Ground Improvement

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Module 01: Introduction

Lecture 05

Excavation and Replacement, the simplest GI method

Hello everyone, good day to all of you. And once again I welcome you to this lecture Ground Improvement and still we are in module 1. Though, I have kept this information one in the introduction part it is already over in module 1. But, I wanted to keep this one in the module one.

I have already started this particular method of ground improvement technique that is the excavation and replacement, the simplest GI method, GI means Ground Improvement method. So, this one I will try to discuss in this lecture and already I have mentioned that the different ways when the site is not suitable for any construction or it has possibility of large deformation or low shear strength or high permeability those type of difficulty when it is there then we generally adopt Ground Improvement technique.

And sometimes close to the ground surface, we will see generally some thickness of soil is quite poor, that soil is generally not suitable for foundation. So, many times one of the simplest solution for those areas will be that you excavate some portion that soft soil at the top and then replace by good soil then it works. But if the work is a very big one, and the depth of that poor soil is quite deep, then sometimes it is not economic, then you have to go for some other techniques.

So, assuming that it is a limited area and small work, then excavation and replacement work well and if it is there, if you apply, how you will apply? What are the different aspects that we will try to discuss in this particular lecture.

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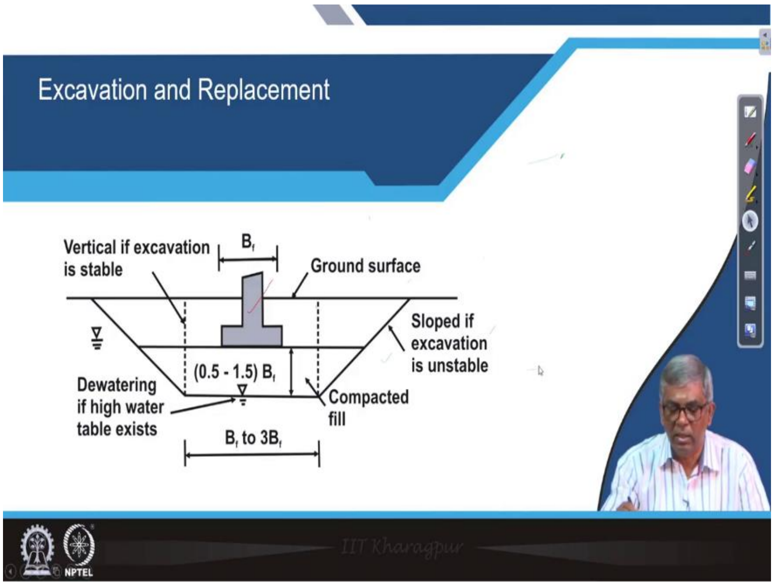

So, let me go to the first slide and you can see that excavation and replacement by enlarge how it is shown you can see here. Suppose, this must depth up soil actually soil is this area is not good, and we can typically excavate and then can replace this soil like this and then foundation can be laid here. But you can see here that there are several other possibilities if there is water table is very close then you cannot excavate then you have to lower dewatering is required, then you can see vertical if excavation is stable.

So, we can excavate like these, if the soil is quite stable, self-standing. If it is not, is very poor, then it is collapsing type then you have to make this slope. Then these are all various aspects of excavation and replacement is mentioned either you can excavate like this, replace this or you can excavate like this and replace this portion and again when you try to excavate like this and water table is close to the ground surface, the difficult to excavate in that case then we will be pumping will be done to lower the groundwater table.

So, these are all different aspects. So, here actually if this is the foundation width and then how much depth is required that has to be designed. Similarly, if this is the footing width, how much this area, how wide it has to be the replaced zone that also has to be designed. So, these are all different aspects, we will go through one by one before going through the design aspect, let us see certain general aspect of this excavation and replacement.

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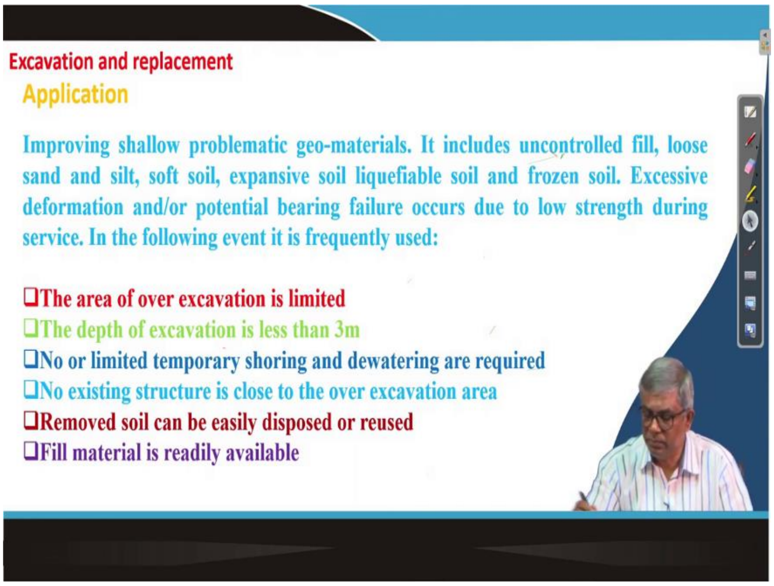

And you can see observe the application on excavation and replacement. The improving shallow problematic geo-materials. So, shallow problematic geo-materials, that means suppose maybe up to one metre so that, to improve that you can use this excavation and replacement method and it includes uncontrolled fill but when actually it is uncontrolled fill, generally it will be not good.

