Advanced Foundation Engineering
Prof. Kousik Deb
Department of Civil Engineering
Indian Institute of Technology - Kharagpur

Lecture - 3
Soil Exploration - III

So, last class I have discussed about different penetration test SPT and SCPT and DCPT and then I have discussed different correlations by which you can determine the soil properties. So, today I will discuss about the pressure meter test.

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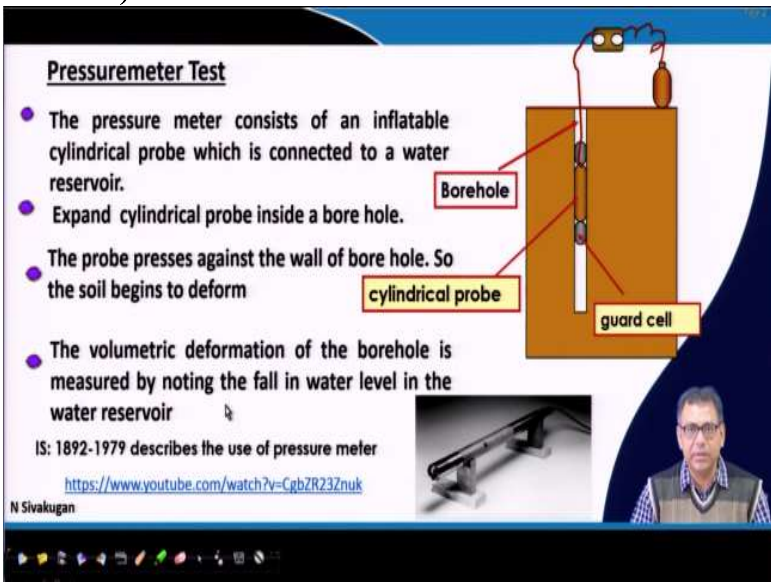

So, the pressure meter test is another in-situ test by which we can measure different soil properties by using the correlations. So, this is the pressure meter instrument so, it has a cylindrical probe and 2 guard cells. So, these guard cells are used to protect this probe within the borehole. So, here also we need the borehole and here the pressure meter consists of an inflammable cylindrical probe.

So, this is connected to a water reservoir so, that means this probe can be expanded so, we apply the water pressure then this probe expands and we measure the volume change. So, this is the mechanism by which we can measure the properties. So, that means we apply the pressure and this probe expands. So, that means it expands and soil starts to deform. So, then we measure this expansion.

And corresponding pressure or you can say the pressure corresponding the expansion that means, the volume expansion we measure so, this cylindrical probe we place it inside a borehole, then when you apply the pressure the soil begins to deform and this probe volume increases. So, we measure basically pressure versus volume plot or we do the pressure versus volume plot, we measure pressure and the volume change. So, volumetric deformation of the borehole is measured by noting the fall in water level in the water reservoir that means, we measure the fall in water level or basically the pressure and the volume.

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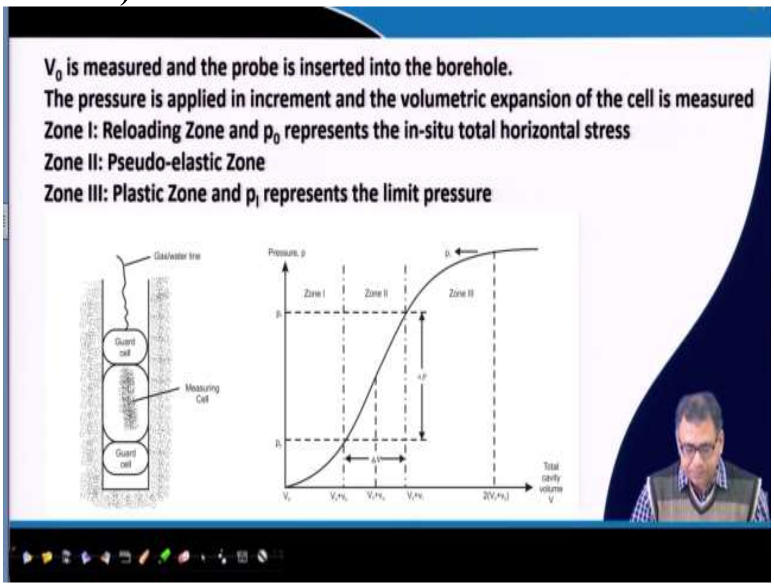

So, now, as I mentioned this is the pressure and the volume change. So, this is the plot that you will get from that test. So, that means, from this curve, we can see this curve has 3 different zones. So, what are the 3 zones? Initial volume of the probe that is V_0 that we can measure generally is this V_0 is 535 cm^3. So, that is known, so, V_0 is known for us.

