Ground Improvement
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Module No. # 04
Lecture No. # 11
Prefabricated drains (PVD s) - II

Today we will have views first of all, in the beginning itself on the use of prefabricated vertical drains and we will take up some example also.

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I will just show you this particular video in which you can see that this is actually prefabricated vertical drain. I was just mentioning in the last class, we have a sand drain in the olden days and we have now a PVD. Actually, the design is not very different, but the rate of construction of this is very fast like you know 10 meters it can go in a few minutes time.

You can see here that it is actually a real time operation; we can see that it is going very fast then it has reached the required depth of installations say may be 10 meters or something then it will be cut that is it. You can see lot of other drains here along this line say for example, this is an installation of drains line along which it is a yeah now its cut.

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This is another one which will give some idea like.

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You have an embankment here, you can see that they are very close. Like you know these are all say for example, this could be the heavy embankment of 5 to 10 meters and not about 5 meters you can say that and you can see it once again like a series of prefabricated vertical drains, installed actually in the field. This is that once it is done you have actually you can see a drainage layer; also here, then you have this embankment may be about 4 to 5 meters.

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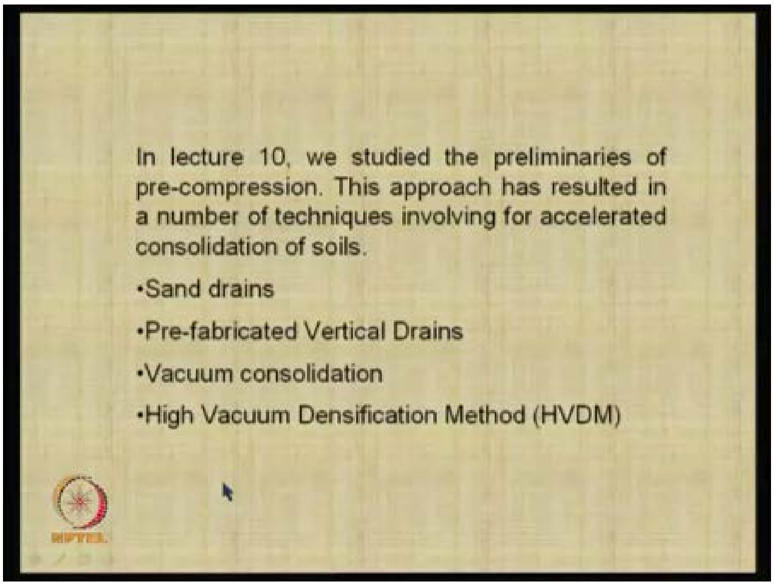

So, in the last lecture that was the lecture 10, we studied the preliminaries of pre-compression. This approach has resulted in a number of techniques involving accelerated consolidation of soils. People started with sand drains and actually the vertical consolidation as well as radial consolidation was taken advantage of. And subsequently, they went to prefabricated vertical drains because, as I just mentioned in the last class there are some problems associated with the installation of sand drains; number one the availability of material itself like sand.

The second thing is that, the way which can be done or the speed of construction could be much higher if you see the prefabricated have the prefabricated vertical drains. You saw it in the video that it can be very good and in many places wherever soft soils exists, we have this prefabricated vertical drains installed all over the places to take care of the loads that are imposed. Then, we will also see vacuum consolidation which is something again like you know we are suppose to construct 4 to 5 meters of embankment. But there is a possibility that if you need to construct that much of height it is, but the somewhat a preload can be reduced even using vacuum you will see its advantages of vacuum consolidation also.

There is another method which is called vacuum high vacuum densification method which has come just about for the past 2 years. Chinese have discovered that and then they find it its very effective compare to many of the other methods also.

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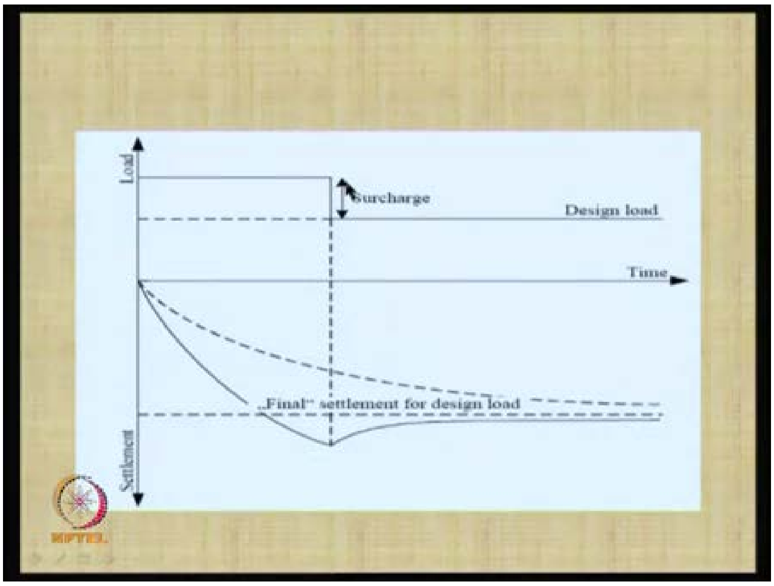

So, as I just mentioned the advantage of the preloading is that or preloading or any of this techniques is that we try to accelerate the process of consolidation into a very short times; say may be less than a year to see that the subsequent settlements are going to be minimal like this is the final settlement for the design load.

You see that to say to take to reach that settlement level this consolidation a regular manner takes very long time. May be, the time could be about years may be 4-5 years, but with this you are able to preamp the whole consolidation and then see that even if there is a release also it is alright. The settlement is less than I mean you are able to achieve that settlement in a shorter time that is an example what we want.

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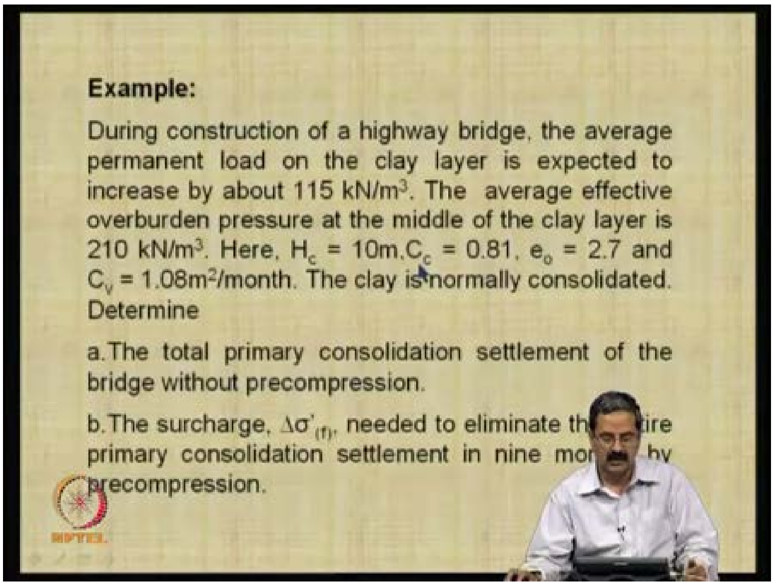

So, as I just mentioned I gave an example last week, last class where you had some sort of surcharge which is because of the pre load; in fact, this 115 no. You assume that there is a permanent load that can come because of the extra load that 115 kilo newton per meter cube. These numbers can be calculated using, you have numbers of theories or elastic solutions where you know the load of load whether it is a uniformly distributed load or point load or even a triangular load.

Triangular load represents the loading because of the embankment. The loads are there and one can calculate what is the extra stress that you get from the particular loading. So, at the some point say for example, you have 10 point 10 meters of the embankment you will be able to calculate stresses at every 1 meter level. What is the extra stress? Because of the embankment in construction of 5 meters it could be very high. But as you just go down, the additional stress that you can expect from the less or it could like that is what we say sometimes twice the breadth like you know, pressure bulb; all those concepts we know. And what we say is that essentially, we would like to see that this loading is taken care and then for in this case the depth. This is a simple illustrative example one should do very systematically and there are some programs available and all that.

So, the average effective overburden pressure the middle of the clay layer is 210 kilo newton per meters cube and then the thickness of the clay layer is 10 meters and the compression index is 0.81 initial void ratio is 2.7; and C v consolidation coefficient of vertical consolidation is 1.08 meter square per month.

We are trying to discuss in terms of months because you have to just convert what you get in laboratory. Value you get normally in seconds you make it to months because we are more comfortable with construction times. So, we will try to calculate what is the total primary consolidation settlement without pre-compression and how much is the surcharge you need to apply.

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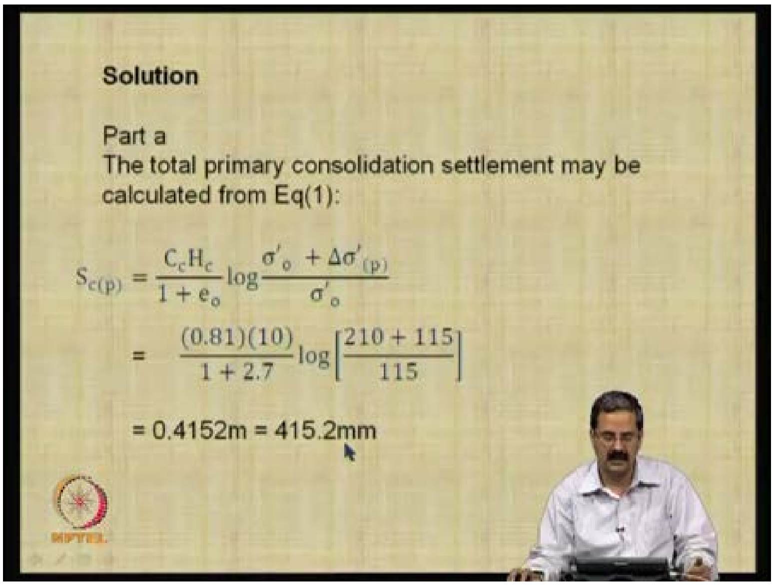

We have seen this in the last class and it is about 415 mm, is a consolidation settlement that you can expect and that with figures like this with the principle that we have studied last class. We can calculate that knowing the degree of consolidation at midplane potential and time factor and all that.

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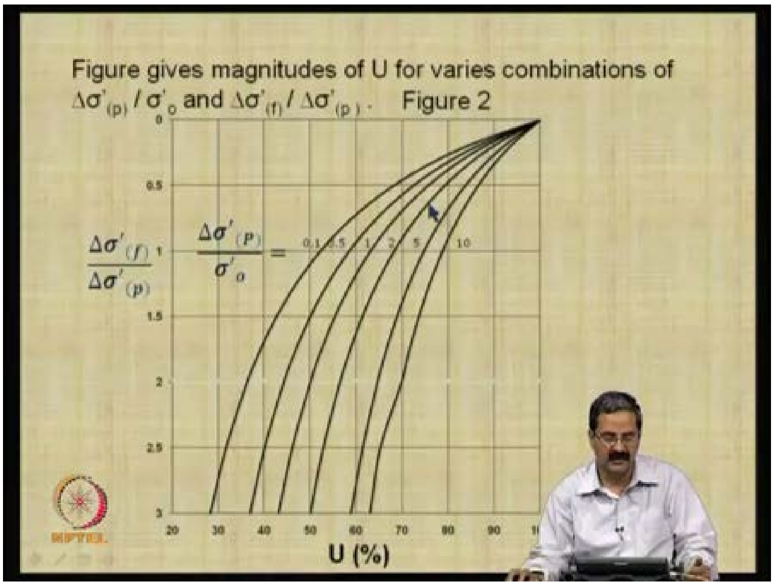

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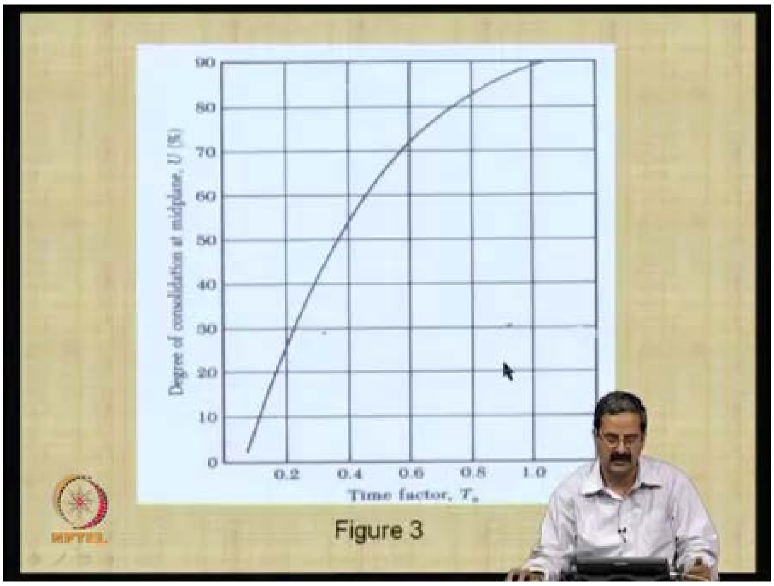

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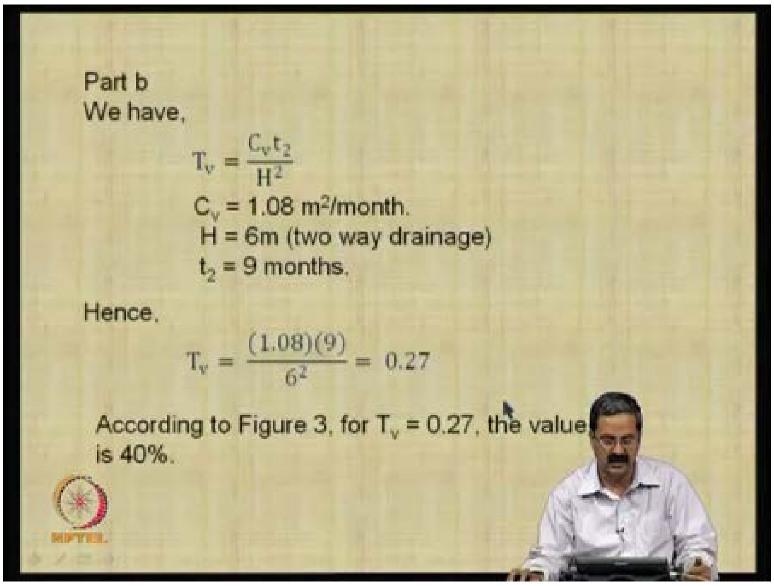

