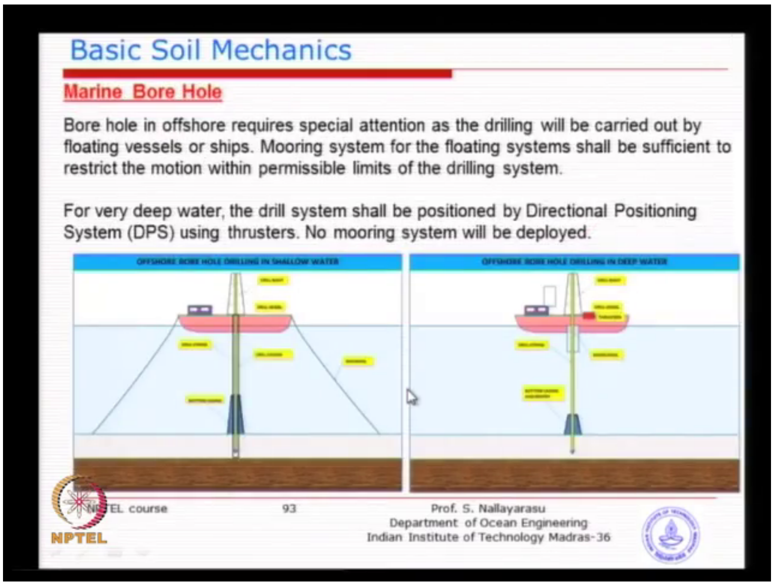

Typically for shallow water and very deep water, we have 2 systems of kind that we need to adapt. One is shallow water in the range of say 20 metre to say 100 metres, typically, most of the shallow water applications. So you see here we have boat, which is basically a drill boat or survey boat, you will have boring lines anchored to the seabed in order to avoid large movements. So this is feasible and technically feasible by say 100 meters or slightly + -. But when it becomes thousands of metre, boring system is impossible because of the length of catenary and also the weight and boring system deployment, removal becomes not feasible.

So normally for deepwater projects, that will system that is adapted is the dynamic position system using thrusters. So the boat will be able to position itself with respect to a target position by using thrusters. Thruster is just like a propulsion system, only thing gives it gives getting the feedback from the position it is right now to the position that it is supposed to be. So if you are doing a drilling at a particular coordinate, so it will be controlled by computer, all the time the thruster will thrust against the movement of the vessel which we need to position it according to the coordinate.

So this DPS is very useful, of course expensive ships only fitted with this type of system. So you can see here the primary purpose of drilling in offshore borehole, we should not have too much of movement because what will happen, when you do, send your drill bit through, it might break, if there is a large movement horizontally it will break. And it will disturb the soil because it keeps moving back and forth, you will see that the soil beneath or soil around or soil inside the bore that you are sending to will be disturbed, means it is not very good.

So we need to reduce the movement, appreciable amount, that means you are mooring system has to be very very good, that means that is going to be a challenge. So you cannot do this boring at any time you like, so you need to go and do boring only when the weather conditions are reasonably good. So you have to plan it if you want to do a bore now, you just need to look at what time, what season that you can go and do boring. During high sea conditions you cannot, if it is then you have to come out. The biggest problem is once you start boring, you cannot terminate and go back next time, so you have to complete the boring.

So you need a longer duration of planned activity so that you can complete the borehole with before the weather conditions worsen. Whereas this DPS based systems can take slightly larger sea states because they can be designed, whereas the mooring based systems is quite tough when the sea conditions are very high, mooring loads become very large, the mooring anchors become difficult to manage, you may not have a larger anchor. In this kind of smaller boats you will only have 2 ton anchor or 3 ton anchor, so you may not be able to position them.

That is why the drill boats of smaller size are only used very shallow water, 50 to 60 meter. Nowadays even for 100 meter water depth, drill ships are used for borehole. So how that is done, basically you will have a casing lowered from the ship to the seabed to a certain depth this will actually prevent the drill streams going through, very similar to our conductors, I think you might have familiar with the previous time, the last time we were talking about the conductor where we were drilling for oil and gas. Exactly same, this is a casing, outer casing and which is lowered from the ship bottom and basically goes up to the top, so that you provide a safety mechanism of a barrier between the external sea conditions and the internal drill flow.

And also you will have a conical based kind of arrangement which will sit on the seabed to prevent any debris entering into the casing itself. At this casing will be driven or probably penetrating into the seabed to certain depth, not too deep, then only you will be able to do the drilling. Similarly here you will have a cone and cup system in the deepwater, of course you will not have the casing all the way 1000 metres because it is impossible to have a casing. So you will have a drill system or the drill stream itself is capable of taking slight loads as well as some movement but not at the sea, they are close to the mixed level because you know that is well the large wave forces will occur.

So you will have some kind of larger casing, we call it moor pull extension from the ship downwards which will prevent the larger sea forces or wave forces attracted by the drill stream. Below which if you go down by say 20 metre, 30 metre, they set of waves will be very very small. So that is why you can freely allow the drill stream to go down. And basically is both of them will be doing the similar job of drilling and taking the samples. Some of the drill ships have got specialised facility including you can take seabed profiles, we can do many other surveys.

