Geotechnical Engineering II / Foundation Engineering

Prof. Dilip Kumar Baidya
Department of Civil Engineering
Indian Institute of Technology, Kharagpur

Lecture – 51
Deep excavation

Let me continue with the sheet pile not sheet pile walls sheet pile wall we consider we have completed. Last part which I wanted to include in this it was a Deep Excavation and for deep excavation actually the issue of lateral pressure will be there because of that there may be collapse. So, that part while discussing earth pressure theory I have discussed partly that up to a certain depth we can excavate without any support.

And in fact, and beyond that if you want to excavate if you do not provide any support then the excavation wall may collapse. So, that is the one in we have already discussed and then I will once again I will repeat that is one. And, then from there what are the modifications required for deep excavation that I will try to show.

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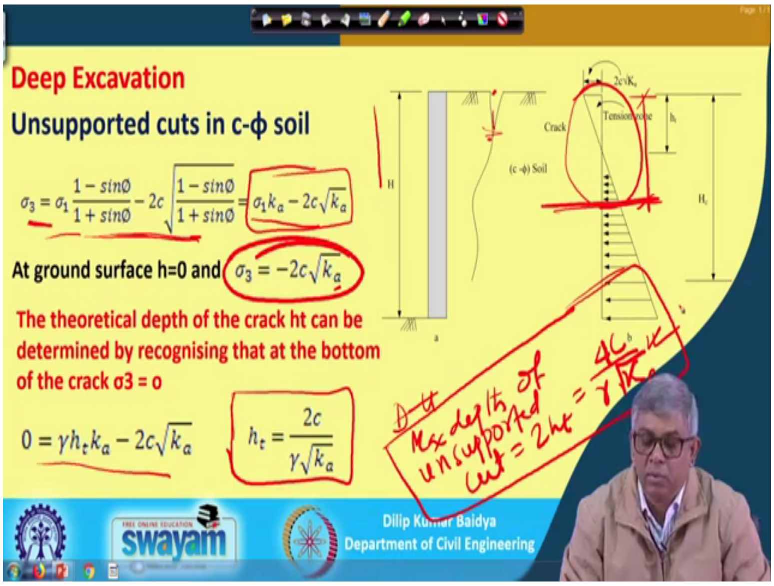

And this is the one perhaps we have discussed and it is repetition once again you can see that the lateral pressure x 3 sorry lateral pressure is 3 sigma 3 in terms of sigma 1 and cohesion this is the expression. And so, you can see sigma 1 k a minus 2 c root k a where, sigma 1 actually if I change the depth it will be changing actually so, it is gamma times h. And, you can see that when h become 0 then your sigma 3 become negative sigma 3 become negative. So, when minus 2 c root k; that means, negative here actually is a tension and soil tension means that will be crack which will have.

So, this is the one situation suppose the surface like that crack may happen and if you go deeper and deeper tension may reduce and at some depth tension maybe 0 ok. So, that is that means, that tension crack can go up to this much. So, to find out that we have done that the theoretical depth of crack ht can be obtained by equating this expression with 0. So, that is what it is done and if you do that then ht expression we are getting equal to 2 c by gamma root k a and if it is purely cohesive than these become 1. So, 2 c by gamma it is in fact, and so this is the theoretical depth up to this tension crack reached and but so, since it was a tension there will be some amount of compression will be; so, because of that we can actually so, this is the diagram pressure diagram.

So, this is minor and this is again plus so; that means, up to this if you excavate there is no pressure on the wall. So, it will be plus and minus get balanced. So, because of that theoretically we can excavate up to this depth without any support; so that means, depth of excavation without support unsupported cut so, unsupported. So, our maximum depth of unsupported cut will be equal to twice ht which is nothing, but 4 c by gamma root k a ok. So, this is the 1 so; that means, in any soil if you want to cut without any support for foundation purpose that is the maximum depth theoretical depth we can go. But, if you want to excavate more than that because of many reason then you have to do something that is what we want to discuss in this.