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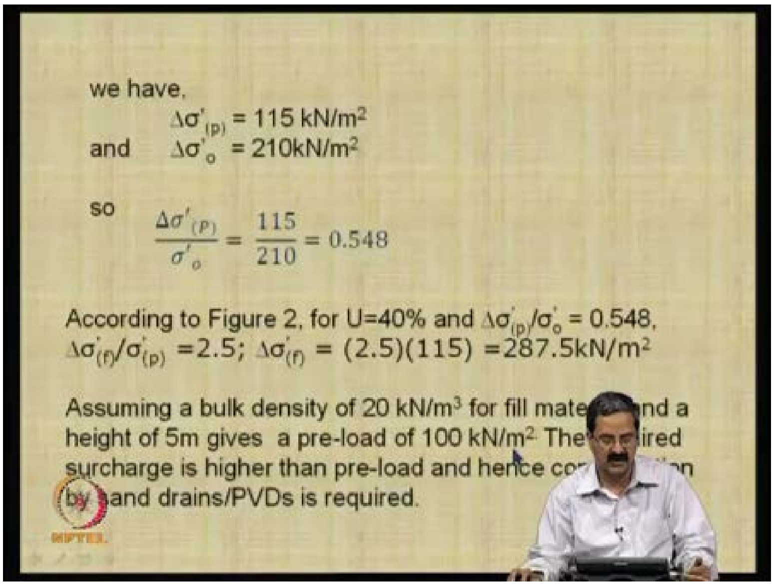

You can just calculate that the degree of consolidation is, you can get and say for example, the preload that you have to apply you know. In fact, we assume some level of 6 months or 9 months time; like as I just demonstrated last class, that within 9 months you must be able to complete this consolidation. So, how do you,… how much of load I have to apply, that one can calculate and this is you can see in this example that is a 287 kilo newton per meter square which is a big number.

And how do you do that? As I just showed you couple of slides last time where you can put sand bags or any of the material and you can this say for example, you assume a bulk density of 20 kilo newton per meter cube and 5 meter high. If you just tag everything it gives a preload of about 100 kilo newton per meter cube and the required surcharge is very high.

So, what we do is that you better try to reduce this required number and you may have only this. Sometimes, may be 10 to 20 meters it is very difficult. So, your objective is to reduce this preload and that is best achieved by using the sand drains or PVD s we will see.

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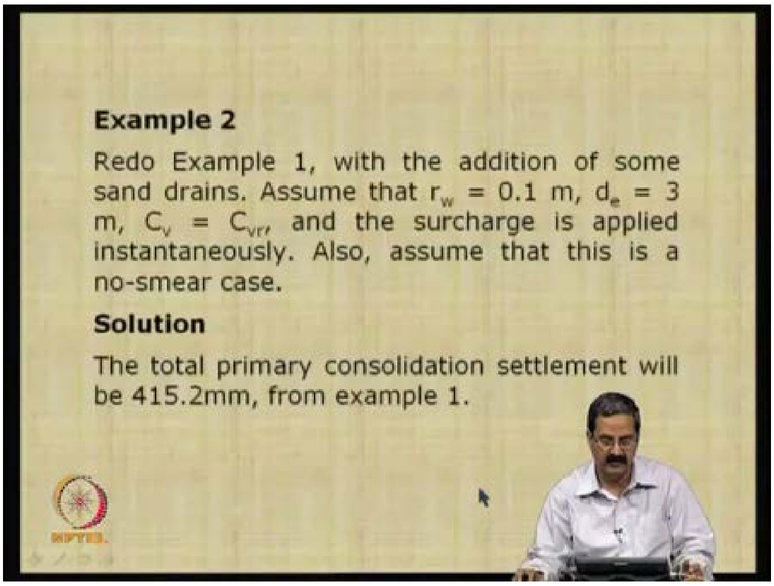

Say for example, I assume I try to deduce the example with sand drains assume that the radius of the sand drain is about 0.1 meters or 10 centimeters diameter; radius or 20 centimeters diameter. And the effective diameter as I just mentioned last time that there is some area of influence around which it acts as a drainage layer. So, you have a sand drain and there is some area around which it can be very effectively considered as a drainage layer.

Now, instead of, like you know early it was essentially a clay, but because of this it tries to draw all the water particles towards a drain and then there is a lot of pore pressure both at the top and bottom if it is a drainage or double drainage conditions and there is a dissipation of pore pressure. So, this d is about 3 meters is an example we assume that vertical consolidation is equal to radial consolidation also this is another assumption we are making and as I just mentioned it could be actually horizontal permeability could be much higher than the vertical permeability because of the layering and all that.

So, and then we I also mentioned that the because of the use of the sand drains or whatever there is a zone next to the sand and the clay where the permeability is low and the layer is not very effective that problem is there is a…So, that we say that it is a smear zone and in this case for this illustration we assume that there is no smear. In fact, the PVD s have the advantage that there is a very less smear compared to sand drains

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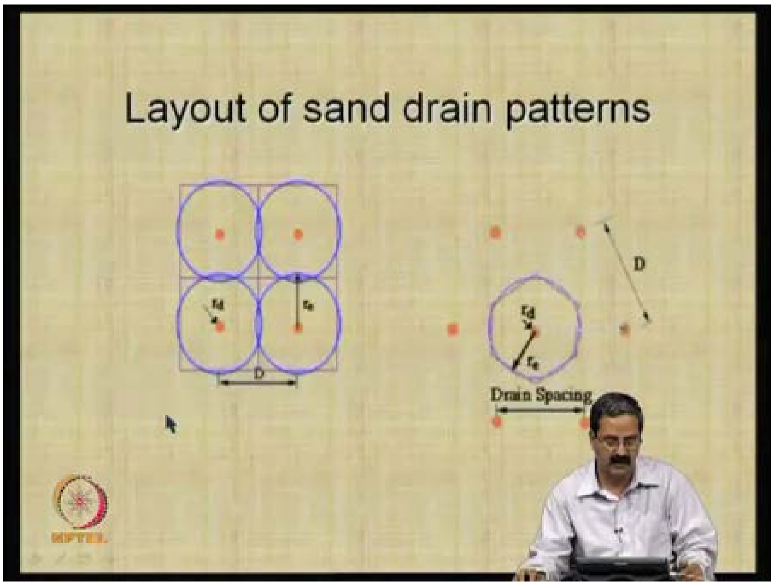

So, we saw that the same example the settlement is about 415 mm and this is a typical patterns that we have seen in the video also it could be triangular it could be square.

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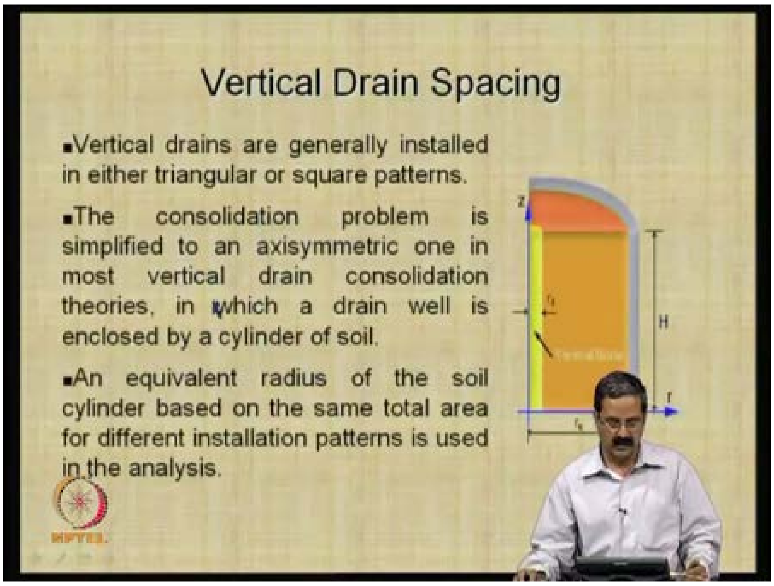

As I just mentioned, there is some radius over which it can be very effective as a drain. And we call it is an axisymmetric problem.

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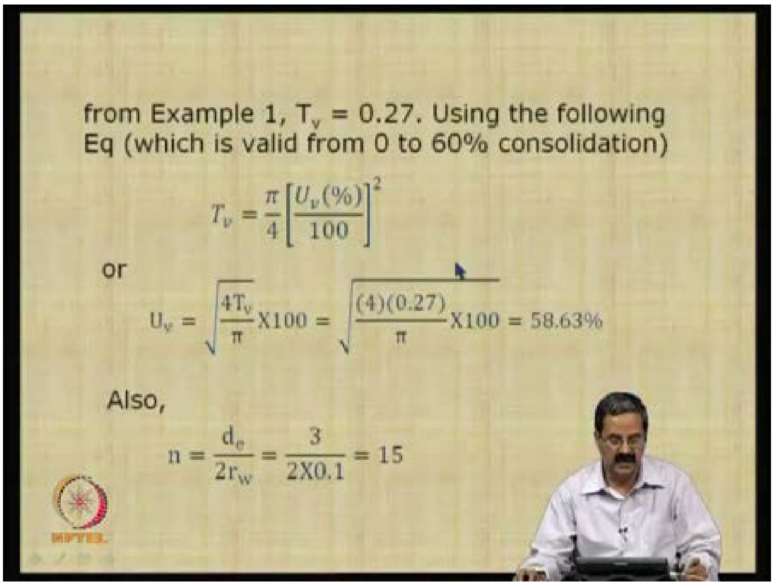

We have this for the same calculation will just see that you know you have this expression from the basic consolidation theory, right. So, like we are trying to calculate U v the point this T v is already obtained earlier and what you are trying do is that, we are trying to calculate the number of sand drains here ok. So, d e I assumed as 3 meters and then the radius of the sand drain is about 0.1 and it you will get a number 15 ok. So, once you get this 15 and this is at actually vertical consolidation number by knowing its time period.

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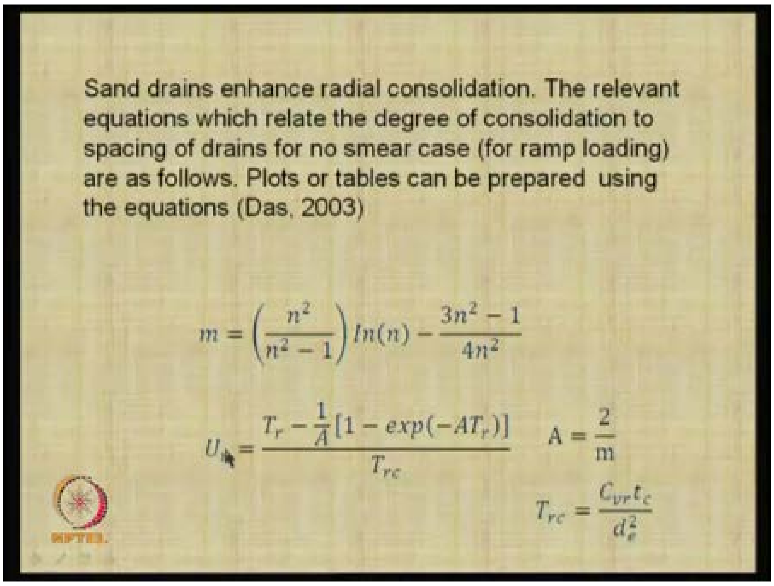

So, there is some as I just mentioned, sand drains enhance radial consolidation. So, we have some equations .As I just mentioned and the relevant equations which relate the degree of consolidation to spacing up drains for no smear case are as follows. Actually, there are 2 types of loading: one is called ramp loading the other one is instantaneous loading in the sense loading can be applied suddenly and then, but ramp loading like you know you sequential slowly construct one by one you know just its like a ramp like may be 10 K p a 10 to 15 K p a 20 K p a 40 K p a 50 K p a 60 K p a. So, that is a load that we can have.

So, one can really that is a case and you have some lot of people have worked on this particular problem in on consolidation theory. In fact, in 1930s 1940s there is all these equations have been derived long back were derived and they are quite useful. And they have an expression called m and m is actually it gives the spacing of its related to the spacing of sand drains and even it can be even sand (( )) also like you know PVD s ok.

So, this is a radial consolidation; you know that degree of radial consolidation. You can see that this particular thing involves 2 terms A the term A which is nothing, but its related to m. m again is related to n and then you have T r which is nothing, but the time period you know time factor for radial consolidation. So, you have again the time factor for radial consolidation. So, you have this numbers t c is the construction time and d is effective diameter this is simple example here.

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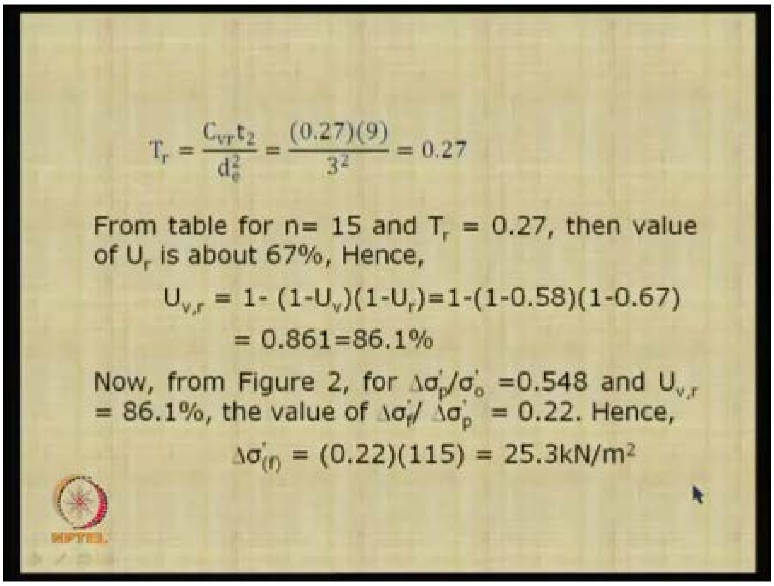

So, the T r is nothing, but C v r t 2 by d square and as I just mentioned we would like to see the consolidation within 9 months time, right? 9 months time that is, what the objective is and d e is d is 3 meter square radial right, its radial; so, 0.27. Actually, one can develop tables or equations. So, people have a tendency; in the olden days what people were trying to,… you have say you may have simple software then you can feed in all the numbers and you will get actually the objective is you get this ah degree of consolidation because of vertical consolidation as well as radial consolidation this is actually objective ok.

