Ground Improvement
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Module No. # 03
Lecture No. # 08
Vibro-Compaction Methods

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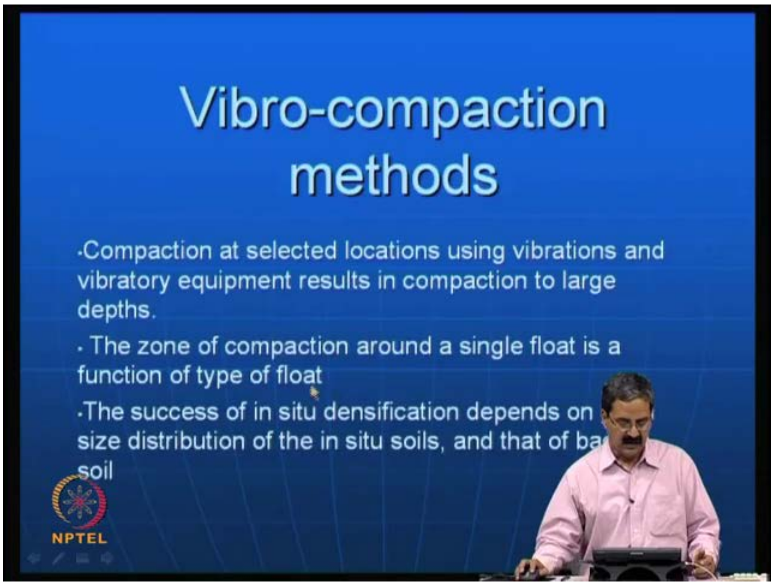

In this lecture, we will be talking about the some more techniques on the ground improvement. Essentially, we would be addressing Vibro-Compaction methods. In this, as I just mentioned earlier, when the soil is very poor and we need to construct some sort of infrastructure on this particular soils, whether it is sandy soils, loose sands or clay soils, we need to use some of these methods instead of going for pile foundations, which are quite expensive and also like energy intensive. So, in these methods what we see is that, we just do the compaction at selected locations using vibrations, like we induce some sort of energy and we use some equipment, which results in compaction to large depths.

As I just mentioned, say for example, if 10 meters is the depth of the soil to be compacted, like as I said the spit value should be about 20 or 25. We need to really have other than what I just mentioned in the previous lectures, like dynamic compaction. Many other methods which are quite scientific like there are many advantages here. So, this particular techniques, like Vibro-Compaction methods are quite useful. Here the principle as I just mentioned is that, it uses the vibratory energy and then a small single float is there and then when you introduce that particular float integral soil, it just vibrates and then, there is a densification that occurs because of the particle rearrangement. And the zone of compaction around a single float is a function of the type of float. In fact, there are different types of floats like that specifications and the success of the in situ densification depends on the grain size characteristics of the in situ soils as well as that of backfill soil.

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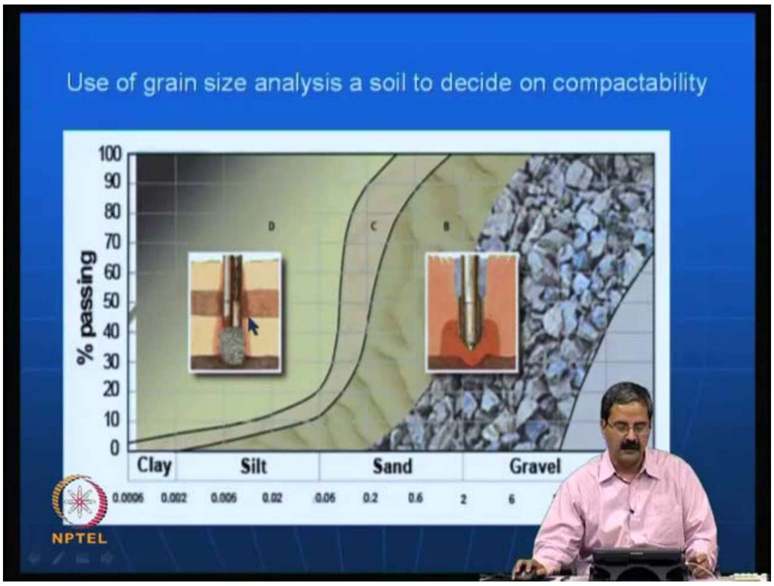

What I meant by this is that, like grain size distribution of soils plays a significant role. Say for example, if I have gravel and sandy material like, you can see this is materials here. This is A and B types here. We just do, what is call Vibro-Compaction in the sense at a selected point. We just densify that and then, you finally from bottom, you construct a column of densified material like dense sand, instead of a pile foundation say for example. So, this is one important thing here. But in the case of clays like you have clays and silts. What we do is that since it is very difficult to get good densities and good friction properties, we introduce some column of materials here which are again, we call it stone columns or sand columns and all that. So, we use this material and then we slowly withdraw the arrangement from the top. So, that way a column is formed and this is called Vibro-Compaction methods. This is called Vibro-Replacement methods.

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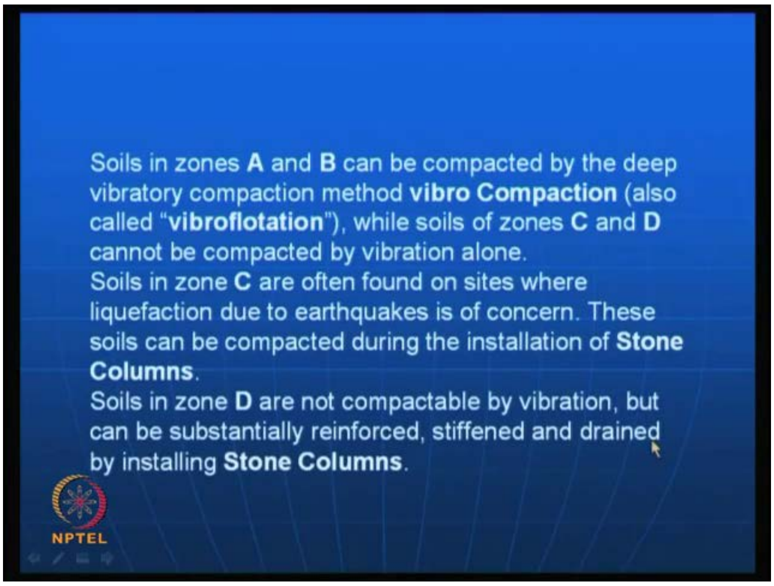

So, both techniques make use of this vibration energy and as I just mentioned, the soils in the zones A and B which I said there are more towards gravelly and sandy materials. They can be compacted by deep vibratory compaction equipment and this is called Vibro-Compaction and while the soils of the zone C and D cannot be compacted by vibration alone. Like vibration for example, in the case of clays we cannot do that. So, soils in the zone C are often found on sites where liquefaction due to earthquakes is of concern. In fact, when the earthquake comes particularly in sandy materials like loose sands and silts, the possibility that liquefaction occurs, the momentary loss of shear strength of soils. Then, whatever collapse occurs is very significant magnitude.

So, we do not have want to have this sort of issues also. So, we would like to avoid this liquefaction as well. And this can be possible by use of stone columns. The soils in the zone D say for example, they are all pure clays. They cannot be compacted by vibration. But, they can be reinforced. In the sense, here putting the sand or the stone material which has a higher strength. So, we say that you are reinforcing the ground. You are stiffening the ground and you can even drain the ground, because stone columns act as a drainage material as well. So, this is what we are going to see today.

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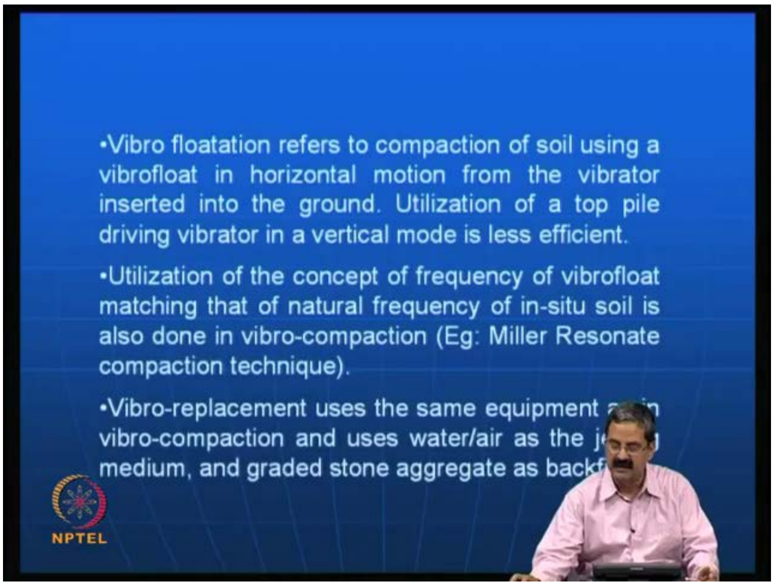

There are some variations in the vibration techniques, for example you have what is called Vibro floatation. It refers to the compaction of the soil using a Vibrofloat in a horizontal motion, from the vibrator inserted into the ground. So, this is what you have that motion in the horizontal direction and utilization of a top pile driving vibrator in a vertical mode is less efficient. In fact, this is a standard question that people have, like can I just use a vibration in the vertical direction or why should I do it in the horizontal direction or can I? See the vibration, say for example, there is what is called natural frequency in vibrations, like if I bring the natural frequency of the machine and whatever is operating system, like vibrator to the natural frequency of the soil itself, can there be any advantage?

So, these are all some questions people will have. So, what people have seen is that, you try to compact it in the horizontal manner in the using the float, like it is in some sort of arrangement its more efficient whereas, utilization of energy from top in the form of a vertical direction is not that efficient. The reason is simple that, see the thing is that the we want to introduce lot of shear forces in soils, like share resistant in the soils would like to introduce. So, when you have columns like this what happens is that, the column is a stronger material and even between the two columns you have to making the material stronger that is an objective part, objective of the whole issue here.

So, by laterally compacting the possibility is that, you would be compacting even the material that is in between, apart from trying to take control of the stone column itself. Even the area that you are trying to do in the vertical manner, because you have a good control there. So, the advantage as I said, it is very clear that the vibration in the form of a horizontal moment is much better. Then people have used this concept of frequency of the Vibrofloat matching that of natural frequency of the in-situ soil. But then there is few companies for example, Miller Resonate Compaction technique. It is one technique people have been using.

Actually what happens is that many of these techniques are evolve, particular contractor, particular group of people evolve the technique and perfect the technique. So, some companies may be happy with the first one whereas, some companies may be happy with the few other ones. So, essentially the equipment, the type of cranes, the type of movement, all the process we have. Then perfect the whole process for a period of time and that becomes there trump card, when they deal with clients.

