Advanced Foundation Engineering

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Lecture – 39
Design of Shallow Foundation – IV

So, last class I have discussed that how we can determine the allowable bearing capacity of foundation based on SPT value if the foundation is resting on sand. So, today I will discuss that how we can design the foundation on the clay soil. So, before I go to that clay soil design part.

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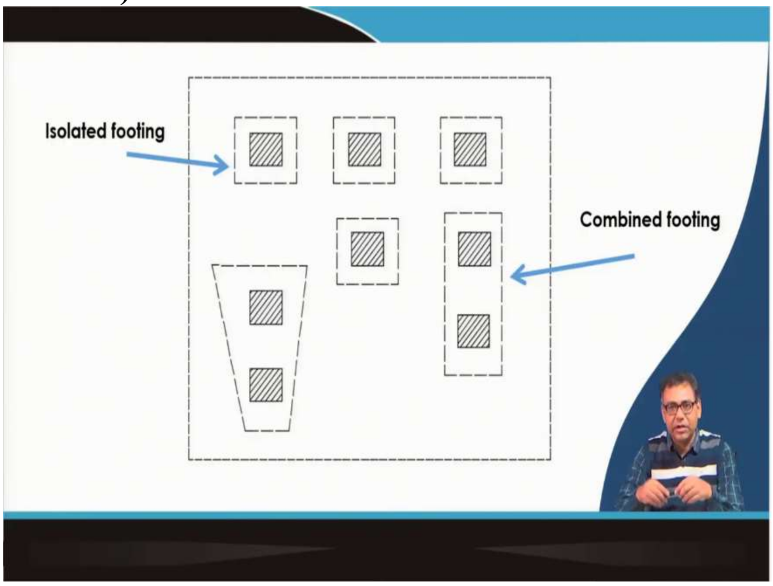

So, I will do give you an idea that how we can use the dimension for a particular combined foundation because most of the cases we have discussed the isolated footing. So, now, as you know that if the influence zones are crossing each other or that means they are touching each other for a particular purpose or for the foundations if the foundations are very close to each other then we can go for a combined foundation.

For example, these upper three footings are the isolated footings and then this is also isolated footing and now, this is the combined footing where two footings or two columns given for one particular foundation, so, this is combined foundation and this is also combined foundation. So, we can go for different shapes of combined foundation. This is a rectangle. This is trapezoidal.

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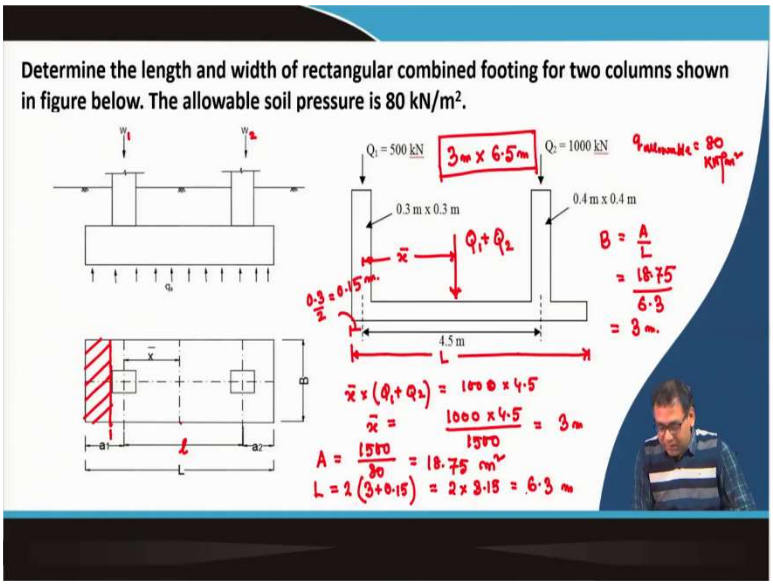

So, now, we will discuss that how we can determine the dimension of a particular combined foundation. So, this is a particular combined foundation which is a rectangle which is more or less symmetrical type of foundation. So, that means these columns are located more or less at equal distance from the edge. So, but here sometimes it is a case where the one edge and the column are in the same line.

So, this is the case where the one column and the edge of the foundation are in same line, but the another column is at a certain distance from the edge of the foundation. So, this is the total foundation width or length you can say. So, this is the foundation length and there is a width in the perpendicular direction. So, there is a Q_1 and Q_2 because this Q_1 and Q_2 may be different and which is acting on the column and so, we have to determine the dimension of this combined foundation.

