Ground Improvement
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Module No. # 03
Lecture No. # 09
Case Studies in Stone Columns

As I just mentioned in the previous class, what I would like to emphasis is on the failure mechanisms of stone columns.

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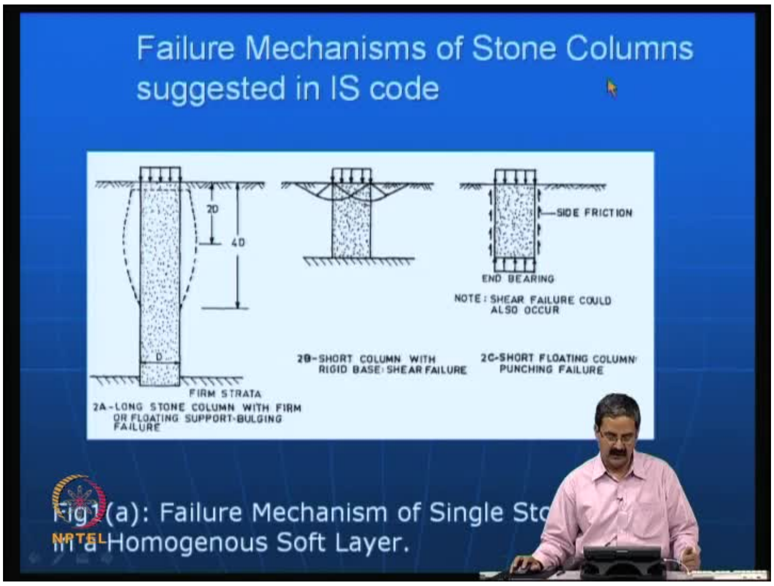

And we need to avoid this formation of bulging and of course that is inevitable. We should understand that the bulging is likely. Then, we should also avoid these types of failures. You know, these are all some of the failure mechanisms that we should be able to understand in a proper manner when you are trying to deal with the stone columns.

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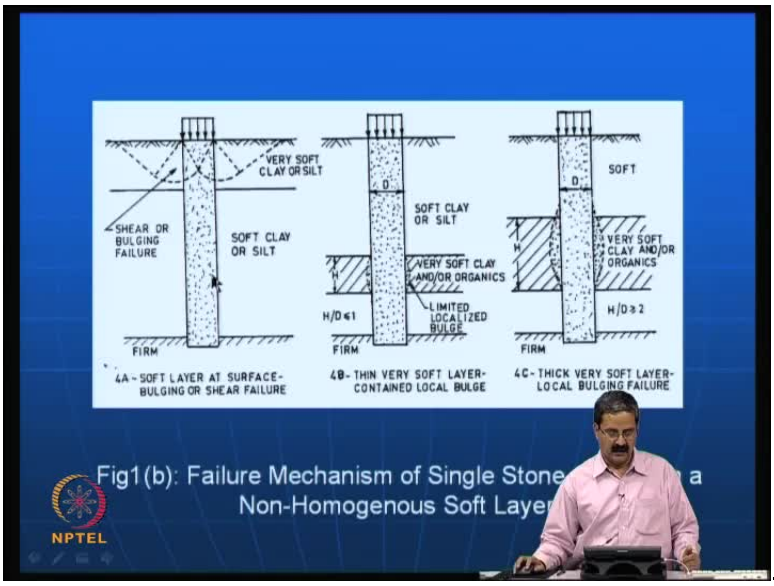

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In fact, IS code also highlights that there is a possibility that if you have a soft soil and then, you have somewhat stiffer soil, the possibility is that the stone column may not be completely effective and you may have just shear planes going like this and if the shear resistance is not sufficient, then the bearing capacity is likely to occur. So, possibly, we should just look at this point like you know was it correct.

Maybe you should go for increased diameter here or something. It is very important to understand that this is some of the crucial issues. There could be another thing like this where you have an inhomogeneous clay. The subsoil somewhere occurring and then the bulging is likely and the other possibility is that it is a thicker strata and the bulging is likely.

One can get a feel of it from the actual investigation, say, for example, if you do a complete soil investigation up to, say, for example, 1520 meters depth, it will clearly highlight you that you have some soft soil here, you have a stiffer layer here and it could be weaker layer there and all that.

If D is the diameter and H is the height, there are some possibilities like this which can occur. H is this thickness of the clay layer.

For example, H by D is less than or equal to 1, the bulging is here. Then, it could be little larger also. So, one should look for proper soil investigation and take care of this particular points. Sometimes, in some places with the S P TC P T profiles if you do, possibility is that, in some places, you have some weaker values obtained, which means that the confinement was not really good there.

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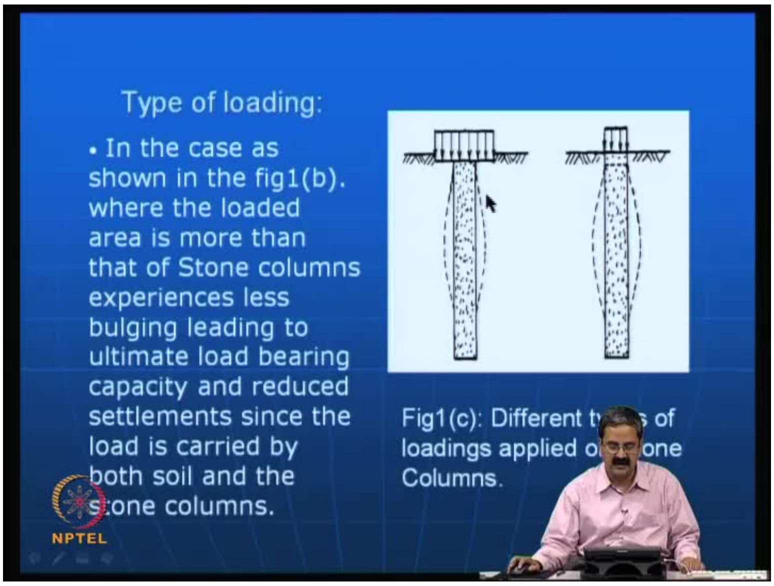

So, as I just mentioned, this is the type of loading one can have, say for example. if you have a water tank or some sort of loading, then the possibility is that, this is one type of the formation of the bulge. Here, we can just have a single load and then, you can even design just to see that the stone column will take care of that load. This is one way.

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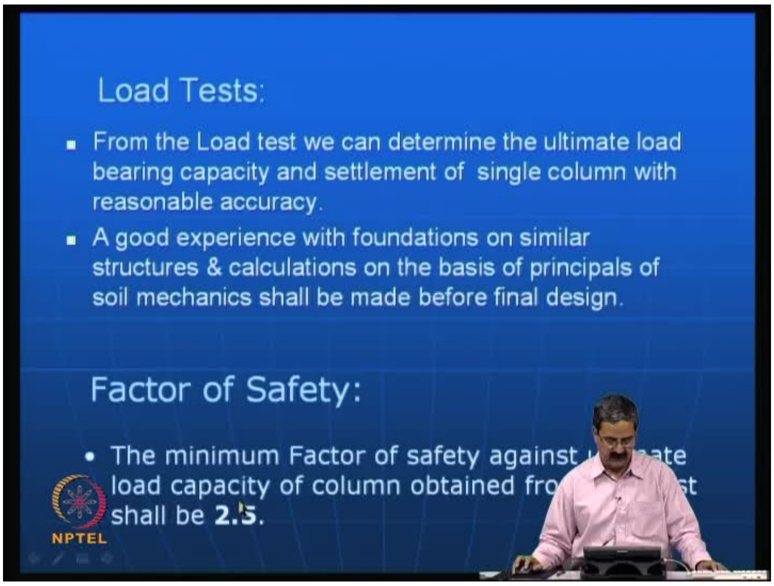

And the best way to ensure that the load is satisfactory like allowable pressure, say for example, you must have design for 100KPR, 200KPA of allowable pressure, say for example, 300KPA of allowable pressure, you must be able to properly do an ultimate load test and also the measure the settlements with reasonable accuracy.

A good experience with foundations on similar structures and calculations on the basis of principles of soil mechanics is important. The minimum factor of safety should be about 2.5.

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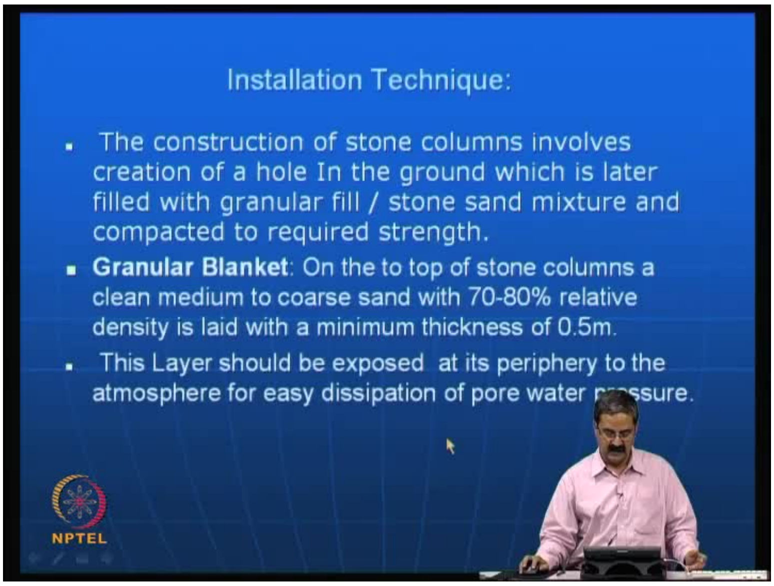

Installation of techniques: we have seen some construction procedures by Keller group. People have been using this construction techniques, in particular, in small projects. The big contractors may not come, so, the possibility is that people try to do their own technique of forming a hole and then putting the sand material and then compacting it.

In fact, this is a technique that people followed in India which is called rammed earth technique in about eighties and nineties particularly in Mumbai region. There was a lot of expansion of infrastructure and there were no good companies coming forward to do construction work in India. People have devised their own methods, in fact, there was one, Doctor Datta who is actually retired chief engineer from Maharashtra PWD and he knew about soil problems. So, he devised his own method, Put a casing, ramming earth. It is a very appealing simple technology and it was very effective in many cases.

And now-a-days, we see that only big companies have come forward particularly from Keller and other groups trying to do something in India. But, apart from that, in the previous times, in eighties and all that, we have a creation of a hole in the ground which is later filled with granular fill or stone sand mixture and compacted to required strength.

Say for example, frictional angle of the soil, that is what people are doing, they did not have sophisticated methods. You have to construct a granular blanket as I just mentioned as per the highest coat. You need to have a granular blanket of medium to coarse grain about 70 to 80 percent relative density is laid with minimum thickness of about 500 mm.

This layer is exposed to its periphery to the atmosphere for easy dissipation of pore pressure because there could be pore pressure mobilization in the clay soil. Clay soil always generates pore pressures because you are trying to introduce sand material or stone material inside and then, there is lateral pressure that is exerted because the soil between the two columns is somewhat stressed. So, the pore pressure dissipation is there.Pore pressure mobilization is a distinct possibility and you should give an opportunity for the pore pressures to dissipate. So, what we do is that we provide a drainage blanket and we see that the pore pressures are dissipated. This is one important thing.

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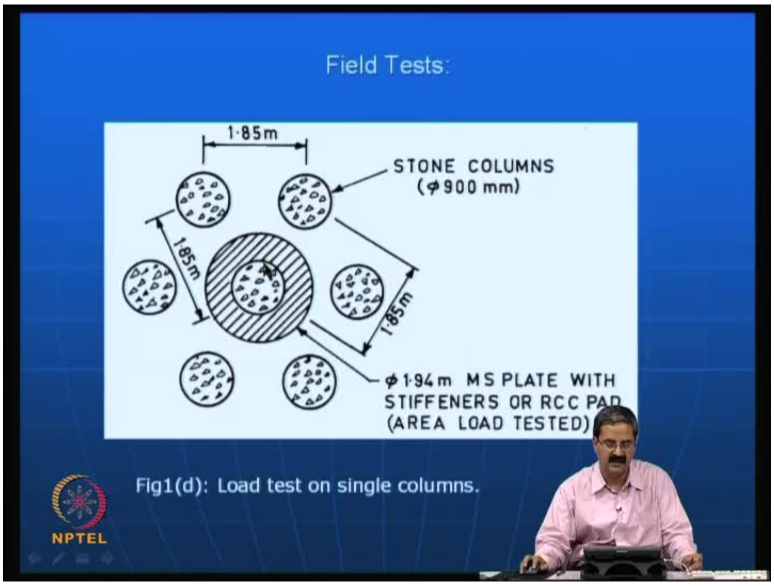

How do we conduct the plate load test? For example, on a single column and may be 900 is a diameter of the stone column and 1.85 meters is spacing between the stone columns and this is a spacing one point. So, you have a 1.94 mild steel plate with stiffness or R C C pad and then this area is load tested. That is what the code says and you can get the load displacement curve.

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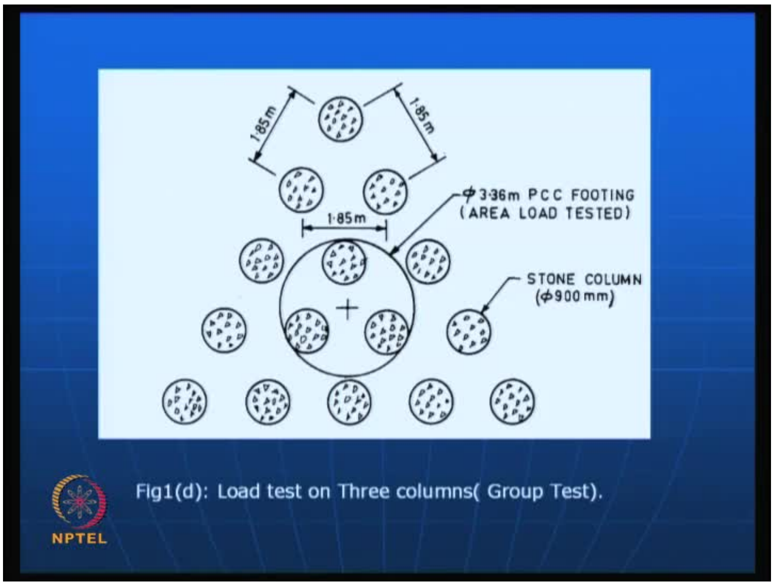

Once you get the load displacement curve, you can calculate the ultimate load. You to have a plate load test, you have a curve like this, then you join the tangents or we have

25mm allowable settlement and all that is one thing. This is another one where we have a group effects, as I just mentioned, there are bigger plate. You have 3.36P C C pre-stressed concrete footing. You put it and then do a load test. This is also another one that the IS code recommends. It is very important that people go by these methods and do some plate load tests and get their this thing.

One important thing is, plate load test is one good thing. We have derived expressions for the load carrying capacity of the single column as well as group of columns, three columns or whatever. We can do that but the important thing is the limitations of plate load test. If the depth of the stone column is 10 meters, you know, P C C is 3.36 or the plate load is about 3.36 meters. Here, one should be careful. Best is that apart from plate load test, we should do cone penetration test because we are doing it in soils.

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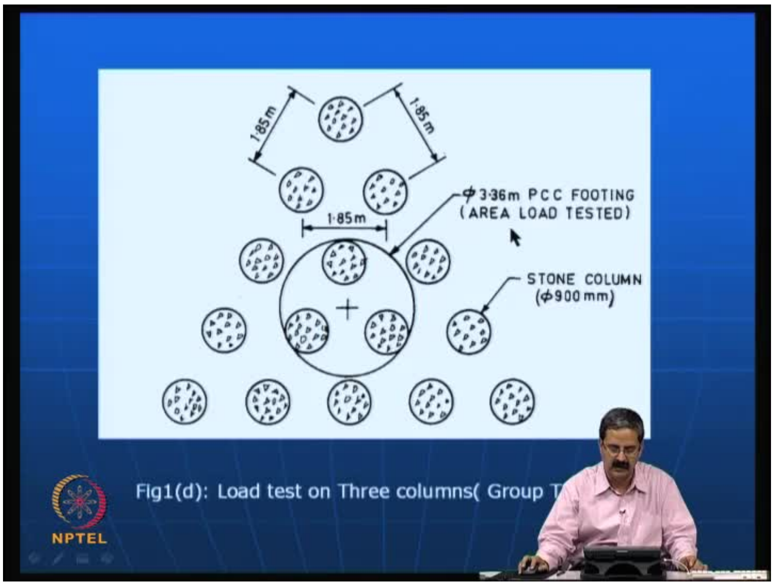

Cone penetration tests are easy. They give a continuous profile. You will get exactly what you want and you will be able to give the confirmation for the persons that there is no bulging at the bottom. There is no problem. Sometimes, we do not know how the column has completely formed. So, you can get some information about the formation of the column by seeing the signature of the improved ground from the C P T profile. That is very important.

