Advanced Foundation Engineering
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Lecture - 2
Soil Exploration - II

Hello everyone, so, in the last class I have discussed about different boring techniques then the test speed and then the SPT standard penetration test and I was discussing about the different corrections that we have to applied on SPT value.

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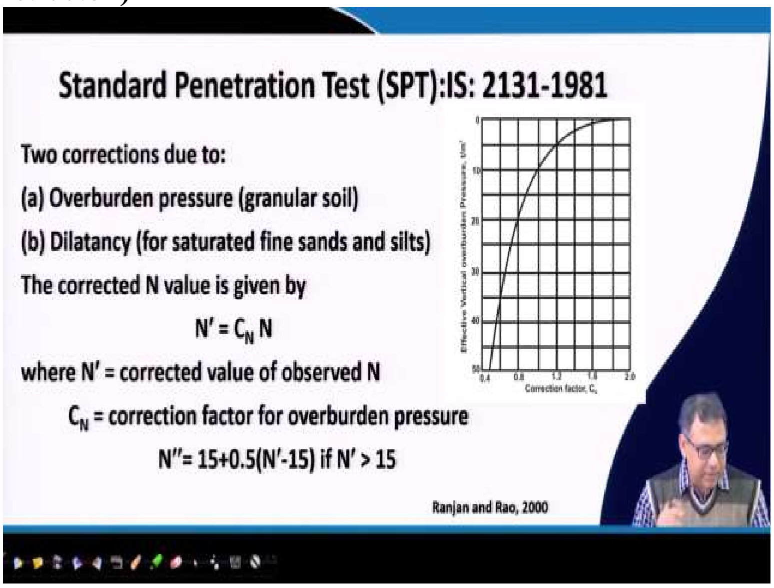

So, as per IS code that we have to apply the overburden pressure and the dilatancy correction. So, this overburden pressure correction is applicable for granular soil and the dilatancy correction applicable for saturated fine sand and the silt. So, in that sense if the soil is clay then no corrections are required. So, corrections are required for granular soil or silty soil. And I have discussed why this overburden pressure correction is required and dilatancy correction is required.

So, as I have discussed that if effective overburden pressure is less than 10 ton per meter square, then the corrected N value should be more than the measured N' value because of the overburden pressure correction and if the effective overburden pressure is more than 10 ton per meter square then corrected N value is less than the measured N value and even after application of the dilatancy correction your N value will also decrease but if the N' value is greater than 15 then only we will apply the dilatancy correction and why it is then I have also discussed.

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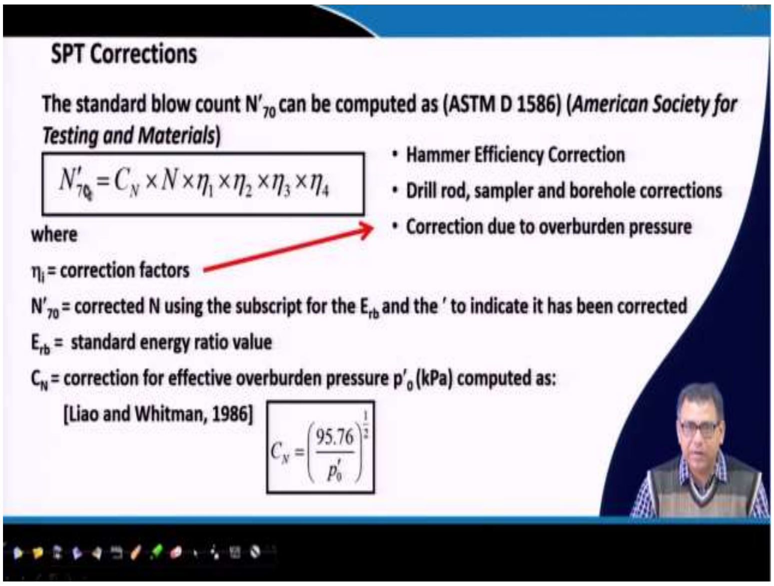

What in as per the ASTM, the American Society for Testing and Materials they have proposed 5 corrections. So, what are those 5 corrections? So, this C_N is the correction due to effective overburden pressure and this is the expression. So, in IS code we use the chart from that chart we can get the C_N value this is the chart this is the effective overburden pressure.

And this is the correction factor C_N that you will get from this chart and but here I will get the C_N value from this equation where p_0' is effective overburden pressure which is in kPa and then in addition to that, we have to apply 4 other corrections, but here dilatancy correction is not required this is not recommended as per ASTM. So, these corrections are the hammer efficiency correction, drill rod correction, sampler correction and borehole diameter corrections.

So, these corrections also we have to apply now and here N means the measured one N' means the corrected and 70 what is 70? Because such 70 is not mentioned as per IS code, but I will discuss what is 70. So, I will go for first what is 70 part so, the first correction is that η_1 this η_1 is the hammer efficiency correction then η_2, η_3, η_4 are the other corrections.

