**Ground Improvement**

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**Module No. # 06**

**Lecture No. # 18**

**Ground Treatment with Lime – II**

In this lecture, what we have seen is that, in the previous lecture we know how to calculate the total; I mean the ultimate bearing capacity; then different settlement and also we will now see total settlement.

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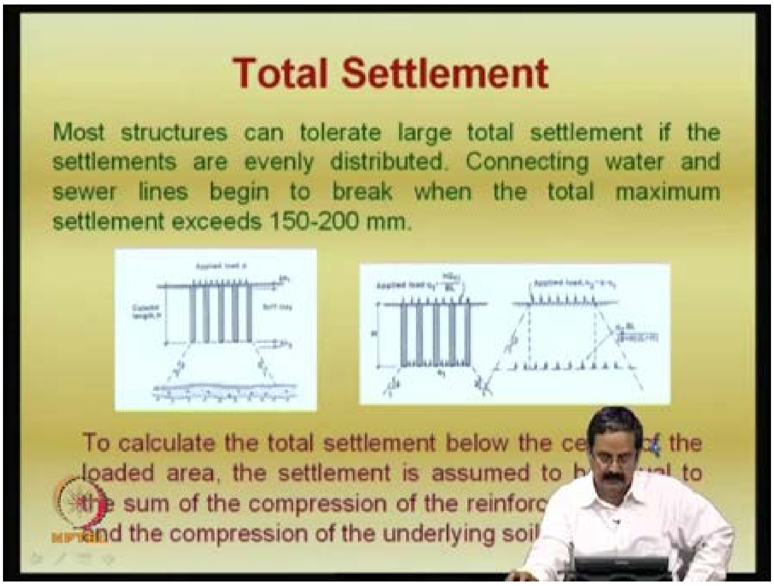


Actually, these settlement calculations, bearing capacity improvement calculations are very important and we need to compare them with the actual results also. You know, for example, the design issues in many of these mixes are very important and for which we need to understand some mechanics part of it, like say, for example - the total settlements, how do you calculate in the case of lime treated soils? Actually, these methods are applicable to all types of materials, soil materials which are treated with, like say, for example, instead of lime columns, you may have stone columns or anything there. People have developed at various times, some design methods, and if you look at the literature, there could be different design methods, but one should understand that all these methods are based on different theories and also lot of practical experience, and the results from each method could be totally different.

But what normal practice is that, people calculate all the values like ultimate bearing capacity, then settlements, then all that, then predict with what is observed; we will see that. And the total settlement predictions are very important and how do you do that is that, like, we have a simple theory which is based on load distribution. This is again an approximate elastic solution theory in which the settlement is composed of two components, that we will see. Why this settlement calculations required are essential, is that say for example, the water supply lines and sewer lines have tendency, like you know, they cannot tolerate differential settle total settlements. If the settlements are going to be higher in materials, then they have they have they crack and all that break up.

So, here you can see a simple diagram in which this is the loaded area, you know, these all the loaded area. You would like to calculate the settlement. What we assume is that the settlement is assumed to be equal to the sum of the compression of the reinforced block.

Actually, this is the reinforced block like see the thing is, this is all strong area compared to the rest of the area and we assume that if there is a settlement of delta h 1 here in the area and then it gets now. There is nothing that exists here, like most of the times there will be always a question that should I take it to the hard stratum, you know like should I say the hard stratum is 10 meters, 20 meters.

So, you take the length of the pile to twenty meters. Actually in most of the stone columns, you will have this or even piles we have this question, but it is not necessary. We have to calculate actually you know, do we know the depth of pressure bulb concept that beyond certain area, loads may not come.

So, if the loads are not coming here, then there is no point. So, at least you need to you do not need to extend the columns to the bottom most level. That is what the point is. So, what we want to do is that you have to calculate this reinforced block delta h 1 settlement and also the compression of the underlying soil, because of this applied load it has two components delta h1 and delta h 2 and you are trying to calculate that.

So, you can see that the load here is about the load that is applied and then load applied on each of this is it is b is area and l is that whatever say for example, assume that it is a tank foundation or some rectangular foundation you have to put that b into l properly.

And it can be even 1 meter length in the case of a payment; the high way embankments you can just take it as one meter and then do that or whatever. So, here the applied, this is a q 1 load that is applied onto this block and then we assume that the q 1 also acts here. And now, the load acting here is q 2 is nothing but the q minus q 1. You know whatever is that load and then how do you get this see this is q 2 here q2 and then what is that it gets distributed here.

So, that distributed load is in terms of the again as I said, b plus h into l plus h. It is like we assume that it is a1 is to 2 rule is followed. So, it is like add on both sides; this becomes instead of b into l, this becomes b plus h into l into h. So, here this is p.

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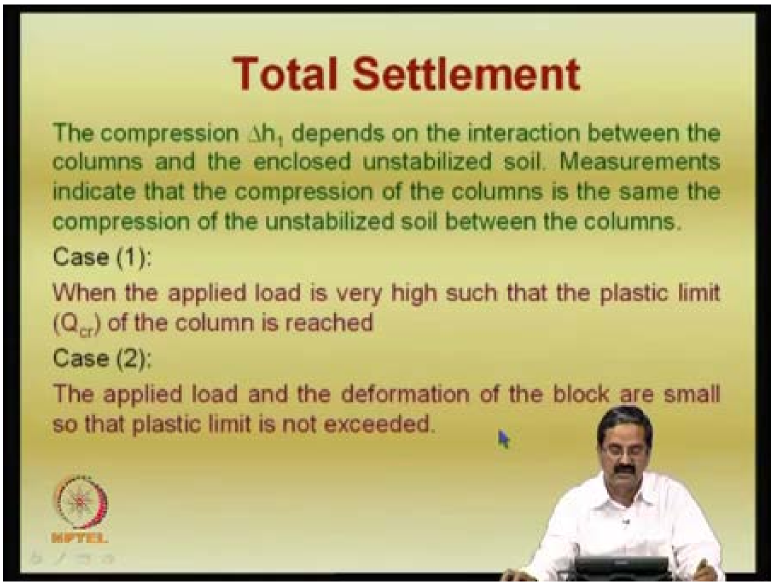


The compression delta h1 depends on interaction between the columns and the enclosed unstabilized soil. The measurements indicate that the compression of the columns is the same as the compression in the unstabilized soil between the columns.

So, we normally say that the settlements are, we assume that because there is a strain compatible to we call it. Measurements indicate that the compression of the columns is same as that of the unstabilized soil.

What is happening is that, load is coming more on the column than the soil; which means that the moment the load is applied, there is they do not have unequal settlements. That is what it means. And there are two cases here, when the applied load is very high such that the plastic limit of the column is reached, like we call it highest load and second thing is the applied load at the at the deformation of the block are small.

So, that the plastic limit is not exceeded. Actually if the loading is higher or lower, we have some analysis here, some understanding of the analysis. As I just mentioned, we have different ways of doing this some of this issues.

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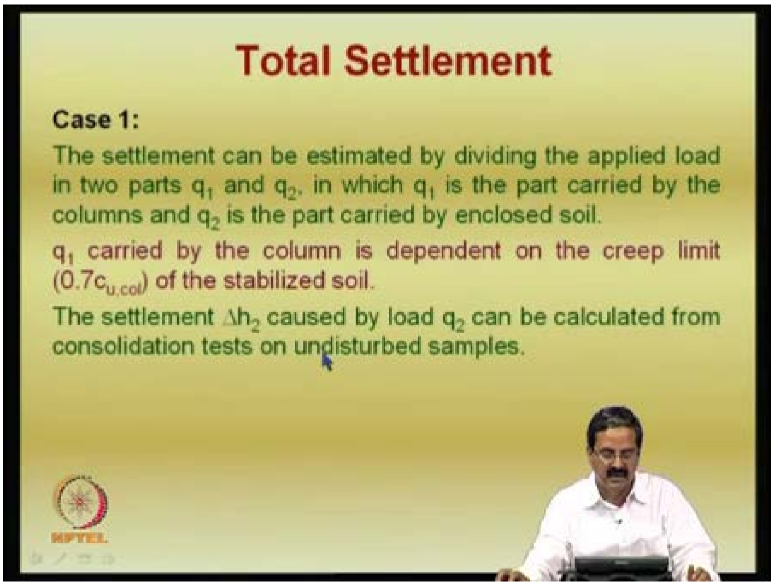


Total settlement, this settlement can be estimated by dividing the applied load into two parts q1 and q2 in which q1 is a part carried by the columns, q2 is the part carried by the enclosed soil. q1 in a column is dependent on the, actually this is a it is not actually the creep limit the limit like you k Now, plastic limit of the soil it is (( )) the c u l of c u l of the of the of the stabilized soil.

If you know the bearing capacity, the c u of the stone column now the lime column treated lime column say for example, you get some 10 kPa (( )) soil, I mean say 20 kPa or something you may get hundred kPa as that treated material here. Hundred into point seven 70 kPa would be the loaded. That is a limit. The settlement it has caused by the q 2 can be calculated from the consolidation tests on undisturbed samples.