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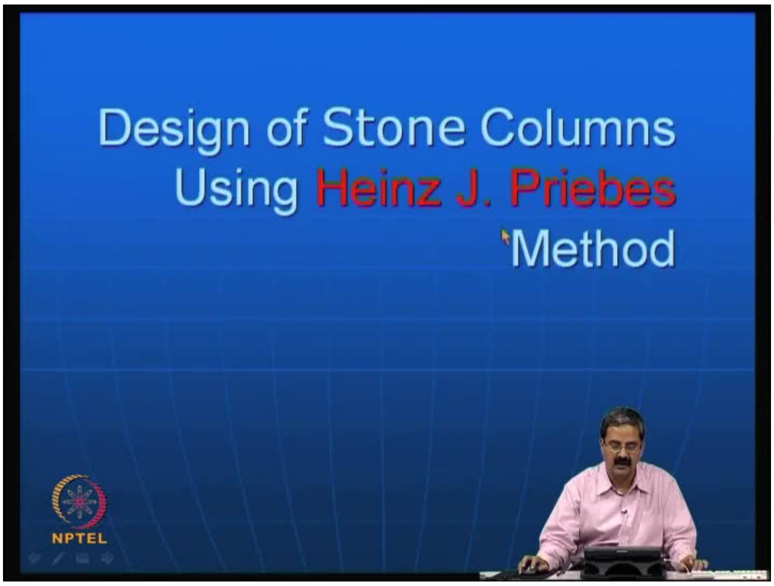

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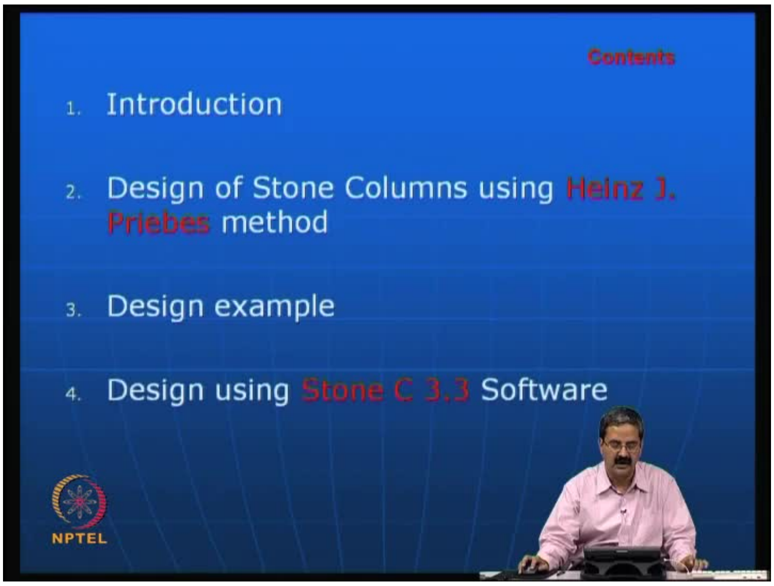

I would like to describe one design method that is very popular, that is used by Keller and other companies. This is very innovative method as well. In fact, there are many design methods. One using limit equilibrium method, one is elastic analysis approach and so the in the limit equilibrium approach, what we did was that by use of the cavity expansion, we are putting a sort of cavity inside and we are allowing it to expand and we assume that there is resistance from the soil.

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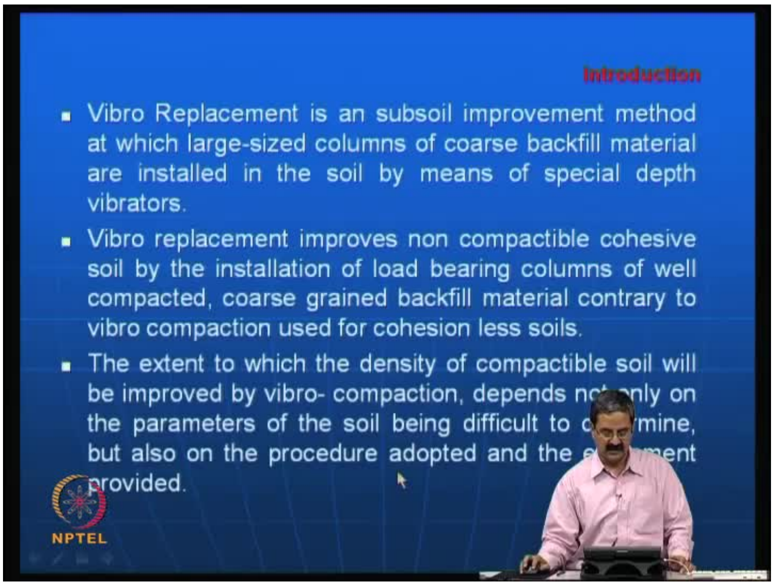

So, we are trying to equate what is the passive pressure and what is actually load applied. We equate it and we get these parameters in terms of cohesion friction angle and all that and then equate and you get an equilibrium equation which will give actually what should be the lateral pressure in terms of the friction angle of the stone column. That is called limit equilibrium method.

We have elastic method also which is also very interesting and the has been very well used for vibro replacement method using stone columns and very important thing that one should understand is that they extend to which the density is improved or the properties are improved depends on the parameters of the soil and sometimes most of the soils are difficult to measure and then there are somewhat complicated.

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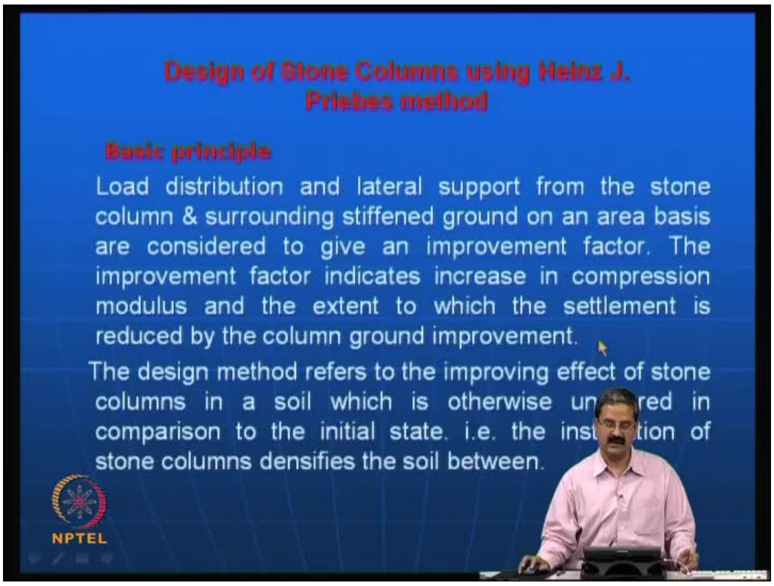

So, still you need to come out with some sort of design method. Actually, here in this particular priebes method, what we do is, load dissipation is there and also lateral support from the stone column. So, that is how you have a stiffened ground and it gives an improvement factor, say for example, you have loads that you have actual clay soil and then you have some stone columns.

Definitely, you have improved the area in terms of how much of area is replaced in the original soil that can be given an idea of the improvement. So, this improvement factor sometimes can indicate the increase in compression modulus like you can do that consolidation test where you get compression modulus and the extent to which the settlement is reduced by the column ground improvement.

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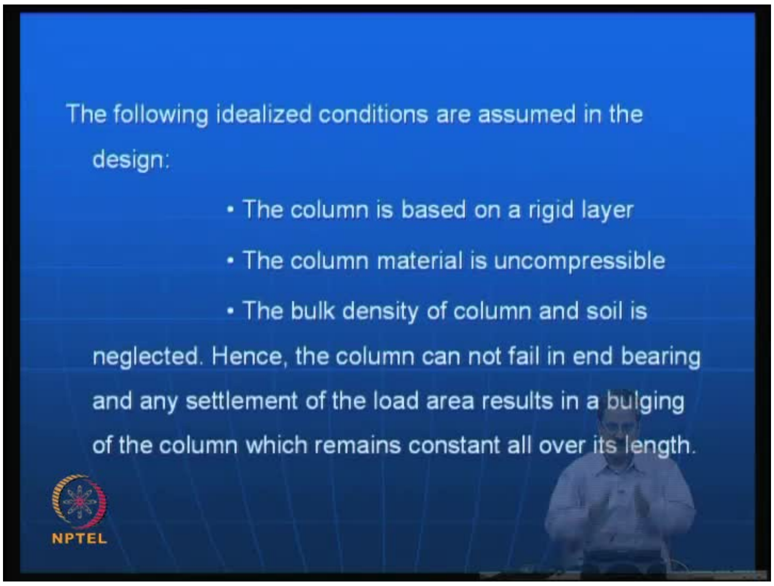

Here, in this design, what we see in these methods is that what is the improving effect of the stone columns in a soil which is otherwise unaltered in comparison to the initial state like how is that the initial state changed to improved state and it is very interesting that there are some simple assumptions in this method. The column is based on a rigid layer. The column material is uncompressible which is of course stone material, still it has some compression.

Bulk density of the column and the soil is neglected. Actually, it is a serious interesting assumption, in limit equilibrium methods, we want that bulk density of the soil gamma b. Then, in this case, we do not use that. What we do is that we will see how we make some assumptions and we propose the theory and we correct for all small things which are supposed to be critical. So, the other thing that we have the since the bulk density of the column and the soil are neglected the column cannot fail in end bearing and any settlement of the load area results in bulging of the column which remains constant all over its length.

Actually, what we assume is that there is a small bulging which is constant in the field. But, we know that in the field, there is a bulging difference. It depends on the over burden of the soil. So, we develop a simple method, understand its limitations and make corrections for it. This is what is in the priebes method. There is a simple difference that why the method is elastic method because it only uses a deformation modulus,then, it uses the strength of the column also.

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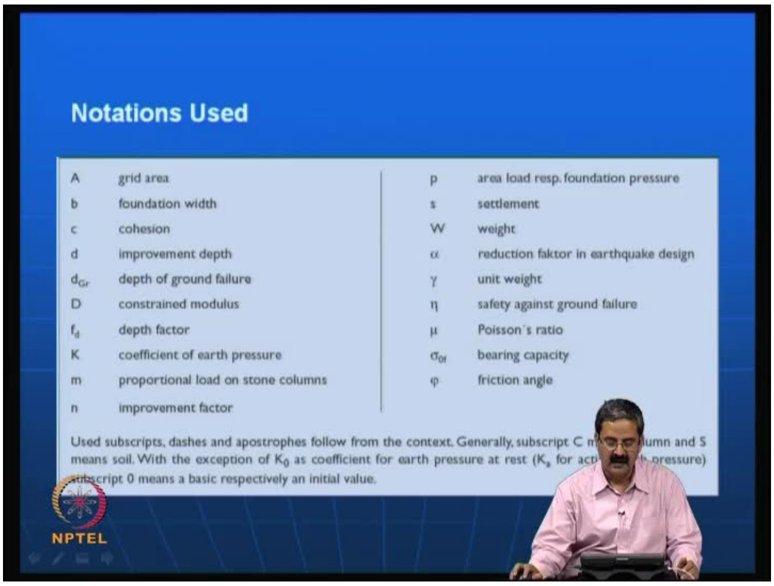

It has number of parameters, which are grid area, foundation width, cohesion, improvement depth, then, depth of the ground failure, constant modulus, depth factor, coefficient of earth pressure, proportional load on the stone columns, like which we just discussed, improvement factors settlements. All these factors are there and we call it one term called basic improvement factor, we call it n naught.

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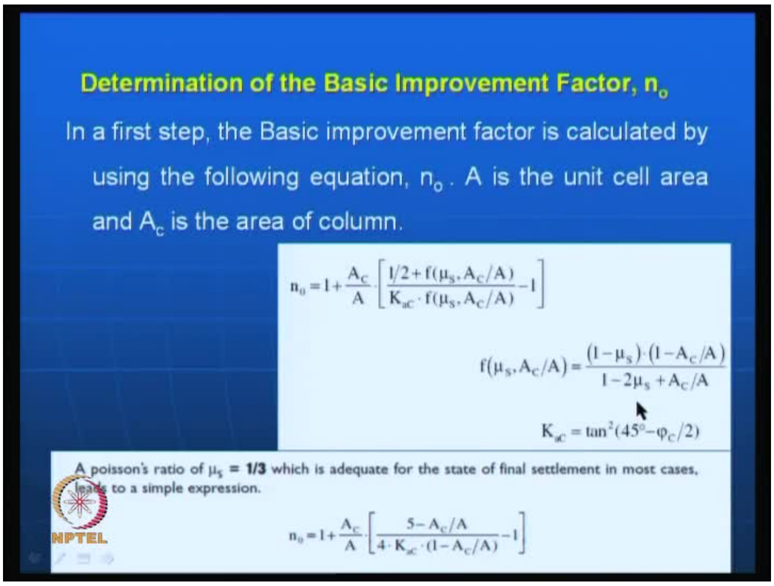

In the first step, the basic improvement factor is calculated by using the following equation. A is a unit cell area and A c is the area of the column, any stone column has some area that it influences so that surrounding area becomes stronger. So, that is called area ratio or we call it A c by A. This is the friction angle of the stone column. Actually, this bearing basic improvement factor is given by some simple expression and we assume that a Poisson's ratio of 1 by 3 like 0.33 is taken and the expression for basic improvement factor is simple, how much of area is being replaced and how much of lateral pressure is developed because of the stone column placement. This is what it gets.

And then, if you just do a parametric, you can simply get some from excel sheet what is the improvement factor and what is the area ratio one can have and you can see that if the area ratio is 1, which is close to, you are trying to replace the whole material with stones. Definitely, the improvement factor is going to be very high which is infinite, which is not possible because of the various assumptions that we have.

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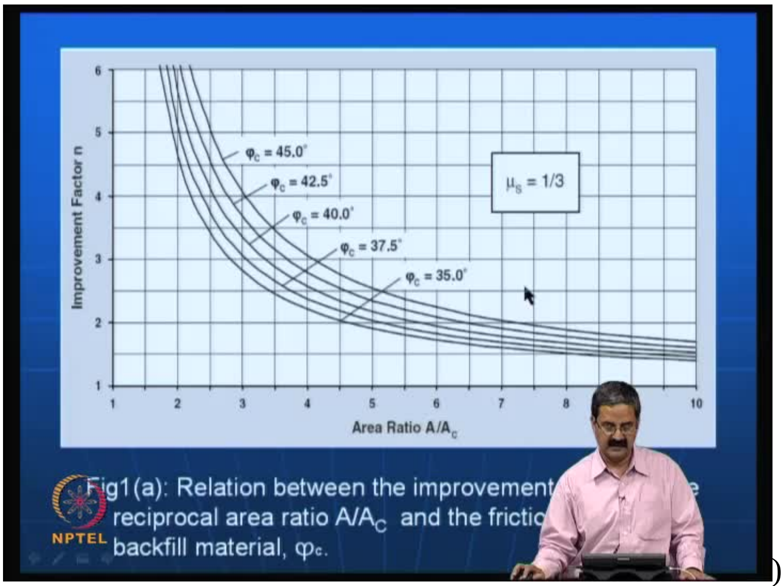

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These are all different friction angles one can calculate like this and since it is not possible to have that particular thing and then there is always a compressibility of the stone, there is a minor correction for it in terms of these factors and there is a additional correction to area ratio and that is in terms of modulus of the column and the modulus of the soil.

Whatever is the soil, there is a simple ratio that they have and they use this correction factor for the improvement. This is one thing. I will just highlight some concepts in this. Then, people can develop their own excel program or even there is a software available on online. One can use the software to calculate all the parameters using the stone column.

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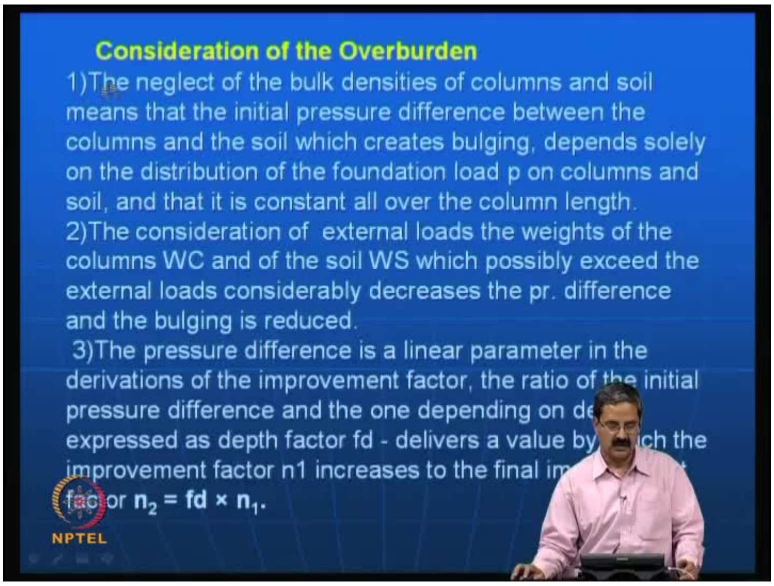

The design method has some assumptions and then it also gives you how to correct those mistakes so that you have a good design method. That is very nice approach. You have idealized way of doing things but that idealization is not possible. So, make corrections and give a final answer that is a very good approach.

