Ground Improvement
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Module No. # 04
Lecture No. # 10
Prefabricated Vertical Drains (PVDS) – 1

Today, we will be discussing on one of the most popular ground improvement techniques - the use of preloading and vertical drains in the area of ground improvement, particularly when you are concerned with soft soils.

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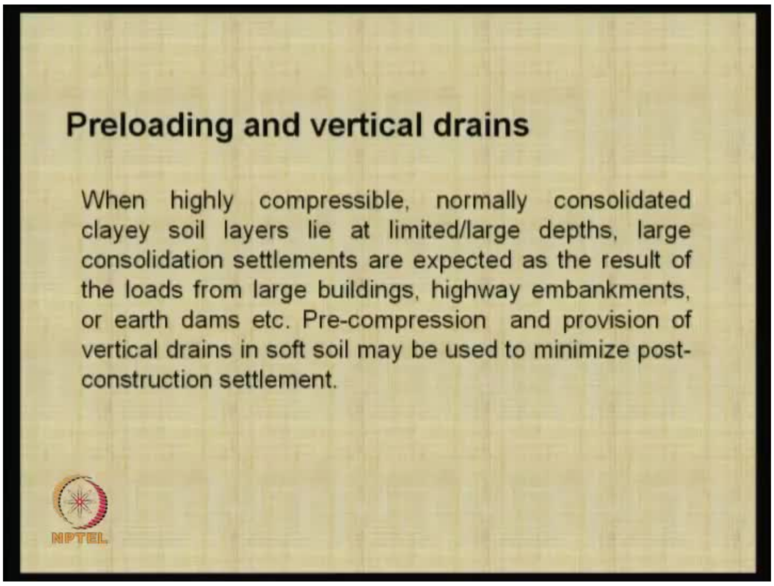

The soft soils are particularly highly compressible, and most of the time they are normally consolidated or their over consolidation ratio is very low, in the sense that it could be 1.3 or 1.5 or less than 2.

Where you have high elastic plus plastic deformations, then the soils could exist where ever, may be 5 meters depth or 10 meters depth or infinite depth. The moment you load these soils for buildings and highway embankments, you end up having a lot of settlements. The bearing capacity of the soil is very low. How do we handle this? The particular problem in soft soils is something that we would be discussing today.

In fact, in the east coast and west coast of India, and many places have soft soils. Say for example, right from Calcutta to Vishakapatnam, to the tip of whole of Tamil Nadu, east coast and west coast, and also Kandla and many places have soft soils and have a lot of settlements. Many of them have port structures, and they have been using some of these techniques. Some of them are not new; they have been using this pre compression and vertical drains more than for 20 years.

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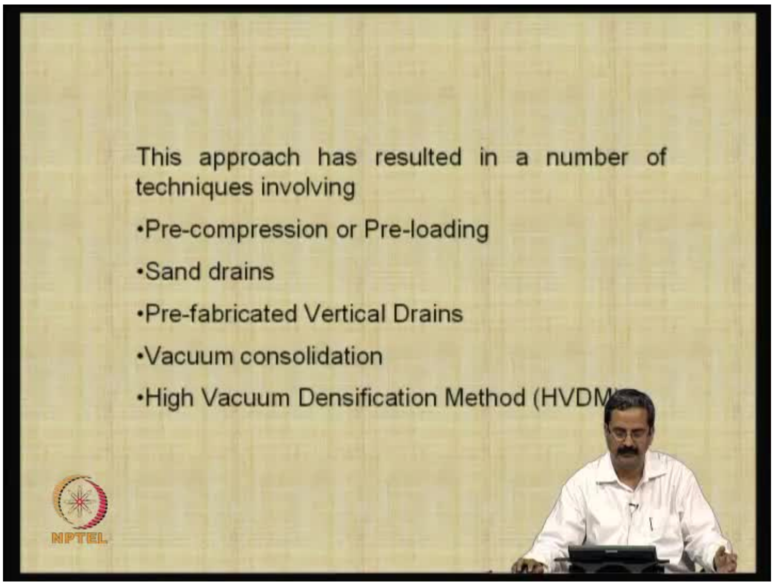

We will just see how they are useful, today in this particular lecture.

This use of pre-compression or preloading has resulted in a number of techniques, which have been used in the field. Actually, as I just said, some of these soils are normally consolidated. So, if you pre-compress or you apply higher load, such that the settlements are going to be less, it is called preloading.

What we do in this technique is that, we apply a higher stress than the stress that is likely to come to the soil, so that the settlements are pre empted, like we accelerate the process of settlements by using preload; so once you construct the structure, you will not have much settlements. That is what we say, is called pre compression or pre loading.

In this case of pre-compression, the consolidation of the soil is in the vertical direction. Say for example, if you apply load, consolidation occurs; and then the consolidation process results in settlement.

The acceleration of the settlements is because of vertical loading; and that is to some extent, but when the soils are of high compressible nature, you need to provide sand drains also. Actually, what the sand drains do is that, they will also provide radial consolidation; so, you have consolidation in the vertical direction, and then the water is also coming out in the horizontal direction or radial direction, so we call them as sand drains.

So, the process of combining both vertical consolidation and radial consolidation has been initiated with sand drains in 1930s, right in the beginning. The moment people understood that they had some idea of the consolidation behavior, they were able to understand that, if you are also able to apply some sort of consolidation in the radial direction, it is helpful.

In fact, I will give a classic example, if you are trying to do a tri-axial test on a clay, if you put filter papers at the top and bottom and also you surround the sample with some sort of filter paper, where you have all the vertical drains, like we call there now, you can actually see that, if you do a consolidation test, there is a big difference in the consolidation process itself; like it could be 3 or 4 times. I do not know if you have observed but the fact is that, if you have radial consolidation alone it is one thing, and when you have vertical consolidation alone it is one thing; but, if you have radial consolidation together with vertical consolidation, then there is an excellent combination.

So, you have sand drains and since sand drains were somewhat the thing that people were using in the olden days. Now you have what is called pre-fabricated vertical drains. You can see that you have pre-fabricated vertical drains which are like these, in which you see that, if you put it in the soil then this is called a geo textile.

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In this drain, you have a drain inside, which has drainage channels; so, the moment you apply the load, water comes here, and then goes to the drainage channels.

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This is one type here, there is another type; like you can have a drainage medium here, like drainage channels, then you also have some more like this, the top one is called drainage; the 'filter me' filter cloth and then this one is called a drainage medium. What we do is that, earlier there was a circular sand drain which is about, may be, 30 centimeters or 20 to 15 centimeters diameter.

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Now you have this type of material where, you have a consolidation which is quite fast using this technique. You will see that, this is called pre-fabricated vertical drains. You also have some more materials in the similar lines; here again some more are there by different companies.

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Actually, what happens with this technique is that, at the consolidation instead of 8 to 9 years or may be 4 to 5 years, it comes down to 9 or 10 months because, you would accelerate the consolidation to construct at least next year. Like you know, you go to a costly area, what you should do is that, may be you try to accelerate the consolidation in a period within 6 months to 1 year; then start highway construction next year, that is a normal plan. So, when these materials help you to consolidate within 9 months to 1 year, then the purpose is served. There is no point in having this plastic material inside the ground, when the purpose is served.

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You have what is called jute geotextile; so this jute geotextile is sufficient and though this is biodegradable, it may last for one and half to 2 years.

Once you put like this, then the same purpose is served as that of this material. The difference is that, this will not stay in the ground; but whereas this stays in the ground.

That way, we can say that you are trying to provide a sort of an environmental friendly technology using these sorts of materials.

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In India, we have another one; this is called coir. This is again the same coir which we normally know. So, both coir and geotextile are abundantly available in India, and people can develop some of the pre-fabricated vertical drains and use it in the field. They may be good for 9 months or to 1 year, but then we have seen that they have all the required properties which are comparable to the synthetic materials, and they are helpful.

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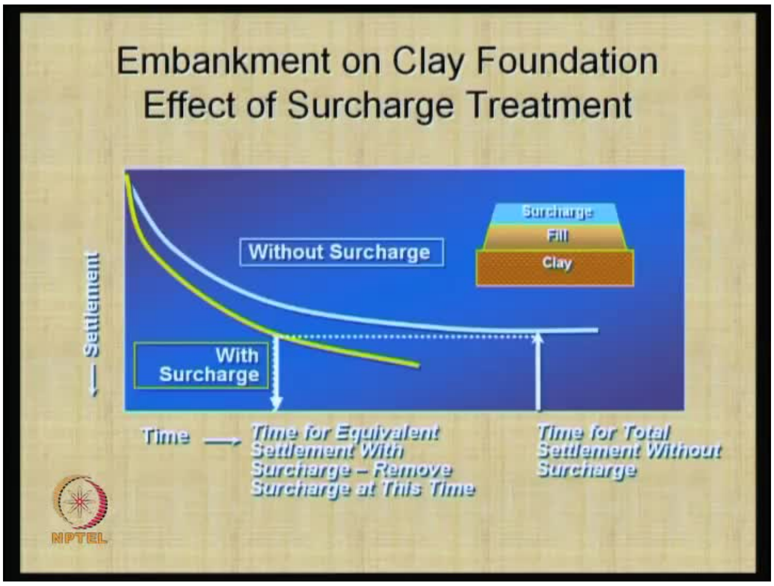

So essentially, we will be seeing some of these materials here. This is a typical example that I would be showing here. This is a clay soil which is about say, 9 to 10 meters; then you have a fill. This is a typical example for a pre-compression. What we do is that, we apply some sort of surcharge which is little. You know, the total load is really higher, fill plus surcharge; they act on the clay soil, and you can see that, if you just plot that settlement versus time, the settlement in the case of this clay without surcharge is like this, and then this surcharge is like this. So, what we are trying to do is that, in this process the settlement that is supposed to take place here is, you are trying to accelerate because of the higher load; it happens within this time. This is nothing but the time for equivalent settlement with surcharge, and you remove the surcharge.

The moment the settlement occurs, you can remove the surcharge, so that, you can monitor the settlements in the field.

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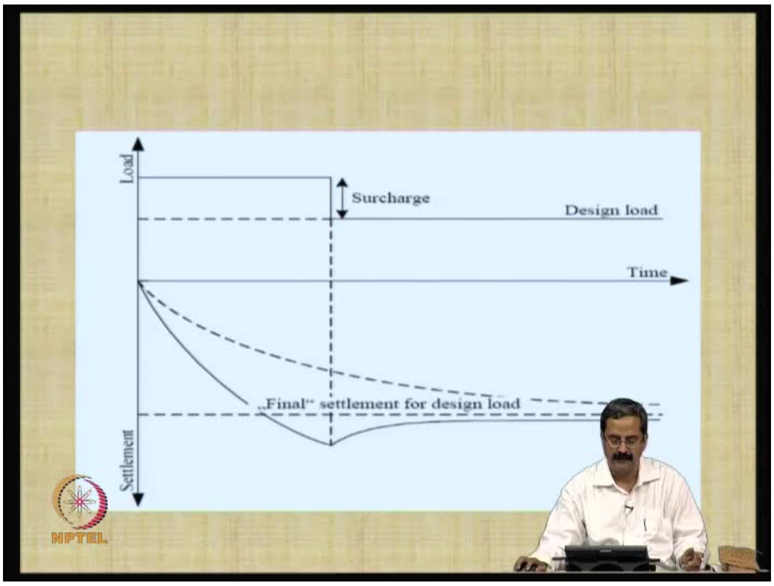

So actually, this is what we need. This is what you have to design for this particular time, which is a very useful input for our own whole design process here. This is a same example, like, you have a design load, say for example, some 100 k p a is acting. So maybe, you put 150 k p a, or 200 k p a. You know, also depending that you should calculate how much of surcharge you should put. So, design load is something 100 k p a you can put 150 k p a here.

So what happens is that, this could be the thing; then remove that and then it comes back. So the thing is, the final settlements are always going to be like this. It is an effective technique for accelerating the consolidation settlements and clay soils.

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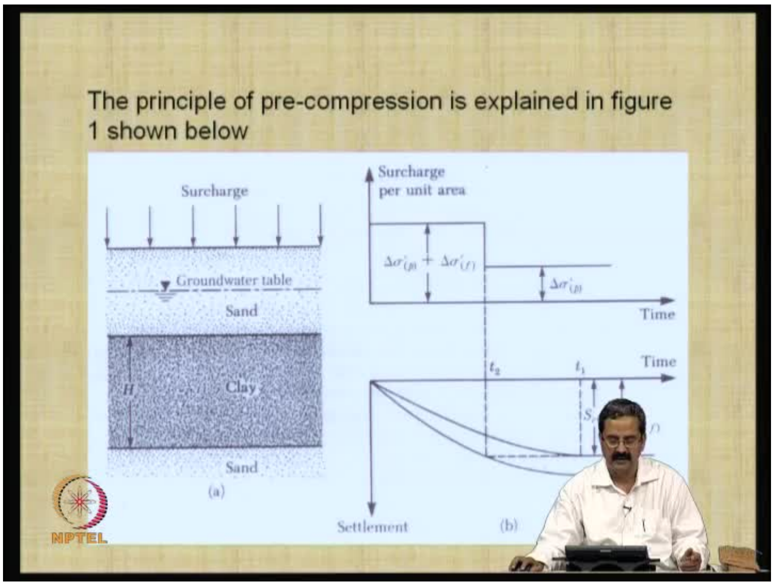

The principle is that, you must be able to calculate this load that you are expecting. This is the load plus whatever is the stress that you are expecting from building, plus the fill total surcharge.

This is higher as I just mentioned. You need like, say for example, S c is a settlement, under the load plus S c is a load under the fill, plus the primary compression. Actually, this is the primary compression.