So, when this is objective, one can use now readymade software, but in the olden days people had tables like if I n equal to 10, 15, 20, 30. What should be the values of T r? You know they were if you just go back to the previous slide, we have a this U r and all that. So, essentially from this sort of expressions one can get the U r and once you get the U r and also the U v which we already got.

So, for example, this is 67 percent and 58 percent is what we already achieved. So, essentially 86 percent. Now, what is a preload that you have to get for this? Again, now we have to go to that figures that we considered earlier and for this effective stress increase and also the degree of consolidation you will get a factor 0.22.

Actually, in the previous case it was much higher; it is only the preload. Now, you can see that actually 115 is a load that the additional stress. So, you will get about 25 K p a; it is much less. You know, you got about 287 K p a roughly; if, remember 287 is a number required, but because of this, you know because the sand drains of this particular size and diameter it got reduced to 25.3 kilo newton per meter square which is a big difference like you know you do not need to go for higher preload. You may just have some sort of say for example, this could be you know, if bulk density has 20 right. So, it could be hardly you know may be 1 and half meters or something; 1 meter or something like that you know, is it not?

So, what I meant was that this is something that one can take advantage of it and the concepts are you know. One more, another important time,g another important point that we have to calculate here is that you should be able to calculate degrees of consolidation at different times after installation.

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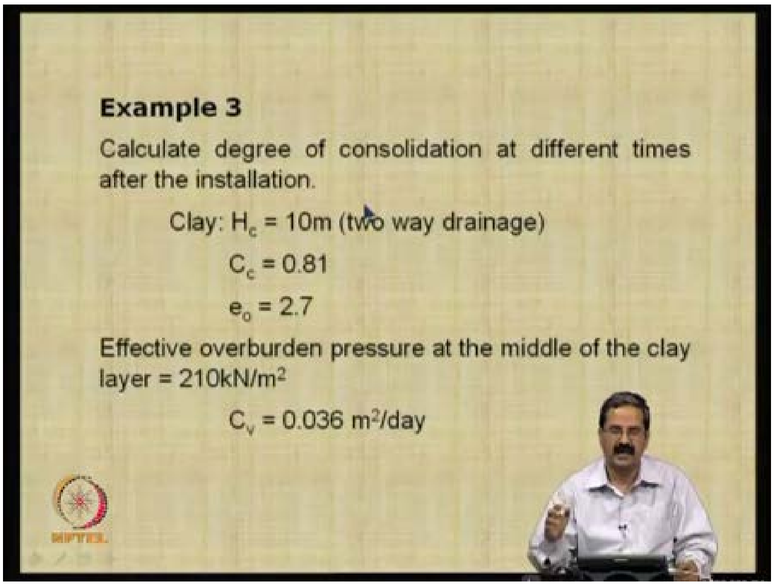

Because we are claiming that or we are, we know that this consolidation you know like it can be very low and then we would like to increase the consolidation using the sand drains or prefabricated vertical drains.

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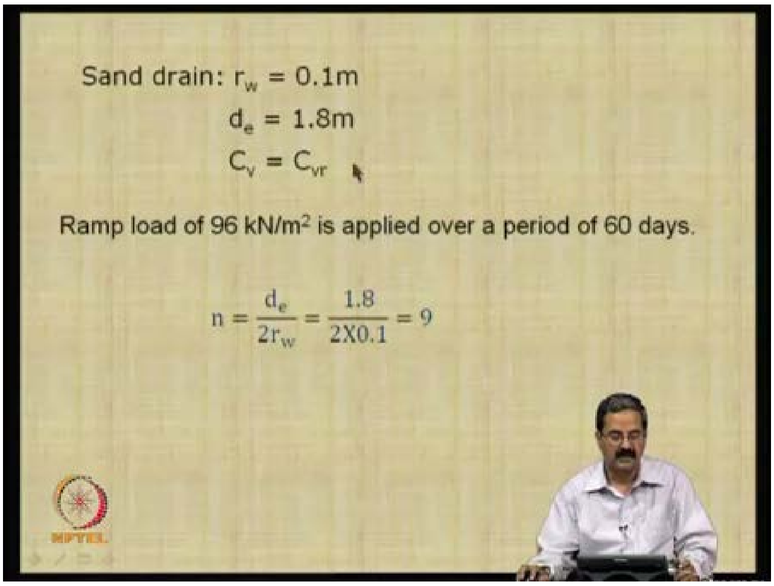

For the same example I will just say little not… the same, but similar typical example I will just give you that the radius is about 0.1 d e is effective diameter is 1.8. You can see that its little different and I i take C v equal to C v r and a ramp load of 96 kilo newton per meter square is applied over a period of 60 days like you know I slowly apply the load. So, that you know actually what happens you know you in a soft soil area you should not allow the things to happen collapse should not occur. Like you know if you if you suddenly apply the load the there is a sheer failure and then you cannot use the area it is something very bad like totally collapses.

So, it will not take any load. So, that is not a requirement here that is a dangerous situation. In fact, So, what we do is that we apply a ramp load slowly we call it ramp load and then we apply a ramp load of 96 kilo newton meter square per over a period of 60 days. So, in this case we go through the same examples I will show you n equal to d e by r w.

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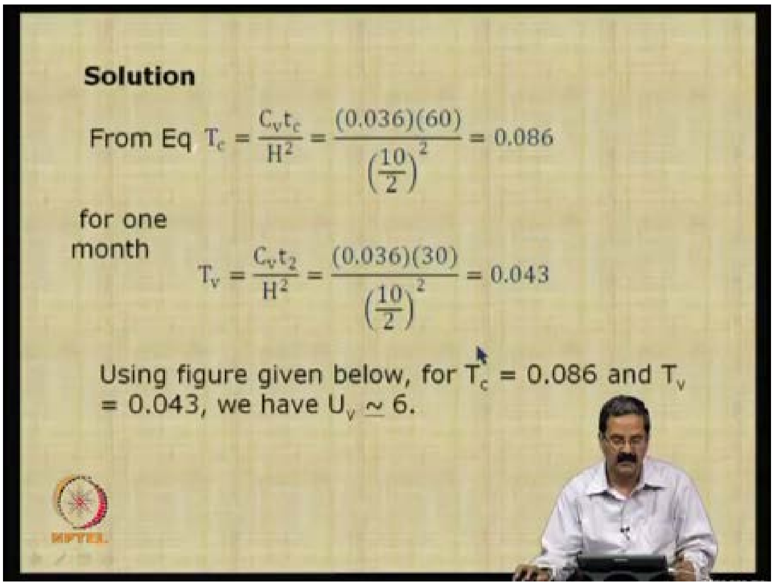

So, this is again number is 9 and see actually there is we calculate here what is the time factor for you know 60 days we have applied and then you know the double drainage and these all coefficients T c is 0.086. You know this factor which is corresponding to full load which is ramp load is you know at the top of the ramp load like you know once you complete that loading it is about 60 as I just mentioned. So, for one see the thing is it is for 60 days its fine, but you must to be able to calculate every month.

Our objective is what is the degree of consolidation? 1 month, 2 months, 3 months, 6 months, like that. So, T v equal to C v two t 2 by H square like C v this is 30 days - 30 we will keep it here and so, you get some factor here .So, for T c is known and also T v is known.

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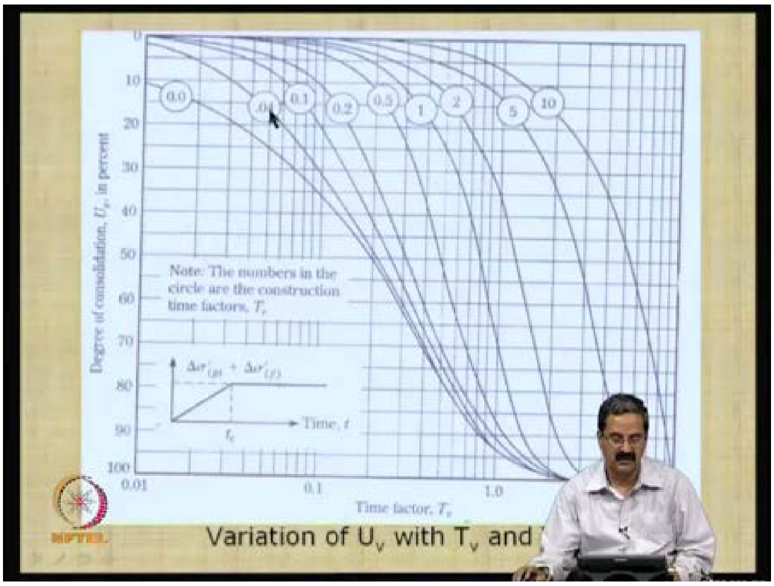

So, and then like I will show you this figure. This is what I was just mentioning that the ramp loading actually like excess pressure that we have applied on the soil ok. So, now this is called the degree of consolidation and then this is the time factor. So, the numbers in the circles are the construction time factors like as I just mentioned we have time construction like in the previous example previous slide; these are the two factors.

Then we are looking at what is the degree of consolidation. It is about 6; it is about somewhere here like you know if you look at those numbers it is quite low. It will be somewhere here because 1 month only you are looking at only 1 month not long time. So, one can really calculate based on you know different time intervals.

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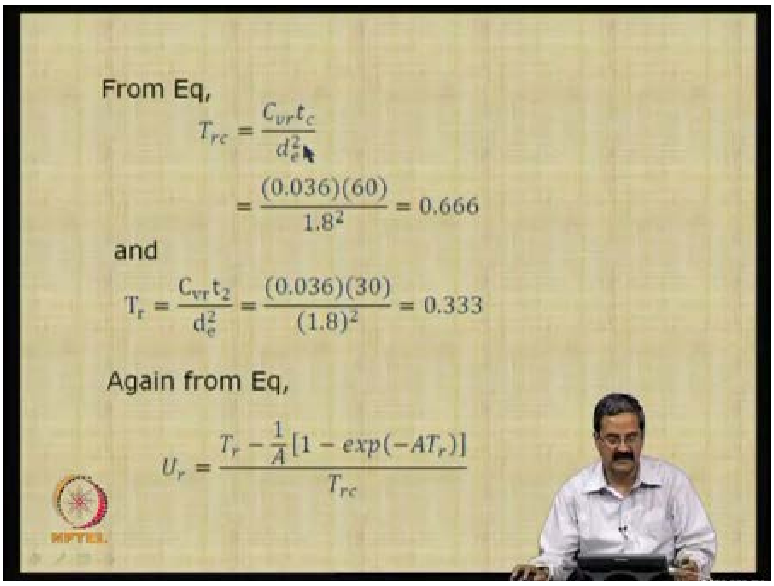

Once you know that I will show you some more information and from again this is another expression that we have for 60 days one can get and again from this degree of one can use the equation as well.

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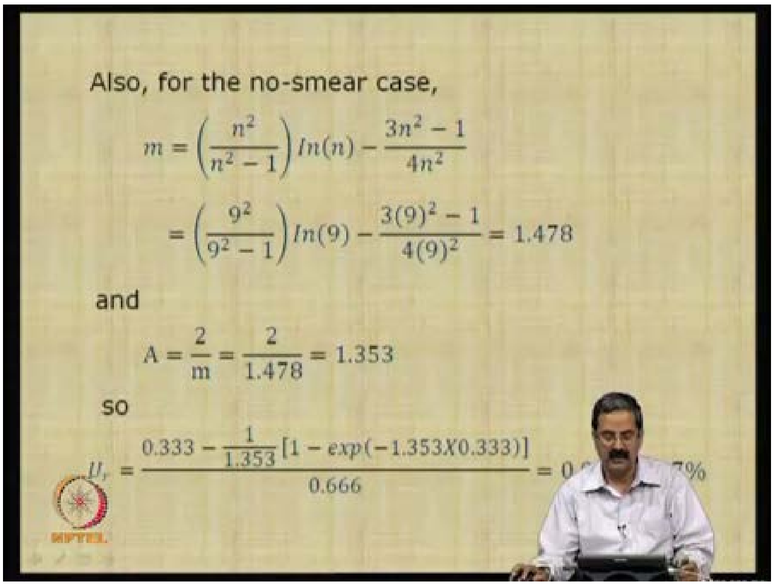

So, you will get all this terms and then for no smear case you will again I have this lot of expressions area is given and for next day it will be 9 9.7 percent of 6 percent ok.

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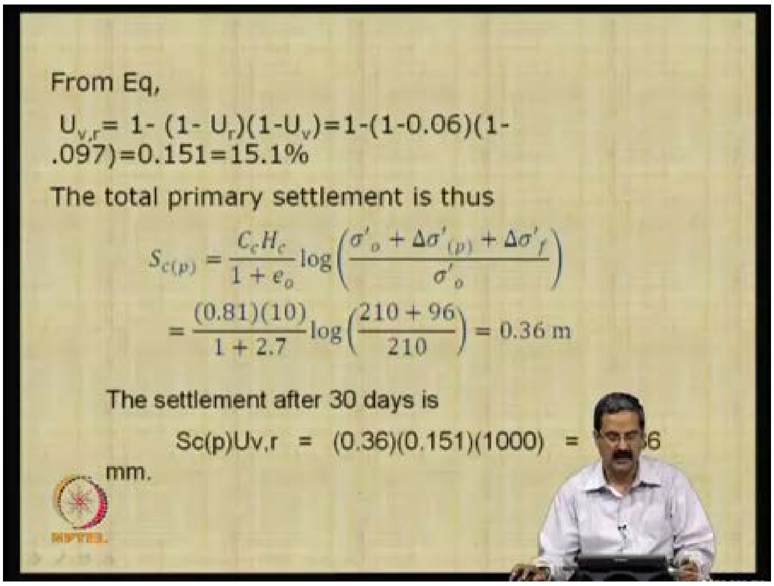

Like that it could be like you know one can increase and then one can again use this equation. And then finally, it becomes 15.1 and the settlement that you have after this you know this time is about say for example, in this same you can use the same expression and then you will get about 0. You know 54 mm. So, like that you know one can calculate some of these numbers in a comfortable manner every month and then you know just see that.

