Ground Improvement
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Module No. # 06
Lecture No. # 20
Grouting Procedures

We would be talking about using grouting as one of the ground improvement techniques in this lecture. This is one of the common ground improvement techniques. It has been used frequently for underground structures as well as foundation constructions. The process of grouting consists of filling the pores or the cavity in soil or rock with a liquid form material to decrease permeability and improve the shear strength by increasing the cohesion when it is set. The cement base grout mixes are commonly used for gravely layers or fissure rock treatment. But the suspension grain size may be too big to penetrate sand or silt-sand layers.

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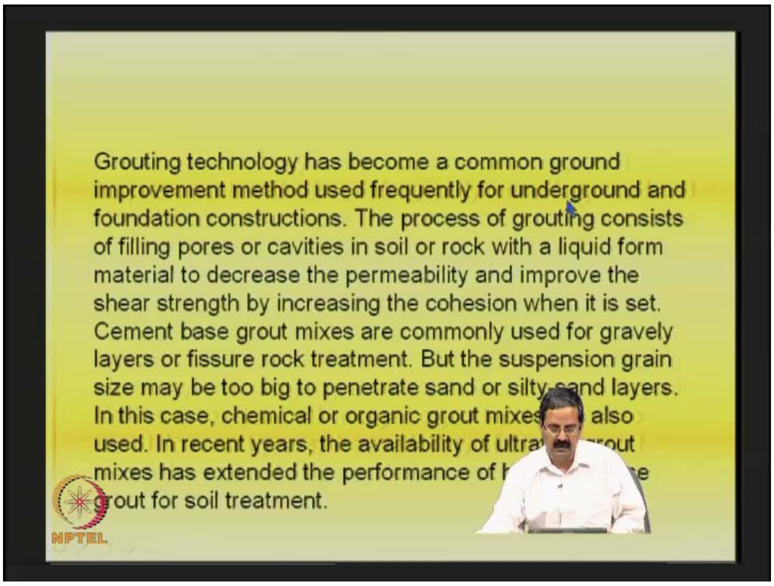

What happens is that, in many cases when you put the grout material, the particle size is important and if the, whatever you are trying to grout, it should get in to this soil system and then stabilize the whole area. It has to occupy all the voids and in some cases, when the grain size distribution of the soil itself is very low, then, it is possible that the suspension may not get into the system. And what we do is that, we try to go for chemical or the organic grout mixes, which is quite useful in those conditions. And now a days, we have even ultrafine grout mixes which are quite useful and they are all very useful for increasing the performance of hydraulic base grout for soil treatment, like in the sense that, if you are trying to use this material, it is going to be very useful in trying to reduce the permeability and increase strength and all that.

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I would like to just show you a typical photo in which, sandy gravel is there initially, but then, if you just mix a ultrafine cement grout, if you have it and remove the soil mass, it is like this. It is so strong. So, it is like a gravelly mass could be converted into a very strong mass and it is quite effective particularly, when the things many complexities are there and when you are trying to stabilize the existing structures or when you are trying to construct something next to the adjacent to the existing structures.

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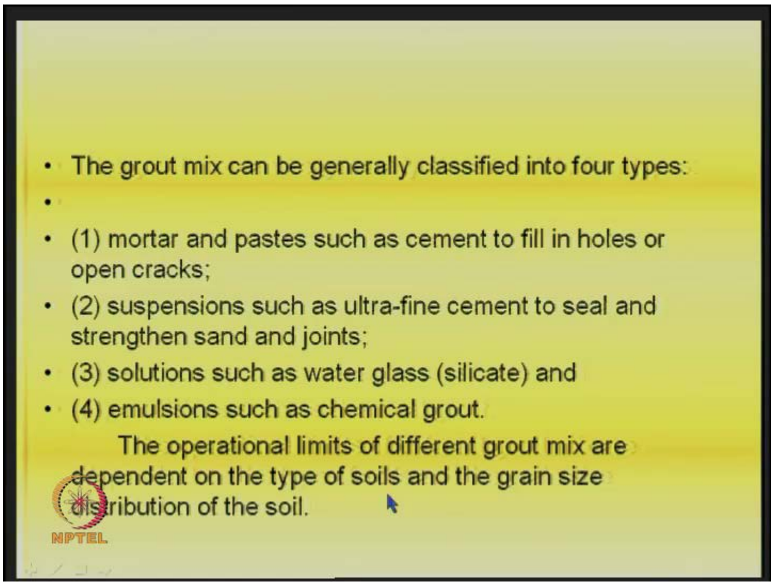

To understand further on this, we can classify the grout mixes into some four classification groups. Mortar and pastes such as cement to fill the holes or the open cracks. Then suspensions such as ultrafine cement to seal and strengthen sand and joints. Solutions such as water glass and emulsions such as chemical grout. The operational limits of the different grout mix are dependent on the type of soils and the grain size distribution of the soil.

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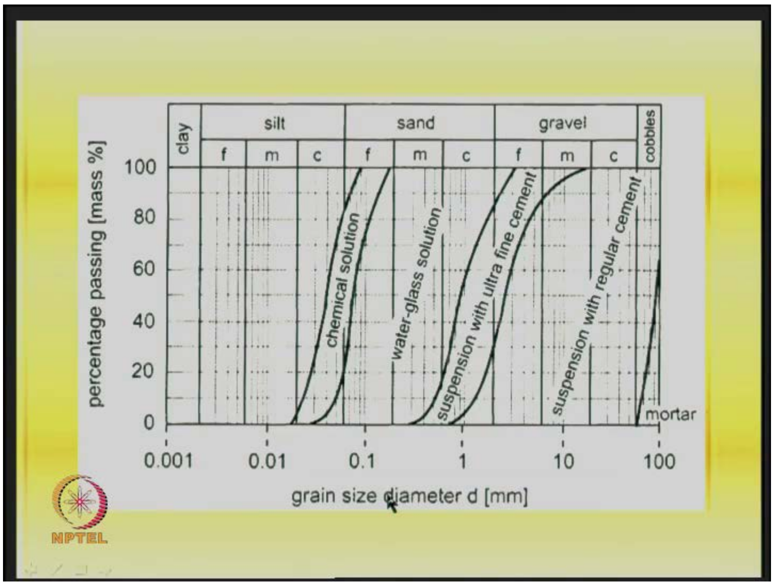

For example, like if the size is too coarse the mortar is sufficient, like but when you have a finite size say for example, 10 mm suspension with regular cement is all right. But then, here in this case suspension with ultrafine cement, then this is water glass solution and in very fine materials like clays and all that, you need to go for chemical solutions.

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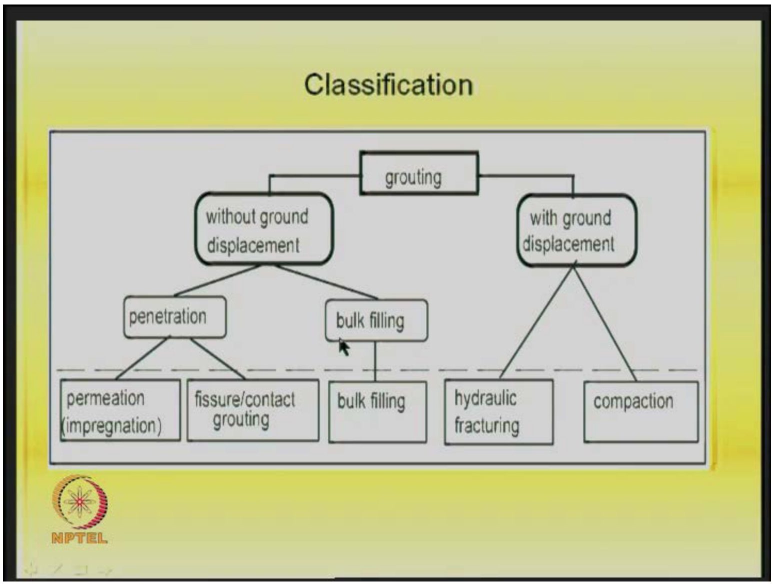

The way that we classify some of this material is that, like in terms of the action they have. You know in sometimes, when you put the grout it can lead to ground displacement like it can form some sort of column and displace a soil there. Otherwise without it is one is with ground displacement, other one is without displacement. And without ground displacement again, it can be classified into just penetration, like say for example, there is some void, it can just fill it up or penetrate that area and then fill it up just like that. Then, even sometimes bulk filling, like if there is a big cavity on the ground, you can use the grout to fill up that particular space. Again in penetration, we have what is called permeation grouting and also fissure or contact grouting.

Like say for example, you try to only, you know without disturbing or without too much of ground disturbance, you would like to see that the gaps are closed, whether they are a fissures or voids. Then, bulk filling as I just mentioned, it is a for example, you have underground cavities, then this is the way that one can fill it up. You should know the exact volume. In fact, you know that GPR and other techniques can be used to find out the cavities in soil areas. In fact, in slopes there could be some problems. So, one can really use the grouting to do this filling and see that, it does not lead to any stability problems. With ground displacement, it leads to some sort of hydraulic fracturing because you are pushing the material and also compaction. So, it really densifies a material that is one thing.