So, this V_0 is the starting point which is known and initial pressure is say 0 and now, we will start applying pressure so, now the volume of the probe will increase from V_0 to certain value and pressure also increases. So, then we will get these 3 zones. So, initially, we do not have these zones and we have to identify these zones. So, we have this graph. So, that once we get this graph say suppose initial period, we will get in some portion this pressure versus volume change is linear.

So, we identify these 2 points, the starting points and ending points, the starting points where this linear zone starts and the end points where this linear zone ends. So, I mean this linear behavior we have to identify these 2 points. So, we will identify these 2 points and the corresponding volume is $V_0 + v_0$. That means and corresponding pressure is p_0 that means to reach this point the volume change is v_0.

And then the another point corresponding pressure is p_f and the corresponding volume change is $V_0 + v_f$. So, that means the volume change is v_f to reach this p_f and this is the middle point which is $v_0 + v_m$. So, that means to reach this first point the volume expansion is V_0 total volume is $V_0 + v_0$ and the second point the volume expansion is v_f.

So, the first zone is called reloading zone and p_0 represent in-situ total horizontal stress why this zone is called reloading zone? Because when we construct the borehole that means the pressure on the soil is released. So, some deformation of the soil will take place towards the borehole. Now, this is not the actual condition because now the soil condition is been disturbed and some deformation of the soil takes place towards the borehole or you can say inside the borehole towards the borehole centre.

So, some soil deformation has been taken place. Now, once we apply the pressure and the probes starts to deform then it will push that deformed soil to its original position. So, this first point, so, at v_0 position the soil will go to its original position. So, that is why it is this pressure p_0 is called in-situ total horizontal stress because that is the in-situ condition of the soil because now the soil initially was disturbed, now we apply the pressure now the probe expands.

So, now it reaches its initial condition due to this V_0 volume change at p_0 pressure so, this is called a reloading zone. Now, the next one is called a pseudo elastic zone because here the pressure versus volume change relation or volume relation is linear and third zone is called a plastic zone and p_l represent the limit pressure now, how I will get this p_l? Now, p_l I will get in 2 ways one is that if because during this test I will get this plot I will get this $V_0 + v_0$ value.

Now, I have to continue the test up to 2 times $V_0 + v_0$ and they are in the test so that corresponding pressure is the p_l or the second option is that suppose your instrument has some limits, so, you cannot go beyond some pressure or some volume change. So, there you have to stop your test. So, that may be the list and 2 times $V_0 + v_0$. So, now in such case how I will get the p_l?

Because if my test ends before these are 2 times $V_0 + v_0$, then how I will get that p_l? Because that time I have to get that p_l by interpolating it. So, that means in the plot, I will identify the point corresponding to 2 times $V_0 + v_0$ and then I extend this graph. So, that is interpolation because I may not measure that value because of the limitation of the equipment.

But I can interpolate these and I can extend this curve up to that point that corresponding to this point and then I can find out the p_l value. So, if I can go up to that point, I can measure but most of the cases it is not possible to go up to that point. So, I have to finish the test before that point. So, I can interpolate that and I can locate the p_l value, which is called as limit pressure.

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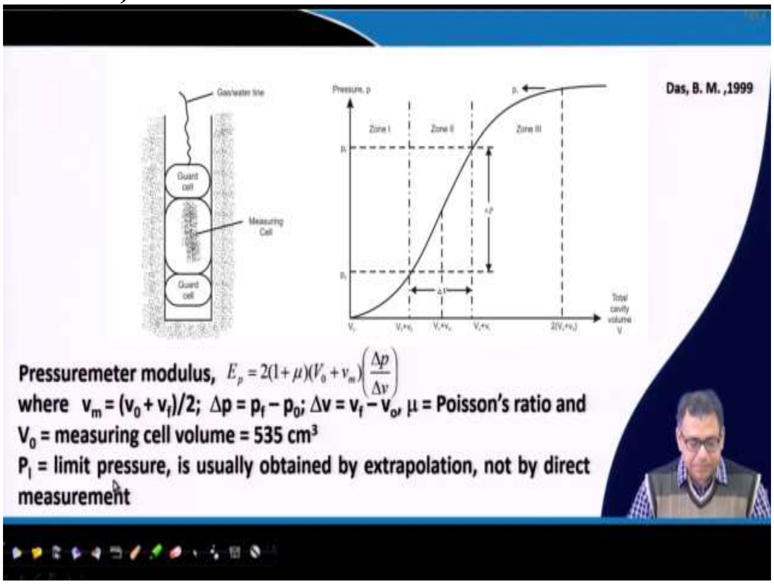

