Advanced Foundation Engineering
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Lecture - 69
Foundations on Difficult Soils - I

So, in this lecture, I will start a new topic that is the foundations on a collapsible soil. So, I will discuss about foundation on difficult soils. So, I will discuss the foundation on two types of difficult soil one is collapsible soil and other is the expansive soil. So, first I will discuss the collapsible soil then I will discuss how we can design the foundation on the expansive soil.

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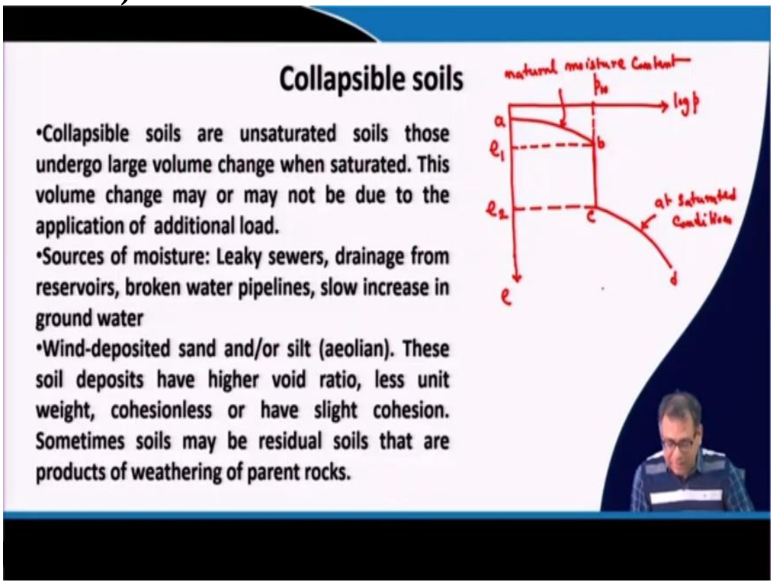

So, now, what is the collapsible soil? The collapsible soils are the unsaturated soil that undergo large volume change when they are saturated. Now, this volume change may be or may not be due to the application of additional load. So that means, suppose soil is unsaturated condition and then when we saturate that soil suddenly there is a huge volume change, large volume change even if we have not applied the additional load on the soil.

So that type of soil is called the collapsible soil. For example, suppose if we draw the $e \log p$ I mean, void ratio and the pressure curve. So, this is the $\log p$ axis and this is the void ratio axis. Now, from here to here, suppose this is the behavior under natural moisture condition, so that means this is the path from a to b is under natural moisture content. So, here soil is under unsaturated conditions, so this is the behavior.

So that there will be a decrease of the void ratio, as we increase the stress, so this is the e_1. So, at that point we apply the stress p_w, so this is we should say, so this is under natural water content condition. So, and then if we apply the stress then the void ratio will decrease and then at this point b, the soil is saturated. So that means, this is under initial from a to b is under unsaturated condition or natural moisture content condition.

Then when we apply the stress then the void ratio decreases and this ab is the path of that soil under natural moisture content condition, but at that point b, now the soil is saturated but without applying an additional stress there will be a large volume change. So, this will be the known path. So that means we have not applied any additional stress, but there is a reduction of the void ratio. After that if I apply the stress then it will behave at saturated condition.

So, cd is the path for saturated condition but at the saturated point or the saturation point, you can say there is a large volume change without application of additional stress. But after that when the collapse is done then a volume change, a large volume change occurs then, if I apply the stress then soil will undergo a path c to d which is under saturated condition. So, this type of soil behavior is called the collapsible soil and we have to design foundation for this type of soil.

So, now when where the source of moisture because we know the soil is under natural moisture content condition, now, if suddenly the moisture content of the soil increases and soil becomes saturated then it will collapse. Now what are the sources of this moisture? The sources of this moisture are the leak of the sewage pipe, drainage from the reservoir, broken water pipeline slow increase in groundwater level, because of these reasons the soil moisture content may increase.

And when the soil will become saturated then suddenly there will be a huge volume change or the collapse of the soil. So, then the foundation will also undergo a huge settlement. So, this is the reason and this type of soil is called a collapsible soil. Now, the wind deposited sand or silt, basically the aeolian soil deposit has higher amount of void ratio, less unit weight, it can be cohesionless or have slight cohesion.

