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

Lecture No. # 21

Grouting

We will continue our discussion on grouting in this class, and I would be talking about chemical grouting, which as I just mentioned is that, when the particle size is too fine, you need to have chemical grouting.

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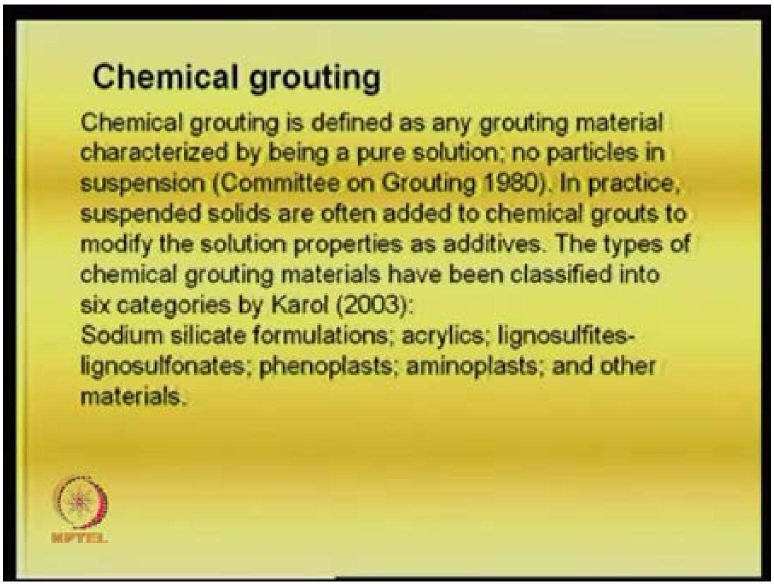

In fact, there is a committee on grouting as I just mentioned, there is lot of activity in international level, where international committee on large dams is there; then, international committee on grouting is there; there is a group on ground improvement techniques, which is called technical committee on ground improvement techniques, they have some rules.

And the chemical grouting is defined as any grouting material characterized by being a pure solution, you know, and then, no particles in suspension - that is one definition, but in practice what we say is that, it is not just a solution like a chemical solution that you have, you need to have some sort of suspended solids, also to see that, the, in the way that it is suppose to be beneficial.

So, what we says that, it is a, the more of our solution and we have many types of grouts here which are chemical grouting as I just mentioned, actually there is one reference by Karol, who did lot of work on this lines and you have lot of chemical materials here; it is called, they have sodium silicate formulations acrylics, lignosulphates, lignosulfonates, phenoplasts, aminoplasts and other materials.

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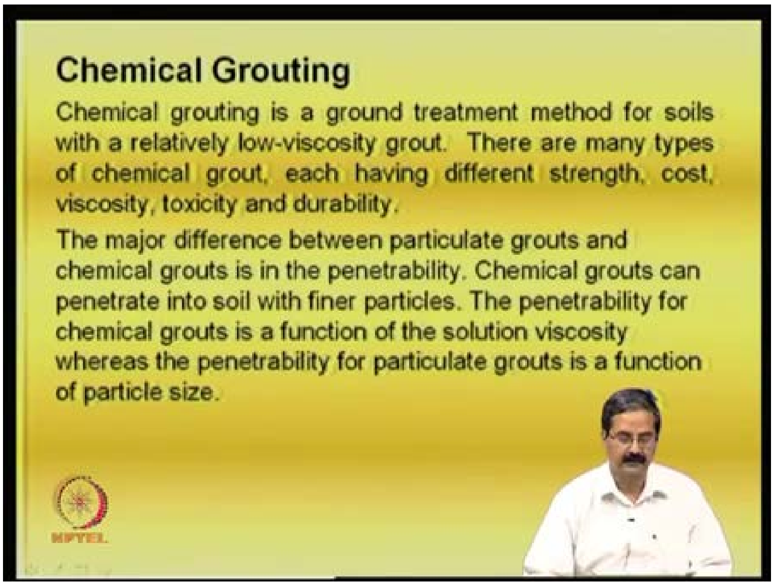

Actually a lot of material is available on this, as I just mentioned, it is a good treatment method for a low, where you know, you need a low viscosity, you know, when the, a low viscosity, like you know, the particles can go slowly into their pore sizes, and then because of the chemical action also, they can be very effective and each have each of this chemical grouts have a different strengths, cost viscosity, toxicity and durability. In fact, they have even some effects also, because they are all chemicals.

The major difference between the particulate grouts, like we saw, you know bentonite or you know cement, and some of them, they are all more particulate grouts, they are called particulate grouts, and the chemical grouts is the penetrable penetration characteristics, we call it penetrability.

The chemical grouts can penetrate into soil with finer particles, the penetrability for chemical grouts is a function of the solution viscosity, whereas penetrate penetrability for the particulate grouts are function of particle size. This distinction is very necessary, because when you are trying to design a grout, you should know what is a size of the particle there, then if the size of the particles is going to be very little somewhat a coarser, then one can go for particulate grouts, means, particles which can be in a suspended form there are bigger size, but in a, when you want low viscosities and other things like the particle size being very low, you need to go for chemical grouts; this distinction is very essential.

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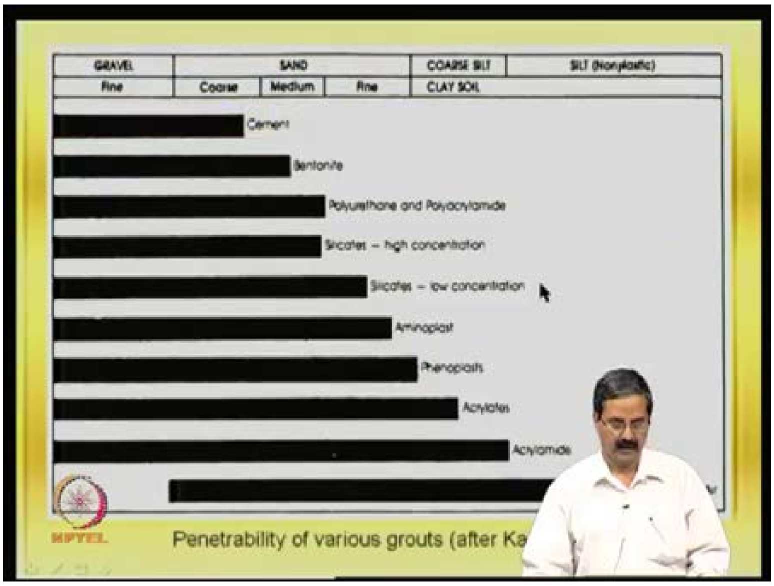

You can see that the grouts chemical grouts have a big variation; you can see that gravel sand coarse and silt sizes are here. The cement could be just applicable to this range cement, but cement plus bentonite or bentonite alone could be somewhat higher, then polyethylene and polyacrylamide properties, they have somewhat higher, you can see that aminoplast and others acrylates and something they have a bigger range of applicability for depending on the particle size; say for example, this material could occupy or serve big range of particle sizes ranging from gravel to coarse silts or clayey soils as well to some extent.

And whereas, a compressed air also, like you know, you along with that you know, you inject compressed air into the system, the possibility is that, it enhances the whole issue, like it can be useful to some extent in some of this grouting system itself, like to increase efficiency.

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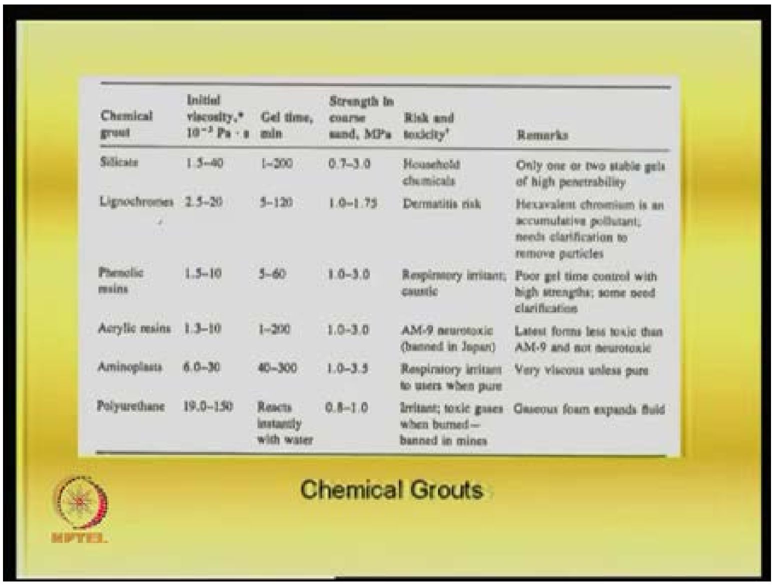

Chemical grout	Initial viscosity,* 10^{-3} Pa · s	Gel time, min	Strength in coarse sand, MPa	Risk and toxicity†	Remarks
Silicate	1.5–40	1–200	0.7–3.0	Household chemicals	Only one or two stable gels of high penetrability
Lignochromes	2.5–20	5–120	1.0–1.75	Dermatitis risk	Hexavalent chromium is an accumulative pollutant; needs clarification to remove particles
Phenolic resins	1.5–10	5–60	1.0–3.0	Respiratory irritant; caustic	Poor gel time control with high strengths; some need clarification
Acrylic resins	1.3–10	1–200	1.0–3.0	AM-9 neurotoxic (banned in Japan)	Latest forms less toxic than AM-9 and not neurotoxic
Aminoplasts	6.0–30	40–300	1.0–3.5	Respiratory irritant to users when pure	Very viscous unless pure
Polyurethane	19.0–150	Reacts instantly with water	0.8–1.0	Irritant; toxic gases when burned—banned in mines	Gaseous foam expands fluid

This is another table that one should have a look at it; depending on the type of chemical grout as I just mentioned, it could be sodium silicate or silicate, lignochromes, all that you have a varieties of materials; their properties are also here given.

And then, you know depending on a, we know, we know, that the viscosity is in terms of the kilopascal's or Pascal's unit of per this thing, so you can even see the second actually, gel time is something that we need to understand that hardening time or setting time.

So, in minutes, it is given, polyurethane it reacts instantly with water, whereas aminoplasts they have, they take some time and all that. So, strength in a coarse sand what is a order of strength they get, you can see that, they have some it is quite good in m p a, you know it is very good.

Like, you know unconfined compression strength of say clay or sand could be very low, it could be just even hundred one, one hundredth of this or much less than that, so, but, then by adding this some of this materials, the, it, it gets improved by this much number which is quite good.

And there are some issues that are like you know as I said risk and toxicity, because they are all chemical in nature and so, there is some risk associated with that, it can be a risk in terms of this skin allergy and all that; it is a silicate, of course, is a household chemical phenolic resins, respiratory irritant caustic.

So, in some places it is also banned, like acrylic resin, they are all banned neurotoxic, then respiratory irritant, irritant and all that. So, when somebody is trying to chemical grouts have been effective, but it does not mean that, they may, I mean, one if you do not take proper care, the possibility is that, they may affect the health, human health or operating persons are there, so, but otherwise, they are like when you are trying to operate, you know, during that one should take care of this difficult, the health hazards, then otherwise it is all right. So, some of the remarks are also here, that how in what in form it is better and all that in the sense.

So, for example, silicate only one or two stable gels of high penetrability are there and lignochromes, hexavalent chromium, is, is an accumulative pollutant and needs clarification to remove particles, particles, the other chemicals are, they have poor gel time controls with high strengths; some certain needs, you know, one should really do some sort of analysis because the fact that you have. So, many chemicals does not mean that, you can use them directly, they need to really do lot of one should do lot of studies with a chemical chemistry background and see that they are very effective and also do not have difficulties when you are trying to handle it in the field.