So, now, from these values I will get the pressure meter modulus, which is the E_p that value I will get this is the Δp, Δp is the difference between p_0 and p_f or p_f and p_0 and v is the v_f - v_0 that is Δv and then V_0 I know that is 335 cc most of the cases μ is the Poisson ratio of the soil so, I will get the pressure meter modulus E_p and as I mentioned the p_l limit pressure is usually obtained by or this is extrapolating because not the interpolation it is extrapolation.

Because it is outside the plot so, it is extrapolation of the plot so, it is not interpolation. So, correct this it is extrapolation because I have to extend this because maybe your test ends here. So, you have to extrapolate these plots so, this is the extrapolation because you have to extrapolate this plot up to this point, but not direct measurement.

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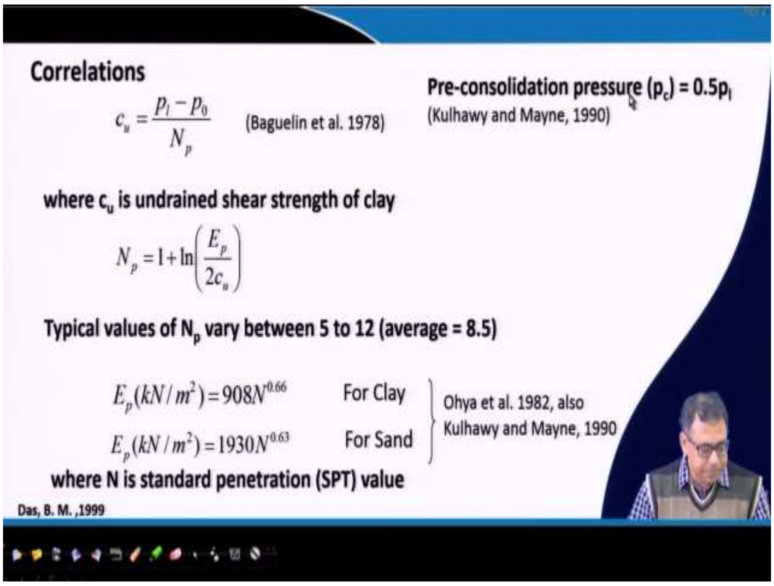

So, again once you get this E_p and p_l, p_0, p_f then again we have to use these values in correlations to get the soil properties again I can get the undrained shear strength or the correlation that expression is $\frac{p_l - p_0}{N_p}$. So, p_l I have already discussed p_0 also I have discussed and this N_p I will get by using this equation and E_p I will get by this equation and I will put it here, but in that case, there will be a c_u and there is also c_u.

So, by trial and error I can get the c_u value there is only one or none, but the solution is very complicated. So, we can use that trial and error you will get the c_u if you use here because here E_p will be given by the equation and c_u I will get from this equation. Another case directly if you use the N_p which varies from 5 to 12 average 8.5 then also I will get the c_u and E_p value I can also correlate with the SPT N. So, that also I can correlate for clay and the sand. The pre consolidated pressure also p_c I can get by using this correlation up into p_l and pre consolidation pressure also I can get.

