Principles of Construction Management
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Lecture – 30
Quality control of grouts in ducts of post tensioned PC members

[FL] and welcome once again to the series of lectures on Principles of Construction Management.

And In this module we have been talking about the process and also study in depth or discuss issues relating to quality control in those processes. This is basically to help us generate an insight into developing new test methods if it is required interpreting test methods the provisions the details that are part of the test methods and finally, if it is required to develop specifications. Now for the discussion today we will talk about quality control of grouts in ducts of post tensioned prestressed concrete members.

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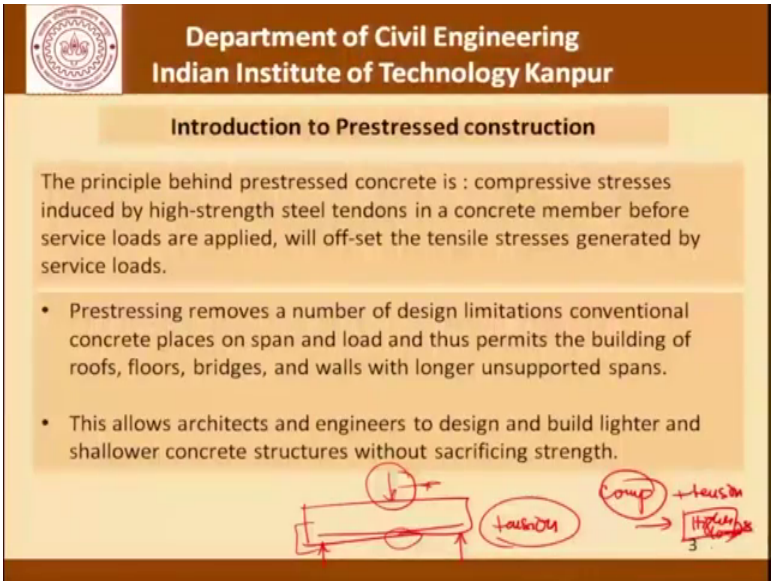

Now, is an introduction to prestressed concrete the principle behind prestressed concrete is compressive stresses induced by high strength steel tendons in a concrete member before service loads are applied will offset the tensile stresses generated by service loads. Basically the principle is very simply understood in the contest of a beam that if you have a beam which is like this let us say it is a reinforced concrete beam which is subject to a load, the part here is subjected to tension.

Now, before the application of this load which is the service load, if this part below the neutral axis which is otherwise subjected to tension. If we could introduce compression in that part then the application of the service load will induce tension and finally, the beam will be able to carry higher loads before tensile stresses become evident and the beam cracks.

So, the idea of introducing this compression which is called precompression before the application of service loads, that is what is at they root of any kind of prestressed construction. Now what this prestressing does is to remove a number of design limitations which conventional concrete places on span and load and permits the building of roofs floors bridges and walls with longer unsupported spans. And allows architects and engineers to design and build lighter and shallower concrete structures without sacrificing strength. So, we are not getting into the details of prestress construction it is important to understand this only from the point of view of understanding the basics of prestressing so that we understand a little bit better the whole concept involved in grouting and so on.

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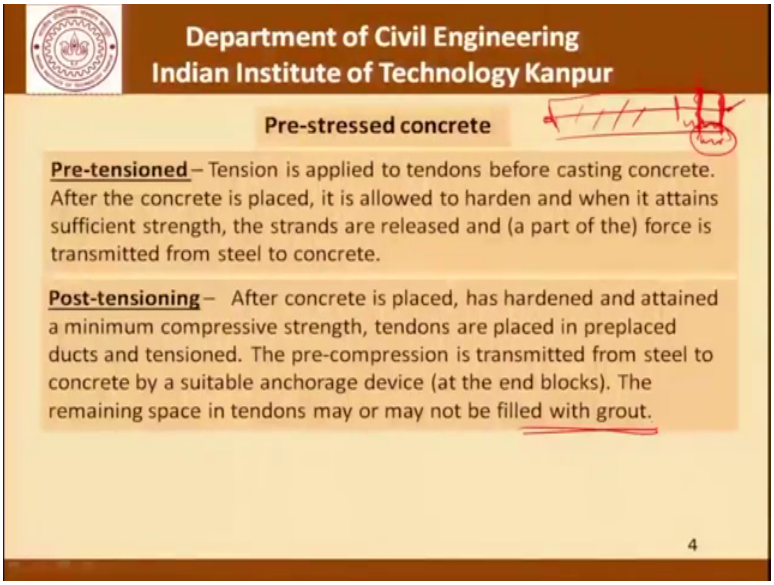

Now, prestressing is done in 2 ways. One is called pre tensioning, where tension is applied to tendons before casting the concrete and after the concrete is placed it is allowed to harden. And when it attains sufficient strength the strands are released and a part of this force is transmitted from steel to concrete. Typically railway sleepers and so

on are done using this technology. Basically the idea being that if we have this is the original length of a steel element the tendon we extend it by this much cast the concrete here while holding the steel in the deform position. And after this concrete as hardened we release the tension in the steel we release the grip that is holding the steel at that particular place. What will happen is that the concrete which was cast at this position will now come to this position the steel which was here will also come to the same position and concrete would experience this amount of compressive strength.

So, this is basically the idea of pretensioned prestressing. So, it is pretension because it is tension before the concrete is cast and it is prestressing because it is being done before service loads are being applied. As again pre tensioning there is the concept of posttensioning in which the concrete is placed hardens and after it has attained a certain compressive strength tendons are placed in preplaced ducts and tensioned. We will see pictures of posttension construction and then the whole process will become clearer.

The precompression is transmitted from steel to concrete by suitable anchorage device at the end blocks of the member. And the remaining space in tendons may or may not be filled with grout. This is where the discussion for today starts that is what is the quality control issues in case grouts are used to filled the meaning space in the ducts after the tendons have been placed.

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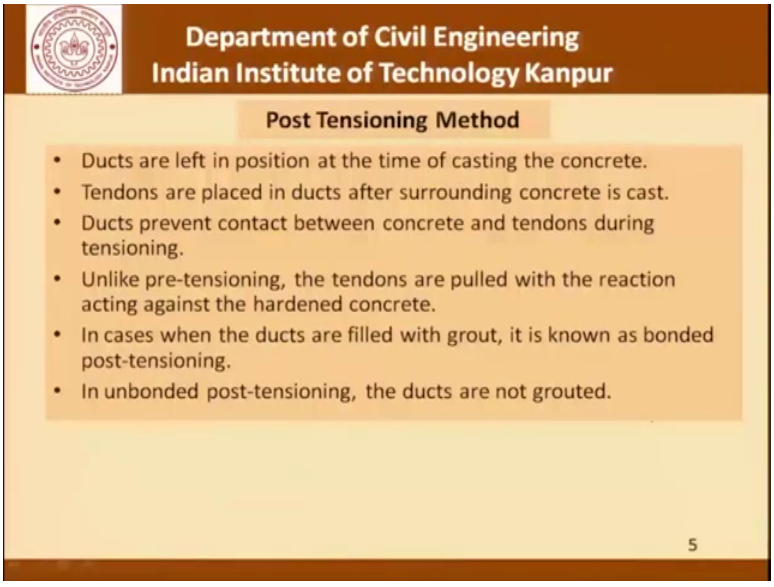

Let us try to understand the process of posttensioning one by one step by step. The ducts are left in position at the time of casting the concrete tendons are placed in ducts after the surrounding concrete has been cast these ducts prevent contact between concrete and the tendons during tensioning unlike pre tensioning the tendons are pulled with the reaction acting against the hardened concrete. And in cases when the ducts are filled with grout the whole process or the whole contraction is known as bonded post tensioning and against that there is what is called unbounded posttensioning where the ducts are not grouted.

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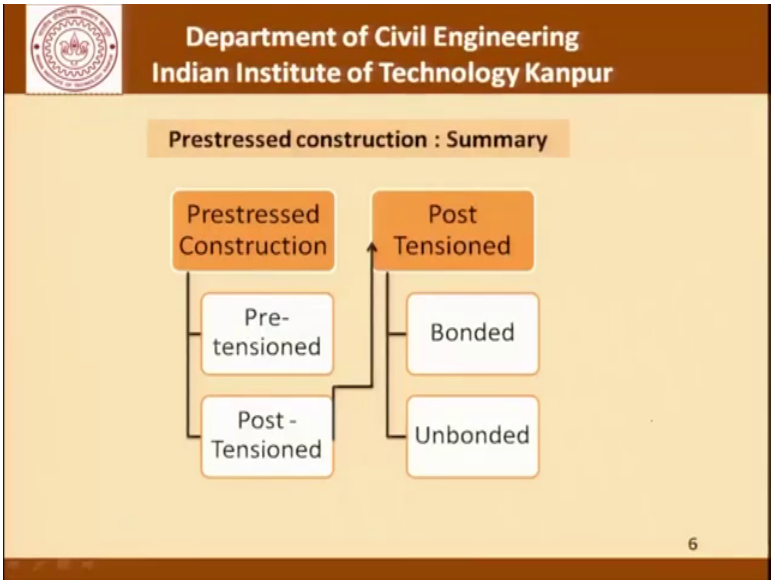

So, to summarise There are 2 types of prestressed concrete construction one is pretensioned and the other is posttensioned and within the posttensioned there is the bonded and unbounded construction. So, once we have this picture in mind we are ready to get started with our discussion on grouting.

