Ground Improvement

Prof. G. L. Sivakumar Babu
Department of Civil Engineering
Indian Institute of Science, Bangalore

Lecture No. # 17

Ground Treatment with lime – I

(Refer Slide Time: 00:17)

Lime in the ground treatment or ground improvement. The lime treatment is something, that has been quite popular with many of the civil engineers and whenever there is a problem with soft soils and expansive soils, lime treatment has been given and essentially, to improve the bearing capacity and reduce the settlements. We will see how this lime treatment can be effected in the field and what are the various factors that can influence the treatment?

And we study, we also have some case studies here and for example, limes, lime can be used for the pavements and the lime columns could be used for improvement of bearing capacity and all that.

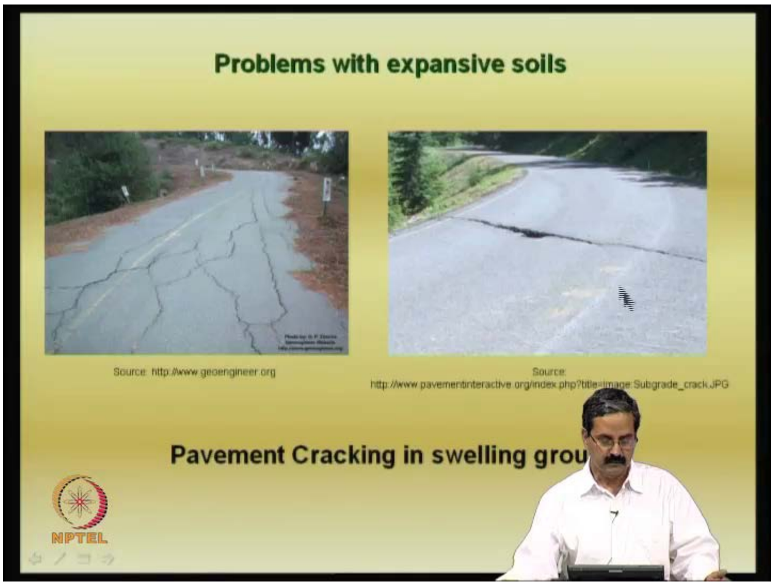
(Refer Slide Time: 00:57)

These are some typical failures that one can see. See, you can see a heave here, you can see very clearly a heave of the pavement you know, because the, you can see, that you know when the expansive soil is subjected to alternate wetting and drying and definitely, when there are some places where there could be more changes than the rest like…

So, this is one place where there is a good amount of heaving in one place with the result, that the pavement has been damaged beyond any, you know, repair or whatever. So, this needs to be repaired in proper way.

And also, like you know, one should, the way that one should do is, that he should be able to examine why this has occurred, what are the issues, that are involved because the, we have materials here. You, now you have various layers of the sub-grade, sub-base and all that. And one should examine why this has occurred. This is another thing that we have like a crack, like in a pavement.

(Refer Slide Time: 02:03)

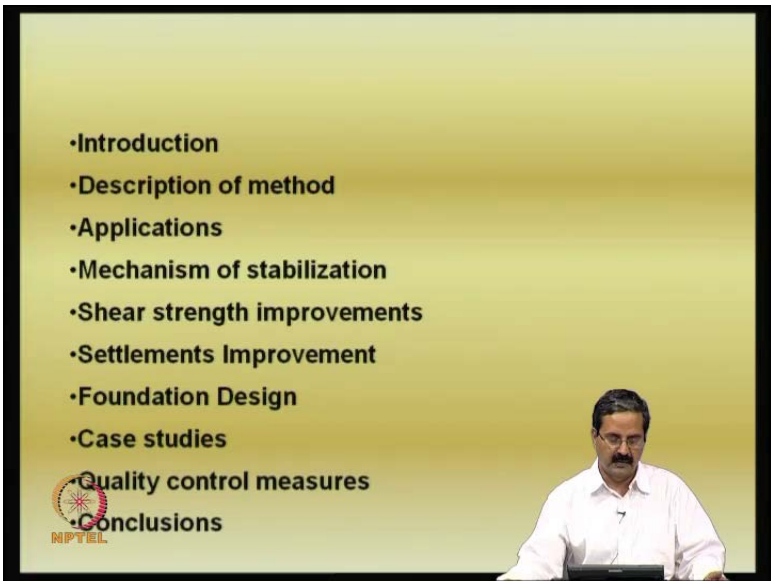


This is another one, that one can see particularly the problems. The expansive soils are quite common, even the, this is another case that we see.

(Refer Slide Time: 02:14)

This is another one that one can see. In fact, one can measure the failures.

(Refer Slide Time: 02:23)

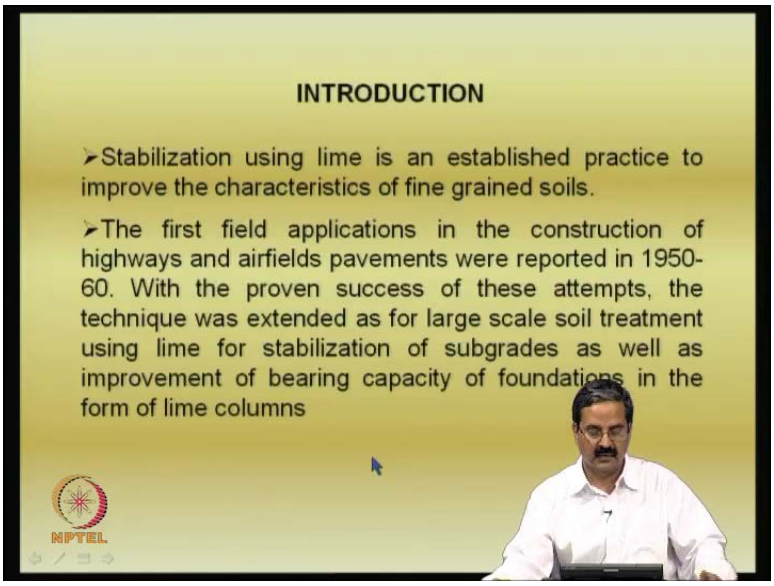


In fact, some, if you do not understand the treatment process, say for example, people have been talking about treatments and if the treatment is not correct, then even there it could lead to premature failures like this. So, the important thing in this case would be that we should be able to understand why these failures are occurring, whether it is in the case of a soft soil or an expansive soil, you know, because all these soils are coming into picture because they are, essentially, poor in terms of their assigned properties and settlement issues. So, one should be really worried about how do you handle this and there should be a systematic way of understanding these techniques, otherwise there could be a problem, you know, where the technique may not be properly implemented in the field.

And finally, it leads to problems, much more problems, like for example I must tell you the classical case of the lime treatment itself. Lime treatment is very effective if there is no sulphate in that soil, but then, if sulphate is present in the same expansive soil, then it, it becomes worse. Say, for example, I, the expanses nature is, in terms of the liquid limit of the soil or the, the free swell and whatever, there are number of tests, that one can do and people have shown, that if you have the sulphate material in the soil and then you try to give a lime treatment to that, it cannot be effective. That is, so, which means that lime treatment, if you want to make it effective, you should really check up if the sulphate is there; if it is not there, then you go ahead with the lime treatment. And lime treatment is also sometimes, you know, you need to add some sort of additives like fly ash or the cement depending on the requirements.

So, we will just discuss today some points of this, like we have some method, I mean, how is it done? What are its applications, its method of doing? What is the mechanics of stabilization? What is the shear strength improvements people have observed? How the settlements have been improved because of this? In fact, how do you go about designing the foundation or even a pavement and all that? How can you do that? And some case studies and quality control measures, we will see.

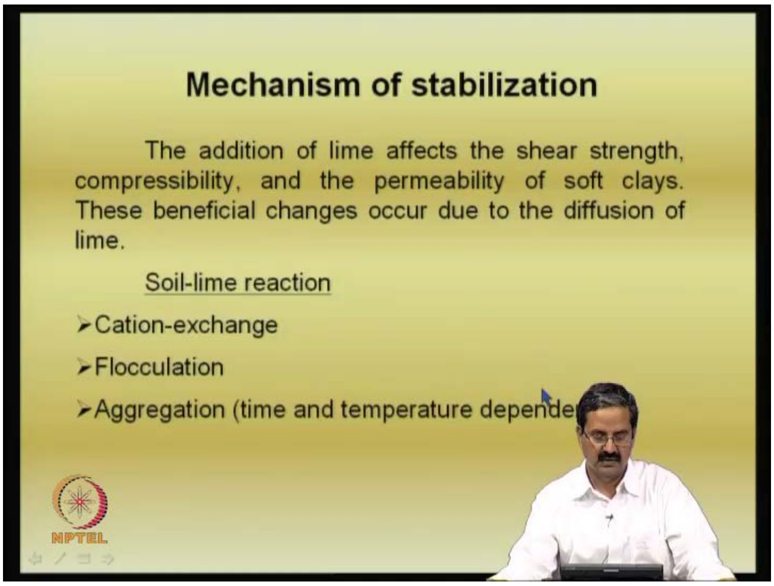
(Refer Slide Time: 04:45)



So, the stabilization using lime is an established practice to improve the characteristics of fine grained soils. Actually, it has been quite effective in all the fine grained soils, not necessarily expansive soils. What are if the soils are fine grained or which means, that they have high specific surface, like say for example, it can just, because of certain ions present in the material or because of the water, water present in the materials. So, essentially, the liquid limit and plasticity characteristics are reflected in higher values, say for example, higher is a liquid limit, you say, definitely higher is a specific surface. So, in treating this particularly fine grained soils, lime treatment has been very effective.

The first applications in the construction of the highways and air field pavements were reported in 1950s and 60s. With proven success of these attempts, the technique was extended. So, large scale treatments using lime for stabilization of subgrades as well as improvement of bearing capacity foundations in, in the form of lime columns.

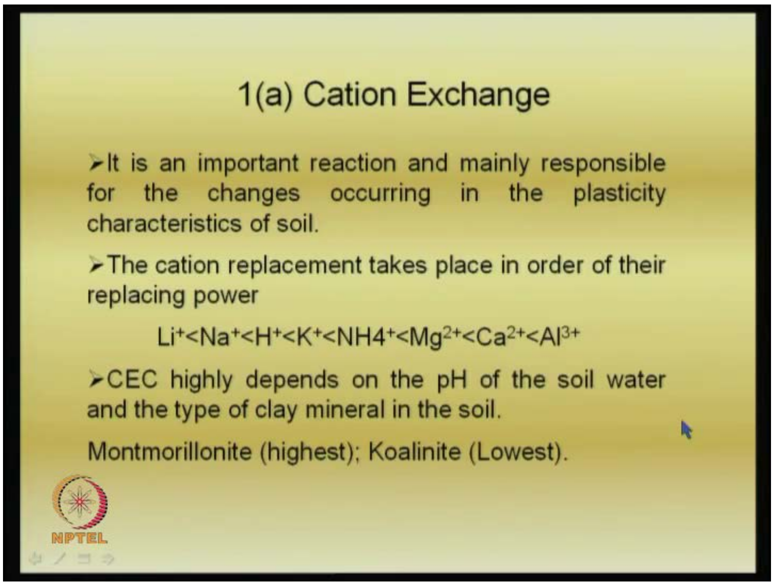
(Refer Slide Time: 05:57)



So, what we should see is that, what are the mechanisms? And the, as I just said, the mechanism, it results in improvement of shear strength, compressibility and permeability. So, what are the reasons or mechanisms?