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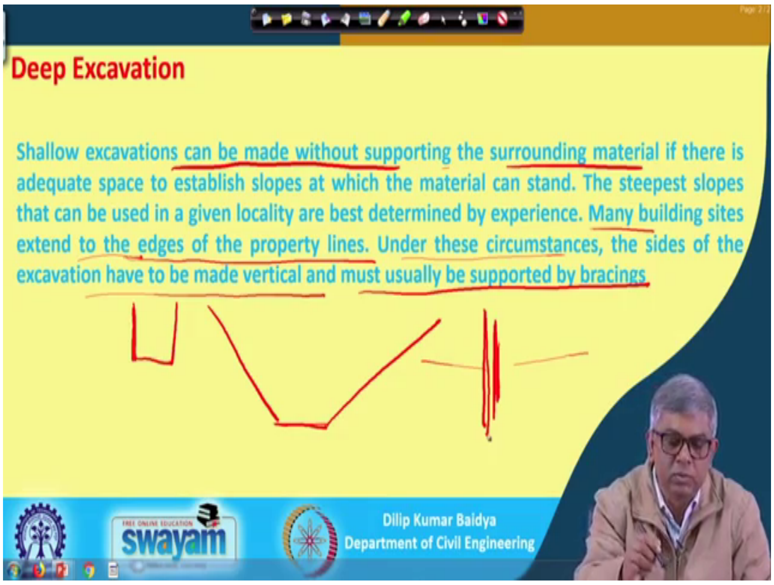

And, you can see here next slide what I tried to show here you can see that shallow excavation can be done without any support as we have shown theoretically up to some depth we can theoretically; up to some depth without any support vertical cut. Suppose, if there is a cut is this much depth and if it is based on the calculation order the; if it is this much we may be able to do without support.

But even so, if we want to go deeper sometimes if you have space available; suppose you want to cut excavation up to this. And, if space available then we can have a slope and then also you can go, but many situation you may not have this provision or this facility or there may be restriction that you have to go to property line is there and you have to excavate very close to that then we cannot slope it and go like this.

So, in that case what you have to do when you have to have deep excavation and almost vertical then we need to give support that is the thing. That means, under these circumstances that needs sides of the excavation have to be made vertical and must usually supported by bracings; that means, when the actually the many building sides extended extend to the edge of the property line. So, this is the property line and you have to excavate here and you cannot provide any source slope this side or this side this side maybe we can give, but this side you cannot go in that case you have to make vertical with some support.

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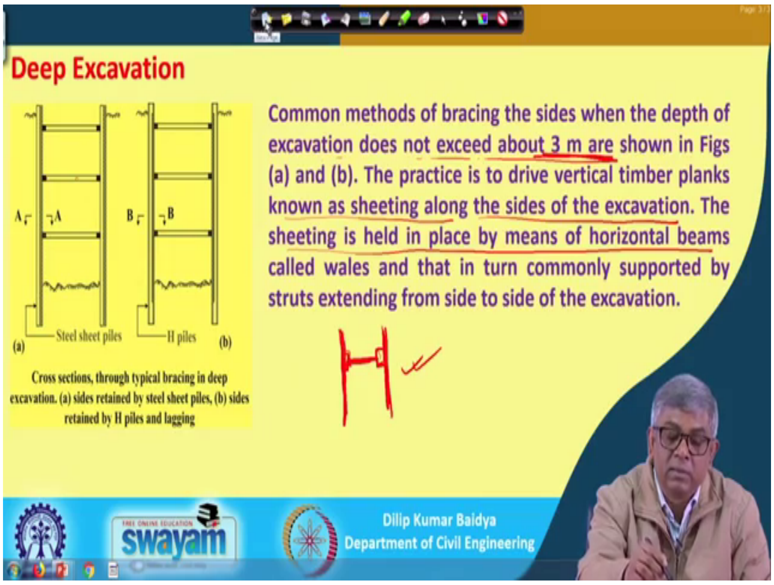

So, this one is shown here actually there are different types of supporting systems are possible; actually when the comparatively shallow excavation suppose 3 to 5 meters. You can see here the common methods of bracing the sides when the depth of excavation does not exist 3 to 3 meter actually, that will be done actually that there will be wooden sheets will be inserted and then there will be some support will be there like that.