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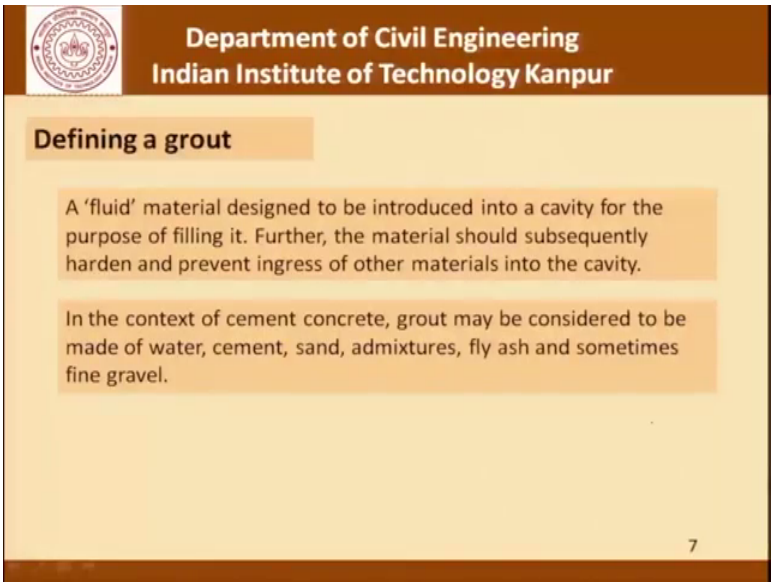

Now, defining a grout a fluid material designed to be introduced into a cavity for the purpose of filling it is; obviously, what is called a grout. Further the material should subsequently harden and prevent ingress of other materials in to the cavity. In the context of cement concrete grout may be considered to be made of water cement sand and admixtures fly ash and sometime very fine gravel.

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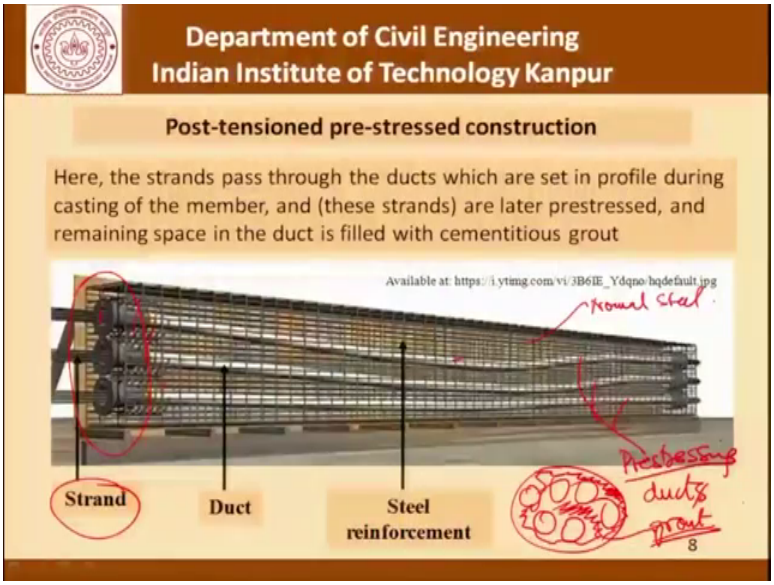

Now, this picture I think would make the whole process very clear. This shows how posttension prestress construction is done. The strands pass through the ducts which are

set in profile during the casting of the member and these strands are later prestressed. And the remaining space in the duct is filled with cementations grout this what is written here.

Now, what you can see in this picture is that we are talking of a girder which has reinforcement the way it is shown the reinforcement has 2 parts. One is normal steel reinforcement and the other is what is shown here and this is the prestressing reinforcement which is not present at the time of casting the concrete. So, this reinforcement cage is placed the way it is normally placed as far as concrete construction is concerned, and you would notice that these prestressing ducts which is shown here these are not straight they follow a certain profile. Now that profiling and so on is a matter of detail and a matter of prestressed concrete design, and we are not getting into that, but we must understand that these are not straight. And if they are not straight that raises certain issues as far as quality control is concerned.

So, we place these ducts inside the reinforcement cage then we cast the concrete around it. So, everything else here gets cast, then we put these strands or tendons into this duct and after this concrete as hardened these tendons are stretched or tensioned. And finally, let go. So, because of this letting go of the tensioned tendons this concrete beam undergoes compression. So, that is what I had explained earlier with the example of pretention prestressing. So, this is what we will get us posttension prestressing.

Now, having said that we will have the situation we will see clearer again that here is the prosection of the duct and we place certain strands or tendons here. And this space in between is what needs to be filled with grout if we are talking about bonded posttensioned prestressed construction. If we do not grouted then we get unbounded posttension prestress construction.

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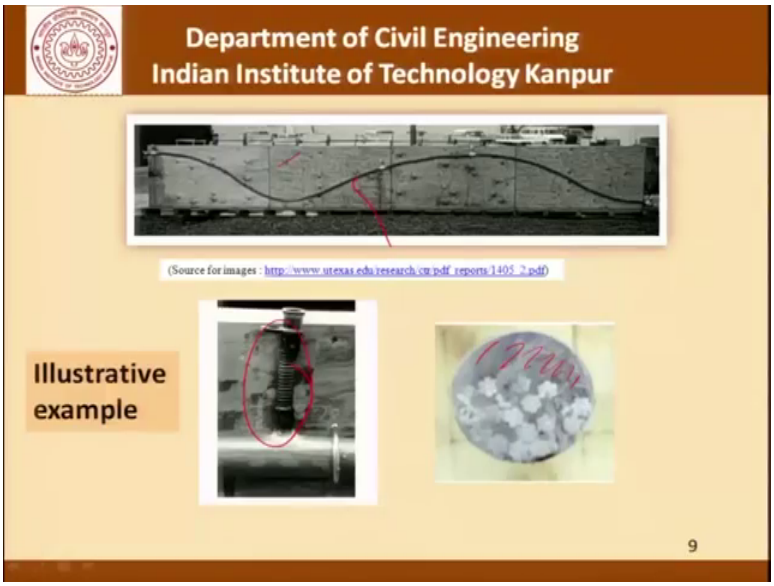

So, now this an illustrative example and we can see that this is the tendon profile is provided by the designer and this the concrete beam. So, the concrete has been cast the tendon will follow this shape because the duct has been provided in this shape and the tendon; obviously, because it going to be sorted in the duct will follow the shape. And if it has to be grouted then this what is shown here that is what the grout will be.

So obviously, we are talking of a situation where there are very small cavities or the passage for the grout is very, very narrow. Therefore, we cannot obviously, place concrete there, concrete means we cannot put any coarse aggregate there fine aggregate itself is a big issue because we may not be able to put even 2 mm or 3 mm kind of sand in it a certain cases of course, we put in some very fine sand fly ash and so on, is allowed to be used depending on whether or not the specifications allow it whether or not the kind of quality control parameters that we have that allows it and so on. So, this picture here is that of a vent and what is the vent how it works that is something which we will see subsequently.

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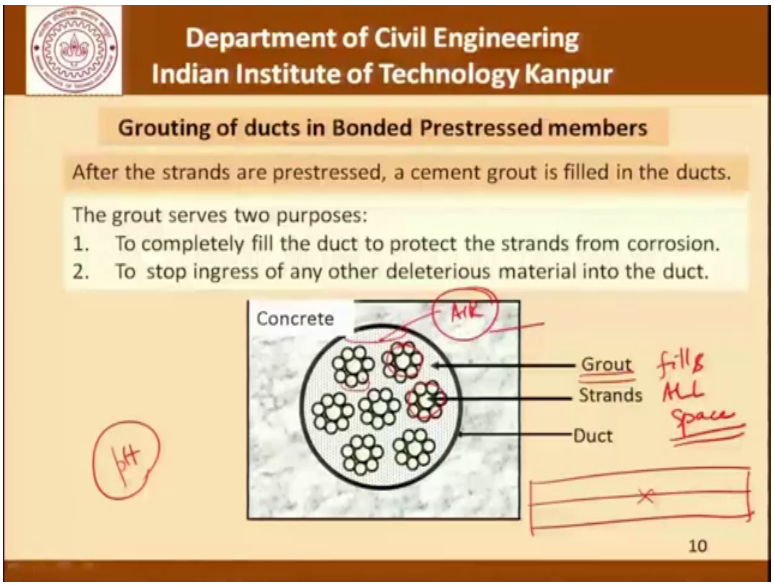

Now, grouting of bonded prestress members after strands are prestressed the cement grout is filled in the ducts this picture at the bottom is a schematic sketch of what I was drawing earlier. So, there is concrete here that is outside the duct, this is the duct casing this strands inside this and the grout which is feeling the remaining space in the duct between the boundary and the strands.

The weight as shown is looks very nice and it appears as if there is enough space for the grout to be moved, but in practice it is very difficult to ensure that grout actually fills all space which is inside the duct. We could be talking of several meters long beam and if we have a beam which has a certain kind of a profile it get which is not straight it is even more difficult for the grouts to be completed.

Now, this grout which we do serves 2 purposes. One is to completely fill the duct to protect the strands from corrosion. And second is to stop ingress of any deleterious material into the duct. Just imagine that if this grout was not there, then there is virtually air inside here and there could be ingress of deleterious materials including water. And that is the been as far as these strands are concerned and we could have onset of corrosion. Prevention of that corrosion is In fact, one of the prime reasons as to why this place has to be filled with grout. Of course, if you are providing cement grout we also know that the pH in the neighbourhood of these strands would become high and the strands would be protected against corrosion because of thermodynamic reasons and so

on that is something which we know from our understanding of durability of concrete reinforcement corrosion. And the other part of it is that by the shear non availability of free space movement of water chlorides and such deleterious substances is also stopped.

