Advanced Foundation Engineering
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Lecture - 40
Design of Shallow Foundation - V

So, in the last class I have discussed that how we can determine the bearing capacity of that raft foundation resting on the clay soil. And then it is observed that the factor of safety that we are getting for bearing capacity consideration is 7.1 which is greater than 2.5 and basically it is oversafe. Now this class I will discuss the second part that is the settlement calculation.

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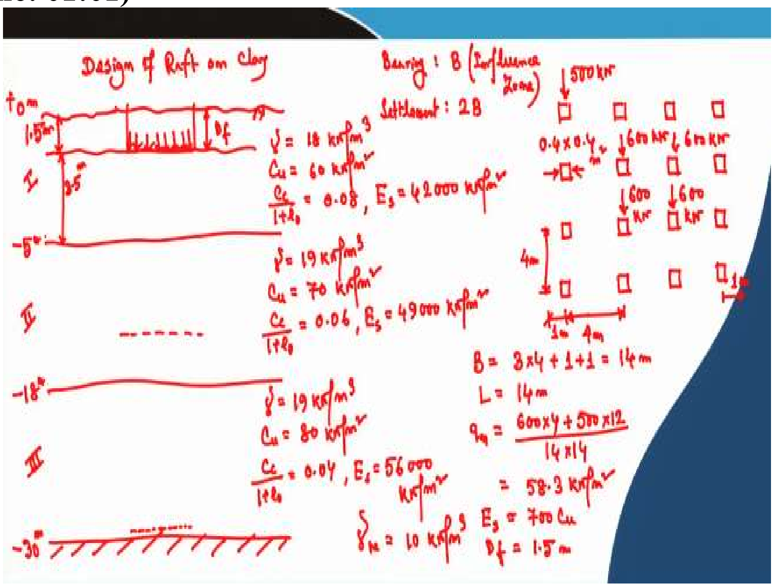

So, this is the soil profile that was taken and for the bearing capacity consideration the influence zone was your 14 m which is B and for settlement calculation it will be 28 m. So, that will be just close to the end of the third layer so, up to 29.5 m from the surface. So, now we have taken the weighted average because the variation is not that significant for the C_u value or the strength parameter.

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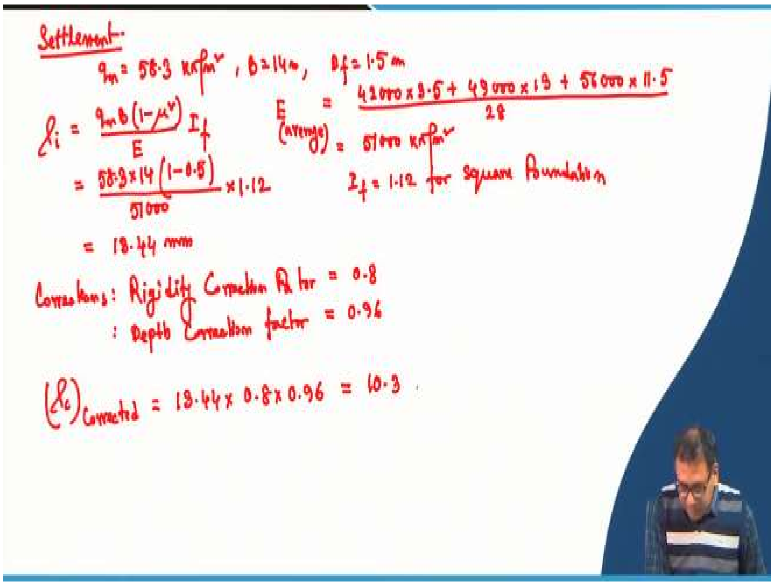

And now we will do the settlement calculation. So, q_n which is 58.3 is coming at the base of the foundation and B value is 14 m and depth of the foundation is 1.5 m and water table is also at 1.5 m from the ground surface. So, here we have to first calculate the immediate settlement so that equation I have given for clay immediate settlement and consolidation settlement.

I have given the two equations and for sandy soils I have given the five equations to determine the settlement. So, for the clay soil immediate settlement which is the elastic settlement, $\rho_i = \frac{q_n B(1-\mu^2)}{E} I_f$, where, I_f is the influence factor. So, here also what E value we will consider and see here also weighted average E value we will consider. So, $E_{(average)}$, like the previous case because we consider the weighted C_u value during the bearing capacity calculation.

