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

Lecture-24
Shallow Foundation: Settlement-II

So, last class I have discussed how you can calculate the immediate settlement of clay soil. Now, today first I will discuss how we will calculate the consolidation settlement of the clay soil and then I will discuss about the methods by which you can determine the settlement of the granular soil.

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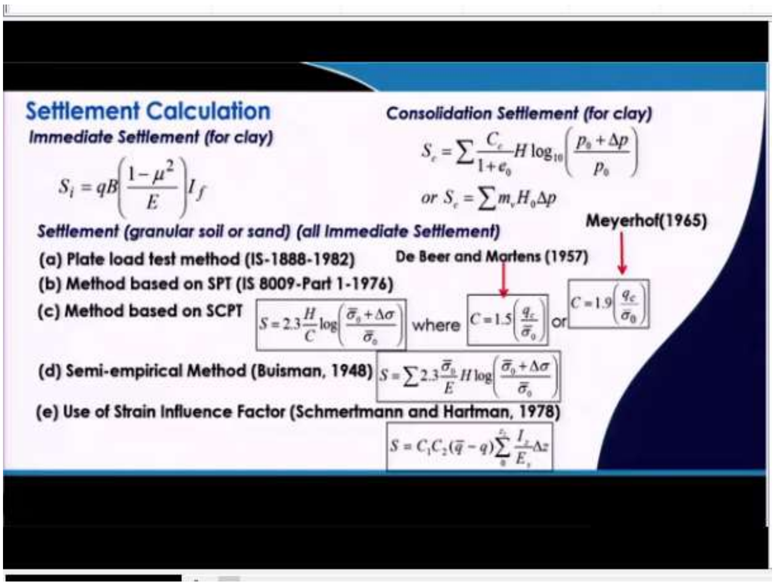

Now, a different procedure that I have discussed that these are the first and second methods for the clay and rest five procedures are for the determination of settlement of sandy soil. So, I have discussed the immediate settlement for clay.

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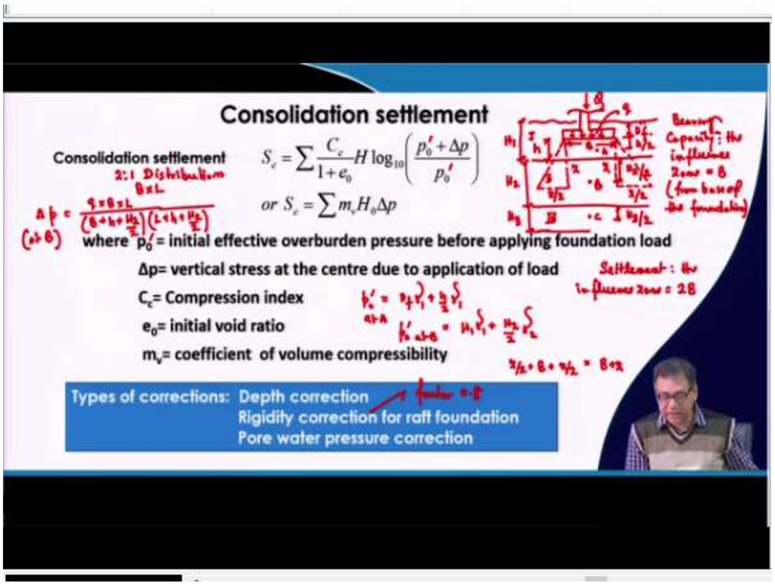

Now the consolidation settlement, so, this is the equations by which I can calculate the consolidation settlement. So, you know this is very famous equation to calculate the consolidation settlement and you have done the derivation or you know how the settlement is coming. So, this is your soil mechanics part. So, those things will not be discussed here because we will directly use this equation.

But I will explain the different terms. So, your C_c is the compression index and e_0 is the initial void ratio. So, compression index you know how you will calculate. So, if you have $e - \log(p)$ curve, then the slope of the straight portion will give you the C_c. So, these are the soil mechanics part. So, you should know these things. So, now, C_c you will get from the oedometer test.