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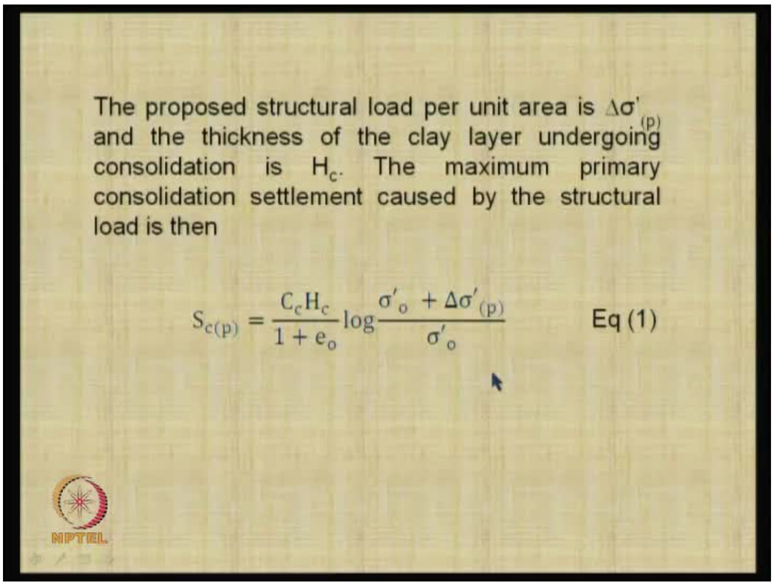

You can get within time t 2, which is required here. To calculate this t 2, we have a simple technique, and we will see that. We know that, this is the proposed structural load. Say for example, I said 100 k p a, and then thickness of the clay layer undergoing consolidation is H c. It can be a double drainage and single drainage condition, we know in solid mechanics.

This is a standard expression that we have for calculations of settlements, like C c into H c by 1 plus e naught into log of this. The stress caused due to the additional load can be used by one. See, with this we have to calculate this stress. You have to use the proper equations. There are analysis methods available to calculate the stress.

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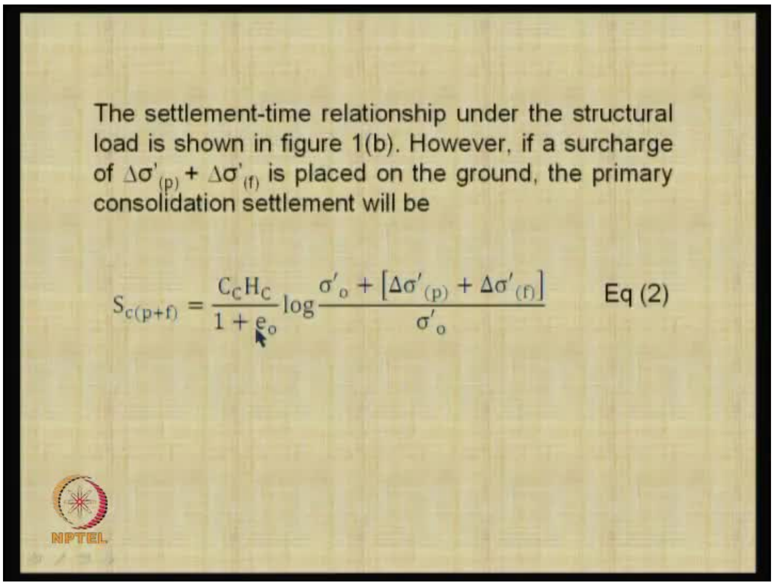

You calculate this stress at a particular point. What is stress? The extra stress because of the load should be able to be calculated from many of the elastic stress distribution theories, we have them.

This is the original over burden pressure. So, you know how to calculate settlement now. The other thing is that, if you have the same extra load, you have higher load. That is it. You have higher load, and of course, e naught is the initial void ratio of the sample or the void ratio at that particular depth.

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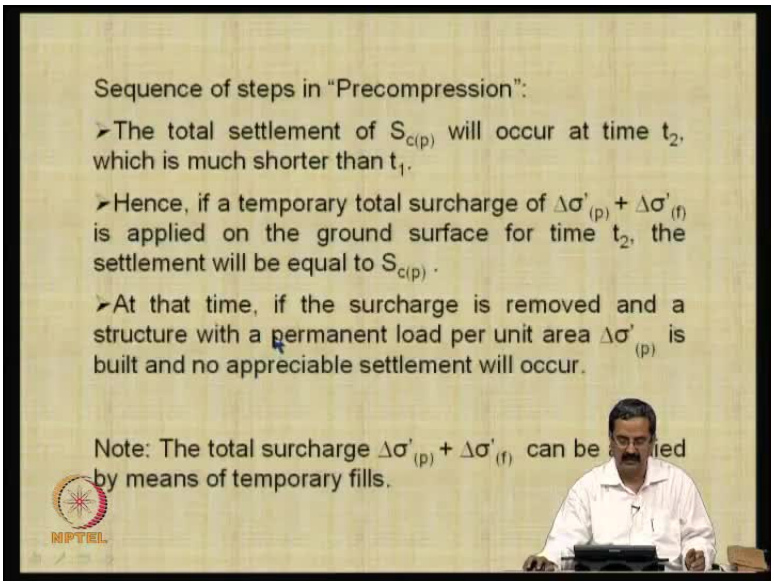

Our objective is that, total settlement should occur within time t 2, which is much shorter than t 1, and then we apply some sort of temporary surcharge on the ground surface for the time t 2. So, for example, how do you apply that temporary surcharge?

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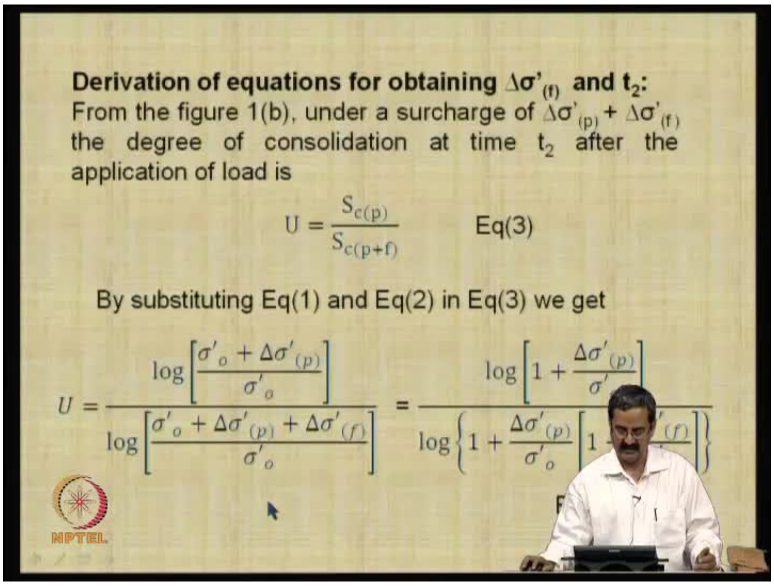

You have sand bags and some of the material that I will show you, or whatever heavy material you know, you can keep it. Then the settlement will be equal to S c p.

At that time, if the surcharge is removed and a structure with a permanent load is built, no appreciable settlement will occur. This is said that, they are all done by temporary fills. So, like this, understanding can be obtained with reference to what is called the ‘degree of consolidation’ at time t 2. This is what we are interested in.

That is defined in terms of the settlement. The ratio of settlement for the load is divided by the settlement at the load for the p plus f.

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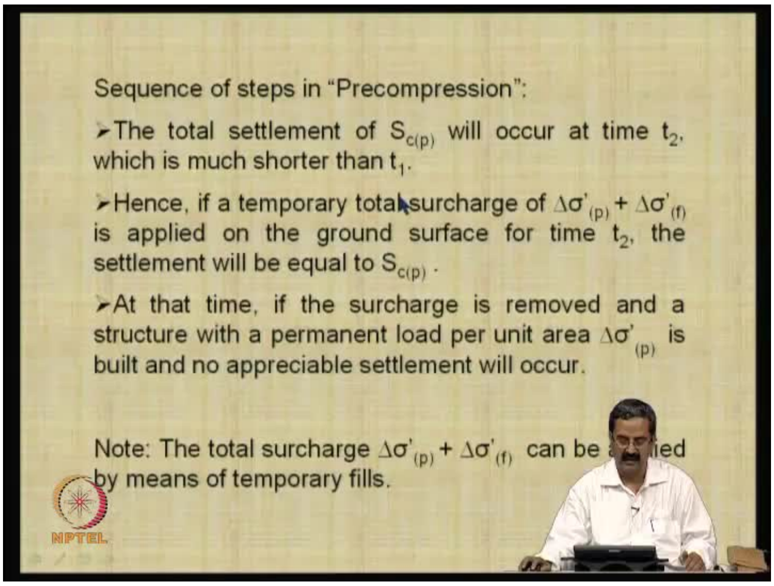

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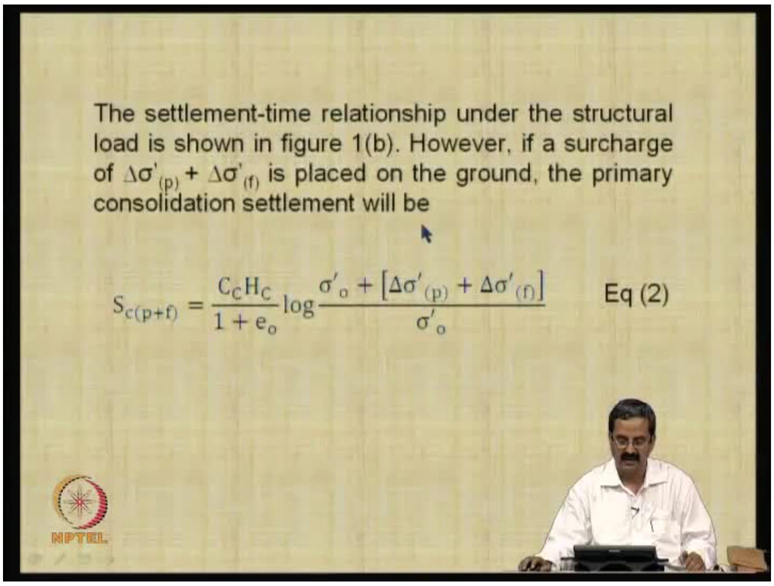

So, we have the expressions for both of them. In the previous expressions we have seen two expressions.

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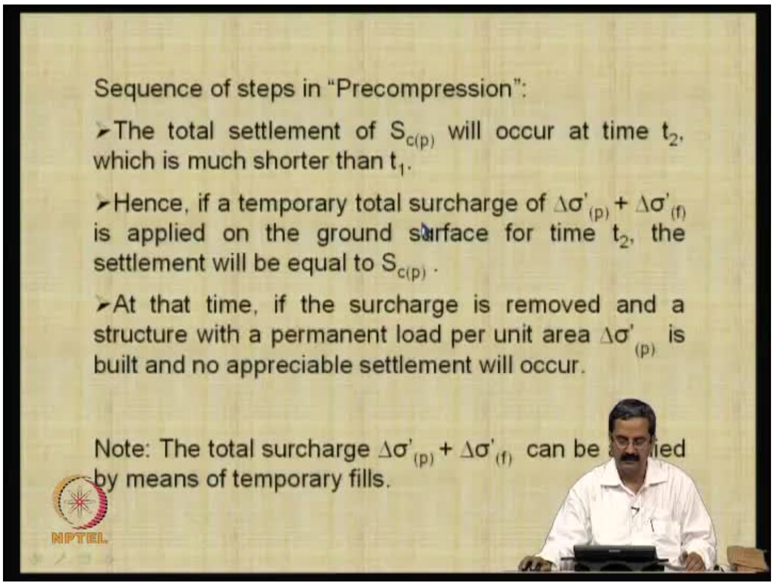
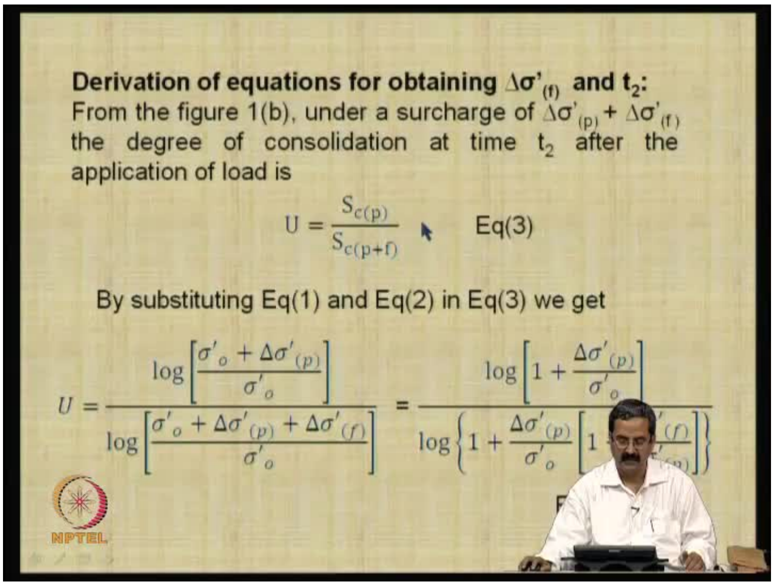


Ratios (Refer Slide Time: 13:20)



With the ratios of that your all other things get cancelled and you have this term. It is simple to understand. These are the simple expressions. What we are trying to do is that, you try to express in terms of this sigma naught here, and then this is one thing.

You try to simplify this particular term, so, the degree of consolidation that you need at the point t 2, you try to express in terms of this. This is one ratio which will give you that. This is one simple ratio, which is an extra load that you should apply in relation to its initial over burden pressure; and this is that load that you should apply in excess or as a ratio of how much of fill load you have to apply.

These two are the 2 ratios that are quite important. One ratio is nothing but, it is a ratio in relation to the over burden pressure- sigma naught. Sigma naught is nothing but gamma into H at any point.

Then how much of extra, say for example, I just mentioned instead of 100, this is 100 k p a, this could be 200 k p a, some ratio one should have?

Actually, the degree of consolidation as you can see, is a function of these two variables. The same variable is coming here also; you can see that this is another variable. So once you know these two coefficients, you can calculate the degree of consolidation at point t 2.