So, that area can be used, loose sand, if it is the ground surface close to the ground it was loose sand is there that can be removed and coarse sand can be refilled, then if it is silt also there that also can be there, soft soil if it is there close to the ground then also can be applicable. So, expansive soil if it is there, then liquefiable soil is there or frozen soil. So, these are defined.

So, by enlarge your main objective it is the shallow problematic geomaterial, but in these it can be of uncontrolled field or loose sand or silt, soft soil, expansive soil, liquefiable soil or frozen soil. So, excessive deformation and potential bearing failure occur due to low strength. So, this type of soil whatever is mentioned, it has excessive deformation or low bearing capacity that is why better to remove unless you use some other technique better to remove it and we can bring it as good soil.

So, that is the way we generally use and now, you can see what is this and then where actually it is not everywhere it cannot be used. So, that is why there are some limitations the area of over excavation is limited that means a small area that sort of this project is small. Even huge project several kilometre long road suppose if you want to make and if this method is to be adopted, it may be expensive, because you have to bring good material.

So, the depth of excavation is less than 3 metre if it is more than that it is not suitable. Similarly, no more limited temporary shoring and dewatering are required if you require some support and dewatering again this may be not good. No existing structure is close to the over excavation area. Suppose I want to excavate and make the replacement but while already there may be some utility lines and all then difficult to excavate, then remove or remove soil can be easily disposed or even used.

So, whatever soil is removed if you have to dump somewhere then easily occupy some area. So, if it is there is a provision that it can be used somewhere then only this method can be used. Fill material is readily available that is most important that you excavate poor material, but if your good material is geo material it is not available close to that then it also become expensive. So, maybe difficult to use. So, these are all some application limitation etc, we have mentioned here. Next slide.

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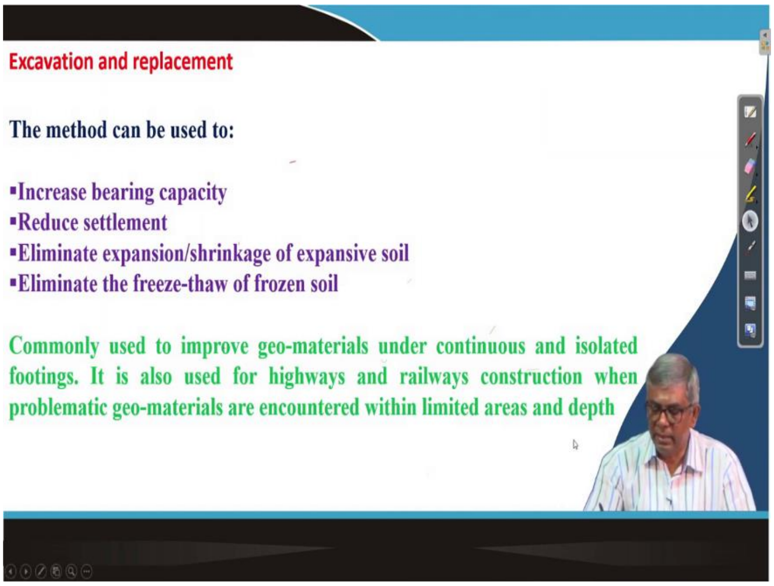

So, the method can be used. Here, what is the purpose of over excavation and replacement? Then, they say the same thing any ground improvement technique the major activities the increasing bearing capacity, reduce settlement, eliminate expansion or synchronise, if there is a expansive soil, then if you remove the expansive soil from the top then that soil shrinkage is also very reduced, they eliminate the thaw of frozen soil that also similarly, these are the different aspects where actually it can be addressed.

Commonly used to improve geomaterials under continuous and isolated footings. So, that is what below the footing. Generally, if your this is the area and your footing location is here, one footing location is here, another footing location is here, another footing location here this is very common, that you excavate this portion and then replace and then construct the footing from here.

Similarly, you excavate here and fill good material then put the so entire area we are not filling sometimes or suppose there is a number of foundations of continuous footing and below that you can excavate and refill and then put the foundation. So, like this, this is the common area and also use for highways and railways. Like, sometimes highway, railway also some portion is removed and then good material is placed to improve the bearing capacity and reduce settlement. Let me go to the next slide.

