Ground Improvement
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Lecture 36
Grouting

Hi everyone. Let me once again welcome you to this course Ground Improvement and we are now in a new topic that is Grouting, before that we have completed seven modules. This is the eighth module is grouting and as I have mentioned in the very beginning in the introduction that we have several types of ground improvement techniques are available and they are not suitable.

One method is not suitable to each and every soil, depending upon soil type and work we have to choose a suitable ground improvement technique and we are going to start a new topic that is grouting and this grouting, today is the interaction and let me, grouting means exactly what actually?

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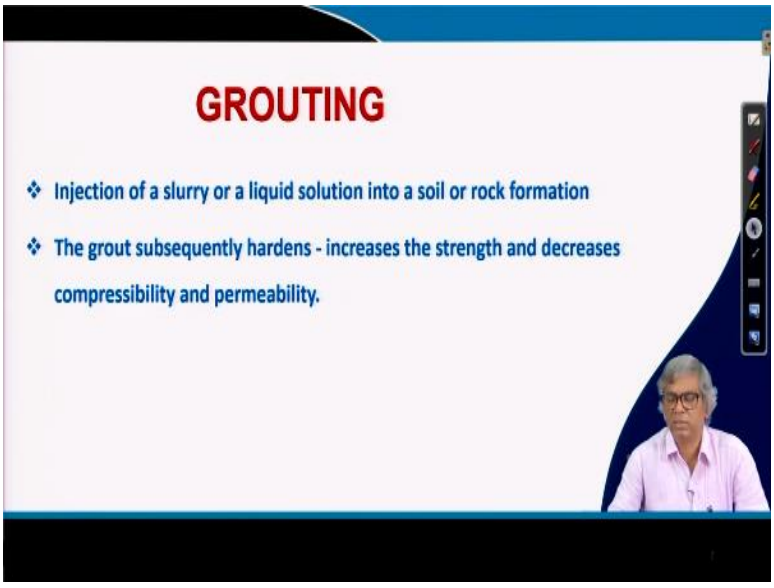

Grouting means that we inject certain some slurry, actually so injection of slurry or liquid solution into soil or rock formation, when the soil or rock, if there is a fracture rocked or if there is a loose soil and the strength is not enough then we generally inject the slurry and what type of slurry that will come later on and that slurry will be solidifying

subsequently and that will give you finally the better strength and stability of the soil or rock mass.

That is what the grouting means, injection of slurry or liquid solution into soil or rock formation and the grout subsequently hardens, increase the increases the strength and decreases the compressibility and permeability of the soil or rock mass, that is the objective finally to increase the strength or decrease the compressibility or control the permeability.

All those purposes actually we do ground improvement, here in the slurry form we inject in the soil where actually we want to improve and when we inject actually that it has some quality then it will be with time it will be solidifying and that that will give you the better strength and also it will give you the compressibility character, better compressibility characteristic, that means settlement or compression will be reduced.

This is the grouting by large and very definition or what is that you can say what is grouting if you say, this is the one we can use.

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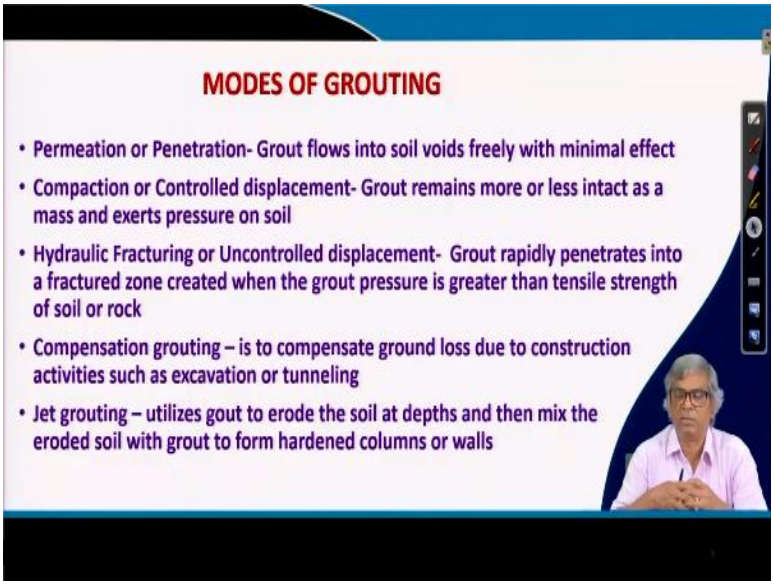

And modes of grouting, there are different ways grouting can be injected. Injection is the purpose that is there and you have to inject but how to inject and that is mode. First one is

the permeation or penetration, this is the one in this grout flows into soil voids freely with minimal effect, that means it will be not too much.