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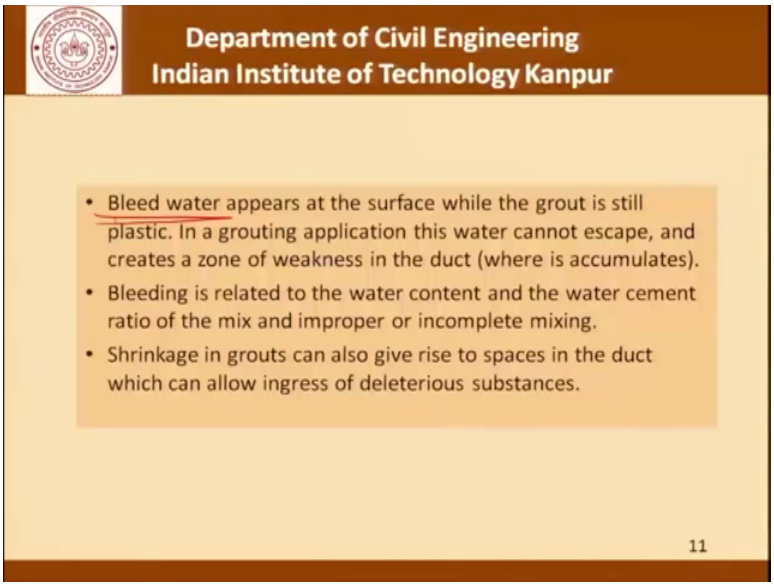

Continuing with our discussion let us try to understand now some of the issues which are involved bleed water appears at the surface while the grout is still plastic. In a grouting application this water cannot escape and creates a zone of weakness in the duct. So, we can imagine that after all there is a certain amount of water that bleeds to the surface of the grout.

Now, that water if it moves and accumulates here or accumulate somewhere at the bottom of the strand, that is not going to be able to escape and there is no way we are able to refill that gap. And that becomes a zone of weakness as far as we are concerned from the grouting point of view.

So, bleed water appears at the surface while the grout still plastics. So, in grouting application this water cannot escape and creates a zone of weakness in the duct. Bleeding is related to the water content and the water cement ratio of the mix and improper or incomplete mixing. So, one of the requirements; obviously, therefore, is that the grout that we use should have as little bleeding as possible.

Shrinkage in grouts can also give rise to spaces in the duct which can allow ingress of deleterious substances. We will see a schematic representation of shrinkage later on.

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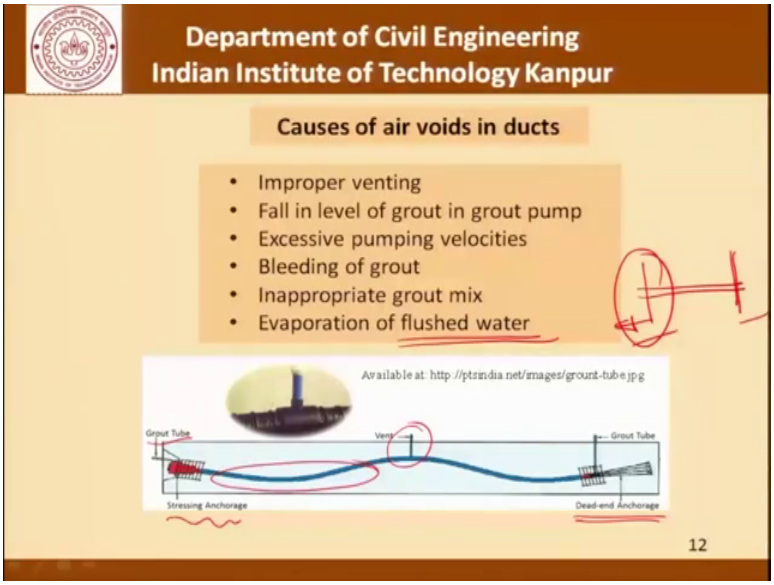

And let us move Forward and try to understand how we get air voids in ducts and avoiding this air voids is the prime concern as far as good quality grouting is concerned.

Improper venting now this here is a designated vent from where the air which is present in this duct escapes as the grout is pushed into this duct space. The venting is not proper they would be air voids fall in level of grout in the grout pump excessive pumping velocities, bleeding of grout inappropriate mix and evaporation of flushed water. We will see later on that before the grouting is carried out there is a flashing exercise which is carried out that is water is pushed through the duct the duct is flushed with water to clean any debri to get rid of any oil that will be sticking on to strands and so on, and if this water evaporates inside that would cause air voids.

In this picture we also see a stressing anchorages the grout tube and the dead end anchorage. So, there are 2 kinds of anchorages one is the stressing anchorage. And the other is the dead end anchorage; obviously, in this kind of a situation when the beam has already hardened the concrete in the beam is already hardened. What we do is keep one end fixed and try to have the a strands pulled by moving one. And so, there is dead end and there is the stressing end anchorage which helps us do the prestressing exercise.

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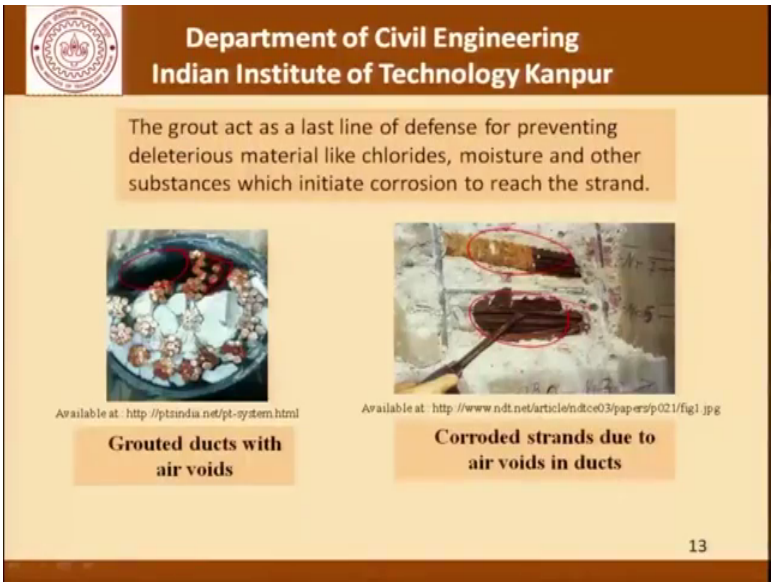

Now, the Grout act as the last line of defence for preventing deleterious materials like chlorides moisture and other substances which initiate corrosion to reach the strand. And here are pictures of what could go wrong we can see in the picture on the left hand side that there are places where the void has not reached. And if this happens of course, we will have corrosion in the ducts. And that is something which we want to definitely avoid.

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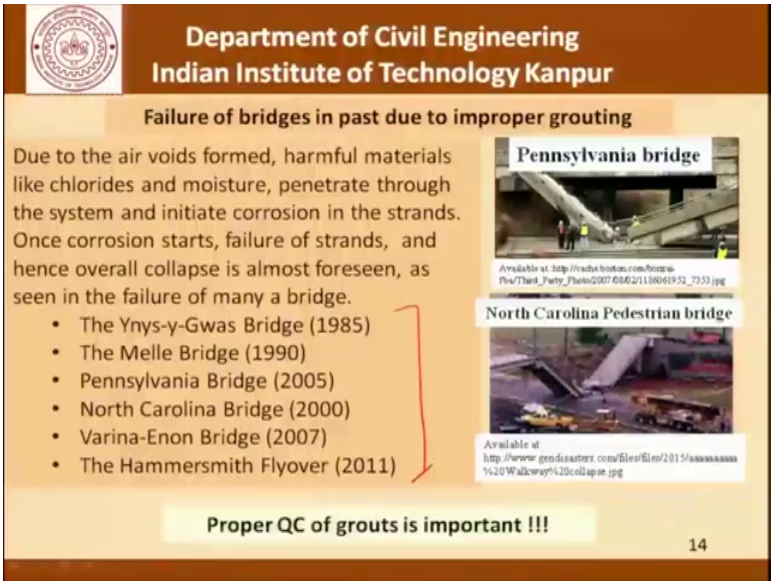

Now There have been reported failures in the past due to improper grouting this is the list of recorded bridges in flyovers which have known to collapse and the collapse is been attributed to corrosion in the strands which has been attributed intern to faulty grouting practices the quality control in the grout and therefore, we must be careful and ensure proper quality control in grouting. I invite you to take a look in the literature and find out more about the failure in these bridges.

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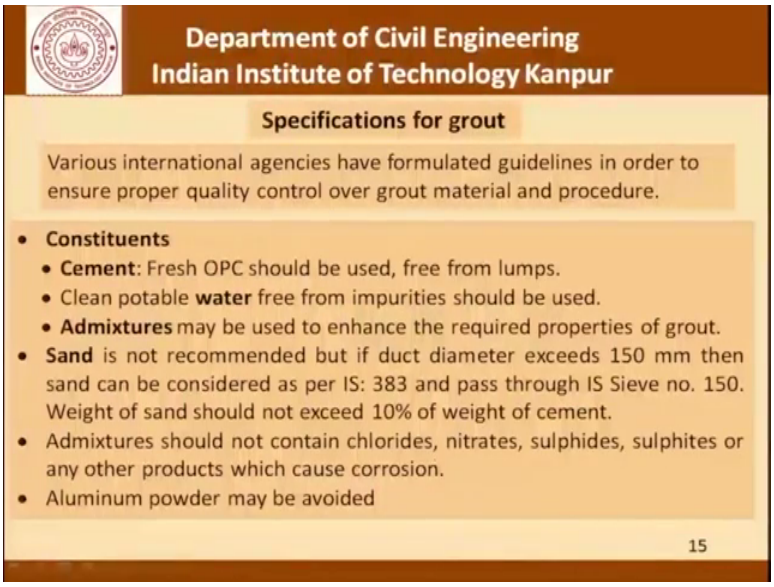

Now, let us come to specifications in grouting which will help us laydown on the ground rules and set standards for how good quality grouting can be done. Various international agencies have formulated guidelines in order to ensure proper quality control over grout material and procedure. And we have specifications for constituents which could be cement we should be fresh OPC free from lumps clean portable water free from impurities and admixtures which may be used to enhance the required properties of grout sand is usually not recommended, but if the duct diameter exceeds a one 50 mm then sand can be considered as per IS: 383 and that should pass through sieve 150 the weight of sand should not exceed ten percent of the weight of cement.

So, basically what we are saying is that whether or not sand should be used is something which the codes decide and that is where there is discretion. So, the practice in one country practice in other country practice at one side practice at another side these could be different. Admixtures should not contain chlorides nitrates sulphides sulphites or any

other products that could cause corrosion. And aluminium powder must be avoided because a long term implications of this use is not known.