So, in this type of soil there is a probability that it may be collapsible soil. If little amount of cohesion is there then due to the saturation, this soil loses its cohesiveness. So, the strength is reduced there is a possible amount of collapse. And if this is the wind deposited sand then the void ratio is very high, so because of the saturation there may be a large amount of volume change. Sometimes the soil may be a residual soil that are product of weathering of parent rock.

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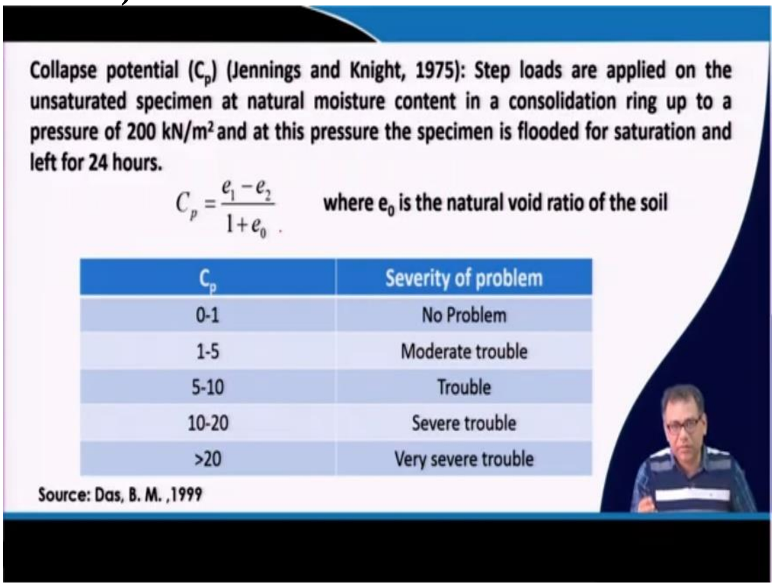

Now that there is a term called collapse potential, so by which we can identify that if the soil has some problem related to this collapse. So, this collapse potential is what? That we apply step loads on the unsaturated specimen at natural moisture content in a consolidation ring up to a pressure of 200 kPa. So that means, we place the soil sample in a consolidation apparatus, or Oedometer and in the consolidation ring under the natural moisture content condition or under unsaturated condition.

We applied the stress or the load on the specimen gradually up to a pressure of 200 kPa and at that pressure the soil sample is flooded for saturation that means, soil sample is now saturated and we left it for 24 hours and then we measured the change in void ratio. So that means, here it will follow the same path that means, from a to b, p_w will be in that case the stress that is applied at point b will be 200 kPa.

And then at a to b it will follow the path for the unsaturated condition or natural moisture content condition then it is flooded and kept it for 24 hours then it will go from a to c. So, we will measure e_1 and e_2. And then we will write this collapse potential, $C_p = \frac{e_1 - e_2}{1+e_0}$, e_0 is the natural void ratio of the soil. Now, if this collapse potential is 0 to 1 then it is okay no problem then 1 to 5 there is a moderate risk or trouble then 5 to 10 it is trouble, 10 to 20 at severe trouble and greater than 20 it is very severe trouble.

So, depending upon this collapse potential, so when you do the consolidation test if we find that this collapse potential is very high or it is within the risk zone then we have to take care for this type of soil when you construct the foundation over it.

