Foundation Engineering
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Module - 03
Lecture - 04
Dynamic Cone Penetration Test

Hello viewers, welcome back to the course on Foundation Engineering. In the last lecture we have discussed about the standard penetration test. And today I am going to discuss the Dynamic Cone Penetration Test, this is one of the very important field test.

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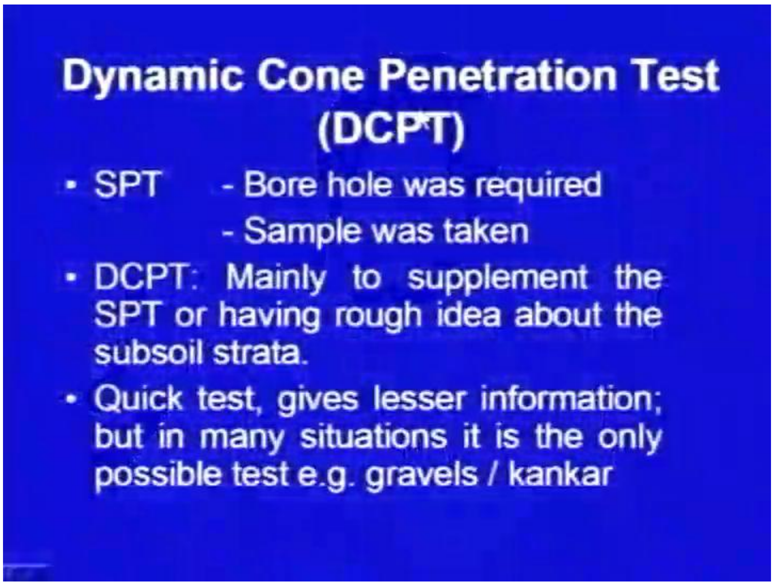

And as you remember, in case of the standard penetration test, which we have discussed last time, there was a borehole, which was required to conduct the test and the advantage of the test was that, we were able to extract the sample. So, SPT standard penetration test, in fact is one of the most popular test and this dynamic cone penetration test is mainly conducted to supplement the SPT or having rough idea about the subsoil strata.

This test is a very quick test, standard penetration test takes lot of time, you have to do the boring up to certain depth, at that boring then you have to conduct the test and then you have to do further boring. So, it takes lot of time, whereas this test DCPT is a quick test; however, it gives lesser information, but in many situation, probably it is the only possible test.

There are many cases, there will be many field situations for example, where lot of gravels are there or kankar is there, then this is the only test which gives you some idea about the soil strata.

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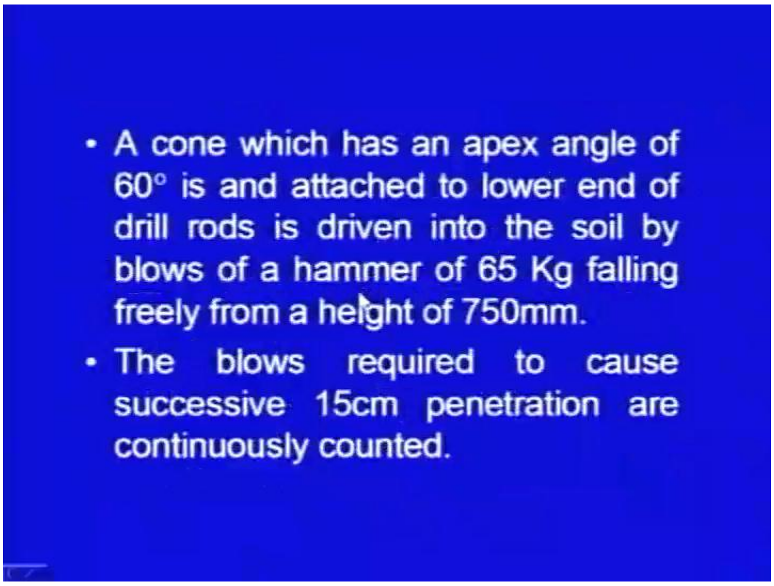

This test consists of a cone, which has an apex angle of 60 degree and this cone is attached to the lower end of the drill rods. And these drill rods are driven into the ground, into the soil by blows of a hammer of 65 kg, which falls freely from a height of 750 millimeter.

So, the principle almost is similar, it is little bit different from SPT, in SPT we had the split spoon sampler, here we have the cone and again, the blows required to cause successive 15 centimeter penetration are continuously counted. So, this is the advantage in this test that, continuously we will keep on recording the data.

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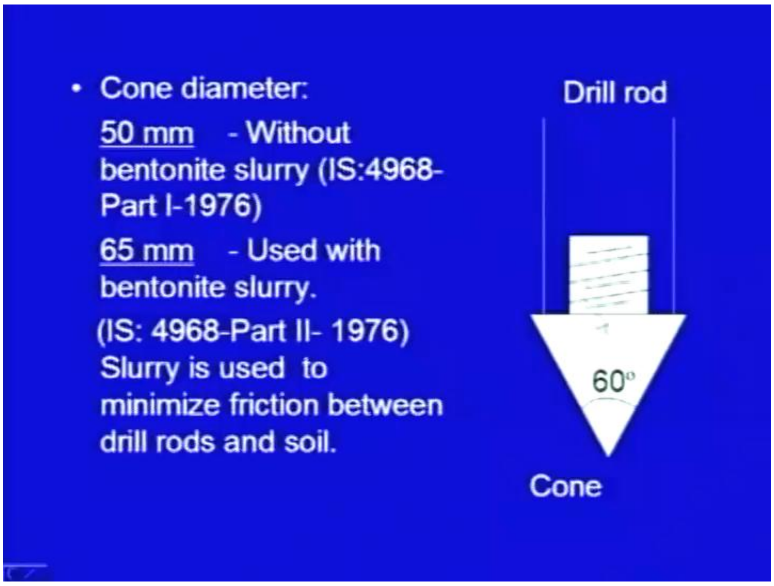

Here, I have shown the cone which is attached to drill rod, this is the cone and it is attached to this drill rod, this is the drill rod, apex angle of the cone is 60 degree and the diameter of this cone standard diameter is 50 millimeter. When, it is used without bentonite slurry as per this IS code, IS 4968 part I, 1976 and sometimes another diameter it is also recommended by the code, the diameter is 65 millimeter it is used, when the bentonite slurry is used.

Bentonite slurry is used to minimize friction between this drill rod and the soil, when this rod is penetrated into the ground; here on the sides of the rod, the friction will be acting to minimize that friction, because what we need is only the cone. Here, the resistance which is being offered at this place, so we try to minimize the friction at the sides of the rod, so here bentonite slurry is used, so these are the standard specifications of the cone.

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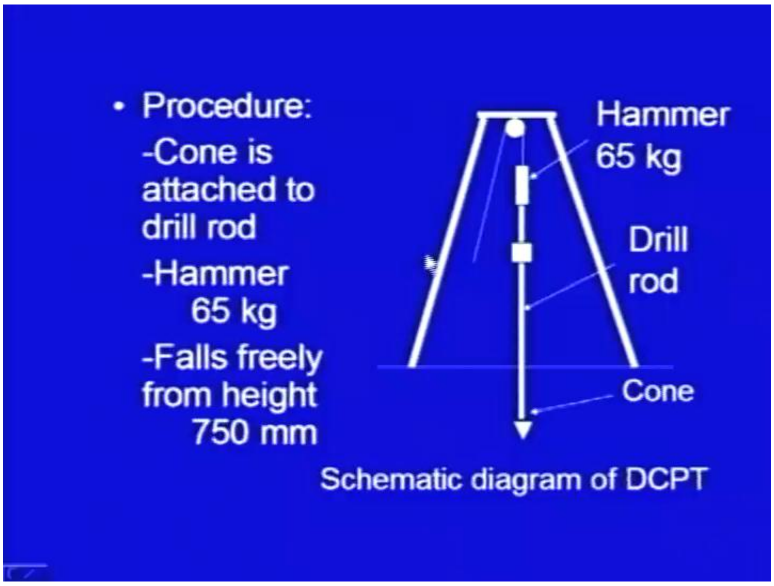

Here is a schematic diagram of the dynamic cone penetration test, this is a tripod, it is having pulley arrangement using which this hammer can be lifted, for a standard height. This is the drill rod, here it is the ground surface and at the lower end of the drill rod the cone is attached, so this hammer standard weight is 65 kg. It is lifted up using the chains or the rope here and the standard height is 750 mm, when it is allowed to fall freely, this will give impact here and due to which this cone will penetrate into the soil.

And here, we put some marks at 15 centimeter interval and we keep on counting the number of blows, which are required to penetrate the cone for 15 centimeter.

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Here is a picture from the field, you can see here, this is the tripod, this one having these three legs and here is a arrangement pulley arrangement here. And here, it is being pulled by through this rope manually or here sometimes some arrangement is mechanical arrangement can also be made. So, this is the rope and here this is the hammer, this hammer is lifted for standard height, then it is allowed to fall.

And here on the drill rod, the markings are made at 15 centimeter and then keep on counting the number of blows required for every 15 centimeter interval.

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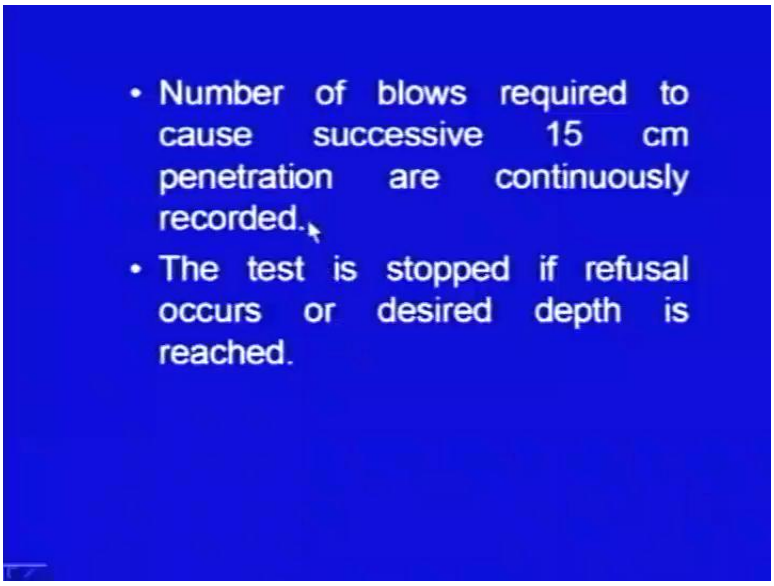

So, as I told you, the number of blows required to cause successive 15 centimeter penetration are continuously recorded and the test is stopped, if refusal occurs or desired depth is reached.