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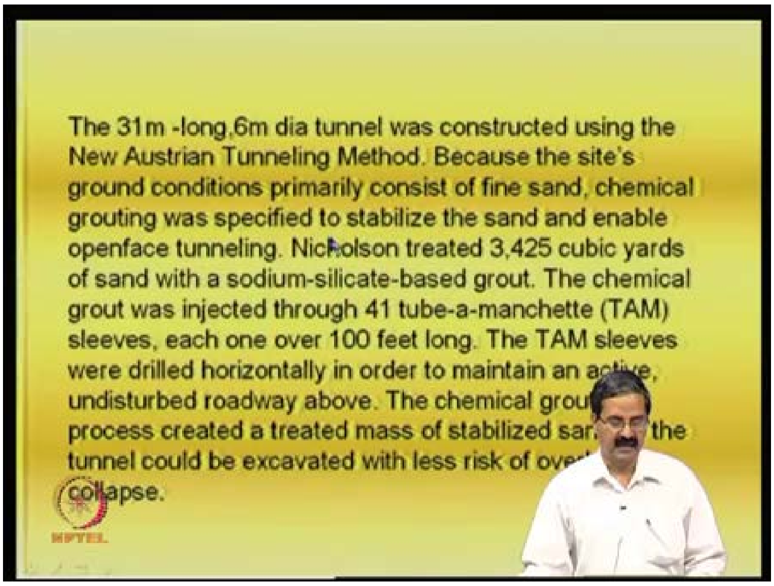

So, I will give a small examples here, this is, in a Michigan state, one construction company has done that, this is a tunnel and then it is about to be its caving in its about 31 meters long, you know 6 meters diameter was constructed using the new Austrian method of tunneling; in fact, this is one method of construction of tunnels, because the site's conditions primarily consist of fine sand, chemical grouting was specified to stabilize the sand and enable open face tunneling. So, in this case, since a fine sand material is that, definitely it caves in and to increase that strength, you know when you are trying to do tunneling, like it is open face tunneling what he called.

So, one should stabilize it, so they that company stabilized it with a sodium silicate based grout. The chemical grout was injected through 41 tube-a-manchette sleeves, each one over, a, 100 feet long. They, the, this machine sleeves were drilled horizontally into them to maintain an active undisturbed road way above, the thing is that, it is placed ahead of what you are trying to drill and the chemical grouting process created a treated mass of stabilized sand, so that, the tunnel could be excavated with less risk of overburden collapse, like the movement you know from the front side.

Like the movement, you know, from the front site, like as I just mentioned here, like if you are able to stabilize the area, much before you start tunneling using this process, then it is fine; so, that is what this company did. It is a very important case study; it is a very good case study, that is, very applicable to many of the conditions that we have in underground water and all that.

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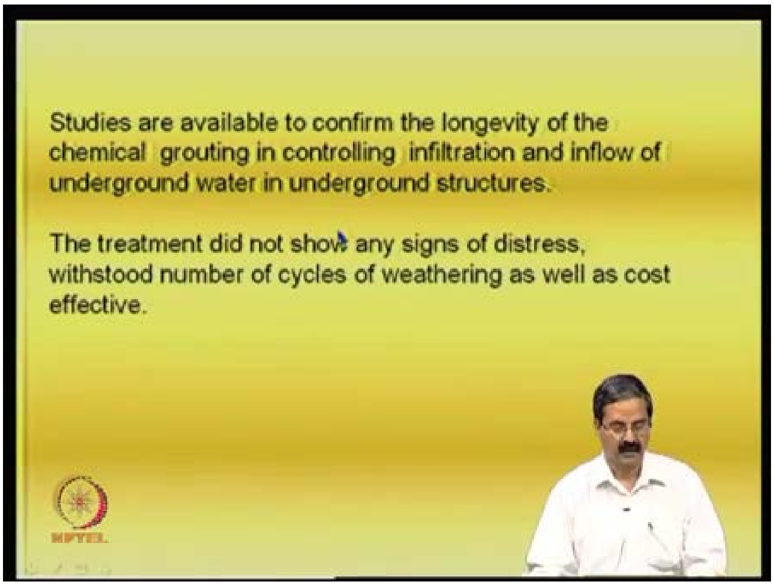

Other important point that, the, I would like to say is that, there have been many case studies, in fact, for particularly underground water control, there is some literature that clearly says that, the chemical grouting has been studied for about 30 to 40 years and they are quite effective in controlling the infiltration and inflow of underground water in underground structures.

See there is seepage also, so, is it effective. So, some, some experiments have been done which show that, these materials did not show any signs of distress and withstood number of cycles of weathering, as well as they are cost effective. Like you know, say for example, we always have apprehensions about is going to be cost effective, is it going to be durable in the long run, because I am just applying a chemical after period, after a few years, it should not collapse or does it lead to some other issues; so, all that people have studied at least for the some cases and showed that definitely chemical weathering is something that is quite useful.

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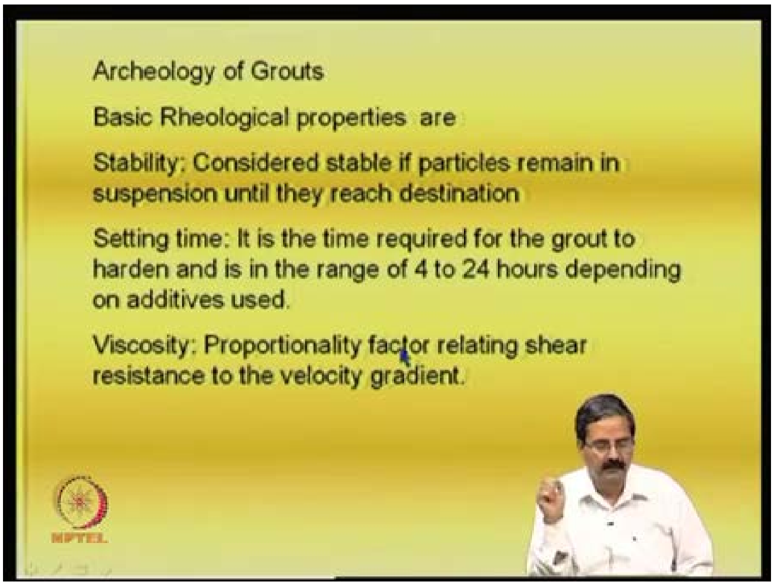

I would like to just stress on some more important points here, that there is a spelling mistake, so, archeology of grouts it is here. The archeology has three considerations stability setting time and viscosity and as I just mentioned, the stability is nothing but it, you considered the suspension stable, if the particles remain in suspension until they reach a destination.

Setting time: it is a time required for the grout to harden and it is in range of 4 to 24 hours depending on additives used and viscosity is a proportionality factor or a constant relating shear resistance to the velocity gradient.

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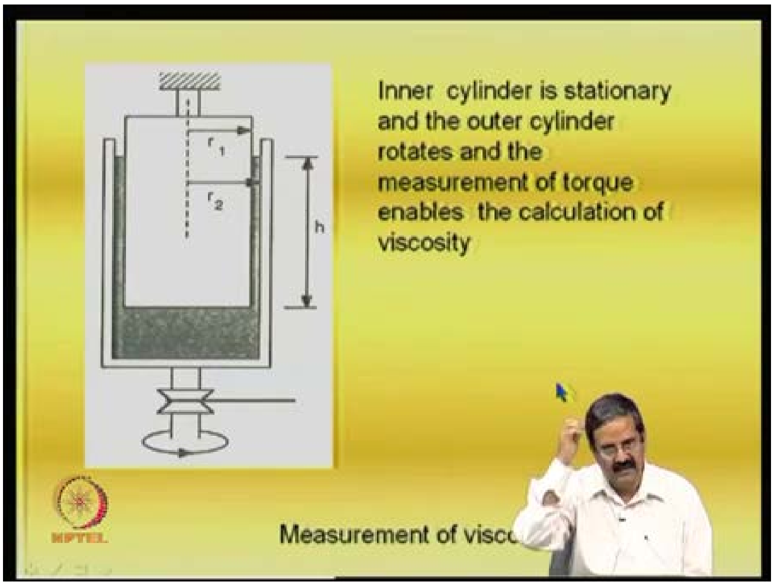

Like as I said, the, there is a force applied and when you just do that, it should not, they, they, it is all there, all viscous fluids like water is one example, water has a very poor shear resistance, but when you start adding some sort of chemicals or you know solids like sands or cement, then it achieves some sort of increase in shear resistance.

So, it is also we call it, we use that simple law of you know, where, the, we assume that as I just mentioned the coefficient of viscosity we calculate and this is a simple example of calculation of viscosity here. And suppose you fill up the slurry here and it has to in a two cylindrical tanks, one is with radius r 1 which is inner one and r 2 is radius out and then it has filled up for a height of h and we assume that the bottom does not offer any resistance and you try to rotate these and try to measure the torque to move certain distance similar to our vane shear test.

One can calculate the, using some simple expressions available in literature, one can calculate the viscosity of the grout. So, that is one can do like you know, you apply a simple torque here, in this manner and measure the viscosity and that one can do that.

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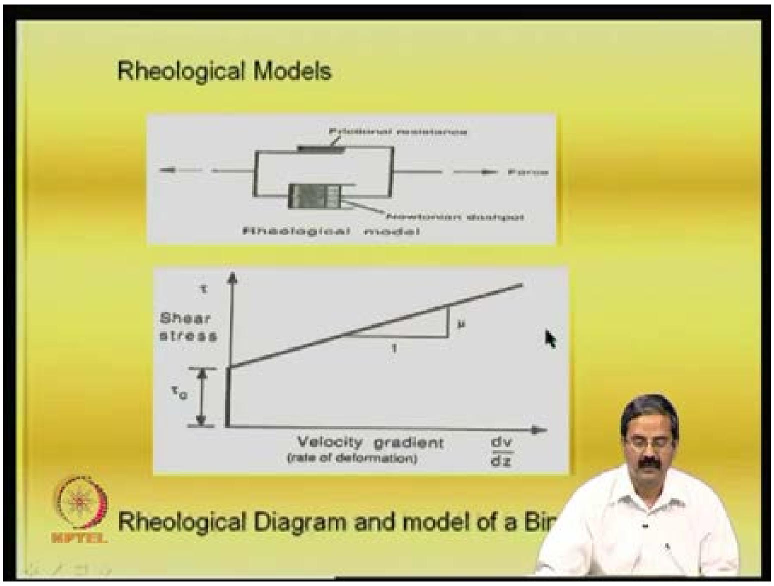

In fact, people have been trying to understand that the rheology of the fluids particularly. So, we have what is called frictional resistance, and we say, it is a Newtonian model, we use, you know, and when we, just like you know, say what it means, is that, this, this is a concept that we have the, the way that you want to model a grout is that, this, the grout has a frictional resistance, and it also, so that the moment you apply a force, it has some frictional resistance and also it has, the, what is called a viscous effects.

So, to model that, we use a simple approach, and we call it a bingham body, and say for example, in this case you apply, you start trying to, you know, allow the liquid to flow, it has to overcome initial shear resistance, which is, we call it tau naught and then as the velocity gradient increases, then shear stress also increases; this is a simple law, we are familiar with a Newton and non-Newtonian fluids, this we assume that it is a Newtonian fluid.

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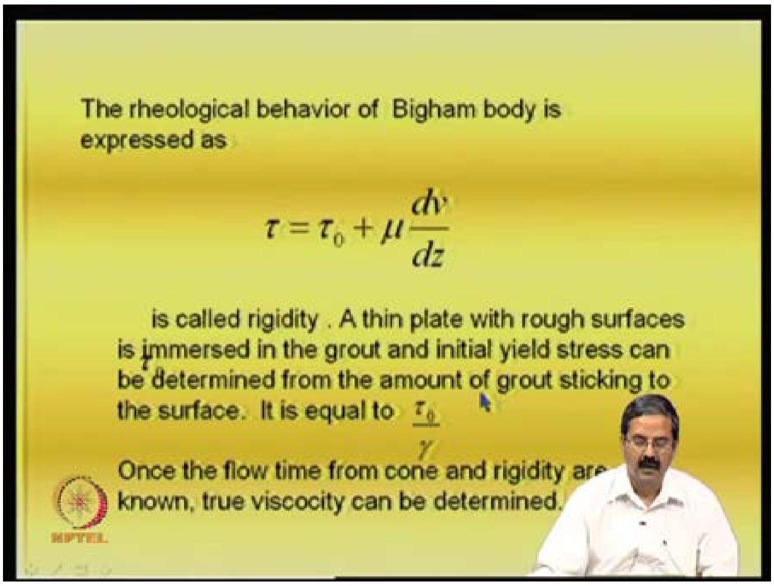

The rheological behavior of the Bigham body is expressed as t is t naught plus mu d v by d z, and this particular thing is called, this particular term is called rigidity. A thin plate with a rough surface is to calculate is immersed in the grout, and the initial stress can be determined from the amount of grout sticking to the surface, we call it is equal to tau naught by gamma. Once the flow time from the cone and rigidity are known, the true viscosity can be determined.