So, that means, from this test you will get the C_c value and e_0 value and then H is the thickness of your soil layer and p_0' is the initial effective overburden pressure before applying the load. For example, this is the foundation and this is the ground surface and you have different layers.

This is layer 1, this is layer 2, and this is layer 3 and so on. So, remember that for bearing capacity equation the thickness of the layer below the foundation base equal to width of the foundation is considered. So, that means for bearing capacity calculation influence zone is taken as B from base of the foundation**.**

So, for bearing capacity calculation the influence zone is taken as B from the base of the foundation, but for the settlement calculation the influence zone is equal to $2B$, where B is the width of the foundation and D_f is the depth of the foundation clear. So, do not forget this, for the bearing capacity calculation we consider influence zone as B from the base of the foundation and for settlement calculation we consider influence zone as $2B$ from the base of the foundation.

So, in both cases it is from the base of the foundation. Another thing you should remember suppose within your influence zone there is a rigid strata**,** suppose this third layer is a rigid strata and your influence zone is going in third layer, this $2B$ settlement calculation the influence zone is going to third layer. So, then you do not consider the third layer contribution.

As it is a very rigid stratum so, it is expected that there will be no settlement or insignificant amount of settlement or negligible amount of settlement. So, in such case your influence zone will be up to the rigid strata, that means, from base of the footing to the rigid strata, but even if that thickness is less than $2B$ because the thickness of the compressible zone may be $1.5B$, and hence that $0.5B$ portion is within the rigid zone.

So, in that case you do not consider the $0.5B$ zone, only consider that $1.5B$ zone or $1.25B$ or $1.75B$ whatever it is, because if there is a rigid strata within your influence zone, then do not consider the contribution of that rigid strata within the influence zone. Suppose within the $2B$ there are no rigid strata then you consider up to $2B$ and that may be within your third layer also, that may be fourth layer, any layer.

So you just remember that. So, now I am calculating the initial effective overburden pressure, p_0' . So, for p_0', suppose this is up to this, this is your influence zone. So, up to this, this is your influence zone and this is the thickness of the first layer say, H_1, this is the thickness of the second layer H_2, but I am not considering the thickness of the total third layer, I am considering the thickness up to the influence zone. Now if the third layer is rigid strata, but H_3 is within the third layer, then you have to consider up to this H_2, remember that.

So, this is the third layer. So, we will consider one particular point at the middle of each layer, below the foundation. So, middle of each layer, so, this is B point, this is C point. So, that means this A point is at the middle of this thickness. So, A point is at the middle of this thickness. Similarly, B point is at the middle of this here I can write this is $\frac{H_2}{2}$.

And if this is h then this value is $\frac{h}{2}$ and this will be $\frac{H_3}{2}$. So, that means at the middle of each layer. Now, the question is why we are only considering one point. So, if you consider more points, your accuracy level will increase definitely, but you have to check whether that accuracy rate is significantly increasing or not. In most of the cases if I take one point, then that is okay.

But if the layer thickness is very high then you can take more points also, in such case you divide a particular layer into number of zones or number of sub-layers. So, for example, you divide the layer 2 into say three more sub-layers and then take the point at the middle of each of the three sub-layers, and you can do the calculation by the same process that I will show okay. So, but in most of my example problems I will take only one point at the middle of each layer, but if you want you can take more points also, in such case your accuracy level may increase.

But if the thickness of that layer is not significantly large, then one point is sufficient. So, that means now $p_0^{'}$ is the effective overburden pressure at each point. So, at each point you have to calculate the effective overburden pressure. For example, A point the effective overburden pressure I am considering all the cases unit weight is same but remember that. Suppose if you have different unit weights and different location and because I have already discussed that thing during that layered-soil bearing capacity calculation.

So, if you have a different unit weight or different location then you have to calculate effective overburden pressure accordingly. So, you should know where you have to use the γ_{bulk}; that means if the zone is above the water table then you have to consider γ_{bulk}. If the zone is below the water table then you have to consider γ_{sub}, but here I am considering all γ are the same, but actually it will not be same in the field, you have different γ, even different layer will have different γ values.

