Ground Improvement

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Module No. # 06

Lecture No. # 19

Ground Treatment with Cement

Today, we would be talking about one of the classical ground improvement techniques, namely cement.

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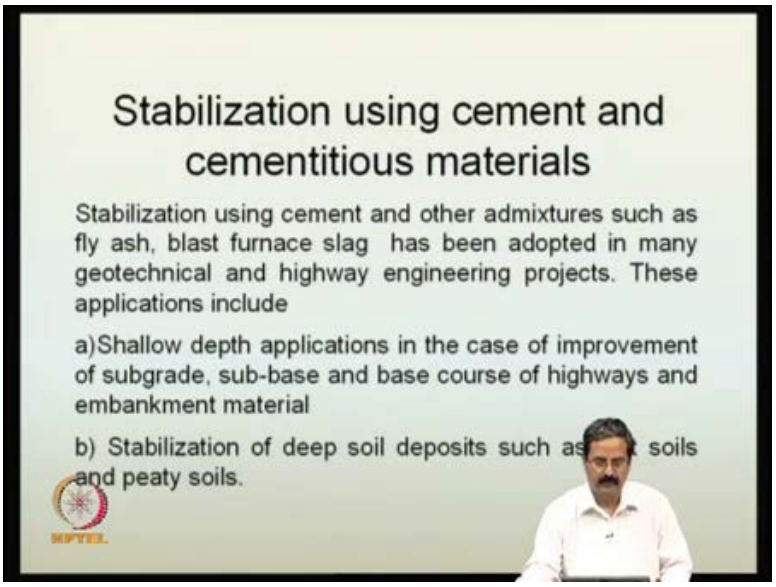

Stabilization using cement and cementitious materials is one of the standard techniques, because what happens is that many of the in-situ soils, they do not have good bonding. So, if you want to increase the bonding, bonding resistance, use of cement or cementitious materials like fly ash, in fact, fly ash also has some sort of cementitious compounds that I will show you.

So, stabilization using cement and admixtures such as fly ash, blast furnace slag has been adopted in many geotechnical highway engineering projects, whether it is slopes or embankments or highways, these have been used very extensively.

And applications include, shallow depth applications in case of ground improvement of subgrade sub-base and base course of the highways and embankment material. As we have seen earlier, we used lime to increase the CBR and to increase the stiffness and all that.

Here we can use cement as well, because many of the industry people are more comfortable with cement, though it is going to be quite expensive in many of the projects. But then, people have been comfortable with the use of cement in many projects. And particularly, right from 70s, lot of work has been done and the use of cement as a stabilizer or as a modifier in ground improvement. The other important point was that, there are some places where the soft soil is so deep and very soft, and you need to construct something like a containment area, or some sort of big structure.

So, you must stabilize deep soil deposits, may be up to ten meters, like we have seen many other techniques, which we had pre-consoled prefabricated vertical drains, then stone columns and all that; this also one of the techniques.

Like as I just said, prefabricated vertical drains, they stabilize area by drainage, whereas here for example, in the case of stone columns, they improve the overall bearing capacity, because you are trying to put stone columns. In this case, instead of the stone columns, either you may put a soil cement columns. That is the difference and we will see how it is done.

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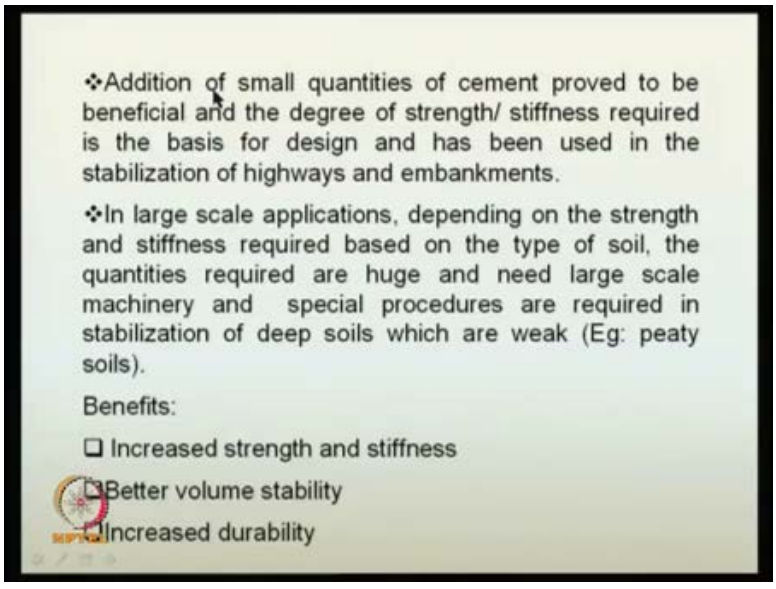

So, if you use small quantities of cement, like addition of small quantities of cement proved to be very beneficial, and the degree of strength and stiffness required is the basis for design and has been used in stabilization of highways and embankments. Like we have seen earlier, that if the c b r is low, we add some sort of binding agent like lime and the c b r increases.

Similarly, we try to add cement as well here, to see that there is in increase in strength, as well as stiffness. Both are required, because we need the bearing capacity to be increased, particularly in the case of highways and embankments.

And sometimes, this is in the case of shallow applications, we can call it a modification of the existing soil behavior. But in some cases, where the large scale applications are there, we need lot of quantities. Of course, here also the quantities are huge, but compared to the cement stabilization for highways and like say for example, if we had some three- ten percent or five percent of cement, then it increases the bearing capacity, that is one thing. But here, you are using large volume of cement and say there, the quantities required are huge and we need large scale machinery, and special procedures are required for stabilization of deep soils, which are weak.

For example, here you may need a simple spreader type of thing. In the case of lime stabilization, we have seen you need a stabilizer, you need a spreader, you need some sort of compaction equipment and all that which is quite simple.

So, one can stabilize the subgrades and sub-bases and all that, but here, in the case of large scale applications we need, say if we want to try to put some columns, we need to have some special type of equipment and procedures, also because it is not easy.

Why I am mentioning this example is that, particularly in areas like Scandinavian countries like Sweden, Denmark and many places, the soil is so soft. Sometimes, it is a particularly Netherland and some places, it is called peaty soil. Peaty soil means organic deposit. Even in India, we have lot of organic deposits, where the soil is, you know actually the problem with the peaty soils is that, they have very high organic content and the settlements are going to be very huge, because of the primary consolidation and the secondary consolidation. There is what is called tertiary, third type of consolidation

called tertiary consolidation, where because if the organic matter disappears, then there is another, some more settlements that do occur.

So, they are all are very tricky and people have used in fact, in places like Malaysia and in fact, in India also, we have lot of organic deposits. Organic deposits essentially come, say for example, you can say that the organic content, organic matter content in a coastal area could be little higher.

So, the settlement is also because of that. As well, say for example, cochin meridian clays, they have some sort of organic content and one should be little concerned about these things. So, when you have organic, because when it is all area of that has lot of trees and other things and finally, it becomes little more semisolid and you want to construct a building there, definitely it is going to be organic soil.

So, all these things need some sort of improvement. And we need to increase as I said, like we need to have the sort of stability, the benefits are that as we know now, that it increases strength as well as stiffness, better volume stability, like you know, volume changes are not going to be very significant, which are reasonably within tolerable limits and increase durability.

So, this is what we will be addressing, and like we addressed some of these things in the lime columns and lime stabilization, would be looking at some of these. They are all equally applicable. All these criteria and all would be equally applicable for even a cement stabilization or stabilization with any of the additives.