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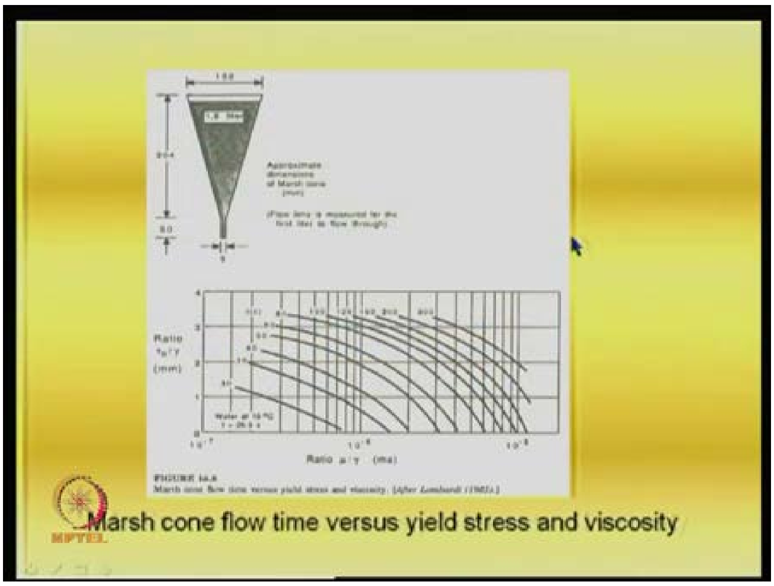

Actually this is called the rigidity, you know, initial rigidity and see the way that we do is that, you try to pass between the two plates and then once you pass through the plates, then, and measure the amount of grout sticking to the surface; we, we know its t naught also could be calculated and its unit weight is also known.

So, one can take that, and also at any point of time, one can use this sort of an equipment called cone testing, marsh cone, in which you try to measure the flow, and once you measure the flow, and there is some simple relationship, that is being provided in literature, which show that for, actually these are all different times.

And knowing this initial t naught by gamma, and one can, you know, the, how much time it takes to come out, flow time is measured for the first liter to flow through, like you know 1 liter is, it is like one, it is a only one point for liters capacity, we assume how much time is taken by the grout mix to see, that the 1 liter of grout has come out.

And once you know the time, and you can find out the flow ratio here, using say for example, these are all in seconds, so once you know that, once we know t naught by gamma for that same material as I just mentioned, t naught by gamma can be evaluated with some that plates arrangement and one can get an idea of what is a actual viscosity, because the objective is to get the this one.

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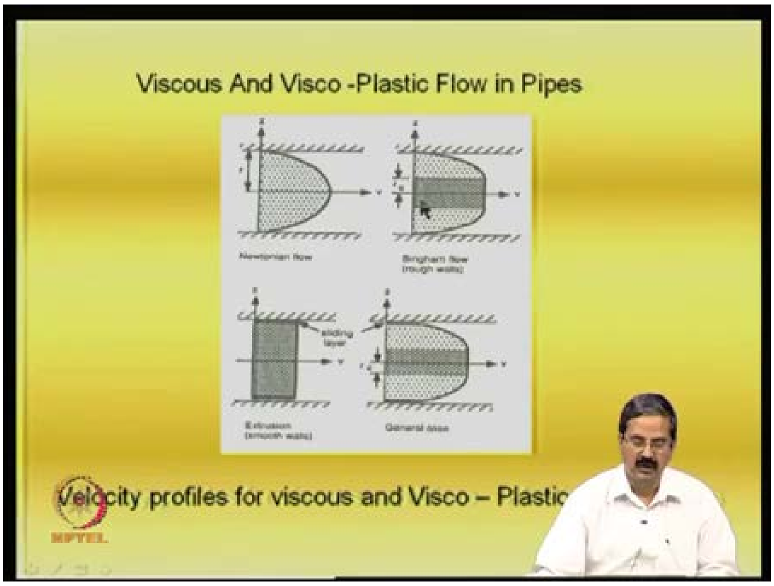

So, you will have this, and you know this, and you will be able to get some understanding of what is its shear, I mean, what is its viscosity. There are also some more concepts on, you know, understanding the gravity, the flow of the grouts in terms of the viscous nature and visco-plastic flow in pipes and all that.

I mean, they have been not mathematical models, then you know coming to permeation we know that, as I said permeation also needs, say for example, there are two types of models - one is for the (( )) improvement, the other one is for the permeability improvement or permeability reduction.

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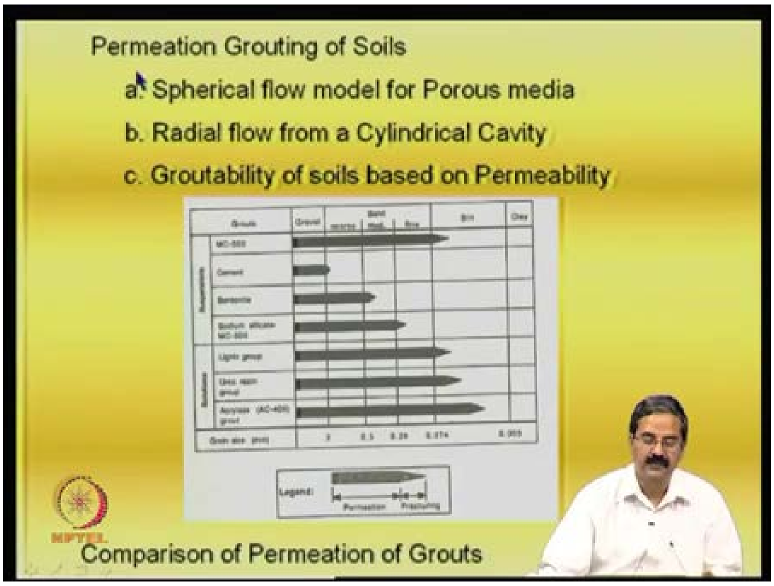

Say for example, here the permeability grouting of soils can needs to be having an understanding of, you should have an understanding of the spherical flow model for the porous media, radial flow from the cylindrical cavity, grout ability of the soils based on permeability.

So, there is some sort of understanding that is given here, and the different types of solutions and suspensions, they have different levels of permeation and fracturing in the sense that, you know, there applicability is clearly known, say depending on, say for example, m c 500 cement and bentonite to what extent they are useful.

You can see that the bentonite is somewhat valid from gravel to sand, whereas cement is only for gravel, whereas this is a, it is another type of thing which can be little longer.

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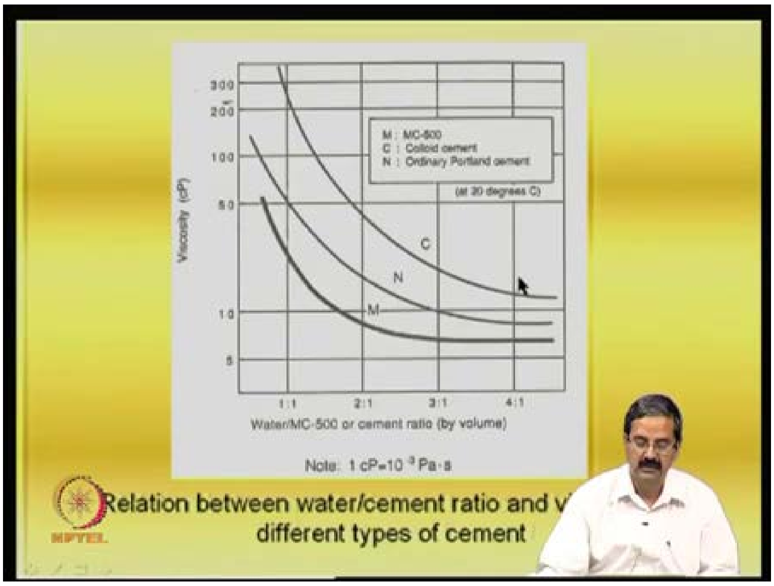

Similarly, in the case of solutions, this is another one that it has; it is valid for wide range of, wide range of grain size distribution as a permeation grout. So, this is a actually, if you just see the previous thing, I was talking about the three materials, one is called ordinary Portland cement, other one is a colloid cement, in which a colloid is a like bentonite is added. The other one was that another, where another compound, you know, it is just an example to see, what a viscosity is, how does the viscosity altered with water cement ratio by volume or whatever.

So, one can, this sort of, you know, a laboratory work is important to understand, because the thing is that, finally, you should be able to do a mix design properly in the sense, that you should be able to fill up all, the cavity.

Say imagine that, there is some space available roughly some meter cube of material, that pour space needs to be filled up, when you need that much of pour space, and you should have some time also, and then you should stabilize. There are three issues there, one is space available to fill up all the pour voids and also the (( )) grain required is another thing and the setting time, you know, the thing is that, it should set little faster, like you know, if it takes long time then it is no use.

So, (( )) set faster. So, may be, suppose you want to construct this particular work in about start the work and at least two, one, two days ahead you must be able to complete the whole of that and we should expect that, that material got stabilized and then you can start excavating there, you know, you know, so that, you can grout or no using some of methods and then start, so that, working on this, say for example, a tunnel project. So, that it is safe.

So, the important criteria is that, you must have a some sort of design, tentative design, in which, the, you have the rough area of the pour spaces to be filled up, in terms of the volume and also the properties of the grout, and also, like these, all based on the your grain size distributions and all that this criteria we have already discussed.

One should be able to establish some of these things very clearly and also it depends on the cost effectiveness also, like you know, as I said the viscosity, you know, you can see that the m, this material has a low viscosity compared to high viscosity, there are. So, how much, how much, did, do you need what viscosity you need, you know, so that, it fills up all the volume should be little, one should have a knowledge of that.

So, it is very important to lot of mix design procedures and come out with proper understanding and one should do lot of laboratory work also, it is not just that the concepts are simple, because I have seen that things are generally empirical here and we should be able to verify based on certain laboratory test and see that you come out with a proper mix design of the grout.

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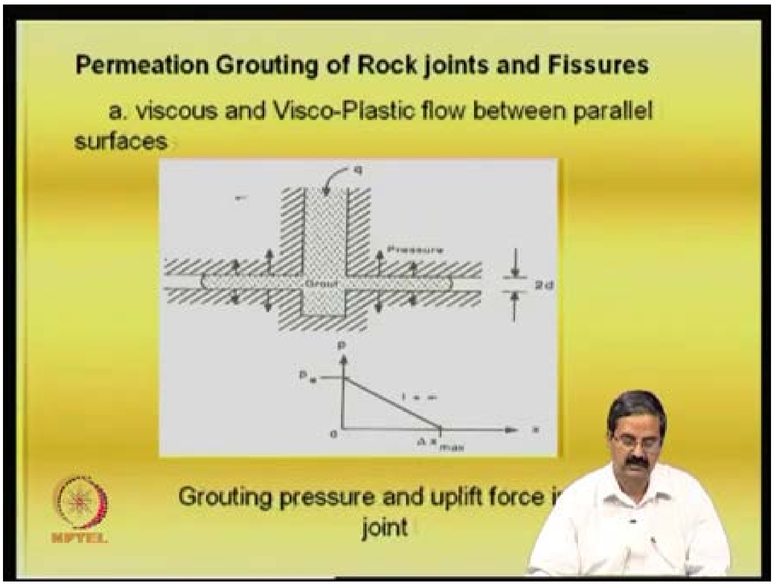

Suppose, in the case of rock joints and fissures, you know, the thing is this is a very typical case in many problems, in rock slopes, and there is some sort of understanding also one should have, and the thing, you know, why is this concept of viscosity and its things are required is that, you must be able to design in some sense, what is going to happen.