So, here the allowable soil pressure or bearing pressure is given as 80 kN/m^2 and I have already discussed in my previous class how we can determine the allowable bearing pressure. So, here that allowable bearing pressure or $q_{\text{allowable}}$ which is given as 80 kN/m^2. So, one foundation is carrying 500 kN and another foundation or another column I should say that one column is carrying 500 kN and another column is carrying 1000 kN.

So, now, we have to calculate what is the centroid of the point of application of these resultant loads that means, Q_1 and Q_2 loads are acting, so, what is the point application of the resultant load. So, for that purpose we have to take the moment of these loads from one particular column. So, we are taking the moment from the edge column center. So, that load say, is acting here, so, that is $\bar{x}$ or here I should write that the resultant force $Q_1 + Q_2$ is acting at a distance equal to say $\bar{x}$ from the edge column center.

From the centroid, are the center of the edge column say so here also it is the center of the edge column this is $\bar{x}$ but this is the plan for this foundation this upper foundation this plan is different where this will be probable plan for this particular foundation. So, this term will not be there. So, the probable foundation plan for this particular case combined footing will be the without hatch portion.

So, now if I take the moment so, $\bar{x} \times (Q_1 + Q_2) = 100 \times 4.5$ because the distance between two columns is 4.5 m, so $\bar{x} = \frac{1000 \times 4.5}{1500} = 3$m, so $\bar{x}$ is 3 m. So, the total or required area of the foundation is the total forces coming 1500 kN.

And your allowable bearing capacity is 80 kN/m^2. So that is your required area of foundation is $\frac{1500}{80}$ that is 18.75 m^2 because here no factor of safety is required to apply because allowable bearing pressure is directly given it is not the ultimate bearing pressure. That means settlement and bearing both the cases are considered for allowable bearing pressure. So, that when settlement and bearing both are considered a minimum of one is given as allowable bearing pressure. m^2

Because last class I have discussed that you can go separately and provide the minimum one and there is a correlation which is available directly, by which you can get the allowable bearing pressure but the last previous case we saw that the settlement consideration is giving the minimum value or the lowest value that you provided so that value is directly given so that is why we multiply the allowable bearing pressure with the area that load should be equal to the load that is coming to your foundation.

So, here based on that, we determine the required area and that is 18.75 m^2 so my L value will be how much because this is the center and here $\bar{x}$ is the distance where the resultant loads or forces are acting and if we consider this as the center of this foundation then my required L will be 3 m that distance + 0.3 m or you can say that this is the edge.

And the dimension of this column is 3 m × 3 m and from the center we have taken the moment so you can write so these will be our $\frac{0.3}{2} = 0.15$ m. So, from this edge up to this center this distance will be $(3 + 0.5)$ because that will be total because we are taking this is the center of this foundation so this will be 2 × 3.15. So, this will be 6.3 m.

So, this will be 6.3 m; so the required length we have decided so that is 6.3 m so L is 6.3 m so the B will be A divided by L so A is 18.75 and L is 6.3 so the required B is 3 m so the dimension of this foundation is final dimension of this foundation is 3 m × if I provide in the round figure so I can provide it 6.5 m so these will be the probable dimension of this foundation you can provide 6.3 m also because that is the minimum requirement.

So, I am providing the 3 m × 6.5 m dimension of this foundation this way we can determine the dimension of the combined footing also if the allowable bearing pressure is given.

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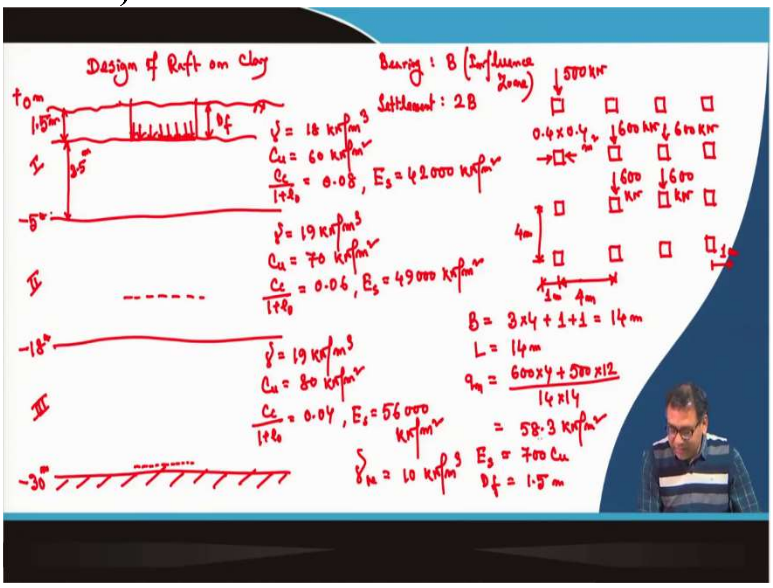

Now the next problem that I will discuss is the design of foundation on the clay soil so here this is the example problem, so we have 16 columns. So, next problem we have 16 columns in a particular building say and the spacing between the columns is 4 m in both directions and the load which is coming to the outer column is 500 kN and inner column is 600 kN.

