Ground Improvement
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Module No. # 07
Lecture No. # 22
Micropiles

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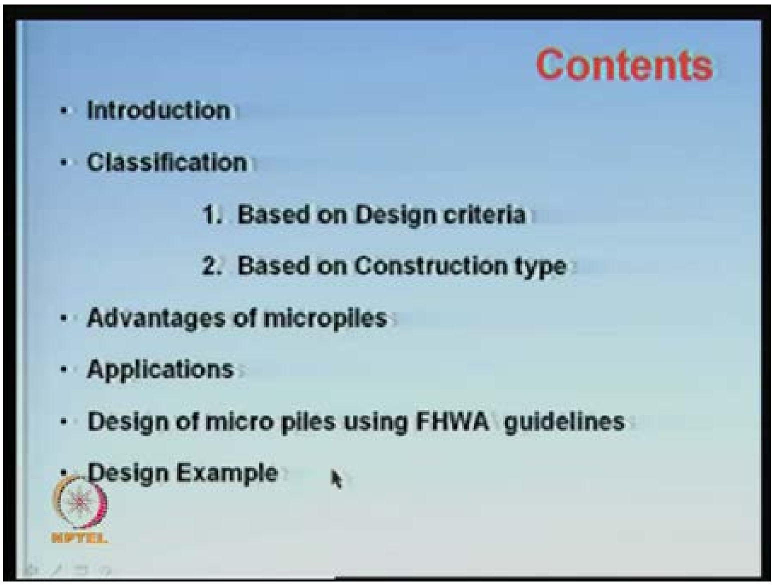

So, we would be talking about the micropiles introduction, how do you classify them. What are the advantages of micropiles and applications. And you have a design example. So, we will see the design procedure as well.

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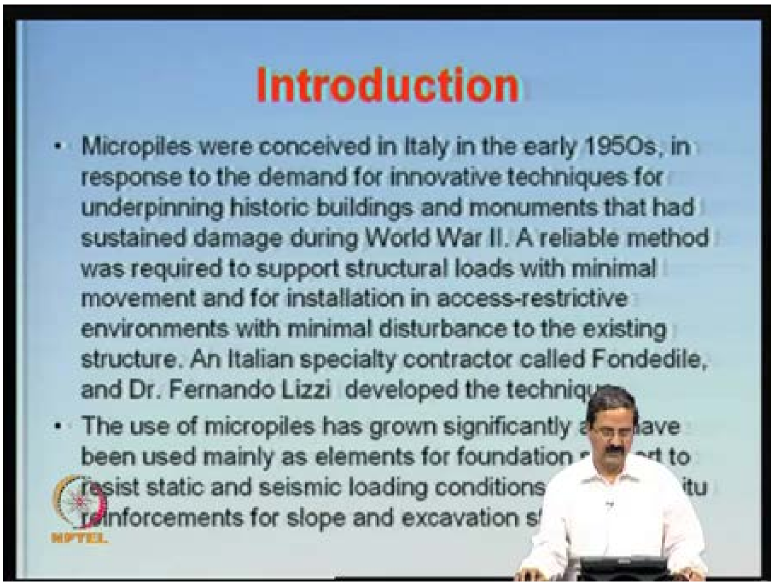

Micropiles are nothing but, it is just small diameter piles. The use is that, they are very useful in many ground improvement problems and we know, we know the difference between a big pile and a small pile, in the sense the diameter is quite, you know you try to design, get a diameter for the load. Here, we are trying to replace that bigger diameter with a small number of piles and the micropiles concept came in 1950's in Italy particularly, when people are trying to develop innovative techniques for underpinning, historic structures or monuments, which had some sort of damage in the world war 2. What happened was that, when you have certain buildings and structure, in structures which have some sort of inclination or something like that, because of some the problems we know that the existing load carrying capacity is less. So, you would like to improve the load carrying capacity by additional structural means. So, it may not be easy for you to put another pile foundation. So, the best would be to drive a small micropile, a couple of micropiles close to the site. So, that whatever is short fall in the load carrying capacity can be compensated by the micropiles. At that time, what they felt was that a reliable method to support structural loads with minimal movement and for installation access in restrictive environments.

What happens is that in many places, when you already have a building and to its very, it is a very difficult to have a big pile install at the same place, because of the access restrictions and the damage that it can cause of the existing facilities and all that. So, what is the time, you know some people did in Italy was that, there was a company called fondedile, a particular contractor and there was also another engineer, doctor Lizzi and they felt that use of a small micropiles, may be simpler than trying to use big pile diameter, I mean diameters of large, the piles of large diameter. So, from that time onwards, the micropiles have been extensively used and it has been used mainly as elements for foundation support to resist static loading as well as seismic conditions, as well as in-situ reinforcement for slope stability and excavation stability. We will see number of examples in this case.

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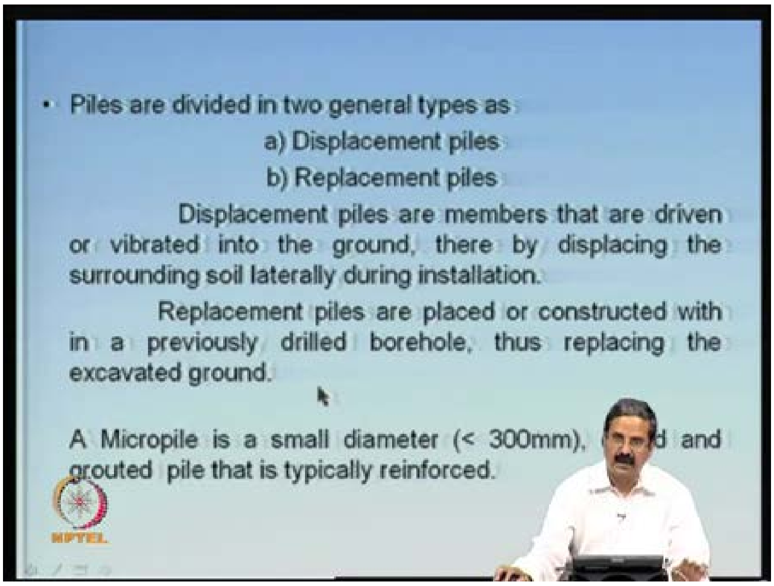

And we know that basically piles are divided into two types. One is the displacement pile, the other one is a replacement pile. The displacement piles are the members that are driven or vibrated into the ground or thereby displacing the surrounding soil laterally during installation. Whereas, replacement piles are placed or constructed in a previously drilled borehole, thus replacing the excavated ground. In fact, you can have micropiles that belong to both categories, like either you can have it as a displacement piles or as replacement piles. Like driven piles or board piles. Only thing is that the diameter is quite small, may be 100 mm or 150 mm, compare to 300 mm is what we have in normal conditions.

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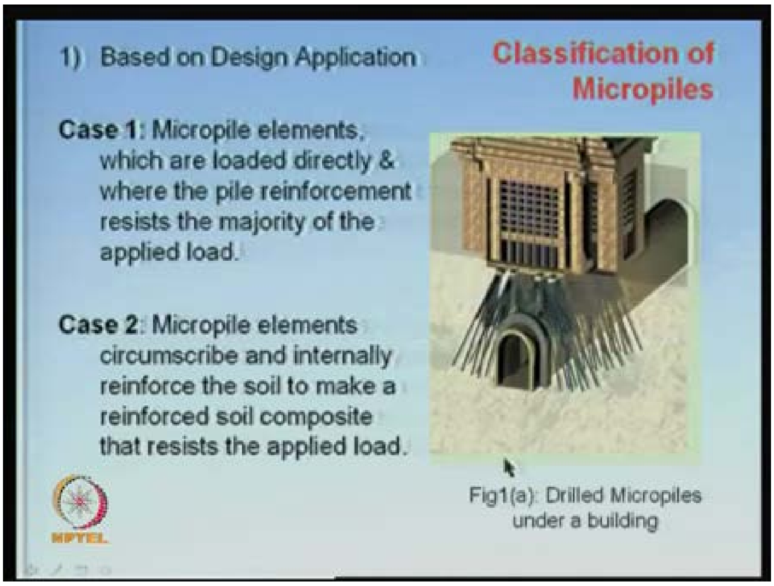

The advantage is that say for example, you are trying to have a tunnel next to the, below the foundation, below the foundation of the structure how do you go about because the thing is that, you have to make an excavation for the tunnel and it is not easy. So, one way would be, that is strengthen the whole system and also excavate in this particular portion, such that the excavation will not collapse. They excavation for the tunnel will not collapse, that is a point here. And the classification is there based on the design application. Case 1 is micropile elements when loaded directly, there are some cases where the load comes directly and then so, the pile reinforcement resists a majority of the applied load.

Similar to our pile design, the total vertical load comes on them pile. So, instead of the pile, it comes on the micropile now and we need to have a series of small diameter piles. that is case 1. The case 2 is that micropile elements circumscribe and internally reinforce the soil to make a reinforced soil composite, that resist the applied load. So, in some cases, you can have some sort of say, suppose these all are reinforce soil area and you can make that, this is in some sense do not lead to instability. So, we will show you some examples, how it can be design both in, both as a direct pile element or as an element that works as reinforced soil.

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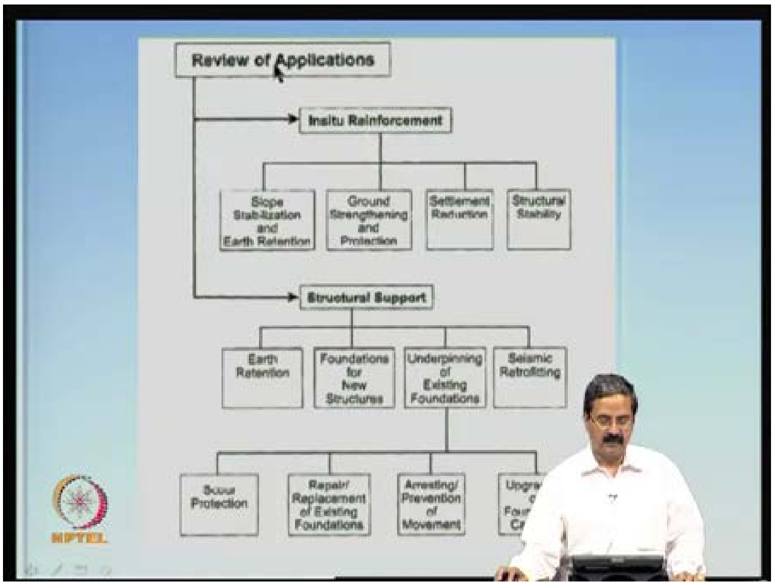

So, actually the applications are too many and it works as reinforcement because what happens is that, when in the case of a slope, why the slope failure occurs is because a driving force are more than the resisting forces. So, we say that the factor of safety is less than 1. So, what we try to do is that, we try to put micropiles such that they increase the, they decrease a driving forces and increase a resisting forces. So, that is we call it reinforcing the slope, that say, suppose you put micropiles or piles along the slip surface failure surface, the possibility is that the a failure surface will not develop. Earlier there is a failure surface that was occurring but then, when you put this micropiles, it will not happen. So, what we do is that we stabilize a slope using micropiles. So, we call it slope stabilization earth retention.