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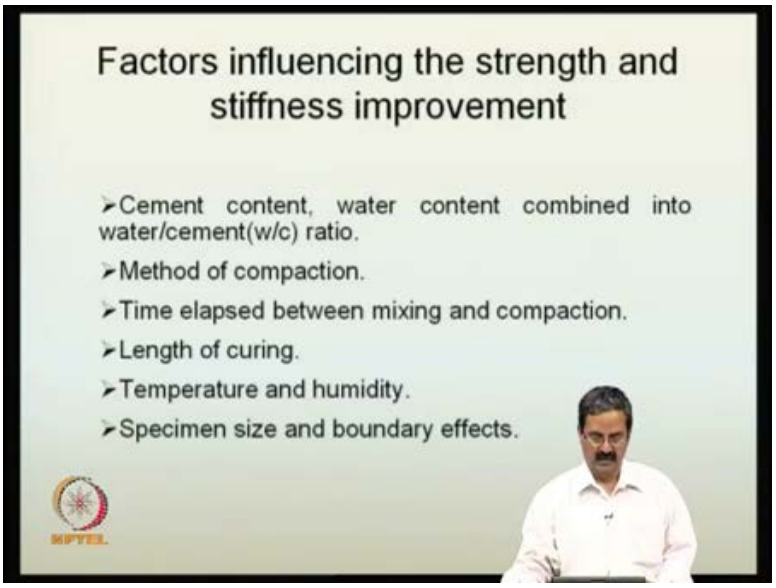

So, what are the factors that influencing the strength and stiffness improvement? We know that, cement content is one of the important variables because soil, say for example, particularly you are taking a sandy material, it could be somewhat course grained, and if you add bit of cement it becomes little more, it binds particles and it increases cohesion.

So, when you add cement content, you also need to add water and water content is because it is required for heat of hydration and all that. So, water content, as well as cement content are important and we call it in terms of the water cement ratio.

Then, the method of compaction, say the thing- there different methods of compaction that we have even in, whether it is a shallow or deep, that also is an important factor because essentially we need to have the proper equipment for the compaction.

So, the other important point is the time elapsed between mixing and compaction. If you mix cement plus soil then, you take it later for compaction. That difference also matters because the heat of hydration is an important variable.

Then, the length of curing. Actually we are all familiar with the cement concrete, and the curing is very important because, availability of water is important for curing or the hydration to take place.

Temperature and humidity are some more important parameters that are quite significant in attainment of strength and stiffness required. Particularly when you are trying to do the laboratory, these specimen size and boundary effects are also important because the thing is that, whatever say you are trying do, it should represent the field conditions to the extent possible.

If you are not able to do that, then the test results that you have in the lab need to be really corrected, or you know, understood in a proper sense to see that they represent the field conditions and also give you proper guidance on the design or the performance.

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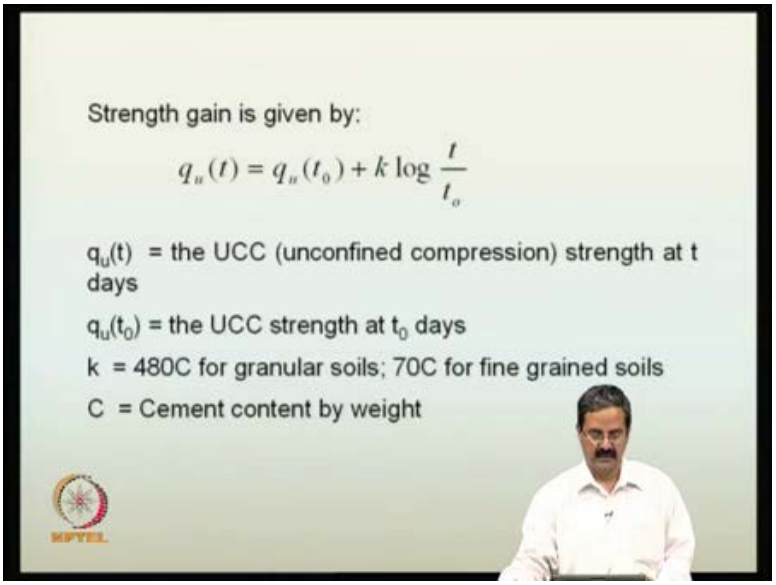

For example, this is simple equation that gives you the strength gain. In fact, professor Mitchell James k Mitchell, who is a well-known authority in soil mechanics, has proposed as simple equation of this form.

Like the uses, this strength at any time is a function of the uses. This strength at the begin like t zero days plus k into log t by t naught. It is a simple exponential equation and k is nothing but, it is about four c four eighty c for granular soils, seventy c for fine grained soils and c is a cement content by weight. There is some sort of information that, he was able to compile.

But then, one should really understand that, the strength gain is a function of the time as well as the type of soil in from this equation, nothing more than that, but one can really check in this actual cases, what is the actual relationship..

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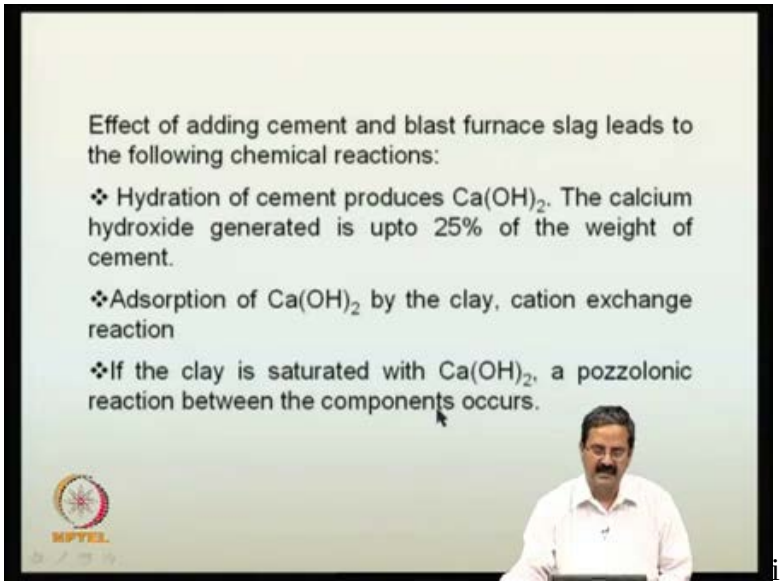

In fact, lot of work is done in laboratory scale in India on these lines.

What happens when you add cement to soil? Say in fact, even blast furnace slag also have some sort of cementing agent. So, it has some the chemical reactions like this- the hydration of cement produces calcium hydroxide. The calcium hydroxide generated is up to twenty five percent of the weight of the cement.

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It is actually a cementation - this is, calcium hydroxide is generated as we just saw in the earlier case. There is a, it encourages h two place flocculation and some of the things we have seen and absorption of calcium hydroxide by the clay, and cation exchange also takes place.

So, the addition of cement is similar to lime except that, it is much more, you know, I mean like the mechanics are somewhat similar. But then, there is some more addition

here like, sometimes even [pozzolonic] activities also, another important variable that comes in here.

If the clay saturated with calcium hydroxide, a pozzolonic reaction between the components occurs. What do we see is that, say for example, there is an optimum lime content in some case, like you know you have an optimum lime content before, after that it decreases.

So, you have an optimum content. In this case of lime, there is a continuous increase of strength, but then we cannot just go by that. We have to really see if we add, say five percent or six percent or ten percent, does it really give you a required engineering properties- is what you are interested.

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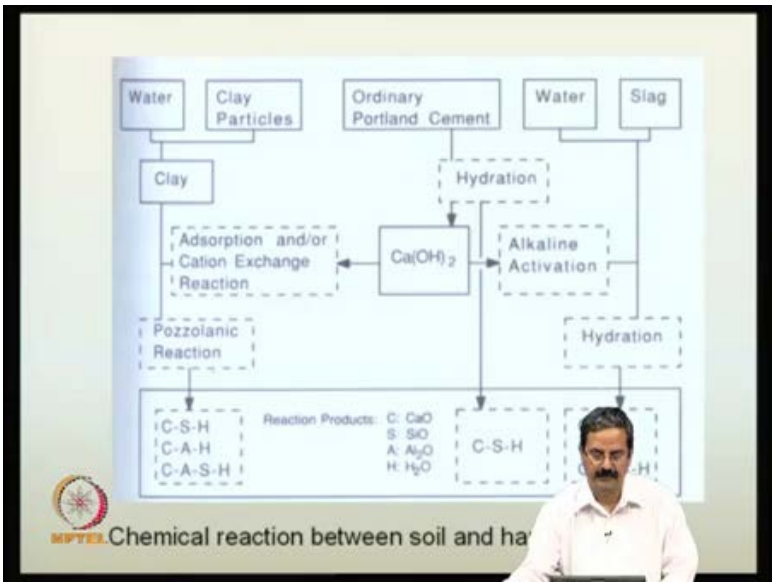

So, if you are trying to put this reactions in some sense, like you have the absorption or the cation exchange reactions, then see water plus clay particles. They have this sort of reactions and when you add ordinary- portland cement and you have a hydration taking place, and we have also seen that its aggregation takes place and some of the this things we have seen.