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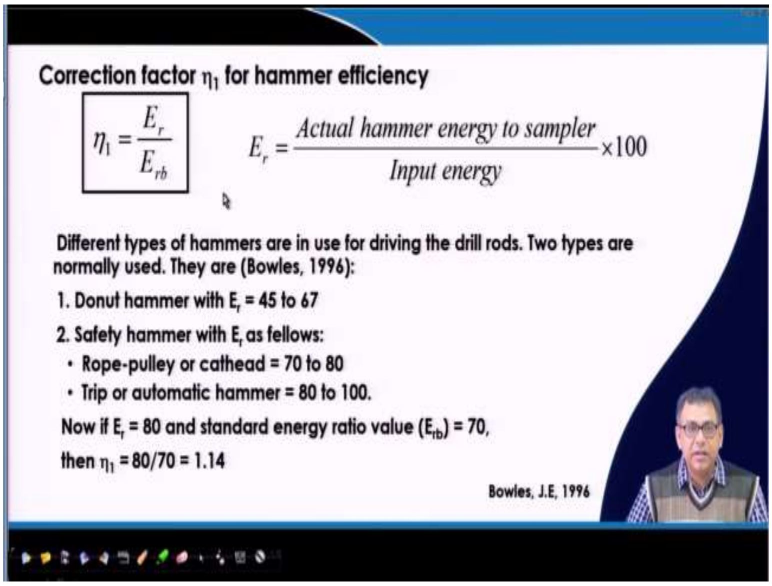

Now, what is hammer efficiency correction, this hammer efficiency correction is the ratio of E_r and E_{rb} what is E_r? E_r means because we know that these are for standard penetration tests this is the hammer weight and this hammer height of fall is this much so, we know there is a standard energy that we are applying during the blows. So, that means we know that this is my height this is the weight. So, this will be the freefall so that means everything is standard.

So, based on that we will get what will be the input energy you will apply during your test. But in actual case, there may be some energy loss because everything may not be in proper shape. So that is why during the test, input energy and the actual energy that you are applying may not be the same. So, that is the ratio is E_r that means the actual energy that you are applying to a sampler and the input energy that you are supposed to apply.

So, that is your E_r and what is E_{rb}? E_{rb} is a standard energy what is standard energy? Because in a site you are doing say 1000 penetration tests and it may not be possible to conduct all the test in a same energy for example, that sometimes your hammer energy maybe 70% sometimes 70% with respect to the energy that you are supposed to apply because you are in as I mentioned your energy it will be less than 100% because of some energy losses that may be your instrument problem or that may be a manual error.

So, that means or the instrument that you are using that depending upon that your applied energy may not be 100% but in all the tests you cannot do a particular energy because some test you may do with 60% some may 70% some may 80% so, a different energy but when you represent them in your report, it is very difficult to see that someone is 80, someone is 70 then 60 so, it is better to represent them in a standard energy.

So, that standard energy is E_{rb}. So, that your standard hammer efficiency is E_r you will get from this equation and then E_{rb}. So, depending upon which type of hammer you are using, so, E_r is available. So, for different types of hammer, these E_r value is given this is 45 to 67% and then 70 to 80, 80 to 100. So, that means this is your different hammer your E_r value you will get so, that means E_r value will get which hammer you are using based on that.

Now, suppose if your E_r is 80 and you want to express that N value which you are measure by applying E_r = 80 to a standard energy ratio of 70 for example, that means you are applying a 80% energy, but now you want to express them in 70% energy that means you applied more energy, but you want to express them in less energy. So, definitely when you want to express them in less energy, your measured N value will increase because during the measurement you applied more energy.

Now you want to express them in the less energy if your energy is less that means there will be more N value. So that is why your correction factor will be more than 1. So, that is there 80 / 70 that will be 1.14 that mean E_r is 80 E_{rb} is 70. So, this is 1.14 if it is reversed that means you are applying the 70% energy and you want to express them in 80% then your corrected N value will be less compared to the measured N value.

So, in such case your correction factor will be less than 1. So, this is the concept of 70, 80. So, that 70 that I have discussed that 70 this is the standard energy by which we will represent all the SPT values, we may have done the test at different energies, but we will represent it with a standard energy that is 70.

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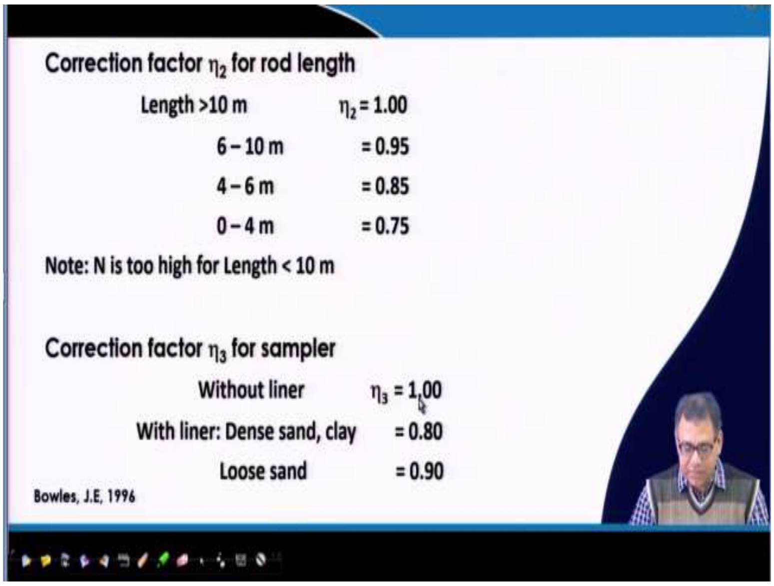

And then we have to apply the corrections for the rod length and that is η_2 if the rod length is less than 10 meters, then I will get a very high *N* value so that is why it is recommended. So, you always use the rod length more than 10 meter or equal to that. So, that means if it is more than 10 meter then no corrections are required then because the η_2 is 1 but if you use the less than 10 because it is not always possible to use more than 10 meters.

So, if you use the less than 10 then you have to apply the corrections and as I mentioned the less than 10 will give you higher *N* value. So, the correction factor will be less than 1. So, this is the correction factor for different rod length correction factors. Similarly, we can use a different sampler so, few samples and few may be liner, few may be without liner. So that if it is without liner, then correction factor is 1, but if it is with liner, then because with liner the dense sand and the loose sand then these are the correction factors.