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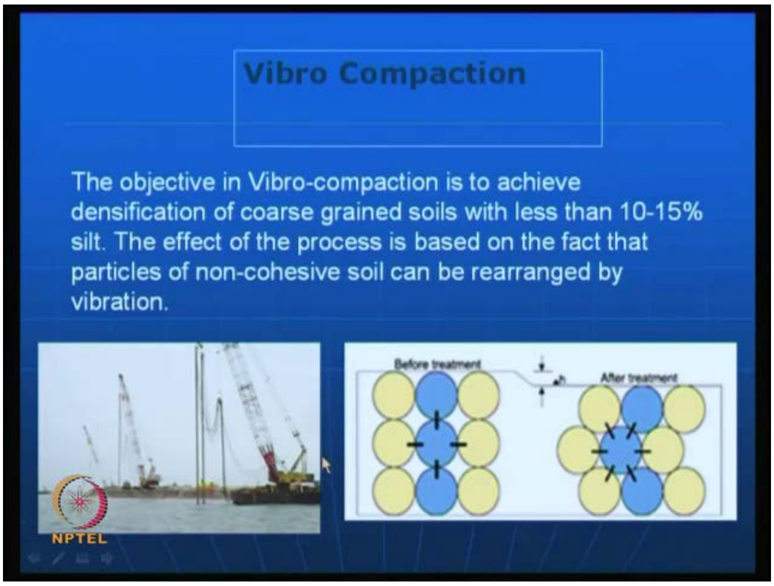

But then whatever is that the process in the objective, the objective is in the Vibro-Compaction is achieve the densification of the coarse grained soils. And as I just mentioned if the silt and clay content is less than its very effective. And the effect of process will based on the fact that the particles of non-cohesive soil can be rearranged by vibration. Like particularly sands, like you can see here. You have some before treatment you have all these particles. And once you just vibrate it all the particles, gaps are there the whites, they get rearrange and there is so much settlement here. In the field, it can be as 1 meter, 2 meters. So, that is what you do not want. So, you would like to density the system by in this manner in the field and this is a typical example how it is done and we will see more of that in the video.

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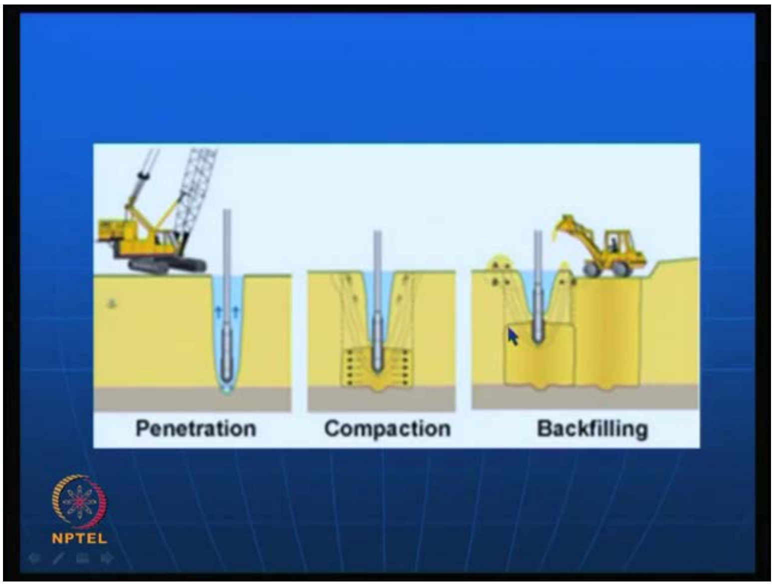

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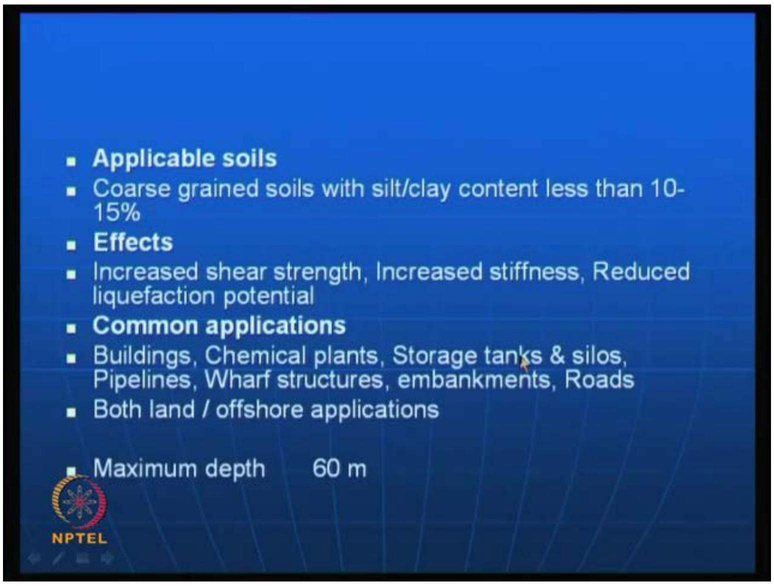

In a simple form it is a penetration. Then, there is a vibration here. Compaction has been done in the horizontal direction, then you also backfill the material. Say for example, you can use the same sand or whatever material you have, make it much more whatever. So, it can be done. So, the Vibro-Compaction is quite good for coarse grained soils with silt clay contents less than 10 to 15 percent. And the effects are that, it results in increased shear strength, means the strength of the ground will be higher. So that bearing capacity of the whole area will be higher. And settlements, increased stiffness is another thing. This stiffness it becomes much more stiffer. So, if you are trying to have some sensitive structures, definitely you need very good stiffness and reduce liquefaction potential. This another important thing that particularly, when you are talking about recurrence of earthquakes in the, particularly in India and many other places, you must be able to take care of the liquefaction potential as well.

So, definitely the use of these techniques have been of significant help in trying to achieve this goal. And where are the common applications? Of course there are many, like building foundations, chemical plants, storage tanks, silos, pipelines, wharf structures embankments, roads, both land and offshore applications like if you want to do something in the land or offshore, you have many applications here. So, the depth is in fact, they are able to achieve about 60 meters which is quite big like.

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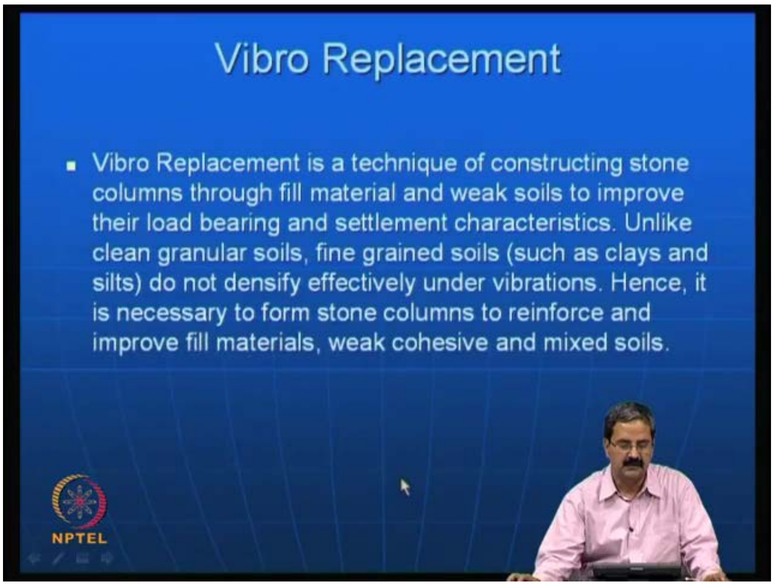

So, that is about Vibro-Compaction. What about Vibro Replacement? The Vibro Replacement is a technique of constructing stone columns, through the fill material and the weak soil to improve the load bearing capacity and settlement characteristics. Like you do not want to have a large settlements or you do not want the load baring capacity you would like to have the load baring capacity improved. So, the advantage the or the difference is that here you have lot of fine grained soils, which do not densify effectively under vibrations hence its necessary to form stone columns to reinforce and improve materials, weak cohesive and mixed soils.

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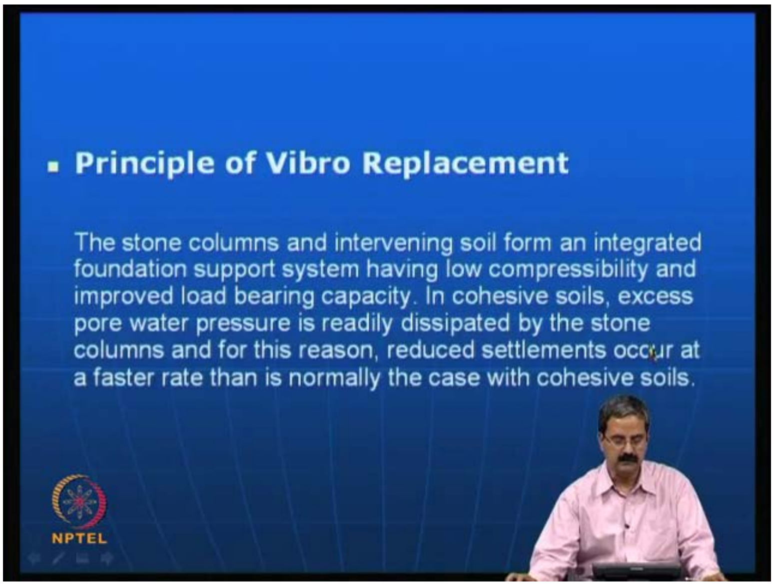

The principle of Vibro Replacement is that the stone columns and the intervening soil, means between the two stone columns, there you have a soil it forms an integrated foundation support which has low compressibility, like less settlements and also improved load baring capacity. In cohesive soils excessive pore pressure is readily dissipated by the stone columns and for this reason, reduced settlements occur at a faster rate than that is observed in the case of cohesive soils. These are very important point, that apart from increasing the load carrying capacity of the ground, they also have less settlements, the drainage is faster. Like say for example, in the case of clays the consolidation is so slow. The process is a time dependent process, like it can take five, ten years or six years. So, you do not want that. If you want to construct a building on a soft soil you cannot wait for the consolidation to complete. So, you would like to accelerate the consolidation, complete the consolidation say for example, it has to occur 1 meter, 2 meters, let it happen faster. So, that they can construct the building. That is what we do here.