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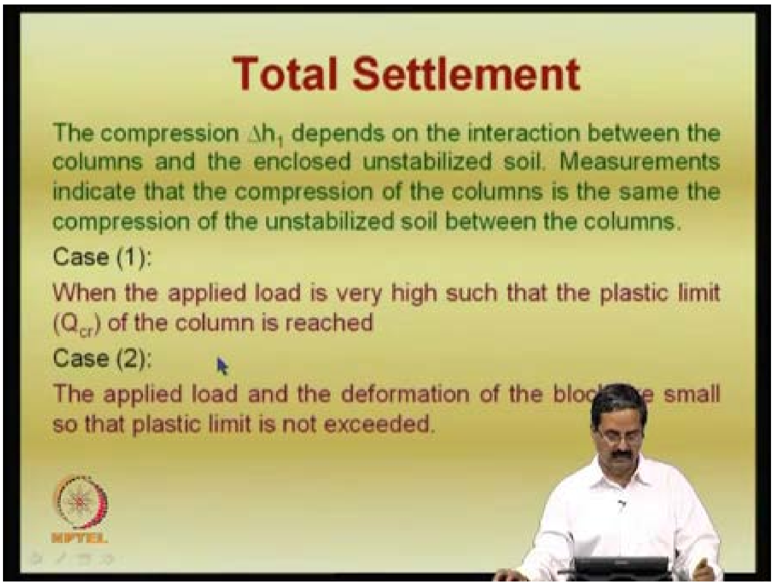


Actually as I just mentioned in the previous case, this is the soil is there and then this is the lime column material is there. The lime column material has some settlement and the stone also; this the lime, in between the two lime columns also the soil between the two lime columns also is clay. So, what it does is that settlement delta h 2 caused by the load can be calculated from the consolidation statements on undisturbed samples. This is another important point that one should see.

And case two is a relative stiffness of the columns with respect to the enclosed unsterilized soil which govern the stress distribution. So, what we do is that, in the second case, what I just mentioned previously; let me go back. First case: when the load is applied such that the plastic limit of the soil is reached. Second case is the loads are small.

So, you are essentially calculating the loads when they are higher in this form like q 1 and q2; calculate in this particular expression and the delta 2 you calculate essentially that. What you essentially seeing is that, you are essentially calculating the q 1, q2 loads under this conditions, when the load is very high and when you know when the load is somewhat lesser. So, in this case, q 1 and q 2 is settlement from this material. Use this.

And q 2 is calculated settlements because of the soil layer beneath the stone the lime columns.

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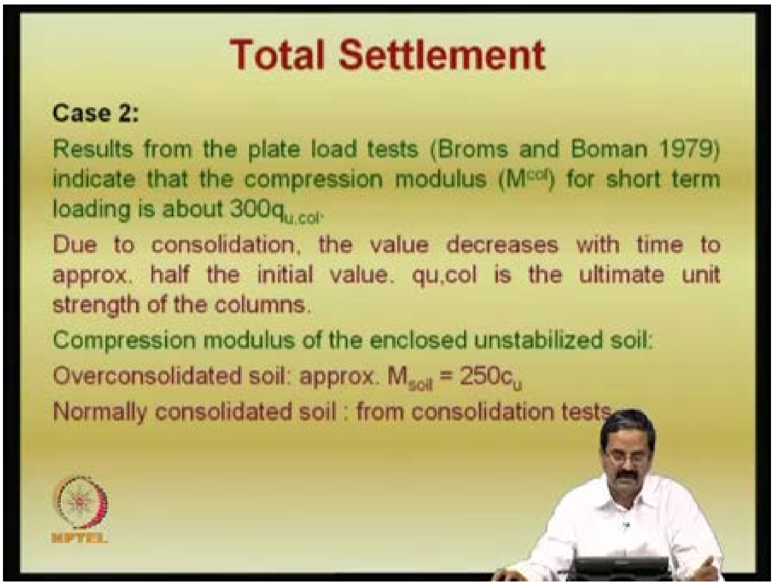


The other way is that if the as I said case two, when the total load is somewhat very less, what we do is that the relative stiffness of the columns with respect to the enclosed unstabilized will govern the stress distribution.

The difference is that in the previous case, the loads are so high that they are tested to. They go to plastic limit conditions. Here loads being lower we try to use the elastic stress distribution type of thing like the loads are shared or you have the concept of m coming into picture here.

So, the settlement delta h 1 of the reinforced block will be governed by the compression modulus of the column material. So, delta h 1 we call it and q column is the average axial stress in the column into height is the column length and then m. m is that factor that we have to calculate which nothing but the compression modulus is.

Compression modulus is say for example, modulus of the soil is going to be very high that it takes all the load, then the load coming on the clay would be much less and one can safely use elastic stress theory concept. So, this is one case here delta h 1is nothing but q is an average axial stress into height divided by m is nothing but the stiffness.

So, what are we getting is that, it is like you are essentially calculating this. So, these two have the same whatever units, and then you get in terms of the units of h delta h1.

And results from the plate load tests indicate that the compression modulus for short term is about three hundred of the unconfined compression or the q u of the column. In fact, as I just mentioned, you have may be a ten kPa for the native soil, but it may be very high you know even hundred times also like it can be very big numbers. They have done some plate load tests and they show that the compression modulus of the column for short term loading is about 300 q u col.

So, it is quite high. The module they are trying to relate modulus. Modulus how do you get? Modulus you will get from plate load test. So, like as I said, you also have in literature, if you want to get e value; e is 10 times q u or some sort of equations we have seen that. Say for example, we have some more equations in literature where if you know the strength properties you can relate it to stiffness this is something like that.

So, results due to consolidation the value decreases with time to approximately half the initial value. q l is the ultimate unit strength of the columns. So, the compression modulus of the enclosed unstabilized soil can be obtained as this is another one like this is another simple example.

Say in the case of over consolidated soils, this is a simple equation that M soil is two fifty times c u. So, even for normally consolidated soils you can get some expression. What it means is that, if you know that you are trying to do, what is that consolidation test and you can do a consolidation test and you from the consolidation test result, you can get this modulus because whatever are the void ratio, the strain you can calculate because you have initial height of the sample, it has a final height.

So, you are trying to you can calculate 1 m value because you can calculate the stress and the strain right. Stress by strain can be calculated and that gives m and for the sample if you do an unconfirmed venture test there itself, say venture test for the same consolidated sample, you’ll have a equation.

One can get an equation like that. That is what people have been doing like even we did in our laboratory some of this experiments where you have a consolidated sample and then you can have from two between two pressures say for example, from 100 kPa to 200 kPa, there is some sort of compression that is going on and then that compression can be converted into shear strain and the total stress applied. Total stress by total stain can give you modulus.

Say for example, 100 to 200, the 100 kPa is a total stress divided by the strain that it has under gone say for example, ten divided by 100 kPa divided by 0.1 give you some 2000 as a modulus.

So, 2000 kPa which means two m p a, this is a modulus so that if you really do a test there, you will get some factor like this. So, one should be very careful with this. Some of this factors and this is one important thing. And you can have some sort of similar relationships, actually if you look at bowels book and many other standard books, you have lot of literature on this.

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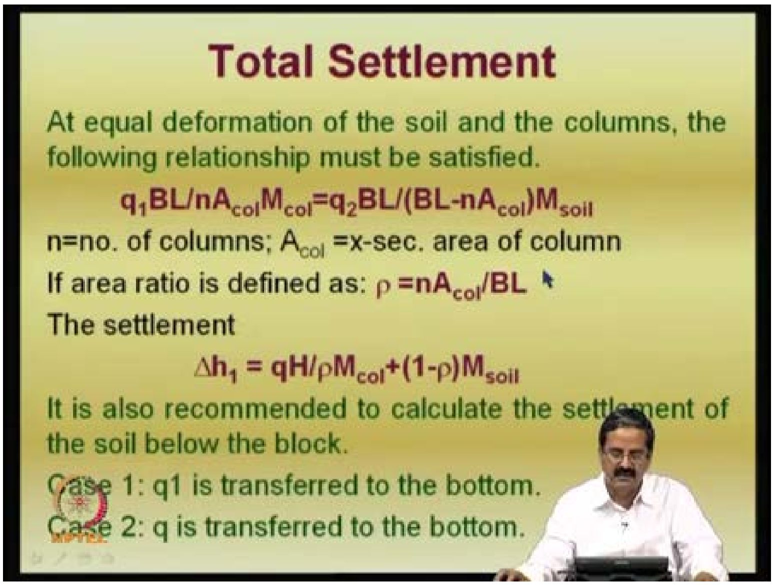


So, as I just mentioned, when the soil is in the elastic state and whatever or when the load is not going to be very high, the equal deformation of the soil and columns we are expecting. And loads, the following relationships must be satisfied. It is like q1 into BL divided by n A column into M column, the area of the column and the stiffness of the column should be equal to q 2 into BL by BL minus n A col and M soil.

You know essentially we are trying to see that, this is the stiffness of the soil, this is stiffness of the column m, particularly compression modulus values. So, you are trying to balance that essentially and n is the number of columns and area is the cross section area. If the area is defined, if we have a term called area ratio, like we are doing this, number of columns say for example, ten piles we have and that area of cross section to total area. This is say, how much of percentage of the area has been replaced with the lime column material. Is it ten percent or fifteen percent one can use that.

So, essentially what you are trying to do is that, you are trying to estimate settlements you know actually the some expressions we are having here and the same delta h one, you can have a simple expression in this form and you also calculate the settlements. q 1 is the transferred to block. Case one again the total load that how much is transferred there are two cases here. So, there are some sort of simple calculations one can make actually. Why this calculations are important is that you should know what you are doing is essentially like these are all very simple calculations I mean may based on some simple assumptions whether like as I just mentioned in the case of stone column that you have two theories; one is based on elastic theory the other one is based on somewhat limit equilibrium analysis.

So, you have to compare the values of settlements, stunt improvement and all that. Because soil mechanics is quite very tricky, in the sense that, for the same problem, there are different ways of solving it and one have the elastic theory, one can have limit equilibrium methods of analysis, one can use a finite element analysis; the different ways. So, essentially one must be very clear about different methods of analysis and then finally, measure it in the field that is what people should do.