There will be between the interconnected void spaces there are some opening voids so through those voids it will just permeate, when the certain material is injected, that material will be with gravity mostly it will permeate and once it permeates and the liquid form and then solidify and then it will give you the desired the improvement.

Another is the compaction or control displacement grouting and under these grout remains more or less intact, that means we are keeping in a certain amount of grout in a particular area in a place and you inject and as a mass and we give pressure at that because of that pressure the surrounding soil will be compacted, so that means with the inject certain amount of slurry or that is grouting.

A grout material and with pressure and because of that it will not permeate much but because of the pressure and it will create some volume and when it will create some volume that means that some amount of volume will be decreased in the surrounding soil, so that way soil gets densified and also this after solidifying the grout also will be stronger materials, so all soil and grout together will form a ground material.

Then hydraulic fracturing or uncontrolled displacement, that is another so again grout rapidly penetrate into a fractured zone created when the grout pressure is greater than the tensile strength of soil or rock. With a particular pressure when we inject and the pressure will such that it will be whatever the shear strength of the soil or rock if it exceeds then it will create some opening or cracks and through that crack it will again enter and then when it will be solidifying.

Then it will be like a one rock mass, so or cracks will not be visible so both together will become a single mass which will have better strength. So that is the hydraulic fracturing, that means we are putting a liquid injection with pressure and when this pressure is significantly high compared to the shear strength of the soil then to or rock, fracturing will happen and through that fracture it will again enter and then it will be solidified and then soil will be densified.

And then compensation grouting, that is that means when there is a because of some activity there may be some ground subsidence to prevent that sometime we inject the grout and that that is compensating grouting, so this is to compensate ground loss due to construction activity such as excavation or tunneling.

When you make a tunnel and then sometime above the tunnel that may be because of subsidence, there may be some danger to prevent that we can inject the grout, those areas that means to compensate the volume loss so that way compensate and grouting will be working. I will discuss all of them one by one again in detail and with figure also in the next one, and jet grouting and jet grouting.

They are actually the by the term itself is quite clear, it will be, the grout will be injected in the form of grout and will cut first soil, surrounding soil and then with the soil and the grout will mix together and then it will form a solid and stronger material that is what, so utilizes a grout to erode the soil at depths.

That means by injection soil will be eroded and then mix the eroded soil with grout to form hardened columns or walls, so that is actually jet grouting. Whatever we have name we have mentioned what it exactly means we have explained.

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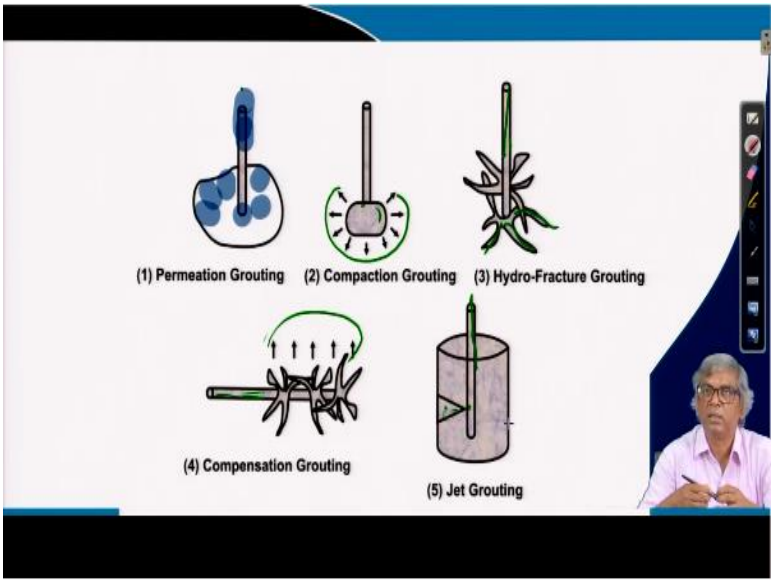

Now we can see those are shown in the schematic diagram. This is the permeation grouting, here in this, through these, particular this one, through these grouts will be entering and then when it will come here because of that void spaces through the interconnected soil, this will be your, it will be thoroughly, it will be spread surrounding area and by that way the certain area will and then when it will be solidified then certain area will be densified.