And it can be said as ground strengthening and protection, settlement reduction. In fact, there is a possibility that there is lot of settlement but, if you introduce this micropiles settlement can be there and structural stability as well. So, that is in the case of reinforcement, in-situ reinforcement we call it. Then, structural support, like you know the, for example, structural support is nothing but the load, it is like you know, you are trying to design the pile for reinforcement and all that and as in earth retention in the sense instead of a conventional retaining wall, you can have a micropile retaining wall.

Then, foundations for new structures, yeah it can be, you know it is much cheaper compared to regular piles. Then, underpinning of existing structures, it is possible. Then, seismic retrofitting. In fact, this the other day I was mentioning that micropiles were used in one of the dams in Bhuj like when the Chang dam failed, during the Bhuj earthquake, when they did the reconstruction, to increase a liquefaction resistance they used micropiles in the foundation of the dam. All along the foundation of the dam, the micropiles were used. Then, like it can also be used particularly in underpinning of existing structures, scour protection, repair and replacement of the existing foundations. Movement, arresting of the movement, upgradation of foundation bearing capacity. These are all, some of the applications one can think of.

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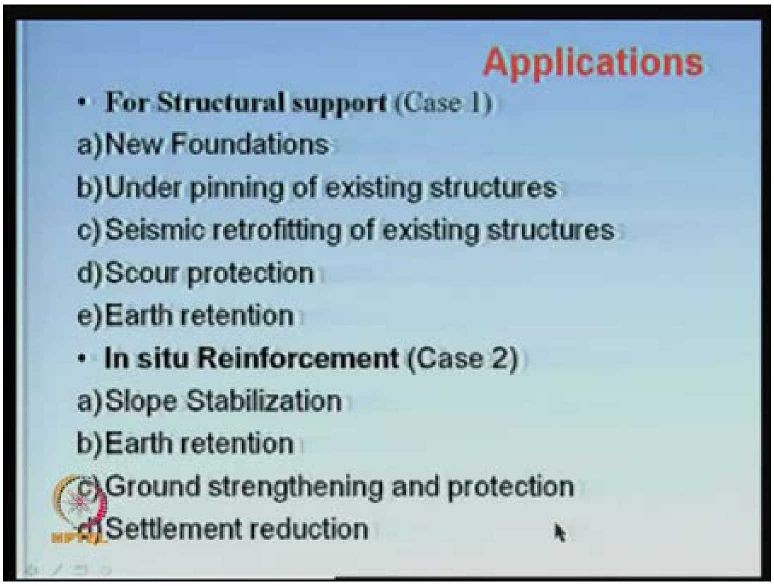

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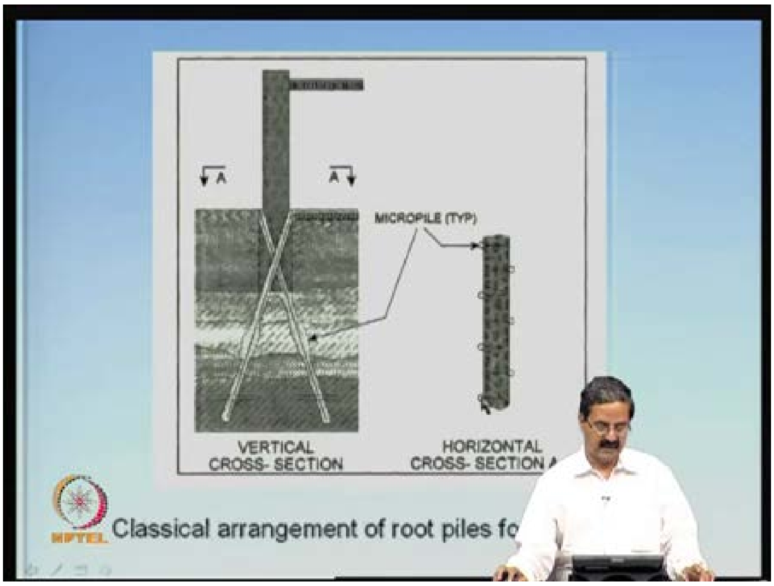

And as I just mentioned, these are all the applications one can think of here, like right from new foundations to underpinning of existing structures, seismic retrofitting of existing structures, scour protection, earth retention and all that. One of the first applications, the way it schematically shown was that, like this is a, there is a load coming on this material here. Then, in order to increase a bearing capacity of the foundation here, 2 micropiles were introduced and the advantage is that, there is a, if the vertical load is coming in this direction, there is a skin friction that develops between this grout and the soil. And in the opposite direction say for example, there is a vertical load and there is friction between the soil and the grout and it acts in the opposite direction.

So, to some extent some load on the foundation is resisted by the grout interface force and this is an advantage. So, if you know how much of force is to be resisted, by the grout makes or this particular resist the, what you call skin frication resistance, as the friction resistance along this material. So, you can design say for example, you want to make as the existing load is, existing bearing capacity is only 10 ton per meter square, you want to make it as 15 ton per meter square. What can be done is that, if you know how much is a vertical component of this pile, if you, just for a given length of piles, say for example, 6 or 7 meters, you know its length and skin friction along this length and you do a resolve that into the vertical direction of this particular pile and as many number of piles, you can have to see that the extra load is taken care of by this system. So, that is a simple way of doing that. We have done some case study on that as well.

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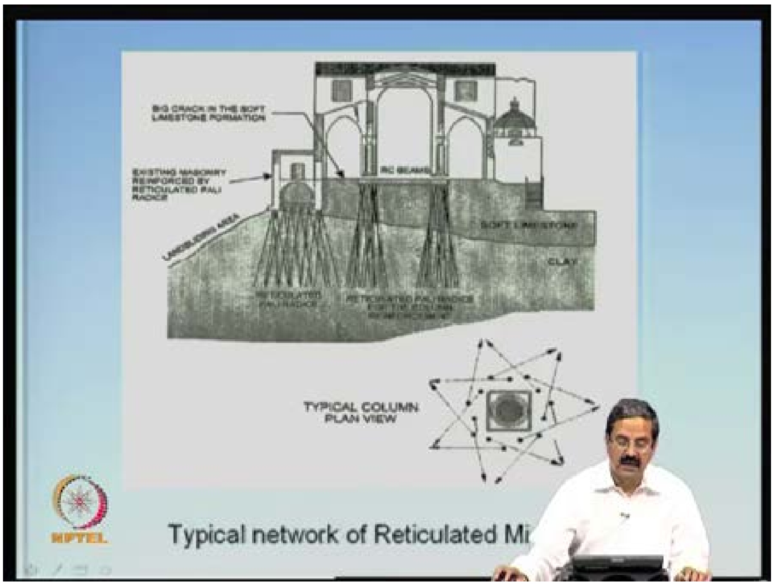

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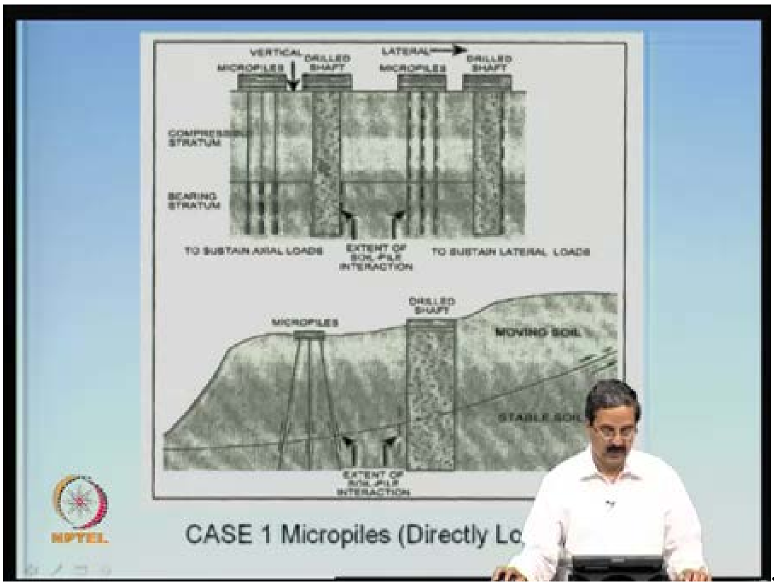

This is another example like, you have an existing masonry reinforced by reticulated piles, like you know, these are all the existing one can have, if you find that a particular building is, there is a tendency for crack, then the possibility is that, then, in order to see that further damage is not there, you put some sort of micropiles here, which is quite useful. This is another important difference that, I think I should highlight to you is that micropiles can take vertical loads as well as lateral loads. So, normally we use particularly in US, we call them as drilled shafts, the big diameter say for example, it can be 2 meters or 1 meter. We call it a drill shaft. So, this is actually designed for the pile soil interaction here, say for example, the basis of this say design is that the pile soil interaction here and this is a compressible stratum, this is a reasonably good stratum, bearing stratum what you call. So, instead of these big diameter pile, what you are doing is that, you have short diameter piles like this and the bearing resistance or the shaft resistance because of this small diameter is sometimes equal or more than this, what you get from here, which means that this is going to be easier, much simpler.

Even the same thing could be done for lateral piles also, lateral load and lateral loaded capacity of the piles, we know how to calculate and instead of this pile which has a lateral resistance like this, we can see that there is only a some sort of lateral resistance here but if you have micropiles, you can have a lateral resistance like this. So, to sustain axial loads as well as to sustain lateral forces, this is very effective. The other application that I want to show you is that, this is a slope. Slope failure can occur like this. This is a failure surface that you have. And this is a stable soil, this is a moving soil and you have a pile and why pile is introduced is because, if I have a, see the thing is, what is happened, this is a driving force, this is a bottom one, resisting forces in the opposite direction. So, the driving force divide by resisting force is a inverse of factor of safety or it from the force equilibrium considerations, you calculate the resistance divided by the driving forces nothing but the factor of safety.

And it can, you have to calculate in terms of the movements, in terms of the force horizontal forces, in terms of the vertical forces and all that you have to meet all that equilibrium equations considerations and calculate factor of safety. And if you know, we know that the soil is poor in shear resistance and now you have a concrete column here, under a Steven steel reinforcement. They can be very good in resisting shear. So, you have got this diameter of the pile such that, this provides earlier the factor of safety is less than 1. Now, we have a pile bigger diameter pile and if you are able to properly design it, you can this shaft is sufficient to take care of the slope. But, they as I just mentioned, instead of the, one can even have a simple micropiles like this.

This is what I said you know, its call directly loaded materials like you know, where the case 1 micropile, this materials are loaded directly and then you get the advantage. We can see that, here you are trying to design it for the vertical component here. You can just see that, you can see a line here, where you have a force here, the same force is now replaced with this micropiles you know, shaft resistance is there. The same shaft resistance you are able to get from here. You know the thing is that here what I just mentioned, case 1 is an example where load is directly taken care by the micropiles, vertical load. Here, same thing but shear is something different that is case 2. So, vertical load is taken care of by this system.