So, and practice is to drive vertical timber planks known as sheeting along the sides of this excavation. The sheeting is held in place by means of horizontal beams called wales; there will be horizontal beams. And, then there will be here also the sheeting and then there will be horizontal beam and these beams will be supported by a strut.

So, this is actually when that between up to 3 meter excavation then this type of wooden plank can be inserted and then there will be cross beam will be given that is called wales. And, both side will be there at this both side wales will be supported by the strut. So, that will be done in most of the shallow excavation. This is the figure almost shown similar thing you can see this side and this side and this may be black one it may be wale and this may be strut.

But, when we have not shown this is actually a picture of deep excavation and which is not applicable, but schematically is almost similar. But, when it is up to 3 meter what I have shown here that you have to insert or drive the sheet pile. Then when excavation proceeds you give the support by wale and then support by strut. So, like that you can proceed.

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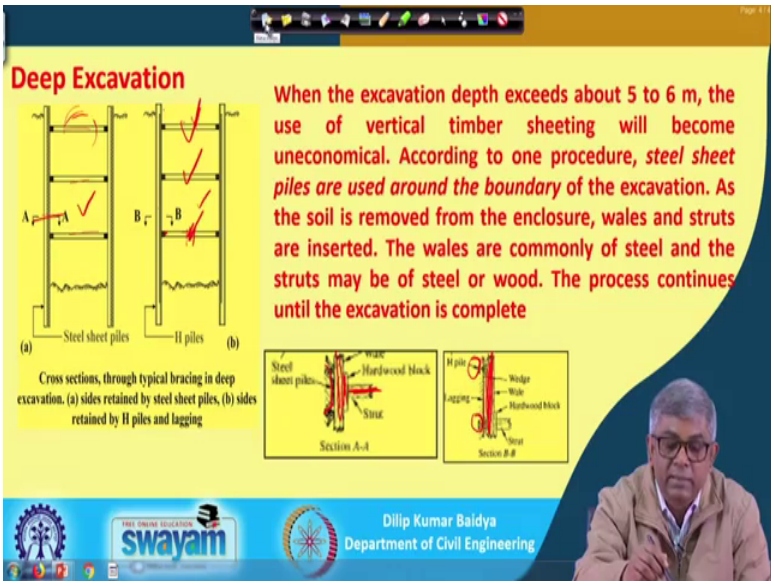

So, this is one way, but if the excavation is deep if the deep excavation you can see again there are when the excavation depth exceeds about 5 to 6 meter; the use of vertical timber sheeting may not be economical. And, according to procedure the steel sheet piles are used that we can see here this is one shown and this is another shown. Initially actually if I take a cross section here what you can see here, here actually there is a sheet pile. And, then sheet piles verticals like that and then there is a this is wale actually there is a beam like and then that beam will be again with some hard route there will be packing will be there and then this is the strut ok.

This is one mechanism and another mechanism is that again if it is then what you can do even drive H pile here some interval H pile. And, then behind H pile just in front of the H piles there will be lagging actually this is called lagging; that means, one line to cover the soil. And, that lagging will be thin comparatively and then over the lagging some intervals there will be wales; that means, beam like in vertically in some interval there will be beams will be there and those beams again finally, will be supported from both sides. So, these are actually struts and you can see that we can say the H pile this these two lines are showing H pile, behind H pile there will be sheet and then this is the wale and then this is the strut.