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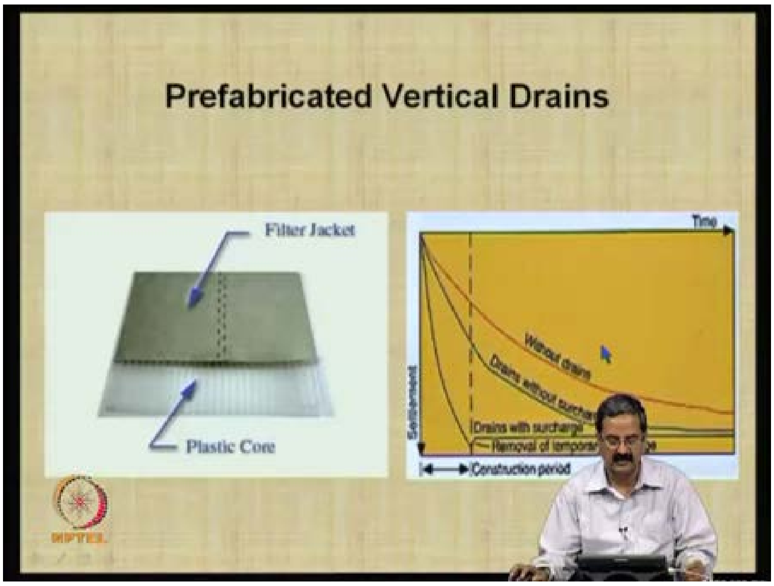

So, this is how like this is what we want to have with time versus settlement is what we would like to have with the PVD now.

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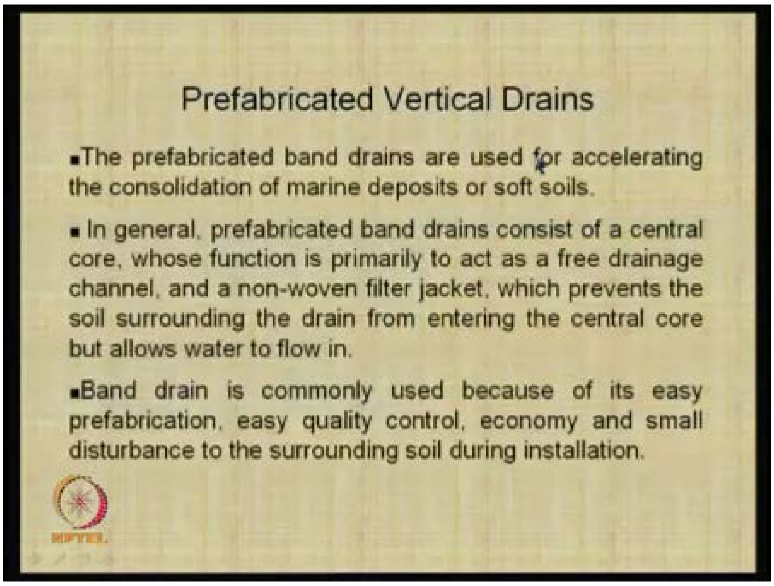

And as I just mentioned, PVD s are much more comfortable to use because of ease of fabrication quality control economy and sample disturbance to soil is very less during installation.

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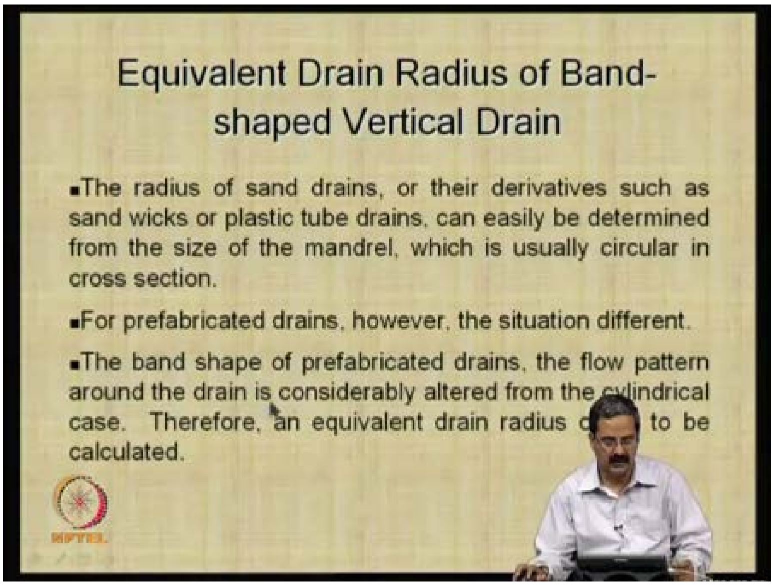

This another important point that one should realize and like the difference is that we had an equivalent diameter there and now since the shape of the sand drain is something you know more of a rectangle the flow pattern around the drain is considerably altered from the cylindrical case.

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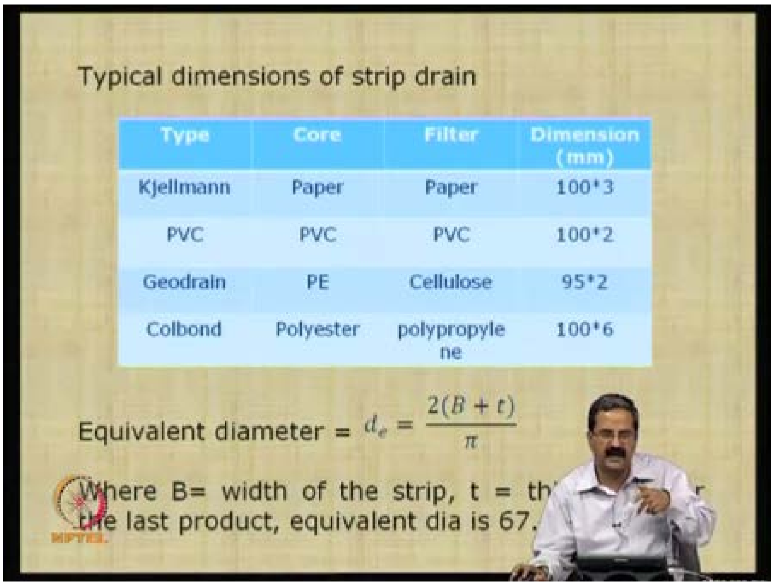

So, you have to calculate the equivalent radius. So, as I just mentioned these are some examples of the PVD s. So, you can calculate the effective diameter like you know like with the 2 into this sort of expression and also then once you know this d e you can also calculate the effective drain you know influence area there is another expression depending on the pattern ok.

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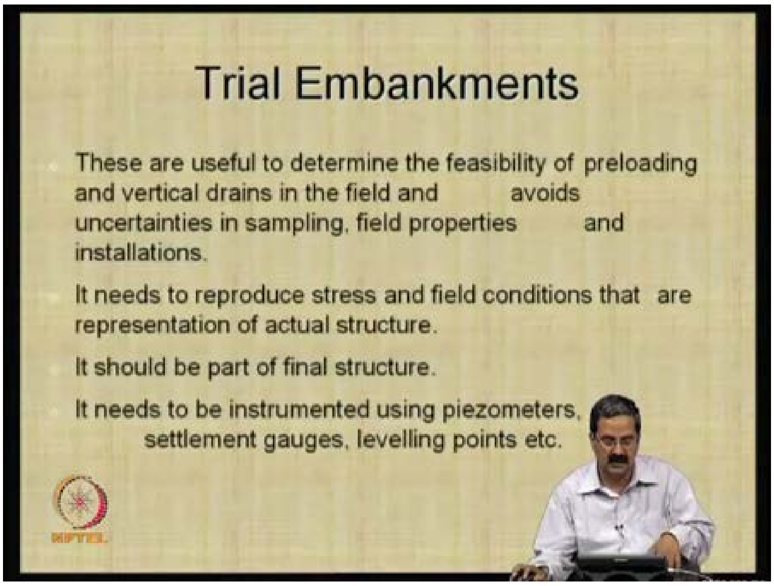

So, once you have those patterns you can go ahead with the design and then complete the process the design is similar, but the advantage is that they are much more scientific. So, the trail embankments are something that are quite useful as I just mentioned and they are quite there are some of the like normally, people do this because it helps in avoiding the sample disturbances and uncertainties in the sampling and field properties this we have discussed.

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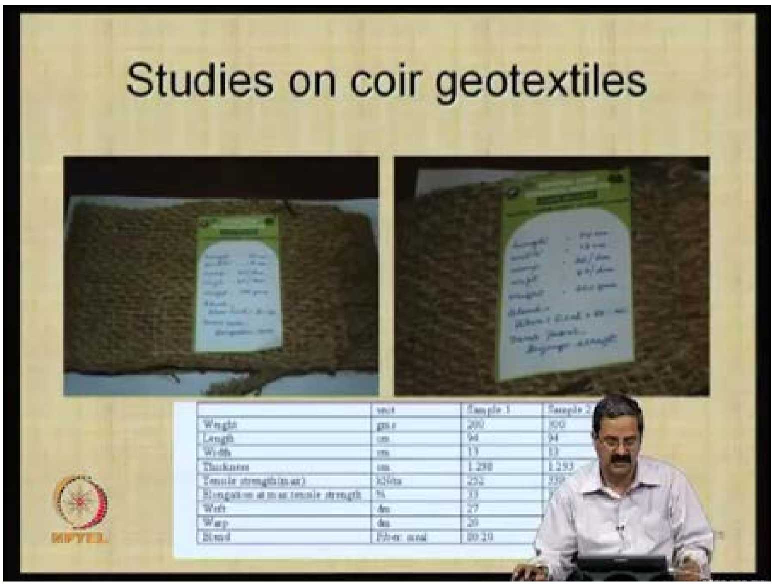

I will just show you some small example what we studied as I just mentioned when the consolidation times of just about 9 months to 1 year one can use coir drains. You know I just showed you couple of drains in the last class where you have number of drains one made of jute 1 coir and all that. So, this in association with coir board of government of India. I just took some material where you have a drainage as well as filter done and these are all the properties that actually these are also given here. What is its tensile strength? What is its,… it is a fiber plus (( )) material coir fiber and the thickness; what is the thickness? What is the tensile property like 338? Whatever is given everything is given.

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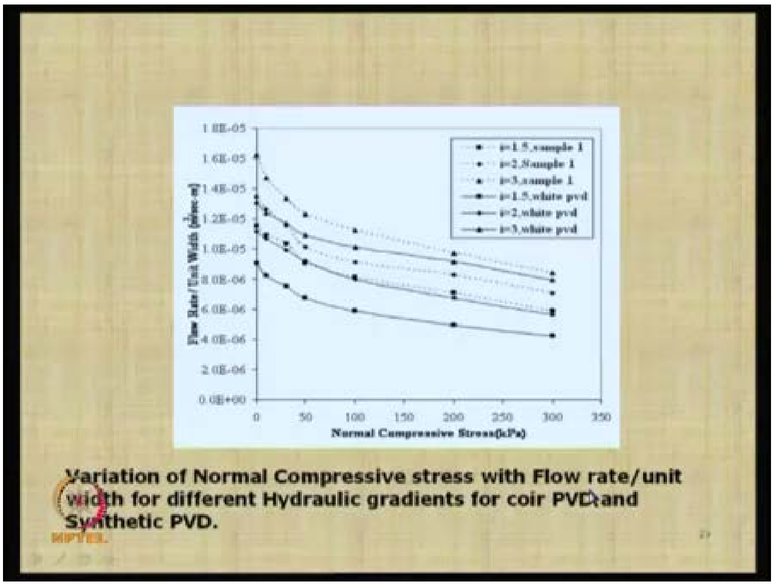

So, I was trying to compare their flow properties with a conventional PVD s that I showed you yesterday. Like you know white color one and you can see that the flow rate per unit width we try to measure and normally and then these are all somewhat compressive materials. Like you know, if we just apply some load there is a compression that occurs and higher is the compression lower is the flow. So, one can see that one can get it and this can be for different hydraulic gradients one can get I equal to 1.5 for the same sample one I just showed sample one.

So, you have relationships like this and you have these two are: sample one is for the coir. Actually, they are all for the coir and then these are all for the white PVD.

There are 3 types I mean PVD s I showed you. So, you can see that you know the whatever you know the thing is the sample PVD s you know for example, these are all dotted lines this 1 2 3 they are dotted lines a little higher in fact. The permeability or the flow properties are here for different compressive stresses you know compressive stress in the field you know what is happening you know there is a that is called compressive stress right. You know there is some, you put a drain, but there is still, there is some load acting on it which we say like you know K 0 times sigma v are whatever.

So, you are trying to look at those things also because you know you want full flow properties established. So, at full depth also there should be a flow like it there should be. So, we try to verify you can see that. In fact, coir drains are really doing well ok.