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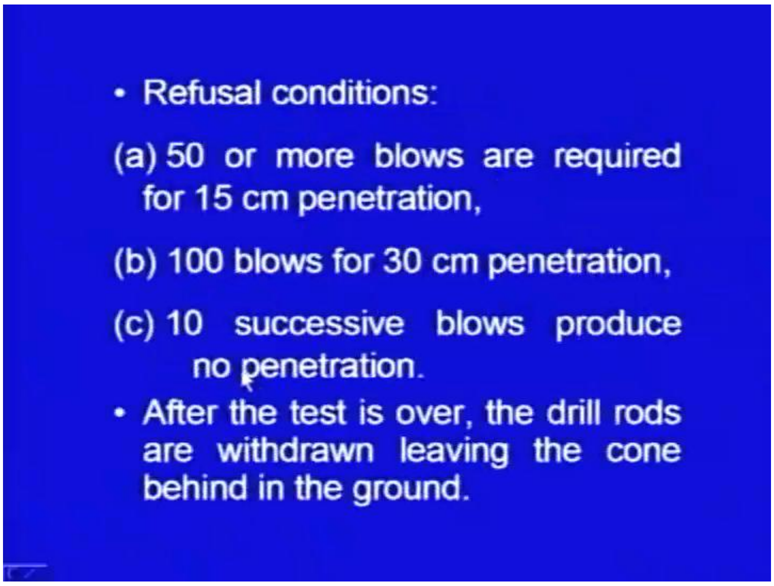

The refusal conditions are same as it were in case of standard penetration test, first condition is 50 or more blows are required for 15 centimeter penetration or if 100 blows are required for 30 centimeter penetration or if in 10 successive blows, there is no penetration, so then we say the refusal has occurred. After the test is over, the drill rods are withdrawn and the cone is left in the ground itself.

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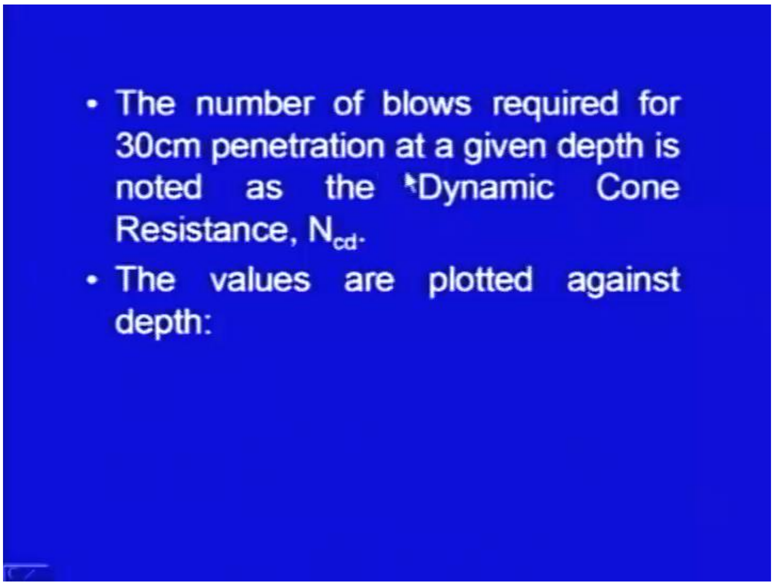

The number of blows required for 30 centimeter penetration at a given depth is noted as the dynamic cone penetration resistance N c d. We are taking the observations at 15 centimeter interval, so we add a 15 plus 15, two values and those values, they are termed as N c d and these N c d values are then plotted against depth.

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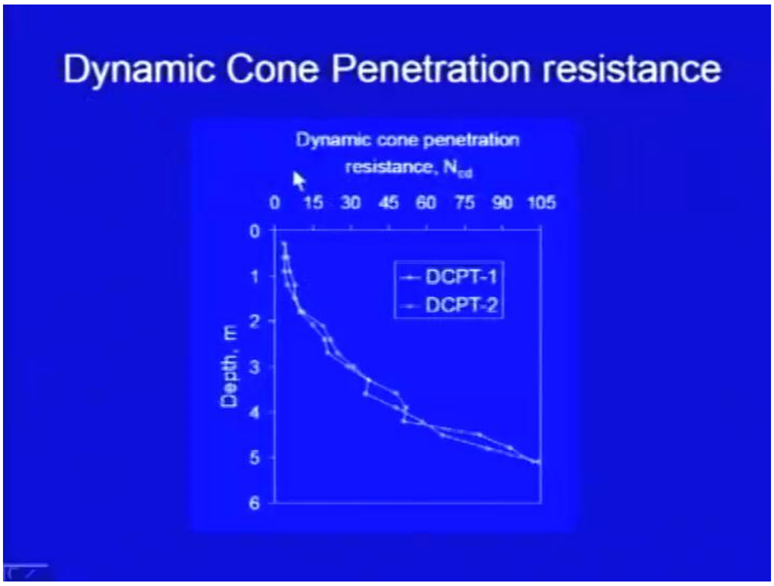

Here, it is an example I have taken from a field study, here on x axis, you can see there is dynamic cone penetration resistance N c d and this is for 30 centimeter successive penetration. So, 0, 15 and 30 we have taken up to 105 and here on y axis we have taken the depth and these were two tests, we conducted very close to each other.

So, you can see the values at 30 centimeter interval, they are varying almost in the same manner with depth, so this is the way the values are represented or plotted.

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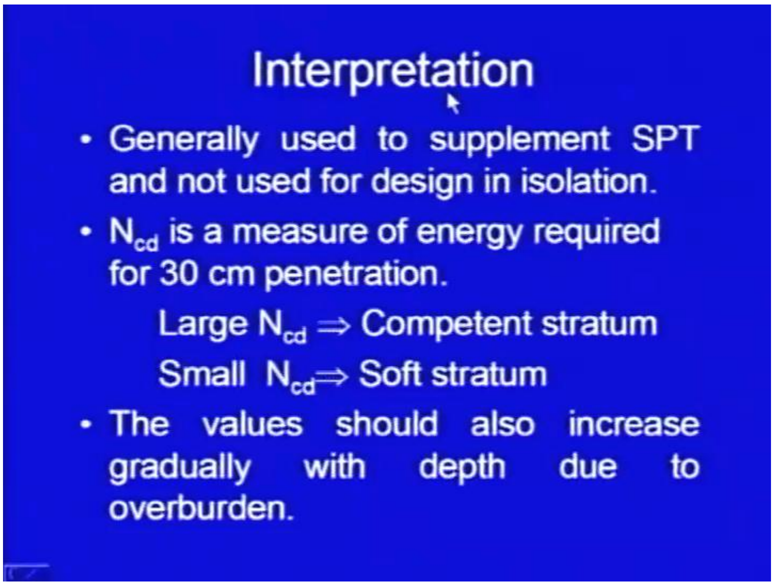

Let me now come to the interpretation of the test data, as I discussed earlier, we are not going to use this test for design purpose in isolation. It is generally used to supplement the SPT data, what I mean by this is that if you have some DCPT values, we should have some confirmation from other test also. For example, if you have SPT and DCPT data together, then you can have a correlation between them and then using the DCPT data then you can go further design.

So, generally it is used to supplement the SPT and not directly used for design purpose, now this N c d which is the value of the penetration, number of blows for 30 centimeter penetration. It is in fact, a measure of energy which is required for 30 centimeter penetration of the cone, like SPT, if this N c d is large, it is obvious the stratum, which we are testing at that particular point will be competent.

If the N c d is small then stratum will be soft, it may be loose, it may be incompetent and these values in general, they should also increase gradually with depth due to overburden. As I discussed in case of the SPT analysis, as you have higher and higher overburden, the confining stresses will be increasing and because of the confining stresses, the strength will increase. So, you are expected to get higher penetration resistance.

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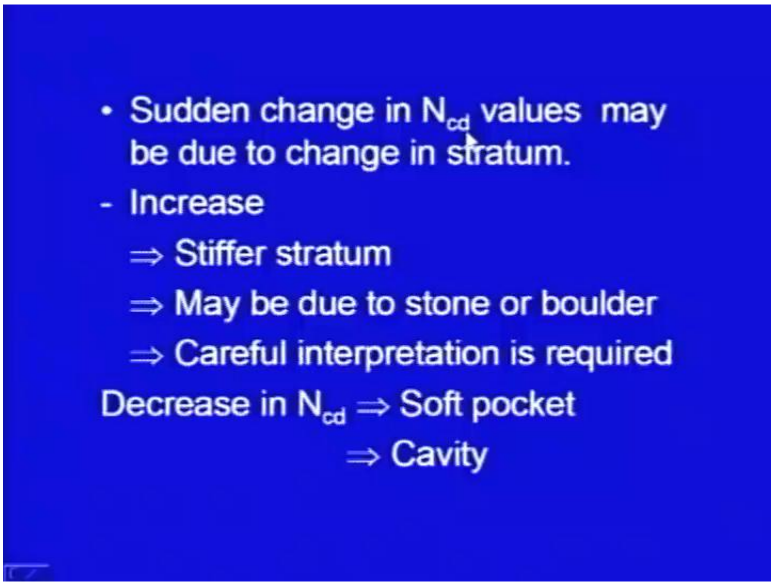

Now, if there is a sudden change in the N c d value, it may be due to change in the stratum. If the N c d is increasing; that means, there may be a stiffer stratum, but it may sometimes give us a false impression, it may be due to some other local problem also.

For example, there may be a small stone or there may be a boulder something like that and because of that, the number of blows may be excessive large.

So, you need careful interpretation, when this kind of the situation is met, but if there is an increase in N c d, sudden decrease in N c d then; that means, there is a soft pocket it may be a cavity also.

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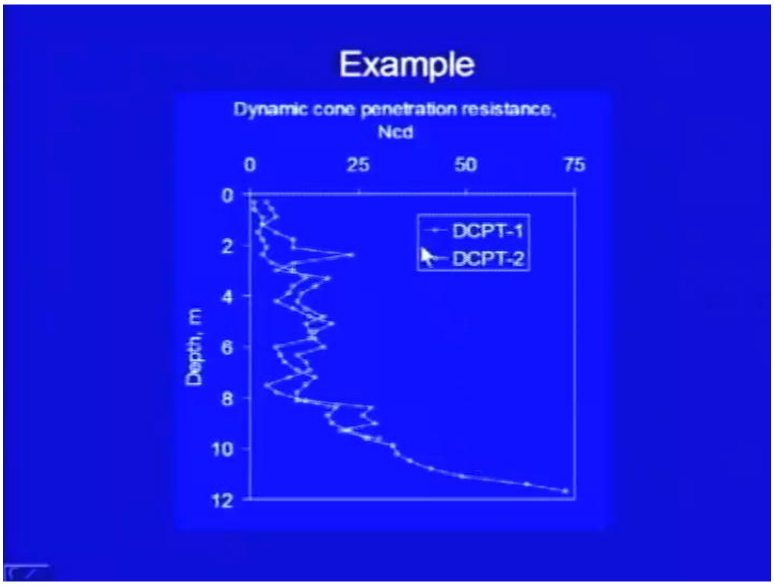

Here, I have taken an example, x axis is representing N c d and here it is depth, you can see there are two tests we have done. Now, in one of the test at two meter depth, there was sudden increase in N c d value, then it came down and then it was falling, this trend. The second test, which was done in the vicinity of the first test, was also having this kind of the trend, but it was not having large value at this particular place.