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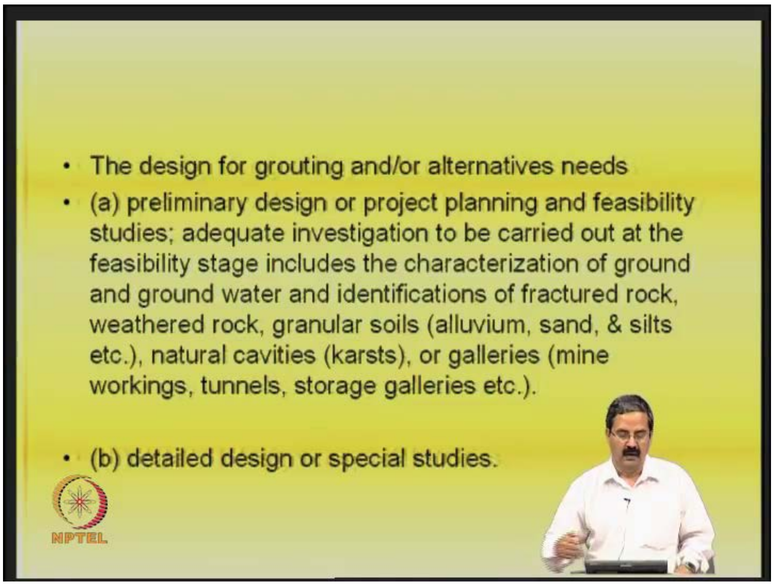

When you are trying to design you should look for certain things, particularly in design of grouting, it has like, first thing is the preliminary design, in which you plan very well to see, if the things are feasible. So, you need find out, have adequate investigation to carry out right in the beginning, which includes characterization of ground and ground water and identification of fractured rock. Say for example, you are trying to characterize the or the area in a rocky slope of a, you would like to see that whether the slope is stable. So, and then it has any underground or water resources in a fresh water or whatever.

So, one should be able to understand, what exactly is a type of rock or soil or whatever. Then, understand what are the water table levels and all that. And identification of the fractured rock. See if the fractured rock exists, it leads to stability problems. So, how do you fill up all those fractures and cracks, joints and all that. So, we should also be able to know about the degree of weathering for the rock. Granular soils also should be known. Say for example, what is the type of soil you have, alluvium or sand or silts etcetera. and you should also have information about natural cavities and have galleries like mine working stunner storage galleries there could be many things like openings that could be there on the ground one should be very careful.

Once you know some of these information, then it is possible to go ahead with a detailed design. Which is again somewhat very tricky, because the thing is that, here many things are unknown in the sense that, it is not unlike other ground improvement techniques, it is not easy to verify. Like whether the systems are satisfactory or not in a clear sense, except that you see that, of course, one can do some sort of testing particularly in the plane ground, one can do some tests say like static cone penetration test and all that for improvement of bearing capacity and all that.

But one should be very careful, because the, it is a very complicated mechanism here. Because, though the objective is simple that it has to fill up voids and also increase the strength. The way it does and also the way, it is going to be effective is something that there is one should be very careful. But it has been very effective in many case studies, that we will discuss. Because there are many problems that one can solve using this technique and there is a possibility that many other techniques may not be very comfortable with this. You know, you cannot do the conventional, other ground improvement techniques. So, in these cases, definitely, this technique of grouting is very helpful to a great deal.

So, the design has will somewhat more careful because you need to have all these basic information and come out with, essentially the design consists of like what type of material you need to choose as a grout, then what should be the spacing, what should be the pressure. There are many methods of grouting that we have. You must be able to identify the type of the type grouting, the type of installation, the type of like quality control we are going to have and all that. So, one may even try to do a preliminary study, on how it can be helpful in a small area and then extend it to a larger area. Because you need to have experience with the technique, then once you have the experience with the technique, then it is quite easy or to adopt.

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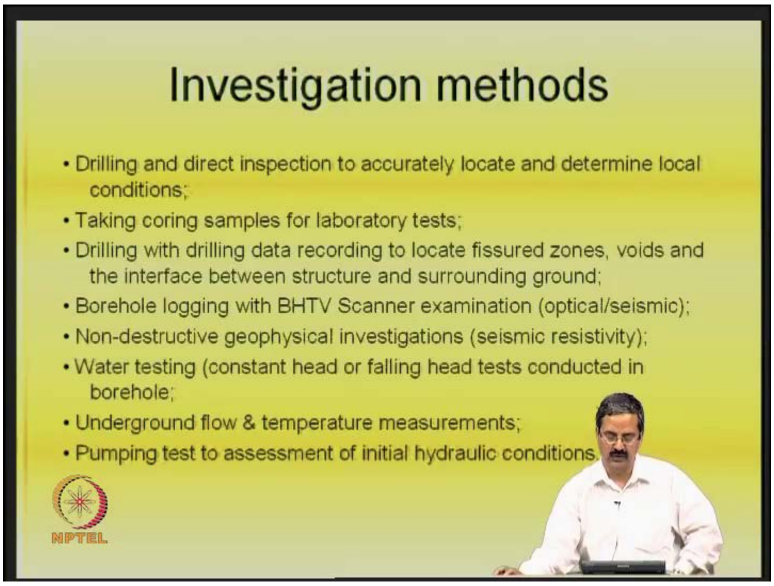

So, in the investigation methods particularly when you are trying to do for the grouting, you must be able to have a direct inspection, you must go for drilling to locate and determine local conditions. Then, take core samples for laboratory tests. Drilling with drilling data to record locate fissures like you know, data simultaneously when you are drilling, you can get, that to locate fissure fissured rocks zones voids and interface between structure and surrounding ground. Say for example, sometimes the interface is a critical issue in many of the problems. So, you must be able to get all that information and we also have what is called bore hole logging with bore hole TVs and cameras and all that. In fact, if you are trying to look for a underground problems or issues, even now a days you have Bore hole cameras, which can give you information about the type of soil that exist and all that.

So, people are also employing non-destructive geophysical investigations, seismic resistivity, then water testing, particularly you can do, you know for example, if you are trying to find out the permeability of the rock or a soil, because you the objective is essentially to find out this pore size here, because the if the pore size is bigger you would like to see that what is its impact and how do you use proper grouting method here. So, the permeability is quite important. Then, you should be able to have the underground flow, how it moves. Say for example, in a particular area, you know the underground movement of water could be in some localized conditions. One should be able to understand that only that area needs to be stabilized. So, many things you know, say for example, the velocity of the flow underground also influences your choice of the grout because the grout material should not get washed away, when you are trying to do the grouting. So, temperature measurements are also important. Then, pumping test asses the initial hydraulic conditions. As I just mentioned, grouting is very effective when the water table is there and all that. So, one needs to examine some of this conditions very carefully. The initial hydraulic conditions are to be known, as well.

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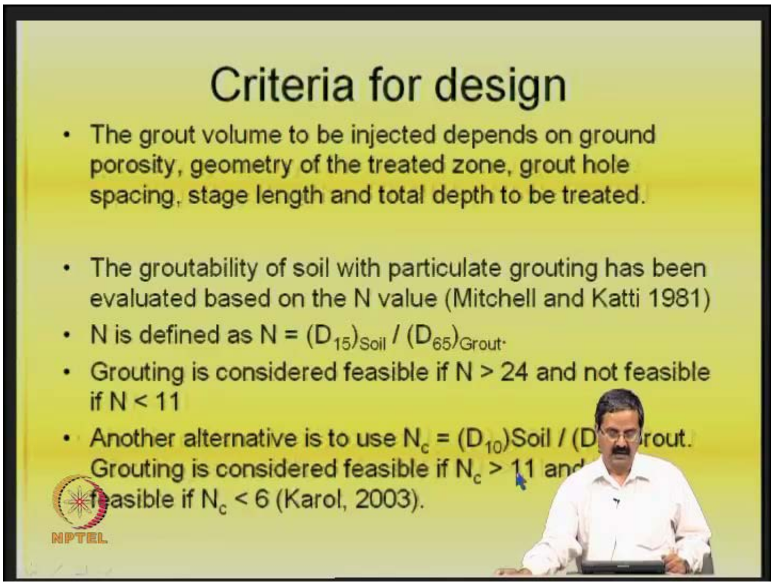

There are certain design guidelines, how it can be done. So, as I just mentioned the grout volume is an important parameter because, if there is a lot of area to be stabilized, finally, you have to pay to the contactor, in terms of the grout volume that you have, he has placed for stabilization. And if you do not have any control, then it is very difficult. and he is also have a somewhat good design basis, which depends on ground porosity, the geometry of the treated zone, grout hole spacing, stage length and total depth to be treated. So, one needs to have a rough idea, good idea of some of these factors such as porosity, geometry, then the grout hole spacing, length and depth. There are some guidelines, to what extent a particular area is groutable. So, for example, they what they define it as N factor.