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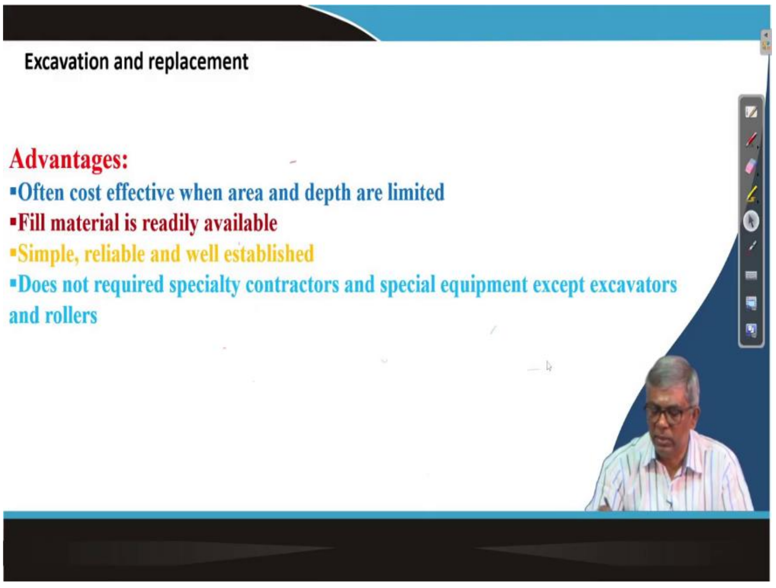

Here actually what are the advantages if you use this, you can see the advantages are often cost effective, when area and depth are limited. Then, it has smaller depth, smaller area than it is generally economic, then fill material is that it is readily available material is available then obviously it will be advantageous to use this method then simple, reliable and well established.

It is very simple because you have to cut soil and you have to pore soil under good soil and reliable also because you understand. Actually if the good material is there bearing capacity theory etcetera is all known, so it is we can understand well, So, because of that it is a very established method and does not require speciality contractors, though excavation and replacement, you do not require any special company or special equipment.

Because of that, it is generally good. So, these are the few advantages you are seeing but at the same time it has many disadvantages. So, you cannot without any question you cannot recommend that since the site is not suitable, you just excavate and replace that method that is the way you cannot do there are several disadvantages. And that I will show you in the next slide.

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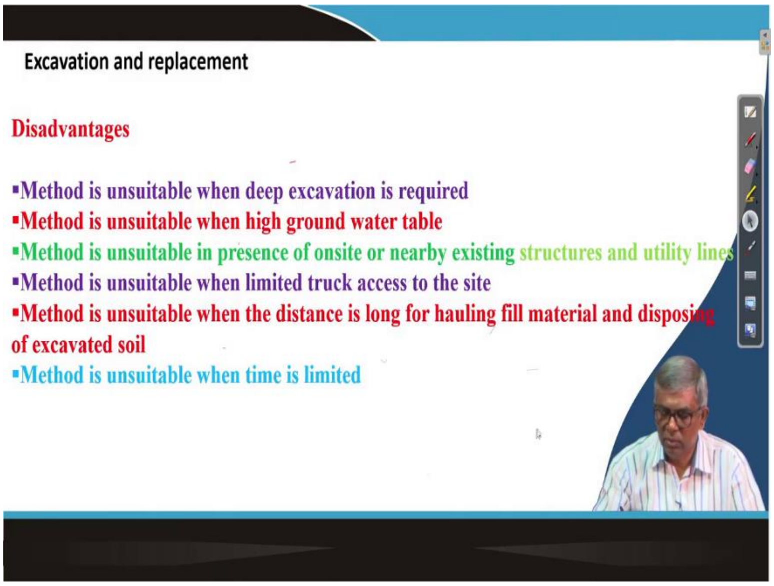

You can see here the disadvantages are more than the advantages you can see here method. It is unsuitable when deep excavation is needed. So, that means, if it is a 4 or 5 metre deep soft soil, then you cannot think of excavate and replace similarly method is unsuitable when high groundwater table.

So, if the water table is just 4.5 metre from the ground then how will excavate if we want to excavate then that water will come and then it will be difficult to excavate. So, dewatering is required. So, that will add some cost. So, that is not suitable. Similarly, method is unsuitable when limited track access to the site. So, then replace that when you want excavate, you have to carry this one and dump somewhere and you want to bring good material also from the site from some source to the site, if that that road is not available, then this method also not suitable.

Access is also is an important. Method is unsuitable, when the distance is long for hauling, fill material and disposing of excavators and that hauling means you have to carry several kilometre distance the good material and again dispose the excavated material again several kilometre then this method will not work.

Similarly, method is unsuitable when the time is limited, that means, when you have to do very quickly the project completion time is very limited, then if you think of excavate and then replace and then compact, all those things that time will not permit so, that it will not be suitable. So, these are actually disadvantages. You have to look at advantages, look at the disadvantages, and based on that you have to see whether really it is beneficial for a particular project then only you can adopt this.