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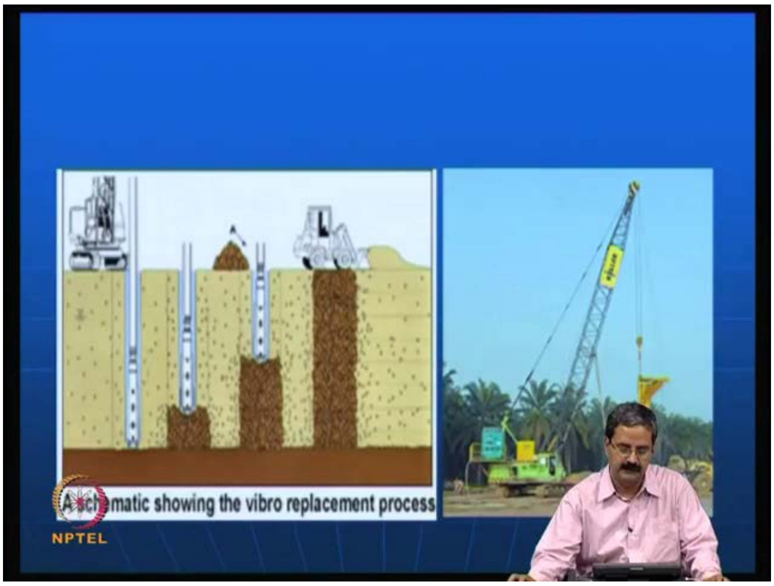

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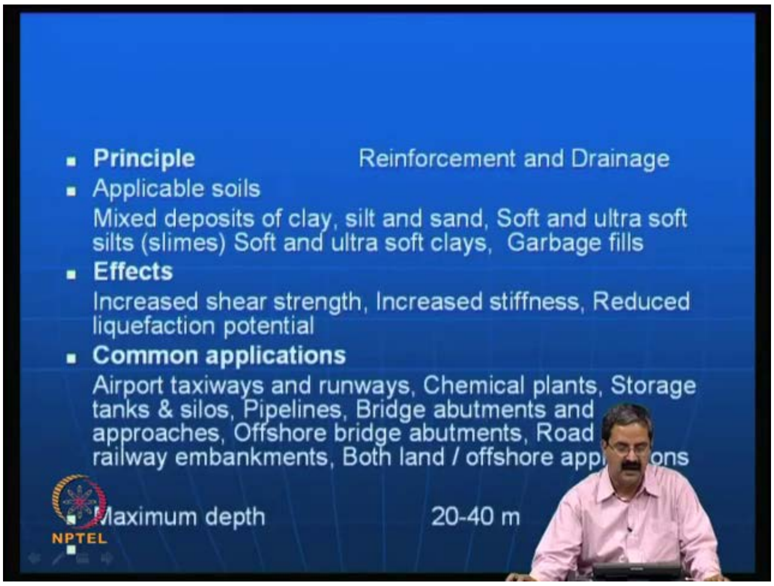

And here as oppose to just a densification in the case of Vibro-Compaction, the principle is here it is reinforcing the soil, like it is because you have a columnar inclusion and it helps in improving the bearing capacity it is not by density alone. It is just the mechanism is very important and drainage is another one. So, it is applicable to mixed deposits of clay, silt and sand, soft and ultra-soft, silts, garbage fills. There are many things one can do and the effects are that increased shear strength, increased stiffness, reduced liquefaction potential. Of course, these are also like people have been using these techniques quite extensively in many places. For example, in many of the east coast projects, I mean west coast projects there are too many.

And it has been use in taxiways and runways, chemical plants, storage tanks, pipelines, bridge abutments, road and railway embankments. If you want to connect rural areas by say for example, you would like to connect the rural road areas to main stream, you have to construct a highway embankment. The highway embankment may pass through very very soft shear where you cannot even walk. So, how do you do that? So, if you cannot improve it then, there is no way that those villagers can come into the mainstream sell their products and all that. So, what would you do is that, we should improve this soil between connecting the village and the town. So, for that you need to use some of the ground improvement techniques which are in this form.

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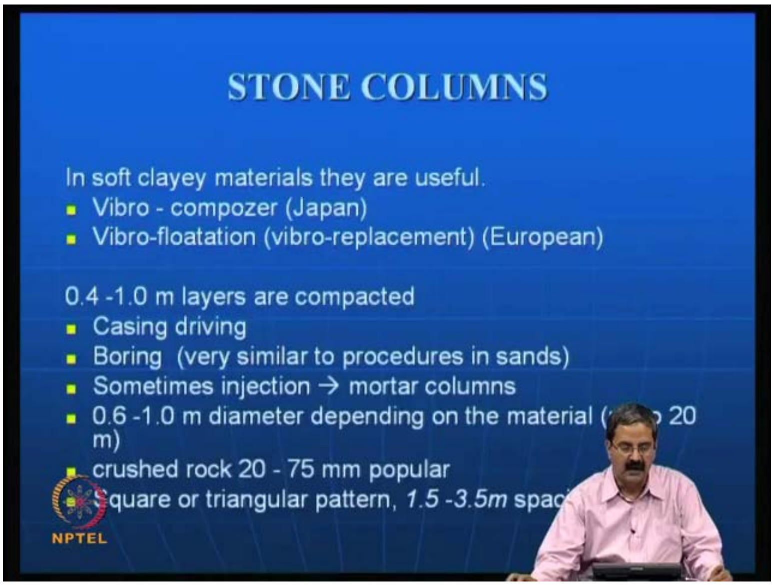

And people have different terminologies here, like people said that Vibro composer they call it. In some places they call it Vibro floatation. And what is the size of the columns? Actually, it could be 0.4 to 1 meter. And then it is compacted in 0.4, it can be even 2 to 3 meters as well. It all depends on your spacing and design. Actually, it could be about 2 meters or 1 meter or whatever. 0.4 you have to design properly. Say particular area like the other day, there is one case where somebody was mentioning that this soil is so soft in that. 40 percent of the clay was replaced by stones, stone column which is quite a big number. So, it is very difficult to really give a proper number here. One should do a design and then see its performance. So, sometimes people do the casing as a driving and sometimes they do boring like and then put a sands, sometimes injections are given. There are some motor columns are also there. So, there are many like typically normal diameters will be 0.6 to 1 meter.

Because that is what we normally use and people can use crush rock. Of course, crush rock is also we may say that it is all stone material but then, possibility is that one can use any of the material that can be stronger than the clay. See the thing is that you will see that if you have a stronger material that takes load than the weaker material. So, they have a square pattern or rectangular pattern or a triangular pattern or whatever. Normally we have a square pattern, triangular pattern and the spacing is about 1.5 to 3.5 diameters.

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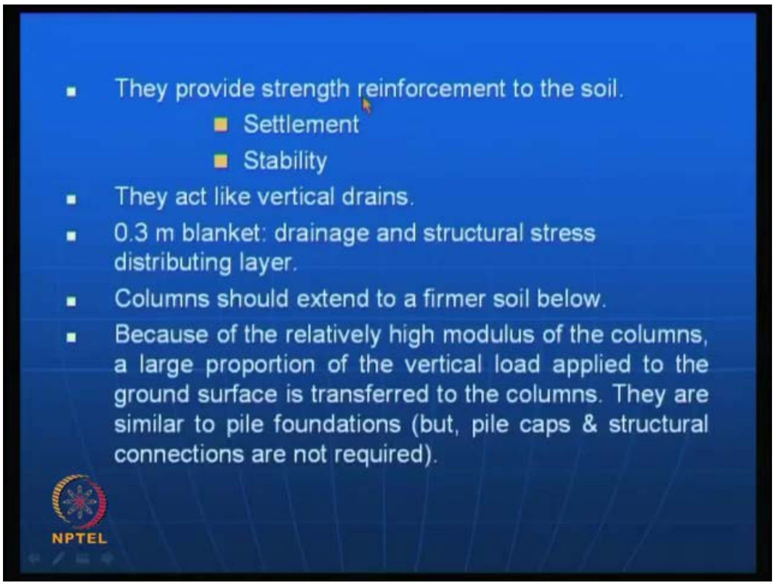

They provide strength reinforcement, I mean they are quite useful in settlement stability, they act like vertical drains and then normally you provide a blanket of 0.3 meters. And it acts as a drainage layer and also the structural stress distributing layer. Like you cannot put a directly on the, see it is very difficult to put on a column. So, you have a some sort of stress distribution layer which is you will see that you have a stone columns here, a couple of stone columns, you have a sand cushion which can take care of that load. So, the column should extent a firmer soil below to the extent possible because of the relatively high modulus of the soil. As I just mentioned the stones have high modulus like stress strain curve, if you just plot for the sand, for the stone, for the clay. Definitely stone will have a very good stiffness, like if you plot the stress and curve the tangent is nothing but the modulus. So, what happens because of this is that large portion of the vertical load applied to the ground surface is transfer to the columns. So, that is a reason like you have a loading platform which is sandy layer or whatever, then you have stone columns. The moment you apply the load, the load distribution takes place to the sand layer and after that it gets transfer to the columns.

And they are somewhat similar but then, you do not need to have, say the pile caps, structural connections like in the case of pile design. You need to go for much more rigorous calculations and of course they are very very costly. There is no doubt about it. Here it is much simpler. Like people have been using many materials which are stiffer compared to the native soil that is the principle here. So, here I would like to show some slides or some videos which can be quite useful in trying to capture what I want to say. There are two videos. One in Vibro-Compaction and the other one is in Vibro Replacement and this is given by the Keller company, which is a ground improvement company.

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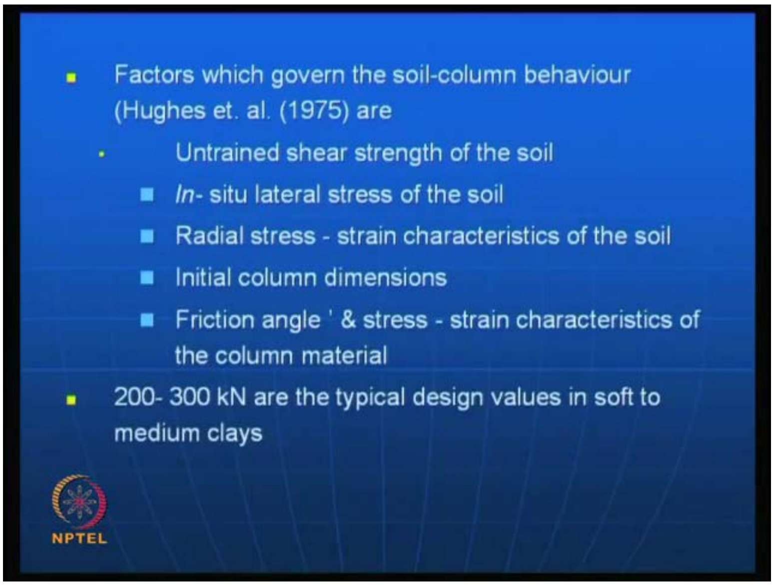

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You can see that they have the steps of, various steps that are involved in the ground improvement operations. In fact, there are Doctor Venu, Raju and Doctor Sri Hari Krishna, who was able to give this material for demonstration and for representation this NPTEL program. You can see that they are doing this particular process here, what I have just showed. Penetration with water jetting.