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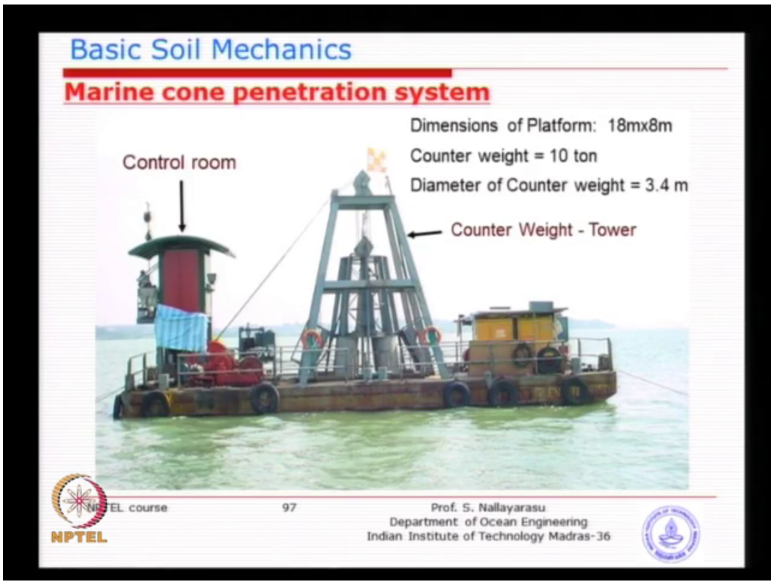

Whereas this kind of, just purely for drilling alone, will look like something like this, something like this. It is a small boat, does not have much facilities, what we have just primary system to take samples or CPT and bring the samples back, nothing will be there. But if it is actually a drill ship, you will have other computer-controlled facilities doing seabed surveys and side stamps Sonar. So basic idea is what we were looking at is to extract information from the seabed.

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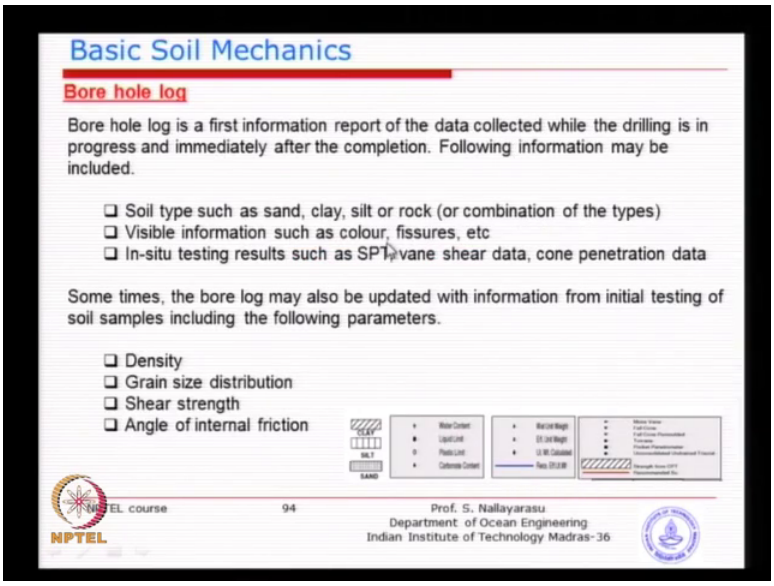

So the information that we are primarily looking at is the file type which I think we have discussed enough in the last few classes. Visible information like colour, fissures for classification purposes, in situ testing which we are going to see what are the best 3 or 4 tests available at the site, SPTs, vane shear and CPTs. And then from the gathered soil you take it to the laboratory and you try to arrive at other parameters of interest, primarily density, grain size, shear strength and then angle of internal friction for variety of soil.

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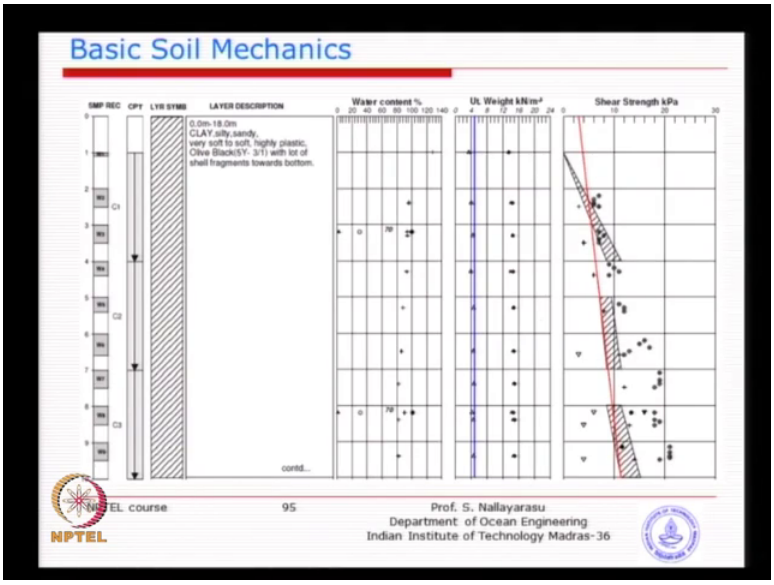

A typical borehole I wanted to show you is taken from one of the recent projects. This is how it will look like when somebody is logging in doing the process of drilling for the. So this particular slide you see here, 0 to 18 metres clay, silty, Sandy, very soft to soft, high plastic, olive block with lots of silt fragments towards bottom. So within this 18 meter, there are several adjectives, basically you see predominantly clay, predominantly clay given in capital letters but also silty, some amount of silt content, some amount of sand content and soft to, very soft to soft, highly plastic.

So these are something that this information will be very helpful later when you want to assign strength properties or when you do the laboratory testing, you would like to see whether the lab test is correct, counter verify and these are some parameters that only will be available to be engineer on-board the ship because he can only see the 1st and information. Of course when the soil sample comes to the laboratory, can also see but by that time some disturbance might have happened. So this is basically the right of, we call it the log file, it is very important.