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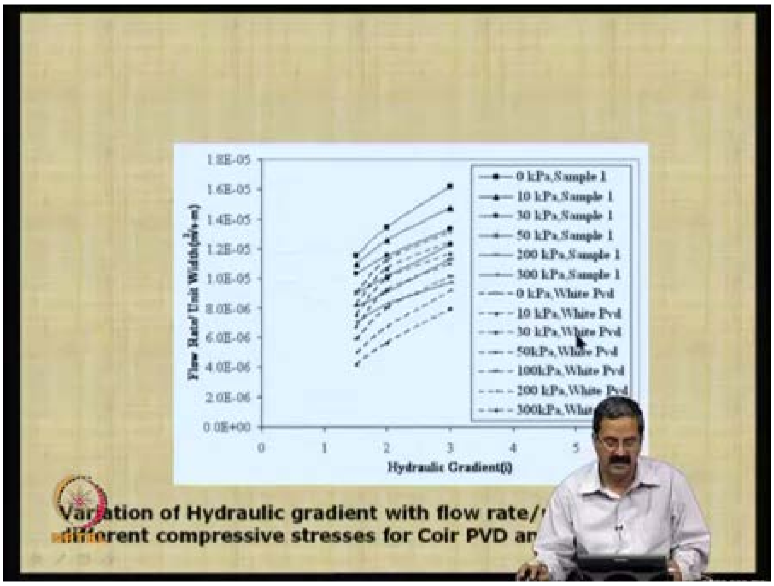

So, this is. In fact, one important point one should know and this is another example that same thing like different hydraulic gradients, how are they performing. Like you can see that all the samples are at little higher than what it is, but whatever you know they have comparable properties. That is one important thing is that when you see the variation of hydraulic gradient with flow rate per unit width, like unit width you should take for different compressive stresses for coir PVD and synthetic PVD.

You can see that the things are quite reasonable, is it not? So, the advantage would be that one can use you know where these materials are abundantly available people should encourage some of the efforts. Of course, all, both have their own advantages.

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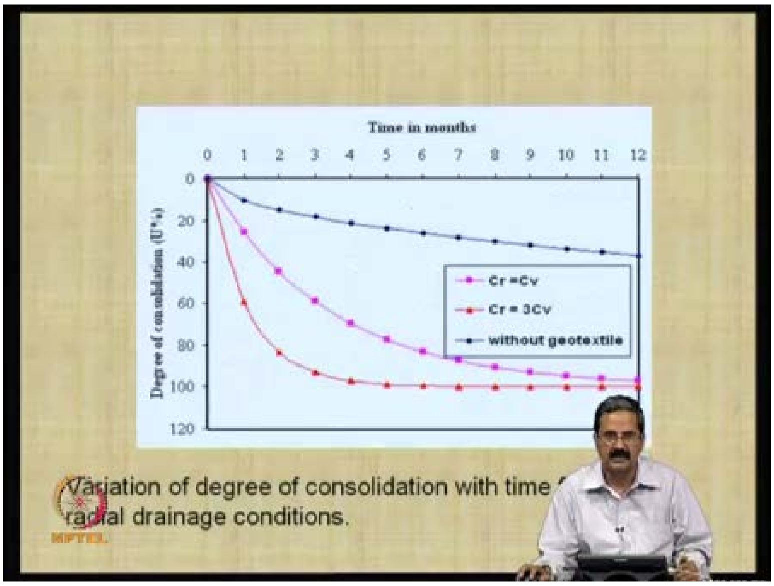

You can see that example that I was just mentioning for a typical embankment that was constructed; I mean, that we can take a typical example of 5 meters and all that. You can see, you know for a period of 1 month without coir geotextile or coir drain you can see that this is about 27 percent after 1 year. Now, as I just mentioned radial consolidation equal to vertical consolidation and if I just see that this is the line, but whereas, as I just mentioned the vertical consolidation will be slightly smaller. So, you put that I mean radial. So, you see radial consolidation is higher than the vertical consolidation; normally 2 to 3 times one can measure you know in the field.

So, you can see that 100 percent is achieved within may be 4 5 months which is a very nice result. Actually, with some of the actually coir properties or they are applicable to both materials, it is very interesting observation that yes some of these materials could be used and we can get what you want; this is an important observation.

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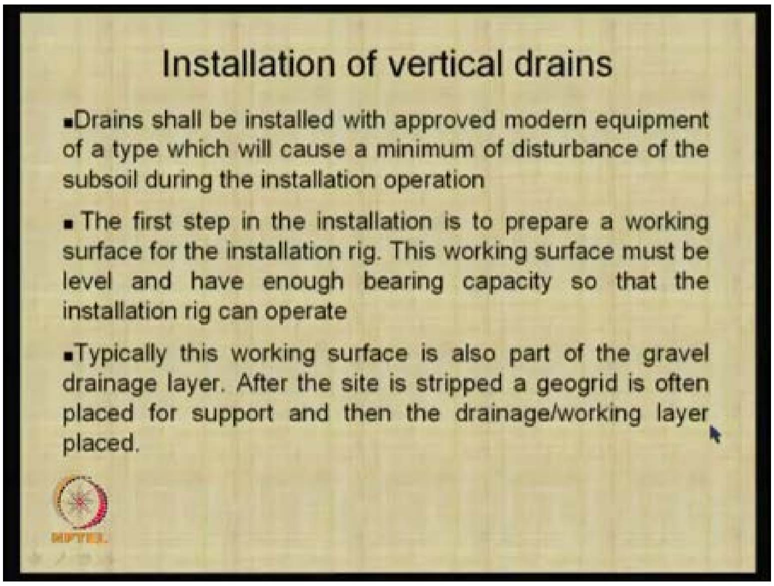

So, as I just mentioned we will see how it can be installed like of course, you saw the video and we should have a very good modern equipment. In fact, you know, say for example, some company is there you know, they must have good approved equipment which causes a minimum disturbance of the subsoil during installation operation. Because disturbance leads to increase reduction permeability that is again an issue and the first step in an installation is to prepare a working surface for the installation rig like you are bringing a big rig there and working surface must be level and have enough bearing capacity so that the installation rig can operate.

In fact, you may not believe there are cases where the installation rig can sink in if the soil is so poor. Definitely you cannot bring in .So, you may have to create a temporary platform for it. I will just show you some more diagrams on this. you may have to create a working platform for the crane to stand and then you know execute the work with some sort of arrangement. So, typically this working surface is also a part of the gravel drainage layer as you just saw the drainage layer is at the top and if this working surface can be a part of the drainage layer its nice because it’s comfortable. After this site is stripped a geogrid is often placed for to support and then drainage and working layer is placed.

Actually, sometimes it is always you know you saw that coir drains were standing and all that and you try to put, cover the sand and then put a geotextile layer; you know, which can work as a drainage layer because sometimes the you know sand is of course, a good drainage layer. But sometimes they say geogrid could be placed. In fact, it can even take care of the uneven settlements say for example, you are trying to put some crane is coming later some sort of all these rigs are coming.

So, if you want to that bearing capacity, if it has to increased you can really calculate what is the bearing capacity that you need and you can provide a geogrid, ok. So, some sort of goegrid one can place to see that there is no problem with this case, ok. Now, So, you have some of the equipment like you know mandrel.

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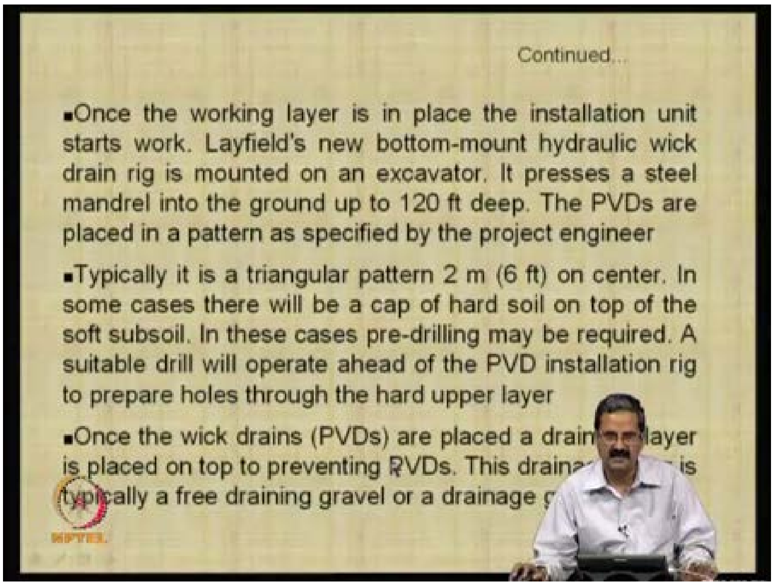

We have seen that it can go up to long depths and it can be a triangular pattern and see there are different types of drilling. Actually, like we will just see that and a suitable drill will operate ahead of the PVD installation to prepare holes through the hard upper layers. Once the wick drains are placed above the drainage layer you know a drainage layer is placed on top to prevent, you know in preventing like you know you need to connect all of them and the drainage layer is typically a free draining layer or a drainage geocentric material.

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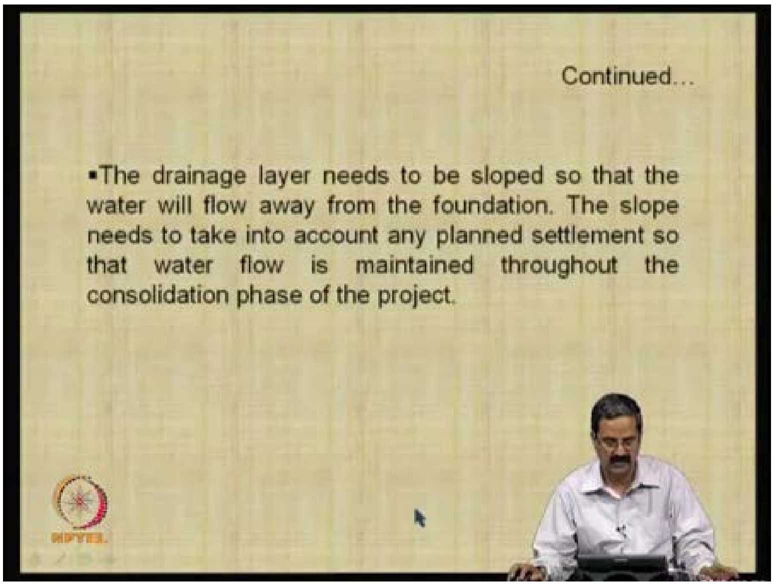

The drainage layer needs to be so sloped that the water will flow away from the foundation area like that is very important the slope needs to take into account any planned settlement. So, that the water flow is maintained throughout the consolidation phase of the project.

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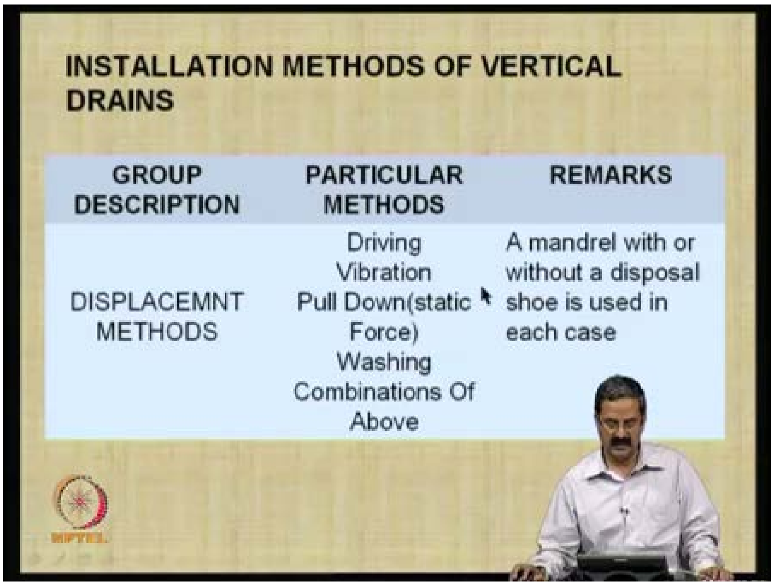

So, how do we install it? there are some typical methods like it can be, you know displacement methods; like it can displace the soil of course, the soil is so soft it can be displaced nicely and particular methods you have vibration; driving vibrations and pull down using a static force, right; washing like you know. So, combinations of above the different types you can drive you know you can use vibration. There are a couple of issues: a mandrel with a, with or without a disposal shoe is used in each case like you know I saw in one of the show you in any of the real photos, where you have a simple shoe and then it gets, it reaches the required depth and see the thing is that it will be like this once you want to remove it, opens up like that. So, it stays there.

So, that is very interesting thing that you put it and when you try to, then it opens up; it forms a shoe just a bottom head wherever is the required depth and then once you know that then you try to pull it back it will not come right because, it is, there is, some force that is preventing it. So, once you realize that you cut it, cut it and then you are operating everything through the computer that you know for example, as I just showed you they are all highly sophisticated ways of handling things and people take them to the required depth and then cut it right up to the appropriate margin. So, that it is not too out of the drainage layer also like it should not project too much out of the drainage layer, right.

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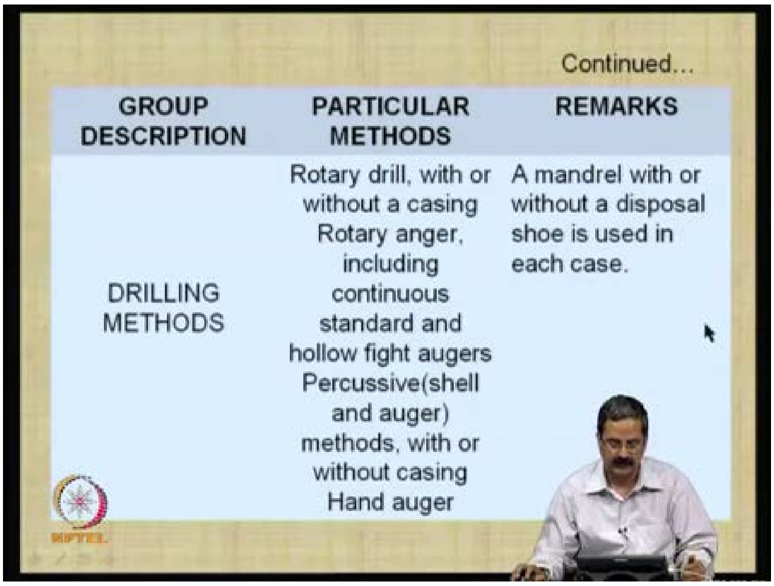

So, one can use drilling methods of course, depends on the type soil and then standard all could be used, ok?