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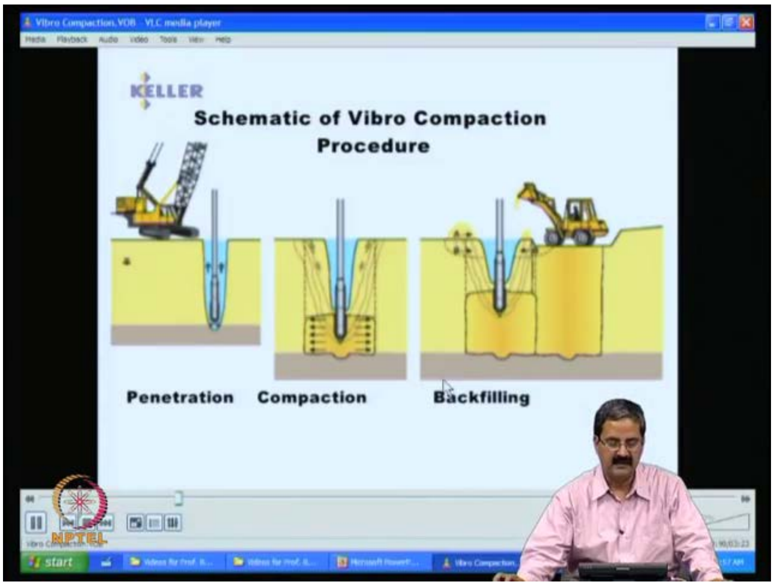

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You can see jets. They have extension tubes. Coupling. It can be either water supply. So, they have an eccentric weight, they have a nose cone. Then you are trying to backfill in the same place the sand. You can see that it is a compacting.

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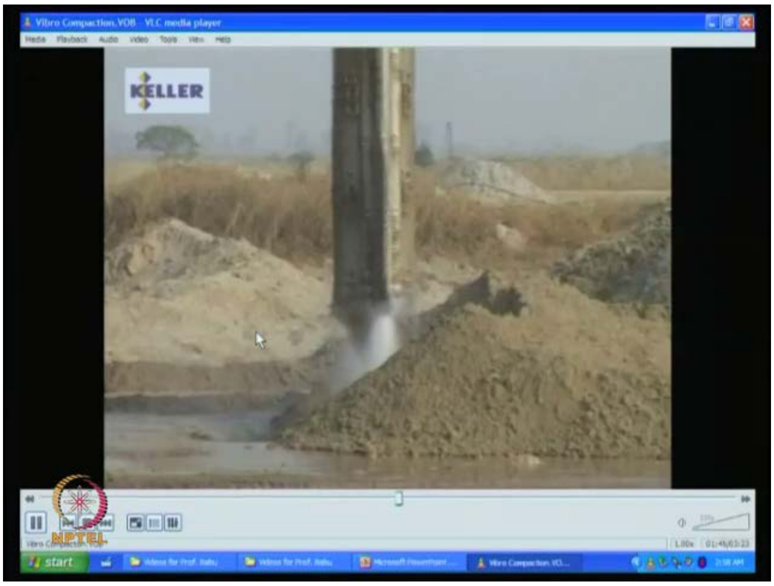

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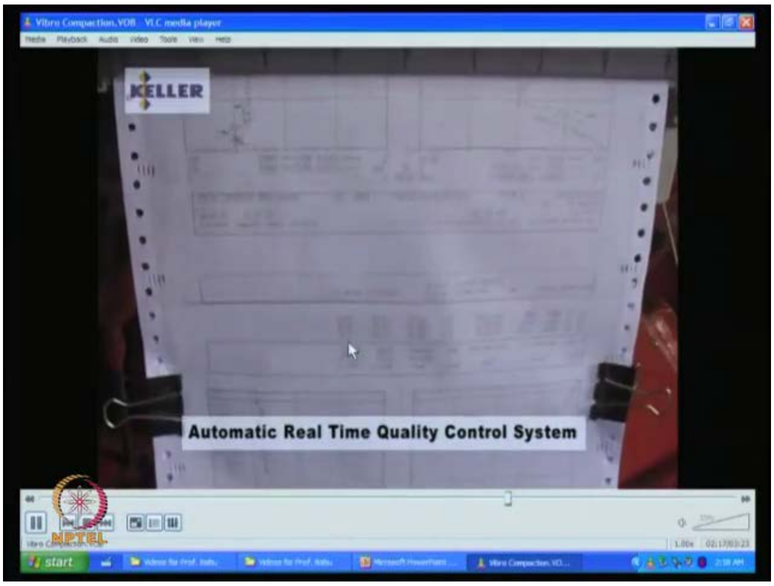

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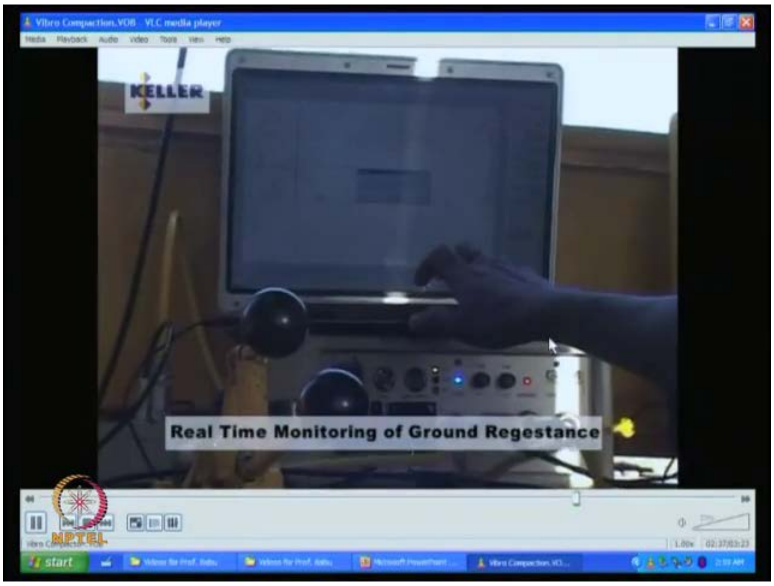

So, some of these companies they have automatic real time systems in which you can see how much of sand has gone in or stone has gone in. And they have immediately the comprehensive test. Immediately they are doing, you can see that. Real time monitoring of ground resistance actually. So, there are trying to see what is the resistance it has, like you can see that this is the old one and the new one little improved. At the bottom portion you can see that it was improved.

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So, like this one can complete this particular in series of lifts right from top 1 meter to, like you can come from top and then there are many applications of this particular technique, right from other things. And the other one was about stone columns. It is a rigorous job. Extension tube, tubing actually, air supply inside, air supply. Stone feeder pipe. Because of the eccentric weight that it has, it introduce the vibrations actually. Aggregate stone is being fed into the stone bucket like this is come from top and then you are trying to lower it. Then, penetration using vibrations and pull down thrust. Vibrator starts compacting and forming the stone columns at the bottom particularly. And they are all looked at in real time, they will be able to see what is the fill, what is the depth of stone columns. You can see here, like there looking at the bottoms.

So, once you complete say at the top level that the compaction, you know completion of the Vibro stone, you compact it again. So, they are measuring what is the diameter because you need it for quality control. It has come very well. And of course, applications too many here. Like highways, bridge approaches, high speed railway embankment, storage tanks and airport infrastructure, too many. So, you have seen that I mean how Vibro-Compaction and Vibro Replacement that is the construction of stone columns is done. Both have been very effective in many of the ground improvement projects and what are the factors that influences stone column behavior?

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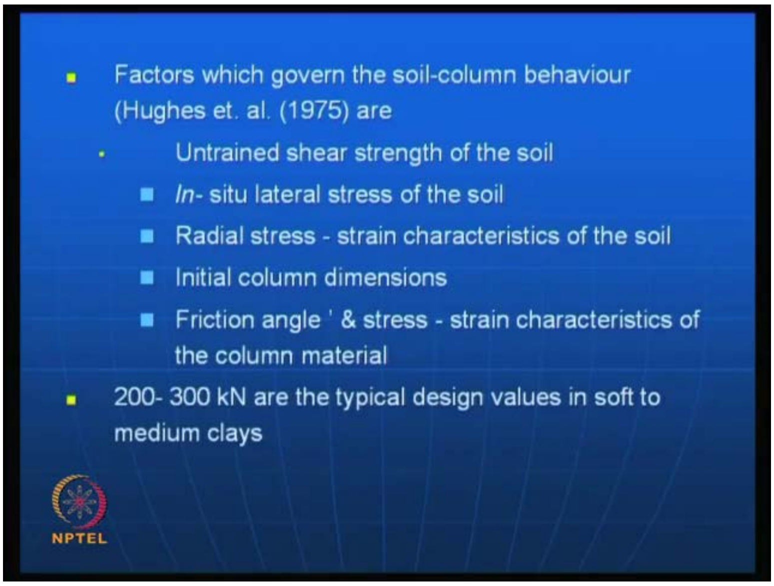

People have studied, in fact, lot of material available. The number one is the untrained shear strength of the soil, like say for example, if the soil is very poor you have to definitely, it needs some sort of improvement, because that is one thing. So, what is the strength of the soil? Is it 10 kPa or 5 kPa? There are some soils which they call it ultra-soft, may be the just like water. So, is it in that particular involvement? So, untrained shear strength of the soil is one thing, then in-situ lateral stress of the soil. Say for example, if the soil is little stiffer then the how much of confinement it can give? Say for example, the moment you put this stones inside, there is a tendency for the stone to go in this form. So, to what extent there is a lateral resistance, because the lateral resistance should be good. If lateral resistance is higher, there are performance of the stone column is better. So, that is one point.

Then stress-strain characteristics of the soil. Say for example, whether it is the soft soil characteristics how is that? Is that over consolidated soil or normally consolidated soil? How it can influence? That is one important variable. Then initial column dimensions, of course, this comes by design. Then friction angle and stress strain characteristics of the column material itself. Like say for example, the soft soil is very poor. It has a you can construct a stress strain curve which is a small, you start from a 0 percent level and then goes to may be 20 percent strain level or 10 percent strain level. Then you also need to have a stress strain characteristics of the friction angle, which will give you the C and phi and all other parameters for both materials. Essentially here this soil, we call it in term of the cohesion because we say that, there is only a cohesion. Say for example, 10 kPa or 20 kPa whereas, stone column material we will say that data is got friction angle say for example, 30 degrees.

And so, all these factors will influence the response of the stone column behavior. What does it mean? Response means I would like to have improved bearing capacity, I would like to have less settlements. So, if you want to have good bearing capacity I must be able to have all these factors into my consideration. I must be able to use some of them in design. So, that is what I mean. So, like what is the typical value for the stone column? What is the load it can take? So, normally engineers have a tendency to, what is the single pile capacity? What is the single stone column capacity? So, one should have a rough idea. We will see how it can be calculated as well now.