Even in the layer also the water table may present. So, we have to take care of all those things. So, $p_0^{'}$ will be in this case that $D_f \times \gamma$ or I should write γ_1 because this is the top layer, the second layer, then $+\frac{H}{2}\gamma_1$. So, $p_0^{'}$ at A. So, this way I can calculate $p_0^{'}$. But remember that this is effective, it is not total. Then $p_{0\ \text{at B}}^{'} = H_1\gamma_1 + \frac{H_2}{2}\gamma_2$ and so on.

So, this is the $H_1\gamma_1 + \frac{H_2}{2}\gamma_2$ and this is the $p_0^{'}$ at A. So, this way I can calculate effective overburden pressure, but now, there is an important term which is ΔP which is the vertical stress at the center due to application of load. So, how you can calculate that? So, there are a number of ways by which you can calculate that, you can use that 2 : 1 method to determine the stress at a particular point.

So, dealing with this design I will use the simplified method which is 2 : 1 distribution. So, what is that? Suppose if you have a foundation, this is the foundation. So, I want to calculate that ΔP at B point. So, I will assume that the stress is distributing in a 2 vertical : 1 horizontal pattern.

Suppose, you have a footing with dimension of $B \times L$ and you have a load, Q acting at the base of the footing. So, that means the stress which is acting at the base of the footing is equal to $\frac{Q}{BL}$. So, total load which is acting at the footing that will be equal to $q \times B \times L$. So, this is the total load, net load acting on the foundation base. Now, when this load will distribute at 2 : 1 distribution pattern, then this loading area will increase as the depth increases.

So, at point B and at the base of the foundation the loading area will not be same. So, the loading area will be increased. So, that is why your stress at that point B will decrease as compared to the surface at the base of the foundation. So, that means as your depth increases the stresses due to external loading will decrease. So, ΔP is the additional stress or the increment of stress due to the application of external load.

So, now, how I can calculate the ΔP at point B? So, I know my area is being increased. So, now what will be that area? So, that area will be $B + h + \frac{H_2}{2}$ because your depth of the point from the base of the foundation is $h + \frac{H_2}{2}$. So now as it is 2 : 1 distribution, if this is your say any depth Z. So, this will be definitely $\frac{Z}{2}$ and this side also, if this is any depth Z, this will be $\frac{Z}{2}$ because it is 2 : 1 distribution.

So, that means if this is Z, this one is Z, this will be $\frac{Z}{2}$, if again this one is Z, this is $\frac{Z}{2}$. So, your total area will be increased by $\frac{Z}{2} + B + \frac{Z}{2}$. So, this will be simply $B + Z$. That means B + the distance from the base of the foundation to that point and that distance is Z, but in this particular case it is $h + \frac{H_2}{2}$. So, that I have written, $h + \frac{H_2}{2}$.

Similarly, this is in the width direction and there will be another one in the length direction. So, this will be $L + h + \frac{H_2}{2}$. So, in this way you can calculate ΔP. So, this is a simplest way and I will use this method for this particular case, when you have solved the example problem or design problem. So, that means, I have discussed how you can calculate the effective overburden pressure, how we calculate the ΔP, then compression index you will get from the lab test, e_0 value also you will get from the lab test and then m_v.

So, if you use this thing this first equation then this is sufficient. If you use because this is H_0 and H both are same, the thickness of each layer. So, you can write this is also H_0 does not matter. So, this will be the sum and if you use the second thing then you need the coefficient of volume compressibility. That is also you have to determine by consolidation test.

So, which one you will use depends on availability of your design properties or design parameters. If you have this C_c and e_0, then it is better to use the first one. If you have m_v then you can go for the second one. So, that means you have to calculate the settlement for each layer, then to get the total consolidation settlement you have to add them. So, that is why it is summation.

So, first you calculate the settlement contribution for each layer. And then we will add them and you will get the settlement contribution for all the layers and that will be a total consolidation settlement. So, again here also you have to apply three corrections. So, one is depth correction factor or depth correction as I mentioned, these are again all valid for the surface footing. So, if we have depth of foundation, you have to apply the corrections.