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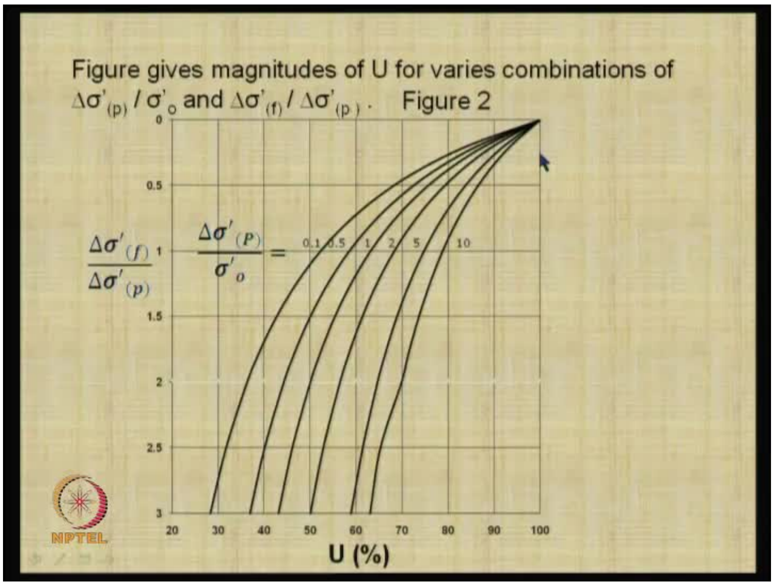

One can do a simple excel plot. Take the same equation, and then plot. So, one can obtain the degree of consolidation here. Like, say for example, you can see that we need a good degree of consolidation. Our objective is to get a very good degree of consolidation.

Then, this is a ratio which will give you the, say for example, this is a ratio of the delta P delta sigma with respect to the initial effective stress, and it can be 0.1, 0.5, 1, 2, 5, 10. It can be some numbers; like, see initially it could be just, say, 10 k p a. How much of extra are you putting, because that is additional load. This is actually the other one, as I just mentioned the ratio of the fill load is coming here.

Using this plot, one can get this information on t 2. Like you have to fix up, it is 6 months or 9 months or 1 year. You can fix it up, and by working out all these combinations you can get the number. I will just see an example.

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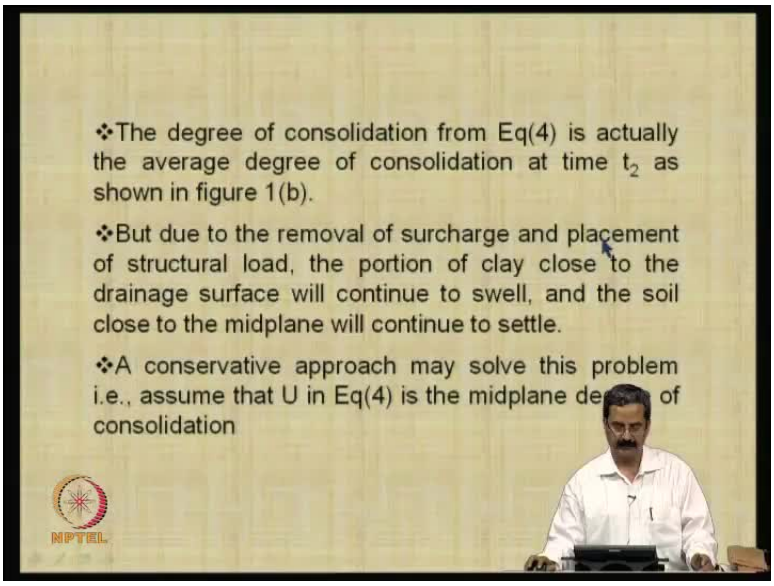

The degree of consolidation that we have is, actually the degree of consolidation at time 2. What we do is that, it is an average value; see, you have, suppose 10 meters there. You are just at some point, and you are calculating the average value. Everything is average.

When you remove the surcharge and the placement of structural load, some portion of the clay close to the drainage surface will continue to swell, and the soil close to the mid plane will continue to settle.

What we do is that, actually, now the degree of clay embankments at different points, will have different degrees of consolidation.

Like you know, you must have seen in the theory that, you have the lines of different degrees of consolidation like this, where you have a both top and bottom. They are open free surfaces, if the pore pressure is 0 then at the mid-point, the degree of consolidation will be little higher, because it is away; that depends on the permeability of the soil.

What we do is that, since you know this particular thing is there, by removal of surcharge and the placement of structural load what it does is that, portion of the clay close to the drainage surface will continue to swell, because you removed the load. So, there is some minor changes in the soil, and soil close to the mid plane will continue to settle.

To balance out, there is an approximate assumption that, whatever degree of consolidation you have, is the mid plane degree of consolidation. We are just trying to average out like this.

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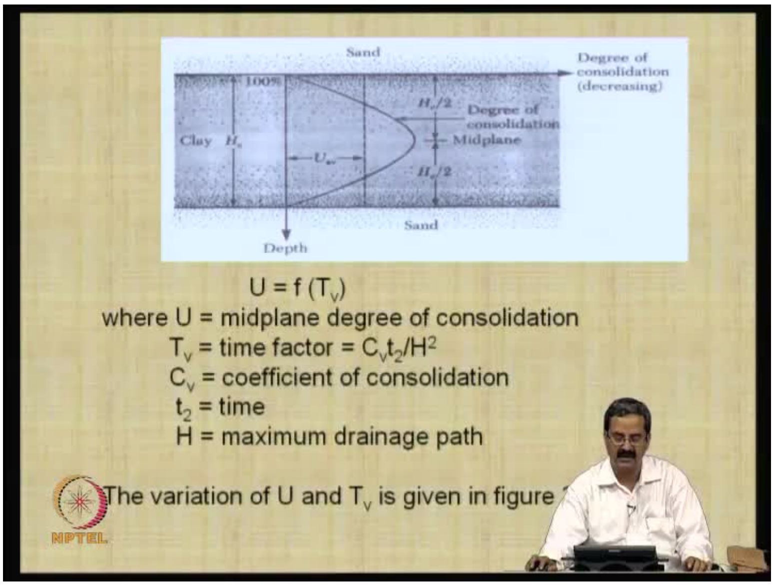

This familiar thing we know, like, we assume that the degree of consolidation that you get is a mid-plane consolidation; and we know this time factor. You know the consolidation theory- C v t 2 by H square. C v is the coefficient of consolidation, and t 2 is the time and maximum drainage path, so we also know this particular plot.

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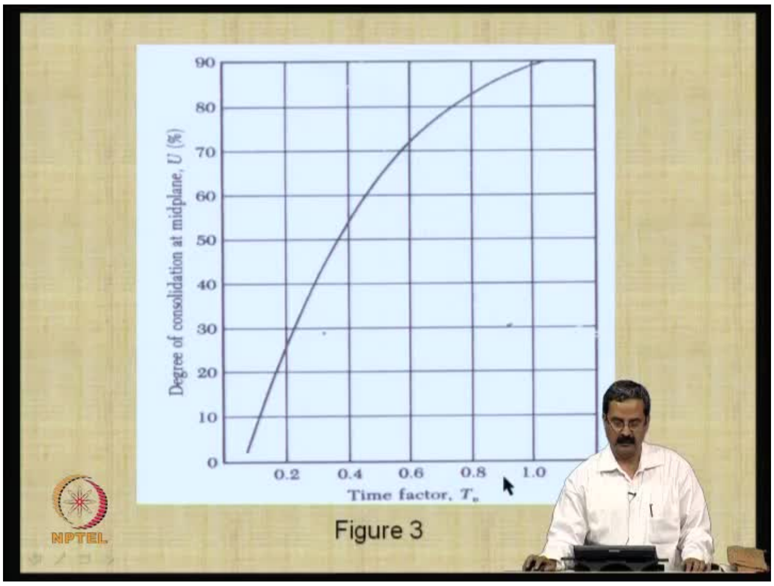

Time factor versus degree of consolidation is the standard thing that we know in soil mechanics.

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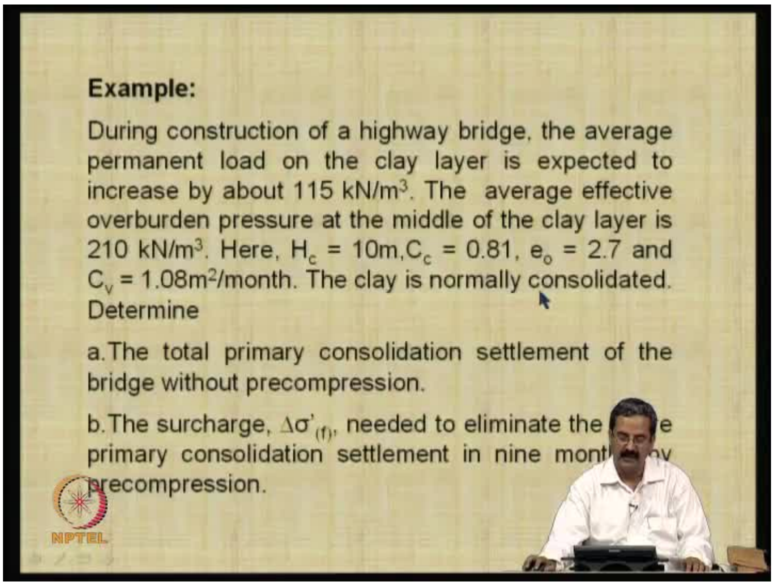

Knowing this, how do you solve the problem? It is a very interesting and simple problem that I want to illustrate. You are trying to construct the highway bridge; and then, the permanent load on the clay layer is expected to increase by 115 kilo Newton per meter cube. You are getting some extra load. There is some load already, and there is some over burden at midpoint, say for example, I said its 10 meters. 10 meters is the thickness of the clay layer. So, at 5 meters the over burden pressure is two 10 kilo Newton per meter cube. How do you get that? Gamma is going to H. This is square 210 kilo Newton per meter square.

Then you know the consoled C c and e naught void ratio, and it is also the coefficient of consolidation. Actually we will try to put in terms of months because, what do you do in lab is just try to calculate for seconds; but I want, for example, 8 months and 10 months, so I am interested in putting everything in months.

This soil is normally consolidated. Now, I would like to calculate the primary consolidation settlement of the bridge structure without recompression.

What is a surcharge required to eliminate the primary consolidation in 9 months by recompression? This is what I wanted to do.

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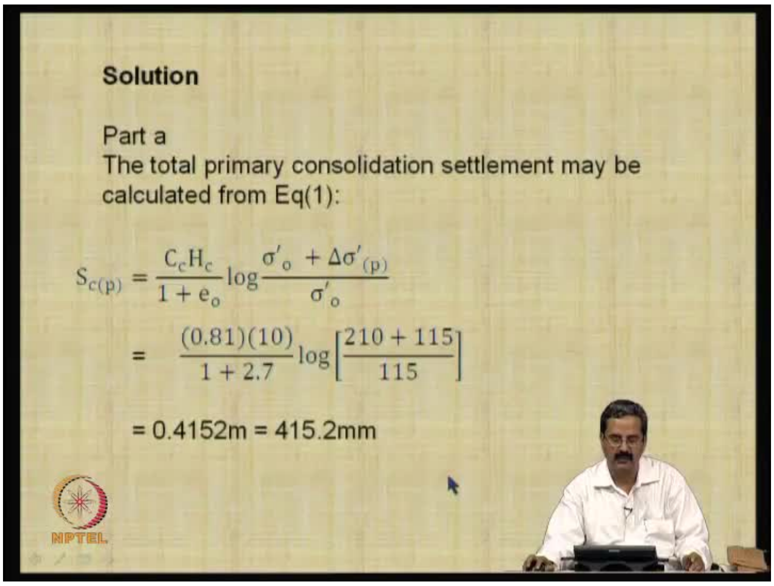

So, I just calculated in these particular steps. What is the settlement you can see? 415 is very high, about nearly one and half feet.

You have all the C c H c and 1.27. All that numbers are given, then I would like to eliminate this by using the recompression technique.

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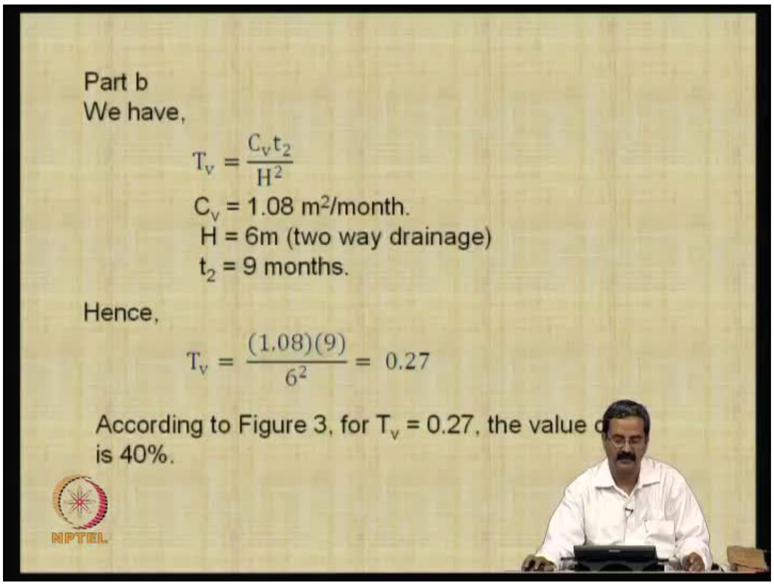

My objective is now- t 2 is 9 months; and all these equations are given. So, I calculated T v and I got 0.27. So we have to figure 3, just as we discussed for 0.27, the value of degree of consolidation is 40 percent.