So, you can see almost both test, they are following similar pattern, but this value this value is excessively large at this particular depth. So, it is required to be treated carefully, we should not take it granted, that it is because of a dense stratum, because of a competent stratum. Probably, this was because of some stone here or some boulder here, so that the cone got struck and we got higher N c d values.

And this, but second test, it confirms this, so whenever there is a sudden increase, then you have to be careful, but if it there is a sudden decrease. For example here, these are the sudden decrease, there the other values are decreasing, there are obviously, it can be some sort of incompetent stratum, soft stratum or may be even cavities.

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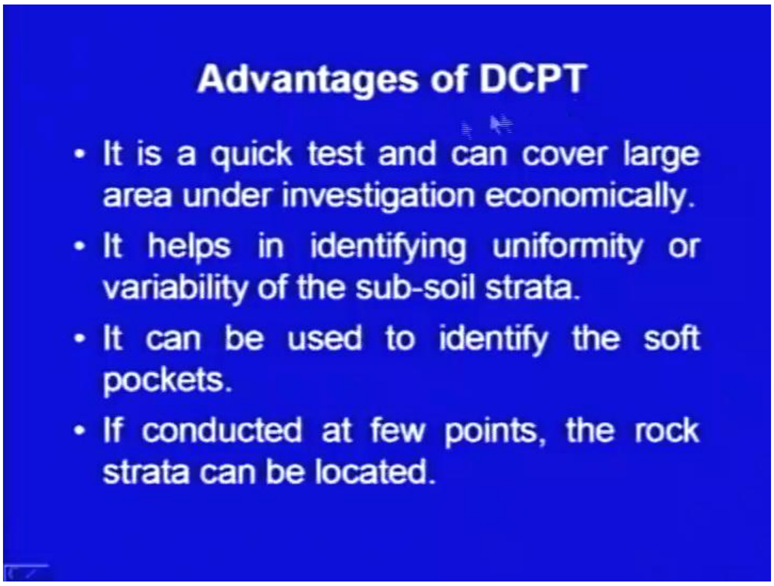

The advantages of DCPT, it is a quick test, we do not have to do boring, we have to attach a cone and then just keep on hammering, it keep on counting the number of blows. So, it is a quick test, economy wise it is a cheaper test, quite cheaper as compared to SPT and it can cover large area under investigation economically. So, if you are working on a very large area, then this test will be very advantageous, what you can do is, you can do some SPT and then some DCPT.

DCPT, you can have all over the area and SPT, you can have for giving some correlation between DCPT and SPT. Second advantage is that it helps in identifying uniformity or variability of the subsoil strata, this is very useful and you can do the test at different locations. And then, as you saw in the previous slide, you can see here the strata, these points they were quite close to each other, so strata is almost similar.

So, same thing here you can do number of tests and then you can check, whether the trend of the values is similar or not, so if the trend of the values is similar, then the uniformity is there. If the trend of the values is abrupt, it changes from place to place and then we have to be cautious. The third advantage is that it can be used to identify the soft pockets, because it is a very quick test, very cheap test and it can easily be used, it can economically be used to identify where the soft pocket occurs.

You have to do the test and if all of sudden there is decrease in the resistance; that means, there is a soft pocket, if conducted at few points and the rock strata can be located. There are certain places where rock is very close to ground, may be 3 meter, 4 meter, 5 meter and if you conduct it at few points, then you can locate the rock strata. Why, I am saying few points is, you should not derive this conclusion from one single test.

Because, again the problem is we do not know, whether it is a rock or it is boulder or stone, which due to which we got excessively large values, so you have to do the test on fairly large number of the points. So, that you can have, if there is some bias, because of some boulders etcetera, that can be removed and then you can have the idea, where the rock strata is located.

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Next advantage is that, it can be used as starting point of the investigation programme; in fact, we prefer it, whenever we go to a site instead of doing other test, first we start with DCPTs. We plan some number of DCPTs and that the results of those DCPTs, they give you the idea of what kind of the ground is there. Once that is over and you know the type of the ground, then you can select further what type of the test have to be done, whether the boring is required, whether the SPT is required or you need plate load test or any other test.

So, in fact this is recommended, that whenever an investigation program is planned, it should start with DCPT, if nothing is already known about the strata. Next advantage is, if tests are carried out close to few boreholes, where SPT data is available, a rough relationship can be obtained between N and N c d. SPT results can then be guessed, this is what I was discussing.

Suppose, you have a big area and then, what you can do is, you can do some SPTs and quite close to them you can do some DCPTs, when you have the data of N and N c d, you can correlate them. Once they are correlated, then you can cover the entire area with DCPTs and then you can guess, where roughly, what is the SPT value which can be expected corresponding to N c d.

And obviously, there you have to do some SPTs also to confirm, whether your correlations are or not, but this is one of the biggest advantage of this test. Because, it is very cheap, it is very quick, you can do a few numbers of SPTs and you can do large number of DCPTs and then you can have the representative profile of the subsoil strata.

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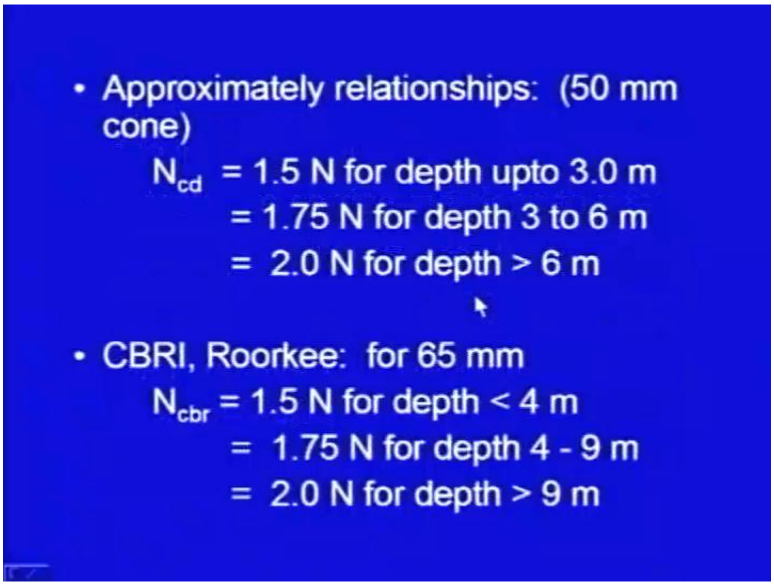

There are some approximate relationships, which have been proposed by different researchers. These are two commonly used expressions, approximate relationships for 50 mm cone N c d, it is for 30 centimeter is 1.5 times, the SPT resistance N and this is applicable for depth up to 3.0 meter. It is only an approximate relationship should be used with caution, then if the depth is 3 to 6 meter, the N c d is roughly 1.75 times N, so if N c d is known, you can roughly calculate N.

Similarly, if the depth is more than 6 meter, then N c d is roughly two times N, you can see, this coefficient is increasing with depth, it is probably because, in case of the DCPT there is lot of friction which acts on the side of the drilling rods. So, this factor becomes higher and higher, so when you use this expression again, it is suggested, that it should be used with caution and it should be confirmed with some SPT tests.

CBRI Roorkee has given another expression, this is for 65 millimeter cone diameter, the N values are roughly equal to 1.5 times this N c b r and this is for DCPT. It is equal to 1.5 N for depth less than 4 meter; it is 1.75 N for depth 4 to 9 meter and 2 N for depth more than 9 meter. So, these expressions can be used, but there should be some confirmation before using these rough correlations.

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So, we have discussed the two penetrations test, first test was the standard penetration test, second test was dynamic cone penetration test and now this is the third test, which is called as Static Cone penetration Test. All these three tests are based on the same principle, the penetration resistance is found out and that penetration resistance is correlated with the soil properties.

Now, this test is now common it is quite popular now, it has being used for soft clays, silts and fine to medium sand deposits and at many a places, it is now replacing the standard penetration test. This test was developed in Holland and sometime it is known as Dutch Cone test, unlike SPT, in case of the SPT we needed a borehole, the advancing of the borehole is a tedious job and here the advantage is again, that no borehole is required.

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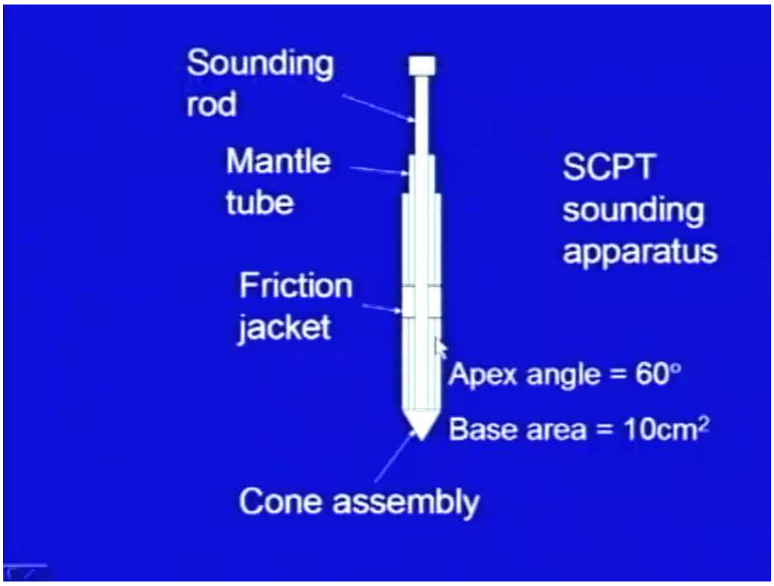

Here is the schematic diagram of the sounding apparatus, this is the sounding rod here and a cone is attached, this particular assembly here this one up to this one, this is called as cone assembly. The arrangement is made in such a way; mechanism is such that, using this sounding rod, you can move this cone assembly. Then there is a friction jacket here, it can be moved separately and then here it is it is a mantle tube. This cone is, it has the apex angle of 60 degree as usual and base area is 10 centimeter square.

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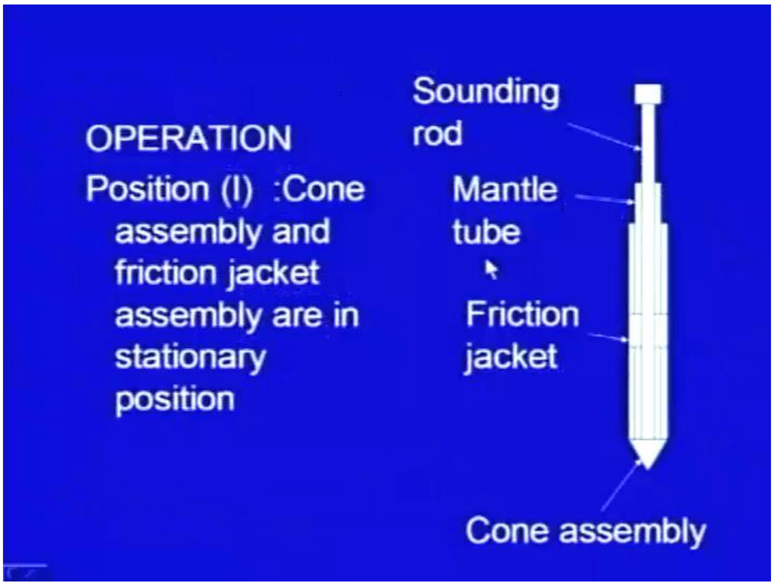

This is the operation, the operation of this test has been explained in four steps, this is the first step, which I am calling as position number 1, this is the cone assembly and here it is entire friction jacket assembly, they are in stationary position. So, this is the first initial position, this particular cone has reached at a certain depth, where we want to do the test.