So, in this case, particularly for rock grouting permeation grouting, when you are trying to use for rock joints, we assume that you have this grouting, the discharge here, then it exerts some sort of pressure here, in the form of a 2 d, and you must be able to calculate the grouting pressure, and uplift force in a joint, because you should not lead to hydro fracturing, you know, sometimes if the pressure is going to be higher, it it could lead to fracturing of the rock itself.

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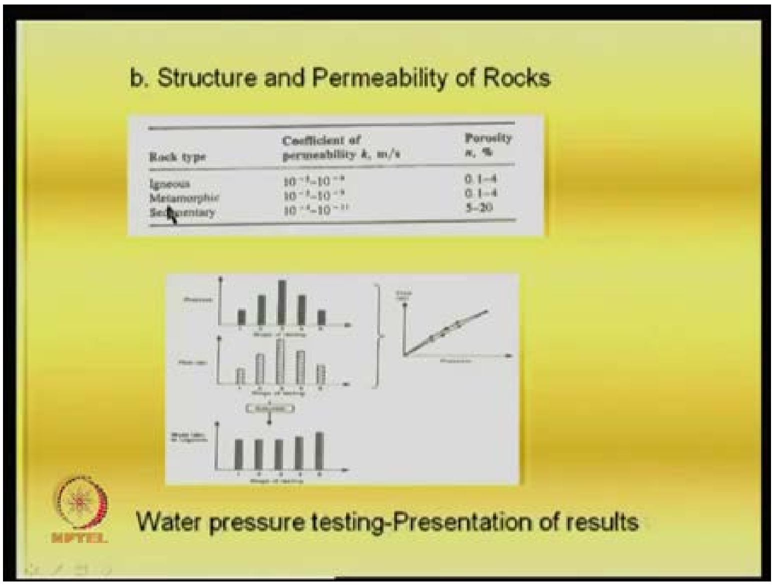

So, one should be careful in some of these things and depending on the type of rock, we have different permeability coefficients and the porosities; so, in fact, there is certain thing, that you, you apply some pressure, you measure the flow rate.

And actually the, the, amount of discharge is measured in terms of the legends, it is legend units, where you try to do the in situ testing of permeability of rocks, and you apply some pressure, and then monitor the flow rate. So, as you increase the pressure, the flow rate increases, and as a pressure is withdrawn, the flow rate decreases.

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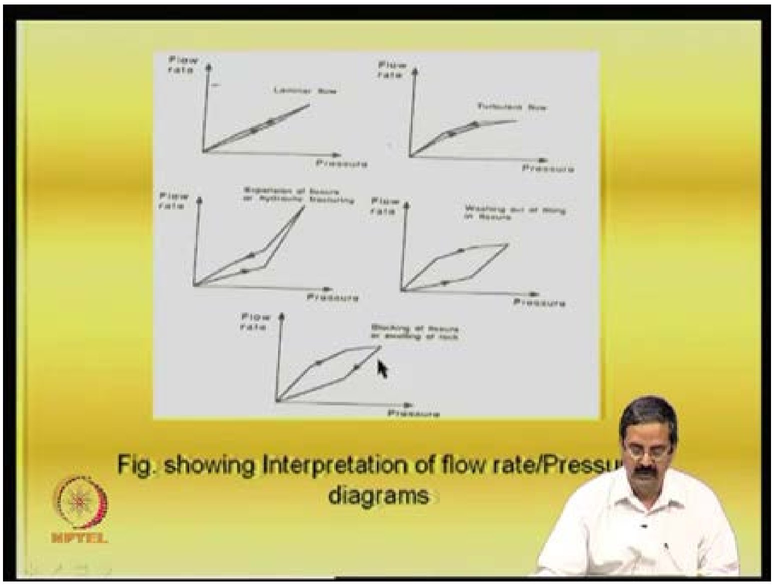

So, in this case there is no problem. So, this is a similar to an elastic soil behavior, in which, you know, the exact see it, it did not lead to any fracturing problems and all that, so, but then, I can show you, there are some cases, where one should, based on the type of the response, you have, you can understand what type of flow it is, what could happen and all that.

There is a typical diagram, in which, if the pressure is applied and the flow rate is monitored, this is a laminar flow; in the case of a rock slope, this is a laminar flow, in which, because there is no much damage to the rock and all that, and if there is a curvature here, we call it turbulent flow, like you know, it all depends on the size of the rock joint.

Then, there is another example here, expansion of the fissure or hydraulic fracturing, what it means is that, you applied some pressure, but during an unloading process for the same pressure, you have a high flow rate.

You can see here, that I just take the pressure at this point, and if I just see the flow rate was less here, but while at the, but then, you know, when during there is a higher flow rate in unloading process, which means that, there is some sort of expansion of the fissure or the hydraulic fracturing is there, which means that the pressure was higher.

That another case was that, like this is another possibility, that you just apply the pressure, then apply some more pressure, then the possibility is that, then come back, then the what happens is that, the flow rate is still higher, and the, the, it is somewhat not sudden, and it, it shows that the washing out of the filling in fissures, say you know in a fissures in a rock joint, there could be many materials, and you probably removed lot of the filling material in the during the testing, that is what it shows.

Like it, it only shows that, there is lot of filled, filled up material in, the, these thing. So, these are all in situ test, then there is another type,, that is called blocking of the fissure or the swelling of the rock.

In fact, like see this is one, one type, like you low, increase the pressure, then during the reversal, you see that the flow rate is much less, which means that, which is unusual, like you know, in the sense that, we say that, there is a swelling of the rock or the blocking of the fissure.

So, there is a somehow the block got, there was a block in the that area, and then, that sometimes you may see that, there could be people call uses term called swelling of the rock, which is somewhat confusing, but then, that is one of the terms, that is used in rocks as well. So, these are all some, so based on some of this test, one can understand what is a pore size or what should be the permeation grouting that is required, and one should have. So, this, some of this information will help great deal in trying to design, the how to close this gaps.

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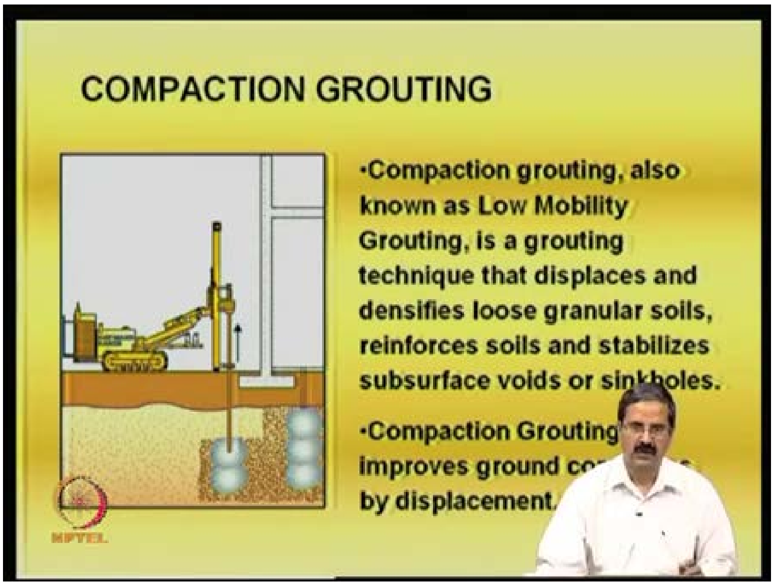

So, now, I will just take up some more examples on the compaction grouting and jet grouting, because as I just mentioned, these are all very popular techniques. As you have seen just in in the video, as well as in the some discussion, we saw that compaction grout, we have it is called low mobility grout, and it displaces, and densifies a loose granular soils, reinforces soils, and stabilizes surface voids and sinkholes. And it displaces ground, and improves the ground conditions, like you can see that compared to native soil here, there is a densification achieved here, and then, there is a bulb formation also, like it reinforces the soils to some extent, though we do not really calculate, it's, how much of reinforcement contribution is there.

Because we know, just exactly we try to what I just mentioned was that, it is, densification is one important property here, then strength improvement by, you know, forming this column is also another important variable here.

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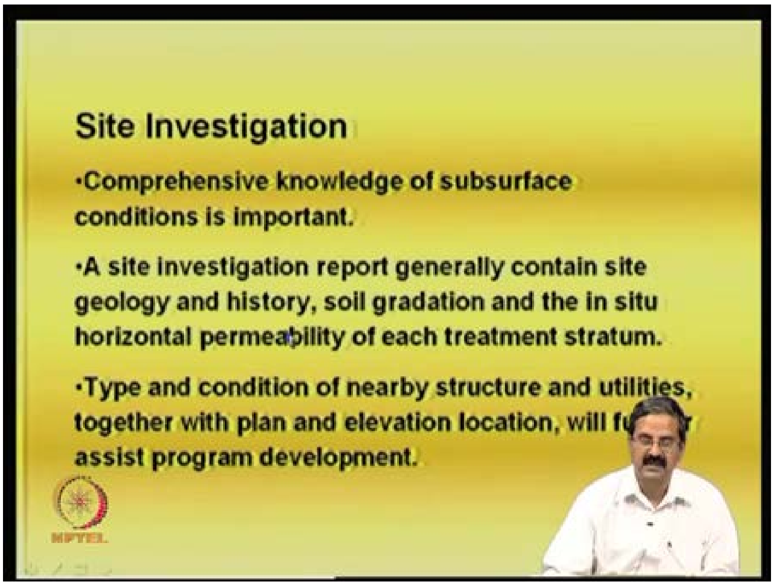

So, all these things will greatly help in reducing, both permeability as well as increasing the strength. So, if you want to do this, you need to have very good soil investigation done, and you should have the site geology in history, gradation characteristics, and in situ horizontal permeability of each stratum.

Typical type and condition of the nearby structures and utilities, together with plan, and will also help in the program, because suppose you are trying to do construction in the nearby, you know, in a highly habituated area or urban area, you need to understand that, that cannot be done that easily, and you must be able to protect all the nearby buildings.

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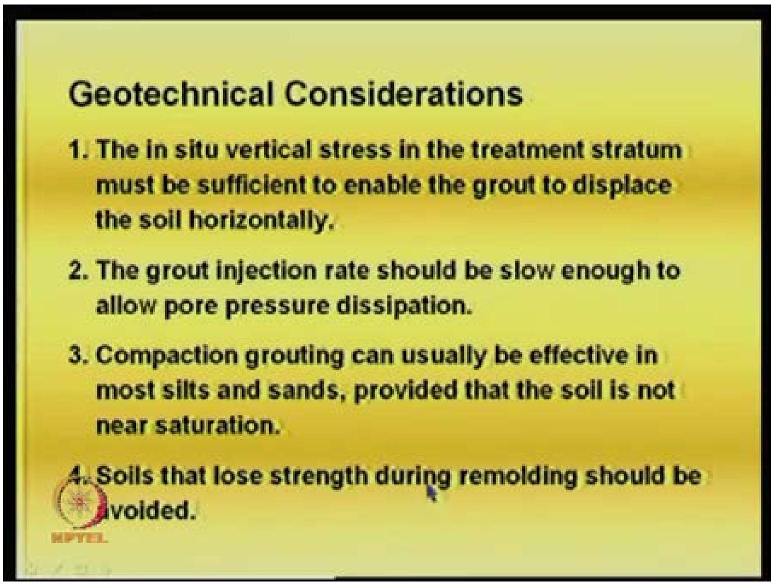

So, the some of the geotechnical issues, that we need to understand also, are that, the, in situ vertical stress in the treatment stratum must be sufficient to enable grout to displace the soil horizontally. Like you know, as I said the in situ stresses should be somewhat, you know, we are using this technique, in the case of loose sands, and the when you apply this, the bulb formation should take place, and density should, you should be able to expand, if it cannot expand, we know that the soil is very good.

So, the, in situ vertical stress, needs to be sufficient enable grout displace horizontally, the grout injection rate should also be slow enough to allow pore pressure dissipation, this is another important variable, like it should not be too fast, because there could be temporary pore pressure mobilization, that could lead to lot of other difficulties. And compaction grouting can usually be effective, in most silt and sands, provided that soil is not near saturation. Similar to testing in sands near saturation, one should be, you know, see that the quick pore pressure mobilization should not be there.

So, we should see that, the, you know, the soil should not be close to saturation, and you know, there should be, of course, it could take some time, because you are trying to densify the system there.