There, there are couple of issues here, one, we call it cation-exchange capacity or the cation exchange; we call it flocculation; we call the other one as aggregation. So, this aggregation is essentially a function of time and the temperature. We will see what is cation-exchange?

(Refer Slide Time: 06:34)



The, we know, when you are trying to deal with soils or particularly clays, the cation-exchange is an important aspect, like we know, that the clays are negatively charged surfaces. And the possibility is, that when you add some material, like lime or something, there is replacement of ions, say for example, there is a sodium ion, then it gets replaced by calcium ion. So, there is, so to that extent, if you have sodium (( )), if you add calcium, a lot of calcium, then sodium gets replaced and it becomes calcium (( )). So, this is what is called action exchange capacity.

So, this is because of this mechanism of action exchange capacity, that there is a replacement of cations that takes places on the clay surface and this is in this order, say for example, the lithium, then sodium, like the hydrogen. So, this is all single valence ions.

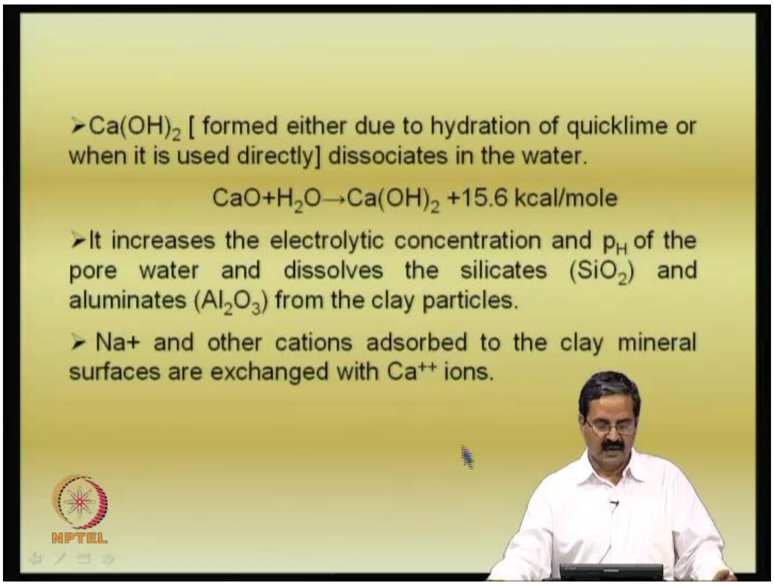
And as you have a higher material, then you know, higher valence that gets, that replaces the lower valence ions. So, for example, these three are all single and then, if you have divalent ions there is a possibility, that it gets replaced by higher valence ions and if you have aluminum, definitely it replaces calcium. And so, it, it also, you know, it is also a function of the ionic radius as well.

So, essentially, this is a rule in which many of the replacements takes place and the cation-exchange capacity depends on the pH of the soil like water. You know, the thing is, that there is a pour water, pour water and, the pour water if has some pH, definitely it has a big influence on the action exchange capacity and also the type of the clay mineral.

We know, that there are the different types of clay mineral and it is montmorillonite, koalinite and iolite and all that. And the specific surface in the montmorillonite is very high and because of which, say for example, sodium betonite has a, sodium betonite has a highest action exchange capacity, whereas calcium betonite has definitely very, very much lower capacity, just because of the valency.

So, so some of the sinks are already well known in geotechnical engineering, particularly when you are trying to study the soil behavior and, and clays.

(Refer Slide Time: 09:18)

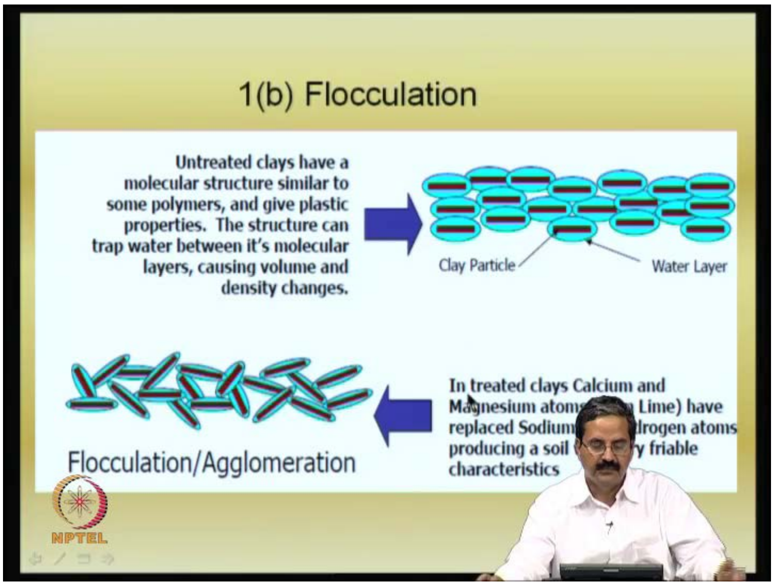


And the quick lime, you know, there are different types of materials here, one can add Ca O, like calcium oxides or calcium hydroxide or even calcium carbonate. But suppose, we have this material, what it leads to is, that it dissociates, with, in water and then it, you have, you form certain compounds and actually you can see that there is also energy release. So, that happens is, that when you add a lime in any form, whether it can be calcium hydroxide or a calcium oxide it increases, it, it results in hydration; it, it results in hydration and it increases the electro, electric concentration as well.

Say for example, what happens is, that there is a tendency for the particles to come together and then, so it increases the electro, electrolytic concentration and the pH, everything increases and dissolves the silicates and aluminates from the clay particles. And as I just mentioned, sodium ions and other cations are adsorbed to the clay mineral are exchanged with the calcium ions.

So, this particular behavior of ion exchange is something, that is very important because the ion exchange leads to reduce the specific surface and also, some sort of, even it could alter the particle arrangement and all that. So, it is a quite an effective mechanism by which the water content in a material could be reduced if you particularly add calcium.

(Refer Slide Time: 10:31)



The 2nd mechanism is that we try to say in terms of the flocculated structure formation. Normally, untreated class, the clays have the sort of matrix where they are all parallel shape, like we assume that, say for example, you take a montmorillonite and montmorillonite has sort of a orientation like this where you have water in between them. There is a lot of swelling here in the vertical direction.

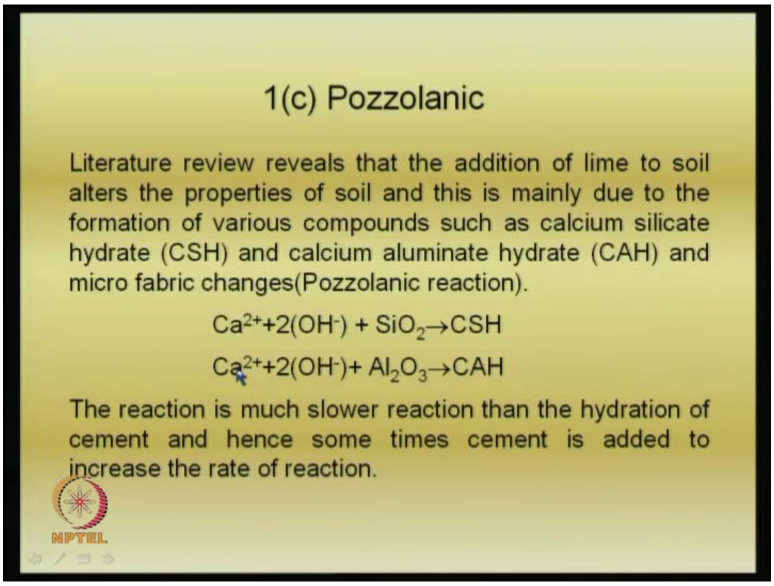
And see, the structure is trap of water between the you know, whatever is, that there is trap of water here everywhere and it causes big changes in the water content, but if you add calcium what happens? Say for example, in treated clays like they have a replaced sodium and hydrogen atoms. They produce some sort of structure like this, you know, you have what is called edge to face flocculation, like you know the edges and there,

there is an arrangement like this, you know, you can see, that there is an important arrangement, that is formed here, which you call it flocculating or agglomeration.

So, this thing will really, you know, compared to the dispersed structure, that we have here, the flocculated structure is something that, that is very, that is very important here and it changes the behavior reasonably completely because the water content, the way it holds the water, it handles the water will be much different. Say for example, you can imagine, that water is added to this, there is lot of swelling and water also can be removed because of shrinkage.

So, what it means is, that this has a tendency for lot of variations, but here the thing is, that water changes could be there, but you know, the water is stored between an arrangement like this. And then, because of the edge to face the flocculation, you will not have that much order of volume changes or water content variations. This is an important concept that one should remember here.

(Refer Slide time: 13:05)



Another important property that we should understand, that lime gives a sort of pozzolanic character to the mixed soil. What it means is that it results in calcium silicate and calcium aluminates hydrate materials and also changes in the fabric changes. So, it leads to two compounds like this and it is like, you know, we understand that the same compounds also exist in cement as well. It is a, it is a, like a cementatious material it is trying to behave like. Now, the soil is supposed to be very poor.

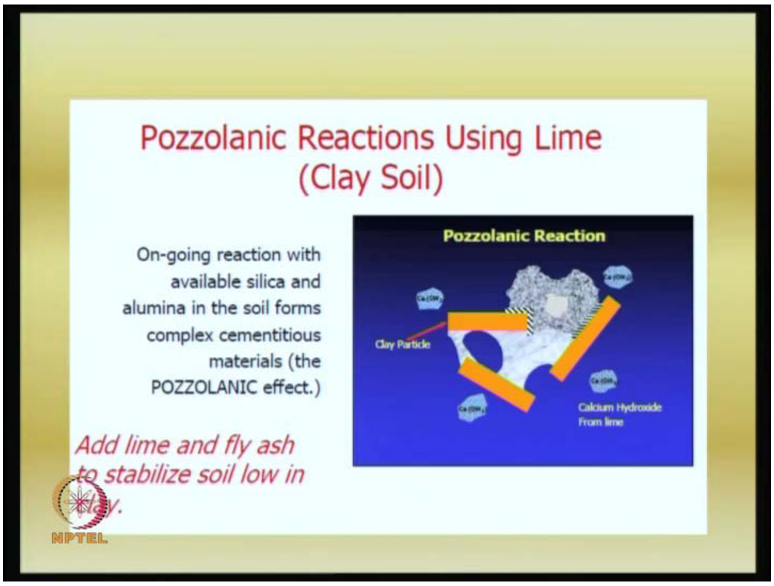
Now, we got rid of all the water present in by, you know, ion exchange and aggregation and the other one is in the long run, the cementation materials, cementation, you know, the compound's cementatious materials formation is something that is very important and because of the cementation, the strength of the soil is much higher.