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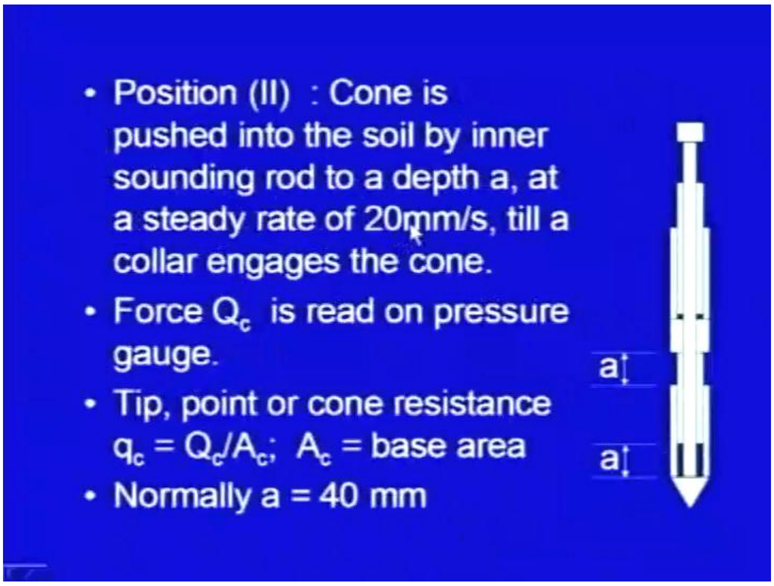

In the second step, the cone is pushed into the soil, this is the inner sounding rod, using this inner sounding rod, this cone is pushed into the soil, you can see now and this assembly was here, this entire assembly it was here. Let me show it again, here in this case, it was here and now it has been pushed using this rod by a distance a and there is a standard specified rate of 20 millimeter per second.

And after this standard distance a, the mechanics is such that it automatically stops and the arrangement is there, where you can read this force Q c, on the pressure gauge. So, there will be some force, which will be required to push this cone assembly into the ground for the known distance and that Q c can be read on a pressure gauge, which is mounted, on the equipment.

Now, this Q c force, which is required to cause this penetration, it can be represented in terms of what is called as tip resistance or point resistance or cone resistance, so here at the tip of the cone, the force required per unit area, that is the tip resistance. So, q c is the tip resistance, it will be equal to capital Q c, this is the force divided by area, A c is the base area and normally this distance is a.

So, in the first step, what you read is total force, which is required to cause the penetration of the cone assembly and from there you can get the tip resistance.

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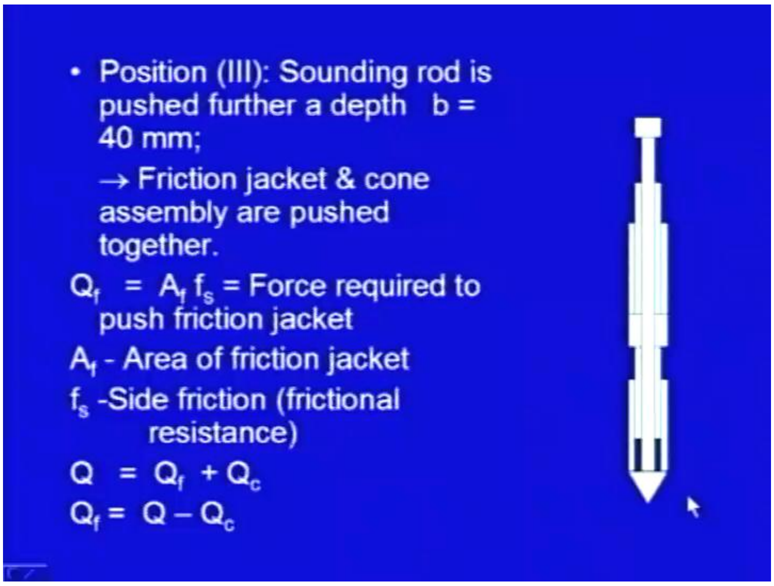

Now, come to the third step, let me explain what do you do in the third step first, this sounding rod is further pushed for a distance b which is again 40 millimeter and this time the friction jacket and cone assembly both they move. So, this will also be moving, this will also be moving, you can see this, so here the cone assembly as well as friction jacket both are moving.

Let me show it once again, this was the initial position and now it has moved this way, so what is the additional force, now which is required is Q f, which is force required to push the friction jacket. And here, the friction is acting over the surface, so Q f, this is the additional force, this will be equal to A f, A f is the area. Total surface area of the friction jacket and f s is the side friction; that is the frictional resistance; that means, the resistance per unit area.

So, this time the value of total force, which you read from the pressure gauge Q, should be equal to this additional force, which is required to move the friction jacket, plus the cone resistance. So, this is the final situation Q equal to Q f plus Q c, from here you can get Q f, so in the previous step we got Q c, Q c is already available with us, so you can get Q f.

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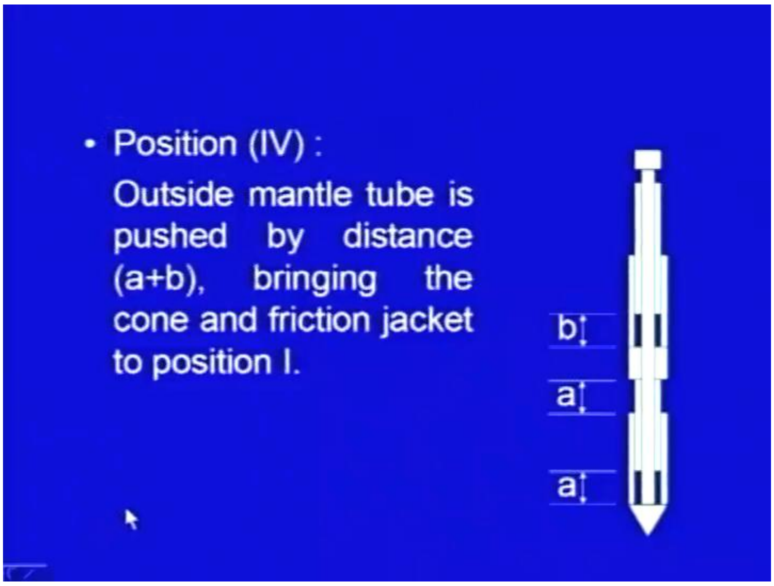

Come to now the last position last step, now this outside mantle tube is pushed by distance a plus b and doing that the friction jacket comes to the same position, which it was having in step 1, so this is pushed further and finally, it reaches this point.

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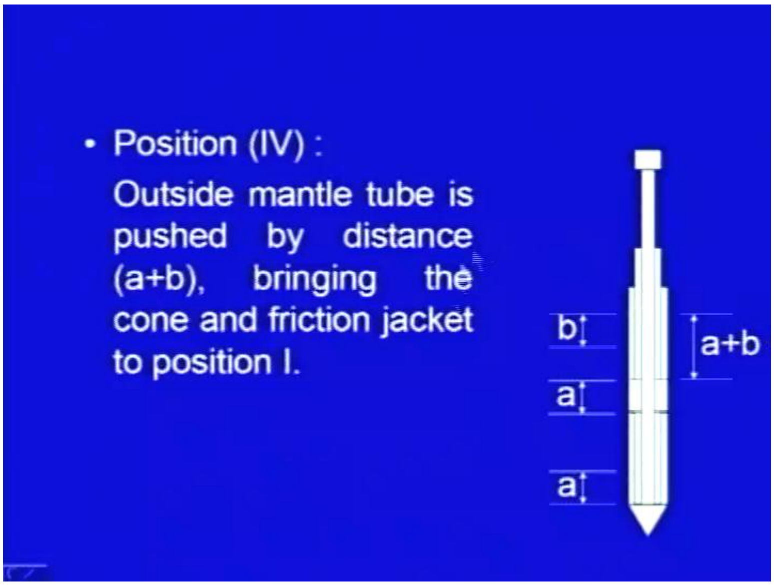

So, now this particular assembly is ready for the next experiment.

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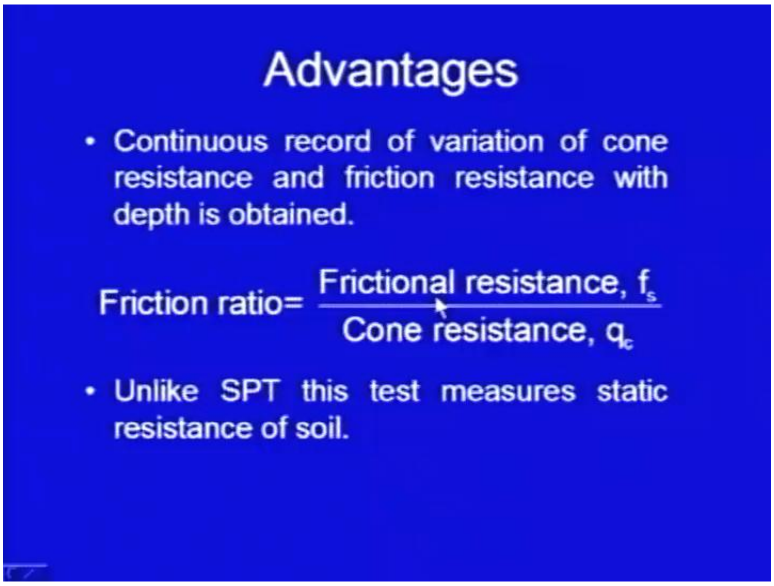

The advantages of this test are that continuous record of variation of cone resistance and friction resistance with depth is obtained. Now, this is the unique advantage of this particular test, previously you are getting a relationship, in case of the SPT, you are getting a relationship for the tip only. In case of DCPT also, you are getting a relationship for the tip only, here you get the both the components, you get the variation of the cone resistance.

So, what is the resistance V is being offered at the tip of the cone, that is available and also what is the resistance being offered by soil in friction at the sites, that is also available. This is term which is generally used sometimes in the literature; the friction ratio is defined as frictional resistance, f s upon cone resistance Q c. Now, another advantage of this test is that unlike SPT, this test measures static resistance of soil, now you see in case of the SPT, as well as in case of DCPT, we were using cones.