So that means, when it is a deep excavation you have to do this way that either steel sheet pile and then wale and then strut or you can give in some horizontal interval H pile. Then there will be lagging, then horizontally in some vertical interval there will be lagging and then it will be supported by the strut. So, when it will be initially it will be drive up to certain depth and then when excavation will be there from the top; when excavation proceeds and it will go deeper and deeper then one by one you have to provide the wale and strut. That is the way actually the support system to be designed and while designing the support system; that means, because of these some load is coming to this strut.

So, you have to design the strut you have to you have to design the cross section of the strut material you have to select. So, for that you need to find out what is the force coming on to this. So, for that you need to do some analysis.

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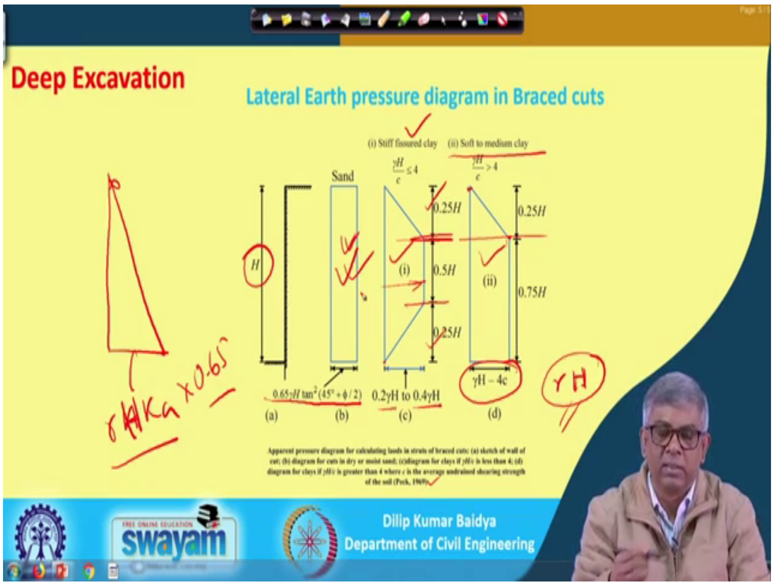

So, that I will try to show in the next slide. You can here you can see here that when there is a deep excavations, suppose of depth H and this is the side of the excavation. And, then different people over the time actually given suggested some pressure diagram behind the also. We have actually when there is a retaining wall or sheet pile wall we have got some different type of pressure diagram. But here actually the practical wall based on experience the different researcher actually like Targazi, Peck and others they have given actually; this is by Peck actually given 3. But, the pressure diagram behind the excavation and when we send this is the diagram; that means, uniform throughout the depth.

And the intensity is 0.65 gamma H tan square 45 degrees plus pi by 2; that means, gamma H square gamma H tan square 45 degree actually in the retaining wall. This tan square 45 degree plus pi by 2 is what it is nothing, but k a gamma H is what? Is nothing, but the pressure vertical pressure. So, vertical pressure multiplied by k a it can be lateral pressure at this point, but instead of a linear variation instead of in the retaining wall linear variation like these 0 here and here actually gamma H k a gamma H k a in retaining wall. But, here actually when sand and excavation is done and behind that sheeting the pressure diagram will be just 65 percent of that 0.65.

And, instead of triangulate it will become rectangle that mean throughout the depth it will be constant. Then in the stiff fissured clay then your pressure diagram will be something like this, it will be trapezoidal up to 20. If the depth is suppose H the one-fourth of one-fourth of H will be this linearly varying and then 50 percent of half the depth actually from there actually it will be constant.

And, then again from there up to bottom again it will be linearly decreasing it will become 0. So, top one-fourth and bottom one-fourth will be of top one-fourth from 0 to increase to maximum and bottom one-fourth actually from the maximum to reach to 0. So, this is the data suppose your diagram and this is the things to be remembered.