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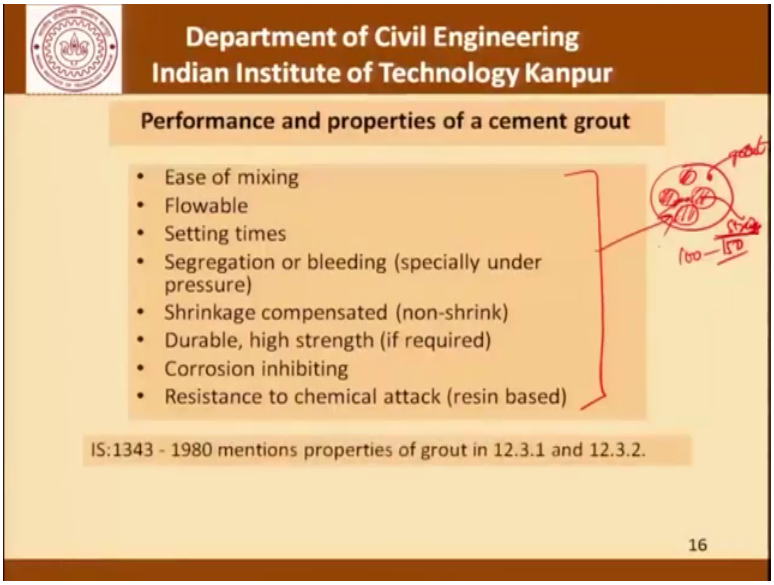

Now, coming to the performance and properties of a cement grout one thing is ease of mixing flow ability setting time segregation of bleeding especially under pressure. One of the issues that dogs concrete engineers and also important from the point of view of grouts is the fact that a lot of are flow ability test whether it is a slump test or it is flow table test slump of process for concrete flow and flow ability could be for concrete and for spaced or motor these test are usually carried out enough free space.

That is there is no obstruction as far as reinforcement is concerned that is not simulated except when you look at like the YouTube test or the l shaped test in the case of self-compacting concrete where there is an effort to introduce the motto of reinforcement. But coming to grouts the whole thing is that we are not pushing grout in a 100 mm or a 150 mm space. We are trying to push grout through very narrow spaces between strands. And once we apply pressure the kind of bleeding that happens in the kind of segregation that may happen, this narrow spaces may introduce segregation which may otherwise not be seen in a regular segregation or a bleeding test.

So, that is something which we need to be careful about and try to evaluate if possible. So, that is what we are talking about here segregation of bleeding especially under pressure. Shrinkage compensation non shrink grouts durability it could be measured in

terms of strength. Corrosion inhibition and resistance to chemical attack. These are the kind of things that come to mind when we are talking about performance and properties of a cement grout from the point of view of the fact that that grout is expected to afford protection to these strands. So, this is what is the grout and these are the strands with the grout expected to protect the strands these are some of the qualities in the grout which are expected.

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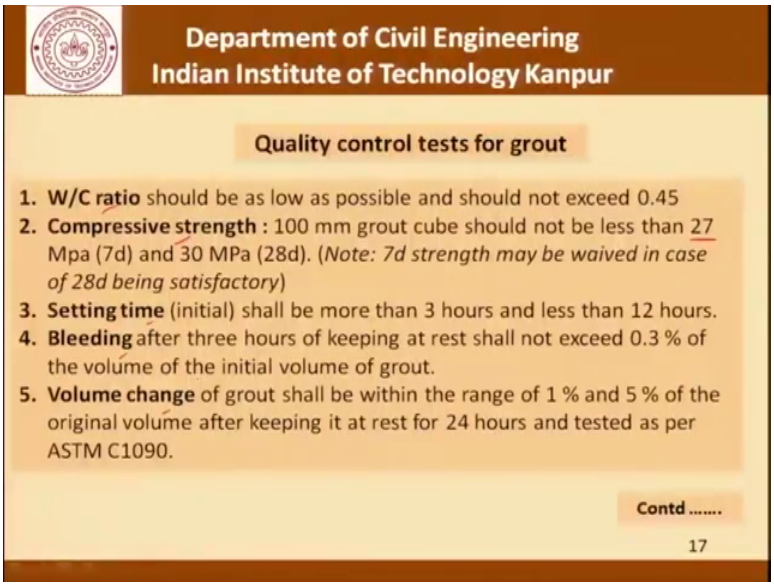

Let us try to look at this picture once again more quantitatively. The water cement ratio should be has low as possible should not exceed point four 5 the compressive strength using 100 mm grout cubes should not be less than 27 Mpa 7 days and 30 Mpa at 28 days note that the 7 days strength may be waived in case the 28 days strength is satisfactory. The setting time initial should be more than 3 hours and less than 12 hours bleeding after 3 hours of keeping at rest should not exceed 0.3 percentage of the volume the initial volume of grout volume change of grout shall be within the range of 1 percentage and 5 percentage of the original volume after keeping it at rest for 24 hours and tested as for ASTM C 1090. The point is that these numbers are not necessarily sacrosanct that these numbers could vary depending on one specification or another, but the point is that the water cement ratio compressive strength setting time bleeding and volume change are some of the parameters which help us define the quality of grout.

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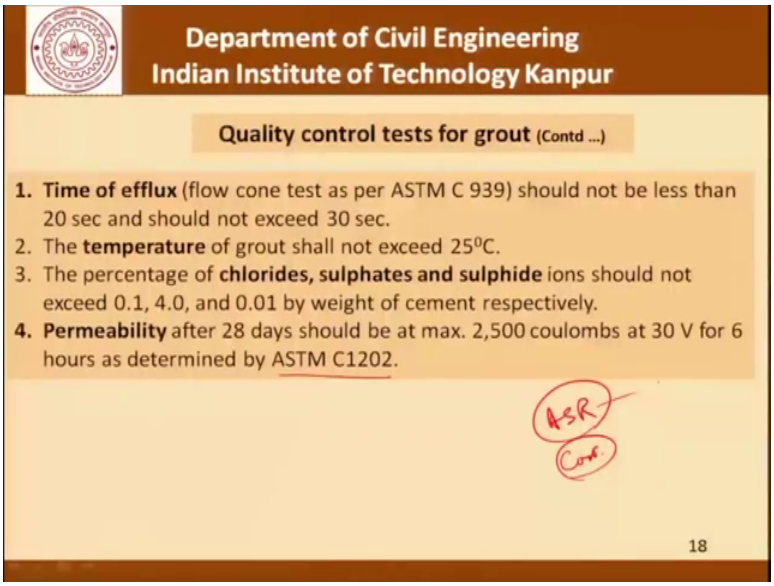

Continue With these qualities there is the time of efflux which could be measured using a flow cone test as per ASTM C 939 and that should not be less than 20 seconds, but should not exceed 30 seconds.

So, please remember that if their flux time increases the grout is becoming viscous. And if it is smaller than the grout is flowing. More flowing grouts are more prone to segregation. And therefore, this business of efflux time is a fine balance between what should be the minimum expected and what should be the maximum permitted. The temperature of the grout shall not exceed 25 degree centigrade and the percentage of chlorides sulphates and sulphide ions should not exceed 0.14 and 0.01 by weight of cement respectively. Permeability after 28 days should be a maximum of 2500 coulombs at 30 volts for 6 hours is determined by ASTM 1202. These test methods is something which we have not covered in detail in this discussion, but I would like you to see some literature on durability related tests especially for alkali silica reaction and corrosion of reinforcement. That would include this test which is the rapid chloride permeability test test, such as the quick chemical test or the petrographic examination which are relevant for ASR.

So, once you understand these test methods, that is when we are really prepared to execute a good job keeping in mind the test methods which are known.

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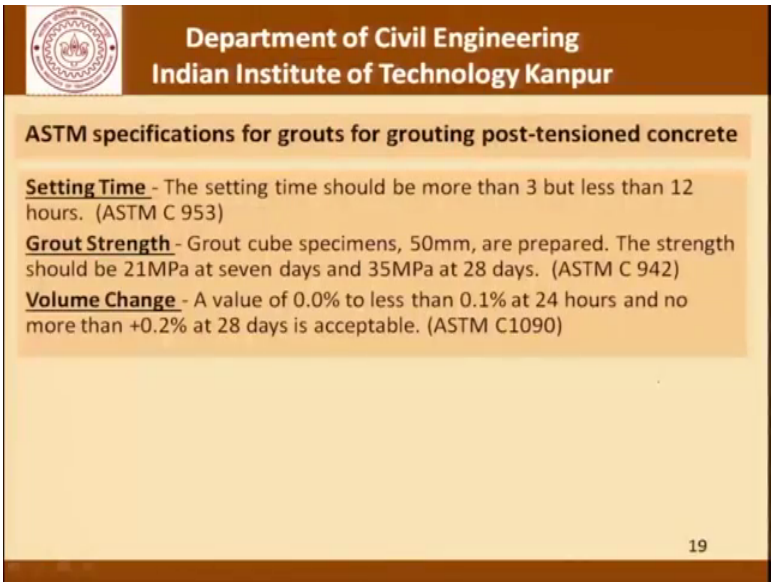

Continuing with the discussion on ASTM specifications for grouts for grouting post tension concrete the setting time should be more than 3 hours, but less than 12 hours the grout strength using 50 mm cubes should be 21 Mpa at 7 days and 35 Mpa at 28 days and volume change is as given here.

So, ASTM on the Indian standards they may have different values, but that is something which a site engineers or as concrete engineers or as construction engineers. We all know that different specifications will give us different values the important thing is to understand the parameters and try to follow the specifications which are supposed to be followed in a particular job.