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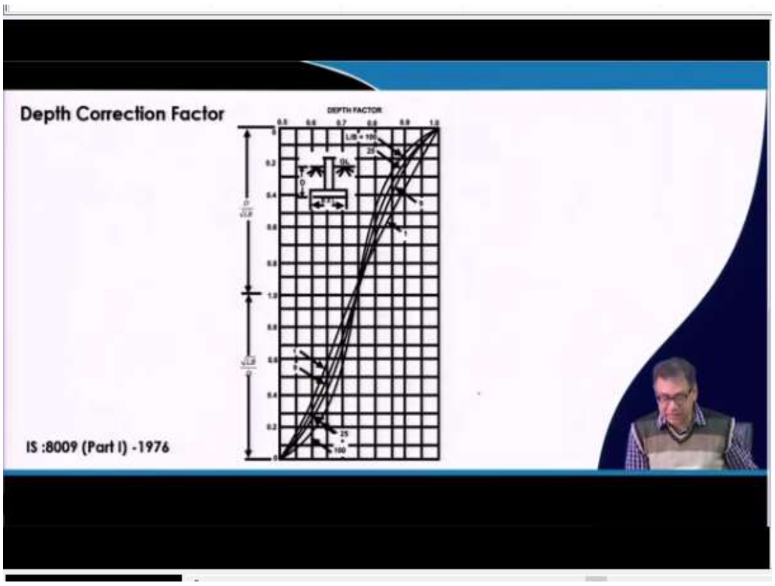

And the same way we can calculate the depth factor by using depth factor correction chart. So, that are discussed and then we have to go for the rigidity correction also. So, all these equations are valid for the flexible type of foundation, if we are using for the rigid foundation you can use them but we have to apply rigidity correction and that value here also 0.8. So, rigidity correction factor will be 0.8.

Then another correction we have to apply which was not applied in the immediate settlement, that is pore water pressure correction, what is that? Because this theory is called the 1-D consolidation theory; that means it is assumed that this consolidation is going only in the vertical direction, but in actual field when we apply a load or stress on a particular soil this pore water can move in all the three directions.

But here in this equation it is assumed that it is moving only in the vertical direction. So, it is only one direction, but actually pore pressure is developed and water is moving in the three directions. So, that is why you have to apply another collection that is called pore water pressure correction.

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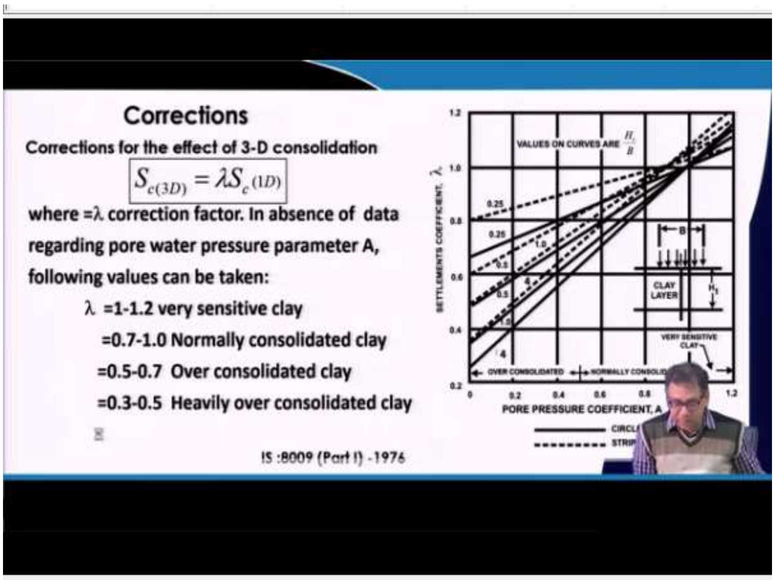

So, that pore water pressure correction that means actual consolidation is the 3-D consolidation, but here the consolidation equation that we are using that is 1-D consolidation equation. So, this is the correction. So, actual to get the 3-D consolidation, we have to apply λ, which is a correction factor. So, that we have to multiply with uncorrected consolidation settlement value.