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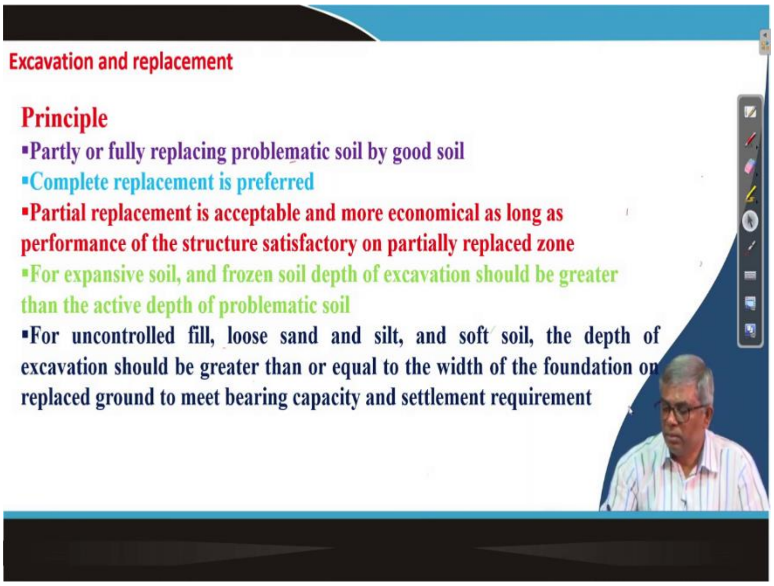

So, next slide, suppose, principle how it works? Partly or fully replacing problematic soil by good soil. This is right from beginning we are telling this is the one step then partial replacement is acceptable and more economical as long as performance of the structure satisfactory on partial replacement. That means, suppose this is the area is poor soil and your foundation location is here.

So, I excavate this much and replace and then I construct foundation here, I excavate here and I will replace and construct foundation here so, if the performance of these foundation is acceptable, then this will be this can be so, it preferable that entire area excavate and remove and then replace, but you can do the analysis that if this is satisfactory then this will be more economical, that is what this point number 3 is mentioned.

For expansive soil and frozen soil depth of excavation should be greater than the active depth. So, that means an active depth means what actually that expansive soil when come in contact with water then it will swell and when it is dried it shrinks that means with seasonal variation, it gives you expansive and swelling and that if this is the site and there will be depth beyond which that seasonal variation will be unaffected.

So, beyond the soil, whether it is dry season and wet season you will not make any change here, but above the soil with change of season actually it will be sometimes swelling sometimes shrinking. That is why if you want to use expansive soil site then at least you have to remove this much. Because this is the area is affected.

So, this is the thing we have to see. For uncontrolled fill loose sand and silt and soft soil the depth of excavation should be greater than or equal to the width of the foundation that is important because when I will put a foundation here if this is the foundation and then you know the bearing capacity failure comes something like that, and this depth is B. So, that is why so, foundation on the playground to meet bearing capacity.

So, greater than or equal to the width of the footing. So, at least B depth should be there at least. So, that is what these are actually principle of working, work excavation and replacement and next.

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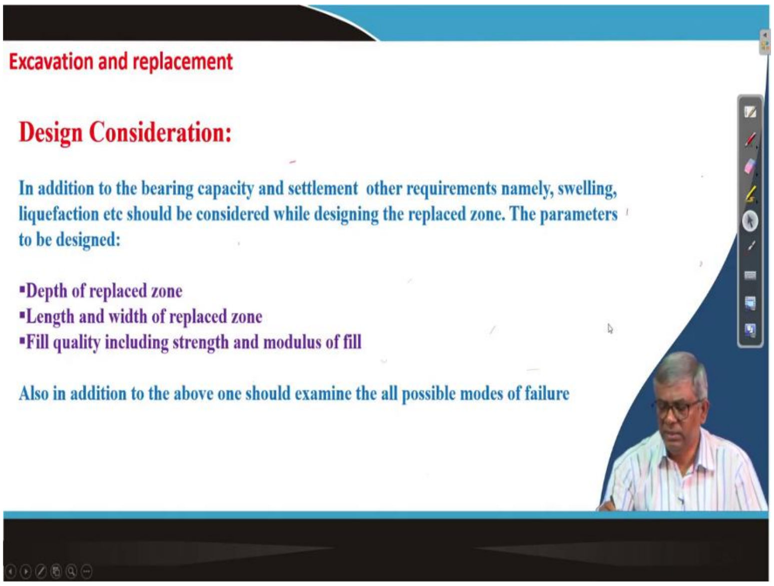

In design consideration, you can see here that in addition to the bearing capacity and settlement, other requirements namely swelling, liquefaction should be considered while designing replaced zone the parameters to be designed, what are the things actually I already have told you that how much wide?

How much depth excavation and replacement so, you can see depth of replaced zone, first thing actually depth of replacement zone to be decided then length and width of replaced zone. So, suppose that means if this direction how much and other perpendicular this how much do we replace that to be decided. Then fill quality include strength and the modulus of fill.

So, that means, when you discover it and use some or borrow material, you have to characterise a borrow material also that it is suitable and it will work. That also has to make sure that fill material of a particular quality, and which will satisfy your requirement that we may be bearing capacity, settlement or many other things whatever we generally check. So, these 3 aspects actually very important to be checked.