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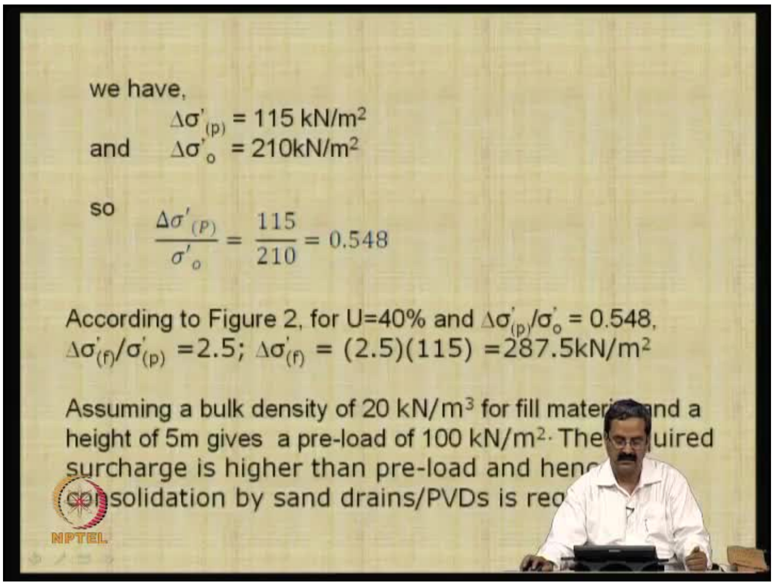

With that in mind, what we have is that, you have d p. This is already known. The ratio of d P by d naught that you will get is 0.458. Then there is a figure that I just showed you that, U will give you the mid plane potential or mid plane consolidation response. For U equal to forty percent, the ratio is 0.458.

And you can work that out with all things being known, the extra fill required is 287.5 kilo Newton per meter square.

Actually the thing is, in this case, I have purposefully taken this soil. The soil is very lose or very poor soil. The soil liquid limit is very high and all that. With the result you can see that, its 287 k p a, which is a high number.

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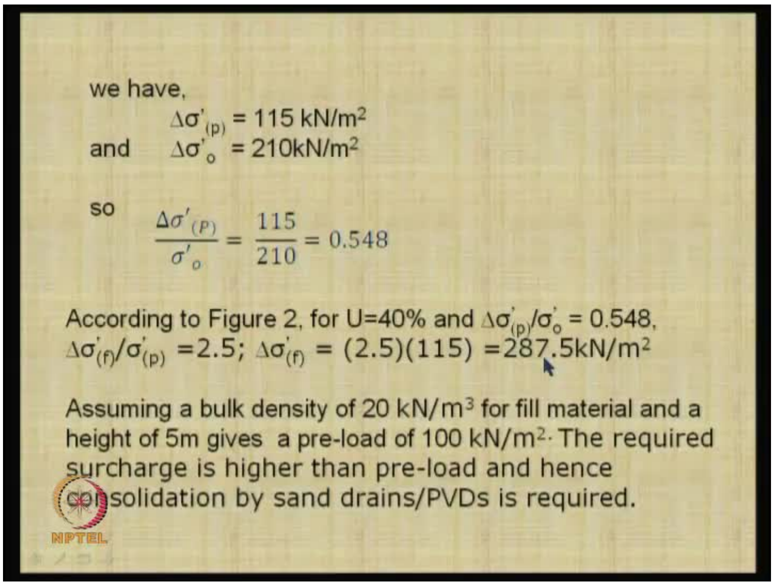

Normally, what they do in the field is that, if this soil is somewhat like, say for example, liquid limit is about 30 percent and all that or 50 percent, one can really say that the load will not be this much. It may be about 100 or may be 150 or something.

How do you do this? Now you got an amount of how much of preload should be applied. The delta sigma f that you got is 287.5 kilo Newton per meter square.

How do you get it? For a simple example, I assume I have a fill. So the fill material I will take is about 20 kilo Newton per meter cube bulk density and height is 5 meters. It gives a preload of 100 kilo Newton per meter square. Suppose I take sand bags which have this density of 20, then load everything up to 5 meters. Density should be correct and proper, say, if it is 19 put 19. So, preload will be about 100. Then if I leave it just for 9 months, you have to mark the settlements also.

We expect that the settlements will be sufficient, but normally what happens is, you are in a place where everything is clay, and to get a preload is very expensive. Like even 1 meter, 2 meters or 3 meters is very expensive.

May be, normally people lift for about 3, 4 or 5 meters. They cannot go far, because it becomes expensive. Imagine a place where everything is clay. What is that? It is an island full of clay, and you want to get sand. Where do you get sand? Or where do you get weights? It is very difficult and it becomes very expensive.

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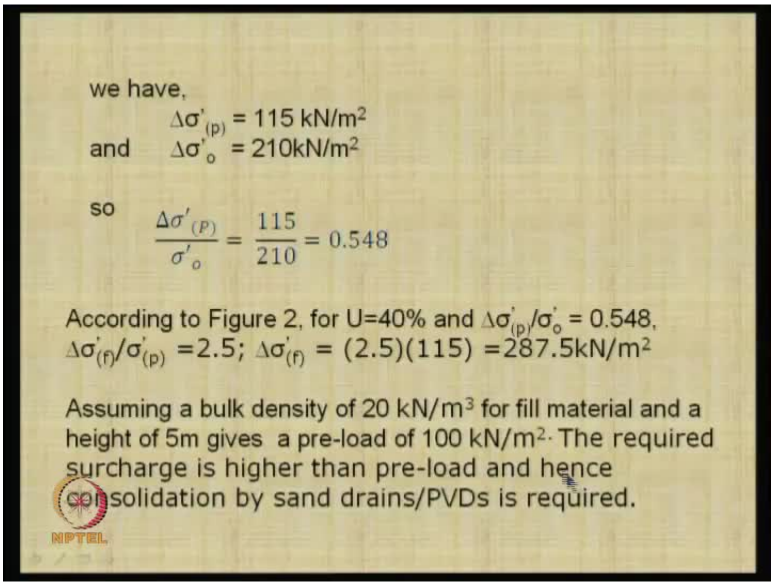

So that is the reason why we are trying to increase this degree of consolidation by other means.

In this case what is happening is, only the vertical consolidation is occurring. Now we try to use the sand drains or PVDs. Let us see what is going to happen. This can be worked out; it is a simple thing. The required surcharge is higher than the preload; and hence consolidation by sand drains or PVDs is required. So we will see.

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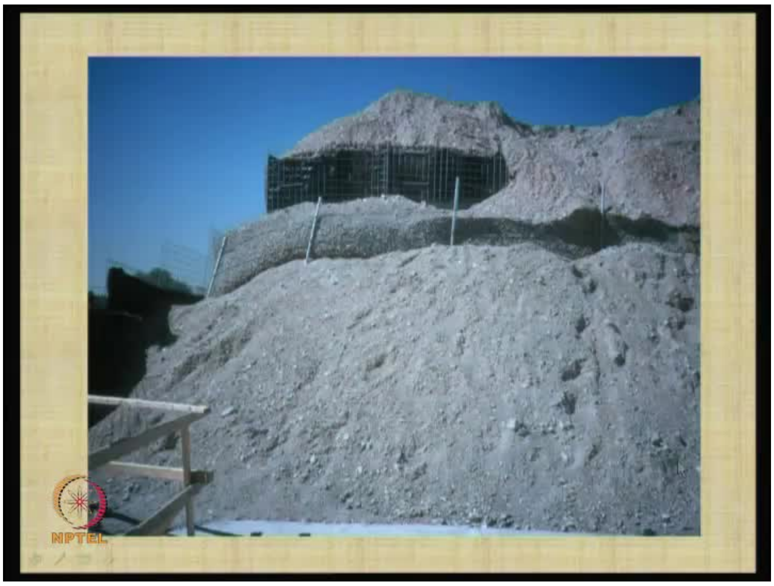

This is a typical pre load. How it looks, like it is so difficult. It is quite difficult, like, you may just dump it. May be this is about 5 to 6 meters or 7 meters, you have to make arrangements. However, we showed that the pre load is effective.

There are a number of issues; but still it is a technique that has been quite useful. People have used it for many years. Before 1970s and 60s this is a technique that people used.

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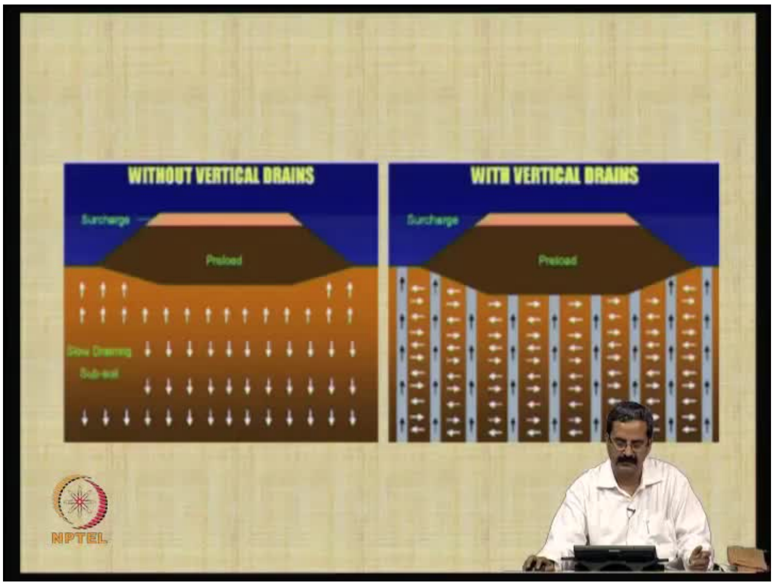

What is that advantage you can see here? Like you have a pre load and you have the extra, whatever the surcharge we are trying to place. The consolidation is only vertical slow draining sub soil, because the consolidation of the soil is less. That is the problem here, because of the provision of the drains like this. As I just mentioned, if you have drains, at every proper spacing and all that, you can see that there is a consolidation occurring because of that. So that is a reason why it is going to be very effective.

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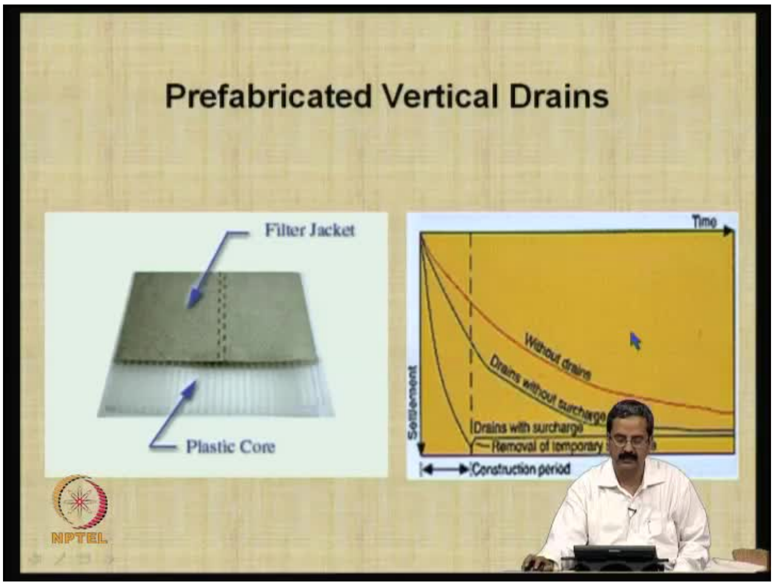

This is, as I said a filter jacket. You have a plastic core, and these things act as drainage channels. Actually, I must tell you the difference; sand is one thing that you can normally use for sand drains.

You will get it and the advantage of the sand drains is that if they are cheaper and economically viable it is alright; but the problem is that, in a period of time the clay and sand gets mixed up, and there will be a problem between the soil, sand and clay. There will be someplace where the permeability is again approved.

Sand column will not be complete sand drain. There will be some other extra, like you know, some area gets smudged or what we call, smear zone. That is, the permeability of the smear zone is very important.

The advantage is that, if you have radial consolidation, you can see the difference here. You can see the time, and then this is the settlement axis, and without drains this is the degree of consolidation.

Drains without surcharge are one thing. Drains with surcharge and removal, you can see that within this construction period. You specify that in some time all consolidation is complete, whatever settlement is over. So, this is a very ideal technique for accelerating consolidation.

So as I mentioned the purpose of the ground improvement technique is very important. In this case we are looking at accelerating consolidation as a main purpose. Say for example, if I say that sand can also work as stone column type of thing, we call it as sand compaction piles; but the difference is that, here it is drainage. The main thing in the sand compaction piles is the bearing capacity that is more important.

One should not mix up both the issues, and one should clearly understand the purpose for which it is designed. Here it is being used because it is a radial consolidation, and it has been quite useful in increasing the rate of consolidation.

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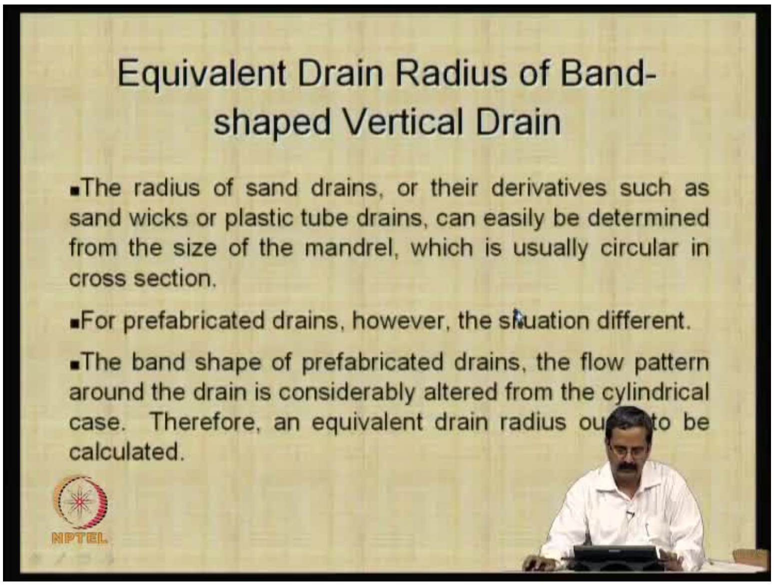

As I mentioned, the radius of sand drains or their derivatives such as sand wicks or, these are all its derivatives. Whether this is a coir one, or this is a jute one, they can all be. We say that sand drains are circular in cross section. Like, we just, say, 10 centimeters of the drain will use it because, this is actually easy to install. Why is this in this shape? The thing is that, the shape is very important. Here in sand drains, we actually make a bore and then put the sand and all that. Here we will see that technique where you install this thing, and then put. There is one specific installation technique here.

To suit that, you should come with the shape; and so for prefabricated drains, the situation is different, in the sense that, it cannot be circular. Actually the band shape of the prefabricated drains and the flow pattern around a drain is considerably altered from the cylindrical case. Therefore, an equivalent drain radius is to be calculated.