And it leads to some sort of reaction products, which are like this c s h, c a h, c s h here also same thing here in the case of c s h, c a h, c a s h. What do we mean is, c is stands

for calcium oxide, s stands for s i o aluminum- a stand for aluminum oxide, h stand for h two o.

So, this sort of compounds do form when you have the sort of, say for example, the hydration and some of these reactions happening and you have these materials make the soil stiff ,they harden, they change their properties basically.

And now, it has, it is a better engineering material- engineering material like if you want to use that, you can use it properly.

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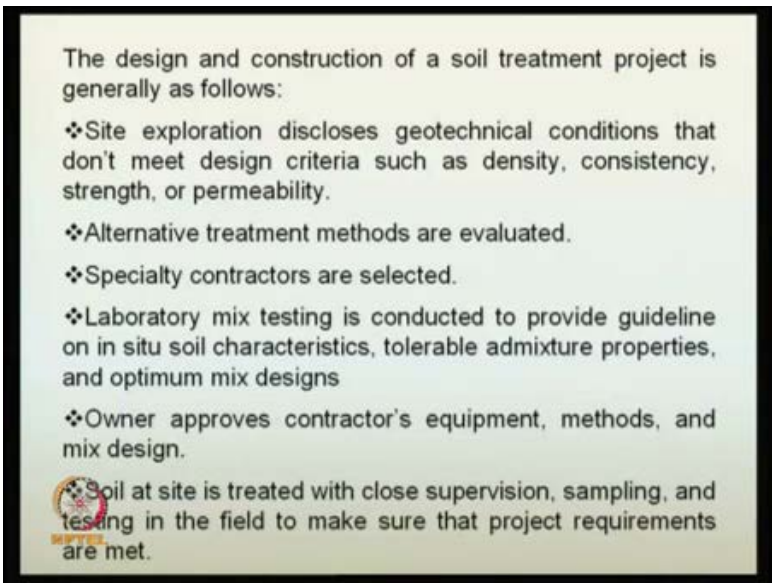

So, when you are trying to design a soil treatment project for example, you know that the soil in this area is very weak.

But then, what should be done, say for example, the government of India or whatever they planning to have, some sort of soil treatment project in some area which has lot of a soft soil deposits or expensive soils or whatever.

So, one should do soil investigation. So, site explorations which will give you- what are the geotechnical conditions, which do not meet the design criteria for example, density consistency, strength and permeability whatever.

So, one can have to look at all these numbers of the in-situ system. You have a soft soil there in the particular area. May be you imagine a highway is coming up for about

hundred meters, hundred kilometers connecting to villages, which are having soft soils as a foundation at the soil medium there.

So, essentially you are looking for many of the engineering properties there, and once you know that the engineering properties do not meet the criteria, then you have to see that they improve those properties in a proper way.

What should be done is that, you need to look for alternative treatments. So, what are the alternative treatments? We discussed many, say for example, one can use lime, one can use cement, one can use a stone columns, one can use prefabricated vertical drains and all that.

So, in a project, what we should do is that, we have a number of methods of doing this, but which is more comfortable, which is more economical, which is more you know where you have contractors, who have experience should only be considered. So, there are many issues there, because finally, you are trying to deliver the project in some sense, in a complete form, without any difficulties and delays- this is very important.

So, what we do is that we have alternative treatment methods, we should be evaluated in a particular project. Specialty contractors are selected say for example, lime stabilization, it has a special contractor or cement stabilization, it has a special contractor.

So, you need to get them the information and how they do the work, say for example, you can. In fact, one can say that, this is my requirement and how would you use your technique to stabilizes hundred kilometers area and what are the techniques we have? what is a cost, say what is a method you are using. So, one can ask.

And then they come out with some sort of quotation, what you call quotation and all the specialty contractors will be able to select, give there information now. Say for example, what should be done is that. It is always advisable to conduct some sort of laboratory mix testing.

Suppose you have Cochin marine soil, take it and then try to find out the in-situ properties. Then, try to find out how the properties are improved with addition of cement or whatever lime or admixture in some combinations.

And So, you try to come out with the tolerable admixture properties and optimum mixed designs, say come out with what are the mix the, you know requirements say for example, the settlement of the completed embankment should be minimum in this number.

So, what is that it gives? So, you have to go for the mix design and you come out with say for example, if ten percent of the cement will give that settlement then, you have to go for that. So, it is something like that. Then owner approves a contractors equipment methods and mix design.

Because there are so many people in this particularly a project, where you have an owner you know, say for example, the government of Kerala or government of Andhra Pradesh, who are trying to construct some roads in a particular area. They have to be comfortable. They have to be happy and they have to understand what exactly they are trying to do here. So, owner is one, then the designer is one, because designer also you should know, what exactly he has the problem at hand, and give some sort of optimum solution.

Then the third one is the contractor and then the treatment, particularly ground improvement exporters. So, the contractors sometimes may not have experience with him. So, he will use the ground improvement, consulting agencies or even construction agencies have some of the subcontractors and they try to quote for a particular project.

So, the owner should be able to understand. Contractor should be able to understand, designer should be able to understand. In general, if the owner agrees that he has, the contractor can deliver this job and if the methods are also in the sense that, they do not lead to delays.

Ah say there could be a some methods that is done in abroad,, but ,, but ,,, but they may not be possible right now in india because the thing is that even to get an equipment it could take three or four months to say for example, in netherland's people have lot of experience ,, but ,, but ,,, but if you want use do in a project then there may not be able to get the equipment you know. So, the equipment could cost above three or four crores.

It may take some time to get some of these materials and there all [me/most] most of the equipment are you know very expensive. So, the owner should be able to understand the contractor's equipment methods in mix design soil at site is treated with close

supervision this is very important sampling and testing in the field to make sure that the project requirement is met.

So, what should be done is that, once the contractor is chosen then, work is started; the work should be supervised very closely because any slip there could lead to lot of difficulties and you cannot go back.

There were many situations that I was able to see, where if there is a slip here in this supervision or if you, the supervising people do not know exactly what it means, then there will be lot of issues there.

So, one should be knowledgeable in that and then, they should supervise properly. Then, sampling also, say for example, sampling is required because you have an undisturbed or a pretreated soil and, at soil, after treatment, how is it it is performing.

So, we need to test all of these and then make sure that the project requirements are met. So, I would like to just give some information

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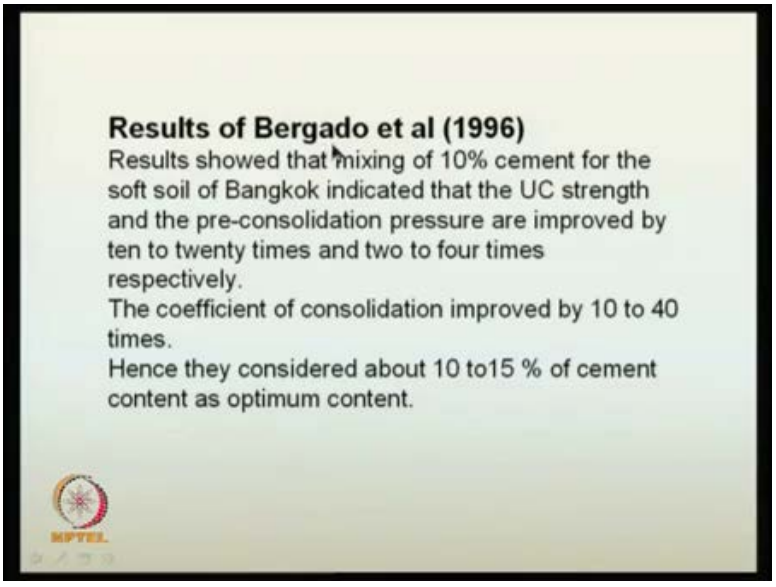

on some information laboratory test results it is a Bergado Et Al in a paper. Its, they did lot of work actually. Whole of Bangkok and Malaysia, you have lot of soft soils. If somebody goes there, it is mind boggling in the sense that there is so much work and ground improvement there. All the airports, all the projects are all having lot of ground improvement techniques.

