Maintenance and Repair of Concrete Structures
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Lecture – 30
Injection Grouts for Concrete Repair

Hi. Today we have Mr. Seshadri who is a Consultant from BASF India Limited and he has been working; he is a Chemist and has been working in the industry of construction chemicals for last I think 38 years and one of the major project in which he was talking is he worked on the 3 gorgeous dam in China for the repair work and deciding on how to inject and seal the crack in dam structure and so today, we will have detail discussion and also on the practical aspects of selecting injection grouts and basically on the how to apply and how to choose the materials especially for chemical injection grouts.

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Thanks Dr. Pillai for the nice introduction and friends, we are going to spend next 30-40 minutes on basically injection technologies, chemical injections for cracks and basically for concrete repair. I am Seshadri. What you see in this first slide, they are not planets, but they just are proportionally sized spheres depicting different types of chemicals. It only says if there is a very narrow crack then the largest ball that is OPC 50 microns it cannot go in.

And same way as a cracks size or a fissure size keep reducing, we need to use different kinds of material or put the other way around. If you take the finest kind of material it is very effective in filling all the narrow spheres, pores, capillaries or things like that. That is what the picture depicts.

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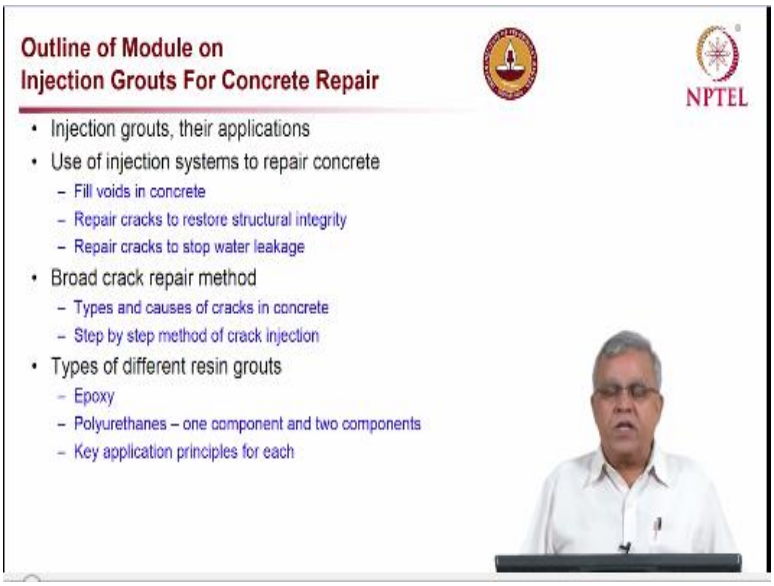

And the module, the outline we are going to talk about something about Injection Grouts their applications. The use of injection system is term to repair concrete. And the broad crack repair methods, types of different resin grouts, you would have heard of Epoxies, Polyurethanes and so on. These are broad topic we are going to cover.

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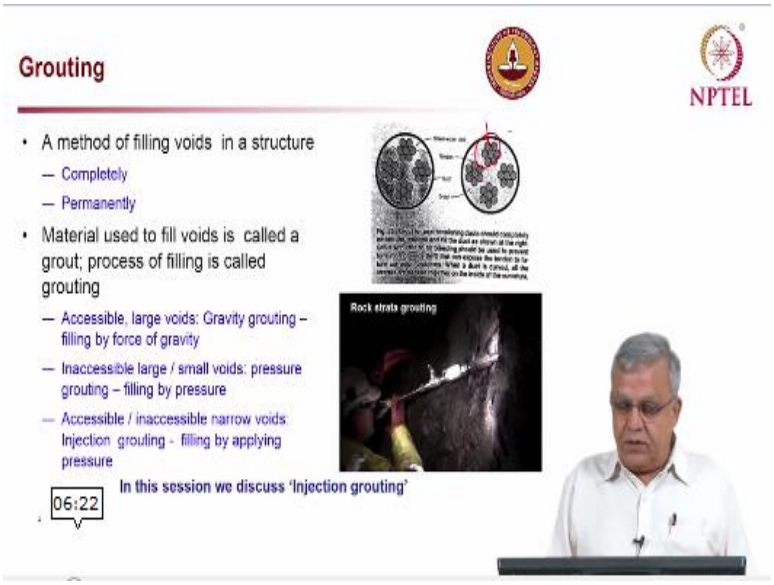

Now let us say, let us look at grouting; what grouting is about. Since we are going to talk about injection grouting, grouting is a key thing. The grouting is a method of filling voids in a structure. Voids we cannot avoid in any sector, you can have voids that are designed that are accidental, the designed voids, for example I can say if an got expansion joint you deliberately design a void there and fill it with some flexible material that is designed voids.

The accidental voids which no engineer likes to have is something like a crack or a honeycomb. Now how to repair that, that is grouting. And when you fill the voids it should be filled completely, and it should be filled permanently. And the material that is used to fill a void is called grout and the process of filling is called grouting. Accessible, see if the voids are accessible and they are large we use a procedure called Gravity grouting method where we use the force of gravity to fill the voids.

But if the voids are not accessible whether it is large or small voids, the other methods of grouting are taken, we apply external pressure to ensure that the voids are completely filled. This is called pressure grouting. And sometimes you got accessible or inaccessible voids which are very narrow, something like a very fine crack or a fissure inside some concrete. Then that cannot be done with pressure grouting, we need to do; actually, it is a pressure grouting, but slightly different equipment and tools and viscosities are used, and we call it as injection grouting.

That is also filled by application of pressure. I will just give you couple of examples. This picture what you are seeing here, this is post-tensioned cable that, you know it is an illustration of it. What you find here these are all for example this is a cable strand and there are several cable strands in duct and the space between the strands they have to be grouted to protect the strands from getting corroded. And here the voids are not narrow, but they are small, but it requires pressure to fill it in, we use a pressure grouting method to fill with cement.

Then we got; you see another example here. This is a rock grouting, rock strata grouting wherein water is leaking through a tunnel and very fine fissures are there in rock and dip hole have to be drilled and particular kind of packer has to be introduced and it is grouted. This is another kind of grouting. So, this is just to give a feel of it.

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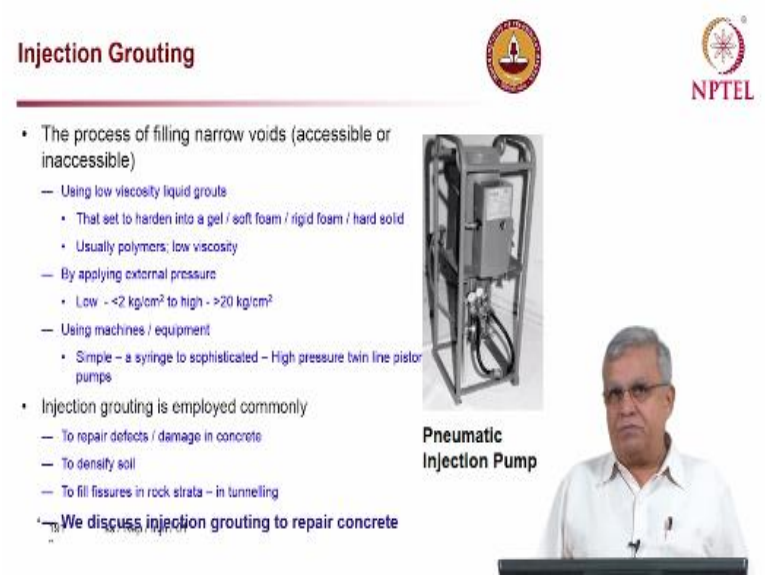

Now we are going to discuss about injection grouting. What is injection grouting? It is the process of filling narrow voids whether it is accessible or inaccessible. And this; this is done using very low viscosity liquid grouts. It sets to harden after some time a gel or a soft foam or a rigid foam or a hard solid. It depends upon the kind of injection grout we are using. Some resin setting to a gel, gel means it traps water inside or it sets into a soft foam or a rigid foam depending upon the application which was a different type of grout.