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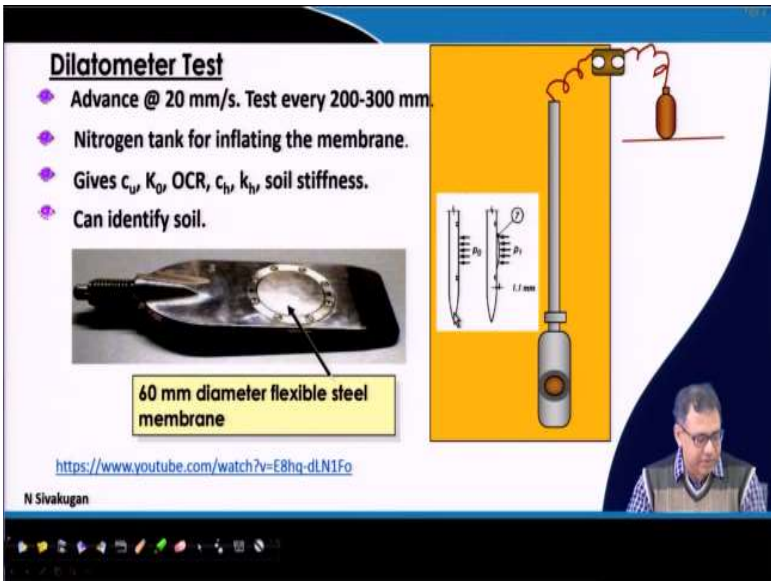

Now, the next test is the dilatometer test. So, the dilatometer test also here bore hole is not required, here the instrument is pushed into the soil at a rate of 20 millimeter per second and we test every 20 to 30 millimeter interval and pressure meter we use the water but here the nitrogen tank is used or nitrogen is used for inflating the membrane. Here also is similar to pressure meter, but the difference is that here there will be a flexibility steel membrane in this equipment.

And that can we have to use the nitrogen for inflating this membrane, so this membrane will inflate and we will get the deformation or the reading and the corresponding pressure we can measure. So, that means similar to the pressure meter test, also we measure the pressure and the volume change. Here also we will measure the expansion of these or inflation of the membrane and the pressure.

So, it will give us the undrained coefficient K_0 value that when the coefficient of pressure air pressure condition over consolidation ratio, then c_h coefficient of consolidation in horizontal direction k_h permeability in horizontal direction soil stiffness, it can identify the soil also. So basically, it has 2 major readings. Actually, it has 3 readings but these 2 major readings we will use for the correlations. So, one reading is called A reading and the next one reading is called the B reading.

So, in A reading I will get the p_0 and B reading I will get the p_1, there is another reading C reading there I will get the p_2, but that will not discuss here. So, here I will get the p_0 by taking

A reading and p_l by taking the B reading. So, it is A reading B reading are different stages by which we are taking different readings.

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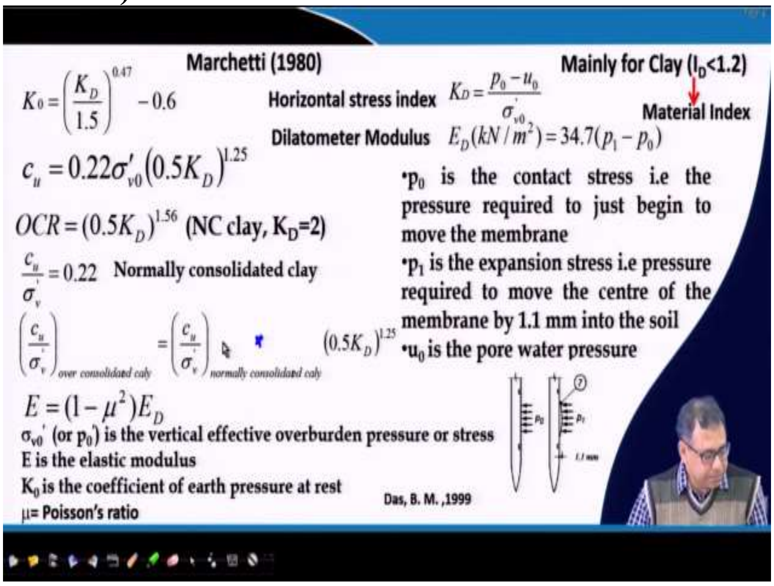

So, once we get these readings, we use these correlations for different types of soil. So, what is that so, here first let me explain what is p_0 and p_l? So, as I mentioned p_0 is the contact stress that is the pressure required to just begin to move the membrane. So, that means here p_0 or the A reading where we have to apply the stress that initially when we apply the stress immediately the movement of the membrane will not take place, we have to apply some reading so, that at that point the membrane will start deform.

So, that the p_0 is the pressure required just to begin the membrane to move so, that is our A reading and p_l is the expansion stress that is the pressure required to move the center of the membrane by amount of 1.1 millimeter into the soil. So, that means p_l is the pressure that we will measure where the membrane will deform by 1.1 millimeter the membrane center will deform by 1.1 millimeter into the soil and u_0 is the pore water pressure.