So, when if there is a deep excavation we can assume first this diagram and then you can find out the intensity of this what is given actually? The value of this maximum value is given 0.2 gamma H to 0.4 gamma H; that means, gamma H is actually actual pressure vertical pressure. And, instead of doing anything just 20 percent to 40 percent of that can be taken as a lateral maximum lateral pressure in this ok. So, if 0.2 to gamma is 0.4 gamma H this is based on the judgment of the designer; one can take actually 0.25, one can take 0.3, one can take 0.35. So, between any value based on the type of soil one can consider this value ok.

So, this is that this diagrams to be assumed first and then post the other thing to be calculated. Next if there is soft to medium clay then another diagram is suggested that is actually top one-fourth top one-fourth height will be linearly varying and it will be 0 at the surface and it will maximum at 0.25 H. So, and then rest of the depth remaining depth it will be remaining constant actually. So, we can see from here to here the pressure is constant and that pressure actually how much actually gamma H minus 4 c. So, the intensity of pressure which to be assumed that is gamma H minus 4 c ok.

So, it is just soft to medium clay and when the stiff fissure clay this is the one 0.2 gamma H 2 0.4 gamma H. And, the type of distribution of pressure behind the excavation is like this while it is the soft to medium clay; type of distribution of pressure behind the excavation is like this when it is the sand the behind the wall behind the excavation distribution of pressure over the depth will be like this. So once this is known and then one can find out the pressure load by another further analysis one can find out the force in the strut. So, for that I will go to the next slide.

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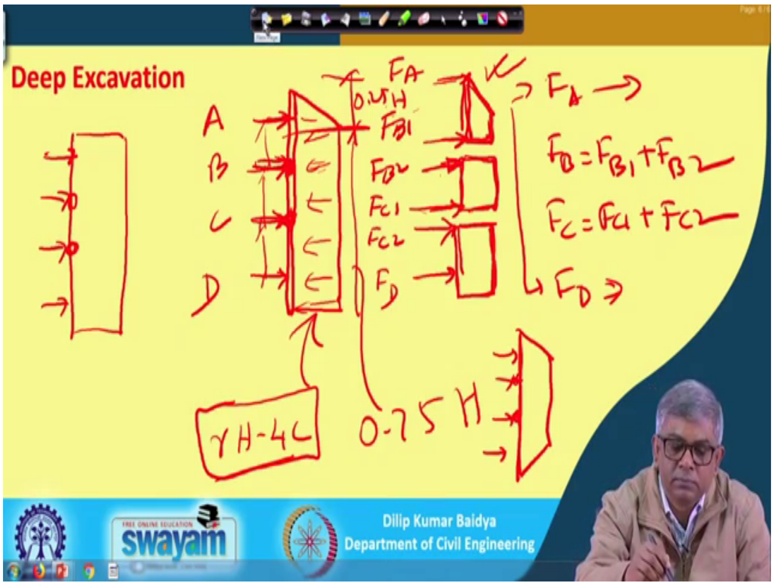

Next slide actually I kept blank and I will just show that how it will be done; let me show you this way. Suppose there is a; this is the excavation and your strut actually somewhere here, somewhere here, somewhere here, somewhere here like that. They are maybe uniformly spaced and suppose based on the soil type the pressure diagram something like this suppose ok. So that means, I will consider now this has a beam and these are the actually your pressure loading.

So, looks like this is a continuous beam and difficulty the being difficult continuous beam little difficult. And, here actually we have to do approximation because of that you know real beam type of analysis you need not do what; for simplicity in analysis what you have to do. If there are more number of supports in between then internal support; that means, accepting the bottom most and top most support other intermediate support we will consider as a hinge. If you consider it as hinge, this is the hinge and this is the hinge then in that case what I will do if I consider hinge then what I will be doing. So, it will be something like this and there will be support like this and this will be one the in between this one and then.

So, hinge since there is a hinge can I can break into 2 parts and suppose this is A this is B this is C and this is D. Then I can say this is a F A and this is suppose I can say these I can say F B 1. And, this one I can say F B 2, these I can say F C 1 and this I can say F C 2 and these I can say F D. So, because of this now loading is known actually on this is now all beams are 2 support and simply support type ok, loading are known. And, then I can find out these and these simply supported I can find this and this I can find out this I can find out.