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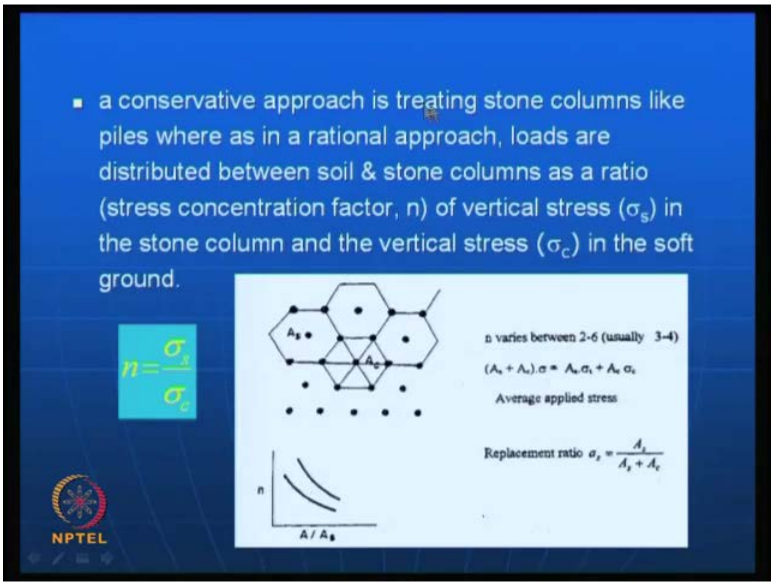

And actually a conservative approach is treating stone columns like piles. That is one thing whereas, in the rational approach loads are distributed between the soil and stone columns as the ratio. Like you have a stone column here, you have a stone column here and what happens is that you apply a load. Actually, this we call it unit cell and actually this is the thing is that the moment you have a load, the load is taken care of by this stone material. As I just mentioned the stones start taking load and this load that that is coming on the clays less. Previously there was some load was actually there was some whatever is the stress clay was taking but now whatever load here or trying to apply it is now being shared by stone column and the clay present.

But then this bring a better material, this will take more and then we call it what is call stress concentration factor, which is actually the ratio of vertical stress in the stone column and the vertical stress in the soft soil. Like we have a term for this, which is the ratio of stress in the stone column and the ratio of this stress in the clay. And it varies from 2 to 6 and usually 3 to 4 are the numbers. So, in fact, from fundamentals one can construct a simple equation like area of the soil, area of the stone columns plus area of the soil, that is the clay into the total stress applied equal to, it can divide like this. Then the area replacement ratio you can define like this. How much of area in that, you have replacing by stones. Like area ratio is what divide sometimes that it is defined like this. So, here you can see that like as I said total area divided by area of stones like it can be, the another way people have say, in fact, this is one expression that people have.

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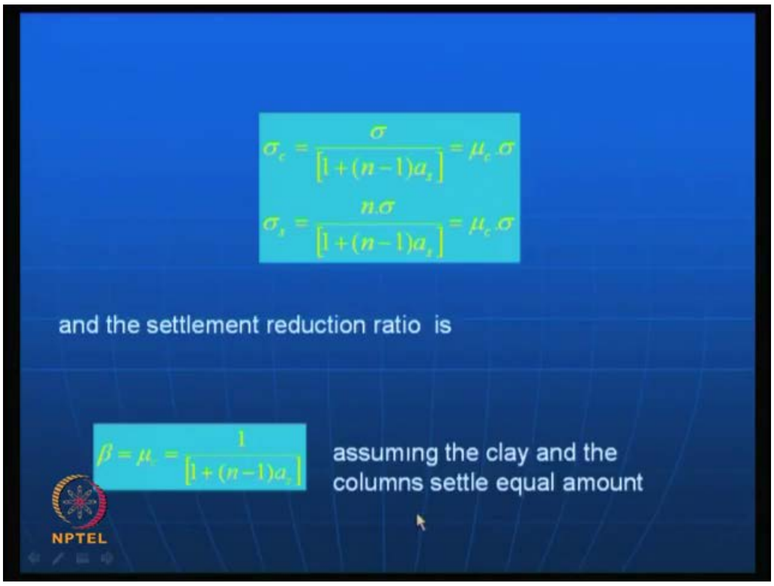

So, the load that can be distributed by, in this manner for the column as well as the clay or given in this form where one can say that, the n is that factor I just explained in the previous slide. This is the load taken care by the clay, this is the load taken care by the stone column. And there is also a term called a settlement ratio we assume that it is the one, we use a term called beta which will tell you the settlement reduction ratio because we would like to see that the settlement is minimum. Say for example, if I say that here constructing a tank, I said the settlement has to be only 25 mm or 40 mm or 50 mm something like that. So, whereas, in the convention case settlement will be about a meter. I do not want that.

So, that settlement ratio one can express in this form which is again a function of the area ratio and also the stress concentration factor. And we assume that the clay and columns settle equal amount. So, the moment you apply the load both settle like you have a clay here, you have a stone column here, the moment because you have a loading plant form at the top the apply a load, they settle equally but in the process, the stone takes more load compare to clay. For example, I just want to give a small, a calculations example here.

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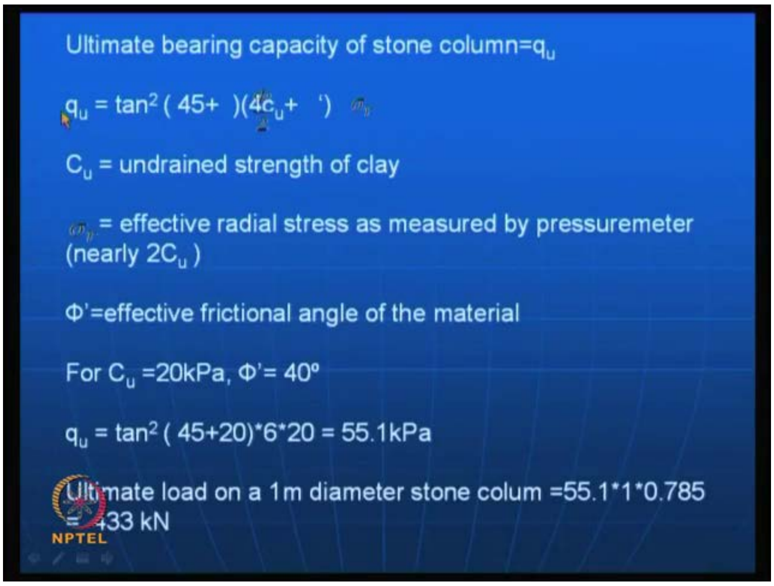

Ultimate bearing capacity the stone column is given by a simple expression. It should be pi C u here. pi by 2 C u and then sigma r. So, C u is the undrained shear strength of the clay, sigma the affected area stress as measured by the pressure meter. In fact, I just mentioned that like many of the test we use like pressure meter, like that is one of the methods to see the condition of the improved ground. We have both C P T test S P T test, we have pressure meter also. The advantage of the pressure meters that there is a radial expansion of this diaphragm and that you will get radial stress from that directly you can measure. So, that is roughly equal to sometimes if then the bearing capacity or the shear strength is C u it is twice. So, phi is the effective frictional angle of the material. So, for example, I am trying to work out a simple example, if the untrained shear strength of the soil is 20 kPa. In fact, this 20 kPa, say for example, you are going to Mangalore area, it can be 10 kPa, 20kPa like that.

And then you have the stone material which has a friction angle of 40. So, one can use an expression like this and then get the ultimate load that the stone column can take because this is the formula here. So, you will get about 51.1 kPa. You can see that from 20 kPa, it got increased to 50, 55 with the presence of using the stone. So, ultimate load on one diameter stone column, you can just calculate in this manner.

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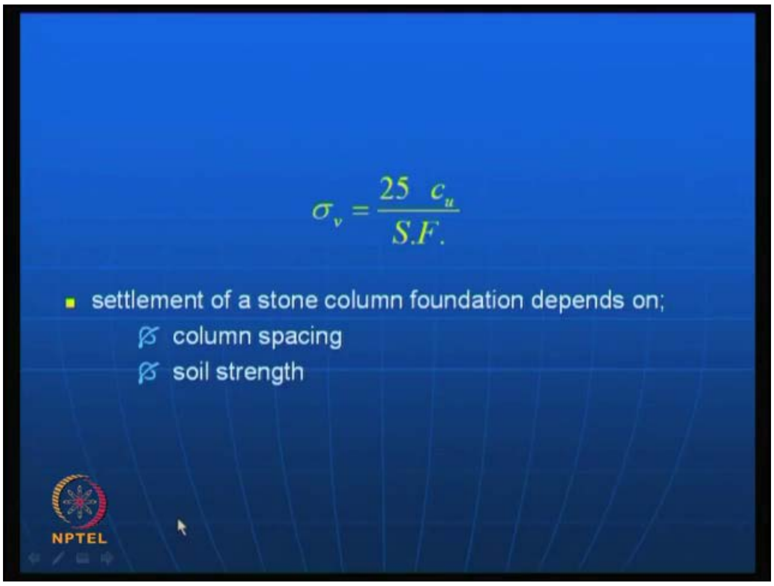

So, you can see that one can, the load you will get a 433, some load which is reasonable number. So, one can calculate the capacity of the stone column provided the properties of the soft soil, properties of the stone material. So, based on that one can get this. And then, normally some empirical relationships are there. Sometimes if C u is the undrained shear strength of the stone column by this process you can at least increase that by 25 times with a suitable factor of safety like 2.5 or something like that. So, the of course this needs to be treated with caution because people have to do the lot of rigorous exercises here.

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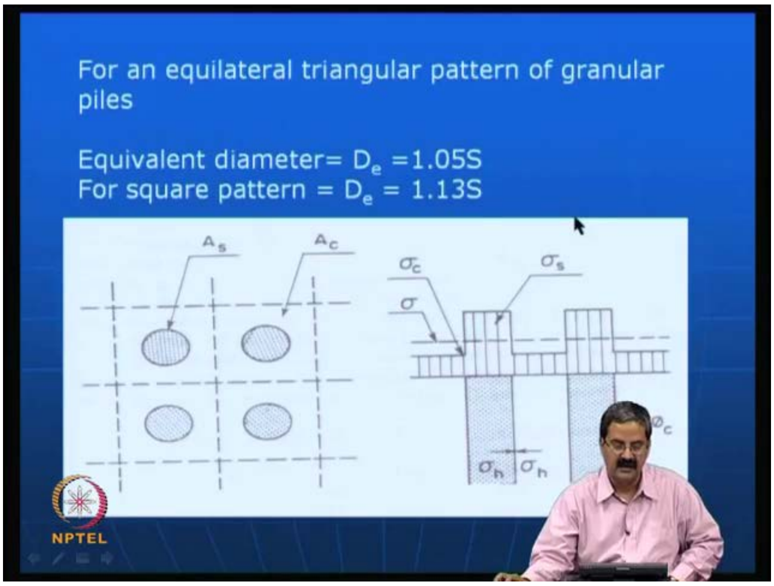

And as I just mentioned there are two patterns. One is the square pattern or even a triangular pattern. So, for equivalent diameter, we call it equivalent diameter for a triangular pattern it is 1.05 times S. S is the spacing of the stone columns. For square it is D equivalent diameter is 1.13 S. This is what I was just mentioning and see this is the stone column which is completely stone and then this is the load by the column like you can see it is a higher number whereas, this is the load in the clay and this is the average number. You can see that this is sigma c, a lower value whereas, sigma s is the higher value and then you get an average number. So, this is what I just meant by the load sharing mechanism of the materials like because the soil is somewhat soft it cannot take load, this will take it. That is the meaning.