And usually they are polymers of very low viscosity and by applying external pressure we apply a very low pressure for example less 2 kg per square centimeter to quite high pressure up to greater than 20 kg per square centimeter or put it simply less than 2 to even more than 20 bars. Using a machine or equipment, to develop this kind of pressure we need some special equipment and machines and it is a very, it is a very simple system is there.

System equipment like a syringe to a very sophisticated complex machine-like high pressure, twin-line system kind of foams. Injection grouting is employed commonly for several purposes to repair defects to damage; repair defects or damage in concrete or to densify soil, but or even though fill fissures in rock strata that is in tunneling work and all that. But what we are focusing here is we discussing injection grouting to repair concrete. And this an equipment, a Pneumatic Injection Pump. This is one of the pieces of the equipment I am showing you.

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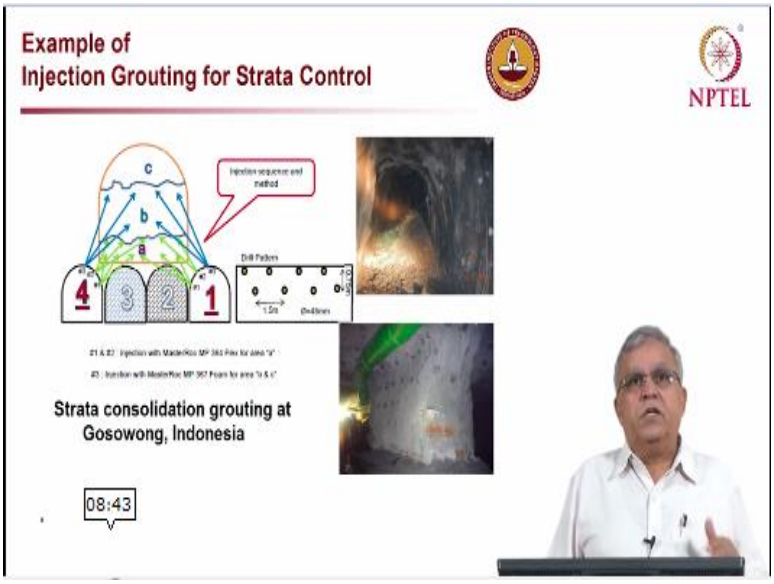

Just I am giving an example of Rock Strata Grouting, strata control. What you see in the picture, you see several arrow marks green, blue and all that. So different density of foam in this field at different areas of the rock strata, what happened was in a tunnel project as you see on the right-hand side the top picture some amount of collapsed place, lot of rock and you know muck and all that they fell down and then this grouting had to be done to hold the strata together so that no more such damage occurs.

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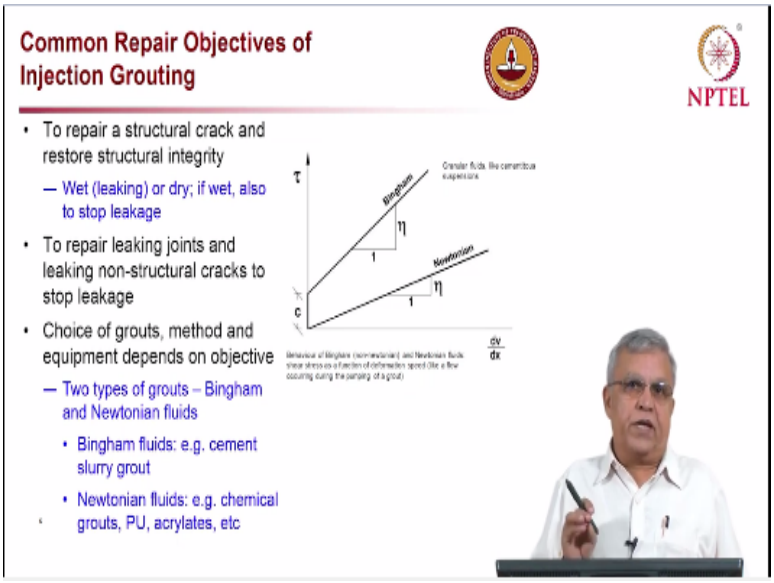

Common repair objectives of Injection grouting, you find it is to repair structural crack or to restore structural integrity and it can be a wet crack; wet means leaking crack water could be leaking out

of it or a dry crack. But if it is wet, we also have to stop the leakage that is if water is leaking you need to stop it. To repair leaking joints or leaking non-structural cracks to stop leakage, this is a second objective.

See one is structural cracks where the main objective is to restore the structural integrity, but if it were to be leaking then you have to stop the leakage also. Then we got the other one and structural crack or a construction joint which is leaking, here there is nothing to do with just structural integrity part of it, but we need to only stop the leakage. The choice of grouts, the method of application and the equipment it depends upon the objective.

And there are two; broadly you can say there are two types of grouts; see all these grouts are fluid in nature. You will be knowing that there are broadly two types of fluids Bingham fluids and Newtonian fluids. Bingham fluids typically are particle suspensions in water or a liquid whereas Newtonian fluids are pure liquids they are chemical grouts something like polyurethanes or acrylates and so on.

This graph, it will show you the difference between Bingham fluid and Newtonian fluid. The eta (η) in other words the shear force that is required to make it deform, deformation could be in the form of flow where what we are interested in flow. The amount of shear force required for making it flow is higher for a Bingham kind of fluid and it is much lower for a Newtonian kind of fluid. This graph, I mean just it gives an idea.

So when we have this kind of chemical grouts what it says; what this graph says is, it has got very low viscosity, it requires very little shear force or a very little force to make it go and fill and even this narrow voids.

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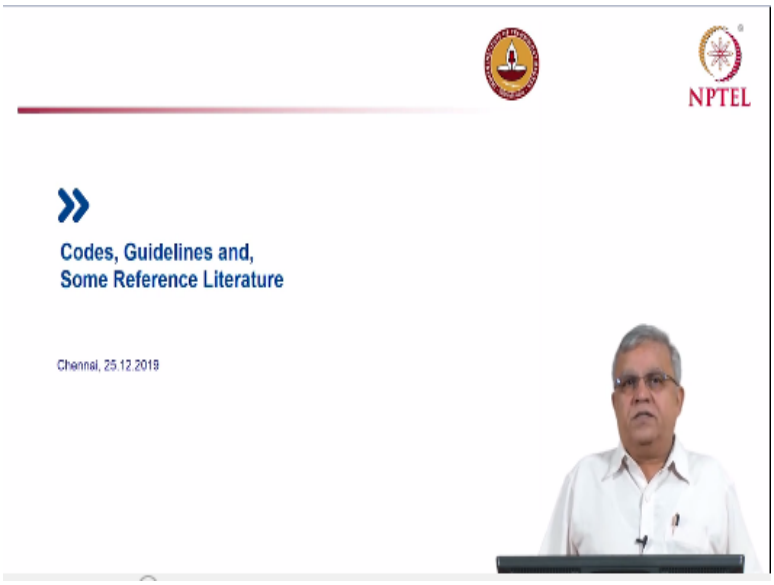

Okay. This are all just a preliminary and just I want to show you a few codes guidelines that are applicable to this particular topic of grouting.