So, here also we will use the weighted average E value so, that value is here you can see the first layer it is 3.5 m then total 13 m for the second layer and for the last layer it is 11.5 m. So, and again I want to mention that if your influence zone is going to that rigid portion that means, if it is below the 30 m part, then you have to consider up to 30 m that I have discussed during my settlement calculation part.

So, that means here influence zone if it in the rigid zone, then we will not consider the rigid zone we will consider the portion above the rigid zone. So, that means here average E value will be 4200 × 3.5 this is for first layer then 4900 × 13 for the second layer then 56000 × 11.5 for the third layer. Because now it is settlement, so the influence zone is 28 m from the base of the foundation. So, then it is 28 m so, these 51,000 kN/m^2. So, the q_n is 58.3, B is 14 and μ value is taken as 0.5.

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Because from the table we will get the μ value for the saturated clay is 0.4 to 0.5 so, I have taken 0.5 you can take 0.45 also, but if exact value is not given then you can take the value from this range. So, I have taken 0.5 and then weighted average E is 51000.

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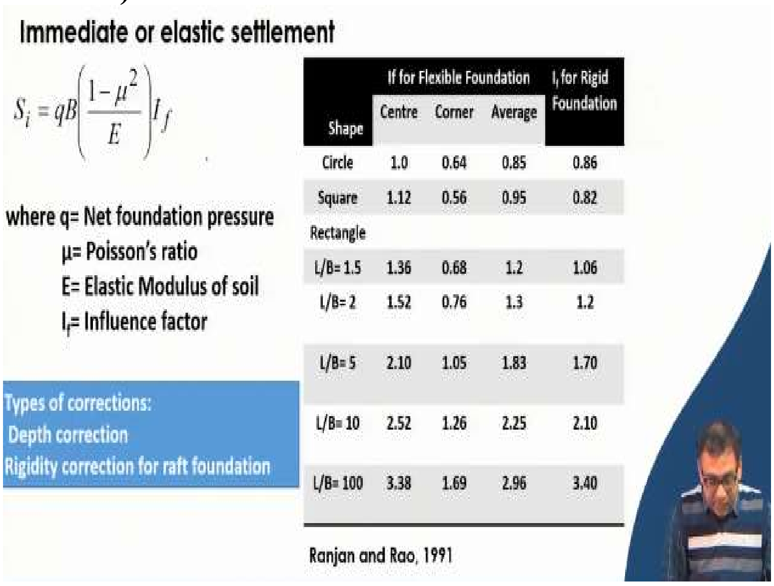

Now, influence factor table is given so, here what I am considering or I am taking that it is a raft foundation, so, it is a rigid foundation. So, directly I can take the, I_f for the rigid foundation, but as later on I will apply the rigidity correction for consolidation settlement. So, that is why I have decided I will take the centre I_f for flexible foundation then I will apply the rigidity correction of 0.8.

So, as I have discussed that this rigid foundation I_f value is 0.8 times of the flexible foundation I_f value at the centre. So, this is for the square footing, this is for the centre for flexible foundation 1.12 then I will apply the rigidity correction then I will get the settlement for the rigid foundation. So, this is 1.12 I will use so, this is I_f is 1.12 for square foundation this is 1.12 so, this value is 13.44 mm.

Now, we have to apply two corrections so, these corrections one is the rigidity correction factor which is equal to 0.8. So, now, remember that if you directly take the influence factor for rigid foundation then this rigidity correction is not required. But here I have taken the influence factor for flexible foundation that is why I am applying the rigidity correction.

Because later on in consolidation settlement calculation whether I take the higher value for flexible or the rigid foundation, I have to apply the rigidity correction for consolidation settlement. So, that is why I have used here the flexible foundation I_f so, that I can apply that rigidity correction of 0.8 here also so, rigidity correction factor and then the depth correction factor.