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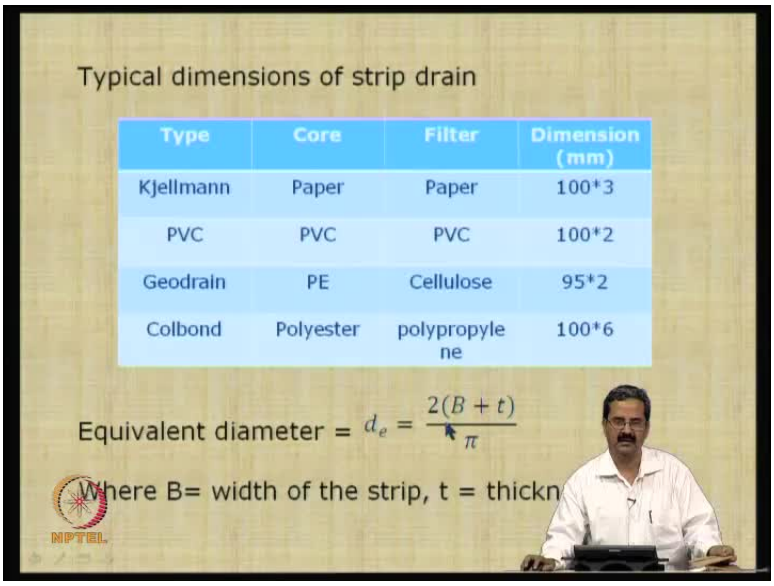

We have a standard diameter in the circular one; but here we try to use an expression like this, equivalent diameter is- 2 into B plus t by pi. This is what we use where B is the width of the strip. This is the width of the strip, and then this is thickness of the strip. So you get equivalent diameter.

So, just to get an idea, what is this? You can see that, it is about, may be, 900 mm or something like that, and these are all different sizes that you can see.

You can see that, Kjellmann is one of the popular persons who did lot of work in vertical drains. In fact, inside one is called core, and the outer one is called filter.

They were using cardboard papers for drainage, and the dimensions were 100 mm into 3 mm. Then PVC is one case, geo drain is another example. PE is the polyethylene cellulose, and colon is another company which has polyester inside. For example, this inside core is polyester and the outside is polypropylene.

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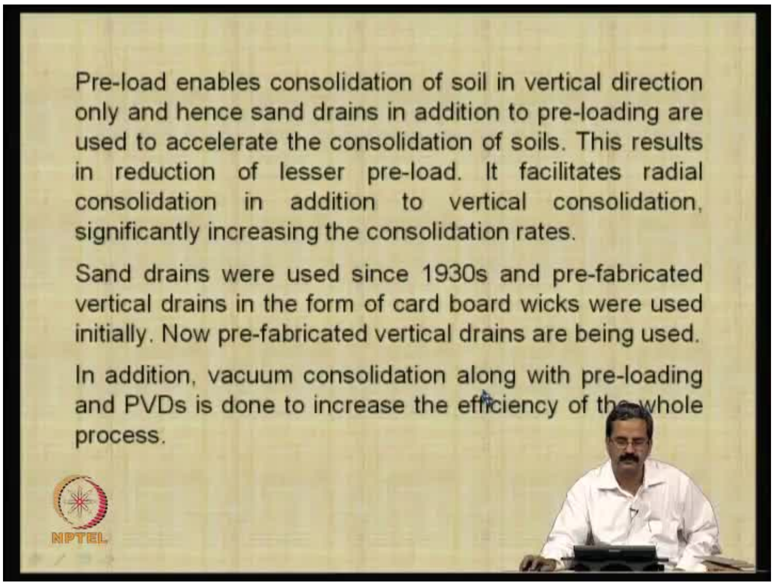

Essentially, the size is something very important. This is very crucial. You know, in the pre loading it is only the vertical one that is effective; but in the case of the PVDs and the sand drains you have the radial consolidation also.

What happens is that, it results in lesser pre load. As I just mentioned, I cannot get all our objectives. In this case, it was to increase the rate of consolidation. In the case of pre load, it was requiring a very huge amount of preload to be applied on the sample.

Here, what we are doing is that, we are able to have a good combination, and come up with radial consolidation in addition to vertical consolidation, significantly increasing the consolidation rates.

As I just mentioned, the sand drains were used since 1930s. Prefabricated vertical drains in the form of cardboard wicks were also used initially up to 1950s and 60s. Now prefabricated vertical drains are being used. Actually, this is quite effective, and in addition there are so many advantages in this area. One way of applying load is that, you apply some load, and you can also apply vacuum. What you are doing is that, you are removing water by adding or loading clay soil. You are trying to remove the water, or reduce the water content. Instead of that, you can as well apply some suction. Say for example, we are used to removing from the specific gravity test. You know we are to vacuum pump, so you try to remove all the air, and all the water, and whatever is present. You try to create a vacuum, which can really suck all the water. That is a one thing that we will see again, and so this is another major advantage in the recent times. We will see some of that.

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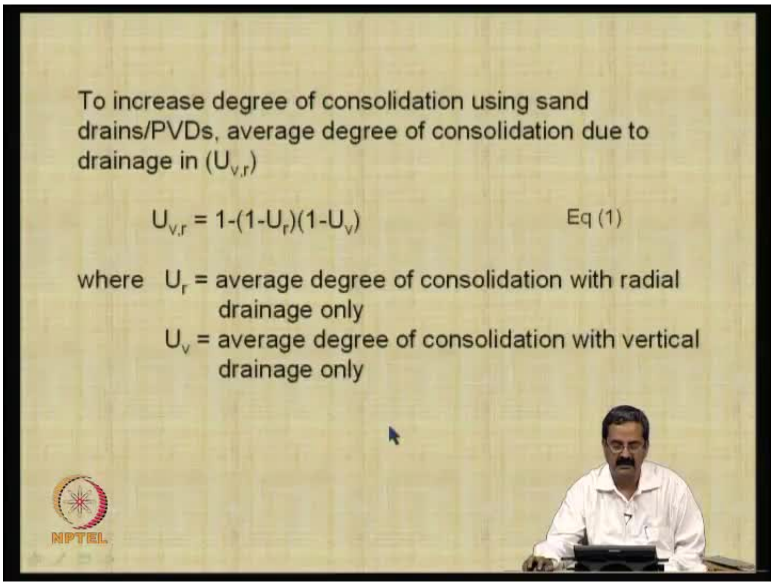

How do you go about calculations is very important. To increase the degree of consolidation using sand drains or PVDs, average degree of consolidation due to drainage is like, say, that U v r.

U v r is nothing but, 1 minus of 1 minus U r into 1 minus U v. So, both radial and vertical consolidation, and the degrees of consolidation are used. How do you calculate them is what we will see now.

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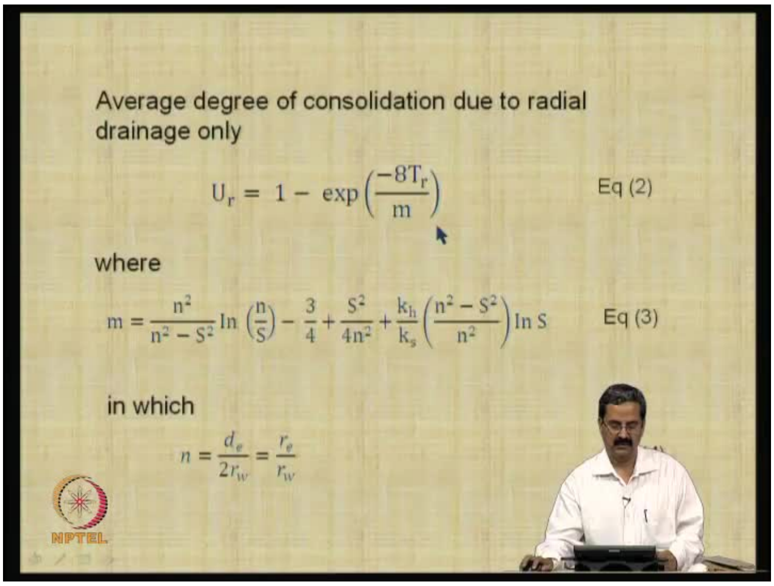

Average degree of consolidation due to radial drainage only; this is an expression which is derived. This term m is n Square divided by n square minus S square. S is spacing of the drains. This is an expression which will have the permeability of the sand drains. Actually, these two are the permeability of the soil in the horizontal direction and the permeability in the smear zone.

As I mentioned, between the two, you have a sand drain, and then you have clay here. Next to that, some amount of material, this we call as smear zone; and the permeability is little low there, immediately after the clay surface. I mean, immediately after the sand. From sand, it should come from the drainage medium. It should come to clay and the permeability needs to change drastically; but it does not. There is some area where there is a low packet of clay, where there is less permeability.

We need to calculate the drain spacing, which is nothing but r e by r w. It is nothing but, r e is the equivalent radius of the configuration, because we act and we assume that each drain has an influencing area around it, and then the radius of that is r e.

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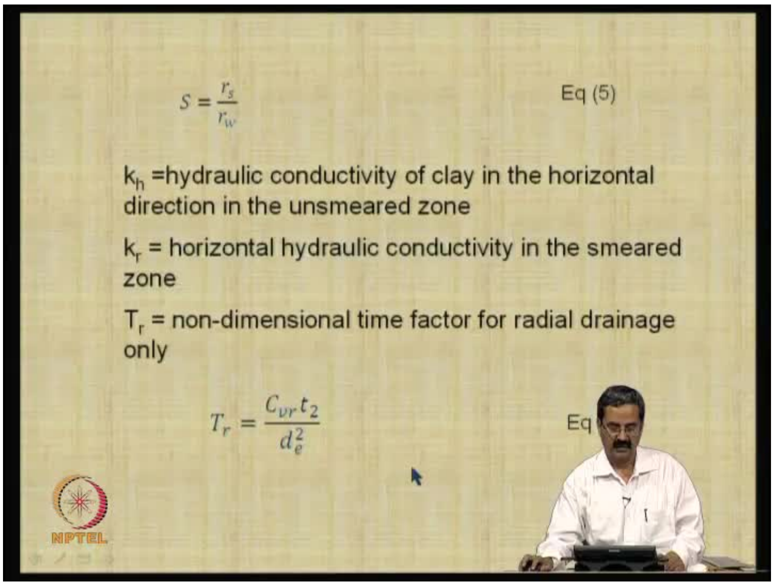

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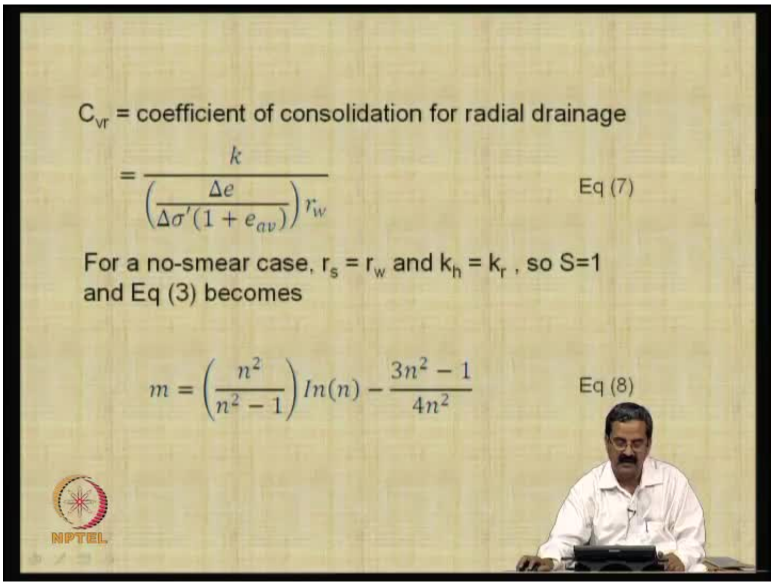

The r w is the radius of the drain, and then as I mentioned, k h and k r is the permeability. Once you know this, say for example, we calculated the C v r.

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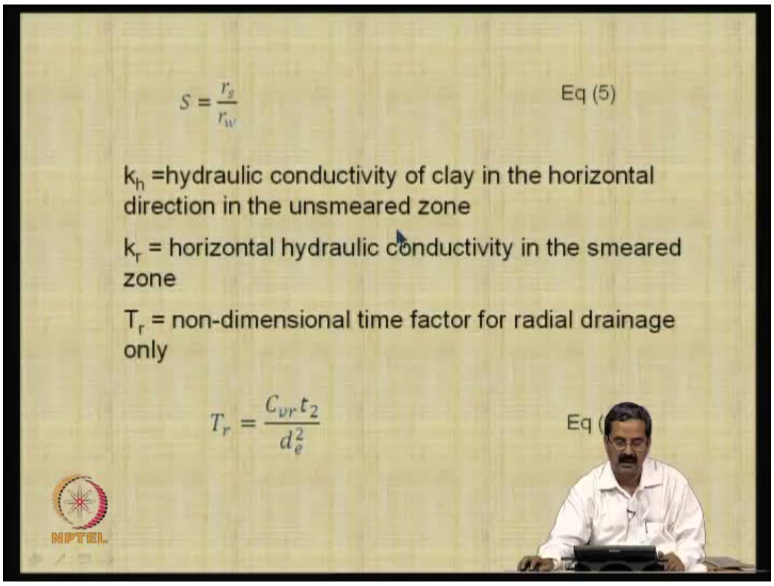

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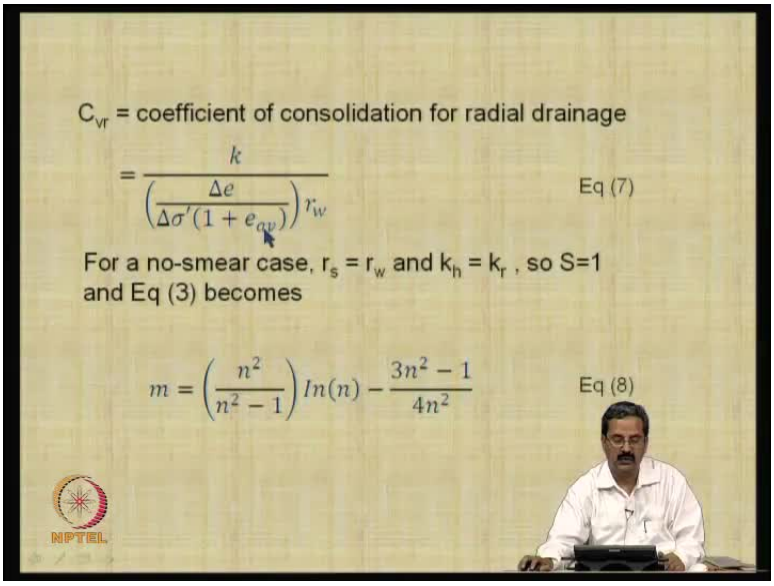

You have to calculate essentially, the time factors. You know this coefficient of consolidation for radial drainage, and you calculate changes in void ratio and all these factors. Once you know this radial consolidation coefficient, then our problem is solved. Essentially that is what we are doing. For no smear case, r s is equal to r w, and k h is equal to k r. S is equal to 1 and whatever is in the earlier equation is much simpler; and this is for radial consolidation.