So, this is a somewhat, this is one important reaction and the formation of the compounds is a very valuable addition to the actual response. Actually, sometimes what we do is that we also add a bit of cement in some cases because we know, that cement is already, you know, the, it much faster, it reacts faster; the formation of compounds is much faster compared to the soils.

So, suppose we have only a lime column, lime plus cement can be added, you know, in the lime, along with lime people can also add a bit of cement to see, that the cement, the whole process of putting the stone columns or I mean, sorry, lime columns or any of these materials could be faster.

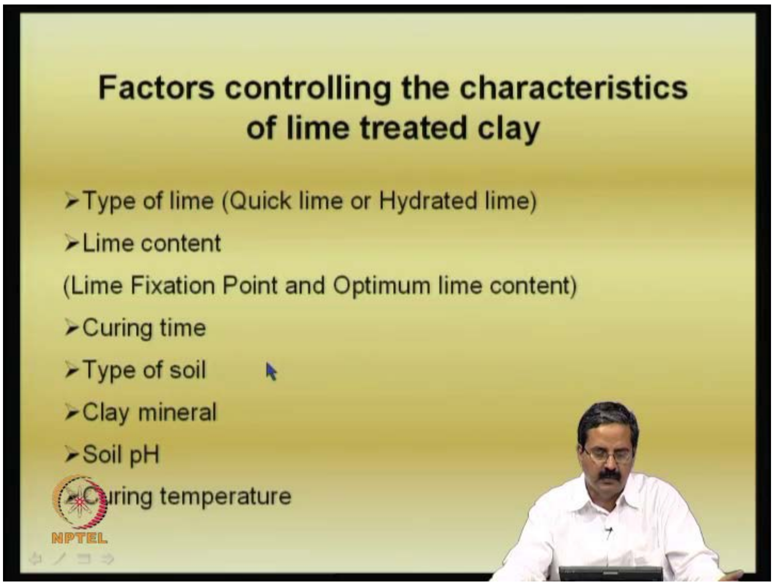
So, essentially, there are three mechanisms, one is the cation exchange, the second thing is flocculation, the third one is pozzolanic reaction.

(Refer Slide Time: 15:04)



So, this is what is, that particular thing. So, you have calcium hydroxide formation here, the ongoing reaction of the available silica and alumina in the soil forms complex cementations materials. So, you can see, that there is a cementation, that occurs and we add sometimes, as I said, in the clay, for example, we add lime and fly ash also, like cement also one can add, you know, depends on if you want improvement in cement properties. You can add cement, but fly ash or any other material could be added because you know, you are trying to increase the, I mean, particle size there you know. Suppose, the fly ash particle size is much higher than the, this clay and fly ash also is somewhat pozzolanic. Actually, some fly ashes are pozzolanic; actually they form cementations compounds, fly ash could be added, so these are all quite important.

(Refer Slide Time: 16:10)

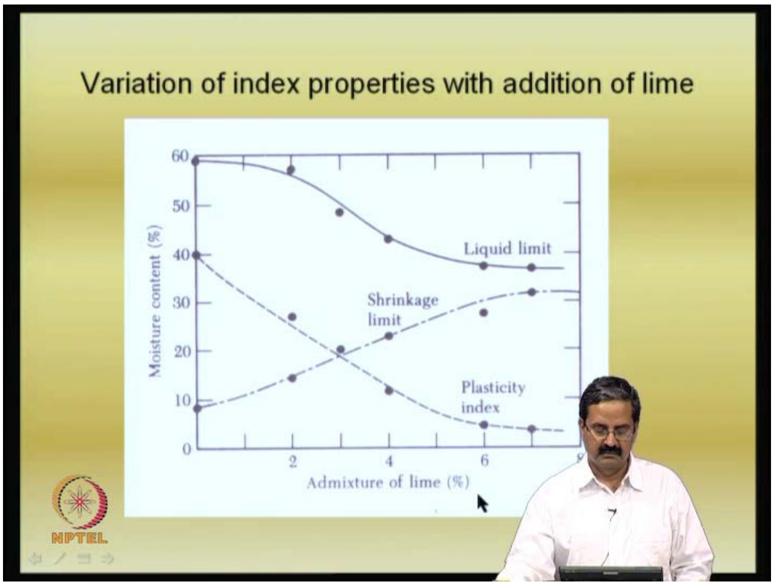


And what are the factors, that influence the characteristics of the lime treated clay? One should be able to understand the characteristics of the lime treated clay and one is the type of lime, whether it is a quick lime or hydrated lime; lime content, like what is the percentage, that you are trying to add; the curing time, say for example, it can be different from one day, 2nd day, one week, one month, one year, it could be different.

People have observed that these properties will increase with time because of the formation of cementations compounds. So, the property of the, the behavior of the lime treated clay is a function of curing time as well. Then, the type of soil, like say for example, essentially the what type of soil essentially, what type of, is it a Ch or a Ci and whatever type of, say for example, depending on its plastic characteristics, one can say right plastic characteristics and shrinkage limit and all that, that is also another material.

Then, clay mineral is another important variable we have, say for example, sodium, no, the montmorillonite materials and then, we also have iolite and kaolinite. Even the presence of this one, the, the type of mineral also influences. Soil pH is another important variable; curing temperature is another variable, why? Because as you said, the chemical reactions do take some time, you know, the rate of reaction could be higher when the temperature is somewhat higher, so this is another variable.

(Refer Slide Time: 17:55)



This is a typical example of how the mixture of lime with water can change the plastic characteristics. For example, if you see the liquid limit, it is about 60 percent here with 2 addition of percentage of lime, 2, 4, 6 and 8, you know, liquid limit has come down, some 60 to 40 percent.

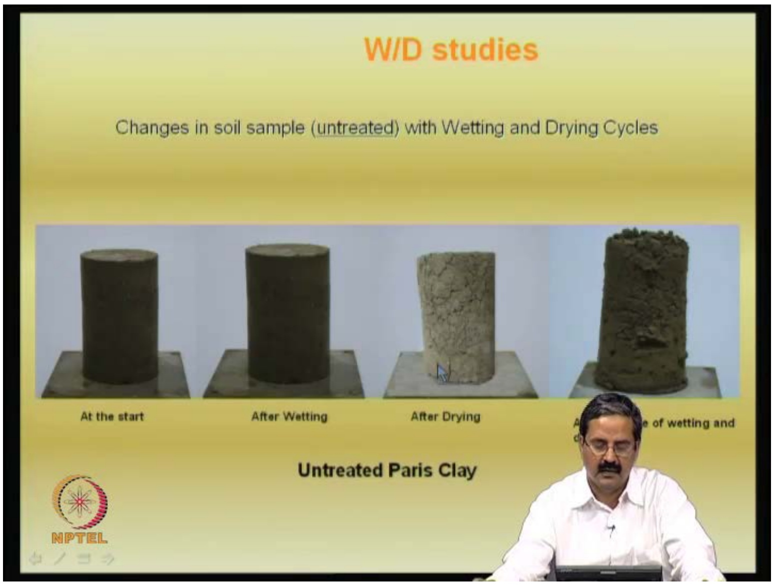
Then, the plasticity index from 40 to, it has come down to about 5 percent, so very good difference. Then, the shrinkage limit is increasing like, see, as I just mentioned, the particles, which have a parallel plate arrangement, say for example, betonite will have a very high water content and very low shrinkage limit also.

So, like, say for example, if (( )) 9, 9 percent is too low, too low value; normally we will have some 15, 20, something like that even in shrinkage limit. But, so the, the moment you add lime, what happens is, that the particle arrangement changes and it holds more water. As I just showed in my previous figure, that the H 2 face flocculation occurs and as a result, the water content will be higher.

Though the, so the shrinkage limit is little higher and even the plasticity index is also lower. So, which means, that you have comfortably reduced the plasticity characteristics of the soil, you have made the soil not so much shrinkable compared to the previous case, like say for example, take the same soil 60 to 9, 51 percent is the range of water content, so at which it can show variations.

But if you add water, I mean, you see the difference, it is too big, like liquid limit minus shrinkage limit, you come somewhere here. The liquid limit is something 40, 36 or something (( )) also quite high. So, it is a very important thing, that the, what it means is, that water content variations will not influence the response too much.

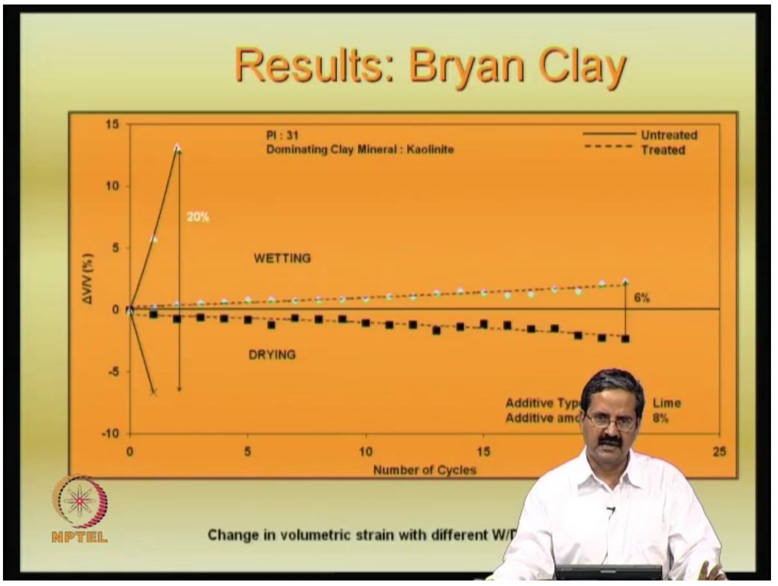
(Refer Slide Time: 20:07)



Actually, that is, see, people can do lot of testing on some of this materials, like one can do basic index property test, you can get some information. One can do unconfirmed compression tests, (( )) tests as that we are familiar with or leaching test, many tests could be done and here you can see that…

Actually, in Ellington University Dr Amanita Gopal has conducted lot of tests on this. And after 7 cycles of the lime treated on, you can see that it has not, it is ok, I mean the strength is ok, you know. They have done some sort of tests in which you are able to see the strength response.