Which is an N value, which is nothing but, the D 15 of the soil divided by the D 65 of the grout. you can see that, you are trying to compare and see that the size of the grout size of the soil particle is somewhat, we know the size of the particle but the D 65 size you know, you are trying to 65 percentile of the grout you are taking, it is much smaller than the D 15 size of the soil particle, then only the grout can penetrate, is it not the grout can penetrate, if the size is going to be very small. So, you are trying to compare with a D 65 size of the grout and also the D 15 of the soil and if the ratio is going to be very high it is good. So, grouting is considered feasible, if N is more than 24 and not feasible N is less than 11. So, there is some sort of criteria given in Mitchell and Katti. It is a review of ground improvement techniques paper. Some people, mention this type of, other type of classification where they call it N c and then, they try to compare with D 10 of the soil D 95 and if it is N c is more than 11, it is okay but it is less than 6, it is not okay.

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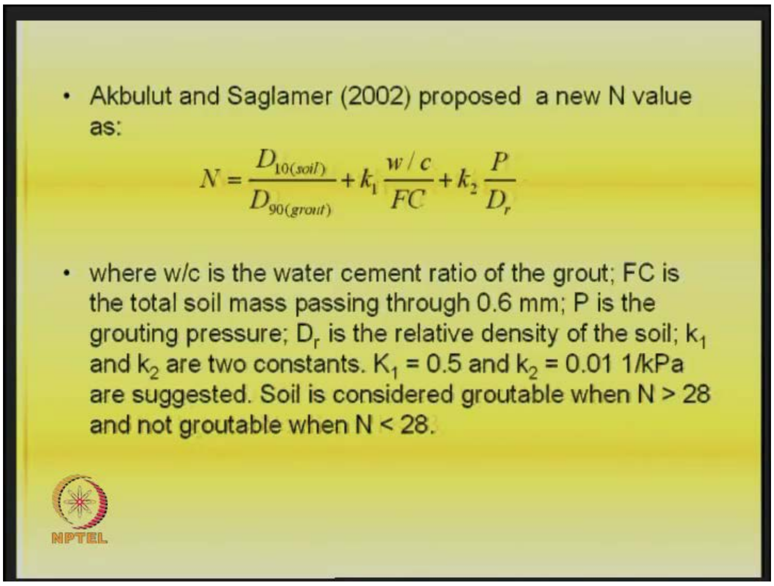

But then some more you know people have been working on this lines particularly when you try to do a very big project, say for example, there is a big dam, (( )) dam or some rock fill dam or whatever dam is coming up, then you need to have the foundation should be stable, there should not be seepage in the foundation, there should not be bearing capacity failures in the foundation and all that. How do you handle that? That is only possible, if you have proper understanding of the pore size, the grout size and some of this information. So, realizing the importance of some of this works, people have done lot of work on this and they gave some sort of criteria.

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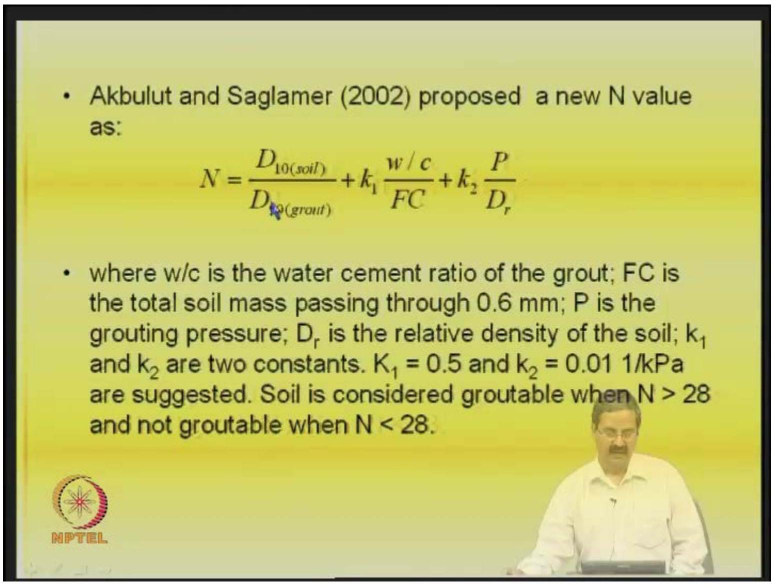

In fact, this is one more such thing, that a new N value has been proposed, actually which says that N is nothing but, it should be able to compare the D 10 of the soil and also the D 90 of the grout. If the ratio is good, it is fine, plus he talks about, you know because in the previous methods that we saw, they only talk about grain size distribution of the soil and the grain size distribution of the grout. It will not take care of the water cement ratio of the cement. It will also do not take care of the fines content, some pressure grouting pressure and then the relative density of the soil. So, these persons, these researches have given some sort of relationship, again it is site specific and empirical. But then, they recognize the importance of the important variables like water cement ratio, then the pressure relative density and all that, because if the relative density of the soil is going to be higher, which is, which means that it is more dense, you cannot grout it that easily.

Similarly, if the pressure is higher, grout pressure, definitely, you can grout more. Water cement ratio, if the water cement ratio is higher, grout can flow easily. So, some of this variables are there and they got based on the work that they did, they made a some sort of empirical equation like one can fit this sort of equations in practice and find whichever is working. You know, you can take lot of data of the site and then, look at yeah, we have identified the water cement ratio as a variable and pressure as a variable and relative density and F c as a variable. So, what is that equation one can give, for this? One can do some sort of study and a similar one study that says is that, like K1 K2 values are in the range of 0.5 here K2 is 0.01 inverse kPa. So, because the K 2 is coming here. So, P is coming here. So, D r is a, what is called percentage. So, you have to put in a proper dimensions here. So, that way K 1 is a, it does not have units, K 2 has units 0.1 inverse KPa. So, these are some values and again soil is considered to be groutable, when N is greater than 28 and not groutable, when N is less than 28. So, this is some sort of criteria these people have and this is something, that is quite useful to go ahead with design.

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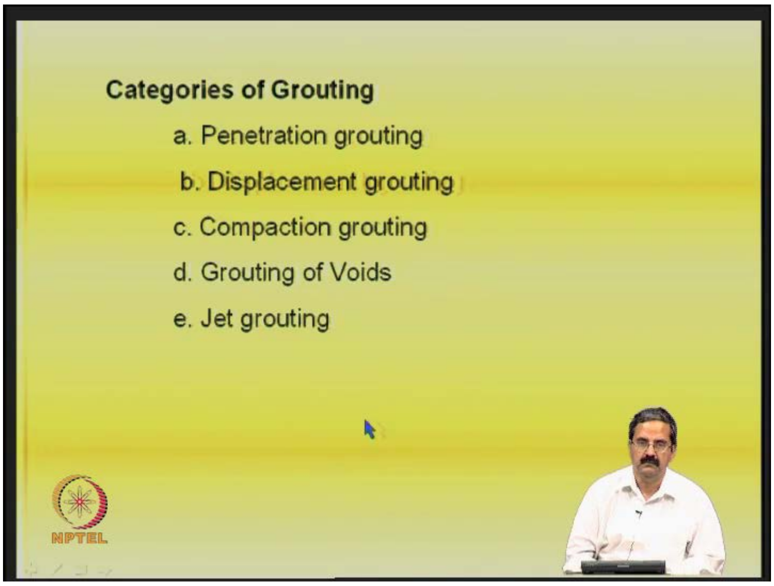

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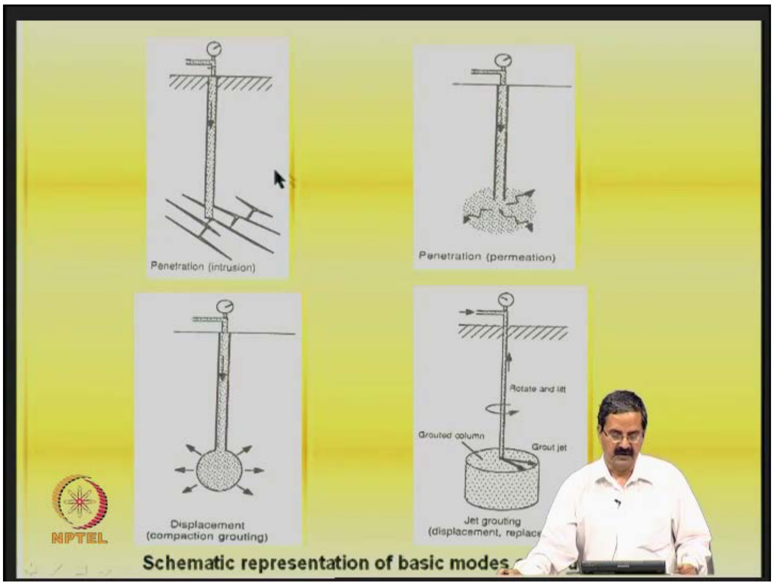

So, again there are also, what is that different types of grouting we have, like one is called as I just mentioned, penetration is possible, displacement is possible, compaction is possible and grouting of voids, you know bigger voids are there, it is possible. Jet grouting is another way of doing. As I just mentioned, you have a pressure unit here and suppose, you are trying to fill up the cracks or the fractures in the particular rock or whatever, penetration is one, is your way like you know, if the grout comes and then fill up, fills up all these spaces. Then, the second other one would be the permeation, like it just the whole area you know it permits in all directions the flow and then stabilizes. Other way would be it displaces, like its typical in a compaction grouting, it displaces means, it densifies the soil that is next to the, this thing, next to the bulb or whatever. You know, you can say that you have a material the densified material here the soil next to it gets densified here. Then, you have another one called jet grouting, where again, this is again a displacement process. So, where there is some action of the jet that comes into picture here. It rotates and all that. We will see some sort of videos now.