So, it is clear what are p_0 and p_l? p_0 is the pressure required to just begin to move the membrane and p_l is the pressure required to move the center of the membrane by 1.1 millimeter into the soil. So, once I get this p_0 and p_l and u_0, I calculate then I will get different properties. So, that will first one is the horizontal stress index. So, this is K_D, K_D is the $\frac{p_0 - u_0}{\sigma'_{v0}}$, σ'_{v0} is the effective vertical overburden pressure.

So, if I know the u_0 if I know the σ'_{v0} and p_0 from here I will get the K_D then I will get the dilatometer modules this is E_D, E_D is $34.7(p_l - p_0)$. So, once I get the K_D and E_D then I will get these properties for the clay. So, those properties this is mainly for clay those properties are K_0, K_0 is the coefficient of earth pressure at rest. So, this is the expression correlation then undrained coefficient this is the expression K_D.

Again, this is effective overburden pressure then over consolidation ratio is $(0.5K_D)^{1.56}$. So, you can see that for normally consolidated clay K_D value is equal to 2. So, if your soil has a K_D value of 2 then we can say this is a normally consolidated soil and if it is more than 2 then it will be over consolidated soil. So, for normally consolidated soil this is the correlation.

So, if I get the undrained cohesion for the normally consolidated soil by using these correlations then I can use this correlation to get the undrained cohesion for over consolidated clay also. So, that is done normally consolidated clay into $(0.5K_D)^{1.25}$ this is into. So, this is actually this value is this is into. So, then I will get the elastic modulus by using these expressions also μ is Poisson ratio and E_D, I will get from here.

So, these correlations are for the clay that means the K_0, c_u, OCR, E and then c_u I can get for a normally consolidated clay and for over consolidated clay also we can get so, this c_u depending upon K_D value I can get whether it is a over consolidated soil or normally consolidated soil. So, if it is a normally consolidated clay directly, I can use these expression and over consolidated soil I have to use these expressions.

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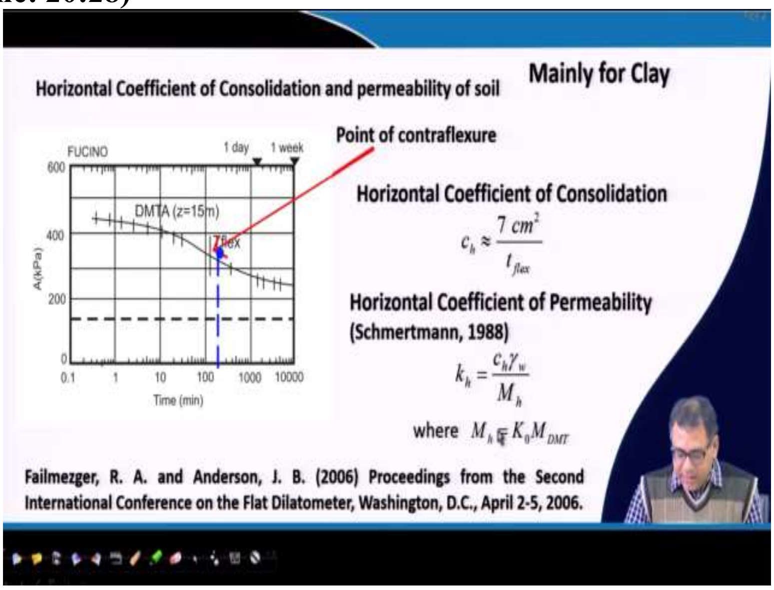

Now, next one is to determine the horizontal coefficient of consolidation and the permeability of the soil and these correlations are also for clay. So, previous correlations are also for clay these correlations are also for clay. So, I will get the horizontal coefficient of consolidation so, that is c_h so, that is equal to $\frac{7\ cm^2}{t_{flex}}$. So, the t can be second or minute so, that means the c_h will be either 7 centimeter square by second or 7 centimeter square by minute depending upon which how you are putting t_{flex} value.

Now, what is t_{flex}? So, here as I mentioned that during this test, we are taking 2 readings one is your A reading and another is your B reading, A reading will give you p_0 and B reading will give you p_1. So, here we will go for the A reading only. So, this is the A reading that is why so, this is the pressure that you will give during the A reading. So, that A reading will take and you will off this B reading I mean B reading will not take we will keep this instrument under A reading condition.