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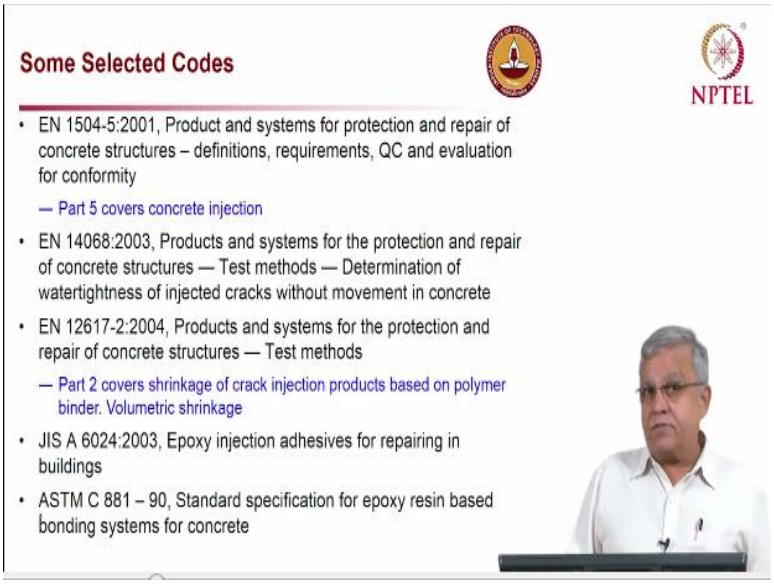

Some of the selected codes for example EN 1504-5 in 2001, it talks about products and systems for protection and repair of concrete structures, definitions, requirements, QC and evaluation for conformity. The Part 5 covers the concrete injection. And then you have got EN 14068 in 2003. These are all products and systems for the protection and repair of concrete; Test methods; Determination of water tightness of injected cracks without movement in concrete.

Then you have got EN 12617 Part 2, 2004, products and systems for the protection and repair of concrete structures: Test methods. Here Part 2 covers the shrinkage of crack injection products based on polymer binder that is basically volumetric shrinkage. Same way we have got Japanese standard for Epoxy injection and there is another important standard ASTM C 881 – 90 which specifies the various properties that are required in an epoxy resin-based bonding system, okay.

Epoxy resin is use for restoring the structural integrity because it has got an excellent bond with concrete and hence ASTM C 881 is quite important. There are many such standards across a globe but individually, each of them individually talks about particular aspect of either a product or its properties or its testing and unfortunately there is no any code, National code whether EN or JIS or anywhere, which talks about how to do the grouting. And these procedures are covered in some of the guidelines by reputed bodies.

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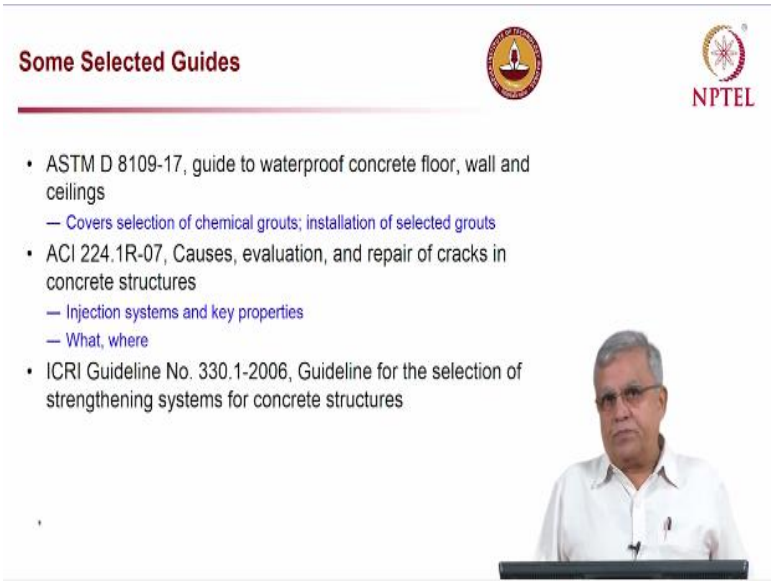

You have got ASTM D 8109 which is a guideline to waterproof concrete floor, concrete wall and ceilings. It covers selection of different chemical grouts as well as how to install it. Then you have got ACI 224, 1R-07 which talks about causes, evaluation and repair of cracks in concrete structure. It talks about what are the causes, how to evaluate and so on. It also talks about injection systems and key properties and what is to be used and where.

Then you have got an ICRI Guidelines, ICRI is an International Concrete Repair Institute Guideline No. 330.1-2006. It is a guideline for the selection of strengthening systems for concrete structures. In that there is a section also that covers about injection systems.

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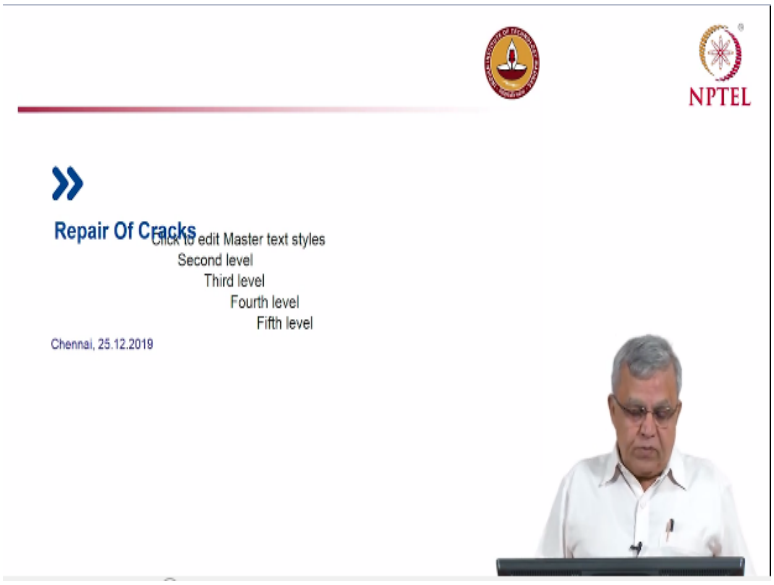

Now repair of cracks.

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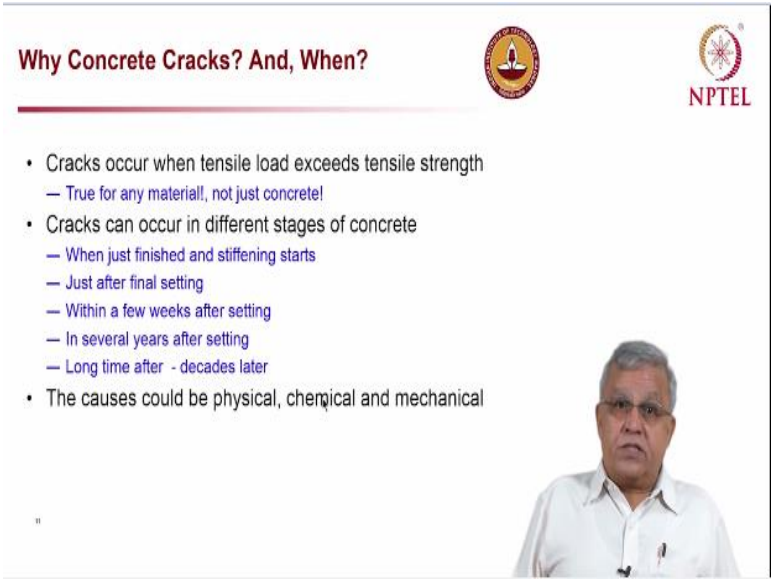

Now, firstly we need to understand why concrete cracks and when. Concrete and cracks, they are considered as two sides of a coin, there is no concrete which has not cracked, which does not crack. And when it is going to crack one has to gauge in a crystal ball because nobody can predict when concrete is going to crack or where. So why concrete cracks and when? A million-dollar question.

There is no concrete without crack, concrete and cracks are considered as two sides of a coin. I am it is impossible to design a concrete structure and guarantee that it will never crack. Cracks can appear anytime for various different reasons. That is why it is impossible to predict when it is going to crack or where it is going to crack. Some of the reasons that; the some of the causes for the cracking we are going to discuss now.