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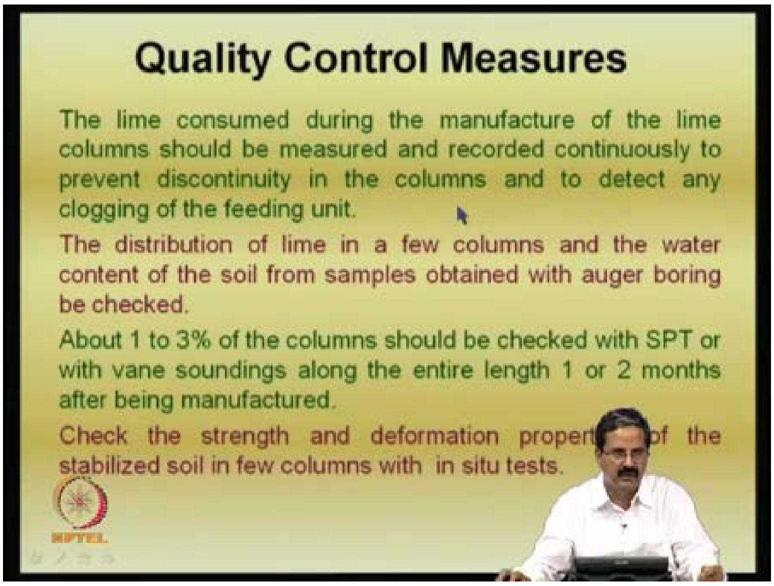


So, these are once type of doing that particularly for columnar inclusions, there are certain quality control measures one should do like particularly in this lime column arrangements, the lime columns they flow.

I mean, how much of lime is coming into the material should be measured and sometimes there could be a problem of they have a it is a chemical material, the continuous flow the material should be cleanly coming into the particular column and then it should form, you just put it and then compact it and then finally, it forms a column. So, the distribution of lime in the columns and the water content samples obtained with auger boring is to be checked.

In fact, you should be able to do some sort of checks in which how is the distribution of lime columns migration of the lime is there and is the lime distribution satisfaction and all that one can see.

And one can calculate the distribution of lime or the diffusion of lime based on the water content. Actually what happens, if the liquid if the water content of the sample is very high in the beginning and immediately after you start finding out the water contents after the lime column installation, if there is a good reduction in the water content definitely it means that there is a diffusion of lime next to the lime column.

So, even some more methods suggest that you have to check one to three percent of the columns for with s p t or even plate load test and all that and one should even vane testing should be done. Essentially what you are trying to do is that, we are trying to have too many assumptions in geotechnical engineering. We would like to see if whatever we assume or trying to or satisfactory and you have to make some corrections for that.

Then check the strength and deformation properties of the stabilized soil in few columns with few in situ tests say for example, once the lime treatment or the you know the for example, the lime columns are put you may you may have to do a plate load test like say for example, you know you have seen the highest code on stone columns, they recommend plate load test. Similar to that.

You have to do plate load test on a single column or a three column or a some different columns arrangements, one should check whether the strength improvement is there whether in terms of the load displacement curves or the plate load test you can get. Deformation property also one can get. So, these are very important quality control check and this forms a very important contribution here.

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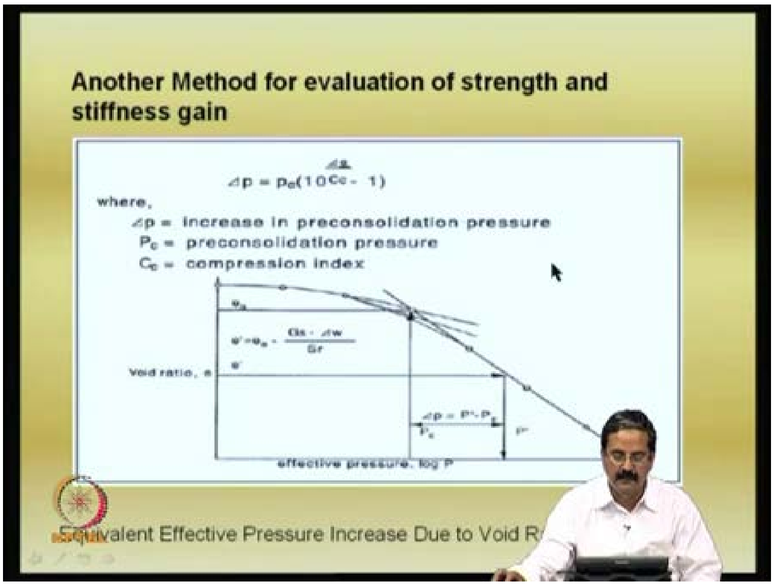


I would like to highlight you another important simple method on how do you find out some of these things. Actually as I just mentioned, in ground improvement we know how we know that you have to improve the ground and then you have to have varieties of treatment, but finally, you should have a rough idea of how to calculate things.

How bearing capacity is improved or strength is improved. So, what I would be discussing would be a method to evaluate again strength and stiffness gain or the increase. The method is simple here like what I am trying to do is that, this is the e log p curve of the in situ soil before treatment and e naught is the initial void ratio.

So, this as some this thing p c already and once what I do, because of the lime addition what is going to happen is that, there is a reduction water content. Because of the reduction in water content, what happens the void ratio will decrease because we have this formula.

Ee is the simple expression relating water content or void ratio. So, the void ratio comes down. So, as per the water void ratio, you have an improved p like earlier it was this much Pc it was and then it now you have added load. So, the load has increased from this to this. So, that is what it means. So, the delta p is what is called the equivalent effective pressure increase due to void ratio reduction is delta p is p dash minus p c.

So, this is one thing. So, we know the how this expression is simple that you know you know that Cc is nothing but the rate the delta e divided by you know the delta of the d log p you know d e by d log p is the Cc.

So, use the expression and then you put it into this is the convert back the equation, you will get delta p equal to p c into10 power d e divided by Cc minus one. The Cc you have already you have the e log p curve for the sample and then Cc could be one, Cc is one variable and here d delta e is already known because of the lime treatments. So, you will get what is the equivalent pressure.

So, this is important calculation because this helps us to calculate how much of, if you know how much of p reconsolidation pressure is there, extra load is there, you know how to calculate extras how much of the extra strength gain is there.

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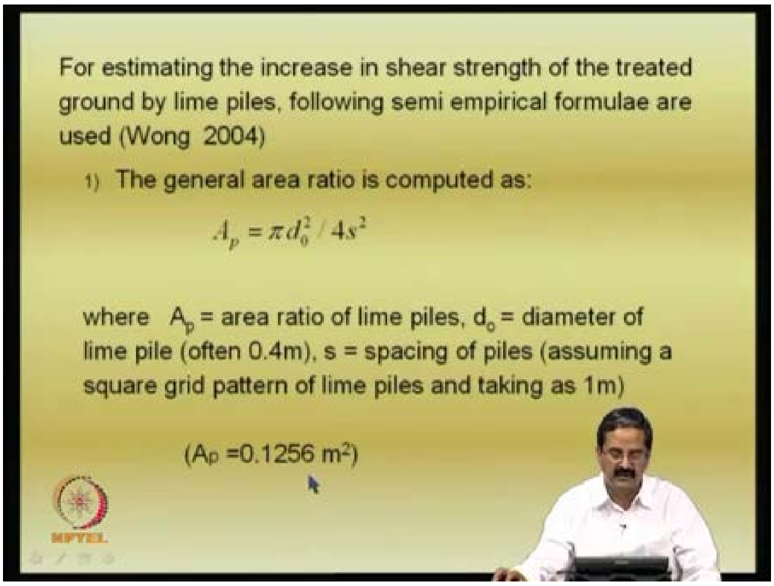


I will show you by an example here; there is a simple method that was given. See the method the area was treated by lime columns and we know what is the area ratio is nothing but if you take a square grid pattern like pi d square by four or pi d naught square by 4 is the area of a single column.

S square is the area of the grid in s square pattern. So, this area ratio like it could be 0.1, 0.2 and whatever is the number it is one area ratio and for example, I am taking an area ratio of the piles delta is 1 say for example, I am taking the 0.4 meter as a diameter of the pile and spacing is 1 meter. So, I will get a p as 0.1256. So, what it means is that you have 1 meter spacing and then stone column diameter is 0.4, a p is 0.1256.

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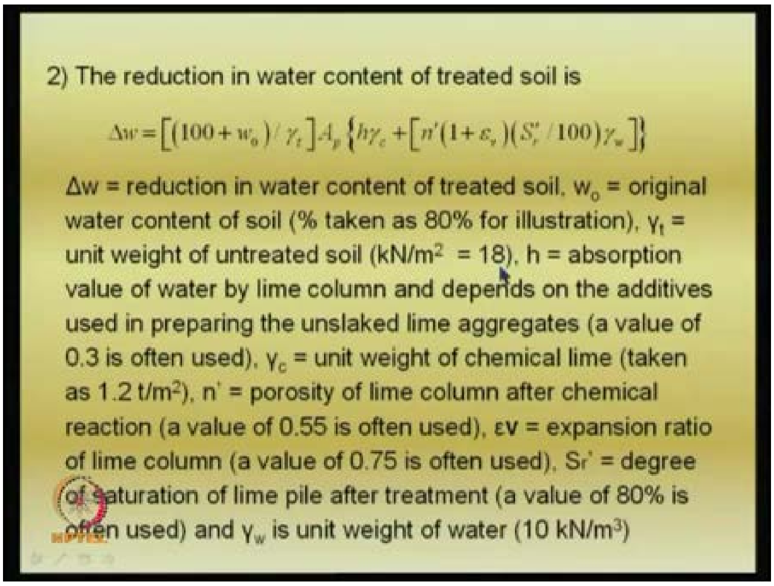


Then, there is a simple; there is an expression for reduction in water content. You know, the thing is we know that there is a change in water content because of the lime addition. So, if you know that water content change, then it is quite useful. So, there is an expression here actually this is based on heat of hydration and other things and in fact, its given in literature. And actually this how is it you get is that reduction in water content of the treated soil is nothing but it needs initial water content. In this case, you know I am just taking it as eighty percent.