Consideration of the overburden, the neglect of the bulk densities of the columns and soil means that initial pressure difference between the columns and the soil which creates bulging depends solely on the distribution of the foundation load p on the columns and in the soil and that it is constant all over the column length. We assume bulging is there. Bulging is everywhere but we know that because of the consideration of loads and bulging could be different in different places.

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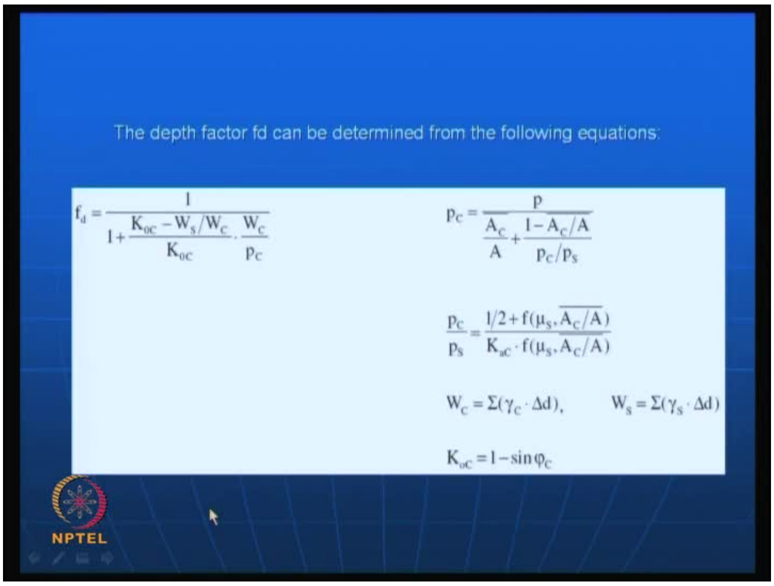

There is another simple correction that they have suggested, which is in fact a function of the overburden and because of the overburden, the improvement increases. The depth factor increases like improvement factor because bulging will be less at the bottom. Now, bulging will only occur at the top because of the overburden is less and over burden is more at the bottom.

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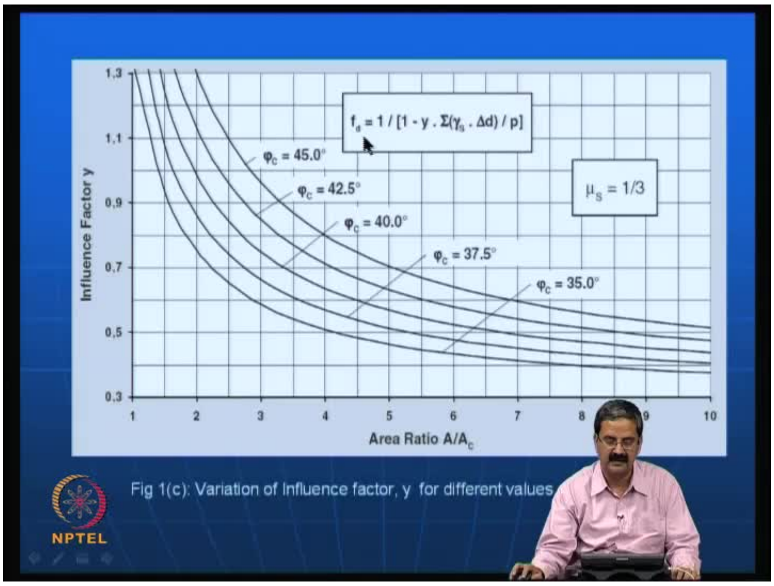

When overburden is less, there is a possibility of bulging because directly it is under the load and there is a possibility of bulging. So for that, there are some correction factors and these are that expressions for that and actually this is for the same mu s.

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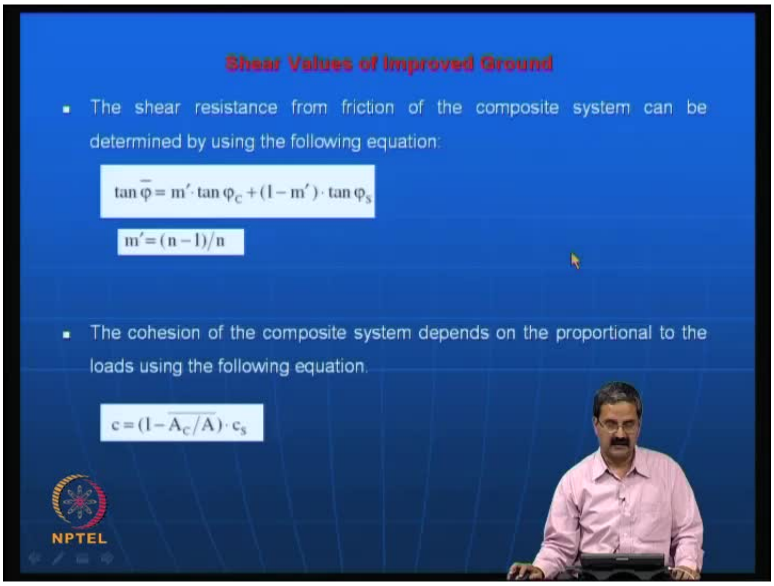

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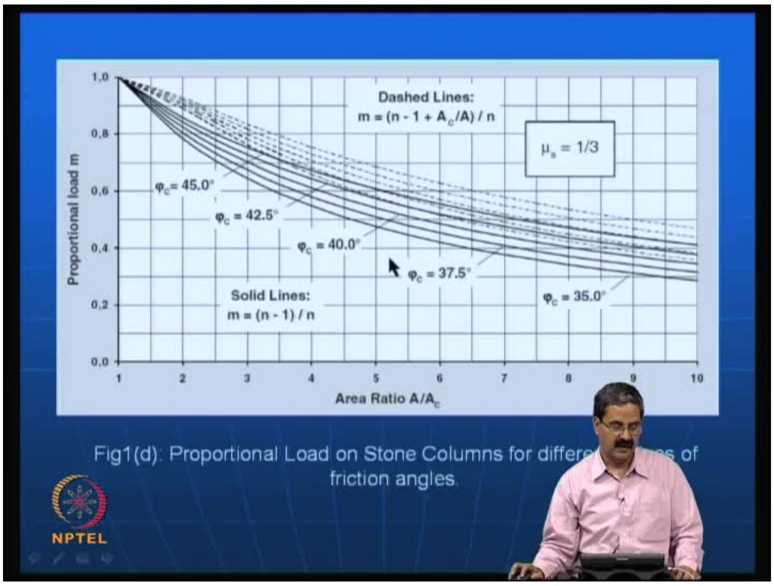

And one can calculate the shear strength properties of the improved ground also. There are some expressions that are given. They are all: what is the improved value of friction angle? What is the improved value of cohesion? What is the proportional load that the soil can take is also as a function of the area ratio. How much of total load is transferred to the stone column?

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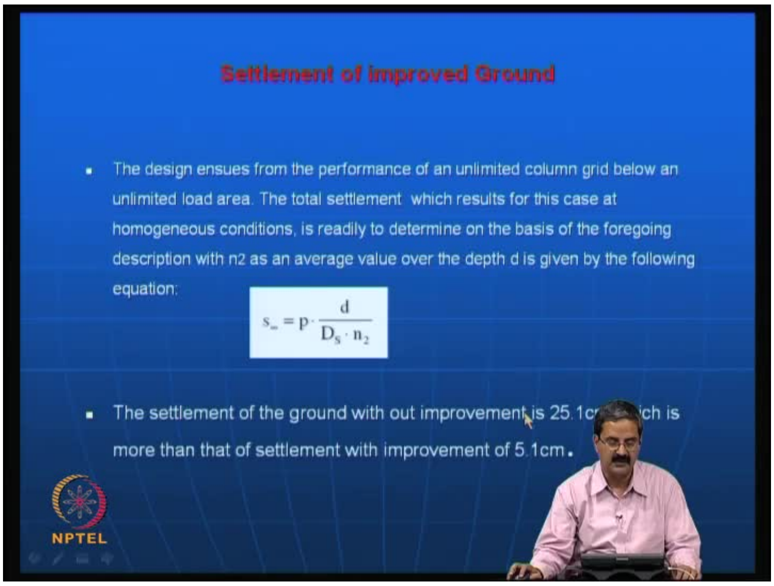

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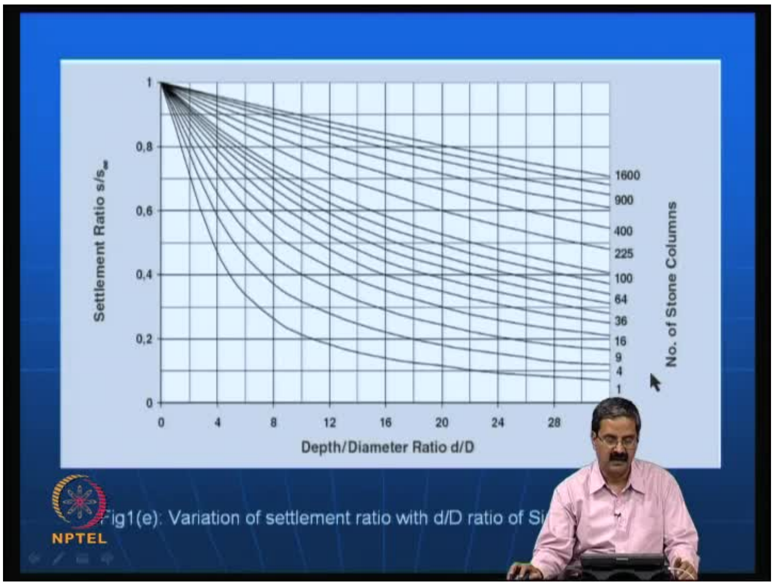

Again, which is the function of phi of the soil area ratio, these are all some understandable ideas and then, he also has some sort of expressions for settlement calculations and then there is a simple example that we worked out and there is another factor that comes into picture here and settlement ratio in terms of the settlement ratio depending on the number of stone columns one can get this on a single footing. This is the simple expression. We will see some of them. It is a very useful contribution because this is widely used by Keller's group, actually many others also must be using, but it is important that we have some of these concepts well illustrated.

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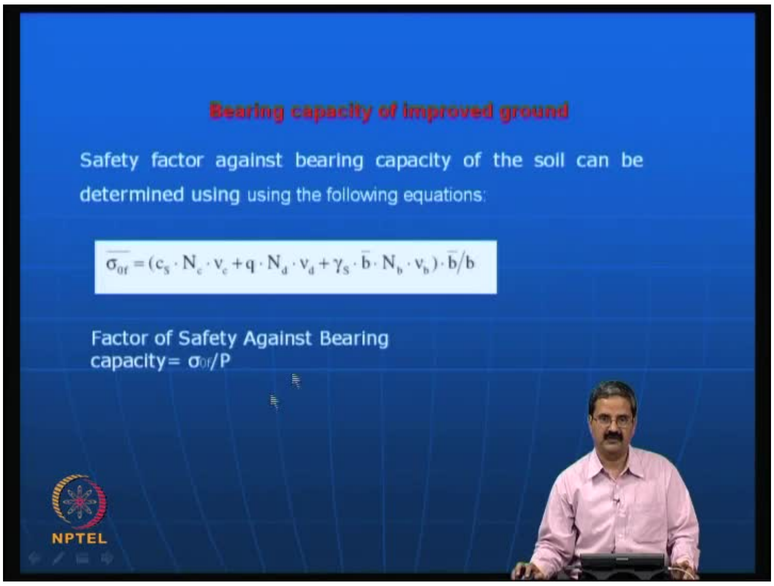

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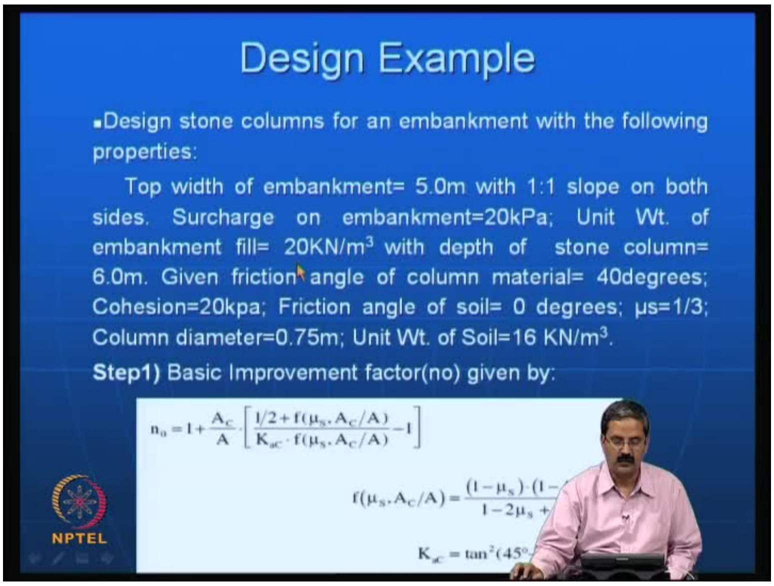

For bearing capacity of the improved ground, one can have some expressions similar to our bearing capacity equation and the factor of safety of bearing capacity you can get and there is a design example that I try to work out, where is the width of the top, width of the embankment with one is to one slope, it's resting surcharge on embankment is about

20 kPa unit, weight of the embankment fill is about20 kilo Newton per meter cube and the depth of the stone column is 6 meters. All that cohesion is known. Friction angle of the clay is 0 degrees. All these column diameters I have assumed.

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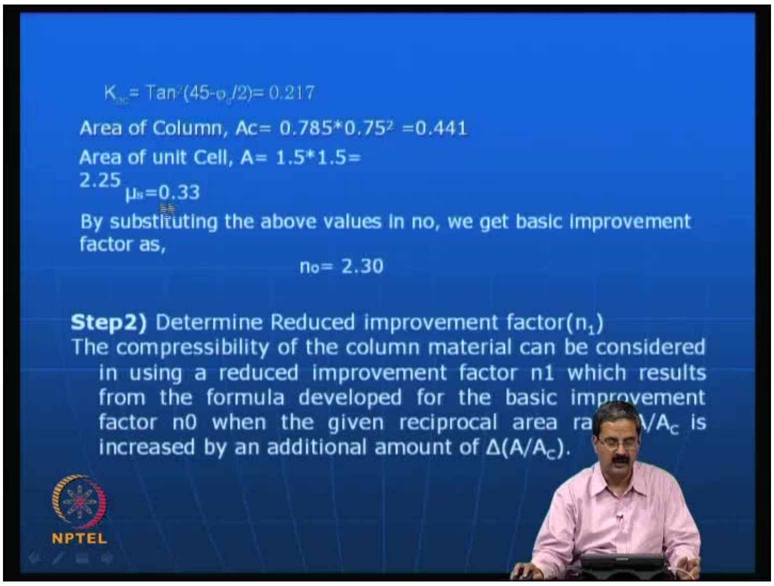

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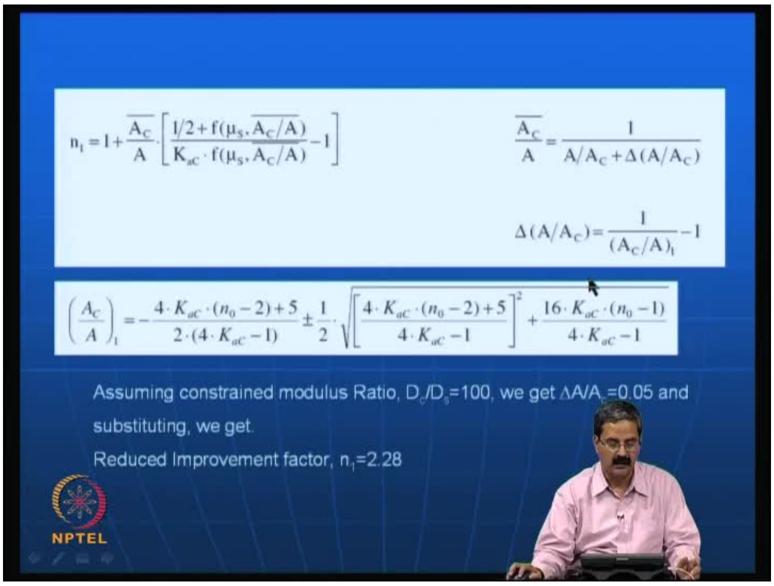

So, some calculations are made here and basic improvement factor is about 2.3, then you try to get n 1. Then n 1, if you just substitute, there is a marginal reduction in n 1 why because it reduces because of the D c by D s factor. We have taken this by assuming this factors delta A by A c. These are all some assumptions we made and one can get this.