Soils that lose strength during remolding should be avoided, say for example, as I said clays, they have some strength reduction, because of disturbance; when you have disturbance, the possibility is that, they should not lead to further settlements.

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So, we should avoid that type of material. So, greater displacement will occur in weaker soil strata. Excavated grout bulbs confirm that compaction grouting focuses improvement, where it is most needed. Actually what happens is that, the excavation, the, the way that bulb forms is that, it goes towards the area where it is weak.

So, the bulb formation will be like that, where the improvement is, where it is more, mostly needed, it goes, the bulb formation is towards that. Collapsible soils can be treated effectively by adding water, during drilling prior to compaction grout injection; we know that, the collapsible soils are something peculiar, in the sense that they collapse with the addition of water. So, best way would be to stabilize collapsible soils is that, you add water; then, there is a collapse of the soil structure, then also do the compaction grouting. So, both combinations of water addition as well as compaction grouting will make the collapsible soil into a better soil; so that, one can do the foundation construction.

Stratified soils, particularly thin stratified soils can be the cause for difficult or reduced improvement capacity, what happens is that, the, the bulb formation, if it is too restricted, because of the ice, say for example, if they have alternate layers of dense and lose material which are thin layers, then it may not be, you know, there could be a efficiency of the process is less compared to a case, where you have a lot of lose deposits, which are uniform, there you have the best benefits.

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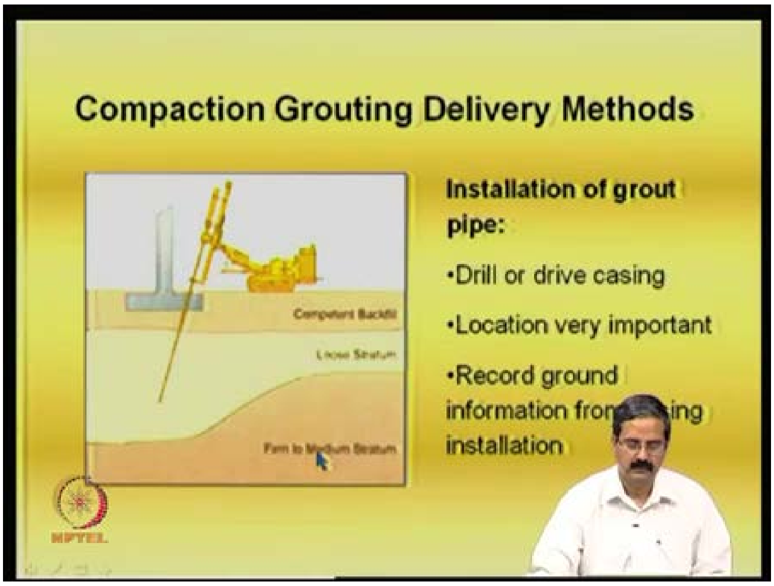

So, here as you just saw in the video, that the procedure consists of drill or drive casing; you put the casing actually, location is very important, you know, the thing is that, say for example, these are all the loose stratum, this is a design to competent backfill everything is fine, but you have a loose soil here.

So, location is very important record ground information from casing installation, like so, the thing is that, even the, the, way that you are putting the casing, can help you to get some information about the strength of the soil.

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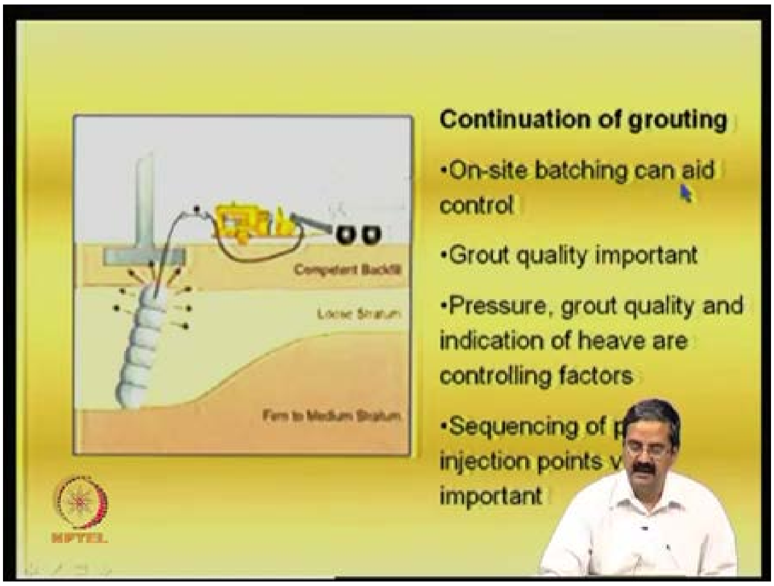

So, typically, bottom-up, like what means is that, we come from bottom, but sometimes it can even be top down. So, we try to come from amidst of two bottom, it can be, it from top also grout quality is important, we expect that, you have done a good research or you know, good mix design of the grout and quality is correct, in terms of the contractor, that see, you may do something laboratory work or done finally, the contractor should be able to come out with this material in a proper way and put it. So, pressure under volume pressure or the volumes of the grout are usually limited, slow uniform stage injection. So, you try to inject it, slow, slowly, that if the formation of the bulb takes place and it is quite efficient.

On-site batching can aid control, like you know, in the site, it can be done in batches grout quality is important pressure grout quality, and indication of the heave or controlling factors, sometimes ground heaving also could take place.

Sequence of the plan of injections point is very important, like you know, where you should start first in this particular plan, say once you have the total building plans and all that, you must be able to decide, where you should start first because or should we come from how do you, like one by one how do you do that, that is very important.

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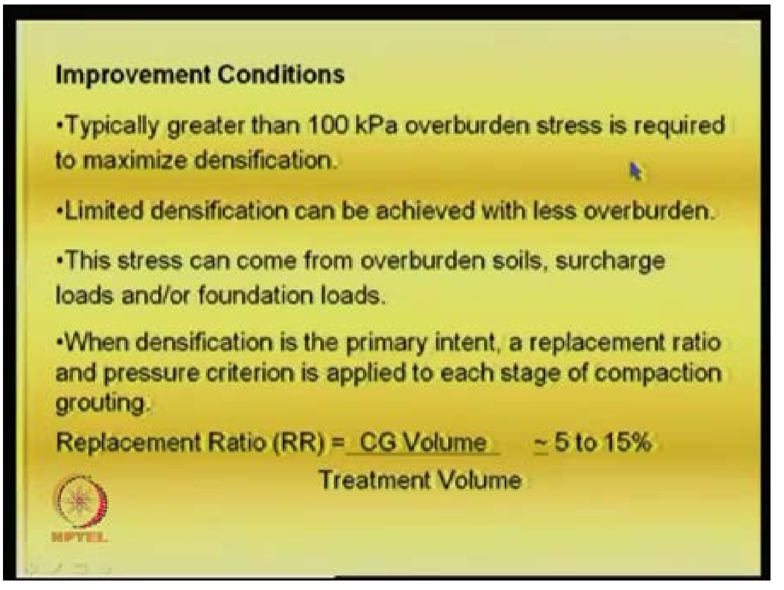

Typically pressures greater than 100 k P a as required to maximize densification, limited densification can be achieved with less overburden, and this stress can come from overburden soils surcharge and load and foundation loads.

Actually, in some, if the overburden is about 100 k P a and all that, say for example, 5 meters, you know, what I meant 5 meters into 18 k P a is about 19 k P a, and so close to 5 to 7 meters or 8 meters, this effect technique is going to be very effective and limited densification. So, the densification is maximum in this ranging, that is what people have observed, particularly certain companies, which have been using this technique very well, and limited densification can be achieved with less overburden, that is what I said, if the overburden is less, you know, the, you know there is no confinement little bit.

So, this stress can come from overburden soils, like you know, if the overburden is there, then it is better or even surcharge is there, it is better. When densification is the primary intent or the reason, a replacement ratio and the pressure criterion is applied on each stage of the compaction grouting.

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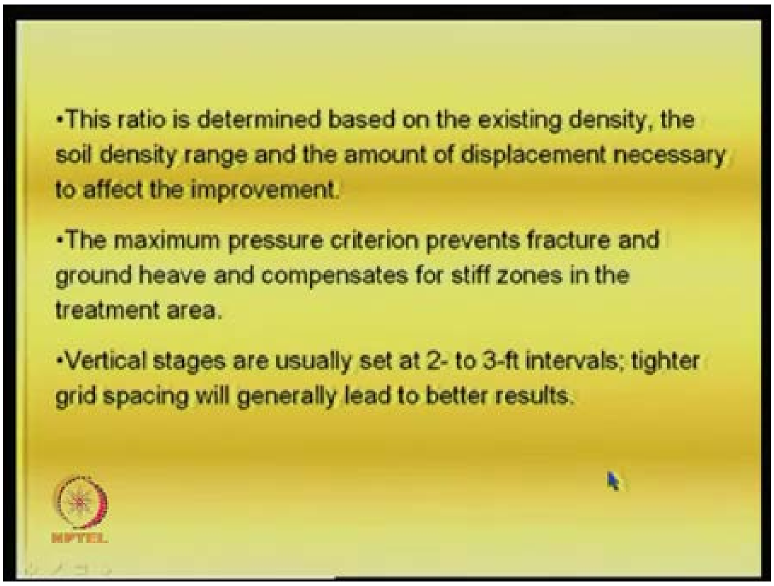

We try to just put in terms of how much of replacement can be done, its compaction grouting volume divided by treated volume, if it is 5 to 15 percent, it is considered to be good. This ratio is determined based on the existing density, the soil density range and amount of displacement required to affect the improvement.

So, you must have a rough idea of the volume, that you are going to increase or influence, you know, volume we are going to, you know, you are densifying the system. So, you must be able to have the approximate volume of the voids that you are going to handle. So that, that you will get an increase in density, later using this ground improvement technique.

Then the maximum pressure criterion that prevents fracture, and ground heave, and compensates for stiff zones in the, they are also important. Vertical stages are usually set to two feet intervals, tight grid spacing generally lead to better results; these are some observations. And the applications are very good, like as I said, it can be used in karstic regions, where you have the formation of sinkholes, and so, you, one can use this technique.

The treatment usually involves a drilling down to down and into the limestone surface to locate, and fill any cavities followed by improvement of the loose soil above the rock surface. These are all many places in Germany and other places, I have seen, where you have this cavities formed, and it is, because of the natural phenomenon, and the cavities can be closed using the compaction grouting.

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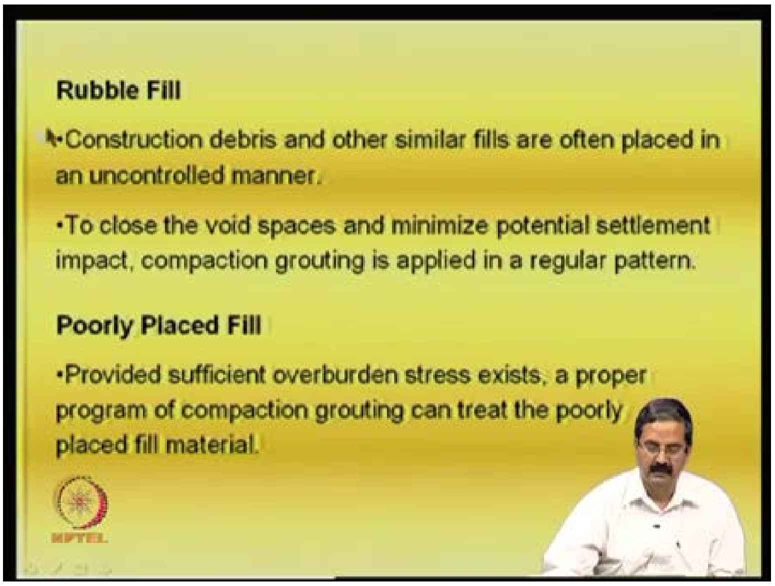

You have a rubble fill, like a construction fill, and which are uncontrolled dumps; definitely, one can stabilize using this. To close the void spaces and minimize potential settlement impact, compaction grouting is applied in a regular pattern; this can be done particularly, when you have rubble fills.