Also in addition to the above, one should examine the all possible modes of failure then, I will show you the subsequent slides that modes of failure when you use the replaced zone or a particular foundation is constructed and what is the different mode of failure can happen or imagine that actually, we will explain one by one.

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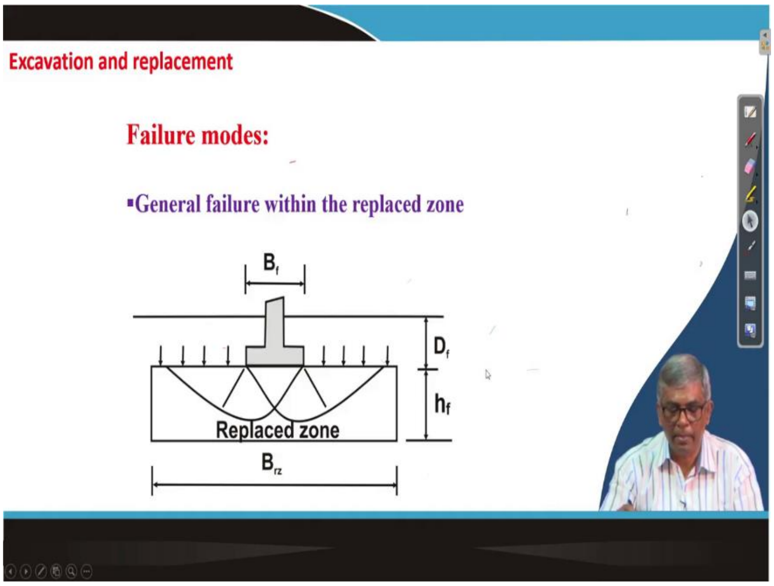

You can see here in this diagram. So, you can observe here this portion is the replaced zone, and you can see that you have decided the replaced zone in such a way with respect to the width of the footing that bearing failure that bearing capacity failure zone is within that zone. So, that is why general failure within replaced zone.

So, that means, what you have to do you have a loading in the footing, you know the size of the footing required or you design size of the footing accordingly you first imagine or as a first trial, you assume this much width and this much depth of soil will be replaced, will be replaced, it will be placed and imagine the general failure, failure will occur within the replaced zone then what you have to do you have to apply with respect to this soil.

This will be considered as a foundation soil and for this foundation soil you had to find out the ϕ then with respect to that phi you find out N_c, N_q, N_γ and then other factors like shape, size and other thing then apply bearing capacity equation from there you find out the bearing capacity, ultimate bearing capacity and you check whether you are required bearing capacity is meeting the requirement or not and if there is any settlement at all this is required that also to be the same.

So, that is actually one first type of failure, which you have to make sure that when you are removing a particular soil and replace. Assume that soil will undergo general shear failure within the replaced zone. So, if you make this zone is very thin, then this bearing failure zone will penetrate that one. Then in that case, you cannot imagine that is something else will happen.

So, if you this one is thick enough, then you can imagine that general shear failure will occur within the replaced zone then you accordingly you apply bearing capacity theories consider these as a foundation soil and then find out what is the ultimate bearing capacity and finally, what is the allowable bearing capacity and then compare what is the requirement. If it is satisfied that is your design.

That means, this is the width required, this is the height required. If you find that with this design, it is not meeting the requirement, then you have to redesign. Either you change the thickness or width everything and then accordingly or if you select a particular material, then it is not satisfying then either you choose another material or assume something else and check. That is the way you have to proceed. So, this is the first mode of failure that general shear failure within the replaced zone.

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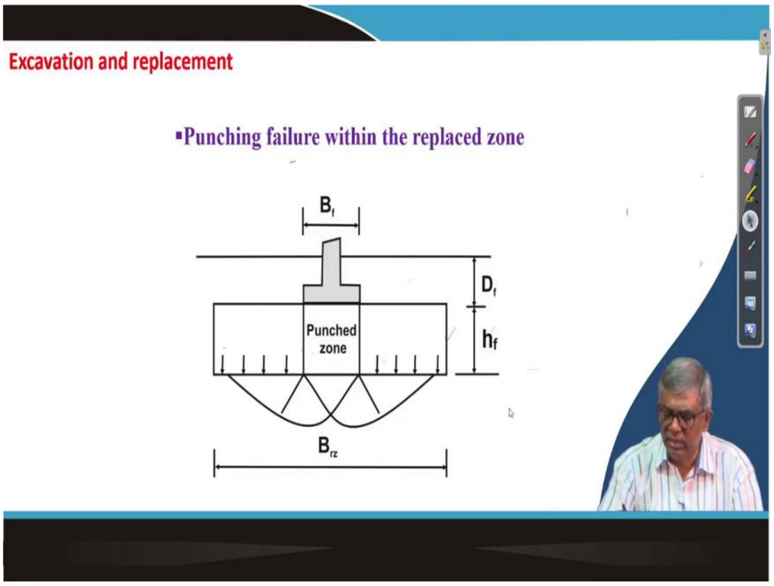

Next mode of failure you can observe this is actually punching failure within the replaced zone. So, what it is happening you can imagine this is the replaced zone and you place the footing somewhere here and what happened that the soil is such either not enough, friction angle is there, spreading is not happening instead of that or it is thin enough, instead of bearing capacity that failure or shear zone develop below this footing it may happen that it will be punched through this. That means, the footing and this soil will be act like a one single footing.