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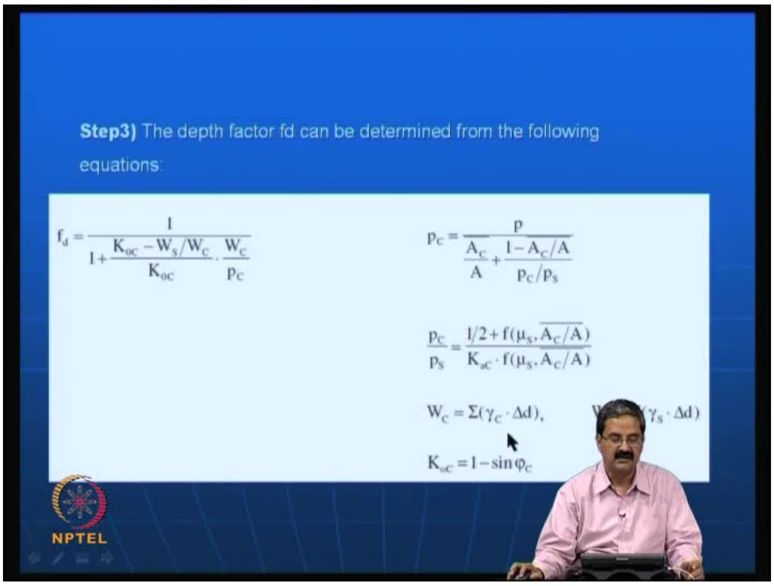

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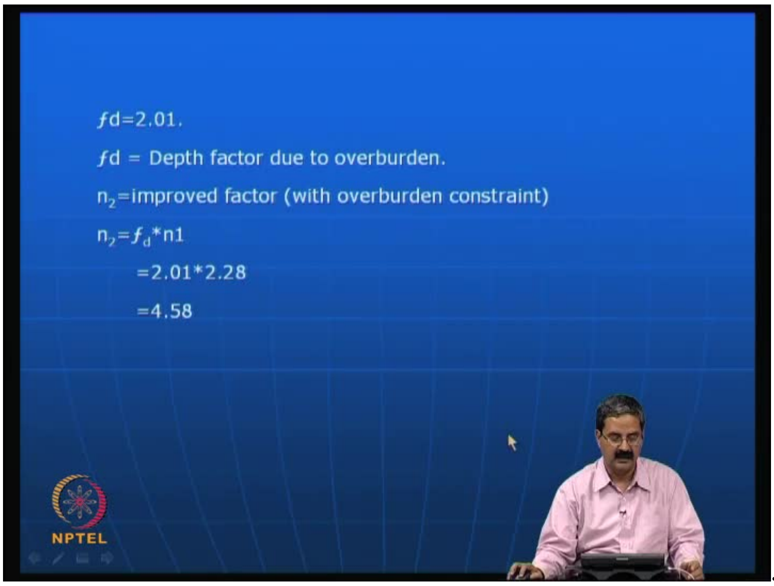

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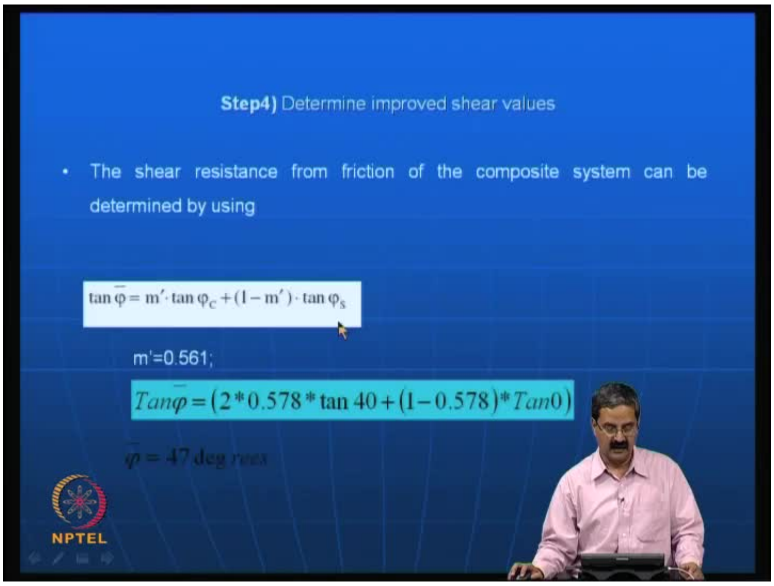

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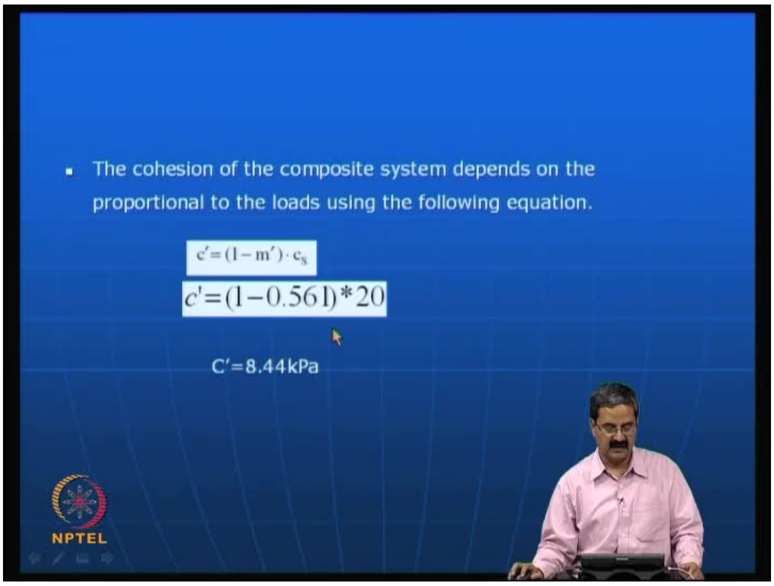

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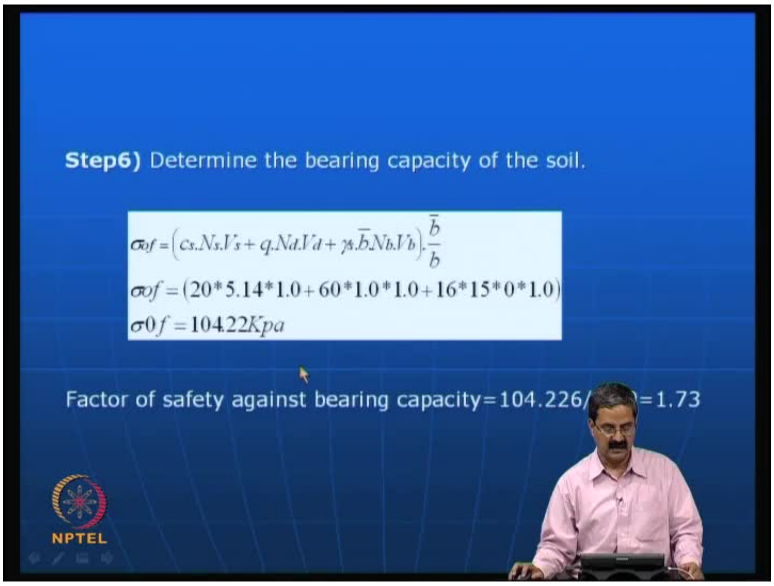

One can make even depth factor and final n two one can correct which means that there is a good improvement in bearing capacity and one can also calculate shear strength and all the other properties and even one can calculate the factor of safety against bearing pressure.

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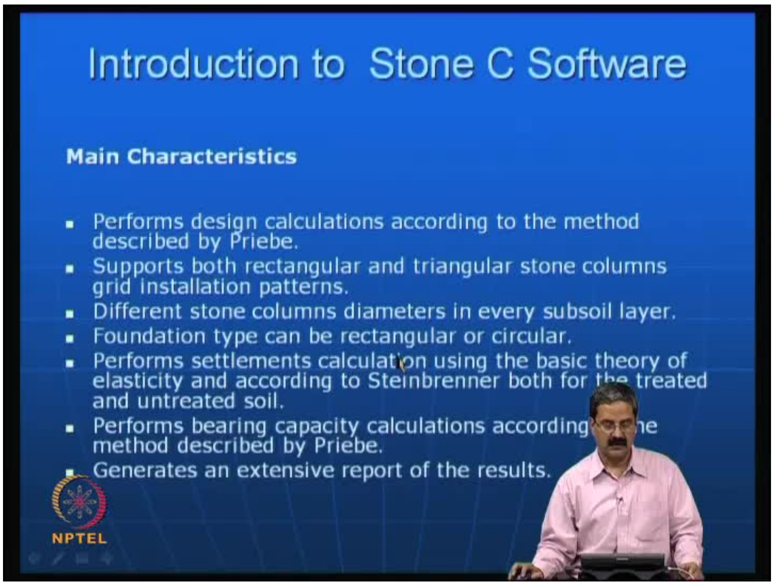

These are easily done by simple software, which can be called stone C. It supports the rectangular and triangular stone columns and one should buy this. That is one important thing. It is available and particularly when you are in stone columns calculations and when you are going back and forth, it is always nice to have something tested. And one can give different stone columns in diameters in every sub layer. Foundation type can be rectangular or circular performs settlement calculation using the basic theory of elasticity. Using of elasticity theory is good for settlement calculations and that is why we use lot of elasticity theory in settlement evaluations. You must have seen.

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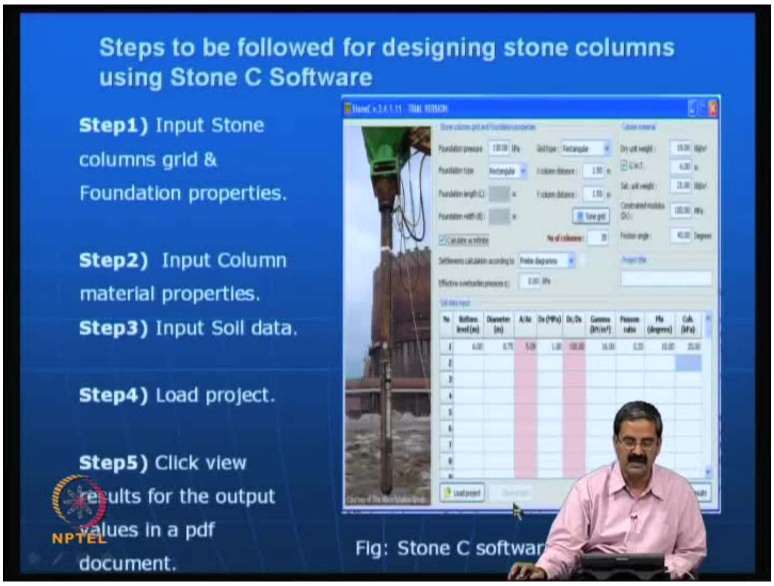

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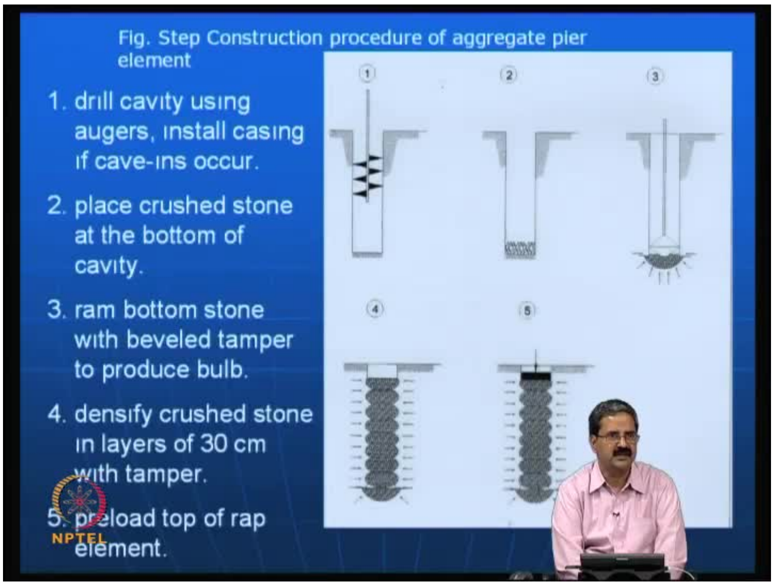

There is another method. It performs bearing capacity calculations also. It generates extensive report of results. This is an advantage and what I want to say is that one can use some of these methods. Techniques like this have been quite effective and there are also lot of off shoots of this stone columns. Actually, what is that you are doing is that, you are trying to create some material inside this soil which is weaker. Obviously, you can do by any means. For example, here, it is called aggregate pier. That man says this particular step, he is trying to create a cavity using auger. I do not have big machinery here. I do not want, it is very complicated.

What I do here is that, I amusing a simple auger install casing if cave-in occurs. If the cave-in occurs, it is a problem. So, if you make an auger, put a casing immediately. Some procedure should work out and start putting the material and then start compacting like that. Stone columns in India are called rammed earth stone columns. They were doing like that only. These are all some innovations. What they do is, place the crushed stone aggregate at the bottom of the cavity, then, ram bottom stone with beveled tamper to produce bulb. Then, densify crushed stone in layers of thirty centimeters like this, then preload top of the rap element. It is called aggregate pier. I do not want to call it is as stone column, but I call it as aggregate pier. Pier is like a pier of pile and this is one terminology people use it and it is good for shallow depths.

For example, you have a small house, big company may not come but somebody can do like this. You have to calculate properly some of these things and check some quality control. I may not follow any standard method but then, I am very sure that this method works. So, you should be very careful in doing some of these operations and design, proper length, spacing, depth and all that. The depth depends on the significant zone of influence, spacing and some of the variables. One can calculate, do a parametric study, it is called aggregate pier and it is quite simple.

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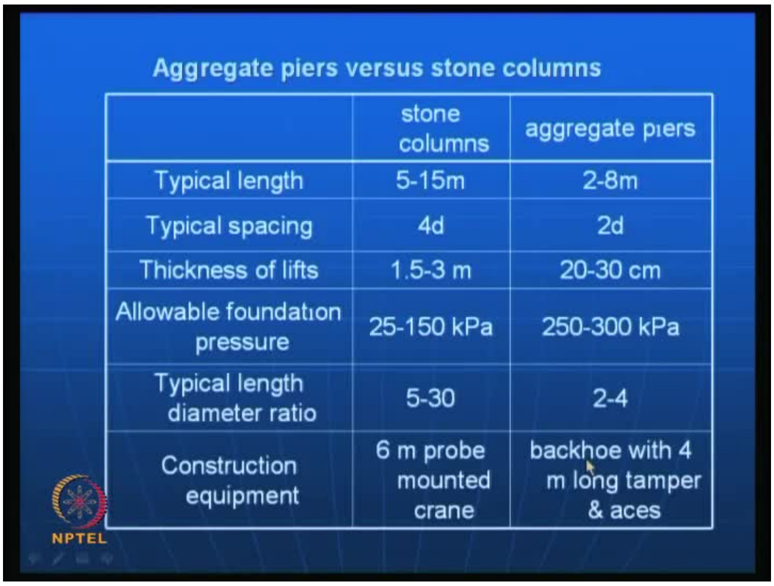

So, what is the difference? One should know. It is even done by standard companies. Many people have different packages for small works, where there is not much, let us do aggregate piers or if you have a bigger job, bigger loads coming up, you go for stone columns. One can have all these choices because finally as a ground improvement company, you need to have different approaches to solve the problems like, if depth is not much, one can use aggregate piers.

You can see that the typical length is about 5 to 50 meters in the case of stone columns where as about 2 to 8 meters in the case of aggregate piers. Typical spacing 4d here, it could be 2d here and then thickness of the lifts, in stone columns, 1 meter 1.3 you can just go whereas here about 20 to 30 centimeters.

Allowable foundation pressure, you can get 25 to 150 kPa, here you can go much higher and typical length diameter ratio 5 to 30, it can be bigger it is 2 to 4 here and construction equipment little probes and little more detailed. Stone columns also could be conventional in the sense you may not need high equipment.