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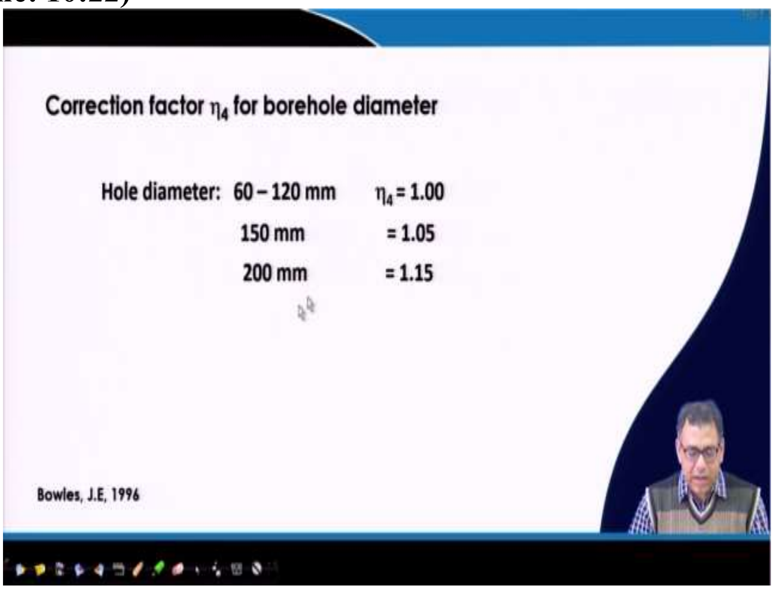

Then the borehole diameter also influences the N value, this is the borehole diameter corresponding correction factor, so, we have to apply all the correction factors, and then finally, we will get the corrected in value.

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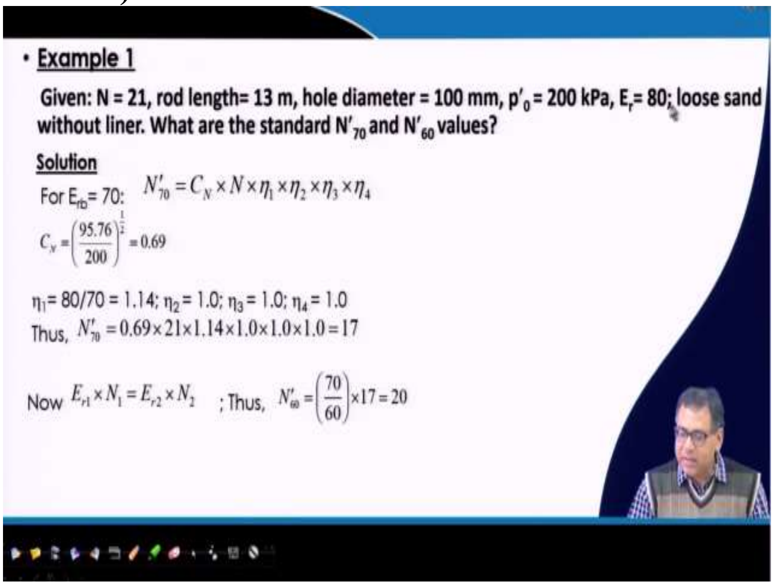

So, this is one particular example that if your N value is 21 rod length is 13. So, if it is 13 means, your correction factor will be 1 because this is greater than 10 then hole diameter 100, $\overline{p_0}$ 200 kPa, E_r is 80 and it is a loose sand and without liner and we want to represent them in 70 and 60 what will be the value so, then all these values I will get because this is E_{rb} 70 and E_r is 80. So, this is η_1 is 1.14, η_2 is 1, eta 3 because this is η_3 is without liner, so, it is 1 then borehole diameter is 100 millimeter.

So, this is 100 millimeter again it is 1, 60 to 120 millimeters it is 1. So, this is also 1 and then we have a $\overline{p_0}$ is 200. So, C_N value I will get from this equation. So, this is a 0.69 so, over all N'_{70} is 17 and then we can get the N'_{60} is 60 also that will be if 70 is 17 and definitely for if I go to lower energy level then N value should increase so, that is 20. So, these are the different corrections for as per IS code and ASTM.

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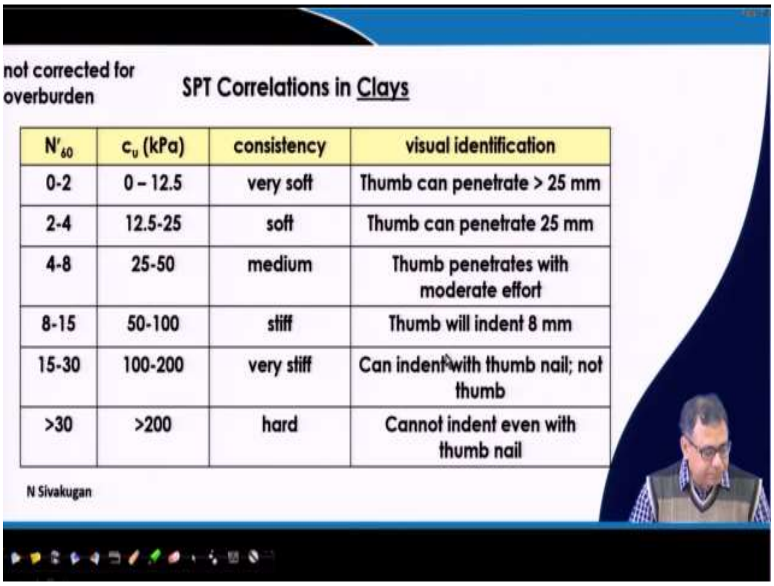

Now, based on the *N* value we can identify which type of soil it is and we can get the C_U value or the 5 value C_U value under coefficient. So, this is by using different correlations. So, this is one correlation that I am showing you, you will get such correlations in book but I am giving one of them. So, remember that sometimes you will find these correlations sometimes it is based on the measured *N* value sometimes it is based on the corrected *N* value and sometimes corrections you have to apply sometimes not.