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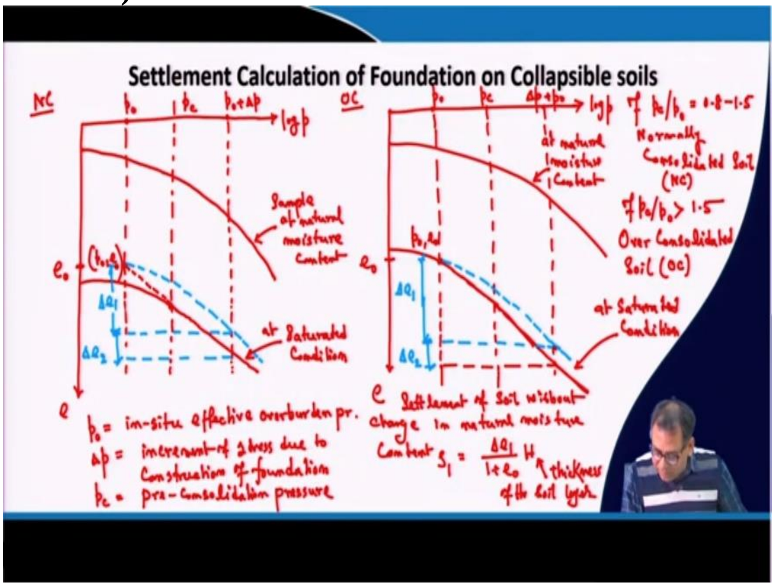

Now, how I will calculate the settlement on foundation which are constructed on the collapsible soil. So, for this purpose, two samples are required, so two samples are taken. So, then both the samples are placed within the consolidation ring or the consolidation apparatus that is the oedometer apparatus and they are placed under 1 kPa stress and they are kept for 24 hours. So that means, we have taken two samples and both the samples are placed in oedometer apparatus or the consolidation apparatus.

And a stress of 1 kPa is applied on both the samples and both the samples are kept for 24 hours. So, now, at this situation both the samples are under natural moisture content condition. Now, after 24 hours, one sample is flooded for saturation and another sample is kept still under natural moisture content condition. So, now we increase the load gradually on both the sample, one is under natural moisture content condition and another is under saturated condition.

And then we will measure the volume change for every load increment and then we will get a path for saturated soil and unsaturated soil or soil under natural moisture content condition. So, I will show you how we can calculate this collapse settlement. So, I will show the two cases one is normally consolidated soil, one is the over consolidated soil. So, suppose this is the *e* value, so now an *e* curve. So, this is the path say, sample under natural moisture content.

Now, we have applied a p_0 stress here. So that p_0 is basically what? And there is a $p_0 + \Delta p$ also. Now what is p_0? p_0 is the in-situ effective overburden pressure and Δp is the increment of stress due to construction of foundation. So that means, the stress is applied up to p_0, so at the p_0 that means, the soil will undergo the effective overburden pressure that it is subjected to in the field.

And then we will add additional amount of stress Δp that is the increment of stress due to the application of the other construction of the foundation. So, this is the p_0 line and this is the $p_0 + \Delta p$ line and this is the path for natural moisture content condition. So, now, then I will get another path, this is the path of this soil. This is the path of the soil under saturated conditions. So, we have taken two samples, one is under natural moisture content condition, another is saturated condition.

So, this is the path for saturated conditions. Now, I should write this curve properly so it will come, so this is the curve. So, what I will do from this curve with the saturated condition I will determine what is the pre consolidation pressure, so that procedure is being explained in your soil mechanics course, you can use Casagrande method by which from this curve you can determine what is the pre consolidation pressure?

So, for example that pre consolidation pressure is this one. So, this is your p_c. So, this line corresponding to p_c which is pre consolidation pressure. So, what is p_c? p_c is the pre consolidation pressure. So, now, if that $\frac{p_c}{p_0} = 0.8 \text{ to } 1.5$ then that soil is called normally consolidated soil or you can say in short NC and if $\frac{p_c}{p_0}$ is greater than 1.5 then it is over consolidated soil or OC. So, this curve that I am drawing, this is for NC, normally consolidated soil.

So, once I get the p_c value then I will extend this line that means this straight line. This straight portion is extended and say this point, so this point corresponding to this e will give us e_0 and this coordinate of this point will be (p_0, e_0). Now, I will draw a curve which is same as this natural moisture content curve, I will draw the same curve actually this curve is less likely, this will be the curve actually.

So, this is the curve which is same as the natural moisture content curve, so that I will draw from this point. So, this curve is same as this curve, so that means this curve and this curve both are same. So, we have drawn this natural moisture content curve, now where it is cutting with this $p_0 + \Delta p$ point. So, there I am drawing one line and here also I am drawing one line.