But, now-a-days, very good companies are going for real time monitoring like as you construct, I should know exactly how much of stone is inside and then you come back and make about 2 meters of stone column and immediately run that static cone penetration test. Check if that S P T value or C P T values are all right. People have been doing like that. That is called real time monitoring of structures and people have been very effective but then, that is very expensive. If the project is very big, one can afford. But in some small projects, aggregate piers may be all right. The equipment that we need is about backhoe with 4 meters long tamper and aces some simple thing.

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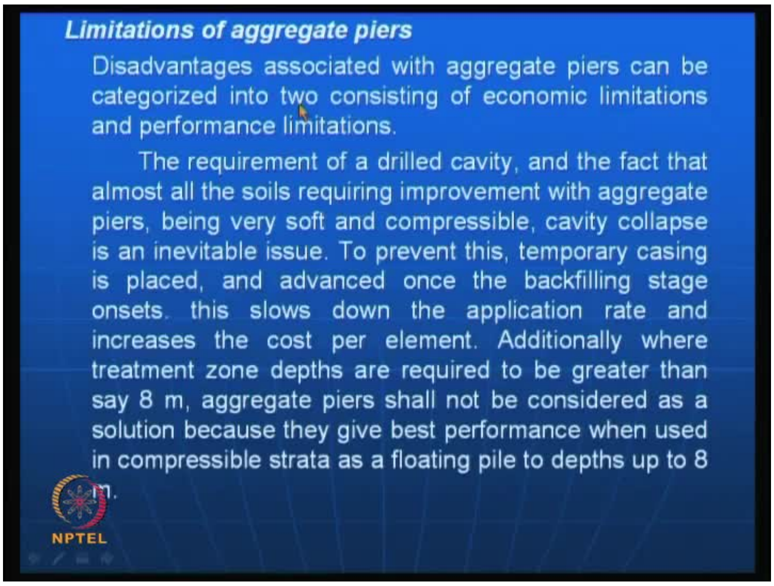

The advantages are there, but then, disadvantages are also there. It can be economic limitations and performance of the requirement of a drilled cavity. You need a drilled cavity and a fact that almost all the soils requiring improvement with aggregate piers, they are very soft and compressible cavity collapse is an inevitable issue. You are trying to use an augur and before you withdraw, if they collapse, it is a problem.

One should have a means of doing it, whether I can leave a casing there or I can withdraw a casing. Sometimes the temporary casing is provided and advanced. Once the back filing stage on sites, this slows down the application rate and increases the cost per element. Additionally, where the treatment zone depths are required to be greater than 8 meters, aggregate piers shall not be considered as a solution because they give best performance when used in compressible strata as a floating pile to depths up to 8 meters.

So, these are all more like floating piles or a simple soil reinforcement system which is quite effective. Infact, people have been using without much of soil mechanics because they find that if you intuitively they feel that if you do like this, definitely there will be an improvement in bearing capacity. So, that is how people have been able to work out and then do that.

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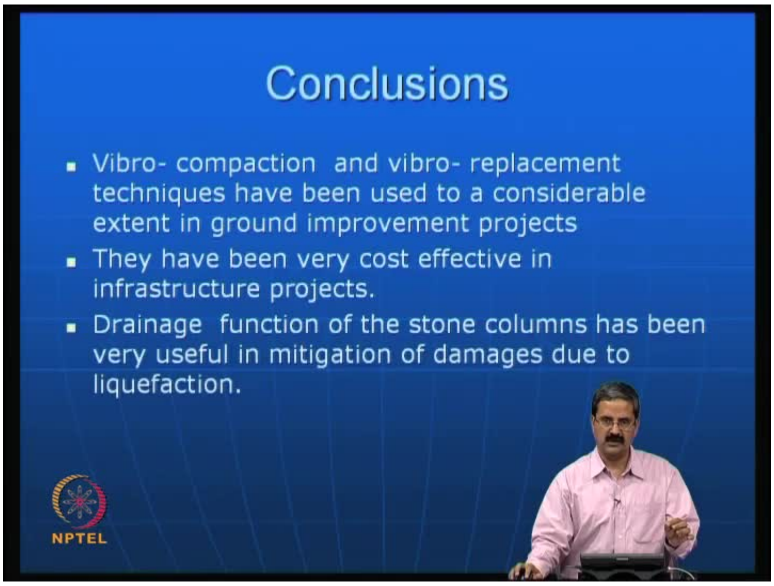

I will give some conclusions now and also show you some case studies. We have vibro-compaction techniques and vibro-replacement techniques. They have been used to a considerable extent in ground improvement projects. They have been very cost effective, in fact, in some places where they could not do anything, you need to use ground improvement techniques.

Then, drainage function of the stone columns has been very useful in the mitigation of damages due to liquefaction. In many places in Japan and all other places where there is maximum problem of liquefaction, this technique has been very effective and people have studied very well. The design that we discussed is about simple static loading, but you should even design the stone columns for earthquake conditions where you have, how many number of cycles it can withstand.

For example, how much of pore pressure it can dissipate because what we do is that earthquake motion is always convert into equivalent number of cycles of some standard. How many number of cycles it can withstand? One should do more detailed studies on some of these things in using stone columns and one can really come out with a proper measure. In earthquake conditions, the drainage or the dissipation of pore pressure is very important and so you need to design for the magnitude of the earthquake and the number of cycles of the same earthquake and also its pore pressure dissipation, all that. So, people have to really do a rigorous job in some of these things.

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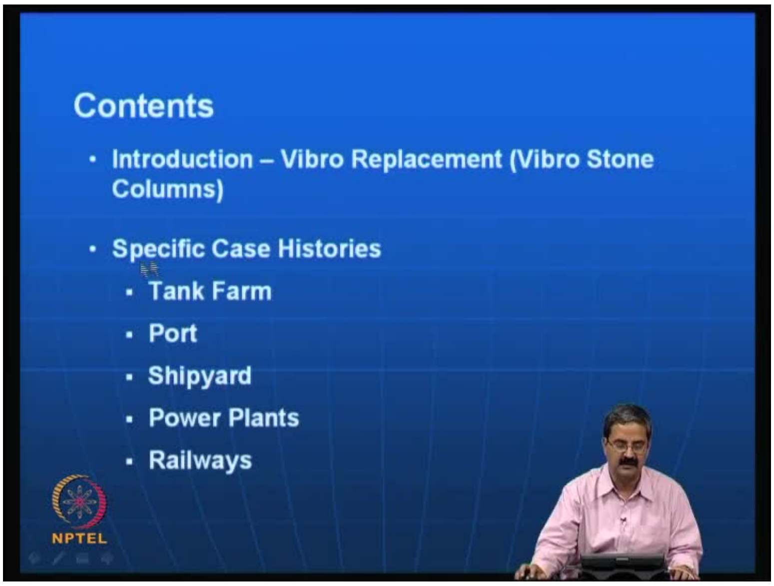

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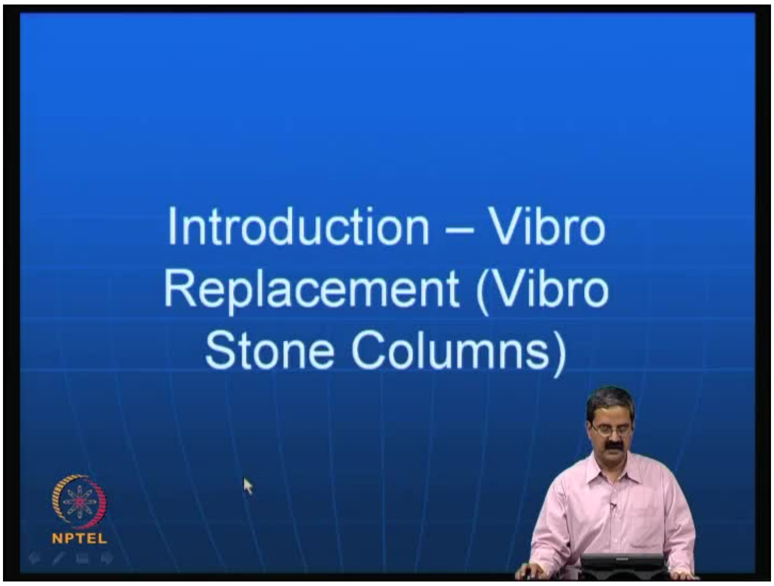

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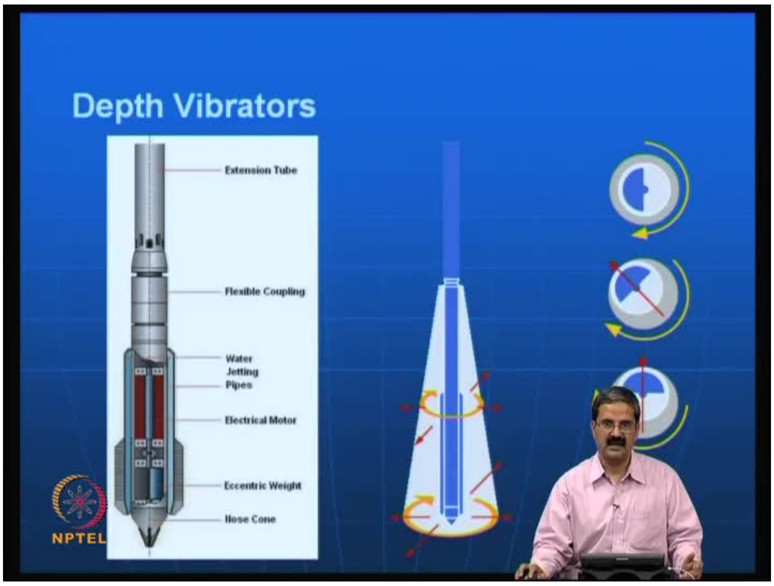

I would like to do is some case studies here. I must thank Keller's company for providing some of these case studies. we will have some specific case studies which are related to tank farm, ports, shipyards, power plants and railways and of course, the introduction we have seen that they have these type of vibrators which has a hose is an eccentric weight, then, it has that water jetting and flexible coupling and extension tubes where if you want to increase the diameter or the depth, you have this thing and this is how it is done.

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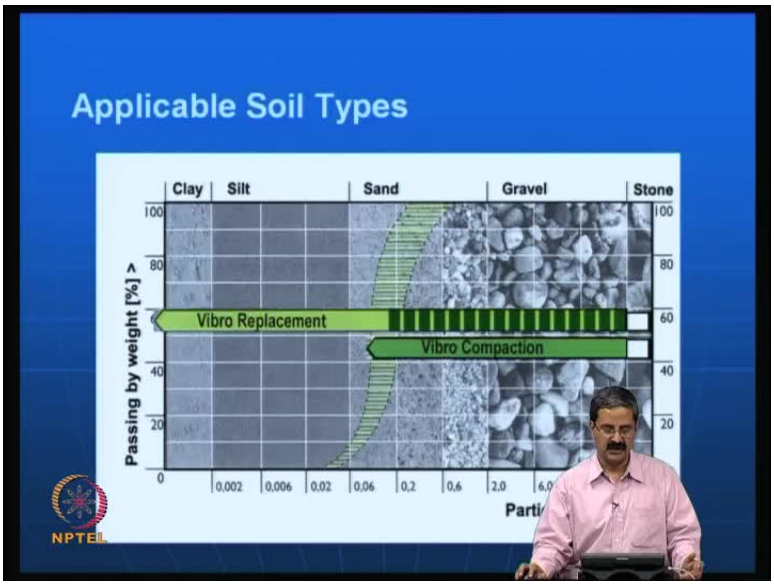

That eccentric weight movement and horizontal movement that is what we were discussing how that force is generated and then transfer to that. It is applicable to vibrocompaction. Vibrocompaction is very good here and vibro replacement is very good here.

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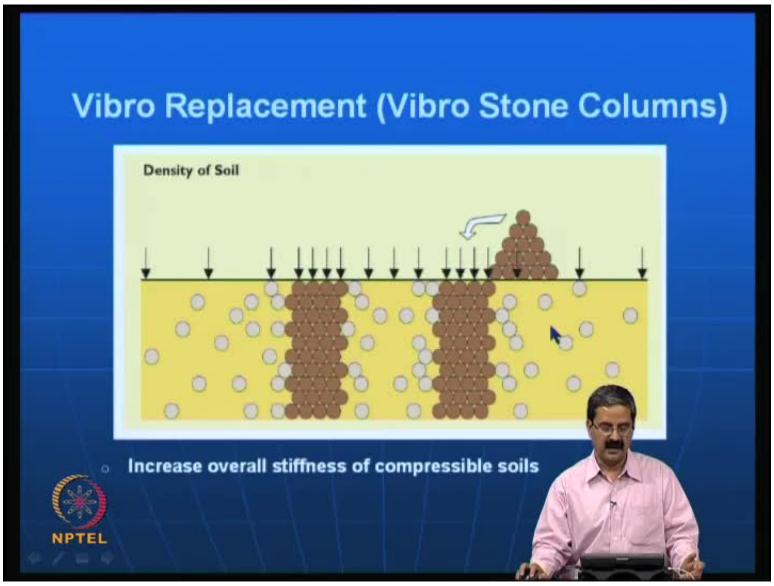

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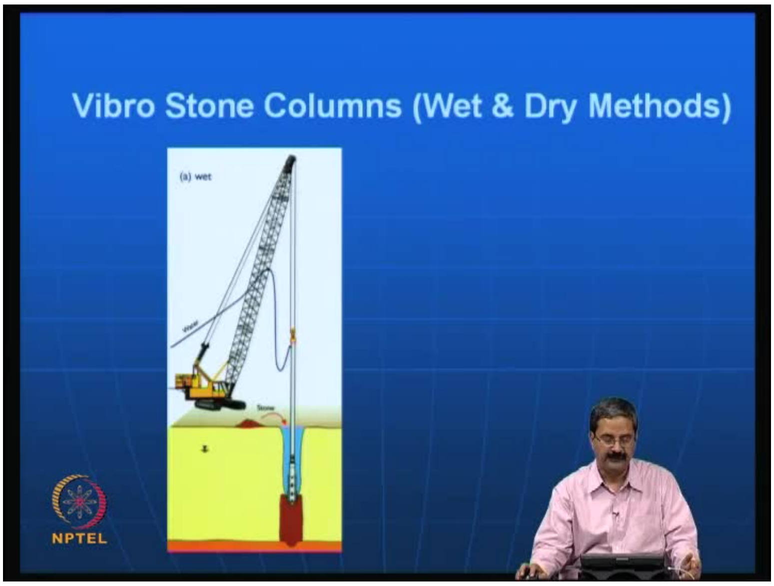

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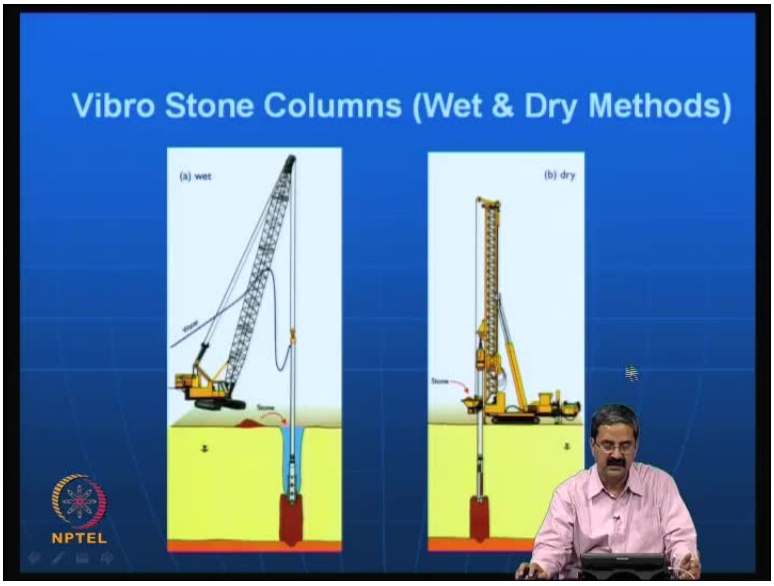

So, this essentially is the function of the soil type and we have seen some of these things, how it helps the overall stiffness of the compressible material and allows the rapid consolidation by providing radial drainage. There are methods also. It is called a wet method and also dry method in which the stone is being putting here.