So, based on that you have to use that correction. So, you have to be very, very careful when you have to use the corrected *N* value when you have to use that measured *N* value, when you have to use some correction some are not. So, for example, this is $N_{60}^{'}$ but here overburden correction is not applied. So, this correlation is based on that so, here it is 0 to 2 that means C_U value 0 to 12.5 kPa it is very soft. Similarly, if it is *N* value is greater than 30 it is hard soil. So, these are some corrections and visual identification also you will get similarly for this is for the clay this table.

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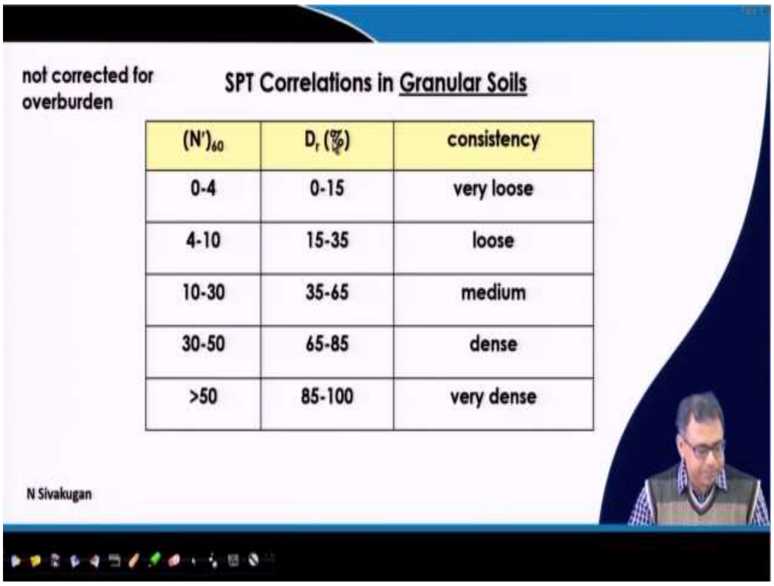

Similarly, for the granular soil also you will get again this is correction these corrected *N* value, but correction is not applied for overburden pressure. So, this is from 0 to 4 is very loose, then greater than 50 is very dense 30 to 50 is dense, and corresponding relative density rd is the relative density also you will get for granular soil.

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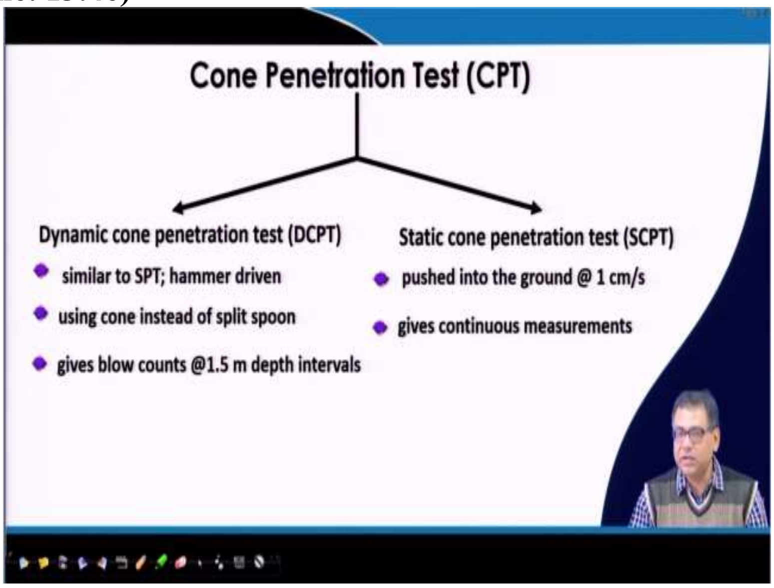

Next, I will go for the cone penetration test PVS 1 is the standard penetration test and the cone penetration test it has 2 types one is dynamic cone penetration test, another is the static cone penetration test. So, in the dynamic cone penetration test is similar to SPT it is also hammer driven and using cone but the difference of dynamic cone penetration test with SPT is that in SPT we use the split spoon sampler, but here we use the cone. So, in SPT we can collect the soil sample, but here we cannot.

So, again the blow counts are given at an interval of 1.5 meters and then for the static cone penetration test so it is pushed it is not the hammer driven like SPT or DCPT, it is pushed into the ground at 1 centimeter per second. And it gives continuous readings SPT also give readings with certain intervals, 1 meter or 1.5 meters. DCPT also give in readings certain intervals 1.5 meter but the SCPT gives the readings which is continuous and remember that in SPT we need boreholes, but in cone penetration test DCPT boreholes are not required because it is either pushed or driven into the soil.