So, this value is Δe_2 and this value from this point to this point is Δe_1 and definitely this is not in proper scale, but this is the value. So that means, what does it mean? That from this original point to this $p_0 + \Delta p$ point for the natural moisture content curve the settlement or the void ratio changes, Δe_1 and for the saturated sample the additional void ratio changes Δe_2 and that is the change in void ratio due to the collapse of the soil.

So, similarly I can draw the curve, similar curve for over consolidated soil. So, for the over consolidated soil also I can draw the similar curve, $\log p$, so this is again p_0 then this is $p_0 + \Delta p$. So, for the over consolidated soil, so again this curve, this is for the natural moisture content. So, this is for over consolidated soil.

So, we have this p_0 line and we have $p_0 + \Delta p$ line and then we have the other soil which is under saturated condition, this is the soil under saturated condition. So, what we will do? We will because here we will locate this point because it is already a straight line. So, extension is not required because here the straight-line portion has been extended.

So, this point will be treated as (p_0, e_0) and this value will be e_0. So, there is a, so I have to draw this curve because this is a p_c line, so up to that this is one change in line then there will be one change in slope. So that mean, here then there is a change. So that means, this is a straight line almost. So, we have already located, so that means here we locate the p_c point.

And then this is the e_0 and then we can take this point and we can draw now the same curve which is from here which is for natural moisture content. So, again this curve and this curve are same and then we will take this point also. So, this will give us Δe_2 and this will give us Δe_1, the same way but two different soils. Now, how I will get the settlement? So, settlement of soil without change in natural moisture content that is, $S_1 = \frac{\Delta e_1}{1+e_0} H$. Now H is the thickness of the soil layer.

This is the thickness of the soil layer or collapsible soil layer, so we will get Δe_1 value form here. So that settlement is without changing natural moisture content. So that will be $\frac{\Delta e_1}{1+e_0}H$.

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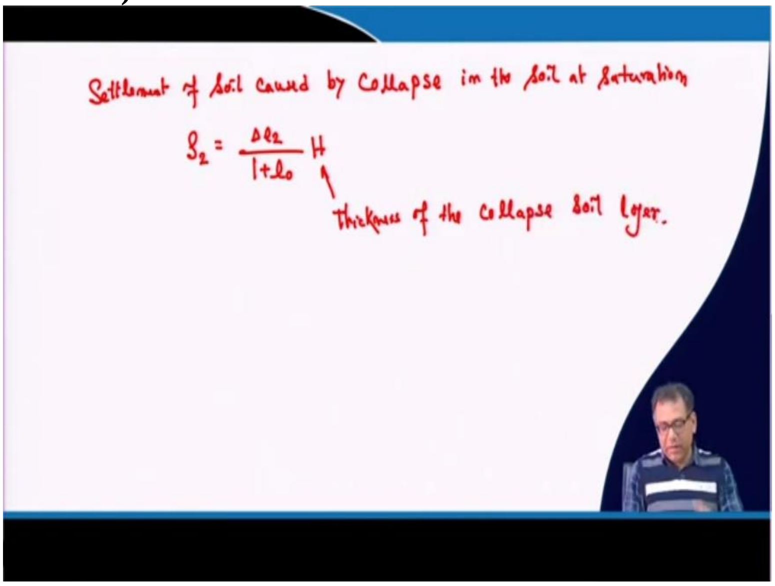

Now, the settlement of soil caused by collapse in the soil at saturation because of this saturation there will be a collapse and that settlement is a S_2, so that you will be $\frac{\Delta e_2}{1+e_0}H$. Again H is the thickness of the collapsible soil layer. So, this way we can calculate the settlement of the foundation.