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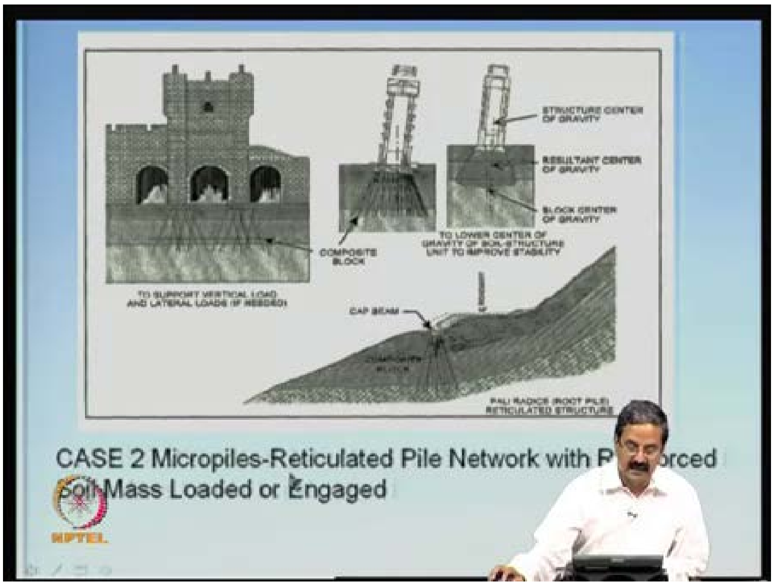

Case 2 is another example of a reticulated pile network with reinforced soil mass loaded or engaged. So, essentially like imagine that, this is a very old building, where you know the possibility is that we find lot of cracks in the building and then you calculate and then find that this is cracks is because of the differential settlement. When you know that the cracks are is because of the difference settlement, you have to see that the strength of the soil in that place is increased and you have to reinforce that. So, you do that and that they are useful in this direction. Even, so what happens is that they create a composite block you know say for example, the center of gravity of the structure you can calculate resultant things also can calculate a to lower the center of gravity of the soil structure in unit to improve stability is done and this is another example of trying to have a strong here, you know this for a slope failure here. And you have a strong soil here, somewhat weak bedrock here, then this a typical soil. So, one can have this sort of micropile here as well.

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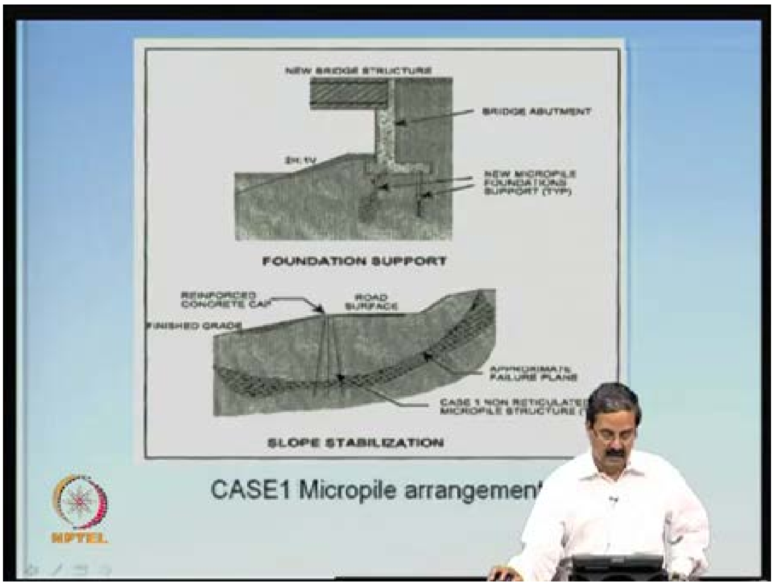

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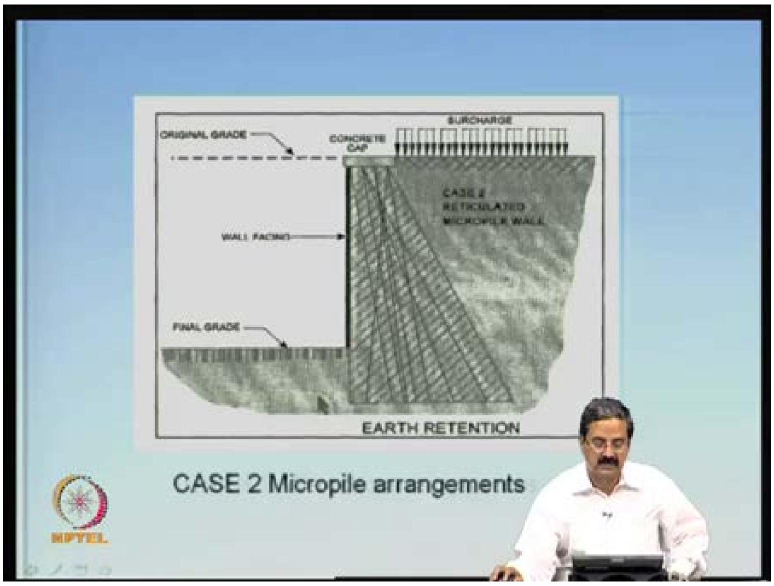

Case 1 micropile, whether the load directly can come like you know new micropile foundation support this can be there in this. This is a bridge apartment. This is a slope then there is another one. Approximate failure surface could be failure plane, could be like this. Now, reinforced yeah concrete cap is here, finished grade is that road surface. So, all that load you know, there is advantage is that you do, you have constructed here, you do not want this sly to take place. So, you are trying to provide some sort of resistance in this manner. This is another classical example, how you know, instead of having a big retaining wall you can have a number of piles which are easy to install and then, it can take care of the surcharge as well as the head pressure. Wall facing is you know, it is a very minimum wall facing here, thinned facing is there. What we did was that we are trying put lot of reinforcement elements in this vertical direction and that can acts as a very good retention system instead of the regular retaining wall.

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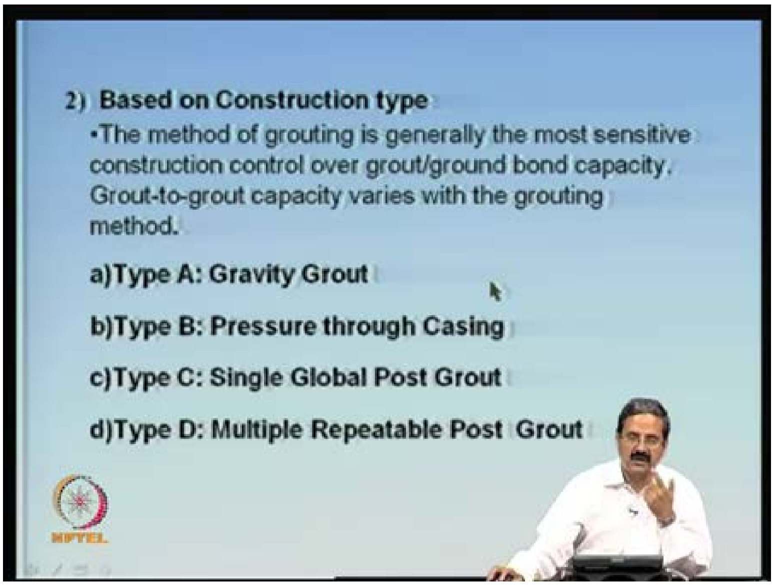

So, this is based on their design. Then, we have based on the construction type. The method of grouting is generally very sensitive to the construction control and the grout, the ground bond capacity should be very good and the grout to grout the whatever, the capacity resistance depends on the grouting method, you can have a gravity grout where the grout you know, cement mix, cement plus sand mix like you have a cement 1 is to 4. You know that could be the grout mix, water content could be little high. So, that it has flowable properties and you can have a pressure through casing, then single global post grout, multiple repeatable post grout. You will see that what is this grouting. What we are trying to do here is that, we are trying to create this columns of grout. So, here the grout type A is grout is called, you know it is a Type A. here, the its placed under the gravity head only using sand cement mortars or neat cement. Type B is in this type, we have a some sort of pressure like you know, we try to remove the casing also and then put some sort of pressure. So, that you know the pressure is also controlled. So, that it does not break the existing rock.

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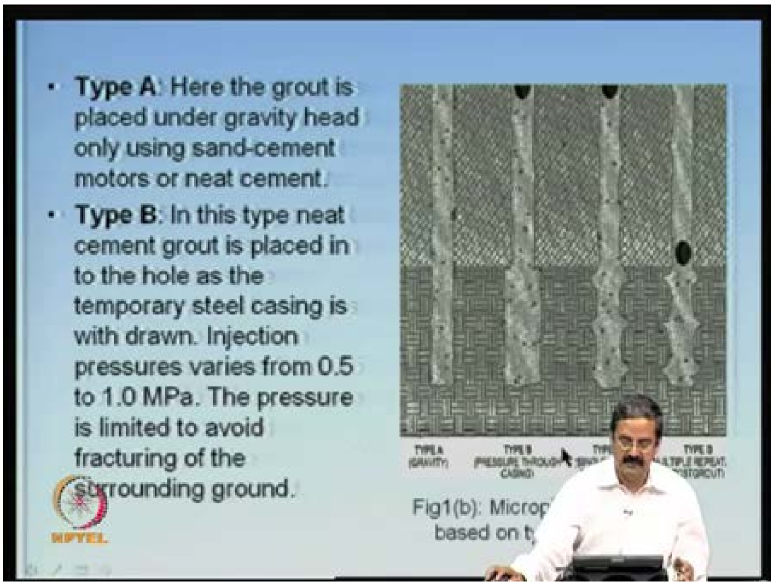

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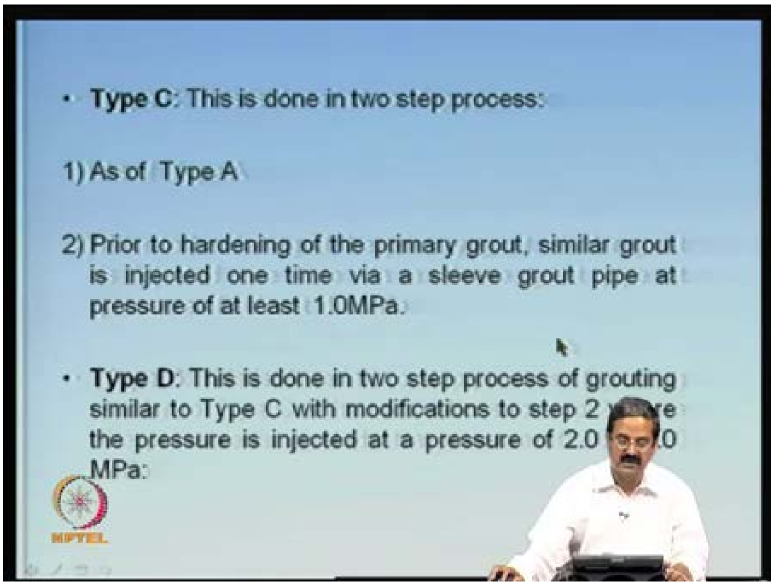

Type C is this and Type D is what we will see. Type C is nothing but, again it is just a gravity type and in fact, what happens is that, you try to have a what you call, you know at every stage its get harden and prior to hardening of the primary grout, similar grout is injected one time via a sleeve grout pipe at pressure of at least 1 MPa. D type, this is done in 2 step process of grouting similar to Type C with modification to step 2, where the pressure is injected a pressure of 2 to 8 MPa. What we do is that little higher pressure is there and then, it is somewhat, it has a sort of structure where, it is called a Type C, global post grout, Type D, multiple repeat of repeated post grout. So, essentially, what you are trying to do is that, you try to create some sort of a structure where, the bond resistance come into picture.