Cracks occur; fundamentally for anything to crack; immaterial whether it is cracks or glass, wood or whatever it is. Cracks can only occur when the tensile load exceeds a tensile strength. When a load of; tensile load is applied on their body and it is exceeding tensile strength the extra energy or force is relieved through a crack. And then cracks can occur in different stages of concrete. As far as concrete is concerned it can occur in different stages of concrete.

May be when it has just finished. See just before finishing the concrete obviously concrete remain a kind of semi-liquid or fluid condition, plastic state, we call it as a plastic state, and it cannot crack. It is something like liquids, liquids cannot crack obviously. So just after finishing it start stiffening at that stage some cracks occur, can occur I do not say they will, but they can occur, and cracks can also occur just after final setting.

Concrete after undergoes final setting due to different causes, some types of cracks can occur, and cracks can occur also occur within a few weeks after setting for a different set of reasons. And crack can also occur in several years after setting and crack can also occur long time after decades later. For each of them there are different causes different reasons that can be applicable and that is why it is impossible to predict when or why concrete would crack. The causes of cracking could be physical causes, chemical causes or mechanical causes.

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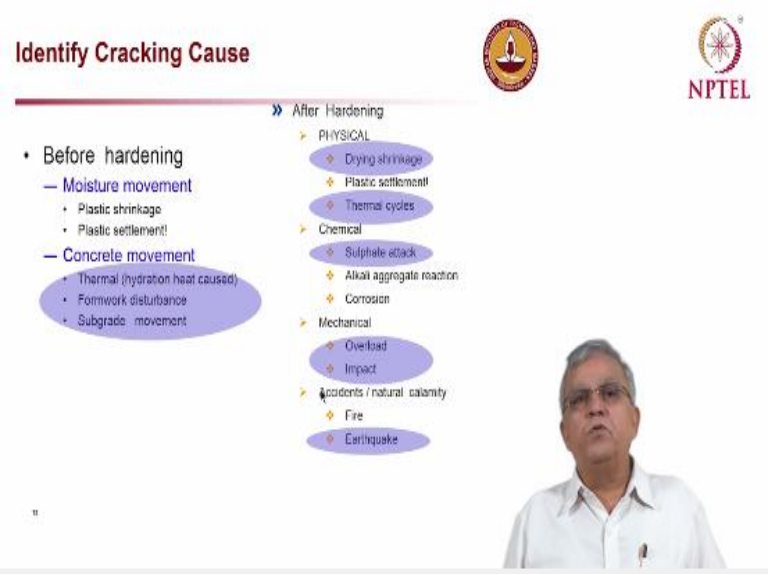

We will see more details. So, for example if we know what the cause of cracking is, we will be able to know how the cracks can be repaired. Now let us see before hardening there are some causes. Moisture movement, moisture movement is from the concrete some about of bleed water will come to the top and that bleed water if it dries quickly it can cause some cracks or there is called a plastic shrinkage, this also is called plastic shrinkage.

Because some amount of bleed water comes it evaporates out, dries out it causes a shrinkage. And this plastic shrinkage will happen mainly in the top layer first and the bottom layers of the concrete still not shrink, so because of the differential stresses cracks can occur. Or plastic settlement, this is very interesting. Plastic settlement is when the concrete is stiffening okay is still not set, not yet set hard it tends to settle down.

When the settlement is happening there will be re-bars or some instructions in the concrete which is obstructing that settlement, which means on either side of the river some settlement will happen but where the river is there no settlement will happen. So, this kind of differential settlements between 2-3 zones of the concrete causes crack that is called plastic settlement crack. Then you have got concrete, cracks caused by concrete movements, and the movement can happen due to several reasons due to thermal movement.

Of course, as you know heat expands solids and when it cooled it shrinks back. But here the heat the source of heat is hydration of cement. When the hydration of cement is in the peak lot of exothermic would have developed, concrete would have expanded a bit when it starts cooling down due to shrinkage the shrinkage stresses will cause crack, they are called thermal cracks. Formwork disturbance, now you have got a slab which has been supported by shuttering and scaffolding and suppose some disturbance were to occur before the concrete has achieved its required strength that would be cracks.

And you have got subgrade movement, sometimes there may be a very big rain or whatever, you know the soil below may undergo some movement for whatever reasons before the concrete has attend sufficient strength and it can crack and you have got a set of causes after hardening of the concrete. These are all before full hardening of the concrete and there are also causes after hardening. The physical causes, physical causes are mainly related to loss of moisture.

See; we talked about moisture loss during the plastic state when the concrete is not set. Concrete can also loose water after setting is called, and it causes a shrinkage called drying shrinkage and you got plastic settlement that can happen after hardening. Thermal cycles like you know in a day peak temperature will be in the afternoon or night will be cold and so on and all that same way and the year also there will be cycles.

This kind of thermal cycles causes lot of shrinkage. Chemical causes, it includes sulphate attack. For example, see sulphates, magnesium sulphate, calcium sulphate or any kind of sulphate, it attacks concrete very severely. It can cause gypsum; I mean calcium sulphate can; gypsum is calcium sulphate first gypsum is formed and calcium sulphate will again react inside forms calcium alumino sulphate and that is having a larger volume on that causes cracks, bulging cracks.

And you have got Alkali aggregate reaction, this is another chemical cause. There are some aggregates which are reacting in nature, which reacts the Alkali present in the cement or concrete or potassium hydroxide, sodium hydroxide, calcium hydroxide they are reactive. And when it reacts the aggregates starts bulging. The bulging of the aggregate exhales lot of pressure on the concrete and concrete cracks.

And you know corrosion cracks we are all familiar with that, most of us corrosion cracks here, here the force is given by the corrosion of steel, steel when it corrodes it expands nearly 8 to 10 times its volume original volume and this expansion exhales lot of pressure and causes a concrete to crack. Then you have got mechanical causes, obviously it is due to overloads. There is a more load on the slab then what it can withstand then; and the tensile zone you will see cracks. Same way you have got impact loads, accidental impact it could be.

And you also have other reasons like accidents and natural calamity. Accidents like fire, impact can also be accident, a vehicle come and hit a pier of bridge, it can cause crack. Other accidents like fire accidents. Fire, and concrete is exposed to localize very high temperature and it is going to crack. Obviously, for same way as a thermal cycle what we discussed. And fire is one thing, and earthquake.

Now I have highlighted a few of these causes and these, the cracks cause by these causes they are all structural cracks normally they end up structural cracks. Those that are not highlighted need not be structural cracks, they stalled off with a non-structural crack. But nevertheless, many of these non-structural cracks if they are not treated in time then they may become structural cracks.

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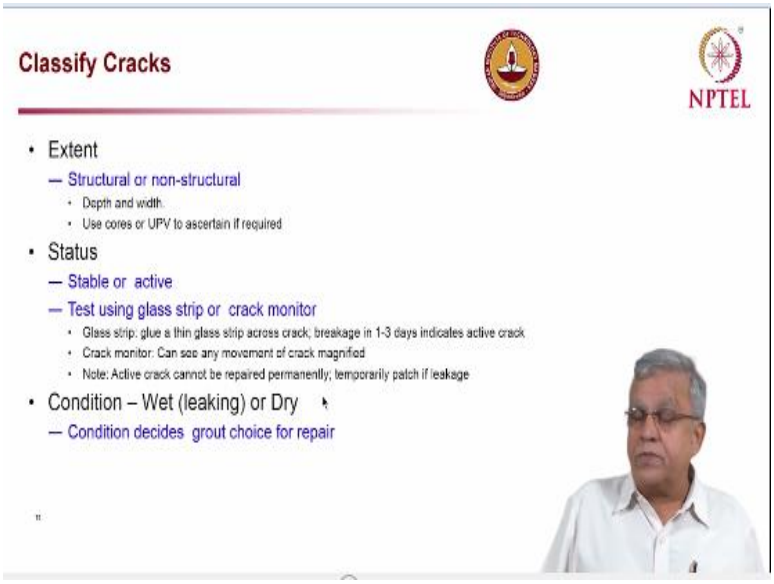

Once you have got cracks, we need to classify that before repairing it. And to classify the cracks already we talked there are three broad categories what is the extent of the crack. We already talked about structural, non-structural crack, if the extent of the crack is more than 20-25% of the load baring area, we called it as structural and we also talk about depth and width of the crack. How wide is a crack? see cracks up to 5 millimeters wide is consider as crack.