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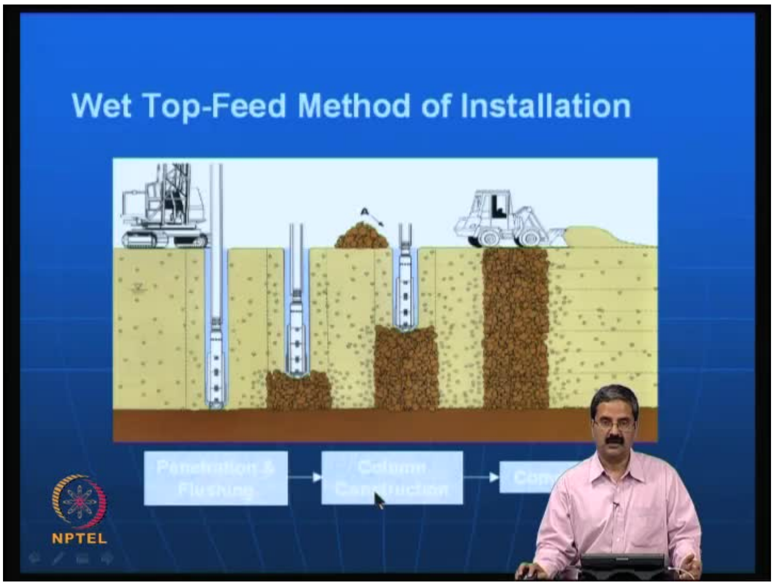

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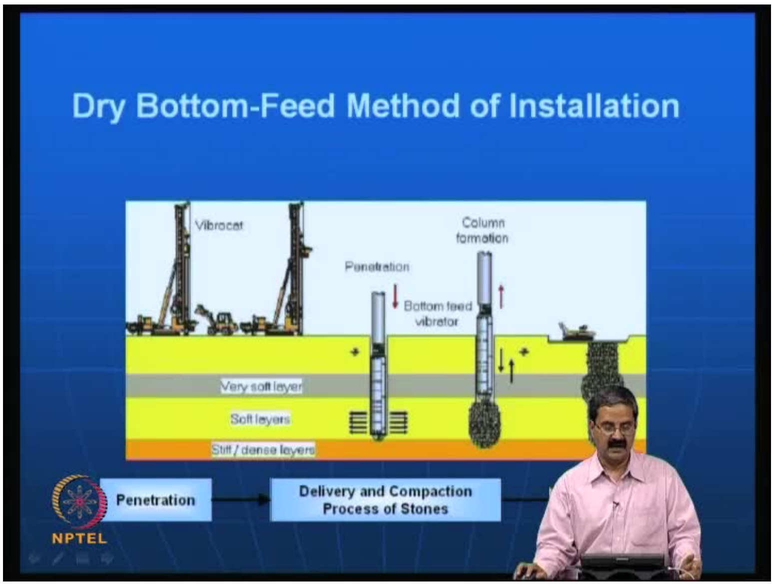

Then, here you have a jetting action and other things we call it wet top. This is again another way of doing this. You have penetration flushing column construction and completion. So, this is a dry bottom feed method of installation where you know you try to do in this manner, you have a penetration delivery and compaction process of stones completion.

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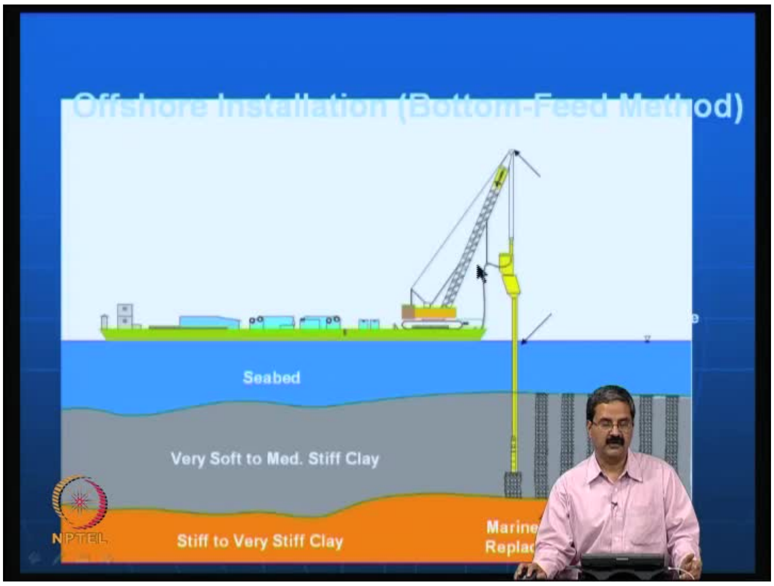

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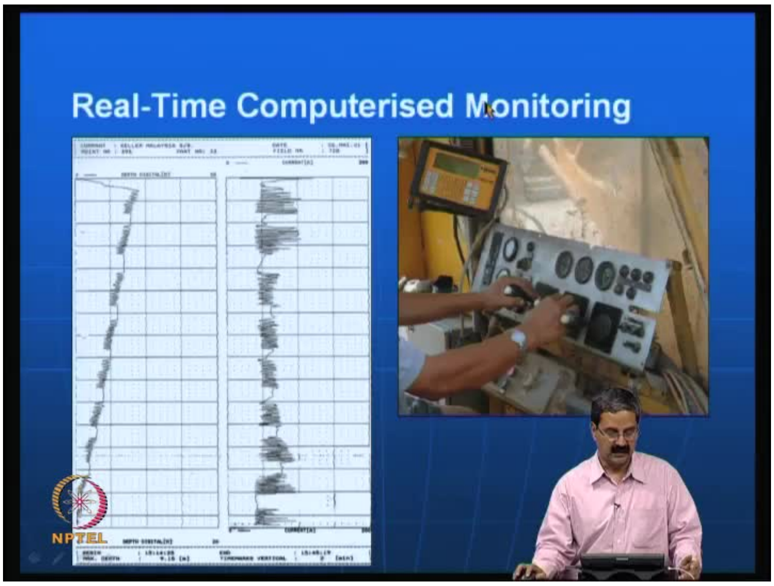

So, these are all some differences that we have. Some are based on installation techniques and in the off shore also they do it. You have a stiff medium clay, you have a barge, In a vehicle, you have to take that and then you have stone columns that are formed here in the soft medium clay and that is what you know. It is very important that you have to have the sort of structures.

Quality assurance and quality checks are also important and people do real time computerized monitoring. You need to have the C P T profiles and all that very clearly with a date and all the information. That is what many of the good companies like Keller and all do.

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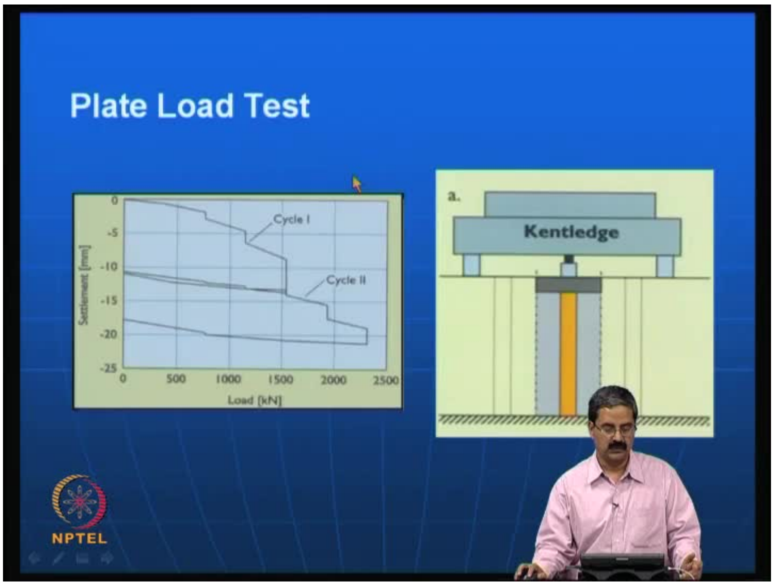

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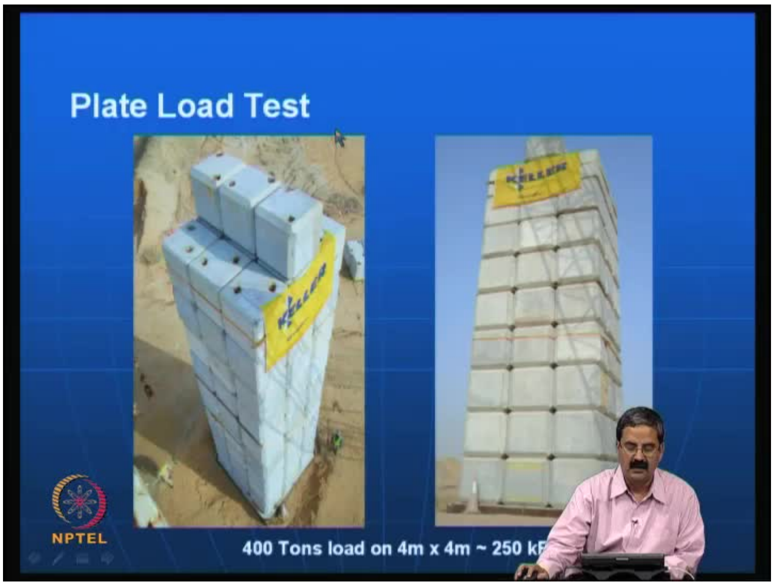

This is a typical load displacement curve, settlement versus load. This is what I was just mentioning and first cycle you can load and unload, again, second cycle. You must be able to understand what is the typical load displacement curve using the plate load test and kentledge arrangement. For example, higher codes specify a kentledge arrangement which is rather cumbersome.

Whereas, in this, people have done a simple case, say, 400 tons on 4 by 4 about 250 kPa. So, to make it believe that you have a platform of 4 by 4 and then load 400 tons, this is how they do it.

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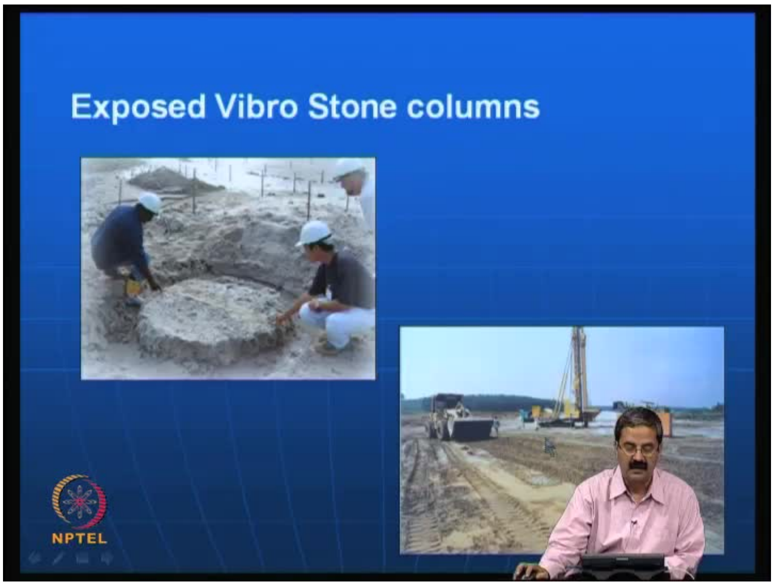

If you want to really see the diameter, you should be able to do that quality control, measure the diameter and so it has been very well used to many applications like tank foundations, particularly soft soils, ports slope stability. Slope stability is another important issue.

Reinforced earth walls, actually in some places where the bearing capacity of the reinforce soil wall is very poor, you need to have foundations like this. Then, isolated footings also it can be done, railways people have done, high way embankments people have done. We will see some of the case studies they have provided to us. In the oil tank farm, in a Paradeep, I will just see that the owner is IOCL. It has 15 number of tanks with 60,000 kiloliter capacity.

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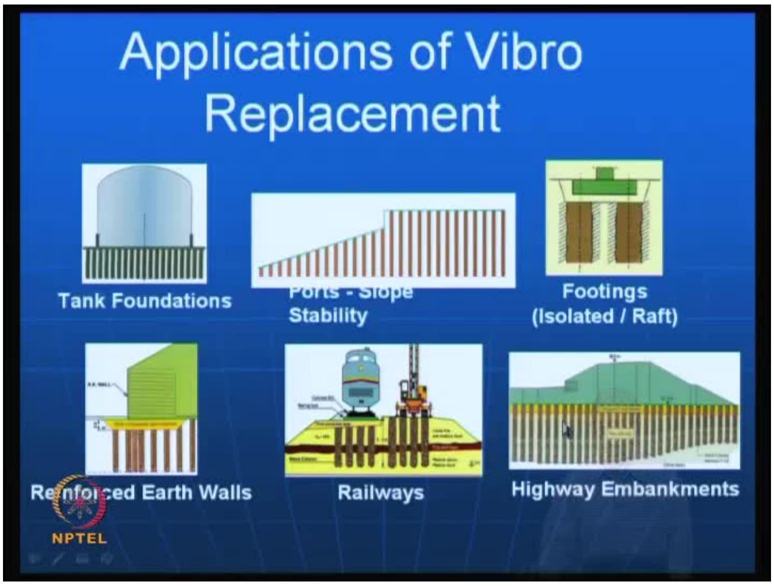

The soil conditions are that it is a reclaimed soil followed by 3 meters clay that is loose dense loose to medium dense. Fine sands up to depth of ten meters and you have a dense soil layers at 10 meters below the ground.

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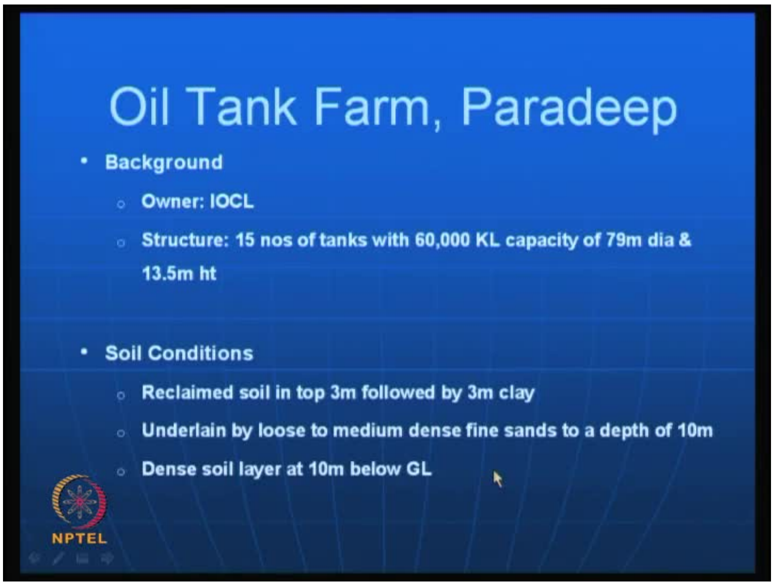

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The problem is that 16 ton per meter square is required and tolerable settlement is 200 mm. So, what they did was vibro stone column of diameter 800 with triangular grid spacing of 2 meters and center to center up to a depth of ten meters was used.

So, they are also using two extra columns on that case and this is the way that they are trying to do. Total length of the stone columns is about 1,60,000linear meters like length. So, they are able use to 4 rigs because you need to mobilize to speed up the construction processes. So, you need to have more rigs to do that. Installation period is 8 months.

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So, routine group column load tests were performed. You should do a stone column group column tests, hydro test are also done and settlements are monitored and which were below 100 mm. That is one thing that was.

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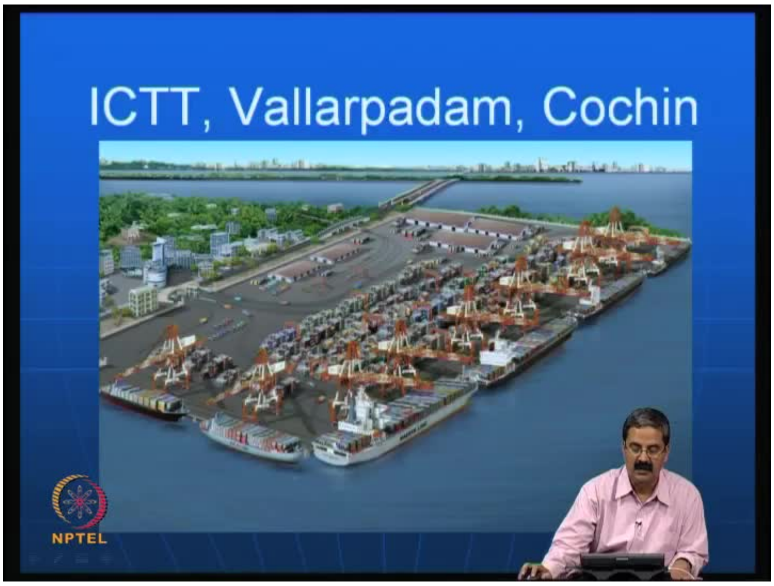

There is another case study that we see a port structure. It is very interesting. It is in Vallarpadam in Cochin. This is the area constructed. In fact, this is what that Doctor Venu was mentioning that it was a very challenging job for them to do.