As you see right now, on the right-hand side you see here water content, unit weight, shear strength, these are information probably derived after the soil sample comes to the lab or sometimes big ships do they have, they do have the complete testing facility on-board. Some of the boring systems that we are adapting West Coast now, the whole lab is on the ship itself. So you do not need to bring the sample all the way back and forth, by the time it comes it may become 15 days, it becomes not very good. So as the sample comes out, we do the testing there itself and then assign the properties.

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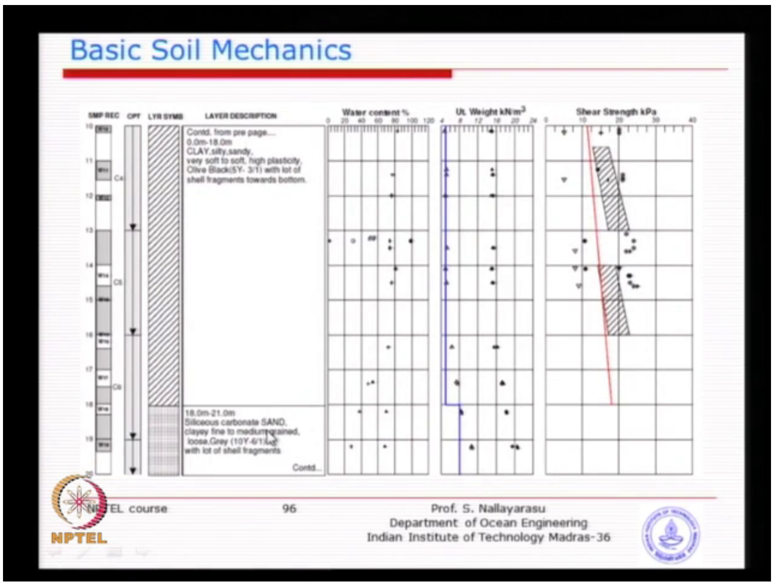

So that is the kind of log we are looking for, from which we can derive the design profiles. So next few pages you can see even 18 to 21 metre is a Sandy material, siliceous carbonate sand, so carbonate content is there. So some people can even visualize by just seeing and there is a carbonate content of this much or you have to go and do a chemical analysis, find out what is the percentage. Clayey, fine to medium grained loose grey, so you can see here this is colour, this is basically the graining, you can see from the visible understanding of the soil itself.

And also find to medium, some kind of understanding with lots of shell fragments. You know, when you look at the soil itself, you can see kind of few shelf fragments, they are potentially not good because under loading they will just break, so that is something that we need to… Typical shallow water, this is just a coastal area actually one of the projects.

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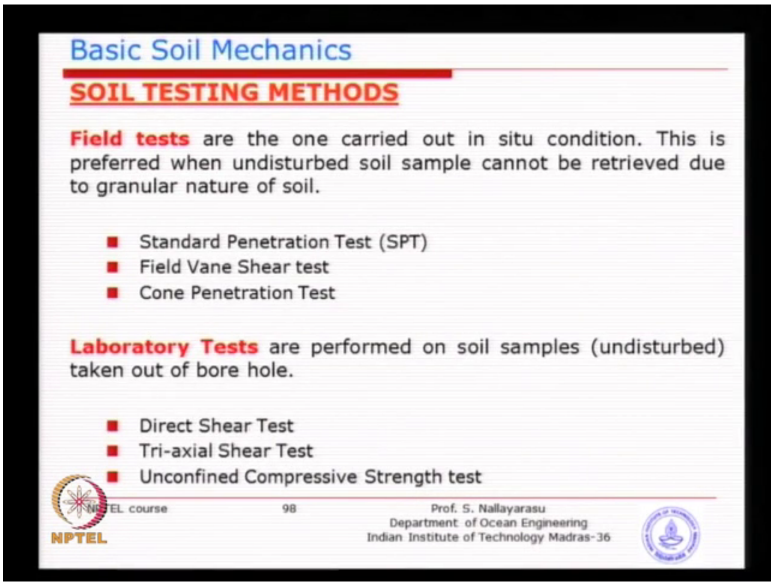

What are the testing that we can do, basically we can do field test, we can also do laboratory test. So field test I think I have mentioned earlier on, standard penetration test, field shear test or vane shear test and then CPT test, all of them are trying to test the soil against some kind of action on it. For example if we take a standard penetration test, I will tell you why this called standard but penetration test, you take a kind of tool with your hand and try to penetrate through like the one that we were talking about, take a spade and penetrate into the soil to see whether how much depth it goes, that is basically the idea of your cone penetration, fall cone method.

Similar idea, only thing is they have standardised the size of the tool that will be used so that the reason is historically it has been used so that you can use the historical information to relate it. So you cannot say I will go and use another hammer or another bigger piece of, you can do that but there is no relation exists in the literature. So we continue to use the standard penetration basically because it is a standardised weight, height and the diameter, so that that information can be correlated with something else. So the standard penetration test is nothing but, you have a rod which needs to penetrate certain height under certain fall height with a specific weight of the hammer.

So just allow it to drop, go down and how many blows required to penetrate a particular depth, so it is very similar to driving a nail onto a hard surface. You take a nail, you hammer 10 times, it does not go through, so it is very hard soil. And if it goes just in one blow itself, it is a soft material. So that gives you an idea but as long as the hammer size is same, as long as the diameter of the pin is same, then it is correct. So that is called the standard penetration test. What we normally do is, let us look at the standard penetration test.