Beyond 6 mm is considered as a fracture, it is no more treated as a crack. Now to see the crack depth to what depth it has penetrated we check cores, we taka core or another very precise way of checking which is UPV that is Ultrasonic Pulse Velocity measurement, but for that you need a very experienced interpreter. And then status of the crack. Status refers whether crack is active or stable, what do you mean by stable crack?

A crack that has formed which is neither increasing in width nor in the length is stabilized, stable crack. Now active crack is which is either increasing in length or in the width that is active crack. And we can check it by some test, very simple test is using a glass strip. You know the kind of glass strip use for using a microscope to check the blood or whatever you know very thin strip. It is struck across a crack using a glue and left for a couple of days and if the crack is active then the glass strip will be break.

There is another equipment piece of small equipment called crack monitor which will magnify any crack movement and it will show up. Now at the end of the day we need to find out status of the crack, it is a very important thing because only active cracks; I am sorry, only stable cracks can be repaired and active crack cannot be repaired. Even if you want to repair an active crack it can continue to crack.

At the best we can patch it up temporarily if there is a leakage. Then condition of the crack. Whether crack is wet or dry, if water is leaking through the crack then called it as a wet crack otherwise it is called a dry crack and condition decides the type of grout that we need to use, the choice of grout and a methodology.

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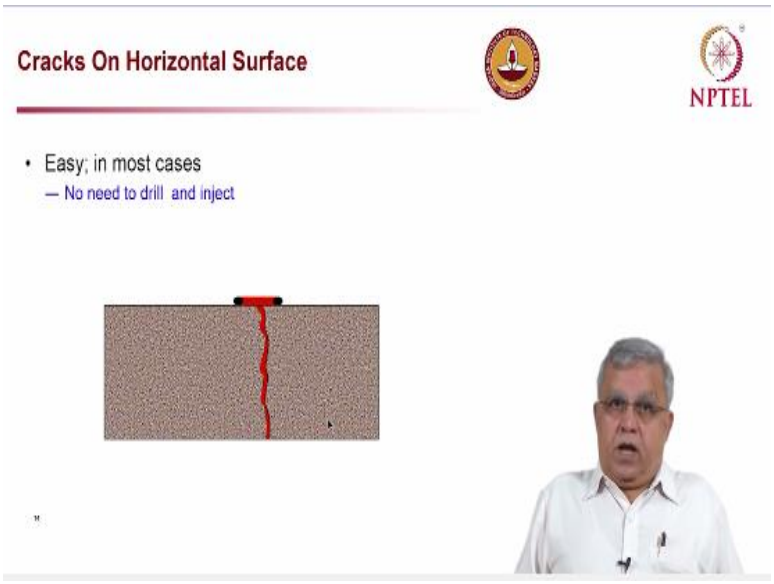

Now let us look at how we can grout a crack. If it is a horizontal surface it is very simple, there is no need to inject. What you see the blank part here it is a kind of a formwork may be about 1-inch height both sides. And we just fill in the epoxy resin in between that and the; it will just flow through the crack by gravity. There is no need to inject easy and, in most cases, it can be applied. And there is no need to drill.

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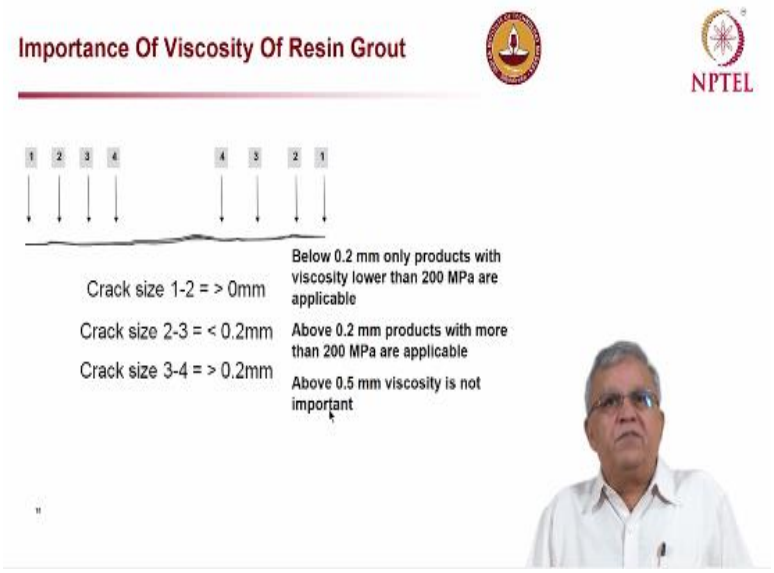

It is possible for most of the crack situations in horizontal but some of the narrow cracks we cannot do it. And when we talk about this kind of gravity grouting or any grouting the viscosity of the resin grout becomes very important and that grout has to be chosen because of that. Say if; now

here you can see an illustration of a crack, you see the numbers 1, 2, 3, 4 either side, the crack size 1 to 2 is greater than 0mm.

The crack size 2 to 3 is less than 0.2mm. Crack size 3 to 4 is greater than 0.2mm. If the crack size is below 0.2 mm only products with viscosity lower than 200 MPS. “Professor - student conversation starts” Sorry, there is a typographical error here, it is not MPa it should be MPS. “Professor - student conversation ends” and above 0.2mm products with more than 200 MPS are applicable that is Mega Pascal per Second and above 0.5mm width of a crack viscosity is not so important because any chemical grout will have sufficient viscosity to grout it. This is to indicate what kind of material can be chosen.

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Then if you have got structural crack dry cracks, we need to only restore structural integrity we discussed that. So, restore the structural integrity we need to inject low viscosity, solvent free epoxy resin only which conforms to ASTM C 881. Why? Because this low viscosity, viscosity is there to penetrate the crack, epoxy resin has got good bond with concrete they are rigid material they are not flexible, so they restore the structural integrity a great extent.

And they normally the kind of viscosity we use is between 200 to 350 centipoise and if it is a shallow crack then single line injection is good enough, single line injection is what we mean is we mix the epoxy resin and hardener, you will be knowing that epoxy it will have a resin and a

hardener both when you mix the polymerize into a solid material and both are mixed and they are injected before the pot life of the material.

Pot life is the time during which a liter of mixed epoxy resin, its viscosity remains intact, injectable. Then for deep cracks, where you know, imagine a dam which is you can have very deep crack there nearly 10 meters deep, 5 meters deep then this kind of single line injection will not be sufficient we need to have Twin-line injection because we need to extract the maximum part life for injecting the resin until the depth of the crack.

So, we use twin-line wherein the resin and hardener both comes separately in two hoses. They get mixed up at the point of injection. Okay, this picture shows you single line injection where you have got a port, a port with a mixed resin system and some air pressure is applied and you have got one line going out here this line, this is taking out the injection resin. The other one is twin-line injection.

We can see here there are two hoses coming together and they get mixed up at the point of injection and enters, here what we are doing is because these two mix there the port life or setting time or gel time whatever you call it; it start from that point. So, I got sufficient time for epoxy to penetrate in very deep crack.