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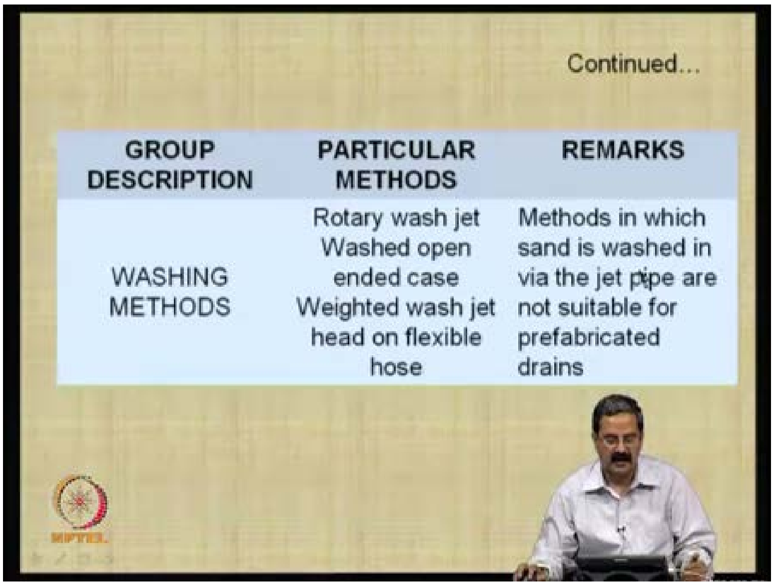

These are all many methods one can have and washing methods one can have these are all you know they are there. You know similar to stone columns and all these methods this types of methods are there in the field, but we should realize and check what type of methods are suitable.

Of course, the contractor normally, he knows exactly what should be used and he has his own way of handling and the project cost sometimes depends on that. Even the cost of the I mean, whole project as well as the efficiency of installation everything depends on the methods that we are using; that is very important. Like, in fact, see the installation from a barge you can see that the mandrels are you know being from here you know the soil is. So, soft in some places like you know you may have to them on a barge like it is possible.

So, one should be very careful and this is one another typical example like you are trying to use PVD s for your constructing some slope here extra slope here. So, this is actually what happened you know one should have see what happens water comes here then that should not create a shear failure here. So, all the water should go through this prefabricated vertical drain; that is how these drains are installed here.

This application here this is not a consolidation type, but the application here is that yeah, PVD s in fact, have been used behind the retaining walls also to increase the rate of drainage. Here is another typical example where you know you try to have 2 slopes, but with 2 slopes the possibility is if the rain comes this material is good and this material is good, but at the interface there is a possibility of weaker layer formation and the water should not enter and then finally, the new soil that you have placed should not come out. So, what we do is that we try to design properly and see that all this you know it is taken care of by proper drainage arrangement.

Like at the bottom at the top all the water should go into this things and then at the bottom you should have a collecting mechanism right, like similar to. In fact, there is a in Vijayawada there is an RE wall which is constructed about 30 meters high. It was like this of course, they had they did not have PVD s, but they had drainage material of made of aggregates ok.

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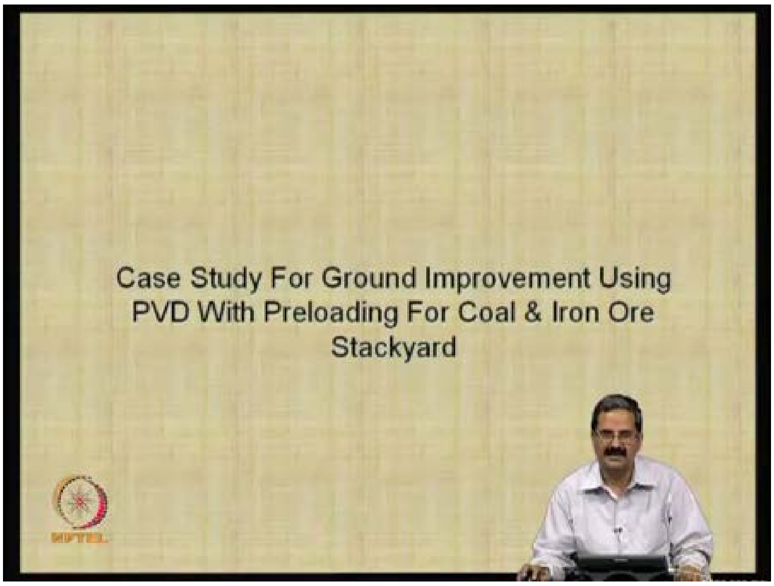

This another one that one can have the top one can connect and all that. So, I just want to give a small example this ah I have taken from one of the suppliers (( )) installers of the geo centric products. Um this is a case study for improving the bearing capacity or using a PVD for one coal and iron ore stack yard.

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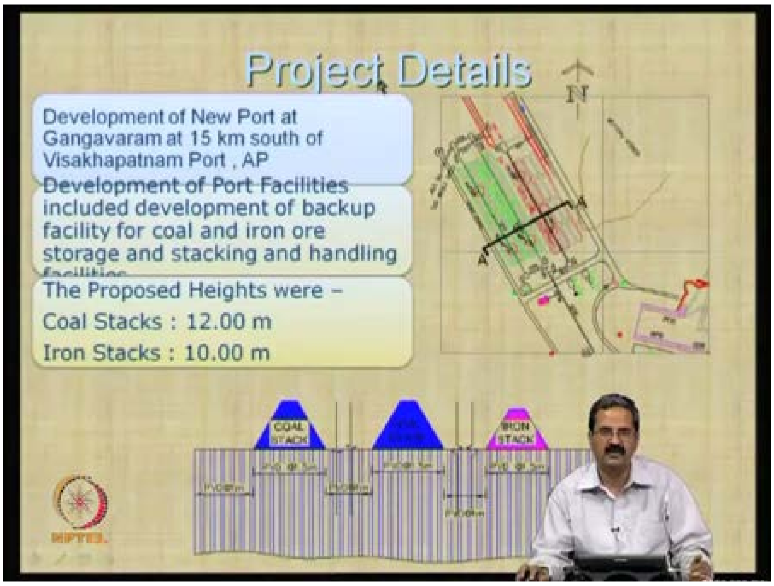

Actually, this is from one I do not know you must be familiar with some of these projects like it is a place in new port in Gangavaram a 15 kilo meters south of the Vishakapatnam and the objective is that they are trying to have coal stacks of coal stack about 12 meters high. Iron stacks of 10 meters and something like that see you can see that coal stack coal stack and iron stack. So, the objective is that soil is. So, poor here that yeah it needs accelerated consolidation and this is the plan of the whole area and like.

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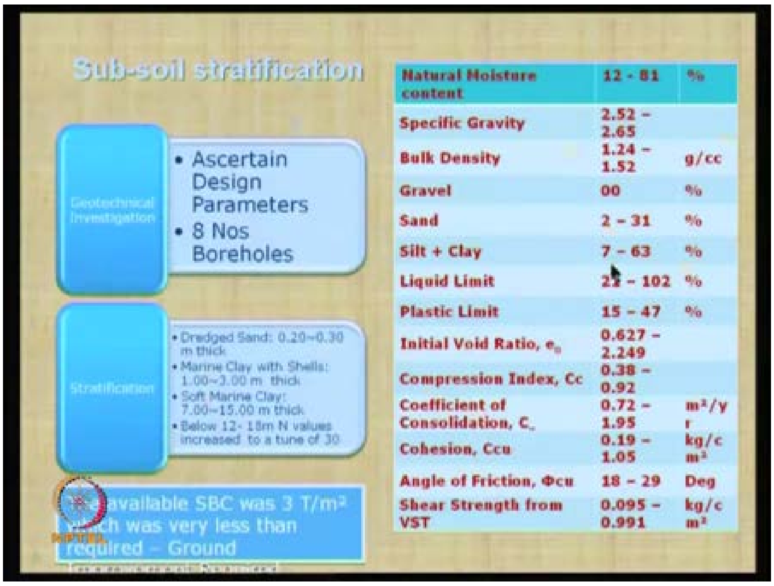

So, I mean the way they did was that they had design parameters to ascertain that you have 8 number of bore holes were made and you can see stratification. In fact, a dredged sand which exists above top layers marine clay 1 to 3 meters soft soil 7 to 15 meters below again n value I think reasonably ok. So, the available bearing capacity was about 3 ton per meter square which was less than the required value required ok.

So, what are the properties? You can see that liquid limit is in the range of 21 to 102.Sand it is more of silty to clay material and plastic limit is in the initial void ratios are you know 0.6 to 2.2. Compression index is given 0.38 to 0.92 coefficient of consolidation values are given coefficient values are given friction angles are given. So, essentially lot of information is available.

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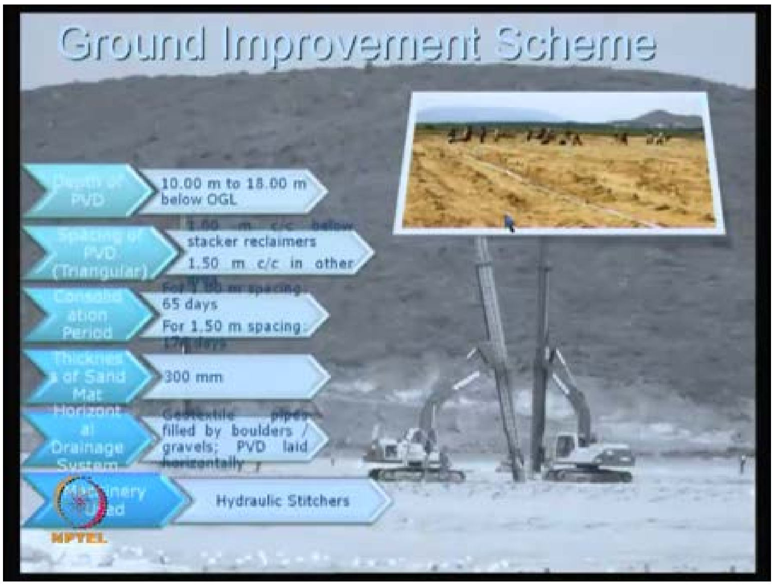

So, they have done it. So, they take they did the PVD s you know 10 to 18 meters below the ground level original ground level they have taken. Spacing is about triangular pattern and you know they have. So, consolidation period about 65 depending on the spacing actually for 1 meter spacing they have 65 days for 1.1 meter spacing 175 days ok. Thickness of the sand mat about 300 mm like what I said drainage layer then horizontal drainage system geotextile pipes filled with boulders as I showed you in the previous slide. One can have geotextile pipes filled with boulders as gravels PVD laid it was laid horizontal.

Yeah some PVDs they can be laid horizontally as I just showed you in the previous slides and machinery was uses hydraulics stitchers. So, you can see here also that it is all horizontally done also. So, this is some example.

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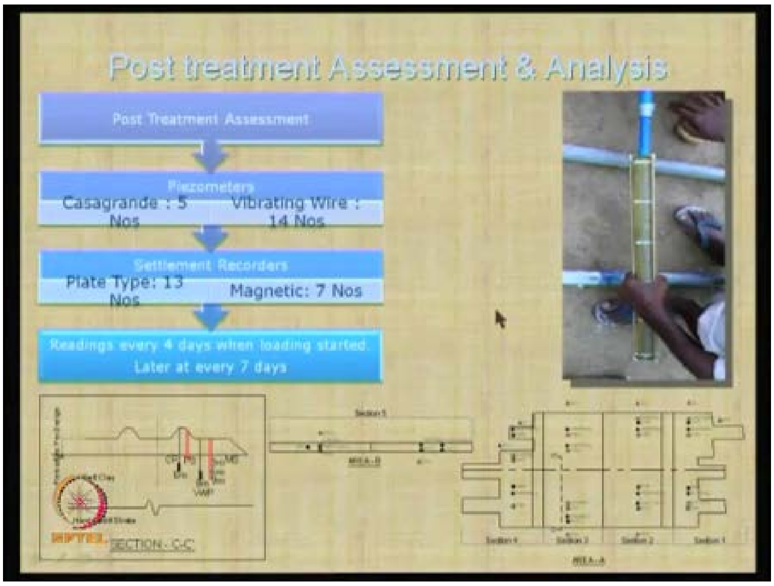

Then, sometimes you know, sometime the contractors also expected to you know see; show that yes, their system works. So, post treatment and assessment analysis: it is a very important project that they have done. So, in fact, they have used a piezometers Casagrande type. We have 5 numbers; then vibrating wire 14 numbers; they have settlement recorders plate type 13 numbers; magnetic 7 numbers; readings for every 4 days that they are taking every 4 days when the loading started and later after that, 7 days like you know as I said, doing the initial process. They could be little, the 4 days and later it was 7 days. So, they have sections here like you can see that this is that piezometer.

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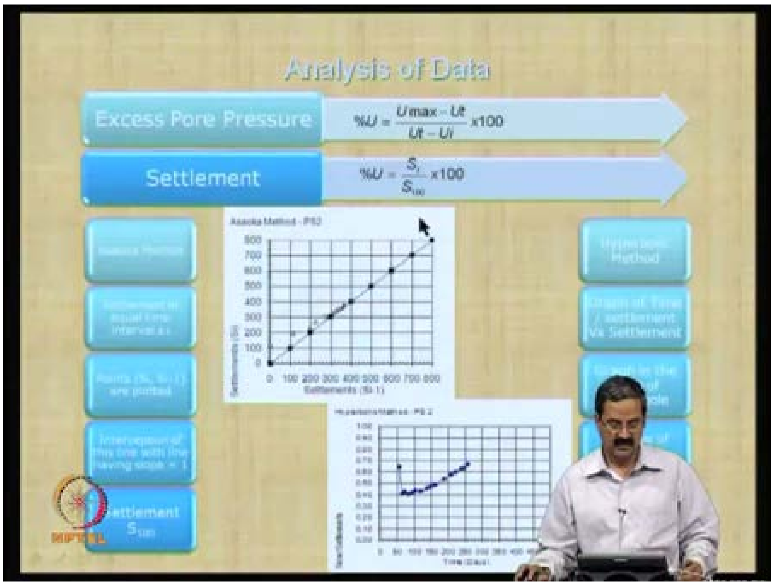

So, their objective is to find out excess pore pressure and settlement ok. So, they have in fact, in theory, in literaturem if you look at it because people are always looking at these issues and the degree of consolidation. How you have to have? See, you may observe some pattern in the field, but you also should try to develop some theoretical models to understand them. In fact, they used a two methods called Asaoka method and Hyperbole Hyperbolic method.