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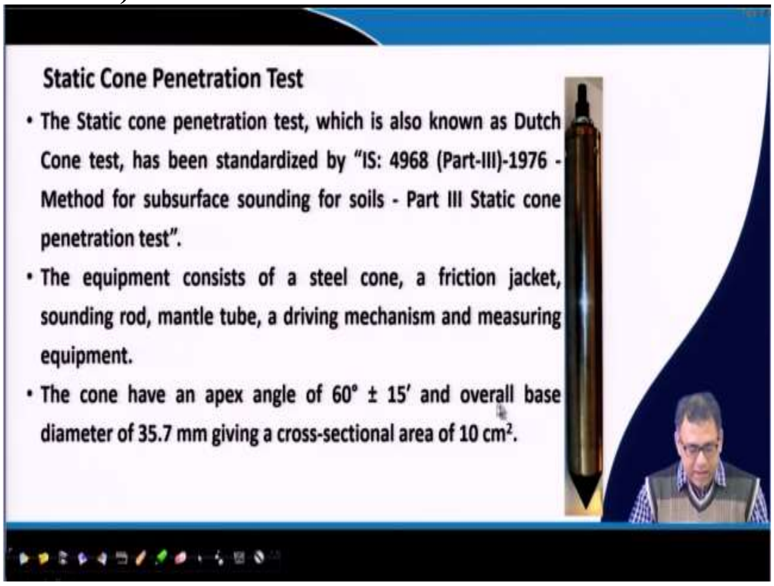

So, the static cone penetration test this is the IS code for this test is 4968 part 3, 1976. So, the equipment those are used here the steel cone then friction jacket sounding rod this is the sounding rod and driving mechanism and measuring equipments the angle this cone angle is 60 degrees plus minus 15 minutes and overall base diameter is 35.7 millimeter with a cross section of 10 centimeters square.

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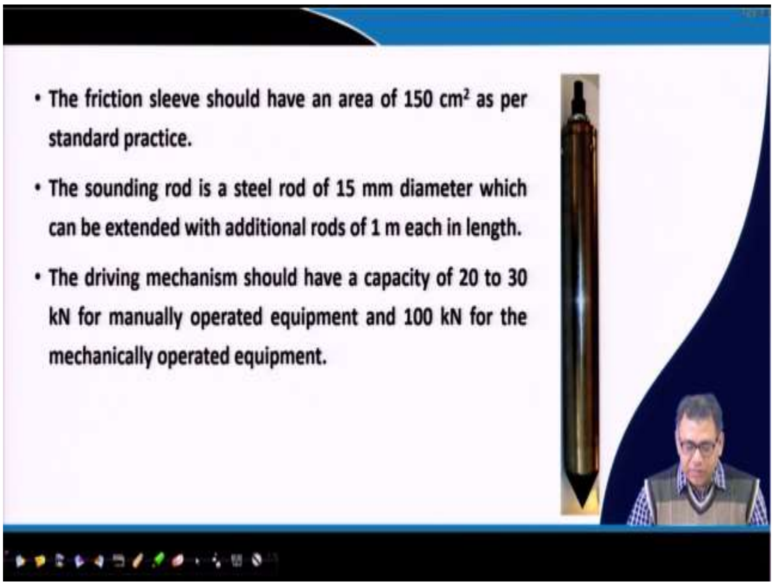

And these friction jacket friction sleeve or this sleeve outside area is 150 square centimeter. Now, sounding rod is a 50 millimeter diameter generally this length is 1 meter each, but we can extend the length of this or length of this cone by attaching additional rods of 1 millimeter each as I mentioned, so, this is the rod you can attach another one and then you can put you can go up to the required depth.

So, the driving mechanism should have a capacity of 20 to 30 kilo Newton for manually operated equipment and 100 kilo Newton for mechanically operated equipment. So, this is the static cone penetration test here we are not applying any blows the driving equipment will push it into the soil.

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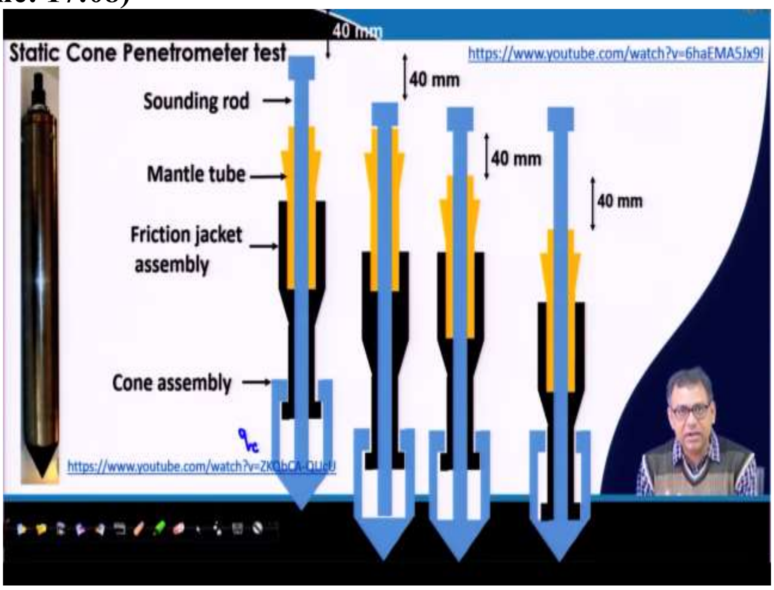

So, now, I will show you by this animation how these things work. So, this is the total assembly of these static cone penetration test this is the sounding rod, this is the mantle tube this yellow one the friction jacket this black one is the friction jacket and the cone assembly is this one. Now, first this sounding rod along with cone assembly is pushed by 40 millimeter into the soil. So, sounding rod so, I can see the sounding rod along with cone assembly is pushed into the soil by 40 millimeters.

So, by which we will get a resistance. So, this resistance will give you the cone resistance which is q_c. So, this stage, the resistance that I will get is the cone resistance which is q_c. Now, the next step this is the same stage the next stage, the sounding rod, the cone assembly and the friction jacket all are pushed into the soil by 40 millimeter. So, initially the sounding rod and the cone assembly is pushed into the soil by 40 millimeter.

Now, the sounding rod, cone assembly and the friction jacket are pushed into the soil by 40 millimeter. So, in the second stage the resistance that I will get is the total resistance that means the cone resistance plus friction resistance so this will be the total resistance now, if I subtract the cone resistance from the total resistance then I will get the friction resistance is it clear?