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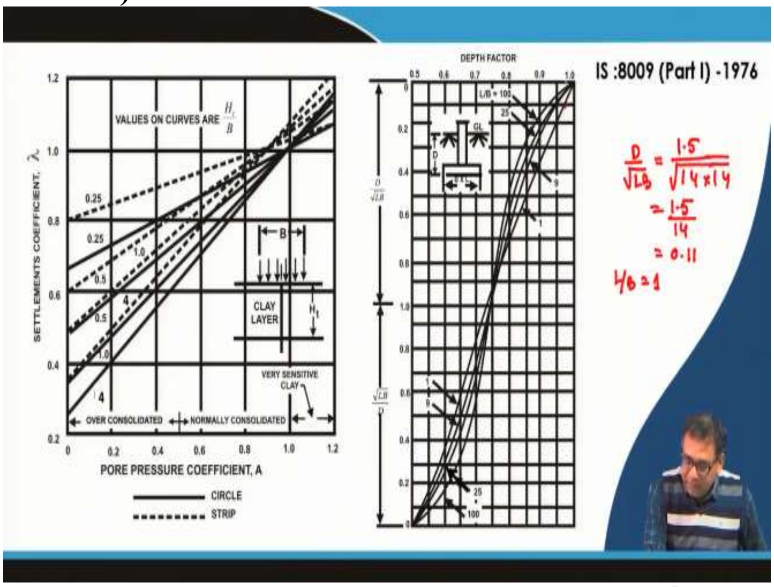

So, that value is how much? So, I will use this chart so, this chart is $\frac{D}{\sqrt{LB}}$ and this is $\frac{L}{B}$. So, this is $\frac{D}{\sqrt{LB}}$. So, that is $\frac{1.5}{\sqrt{14 \times 14}}$, because, D = 1.5, L = B = 14. So, this value is 0.11 and $\frac{L}{B} = 1$ for square so, 0.11 this is 0.1 this is 0.11 and this is for 1. So, this curve is for 1, so, the value of this correction factor is roughly 0.96. So, this correction factor is 0.96.

So, the depth correction factor is 0.96, so the immediate settlement corrected that will be 13.44 × 0.8 × 0.96 = 10.3 mm. So, the immediate settlement corrected is 10.3 mm.

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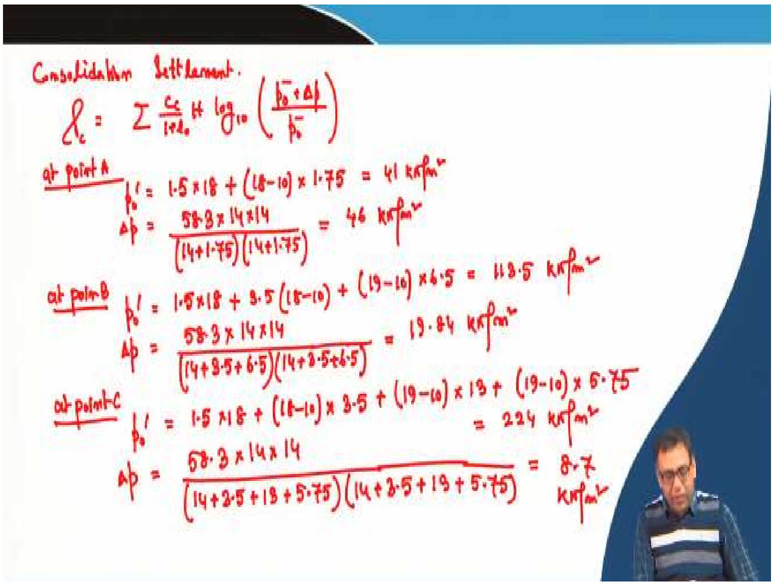

So, next part I will calculate the consolidation settlement. So, next part is the consolidation settlement that consolidation settlement equation is given. So, that is $\sum \frac{C_c}{1+e_0} H \log_{10}\left(\frac{\bar{p}_0+\Delta p}{\bar{p}_0}\right)$. Now for this purpose remember that because here we have assumed that this total soil is normally consolidated soil. So, there may be a possibility the soil may be in the over consolidated stage. So, in such case C_c you have to replace with this is compression index.

So, you have to replace the compression index and there is a possibility that initially the soil was in over consolidated stage. Now, when you apply the stress due to the external load the soil will go to the normally consolidated stage. So, in that case for some portion it will be your C_c and some portion will be the compression index. So, based on that you have to determine this consolidation calculation. So, here it is normally consolidated soil so, I have to use the total range C_c.