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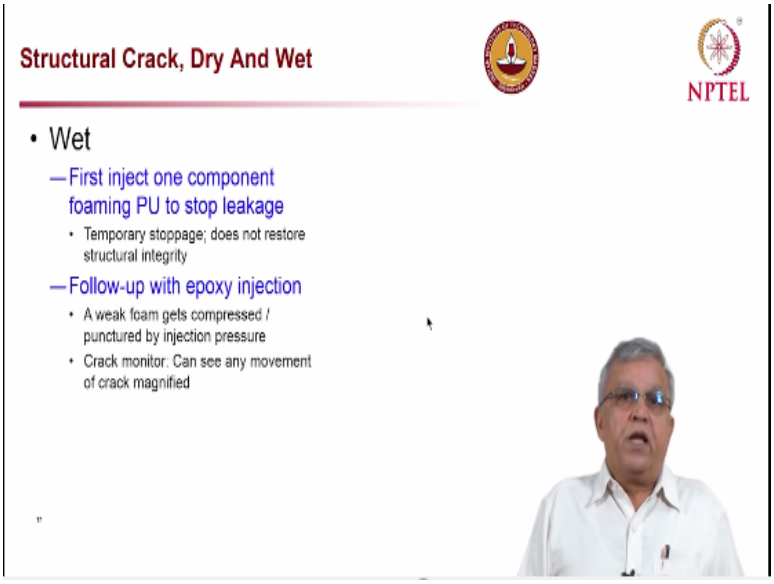

Then you have got, or we talked about it, Wet and Dry cracks. But if it were a wet crack that is water is leaking or there are, there was wetness there because water has leaked then what we need to do is first we need to inject a one component foaming polyurethane to stop leakage. Directly, see because it is a structural crack, we need to inject epoxy resin to restore its integrity. But before injecting epoxy first we need to inject polyurethane to stop the water coming out of the crack because water and epoxy they are enemies they do not go well together.

So there is no need to worry because if you have already, if you have done the PU injection then why we need to do epoxy injection, the reason is this polyurethane it makes a temporary stoppage, it will stop the water for some time and because it is foamed it will not stop it permanently, because as a water pressure increases it can get washed away and PU it does not restore the structural integrity, it is a soft material, it is a foam.

And we need to follow it up with epoxy injection; when the water stops then again we inject with epoxy into a same crack because of foam is weak it gets compressed and allows epoxy to penetrate or foam can be even punctured by the injection pressure. And we saw these pictures earlier.

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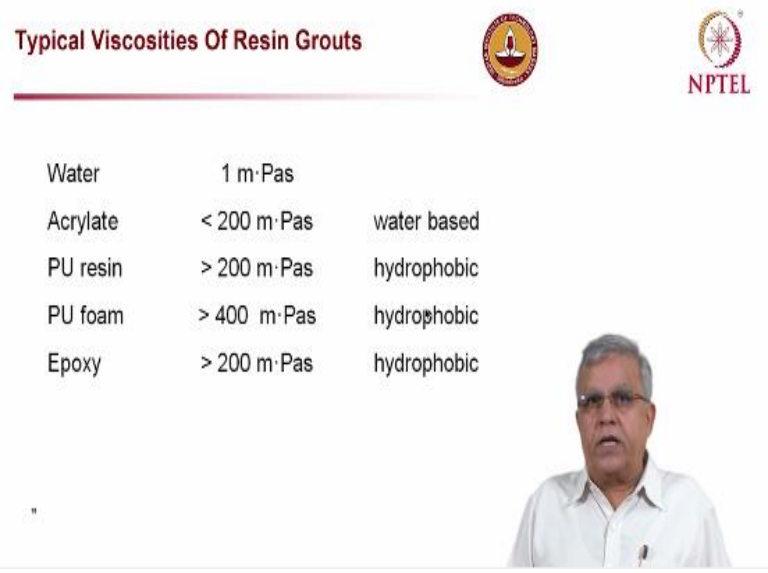

Then we have got typical viscosities of epoxy resin, I mean different resin grouts. Say water is 1 Milli Pascal Second then Acrylate which is a type of chemical which is used for cracking issue is less than 200 Milli Pascals. PU resin, there is one type which is hydrophobic which is more than

200 Milli Pascals. You have got PU foam, foaming resin, which is more than 400 Milli Pascals, Epoxy is about more than 200 Milli Pascals. So, this gives you an idea what different types of resin and what kind of viscosities are available.

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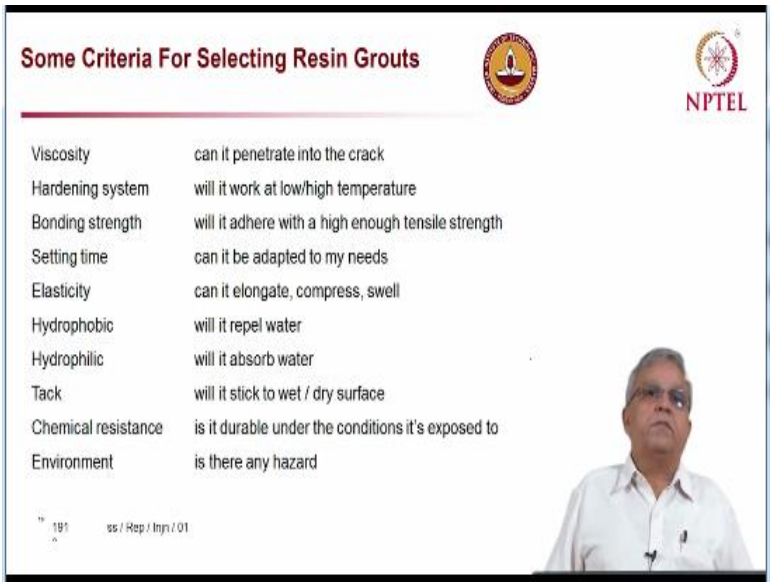

Some criteria for selecting a resin grouts, which resin grouts to be selected. We already discussed one is viscosity another is the hardening system whether it will work at the kind of temperature where the job is being done, bond strength will it adhere to with a high enough tensile strength, setting time whether it can be adapted to the actual job because some jobs may require a long setting time material.

Elasticity, whether it can elongate, compress or swell. Hydrophobic, whether it can repel water. Hydrophilic, whether it can absorb water. Tack ,will it stick to wet and dry surfaces. Chemical resistance, sometimes you got situation, underground situation and all that where there can be subsoil chemicals. Some criteria for selecting a resin rods or a viscosity we already discussed, then we have to look at the hardening system that whether it will work at the kind of temperature where the job is being done.

The bond strength whether it will adhere to the substance with the high enough tensile strength, whether setting time, what kind of setting time is required for the job; whether it has got that kind of setting time because some jobs require a long setting time because you need more time for

epoxy or PU or whatever to flow in. Then you have got elasticity whether it can elongate, compress or swell. See when we are talking about structural repair, we do not want it to elongate or compress or swell you see, but it is only for non-structural cracks this elasticity is required.

And whether it is hydrophobic or hydrophilic whether it can repel water the chemical grout or it observes water. There are some resin systems where it observes water, swells and further seals the crack. Some situation it is required. Tack, whether it will stick to wet and dry surfaces. Chemical resistance because some subsoil chemicals would be there whether it will react with the kind of grout what we are having and so on, so all these factors need to be considered before choosing the grout.

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I am just showing you one video just to give a feel of it and I wanted to avoid the name of the company or the product name but you know videos are made with some names and all that, hope you do not mind and you can see the video now. The video shows you 2-3 different types of grouting systems in the laboratory a kind of a demo and you will also see how the result of the resultant material after polymerization.