So, the results what here showed was that, for the Bangkok clay a, which is very soft actually, ten percent was cement, was added and they observed that the unconfined compression strength increases by about ten to twenty times. Say for example, the value may be five k p n in initial, it increases to fifty k p a. May be ten k p a becomes hundred k p a.

So, there is good improvement strength, because of the addition of ten percent lime. Also the pre-consolidation pressure, like we know that the settlements are very important. If the pre-consolidation pressure is higher; the settlements are going to be lower.

So, it also increases by say for example, instead of hundred, it becomes two hundred k p a or if it is two fifty k p a, it becomes five hundred k p a like that. So, the pre-consolidation pressure also increased very well.

And the coefficient of consolidation improved by above ten to forty times because, again one can also calculate the consolidation and as I just mentioned, the mechanisms that we discussed already like cation exchange formation and cementation form and flocculation of flocculation, and then formation of this- what you call the flocculates or some of them are examples here, which will make this cement plus soil. In fact, we call it soilcrete, you know it is not sometimes called as, instead of concrete we call it soilcrete. Some people use the term. So, they consider about ten to fifteen percent of the cement content as optimum and they did lot of work.

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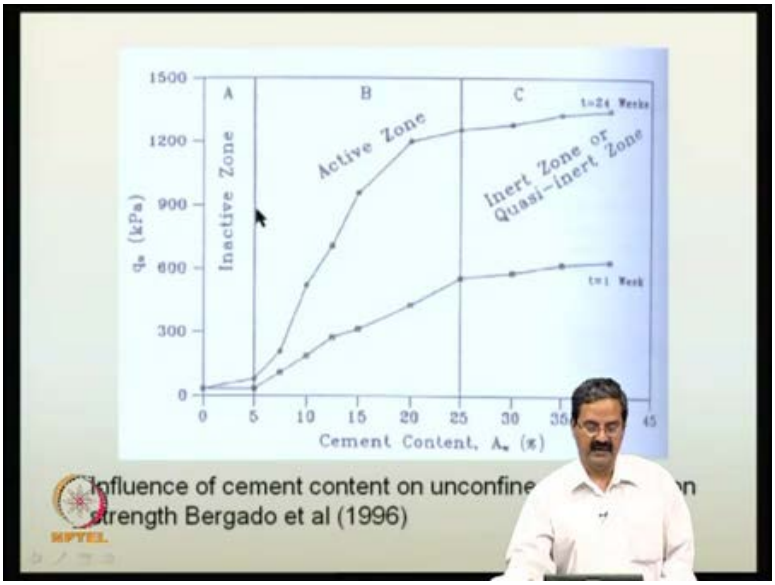

For example, this is an important observation that they have made. The cement content actually, it is about five percent inactive zone, because it needs some time.

And once we start increasing, ten to fifteen and all that, you know it continuously increases. There is no problem with that. Its t at one week and then it is twenty four weeks. But then, one can see that a cement content in this range- twenty five percent could be all right. Like, which means that this is a zone of very active reactions and all that it is very strong but then, in the field you may not need that much. So, ten percent may be sufficient.

Say for example, you want a good bearing capacity. You do not need to go for twenty five percent, ten percent may be sufficient. So, that is what I want to say that, one should be able to choose. These are all required from the laboratory point of few. And when you are trying to choose, we should choose what we need and get back that information and then, using the design that is what its required.

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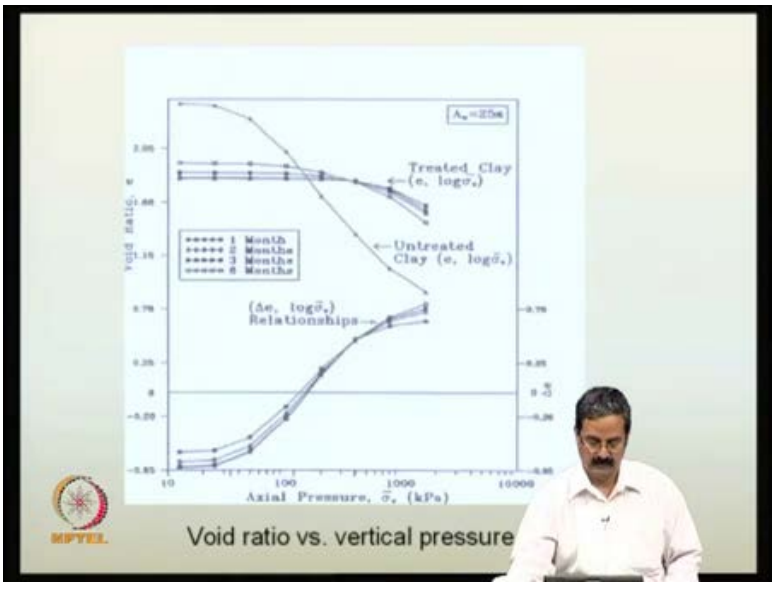

This is another example. Like this is an axial pressure, and then this is a wide ratio. So, you can see that again, the cement content is higher. So, untreated clay, the e log p curve is like this is very stiff but you can see that of course, this is a volume change. Actually, these are all volume changes.

So, we can see that, after one month- two months- three months and six months, they did the you also have e log relationships. You can see that, there in a narrow band. You know there time effects of course, like you can see here that, one month, it is somewhat like this.

So, you have variety. Definitely you can see that, compared to this, where there is a significant volume change, these values are quite, In the sense that, one can say that the settlements are going to be minimum. Like, this is what we mean by, you know if you just see, the pre-consolidation pressure is also little higher. Like, you know- how do you get the pre-consolidation pressure?

We just draw the tangents on either side, using the consequent a method. Say for example, in this case, if we do that, may be you'll get about eighty k p or something like that, but the same thing, if you just do here- it could be about- you may get about five hundred k p a. So, that could be one ratio of improvement that one can accept.

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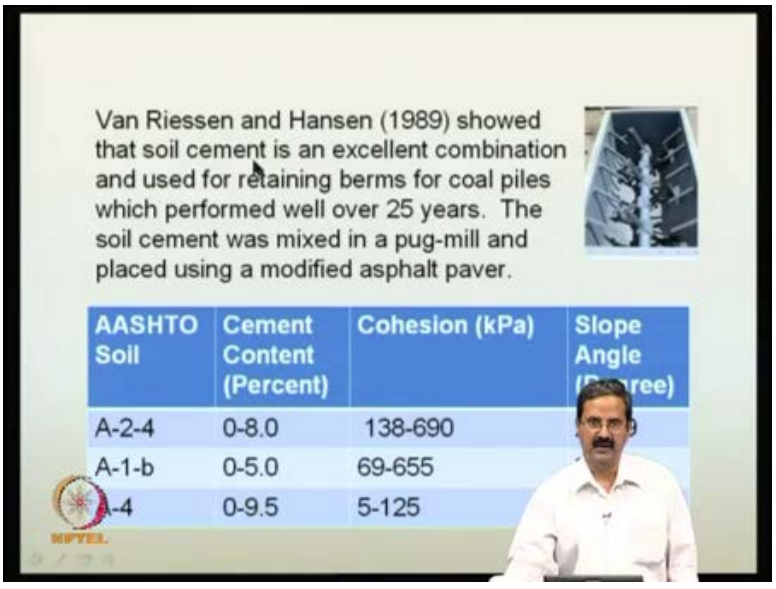

There some more studies people have done, particularly in the field scale. As I said, soil cement or soilcrete is an excellent combination and it was used for, you know in a particular coal dumping area, they have used this particular material and essentially for retaining berms, you know for example, what happens is that you need to retain lot of coal material.

And unless you retain them in a proper way, it is, they occupy lot of spaces and they have given that, about for twenty five years- these methods have- you know in the, as we said in the olden days, people are only knowing about cement stabilization or lime stabilization.