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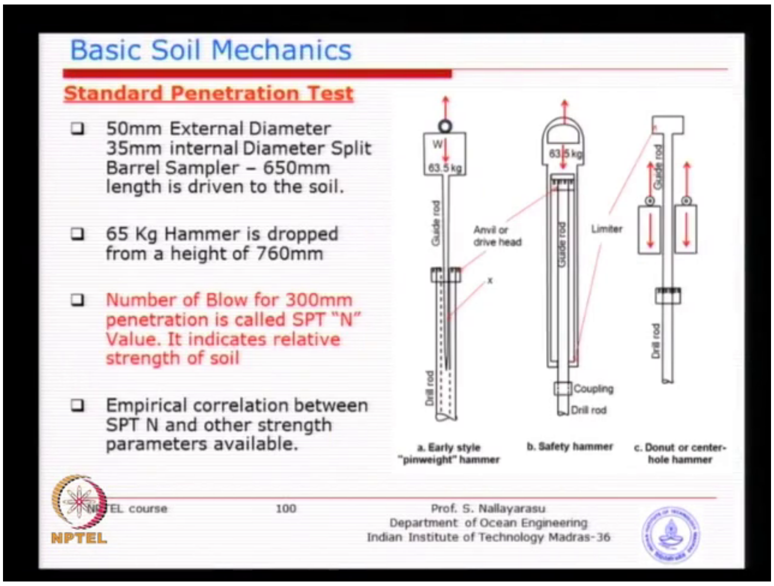

You have 50 MM external diameter with 35 MM internal diameter as a split spoon barrel which is nothing but a pipe which you can open later on. And 650 millimetre long is driven into the ground and use this hammer, anyone of them, these are all historically, evolution of various types. But the weight is 63.5 KG as given by one of the ASTM, I forgot to mention here, is one of the ASTM codes gives this specification for diameter and weight, height of fall, height of fall is 760 millimetre, it is about two and a half feet with 65 KG hammer dropped from that height.

So if you have this split spoon Sampler inserted into the soil and just drop. But controlled drop, it is just not going to be hammering anyhow. So you will have sleeve through which it will just fall down, lift it off, fall down, left it off. And how many blows that you require to achieve a 300 millimetre penetration, so just that whatever the sampler and you have inserted into the soil is called the end value, the blow count value.

You might see if you go around several construction sites, some people will be having a rope which actually you keep pulling up and down, they may not even have a diesel engine, normally for good geotechnical exploration company will have a diesel engine with a counter, so you just switch on the cam will actually rotate, it will go up, down, go up down. But some places, just the people are doing, you know keep moving the rope up-and-down. So you can count the number of blows by 1, 2, 3, 4 and so on and find out.

So this number higher means it indicates soil is stronger, stiffer, denser, is not it. If it is the number of blows are very less, then it is loose, or soft clay or the material is having too much of porosity. So that gives you an idea the blow count is lower, higher, medium. But what kind of number we are looking at is basically ranging from 0 to 50. So 0 means the material is very soft, that means you do not even need a blow because insertion of the barrel itself is just going down. And many occasions you will see that coastal areas, you will see the SPT values like 0, 1, 2, 3, that kind of order, because it is very very soft clay.

Whereas when you go to a very dense sand, very dense sand with an angle of internal friction of say 35 degree, 40 degree, you may require several number of blows to achieve such similar 300 MM penetration like it might take 40, 50, 60, 50 and higher means the soil is fully denser, you are unable to achieve any penetration. So that means this number is going to give very good advantage of relating with anyone of the parameters. You can relate with SPT value with density, you can relate with the angle of internal friction, you can also relate with the shear strength of the clay soil or any other parameter as long as you have done the testing in both sides.

You do the SPT, you take the same soil sample and bring to the laboratory, do some test in the laboratory, relate them which has been done by several researchers, starting from Tarazahi and Peck, they have they have done one first paper in 1976, in fact Professor Peck has actually given Tarazahi lecture on SPT and bearing capacity. So if you look at the paper, it is very well explained what I was trying to explain today. You know basically the relationship between the 3 or 4 parameters with respect to the blow will give a very basic information.

In fact if you look at most of the construction sites in India, they use only this because it is quite simple, does not require much of instrumentation, accuracy is good because seldom you can make mistake here because there is nothing else, there is only what we are looking at is the penetration and the number of blows that you actually count. I am sure you will not be able to make mistakes. So that is why and it is very fast, very fast, within half an hour you can complete one test and very cheap, you do not need any deployment of instruments and all.

So that is why everywhere people are very commonly using this is SPT method because of its nature and easy to use and you will find, you bring any soil report from any particular point, you will find SPT is there. But unfortunately will not be able to use it for offshore applications because of the nature of drilling that we are trying to do. Lowering this SPT machine into a water depth like this and monitoring the blows will become very difficult.

So that is why most of the offshore projects we do not recommend but onshore and coastal, people still use this method, whereas offshore we need to try and find out alternative method because it is quite deep, especially when you have a borehole of 100 meters, it is very hard to manipulate and operate this.