And then so, for that purpose we have to divide these settlement range into three zones we have taken so, we have to take the middle point of each layer, this is A point, this is B point and this is C point this is the middle of each layer. So, this layer thickness is 3.5 m divided by 2. So, this thickness is 3.5 m divided by 2 which is 1.175 m and this one is 13 by 2 it will be 6.5 m and this one is 11.5 divided by 2.

So, this is 11.5 divided by 2 so, these will be 5.75 m. So, this way we have selected three points so now I have taken only one point at the centre of the layer but as I have discussed that you can take multiple points also. So, you will get slightly better result more accurate result, but here I have taken 1 and which is sufficient.

So, now, we have to apply this equation at the points A, B, C now for at point A the $\bar{p}_0$ is equal to that for the top layer it is 1.5 then it is 18 where water table is not present that is above the water table, then you will go for the submerged unit weight and that is (18 – 10) × 3.5 divided by 2 that means 1.75 and that is equal to 41 kN/m^2.

So, Δp I have taken 2 : 1 distribution so Δp is $\frac{58.3\times14\times14}{(14+1.75)(14+1.75)}$ because we have taken 2 : 1 distribution so this is 46 kN/m^2. Similarly point B, $\bar{p}_0$ which is again 1.5 × 18 then 1.5 × 18 then 3.5 × 8 then 6.5 × 9 then + 3.5 × (18 – 10) + (19 – 10) × 6.5. So, this is 113.5 kN/m^2 and $\Delta p = \frac{58.3\times14\times14}{(14+3.5+6.5)(14+3.5+6.5)}$.

Because this 3.5 + 6.5 is the distance of the point B from the base of the foundation. So, this is 14 + 3.5 + 6.5 so this is equal to 19.84 kN/m^2. Similarly at point C, $\bar{p}_0$ = 1.5 × 18 + (18 – 10) × 3.5 + (19 – 10) × 13 + (19 – 10) × 5.75 = 224 kN/m^2. So, $\Delta p = \frac{58.3\times14\times14}{(14+3.5+13+5.75)(14+3.5+13+5.75)}$ = 8.7 kN/m^2. So, we have calculated the $\bar{p}_0$ and Δp now we have to apply this with the equation for every point.

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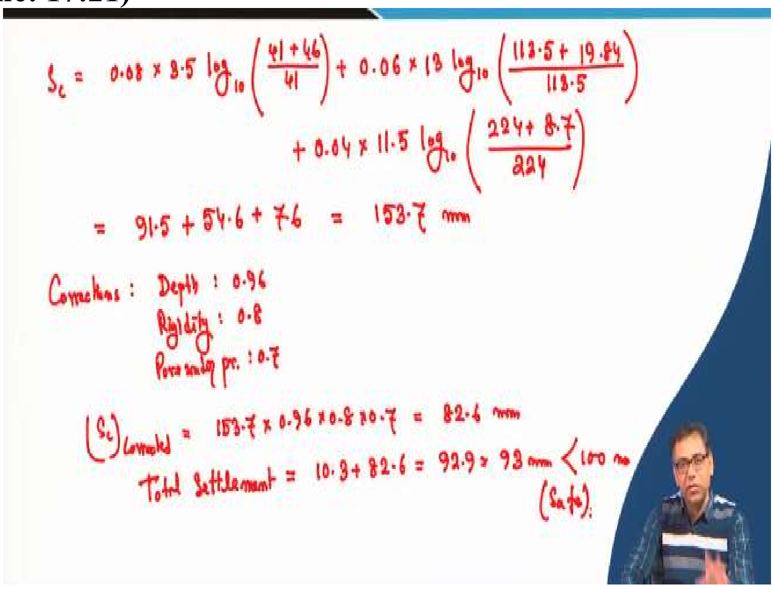

So, for first layer $\frac{C_c}{1+e_0}$ = 0.08 and thickness of the first layer below the foundation is 3.5 m then $\log_{10}\left(\frac{41+46}{41}\right)$. Then for the second layer 0.06 × 13 m is the thickness of the second layer then $\log_{10}\left(\frac{113.5+19.84}{113.5}\right)$ then for the third layer 0.04 × thicknesses 11.5 then $\log_{10}\left(\frac{224+8.7}{224}\right)$.