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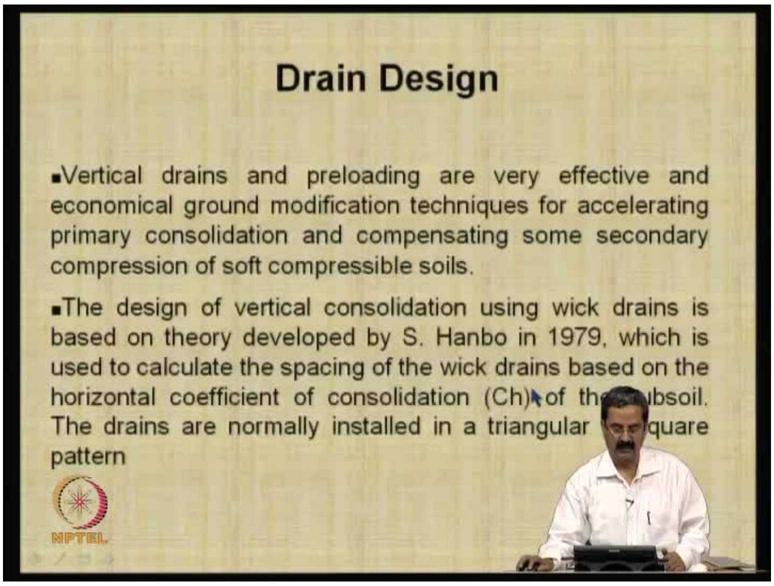

Next one is, you have a similar equation for the vertical consolidation, which we know from the soil mechanics theory like, T v by degree of consolidation between 0 to 61 equations. We have those things.

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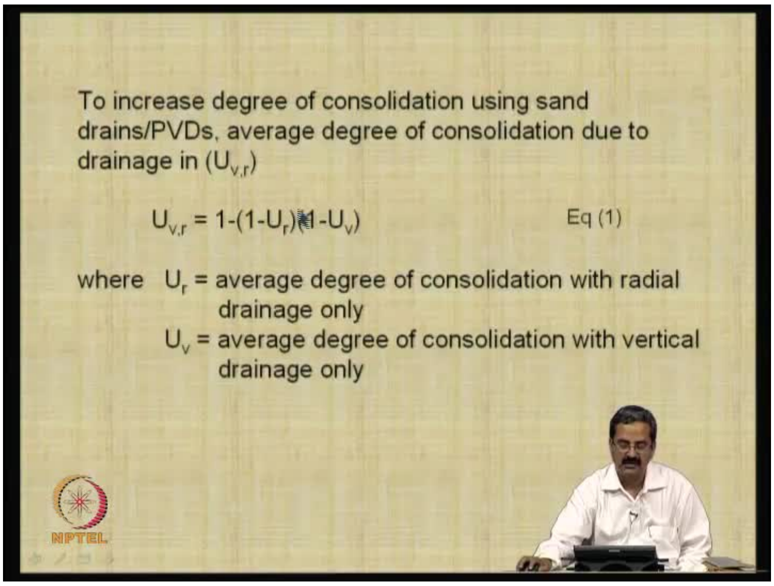

So use those equations and go ahead with design. Then use these expressions. U r is to be calculated. We know U v from fundamentals of soil mechanics, which is the vertical consolidation theory. So, using the time factor and all that, one can calculate. You substitute that, and there will be a big difference. This is the one that causes major difference. So this vertical consolidation is known. This is what you have to calculate.

This is a function of, as we just saw, the permeability of the soil. Permeability of the diameter also plays a role as we just saw.

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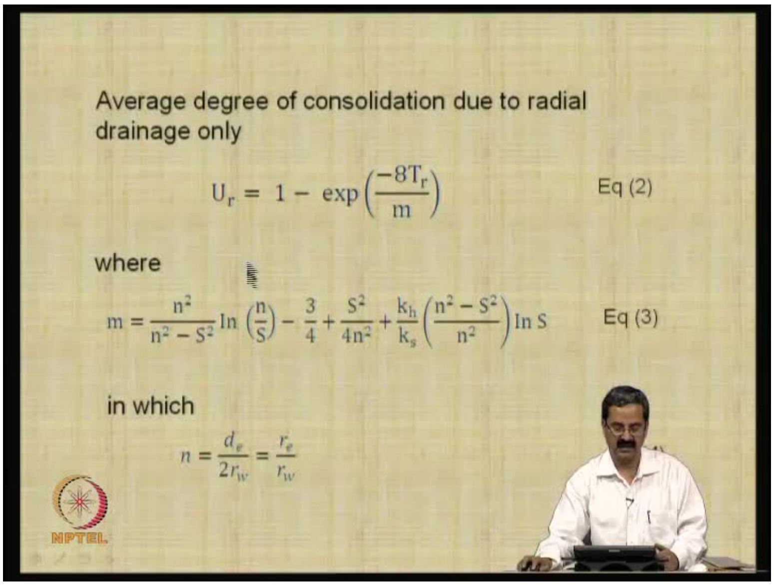

You know number of sand drains, like, how many sand drains you have to put finally and all that. All these things are important, and once you calculate that and use that in regular equations, like, one can get a simple degree of consolidation with drains or without drains. If the horizontal permeability is equal to vertical permeability what normally happens is that, horizontal permeability will be higher than the vertical permeability. You can calculate that also.

In fact, we have made some calculations, which I will show you later; where it is also a very significant variable, because many of the soils are stratified in nature, and we cannot take vertical permeability to be equal to horizontal permeability. Always the horizontal permeability is higher.

So once you put in that particular thing, then one can develop some sort of equations where the degree of consolidation without drains is very slow.

With PVDs, taking vertical and horizontal permeability as same, there will be very good difference; but if you really take the permeability in the horizontal direction as higher than the vertical one you get a very good difference too.

You may see that it is very effective. As I just said, within 9 months or 6 months whatever you want, you can design the spacing and all that; and then complete the project. That is the beauty here.

It is very simple technique, and one can effectively use that. We will see how it can be done in the field and all that.

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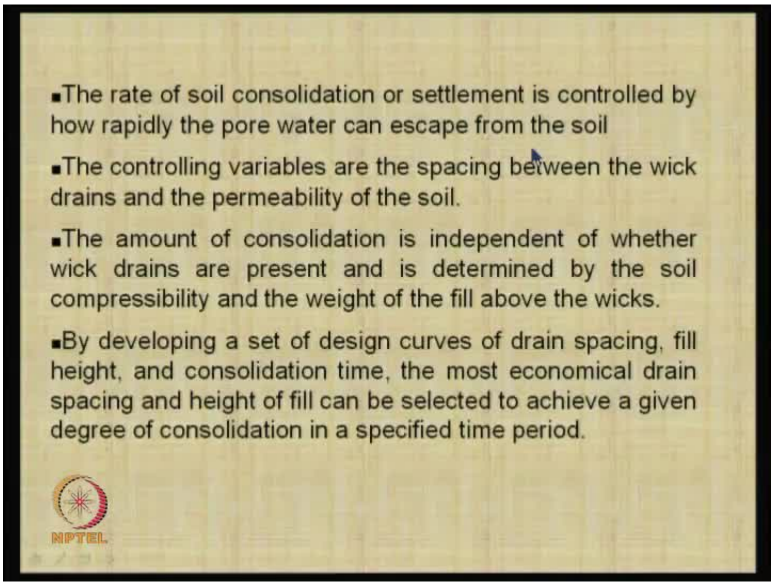

Essentially as I just mentioned, the rate of consolidation and the settlement is controlled by how rapidly the pore pressure can escape from the soil.

The spacing and permeability of the soil are the important variables. Actually, what we do is that, we develop a set of design curves of drain spacing, fill height, and consolidation time. The thing is that, there are 3 or 4 variables here. The thing is, you also have the preload. Preload is there; but if you want to minimize the preload, like you have to see what spacing you should provide, if you provide a wider spacing the probabilities is that, the preload will be higher.

Then if you want to reduce the preload, you need to come back to a closer spacing. Then the permeability also you cannot change. The permeability in both the horizontal and vertical direction should be measured in the field. Laboratory test will give you some information, but then, field permeability results are very going to be very accurate;

because you cannot make an error in this case because, everything depends on the permeability of the in situ soil.

You need to develop a set of design curves. It is a parametric study that one can do. Addressing what should be the fill height, consolidation time, the spacing, and all that. You will get reasonably, like, you have specified. Say for example, instead of 6 months you want to show 1 year. You can say that, the thing depends on your requirement. If you can allow for 1 year, it is different from 9 months. You can do a parametric study of all these factors, and fix up a particular and the most appropriate thing. Like for example, the fill quantities. The fill quantity is that which you want as preload. You may be limited, so you need to consider that. That is an important variable because it is going to be very expensive.

In a project, to get pre load from different places, you need to say 5 to 10 meters. If you want to construct it, it is not possible. So, you would like to reduce it to a maximum extent, and see that there is an optimum combination of all these factors, and that it is going to be cost effective.

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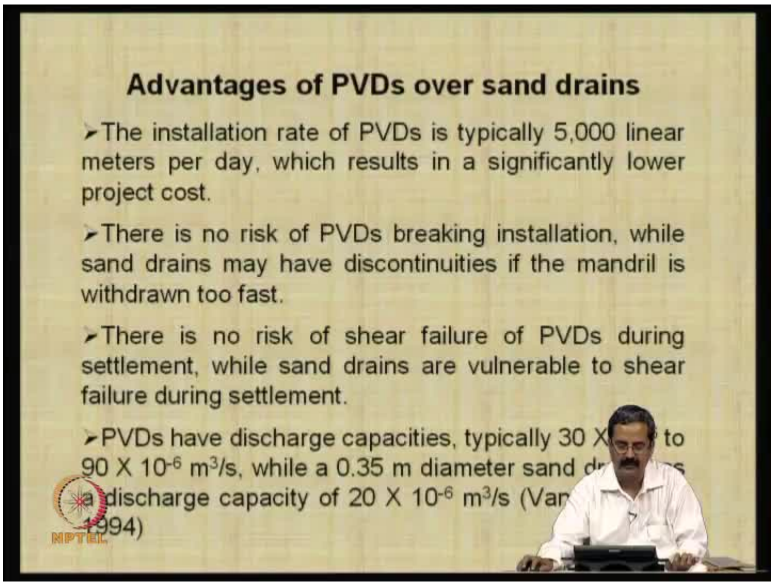

I would like to just highlight some advantages of the prefabricated vertical drains over sand drains. In fact, sand drains have been effective; but the fact is that, these are all sand drains which have a sort of a bore, and then puts the sand material; whereas, for some materials, you have to have machines to do that. In fact, 5000 meters per day can be done. It is very fast; like, one can do very fast. What you should do is that, you just say 10 meters is the depth of soil to be improved. So, there is a machine that takes it down. There is this thing it does. You have to cut it, and then a drain gets established.

The advantage is that, they are very fast. That is the number 1 reason. There is no risk of PVDs breaking installation, while sand drains may have discontinuities if the mandrill is withdrawn too fast. If you remove that particular mandrill, the problem is that, these are all somewhat stronger material. In fact, the sand material fills by shear strength and all. Those things are some of the important ones, and they may have discontinuities also in the process of doing that.

It may not be as good as compared to this. The number 1 reason is that, the shear filling of the PVDs during the settlement is less; whereas sand drains are vulnerable to shear failure during settlements. There could be some movements and all. That it is not easy in terms of the quality control.

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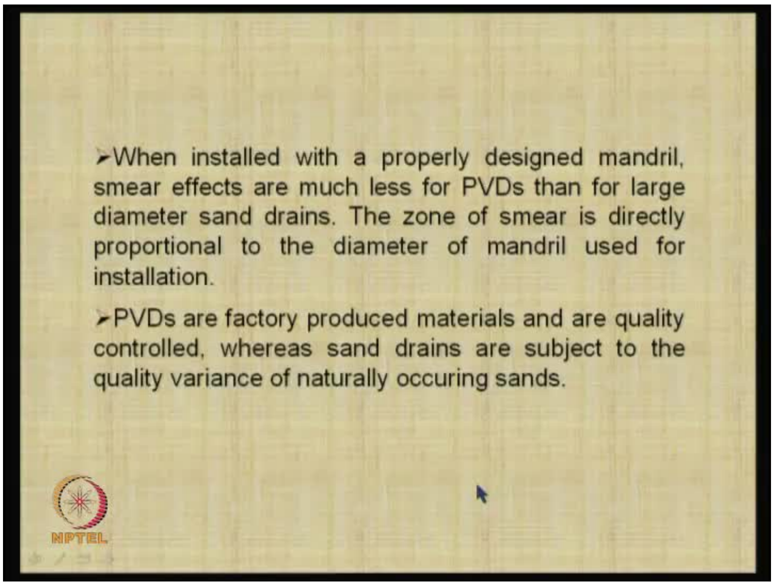

The other important thing is that, PVDs have discharge capacities, which are very high. Actually, the beauty here is that, as I mentioned, this filter always allows only water, and all the clay is outside. It is then only water that goes inside. So, it is an excellent filter cloth; and the inside is the excellent drainage cloth. All the water will come up. It gets pumped up, and either it goes down or something. It is all by gravity, what is released is because it is open to atmosphere. Then water comes out. So, you can see that the drainage capacities are quite, say for example, 30 to 90 here. Whereas, the discharge capacity with, say, 35 centimeters diameters, sand drain has a discharge capacity of 20 into 10 to the power of minus 6 meter cube per second. How much of water? This is here. You can see it is more- 30 to 90 about much higher.