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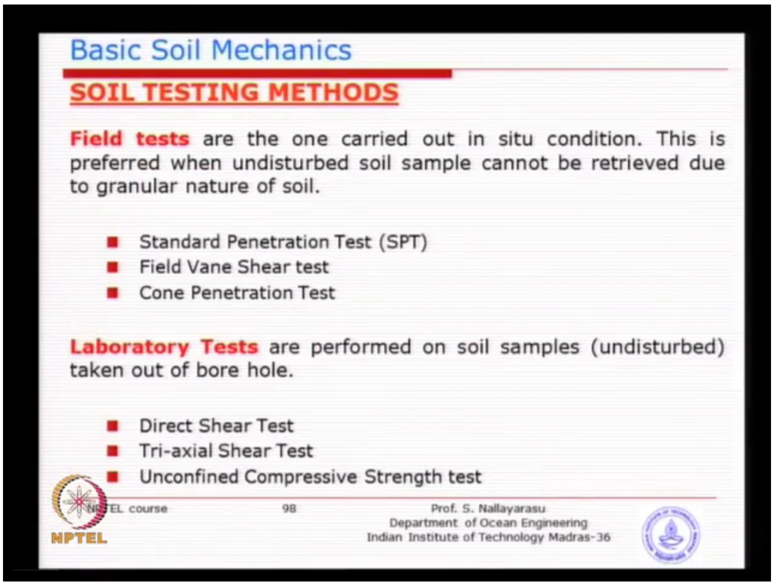

So standard penetration test is one of the best method for shallow bore holes and where you cannot bring undisturbed sample, especially whether if the soil is too soft or if the soil is fully coarse-grained, you know you could pick up the undisturbed sample, this will be the best method which can be adapted. The second method is the vane shear test, is again, is a very simple, imagine you take a Spade and insert it into the ground and try to rotate the Spade, you know what equally. So what needs to happen, it has to break the soil at that periphery of the Spade edge, is not it.

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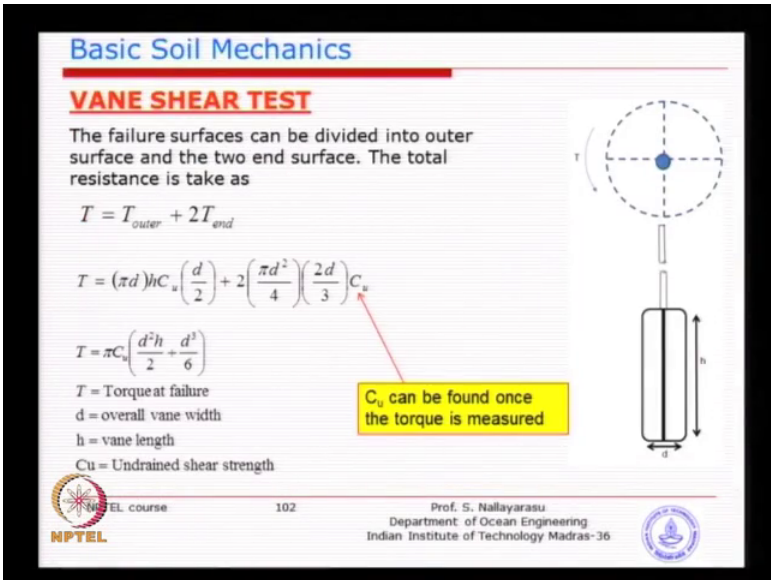

So basically is trying to break means it is shearing the soil and that is exactly the idea behind. If you look at vane shear, it is nothing but a tool attached to a simple rotating machine which can measure the torque or the effort required to rotate it. So it might have 4 blades like this, you see here in the picture, you got crisscrossed plates attached to a stem and we can rotate by means of a hand tool or by means of an electronic or electric tool which needs to measure the torque and the angle of rotation and the speed which is…

And just what we have done here, there is a shearing surface at the periphery and there is a shearing surface at the bottom, you know it has to break the bond between the soil to soil and that is exactly the formula, just you can derive this. And the relationship between the measured torque and the shearing strength of the material is derived. So as long as we know the torque value, we can calculate what could be the shearing value of the soil itself. So it is a very simple, we have field with, you know you can do this test in the field or you can do this test in the laboratory, miniature vane, you just make a smaller one because you do bring a smaller sample.

You cannot maker bigger machine, so you bring a, we call it miniature vane test, Vane shear test. Or if you go to the field, you can use this directly into the borehole, of course it cannot be very big also. The one of the problem with this machine is also to lower into a deeper borehole is very difficult. Many times we do this in shallow open pits, you know when you are doing onshore projects, very shallow foundations, you just excavate, you do not do a boring, normally for onshore building type of projects, people do not do boring, we can make a big sized pit and as you go down, you excavate and do this kind of testing, 2 and 3 places.

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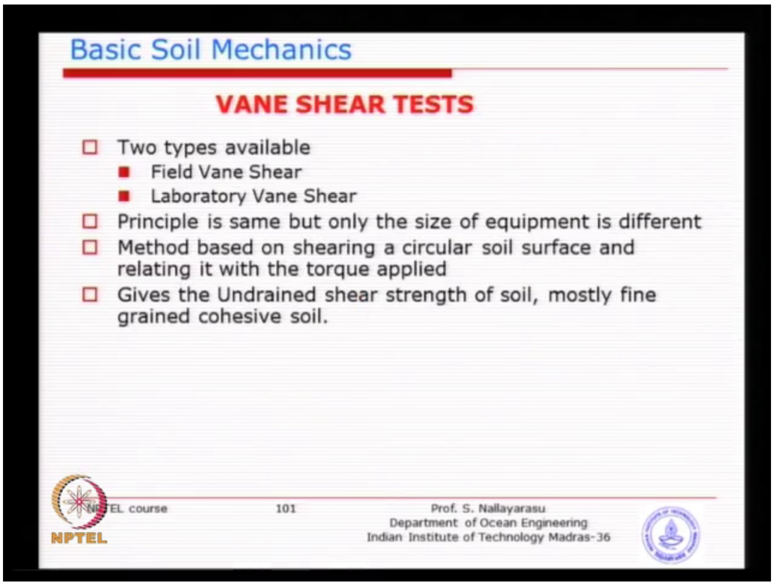