(Refer Slide Time: 20:27)

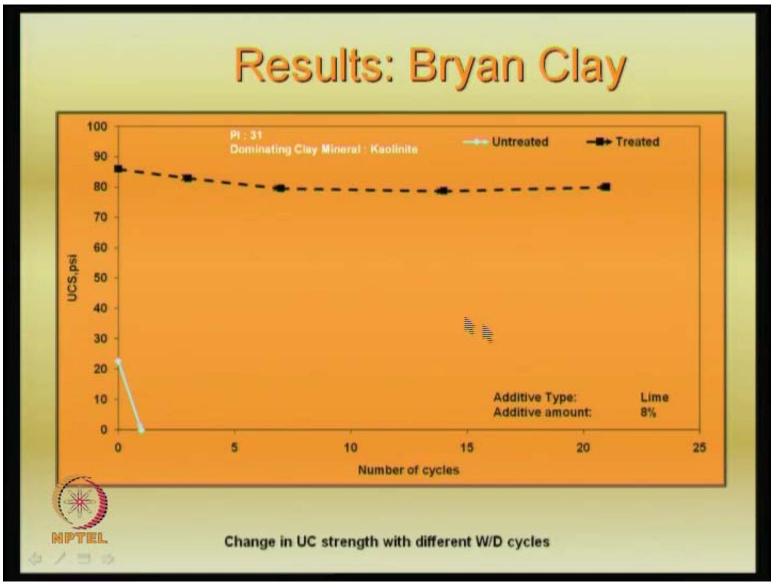


Actually, the thing is, that the behavior of soil is influenced by cyclical, you know, alternate wetting and drying cycles. This is another thing, that you see here, that volume change response and say for example, if the addition of lime of 8 percent and then dominant clay mineral is kaolinite and the plastic index is 31, during wetting and drying, the volume change has come down over a number of cycles, this is another important.

21 cycles they have tested, you can see that untreated material is like this, whereas treated material is like this. What it means is that the treated material is able to withstand more number of variations because of minimum change in water content, whereas you can see, that the untreated material has a big volume change.

It can (( )) have a volume shrink, it is actually expansion, this is shrinkage; minus sign shows shrinkage. So, here you can see, that even if there is a number of cycles have been done, the extent of change, you know, it is 6 percent, whereas it is 20 percent here. So, it is a quite a big difference when you try to treat the in-situ soil on expansive soil with lime and it is a good difference, the content here is about 8 percent, its number of cycles have been done here.

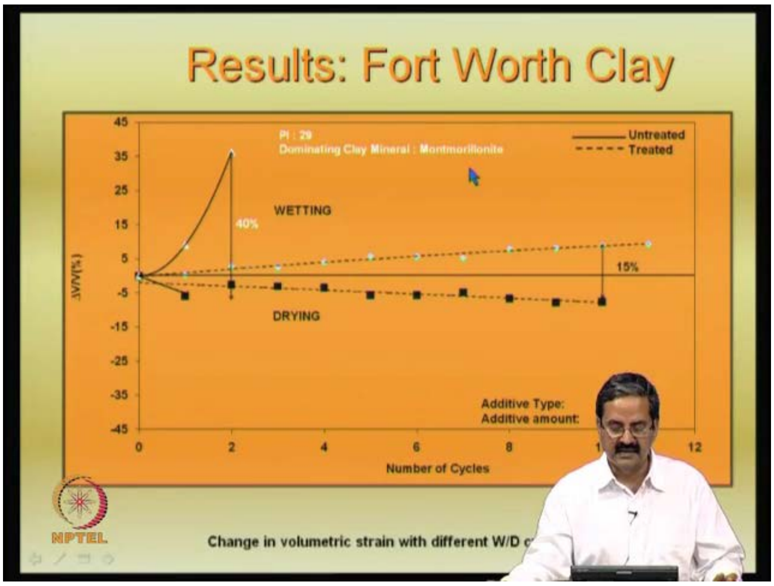
(Refer Slide Time: 22:07)



This is another one unconfirmed compression test. Again, see, that it is somewhere here in the case of untreated material the shear strength we use. Actually, it is so poor, that it is a very small value.

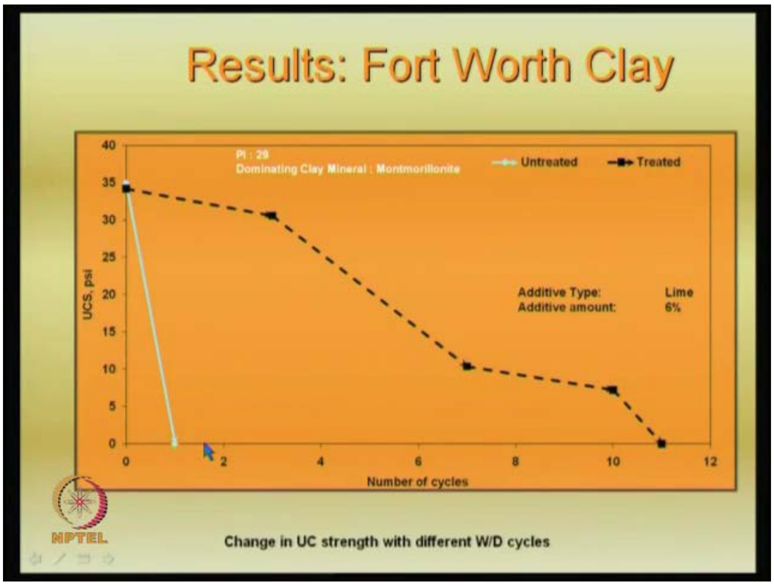
But here you can see, that the kaolinite, of course is a domination clay mineral here, it is quite consistent here in the range of about 80, 80 psi, which is, which is, like if you just convert, one can convert into using several multi, multi, multiplication factor to get into kpa and this is quite a good number.

(Refer Slide Time: 22:44)



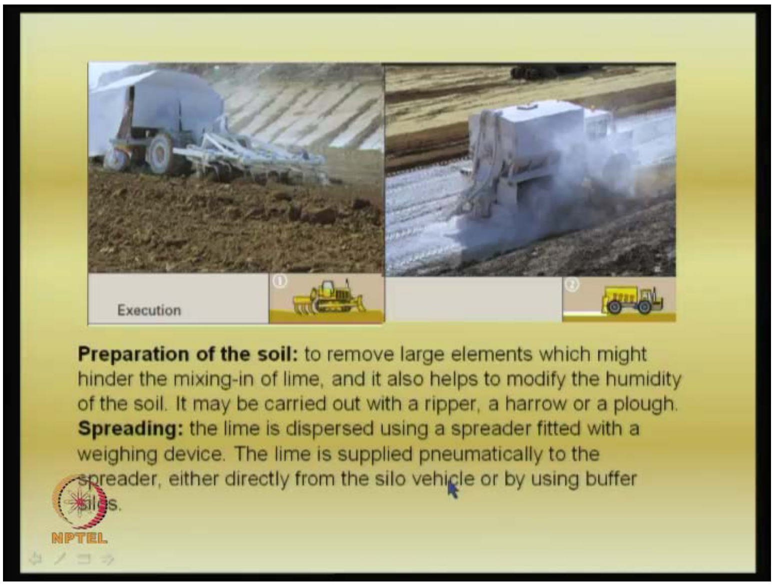
In this case, its dominating material is montmorillonite and the previous cases, all kaolinite, here in this case its montmorillonite. See, montmorillonite, it is about 40 percent, the difference and the case of, but then over a number of cycles here has come down to 10 percent.

(Refer Slide Time: 23:05)



Here also, about strength you can see, that number of cycles is, you know, the strength reduction is there and then, it is very drastic here.

(Refer Slide Time: 23:13)



What we meant was that the strength reductions are also a function of the clay mineral. In fact, I just mentioned in the beginning, that the type of soil has an influence in controlling the volume change and also the type of clay minerals, say for example, if you take a very, the clay of high plasticity, it will have a very good effect, whereas, if you take a low plasticity soil, it will not have that much effect.

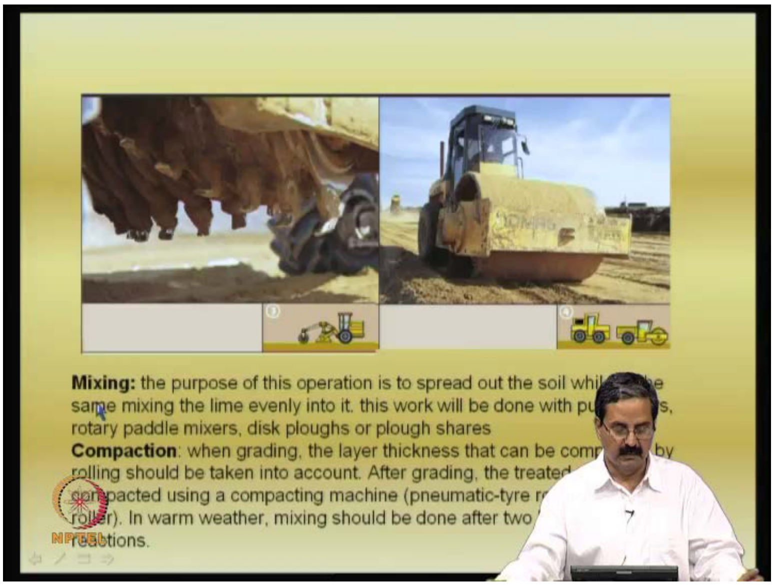
So, with this and then, the clay mineral is also another important result, which has been brought out very well by Professor Pala where, like you know, they were all working on. You, now the thing is, that they had a peculiar problem of pavements in expanse soils in Texas University and Texas, whole state of Texas has lot of expanse soils and they were working very seriously on why, though the treatment is done, the soil treatment has not been effective. So, they were able to investigate and come out with a couple of reasons on why the lime treatment has not been effective here.

And so, that being the basic information on how do we understand the soil behavior when lime is used as an admixture, we should be able to understand how do we do in the field. What we do in the field is, that actually, you have to take the first step of remove the last element, which might hinder the mixing of lime; mixing in, we just mix up the lime. And so, we try to say, for example if you are trying to make a road, you have to really clean this material and also what happens is, that if you just digging and all that you do, the humidity also gets altered. And one can, if, if you do not have machines, one can even do with the simple plough and all that.

And what the second is, so once you clear the, do the proper gridding arrangements in the field. What should be done is, that you can spread the line, they have a machine, here one can have a machine, which is like a tractor one can have in India and of course, we have. In fact, I must say, that we have Indian roads congress guidelines on how to stabilize soils in, for roads.