When installed with a properly designed mandrill, smear effects are much less for PVDs than for large diameter sand drains. As I mentioned, the sand drains have smear effects. The zone of smear is directly proportional to the diameter of the mandrill used for installation.

PVDs are factory produced materials and are quality controlled. Whereas sand drains are subject to the quality variance of naturally occurring sands. Sand occurs naturally, it is a natural material.

There could be problems of gradation and all that. It is not easy to get; but whereas it is quite simple. The thing is that, the purpose that you want to have from sand is a good drainage, but that depends on the gradation characteristics of the sand, its availability, its time effects, and there are so many issues. Of course, the time is short here. Like, you would like to have about 9 months. The fact is that, they are all process materials. That is a very good advantage.

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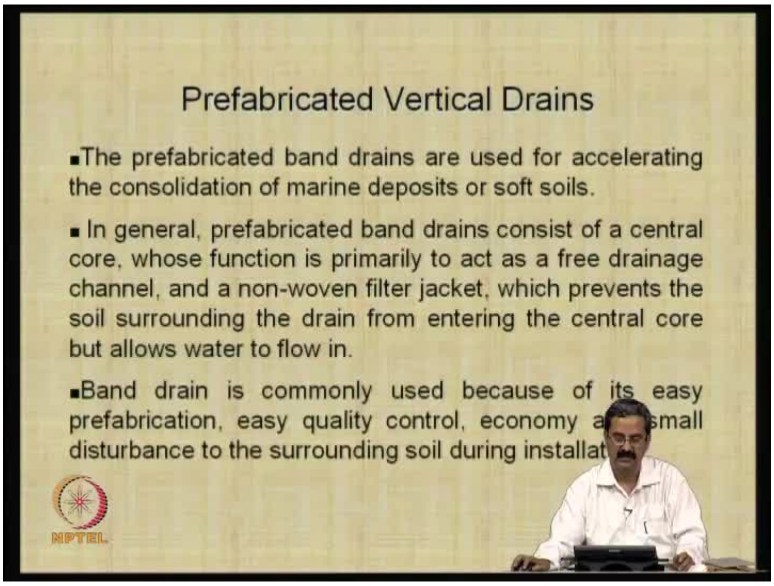

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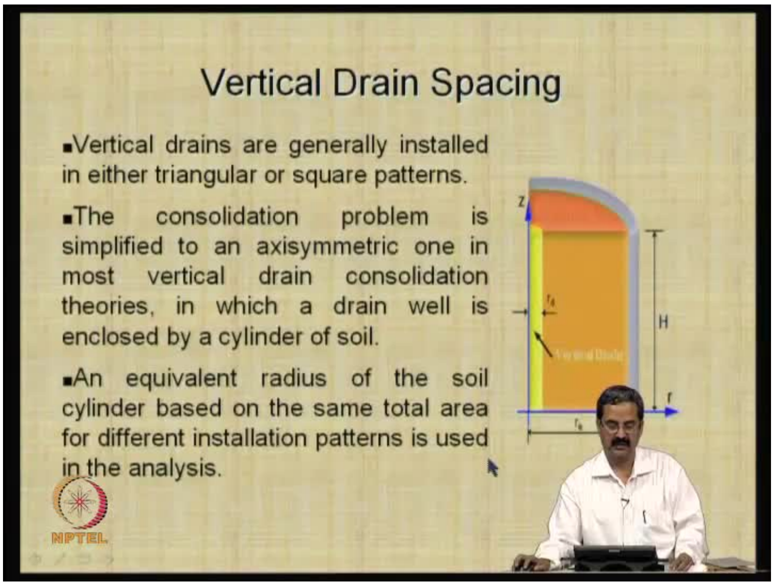

That is the reason why- because of its ease with which it can be done. Like easy fabrication, easy quality control, economy, and small disturbances from soil during installation. These techniques are particularly using PVDs in a significant way. As I mentioned, the vertical drains can be in some spacing, either it can be triangular or square, similar to stone columns.

Consolidation problem is simplified to an axisymmetric one. Say for example, there is a Baron’s theory of radial consolidation. One should read that. There is a Baron’s theory of radial consolidation which is we know. That is a 1 dimensional consolidation, which is vertical. So, you need to read this, Baron's papers and some more additional papers which we have. It is a very classic work. So, we use that particular thing, and we assume that we have a material here. Then it has an effective drainage area, and that is what we call it.

An equivalent radius of the soil cylinder based on this same total area, for different installation patterns is used. Say for example, installation is also an important variable here.

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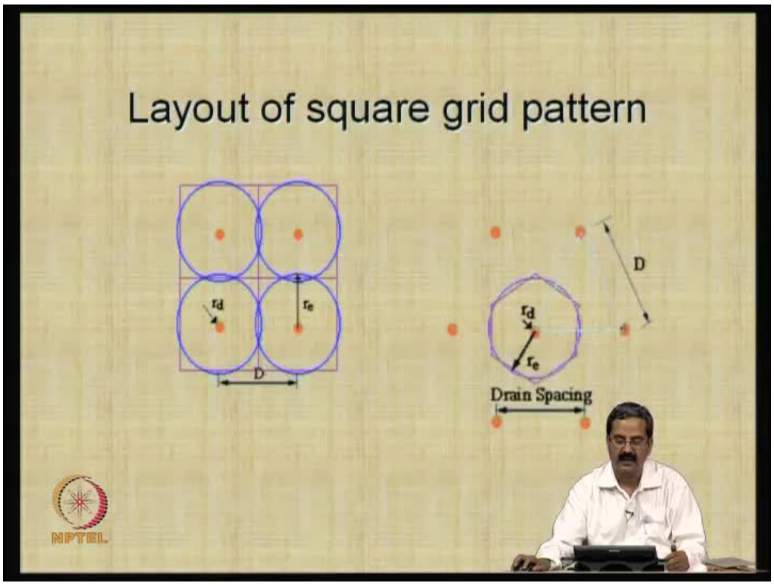

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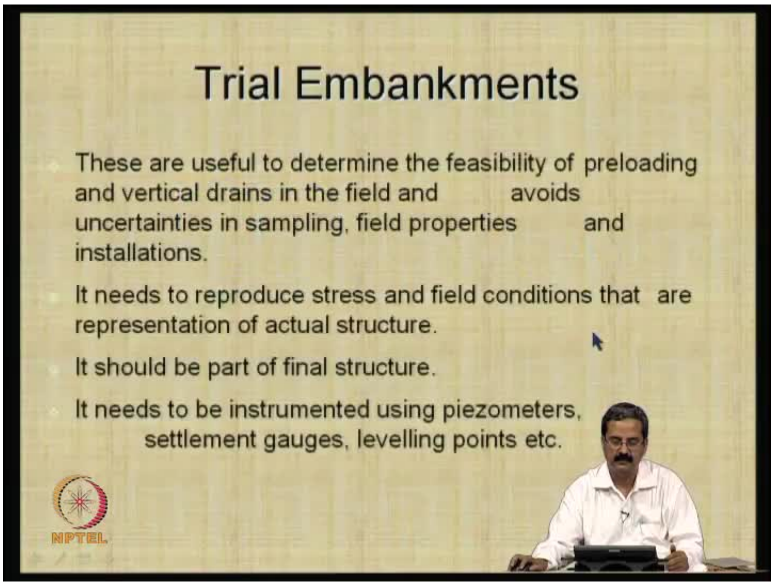

This is a square pattern. This is one way. You have 4 sand drains here, and the triangular is also one thing. Like, it can be a hexagonal type. This is one important thing. A very important thing is that, when you are trying to construct the preloading, and all these equipments, or even the sand drains, or even the prefabricated vertical drains, one should really do some sort of trails in the field.

How do you do the trails in the field? Actually, this is a very popular concept in west, particularly in Netherlands. Say for example, if you go to Scandinavian countries, like Denmark, Finland, and all the soil is soft and many of the techniques will not work.

The maximum ground improvement techniques were done in those areas, in the 60s and 70s. Even now, it is an exciting area for geotechnical engineering. If somebody has a chance, it is an exciting area to be in. Countries like, Scandinavia, Denmark, Netherlands, and Finland, all have lot of geotechnical activities going on. They have done lot of quality work, and they have been trend setters for the rest of the world.

They say, because we try to work on the properties that you obtain from the lab, or from the field, and then you are trying to access the performance of the embankment.

Best way to construct an embankment itself, like 5 meters height or 3 meters height or whatever height you want. The advantage is that, if you have that type of thing, it avoids the uncertainties that you have, with reference to sampling, and other difficulties like, installation. The other advantage is that, if at all you have decided about constructing a pile embankment, say for example, if you are trying to construct a 5 meter embankment connecting two villages, say for example, villages are 20 kilometers apart. You need a highway embankment between the two villages. Then, the height of the embankment is about 5 meters, the slopes, and everything is known.

You can as well construct about, say for example, 100 meters or 50 meters of trial embankment, and then do all the experiments, before you really take up the work. Once you understand everything from that, then, that can be used as input for improving the rest of the work. That is the thing that we are trying to do here. So, it needs to reproduce the stress, and field conditions that are representation of the actual structure.

So you can use whatever information you get from that in a proper way. It is better that it is a part of the final structure. Say for example, if the alignment between two villages connecting them by a distance of about 20 kilometers, that particular thing, for example, 50 meters, could be a trial embankment.

In fact I have had opportunities to see many trial embankments in Bangkok. Bangkok soft soil is so bad that they did, particularly Asians did so much of work on soft soils. They have particularly professor Bergado, and there are many people working. Then, Singapore soil is also very soft, and very tricky. You know, clay problems are always tricky.

They did lot of work using some of the concepts. They say that, it should be the part of the final structure. Actually the thing is, you have to measure the performance of the trial embankment. How do you do the measuring? You have to measure the pore pressures. You have to do the settlement gauges. You have to have leveling points, and all that. Essentially, why you are doing is because, our objective is to reduce the settlements.

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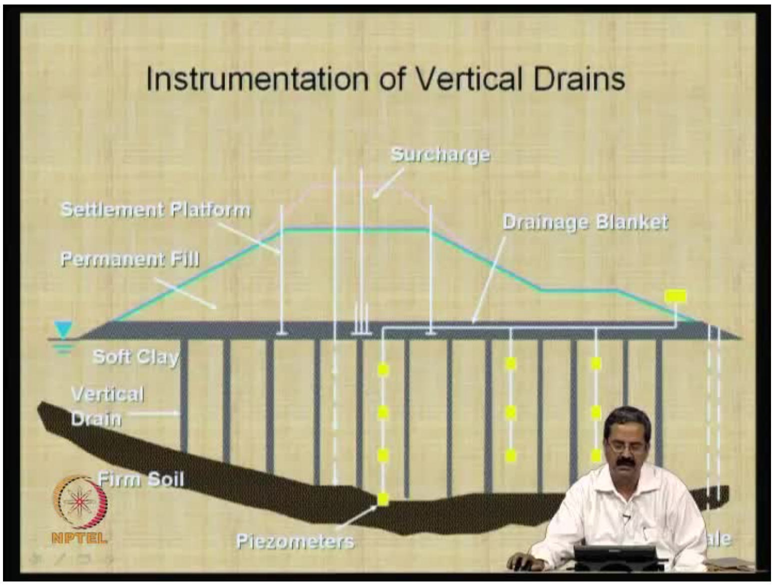

You can see here one simple example. See, there is a water table here. Most of the time, there is always a problem. Water is exists there, and you are supposed to construct. Sometimes, you should construct the water also.

How do you do this? All this is soft soil, here. Then, you have an embankment here, which is supposed to be a proposed embankment. You can put a surcharge like this here.

You can put a surcharge here, so, this is a drainage blanket. See, these are all the PVDs or sand drains. The thing is that, the sand drains, as I mentioned, when the water comes out they are open to the atmosphere.

There is no pressure there. That is how it is, and these are all that. Here you see that, these are called settlement platforms. You have to see how a whole embankment is settling. You have 1, 2, and 3 settlement platforms that have been installed. You can clearly see that, they are installed in the drainage blanket. It is very clear. Then, this is the either side of the central line. It is also very clear.

You have the sort of settlements gauges clearly. Then, the piezometers. You are trying to measure only one side of this thing, because, this side is actually a uniform area. You can see that the area is quite uniform.

You put piezometers here. Piezometers measure pore pressures, because you are applying load; and when you apply load, see the thing is, before construction of this embankment, there is no pore pressure, is it not?

There is no pore pressure. Like you know, you are trying to measure pore pressure here. There are 4 points here, so, you are trying to construct pore pressures.

What we do is that, these pore pressures are continuously measured. Whatever frequency of intervals there could be, and once you measure the pore pressures, and settlement gauges, you will be much more comfortable.

That is a very important concept here. That instrumentation is a very vital component, particularly in soft soils. So much of work was done on these lines. You are applying some stress. Then, you are trying to measure the pore pressures, and you are trying to measure the settlements.

Constitutive modeling has been a very powerful tool to understand all of this. Like, suppose there is an extra load applied. How much of pore pressures has been mobilized? How much of settlement has occurred?

That is what one can do here. See, they keep on constructing. The way we start is that, this is a pore pressure, and this is a settlement gauge. The moment you put some layers of, say for example, 1 meter embankment. Then, the pore pressures will be mobilized, and the settlements induced. Measure the settlements and the pore pressures. Put one more layer of compaction, or the sand. These are all embankments. Keep on putting it. Even put the surcharge also. Monitor for at least 1 year, or 2 years. Then, because it is one full season, it will give good information.

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This is how we do that. This is a typical construction. In fact, you can see the sand is coming here. This is what it is going on in the paddy field.