So, you should have a rough idea with the void spaces again, of course, it is not easy, but then, you need to have an estimate, because the advantage is that, the you should have a good quality control in the or the even the measurement of grout going on to the system. Then, poorly place fills, like suppose, a, we know that the compaction is not done for the fill well, then if there is sufficient overburden, a proper program of compaction grouting can treat the poorly placed fill material.

I have told you some case, where they you know, 10 meters of filling has to be done, the first 2 meters, it was not done well, next 2 meters it was, then next 2 meters it was, but then, see when you the problem is that, after say 5 or 6 meters are depth, we are, suppose you realize that based on the c p t test or s e p t test, that the soil is not good at location. The best way would be probably, that you need to a find out its density and back calculate certain things, and find out, if you can densify that area, so, poorly placed fills also could be stabilized using compaction grouting.

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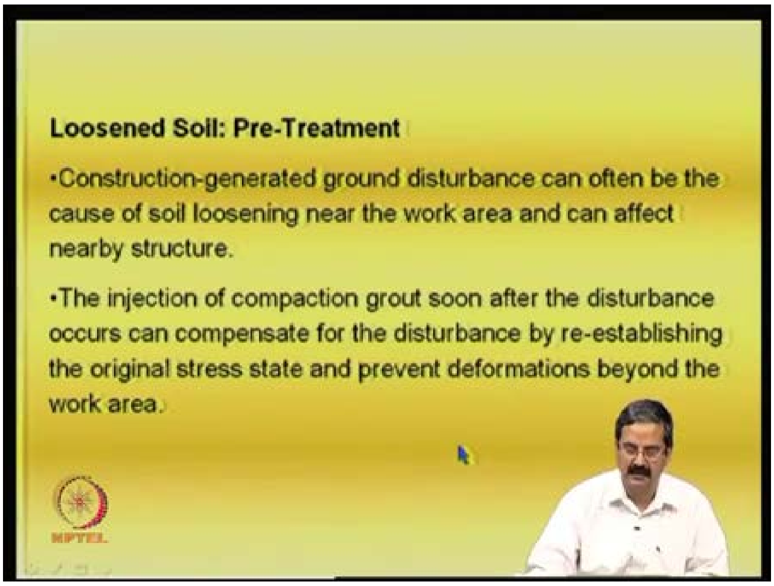

Then loosened soils construction generated ground disturbance can often be the cause of loosening, like what happened is, because of the construction induced vibrations, and all that, there is a loosening of soil structure, and what happens is that, if you are able to, that could affect the buildings, lot of buildings, like this is a case, you know, in some cases, if you try to do some excavation here, there is a possibility of instability occurring, and then, that could lead to some problems.

So, one should really analyze this problem, and effect the improvement, and it is possible, that you can use this technique, and you can inject the compaction grout soon, after the disturbance occurs, and it can compensate for the disturbance by re-establishing the original stress state, and preventing the deformations beyond the working area.

Suppose, you have known that, there is a loosening of, likely loosening, one can do the pre-treatment, like what happens is that, there could be a a ground movements, that could occur, because of certain excavations and refilling and all that, one could understand that, yes, the possibility is that, if you remove the soil here, there is a possibility of disturbance of the nearby soil stratum, they may get stress release will be there, because you remove excavation, so much of cubic meters of soil is removed in one area, the other, the, all nearby areas, they tend to relax, because the soil under the their foundation start coming this word, towards the excavated area and one should stabilize that.

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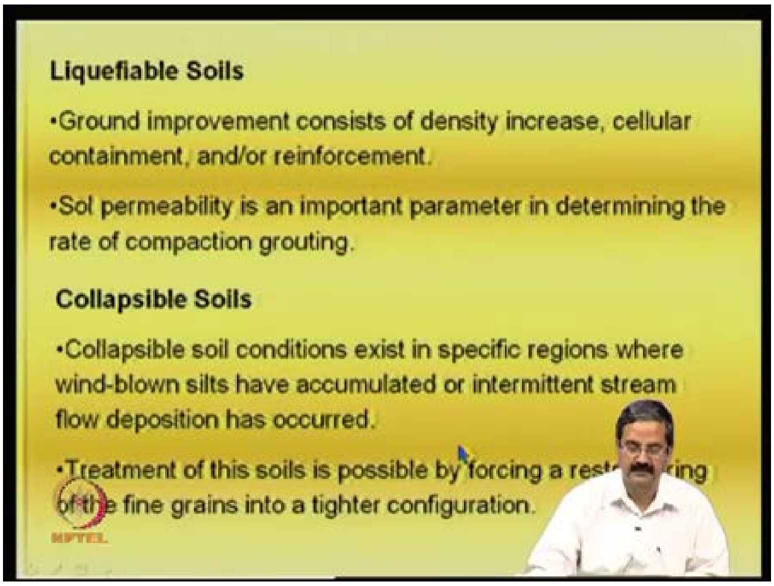

So, one could anticipate those things and then stabilize, of course, it can be very effective in the liquefiable soils also, and ground treatment consists of density, increase cellular confinement and reinforcement, of course.

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Soil permeability is another important parameter in determining the rate of compaction grouting, of course, collapsible soils also is very effective, this we can, I have seen. So, that way the advantage of the compaction grouting on, that it can pin pointedly treated, treat the area speed of installation is good; wide application ranges effective in a variety of soil conditions; can be performed in a very tight access and low headroom conditions. Non-hazardous, no waste spoil disposal, like you know, sometimes, if you use certain techniques, there is a waste also generated, like 10 percent, 5 percent; there could be some difficulties of disposal.

So, here, since we are using particular grout, there could be a possibility, that there such possibility are less here. No need to connect to footing or a column to, in some cases, sometimes its required to connect to footings or columns, if you are trying to use some techniques, but here, there is no such requirement, like you are trying to put some pile foundations; pile foundations should be connected to the original structure, because they have to take care of the load, some of the load, that is, the, the should be, now imagine that, the load is not that particular pile foundation group is not able to take care of the load, and then there is a possibility of differential settlements.

So, you need to put an additional pile. So, additional piles have to be connected to the original system, in which there is a load sharing proper load sharing, but then imagine that it is not done, like you know, then, it is a serious structural problem in that case. In this case what you are trying to do is that, by improving the ground all round close to the pile foundations; we see that, the piles are the, say for example, you design the piles based on the skin resistance and shaft resistance, if that is going to be little higher then its fine.

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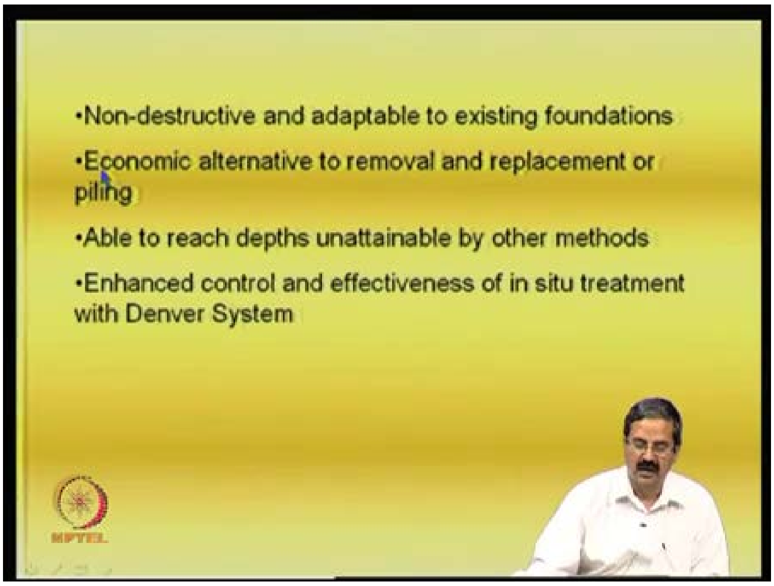

So, non-destructive and adaptable to existing foundations economic alternative to removal and replacement or piling; able to reach depths and unattainable by other methods; enhanced control and effectiveness of the in situ treatment with another systems.

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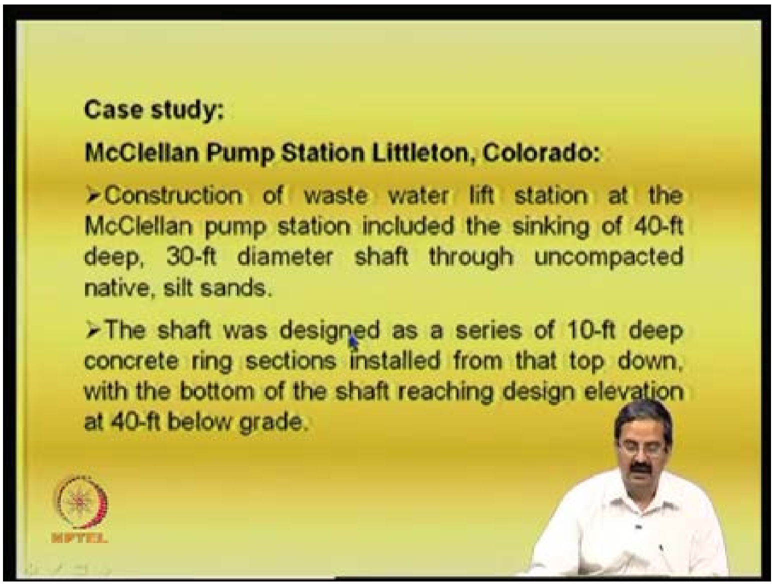

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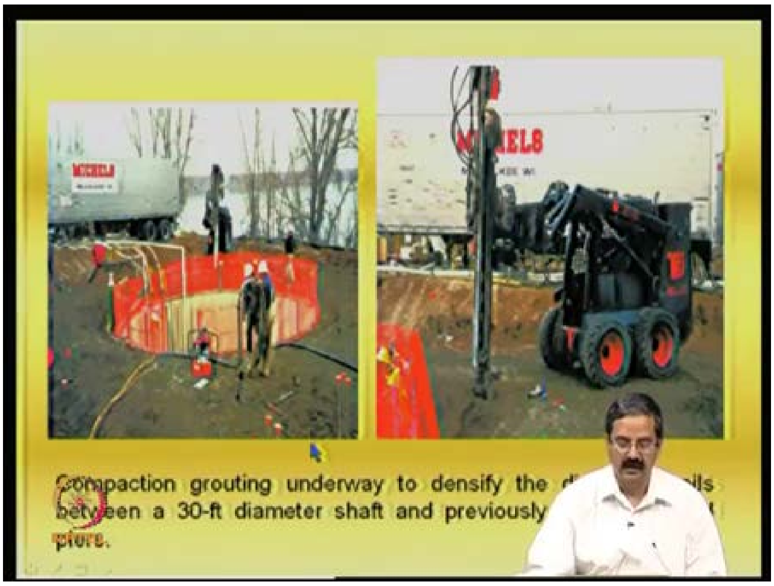

Just small examples, like in a waste water lift irrigation scheme and shaft was designed as a series of 10 feet deep concrete ring sections, installed from top down, like you know, what you do, is that, for a water supply treatment plant or whatever you need to construct vertical shaft, how do you construct a vertical shaft, you have to have a series of rings place them.

So, if you want to do this, you have to stabilize, you know, it is not easy to do this sort of construction. So, because, say for example, as I just mentioned, it is a 40 meter deep about 10 meters, more than 12 meters deep and about each 30 feet diameter, you know diameter of the shaft is about 10 meters.

So, the material is un-compacted native silty sand, so the shaft was designed as a series of, you know, 10 feet deep concrete ring sections installed from top, and so, the, the bottom one reaches a designation level.