So, this can be imagined as a footing. So, that means entire load is now transferred here. So, you have to see what is the bearing capacity here? Based on that you have to see the requirement whether meeting or not. So, this is actually second category of failure mode that is punching failure within the replaced zone.

In first case what we have shown that typical bearing capacity failure zone from below the footing. Whereas, here instead of this below the footing just below the footing an entire depth of replace soil. Assume that it is together with the footing and it is transferring the entire load at this layer and then you see what is a bearing capacity there and accordingly you have to check whether it is meeting your requirement or not.

So, that is what you have to do. This is actually the second category of failure mode and it has to be checked this also other may be satisfied, but you have to imagine this also may occur I am imagining that the first mode is occurring and it is satisfactory, but simultaneously this mode also may be there. Then I have to imagine this way and see the bearing capacity requirement and then if it is satisfied, then only again that is punching failure also will not occur that can be ensured.

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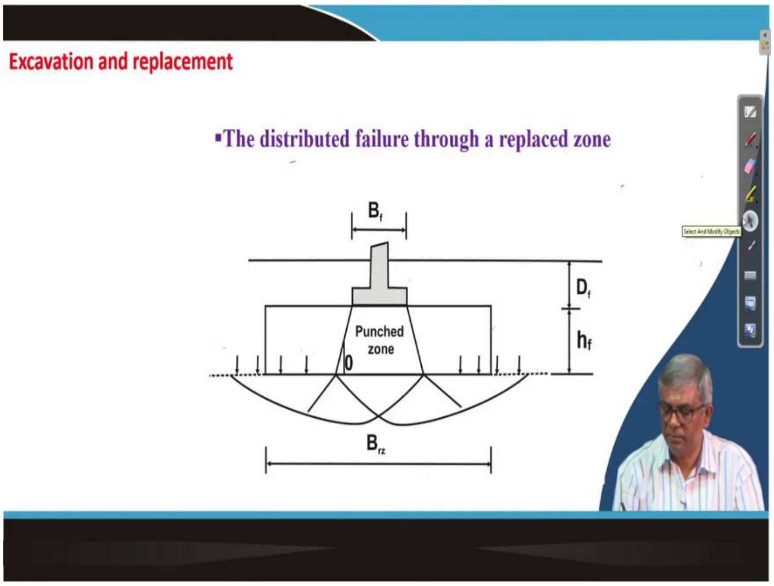

The third type of failure that is you can observe here the distributed failure through a replaced zone. You can slightly different is a mixture of first and two you can see that typical bearing capacity failure zone did not develop here, but instead of punching vertically a little friction, because of little friction and this load actually like typically in consolidation calculation, etcetera we want to find out the stress increases particular depth generally take some disperse zone.

Similarly, here this footing also when is supported here it is dispersing the load little wider area and at this level it is becoming this much wide. So, you can imagine this is a new footing now, and with respect to this footing, and whatever same load is here on this enlarged footing and then you do the bearing capacity analysis here and then you satisfy and find out what is the bearing capacity here and then with respect to this.

What is the bearing capacity proportionally you can here, whether it is meeting the requirement or not if it is meeting then it is acceptable. If it does not meet then it is not acceptable then accordingly you have to consider this. It is actually third mode of failure can also happen. First one you have to check, second one also you have to check, and third one also you have to check.

Everywhere you have to see that no one is critical. So, the first two may be satisfactory, third one is not satisfactory that means this failure will occur with this mode. So, that also has to be to, so if is not satisfied then you have to redesign.

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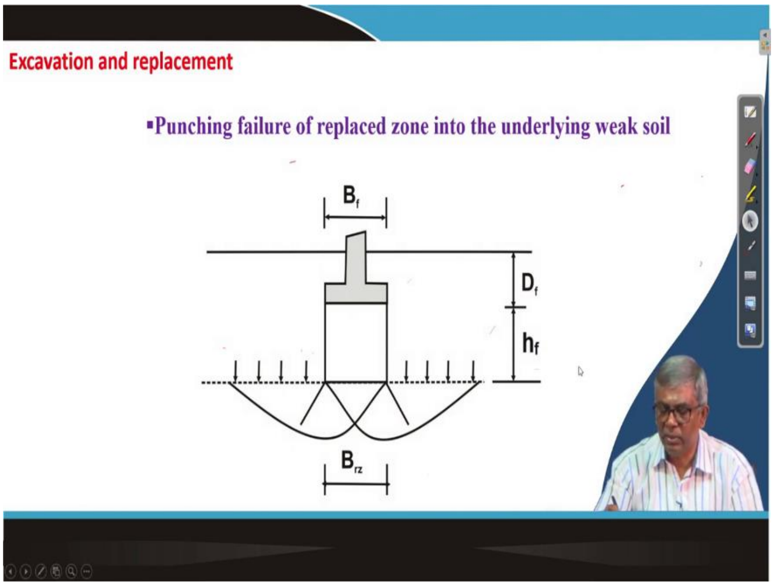