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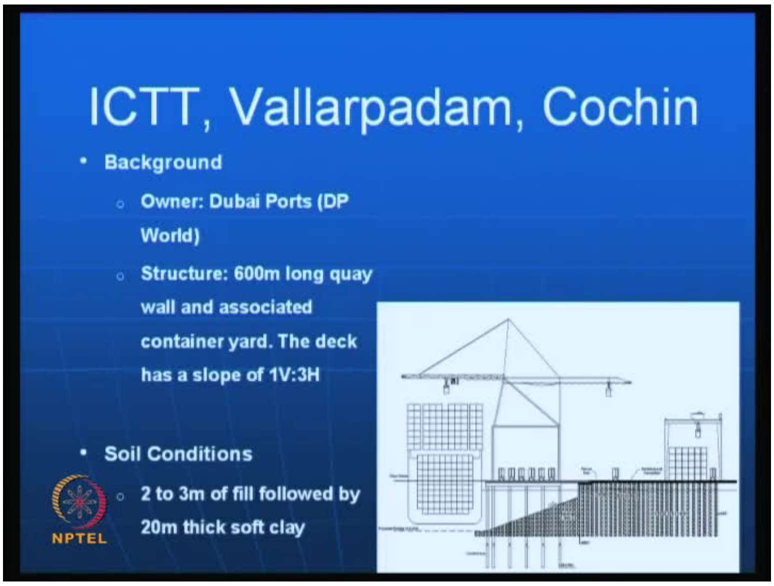

It is a 600 meters long quay wall and associated container yard. The deck has a slope of one is to three. Soil conditions: 20 meters of thick soft soil, first 2 to 3 meters is a fill and its quite tuff and there is another medium stiff material.

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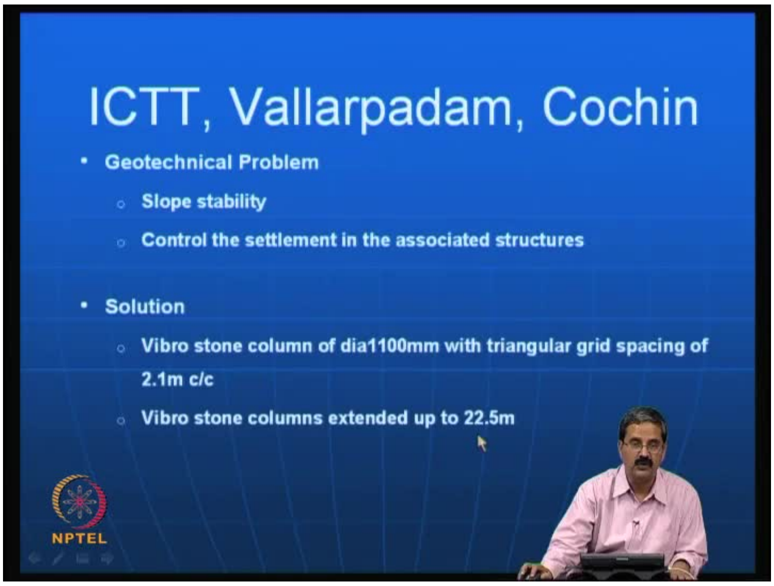

The issue is that slope stability is an issue, settlement control is an issue and the solution was that they have done a rigorous design and then came out with a configuration of 1.1meter diameter stone columns with a spacing of 2.1 center to center, then, the depth is about 22.5 meters. You can see the depth. Then, the length of the total stone columns, say about 22.5 meters into number of columns. It gives the linear meter length of the stone columns. 4 rigs were used here. Installation period is 8 months.

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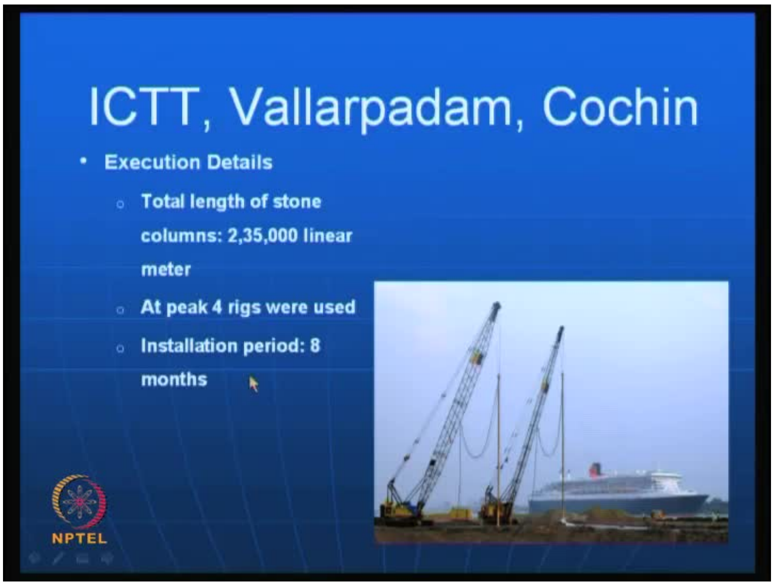

The beauty is that within 8 to 9 months or a 1 year, they are able to finish the project. Normally, you know that you cannot recover the area. But, then, using a ground improvement technique, within a period of less than a year they are able to see that this ground is ready. You can do something, construct whatever you want. That is something very interesting.

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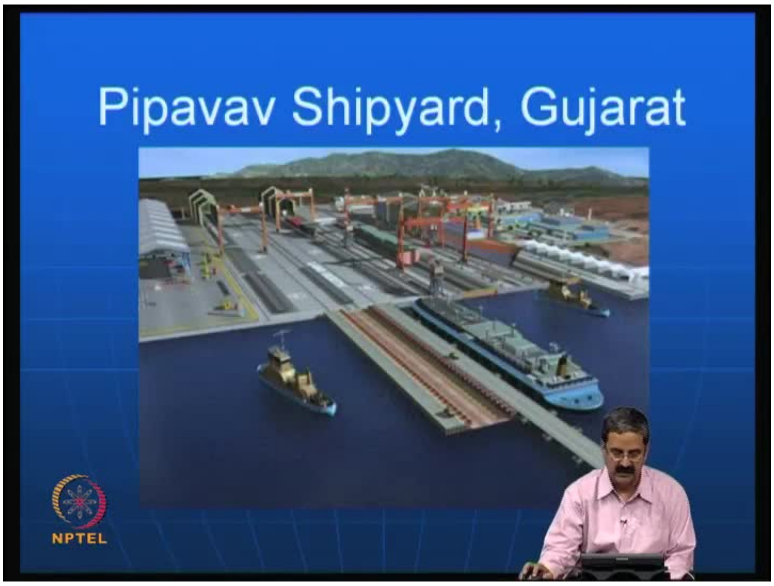

There is another case study, in Pipavav Shipyard in Gujarat. I should thank them. they have been very kind to spare some of the information here and again we have a quay wall here and soil conditions are something S P T value is nine and then it has a marine clay of 4 to 6. It is quite tuff and then, you have another weathered rock at the bottom.

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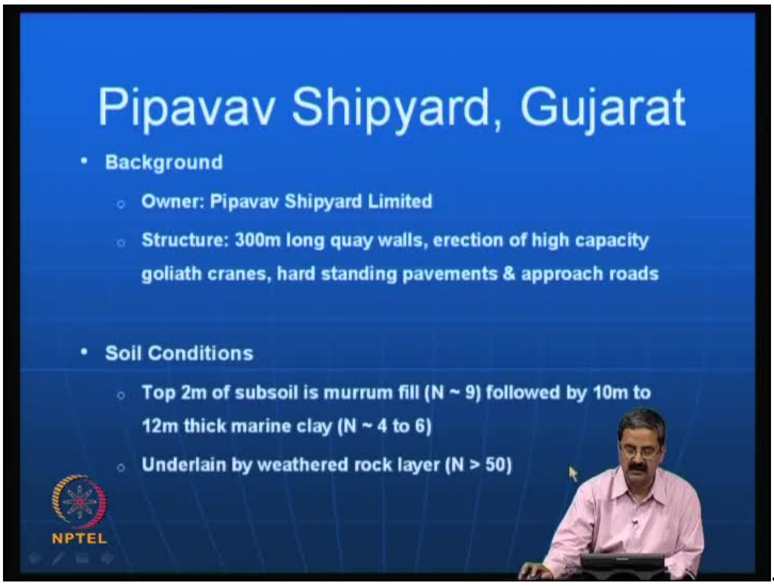

Problems are that, definitely, when you have such a soft soil of S P T, such a low number, you have settlement problems. So, limit the settlements increase the bearing capacity for hard standing pavements. Bearing capacity requirements, say for example, they have to construct pavements on such materials. You need to have a good bearing capacity. They want to have even good bearing capacity for pavements.

So, solution: vibro stone column of 900 mm diameter with triangular grid spacing of 2.5 meter center to center. The vibration vibro stone columns extended up to 15 meters depth. This is another important point.

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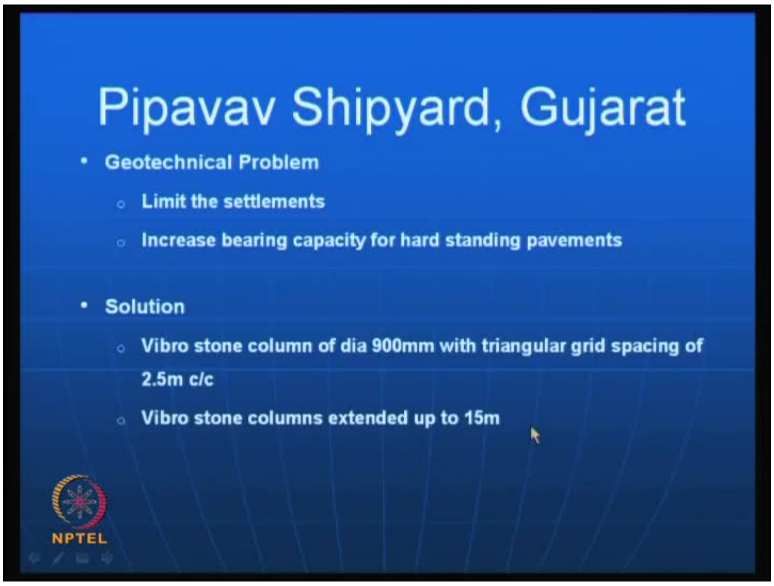

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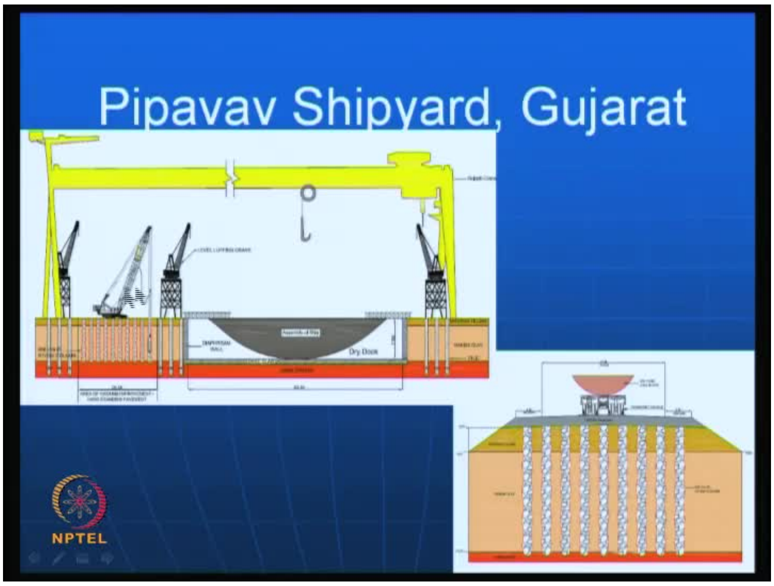

This is the way it is done. You can see that you have stone columns here, hard strata dry duck. All these are all stone columns. They need to have this sort of arrangement which is very complicated. Dry drought is here, then, you have assembly of the ship here in an area that has so much poor soil. It is not easy.

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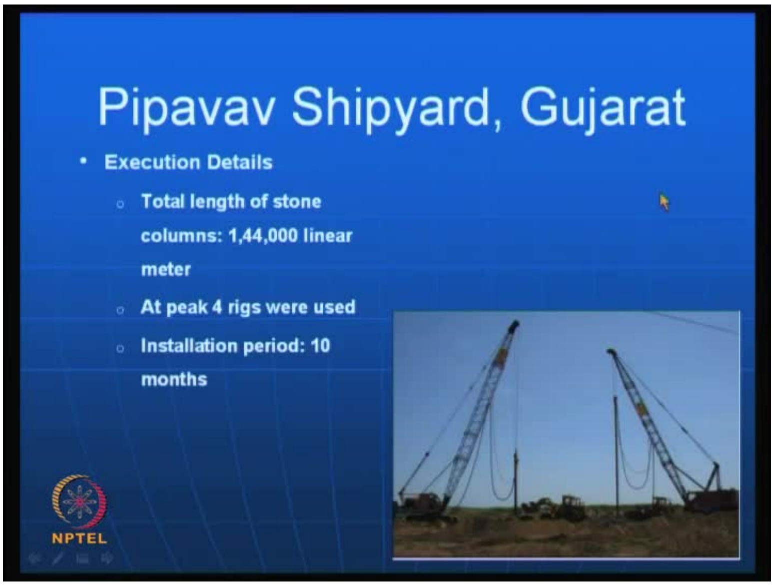

The total length of the stone columns is about one length used is 1.44,000 linear meters. one point its 1,44,000 meters at peak. Again, they were using 4 rigs, they had this constant installation period 10 months. It is a quite good. Then, we have some more case studies on power plants like in Chennai. It is a background. NTPC is the owner. Cooling towers, they have soil conditions: sub soil has seven to nine meters of soft soil, S P T value is 0 to 6 and again it has a dense sand S P T12. It is actually less than 15. It is very poor. It is very difficult.

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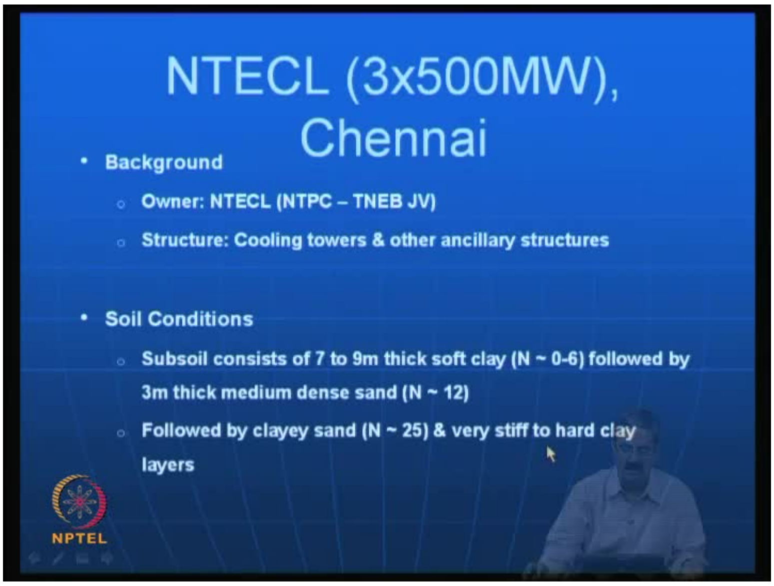

Say for example, in a clay, S P T value is all somewhat meaningless because you know there is a water table. We do not know what exactly it means. Then, you have finally a clay sand with S P T of 25.

The issue here is as usual, increase the bearing capacity and limit the settlements and solution is that they came out with their own calculations and methods. This people take some projects, then they have to design, they have to show that it works and in this case, they are able to show that nine hundred meter diameter triangular grid spacing bearing from 2 meters to 2.5 center to center was used.