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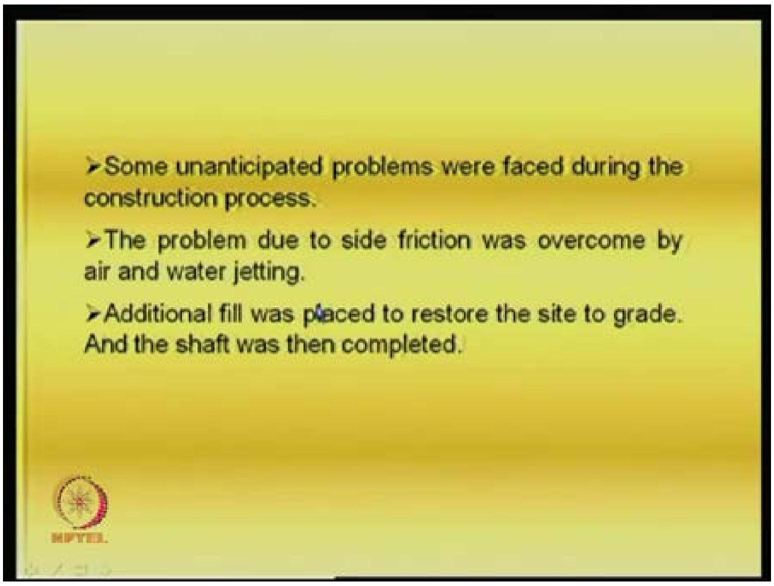

So, for this compaction grouting was undertaken to densify the disturbed soil between 30 feet, and previous the work, they have done. So, what they found was that, there are some problems that they were facing during the construction process.

So, finally, I mean, the, the problem due to side friction was overcome by air water jetting and additional fill was placed to restore the site to grade. So, it is possible to solve even construction of some of these issues, construction of shafts vertical shafts in this manner.

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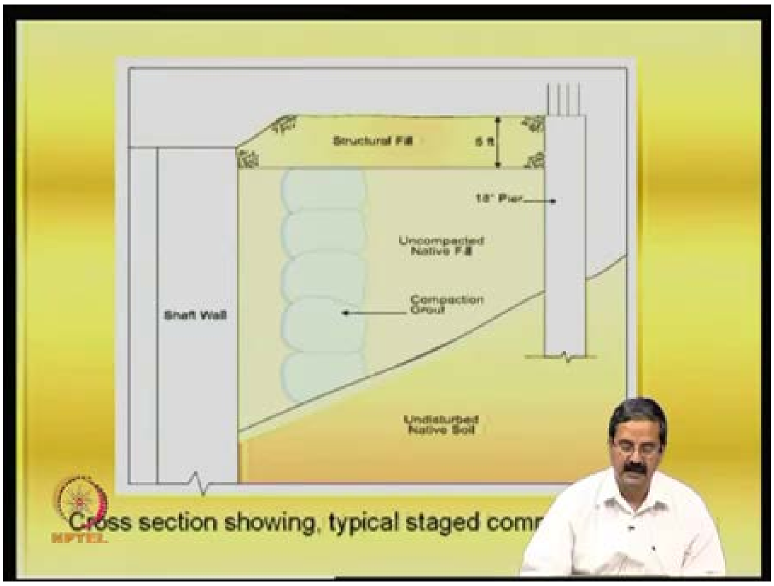

So, this is a shaft, this is a structural fill and this is how it is done. So, normally, to to do a shaft like this, it is not a very easy, like you know, you are trying to do a vertical like think of a well, of, say this is a 10 meters here, if you want to do, that the the problem is that, you should design for these earth pressures, and there will be lot of problems and the soil is so loose.

So, the the technique was that, they said that, you know, you, they are placing the rings. So, how do you place the rings; so, it is not easy, and so, what they did was that, compaction grout was here placed, and stabilize, the whole area was stabilized, and the earth pressure coming on this was less; so, this how it is done.

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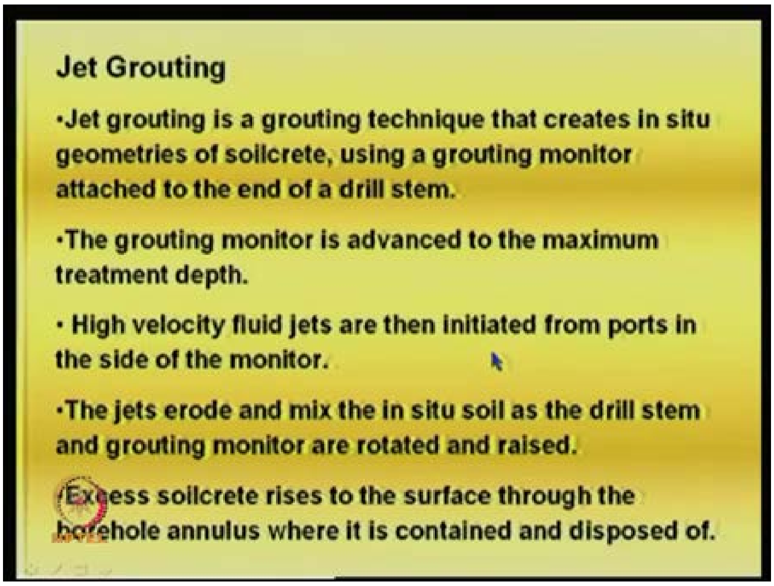

So, that is about compaction grouting, now I will just give some more examples on the jet grouting, as I said, a jet grouting has, you know, you have seen, anyhow, three types it has, we will see that. Jet grouting is grouting technique that creates an in situ geometry of soilcrete. We call it, instead of concrete we call it soilcrete, here using a grouting monitor attached to the end of the drill or stem. The grouting monitor is advanced to the maximum treatment depth; you take it to the maximum depth.

High velocity fluid jets are then initiated from the ports in the side of the monitor, like you have seen, there is single type, three second, and three jets are there, and the jet grouting jets will come. These jets erode and mix in situ soil as a drill stem, and grouting monitor are rotated and raised. So, by you know, in this process, the material gets mixed up and the soilcrete is nothing but, you know, it is a the material, that is densified column, densified material, it is a grout mix actually.

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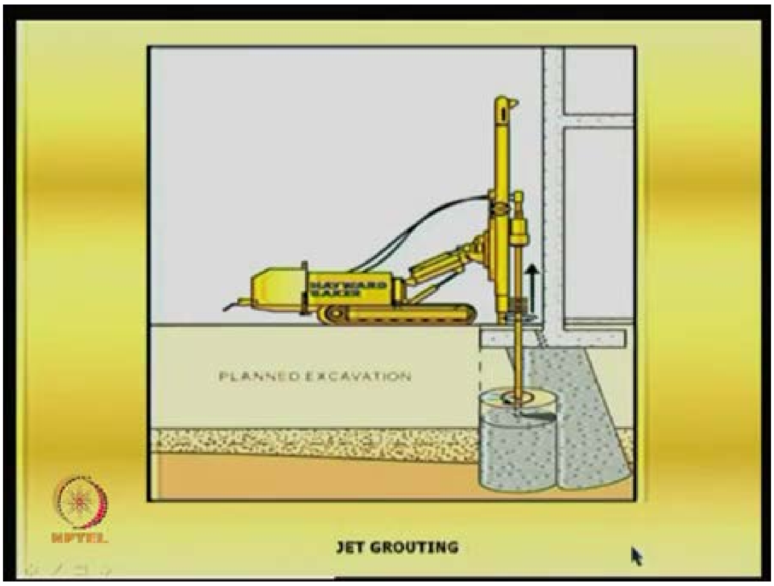

So, the excess soilcrete raises to the surface through the borehole annulus, where it is contained, and disposed off, this is, what it is done, you can see that, jet grouting, you know, you have done one in inclined, then the other one is coming like this, see it has, that it creates, because of their pressure, its mixed.

So, actually, I must thank this Hayward baker company, in which, you know, they did extensive work, you know, I am I have taken lot of material from them, where they are able to do this show, very cleanly how the techniques are done.

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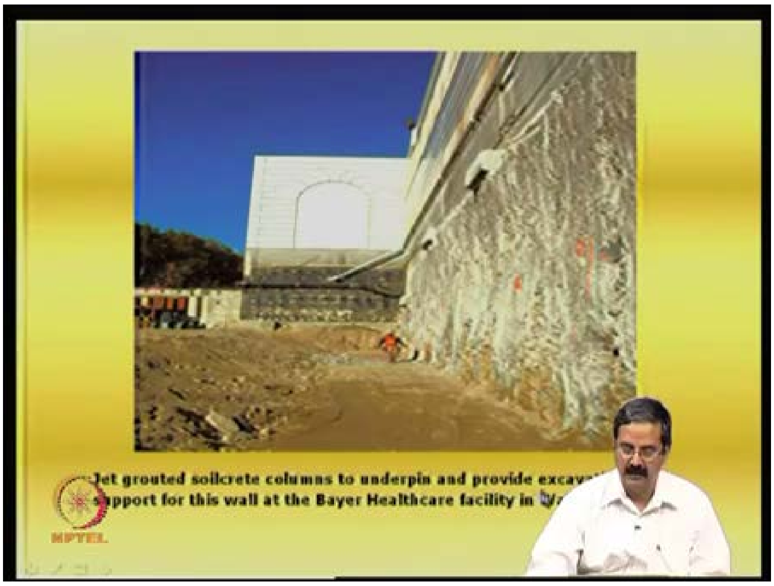

So, you can see that this way it is done. So, this is an example of a soil jet grouted soilcrete columns to underpin and provide excavation support for this wall at Bayer healthcare facility in Walpole area.

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Like you know, you have a building here, just next to that, it is not easy to go for an excavation like this; it is so tough. So, they used this method, which we just saw just now, see doing like this, and now, there is no stability issue at all. Jet grouting stabilization at another place, for the construction of new sewer tunnel, you know, at, the, another place. So, these are all, you know, the (( )) shafts, vertical shafts, and tunnels, you know, actually imagine that, you need to construct vertical shafts, and the tunnels, and all that, and stabilize the whole area, and it is not easy; you know, these are all very complicated structures, particularly design may be easy.

But during construction it is not very, it is, it is not very easy one, it is very challenging and one should really see that, whatever of the geotechnical issues, that they did not give difficulties in the erection of this facilities.

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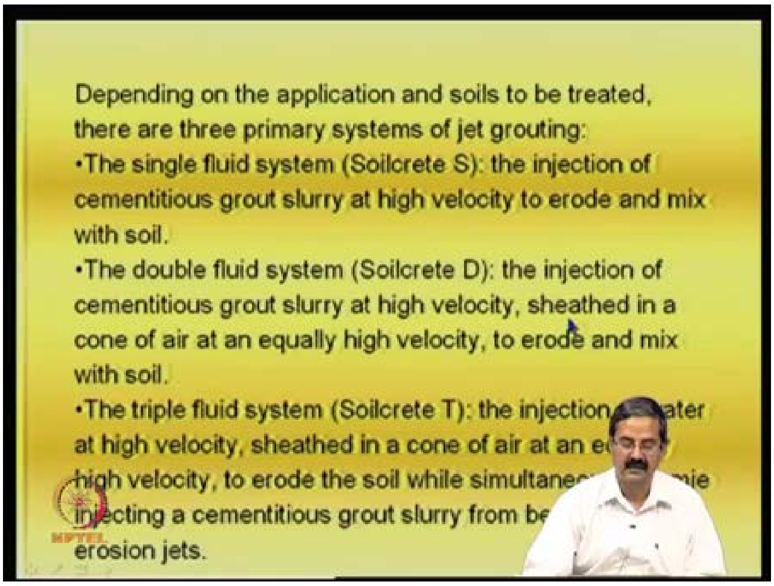

So, depending in the application and the soils to be treated, there are three primary systems of jet grouting. A single fluid system called soilcrete S. So, we have a single fluid, the injection of the cementitious grout slurry at high velocity, to erode and mix with soil; this was a single jet, I showed you that examples, I will show you again. Then double fluid system solicrete D, we call it, it is s is single, d is this thing; the injection of this cementitious grout slurry at high velocity sheathed in a cone of air, at an equally high velocity, to erode and mix with soil.