So, now we can use this chart which is given in IS code. So, this chart you can see for this is a pore pressure parameter A and you know that the pore pressure parameter A and B, so two parameters are there. So, it is in terms of pore pressure coefficient A. So, that means if A is 1 to 1.2 then it is very sensitive clay, then 0.5 to 1 is normally consolidated clay and 0 to 4.5 is over consolidated clay. I have discussed what is normally consolidated clay, what is over consolidated clay.

And these are the values of the curve $\frac{H_t}{B}$, H_t is the thickness of the layer below the foundation. So, that means the thickness of the influence zone I am talking about below the foundation is H_t and B is the width of the foundation**,** dotted line is for strip footing and firm line is for the circular footing and this is 0.25 0.5 1 and 4. So, this one is 0.25, then this dotted line is for 0.5 this one is for 1 and this dotted is for 4. Similarly, this firm line is for 0.25, this firm line is for 0.5, this firm is for 1 and this is for 4.

So, in this chart if you have the A value then corresponding to that A value whether it is a circular footing or a strip footing and if it is in between that then you can linearly interpolate the value. Suppose you have a rectangular footing then first to calculate circular or for square also you can use the circular footing part. So, which is same more or less for circular or square you use the firm one, and strip you use the dotted one.

And if it is rectangular footing, then you can interpolate the values. So, that means here if you have the $\frac{H_t}{B}$ ratio you know that and if you have the A value, then you can calculate the coefficient that is λ by using this chart. But sometimes these A values are not available. So, if you do not have the A value, then you can use these ranges also. These ranges also you can use to get the λ value.

So, for very sensitive clay it is 1 to 1.5, normally consolidated clay it is 0.7 to 1, over consolidated clay 0.5 to 0.75 and heavily over consolidated clay 0.3 to 0.5. So, if you have the A value, then you can use this chart if you do not have the A value then you can use the value which is given from this range, because it is a range, but here if you have A value then actual value you can get from this chart. But here you can get a range, but if you do not have the A value you can use these ranges.

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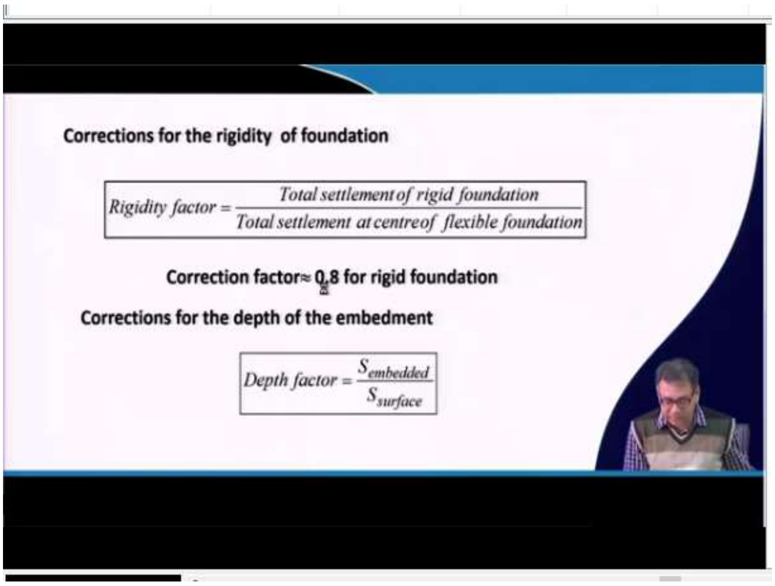

So, now as I mentioned this is the rigidity factor and depth factor. So, that means you have to use these correction factors and this rigidity factor is 0.8.