Whereas in these, whereas in the compaction grout you can see with pressure this much amount, initially it was soil, his much amount of compaction, the grout is actually with pressure is forced and injected so that much volume will be reduced in the surround soil, so this, this surrounding soil will be densified because the same amount, same volume will be reduced in the soil and volume reduction the soil means densification.

Densification means better strength and lesser compressibility, that it will be ground improvement will happen. And here is a hydro fracturing, you can see here through this again the grout material is injected and with pressure and suppose some cracks are formed like this and through these cracks grout will be entering and when it will be solidified then again, the cracks will not be there. Two masses will be together and they will be, they will form a stronger material.

Similarly, here at the compensating grouting suppose, this is some tunnel is made and then from the above soil there will be tendency to subside, downward because of that from here around the tunnel we can inject grout and that is the compensation grouting. And jet grouting you can see here through this tube, it will be there through narrow opening, the jet will be in the form of, and jet will be given.

And then if I all around it can then this much volume, like a cylindrical cut volume will be created and soil will be eroded and then eroded soil will mix with this grout and then finally this is a solid cylinder, stronger cylinder will form, grout and soil mix and that will act as a stronger material compared to whatever it was there before. This way the ground improvement can be done.

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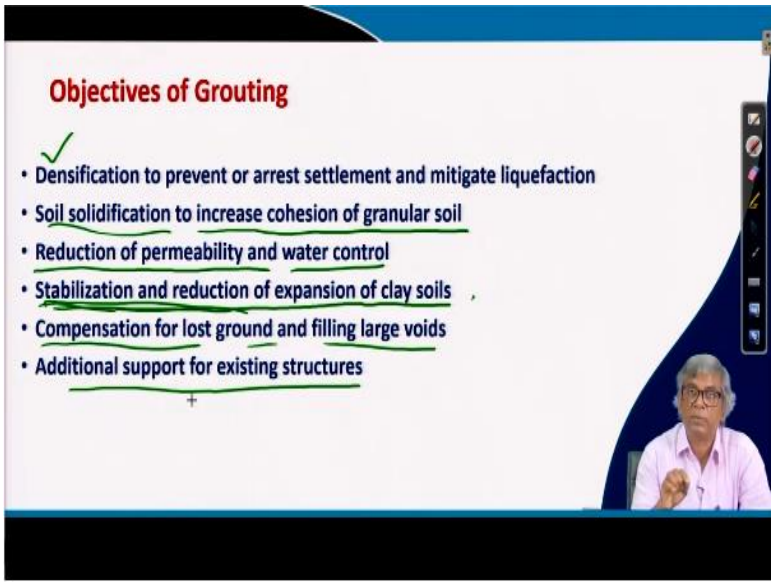

Let me go to the next one. Objective of grouting, there are like any ground improvement, whatever there will be definite purpose here a number of objectives are there and you can see here it is listed like previous any ground improvement techniques that densification is one of the, densification to prevent or arrest settlement and mitigate liquefaction.

If there is a loose soil and then that it will have tendency lesser shear strength, more settlement and also there is a chance of liquefactions, all three can be prevented if the densification is done by using grouting. Then soil solidification to increase cohesion of granular soil. When the soil grains are in the loose form and then through that if you inject the grout and then it will become a solid mass and that way it will give you better strength then reduction of permeability and water control.

Many soils will have, will show the application later on how it is used, through the soil that in some hydraulic structure we generally do not want water to flow through the main structure, then actually it will create some danger in the future so to prevent you have to minimize the water flow and so to reduce that generally this permeability, that grouting can be used to minimize or to reduce the permeability and once reduce the permeability then flow will be arrested, so that is another.

Stabilization and reduction of expansion of clay soils, the expansive soil again with seasonal variation when come in contact with water and when dry they sometimes swell and sometimes sink, that soil can be sometime treated with grout and then it solidified then it may not have reaction with water and that way it will be ground will be improved, then compensation for lost ground or filling large voids.

Whenever this will happen like we have given example of tunnel in the previous slides and additional support for existing structure, that can be I will show you that when particular existing structure sometime suppose one side is settling more compared to other side and then there will be some distress in the, damage in the structure, to minimize the damage or repair the building sometime we can do some activity below the foundation and perhaps the grout is one of the best one.

Without disturbing the original structure, we can treat the below ground, ground below the foundation and finally stable the structure, that is again another additional support. So that means by injecting the grout we provide additional support to the structure, so these are various objectives of grouting.