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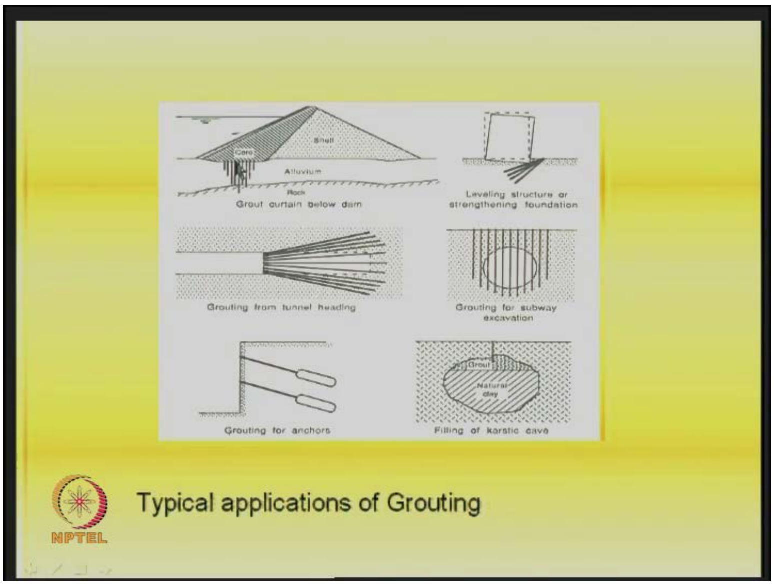

The typical applications are, say for example, you have a dam and you do not want the water to flow like this because, if you do not have you know, water storage, otherwise will not be there, you know you are supposed to have this dam for about, whatever you know water should be stored. But, if you have a very weak alluvium soil like this, then the problem is that the grouting you know, the permeation is there and you will not have water at all here on the upstream side. So, what we do is that we grout this material. So, that there is no water flow and then the head in a dam is maintained. Then, the other one is that leveling structure or strengthening foundation. Say for example, there is a possibility that the foundation tilt is there. So, you would like to stabilize it. So, put some sort of grout injections in to the system and so that, it will not repair, get damaged further.

Another one was that, like you know, you are trying to make a tunnel here. Suppose water tunnel or anything subway or under pass or whatever, then the area you know, it should not cave-in. When you are trying to put the tunnel, the front end should not get caved in. So, you try to grout this material and then complete this process, because otherwise, it will collapse like this. That is a very risky operation. Then, in some cases grouting for survey excavation also it can do like this. So, that the at least area next to that is somewhat stable. Then, we have in specialized applications, what is called ground anchors and for example, the ground anchors will consist of a anchored zone here. We call it this, this is called, this is again to increase the passive resistance we try to create a bulb here. This is a reinforcement, like it is an anchor rod, at the end of the anchor rod, we have some pressure bulbs to increase the passive resistance and this is also called, so grouted anchors we call it. And filling up of caustic curves, say for example, as I just mentioned there could be some openings that are there, because of certain geological anomalies like dissolution of material from the underground, because of certain reactions. The possibility is that you have cavities, then you have to fill it up. So, grouting is the another alternative.

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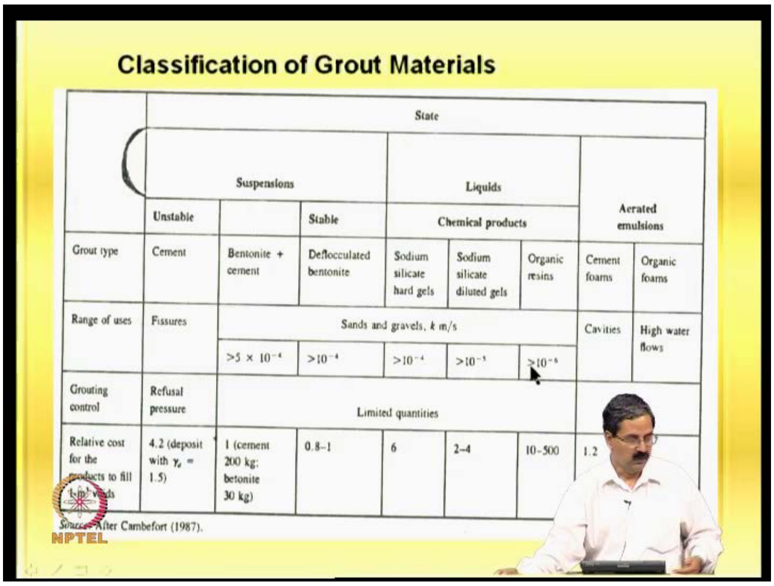

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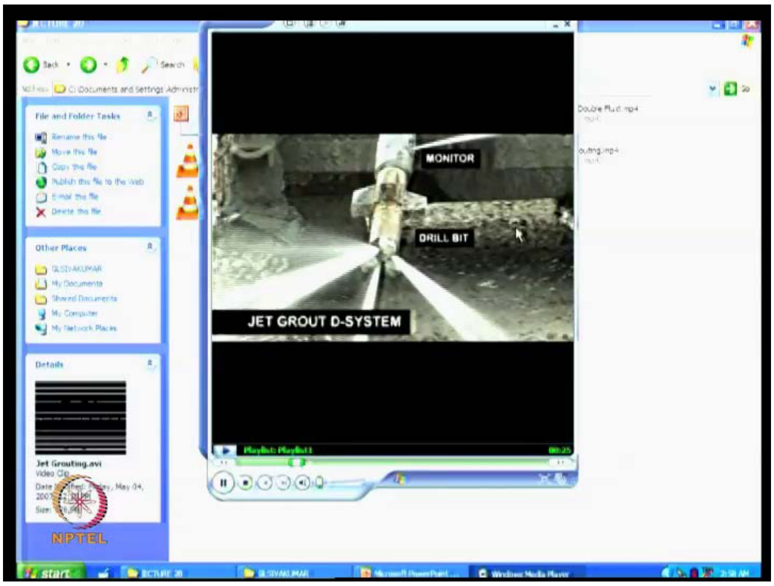

So, what I would like to do is that, I will just try to show some videos at this stage. So that, you will understand how the process is done. So, if this is one thing, this is actually jet grout columns one can get, has 2 to 3 meters, you can see that and they will show you, how it is done. Say for example, a drill bit jet, it is called jet grout d system, you know the water is gushing out of this. The way the process is done, we will see that now. You have a cement tanker, cement is fed to the screw feeder. You can see that it is all mixed at some 330 rpm, the grout is delivered in the pipes. Then, there is a high pressure pump, you know to control the pressures actually. We have a control panel and all that. Grout is then pumped to, that the rig, have to go into the ground. So, this is how the final result looks like. You can have a, like you know it can be like a similar to or stone columns or something. You have very. So, I must thank Keller for giving this video.

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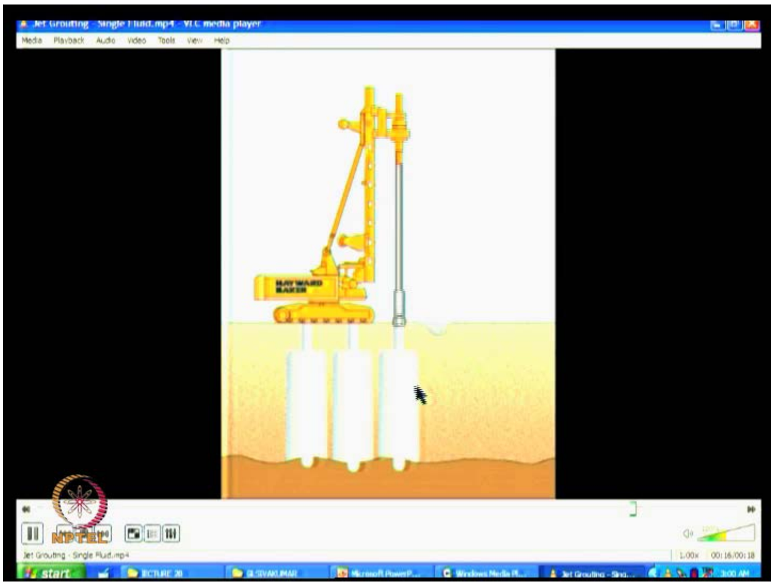