So, the lime should be dispersed in this particular material and how much of lime is coming out of this material is very clearly known by a weighing device. The lime is supplied pneumatically to the spreader; spreader is something, that it distributes, like you know, you have a water sprinkler type of thing for, you know, you must have seen lot of vehicles like this. So, you also have a sprinkling of lime here and this has some containers, which is called silos and all that.

(Refer Slide Time: 26:07)



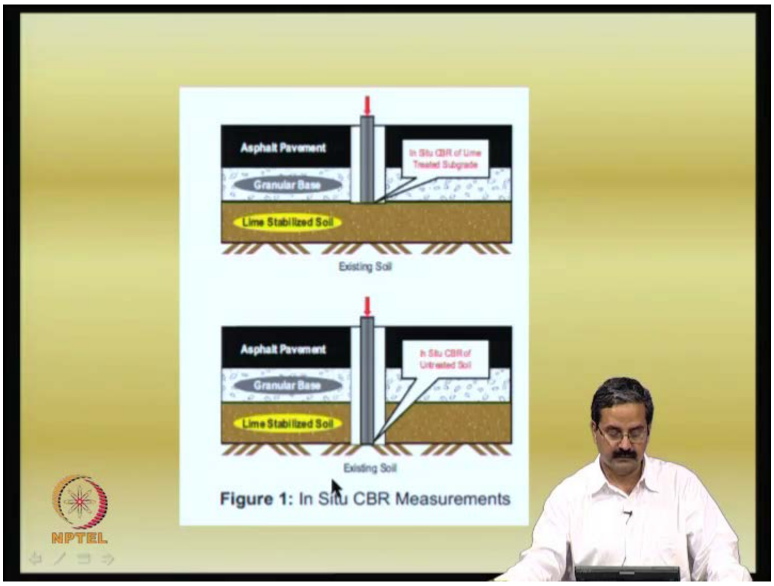
So, so, once you have this spread, then you have to do the mixing, mixing of the, the purpose is to spread out the soil while the same, at the same time mixing is evenly done. You know, you have to properly mix and see, that this can be done with pulvimixers, rotary paddlers and many things can be used, you know, to really mix the both of the top soil. And the, say for example, 30, 20 centimeters or 30 centimeters you would like to mix, you remove that much amount of soil and put that and then mix them thoroughly and then do the compaction, that is what we do normally.

So, compaction thickness should be, you know, properly determined, as I just mentioned in the beginning, in layers of 30 centimeters or 25 centimeters it should be done, that should be arrived at based on some testing and after grading, like you know, once you just see that, you know, put a tape and then see, that ok and this is the thickness of the middle part was about, say 300 or 400 mm.

Then, you put the rolling there and then do it and then, maybe, the compacted thing, some 400, it may come down to 300, 3 or 400 mm to 300 mm it can come down and that could be the, that could correspond to the maximum dry density and optimum moisture content using the lime. So, that is what is important.

And once you achieve that, it is fine, the road is ready and then, after that you can go for subsequent layers. This is just in the case of unpaved road, you know, you are trying to lay the, you know, the, say for example, and an expansive soil subgrade. You remove some place, some amount of you remove, some amount of material and then use this. In fact, there are some places where you cannot even walk and sometimes spreading the, using the lime can really make the surface workable, that is like, you know what happens? Water, water is released, then the soil fabric changes and all that, one can do some sort of loading operations quite comfortably; that is what people have been doing in the olden days.

(Refer Slide Time: 28:35)

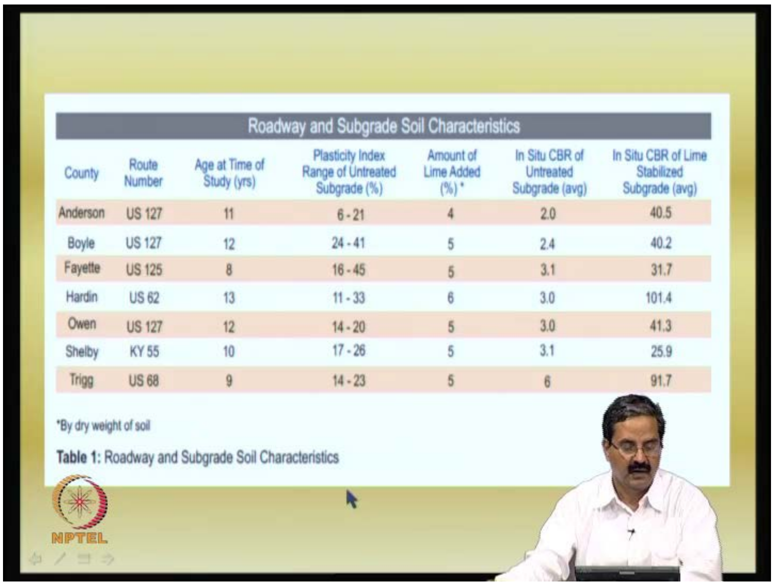


I will just give you some example of durability studies that were conducted by a company, which deals exclusively with lime, lime treatment. In fact, they have taken lime treatment as their own profession and then they go about doing this job very well.

Similar to field CBR, similar to in situ laboratory CBR, we can also do the in situ CBR test. They have done the in situ CBR test for the existing soil and then lime, you know, untreated soil. So, this is what, say for example, the in situ CBR of the lime treated soil was done at this point; in situ CBR of the untreated soil was done at this point.

So, you, you have these two measurements and over a period of time for the pavement layer, which has a lime, lime treated soil as well as a GSB, as well as asphalt pavement, they are trying to compare what is, what is happening. So, they, they measured the CBR only.

(Refer Slide Time: 29:41)

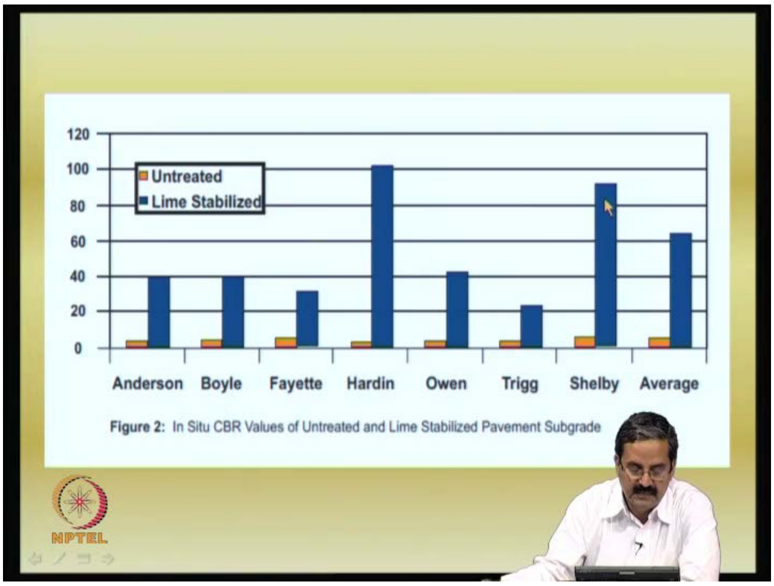


And you can see, that for example, these are the different counties in US, these are all the highways, the time duration of studying, 11 years, 12 years, 13, you can just see the number of years of study.

Then, see, because the area is being different you have different types of plastic index values, you can see 6 to 21 in this, here is the higher range 24 to 41 and 16 to 45. So, say the highest and lowest in here.

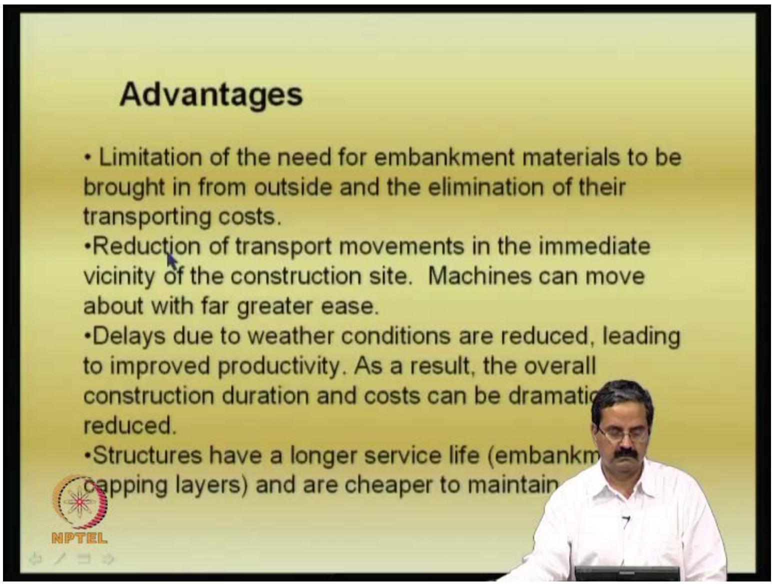
And what is the amount of lime added? It is about 4 to 5 percent, 6 percent is here, somewhere here and in situ CBR of the untreated subgrade, it is 2 percent, you can see, 2, 2,43 and like this. But then, once the treatment was done, the average CBR is improved so much, like about 40 percent, 40, 31, you know, one naught one, you can see that, one naught one percent, you can say it is high numbers, it is a very good number and definitely it helps.

(Refer Slide Time: 30:53)



So, these are all the same thing that is plotted in terms of a histogram for the all the areas, that they studied and it is very clearly you can see, that lime treatment has been very effective.

(Refer Slide Time: 31:09)



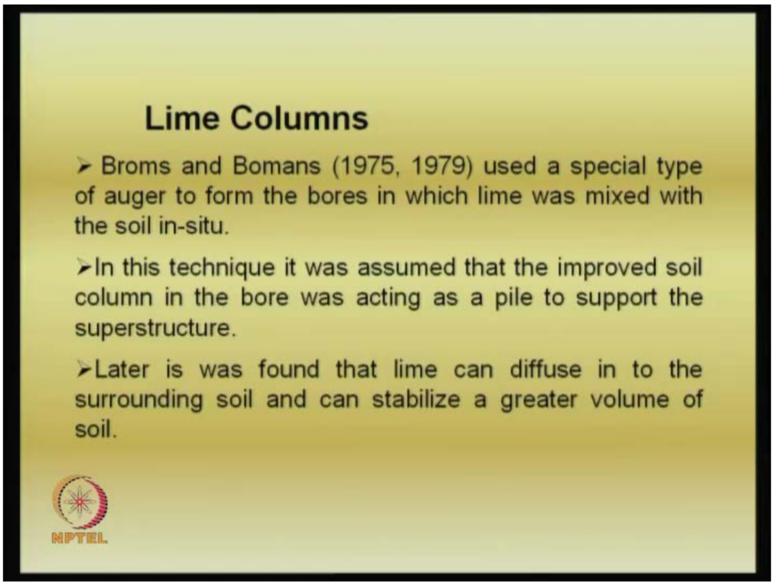
And so, the advantage is, that the limitation of the need for embankment materials to be brought in from outside and the elimination of the transporting cost. The big difference that you are getting is that you do not need to, you know, the neglect the soil. The in situ soil is there; you can treat it with lime and make it embankment material. So, the cost of transportation of the material itself is less, as you know the embankment material. Say for example, if you want to get a clayey material or a sandy clayey sand or sandy clay material, which is somewhat good in its properties, it is very difficult to get, particularly in areas where there is lot of soft soil and expansive soil. So, that way, when you have this, definitely you know, you have both, actually the cost of material is not there and even the cost, the elimination of the transporting cost.