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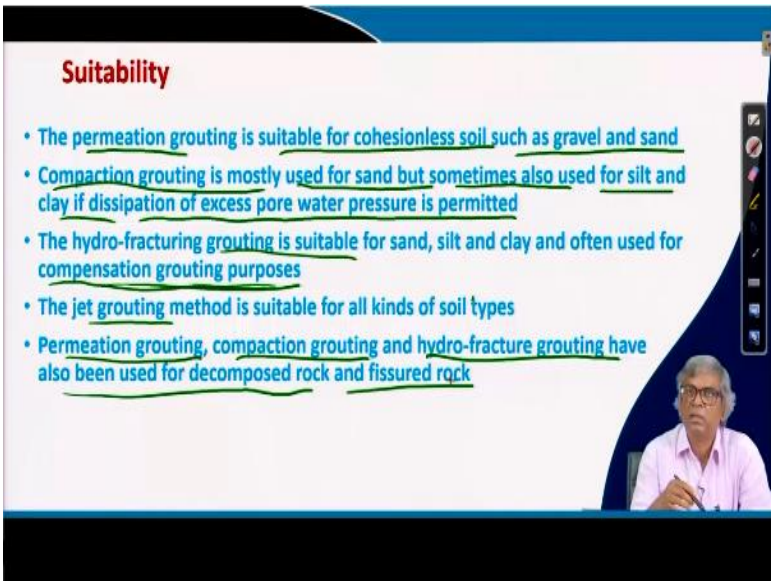

Let me go to the next and then suitability, where actually can be used. Different modes of grouting we have mentioned, all modes again not applicable for all types of soil, there are

some applications you can see that permeation grouting is suitable for cohesionless soil such as gravel and sand, when there is a gravel and sand that cohesion will be less and the particles are loosely present.

To create bond, we can inject grouting in the form of permeation grouting, because it has large voids if I pump or inject immediately it will flow within some area with gravity itself and then with solidification it will give better strength. Similarly, compaction grouting is mostly used for sand but sometime also used for silt and clay if dissipation of excess pore water pressure is permitted.

That see sand why it is not use clay, suddenly if you apply pressure and then excess pore pressure will develop and that creates some problem, because of that generally the compaction grouting, that means we inject grout with pressure and create some vacuum and that same amount of volume will be reduced in the soil mass, that can be easily done in the sand and silt, clay also can be done but if I do suddenly like this then there will be excess pore water pressure developed, we have to have some arrangement to dissipate of pore waster pressure that is what is mentioned here.

Then last one, the hydro fracturing routing is suitable for sand, silt and clay and often used for compensation grouting purpose. whatever comparison grouting so that is what that area hydro fracturing is done for compensation purpose, that is what it is mentioned here and jet grouting method is suitable for all kinds of soil types, of course gravels and all may be difficult but otherwise sand, silt, clay for anything we can by injection we can erode the soil initially and then mix with grout and then grout column can be formed which can be much stronger than the actual ground soil.

That is the one, then permeation grouting, compaction grouting, hydro fracturing grouting, has also been used for decomposed rock and fissured rock. Rock generally a stronger material but when it is a decomposed rock, that means original rock is decomposed in the almost in the soil form and disintegrated which is loose and also fissured, when there are number of cracks because of the cracks actual strength will not be realized.

To improve that sometime all sorts of grouting, anything like permeation, compression or hydro fracturing anything can be used all that that type of rock, these are by and large the different types of grout can be used for improving the soil depending on the situation and requirement.

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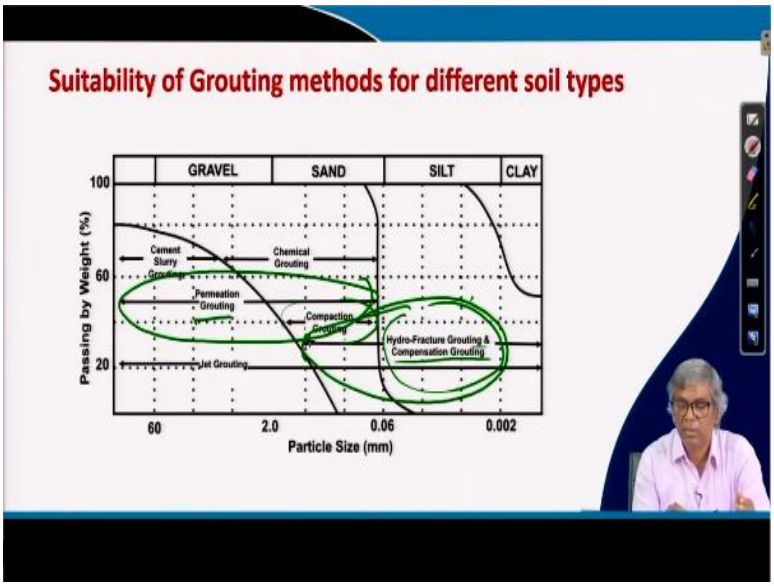