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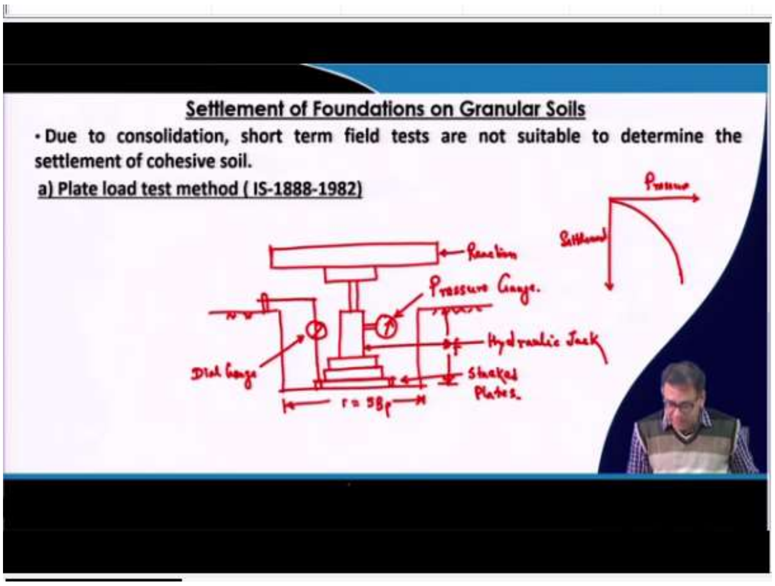

Now, next one I will discuss about the settlement calculation for the granular soil by using the plate load test, then the SPT value, then the SCPT value, then the influence chart method or semi-empirical method. So, the plate load test is done in the field. So, this is a field test for the shallow foundation by which not only the settlement, we will get the bearing capacity of the foundation also.

So, we will get the bearing capacity as well as the settlement by using plate load test. But the advantage of this test is that in most of the field test what we either calculate or determine the soil parameters directly or indirectly, then we use those parameters in our bearing capacity equation and then we will get the bearing capacity. But in the field plate load test directly in the field we will get the bearing capacity without using any parameters.

All these things are direct value we will get that, now from the field. So, that is the advantage. So, but this is a short term test. So, it is not suitable for cohesive soil generally. So, that means although we have the equations or the correlations available for cohesive soil also but this is recommended for cohesionless soil. Because that will give better result for cohesionless soil because these tests are short term test and your cohesionless soil settlement is short term with immediate type of settlement.

So, that is why you use these tests for cohesionless soil and this cohesive soil settlement is a long term settlement. So, that is why it is not recommended to use these test data directly for the cohesive soil. You can use them, but you have to cross check it with other methods also in case of cohesive soil. So, the plate load test should be done at the base of the foundation that means the depth of the plate should be equal to the depth of the foundation.

So, that means suppose we have a test plate. So, this is the test plate. So, in depth we have to conduct the plate load test and depth should be equal to the depth of the foundation. So, then we will place this stack plate because these will help us to give the load on the plate. So, this is your hydraulic jack and then through this hydraulic jack we will provide or apply the pressure and we will use the reaction frame also. So, this is the reaction frame that you will use.

So, basically we will apply this hydraulic jack and these loads will be applied or pressure will be applied through this reaction frame on the plate. So, basically we are applying the pressure on the plate and then we are measuring the settlement of this plate. That means the ultimate output will be pressure versus settlement. So, we are applying the pressure and we are measuring the settlement. We are placing the plate at the base of the foundation and then we are applying the pressure.

So, generally the minimum width of the test pit should be 5 times the width of the plate and ideally this should be the D_f, but if it is not then again we have to apply the correction. So, now as I mentioned we have to use the dial gauge, so we have to use the dial gauge to measure the settlement of the plate and then this is the pressure gauge which will give us the pressure reading and this is the dial gauge which will give us the settlement values.

So this is dial gauge and this is the pressure gauge, this is reaction frame and this one is the hydraulic jack and this is the plate. So, we will get the settlement and other pressure corresponding to the settlements, suppose this is the pressure and the settlement. So, we will get this type of curve. So, that means here we will get the curve and now from this curve, we will get the bearing capacity of the foundation as well as the settlement of the foundation. So, that I will discuss. So, ultimately we will get the pressure versus settlement curve.