So, in this test I will give you the cone resistance and the friction resistance separately first stage we will give you the cone resistance, second stage will give you the friction resistance plus cone resistance that means the total resistance. In the third stage, what I will do that this mantle tube is pushed into the soil by 40 millimeter. And in the fourth stage, the mantle tube along with the friction jacket is pushed into the soil another 40 millimeter.

So, remember that the first 2 stages are required to measure the resistance. But the second 2 stages are required to bring back this instrument in its original position. So, one question may come that the second stage also we push the friction jacket first stage also we pushed a friction jacket why? The first stage is friction jacket is supposed to measure the resistance, but the fourth stage friction jacket is pushed to bring the instrument into the original position the fourth stage will give you the original position.

So, that means the first 2 stages are used to measure the resistance and third and fourth stages are used to bring back the instrument into original position.

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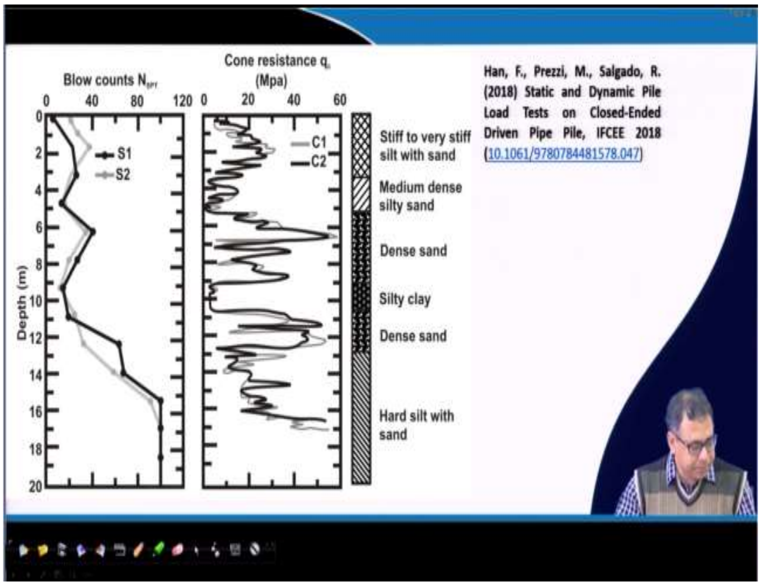

After doing the SPT and CPT static cone penetration tests finally we will get this type of data. So, this is the SPT blow count with depth S1 and S2 are 2 different boreholes and this is the SPT cone resistance only cone resistance along with depth for 2 different boreholes C1 and C2 and we can identify the soil also because by SPT we can bring the soil or the by the in borehole also we can identify soil. So, this is the soil type and this is the cone resistance and this is this the SPT value.

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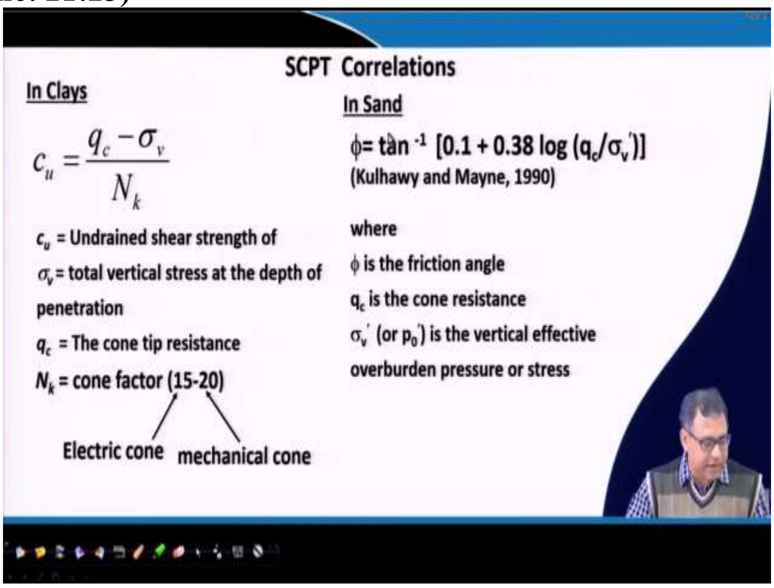

So, once you get the cone resistance and the friction resistance then we will use the correlations like SPT also and these we use the correlations and then for the because all SPT, CPT or other cone penetration test and other field test there are a number of correlations are available, but I am giving few of them. So, for the clay we can determine the undrained shear strength or undrained cohesion by using $\frac{q_c - \sigma_v}{N_k}$ what is q_c? q_c is the cone resistance that I will get from the first stage.

And then σ_v is the total vertical stress or total vertical overburden pressure total not effective total vertical overburden pressure and in case the cone factor, so, if you use the electric cone then it will be 15 if you use the mechanical cone it will be 20. So, if you put these values you will get the C_u similarly, for the sand also we can get the friction angle and that is the equation.

And here this is σ_v' that means the effective vertical overburden pressure and here it is σ_v this is total this is effective and this is again the q_c that is the cone resistance and this is the expression we can use for the clay and the sand to get the strength parameter.