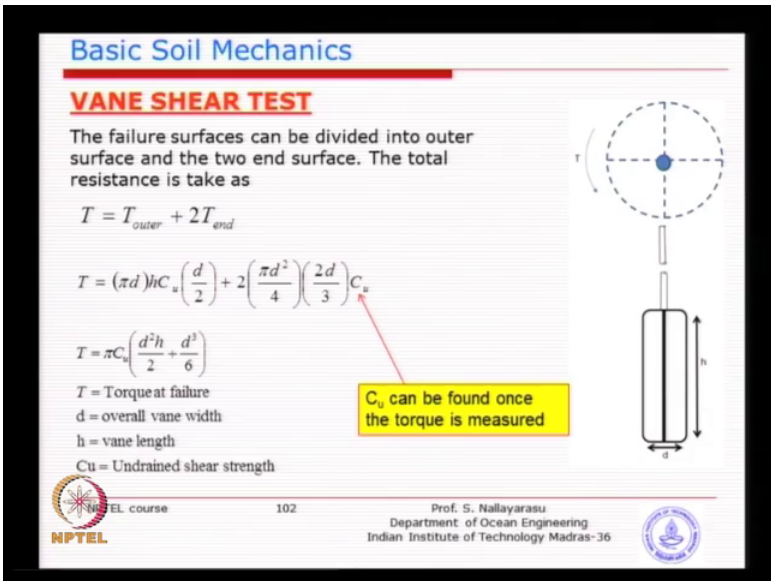

So such situations you can use, but of course the mini vane can be used in the laboratory, you bring the larger soil sample and put that want to do the testing. Basically Vane shear, not very commonly used for offshore applications but the understanding is very simple. You know, you are trying to shear out, the last one is basically the cone penetration, very similar to SPT, only thing is the shape of the cone that is penetrating to into the soil is very similar to fall cone tests, there you actually allow it to fall but here you apply a pressure to penetrate at a particular rate.

You know you will have an electronic system continuously monitoring the rate of penetration and the resistance offered by the soil at the tip on the side. So basically you will have a strain gauge inside, I hope most of you are attending these our laboratory course on instrumentation, is not it, you might have seen the strain gauge. So this conical rod will be fitted with strain gauges to measure the end strain as well as the side friction strain. So you just push it into the soil at a particular rate of penetration because you are under the hydraulic machine will start penetrating and basically something like this.

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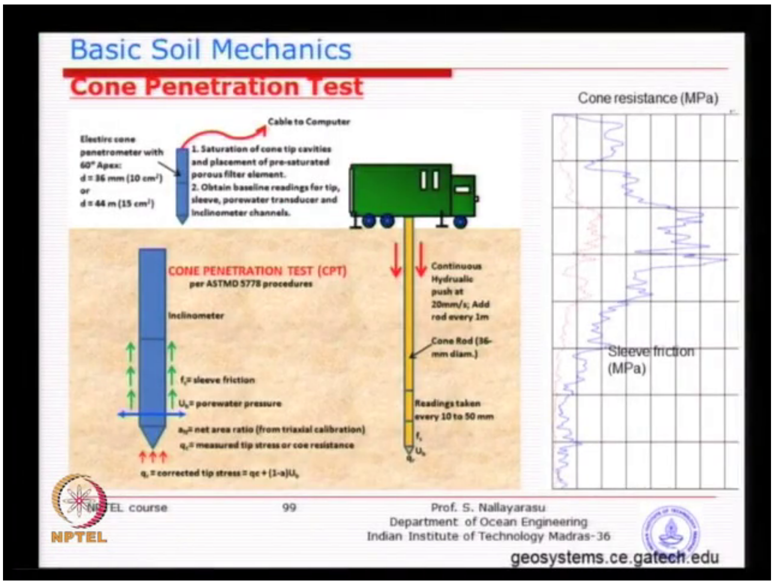

Of course this is, this picture shows onshore truck but you can mount the whole thing into a floating bars and basically one of the biggest worry is stabilisation and verticality. You know that is where now sophisticated systems are available to adjust the verticality for offshore drilling. So you can see on the right-hand side, you know the picture of the friction between the soil and the sleeve are on the sides and the cone resistance at the bottom will continuously record it because this is a great information because normally when you do borehole, you take discrete intervals to take samples, is not it.

Whereas this one gives you continuous resistance which can be integrated if you have a numerical integration scheme you know you just digitise this data, take it into a computer program and you can integrate the whole thing by numerical means and get the capacity, extrapolate to actual pipe, because this cone diameter is known and sleeve friction is known, and bearing is known, so that is why this CPT-based method gives very accurate results because you are not disturbing, you are not boring and that is why very very commonly used in offshore.

In fact every offshore borehole that we do, we do take soil samples as well the CPT measurements, then later when you do a laboratory testing, you compare the results with what you have gathered through CPT. So CPT is basically a cone, unfortunately I do not have a photo, I will show you a photo, we have a rod of this much size which is fitted with all the instrumentation inside and have the hydraulic device which can penetrate whichever the depth. So this CPT is very commonly used for offshore because of its easiness and continuous sampling is available.