So, some people they add lime, some people they have added the cement .So, in this case, it was reported- in eighty nine and then they said that, they are observed for above twenty five years and find that the cement was, cement soil was an excellent combination. The how did they do that? In fact, they had a pug-mill. In fact, there are so many equipment nowadays. Mixing it has some sort of mixers and all that.

So, you add soil and cement, and then add some required amount of water for hydration purposes, and the soil is ready and start putting it in the paver. So, you can use it and dump in construction embankment, can be done.

So, these, another study, the some result- they have observed actually- you know ash too has a different type of soil classification, in which they say, use a one to a eight type, a one, a two, a three, a four, a five, a six, a seven, an eight types, one represents a good soil and an eight represents poor soil.

So, the increasing order of difficulty is like, indicated in that manner, and in this case, in whatever they have tested, say if the soil is a two type, and if you add eight percent the cohesion, you know the thing is, that cohesion, has improved to this range one thirty to six ninety k p a, which is quite good.

And because their objective as to, this is a coal ash material. Whatever they would like to pile it, or you know they want to store it properly; they are able to use a slope angle of twenty nine to forty nine degrees. Slope angles are, you know say for example, if your twenty nine is increased to forty nine, that is what it means.

They originally, it was a one thirty eight k p a and it got increased to six ninety k p a. And the slope angle at which they are able to store was from twenty nine, it was increased to forty nine. This soil is a one. b type is another one, is about five percent was added and it sixty nine was initial like whatever is the number you have, and it increase to six fifty five something like this.

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So, thirty eight to fifty five is a good difference, and a four is something very poor, little poor. Compare these two, and you can see that the cohesion improves from five to one twenty five, and the friction angles are in this manner.

What it means is that like.

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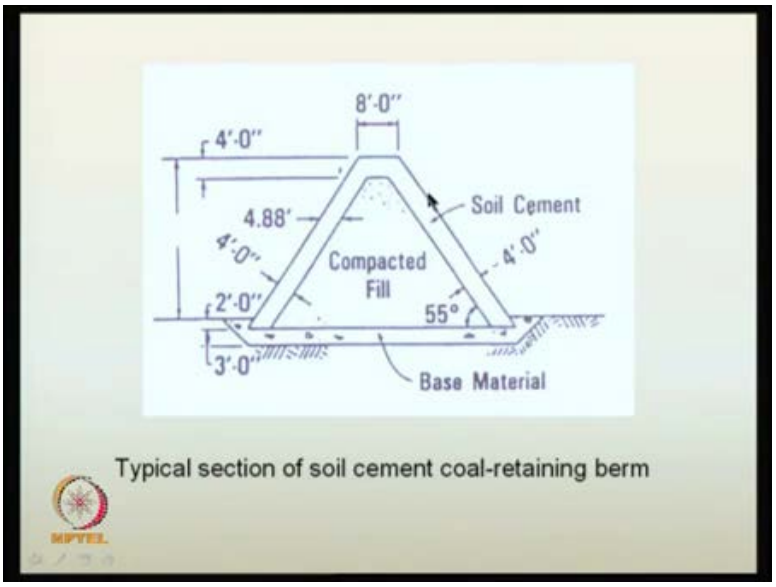

I will show you the diagram, like this is a compacted fill. So, using soil cement, they are able to go for steeper angles. Otherwise what happens, only compacted fills cannot be very, you know steep.

So, if you have a material like this soil cement, it is a good cover and its angle is fifty five degrees here. So, this is what they have done in their area and the

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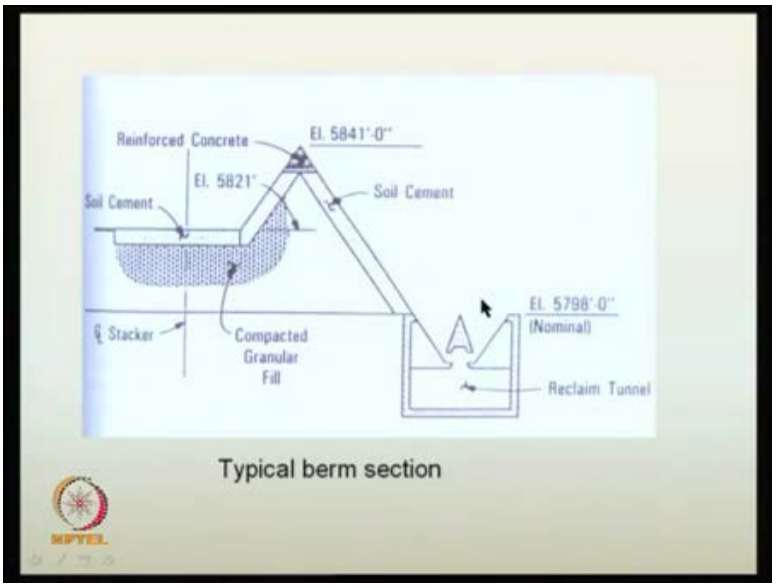

other one was that, in some other place like- they have to construct a berm say, this is a soil cement area block and this is a granular material. So, this is another one, they have used in some place, in soil cement as well in some of their.

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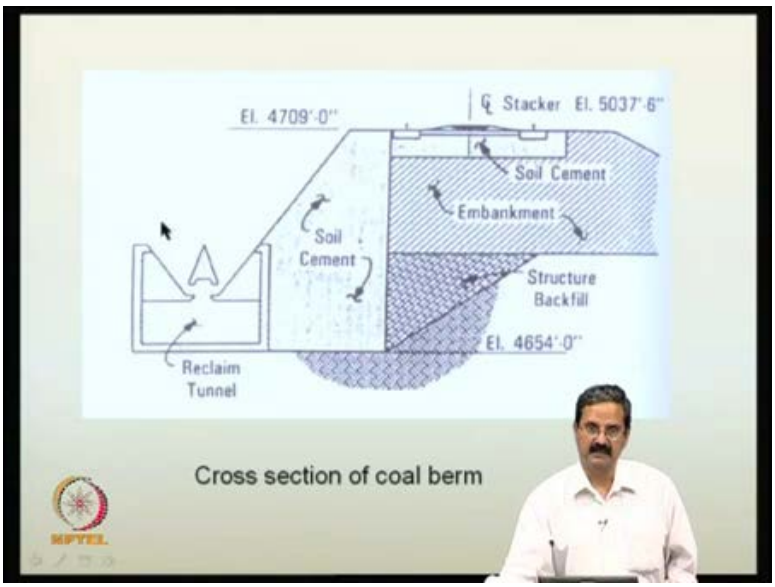

Same project in the same project. This is another interesting example, where soil cement was used. Soil cement was used, instead of the regular retaining wall. You can see that, instead of regular retaining wall, one can use this soil cement as well, which is quite useful.

So, in the case of, say for example, this again a soil cement block. In fact, that is also quite useful. So, instead of the poor soil, they use the soil cement block here. Soil cement material mix actually. So, it was quite helpful.

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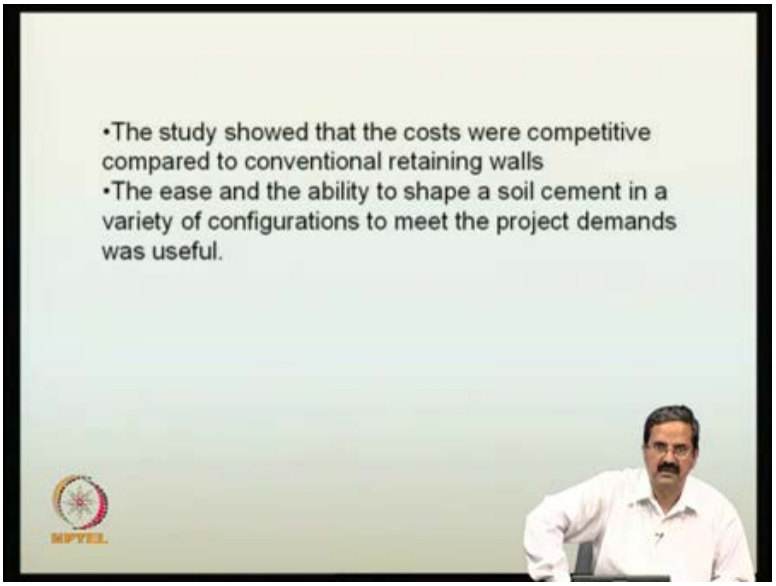

So, what the study showed was that, the costs are very competitive compared to conventional retaining walls, or even any of the shoring systems. The eases and ability to shape a soil cement in the variety of configurations to meet the project demands, was useful.