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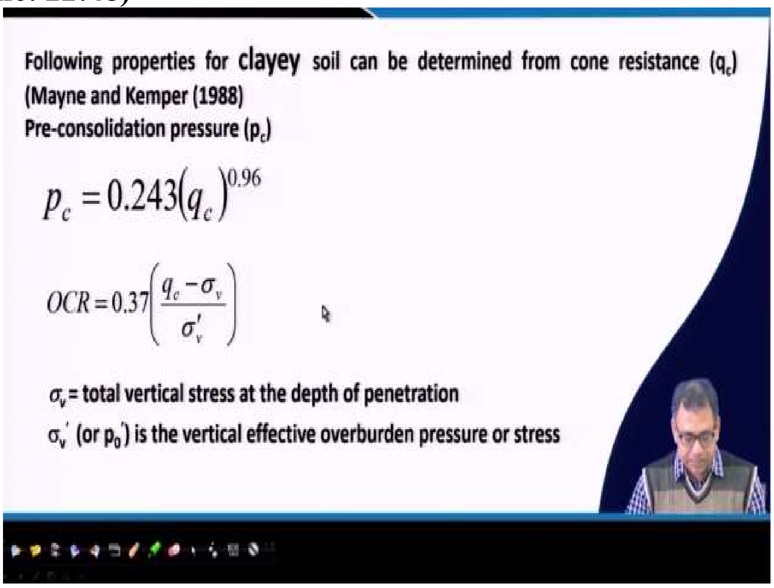

Then we can use these CPT for the clay soil to determine the pre consolidation pressure. So, what is pre consultation pressure that means, we know the soil may be normally consolidated or the over consolidated and if the present stress on soil is more than the stress which soil already has been experienced, then this is called the over consolidated soil and sorry this is called a normal consolidated soil and if the current stress is less than the stress that soil already been experienced, then that is called the over consolidated soil.

So, the pre consolidation pressure is the p_c that when the stress which soil already been experienced. So, now, if your current stress is more than p_c, then we can say the soil is normally consolidated that means, the current stress that soil is experiencing is more than the stress that soil has already been experienced. So, that stress is p_c so, now the soil stress is more than p_c.

So, it is normally consolidated but if the stress is less than p_c that the current stress is less than p_c, then the soil is called the over consolidated, because the previous stress was more than the current stress. So, that p_c value is very important to identify because based on that we can identify whether soil current state is over consolidated or the normally consolidated. So, if the p_c value expression we can get by p_c value we can get by using this expression.

So here q_c is the cone resistance and over consolidated ratio also you can get by using these expression σ_v is the total vertical overburden pressure and σ_v' is the effective vertical overburden pressure and for no further normally consolidated stress normally consolidated soil we generally consider the OCR value is equal to 1 and over consolidated soil OCR value is greater than 1. So, this is your OCR also you get from the cone resistance.

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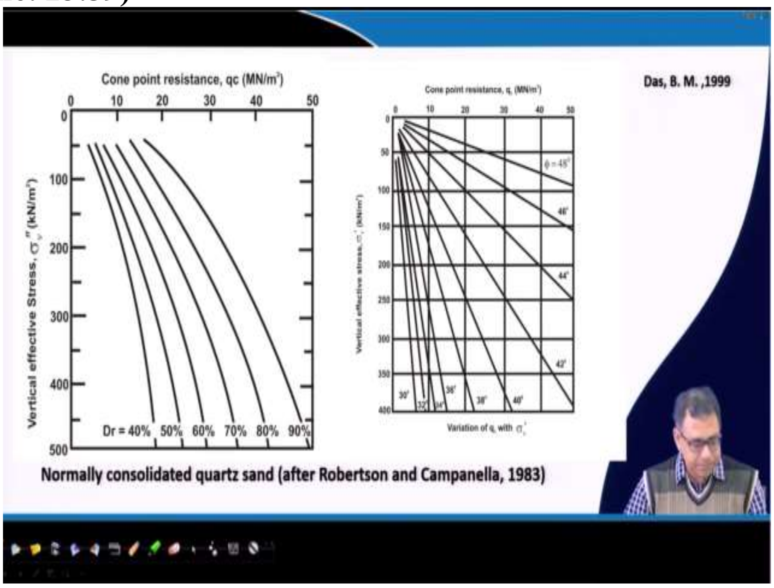

And we have different charts also by which also we can determine that soil relative density or the friction angle. So, this is what the sand if I know the cone resistance if I know the vertical effective stress or vertical overburden pressure, so, we know these values and the cone resistance then you will get the relative density of the soil and we will get the different friction angle of the soil also.

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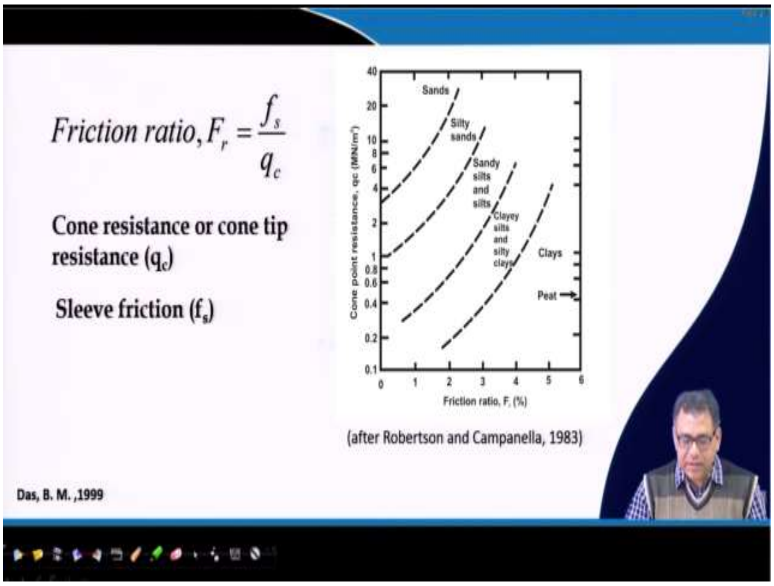

Then, if I know the friction ratio is the ratio between the friction resistance or the sleeve friction and the cone resistance or the tip resistance sometime it is called tip resistance $\frac{q_c}{f_s}$, f_s is the sleeve friction. So, if I get this ratio F_r and then if I know the cone resistance q_c and the friction ratio F_r then we can identify which type of soil it is. So, that it can be clay it can be clayey silt or it can be silty clay, sandy silt, silty sand, sand. So, if it is in this zone friction ratio and the cone resistance will be sand. So, this way you can identify the soil also.