And the reduction of the transport movements in the immediate vicinity of the construction site machines can move about with greater ease. What I just mentioned was, that like the soil is so poor, you know, nothing can move, but then, if you just put some sort of lime or sprinkle lime and definitely there will be some reactions take place and within a, you know, you can start using that. In fact, I was just mentioning a few minutes back, that it takes 2 hours, you know, to have the initial reaction to take place. In fact, just need to mention, that say for example, in warm, warm climates how much of, see, that how much of time we should wait? Just 2 hours is sufficient; you sprinkle the lime on that material and then try to mix it and then, that material becomes easy to handle, you know, one can work with that.

So, delays due to weather conditions can reduce leading to improved productivity, in fact, this is another important variable. As a result, the overall what happens? See, the weather conditions are very poor, like you know, if the area is the, if there is a rainy season and all that and there is not much change in the water content or you know, the thing is, you would like to do that work, whatever, you know, water removal and all is not easy. You know, you want to, in a rainy season you want to remove the water, it is not that easy, but if you add lime in that stage, definitely you know, the weather, even one can overcome weather conditions and treat that soil areas. Say for example, the total surrounding conditions are like, you know, the ambient temperature is very low. Say for example, in US, sometimes in winter it can be very nasty and then you cannot expect, that you know, you should wait for some 6 months or sometime. So, one can use lime, lime and then bring about, you know, whatever construction operations you can do, start with that and then make things ready. So, this is one thing and this helps in the overall cost as well.

The structures have a longer service life like embankments, and capping layers means cover, you know, like a pavement capping or a pavement is same. They are cheaper to maintain because definitely, you have made the in situ soil as much better material or whatever is that field material you are using, that it is much better because this strength properties are expected to be much better, the compressibility everything are much improved.

(Refer Slide Time: 34:37)



So, now I will talk about lime columns.

Excuse me, hello!

Yeah, tell me sir.

There is no clock here.

Oh timer is not there.

Oh, it is there; ok it is there.

Okay, you can continue.

No, no, no, no, the thing is you are putting in another place I am only watching there you know.

Now, you are able to find it.

Yeah.

Ok, yeah then you can continue.

I am not able to synchronize my this thing and I am looking for watch most of the time than that thank you. So, I think you can edit it.

So, now, I would be talking about lime columns, which is quite again an innovation in lime columns. This, it was, you know, if you go to Scandinavian countries like Denmark and Sweden and all that, the soil is so soft, you do not get, clay, sand at all. And you may say about any other technique, it will not be very, you know, easy like geotextiles and geosynthetics, they came recently.

But in 70s and 60s, it is prefabricated vertical drains and many people have also worked on different techniques. In fact, when Professor (( )) he is actually from a Swedish geotechnical institute, SGI, it is called, they, they did lot of work on lime columns and lime stabilization, they have an ISE paper on how to construct lime columns.

In this actually what, see the thing is, that the in the case of roads it is simple mixing and then we need about top one half a meter or something to treatment, half, half to one meter, but you are trying to talk about embankments, which are, say 5 meters height or you want to have a, what do you call the foundations loading from, foundations on soft soils, you have to treat the soft soil in some manner.

So, when you do that, say the alternative, say we discussed about stone columns and other methods, lime columns are also very important because when you have, you know the advantage is, that see the, in expansive soils, lime, lime columns are better definitely, and soft soils lime columns could be also used. Of course, you have other techniques, as we just discussed the prefabricated vertical drains and stone columns are there, already there, this is another method. So, you have a number of methods in trying to improve the bearing capacity and reduce the settlement.

So, what we do is that in this technique we assume that the improved soil column in the bored was acting as a pile to support the superstructure. Later, actually people find, that you know, the lime column area, say for example, this area, you know, say for example, the shear strength of the soil in the clay is so less.

But when a lime column itself, you know, when you treat and all that, that material, you, it has some zone of influence around it, some, some, this thing definitely, that is a much stronger material than that. So, one can treat that as a pile and people have also observed that it is not just about treating it as a pile. In fact, lime can defuse, you know, the thing is that lime, you know, if you know the permeability of the nearby soil, the diffusion can take place and the lime can, in fact, stabilize a more amount of soil, is a very important concept here.

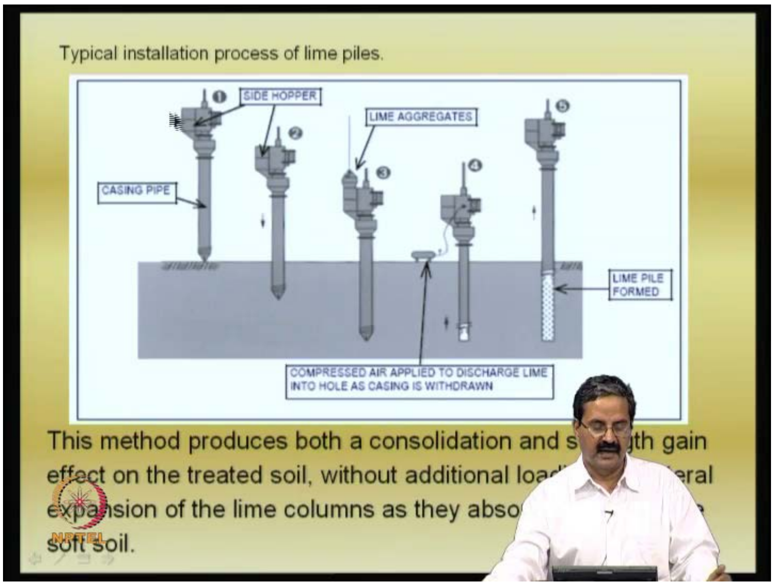
People have studied lot of, you know, work on this, you know, they did lot of work on diffusion of lime in soils and in fact, you know, in many places in Madras IIT and many other places where, even in Indian Institute of Science. So, what we do is, that we create lime columns, then we study the concentration of cations, calcium ions. If you study the calcium ions concentration, definitely it will tell you, that with initially it was less, but as you go on with the time, concentration of cations also increases next to the lime column.

So, this is a very important concept and this is somewhat different compared to what we know in the case of stone columns. In the stone columns and pre fabricated vertical drains they have some area that exist around them which will make them you know somewhat we say that it is an equivalent area over which the lime pile or the stone column or the p v d can be effective.

P v d is effective because drainage is an important area of function stone column is effective because there is a load sharing mechanism that comes into picture and then because of the load redistribution, the, it, the area of influence is somewhat higher because of the diffusion of lime here that area of influence is governed by this factor. So, the area of influence is an important concept in soil mechanics.

One should understand what material if you put what happens and what is the area of influence it has, like people can, as I just mentioned, gave an example, that the sand drains should not be confused with sand columns. Sand drain is a sand drain, it is only for drainage, it has some area and permeability is a controlling factor. And whereas, sand column is something as strength related aspect, strength and stiffness come into picture.

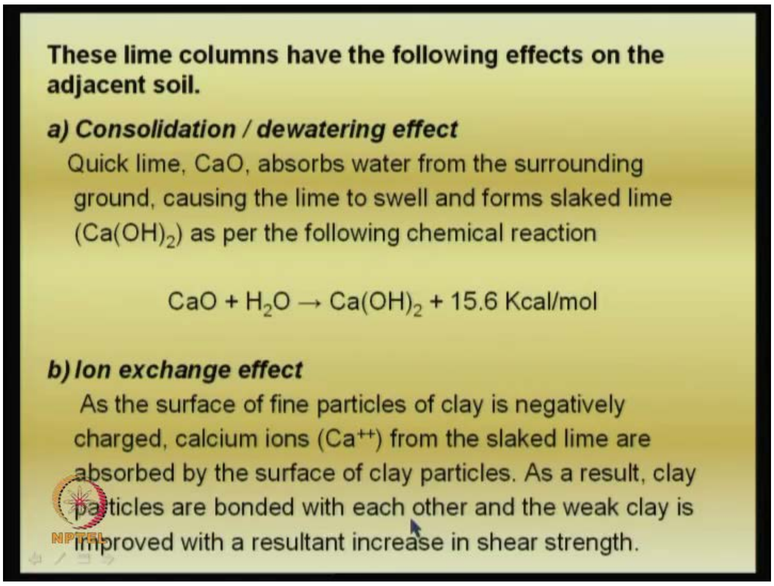
(Refer Slide Time: 40:26)



So, how do you do this installation? Say, for example, this is a hopper like, this can be connected to any of the vehicles or something like that, just insert and they have lime aggregates and materials and all that go to the, you have a compressed air arrangement applied to this as lime into the whole, as a casing is withdrawn, the, you are trying to remove the casing and then, the lime is getting added here. And you can complete the whole process and you have the lime column formed.

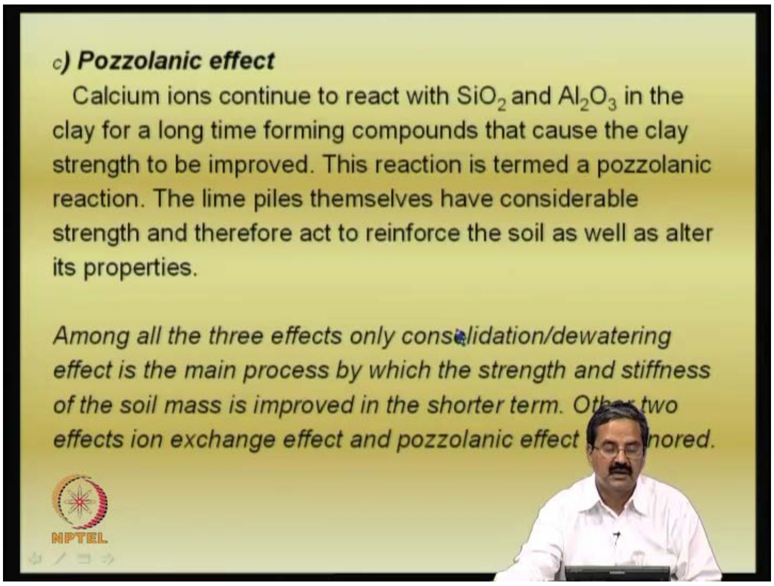
And actually, see the thing is, that in the design of stone columns, actually we said, that there are couple of things like a flocculation and ion exchange process, the water content is removed as I just mentioned. Because of the hydration the, the lime columns produces a consolidation effect, like as I just mentioned, a pre-consolidation effect in which water content is removed. And because of it there is a strength gain effect on the treated soil without additional loading. I have not done any additional loading to reduce the water content; I have just added lime, which has equivalent effect. And why, because it has even lateral expansion also, this is another important factor, that can come into picture.