One of the first thing about; these are all PU resin systems. One of the first things is they have to mixed in 1:1 but now what he is mixing is only the activator. He is activating one of the components, now he is activating another component mixing another chemical. Now this is now

you have got one dark colored component A color as component B. Both will be mixed in the ratio of 1:1. He is measuring accurately in a paper cup and it is also the color as well.

This a type of PU resin system and it is mixed and poured. Now stop clock is on and the curing time is 10 seconds to 3 minutes. You see the consistency of the liquid. Gradually it is getting thickened, see. Now it is becoming thicker and thicker you see. And the same thing happens when this materials inside a crack or a fissure. Say within about the short time it was already become a kind of a soft solid, see.

Still it is getting polymerized and it has polymerized now. Now it is rubber like material, it can withstand lot of high-water pressure and balances this kind of material. And you see this, another kind of material which is rubber leg which can withstand more pressure of the water. Again, the same thing, activate one component by mixing something some chemical, some catalyst and after studying it you activate the other component.

Now as long as these two components the white colored one and the colorless one these two separate components do not come in contact together. These two cannot react. Now they are measured 1:1 each of them, see and exactly same procedure what we did earlier the blue colored material and now they are both mixing to this beaker and the clock is on. Again of course inside the crack nobody is going to study it but very pressure of injection will make it stand.

You can see again the consistency how it is gradually becoming thicker and thicker. From droplets it is coming kind of thread and now thread become thicker thread. This will gel; this kind of material set within about 4 to 17 minutes. Now you see it has become almost semi-solid. This exactly is what is going to happen in fissures and concrete cracks, and these are used only for non-structural cracks only to stop the water flowing out.

Now after it sets now both are taken out, you see the green one is soft, the white one is not so soft, it is a bit hard. So, this also indicates the different kind of pressure it can withstand. And they are very, very elastic and they come back to their original position very easily. And it can bend it will

not tear, now it is very, very tough material, it also shows what all the kind of penetration it can withstand without taking.

So lastly you have got one more system which is actually it is not for concrete because it is just to give as in information. This is for silty or sandy or weak soil if we you got. How it can be strengthened? So easy, in that small vessel you see that sand and again you mix activating a material. See note one important thing when you are activating and studying the stirrer is kept separate.

The stirrer used for one component is not used for the other component because it will set in reaction. Now here water is added to dissolve that particular activating salt and it is stirred and then mix into the other component and again 1:1. Now you see what happens, he is measuring precisely 1:1 and this both of them will be mixed as was done earlier and you see it is so low viscosity, it is like water or even thinner than water I do not know.

Now it is poured into the sand. Supposing you have got sandy silty soil you have to just inject it inside it penetrates and it makes that sandy material into one single piece. It is more like a; it; see. So that sand has become like a cake now you see. It is quite hard. So, this is the one way of strengthening the soil, just because it was air just to give a feel. Injection is also use for non-concrete purposes that is an objective, right, we seen this.

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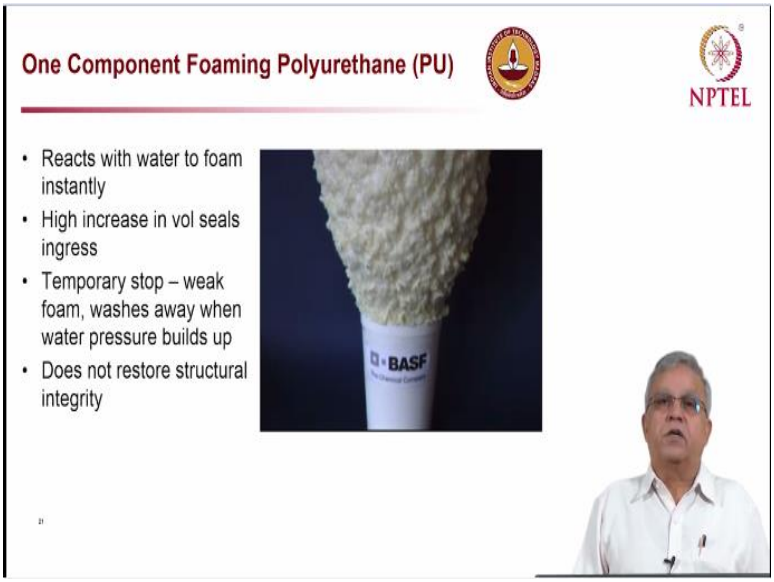

Now there is a one component Foaming Polyurethane (PU) and it reacts with water to foam instantly. Why it is required? Supposing there is a crack through which the water is coming out we inject it to immediately stop the water. High increase in volume of; volume seals crack. It is a temporary stop it must be followed up with epoxy. This is just to show; sorry about the brand name there but this is just to show how much volume will increase, foaming, how it can seal. Obviously, it is weak, but it stops the water temporarily, so which we can later on follow it up with epoxy.

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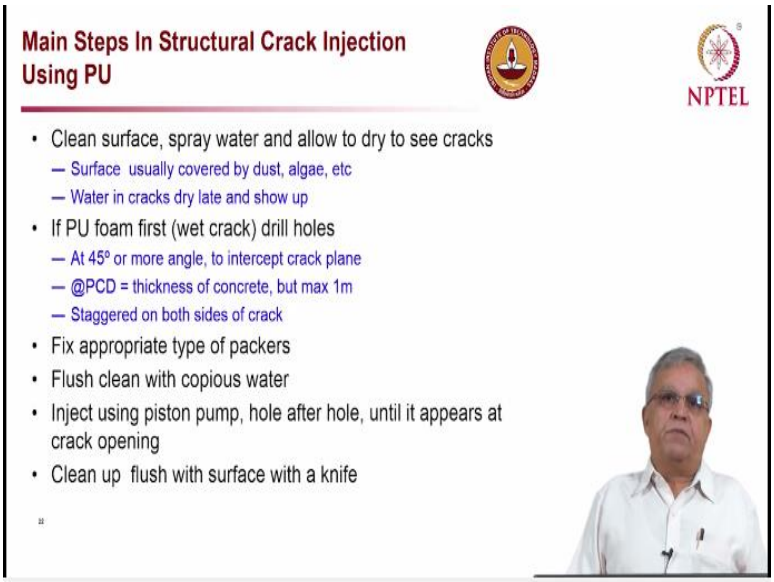

So main steps in crack injection clean the surface, spray water and allow to dry, see cracks many times is not easy to see. So first we have to wash the surface, clean the surface and spray some water so that when the surface dries crack, water in the crack will dry up slowly you see a line.

And then, if we are going use polyurethane foam first is if it is a wet crack you need to drill holes at 45 degrees or more angle to intercept the plane of the crack and the PCD of the hole should be equal to the thickness of the concrete member but maximum 1 meter.

It should be staggered on both sides of the crack and then in the holes fix appropriate type of packers. Then flush clean with lot of water, pump water inside and inject using a piston pump, hole after hole until it appears at the crack opening. When you inject the foam comes out of the crack opening and clean up the flush with surface, fresh surface with a knife.