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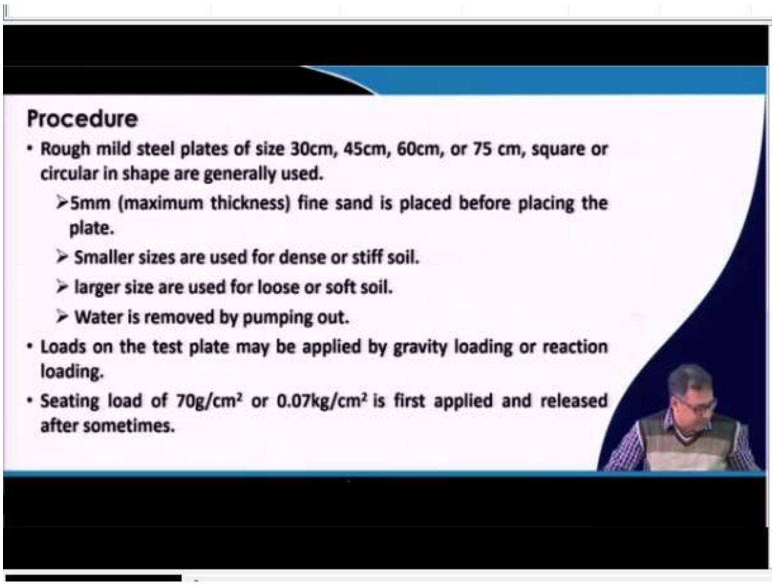

And you should know though some tips and the procedure for this particular case. So, we can use the rectangular plate or circular plate of size 30 cm, 45 cm, 60 cm and 75 cm. So, why 30 cm and 75 cm are the two limits? Because, it is observed that if the plate size is less than 30 cm, then the results that you are getting are not reliable, so, not good. So, that is why do not use any plate which is less than 30 cm.

And 75 cm also it is observed that after 75 cm the difference or the effect of plate size is not significant. It is negligible. So, that is why you use 30 cm to 75 cm plates because after 75 cm no such size effect is there. So, when you do the plate load test before you place the plate in the foundation bed or the soil, you place a 5 mm thick sand pad then you place the plate.

The smaller sizes plates are used for dense or stiff soil and the larger size is used for the loose and the soft soil. So, if there is water within your test pit, you just pump the water and remove the water from the pit. And so, these loads are given in a reaction frame. So, that I have discussed and before we apply the actual load a seating load up to 70 gm/cm^2 or 0.07 kg/cm^2 is first applied on the plate.

And then it is released after some time, why it is applied? Because it will make sure there is a perfect contact between the soil and the plate. So, it will act as a seating load.

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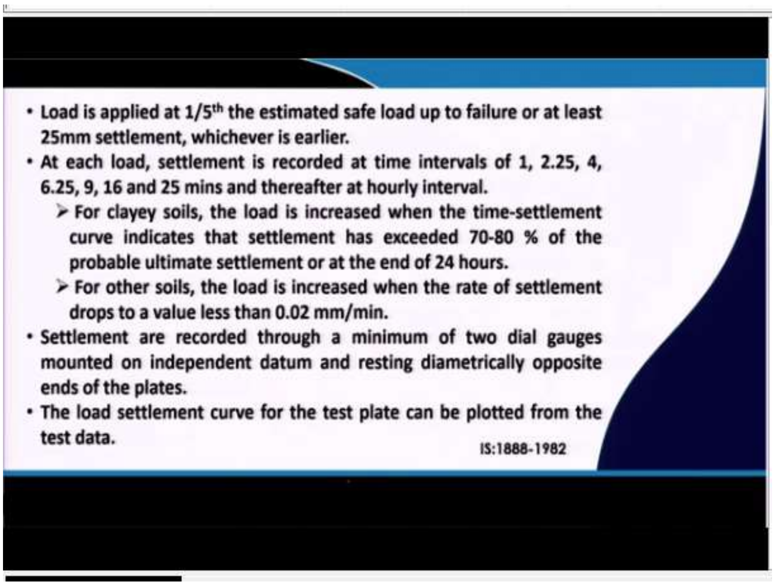

So, then load is applied as $\frac{1}{5}$ of the estimated safe load up to the failure or at least 25 mm settlement whichever is earlier. So, these are the procedures. So, in the next class, I will complete this part. So, there are some more tips. So, you should know those tips and again, I have discussed the advantage of the plate load test, but there are some limitations or disadvantages also. So, I will discuss those things in the next class. Thank you.