The cone was dropping for a given distance, it was imparting energy, so it was a dynamic sort of test and it was not a static test. So, this particular test, it gives you the static resistance, so that is the advantage.

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It has the test has some limitations also, for example you cannot have a sample, in case of SPT, the advantage was that at particular depth, whatever is required. Suppose, you want to see, what kind of the soil is there at 10 meter depth, you are able to get that particular sample, so here no sample of the soil can be obtained; this is one limitation. Secondly, the test is not suitable for gravels and very dense sands, because there will be some mechanical problems in inserting the friction assembly the as well as the cone assembly, so this is not suitable.

Third limitation of this test is, many a times the sites are very rough sites, there may be hills, there may be no space available, so this particular test is having very heavy equipment. The equipment is very heavy and it may not be suitable for tough sites, like hills or for those sites, where enough space is not available.

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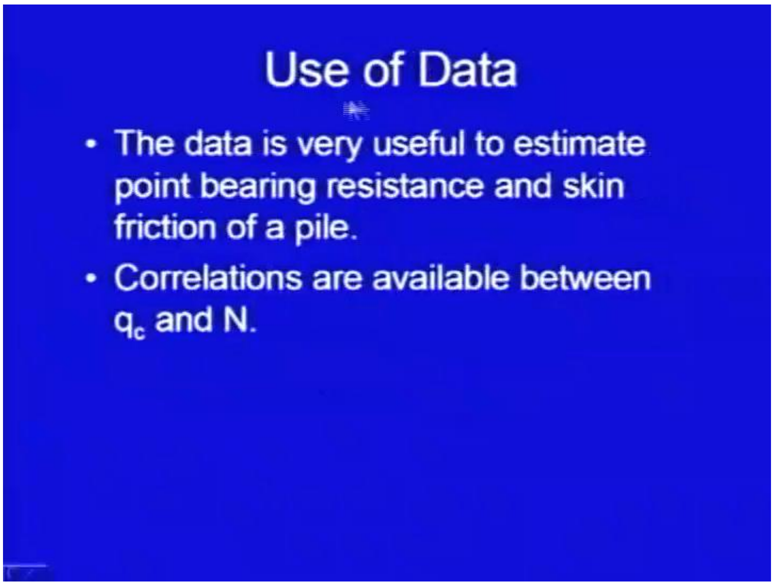

Let us now go to the point, how to use the data of the SCPT, if you have seen a pile, then you will be studying it in detail later on. That in case of the piles, the pile will be resisting the load in two ways, one is through the skin friction, which acts on the sides of the pile and second resistance comes from the tip. So, this particular test is very useful in those cases, the data is very useful to estimate point bearing resistance. Point bearing resistance is the resistance which is offered at the tip of the pile and skin friction of a pile skin friction is at the sides.

So, this test data is very useful as I told you, it gives you at any depth, there are two components available, it gives the both the components, so this is a very big advantage of this test and then the correlations are available between the q c and the N. If you know N, then there are standard methods tables are available using which you can estimate the phi value of the cohesion less soils.

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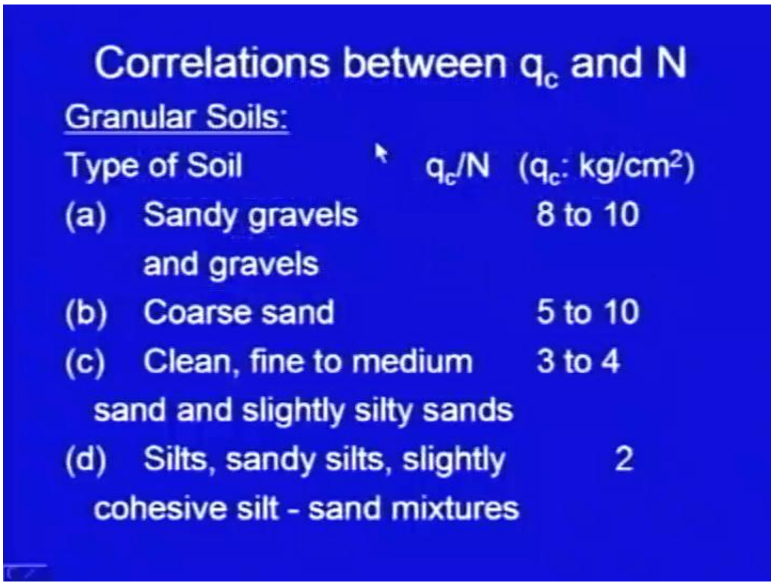

Here are only few correlations, I am giving there are several correlation available in the standard books. So, this is one of the correlations, here it is the type of soil and this is the ratio q c upon capital N, N is the penetration resistance, SPT penetration resistance and q c please note it is in kg per centimeter square. For sandy gravels, this value roughly varies from 8 to 10, if it is coarse sand, then this ratio varies from 5 to 10.

In case of clean, fine to medium sand or slightly silty sands, this factor is around 3 to 4 and sandy silts, slightly cohesive silt or sand mixtures, this ratio this factor is around 2.

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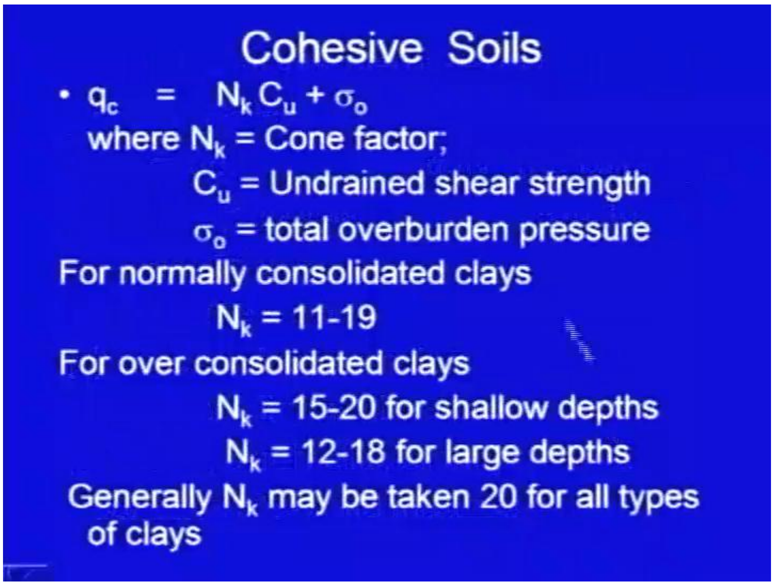

Some expressions, some relationships are also available for cohesive soils, only one I am I have given here, if you know q c, you can correlate it with the undrained shear strength of the cohesive soil. The expression is q c equal to N k into C u plus sigma 0, N k is a factor which is known as cone factor, it is an empirical factor, which has been obtained based on past experience. And then plus, here we take the total overburden ratio, it is not effective, but it is the total overburden pressure.

So, if you know q c, you know the overburden pressure and if N k is available, you can find out roughly what is the value of the undrained shear strength, the suggested values of N k are for normally consolidated clays. It may be taken between 11 to 19; it has been found to vary between 11 to 19 and for over consolidated clays, N k has been found to vary between 15 to 20, for shallow depths and between 12 to 18 for large depths.

Generally, N k may be taken 20 generally for all type clays, you can take N k equal to 20 and roughly, then you can get the undrained shear strength.

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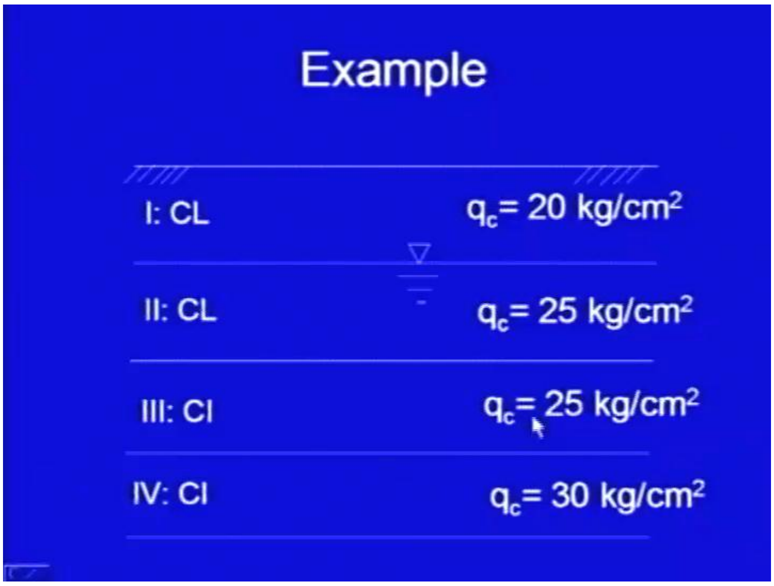

Let me give an example, how you can solve the problems using this method, let us say, this is the ground surface and these are the layers, they are clay layers. And here, it is the water table and we have measured the q c values, using the SCPT test and then these are the values 20, 25, 25 and 30 and so on.

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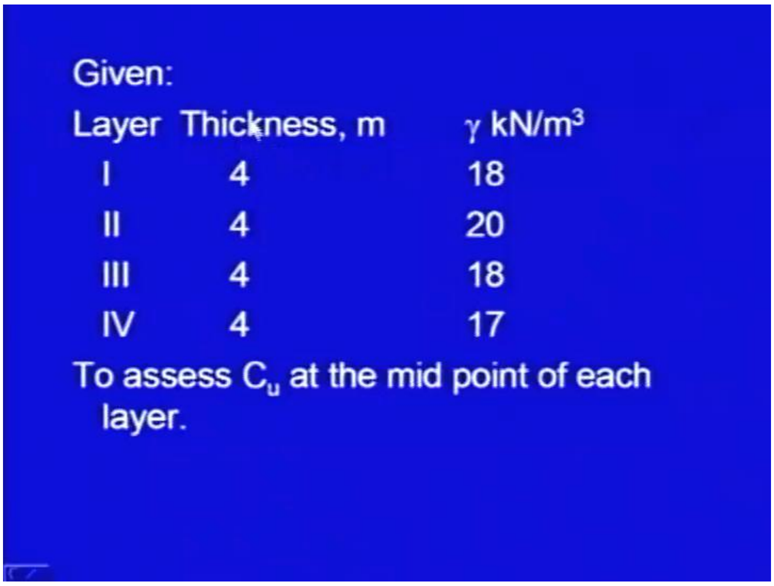

The details of the different layers are like this, first layer is 4 meter, all of the layers are taken of same thickness 4 meter and gamma values the unit weight are available unit weights are available. For first layer, it is 18, second layer it is saturated, so gamma saturated is 20 and for third layer and fourth layer, these are the unit weights and we are supposed to find out C u, at the mid points of each of the layer.