Similarly, the last mode of failure you can see here that punching failure of replaced zone into the underlying weak soil. Punching of failure of replaced zone, into the underlying weak soil. So, you can see here that this soil and then you can have the bearing capacity failure. Here, then you can do the analysis how bearing capacity we are getting and then accordingly you can even, if it is satisfactory.

All four are satisfied then your design is acceptable, and then that means what actually, first of all you have to initially adopt some design that means this much length and this much thickness, this much width, replaced zone and then based on that you imagine the failure mode 1, failure mode 2, failure mode 3, failure mode 4.

If all 4 satisfied then if all 4 are satisfied, then your design is okay and if any of the mode actually shows that unsatisfactory that means that whatever initial design you have adopted that is not acceptable. So, you have to change those and then finally, make final design or modified design. So, these are all basically different types of failure mode can happen when you use the soil partially replaced.

Now what I will do, I will discuss with respect to first one other three actually, I wanted I did not want to spend much time because it is comparatively simple. So, only thing is whenever is a first mode of failure is taking place.

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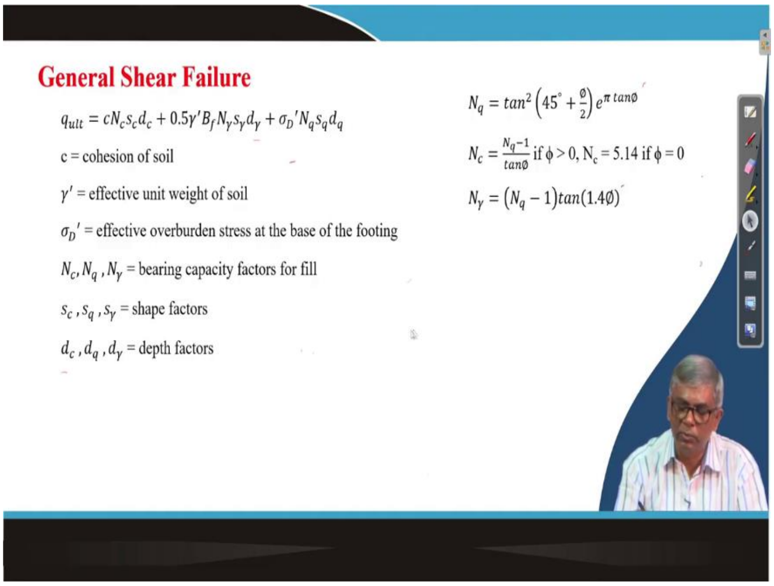

For example suppose, you assume that the replaced zone you have the footing something like this and your replaced zone is this and your bearing capacity failure will be something like this. And that means general shear failure within the replaced zone. So, what are the equation we generally use? That we have a number of bearing capacity equations are available that Terzaghi, Meyerhof then many others also.

So, most generalised bearing capacity equation which we use, this is the one because in this shape factor, depth factors are there, inclination factor we have not included here because assume the footing is vertically loaded, and then you can see 3 components, c N_c S_c d_c, 0.5γ, this is for stiff footing of course, 0.5σ', B_f, N_γ, S_γ, d_γ. Similar σ' N_q, S_q, d_q.

$$q_{ult} = cN_cs_cd_c + 0.5\gamma' B_f N_\gamma s_\gamma d_\gamma + \sigma_D' N_q s_q d_q$$

c = cohesion of soil

γ = effective unit of soil

σ_D' = effective overburden stress at the base of footing

N_C, N_q, N_γ = bearing capacity factors for fill

s_c, s_q, s_γ = shape factors

d_c, d_q, d_γ = depth factors

$$N_q = \tan^2\left(45^\circ + \frac{\varphi}{2}\right)e^{\pi \tan\varphi}$$

$$N_q = \frac{N_q - 1}{\tan\varphi} \text{ if } \varphi > 0, N_c = 5.14 \text{ if } \varphi = 0$$

$$N_\gamma = (N_q - 1)\tan(1.4\varphi)$$

So, like that, B_f means B footing, width of the footing. So, this is the equation actually we have and where c is the cohesion, γ' effective unit weight, why effective unit weight? If there is water table then you have to submerged unit weight. Then σ' effective overburden pressure. Why effective overburden pressure?

If there is a water table is here, then ultimately total effective total overburden pressure, instead of taking total overburden pressure, you need to take effective overburden pressure that means submerged unit weight of water has to be taken and three bearing capacity factor N_q and N_c, N_γ they are function of phi and that is available in any book standard book we can find out, S_c, S_q, S_γ is shape factor, d_c d_q d_γ is depth factor. And N_c, N_q, N_γ though it is available in the form of chart.