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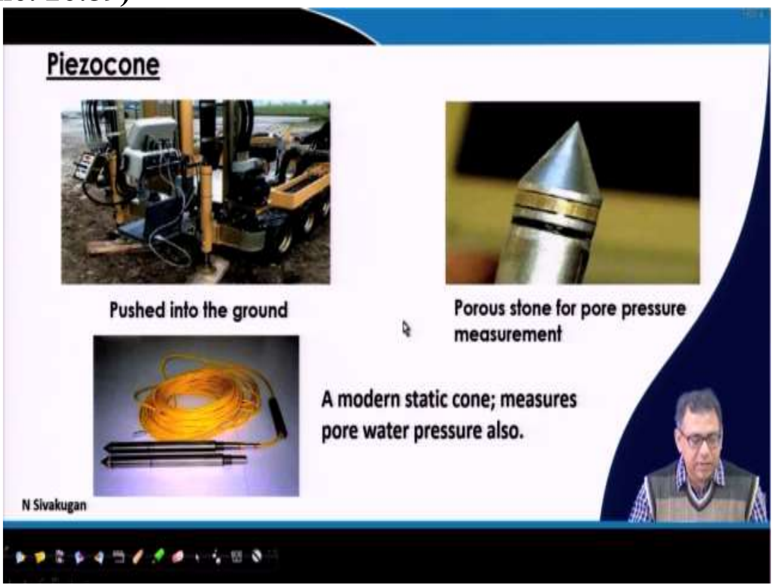

Now modern static cone test the pore pressure can also be measured. So, here we can also have cone resistance friction resistance we can measure as well as the same time we can measure the pore pressure also by using modern static cone penetration test all this piezocone which is called the piezocone.

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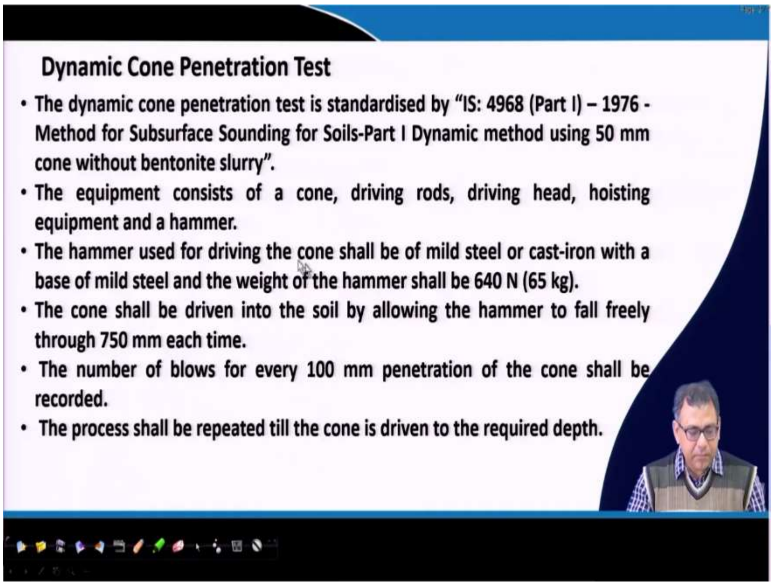

Now, next one is the dynamic cone penetration test where in the static code penetration test it is pushed into the soil, but here it is inserted into the soil by hammer blow which is similar to the SPT. So, here also the hammer blow, hammer weight is 65 kg and with a free fall of 750 millimeter and number of blows required for every 100 millimeter penetration is recorded. And these processes repeated up to the required depth.

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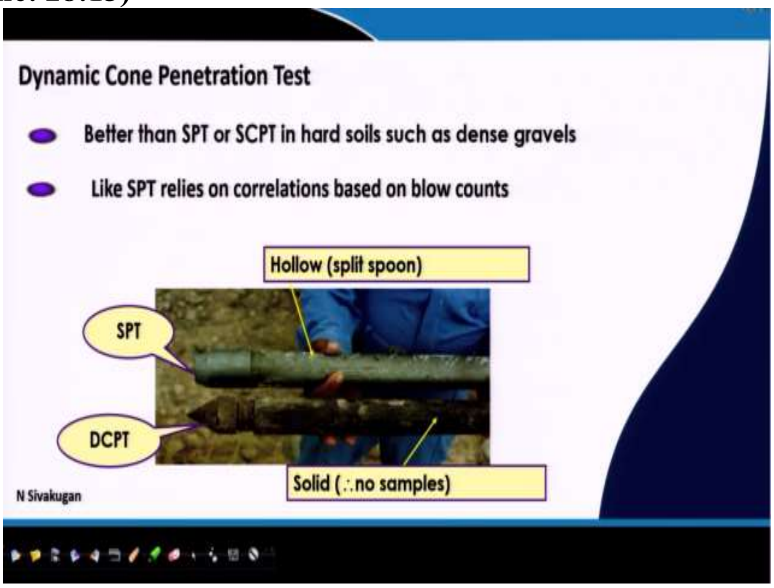

And the major difference as I mentioned that in the SPT we can collect the soil sample we can use the split spoon sample, but the DCPT we use the cone so we cannot collect the soil sample. So, this DCPT is better than SPT and SCPT static cone penetration test in hard soil such as dense gravels. And like SPT also we can put correlation for these blow count with different soil properties. So, this is the cone penetration test so, in the next class, I will discuss about the other different these soil exploration methodologies by which also we can get some parameter which will be correlated with different soil parameters. Thank you.