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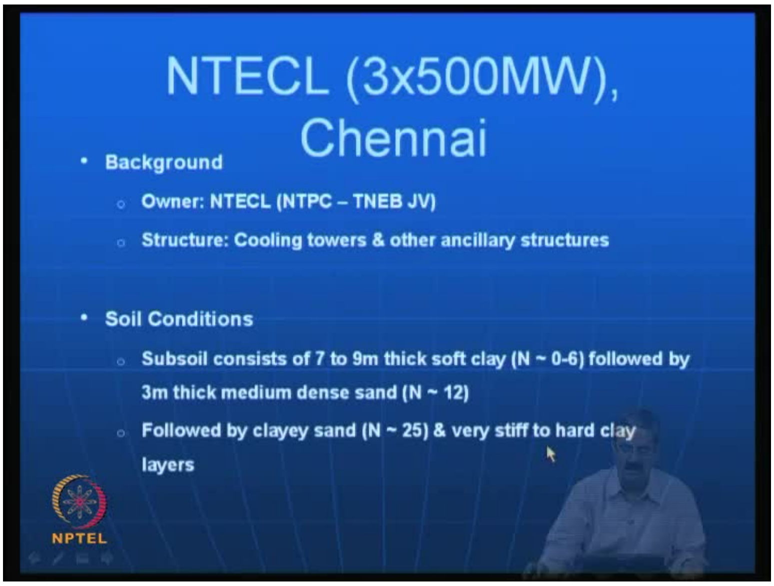

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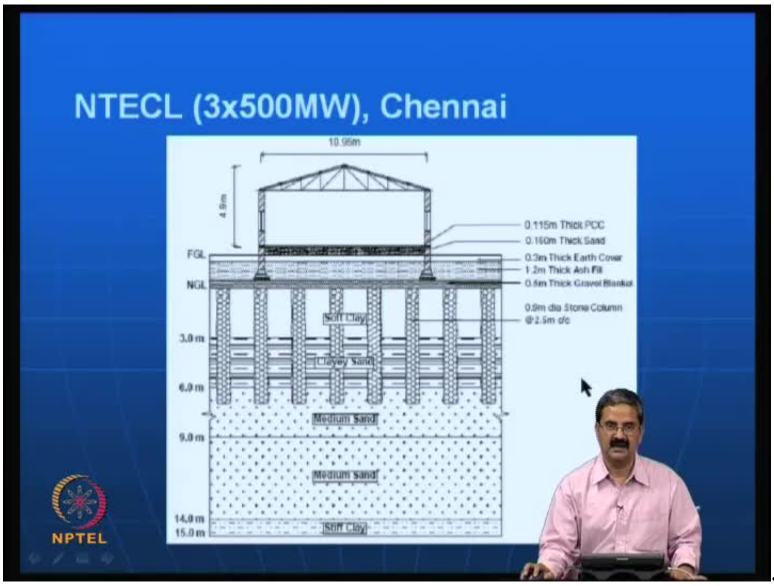

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The columns extended up to 11 meters and this is the case. You can see that soft soil is here, clay sand is here, then medium sand. You have a stone column in this form. You know that is very useful. These are all number of columns, 300,000 linear meters of peakstone columns are used and installation period, it took more time 20 months here.

Then, another one which they have in Delhi and you have some material like this. Soil conditions again S P T value is very low 5 to 10 dense sandy material, S P T again has the seismic zone. It comes in a seismic zone and the peak ground acceleration design should be 0.24 and so the issue is again the bearing capacity improvement. We should check for the liquefaction potential and also see that the liquefaction possibilities are minimal or do not exist at all. We should reduce that.

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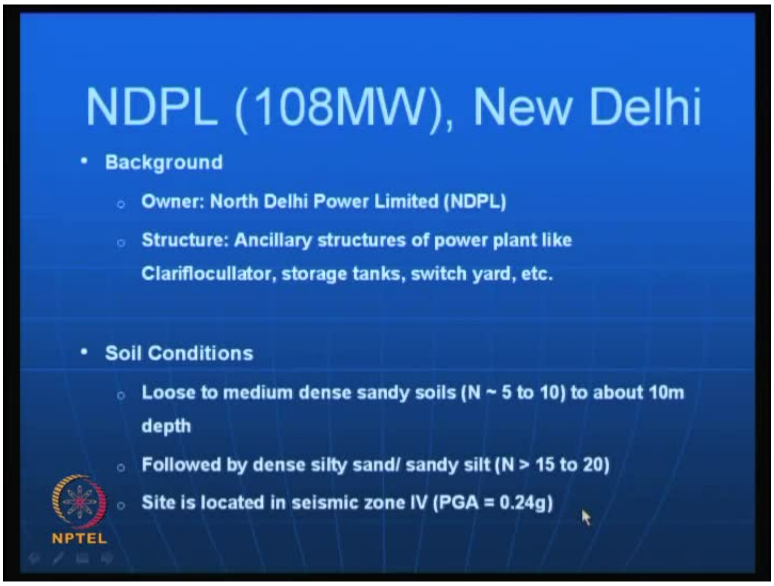

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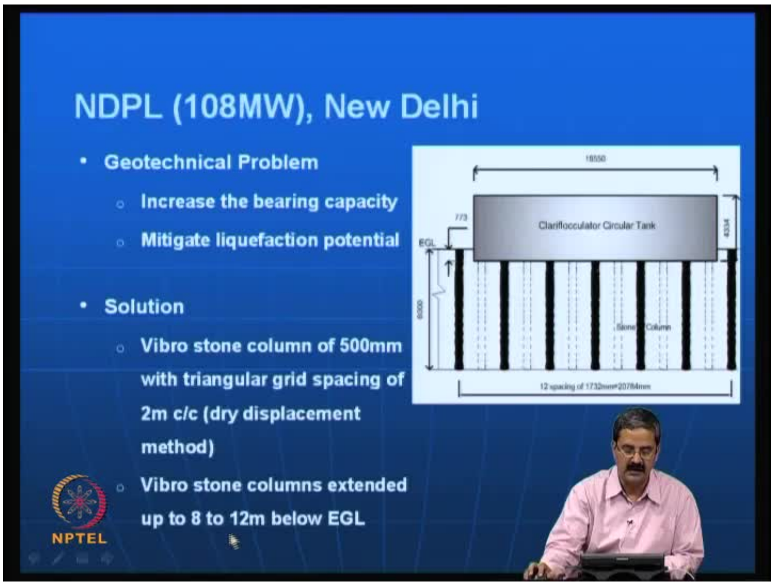

They were able to see that circular tank here and then the stone columns of 500 mm diameter with a triangular grid of 2 by 2 meter centre to center was used. They extended from up to 8 to 12 meters below the ground level and so these are all some of the details again. They have used displacement method. Installation period is 8weeks.

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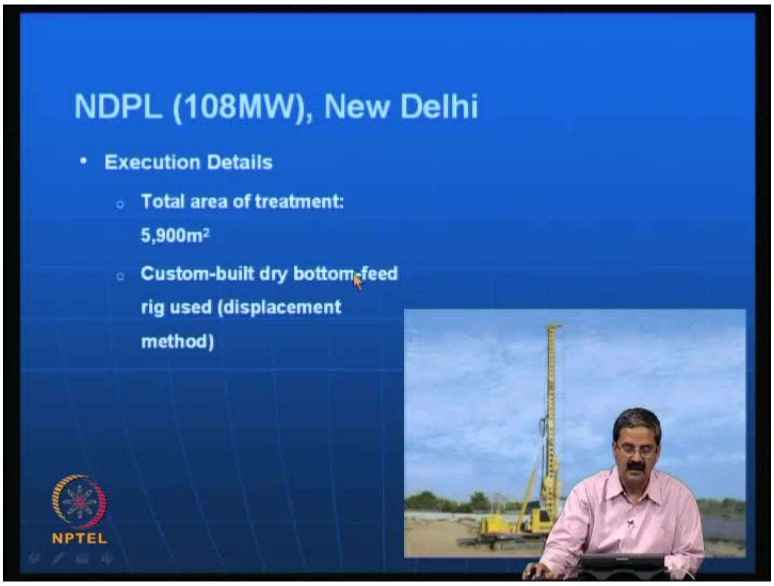

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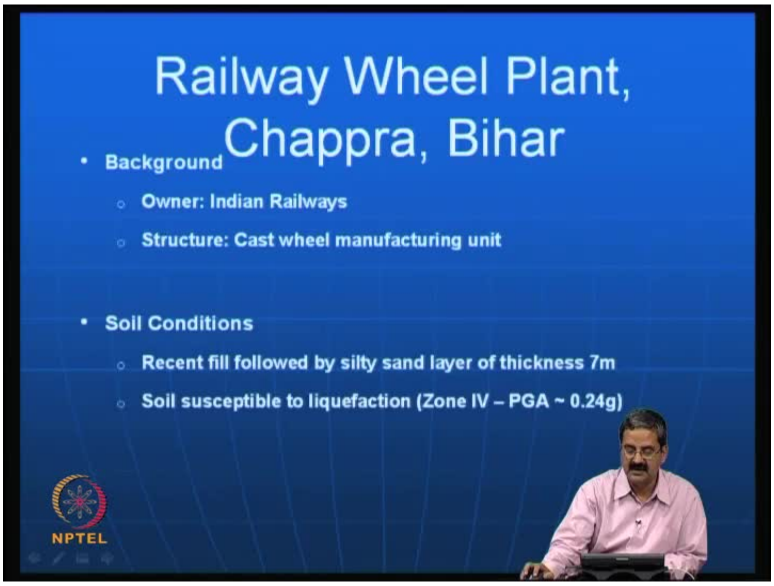

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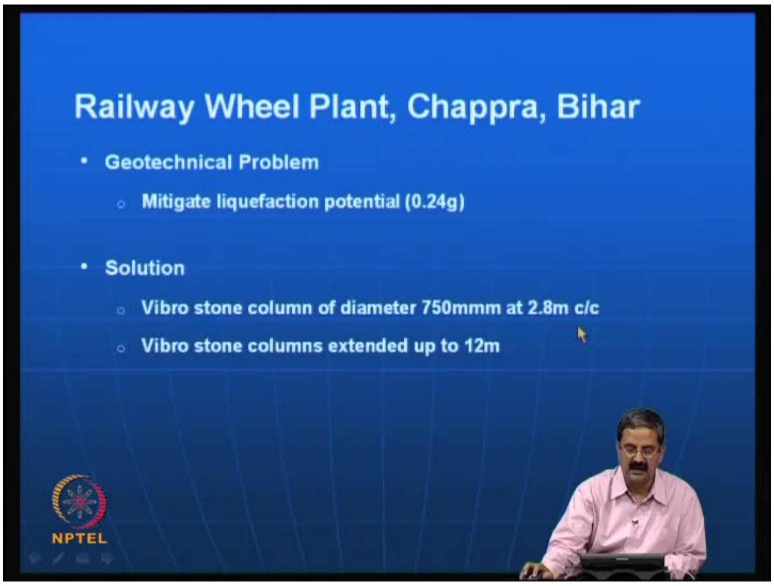

This is another case study in railways. The problem here again is a softsilty sand layers of 7 meters thick and a soil is susceptible to liquefaction because the peak ground acceleration is 0.24 g which you should do in the design and geotechnical problem is that essentially, it is liquefaction resistance one should provide and the solution is that they came out with 750 mm diameter at 282.8 meter center to center and then they extend up to 12 meters and again the length of the stone columns is used 11,000 linear meters and one rig was used. It must be a small project. Installation period is about 2 months.

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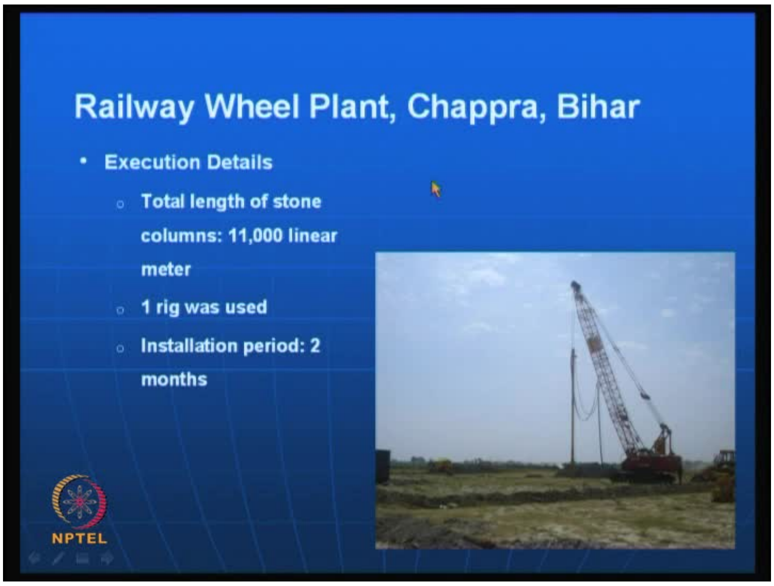

I am sure that with many of these ground improvement techniques in practice, one can understand the stone columns as a viable method for improvement of ground and I should say that there are many issues. Apart from that,I was also talking about stress and properties of the stone as well as clay soil and also I was mentioning about the confinement of the stone columns.

I would like to talk about this in much more detail, these two things because I see that the confinement concept is very interesting in the sense that you have a stone column, you put some sort of confinement and then people have done lot of studies in fact people have done lot of research particularly, in the form of PHD's. Atleast, 5-6 PHD's are there in this area which talk about use of confinement in the stone columns.

The advantage of the confinement is that you can reduce a stone quantity itself. There are two issues here. One is that you are trying to avoid that failure mechanism. We discussed about different types of failure mechanism like something occurring at the top and then something occurring at the bottom and all that. Particularly, bulging occurs in the top and then if it is a shallow stone column, the possibility is that failure surface develops there itself.

So if you want to really avoid that, one can really provide confined stone columns which will number 1, because of the hoops stress that is generated, what you are doing is that, now, the another design variable is coming that you are trying to provide some sort of confinement pressure using circular member so, that introduces some sort of hoop stress and it you can have different types of materials, you have a loose material like a geotextile gives the confinement.

You can have a stiff material like a geogrid that can have a confinement. You may have some other stiffer material, stiffness of this encasement is very useful and one can really do a lot of analysis on this. People have done lot of work on particularly, doctoral programs. I have seen at least3 or 4 thesis and some more field studies in Germany where the people are trying to work out on this.

And another significant role that I find is that in terms of practical applications like this will particularly, the encase stone columns will lead to lot of savings in aggregates. For example, in a particular project, if you are using some amount of aggregates and if it can reduce by some 30 percent, or 40 percent, definitely it is going to be very effective.

This confinement is nothing but geogrids one can have and their plain plastic material one can use them. That is one important point and from research point of view, I find that it is a lot of scope for numerical analysis, design, guidelines and all that you know because you have to generate design for hoop stress. So, the design procedure is somewhat different now because, earlier, we were trying to design, from limit equilibrium methods, we assume that there is a cavity expansion and then there is a resistance from because of the lateral pressure. So, you are trying to do this. That is one side. You have another variable that is coming in which is in the form of a hoop stress or the stiffness of the geo material that you are using. It can be a geogrid or any other material.

Lot of papers have come on this in the recent times, how it can be done and lot of laboratory work is done. Lot of numerical work using proxies, using flack, lot of work has been done and that has been a very useful contribution and apart from it, I see you people have expert in this technique in Japan because particularly, the use of both confinement and even this drainage function of the stone columns is a very valuable system where you are trying to design for how much of pore pressure is mobilized because of that earthquake and how much it can be reduced and how many number of cycles it can withstand. So, there is some sort of refinement in this analysis also is being done. What I find is that these stone columns in whatever form they are essentially column inclusions, it is more like reinforcing the ground. It can be from stone columns alone. It can be just sand compaction piles.

If you just look at literature, people are using different terms, but the only actual thing that comes out is that it is working as a reinforcement in the vertical direction because there is a load applied and then you have some columns that are taking the load and a load coming on the other soil which is the native soil is less.

So, the column inclusions have been very effective. We can call it a stone column. You can call it a sand pile. You can call it a compaction pile. Y There are two types. One is vibro compaction and then the other one is vibro replacement. Methods in a way are similar, but then, in some place, you are using stone columns because its stone is available. You can use flash, for example there is a thermal plant and then you can use a flash nearby and then there is soft soil, you can use many things.

Some companies have a standard protocol, because they have established there some efficient process of using their own techniques, but then, at the same time, it is possible for us to try to optimize on designs by using varieties of ways, even this aggregate piers, rammed aggregate pears they call it R A P.

R A P we must have seen the word R A P rammed aggregate pier. Even that is good enough in fact for small buildings of 40 by 50 site if you have and if you want to increase the bearing capacity, what you just need is an agar and then you just put some sort of ramming, start ramming it and then construct it. For example, 5 meters or 6 meters, then put some sand layer here. That is it.

You do not need a big contractor to operate some of these things. These are all simple. You should make sure that the design is correct because it involves some design and also some spacing length and all that one should work out and if you are able to work out some of this design details properly, I think you have lot of solutions for some of these materials and this has a significant role.

So, with this, I feel that you know some more case studies on stone columns, particularly, on the varieties of stone columns in like as I just mentioned even the rammed earth technique, you have some case studies you know one can have and then even case studies on the use of what you call the confined geocell confined the stone columns whatever.

You have lot of techniques. But I think, one should go through the literature because ground improvement technique is the area that you know that has still longer time to go because when sites are limited and then infrastructure is growing, you may have to end up ground improvement projects on moon. There is no other substitute.

Thank you.