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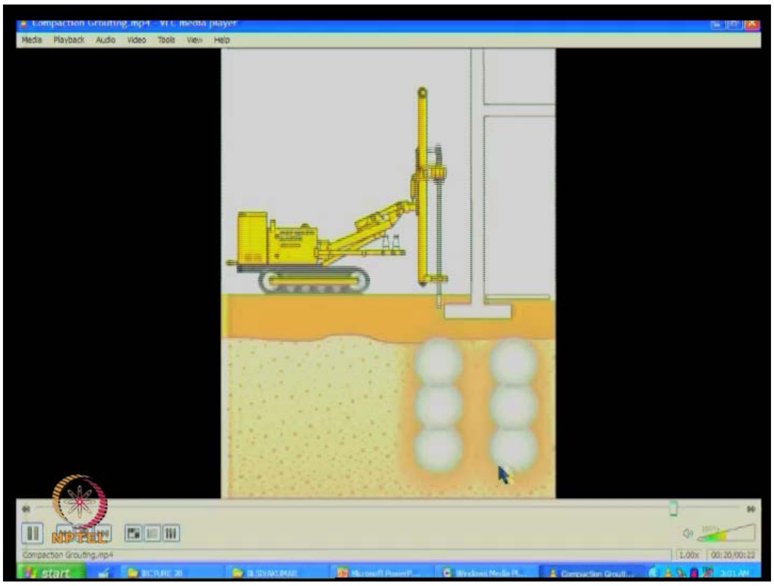

We also have some more material, jet grouting is the another one here, the way it does you can just see that, single jet grouting, in a single flow. It is one, right, you can just see that. The way it does, now you have grout and air grout coming into, air, water, grout, all three of them simultaneously come. Then, this is a jet grouting, what we see now will be on the compaction grouting. Say for example, if you are trying to increase the bearing capacity, like as I just mentioned, it is called displacement grouting. I mean there is soil is displaced and there is a compaction zone created. You can see that, this is the way it is done. So, it is an important application.

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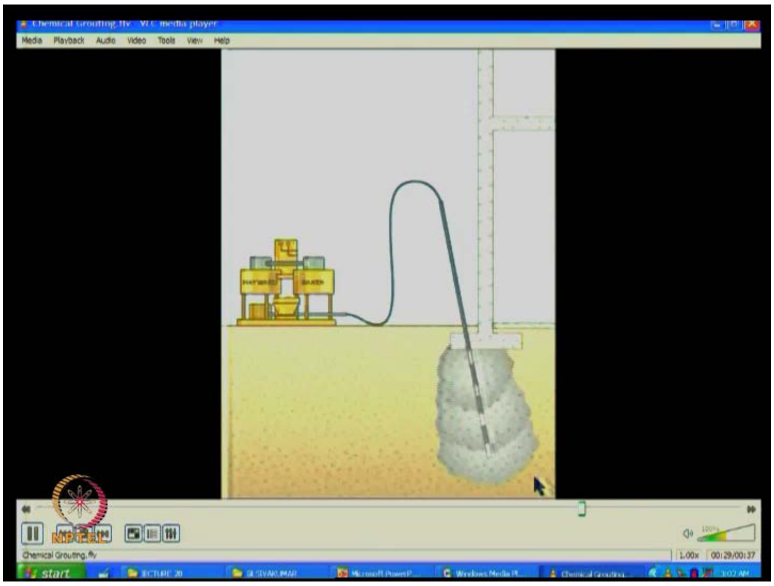

We also have chemical grouting, as I just mentioned, when the size of the, like then you are trying to feed that. So, these are all different types of materials and as I just mentioned these are all the different types of applications, of course, applications could be too many. So, we should be able to understand, what are the different types of suspensions or grouts you have. Since you have seen that, there are three or four types here. Say for example, here the, as I just mentioned, you can have suspensions the state of the grout could be in the form of suspension, it could be in the form of a liquid or even it could be in the form of aerated emulsions or foams.

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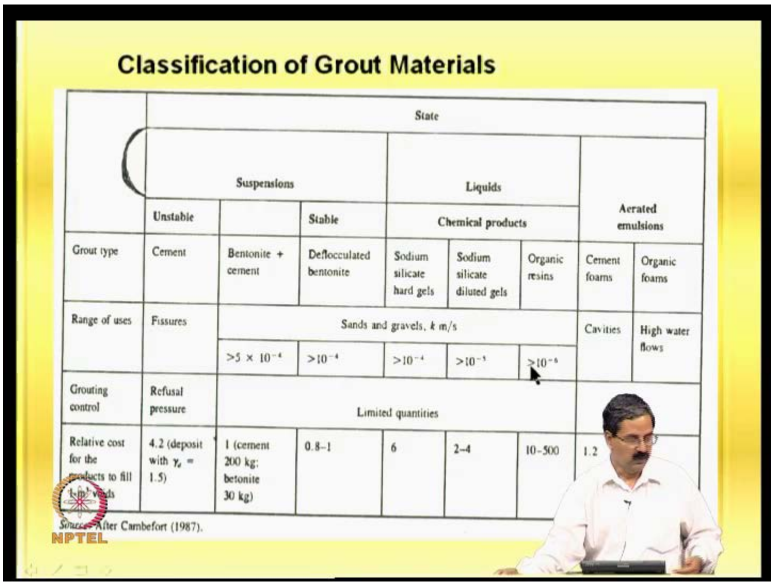

Grout type, if it is there, say for example, suspension type is unstable and stable. I will discuss that later, what is stable and unstable. What it means is that, you have a suspension and the particle, before you know all that material should reach the required depth of that material the moment, you suspension all the particles will be in moving and all the particles should move the desired depth and then, only starts setting. So, before that it should not set. So, if all the particles start setting only after there is a desired depth, we call it stable. And that is sometimes, cement may not be, you know if you take a grout type, if you use cement may not be completed like that.

So, if you are able to have bentonite plus cement or a deflocculated bentonite, definitely, it is a stable suspension. Then, you also have what is called, so, in this particular classification of grout materials, what we will see is that, we have suspensions, we have liquids and we have aerated emulsions. And say, if the grout type is cement, like it is somewhat unstable in the sense that, as I just mentioned, the suspension should be able to start settling only after reaching the desired areas, it should not settle in between. So, that we consider as stable and if it is cement normally, you know it is little quicker. So, there is a possibility that it can form you know aggregations in a faster manner compared to say, for example, you have bentonite plus cement, if you add bentonite could prevent the tendency.

So, cement is quite useful in the case of fissures, say for example, if they have rock, jointed rock and all that, it is quite useful. Then, how do you control the grout refusal pressure. So, we apply, you will be able to fill up all the things and then, if the pressure is stops, then you can say that it is not necessary then, say for example, in a particular case, this is a very interesting example here, particularly given in a textbook. The relative cost we will see the it is 4.2 factor, but if you use bentonite plus cement or bentonite plus deflocculated bentonite, it is 1 or it is 0.821, which means that the, it is going to be compared to cement bentonite plus cement is going to be cheaper. Then, as I just mentioned, depending on the cases, say for example, even the bentonite suspensions, they are all quite useful when the permeability is somewhat lower, you know up to the range of minus 4 in the case of sands and gravels.

But, then beyond that, as I just said, there is a possibility that the clay type will get in and then, you need to really, you know with the permeability going to be minus 6 minus 5, you need to go for chemical products like liquids, which say for example, sodium silicate gels, you know gel is something, it is a formation of harden masses. So, sodium silicate gels or organic resins could be used and you can see that, they are going to be little expensive, when you compare with this particular, you know cement 200 kg and bentonite 30 kg combination. If you try to take it as 1 unit, just using cement alone could be little expensive. But when you are trying to use chemical products definitely, the chemical products are going to be expensive. But then, the situation in a particular case, demands that you should go for this type of material, where the particle size is not really amenable then, it is very important.

So then, there is a possibility that, this is one and aerated emulsions like cement forms and organic forms are also used to fill up cavities and high water flows and it is just a filling till the grout control is like, you know what we do in this case is that, we try to actually true, you know people do lot of laboratory studies also, say for example, you add one this much of cement and this much of bentonite or this much of chemical product and all that. One should do lot of analysis laboratory testing and then, go for some sort of criteria otherwise it becomes very difficult. So, one can really do some sort of experiments essentially, what we are trying to do is that, you should take an undisturbed sample from the material and then you are essentially looking for strength improvement and permeability reduction. So, you can try to take which amount, whatever is the percentage of, there are different chemical products here we have and depending whichever gives the best performance according to our criteria, one can choose and then, use it in the field with a adequate margin of safety.

So, even these cavities and high water flows also have the same issue that, you need to fill up the cavities, that is one thing. So, you can see that, these are also going to be cement forms are somewhat cheaper but organic forms are expensive. So, essentially the objective here is to solve the difficulties that you have. So, essentially what we should do is that, these are all achieved in a proper manner without sacrificing its suitability as a material, both in terms of permeability reduction as well as strength improvement.