(Refer Slide Time: 41:56)



Later, we will see, that the, even the lime columns also have the same thing except, that you know, like quick lime and all that it has just mentioned, it forms the slaked lime. This is a quick lime and this is a slaked lime and then you have the heat of the reaction. And cation exchange takes place; this is one important, same mechanisms also control the, the stone column or the lime column behavior.

(Refer Slide Time: 42:25)



And pozzolanic activity or the pozzolanic effect is also there and another important thing, the lime piles themselves have a considerable strength and therefore, act to reinforce the soil as well as alter its properties.

Say, there are so many mechanisms, that it has advantages, that, and then it is cost effective also, it is economical. So, normally what we do is that if suppose you want to design, we are essentially looking at consolidation dewatering effect as the main process of strength gain and normally, you know, I will just show you a design method, how it can be done.

(Refer Slide Time: 43:07)

And how is that the strength of the soil is improved? People have seen, that like you have seen just now, that the CBR is nothing, but the strength of this in situ soil and you add lime, the strength of the soil is increased by about 30 times, 40 times, 50 times. In some cases, in situ CBR test was done in some cases, we have seen that.

Even you have saw the results of the unconfirmed compression tests from (( )) aware, it was very clear. Even in our lab we have lot of experiment results, where it was very clear, that the treatment using lime produces strength improvement.

So, actually, what you get from the lab is something, that you know, it is just for simple mixing and then, in simple testing people normally do and then they make some inferences, that it is very effective. But what happens in the field is, that the area, that you are trying to handle is very big and the strength of the soil stabilized in the field is much higher than the, that of samples prepared in the laboratory.

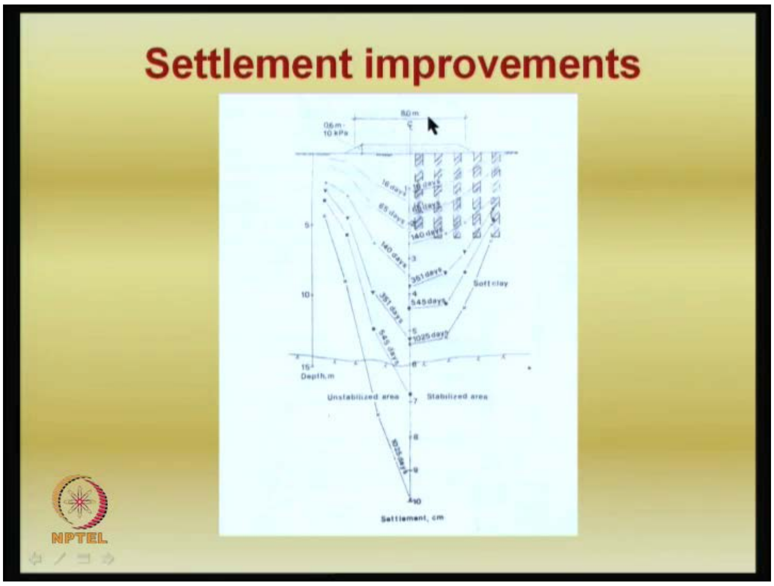
The soil stabilized in situ is subjected to a pressure from the overburden and from the surrounding soil, where the confining pressure for the samples that were stored in the small containers is small, like, see the thing is, that in the lab what are you doing. You know, the thing is, that if you want to do, see the, you mix the soil, untreated soil is one plastic bag, then 2 percent plus lime, 2 percent lime plus soil is one plastic bag, 4 percent lime plus soil is another plastic bag. So, you test all the three of them.

And then, you have low strength here in without lime and then higher strength in some 2 percent lime and much higher strength in 4 percent lime, but then, you are just trying to, you know, just compare all the three of them without bothering about the concerning effect in the field. It will show you some 30 percent difference or 20 percent difference in the lab.

But then, in the field what is happening because of the, you know, say for example, if you are handling 10 meters height of the depth of embankment, definitely you know, the pressure at 2 meters is 22 into 20 kpa say for example, 2 meters is 40 kpa or maybe, 35 kpa. But then, if you are handling 10 meters, definitely 10 meters into 18, 180 kpa, you know, it is 180 kpa, it could be and you know, it is much different.

So, the stresses are going to have a significant influence, in situ stresses are going to have a significant influence on the behavior of lime treated soils, which is not. So, what we want to say is, that the behavior of lime treated soil in the field may be much higher compared to what you find in the lab; that is what the inference of this.

(Refer Slide Time: 46:08)

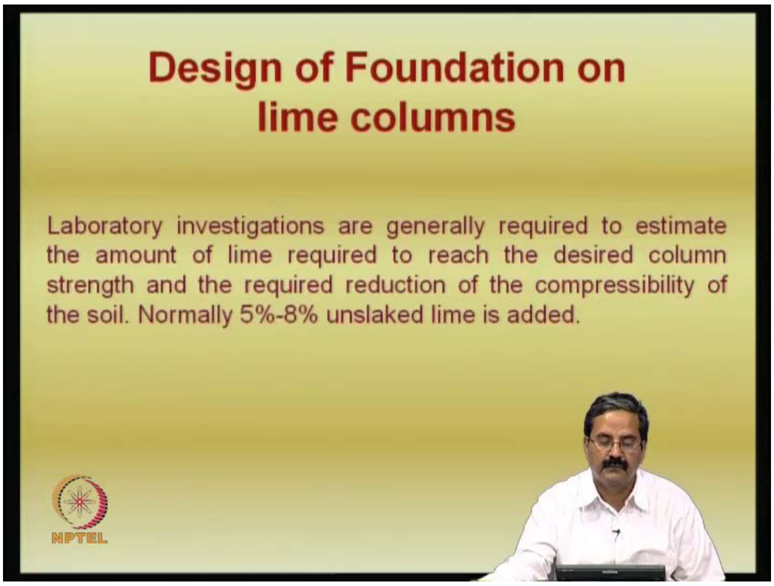


Actually, people have observed the settlements, you can see, that this is the stabilized area, this is unstabilized area. In the case of an embankment, you have about, it is a small embankment, 0.6 meters height and 10 kpa is the load only and these are all the settlement profiles, settlement in centimeters, so like these are 10 centimeters, 100 mm.

You can see, that in the, in the case of treated soft soil, the settlements are only here, you know, like the, beneath the foundation they are maximum, it is may be 5.5 here, this 8 meters is the width of embankment. So, about 5.5 here, then it comes down like this, at the edges, of course it is minimum. So, 10, 20, say for example, it has been measured for 16 days; 66, 140, 351 and 545, 10 25 days. So, the, there are different time durations and you also have settlements.

In the case of untreated soil you can see, that it is very high. So, from strength point of view as well as settlement point of view, lime treatment has been very effective.

(Refer Slide Time: 47:31)

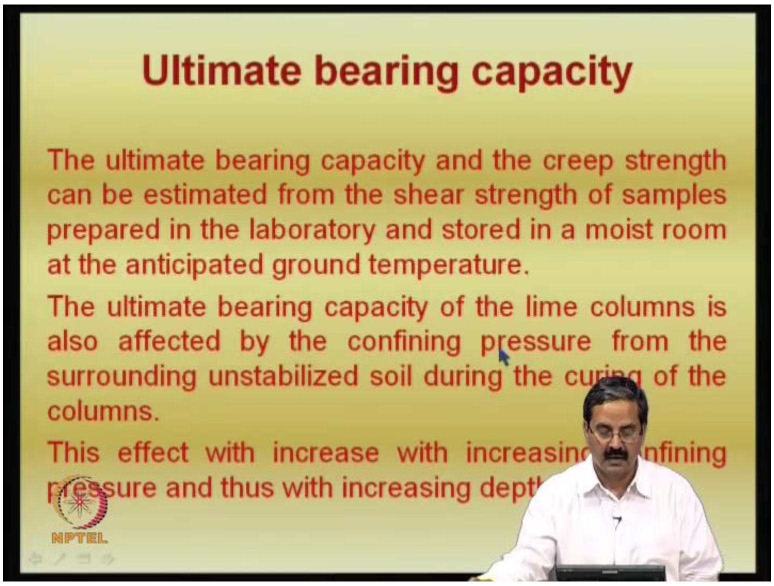


So, how do you go about the design? Design is something, that we need to understand and first thing, that we should do is, that what is the optimum content of the lime that we should use for treating the soil? What you should do is, that as I just mentioned, maybe, you can take the unconfirmed compression test as the basis, like say for example, you are trying to construct an embankment on a soft soil, take the soil at its natural water content, make a sample, add lime, make a sample and get its unconfirmed compression test or all other properties, like you know, you need to estimate, you knew both, strength and compressibility, permeability, everything, measure all the properties within the undesirable state.

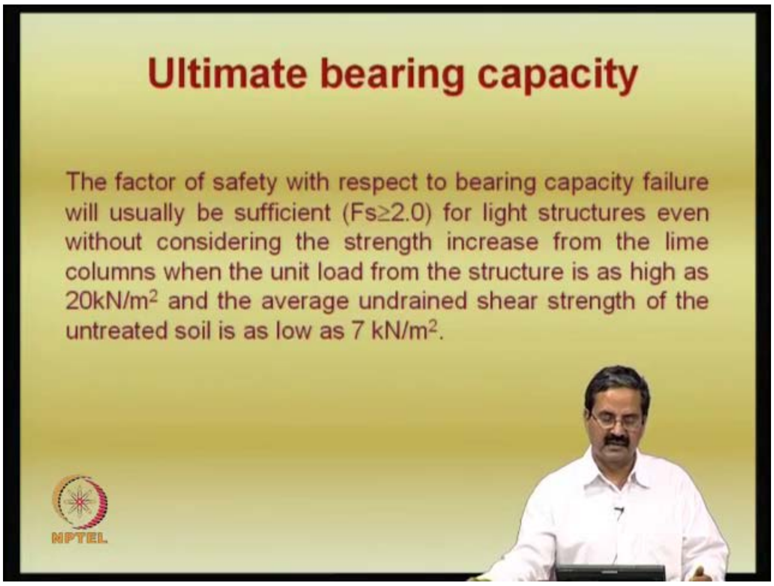
And then, measure them at various contents, lime contents, like 2 percent, 4 percent, 8 percent or whatever, then you could find out the optimum content at which without sacrificing any other thing, maybe you will be able to achieve the required settlement or shear strength improvement and all that.