Actually, here the difference actually in the Asaoka method, the settlement at equal time intervals is measured. Plots between the present settlement and the previous one are plotted and the intercept of this like they have they will have a slope. Actually, of one you know this actually you will see that if you have 100 settlement s minus 1 and the current settlement they just try to plot this line here, ok. They also based on this and some more analysis they would like to get the settlement s 100 you know (( )) ultimate settlement; this is one way. There is another method which using a Hyperbolic method. In fact, a Hyperbola is a standard constitutive model in basic mechanics which is actually we call it Duncan Chang model. What we do here is that we calculate the graph of time versus settlement - versus settlement we plot and so, actually whatever is that curved form it becomes a straight line in the, if you plot time versus settlement versus settlement plot and graph in the form of a Hyperbolis then, the inverse of this slope of the parabola.

So, this Hyperbola is converted into suitable coordinates and one can calculate ultimate settlement ok.

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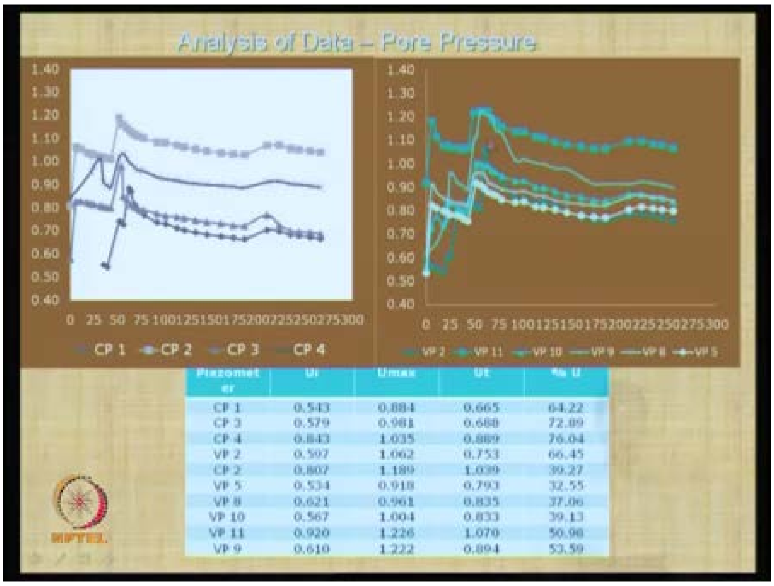

The settlement long settlements, long I mean long term settlements one can calculate and these are all typical observations they had for pore pressures pore pressure variations and all that they had some understanding of this then settlements also are measured.

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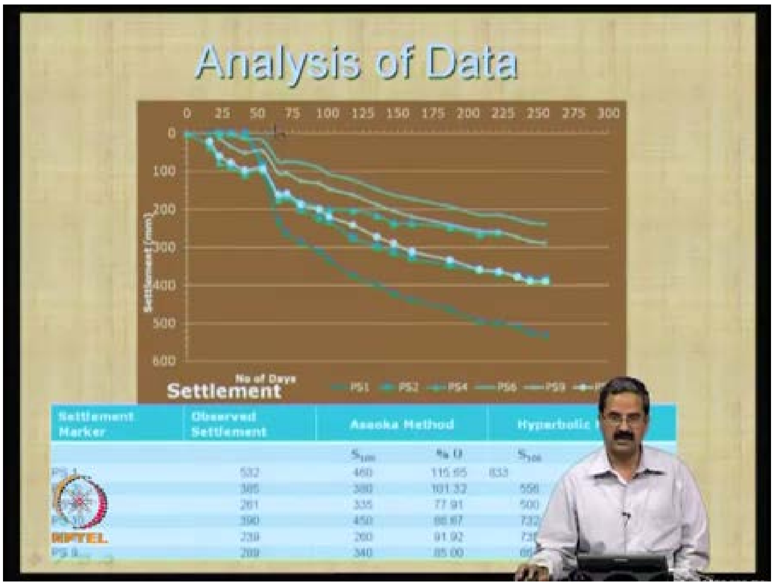

Then you can see that the observed settlements are there is the 2 methods they have tried to obtain what I mean, understand what these 2 methods give and…

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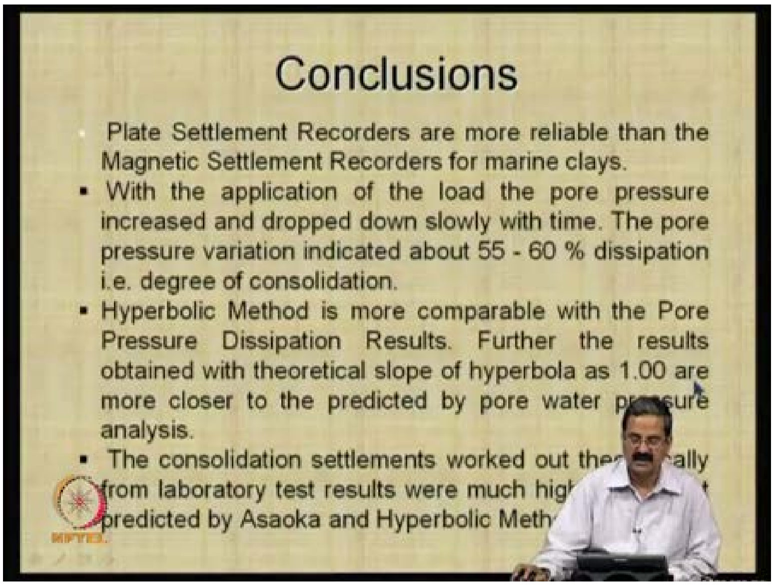

What this found was that I mean actually, this some of the case studies they have there only their things were only specific to that particular problem and also their ability to interpret the data available. So, what this observed was that the plate settlement recorders are more reliable than the magnetic settlement recorders for marine clays. With the application of the load the pore pressure increased and dropped down slowly with time the pore pressure variation indicated about 50 to 60 percent dissipation degree of consolidation.

Hyperbolic method is there; more comfortable with hyperbolic method and so, it is since its much more close to values that you obtain. Like you know, you have to, you have a pore pressure I mean, you have a equation for using the hyperbola to measure settlement, predict settlements and pore pressures that seem to be reasonably compared to Asaoka method.

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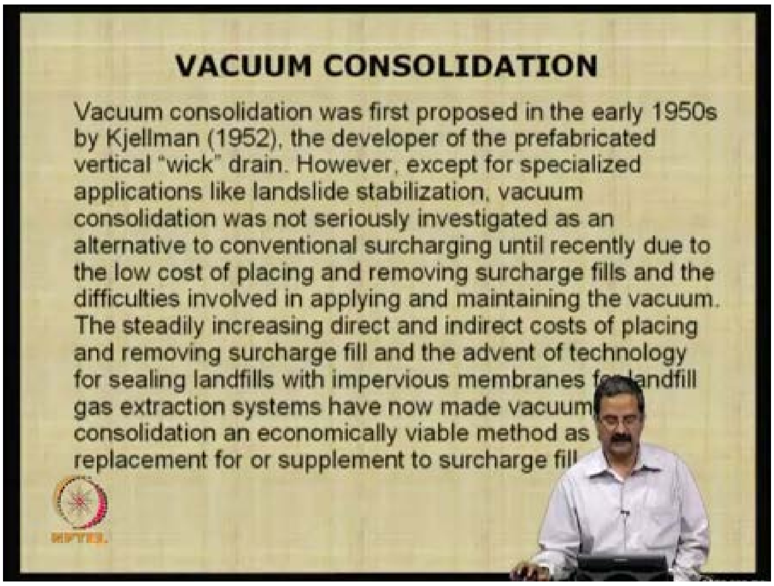

But, you know as I just mentioned, these are all some specific thing case to case basis and another important point that I would like to indicate here is that there is another technique called vacuum consolidation. Vacuum consolidation is something again people have proposed in 1952. Like you know you create a vacuum in the lab like you know the advantage of the vacuum is that the you try to remove all the air present I mean, like you know if you want to reduce you know even in soils there is a saturated soil and if you just create a vacuum what there is a drainage that takes place you know you have an accelerated drainage that takes place.

So, they were using it in some applications like landslides; but then what prompted people to use this vacuum consolidation was that the conventional surcharging was little costly because the cost of placing and removing the surcharge fills. You know you have to place a surcharge and remove the surcharge and difficulties they were there you know. that was one thing that what they had and there was also people did not perfect how to maintain the vacuum properly. But then the situation now is somewhat different that the direct and indirect costs of placing and removing surcharge with the (( )) sealing landfills and impervious membranes of landfills.

Actually, vacuum technology has also improved. What we have to do is that you will see that the vacuum technology has improved and also the possibility of you know the cost of the fill that you have to place for surcharge was also expensive.

So, actually this people have to use geo membranes in landfills and you know, then you have to create some vacuum also use some sort of vacuum technology for sealing. Actually, you can see with the advent of technology for sealing landfills with impervious membranes for landfill gas extraction systems. So, the technology has improved. So, much that it has become little more economical or viable as a replacement or supplement for surcharge fill.

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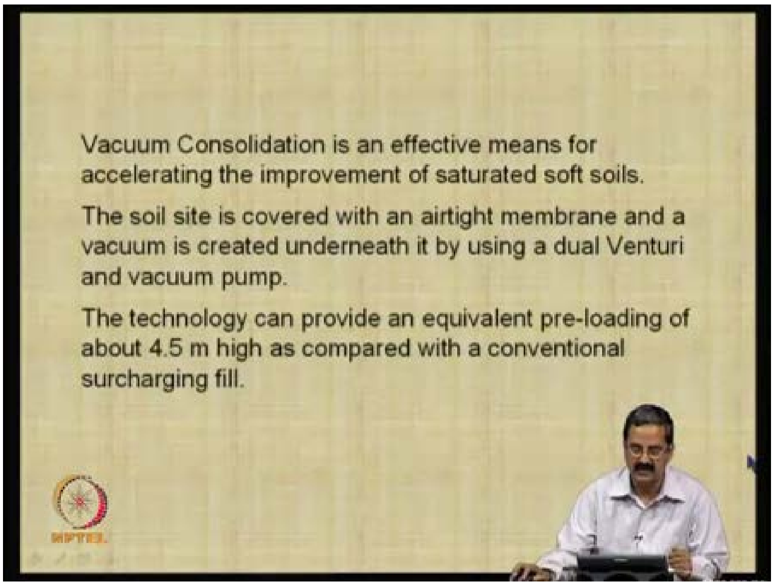

You will see that how it is. So, it is an effective means of consolidating or accelerating the improvement of saturated soft soils and this the soil site is covered with an airtight membrane total thing has to be compared completely covered with an airtight membrane and a vacuum is created underneath it by using a Venturi and dual Venturi and vacuum pump. There is a system of pumping system here. The technology can provide an equivalent preloading of 4.5 meters high which is as compared to a conventional surcharging fill.

So, here you can see clearly that you have to go for instead of going for 4.5 point meters of sand bags or whatever surcharge. If you apply you know properly this vacuum one can get a very good effect.

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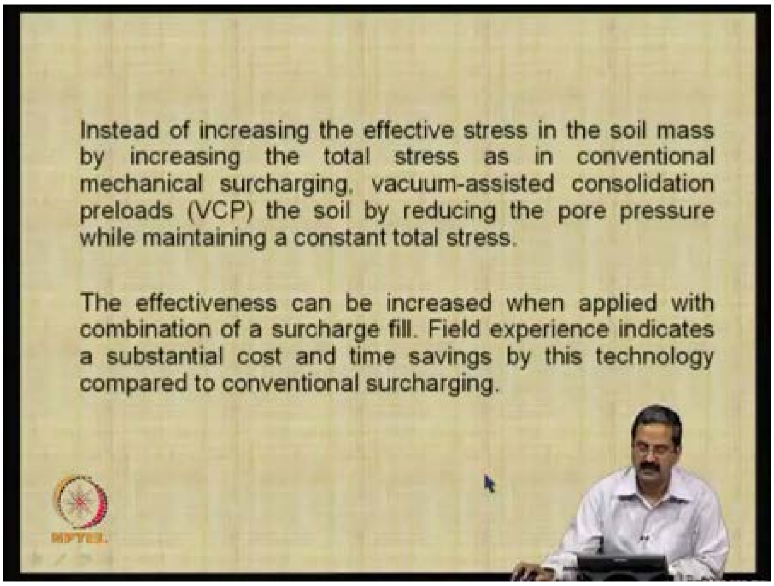

So, what happens here why is it effective? What it does is instead of increasing the effective stress in the soil mass by increasing the total stress like what we do is that you keep on loading and allowing it to consolidate here. In the vacuum assisted consolidation preloads the effective stress the pore pressure is reduced while maintaining the constant effective stress actually constant total stress is same, but your removing water the effective stress increases. That is what the effective stress can be increased when applied with the combination of surcharge fill. Field experience indicates that a substantial cost and time savings by this technology compared to conventional surcharging.