This water content I am taking as initially water content is very high. May be this water content, it exists in the visage soil or some place in east coast or west coast and unit weight of the soil is 18 I am taken and h is the absorption of value of water by lime column and depends on the additives used in preparing the unslaked lime aggregates.

Actually there is a value. So, this h value is something this is all known like we know the initial water content gamma t is a unit weight of the treated soil and this factor is something that h and some of this factor we should get. h is absorption value of water by the lime column depends on the additives used and we take a value of 0.3 here. Then gamma c is the unit weight of the chemical lime. In fact, the chemical, the lime or the calcium oxide, the weight-unit weight is quite low may be 1 to 2 ton per meter square meter cube sorry meters cube.

Porosity of the lime column after chemical reaction we assume that the porosity you know because of the void ratio increases, void ratio increases, if you put the lime. Because it becomes more aggregated than the parallel plated. So, e v is another expansion ratio of the lime column, there is another value which is taken as 0.75 and s r is the degree of saturation after the lime pile after treatment.

Initially we assume hundred percent, but once you treat the soil with lime what happens is that the void ratio is the void. It becomes more void like you know because of the practical aggregation and we use the degree of saturation of eighty percent and we know the unit weight of water is ten kilo Newton per meter cube. So, you put all these numbers here and you get water content change as something like 5.5 percent.

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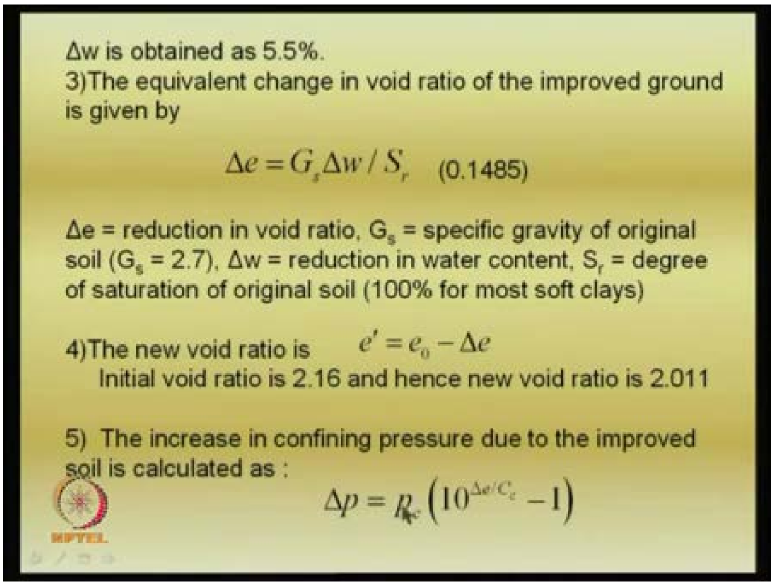


So, initially water content is about eighty percent. Because of the addition of lime I got it reduced by 5.5 percent and its quite good. I mean the thing is for which like now further I am trying to calculate say for example, the new void ratio.

What is the initial void ratio? Initial void ratio is nothing but 2.16 because 2.7 into 0.8 that is 2.16. And now new void ratio I can calculate and this delta p how much is that one can calculate and p c you know where it is changing that, it is 100 and one can use some term.

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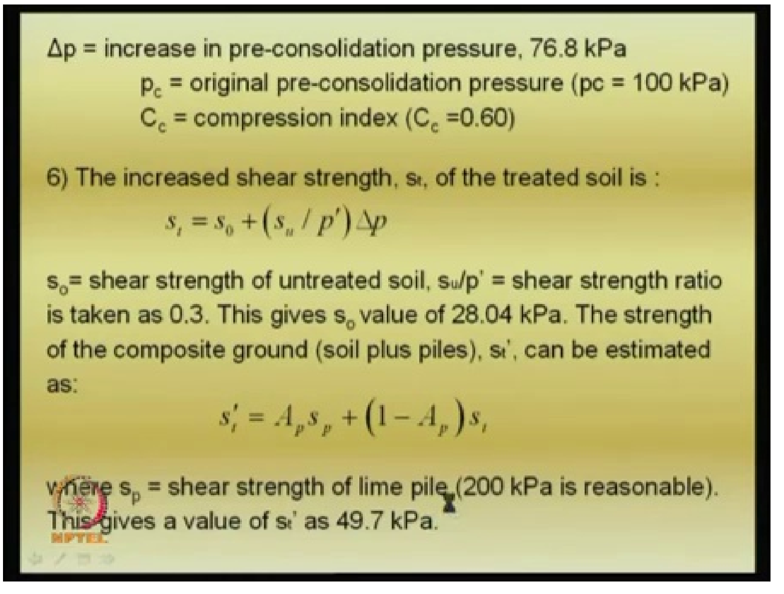


So, the delta p is about 76.8 kPa which is quite good. The thing is just by adding lime and I just made an effect of about 75 as 86. 75 kPa extra load I have applied which is something like you can compare with any other thing. You know the thing is you have about surcharge methods and other things. And you know to apply surcharge of this, you need 4 meters height of surcharge and it is a consolidation is only occurring there.

But then here, you have chemical changes also soil is improved and all that and Cc numbers I have calculated. And another one that I would like to show you is that, the strength of the increased strength of the soil like initially, there is some and I just I know Su by p dash is another variable like which is actually established for many clays. And if you see in bowels book also, it is given like you know for various types of clays, like if you want to construct an embankment on a soft soil how much of load you should do.

You have what is called s u by p dash equations which are, say for example, 0.2 s u by p equal to 0.3 or 0.2 or something people say, it is there in literature and in this case, I have taken as 0.3 actually. So, if I take s u by s p, it is nothing but the ratio of shear strength divided by 2 overburden pressure. You know it is actually one can get this equation in this thing.

Shear strength will be say for example, 30 kPa and overburden pressure is 100 kPa. If I go to a depth of 5 meters and 5 meters into 20 is 100 and if I measure the strength there, it will be30 kPa. What it means is that. So, that value if I put and then the delta p is also known. So, one I will get this as shear strength increase. You can see that, then I need to get this a treated soil strength is there and so, if then what is the strength of the composite ground. It’s another important variable.

There is I think you have to substitute some other number. So, you will get some whatever you know, these are all simple steps one can have to have the calculations here. And now the next objective is to get the improved strength of the ground. Again we are trying to use a very simple formula which is again based on the area ratio and

I just mentioned a few minutes back that the strength of the lime treated ground could be higher, 10 times higher like if it is 20 kPa for lime, it could be 200 times here. So, that same number one can use here like it is s p here area ratio. So, there we have got some 0.1256 as area ratio which is nothing but the ratio of lime piles in the 1 meter square area. So, that is 0.1256 into 200 into 1 minus this thing.

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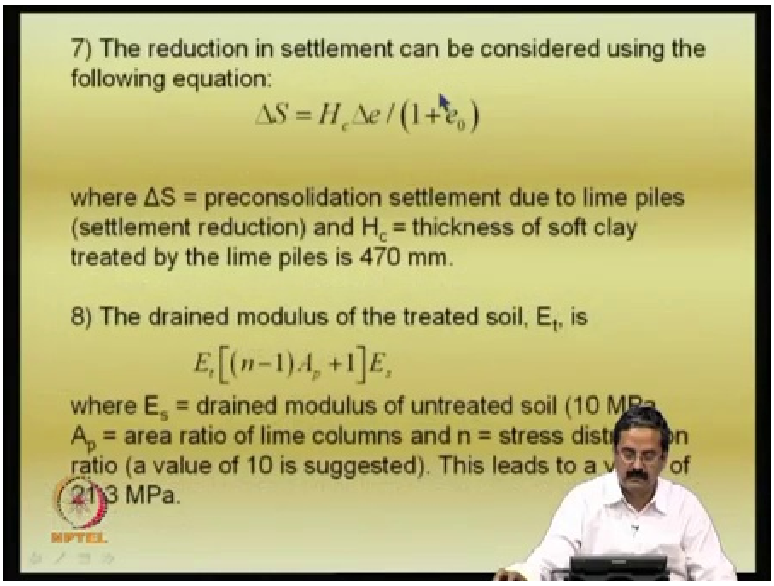

So, you will get some good increase. So, one can estimate even the settlement, preconsolidate settlement how much of settlement you have accelerated here. Because you removed water right. So, I mean what is that preempted settlement is, you know if you take the h c as a thickness of the soft soil, the it is about 470 m here one can have all these calculations done and its comes.

Then there is an addition here. So, what it means is that, you have to calculate the drained modulus of the treated soil also. Like e s is the drain modulus of untreated soil. Actually this because untreated soil is quite poor, I say it is about 10 m p a and all these area ratios are then n equal to stress distribution ratio. It is ten is what some companies say .And then this leads to 21.3 m p. a. ten m p a has [vocalized-nose] become 21.3 m p a.

So, what you are trying to do is that, there is an increase in strength. So, there is an increase in stiffness. So, we have used the simple mechanics of soil mechanics and trying to use an elastic theory as I just mentioned like, you are essentially trying to use the simple theory of getting this. And if you know the in situ e log p curve of this and some assumptions you make some assumptions, it is possible for us to calculate the strength gain as well as stiffness gain which can be used in our calculations.