So, all four inner columns the load is coming 600 kN and all outer column load is coming 500 kN. So, initially we have to check it for the foundation for every column if the isolated footing is fine then you can provide isolated footing provided all the settlement criteria, I mean the differential settlement or the torsion, rotation or your maximum settlement criteria are satisfied.

But in this case it is observed that these individual isolated footings we cannot provide for these type of soil properties and for this type of loading condition because your footings are overlapping with each other or may be some differential settlement issues are there so we have to provide a combined foundation for all the columns and that means we will provide a raft foundation.

So, I will discuss about the design of raft on clay. So that total width so that rafts so for the initial trial we will consider our length so length or B it will be same because it is the square pattern of building so if your length of the raft or width of the raft will be so we are taking the minimum width will be that so this column dimensions are also given so this column dimension they are given your 0.4 m × 0.4 m square.

So, the minimum dimensions will be this is 4 m 4 m 4 m so this will be 3 × 4 m and then both sides is $\frac{0.4}{2} + \frac{0.4}{2}$ so, it will be 12.4 m which is the minimum dimension that we have to provide. But for first trial if you provide just edge of your columns the edge of the foundations, so, rather than you provide some distance beyond the edge of the foundations also beyond the edge of the column also.

Because in previous case we knew we provided the column at the edge of the foundation that is a special case some restrictions are there otherwise, we provide some distance from the edge of the column also, but here also we provide some distance from the edge of the column. So, 12 m is the minimum distance that we have to provide and then I have decided to provide 1 m extra in both the sides from the center of the edge column.

So, that from the center of the edge column 1 m addition this side and 1 m this side. So, our minimum dimension for the first trial is 14 m and obviously, L will be also 14 m because it is square shaped building and for the first trial now, we will go for the net stress that is acting on the raft. The total stress, the total amount of load is 600 × 4 + 500 × 12, because each of the four columns are carrying 600 kN and each of the 12 columns are carrying 500 kN load.

So, the total load is this much and then the area which is 14 × 14. So, q_{net} is 58.3 kN/m^2. So, the net stress which is acting on the foundation is 58.3 kN/m^2 now, the soil profile. So, this is the ground surface and we have a soil profile which is 3 layered soil and there is a rigid layer below the third layer. So, this is the third layer this is second layer and this is first layer.

And properties of the first layer are given the unit weight is 18 kN/m^3 then undrained cohesion, C_u is 60 kN/m^2 then $\frac{C_c}{1+e_0}$ is 0.08 for the first layer and E_s is the elastic modulus. So, we are given the range of E_s value with undrained cohesion, C_u so, from that given range roughly we are taking $700C_u$ as the E_s or E_u. So, $700C_u$ will be your 42,000 kN/m^2.

For the second layer unit weight is 19 kN/m^3 undrained cohesion is 70 kN/m^2 $\frac{C_c}{1+e_0}$ is 0.06 and E_s is given 49,000 kN/m^2 for third layer unit weight again 19 kN/m^3 undrained cohesion is 80 kN/m^2 $\frac{C_c}{1+e_0}$ is 0.04 and E_s is 56,000 kN/m^2, so, this is a soil property and water table is located at a depth of 1.5 m from the ground surface.

And the thickness of each layer this is 0 m this is -5 m this is -18 m and this is -30 m so what are these the depth of the soil layer is up to 30 m after that it is the rigid layer and the thickness of the first layer is 5 m, second layer is 13 m and third layer is 12 m and all the properties are given so these properties are basically the lab properties because $\frac{C_c}{1+e_0}$ are determined from the consolidation test.

So, because you can use different correlations of the field test data and then you can determine the C_u values also but most of these data are tested in the lab and then these data are used. So that means these data we obtain from the laboratory test so that means here these are the data which is given and these E_s we have used these correlations and then we got this E_s with respect to the equation, also we can determine E_s in laboratory if we have the undisturbed soil sample and you will get the elastic modulus.