So, separately if I calculate then it will be 91.5 + 54.6 + 7.6 so total settlement is 153.7 mm so this is uncorrected.

So, we have to apply the corrections so what are the corrections? So, again the corrections are so for depth correction this factor is 0.96 and remember that when I discussed the example problem or the plate load test then I discussed that if the depth of the plate and the depth of the foundation are different. Then when you apply this depth correction in that case *D* will be the difference between the depth of the plate and the depth of the foundation.

So that will be your *D* based on that you have to apply the correction factor so and then you have a depth correction factor as 0.96 and then rigidity correction factor is 0.8 remember that the design of shallow foundation or isolated footing is same as the design of raft foundation only difference will be in that case we will not use that rigidity correction. Because that isolated footing you can say as a flexible type of foundation and raft foundation is a rigid type of foundation.

So, this is correction and now the third correction you have to apply which we did not apply in the immediate settlement that is a consolidation correction. So, that is pore water pressure correction and that value we will take from the chart you can see your chart.

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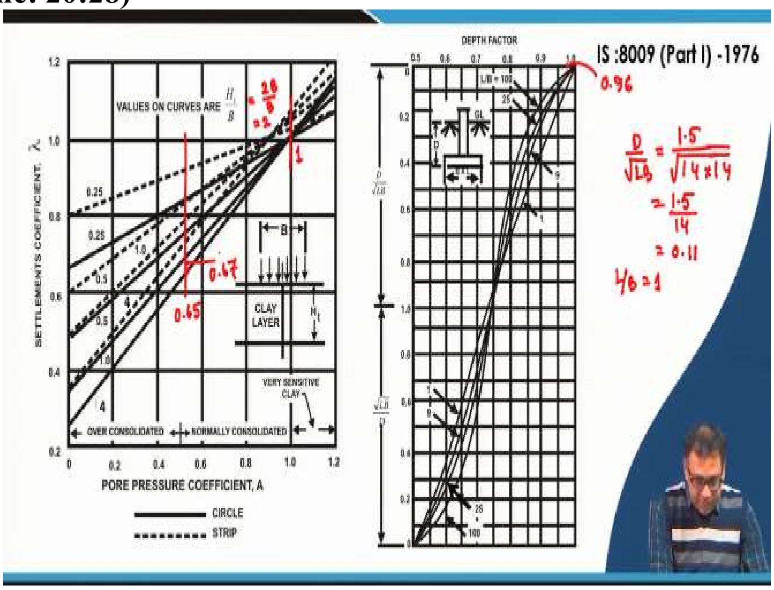

So, we can use the square footing part so, that correction factor you can see that for normally consolidated soil. So, this is the normally consolidated soil range because here *A* value is not given and during my class, I have discussed that if nothing is given then for normally consolidated soil you can take 0.7 as the correction factor for pore water pressure. So, here this is normally consolidated soil is the firm line you can go this range.

So, these ranges from 1, 2 point this is the range so 1, 2 around 0.6. So, this is the range actually so for normally consolidated soil for square footing. So, this is the probable range, so which varies from 1, 2 this is the lowest value which is 0.65. So, this is I can see 0.65 and this is 1 and definitely it will be this line because your H is the thickness of the layer below the foundation base and with B and thickness of the layer is here it is a $2B$.

So, this mean we are taking the thickness of the layer say $2B$ and this is B so, this is 2 so, 2 means this is 4 this is 1. So, that means this value will be somewhere here. So, this is this value we can say this is 0.6 this is 0.7 this will be around 0.67 or something so, this is the range, but it can be in this area also but here no information is given. So that is why I have taken it as the lower range so roughly 0.7 I am taking.

But if this A value is given then from this chart you can determine that what would be the correction factor, but if nothing is given, you can take 0.7. So, here also you can see that for normally consolidated soil it varies from 0.65 to 1 and we are taking around 0.6 so which is reasonable. But if you have this half value particularly then you should get that correction factor which is actual correction factor, but here I have taken 0.7.