In fact, this is what I was seeing in Kerala also, where you have a lot of paddy fields. Then, between two villages, you try to construct a road. You have to reduce and destroy all the paddy fields. Then you can go ahead with the construction. So, what I was wondering is the cost of development. It leads to reduction in the food grains consumption in the area.

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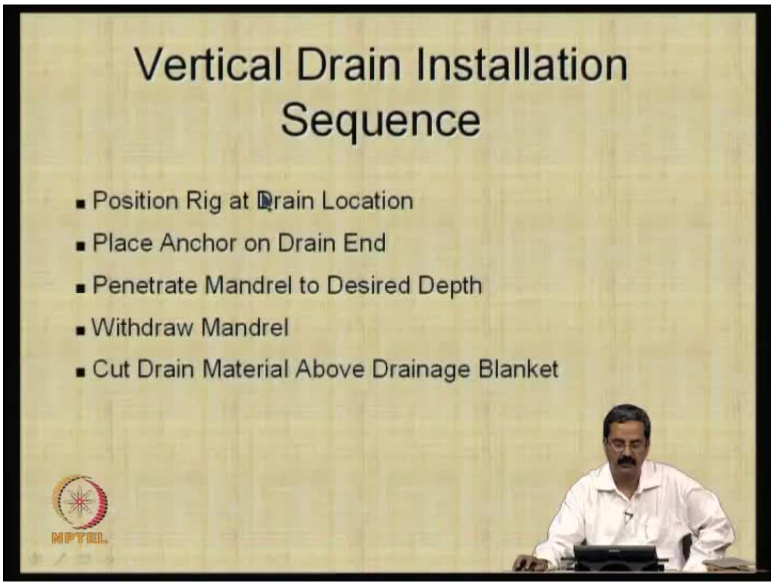

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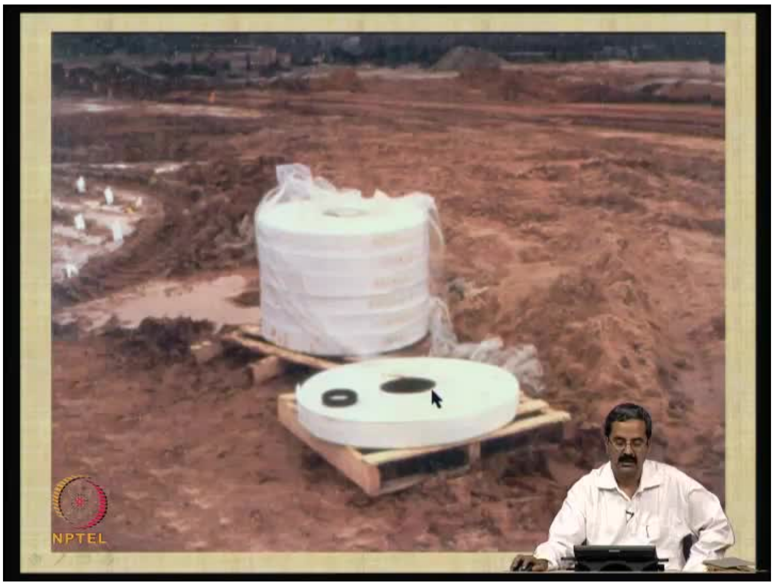

How do you do that? Actually, we have to have a rig here. You have to position the rig at the drain location, and place the anchor at the drain end. Penetrate the mandrill to desired depth. Withdraw the mandrill, cut the drain material above the drainage blanket. That is what we do. This is the type we have.

This is all, like I mentioned all these roles to about, the cost may be per meter of some numbers, like, 2 dollars or whatever. In fact, the 30 rupees, including the cost of installation also, I mean there are some different rates, one needs to workout in consultation with the suppliers. You have suppliers, and you have installers also. You have full time persons taking care of everything.

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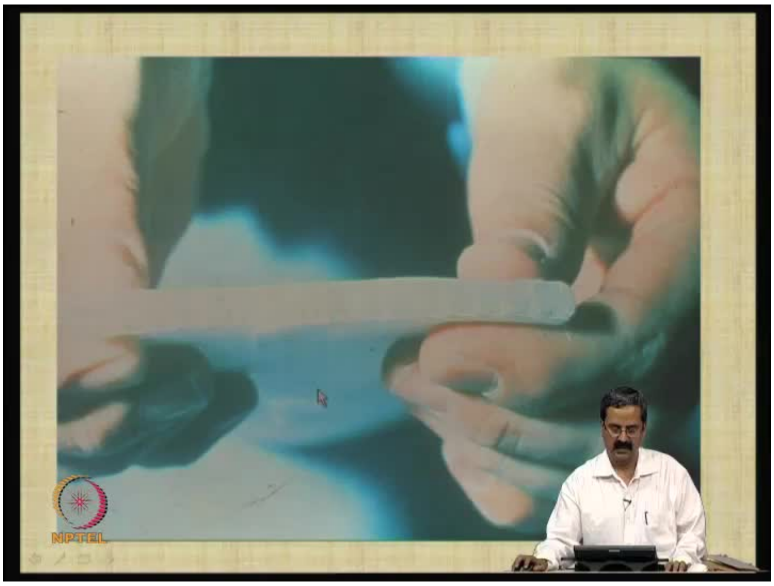

So, this is that particular drain.

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This is done in the field. You can see that this is that mandrill.

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This is like that first one.

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Then, you insert it into the soil.

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You cut it, here leave it here.

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It is like this.

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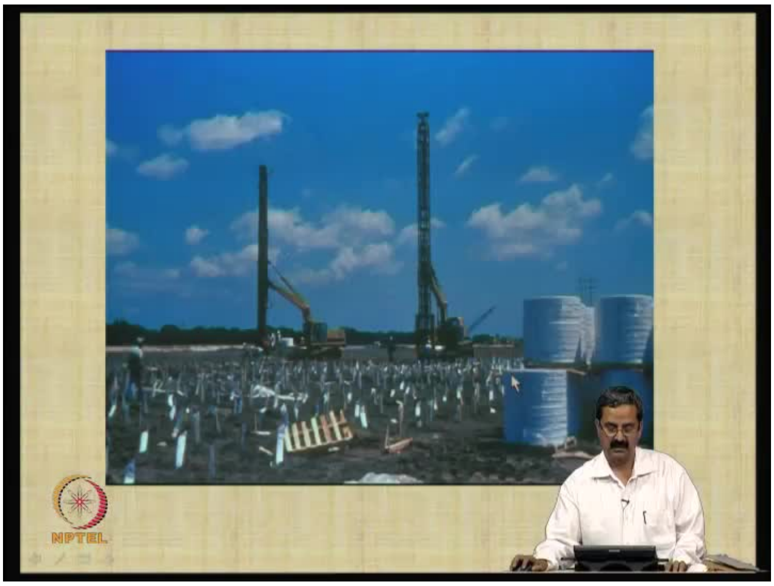

Then, put your sand blanket, or whatever.

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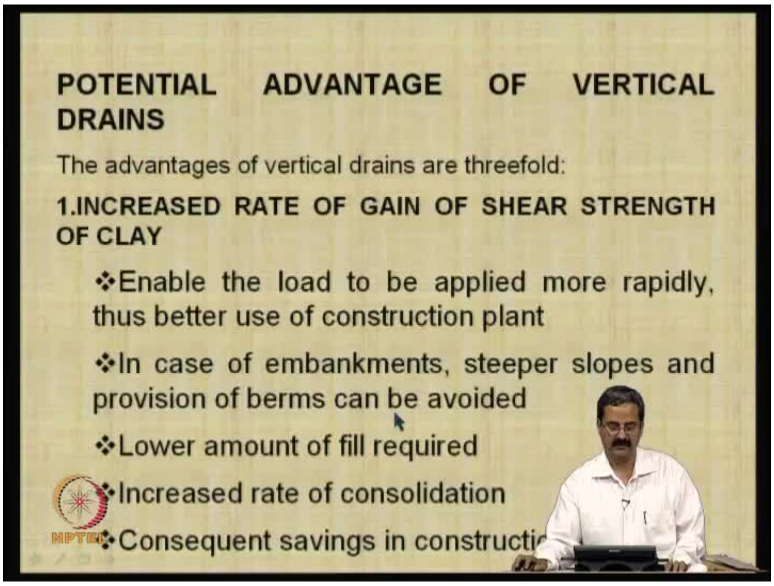

The advantages are that, it leads to increased shear strength of the clay. It enables the load to be applied more rapidly. Thus, leads to better use of the construction plans. In case of embankments, steeper slopes and provision of berms could be avoided

Sometimes, these are some of the standard techniques of provision of berms, to improve the stability, and all that is normally done. Lower amount of fill is required. As I mentioned, it greatly helps in reducing the amount of preload required, an increased rate of consolidation, and it saves a lot in the construction.

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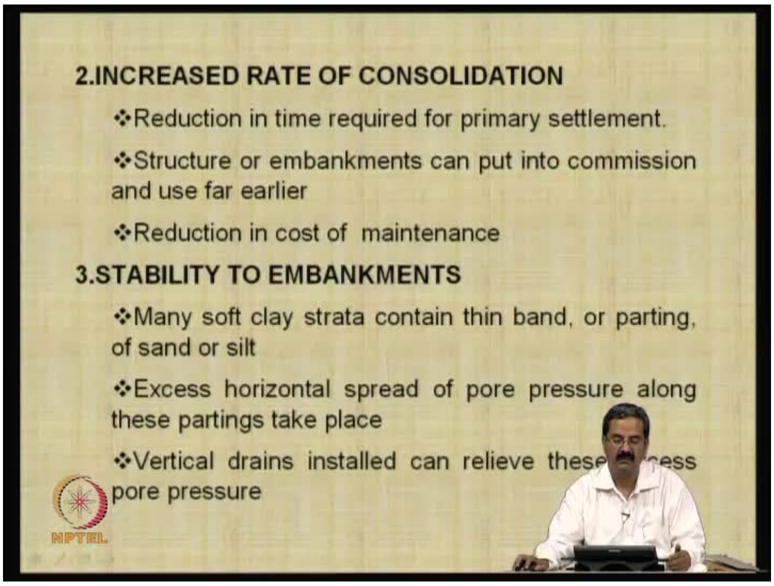

Increased rate of consolidation, and reduction time required for primary settlement structure, or embankments can be put into commission, and far earlier reduce the cost of maintenance.

In fact, the other thing is stability to embankments. Many soft clay strata contain thin bands, or parting of sand, or silts. You know, in some places where you have alternate layers of clay, and you have a sandy material, so, there will be some pore pressures developed and all that. If you have a drainage system like that, it will release all this excessive pore pressures. That is a very important thing.

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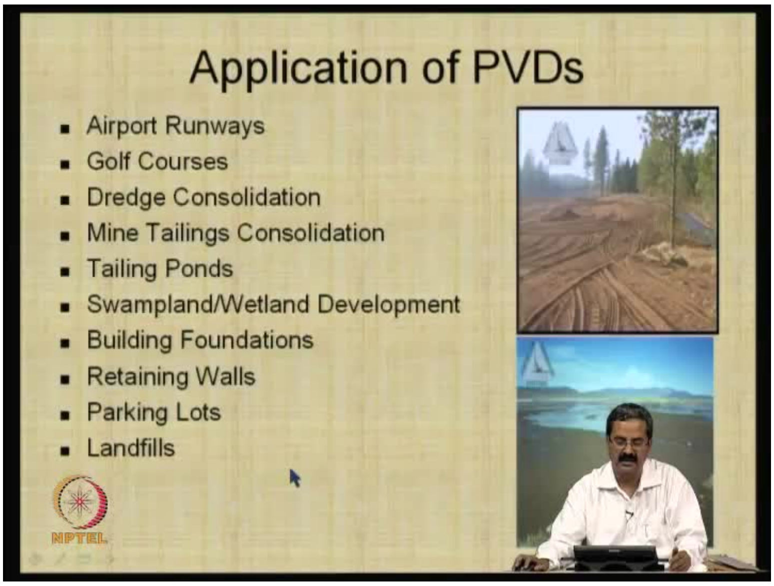

Applications of PVDs have been too many. Like, people have been able to use in airports, or golf courses, dredge consolidation, mine tailings, tailing ponds, swamp areas, and wetland development, building foundations, and retaining walls. In fact, it can be even used for drainage purposes also. Parking lots, landfills, and wherever there is a possibility of increasing the acceleration of drainage, or the consolidation response, these are been quite effective.

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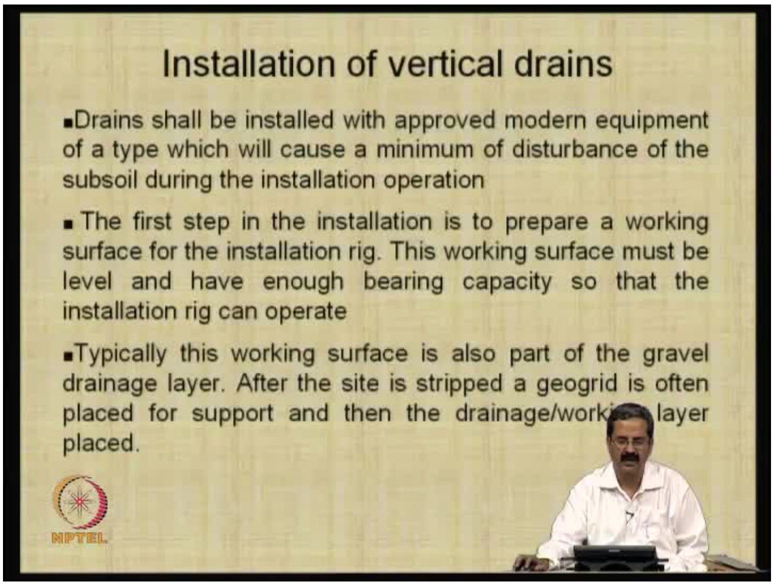

Nowadays, of course, these are all about installation techniques, where it can be done with modern approved equipments, such that there is a minimal disturbance to the sub soil. So that it does not lead to the permeability being low here. At this stage I will stop, and we will continue it further. Thank you.