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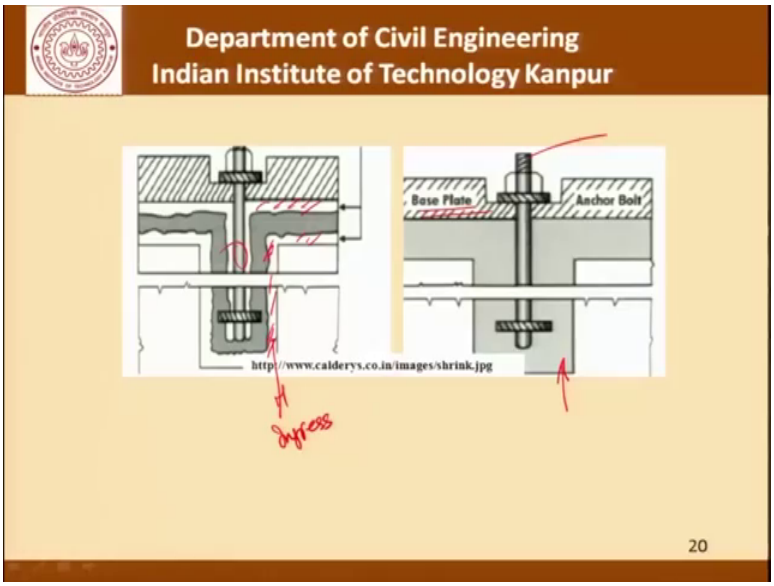

Now, this Picture here is a schematic representation of shrinkage. So, if we see here so, this is the space which has been created because of the shrinkage of the grout or shrinkage of the motor. So, as again this if we see this picture here there is no space that has been created and this is an example drawn from grouting a anchor bolt in the case of a foundation or something like that. Where we see that if we do not use proper shrinkage compensation material we could have these spaces which will then become a zone of weakness and permit ingress of deleterious material, which could damage the bolt or whatever the reinforcement and so on.

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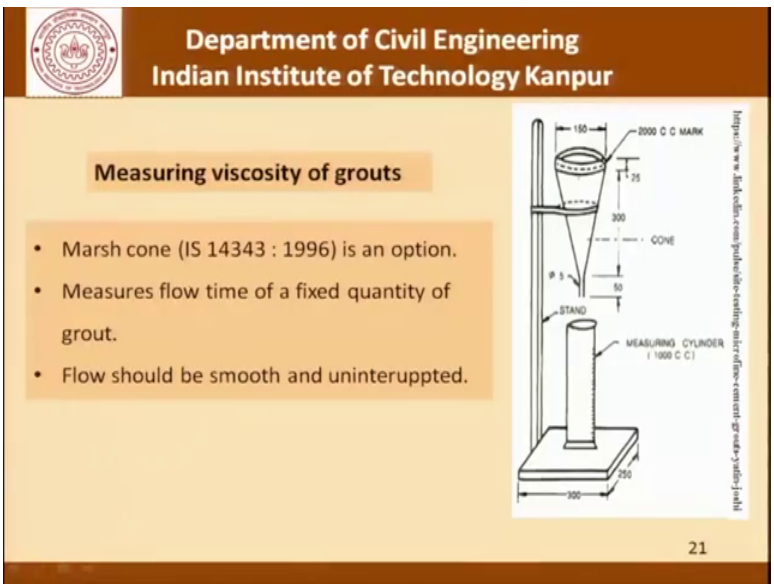

Now, this is a schematic representation of measuring viscosity of grouts using let say the marsh cone you must ensure that the flow smooth and uninterrupted.

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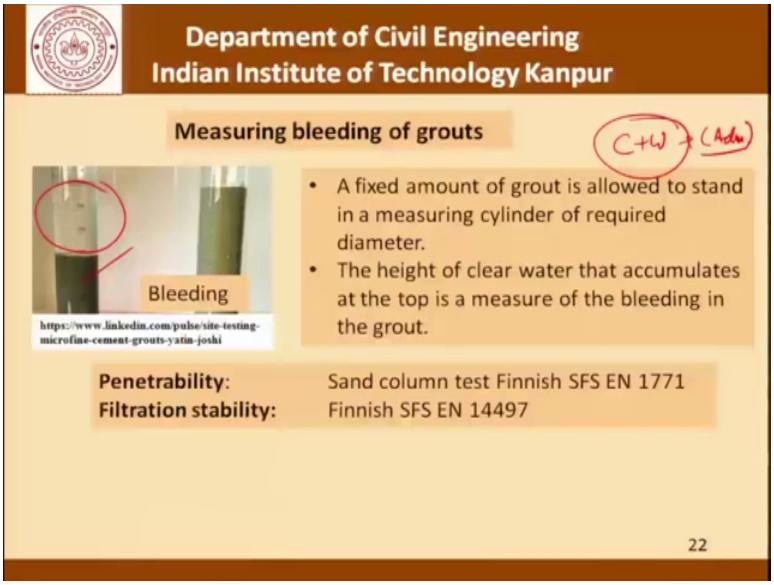

As far as bleeding is concerned is a very simple test of fixed amount of grout is allowed to stand in the measuring cylinder of required diameter. And the height of clear water that accumulates at the top is a measure of the bleeding in the grout the ground is basically a paste it has only cement and water plus of course, maybe some admixtures.

Now, I invite you to do a simple test take some cement and water in a measuring cylinder let it stand and you will find that very clear water appears on the top of this measuring cylinder very quickly. Depending on the kind of admixture that those saves the water cement ratio the time could be different, but this is a very clear water that appears in the top. So, the cement particles they settle down on account of flocculation and densification and this is something which is highly undesirable as far as grouting is concerned. This water if it accumulates in the neighbourhood of the strands or at the top of the duct that is what is the origin of a lot of air voids in the system.

Apart from these tests there a test like penetrability and filtration instability which can be carried out using several standards what I have quoted here is finish standards and I would invite you to take a look at what these standards are and how the test are carried out.

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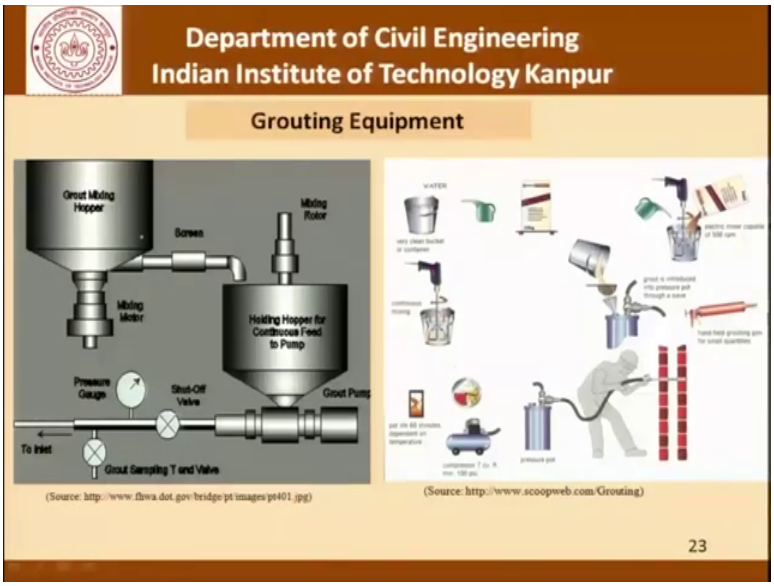

This picture here only shows the grouting equipment and why it is important to just go through this is because there are specifications for the equipment also. Because it is important to understand that the quality is not only for the material it is also for the equipment it is also for the process.

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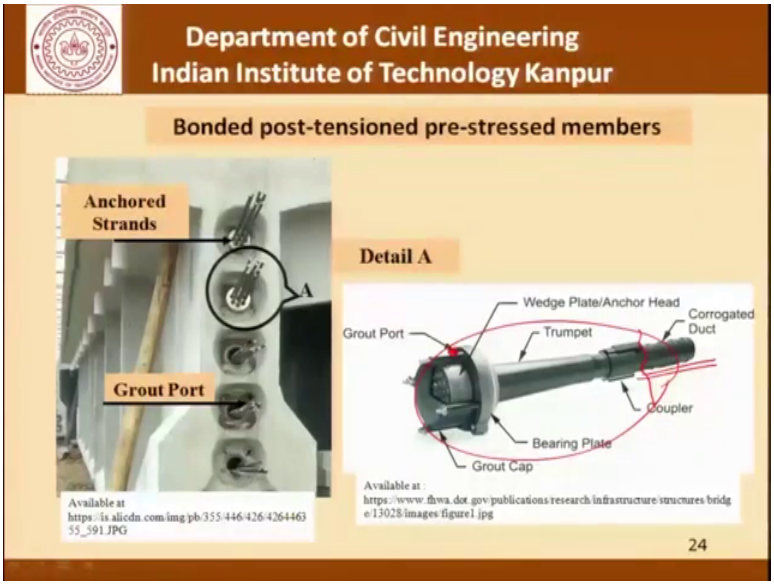

This Picture here shows you a completed I girder where we have anchor strands the grout port and this is the entire assembly which we use before the duct. So, there is the duct

that starts here and this duct is connected to this assembly and we have the grout port somewhere here through which the entire grouting takes place.

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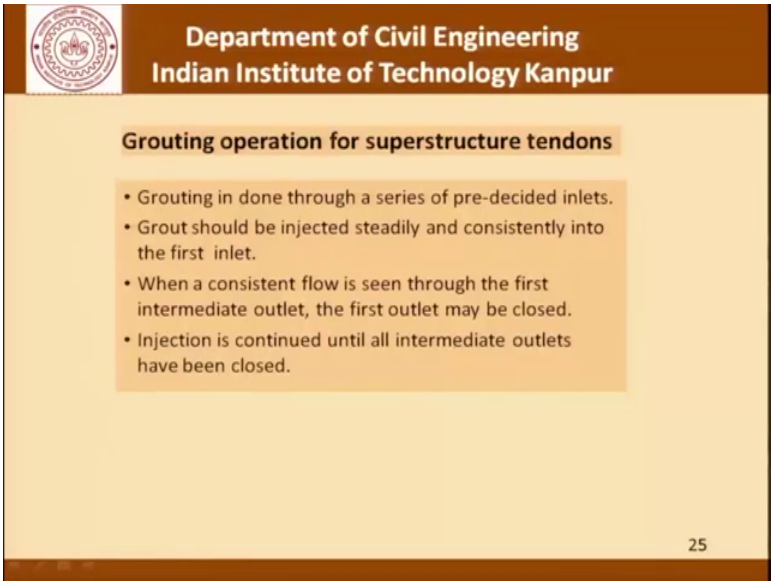

Now, as far as the operation is concerned the grouting is done through a series of pre-decided inlets. The grout should be injected steadily and consistently into the first inlet and when a constant flow is seen through the first intermediate outlet the first outlet may be closed injection is continued until all intermediate outlets have been closed.