And we will take the reading at different time intervals clear. So, that means we will keep the instrument under A reading condition and then at this condition will keep on taking this reading with different time intervals. So, these are the different time intervals you can see this 1 day, 1 week and we can take this 1 minute then 5 minutes then 10 minutes. So, different time intervals we will take the reading and so and we will plot these readings with time this is x axis is time in minute and y axis is the A reading so with time.

And then we will identify there will be a change in curvature in the curve you can see so, this is the curvature and then there is a change in curvature. So, this is one curve and then it is the change so, we have to identify that point. So, that point and the corresponding time will give me the t_{flex}. So, this is called point of contraflexure and this is small t_{flex}. So, these points of contraflexure we have to identify by plotting this A reading and the time.

So, this is the point of contraflexure and that means where your curvature changes to identify that point and the corresponding time will give me the t_{flex}. So, you put this and you will get the horizontal coefficient of consolidation. Now, the horizontal coefficient of permeability I will get by using this expression this is c_h I will get from this expression then M_h, M_h is the $K_0 \times M_{DMT}$. So, K_0 it is the coefficient of earth pressure at rest that I will get by using this expression K_0 I will get then c_h also I will get from these expression. This is γ_w is unit weight of water and M_{DMT} I will explain what is M_{DMT}?

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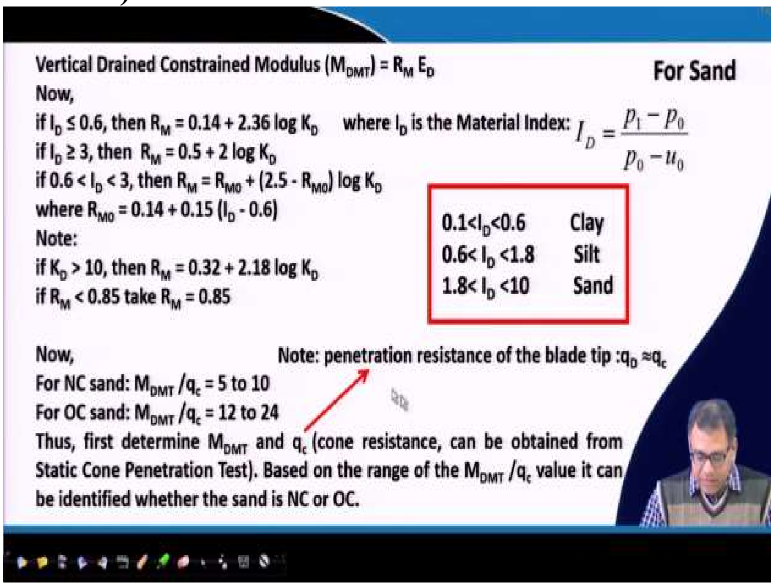

Now for this M_{DMT} which is drained constraint modulus of the soil the constraint modulus is generally 1 / M_B, M_B is the coefficient of volume change. So, and this M_{DMT} will get $R_M \times E_D$, E_D I will get from these expressions and how I will get the R_M. So, R_M I will get by using these conditions so, to get the R_M we have to identify the I_D which is called material index.

So, I_D I will get by using these expression $\frac{p_1 - p_0}{p_0 - u_0}$. So, p_1, p_0, u_0 I have already explained so, this I_D I have to calculate material index based on this I_D I can identify the soil type also if your, I_D is less than 0.6 and greater than 0.1 then it is clay if it is less than 1.8 and greater than 0.6 then it is silt if it is within 1.8 to 10 then it is sand. So, here in previous expression as I mentioned it is valid for I_D less than 1.2.

So, it is mostly clay because clay is 0.6 some silt is also there, because it is less than 1.2 but it is mostly clay. But if these expressions if we have to use if I_D is greater than 1.8 then only those expressions are valid for sand if your, I_D is greater than 1.8 because that is then only your soil is sand otherwise soil is not sand. So now by these conditions I_D I can calculate for clay I_D, I can calculate for silt I_D, I can calculate for sand also now, if your, I_D is less than equal to 0.6 that means it is clay then R_M will be this equation.

So, I will get the R_M for the clay by this equation, this is the K_D this is log 10 R_M and I will put R_M here and I know the E_D I will get the DMT and that DMT I will put it here I will know your

K_0 I will know the M_h and that M_h I will put it here I will give the K_h the horizontal coefficient of permeability is it clear. Now I will go for the sand part. So previous correlations are valid for the clay these correlations are valid for the clay, mainly clay, now I go for the sand part.