Now, the design criteria, you will have design criteria, that say for example, there is so much load is coming because of the road construction and what should be the strength of the soil below the road? How much it should be one can design? So, essentially, what people have seen is that 5 to 8 percent of the unsliced lime is added. So, that is fine; from the laboratory one can get that information.

(Refer Slide Time: 48:58)



(Refer Slide Time: 49:26)



And the how do you get the ultimate bearing capacity? The ultimate bearing capacity is obtained from the strength of the samples, like you know, actually we, you know, for example, unconfirmed compressive test is one simple device, simple test one can do and as I just said, the confirming effects are there, particularly when you are trying to use this.

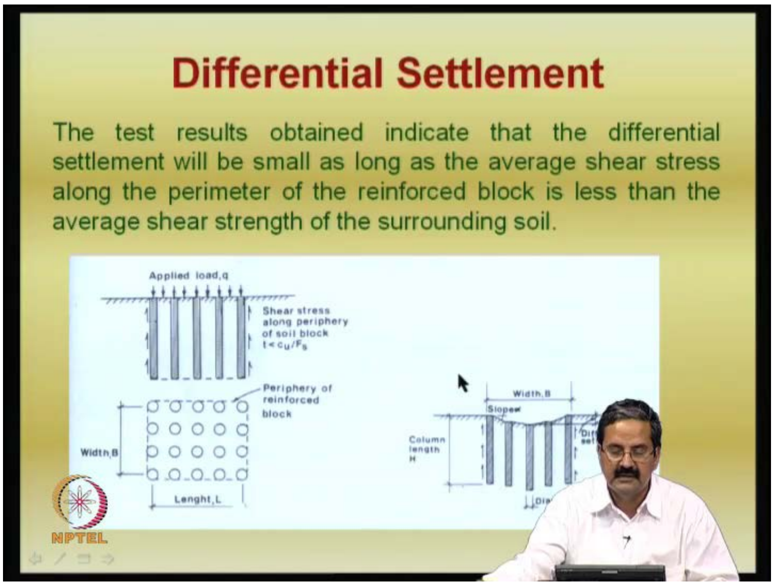
So, like suppose, you know, the unconfirmed compression test divided by 2 will give you the c value, is it not? So, you will get a c value and then use 5.14c for Cu as the ultimate bearing capacity and you know, you treat that as soil clay, maybe Cu could be 10 kpa and it could got it, got improved to 50 kpa because of the lime treatment. So, it is a, there is a 5 time increase in the ultimate bearing capacity, even if you multiplied by 5.14. The ratio being same for both cases, the ultimate bearing capacity could be (( )); instead of 50 kpa, now it could be 250 kpa.

So, the factor safety could be about two or whatever bearing the factors of safety have certain sanctity here in our geotechnical engineering, though you may have different factors for different conditions. So, in this, you know, we do not consider the strength increase, you know, like because of other chemical reactions and all that. It is just, that you know, we try to say, that the, the, you know, like because of the, we do not give the importance to, what you call, the overburden effect.

Say, as we go down, definitely the strength improvement is going to be higher, but we will not, we will not give importance to that and we just take a conservative design, that yeah, we, the strength is same with depth. So, that is a conservative assumption and say for example, the unit, this same assumption one can use when you have the loads could be about 20 kpa. Actually, you know, the thing is, even the IRC code says, that you have to take the load on the highway as 1.2 times the unit weight of the soil, 1.2 times the height. Say, 1.2 into h is, say for example, 1 meter, you know, 1 meter or 2 meters and you know, unit weight is we know.

So, you just multiply, it comes to about 22 kpa and all that. It is also similar, you know, 20 kpa is what we assume for bridges or pavements and all that. And if you want to design an embankment in a place where the soft soil is there, you have to use this load, about 22, 20 kpa you should use and the shear strength of the soil could be low, you know, the thing, if these are all immaterial for us how to design this.

(Refer Slide Time: 52:10)



Another important point, that we should give weightage to, that is, that suppose, you are trying to construct a structure here. So, the, you need to calculate the ultimate bearing capacity is one thing, like you know, the thing is, that bearing capacity is one thing, you should also calculate different settlements and total settlements, that is very important, then the design is complete.

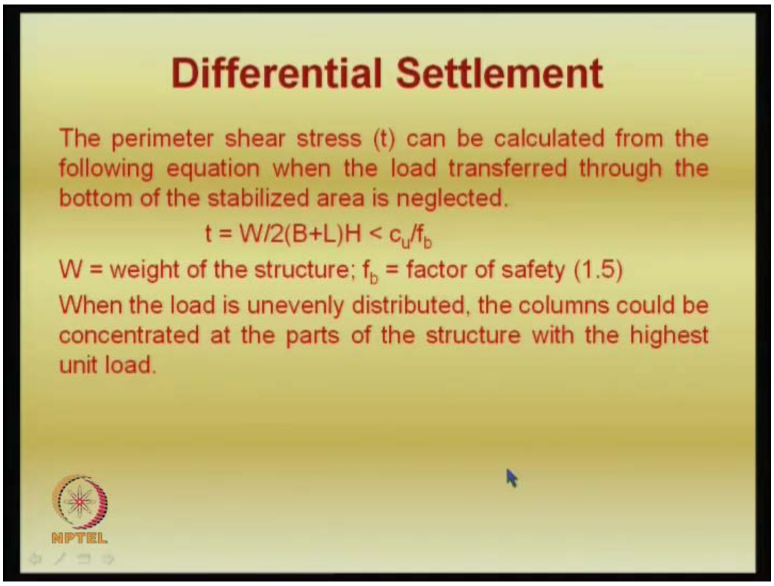
So, the, how do you calculate the differences, the settlements? There is a simple assumption here, that the, you apply load like this, maybe, whatever is a pressure that comes, it may be from the highway or something, whatever or even from a building, the total, the periphery is this, which is just here. The shear stress along the periphery of the soil is say t, it should be, see you can calculate the shear stress and the shear stress you can, you know the, what is a load? You know, that thing is, the shear stress is nothing, but the load, that is coming, you know, load divided by the perimeter. So, the thing is, that you have some load, say for example, 100 tons or 1000 tons, whatever is the total building load, take that.

And then, say for example, you are trying to construct, this is 10 meters depth and this is 10 meters width. So, 10 meters into 10 meters is the plan area. Say, for example, this is 10 meters, this is 10 meters and the depth is 10 meters as a small example and that is, actually, you can calculate the perimeter and the total load is, say for example, 1000 or whatever is the load, 1000 divided by this area of cross section will give you the load, that is coming, that should be less than, that is called a shear stress, that is coming here.

And vertical stress, actually you can have a, that is actually the vertical stress. You can also, this way they are computing the shear stress, it should be less than the, the Cu of the soil divided by some fact of safety. So, this should be satisfied.

And apart from it there is a different settlement, as I just mentioned, we should calculate and the different settlement is like, you know, the thing is this column has settled and all that.

(Refer Slide Time: 54:23)

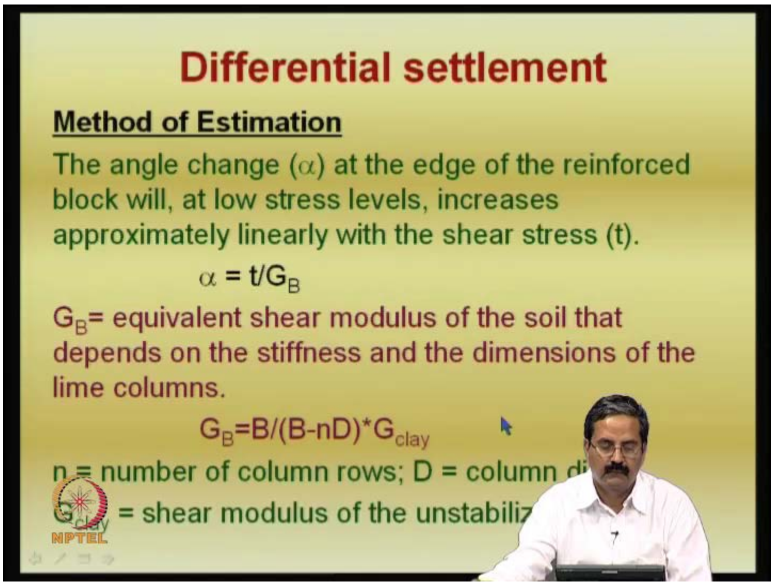


So, the perimeter shear stress can be calculated from the following equation when the load transferred through the bottom of the stabilized area is neglected. So, this is what I just mentioned, like people are (( )).

So, once you know the weight of the structure and all that, one can calculate the fact of safety is there. So, when the load is unevenly distributed, the columns could be concentrated at the parts of… With the highest load this is another simple way that we try to do, that when the loads are uneven, say for example, in the case of an embankment there is no problem at all.

And you just add all the loads and then put the columns in a proper way with proper spacing and it is completely done. But when there is unevenness, say for example, you are trying to construct, say heavy loaded area in some place, you know, heavy loaded. So, how do you do that? It is also could be done, it is not an issue at all.

(Refer Slide Time: 55:20)



There are, we also can estimate the differential settlement. We have, you know, the thing is, that there is a simple method. See, the thing is, that the, the method of estimation is, that as I just showed you, that alpha, which you have here in this point needs to be calculated. This alpha you can get in this expression, like what we do is that the shear stress divided by the shear modulus; the shear modulus is nothing, but the shear bond or the material, you know, the thing is, that you are trying to talk about the improved soil.

What is that? The G B is nothing, but the equivalent shear modulus of the soil that depends on the stiffness and the dimensions of the lime columns. So, you have to calculate the stiffness of that to calculate the distortion. So, the G B is nothing, but it is like, we try to take some ratio and proportion type formula, we know the stiffness of the soil, clay, say for example, 10 mpa, you know, 10 mpa, 5 mpa, it can be very low value. Say, for example rock, it could be 100 mpa; for steel it could be some mpa, you know.

G B is a shear modulus, so you can calculate the shear modulus knowing it is Young's modulus also. So, B minus nD; n is a number of columns and then d (( ))…

…area over which the clay is there; this is a total area. So, you are trying to use some ratio and proportion method knowing the foundation size, like say for example, B into D and a number of columns and also the G or the clay, you get this G B, once you get this G B, you can calculate the inclination. So, this is one way of calculating the differential settlement and of course, total settlement also could be calculated. So, what we see is, that we have a simple design methods, which are quite useful and we will see some, how do you handle this.

Thank you.