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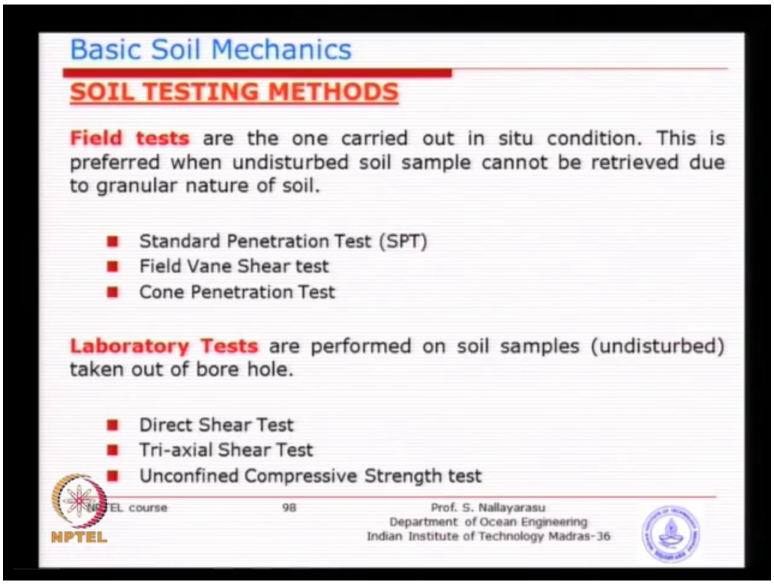

And among these you can also bring in samples when you are doing this at the intervals and you take the samples and pack it up and bring to the laboratory. You can do 3 tests, the last one is not commonly used for soil, it is used for rocks, whereas the first and second is predominantly used for soil samples, direct shear interest and tri-axial.

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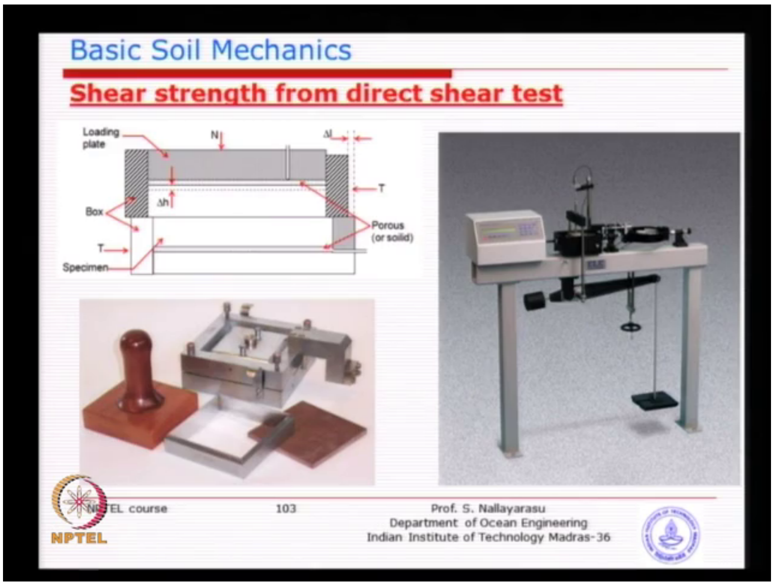

Direct shear test, I will just show you the photograph of the apparatus, so you can see here the bottom piece and the top piece is sliding. So you can see the soil sample is kept within this and you just try to shear off, one of the biggest disadvantages of this method is the failure plane is predetermined. We determine the failure plane which is not very good, because the soil will fail according to the weakest and according to the nature of state of stress, whereas here we are trying to shear off at a particular if it so happens that the soil sample at that location has got weakest bond or weakest friction, then we are not actually predicting the actual failure load.

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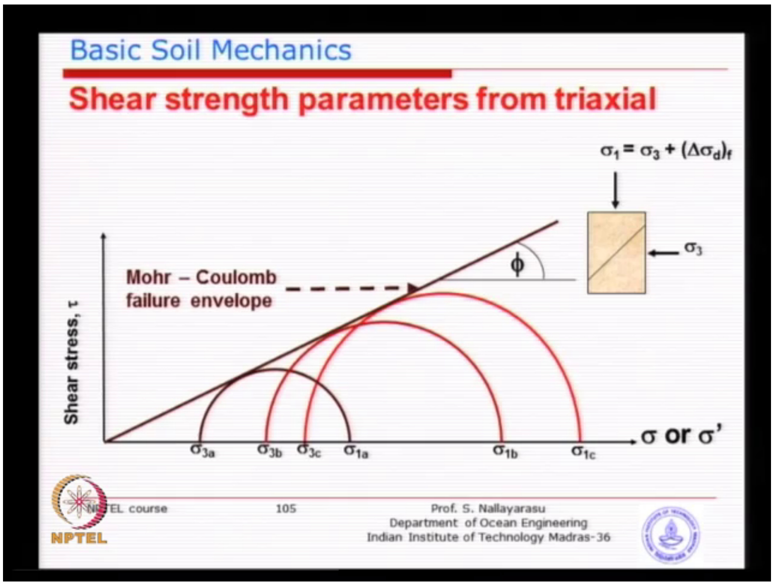

So that is one of the boring, but this test is so simple, imagine if I have, if I have larger normal load, the failure will be, the larger effort is required to break it. So normally we do 3 or 4 test with different values of normal load and you can just plot it, you will see something like this, you know you repeat the test in order to get the failure plane which is basically our angle of internal friction. So this method can be adapted to any type of soil but predominantly we use it for coarse-grained or mixed soils, you know basically most of the times which you cannot use other methods to do testing, then you can use this direct shear test.