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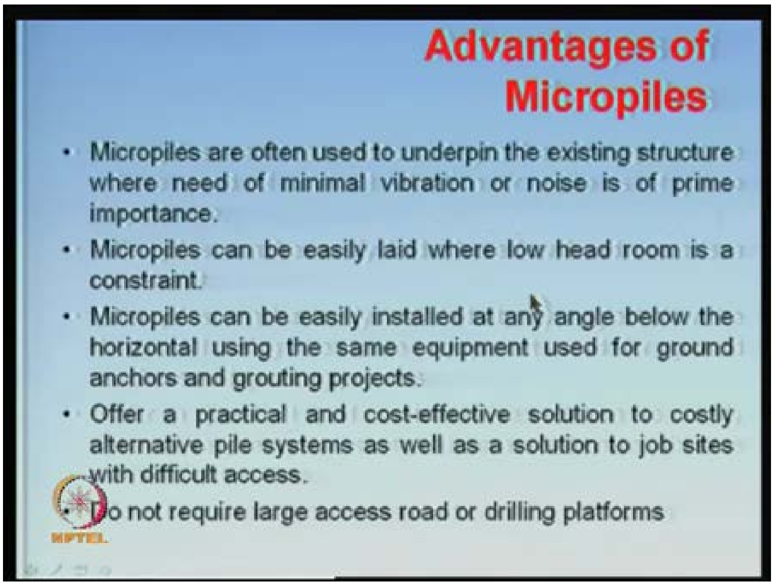

The advantages of the micropiles are that, they are often used to underpin the existing structures, where need of minimal vibration or noise is of primary importance. Say for example, if you want to construct any other ground improvement technique in an existing town area, where you know things are very difficult like, say for example, any other technique, if you want to use it is not easy. The existing structure, you would like to stabilize. So, micropile is one of the best one. In fact, soil nailing is another one, that I will show you later. But micropile is an, is a very good technique, micropiles can be easily laid when low head room is a constraint like you know, when there is not much place to move around and place equipment micropiles can be easily done.

Micropiles can be easily installed at any angle below the horizontal using the same equipment used for ground anchors and grouting projects. In fact, the equipment is not very different from what we have in the case of grouting projects or ground anchors projects, where extensive grouting is done. So, the same equipment can be used to install micropiles. You know the micropiles are nothing but grouted columns. So, definitely, one can use this. They offer a very practical and cost effective solution to costly alternative pile systems as well as a solution to job sites with difficult access. This is another one and then, they have, they do not require larger platforms, drilling platforms and all that.

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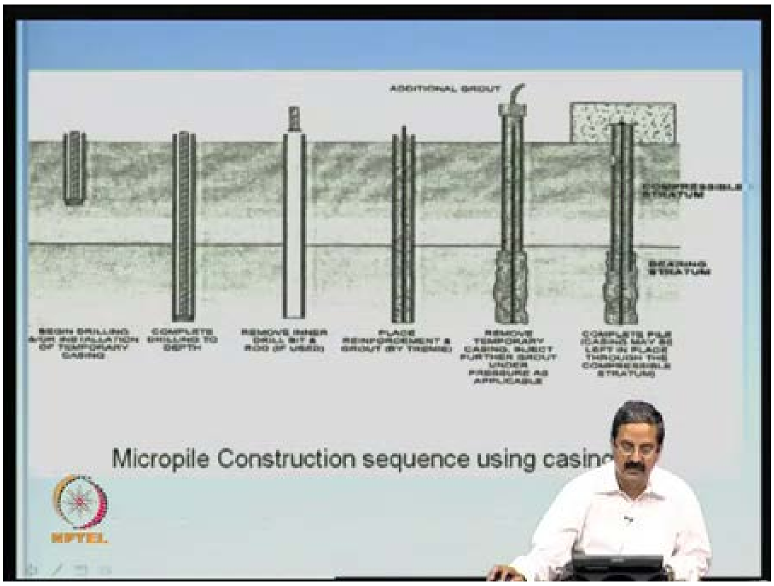

So, how do you do that, of course, there are different ways like I will show you. Begin drilling or installation of a temporary casing, like you know, you have a temporary casing also sometimes outside. So that, it should not collapse, right. Casing is required, when you are trying to make a borehole to see that the borehole does not collapse. So, you go to the required depth, then remove the inner drill bit and the rod required. So, remove the drill bit, like we have seen couple of techniques where, use a drill bit also to go to a particular depth. So, what we would use that remove that, then place a grout, place a reinforcement and grout by trimming. So, you put some reinforcement rod and put grout. So, this becomes the micropile. So, remove temporary casing, sometimes if you want you can even improve the, see this is a temporary casing is there, you remove the temporary casing inject further grout under pressure as applicable, like you can even keep on removing this or if you want to retain it also, is fine. So, we can, in fact, the advantage here, you can see that you have a bigger pressure bulb, I mean pressure grouted area and that could increase the bearing capacity of the pile foundation here. So, then after that, you put a cap, that is what we do here.

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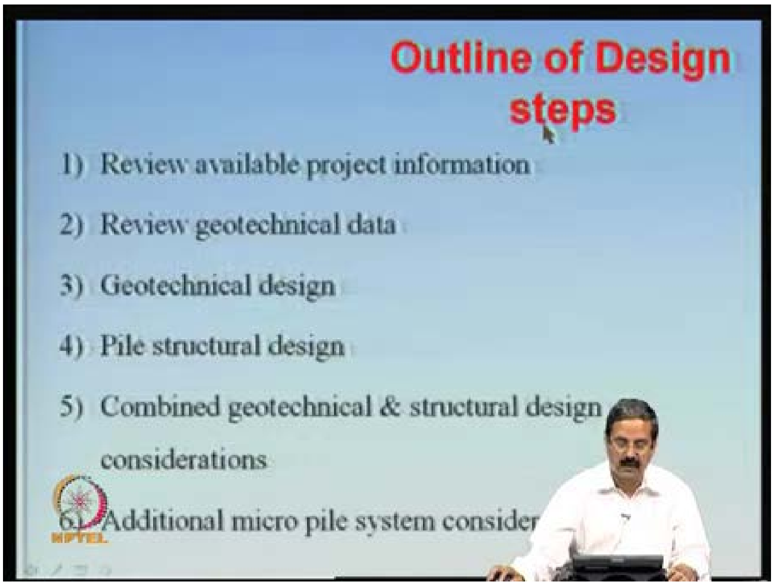

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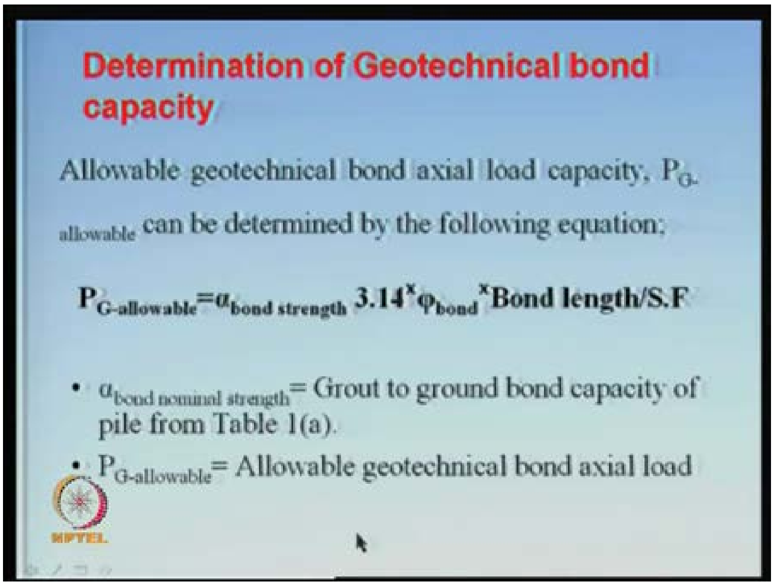

So, there some certain design steps that we should do, we have review of available project information, have a geotechnical data information, geotechnical design, pile structural design also, combined geotechnical structural design considerations, additional micro pile system considerations. Actually we have to see, there are two issues that I was just mentioning, one is you try to design the pile as a, micropile as a pile, that is one case. Taking it as a structural member. The second case is try to design it as a reinforcement. There are two examples the critical distinctions here. Now, I will be talking about determination of the pile as a micropile similar to what we use in the case of piles.

Here, what is important is that because of the grout, we have axial load carrying capacity is obtained and because you are putting a column of grout, what is a load allowable on the grout is how do you get it, is nothing but the, the alpha is nothing but the bond strength into the pi, pi it is actually essentially the diameter and it is the friction and then, the length of the micropile we assume that, wherever is a length that you know whatever, wherever you have putting the grout, that length we will take and then. So, to factor of safety we apply, is essentially nothing but, it is the surface friction that gets mobilized between the pile and the soil.

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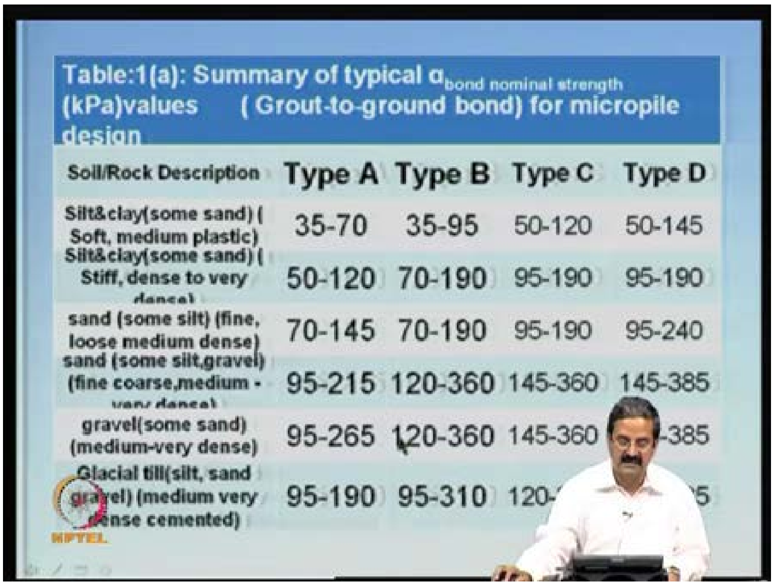

Table:1(a): Summary of typical $\alpha_{bond\ nominal\ strength}$ (kPa)values (Grout-to-ground bond) for micropile design

Soil/Rock Description	Type A	Type B	Type C	Type D
Silt&clay(some sand) (Soft, medium plastic)	35-70	35-95	50-120	50-145
Silt&clay(some sand) (Stiff, dense to very dense)	50-120	70-190	95-190	95-190
sand (some silt) (fine, loose medium dense)	70-145	70-190	95-190	95-240
sand (some silt,gravel) (fine coarse,medium - very dense)	95-215	120-360	145-360	145-385
gravel(some sand) (medium-very dense)	95-265	120-360	145-360	[illegible]-385
Glacial till(silt, sand gravel) (medium very dense cemented)	95-190	95-310	120-[illegible]	[illegible]5

So, grout to ground bond capacity of the pile, you can get this and this is what I can see. Say for example, if I trying to use a Type A, Type B, Type C, Type D, depending on the type of soil, we have this materials. And once you know that, see that is called a skin friction. Essentially, what you got was the skin friction, then you can also get the end bearing also and you know end bearing is like a similar to driven piles, one can get or even load test as one can do and then once you get the ultimate load factor of safety, you will get that the other one also, like the axial capacity of the micropile.