So, if I do this simplification; that means, if I assume the intermediate supports and hinge then I can break the hinge and I can assume the beam system into a 3 beams like this. And then based on consider equilibrium; that means, summation of forces equal to 0 and summation of moments where with respect to a point is 0. If I do that then I can find out all F A F B 1 F B 2 F C 1 F C 2 and F D all I can find out. And finally, F A will be F A whatever coming from here F B will be equal to F B 1 plus F B 2. And, F C will be equal to F C 1 plus F C 2 and F D will be equal to whatever I have got.

So, F A and F D directly I am getting and F B and F C I have just summation of these two parts like that. So, it is a very simple so, if you know the depth of the excavation then and type of soil then immediately I will get this pressure diagram. Pressure diagram actually suppose if it is a fissured clay and that I mean soft clay then actually what will happen. If top or 25, this is actually 0.25 H we know that; this is 0.25 H and this is actually 0.75 H. So that means, and what is the; what is this value? That is actually gamma H minus 4 c, if it is a soft clay.

So, this intensity I know, this distance I know again the spacing I know between the strut the spacing I know. Then if I assume hinge here then I this entire beam can be I can modify to these 3 beams and when it 3 beams, then considering the static equilibrium I can find out this F A F B 1 F C 1 F C 2 and F D. And then from there finally, I can find out F A F B F C F D ok, I hope it is clear enough very simple analysis it is if you go for a continuous beam analysis will be quite rigorous.

But, here actually not necessary because it is only support system and. So, approximate calculation can be based on this can be done and it will get higher side in fact, so, that is better. So, this is the type of analysis one can do for finding out the strut. So, instead of this suppose if the another excavation is done on the same; in that case your diagram will become something like this, your diagram will be as we have shown sand actually pressure diagram something like this. And, struts are like this then again this one will be simpler than this actually.

And, if it is a stiff or fissured clay then your diagram will be something like this. This is the excavation and supports are here, suppose supports are here and your diagram will be something like this. So, again similar way the way I have divided here this also can be divided considering hinge and here and here, considering hinge here and here and here I can divide the 3 parts and I can find out the all components and finally, to find out the actual loading in the strut.

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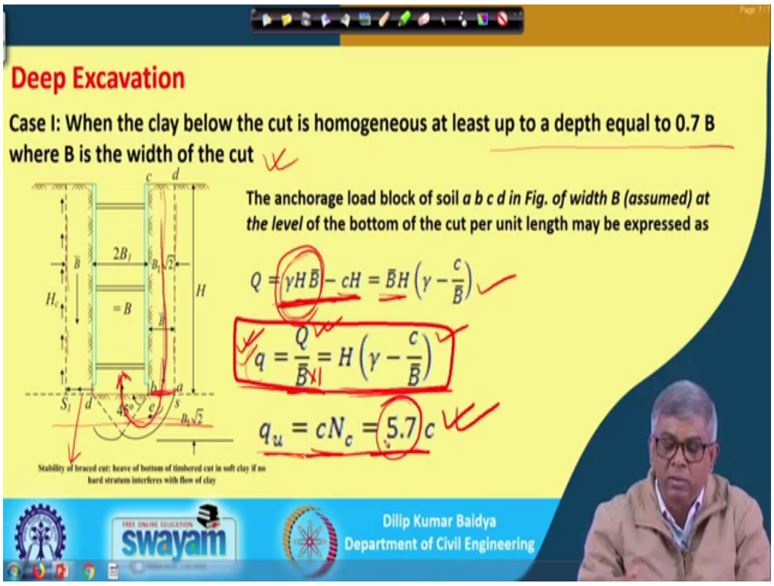

Next one actually as you have mentioned here actually that when you will excavate deep and then there is a chance of the weight of soil, if it is soft soil and then that may be as along some along some vertical surface it may fail. And, this entire mass this soil mass can try to have tendency of moving upward that mean bottom can fail actually heaving can be there and then finally, it can fail. So, that for that analysis actually one can do this one can find out the factor of safety against heaving or bottom failure.