Actually because of the cement soil block, you know it was able to you can put into any shape that we have seen. Like you know, this is one thing. This is another case where you are able to handle it well.

So, the use of cement plus soil has been quite effective in many of the stabilization projects.

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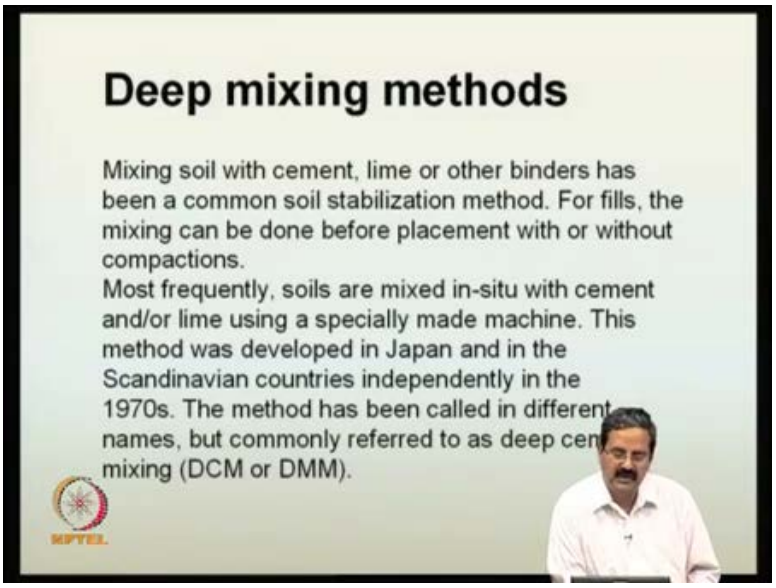

What I will show you now is a sort of say, this use of cement, for shallow stabilization, it is very clear.

But then, when you are trying to use for deep stabilization, again people have been using it without, I mean they have been doing very well because that is, that is a necessary there. Like you know, if you are, if you are trying to particularly, in if you go to Sweden or many of the institutes, they have-what is called Swedish geotechnical institute.

If you go to Finland, they have Finish geotechnical institute. Then, you go to Netherlands, they got Delft geotechnical institute, Delft Geotechnics- they call it or if you go to Norway, they call Norwegian geotechnical institute.

So, you have varieties of institutes, very good institutes which are just working towards, just exclusively on these problems, they give you know, they are doing very practical work on these lines, practical advanced work as well.

So, particularly, even in Japan and many places, this was done and most frequently soils are mixed in-situ with cement and or lime using a specially made machine. This method was developed in Japan and Scandinavian countries, as I had said in nineteen seventies itself.

People have been, you know- because after the two world wars, people are looking for development in their own countries and when you want to try development, your only

routes are one alternative embankment, bridges and all that. So, when you try to have soft soils, only alternative is that you have to improve the soil.

So, deep mixing methods are called in different names, but they are called deep cement mixing or d m m. So, this is a standard deep mixing method. They call it, this is one way of addressing the issue.

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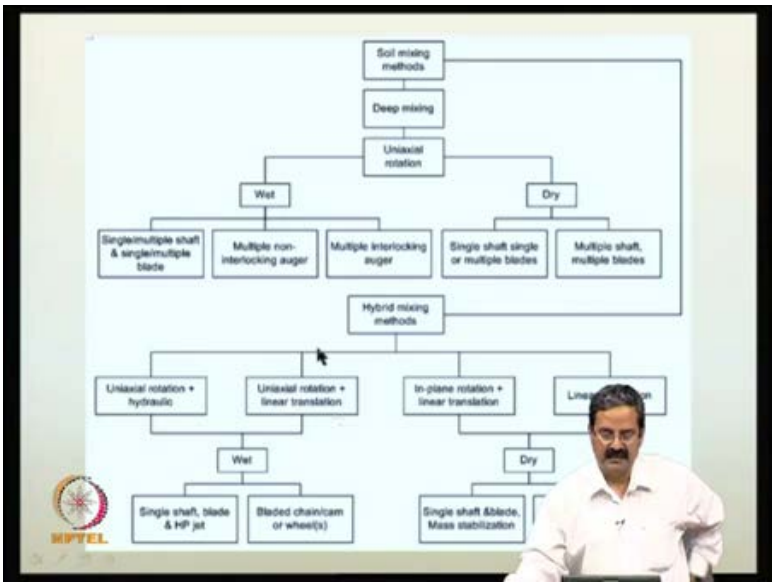

So, I want to show you, what are all these methods like- soil mixing methods, deep mixing. Actually, it can be uniaxial rotation. You know, rotation of whatever is a mixing device you have.

So, it can be a wet mix, it can be a dry mix and say for example, in the case of wet mix it can have single or multiple shaft or a single or multiple blades, like I will show you a video now . So, it can be multiple non-interlocking augers, multiple interlocking augers essentially. It can be of shafts and augers and dry single shafting or multiple blades, multiple shafts. So, you have some sort of mixing procedure here, and you can even have hybrid mixing methods, where it can have uniaxial rotation plus addition of water, adding water.

Uniaxial rotation plus linear translation, some sort of movement, in-plane rotation plus linear translation. So, there are certain ways of doing it, you know particularly, these all depend on the type of equipment you have. You know, say for example, some company

may find that, that is a better way of doing it, some company may say that this is a better of doing it.

So, mixing again has lot of different type of equipment. It is just that, you should know that there are so many methods, that is then you know it is very important that, they are available in a site and we should understand what it does.

So, yet again, a single shaft and all that, we have some sort of dry single shaft and blade in mass stabilization. Ploughing is also possible; like you know when it is dry you can plough.

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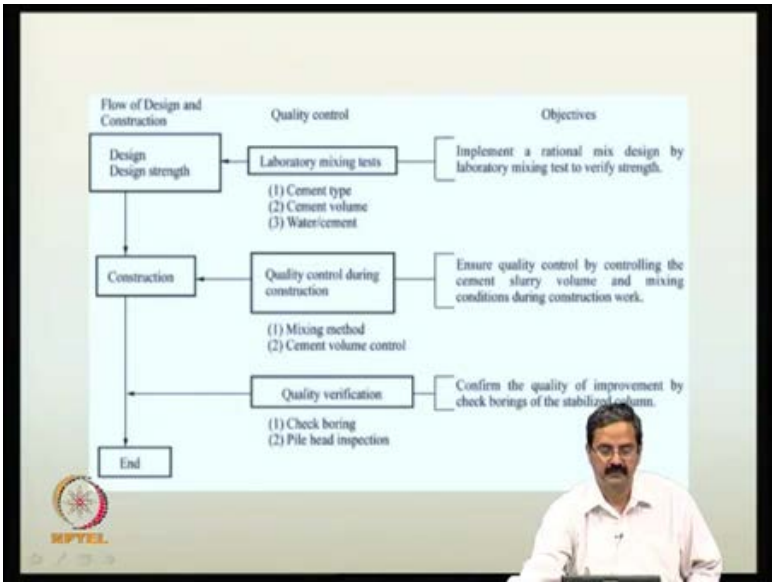

I just, before I try to cover some more points, one should understand in this particularly, how do you design in the case of a deep mixing project?

One is that, you need to know what is a design strength of the area? Say for example, I know that, now the in situ strength is about only the soil. It's an edits liquid limit and the shear strength is hardly two k p a and, I would like to make it to fifty k p a or twenty five k p a. How do you do that?

So, now twenty k, twenty five k p a would be the design strength. So, then corresponding stiffness also. So, what I do is that, I come out with some sort of mix design program. I take the soil and then go to the laboratory, try to add cement, what all that you know there are. So many factors affecting the stabilization of cement.

And once I do the laboratory testing, then come out with the some sort of specifications for implementation in the field. Here, the objective is what- implement a rational mix design by laboratory mixing to verify strength.