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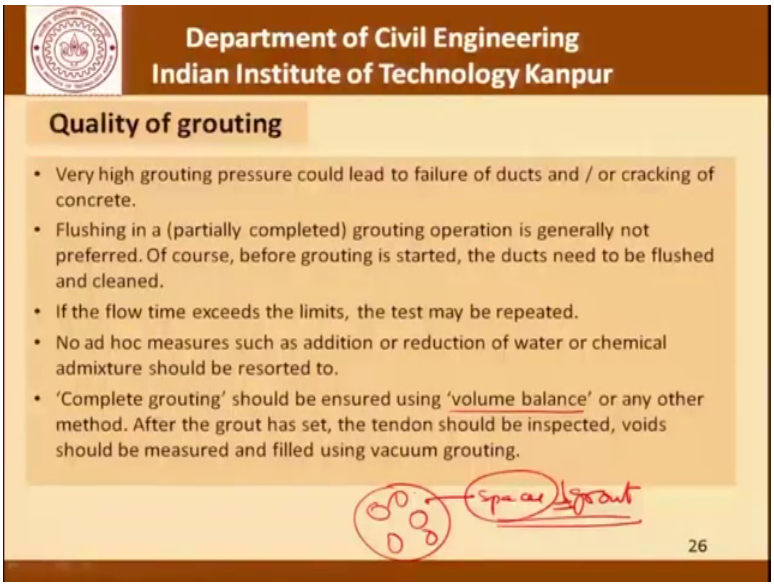

So, as far as the quality of the grouting is concerned we are not talking of the grout we are talking of grouting now a very high grouting pressure could lead to failure of ducts and or cracking of the concrete surrounding it.

Flushing in a partially completed grouting operation is generally not preferred of course, before the grouting is started the ducts need to be flashed and cleaned if the flow time exceeds the limits the test has to be repeated. No ad hoc measures such as addition or reduction of water or chemical admixtures should be sorted to complete grouting should be ensured using volume balance or any other method. After the grout has set the tendon should be inspected voids should be measured and filled using vacuum grouting.

So, when we talk of volume balance what we are essentially saying is that we know the volume of the duct we know the volume of the strands and therefore, we know the volume of the space here. And the amount of grout that has been used should be equal to this space. So, this is what the volume balance we are talking about this is one of the ways of quality control.

But what we must understand is that this does not ensure that all the grout has gone only in the space here, if the grout has leaked into the concrete and has gone through the duct into concrete or somewhere else then there would still be the possibility of space within the ducts and that something which we need to avoid. We need to have tests to be able to address that issue and find out if there are any a voids in the duct after the completion of the grouting operation.

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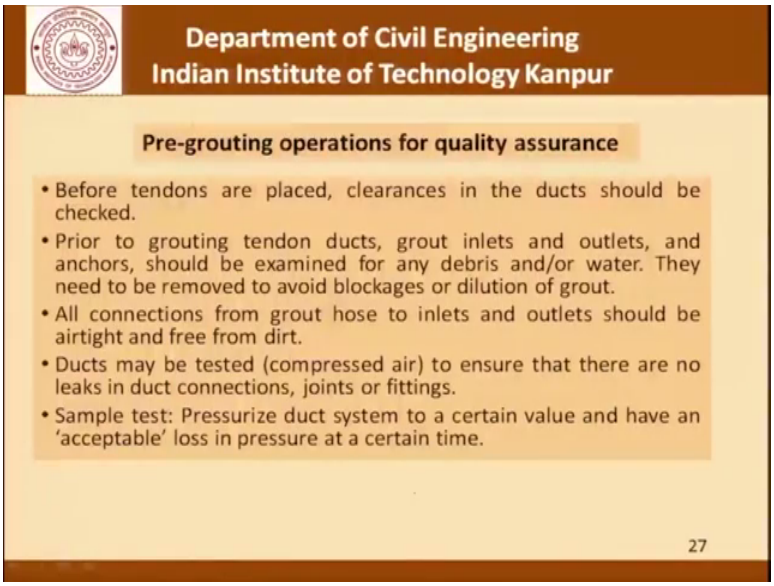

Pregrouting operations for quality assurance before the tendons are placed clearances in the ducts should be checked prior to grouting tendon ducts. Grout inlets and outlets and anchor should be examined for any debris and or water. They need to be removed to avoid blockages or dilution of grout. All connections from the grout hose to inlets and outlets should be airtight and free from dirt ducts may be tested using compressed air to ensure that there is no leaks. In duct connections joints or fittings and sample test means pressurize the duct system to certain value and have an acceptable loss of pressure at a certain time.

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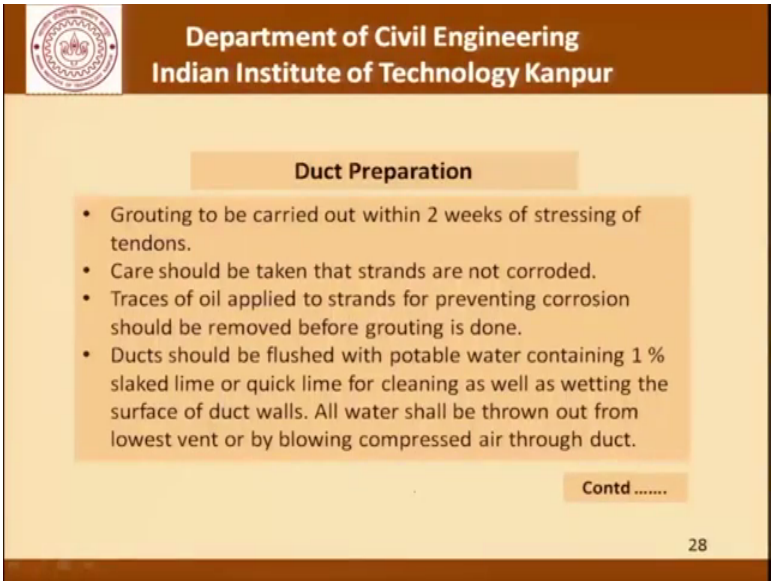

As far as duct preparation is concerned grouting to be carried out within 2 weeks of stressing the tendons we cannot leave the tendons on grouted if that is what is the design for more than 2 weeks care should be taken that strands are not corroded traces of oil applied to strands for preventing corrosion should be removed before the grouting is done.

Duct should be flushed with portable water containing one percentage slaked lime or quicklime for cleaning as well as wetting the surface of the duct, walls all water should be thrown out from the lowest vent or by blowing compressed air through the duct.

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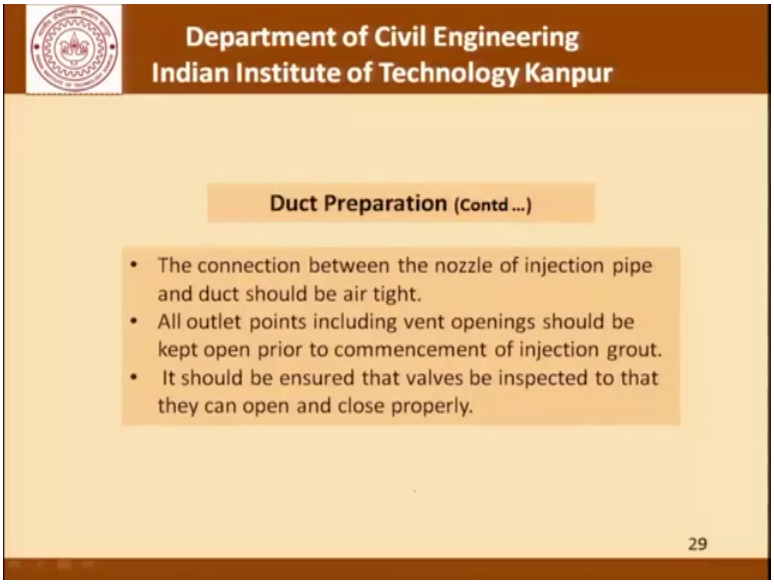

And continuing with the preparation, the connection between the nozzle of the injection pipe and duct should be air tight all outlet points including vent opening should be kept open prior to commencement of the injection of grout. And it should be ensured that valves be inspected So that they can open and close properly.

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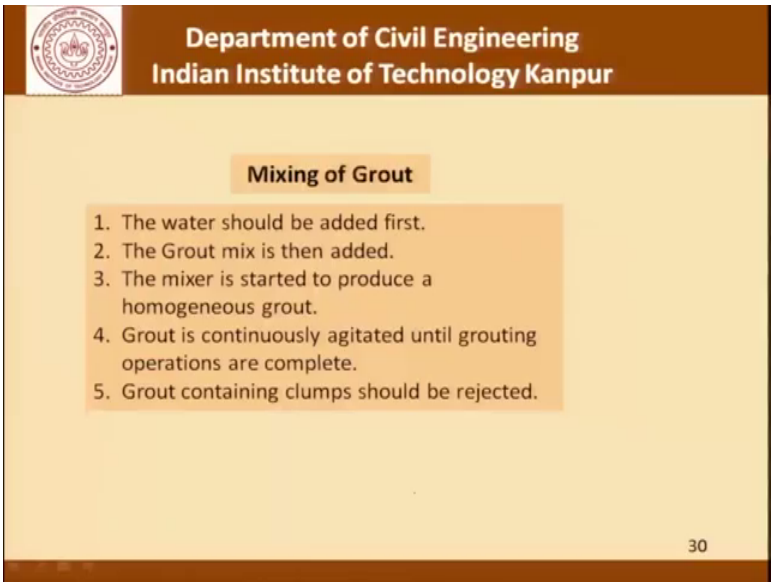

As far as mixing is concerned, the water should be added first the grout mix is then added the mixer is started to produce a homogeneous grout, grout is continuously agitated onto the grouting operations is complete and any grout containing clumps must be rejected.