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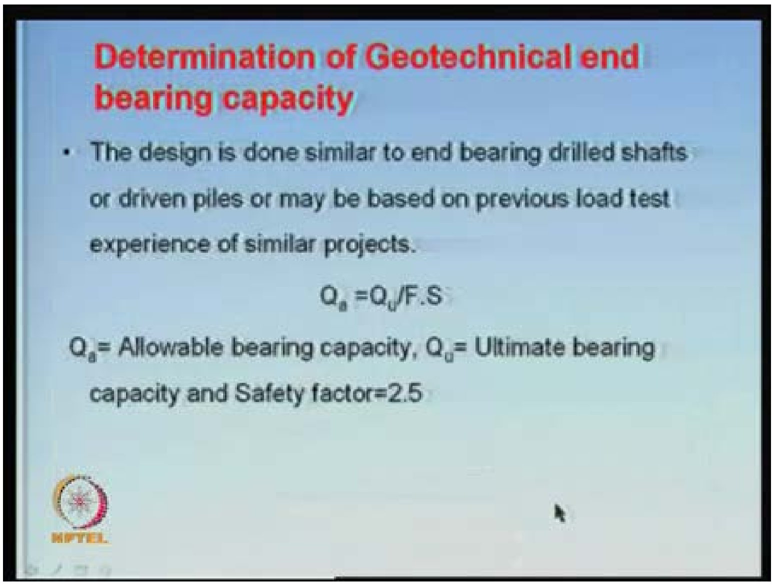

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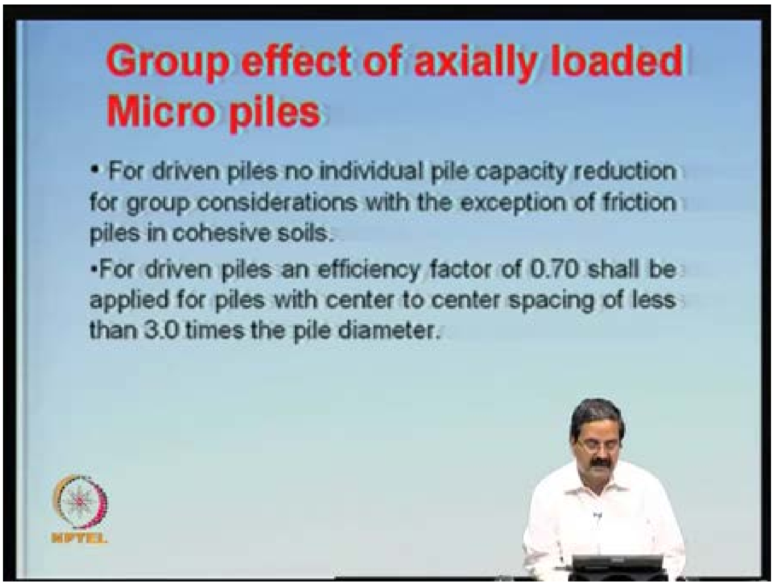

So, normally we try to put them in the form of group of piles and for driven piles, no individual capacity reduction for group considerations with the exception of friction piles and cohesive soils. Actually, we try to use some sort of you know, when the to consider group action, we try to use an efficiency factor of 0.7, we do not assume that its fully 1, we use an efficiency factor 0.7, similar to pile design and with the center to center spacing of less than 3 meters of the pile diameter. Essentially, when they are too close, we take this reduction, otherwise it is not necessary like sometimes, you know it is similar to a pile design, we try to make this group efficiency correction also.

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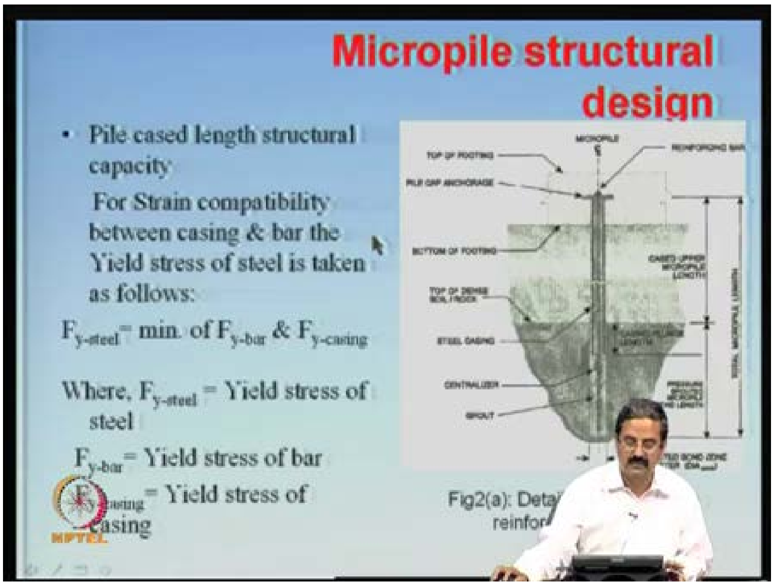

So, that is from geotechnical conservations, where you try to get the shaft resistance as well as the bearing resistance based on pile soil interaction and all that. It is a some design procedures we have and in the case of structural design, what we do is that we have to normally, you also do in the pile design that we calculate the structural capacity of the pile. Structural capacity of the pile is calculated, geotechnical capacity of the pile is calculated and whichever governs the design you take it, take it appropriate. So, we have to ensure that, there is a enough friction available and also the structural capacity is also calculated and how do you calculate the structural capacity, like say for example, in the case, if you have a casing here, as a for the main, say member here and what we do is that, we assume that the yield stress, what is the yield stress. So, we assume that some sort of strain compatibility between a casing and bar and the yield stress of the steel is taken as Fy steel is minimum of Fy bar and Fy casing.

There are two members here, one is the steel yield capacity, like as I just mentioned at the center of the micropile, we have one rod and then casing is also there, which away is the minimum of them you take, say for example, you may have mild steel as a casing and you may have a ribbed (( )) as a reinforcement, like you know which has that, say for example, 250 MPa will be the cover and 415 MPa will be the central rod. So, whichever is minimum, we take for calculations. So, these are all known and what is that tensile load that can be allowed. You have this sort of simple expression also, what is a load. You know, the thing is the micropiles can also be designed for taking tension and compression and all that. You know lateral forces because, so, in this case since a pile is subjected to lateral force, for example, you have all these forces developed. So, you must be able to check.

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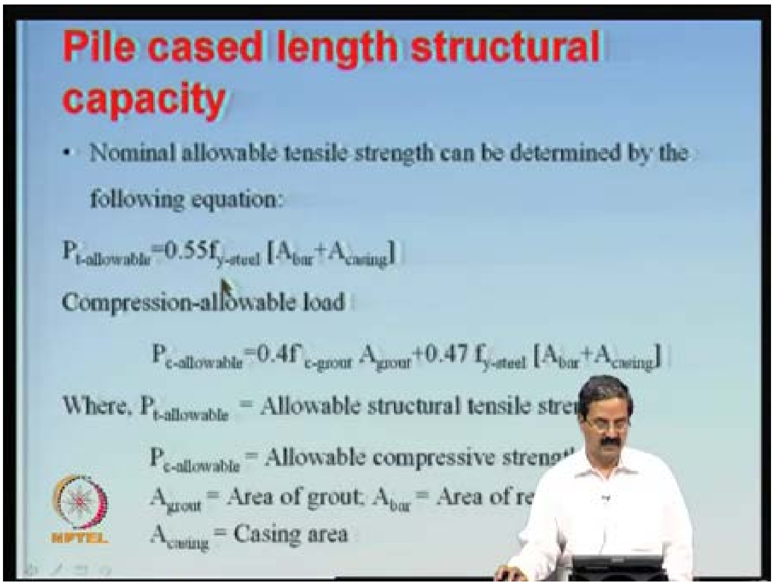

Here, we try to take like a similar to 0.55 similar to a factor of safety of half or some, 1 point, I mean 2, factor of safety of 2 or little more than that or little less than that. You will get 0.55 Fy steel into A bar, area of cross section of the bar central, plus the casing. So, that is in the case of tension and in the case of compression, we have a 0.4 into the C grout into area of the grout plus 0.47 Fy into steel into, like area of the bar plus area of the casing. So, we are trying to divide on the compressive load that one can take from the this thing, is that this is an a simple expression. This is an expression for tensile capacity that allowable because you are using term called 0.55 here and this also we in the case of compression, we have factors like 0.4 and 0.47 and the corresponding areas of grout are there here. In the case of grout you have this and in the case of steel material you have this.

So, total compression, you know because the micropile consist of both central rod, casing and the grout. So, for all the three things, you should have. So, once you have this sort of information and what we do is that. Yeah, even for uncased also one can get some sort of expressions like this. You know casing are, there are two types, one case type, the other one is non-case type, without casing or whatever. So, without casing also one can do that, with a simple calculations like a skin friction is a basis and say for example, that is what we have done here. Bond strength and we use transfer allowable also we use in the same thing, except that I removed casing here, nothing else and a compression allowable load again casing is not there. So, you the same expressions are used in same concepts are used to get the allowable loads on the micropile based on geotechnical considerations as well as structural considerations.

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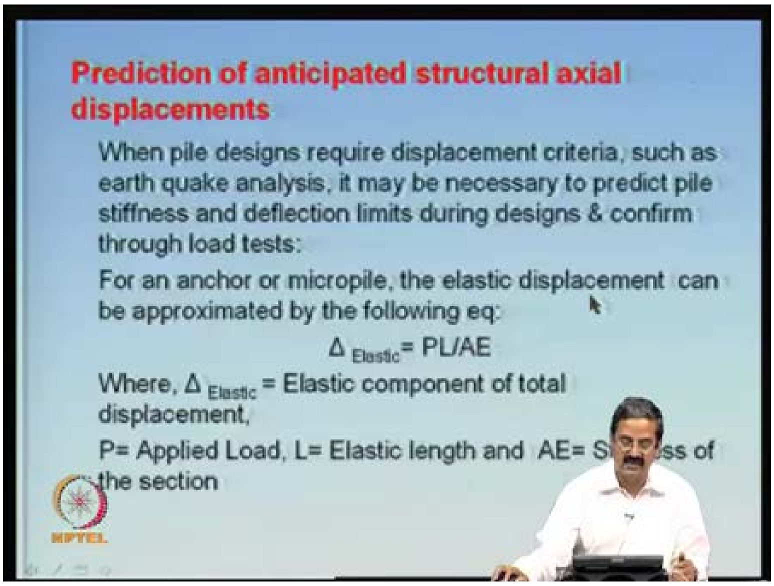

So, sometimes when you are trying to design for earthquake conditions, it is necessary to find out, what is the deflection that it can go undergo. So, for a micropile you know this is a displacement, that it can undergo like you know, with a simple strength of material formula, where you have this expression. So, it is simple to calculate because we assume that the loads are all elastic, loads are within the elastic range. I will try to give a small example. Design micropiles for an embankment with top width of 4 meters width and 2 meters high with 1 is to 2 slope on the sides with the unit weight of embankment fill of 17 kilo newton per meter cube, on soft soil to improve the bearing capacity in a uniform deposit of medium clay with unconfined compressive strength of 100 kilo newton per meter square. Consider the diameter of micropile as 0.1 with a minimum spacing of 3 times center to center.