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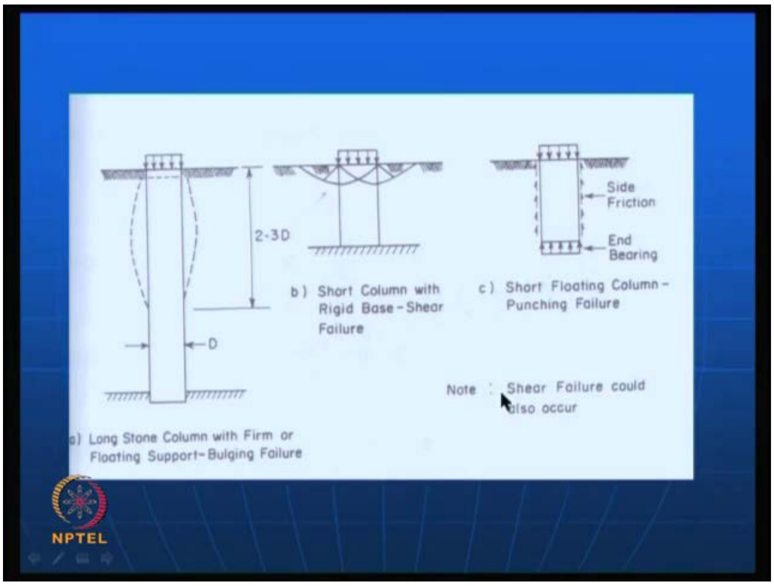

And see once you try to construct this stone columns, we have to see under what conditions they are fail. Like you introduce a technique, you should be careful about the fact that it should not fail. So, you are trying to now introduce a stone columns, you should see under what conditions it can fail. So, one classical example is that you have a long stone column introduced on the, with a form or a floating whatever it can be ending at the this can be a form strata or it can be there is no material here itself.

So, the possibility is a there could be a bulge, bulge like this. And normally this is restricted to 2.2 to 3 times D. This is one type of failure that one can have in the stone columns. And of course, it is not a failure, it is just that, what is happening the lateral resistance of the soil here is less. That is what I meant. Just now in the previous slides I have said that the lateral resistance of the soil should be good. In fact, people have done lot of research to eliminate this and they call what is called, they call it, they are putting some geocell material or a geocentric material to avoid this type of bulging failure. We call it bulging of the stone column. If it does not bulge, its good for you, is it not? You are trying to apply the load, load is transferred completely by this, taken care of by this.

But if it bulges there is a possibility that it is not a very effective. So, you would like to avoid it. So, some people have done, you just in your construction process put a sort of casing made of a geocell or some sort of material and see that it is completely there and this sort of failure is avoided. Then suppose the material is what is called (( )), depth is less there is a possibility that it could fail like this which is a simple classical soil mechanics type of failure, which is called a shear failure. So, that also we do not want. The third one is there could be a side friction and end bearing. These type of possibilities also there. So, essentially we should see that this failure mechanisms are understood, proper perceptive and the columns will not have this problems.

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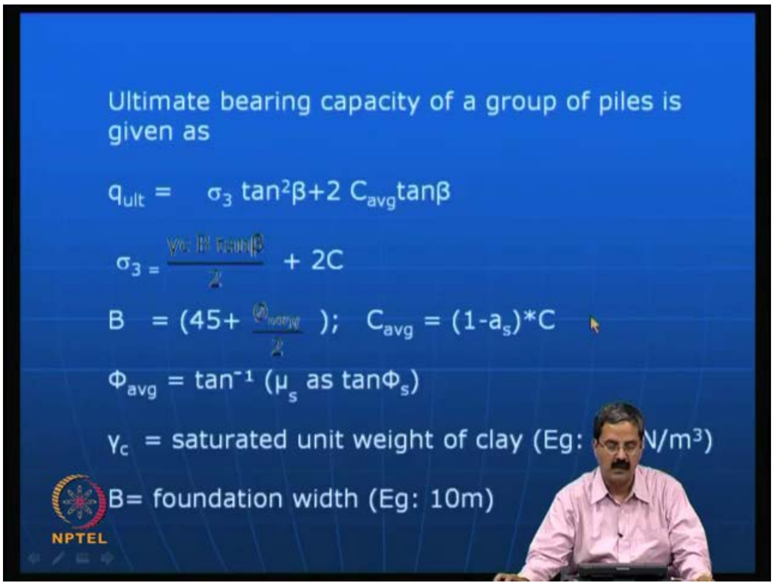

So, there is another expression that have for ultimate bearing capacity the group of piles. So, when I have a group of piles or there is a granular piles we call it actually. We call it granular pile not an R C C pile. The key ultimately is given in terms of the lateral stress into tan square beta plus 2 C. C is the average value tan phi B and actually as I just mentioned that the lateral stress sigma 3 will give you that influence. So, that is coming here in terms of the gamma c B into tan beta by 2 plus 2 C and then beta where this is beta is nothing but 45 plus phi average by 2 and C average. These are some simple expressions. Actually, what we are trying to calculate is that, we are trying to calculates soil is has some cohesion sand has some friction. So, since two materials represent you are trying to calculate average values of cohesion for improved ground which is quite useful. Like it is, we call it C average and then friction average. And then this is saturate weight of the soil clay. For example, if you take it as 20 kilometer per meter cube and you have, I am just trying to illustrate with another example because what you saw just now was the capacity of the single column. Now, how the group also behaves one should understand.

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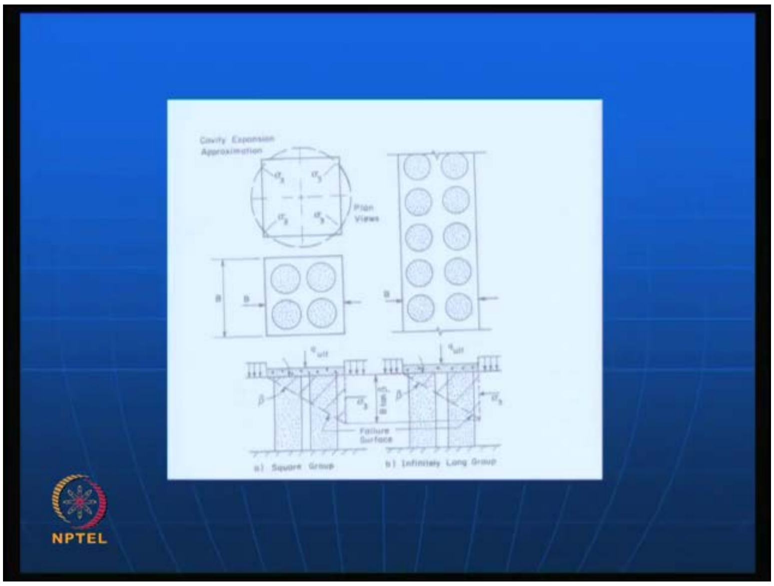

So, this is what I meant like you have, single column we know little bit but this is like, you assume that there is a load this particular you have a, B is a width of the foundation and say this is the, say for example, some tankers square building. And you are trying to calculate all the parameters like lateral stresses and all that.

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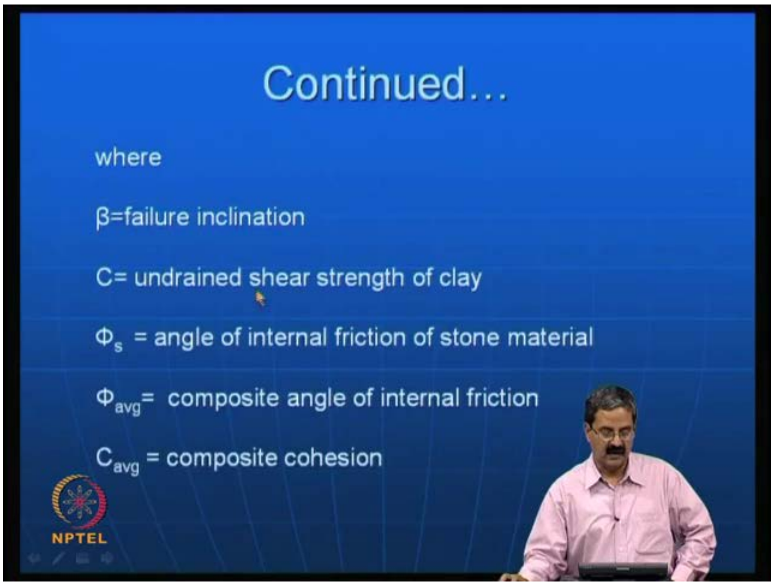

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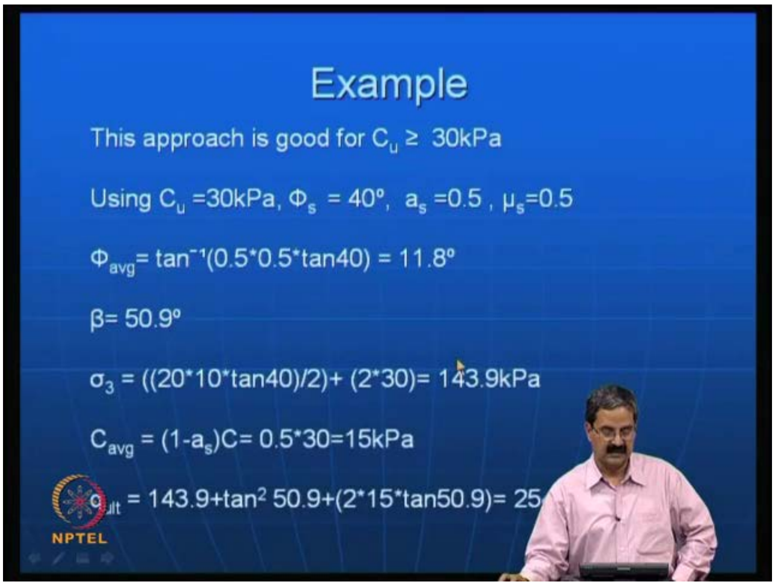

And this is whatever I just saw, we are trying to calculate the same thing here using these parameters. And this approach is good for values of cohesion more than 30 kPa and use some of these properties like C u equal to 30 kPa or phi s equal to 40 degrees. The a s is 0.5 and (( )). So, this is actually friction and some of these factors if you just calculate you can just see that the ultimate bearing capacity is about 254. I use 30 kPa material, now I just increases it to 254. You can see that about 5 times I can increase the capacity of the load. Like this is the actually 5.14 C u is what is call the ultimate bearing capacity of clay 5.14 into 30 is about 150. So, i just. So, if the C u of the soil 5.14 into C u, we call it as ultimate bearing capacity. Now we have increased it to 254. It is about good, about twice close to 2.