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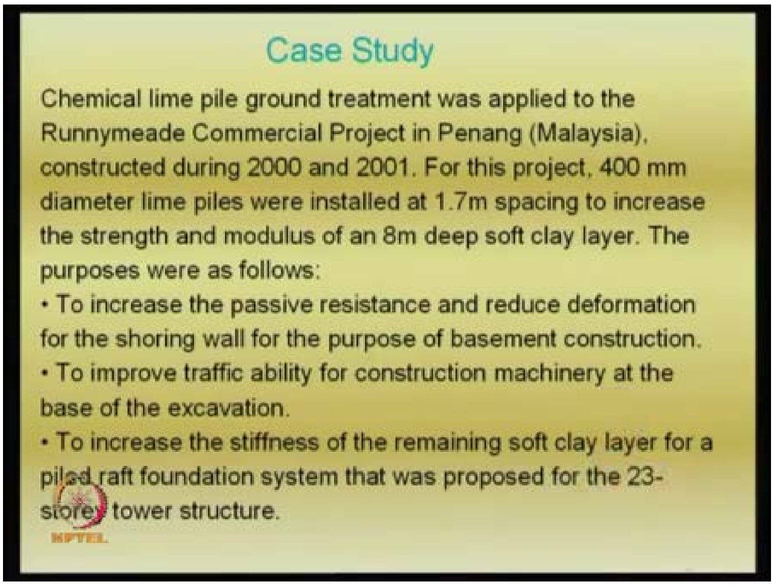

Now, I would like to describe few case studies. One is it is actually a case study in Malaysia. It was constructed in about 2000 and in this case, 400 m diameter lime piles were installed at 1.7 meters center to center spacing to increase the strength and modulus.

Like an example that I just discussed, one can use that method to check this. In fact, see nowadays what is happening is that, there are methods that are well established by the companies like as I just said, for stone columns the company Color has one method that is going to be a Priebe's method.

And so, they find that it’s very appropriate for the way that they are doing the things. So, similar to that, the previous method which I just discussed was given by some other company and some other authors also followed it in this example.

So, for example, I will show you, the purpose of the lime treatment was very clear here; to increase the passive resistance and reduce deformation. So, the lime piles what they do is that they increase the passive resistance. Passive resistance is that when the see the there is a reinforced soil.

Say for example, it increases passive resistance like see the thing is that, it reduces the movements of it resistance the movement in a passive way. So, it resistance the movement of the soil in a passive way.

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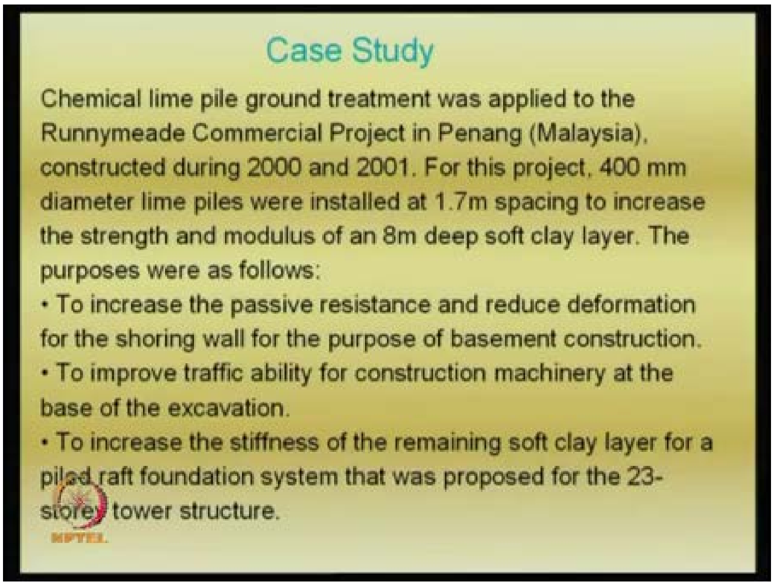

So, this is what is called, say for example, if you put lime columns actually you know what the material the or the even the stone columns. That is why if you use the concept of cavity expansion theory where we calculate say for example, k p is a term that is used instead of the k a k a stands for the active at pressure coefficient and k p stands for the passive at pressure coefficient.

So, if you insert that what is the trying to do is that the passive resistance is increased like you have some material in the area there you made it very stiff and then because of that there is a passive resistance increased and because of that it reduces deformation for the shoring wall for the purpose of basement construction.

To improve traffic ability for construction machinery at the base of the excavation. In fact, you know this soil is so poor and you cannot even walk. The thing is that you have to make it little more workable. So, people use the lime treatments sprinkle lime to increase the strength stiffness of the remaining soft layer for a piled raft foundation system that was proposed for the twenty-three storey tower structure.

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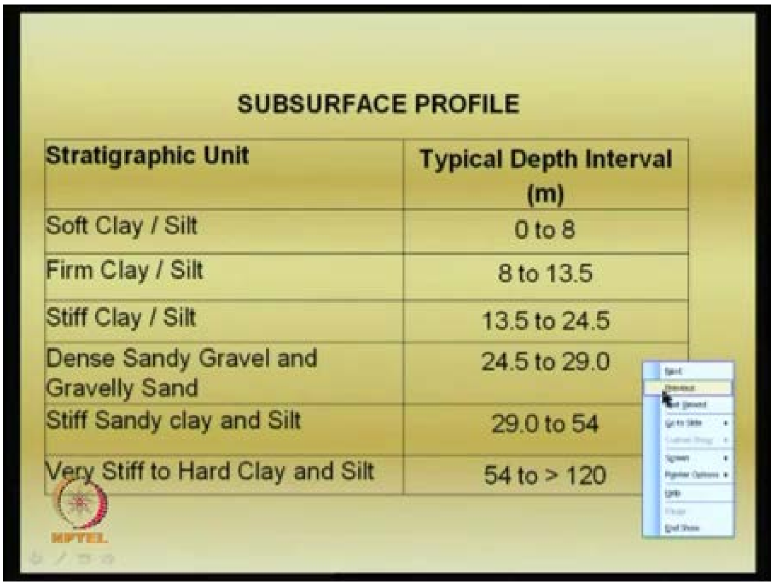

SUBSURFACE PROFILE

| Stratigraphic Unit | Typical Depth Interval (m) |
|---|---|
| Soft Clay / Silt | 0 to 8 |
| Firm Clay / Silt | 8 to 13.5 |
| Stiff Clay / Silt | 13.5 to 24.5 |
| Dense Sandy Gravel and Gravelly Sand | 24.5 to 29.0 |
| Stiff Sandy clay and Silt | 29.0 to 54 |
| Very Stiff to Hard Clay and Silt | 54 to > 120 |

You can imagine that the height of the structure is twenty-three floors and you are looking at its improvement of the bearing capacity. So, up to twenty-three or forty, they have got the stratigraphic profiles, 0 to 8 meters is a soft soil, 8 to 13.5m firm clay and you have varieties of materials here and the depth of investigation is quite good.

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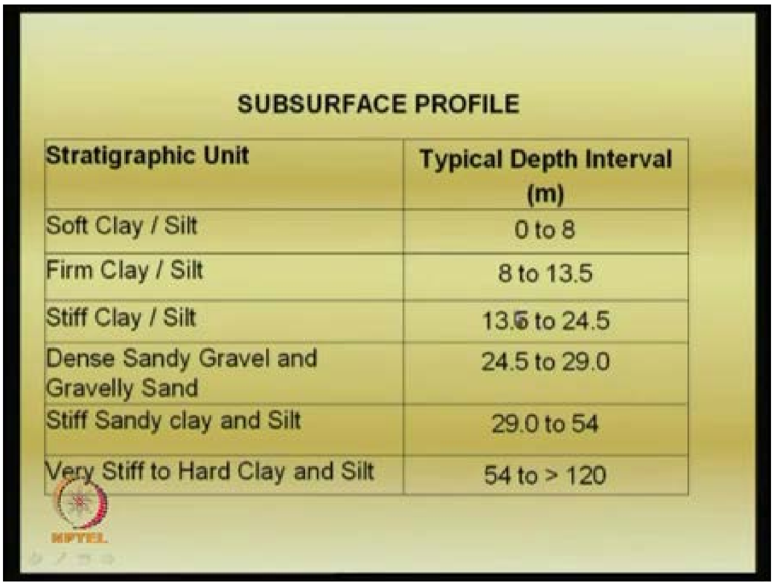

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Like they went to say for example, 23 meters is suppose to be the previous case, it is a twenty-three floors storeys and you can see that the depth of investigation was quite large about 100 meters which is quite good. Because they have to be very sure about the safety and settlement aspects when you are trying to deal with a technique which you want to be again you want to save on the construction of foundations, you cannot provide piles.

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SOIL PROPERTIES OF UPPER SOFT CLAY LAYER

| Borehole | Depth (m) | N.M.C. (%) | WL | WP | PI | Silt (%) | Clay (%) |
|---|---|---|---|---|---|---|---|
| BH1 | 6 to 6.5 | 97.1 | 65 | 35 | 30 | 55 | 42 |
| BH2 | 2.5 to 3.5 | 100.7 | 54 | 29 | 25 | 57 | 38 |
| BH2 | 5.5 to 6.5 | 110.3 | 55 | 30 | 25 | 56 | 42 |
| BH2 | 5.5 to 6.5 | 110.3 | 55 | 30 | 25 | 56 | 42 |
| BH4 | 3.5 to 4.5 | 104.7 | 58 | 29 | 29 | 52 | 44 |
| BH5 | 6 to 6.45 | 94.1 | 54 | 27 | 27 | 53 | 43 |
| Minimum | _ | 94.1 | 54 | 27 | 25 | 52 | 38 |
| Maximum | _ | 110.3 | 65 | 35 | 30 | 57 | 44 |
| Average | _ | 102.9 | 56.8 | 30 | 26.8 | 54.8 | 41.8 |

So, what does this borehole information say? There are some numbers of boreholes you can see; the water content is 97 and 100 percent. It is very high, average is now one naught it is a very liquid actually. Liquid limit is about 56, natural water content is more than the liquid limit, and you can see that. Plastic limit is there. Plastic index is ok. Silt is there, clay content is there which means that it is a very tricky material when you have all the boreholes up to seven meters, they say.