But if your, I_D is greater than 3 then which is basically sand then R_M can be obtained by using this expression. If it is in between 0.6 to 3 then R_M will be obtained by using this expression now here what is R_{M0}? R_{M0} can be obtained by using these expressions. Now I can obtain the R_M for clay, silt and sand depending upon I_D value. Now note that if your K_D is greater than 10 then you have to use these equations because this is the based on the I_D but these are the 2 special cases.

Suppose if your K_D is greater than 10 then directly we use R_M can be obtained by using this expression then I_D classification or I_D different types of I_D are not required. So, if your K_D is 10 so that means initially you check what is your K_D value if your K_D value is greater than 10 directly you use this R_M expression. Now if your K_D is less than 10 then you based on different I_D you calculate the R_M clear?

If your K_D is greater than 10 using this expression and if your K_D is less than 10 then based on different I_D value you will get the different R_M value and another condition is that if by any chance by above expression is giving the R_M less than 0.85 then you take R_M = 2.85 your R_M cannot be less than 0.85, R_M you have to take 0.85 or more. So, now for it is very difficult to identify whether sand is in normally consolidated state or the over consolidated state.

Because in clay you can do the odometer test and you can identify what is the P_C and whether you can identify the soil is because you can identify the P_C which is very important to understand whether soil is in over consolidated state or the normally consolidated state but in the sand doing odometer test is difficult because of its disturbance. So, here by the dilatometer test approximately we can identify whether sand is in over consolidated state or normally consolidated state.

How we can do that? Because once we get the R_M for sand, then also we will multiply with E_D, I will get the M_{DMT}. So, then that M_{DMT} we divide it with the q_c that mean the cone resistance that means the static cone penetration test I will get that value I have already discussed the static cone penetration test. So, therefore the static cone penetration test I will get the q_c and that M_{DMT} divide the q_c now for normally consolidated sand the M_{DMT} / q_c is within 5 to 10 and for over consolidated sand this varies from 12 to 24.

So, based on the I_D value, we have to calculate the R_M and that R_M we will put it here we will get the M_{DMT} and then we will divide by the q_c then we will identify based on these range whether soil is in normally consolidated state or over consolidated state. So, this way we can identify that.

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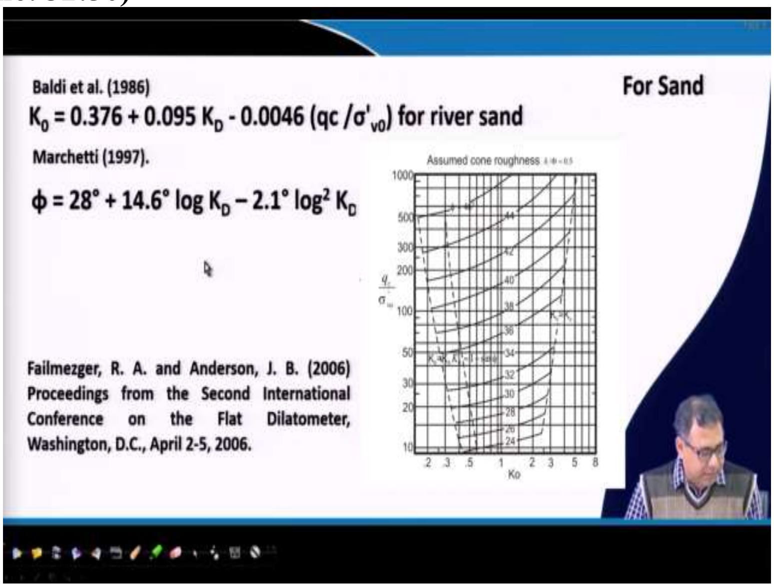

So, now, in the next one for the sand also you can calculate the K_0 by using this expression, these q_c this is the cone resistance that I will get the static cone penetration test that is σ'_{v0} that means effective overburden pressure. Now, I can get the ϕ also by using this expression, I can get the ϕ by using these curves also because I can get the K_0 by using this equation.

If I know the q_c and effective overburden pressure then I can get the ϕ value also for the soil. So, either I can use this chart or I can use the expression to get the ϕ value of the soil. So, here in next class I will discuss a few more in-situ tests by which we can determine the soil properties. Thank you.