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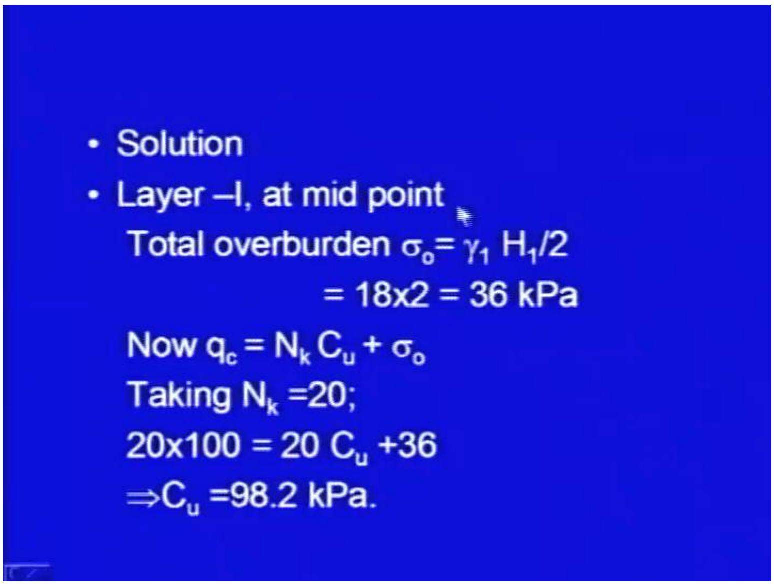

Let us go to the solution, we start with the layer number 1 and at the midpoint of the layer 1, calculate the total overburden pressure, so it will be gamma 1 into H 1 by 2, that comes out to be 36 kilo Pascal. Now, use this relationship, q c is equal to N k into C u plus sigma 0, N k is 20 and in this case was 20 kg per centimeter square convert it into k P a. So, 20 into 100 is equal to N k is 20, C u plus and this sigma 0, from where you can work out the value of the undrained cohesion C u.

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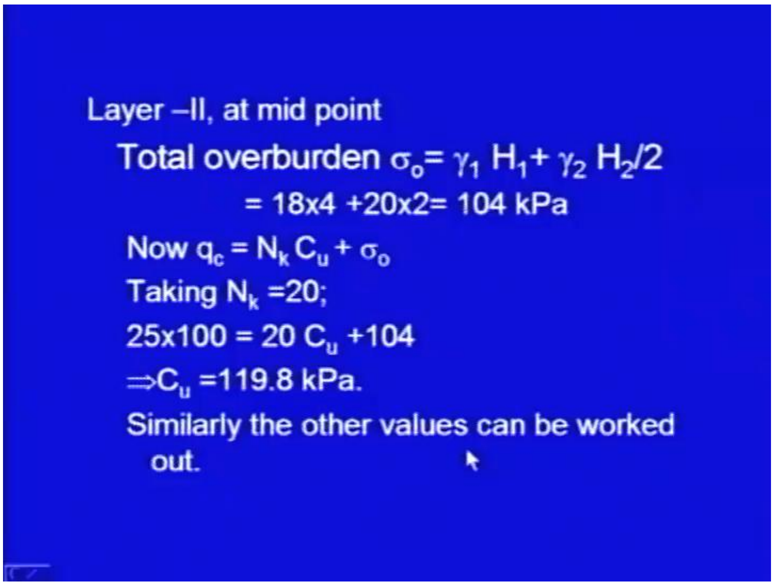

Similarly, for the layer number 2, the overburden pressure, sigma 0, will be equal to we are calculating the overburden at the midpoint here, so gamma one H 1 plus gamma 2 into H 2 by 2 here. So, this comes out to be equal to 104 k P a and again using the same equation N k into C u plus sigma 0 and q c in this case was 25 kg per centimeter square converted into k P a. So, 25 into 100 equal to 20 into C u plus 104 and from where C u is this much, so in the similar manner you can calculate C u values for the other layers also.

So friends, we have discussed the penetration tests, the first penetration test was standard penetration test, in which the borehole was required. The second penetration test was DCPT, Dynamic Cone penetration Test, this was a very quick test, very cheap test, but it is used only for the supplementing the SPT results and the third test we have discussed the SCPT. So, all these three tests are very important and we have discussed them in very much detail. Now, I am going to discuss in brief, few more tests, which are generally conducted in the field.

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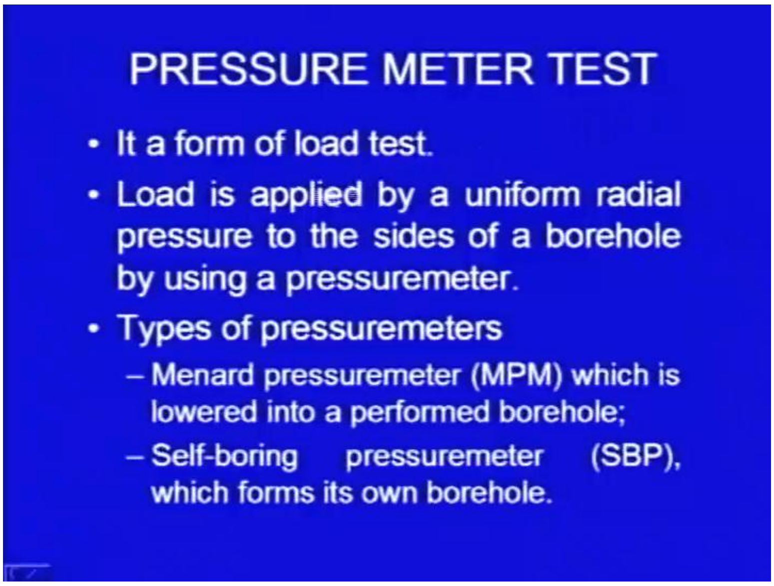

The first test is pressure meter test, it is a form of load test and what is done in this case is load is applied by a uniform radial pressure to the sides of a borehole, by using a pressure meter. So, it is basically a test in which load is applied on the sides of the boreholes, so borehole is needed, pressure is applied on the sides of the borehole deformations are measured. And from there, you get the modulus of deformation, this is the basic principle, only in brief, I am going to discuss this test.

There are two types of the pressure meters, which are used one is Menard pressure meter, MPM, which is lowered into a performed borehole. The second type of the pressure meter is self-boring pressure meter, SBP which forms it is own borehole.

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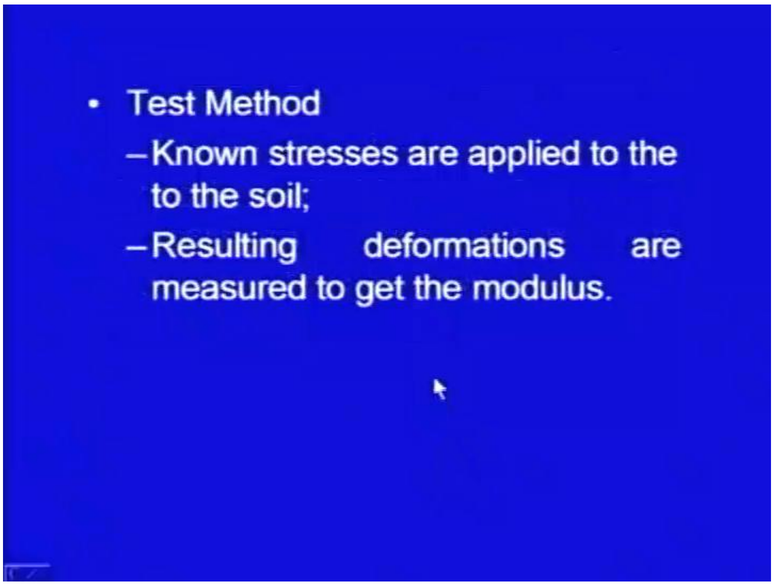

So, the philosophy of the test is that known stresses are applied to the soil, in fact to the walls of the borehole, resulting deformations are measured and then we get the modulus.

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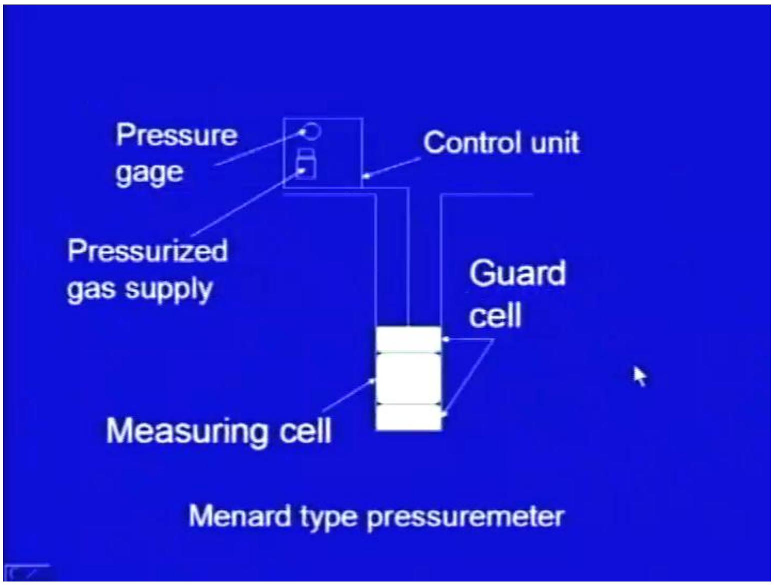

I am not going in detail for this test, just philosophy is being discussed here, this is the schematic diagram of this test, here it is the ground level and here it is a borehole. And in this borehole, here this is the measuring cell; these are the guard cells at the top and bottom. And then, pressure is applied, because of this pressure, there will be some deformations in the wall.

Those deformations are measured; they are recorded through this control unit, which has the facilities for providing gas under pressure and some pressure gauge and monitoring equipment. So, it monitors the deformations corresponding to particular pressure and that data is used to calculate the modulus of the soil.

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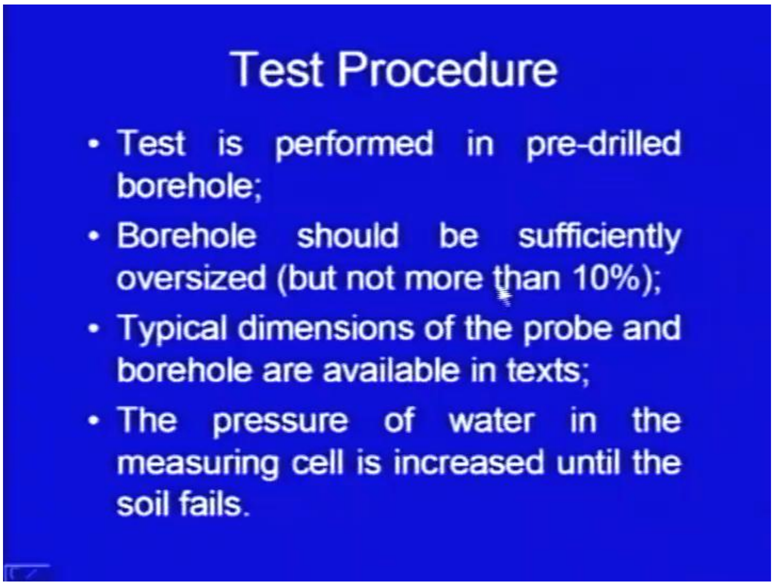

The step by step procedure of the test is as follows, it is the test is performed in pre-drilled borehole, so again we need a borehole, the borehole should be sufficiently oversized, means it is diameter should be little bit more, but not more than 10 percent. The standard tables are available in the books, for different sizes of the pressure meters, typical dimensions of the probe and boreholes are available, the pressure in the measuring cell is increased till the soil fails.