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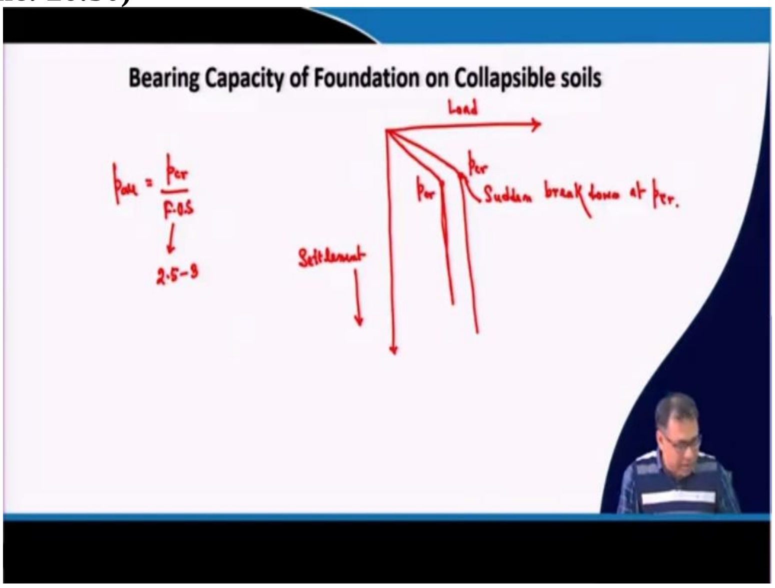

The next one is that, how I can calculate the bearing capacity of the foundation in collapsible soil, so we will have to do the field test or field plate load test. So, once we get the plate load test data, so we will find, so this is the load versus settlement. So, we will find this type of curve. So, this is the load versus settlement curve and there will be sudden fall of the curve, like this.

Or there will be a very quick duration, there will be a huge amount of settlement or there will be a sudden fall of the load or settlement there will be huge settlement. So, this point is called p_{critical}. So, these are called critical stress or critical pressure or we can say this is the sudden breakdown at these points. So, there will be sudden break down at p_{critical}. Now, the $p_{\text{allowable}} = \frac{p_{\text{critical}}}{\text{Factor of safety}}$.

So, generally this value is taken as 2.5 to 3 and this type of behavior is very common for saturated condition as compared to the dry soil condition. So, this way we can determine the settlement of the foundation on the collapsible soil and if I do the plate load test, we will get the bearing capacity of the foundation on collapsible soil.

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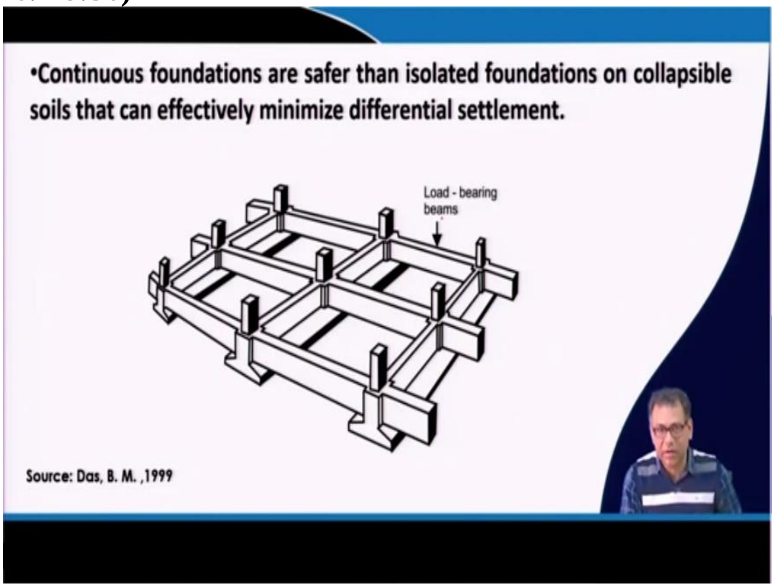

Now, still we can take some precautions when you can start foundation on the collapsible soil. So, the continuous foundations are safer than the isolated foundation on collapsible soil that can effectively minimize the differential settlement. So, this type of load bearing beams we can provide to connect the columns. So that, there will be a continuous type of or a type of foundation is not an isolated footing. So, isolated footing is not a good idea. So, we can provide this type of foundation.