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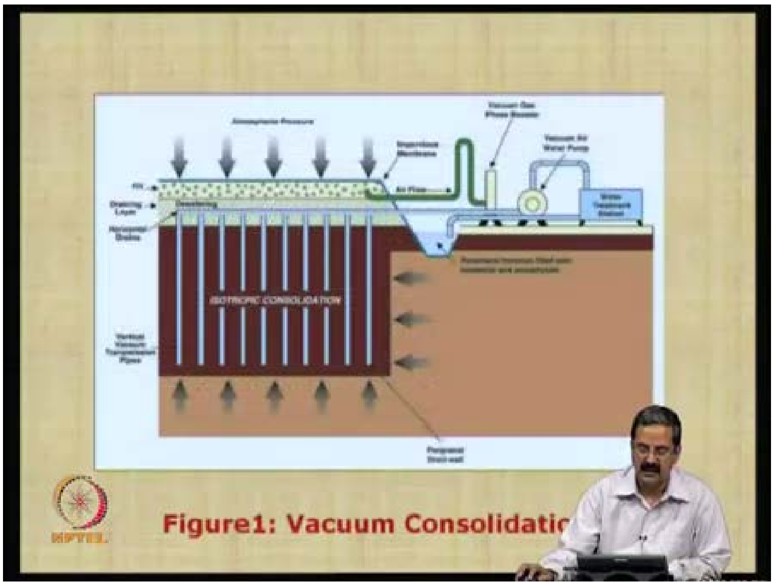

Of course, these are all (( )) the many places outside and you can see that here this is an example. This is a area to be consolidated and these are all the sand drains and you can see that you have an you have a geomembrane here which is laid like you know you have done everything, all the process is clear like this is a dewatering. This a drainage layer this is a fill and whatever fill know it you are going in lifts actually 1 meter or something like that. So, what we do here is that we are creating the vertical vacuum there is a vacuum pipes. So, yeah they are all connected and then because of the. So, this is a yeah this is a vacuum air water pump vacuum gas phase booster.

So, there is some more additional arrangement. In fact, you know you are trying to increase the effective stress in the fill. Also, increase the effective stress means if you put air you know like we know that the if there is an air into the soil system, effective stress increases you know the total. Actually, earlier it is only the pore pressure in a saturated soil. But, if you have air pressure which is called suction or negative pressure the effective stress increases it will be much stronger like similar to a saturated soil and unsaturated soil. Unsaturated soil will be much stronger and less compressible compared to this thing ok.

So, you can see that this we have a system here also you have a are trying to consolidate this portion also by a suitable arrangement by arrangement like this.

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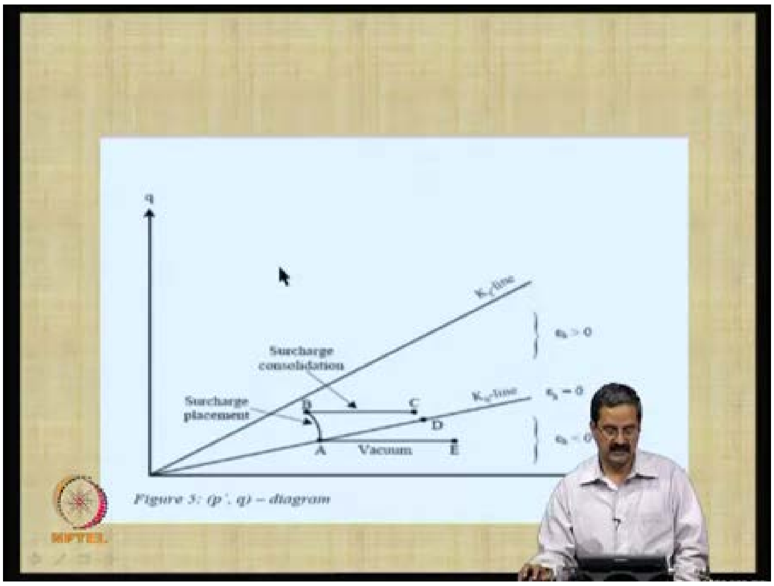

The principle is that like we are all familiar with the p q diagram p is nothing, but sigma 1 plus 2 sigma 3 by 3 q is sigma 1 minus sigma 3 and soil actually this is a line which is called K 0 line K 0 line means which is the along this line K 0 conditions prevail which means that there is no lateral horizontal strain, right? The air pressure is at rest air pressure is at rest. So, what we do normally? Now, you start loading actually in the field. So what? By process of surcharge placement what are you doing? We are trying to because the rate of loading is faster than it can consolidate, you can see that the p value p will come down you know this is the effective actually p dash is mean effective stress p p dash here. It is here then it will come down A bit up to B this small difference and so, that is why you have to control both. Why is it happening? That is because there is a pore pressure increase because the soil is poor like consolidation rate is not very effective.

So, what happens if you really start loading faster? The rate of loading will be very faster then it may even reach the failure line which is nothing, but our which we get from C plus sigma tan 5 or whatever, right. You know like you can plot the (( )) circles; you can get this you can get from that line, right? For the effective stress analysis you can get K f line you can also get K 0 line from the consolidation theory consolidation thing.

So, this actually you know, if you try to increase the rate of loading what happens? This is, may lead to failure which we do not want. So, what we do is that in the,… why we need monitoring in the field? why do What do you monitor? what do you monitored It is actually the pore pressures we monitor. See that the pore pressure is not really leading to higher I mean, q will increase, but at the same time q it should not lead to failure. So, we do not want this point to reach here.

So, that is the reason why we are measuring effective stresses and pore pressures in the field. So, the advantage of the... So, in the regular surcharge consolidation that is what we do. So, we apply lot of stress right, lot of stress and so that, this is what, preloading is done. So, that it moves away from the failure line that is fine; that is what we do. That is actually you can see that there is always some horizontal strains there you know because, the movement the soil is the soil state. We call it is in this range then there is always some horizontal deformations that exists.

But the if the horizontal deformation is too much then the total collapse takes place, right? if the horizontal deformation should not be too high you know because it is a combination of shear and volumetric strains and it should not lead to failure. So, you can see that this is a region in which horizontal strains are higher and this a region along line along which horizontal strains are 0. And here what is happening? You have created a vacuum which means that you have increased the effective stress.

So, p has increased to a particular point and the still the it is not strained you know there is no strain there you know they always you know like see you that the compacted sample will have a less compressibility compared to a saturated soil as simple as that. So, you can see that here because of the vacuum at the same effective see the same effective stress you applied vacuum and it resulted in it actually it results in this q q p plot it is like this, but you know you will get the effective stresses increased, right because that U a component you have to add.

Say for example, pore pressure I mean, pore pressure is generated like you know the you say sigma dash equal to pore total stress minus pore pressure minus no this plus actually this becomes additional.

So, the effective stress will increase because it is the, it is opposite of it is a suction it creates a suction. So, in the process the total effective stress is increased; the effective stress equal to total stress minus pore pressure plus suction. So, that is what it is and some constant whatever you know. So, that is what exactly we are doing its isotropic type of you know the pressure is isotropic like you are withdrawing the pressure from all the 3 directions or applying pressure in all the 3 directions what I meant.

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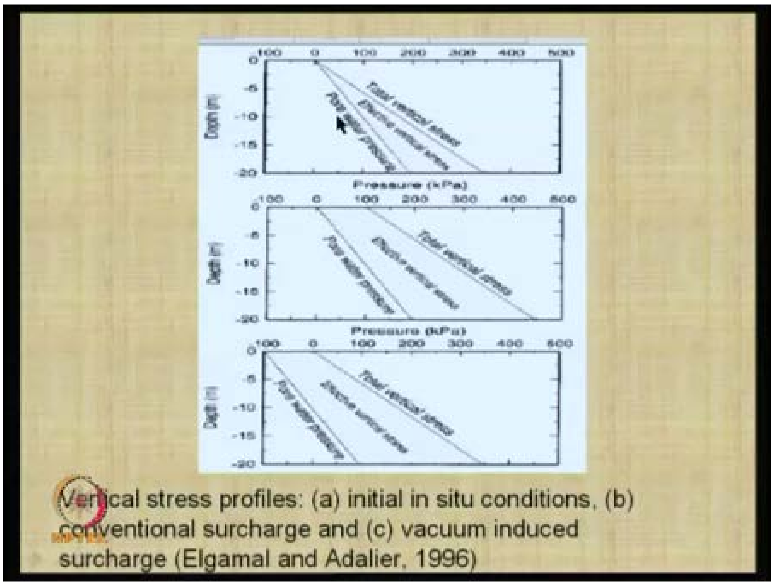

Vertical stress profiles: (a) initial in situ conditions, (b) conventional surcharge and (c) vacuum induced surcharge (Elgamal and Adalier, 1996)

You can see some more, I can have a clear idea on this vertical stress profiles like in situ soil conditions, what do you do? You can see that this is a total stress total vertical stress how do you get gamma b into depth like up to say 5 meters, 10 meters, 15 meters, 20 meters. I will get this effective stress you can see.

Say for example, at 5 meters depth the effective stress is about 100 meters. So, which means like say 5 into 20 is 100 like 10 into. So, like 10 into 20 is 200. So, it is like this the this is called a total effective stress. Then you have also measured pore pressures right? So, if you measure pore pressures this is the line and. So, this is the effective stress region right. So, this is this is one what we say. So, you can always measure this normally what do you measure you measure only total pore pressures you know total stresses right in the field.

How do you measure pore pressure? It is like water column rise you know, gamma w into height if there is a water pressure you know raising water pressure is nothing, but the pore pressure excess pore pressure, right? If you put some next to a soil and there is a pore pressure like you know it's a it is a there is undrained situations and there is always a pore pressure excess pore pressure in relation to atmosphere.

You just measure that and then measure that it is in terms of the column of water like if it raises by 3 meters or 2 meters into its gamma into means 10 kilo newton per meter cube is approximately the effective stress. So, this is in situ conditions now what did you do because of the consolidation or the surcharge conventional surcharge.

You have increased the total vertical stress and the pore pressure line is here. So, you have increased this range of effective stresses that is what we did and you can see that it starts from 0. Pore pressure is 0, right? And, then it increases now with vacuum assisted surcharge it can go up to minus 1 you know 1 bar. 1 bar is the pressure that you can apply; so minus 100 K p a. So, this is the region and this is that. So, you can clearly see that you have increased the effective stresses you know effective stress in the sense that you are create you are able to create an effective stress field less using this suction that is what it means.

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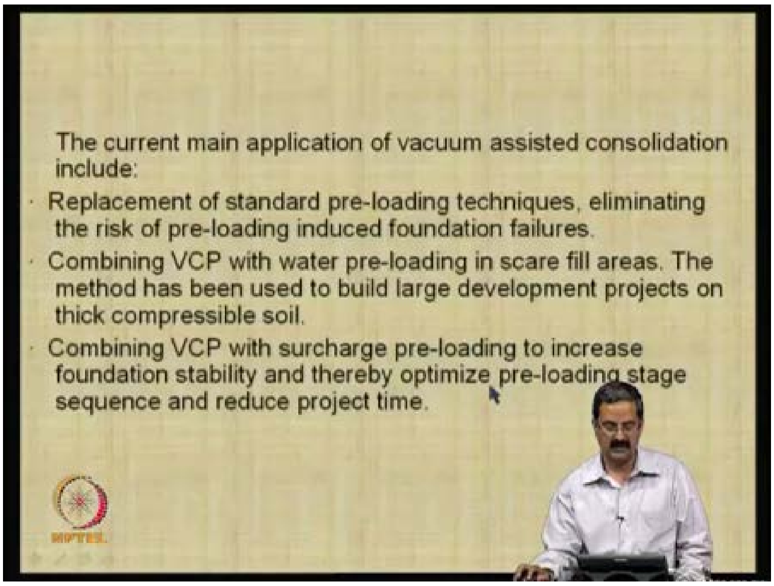

So, what we are trying to see here is that the current main application of the vacuum assisted consolidations, include replacement of standard preloading techniques like as I said. Standard preloading test means adding lot of sand bags and all the this thing and because the problem is as I just mentioned, it eliminates the risk of preloading induced foundation failures like you try to stack in all the preload that in one place. But it could lead to failure. So, what should be done? You try to combine the vacuum consolidation preloading with you know both you can have both of them in some sort of a scare fill areas are going to be you know where there is a scarcity of fill scares actual.

The method has been used to build large development projects on thick compressible soil they combining VCP with surcharge preloading to increase foundation stability and thereby, optimize preloading stage sequence and reduce project time.

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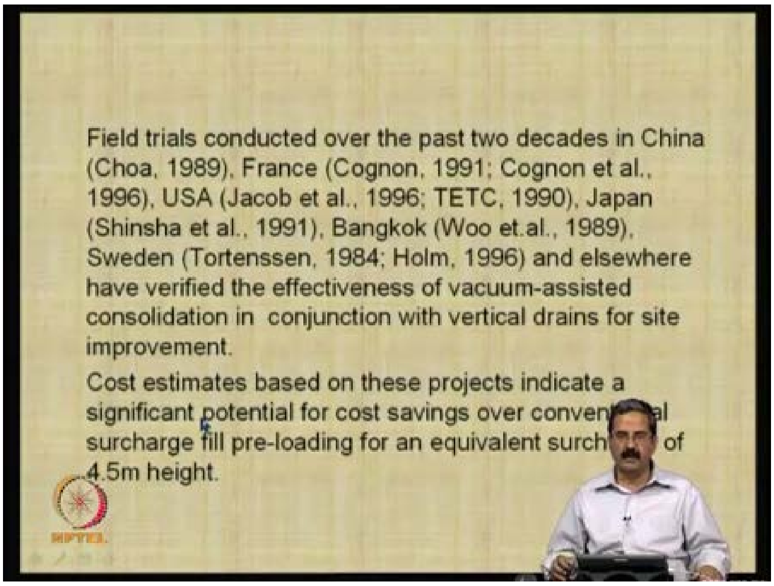

In fact, you can even optimize on the construction process itself. You know the application of vacuum; you know once your sealing systems and everything is perfect. Vacuum systems you know it just takes 2 days or something like you know just to stabilize you have to apply vacuum. Exactly what you are doing is, you are applying vacuum and people have been doing lot of field studies here.

Say in China then in France and USA and Bangkok and many places they have verified the effectiveness of the vacuum assisted consolidation in conjunction with vertical drains for site improvement. Cost estimates based on these projects indicate a significant potential for cost savings over conventional surcharge fill preloading for an equivalent height of 4.5 meters height.

So, there is lot of advantages and I will take up a few more points on this and also I will talk about a few more issues on the ground improvement using dewatering techniques; thank you.