That also we can determine but here that data is not given so that is why you have to use the suggested correlation and that is within the range you have taken $700C_u$ so E_u is $700C_u$ that we are used here now this is your soil data now these are the loading condition and we have decided we will go for the raft foundation now for the first trial we are putting our raft at a depth of 1.5 m where the position of the water table so this is the position of the raft so the depth of foundation of the raft, D_f is 1.5.

Then you will go for the first trial. Another property is given the unit of weight of water is also given 10 kN/m^3. So, these properties are given and we have placed the foundation at 1.5 m below the ground surface because these up to 5 m the soil property is same so we have placed it here suppose even the shallow depth you have a very soft soil or the poor soil then you can place slightly in greater depth also so that you can place the foundation on a better soil but here the soil properties is same so we are putting it on the 1.5 m below the ground surface.

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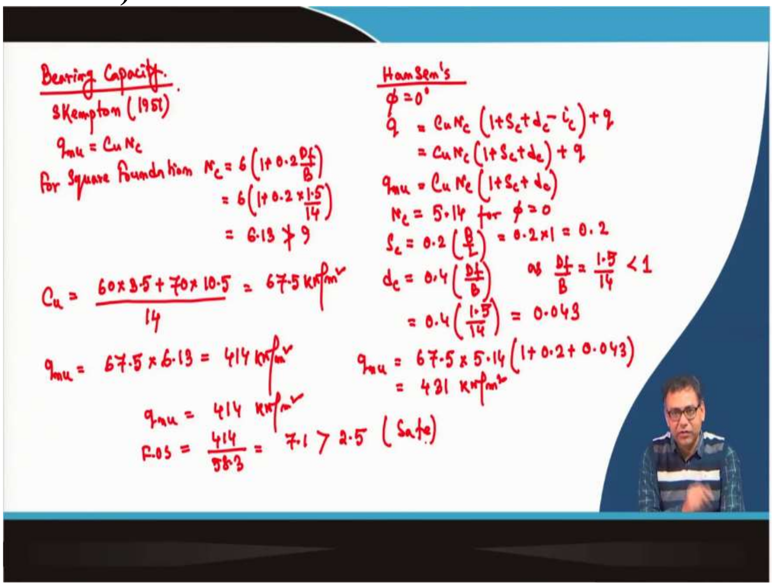

So, now we have to go for the two checks one is for bearing capacity and another is for settlement so first we are going for bearing capacity check so as I have mentioned during bearing capacity discussion for shallow foundation that it is better to use two bearing capacity equations so here it is only clay so I have decided I will go for Skempton's bearing capacity equation which is applicable for clay only.

Because here all layers of the clay soil and then I will use Hansen's bearing capacity equation and then we will decide that which value we will use so first we will use Skempton, 1951 and that bearing capacity equation is net ultimate bearing capacity is $C_u N_c$ and for square footing this is because if the square foundation $N_c = 6\left(1 + 0.2\frac{D_f}{B}\right) = 6\left(1 + 0.2 \times \frac{1.5}{14}\right) = 6.13$ which is not greater than 9 because it should not be greater than 9.

So, we can use 6.13 So, N_c value we got that is 6.13. Now, what is the C_u value because, as I mentioned in my previous example problem that for bearing our influence zone is B and for settlement it is $2B$. So, B is 14 m. So, for bearing, influence zone will be your 14 + 1.5 = 15.5

m below the ground surface. So, for the bearing influence zone usually up to this which is 15.5 m from the base of the foundation.

So, up to 15.5 m will be the influence zone for the bearing and for the settlement it will be 28 m + 1.5 m. So, 29.5 m up to here say 29.5 m. So, now, the question is which you will consider because it is on the first layer it is on the second layer also in the first layer C_u value is 60 kN per m square where the first layer is 3.5 m but the maximum part is in second layer because 3.5 m is in first layer and out of 14 m around 9.5 m is in the second layer.

So, the majority part in the second layer. So, and secondly our C_u is 70 kN/m^2. So, now what to do so, if suppose your difference of the C_u is very high then we can go for the lowest C_u value for our design to be on the safe side. But here difference is not that high that significant you can see it is 60 kN/m^2 then 70 then 80 kN/m^2.

So, that means here we will take the weighted average value and another thing I want to mention that I have discussed that you can determine the bearing capacity for layered soils but that theory is applicable if you have a very strong lower soil and very soft upper soil or very weak upper soil or strong lower soil or very weaker bottom soil and the stronger upper soil. That means the variation of the value is significantly high.

So, the top soil is very strong and the bottom soil is very soft or bottom soil is a softer soil compared to the upper soil. So, that means there is a significant difference of C_u value in such case you can use that theory also and determine the bearing capacity of the foundation in layered soil case but here that theory may not be applicable because here the difference is not that significant. So, you can see that theory which I have discussed for two-layered soil.