So, for that some temporary some approximate analysis one can do and that and for doing that one can do two different cases. One is when the clay below the cut is homogeneous at this up to depth equal to 0.7 B actually; that means, below these below the below this cut is the cut level is here. And, from here actually at these 0.7 B is actually the same homogeneous soil to have actually this type of failure actually. So, that is the thing actually requirement.

If it is so, and other alternative what is that there may be theme there will be some other hard layer is there before that. So, that is another condition that I will show later on. So, this one actually the so, one where this mass actually sliding actually from trying to come and move this way then actually how much is the load a b c d; actually you can see a b c d how much is the load. So, if it is width is B bar so, gamma H and multiplied by B bar. And, if I take unit length then gamma H B bar is the weight and these weight partly supported by this shear along these lines shear along then you can see.

So, because of that we can say c times H over the depth actually and if I take width actually 1. So, that may be so, total loading of soil weight is this gamma H B bar and it will be partly registered by c minus c into H so; that means, net loading will be gamma H B bar minus c H. So, if I take B bar into H so, gamma minus c by B bar so, this way can be written. So, q actually suppose that is intensity of pressure that will be Q by B bar suppose that must; so, actually Q by B multiplied by 1. So, actually perpendicular to the board I can assume length actually 1.

So, it will be Q by B multiplied by 1 and in that case you can see the q expression for q; so, if I divide by B bar then become H gamma minus c by B bar. So, this is the expression for small q; that means, because of this when this entire mass is trying to slide then at this level what is the pressure it is giving that is q. And, we know that at this level and what is the ultimate bearing capacity of the soil; ultimate bearing capacity of the soil for soft soil generally we are we know that c times N c.

And for soft soil for soft soil you know that c value is 5.7 or 5.14 anything angle between can take. So, 5.7 c; that means, your q ultimate is 5.7 c and actual pressure we are giving this much. You are giving pressure because, of this depth of excavation this much pressure is coming at this level and bearing capacity at this level is 5.7 c irrespective of height and anything. So, now we have to see we have to compare this and this and based on that we can find out what is the factor of safety available; you can see this next slide.

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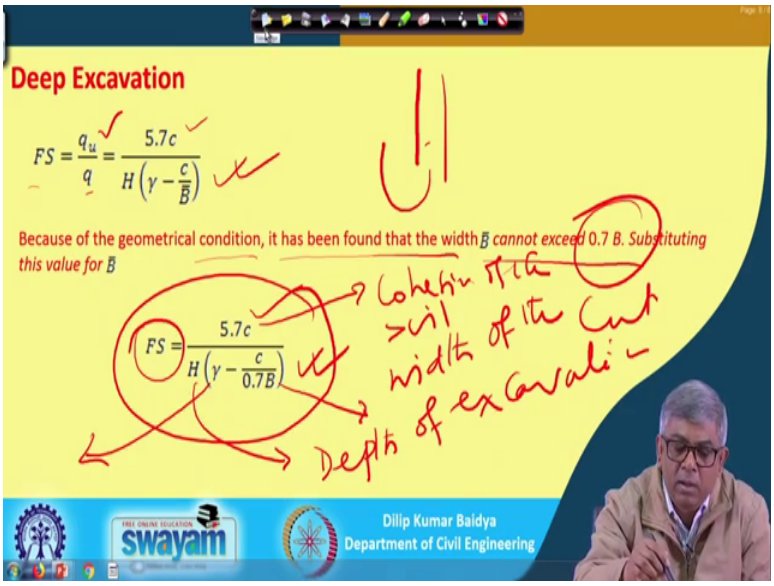

You can see that factor of safety will be q u divided by q ok. And so, if this q is much smaller than this q ultimate that will be safe and if it is this q become much much bigger than q this q that will be unsafe. So, because of that we find out factor of safety by q u by q. So, the expression is 5.7 c by H gamma minus c by B bar. So, this is the general expression and because of the geometrical condition it has been found that B bar cannot be more than 0.7 B. So, if you can B bar can be substituted in this then your factor of safety expression become 5.7 c divided by H gamma minus c by 0.7 B.