Let me go to the next one, and suitability as we have mentioned already and this figure also very clearly indicated here, and you can see there are different types of gravel, sand, silt, clay in this vertical, in this scale it is mentioned and there are three zones it is divided. If it is in this zone the soil is then hydro fracturing grouting and compensation grouting is suitable, and in fact hydro fracturing and compensation grouting will be applicable from here to here, that means sand and silt, clay everywhere it can be there.

Whereas compaction grouting you can see only in these zones, if the soil is in this zone, then compaction grouting will be there and then permeation grout you can see from sand to gravel, sand to gravel so you can see from, if it falls in between the soil classification if you do and if it falls in between any zone that means you draw the grain size if comes under anywhere then permeation grouting can be done.

Similarly, jet grouting you can see whatever will be the, if that is from the side you collect the soil and drew the granule size distribution wherever the grains, whatever may

be the grain size distribution curve you can see the jet grouting is applicable over the entire range, whereas permeation grouting is applicable only within this zone and hydro fracturing is only will be in this zone.

like that so these graphs actually or this chart gives you some sort of guidelines, that means you have a site and you need to do grouting to as a ground improvement technique and then depending on the soil what type of grouting will be used so that you will give you the guidance, that it will give you some guidance this graph.

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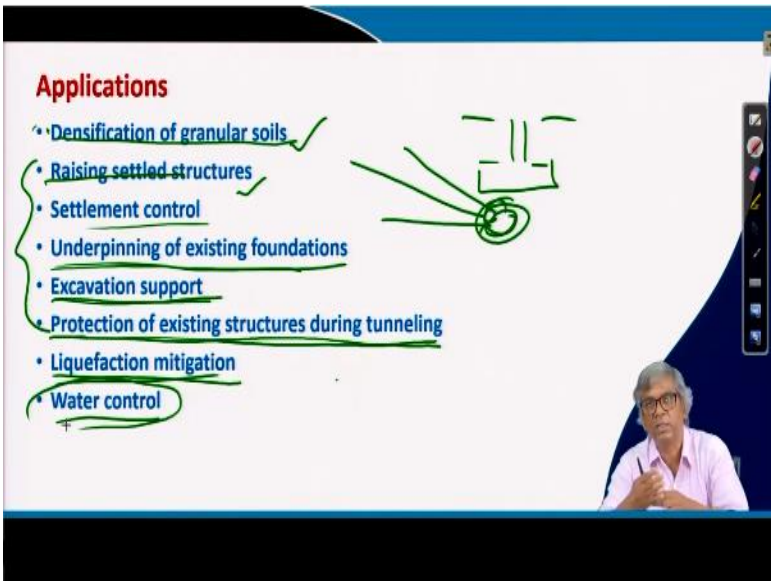

And then application, so again application is mainly ground improvement but there are many different types of application you can see, densification of granular soil can be done, then raising settled structure, I will show some figure later on, that suppose some footing is there and it is settling we can inject, we can inject grout here and we can lift the position, that I can tell you some case study also but anyway I am not planned that one, so whatever I have planned let me talk, I may discuss that one separately.

Some of the case studies where by using grouting this type of repair or renovation is done. Then raising settle structures, that means when structure is settling that can be raised by injecting grout, then settlement control, obviously that is very important because once you densified then settlements will be restricted, then underpinning of

existing, this is they are all underpinning that means below the existing structure whatever activity will do that the underpinning existing structure.

Then excavation support, protection of existing structure during tunneling, then liquefaction mitigation, water control, that means reduction of permeability. These are the different ways, ground improvement generally at the beginning we have mentioned that the increase in shear strength, decrease in compressibility and reducing permeability, so these are actually in different ways though we have mentioned, the objective is that only somewhere we want to increase shear strength.

Densification of granular soil means this is the increasing shear strength and raising settlement, settlement control, existing foundation and excavation of support, they are all settlement control and protection of existing during tunneling, liquefaction mitigate these are water control that means reduction of permeability, these are all by and large the three different categories we can mention but otherwise they are out of these three, either increasing shear, strength decreasing compressibility and decreasing permeability.