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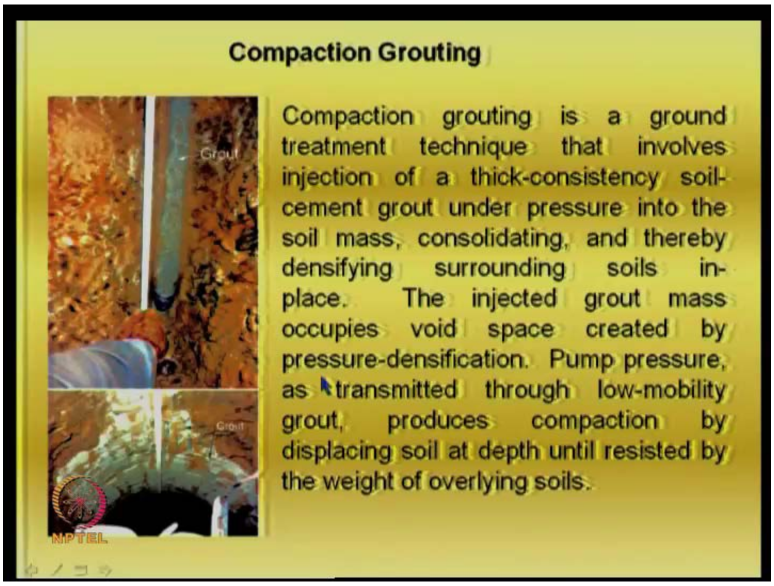

Few more examples here, like we have seen a compaction grouting. It is a, it involves injection of a thick slurry, under pressure into the soil mass, it consolidates and densifies the materials in place. The injected grout mass occupies the void space created by the pressure densification. So, pump pressure as transmitted through the low mobility grout, produces compaction by displacing the soil at depth, until resisted by the weight of the overlying soils. That is why, you just see the formation of bulbs and strong substances. And when injected into the dense materials or bedrock, compaction grout remains somewhat confined, since the surrounding material is quite dense.

However, when injected into the under-consolidated or poorly-compacted soils, grout is able to push these materials aside. So, when grouting treatment is applied on a grid pattern, the result is improved compaction of displaced soils, greater uniformity of the treated soil mass. As a secondary benefit the resulting grout columns and add strength in the vertical axis as a typical grout compressive strengths exceed those of the surrounding soils. We have seen that presentation by the Keller, in which, you know the objective essentially treat the ground in the form of a grid or whatever and improve the bearing capacity but you also have the formation of columns here. The possibility is that, the compressive strength of the grout could be much higher than the, higher than the surrounding soil and that can be used as a basis, in which one can evaluate the bearing capacity improvement or little settlement reduction. This is a very important point here.

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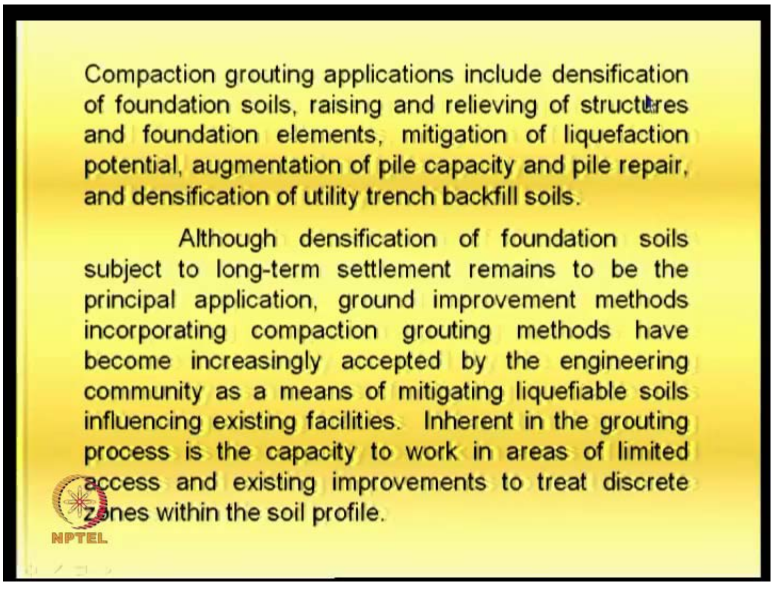

So, the compaction grouting applications include densification of foundation soils, raising and relieving of structures and foundation elements, mitigation of liquefaction potential, augmentation of pile capacity and pile repair and densification of utility trenches, backfills. Say for example, you know that the piles that you have designed, may not have adequate strength or capacity. Then, how do you go about repairing it or improve the capacity of the piles. So, this is a very good remedial measure in the or restoration measure, when things are you know, when there are no other ways of doing it. Although, densification of foundation soils subject to long settlement remains to be the principal application, ground improvement methods incorporating compaction grouting methods have become increasingly accepted by engineering community as a means of mitigating liquefiable soils influencing existing facilities.

As I just mentioned, since you have an excellent equipment and quality control like you know, you have machine control, the possibility is that, yes, this method can give good, I mean improvements, that is what it means. The another advantage is that in the inherent in the grouting process is the capacity to work in the areas of limited access. Say for example, there are some places where you do not have access to, like you know how do you construct certain approach, to do certain repair job. So, when you want to do a repair job, an approach for that particular location is also quite important. And the advantage is that sometimes the you know, the grouting these sort of grouting can make it, you know it is possible that, with grouting you can make corrections in places where there is a limited access as well, which is a very useful advantage in many issues, many say for example, many urban areas.

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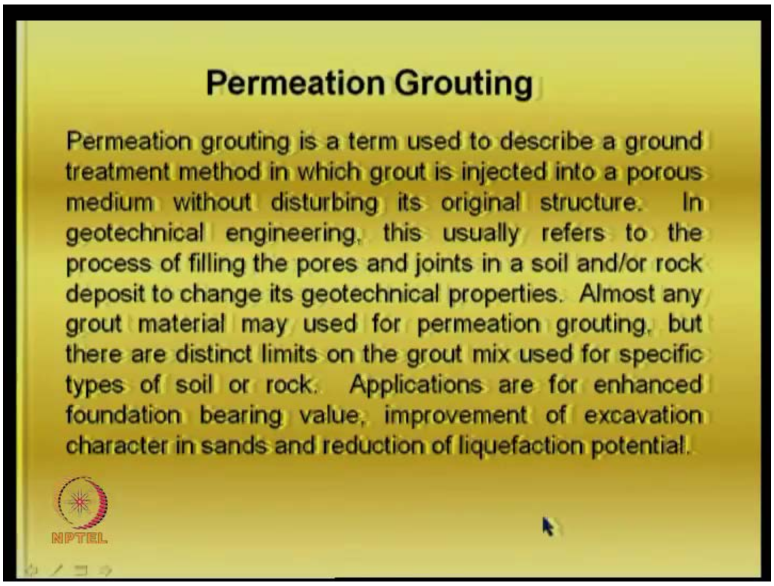

Ah as I just mentioned, we have another type what is called permeation grouting. It is a term used to describe ground treatment method in which grout is injected into a porous medium, without disturbing the original structure. As I said, it is just to fill up the pore voids and it just essentially fills up the pores and joints. So, that the pores and joints could be filled up in a proper way using permeation grouting. And the advantage, as I just mentioned are that, it has enhanced bearing pressure and also the improvement of excavation character in sands and reduction of liquefaction potential.

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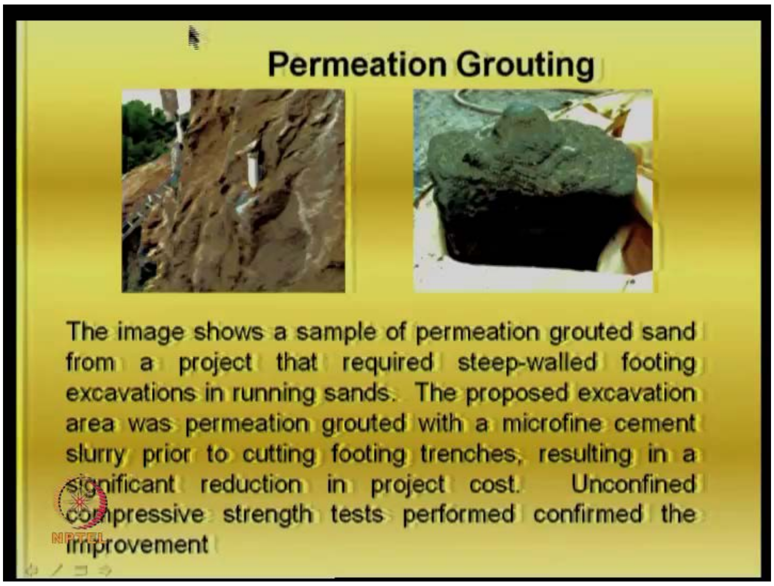

I will give you a small example. this is you know, what is called a running sand which is like you know, add water it starts flowing, you know say for example, there is a water table, there is a water flow and the sands continues to move away, you know because sand cannot take any, you know it does not have cohesion and the possibility is that, it just runs down the slope. So, when you treat with permeation grouting, say for example, this imagine that, this is a condition next to a foundation. So, you have a foundation at the top and because of that, say for in a, it is in a hilly slope. And then, you have a foundation at the top and you the possibility is that the foundation area is now exposed and if there is a rain, the possibility is that the whole foundation soil gets washed away.