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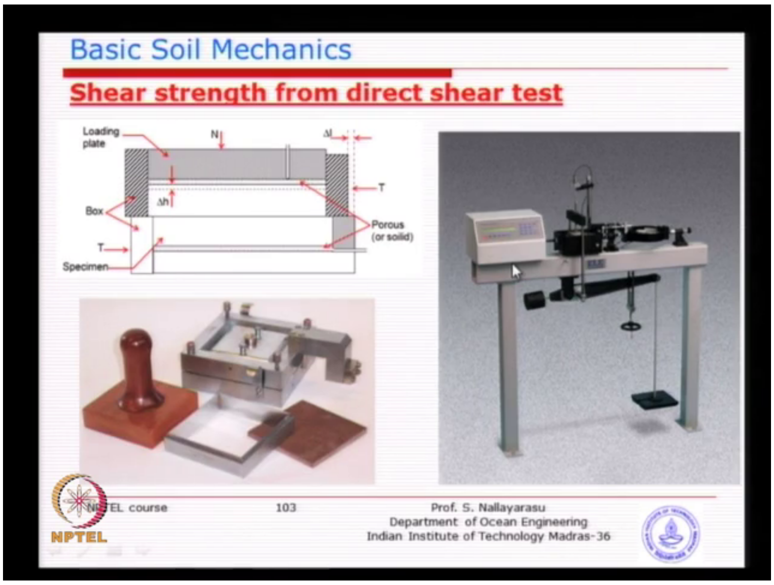

So sometimes you have, you know you can see on the right-hand side, basically it is fitted with instrumentation, so you can get the results in a computer you can connect it or you can control the normal load by adjusting. So you can see a simple setup which is very similar to the one that we have in the civil engineering lab. We used to have these things in our department but we have donated to them. 2 years back we have given back to civil engineering because nobody is there to maintain these equipments.

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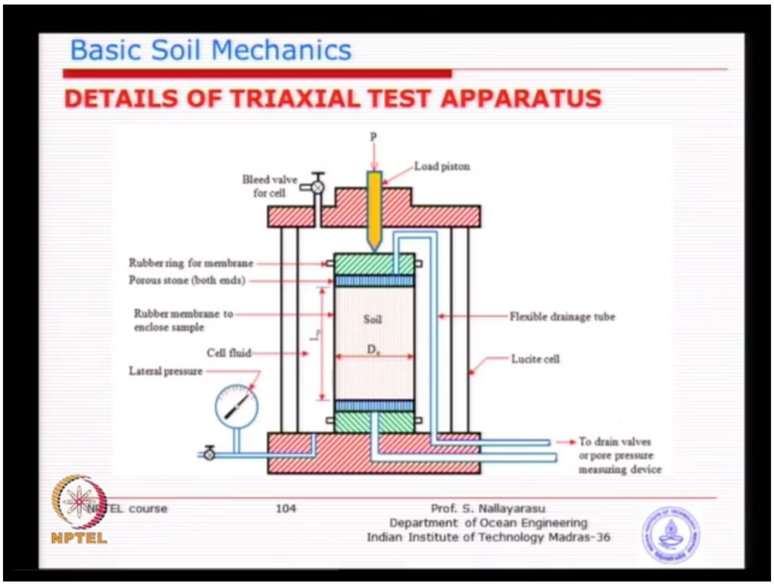

The basic idea is shear test is quite often used for coarse-grained as well as the other type of soil. The other test that we can do is the tri-axial test, very common and in fact reasonably accurate. So you can see the setup, you have to bring in a soil sample of a circular cylinder, that is one of the, so you have to be, if you cannot get such type of undisturbed sample, you cannot do this testing. So you will be having a membrane around this sample, kept it in this place, between 2 top and bottom leads of the test arrangement.

So you can see here various components, you also have an external cell which you can fill with fluid, so to create the lateral pressure. So we have several tests, you can have 4 or 4 combinations of different tests, drained, undrained, that means when you are compressing, you can allow the water to drain, that means the drained condition. And you can also have external pressure which is creating the lateral pressure on the soil sample, consolidated unconsolidated and you have the normal load. So you are trying to create the tri-axial system which is available in every geotechnical lab.

You can measure the pressure, the lateral pressure from the pressure gauge and you also have the porous material placed at the top and bottom to allow the drainage. Now if you look at the offshore condition, we do not have a drained condition, so always we do testing with undrained condition and that is why sometimes we call it undrained shear strength, because offshore conditions you cannot have drained system, whereas onshore for example if you have a building somewhere here, when the load is applied, what will happen?

The water will try to escape wherever it is possible to go or it can come out. In fact in recent one of the projects, we had a soil where the strength is only about SPT values of 1, 2, 3, something like this and it was not suitable for construction of heavy plant, it is very close to coastline. So what they did was, they were trying to use that place but then when you try to do loading, this soft clay is going to get disturbed and going to disperse and fail terribly. And that is what happened when they actually made up that area by filling Murum soil on top, red soil.

After a month, the areas were just sliding down, failing because the clay could not take any loading. So what we then did, you drill holes at several places, insert drainpipes and then apply a surcharge load. So what happens is the water from underneath squeeze way, come out and when the water is coming out, the soil settles by all most a metre, then you do the SPT again, you find that SPT has become from 2-3 to 10-15 because soil has consolidated, the water has come out.

So basically the same idea but unfortunately in offshore conditions you could have a situation because everywhere there is water, so drained condition is not feasible because everywhere same hydrostatic pressure is applied. So basically you can do drain condition, you can do undrained condition, you can do external with and without external pressure. So 4 types of test can be carried out in this triaxial machine and the results will be compiled very similar to this, again you will have normal pressure, you will have lateral pressure, drained condition, undrained condition.