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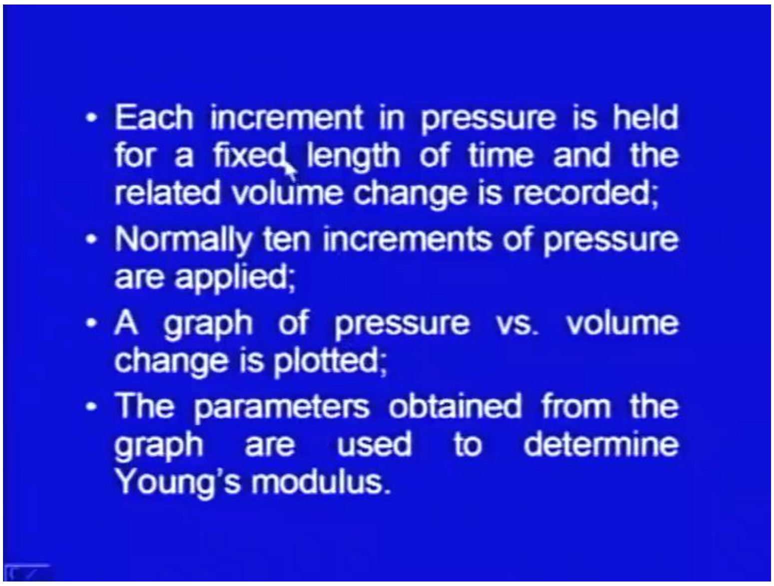

Each increment in pressure is held for fixed length of time and the related volume change is recorded, so this is the basic philosophy of this test. Generally, around 10 increments of pressures are applied and then a graph of pressure versus volume change is plotted. I am not going in very much detail, from that graph you can compute some parameters and they are used to determine the Young's modulus.

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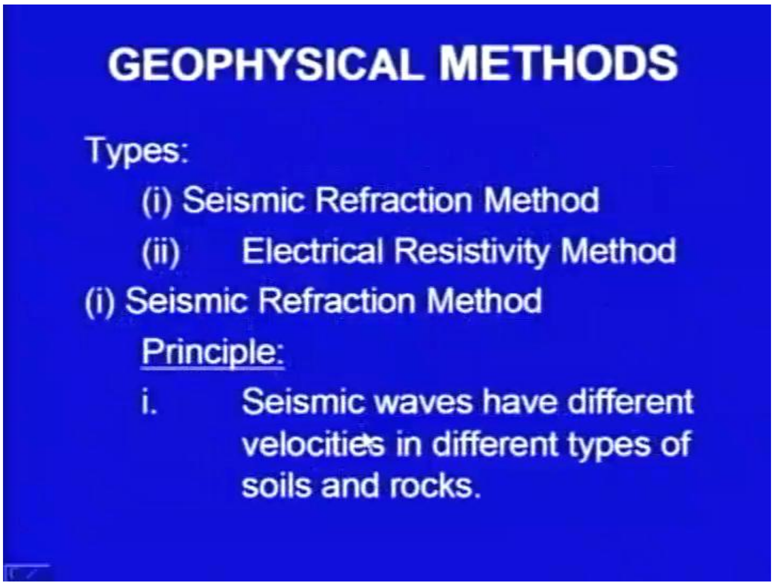

So, I have discussed only the philosophy of the pressure meter test, the details are available and most of the times in the field, we do the penetration tests. Now, few more tests are there, the tests are come under the category of geophysical methods, again I am not going in detail, I am just briefly discussing them. There are two types of geophysical test, which are conducted seismic refraction and electrical resistivity test, these are the two methods or two tests which are conducted.

let us, come to the first 1, it is the Seismic Refraction method, the principle of this method is that seismic waves have different velocities in different types of soils and rock. So, if you are able to measure the velocity of the particular wave, then you can have the idea of the medium; that may be soil or rock, what kind of the medium it is there.

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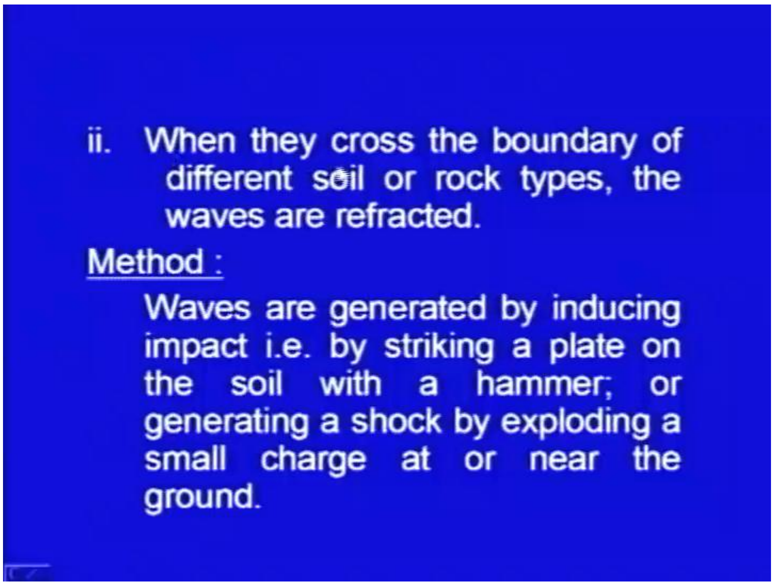

Second principle is when these waves cross the boundary of different soil or rock types, the waves are refracted, so this is the property of the wave, which is used by this method. The method consists of, the waves are generated at a particular source; they may be generated by inducing impact or by striking a plate on the soil. With the hammer or may be by generating a shock by exploding small charge at or near the ground, so there will a source of wave.

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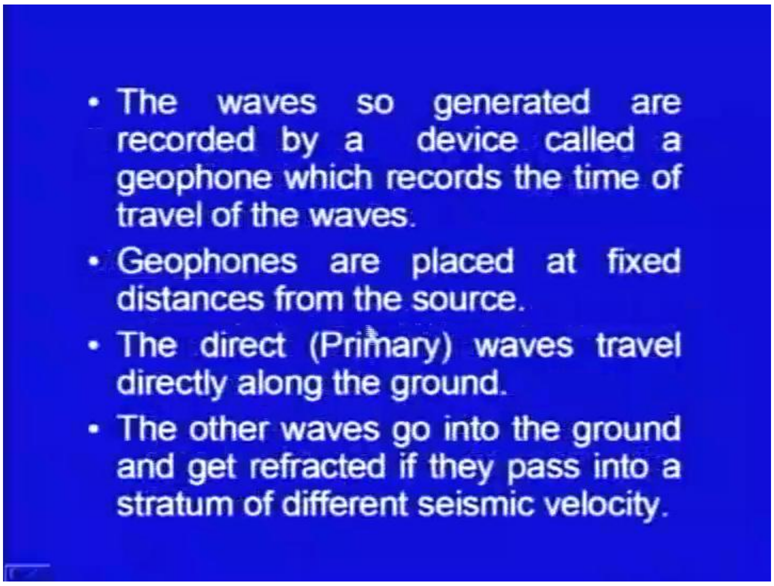

Now, these waves which are generated at the source, they are recorded by a device, this device is called as geophone. So, several geophones are placed in the ground and they record the waves and they record the time of travel of the wave, these geophones are placed at fixed distances from the source. Now, when the wave is generated, there are two types, there are two ways in which the wave will reach the geophone.

There are direct waves or these are called as primary waves, they travel directly along the ground, these are called as primary waves. There are other waves which will go which will travel into the ground and when they meet a boundary of different soil layers or rock layers they get refracted. So, the other waves they go into the ground and get refracted, if they pass into a stratum of different seismic velocity.

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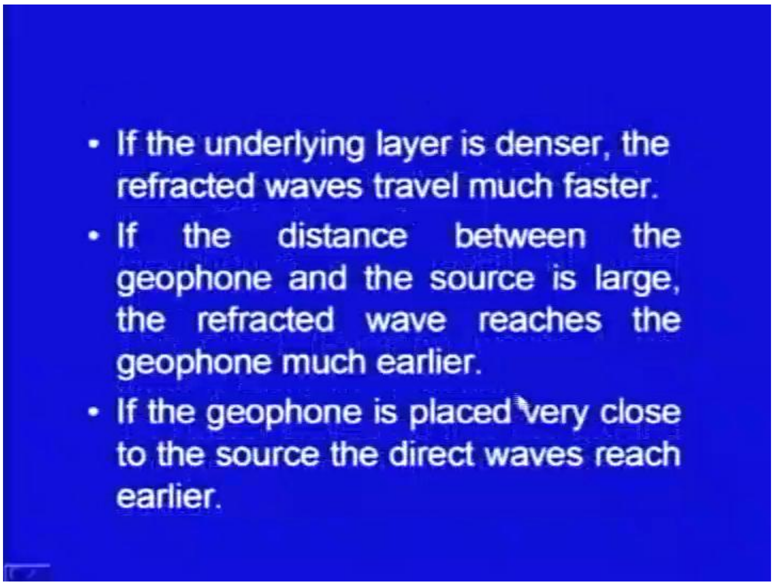

If the underlying layer is denser the refracted waves travel much faster, so if the density is high, the velocity will be more. Now, if the distance travelled between the geophone and the source is large, the refracted wave reaches the geophone much earlier.

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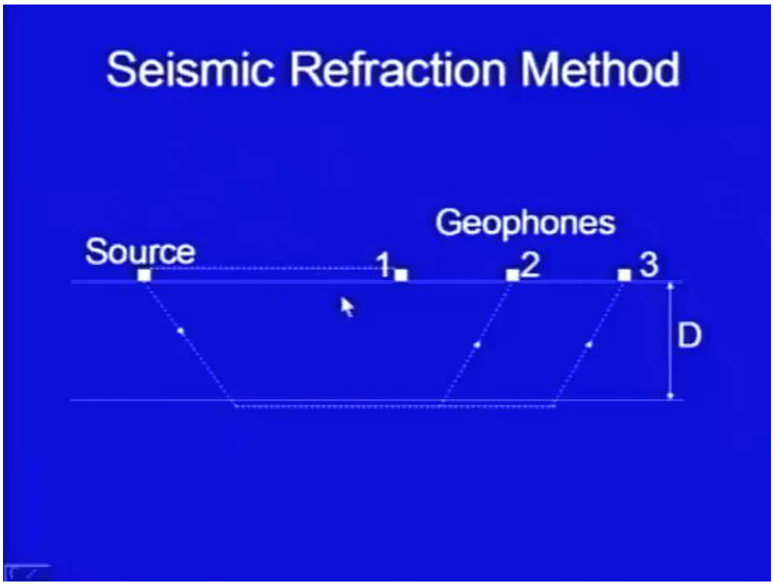

Let me explain it, using this particular figure, here is the source and this source is generating the waves, so what is happening is, there is one wave, which is directly going this way, it has certain velocity. Then, another wave, it goes into the ground and let us say here is a boundary of two different soils and then it gets refracted and goes to the geophone, these are geophones 1, 2, 3 and so on.