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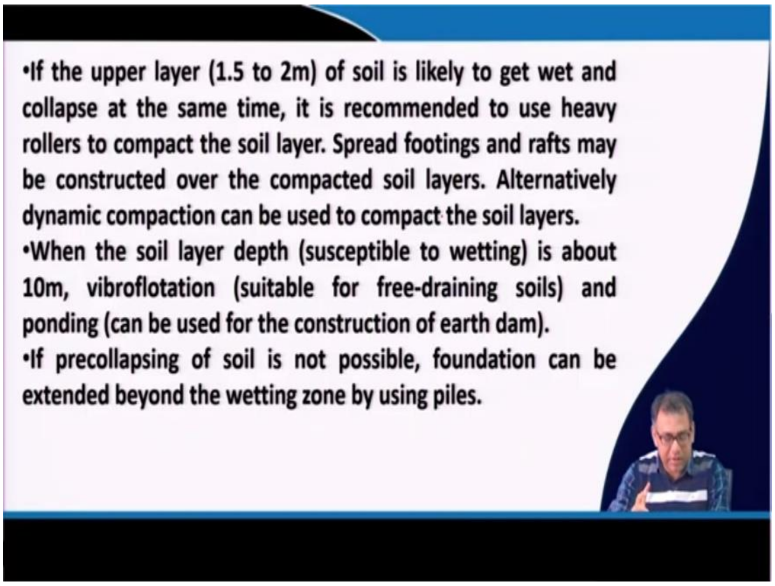

And then if the upper 1. 5 m to 2 m of the soil layer is likely to get wet and collapse at the same time, then it is recommended to use the heavy roller to compact the soil layer. Suppose if the collapsible soil layer is a shallow depth or shallow, the thickness is small then we can apply the heavy roller to compact this soil. Suppose, as I mentioned, so this soil has very high void ratio.

Now, if we compact this soil and then we can reduce the void ratio then we can minimize this collapse of the soil or minimize that settlement. So, then spread footings and rafts may be constructed over that compacted soil. Now, foundation can be constructed on the compaction soil or alternatively we can use the dynamic compaction also, so that can be used to compact this soil layer.

So, these ground improvement techniques, dynamic compaction, vibroflotation, so these are all the common ground improvement techniques, so those are taught in your ground improvement course. So, you can see any ground improvement book or any ground improvement course then you will find what are these techniques? But here there is no scope to explain all these ground improvement techniques in this course. So that is why I am just giving the names.

So, what are the techniques you can use to minimize this collapse of the soil? That means, you can provide the heavy roller or you can provide the dynamic compaction to minimize the voids and to minimize the collapse and then we can construct the foundation over this compacted soil. Now, if the soil layer depth that mean collapsible soil layer depth is large, so that is 10 m then we can use the vibroflotation which is suitable for free draining soil.

And that means we can provide vibroflotation to compact the soil or there is another option, if I saturate the soil or that is called the ponding, if I saturate the soil before the construction, so in my first picture I have shown, so this is my settlement. So, this is the unsaturated condition then soil has been saturated. So, then there will be a collapse or large deformation then if I apply this load then it will follow condition under saturated state.

So that means, if before the construction if I do that collapse of the soil by saturation and then we will follow the c to d part when the construction will start when the load will be applied. So that means that sudden collapse or sudden void ratio increase or volume change will not happen. So that means, either we can compact the soil or we can make the soil saturated, so that you will get the collapsible volume change before the construction is started, so these are the options.

Now, if the pre collapsing of the soil is not possible or the compaction also not possible then we can extend our foundation beyond this wetting zone or collapsible soil zone by providing piles. So, these are the techniques by which we can minimize the risks of the collapsible soil settlement or the huge volume change or large volume change on the foundation and then we can calculate the settlement of the foundation on collapsible soil.

And then this value, the acceptable settlement is up to 30 cm. So that means, this collapsible soil settlement, so this is up to 30 cm. So that means, this value should not be greater than 300 mm. So that means, we have to make our foundation such that, so this up to 0.3 m or 30 cm or 300 mm settlement it is okay, but it should not be more than that. So, also we can calculate the load carrying capacity of the foundation by using plate load test.

And then once the foundation will be constructed, if the soil is collapsible soil then we can improve that soil by using vibroflotation, if the thickness of the soil zone is large or for shallow thickness or the shallow depth we can provide dynamic compaction or the heavy roller or we can go for the ponding also, if these are not possible then we can extend our foundation beyond the wetting zone by providing pile foundation. So, in the next class I will discuss the foundation on another type of difficult soil that is the expansive soil. Thank you.