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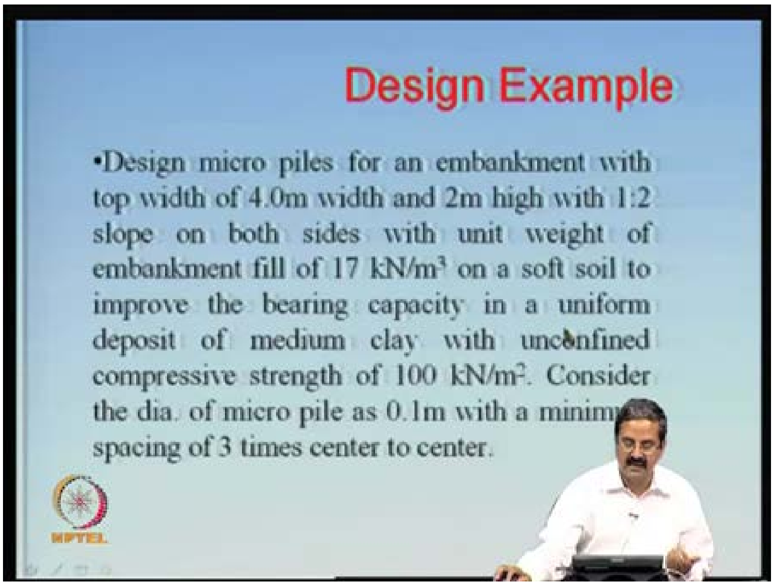

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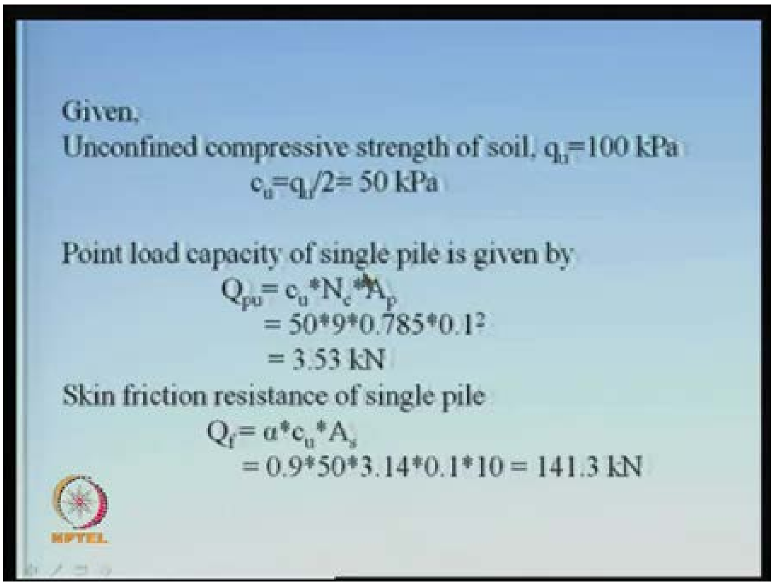

So, what you are trying to do is that you are trying to construct an embankment in a soft soil, reasonably soft like you know, I just said there is unconfined compressive strength is about 100, which is not its reasonably good. What we do is that, we try to calculate it is first thing is a single pile skin resistance. So, you know the shear strength 100. So, you want the unconfined compressive strength. So, c u will be half of the shear strength. So, 50 KPa. So, point load capacity of the single pile is nothing but c u into N c into A p. So, you will get this number and then, skin friction resistance of the pile, alpha c u into A s, where A s is the length of the pile, actually 10 meters is what I have taken in this case. And so, I am just taking pi d, not pi d square by 4 into l, I am just taking d diameter as the, this thing. That is why, you get here you know for simply steel, normally, we have two types of considering here, either pi d square by four into l or just pi d l. So, normally for pi d l is used here, in some simple approximations.

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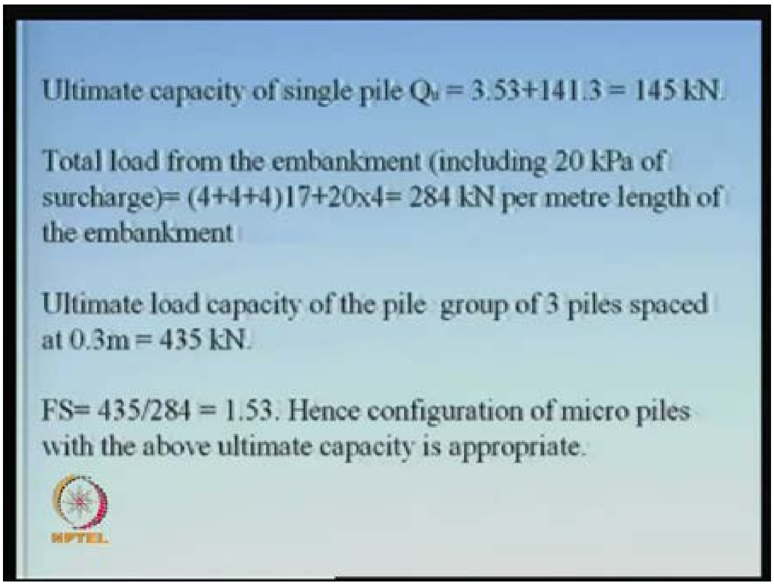

Particularly, when it comes to skin friction. Then, you calculate both the loads three point, you can see that skin friction of the single pile is much bigger, had it been a normal pile, this is somewhat higher. Say for example, if the diameter is going to be higher like you know, diameter directly comes here like A p a, A p a is the area of the pile. It comes here, then this will dominant. But, here you can see that the pipe, the pile diameter is smaller and you have this one dominants the thing. So, what I want to say highlight you is that, here that if you have small micropiles which are easy to install, they can take care of the carrying capacity of the bigger pile itself and advantage is that it is very fast it is convenient, it is quite easy to do the things. So, once you have the total load of the you know, you are trying to calculate the single pile capacity, say for example, 145 kilo newtons, then assume that the total load like you know the embankment is about 4 meters width and then, it has a 1 is to 2 slope. So, it has that 4 meters if and then, unit weight is this much and surcharge is this total load.

So, I calculate and 284 kilo newton will be the load per meter length of the embankment. That is what we get, actually I am not using any load distribution factor here, I am just assuming 20 KPa as working on that, then it has a side slope. I am just calculating the what is the total load that is coming on the base of the embankment. Say for example, as I just said the height of the embankment is 4 meters. So, below 4 meters, I will get this much stress and I am not assuming any stress distribution and I am taking total load as it is. So, definitely, this is the load and ultimate capacity of the pile group of three piles which has spaced at 0.3, you know say 145, 145 into 3 is 435. And so, 435 divided by 284, factor of safety is 1.53. Hence, the configuration of micropiles with the above ultimate capacity is appropriate. So, this is what a simple statement that one can make.

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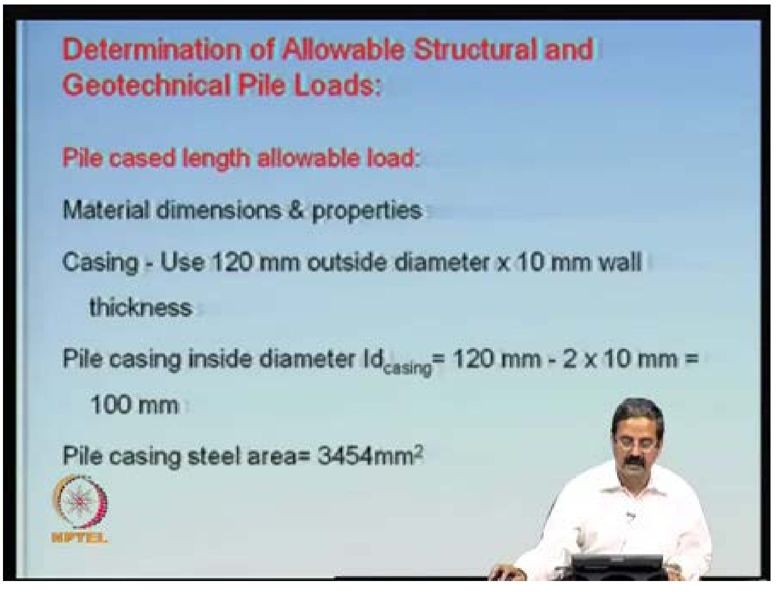

And now, I will look at its structural capacity also because thing is that structural capacity should be, you know more than the geotechnical capacity because it should more work as a pile micropile. So, you we can use 120 mm diameter outside, you know O D and you have steel pipes or simple casing and you have all these steel diameter area calculated and all that. And we know the yield strength of this material like as I just said yield strength of the casing is one like, 240 MPa it should be and use reinforcement bar of 415 MPa and 25 mm diameter, compressive strength we know, strain compatibility 2, we have seen this formula and 240 is the minimum I have taken.

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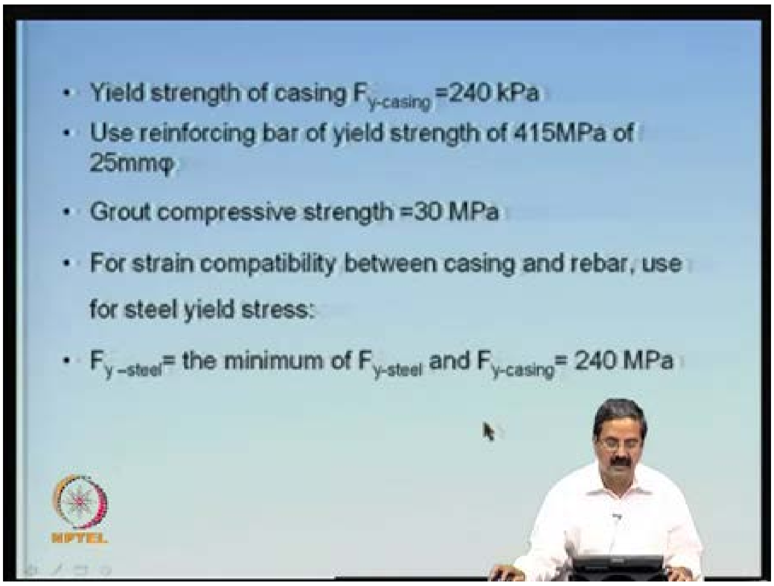

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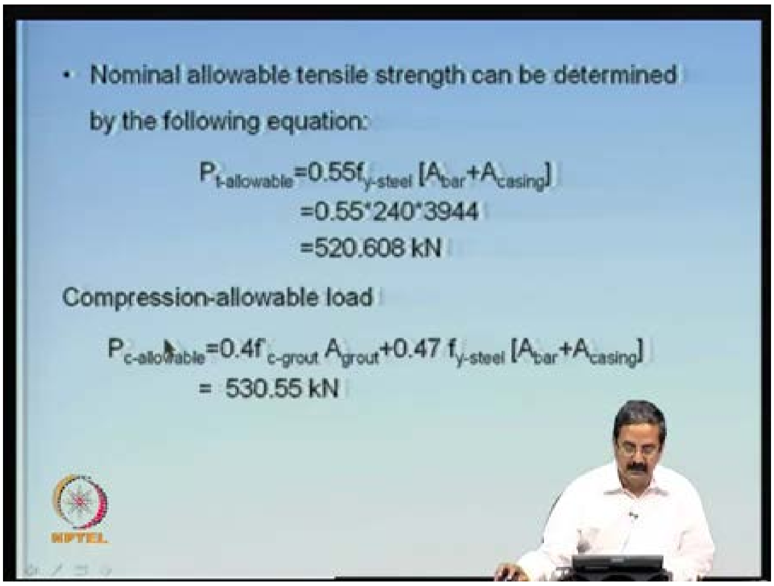

And normal allowable tensile strength can be determined, using this equation. This also is the maximum load, then compression allowable also, one can calculate. You can see that the allowable tensile force is tensile load is to 520 and then, allowable compressive load is 530 and you can see that the allowable geotechnical capacity, like you know the depending on the type of material, it is about 190 KPa and once using this the what is the total load available, you can calculate using its bond strength and the length you know, 10 meters is the length, I get 238.