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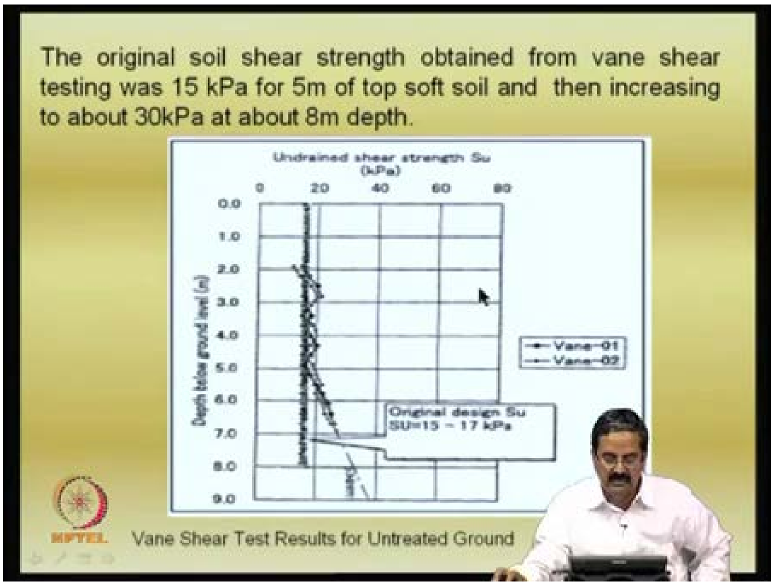


You can see that the original shear strength obtained from the vane shear test was about 15 kPa for 5meter. So, you can they have done you know vane shear testing also. So, they have done the vane shear testing for 15 kPa and so, it increases up to 5 meters is about 20 15 kPa then it increases with to about 30 kPa at about 8meters depth. These results with the vane shear untreated ground.

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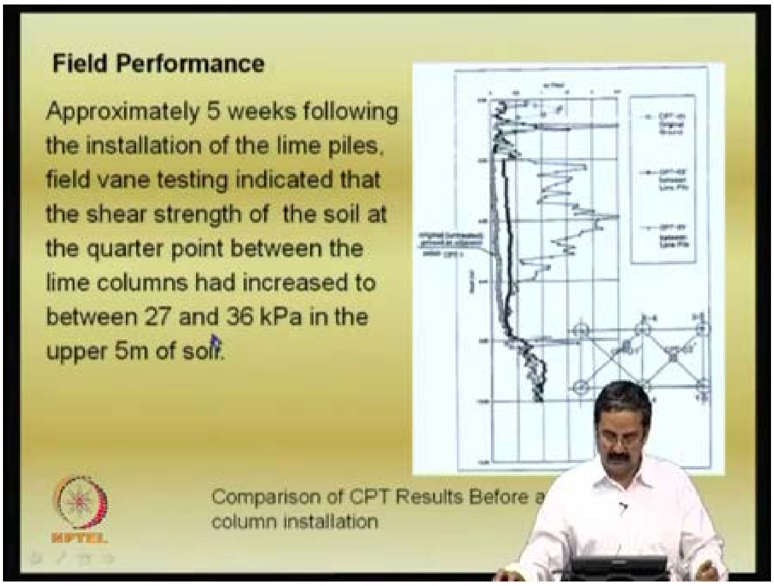


So, after the, 5 weeks after following the installation of number the vane testing was indicated the shear strength of the soil at the quarter point between the lime columns was increased to 27 to 36 kPa.

You can see that it is a very good increase. So, from 15 kPa it has become almost double. So, this is that area where it is quite comfortable. So, just like as I just said, you are only accounting for, we assume that the treatment the effectiveness is because of what you call dehydration, the removal of water.

Then after that, there could be long term benefits also and definitely the construction of lime [tiles/piles] piles is much easier and it all depends on it is a small building or whatever or whatever may one should be comfortable. People normally in any contractor in a west, you will have all that people ready for it like you need to have information from stone columns, p v d's, lime columns whatever all that methods or even geogrids.

Everything is they available then you have to make sure that yes it the technique works in a given situation and then try to come out with which is cheaper. Also you know because if it is very expensive and you should also have a proper performance monitoring like you must be able to do like this, a test like this. If the test does not allow, it will be anything then it is very difficult. Because how are you sure about the quality of the work done is something very important and if I cannot give you that the strength improvement will be like this in calculations and also show you later with c pt or s pt or any other test that the strength improvement has not is is achieved then if the say for example, it is 15 kPa and now it is 36kPa which is quite good.

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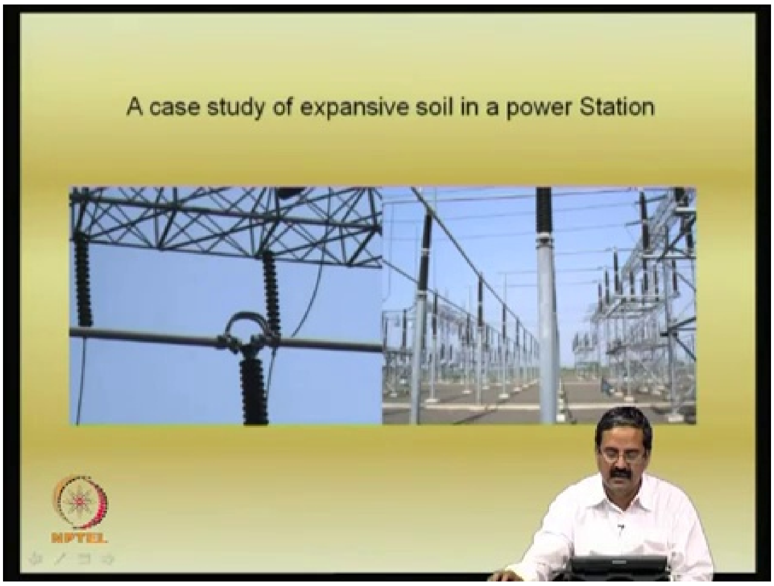


So, another case study that I would like to mention. This is actually power station in near Hubli. About 4 years back what happened was that, there are lot of floods and the substitution has its founded on, actually you have an expansive soil everywhere, that is an expansive soil exists there and then since you want construct simple structures, you need to have, they put remove some soil of expansive soil layer and then put some sand cushion or murram cushion they call it; like this is what they do.

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We can see that these are all expansive soil here. Black one, you can see that this is the one sand cushion they put like say for example, people say about 50centimeters or 2 feet or something. Then they start constructing things like this.

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You have a substation nicely lined up and all that. But what happened was that four years back, there were severe floods and the whole area got inundated and there was nobody to even like the whole area there was a power cut and all that they shutdown everything.

But then, they left it then they found that, after all that drawing. Because of the inundation what happened, the whole area got swollen, the expansive soil area that is there in this area; you can see that this is also black colour. This removed soil is an expansive in nature and you can see that, it was resulted in deformations like this. It is out of line you would know they have to be in line actually.

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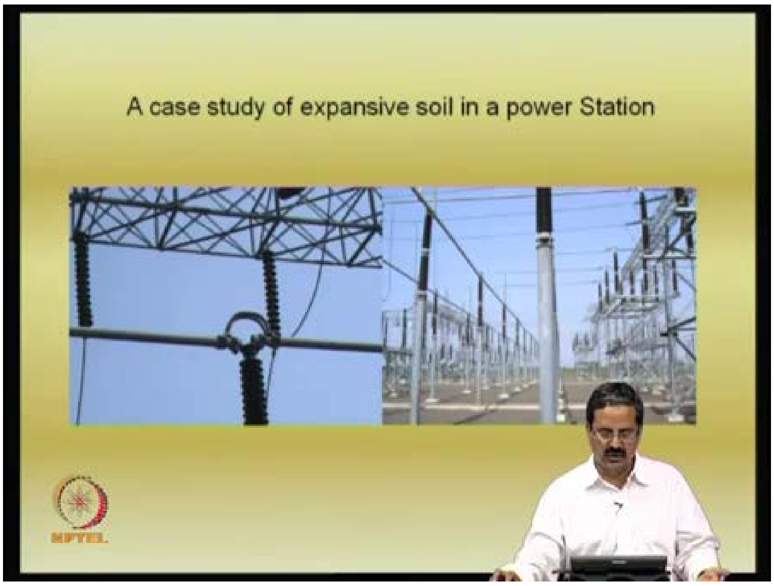


All the electrical things have to be very, they have lot of tolerances and if you have an expansive soil, the problem with expansive soil is that it heaves and then shrinks. So, the possibility is that, it could cause total settlements as well as different settlements. And in this case, the problem is that tilt like this; the pole should not be tilted away with respect to something.

And the thing is that, what type of foundation they have. They will not have any foundation. They will have a minimum foundation which could be about 1.2 meters or some 2 meters depending on the type of whatever they have depending upon the junctions loads coming on that.

They have lightly loaded structures; the load that comes on this is much lower compare to the swell pressure. In fact, the expansive soil in this area has a lot of swell pressure; it could be about one 50kPa and all that. The load that is coming here is so low that definitely you expect during heaving and shrinkage, this you can this you can see that this out of line actually.

Though it may not be visible to the naked eye, particularly these are the visible and then they have to shut down all the operations and then they have to they restored it, but the problem was that it was not satisfactory.