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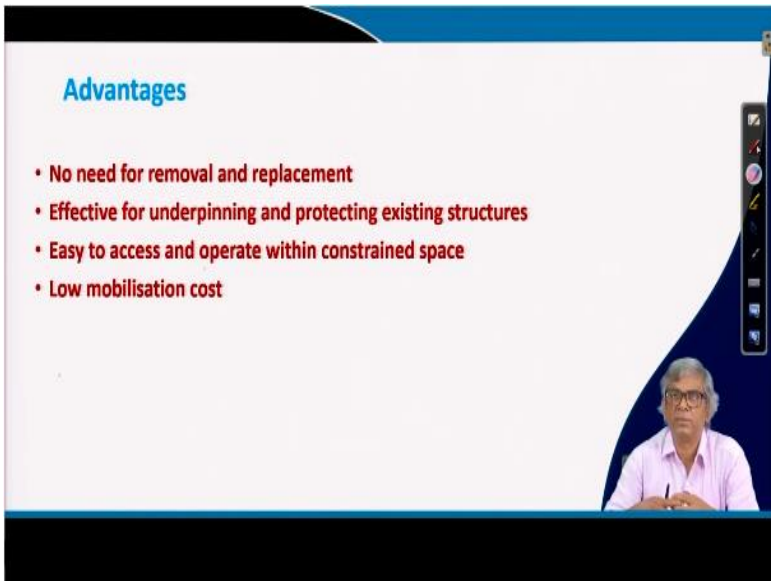

And what is the advantage? There are each and every ground improvement technique there will be some advantages, some disadvantages and here if you use grouting there no need for removal and replacement, obviously that so there are some ground improvement

techniques where we excavate the poor soil replace, good soil, here that activity is not there.

Effective for underpinning and protecting existing structure, that is the very important use of grouting, underpinning work and protecting existing structure as already I have mentioned that after constructing any building or the structure and then we may find that it is settling more than the expectation and it is causing some damages to the structure then in that case we can do underpinning activities and to arrest that type of settlement.

And then that is very effective, without any excavation simply inject that is the advantage and easy to access and operate within constant space, very smaller area is required and anywhere it is required we can move and then we can do the activity. And low mobilization cost, equipment is not too big, as a result we do not have huge mobilization cost as a result you may have cost effective also overall. These are all advantages.

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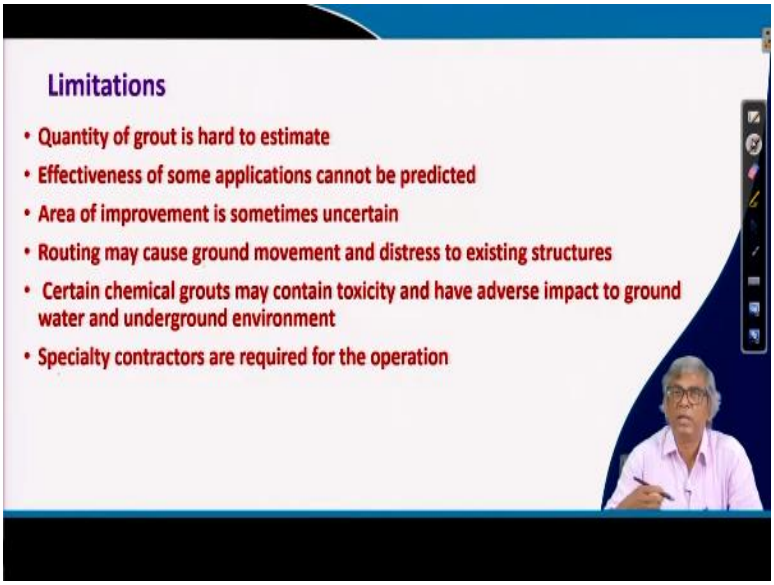

There are some limitation of course, this sometime when you plan for a grouting in a particular project and whether you do permeation grouting or compaction grouting anything very difficult to estimate the quantity, though we do some estimate but quantity of grout is hard to estimate because sometime it will be taking much less than it is expected or something it will take much more than it is expected but though we do some

estimation, so but it is difficult sometime and effectiveness of some of the applications cannot be predicted so that is another disadvantage.

And area of improvement is sometime uncertain, when you are doing permeation grouting or compaction grouting how much it will be really will be that very difficult to ascertain and then grouting may cause ground movement and distress to existing structure, and certain chemical grouts may contain toxicity and have adverse impact to ground water and underground environment.