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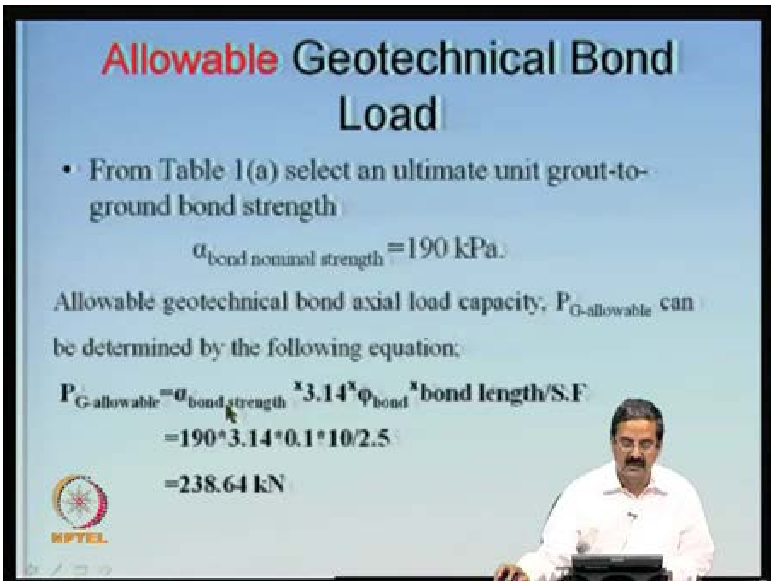

So, 238 kilo newtons is quite good compared to 530 and then, we also had calculation about the number of piles calculations, based on some you know load and all that how many number of piles are required. And based on the properties of that soil and other things. So, you are able to get some idea that, micropiles a system can be designed and it should be such that, it should have proper spacing and diameter to take care of the load and also that it should comply with geotechnical capacities as well as structural capacities and once they are satisfactory, one can go had with design. I mean implementation, in the sense that there is again some more things in the implementation. Once you have the designed some micropile diameter, it is important that you have some more analysis done. Then, I will show you another example in the case of which, this is what you was saw in the case of structural capacity, micropile has that advantage that it is working more as a structural member.

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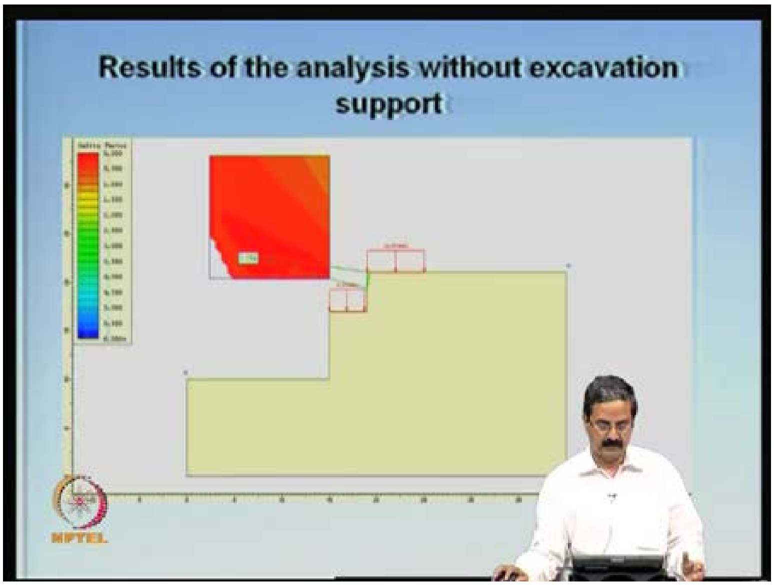

Now, I will show you some example like, where it is required that, it work, it acts as the shear for shear capacity. In fact, this is an example of an, for a railway project there is a particular big tunnel on under, the under pass box was coming here and then there is a surcharge load is applied and they wanted to see without, they wanted to see what is a stability of this members and then you have a system here. And then there is train track here like railways are also going at the top. So, they wanted to see that this particular area is not, is to be stabilized in using some technique and what I did was that I did some sort of analysis and I find that without any reinforcement, this slope is not stable.

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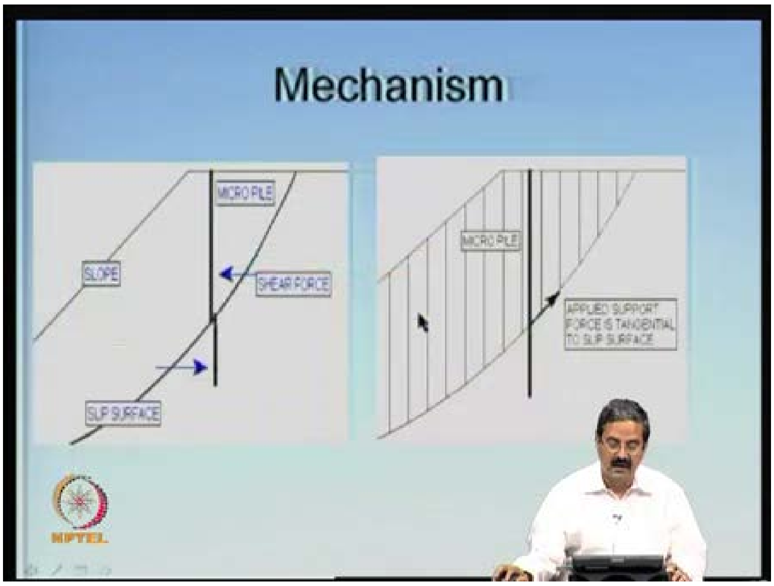

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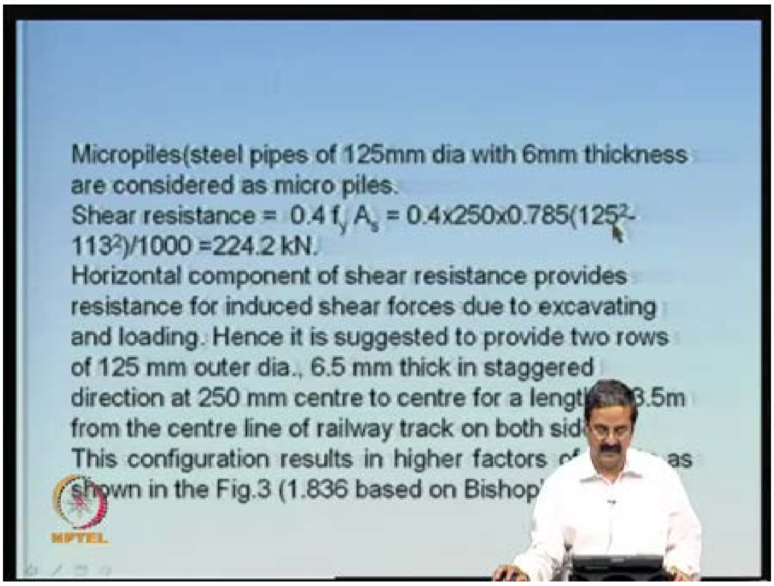

And this is a type of micropile resistance, you know the shear failure occurs like that but if you have micropile, this can apply some sort of force and this is how, the micropiles act, if the force will act here. So, what I did was that, I took a micropiles of like, they are made of steel pipes. So, 120 mm diameter with 6 mm thickness and use them as micropiles. So, the actually you, if you go to tables, we know what is the shear strength of steel also like you know, shear strength of I mean steel is very good in tension but it can also be used as a shear member because, you know when compared to soil, it is a shear resistance is much higher like it cannot be sheared easily.

So, what is its capacity, if you just look at the books, it shows that, if you note the its yield strength, it is 0.4 fy . So, 0.4 fy into A s. So, you have that area of this thing and all that calculations 224.2 kilo newtons was a shear resistance from single pile. So, the horizontal component of shear resistance provides resistance for induced shear forces due to excavating and loading. So, there is some, the moment you start excavating there is a tendency to fall and also there is a load that is going because of the traffic. So, what I suggested was that, you should have 2 rows of micropiles and the length, the diameter everything is known, diameter and then, I was just, show you and then when I just made the calculations, it has a factor of safety of 1.836 compare to 0.2 earlier, like this is the type of diagram that you get, like you know in the early previous case.

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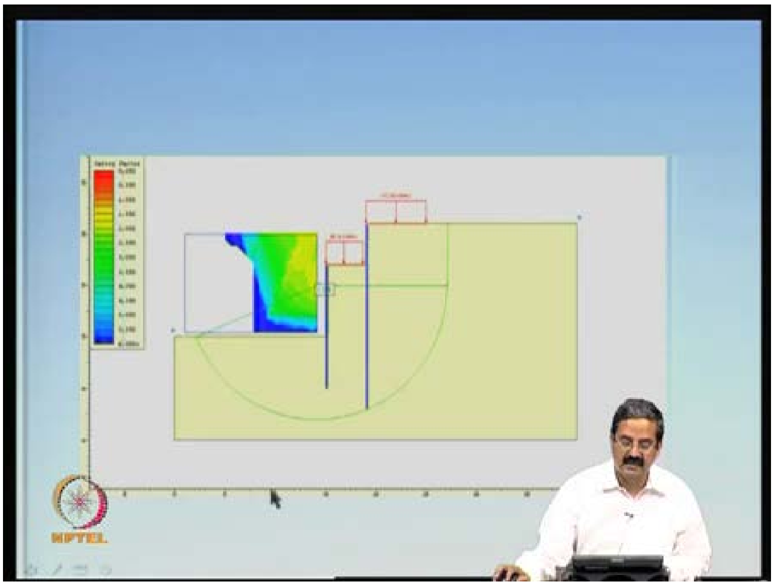

The shear force was about you know, it can you have a number of shear failures that could occur, this is the load that you have and this is about 10 meters actually and this is the way that it should happen and then, the factor of safety is quite good. So, what I want to say is that the, one should really understand that micropiles should be designed both for can be design both for its structural capacity as a compression member as well as tension member and it can also be design for shear capacity depending on the situation.