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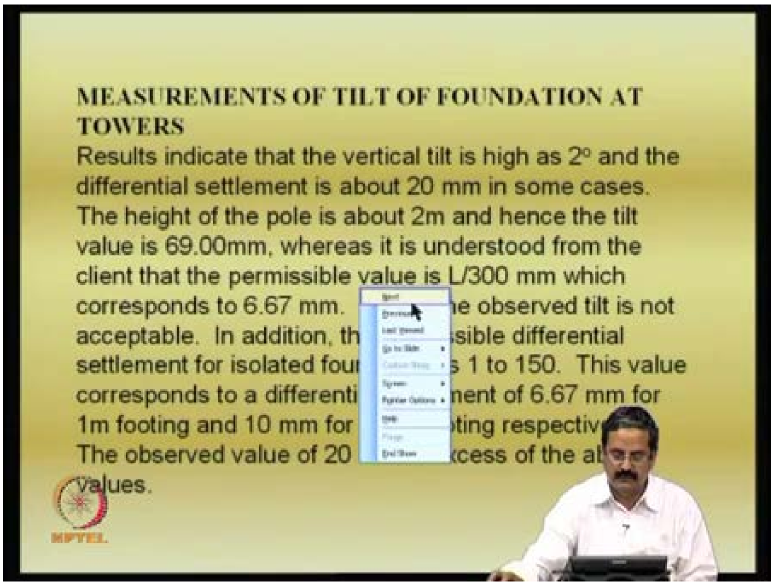


So, what I did was that, I need a total service. I would like to first want to know, what the vertical tilt is, the vertical tilt is this like how much of tilt is there in the pole. Vertical tilt and then the horizontal tilt; horizontal tilt of the foundations as well as vertical tilt of the vertical members.

So, in cases. So, when we did with a total station, I was able to see that the differential settlement is about 20 mm. in some cases, say for example, as I just mentioned, it is resting on about one point to meters foundation and it got tilted it is about 20 mm though number is small, but then this foundation size also very small.

The height of the pole is about two meters, its electrical poles of 2 to 3 meters average height and there is a tilt is about 69 mm. You can see its quite big and you know the electrical aspect, the electrical transformer, the substation rules and they have some guidelines on erection of this facilities.

The permissible value is about l by 300 which is corresponds to 6.67 mm. So, you can see that the permissible tilt is about 6 to7 mm whereas; it has already tilted 69mm which is quite high. So, the tilt is not acceptable. In addition, the permissible differential settlement of the isolated foundation is, we know that if you see in soil mechanics 1 in 150 is the differential settlement allowed.

But so, this corresponds to about 6.67 mm for 1 meter footing and the10 mm for 1.5 footing respectively. So, the observed value of 20 mm, what I observed was much excess again. So, both total and differential settlements were not satisfactory and what we did was that we have to rehabilitate that with some sort of measures using like, see thing is that now it is already a constructed structure. So, you have to bring it back to the actual condition.

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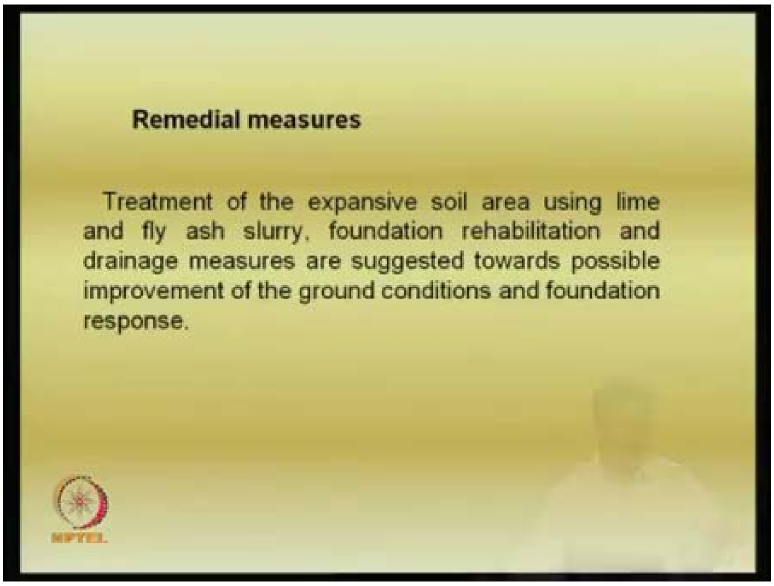


So, what we suggested was lime slurry injection. So, the treatment of the expansive soil area using their lime and fly ash slurry, foundation rehabilitation and drainage measures are suggested towards possible improvement of the ground conditions and foundation response. What we did was that, since the thing is that, first of all, they did not understand that the expansive soil has such it creates such a havoc. So but then, when it has this type of distress, you need to solve this issue. So, what we did was that, the lime of about six percent lime and also the fly ash, as I just said, the liquid limit of this expansive soil is about eighty-five to ninety percent liquid limit. Then the shrinkage limit is about ten percent, we got it tested and all that. And after that using lime about say six percent. What is the liquid limit and what are all the limits and all that we got; we know that liquid limit will come down and all that and everything will be all right.

And then, we also added fly ash why because, it also increases, it is like a mechanical modifier. Fly ash is somewhat core shell and it has also stabilizing agent as I just mentioned sometime back that, use of fly ash is also very good. So, lime plus fly ash in the form of slurry; slurry means, you mix it at a very high water content and then pump it under the foundations. So, if you pump under the already existing found[ation]- actually the first thing is that we have to rehabilitate the foundation.

You know the thing is, foundation rehabilitation is very important. If something is tilting like this, remove the soil some amount of soil somewhere, see that it comes back to the original condition you have to liberate there are. So, many electrical poles in the area you have seen the many about forty to fifty poles electrical thing, you have to go to the foundation, measure the actual movement, you have already measured the movement and remove some amount of soil and make it you know structural adjustment of the foundation itself.

The foundation itself is not very big actually. It can be handled, it is just may be 1meter by 1 meter, 2 meters some size. So, you have to apply some sort of load or something and apprised some sort of pressure should be applied or you remove some soil and then remove the pressure and all that. Make sure that the limits that we got like whichever it was, all exceeding where whichever was I was just mentioning all these are all exceeding.

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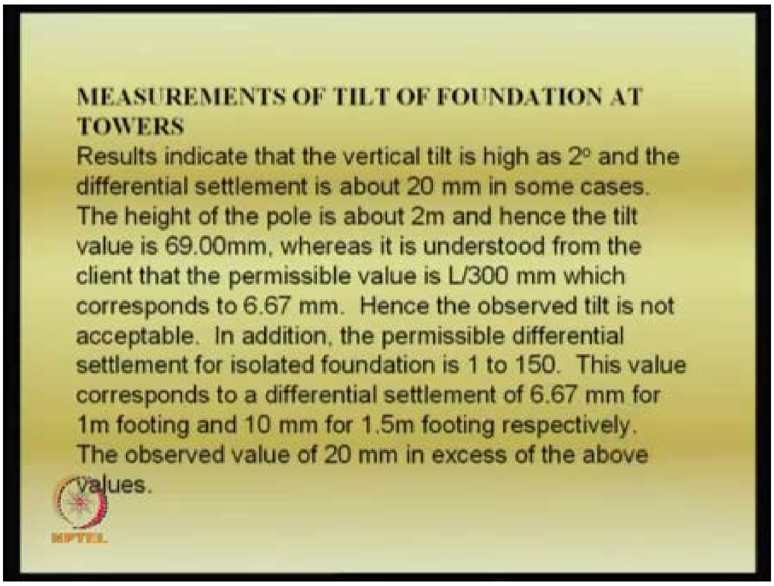

See that somehow you bring back to the original condition and then see that these limits are achieved for all the poles and do that lime treatment. Because the problem comes from the actual soil itself, like it should not occur. So, first thing is that they should be brought back to the actual conditions in some form by loading or removal of soil and whatever. And in fact, the removal of soil to increase the to you know to reduce the tilt was done for Leaning tower of Pisa itself.

You know the Leaning tower of Pisa had an inclination that makes it very attractive. That is why they do not want that Leaning tower of Pisa to be perfect. So, they wanted an acceptable inclination they are in fact, they could very successful in that. And same thing you know we try to we have suggested here that, you would remove some amount of soil to see that it comes back to the actual conditions and it is a structural adjustment by some loading or whatever.

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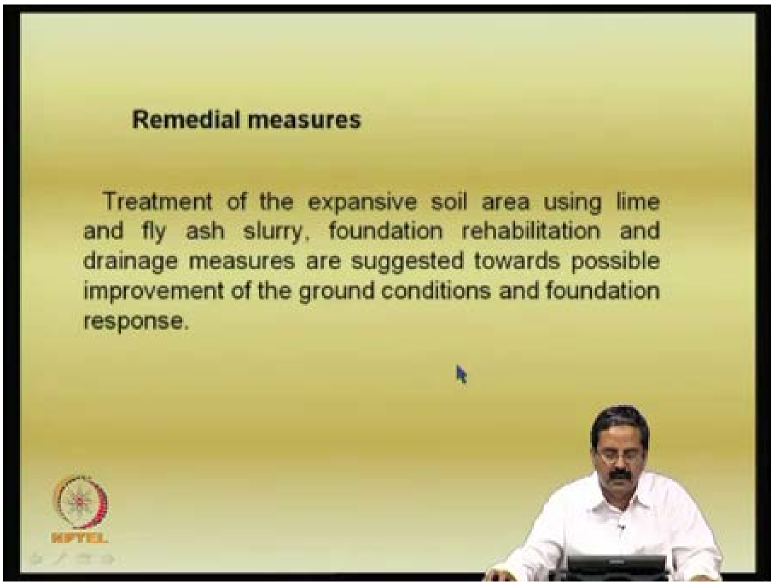


Put some sand bags next to the foundation, use some pressing or remove soil and all that and what is whatever you confirm it from your measurements, use your survey to see that it comes back to the actual required levels. then the foundation treatment was done using the fly ash slurry with following suggested rules and it was expected to be satisfactory.