So, my $S_{c(\text{corrected})}$ which will be 153.7 × 0.96 × 0.8 × 0.7, so which is 82.6 mm. So, total settlement considering consolidation and the immediate settlement will be 10.3 + 82.6 that is equal to 92.9 mm or close to 93 mm which is less than 100 mm which is the permissible settlement as per IS code for raft foundation resting on the plastic clay so that means it is safe.

So, but it is not oversafe it is properly safe I mean I should say because it is not oversafe not this value is exactly close to 100 mm. So that means we can say that even if it is oversafe against bearing but in settlement it is not oversafe. So, the dimensions and that we have chosen for the first trial, we can provide that dimension of the foundation suppose this settlement is greater than 100 mm.

Then you have to again do the second trial with new dimension and you have to check whether the footing is safe or not but that means you have to increase the dimension in that case and you have to check whether the foundation is safe or not against settlement. So that means here this particular case the settlement is the main design criteria because it is mainly controlling the design because your settlement is just safe.

But bearing capacity is oversafe so that is why we will provide the dimension that we have chosen for the first trial. So, this way we can provide the dimension of the foundation which is resting on clay. So, I have discussed the foundation which is resting on sand basically I have used the field test data in such case and then I have discussed how we can design a foundation resting on clay.

And then once you get this dimension then you can consider the soil structure interaction part and then also you can get the bending moment and the shear forces also and then considering the soil structure interaction also you can see whether the settlement that you are getting without considering this soil foundation interaction and then the settlement that you are getting considering the soil foundation interaction are close or not.

So that check also you can do that means once you get this dimension then you can go further that the soil foundation interaction part that I have discussed and then you can determine the bending moment and shear force also and then the other parameters remember that in this particular course I have discussed only the beam resting on elastic foundation because I have given the concept of that soil foundation interaction because the detailed discussion is not in the scope of this course.

So, but that beam you can use for model some different types of foundation like the strip footing I have discussed the strip footing if you can model it beam with infinite length and you can model with beam with finite length. So that means you can model beam under plain-strain condition for strip footing or when the beam with infinite width and then you can model the beam with your beam with finite width also.

So, in those cases you can use the beam on elastic foundation concept then you can use it for your railway track all these cases for combined foundation for strip footing, railway track so those cases you can use that beam on elastic foundation concept. But suppose if you are doing rectangular or square raft or a circular raft so in those cases you have to use the plate on elastic foundation so that means but that concept, I have given that beams on elastic foundation.

So that is a similar concept you can use it for the plate and then you can analyse so because the scope of these study to introduce the soil foundation interaction it is not a total course of soil foundation interaction. So that concept are given but remember that sometimes only beam concept is not sufficient you have to go for the plate also but this concept is similar that means the concept that given for the beam so that you can use firstly foundation combined plates on elastic foundation by using the same concept.

So that you remember before you do the check for considering soil foundation interaction. So that means I have finished the shallow foundation part that means in the first module I have discussed how to determine the soil properties by using different field tests then I have discussed the bearing capacity calculation, then I have discuss the settlement calculation for shallow foundation then I have given you the concept of beams on elastic foundation.

Then for the shallow foundation how you can establish the interaction between the foundation and the soil and then you can determine the bearing capacity you can determine the bending moment, shear force, settlement of the foundation then in the last module I have discussed that how you can use those concept that I have discussed that means the bearing capacity, settlement and then the beams on elastic foundation and you can design your foundation.

So, here the design means I have discussed only the dimension or the proportion of the foundation based on the field and the laboratory data. Now, from here also, once you get this proportion you can determine the bending moment and shear force by using the soil foundation interaction, if that foundation is suitable for your beams on elastic foundation concept otherwise, you can use the same concept for plates on elastic foundation.

And then finally, you will get the bending moment, shear force and then you can finally, complete your structural design part also. But the structural design part is not in the scope of this course, here we will discuss only the proportion or the dimension of the foundation and that I have discussed. So, in the next class I will start the new topic that is deep foundation. So, first I will discuss the pile foundation then next topic will be the well foundation.

So, in pile foundation I will discuss all different types of loading conditions that mean in the pile under compressive loading, then lateral load then the under uplift. So, in the first in the next class, I will discuss the type of loading that is pile under compressive loading. Thank you.