So, essentially what you are trying to do is that, you come out with some sort of mix design philosophy in which you can have a good design strength, which is with all the variations that you have, like you know, there could be some variations but, one can get this sort of information.

So, this is during the initial stages then, when we start constructing quality control during construction, how do you do that? Actually, this is a function of mixing method. The way you mix, the mixing methods as I just said, will have dry mix method, wet mix method and all that. How do you control the volume of the cement that goes into the cement, there is another one.

So, here the objective is- what ensured quality control by controlling the cement study volume. Like you know, you added, you need to add the cement in the form of a slurry and it has to get into that area, and then these conditions are also, should be there is simply satisfactory.

So, once have these two objectives met, then quality verification. Once the project is done, how do you verify quality verification is- check boring, use a boreholes then pile head inspection also could be done. Like you know, say for example, at a particular thing you have a cement column pile, and you can see it is a top head. Confirm the quality of improvement by check borings of the stabilized column.

Actually they become so strong and hard that, you can remove it like- there will be a good course.

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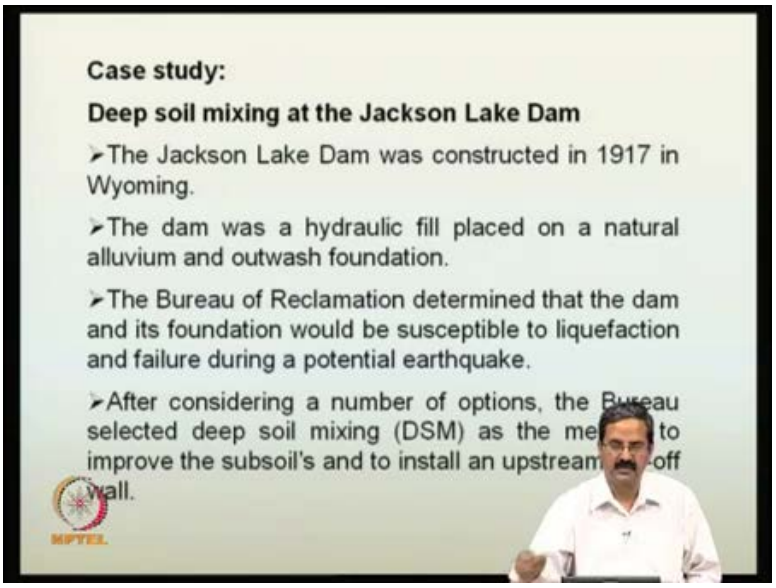

So, I would like to give a small example here. Deep mixing at Jackson lake dam. The dam was constructed in nineteen seventeen, and see normally what we do is that, in the construction of dams there, it was placed on a natural alluvium, and in it they have foundation is also, somewhat.

In fact, I must tell you the example of another one, which we have in, which failed during the earthquake of Bhuj. That dam was also, it is called Change dam, it was constructed in nineteen fifty six, but it failed because it had a liquefaction problem.

So, what they did in the case? We will see here, the bureau of reclamation determined that the dam managed foundation would be susceptible to liquefaction failure, during a potential earthquake. They assume that, yes, we have the statics of earthquake occurrence, we know what will be the shear force that can come, extra shear force that can come because of the earthquake.

Whether the soil has that resistance, if you say you know the soil strength cannot, it is not sufficient to withstand the shear load that comes from the earthquake, then what should be done, is that you should increase the shear strength of the soil.

So, what they did was that they had number of alternatives in this particular case, and then, the use deep soil mixing as a method to improve subsoil and install upstream cutoff wall.

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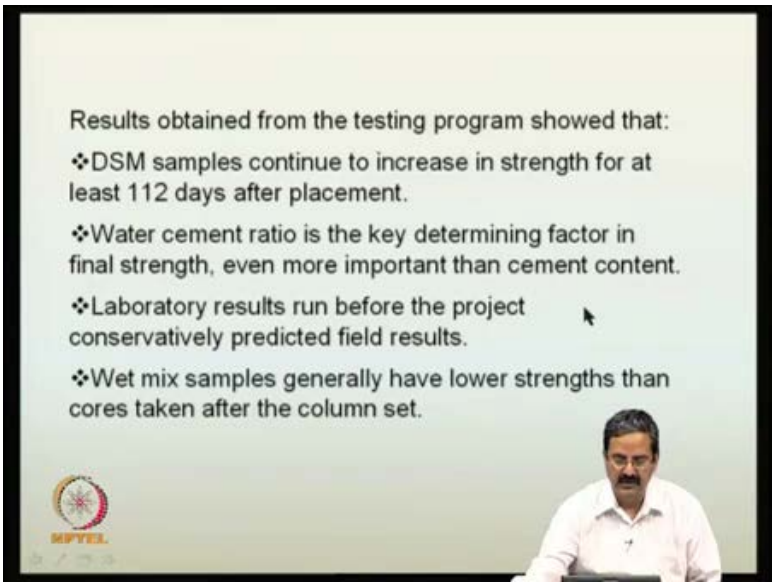

I will show you that. So, they also did some sort of laboratory experiments. They showed that, the deep soil mixing samples continue to increase in strength for at least one twelve days after treatment. As I just mentioned, the shear strength improvement is somewhat, it increases with time, and water cement ratio is a key determining factor in the final strength. Even more important than cement content, as I just mentioned water cement ratio is more important. You know it is not the water alone that, like or the cement content are own separately- you can treat. You cannot treat them as a separate entity here.

You have to take as water cement ratio because; water is required for hydration of cement. So, this is a principle mechanism here. So, laboratory test run before the project conservatively predicted field results.

In fact, laboratory test also done and when they added this much of cement and found that yes, make some calculations, they found that yes! I think this cement stabilization was very good, and it is going to be very conservative. Conservative means, in the sense you are on the very safe side.

And one more observation there noted was that, wet mix samples generally have lower strengths than cores taken after the column set

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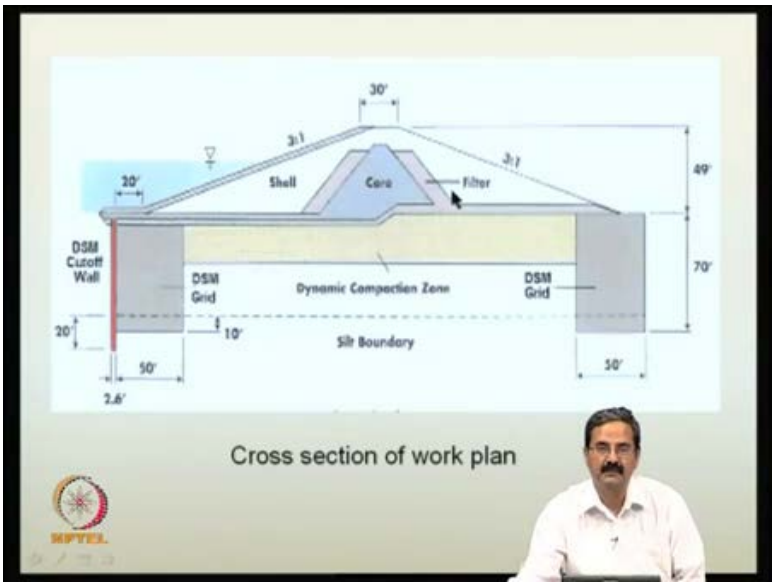

So, this is one example, this is a core, this is a shell of the dam. We have a filter also on either side, these all are filters.

So, when an earthquake comes, all these materials should not be, you know this is subjected to earthquake, you know. So, this is water level, and assume that, there is an earthquake. So, the whole dam collapses and all the water, I mean floods and because of the collapse of the dam, as a shear strength of the soil here is less.

So, what we do here is that, you try to provide what you call the d s m, or you know use stabilizes area vertical cutoff you have, and use this once you do that. So, verify that it iss satisfactory, then it is satisfactory. That is it.

In fact, in same work was done for, they when you know Bhuj earthquake, number of dams failed and about at least many dams unfortunately. It happened in january twenty sixth two zero zero one. And it was not, it was actually a dry season which means that there was no water behind the dams and when it failed, all this about at least many dams failed and I was able to investigate at least four dams as a part of the research project. I went there after the earthquake occurred. I went their dam sections, collected the profiles and also collected the profiles of the new sections which they had.