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This is another example that I want to highlight to you, where say for example, this is in place in Malleswaram where you have buildings on all the 3 sides and the depth of the excavation is about 7 meters and the thing is that, it is not easy to you know, it is actually a very old complex, they have removed that area then, they want to make you know this sort of construction. So, it is very difficult to construct a retaining wall to see that the building, they above the you know, you cannot do that. So, the thing is that, before you start any even excavation you should do the micropiles first, then remove the soil. The operation is that like you can, as I just showed you in the example in the previous example, you know you design the micropiles for certain shear load like say for example, these micropiles will take care of the shear load that comes from this building.

Like say for example, the weight is not much but the load that exist because of the apartment next to that, will cause lot of shear force and the shear force has to be resisted by the shear resistance of the, at the micropiles, at the interface. So, what was done was that, the first thing the way it should be done was put micropiles first. Then excavate later, because the moment you do the, if you do anything further without stabilizing it leads to lot of problems, you know even if you excavate a bit of say for example, 2 meters also it could lead to collapse. So, first step would be to put all that in the surrounding area you know, say for its about 50 by 80 site you know, 50 feet by 80 feet site, completely put this sort of micropiles all round and also this is actually you know, if there is a for gas removal and all that.

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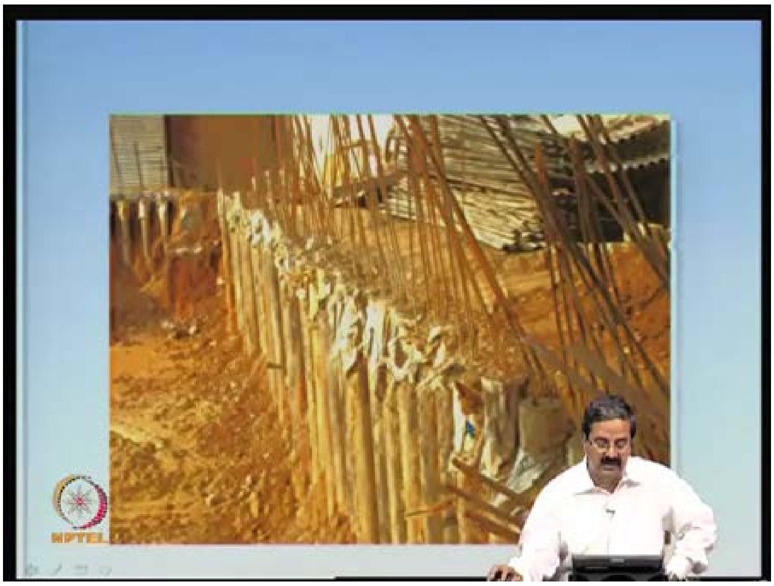

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So, you can see that the it is very deviant about 10 meters actually. A closed view look you can see here that this is the pile and this is the reinforcement, instead of 1 rod what I just mentioned, it can have 3 rods, it all depends on the shear capacity. Then, you can have another close look, you can see that the way, it is not see water table is there. Say when you have water table also, it is not easy to do say for example, it can collapse. You know particularly, when there is a water table at the bottom of the foundation the possibility is that it can collapse. So, they have, you can see all the micropiles which have about 1, 2, 3, 4 members and then they provide enough shear resistance.

In fact, I have been solving another case similar to this, in the north east where it is a slope of about 10 meters and you have a train track like this and you know you are trying to stabilize the slope next to that and we have come out with a design system where they have already have a fixed pipes. There is a particular size diameter, they want to use and they want to have a combination of whatever, see this in some places they know only as consents on the sizes and consents on the diameters. So, you should come out with proper combinations of the materials like you know, this is a steel casing.

This isa central reinforcement rod and this is a grout. In fact, you know you can see that if you are able to design properly this grout mix, one can get very good capacities for shear resistance. Then, that way one can get very good improvement here. And so, similar case was also done in the case of project in railways in north east, what I would like to say is that micropiles is a very versatile in-situ ground improvement technique and it has been used very well in many stability problems, whether it is in terms of the increase in bearing capacity or in terms of the shear resistance additional shear resistance.

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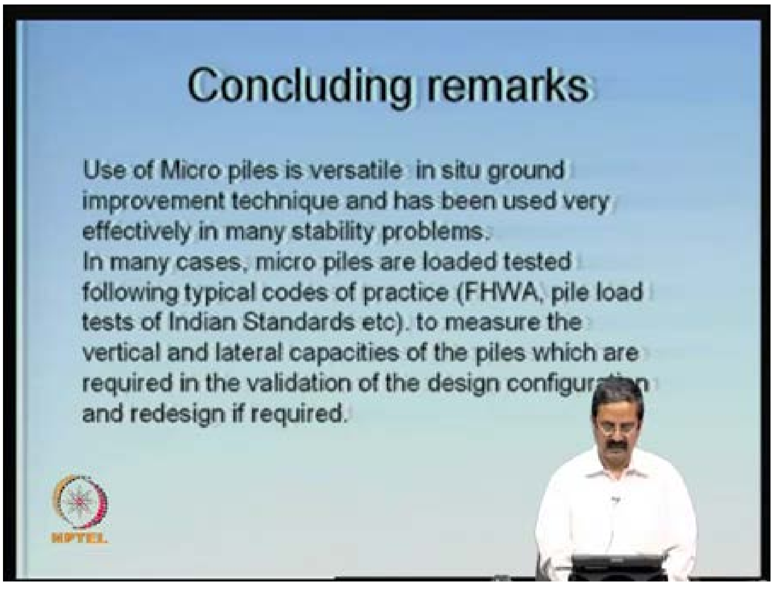

I wish to mention another case study, where in Mysore you know, the bearing in, particularly in one of the places they wanted to construct a marriage hall and the, they went to had with a construction but then, they found some sort of distress, the even during the construction for the simple foundations, then when they did the SPT test, the bearing capacity, earlier they have taken 20 ton per meter square as the bearing capacity and went ahead with design but then the investigation showed that the bearing was only 7 ton per meter square. So, they have to make it up to see that it is 20 ton per meter square is exist, is the available, otherwise they cannot go ahead with construction. Actually, that is actually little bit of loose dumped material and normally the tendency is that, if you the, you need to calculate if you want to calculate the foundation sizes, you must assume some bearing capacity and come out with a widths of the foundation and other things, area of the foundation that can distribute the load.

But if the load bearing capacity is going to be low, then you need larger areas. So, what they did was to avoid this operation in fact, we calculated what is the number of micropiles required to give this bearing capacity, extra additional bearing capacity which was required. Earlier what is required was 20 ton per meter square, what is available was 7 ton per meter square. So, the 13 ton by meter square the load was in fact, supplied by micropiles skin friction. So, we know that for 1 meter square area, you need 13 tons, 1 meter square area, you need 13 tons of skin friction. So, that we know that. So, we use that information to get the length and the diameter. So, we know this basic formula now, we have seen that, how it can be obtained like you know, you know the skin friction of the pile and the soil and you know the pi d, you use the pi d and the length and then, once then, some loads you can assume.

Taking it as vertical, see if you are putting the pile as vertical is one thing it is fine. You know, if you are putting inclined, you have take a normal component of that and once you do that, then it can be solved. So, essentially what you are looking at is calculate the number of piles that are required. So, as I just mentioned it has been very effective in many ground improvement problems and the thing is that, we assume something here like you know the thing is, I assume some numbers here to calculate the, to calculate in to what should be the micropile capacity, say for example, you may design the piles using this standard practice but best is to do the testing. Lateral load test or a vertical load test, vertical load test or a lateral load test one can do using the same testing like you know, we know how to do a pile load test. So, we do a pile load test and see whatever you have, you can calculate both skin frictions, shaft friction and all that and once you know that yes, for this length of pile this is correct, then you can even modify the design.

The same thing with lateral capacities also. In fact, in the particular case that I just mention in the case of north east, the lateral force required was quite high because of the requirement that you know, it should be designed for even the earthquake conditions, like you know when you design for earthquake conditions the lateral force resisted will be higher and so, once you have, so, you must be able to design for lateral force also. So, if you are you may design but then you should check. So, what I suggested them was that, they should just anchor, they do a proper the lateral load test. So, for example, one can do lateral load test for 10 meters, 15 meters or 20 meters. 3 piles one can install and then, calculate what is a actual load, lateral load capacity of the each pile.

And whichever is really giving the result, you know because say as you just you have seen some assumptions in the theory that, like you know the bond capacity and all that. It is very, they are all rough estimates. So, it is better to just properly get the numbers from the field and take that number and then, once say for example, I assume a length say for example, in the particular case they have taken cohesion is about, low value of 10 kp and friction is also quite low. 17 or 18 degrees which is quite low and once you have low values of cohesion friction, the lateral force is going to be very high. So, I had a doubt that, it may not be appropriate without going for complete plate load test, lateral load test.

So, I suggested that, though I was able to give the design based on the design parameters that they have given, it is better that we check the actual correct load carrying capacity by using lateral load test. Which are again available an IS code. So, they are planning to do that and the fact is that once you have which length will give the correct load carrying capacity, once I gets for couple of piles, then I can use that as a design basis and complete scheme could be given to see that that slope is stabilized under that earthquake force and even it shows as a permanent slope stabilization measure. So, measurement of this lateral load capacities or vertical load capacities is very important and they are required in the validation of the design considerations and sometimes you may have to redesign their structures.

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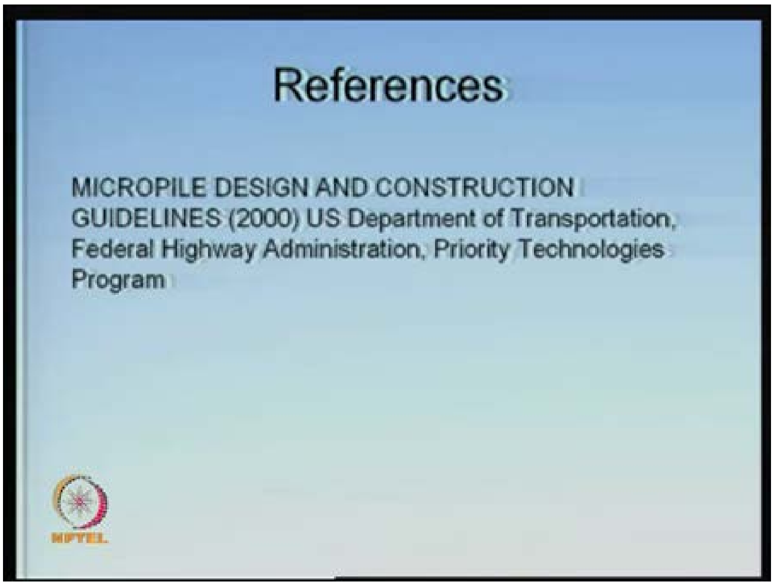

So, we have lot of information on this micropiles, particularly the very good guidelines on the US department transportation has given, which has been very useful compilation of all the design methods construction methods, the load testing and all that and there was a good body of information available on this. So, actually they, as I just mentioned the advantage of this thing was that, it is acting as a densifying material, like you know system as well as like, it can also give reinforcement also. So, it is a very good method for ground improvement. Thank you.