Whatever grouting material you use sometime it have toxicity and because of that ground water if it mixes with then it will cause some problems, this is also a very serious limitation for this and specialty contractors are required for the operation, sometime grouting some special contractors will be required otherwise this will have some technique and of course specialty person and a skilled person and special contractors will be required with some facility.

That is these are limitation so major limitation is grout estimation is one difficulty, another is that toxicity is a problem and this is special contractors is required, these are all by a large the limitation, major limitations.

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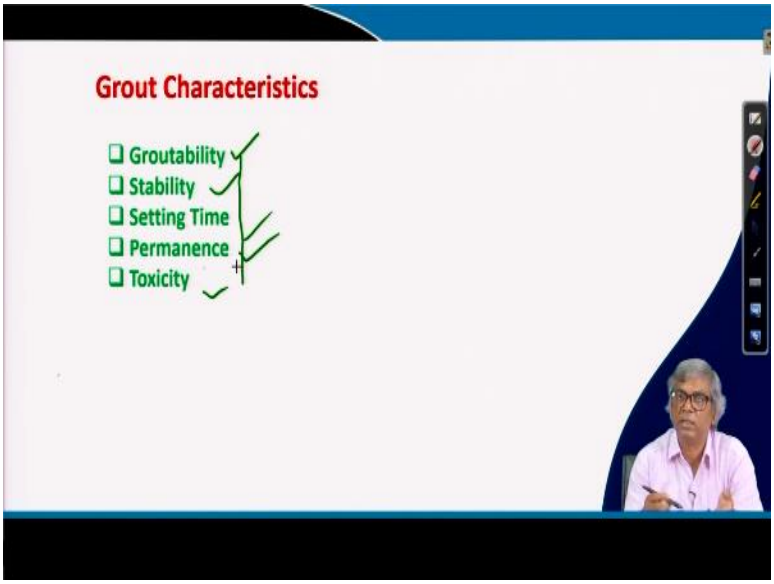

Then grout characteristics, there are grout characteristics will be that means whether grout is good, bad and that some characteristics should be there, that characteristics will be measured by there are number of parameters, one is a groutability and then stability, then setting time, permanence and toxicity.

These are the things so particular grout you selected then what is the grout ability that to be estimated, stability estimated, setting time to be estimated, permanence to be estimated, toxicity to be estimated and that will be the characteristics of the grout, so depending upon the situation you have to apply accordingly.

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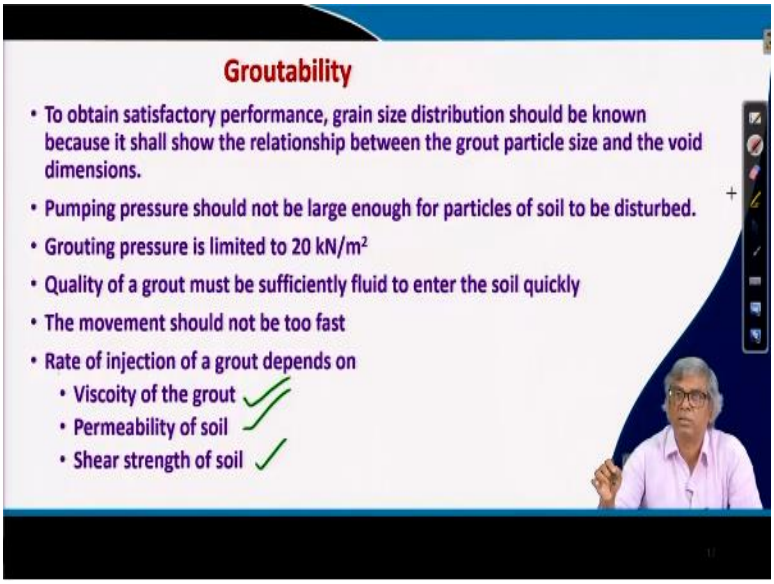

That means to know the grout ability grain size distribution very important, as we have mentioned before, then to obtain satisfactory performance, the grain size distribution should be known because it shall show the relationship between the grout particle size and the void dimensions.

Until and unless you determine the grain size distribution, then actually whether it is grout able or not, because of that we for silt and sand we use something, for clay you use something, gravel we use something, grain size distribution is very important to know the grout ability.

And then another thing is a pumping pressure should not be large enough for particles of soil to be disturbed, for injection of course, some pressure will be required that pressure should not be so much that the soil particles will get disturbed heavily, that is another thing actually. Grout ability means if you have a high pressure obviously the more grout can be injected but with high pressure is you have to have the pressure in such a way that the minimum disturbance in the soil will be there.