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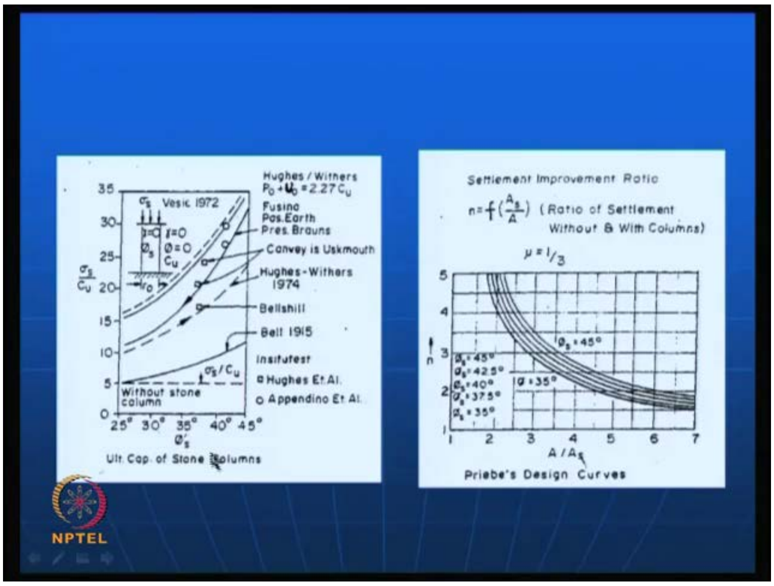

These are all some more experimental results that we have on how the, depending on the friction angle of the soil, the stone column, so what happens? So, lot of research is done like say for example, as I said without what is that, this is a load thereby its shear strength. I just gave an expression that the ultimate load divided is equal to 5.14 C u, just mentioned that. So, you can see here that without stone columns you have that number, 5. somewhere here. This is a standard equation we have in basic bearing capacity equations. Now, what I am trying to do is that I am trying to put some reinforcement stone column material here and people have different researches have given different types of equations and they observed also in the field like somebody from Bell, like Hughes and there are so many. So, you can see that depending on their friction angle and whatever is the material available, there is some more literature from literatures these are all taken. You can see that significantly that ratio instead of 5.15, it can be as high as 15 and it is a function of actually friction angle has to be at least 25 degrees of the sand. And if you increase the friction angle, you have an excellent effect, like 45 degrees you have some 15 to 30, that ratio increases. So, the thing you have a good sandy material or sand can be used as we call it sand column.

Like if the clays not I mean if the stone is expensive, use sand and if we have a friction angle of 25 degrees then definitely from 5 you are increasing it to 15 or whatever, 10 at least. So, you can see that it is a very good improvement. Whereas, if we have a very good material definitely like you can use, say for example, a construction debris, you can use particularly if you trying to talk about sustainable development. Aggregates of course, stones are quite expensive in. So, some things could be done. So, this is about another one, where depending on the friction angle of the soil how this distribution, load distribution is altered?

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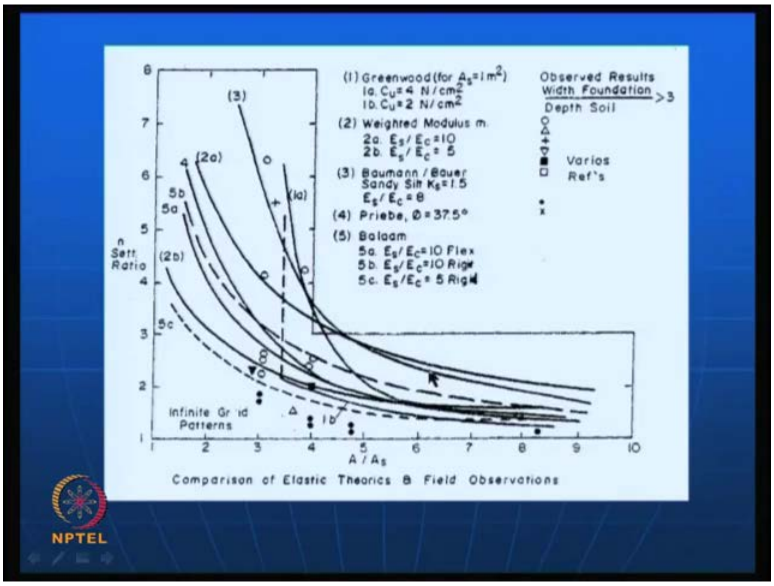

This is another interesting thing from the field. Like because as I said ground improvement techniques are done in the field, it is not in the lab. And people make lot of assumptions in doing a design and it is very risky. They would like to verify to what extent they are correct. They try to check that their concepts and try to come out with lot of analysis and this is one type of analysis. So, for example, this is the area of the a by a s. Total area divided by the area of the stone column. So, you can see this plot where if the and then this is settlement ratio.

So, we can see that as the settlement ratio means settlement improvement. Actually, if the sandy material is very high what happens? If you have lot of sand definitely the settlement reduction is very high. You do not want particularly in sandy materials and all that are in stony material settlements are going to be less. This is what is called infinite grid patterns or whatever. So, settlement ratio is going to be very less. Whereas, you have lesser sand or lesser stone material, there is a marginal improvement. That is it. So, you can see that they have done for different materials, like say for example, green wood for area of stone column has 1 meter square, like 1 into 1 meter or little close to that. And

C u value means which is called untrained shear strength value 4 and 2. And so, he got some equation which is like here, 1 b. This is 1 b. So, 1 a is here.

So, then there is another way of, people are looking at these are all measured, like comparison of elastic theories and field observations. People have made some of these theories, actually there are different theories based on the observations. Say for example, whatever I have just said phi and all that, there are limit equilibrium methods. Like if I know the phi of the sand or the stone column we use, we are trying to say that you are putting a sand material inside and then when you are applying the load, there is a bulging type of thing and there is a resistance offered by the surrounding soil. So, based on this concepts which is called limit equilibrium concept we have derived that equation actually, that whatever equation that we had to calculate the bearing capacity improvement for a single stone column and a multiple columns. This is based on some limit equilibrium methods and we also have elastic theory approaches like particularly by Pribe and others. That I will show you. Here the Priebe is there.

So, we can see in this particular figure that for the field observations, essentially we are not interested in simple analysis. We would like to see how other theory works in the field. So, you can see here that the theory that the Greenwood had, which is a essentially a chaotic expansion theory based approach he has C u equal to force N per centimeter square and these are 2 values you can see one curve here, the other one is here somewhere. So, which means resemble good. Then weighted modulus M like actually the settlement is essentially a function of stiffness of the materials. If the stone is a very stiff compare to clay it is 10 times here. So, you can see the 2 a is here. 2 a material you can just see that, it is very good. So, if E s by E c is 5 times, it is somewhat low here. You can see that, it is expected.

So, like that somebody has also done in terms of other things. Priebe is another one, like I will explain that method in a again in detail, like for 37.5 degrees it is somewhere here. This is again a theoretical method. Somebody has again done some more calculations. All those things are here. What I want to say is that, it is a very interesting that you have theories and these are also measured values. So, which means that you have to have some theory to calculate, you also should have measurements to do the analysis. To confirm the analysis and also to make sure that you have to give a guarantee to the actual persons who are the owners. Say for example, you have trying to improve the soft soil

properties in Kerala. I have to give you a guarantee to the Kerala government or the fortress authorities that, yes, the stone column is working and it has taken so much of load you have the so, much load from your containment facilities and now this is a load that the stone column is taking and the performance is going to be very good because it is tallying with all the field observations. So, that is how I would like to justify my design.
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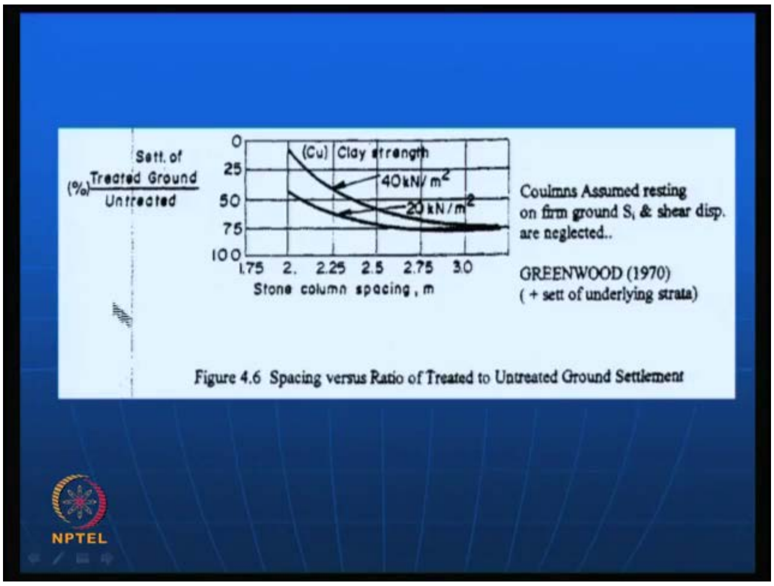

So, this another interesting point, where you can see that the depending on the stone column spacing, spacing ratio of the treated to untreated soils like, you can see that depending on the stone column spacing what is the effect of settlement. Settlement of treated and untreated ground ratio. Again here you see that if this ratio has to be, the settlement it should be low because settlement in the case of treated material you expect low value. Say for example, instead of you may expect 25 mm only instead of 100 mm. So, it is 25 percent. So, that 25 percent is here and if you can see here that the reduction is good in the case of, there are two materials here. It is actually a function of the undrained shear strength of the soil.