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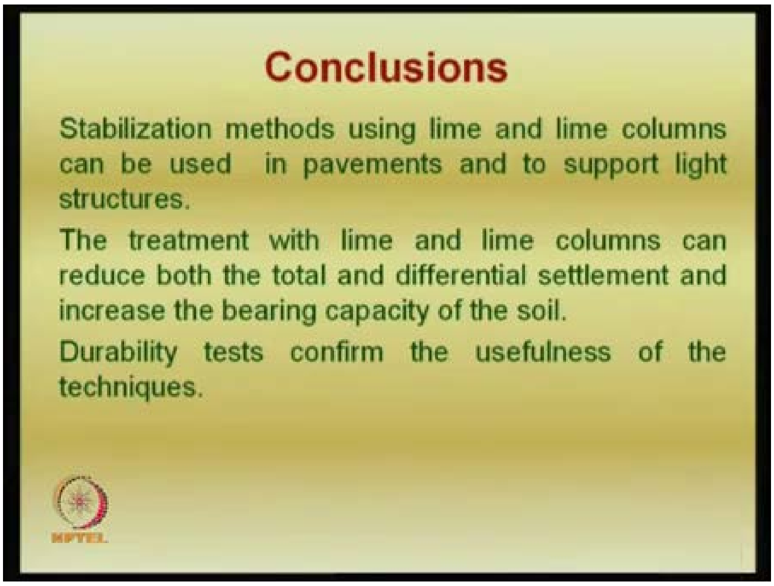


So, what I would like to say is that, the stabilization methods using lime columns in fact, you should use also some additives if required, but there essential stress is lime and lime here, like one can say, one can use as I just used fly ash, one can also use cement also, as I just mentioned to increase the rate of reactions or the formation of the cementations material.

Say for example, cement itself is quite expensive. So, why do use cement. Use only the lime and may be little bit of cement could be used to increase the…. So, if you are able to get a very good strength improvement based on our calculations and observations it's satisfactory. You do not need to a pile foundation.

So, essentially these methods could be used for like payments, particularly lime treatment is a very excellent method and also to support structures light structures. The problem with many of the structures is that particularly expansive soils and light structures is a very bad combination that the expansive soils have swell pressure which could be a…, but 100kPa or 150 kPa not less than that or even it could be you can measure in situ swell pressure also.

You can take an undesired sample or you can do a lot of test there. So, the swell pressure should be higher. If it is higher than the loading then it is coming it is a serious problem. This problems occurs in many cases in India where the canal lining, expansive soil is there everywhere in India; you are trying to put canal linings and if you have canal linings what happens, the lining is so thin like it is just a 150mm concrete slab or some sort of lining, and it swells the whole thing is gone. And there are so many areas in many places particularly in Maharashtra, Karnataka or even in some place in Andhra where the expansive soils have really make made a havoc. In fact, there is a some more problems connected with many issues on expansive soils even in some places in Andhra pradesh where say for example, one of the big projects like polavaram dam, many of the canals have expansive soil layers that are there. So, one should really understand some of these behavioral aspects properly. you have to measure its expansive nature; in the sense, liquid limit, plastic limit you should disturbed representative samples as well as disturbed samples as well as field samples. Because, what happens is that, many of the cases like if I was talking about, the swell pressure; swell pressure in the lab is different than in the field because that is very clear.

So, if you design the swell pressure for this say for example, if the swell pressure is 150 in a lab, you may get only a 50 kPa in the field. So, there is a big difference because, in the field, the sample sizes are a big mass and then you have lot of sample fixtures, factures and many other things.

The swell pressure may not be that much compared to what it do in the lab. In the lab, you take an undisturbed sample and then even if it is undisturbed sample, the possibility is that it could be little higher. Because if the sampling itself is you are suppose to represent a big volume of soil. So, one should be very careful in characterizing this expansive soil as I just mentioned the other one very important one was that you should not use lime treatment when you have a sulphate bearing layer present.

So, you should find out the sulphate content and if it is tolerable within, there is some specifications actually given in particularly the codes. One must refer to the codes by Texas department where they have somewhat standardized.

So, one can see that and then avoid such problems. Because you may say that the expansive soil I mean, the treatment using lime; it is not applicable to all this relations. One should be very careful. And the other thing was that, even the its claim in that is also very important. So, one should do some more information details on this. And so, one can use this treatment and then one can calculate; I just showed you all the calculation methods of calculating total the bearing capacity, then different settlements, total settlements and all that one can work out stiffness and all this parameters. These are all the calculation methods and finally, you should use measure this in the field.

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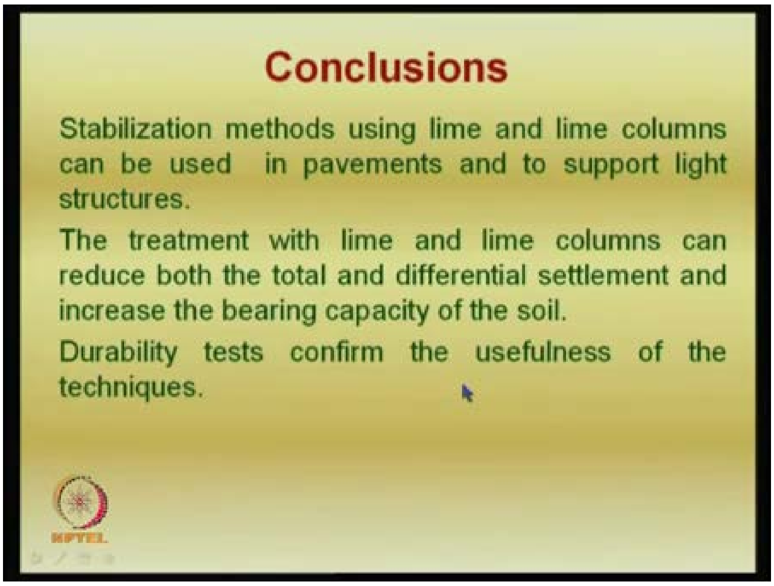


And durability tests also in fact, in some cases where I just showed you that payment for about 10 to 15 years was all right. It is very good like payments do not last even for 6 months, but if lime treated soil can serve for about ten years it is very good.

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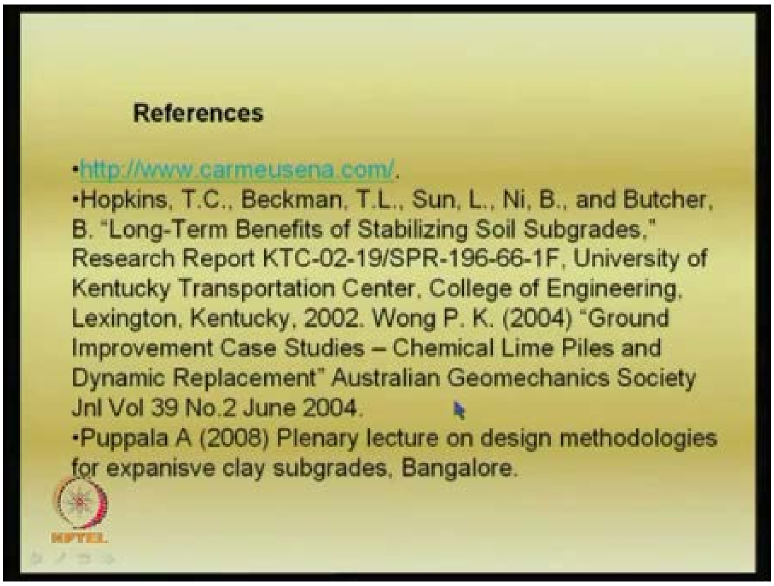


So, what I want to say is that this lime is a very useful technique. Lime addition particularly using lime is quite useful. So, I have couple of references in this that where we have some from the homepage of a particular company I got some information and also that some it is a research report and also on the from Texas end.

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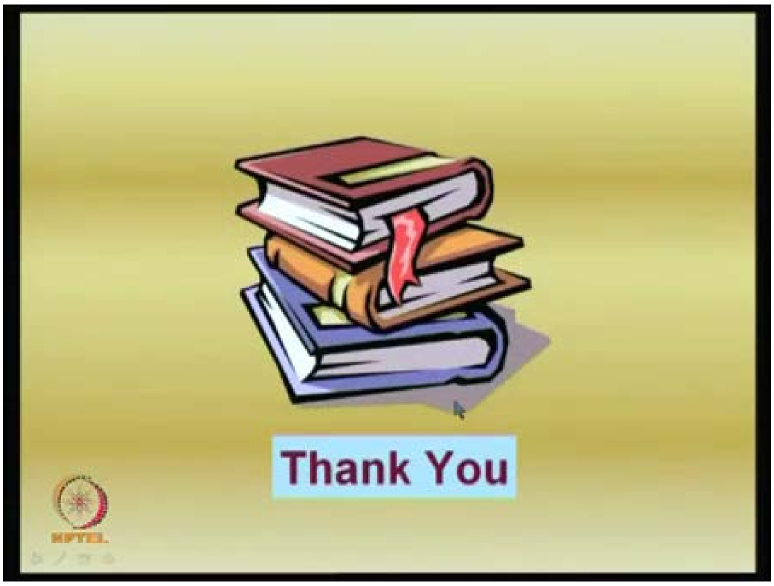


So, I am sure that you will have a good understanding of some of these aspects of lime treatment in whether it is in expansive soils and soft soils. Thank you.