And grouting pressure, if I consider that generally routing pressure is limited to 20 kilo Newton per meter kPa, 20kPa, more than 20kPa generally should not be used and quality of grout must be sufficiently fluid to enter the soil quickly, that is another thing, if it is too solid type then that is not a good to injectuality of grout must be sufficiently fluid to enter the soil quickly, so that is another grout ability criteria.

The movement should not be too fast, if the grout material move fast then automatically it will take away the soil particles also, instead of filling the voids it will create voids, so that is actually the movement should be should not be too fast. And rate of injection of grout depends on again there are number of things you can see, the viscosity of the grout and permeability of the soil and shear strength of the soil, so based on these three how the injection rate that actually will be fixed by.

The grout ability you have to study this, whether the particular grout, whether groutable or not ah that to be assessed before selecting that.

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And a desirable property of grout and now this you can see it should have a typical some viscosity and that viscosity again suitable viscosity, that means whether it is large or small or high or small or low. High viscosity for coarse grained and moderately permeable soil, whereas low viscosity for fine grained soil and low permeability soil.

And another desirable characteristic is correct setting time, if its take too long or too short that will not be suitable, it should be have appropriate setting time, the maximum volume with minimum weight, if the grout another important characteristic that should have more volume and minimum weight, because if it is more weight ultimately soil unit will increase that will like soil unit weight is more it will create many problems which I will discuss later on.

Then again, another thing is the strength grout, when it solidifying then it should have certain strength also and it could be stable and should be durable. This is the required ah property or desired property of the grout, that means when you will be selecting you will be examining those aspect.

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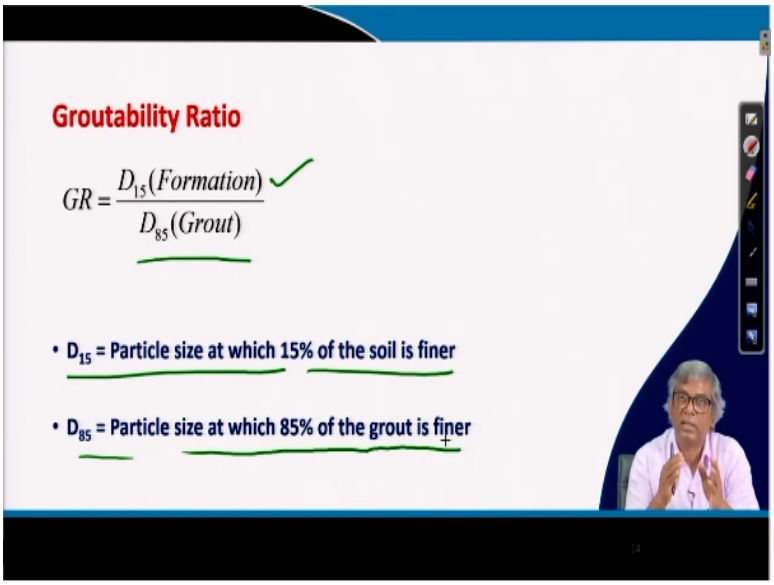

And then groutability ratio, this is actually, first of all whatever grout ability we have explained before that is a qualitative, different ways we have explained but here when you are going to execute grouting, then you have to compute the grout ability ratio and that is given grout ability ratio is given by D_{15} of formation by D_{85} of grout, D_{15} of formation means the existing soil and for that D_{15} to be estimated.

$$\textit{Groutability Ratio}$$

$$GR = \frac{D_{15}(Formation)}{D_{85}(Grout)}$$

$$D_{15} = \textit{Particle Size at which } 15\% \textit{ of the soil is finer}$$

$$D_{85} = \textit{particle Size at which } 85\% \textit{ of the grout is finer}$$

At D_{85} of the grout, D_{85} of the grout material and that to be determined, that that will give you some value and again that value if it is below this are greater than this depending on that whether groutable, not routable that I will discuss later on maybe. Right now, I will just be defining this in the grout ability ratio where D15 means particle size at which 15 percent soil is finer.

D_{85} particle size at which 85 percent of the grout is finer, so these two things give you a value and the based on that value whether the soil is groutable or not that to be

determined, that is what is the guideline that I will be discussing in the subsequent lecture somewhere later on and with this I think I can close here today for this part.

Various aspect of routing we have explained here and particularly main thing which we have discussed mode of the of the grouting and suitability, advantage, limitations and then grout characteristics and grout characteristics there are number of things are there we have discussed one or two, I will discuss rest of the things in the subsequent lecture, thank you.