Like they already started constructing in many places, because you know the development is something very important. They cannot, they have to supply water to the people. So, they started immediately constructing all the earth dams.

So, I went about after an year later, where they were having lot of activities. Collected lot of data on the liquefaction of the dams, and one of the dams actually, it just sunk in because the soil was- whatever soil that was there, beneath you know, because the pore pressure dissipation was, I mean pore pressure was there. So much because of the sudden loading due the earthquake, then there is a momentary loss of shear strength of the foundation and the whole thing curved in.

Say for example, the whole material, some about six- seven meters and luckily, there was no water and it was quite a catastrophe. So, what they did was that. So, they did not know about it earlier. Then after that, at least during reconstruction what they did was that they used micropiles for increasing the stability of the foundation.

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So, when I just did analysis, it showed that yes the micro piles as they used, they even flattened slope also. So, when the flattened slopes and this thing then, it was all right. So, we are able to see that yes, it is also performing satisfactory now! Of course, its tested for earthquake conditions.

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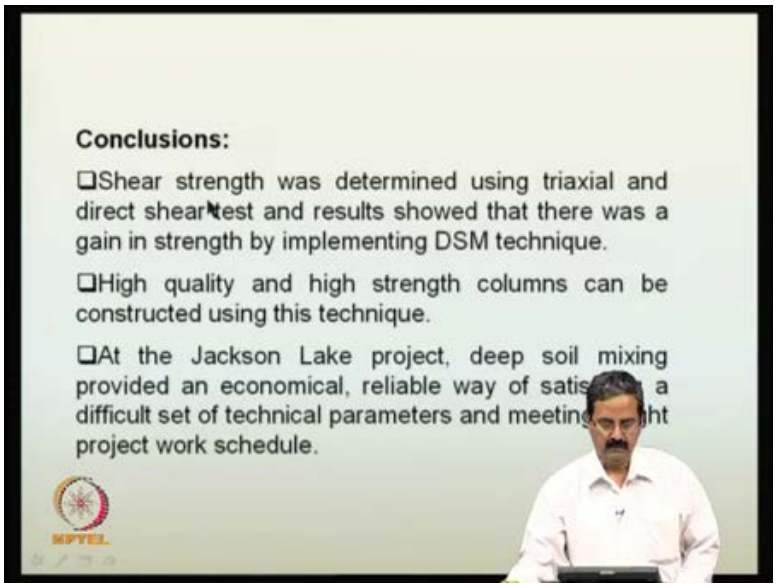

So, what I want to say is that, shear strength was determined using triaxial and direct shear strength and results showed that there was a gain in strength by implementing d s m technique. High quality and high strength columns can be constructed using this technique.

And at Jackson lake project, deep soil mixing provided an economical reliable way of satisfying a difficult set of parameters, technical parameters meeting a tight project schedule line. Actually, what is happening is that in most of the cases, we should know how this works. Like say for example, here if there are very nice statement is here that, they are able to get this shear strength assessment using triaxial and direct shear test we have to do number of tests and they are able to see that there is a good improvement and strength and they are able to observe that high quality and high strength columns can be obtained. Actually, the thing is, main important thing is that the way that you get the columns, very nice see, you have a very, I will show you that video now.

Where the soil is so soft, you can just mix it but once you mix cement and all that, it become so hard that it is like a column.

So, deep soil mixing was something very convenient. In fact, many people have been working on these lines because, the soil when it is so soft, you cannot do anything.

So, you need to improve that and the reliable way of satisfying a difficult set of parameters like I say here, the technical parameter is that, it is a liquefaction resistance. It is not easy to achieve like, you know reconstruction as I just mention in the case of Chang dam was possible.

But now having known that you know, if dam did not collapse, actually dam was still there and you would like to see that it is improved. You have to do some sort of in situ stabilization techniques like this.

So essentially, you have to have a technical parameter and also you know, sometimes whatever technique you use, should be able to, should not delay the project actually because there are many cases where you try to choose a technique after the technique everybody now is after the technique, those technique may just only is important in to their ascent of five to five percent or something.

But in fifty percent of the people would be worried about it. So, it is not correct. So, one should be understanding that, you need to have a set of technical parameters that you should satisfy and also the project schedules.

So, I just followed the couple of good books on this as we know like, particularly this an engineering principles of ground modification and all that now what I would like to show is that a video on how it how it can be done actually. I must thank keller as usual, they are able to a supply with us a couple of material

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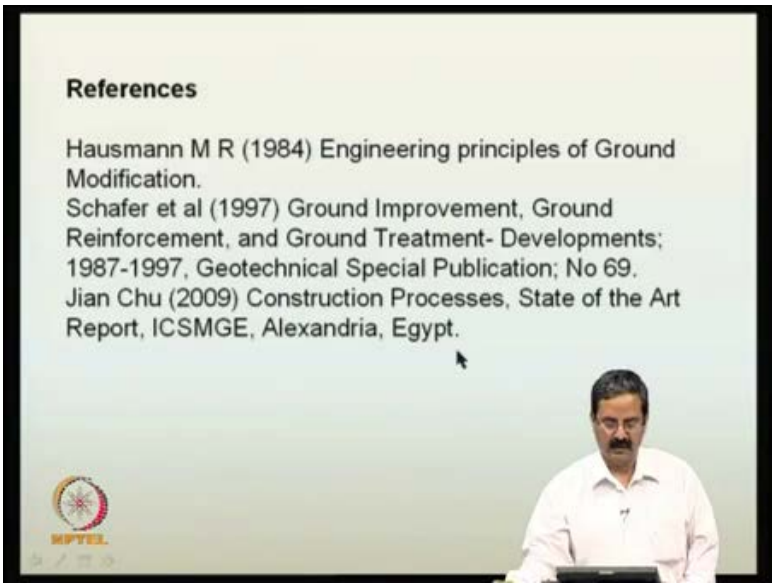

Columns can be very big diameter, half a meter, one meter whatever you want.

You can see the jet of water.

Mixing process

Quality control here about the amount of cement it has gone in and you can also see the results about the you can see this is an interesting case, you can see that the soil before treatment was like this, and after treatment it is. So, good.

These are all some more and required. So, you vocalized-noise, you have seen that the sample is so hard and good in the sense that, yeah definitely you can expects say for example, you want a stiffness of five hundred n p a or whatever, you can get that. That is a very important point.

Then I would like to show you a few more videos on the deep mixing and actually you have two types, as I just mentioned of course, we will have some more information on that. You have one- is called dry mixing the other one is called wet mixing. So, this is a dry mixing method.

I will show you the wet mixing method, yeah you can see that even for a very big projects. So, what we see is that, in this particular technique you need to be very clear.

The mechanics are very clear that, what should be the strength load coming under the soil and what should be the improvement in bearing capacity, what should be the settlements that you may expect if it is not treated properly.

And if you treat this soil, you know whether it is with, you know in this case, we are taking cement columns. In fact, cement columns- what should be the expected improvement in strength and stiffness. If you are able to estimate, and then also as I just mentioned in the previous slide that, you must be able to do the quality control properly.

Like in this case, what we saw was that, like once you mix design, do a good mix design and establish all these mix design formula, and then use the equipment that I just showed you, lot of methods that we have here like as I just mentioned about the different types of methods.

You saw just now in the video, that there could be, there are some examples, but different companies have different methods of doing it and In fact, I said even ploughing is also possible like you know, it all depends on you know the cost effectiveness in a particular situation.

But if you want to do a quality job, one should go for very good equipment and also very good program of laboratory mixing, and then getting all these parameters properly.

And construction also should be properly done, because it is not easy. Particularly, if something goes wrong, it is not easy to correct in the field and verification also should be very good.

And there are people do lot of analysis here. What is a possibility that you get the design strength in the field correctly, and what is the quality control program one needs to have to make sure that whatever you do is all right.

So, one should really look at some of these factors in a thorough manner, in a comprehensive sense and that leads to you know- very good ground improvement system, improved system actually using these cement mixing, whether it is in the form of shallow treatment or deep treatment.

Thank you.