The solution would be in those cases is that, you have to construct a retaining wall which does not allow the sand to go out, but the other area would be, so, that way a stepped retaining wall may be necessary in some cases but then, if you are able to use a micro cement and permeated with, in this area the possibility is that, it could be stronger. You know because of the improved cohesion and you know, it does not allow the water to just flow like that. So, it is impermeable. So, with that condition the possibility is that, it could be much stronger and it could lead to even savings in cost. Say for example, in retaining wall may be necessary or even not necessary, depending on the improvement in strength you get or it can definitely reduce the cost of retaining wall in some cases. And people say for example, if you test unconfined compression test of this material or this material which is treated with permeation grouting, see permeation grouting is just a cement slurry, except that it has filled up all the voids. So, it can also bind all the particles and if it can increase the strength in this manner definitely, it is going to be very advantageous and it leads to lot of improvement in shear strength, reduction permeability, all these advantages are inherent in this permeation grouting.

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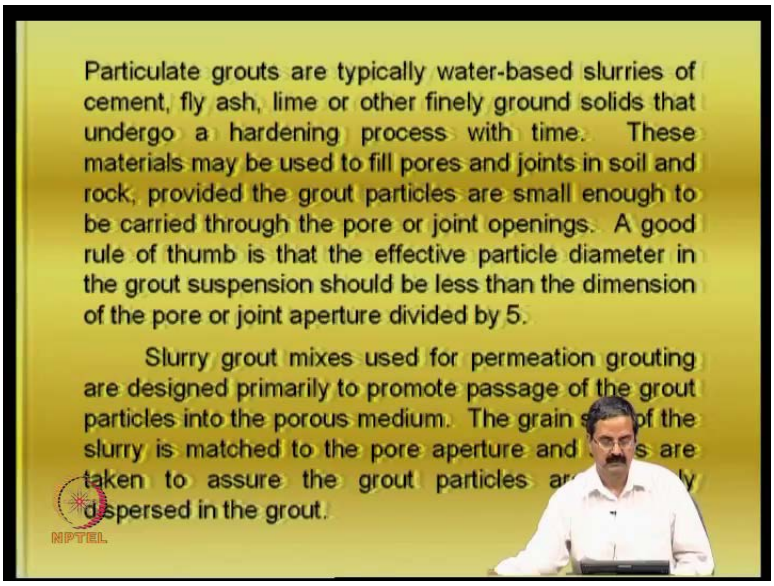

In fact, people use many types of particulate grouts. see the like as a, I was trying to say that the particle size is very important and it can be from cement, fly ash, lime or any other material and they have a hardening process which is a function of time. Like you know, the hardening is like, it sets for some time then, the strength increases if you wait. Say for example, the shear strength or the unconfined compression strength or whatever, it varies with, it increases with time. Because the many of this materials are you know, the cement their time, there you know, their response is time dependent and they have the pozzolanic action, as we discussed earlier. And these materials can fill up pores but then, the if the, I mean like we also discussed, some sort of criteria, you know if the pore size is going to be smaller then, it is not going to be effective. Like as I just mentioned, we discussed couple of criteria to you know, have a understanding of what should be the suspension size and what should be the depending on the particle size of the soil, what should be the suspension size.

A rule of the thumb is that, effective particle diameter in the grout suspension should be less than the diameter of the pore or joint aperture by a factor five. You know like, we also discussed some of this things in the factor called N and the slurry grout mixes used for permeation grouting are designed primarily to promote passage of the grout particles into porous medium. So, we are trying to really see the grain size of the slurry and we try to see that it matches or satisfy certain criteria and to see that, it has certain relationship with pore aperture size of the, grain size will match with the pore size of the existing soil or the rock, if the there is a joint. So, steps are taken to assure that the grout particles are properly dispersed in the grout also, like sometimes, you may have to have a dispersing agents like you know, to see that the it is stable.

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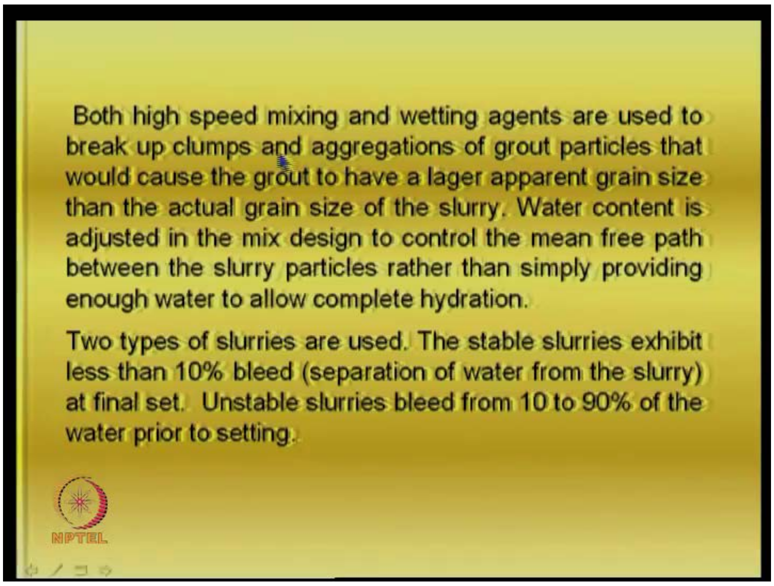

Both high speed mixing and wetting agents are used to breakup clumps and aggregations of grout particles that, would cause the grout to have a larger apparent grain size than the actual size of the slurry. So, we try to have some sort of agents, which will see that the clumps or the aggregations are not there and water content is adjusted in the mix design control, the mean free path between the slurry particles. So, other important thing is that, the water content should be sufficient to see that water is available everywhere in the grout, than simply having water for enough hydration. See the objective here is to see that, the water is there, distributed, well distributed in the complete grout and so, that is a way that water content is given, rather than just for say for example, in the case of cement motors and all that water cement ratio is somewhat critical.

I mean like you know, we have a lower cement ratio but here, the objective is to see that there is lot of water available to see that, it has a mean free path is somewhat higher like if there is a water movement everywhere and there is that flow ability also compared to what you see in other cases. Two types of slurries are used the stable slurries exhibit less than 10 percent bleed, separation of water from the slurry. Actually, what happens is that, when you add water to the slurry the possibility is that, if you add excess water, it may just be floating at the top, that is what we call it bleeding. Separation of water from the slurry is called bleeding like definitely, the excess water is there. So, we say that, the slurry is stable if it does not have more than 10 percent water coming out of it and unstable slurries bleed from 10 to 90 percent of the water prior to setting. So, the way that we try to understand that is also in terms of the water bleeding.

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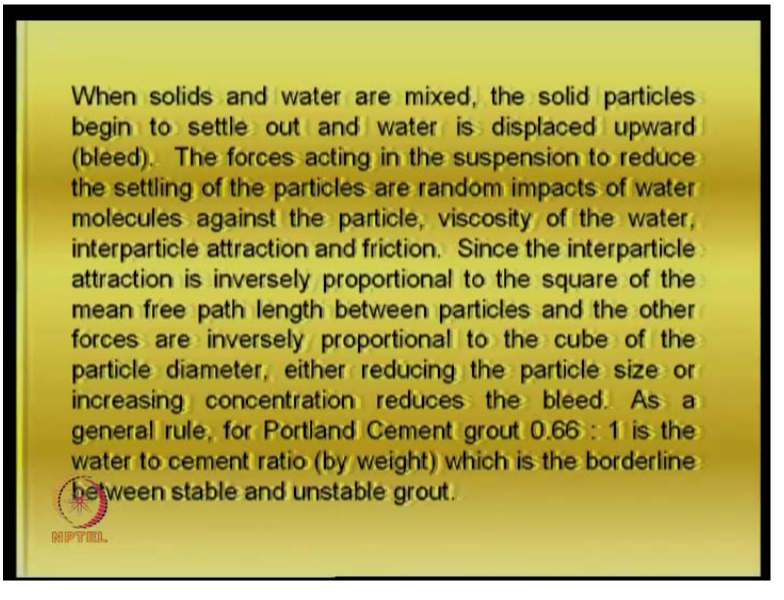

When the solid particles and water are mixed, the solid particles begin to settle out and the water is displaced towards upward in the, what happens that when all these things are mixed, there is a tendency to for the water to come out, the forces acting in the suspension to reduce the settling of the particles are random impacts of the water molecules against the particle, viscosity of the water, interparticle attraction and friction. See the thing is, in the case of grout, imagine that you are doing a hydrometer test. You are trying to do a hydrometer test. Hydrometer test is a simple example of say slurry. So, the forces acting in this soil suspension or grout suspension or essentially, they are all you know we try to characterize in terms of the Brownian motion there but here, in this case, the impacts of water molecules against particles viscosity of the water, interparticle attraction and friction. So, we also have importance to this interparticle attraction, because we do not want, we want all the particles to settle, I mean reach the bottom. It is not that, they try to form aggregates or coagulates in the process.