So, the waves will get refracted, if there is some other boundary here, they get refracted, so geophones will be getting these waves from the source, some will be coming directly, another one will be coming from the refraction. Now, if the geophone is placed very close to the source, the direct waves reach earlier, now velocity of this wave is a smaller, but this distance is also small this velocity. If it is a dense medium, which is generally there, so this velocity will be higher, but this distance is also large.

So, what is happening is, if this geophone is very close, if it is here, then this wave will reach this point first, whereas if the geophone is very far away, then this wave will be reaching it first, because the distance being taken by this layer also becomes very large. So, in nutshell, if the geophone is placed very close, the primary wave will reach it first, if the geophone is placed at a far off distance. Then, the primary wave will not reach first, but this wave will reach first.

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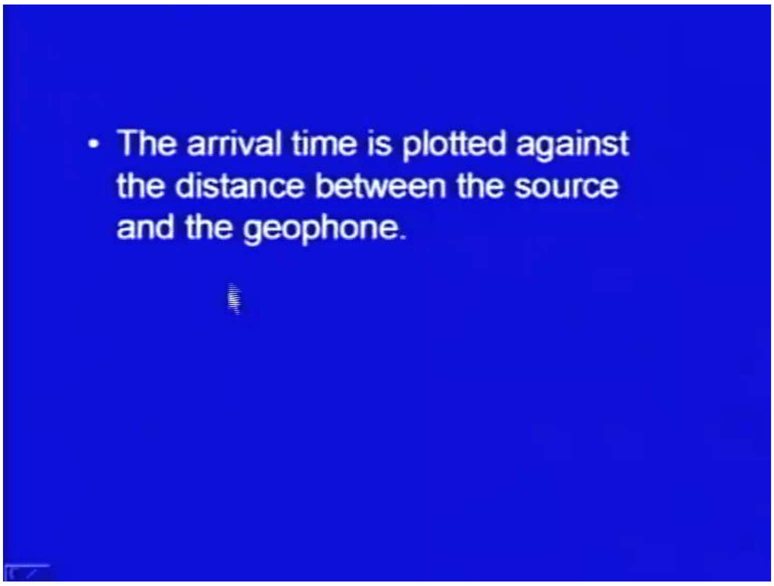

So, what we do is we record the arrival time; the arrival time is then plotted against the distance between the source and the geophone.

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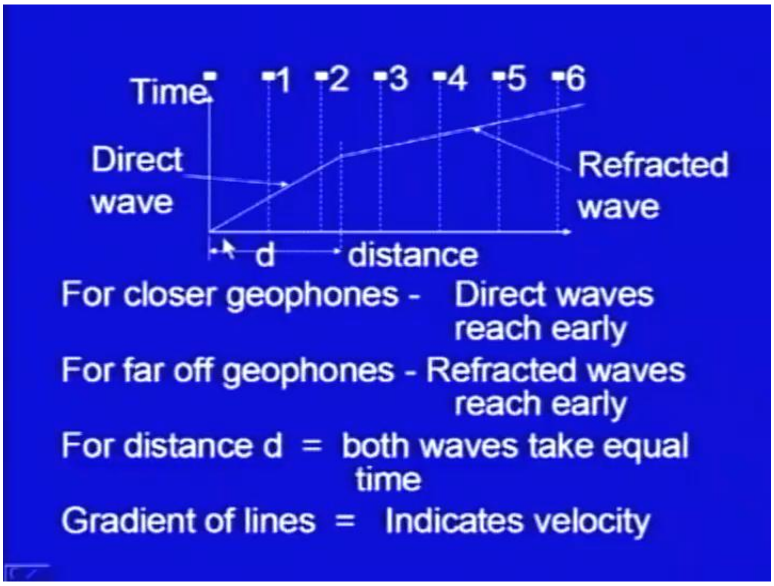

Here it is, I have shown the plot, here it is the distance, these are the geophones, 1, 2, 3, 4 5 and 6 and here I have plotted time. So, when you plot times for different distances, you will be getting two different straight lines, these two straight lines are meeting at this point, which is at a distance d away from the source. So, here it is the source and this is the point, where these two lines are meeting.

So, as I told you, if a geophone is here, the direct wave will reach it first, so this is the time which is recorded, this is also closer, so the direct wave is reaching first. So, this is the time, but for this portion, for these geophones, the second, the refracted waves are reaching early. For this particular distance d, d is the threshold value, it is that value for which both the waves, they take same time.

So, these this wave, this curve and this curve they meet here, so both the waves they take equal time for this distance d. So, what we do is, we plot this curve and by joining them then we can find out the distance d, which is for which both the waves will be taking equal time and if you find out the gradient of these lines, see here it is distance and here it is time.

So, if I take the inverse of the gradient, the gradient is time divided by distance, if I take inverse, then it is distance divided by time. So, the gradient of this line is a measure of velocity distance per unit time is nothing, but velocity. So, the gradient gives you the idea about the velocity, so from this curve, we get this distance d.

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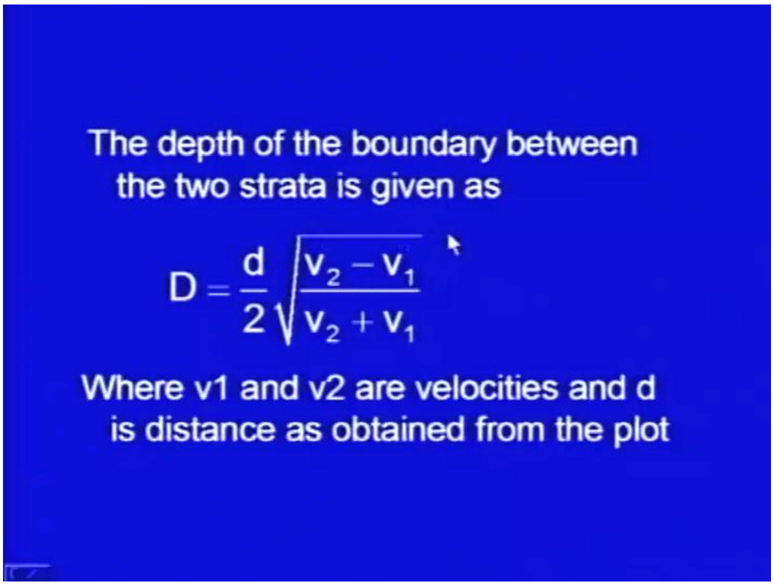

And then, this is the equation, which can be used to find out the boundary between the two strata, Capital D is equal to d by 2, this is d distance, which we computed from the graph and V 1 and V 2 are the velocities. So, Capital D equal to d by 2 root V 2 minus V 1 upon V 2 plus V 1, so these values are available from the graph and then you can find capital D, that is the depth of the boundary.

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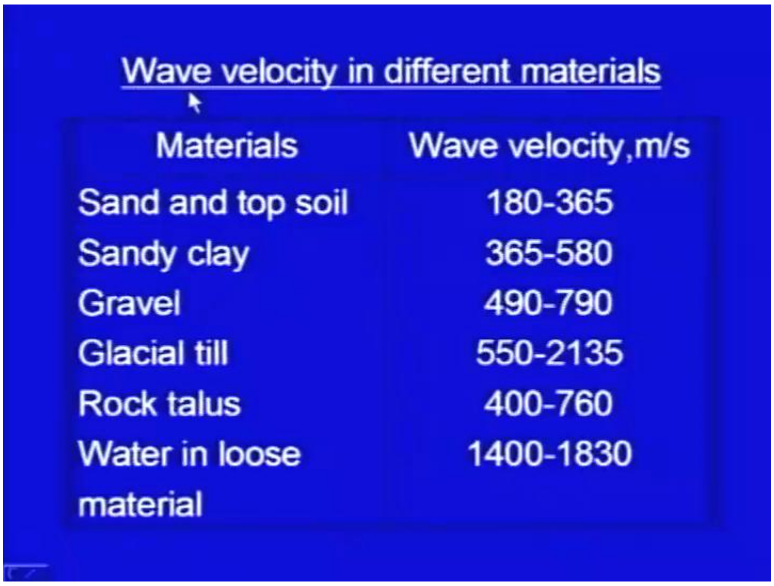
Wave velocity in different materials

Materials	Wave velocity,m/s
Sand and top soil	180-365
Sandy clay	365-580
Gravel	490-790
Glacial till	550-2135
Rock talus	400-760
Water in loose material	1400-1830

Now, if you have the velocities, then you can have the idea about the material also, so velocity is available from the curve and this is the table, which gives you the range of wave velocity for different types of the material. For example sand, sandy clay, gravel, glacial till, rock talus and so on.

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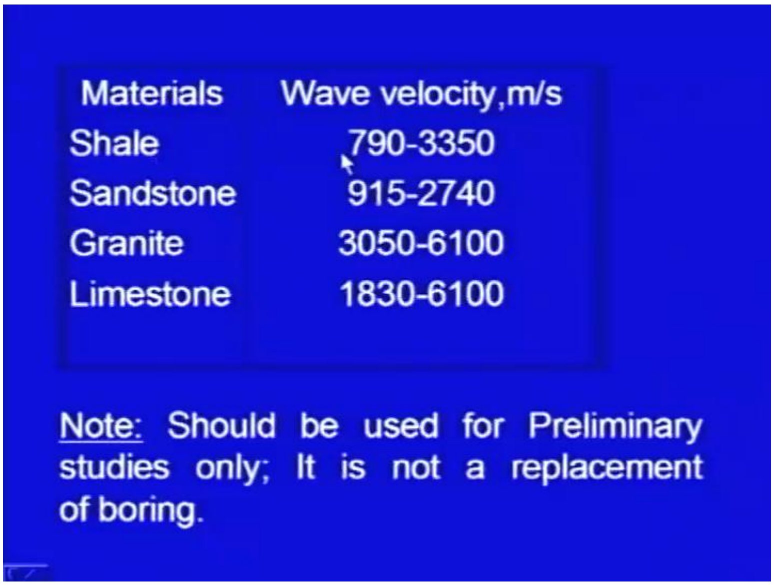

These are another this is the continuation of the same table, for different soil or rock materials standard wave velocities are available and you can have the idea about the particular soil stratum. And again, but one caution, which I would like to put is that, these tests should be used for preliminary studies only and it should not be taken as a replacement of the borings.

So, friends we have discussed the several field methods, field tests, we have discussed the penetration test in detail, the SPT, DCPT and SCPT, those are the tests most of the times we use. Then, I gave you some idea about the pressure meter test; then we started the geophysical methods. So, seismic refraction method, I have given you some idea and in the next lecture, we will be discussing the resistivity method.

Thank you.