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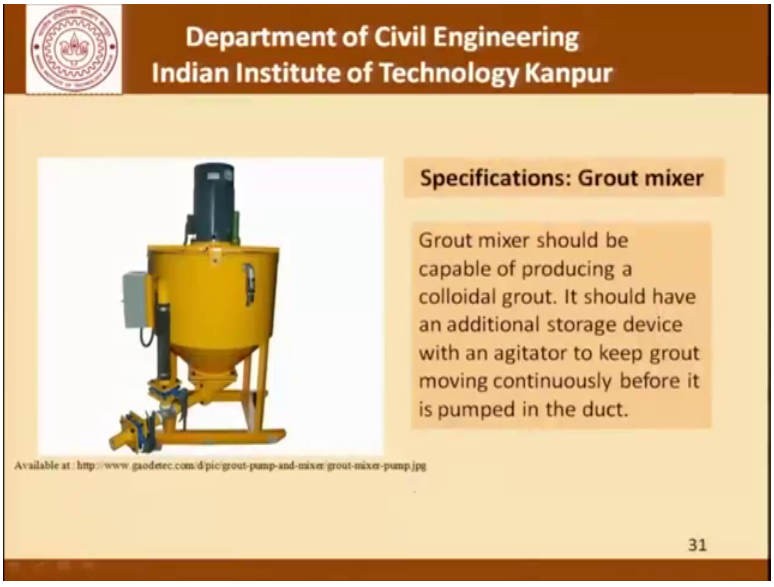

These are the specifications for the mixer and these are the Specifications for the grout pump.

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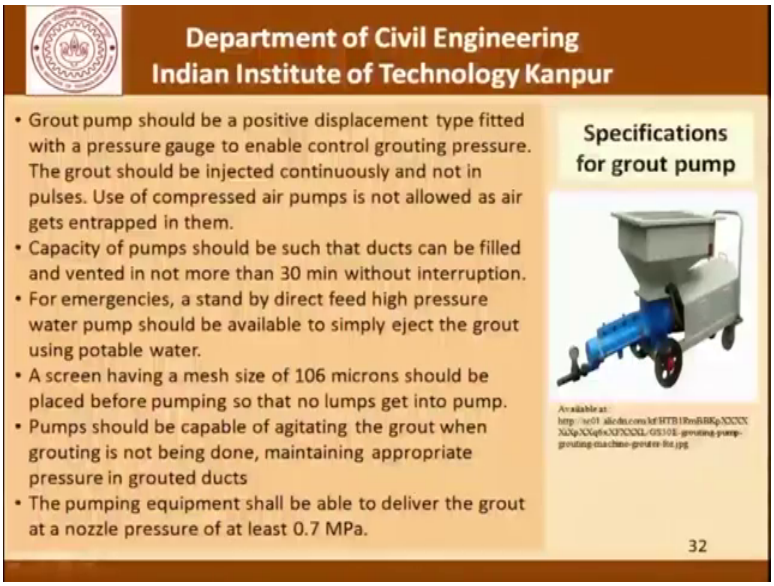

We are not going into details of this it has been included basically to tell you or share with you the fact that a lot of exercise goes into defining the entire quality control procedure for each of the operations which may be important at particular site.

Now, as far as injection is concerned, we already talked about it.

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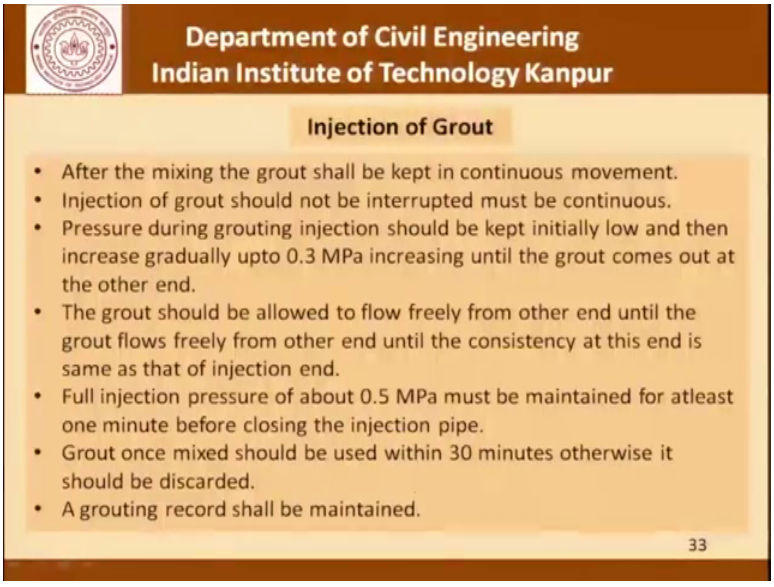

And I am going to leave this slide with you to read and understand yourself and before we close.

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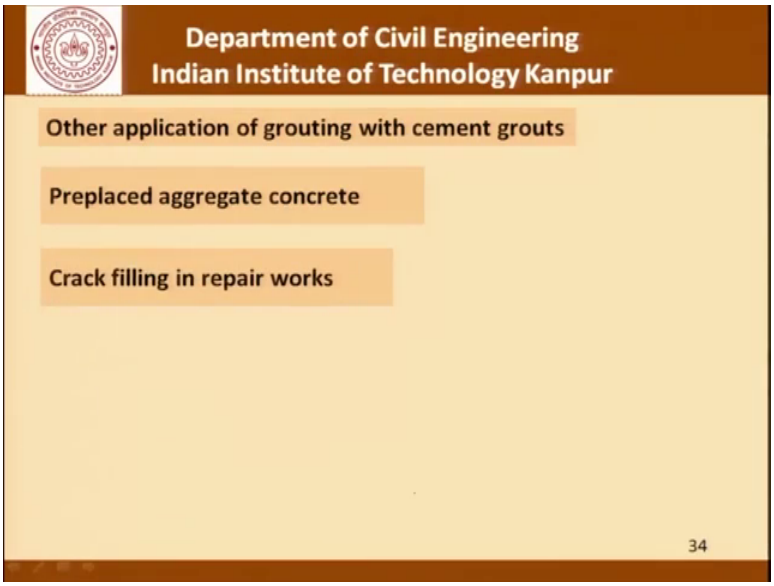

I will just like to briefly mention 2 things one is some other applications of grouting with cement grouts preplaced aggregate concrete and crack filling in repair work are 2 example that come to my mind and I will Show you just a picture of the latter where we are trying to use grouts to fill cracks in a repair and rehabilitation operation.

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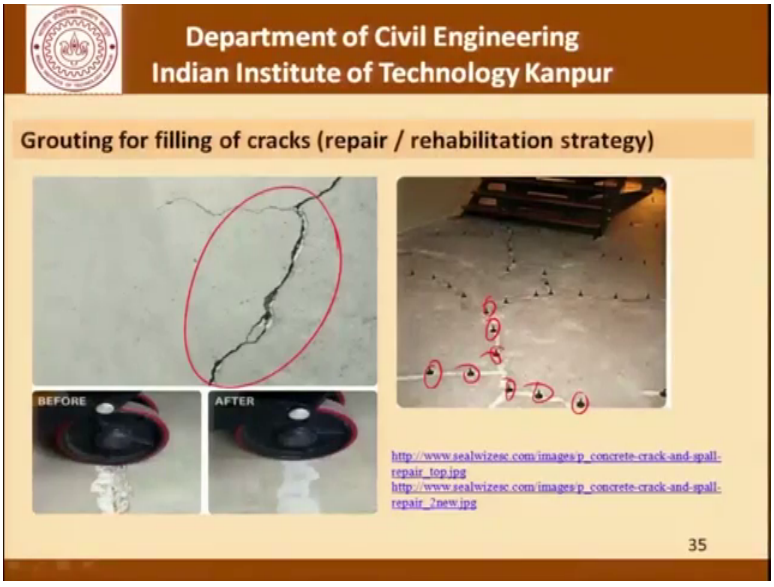

So, this is a crack in a concrete structure and we are trying to fill this up using grouting. So, these are places where successively grout is being injected and we ensure that once

the grout appears in the next nozzle we tried to seal that and move forward. So, by doing that throughout the structure we achieve a complete sealing of the concrete crack.

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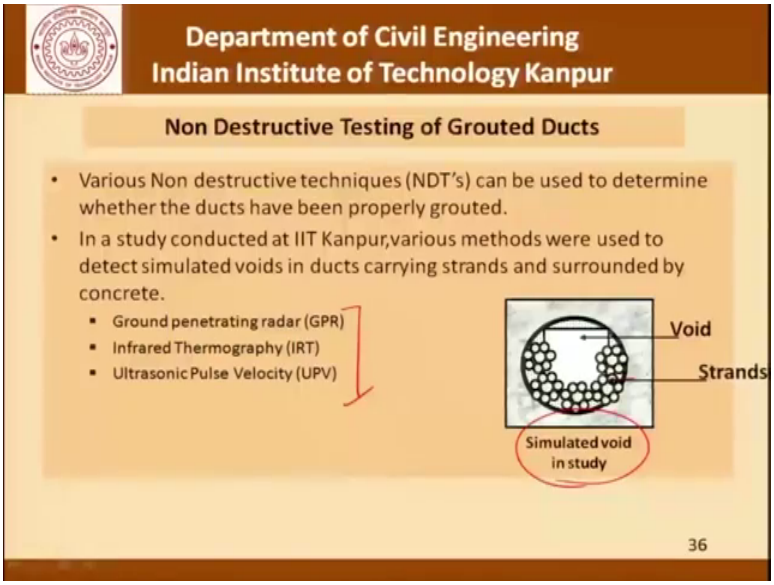

Moving forward the next thing that I wanted to share with you is some tests which are carried out after the grouting operation has been completed, and that work was carried out here at IIT Kanpur and that something which is of interest was, these were the 3 methods which were used to check if a simulated void in the duct could be located After the grouting operation has been completed. The test were ground penetrating radar infrared thermography and ultrasonic pulse velocity.