So, then we also should see that, the interparticle force attraction is inversely proportional to, we know that the interparticle attractive forces are proportional to square of the mean free path length between the particles and the other forces are inversely proportional to the cube of the particle diameter, either reducing the particle size or increasing the concentration, reduces the bleed. So, what you are trying to do is that, we do understand that the interparticle forces are also important, like you know all the cement particles are going down. You know we are assuming that, we are assuming that the cement particles are going down and you have the interparticle attraction is inversely proportional to square of the mean free path length, between the particles like you know, it is similar to f1 f2 by d square formula. A simple formula that, we know that the interparticle forces attraction is equal to you know, f1, the two particles, they have two charges or something that is, that we know in the basics and also its proportional to inversely proportional to cube of the particle diameter.

So, that way, the reducing the particle size or increasing the concentration. So, either you can reduce the particle size or increasing and increasing the concentration means, it is indirectly leads to that the free, mean free path. And so, bleeding means the availability of water should not be much. If it is too much the possibility is that, the bleeding is also higher. So, there should be a proper mixing and all that. One should do some sort of experiments, trial experiments before one prepares some of this material and as a general rule the Portland cement grout, it has a 0.66 is to 1 is the water cement ratio by weight, which is the borderline between stable and unstable grout. You can see that this water cement ratio is somewhat higher than what we are familiar, which means that, you need to be little more you know the properties like, the viscosity and some of this things are important and it should be able to flow. The grout should be able to flow and fill up the voids, that is what, it means.

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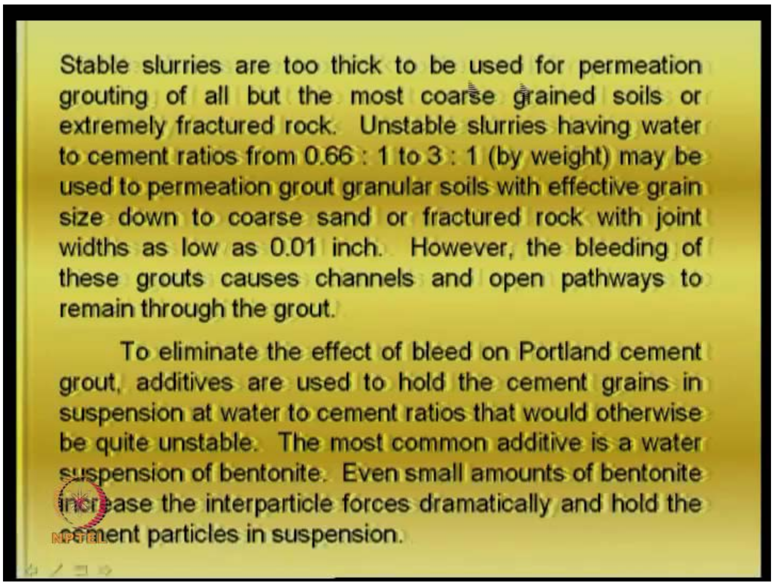

Stable slurries are too thick to be used for permeation grouting of all, but the most of the coarse grain soils are extremely fractured rock. Unstable slurries having water cement ratios point 0.6 to 3 is to 1 by weight may be used for permeation grouting, which means that, if you are trying to say that the permeation is an important parameter for you, go for a somewhat higher ratios like 3 is to 1 and then, you need to have also the grain size distribution characteristics into consideration. So, the bleeding of these grouts causes channels and open pathways to remain throughout the grout. To eliminate the effect of bleeding on Portland cement grout, additives are used to hold the cement grains in suspension, at water to cement ratios that would be otherwise be quite unstable.

So, we also add some sort of additive and the most common additive is the water suspension of bentonite. As I just mentioned, we have seen that bentonite helps great deal. Like we know that, the bentonite has the property of you know, it is a more like a repelling agent. You know the thing is that the attractive forces are very minimal there, you know there is a bentonite particles tend to float easily in water and definitely, when you mix with cement, definitely it has got very good advantage and even small amounts of bentonite increase in the interparticle forces dramatically and hold the cement particles in suspension. Like you know essentially, what you are trying to do is that the interparticle attractions are, I mean there is a separation actually.

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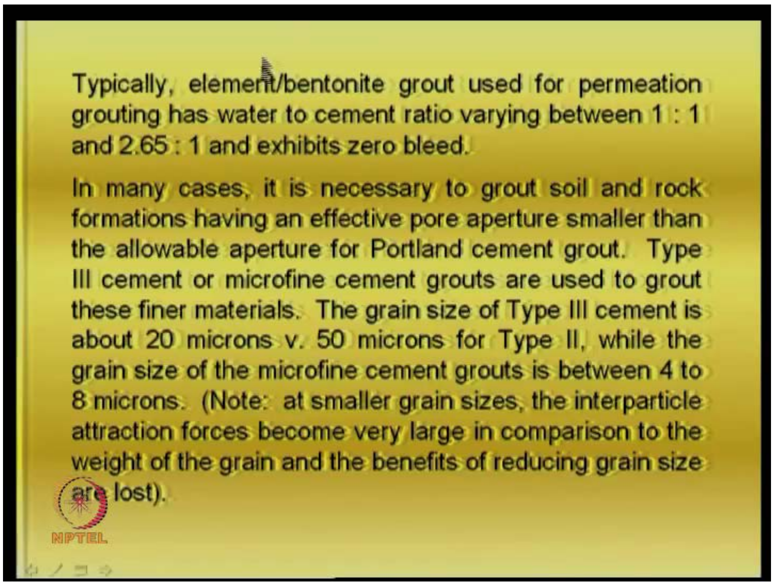

Typically element bentonite grout used for permeation grouting has a water cement ratio varying between 1 is to 1 and 2.65 and exhibits Zero bleed. So, we have to even say the thing is the, if the problem of the zero bleed is also solved because the availability of bentonite makes it to take all the water and water does not flow that easily because of the presence of bentonite. In many cases it is necessary to grout soil and rock formations having an effective pore diameter smaller than the allowable aperture size from Portland grout.

So, what we should do is that, the possibility is that in certain formations the, it is somewhat coarse and the Portland's cement grout if you have you know, the possibility is that the, that may lead to some certain difficulties, in the sense that one needs to grout them, to make them more stable, say particularly you are trying to talk about a dam structure or the foundation of the dam, which has lot of somewhat some pore size structure and then, the possibility is that, you are also having a cement slurry in being used in some of those things. So, the best thing would be that you also try to stabilize this area. In fact, a lot of applications of the grouting is only, in dam construction. Actually, there are books on dam construction and grouting alone, just grouting alone there are so, many books written, very well written and grouting itself is a very good subject. One can do lot of research experiments and it is a big area itself.

So, there are different types of you know, as I just mentioned, there are different types of cements and micro fine cements are also there. Now a days in market and they are very fine, say for example, we call it type two cement, type three cement and they could be in the size of 50 microns, 20 microns and all that, and we do not, see we do not refer to, too much fine size because the possibility is that, it may lead to, say for example, at small grain sizes, very fine sizes the interparticle attraction forces become very large in comparison with the weight of the grain and the benefits of reducing grain size are lost. Say for example, you have to try to balance out the gravity and the interparticle forces. So, you must be able to balance out that. It should be able to go to the required destination as a grout. So, the weight is required to some extent, the force of weight but at the same time, it starts just getting suspended in the form of a few particles in this grout, then the purpose is not solved.

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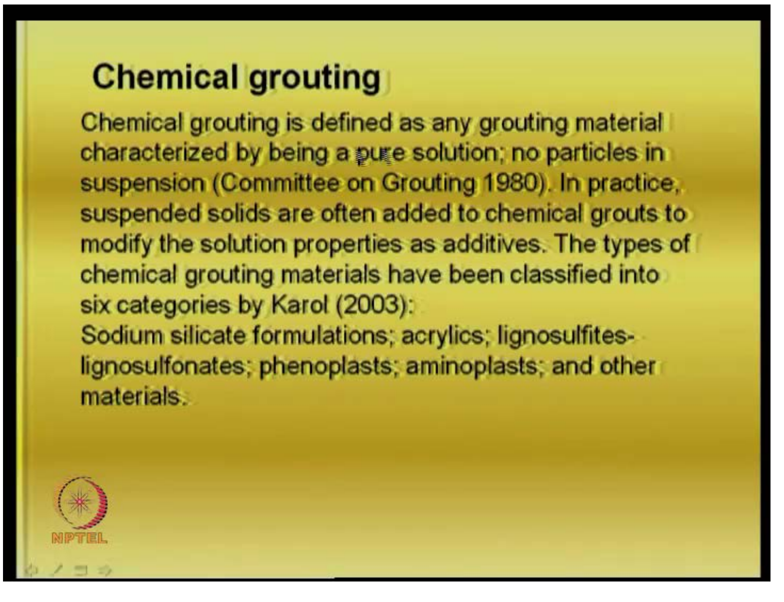

So, you must be able to, there should be balance of forces of gravity as well as inter practical forces and that is where the choice of the grout is chosen. I must tell you that many of these things do operate in a, you know, in a clear way and then, one should make some sort of understanding of you know, attempt at understanding some of these ideas that are there. Because, what happens is that the possibility is that, the grout may not be effectively working and if it is not working then, you know it is very difficult to repair. Particularly, in grout suppose, if it does not work then, it is very difficult to repair, that is one important problem. So, I will stop at this stage. We have some more information about other things. We will take a break now.