Even for this three-layered system also you can convert it to two-layered system, that is not a problem, because suppose your bottom layers are very soft layers. Then you can take the weighted average for the bottom layer and make one bottom layer as the soft layer and the stronger layers. You can take the weighted average and make it two layers so then the stronger layers in the top and the bottom layers are the softer layers.

In such case you can take the weighted average and make one strong bottom layer as top layer and one soft bottom layer and then you can use that theory that I have discussed for layered soil or vice versa that mean I have discussed also how you can use if there is a softer top layer and the stronger bottom layer also that theories also, I have discussed. So, both the cases you can do, but in such case your soil has to be such that there is one which is stronger portion and one is any softer portion like this.

But here it is not the case it is more or less the same C_u value you can see 60 to 80 is varying in example problem, but sometimes it can be C_u value for one layer is 21 or 24 and for another layer another it is 100 in that case you can use the theory which is proposed or some layers the range of C_u value in the bottom is say 20 to 40 and the upper layer is say 100 around 100 then that case you can use or in opposite is some layer in the top it is 20 to 40 something like that and bottom layer is stiff, say 100 kN/m^2, 120 kN/m^2.

In that case, you can use the layered soil theory but, in this case, it is more or less same. So, that is why we will take conventional bearing capacity theory by taking the weighted average of the C_u values. So, that weighted average we will take. So, this is this layer you can see this is 3.5 m and this one will be 9.5 m or 3.5 and this will be a 10.5 because this is total is 14. So, this will be 10.5. So, we can see that C_u value will be 60 kN/m^2 for the top layer then 3.5 m for the top layer.

Then thickness then the bottom layer is 70 × 10.5 total is 14. So, this is 40. So, C_u value 67.5 kN/m^2. So, one thing you can do, you can directly use the 60 kN/m^2 to be in the safe side, but as your 10.5 m most of the part is in the second layer. So, that is why I have taken the weighted average value. So, 60, 67.5 kN/m^2. So, $q_{\text{net ultimate}}$ is 67.5 × 6.13.

So, that is 414 kN/m^2 this is as per Skempton. Now, I will use Hansen's bearing capacity equation. So, if I go for Hansen's bearing capacity equation, now, for $\phi = 0$, ultimate bearing capacity, $q_u = C_u N_c(1 + s_c + d_c - i_c) + q$ but here the inclination effect is not there because loading is not inclined it is perfectly vertical. So, that is why the modified equation will be $q_u = C_u N_c(1 + s_c + d_c) + q$. So, i_c we will not consider because inclination is not present here.

So, on my net ultimate, q_{nu} will be $q_{nu} = C_u N_c(1 + s_c + d_c)$. So, net ultimate bearing capacity, q_{nu} that means $-q$ we have taken the net ultimate. So, from the chart we can see the N_c value for $\phi = 0$ is 5.14 and the shape factor, s_c is $0.2\frac{B}{L}$. So, this is $0.2 \times 1 = 0.2$. Now, depth factor d_c is $0.4\frac{D_f}{B}$ because as $\frac{D_f}{B} = \frac{1.5}{14}$, so it is less than 1 so you have to use these correlations. So, that is $0.4 \times$ our D_f is 1.5, B is 14 so this is 0.043. So, net ultimate bearing capacity, q_{nu} for Hansen is 67.5 kN/m^2 that is weighted C_u that is N_c is 5.14 then $1 + s_c$ is 1.2 and d_c is 0.043.

So, this is 431 kN/m^2. So, we have used two bearing capacity equations, one is Skempton and another is Hansen and Skempton is giving 414 kN/m^2 and Hansen is giving 431 kN/m^2. So, I am using the lower value of these two so that net ultimate bearing capacity, q_{nu} that we are using is 414 kN/m^2. So, factor of safety that we are getting is our net ultimate bearing capacity is 414 kN/m^2 and the load which is acting is 58.3 kN/m^2.

That is the net stress which is acting on the foundation so this is 58.3 so factor of safety is 7.1 which is much more than the 2.5 so for the bearing it is oversafe and we have done the checking for bearing only and as for this checking it is oversafe so now we have to do one checking that is for settlement. So, we have done one part that is the bearing capacity and that part it is oversafe.

But let us see how we will do the settlement check and what is the settlement value for this particular raft foundation on these particular soil strata? Then based on these two considerations, we will decide what will be the final dimension that we will provide so in the next class I will do the settlement calculation for this particular foundation and then we will decide what would be the actual dimension of the foundation thank you.