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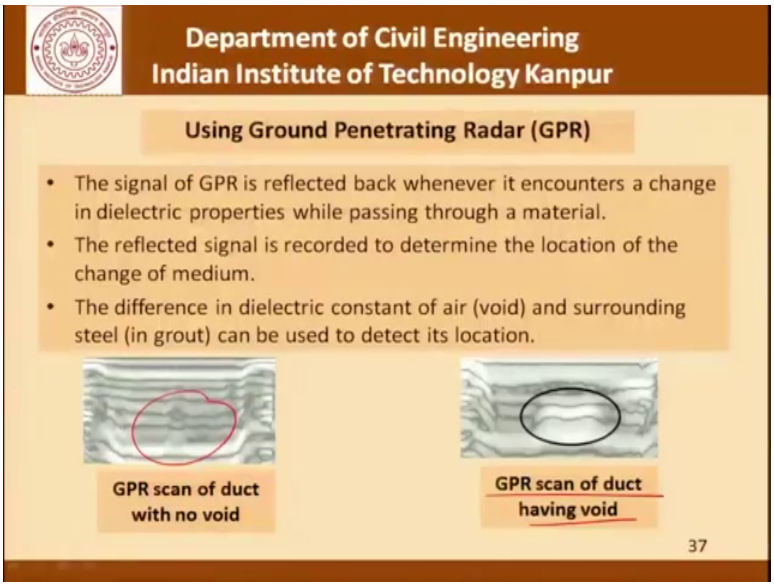

So, these are the Results from the ground penetrating radar system and we find that the GPR scan of the duct having voids is different from that which is seen in the case of ducts which have no voids. Of course, the application and the interpretation of this data requires certain amount of expertise in handling GPR systems.

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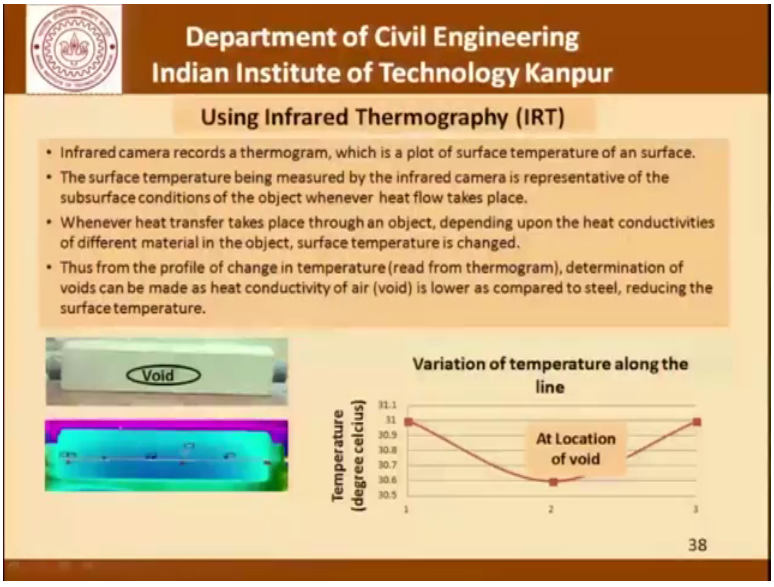

This is the result from the infrared thermography and this is the result from ultrasonic pulse velocity studies.

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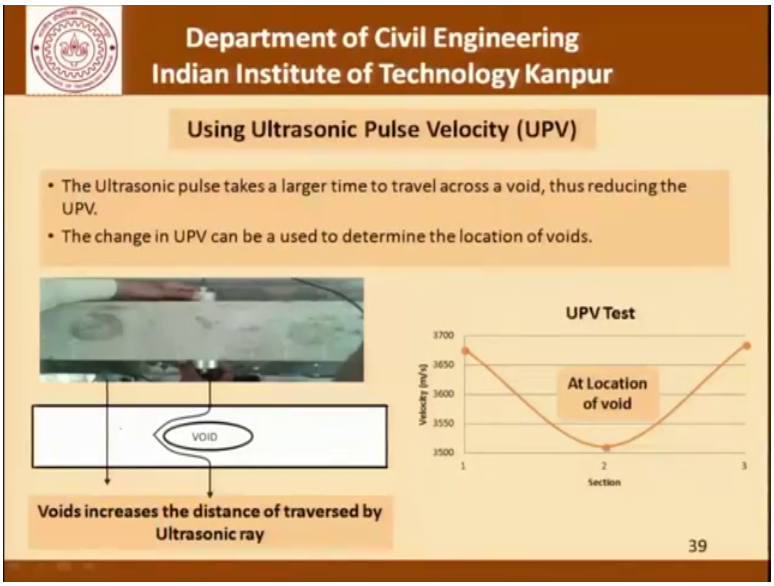

And sometime later perhaps I will upload some material which is interesting related to this. So, that you can go over it at your own time now before we close the discussion for today try to see if you can do.

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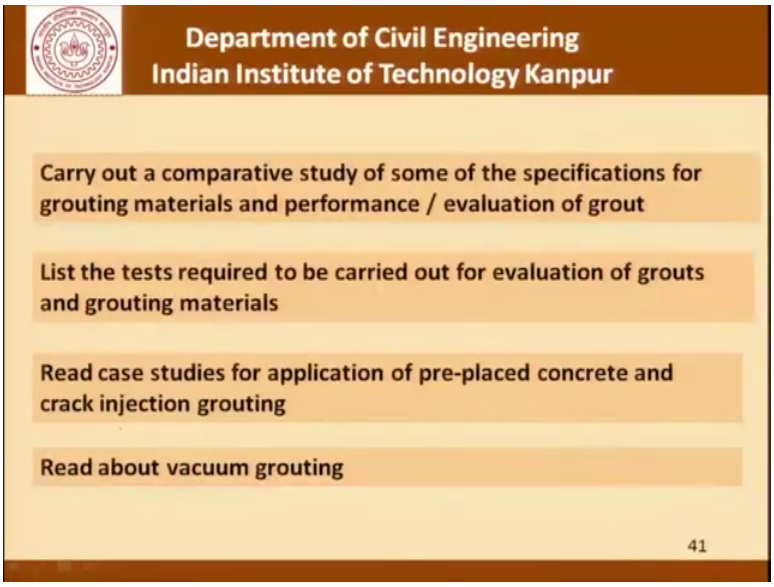

Some of these assignments carry out a comparative study of some of the specifications for grouting materials and performance evaluation of grouts.

List the tests required to be carried out for revaluation of grouts and grouting materials some of them we have already discussed and if you look at literature you will find some

more you can drop a comparative statement and try to see how they are differ how they are similar. Read case study for application of preplaced concrete and crack injection grouting that we talked about here. Read about something called vacuum grouting that something which we have not expensively done here, but it was briefly mentioned in one of the slides today you can do little of more reading on that this is the list of references.

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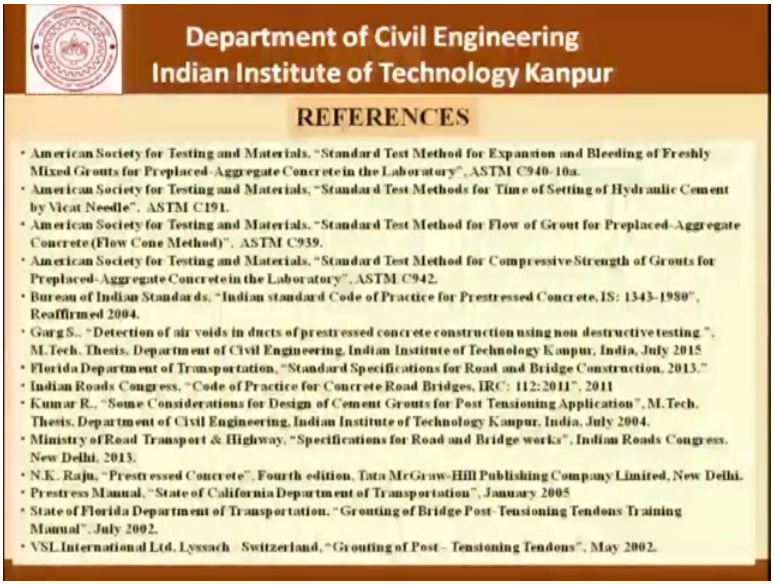

It is an extensive list we can try to see some of them for more details of grouting operations in the quality control continue with the websites relating to grouting.

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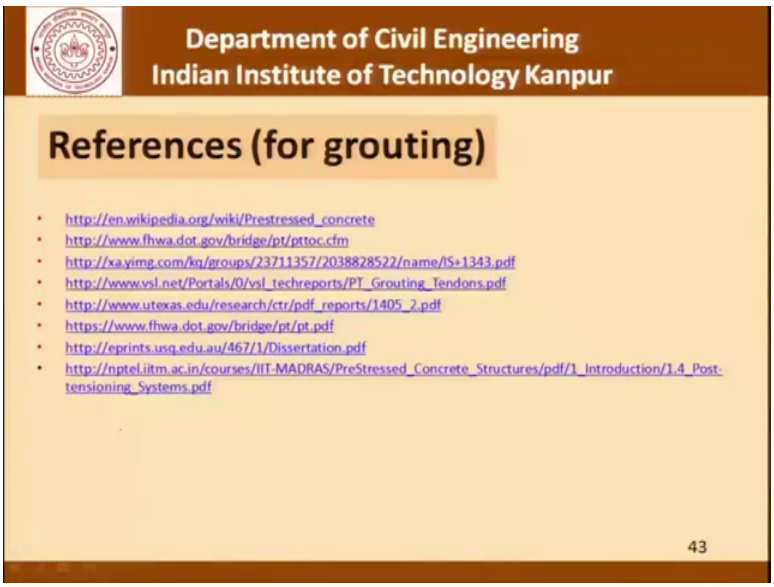

And finally, I look forward to see you once again in a different lecture.

Thank you.