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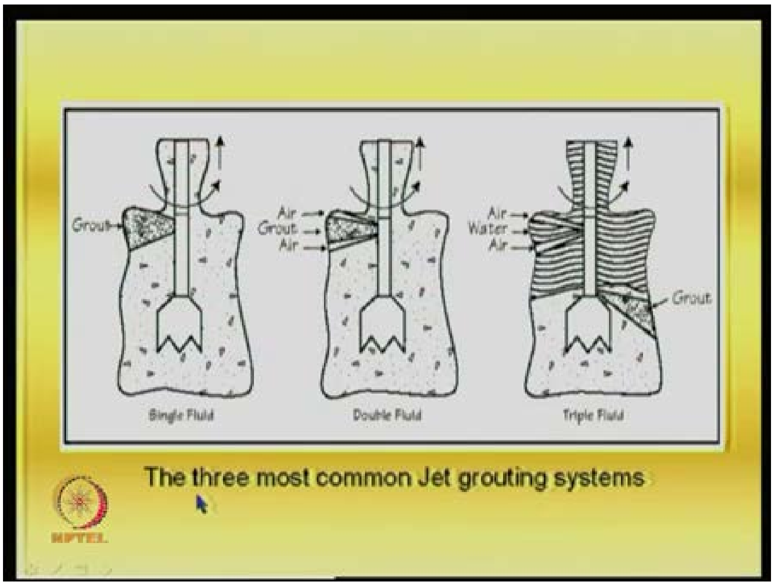

So, you have grout slurry plus air; then, you have triple fluid system, we called it soilcrete T, in which you have water plus, air plus the grout three of them coming together. It is a single fluid system grout plus air and all that term triple fluid system.

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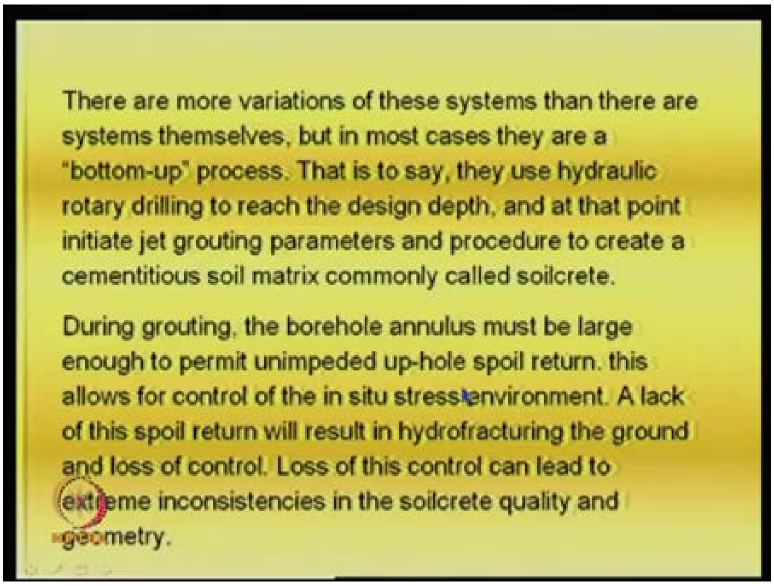

There are more variations of these systems than there are systems themselves, but in most cases they are a bottom-up process, like we try to do from bottom. This is to say that, they use hydraulic rotary drilling to reach the design depth, and at that point, initiate jet grouting parameter produce procedures to create a, a cementitious matrix soil matrix commonly called soilcrete.

During grouting the borehole annulus must be large enough to permit unimpeded up-hole spoil return, like you know, while in the annulus space, you know, when you are trying to that the spoil whatever is there, it should be able to come. This allows for the control of the in situ vertical stress environment. A lack of this spoil return will result in hydro fracturing of the ground and the loss of control. Loss of this ground control can lead to extreme inconsistencies in the soilcrete quantity and geometry.

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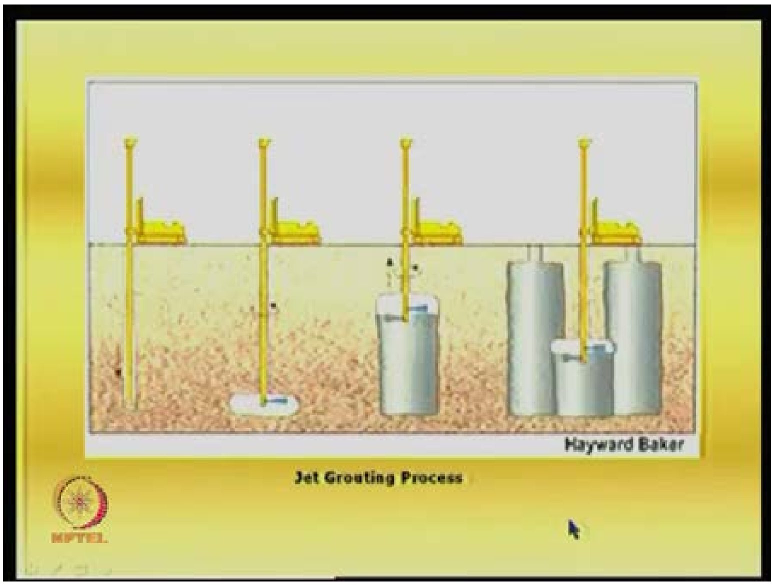

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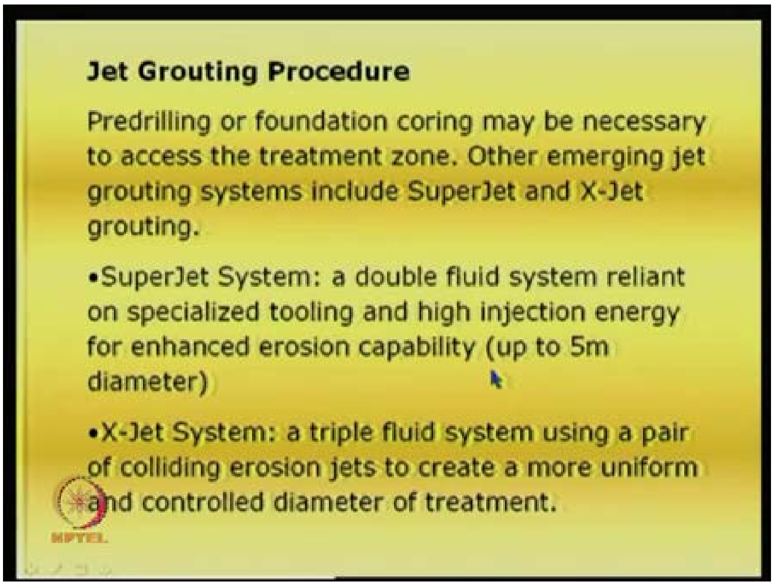

These are some issues, that they have like (( )) you can see that, jet grouting process and the way it is done single jet, it is like, you know, so this is how it is done. The predrilling or the foundation may be necessary to access the treatment zone, other emerging jet grouting systems include super jet or X jet grouting; there are some advanced systems as well in this case.

Super jet system, means, a double fluid system reliant on specialized tooling and high injection energy, for enhanced erosion capability may be up to 5 meters diameter, you know, see, they, what it is that erosion capacity, it is in terms of the diameter of the column that we are thinking. So, if you have a super jet system, it needs about five, it can create five meters diameter columns think of very, very soft soil Japan, you know or many places, of course, in India,, this is the way, that they have been doing it, like you know, we know some institutes in saga and other places soil is so soft.

So, they have to go for the advanced ground improvements techniques like this. X jet system a triple fluid system, using a pair of colliding erosion jets to create a more uniform and controlled diameter of the treatment. They have colliding jets here that is a difference. So, what I would like to show to you is that, the ground improvement has been a very versatile technique and has been proven to be suitable to many ground improvement applications and these are all the references that I have followed for this.

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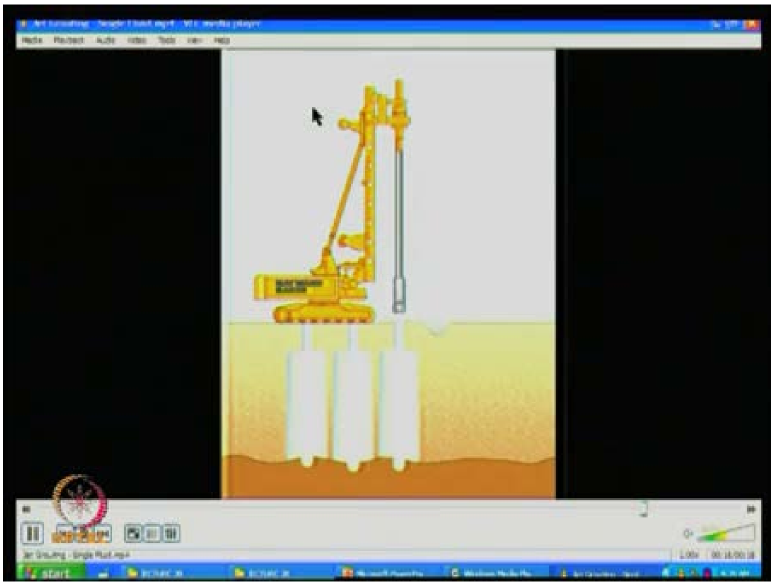

Before I just conclude, I think we should just have a look at some of the videos that we have done again. So that, it enhances your understanding here, like as I just mentioned, this is a single one, of course, as I just mentioned, this was done in India also by Keller and other group of companies, thus companies doing a business in these lines.

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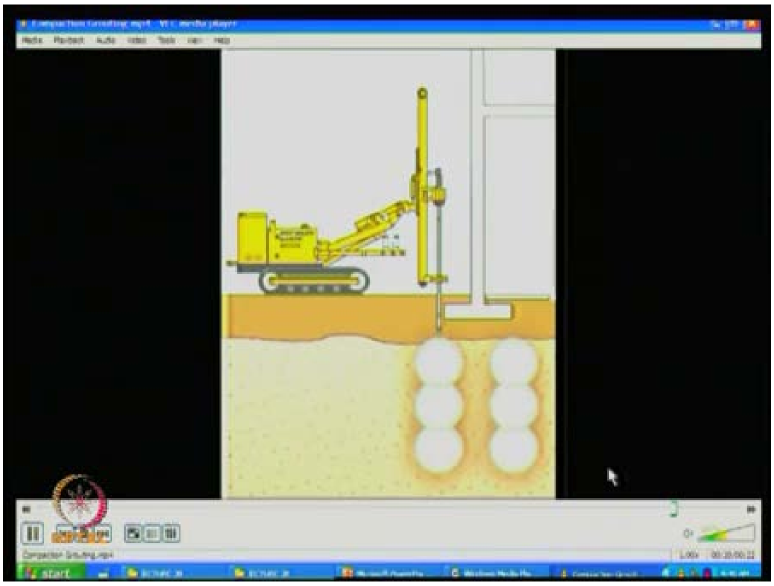

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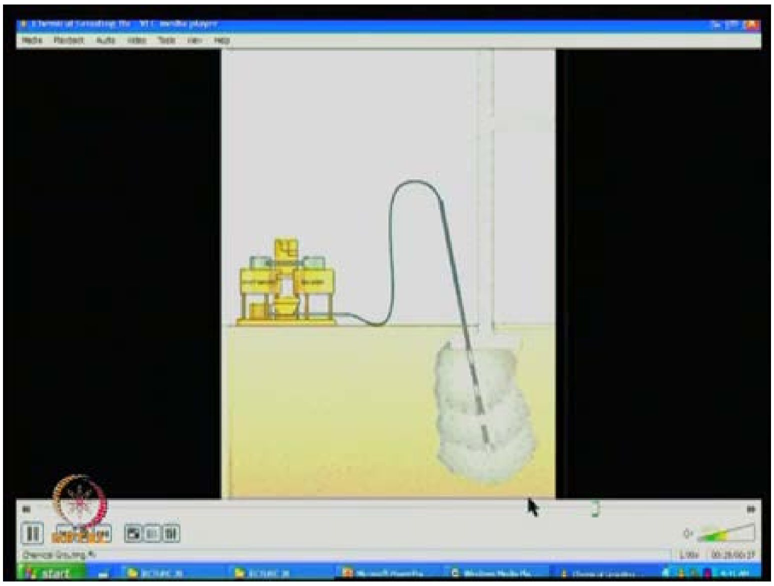

You can see grout and air coming; you can see that the spoil, you know, whatever is the spoil that can come out with that is also there. So, you have air water and the grout, you can also have a look at the compaction grouting.

The way it does things, here you can see that, it is somewhat slower as I just mentioned, the pore pressure, mobilization, dissipation, they are all quite important, like it has a a different way of, you can see that the. Thank you.