So, this is the final expression for factor of safety for a deep excavation against bottom heaving and for a soft clay. When the excavation is done deep excavation done in a soft clay then factor of safety against bottom heaving is the expression 5.7 c H gamma minus c by 0.7 B. So, here actually B is the width of the width of the cut width of the cut and c is the cohesion of the soil of the soil. And, your H actually depth of cut or depth of excavation and gamma is the unit weight of the soil. So, everything is known one can find out the factor of safety.

So, if that situation arise that soft soil one can also have to one has to check the factor of safety otherwise we are excavating. But, because of the soil movement from like this it will be moving like this, then a lot of pressure will come on this wall and some failure may occur ok. So, this is one type of factor of safety as I have mentioned that if the below the excavation if the submission depth is homogeneous. If it is not so, if it is the other type; that means, this is the one you can see that hard stratum is there at shallow depth that.

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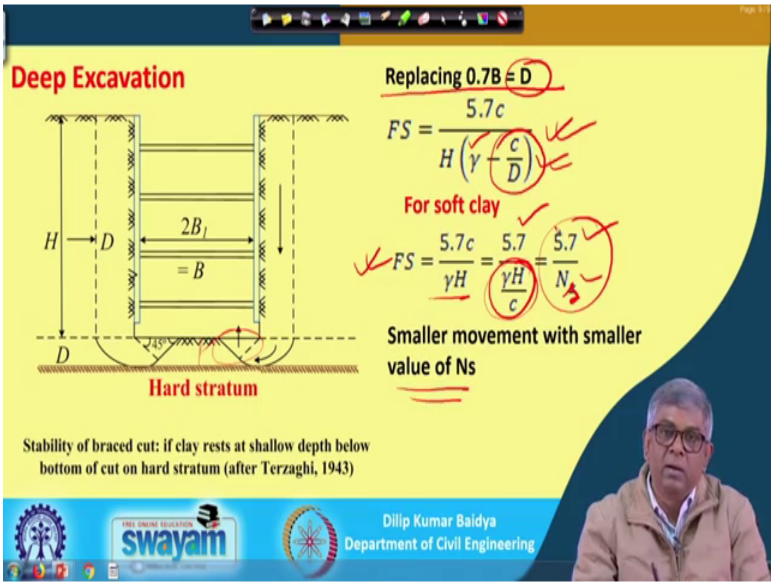

So, that this entire failure mechanism is prevented in that case you can see that 0.7 B instead of that I can restrict now D only. So, you can there actually we have shown that B bar we have replaced by 0.7 B. So, there actually instead of 0.7 B now you can put D.

Then your expression for factor of safety become 5.7 c H gamma minus c by D. Now, this part actually compared to smaller than this; so, because of that we can simplify this factor of safety equal to 5.7 c divided by gamma H. And, you can see and you can express in some well known term that is stability number that is 5.7 by gamma H by c this is actually stability number.

So, 5.7 by N s this is this will be s actually 5.7 by N s; smaller movement with smaller value of Ns actually you can see; that means, factor of safety will be more when Ns is small. And if it is Ns is big then factor safety will be reduced actually that and then; that means, it will be unsafe. So, that is what one has to find out this stability number and then find out these ratio and see the smaller means more less movement and big means bigger movement and failure. So, with this actually I will let me these are the things actually related to deep excavation we need to know. So, with this perhaps I can stop here and I will take some problem in the next lecture.

Thank you.