So, in the case of somewhat stiffer soils it has been there is a good reduction. Stiffer in the sense it is not very stiff. Again it is good for stone column applications. That is what i meant. See, it has been quite effective here and here say for example, in the case of, if the spacing is 2 meters and the settlement of the treated ground to untreated that ratio is actually more in the case of 20 kilometer per meter square. In the sense, it is about 55 to 60 percent whereas, it is 10 percent here. Actually this material is already stiff, 20, 40 kilometer per meter square, here the material is already stiff and definitely there is a good improvement but the there is. So, here in this case it is about 55, 25, about 45 percent. So, we can see that for the spacing, you can really come out with some understanding of some of these things. Actually, these are all done in lot of field studies.

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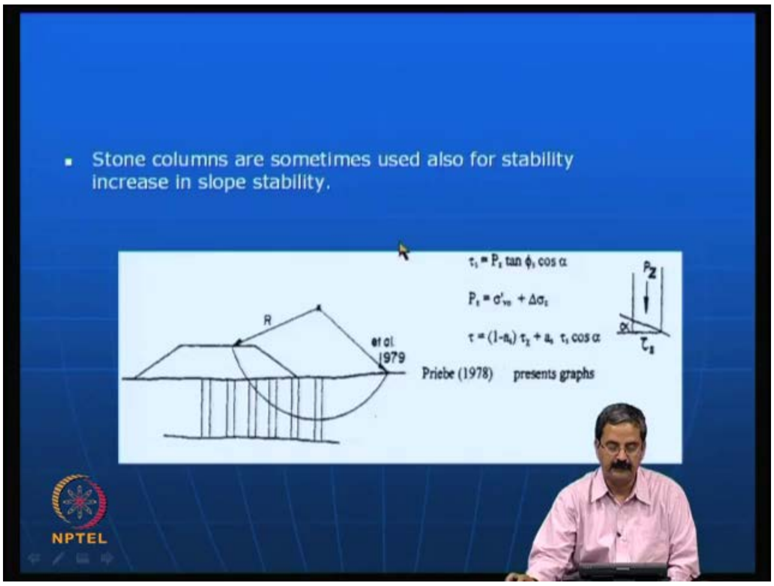

And actually this another classical application in highways say for example, this is a highway embankment. You would like to construct the highway on that. Say for example, you are from some soft soil areas whether it is a Paradeep or whether it is Kandla or whether it is Mangalore or Calcutta where, you have lot of soft soils, you construct a highway embankment may be about five meters and the classical thing is that the slip circle analysis should be done and if the slip circle analysis shows that the factor of safety is less than one. So, you cannot really have any use of that.

So, what you do is that, you construct the stone columns like this in this form and then you can calculate the C and the phi. Earlier here it is only C, C of the soil and all that. So, the thing is that you have, you take the improved properties of the material like from this you can calculate equivalent cohesion and equivalent friction of the stone of the material in which stone columns are present. And then use it in a stability analysis and you can get a factor of safety of 1.3 or 1.4. Earlier if the factor of safety was less than 1. It is not acceptable. Now that the use of the stone column, you can improve the stability of the slopes or the highway embankments in a comfortable manner. That is very important application in many of the stone columns.

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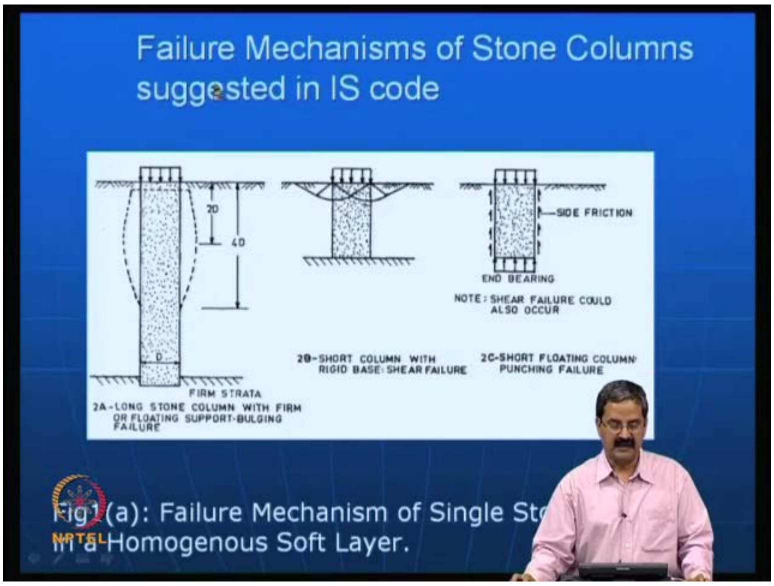

And actually this is some of the, normally in India we try to follow the I S codes. I would like to highlight the failure mechanisms that we just discussed earlier. They are again reaffirmed in I S code that we have this bulging formation at 2 D to 4 D. And this short column is also like failure is also another possibility, like what happens is that this is one type of failure that one can expect. So, that one should avoid. The fact is that you are trying to have that loading platform. See the soil is so soft here and then, but you have with their loading platform then this type of, which is again a sandy soil and then you have a stone column here, this problem will not be there as simple as that.

Then, this sort of the having side friction actually sometimes it is, it depends on the type of construction or the method that we use actually. So, if you are using some boring methods and all that, the possibility is that there is not much effective. There are gaps or some sort of things. So, the side friction may be very less. So, it will not be affective. Actually, the objective is that it tries to expand laterally and then there is a lateral force in the opposite direction. When you have vertical force and then there is a lateral resistance then it works.

But suppose there is a slip in between like there are some gaps and all that, it will not be very effective. So, we do not want this possibility also. So, essentially we need to understand the failure mechanisms and so that they are not occurring in the construction actually. In the case of a non-homogeneous layer which means that you have some more soft soils somewhere present.

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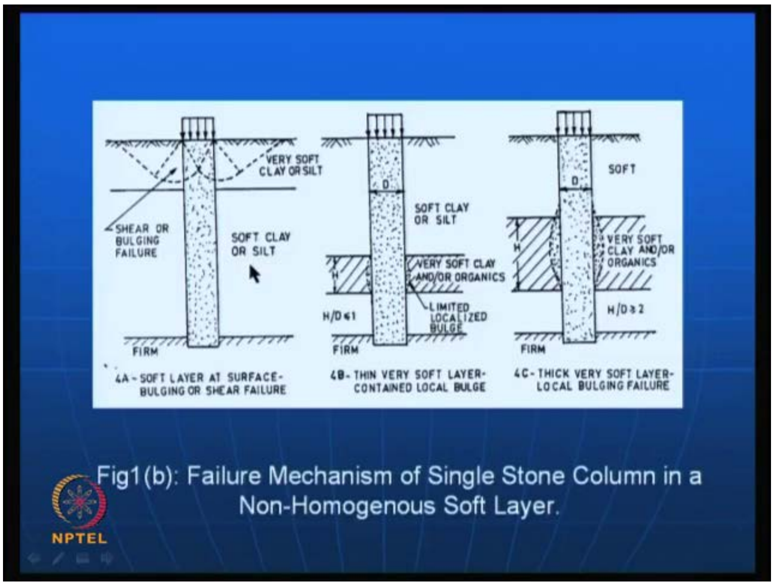

So, what it means is that you have a soft soil here and then reasonably better material the failure plane is only here it is not deeper. Again you have a soft soil here the failure plane is only here. So, this is what. So, one should know that where it can fail. So, that see the thing is why you are trying to do all these things is, in a soil investigation, it should be a proper soil investigation and try to identify where are the weaker areas, where are the stronger areas, because soil is not uniform. So, everywhere along you know the total area you must be able to find that exactly you know you may say for example, in this area if this happens the load carrying capacity will come down. So, possibly the some of these things, one should be careful say for example, this also another problem. So, one should see that the local bulging in some cases like this or possibilities and one should understand that it is one should avoid this.

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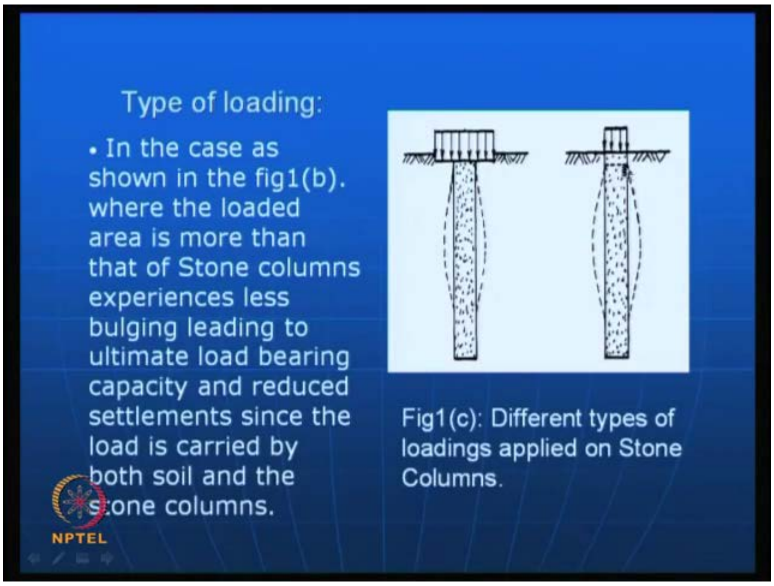

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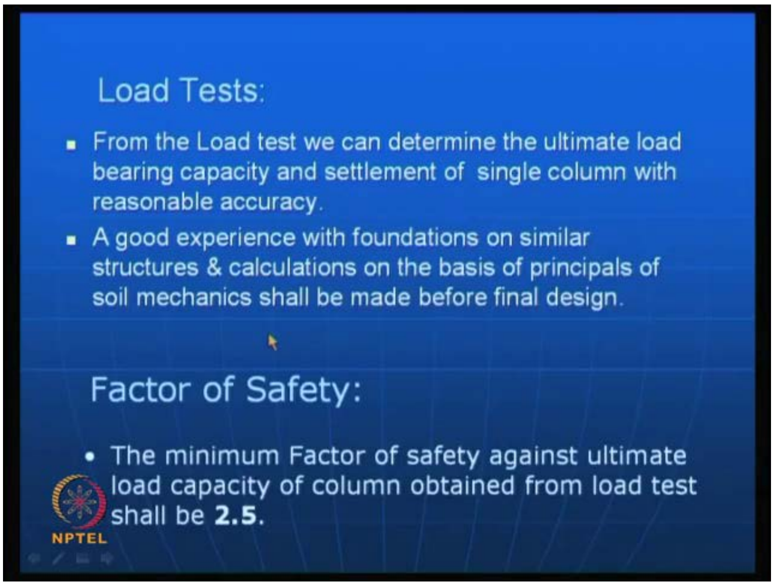

So, this is another type where we can expect, say depending on the loading say for example, you have a distributed load, you have a just a load working on a column itself. This one type of failure, it starts from here. So, little bit like there is a little bit of settlement and then it just starts like this. Here like this. So, there are number of issues that one needs to understand and what we should do is that, one should do load test. There is a one alternative that is a only way and maybe I will discuss that next class.