Sometimes one can find out from using this equation N_q is this expression, N_c by this expression and N_γ by this expression, one can directly find out this approximate of course. Because whatever mathematical equation they have got, and finally, they have tried to fit N_q, N_c, N_γ by these 3 equation. Most likely it is given by Meyerhof.

So, these are the things then after determining this parameter depending of the shape of the footing and then N_c, S_c and d_q; S_c, S_q; d_c, d_q can be obtained. And for that we have a table. In our next slide I will show you. You can see here that for calculating S_c d_q, S_c S_q S_γ, d_c d_q d_γ.

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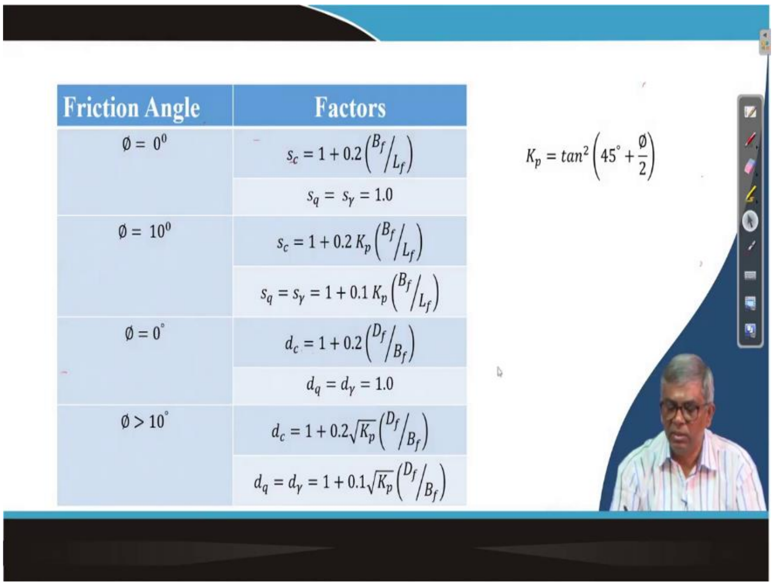

This is the equations are given. When ϕ is equal to 0˚then Sc equal to this and S_q equal to this, S_q S_γ is equal to 1 and when ϕ equal to10˚ then S_c equal to this and S_q equal to this. And when ϕ equal to 10˚ d_c equal to this and d_q, d_γ equal to 1 and ϕ greater than 10˚. So, these are the values in the form of empirical form it is given and one can use it.

Friction Angle	Factors
$\varphi = 0^\circ$	$s_c = 1 + 0.2\left(\frac{B_f}{L_f}\right)$
	$s_q = s_\gamma = 1.0$
$\varphi = 10^\circ$	$s_c = 1 + 0.2k_p\left(\frac{B_f}{L_f}\right)$
	$s_q = s_\gamma = 1 + 0.1k_p\left(\frac{B_f}{L_f}\right)$
$\varphi = 0^\circ$	$d_c = 1 + 0.2\left(\frac{D_f}{B_f}\right)$
	$d_c = d_\gamma = 1.0$
$\varphi > 10^\circ$	$d_c = 1 + 0.2\sqrt{k_p}\left(\frac{D_f}{B_f}\right)$
	$d_q = d_\gamma = 1 + 0.2\sqrt{k_p}\left(\frac{D_f}{B_f}\right)$

And if of course, if the ϕ is greater than 10˚some that may be limited values can be used or you can if some increase can be taken and where in the sum of the equation K_p is there the expression for K_p is given here and so, from this equation depending upon your ϕ values, or shape of the foundation we can find out all parameters and then going to the original bearing capacity equation we can find out what is the ultimate bearing capacity from there you can find out net ultimate net allowable and then finally allowable bearing capacity and that comes actually within the requirement limit then your satisfactory.

$$k_p = \tan^2\left(45^\circ + \frac{\varphi}{2}\right)$$

So, this problem this is the way you have to do analysis. And typically one practical example I could have taken but time is not there now, so, I will do some time that over excavation replacement method. One example I will be taking that originally site what soil was there and then it as a first trial this is the soil you assume to be used as replaced soil, this is the thickness, this is the height, and this is the width.

And then find out whether this replaced proposition whether suitable or not. So, some calculation we will be doing so, I will take one problem later on and to explain how to use this calculation for designing, excavation and replaced method.

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And, so, with this by enlarge I will just close here excavation and replacement method. In next class of course, I will be starting with some other ground improvement technique. Only thing is the introduction regarding over excavation and replacement together is in the module 1 it is completed.

Now, I will be going to the module 2 where the shallow densification will be the subject. And there are again different methods are there we will discuss one by one. In between if I get a time I will take 1 problem to explain how to design over excavation and replacement method. So, this is the one. So, with this, I will stop here today. Thank you all. Thank you.