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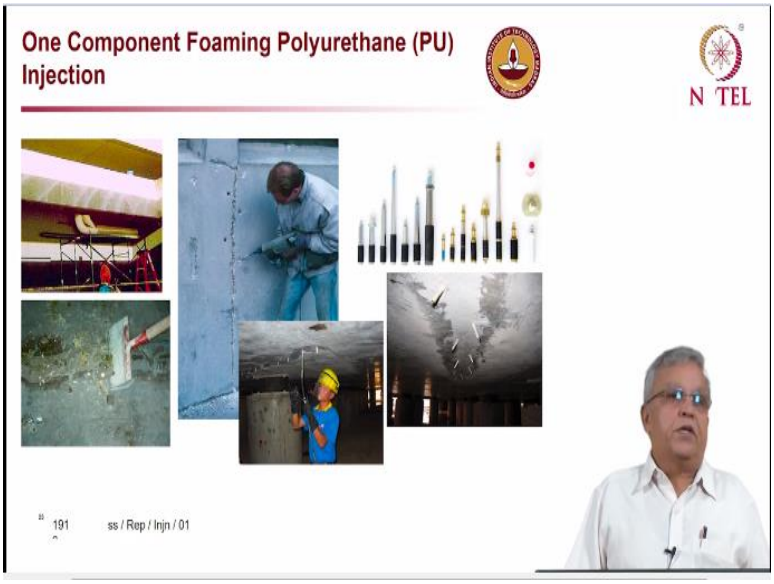

So, this is a crack lot of cracks were cleaned it up and expose the crack and drilling the hole at 45 degrees angle on both sides of the crack. And there are different types of packers, different types of packers depending upon the job the depth to which we are going to inject and so on, we chose the right packer and these packers are fixed in a crack and then through a holes it is injected and after all the injection is over it is cleaned up with a sharp edged tool everything is cleaned up.

Okay, the pictures what you are seeing here they are not; all those pictures are not taken from a polyurethane injection site, some of them are from epoxy injection. But just to give a concept how it is done I just pick the pictures.

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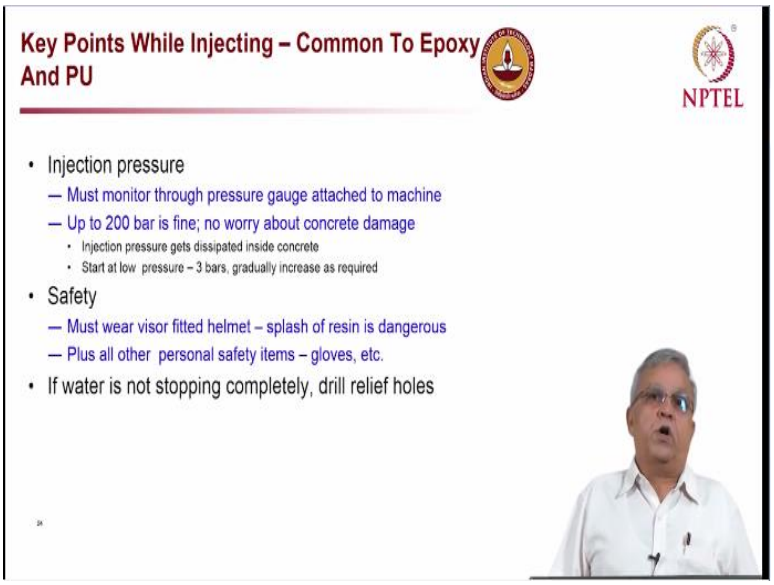

The key points while injecting common to Epoxy and PU, both epoxy and PU these are the common things we need to look in, injection pressure. We must monitor the injection pressure because there is a pressure gauge fixed the machine; we must monitor because it is important. Up to 200 bar is fine; no worry about the concrete damage, because even if we inject 200 bar pressure inside the concrete the pressure gets dissipated and it is not going to affect the concrete.

Now, then we need to start at a low pressure say at about 3 bars or 2 bars or something like that gradually increase it, whatever is required and then safety. During injection safety is very important, you must wear a visor with helmet with visor and goggles and hand gloves and other personal safety items because if some splash were to occur they are all poisonous and toxic and if water is not stopped completely during injection you need to drill some relief holes to release the pressure and continue injection and finally inject through those release holes also.

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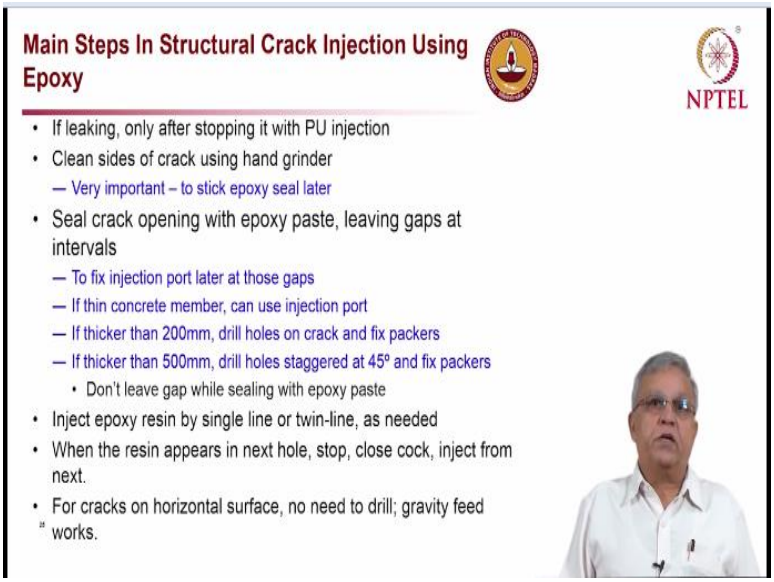

Main steps in structural cracks injection using epoxy. If it is leaking, only after stopping it we can do stopping it with PU injection we can do the epoxy injection. Clean the sides of the cracks, before we do epoxy injection you must clean the sides of the crack using a hand grinder. It is very, very important because we need to seal it later with epoxy sealer and if it not cleaned it will not stick, if it does not stick due to the pressure it can come off and epoxy can hit the eye.

Seal the crack opening with epoxy paste, leaving gaps at regular intervals, this is to fix injection ports. If thin concrete member, we can use injection port. If thicker than 200mm you need to drill holes and inject, fix a packer and if the thicker; a member thickness is more than 500mm you need to drill holes staggered at 45 degrees and fix packers. Do not leave gaps with epoxy paste sealing epoxy paste when you are doing packer fixing. Inject epoxy resin for cracks on horizontal surface, already we discussed no need to drill just gravity feed is good enough.

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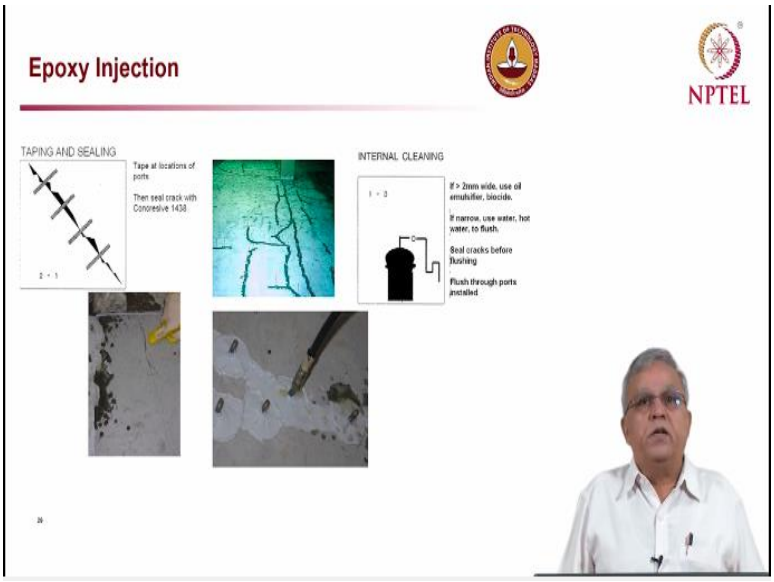

Now epoxy injection. What we have done is here is first we applied some kind of a tape across a crack at regular intervals so that when the rest of the crack is sealed, we remove the tape and then fix up port. Here in this picture you see lot of such nipples they are fixed into the crack and the crack is sealed. After the crack is sealed and ports you know, these packers are fixed we need to flush with water through the port, we need to pump water to clean up inside and then inject epoxy through one port after the other.

And you can see sometimes you have injected one crack with epoxy there is another minor crack which was not visible at all earlier through that epoxy will starts coming out showing that there is one more there, one more crack.

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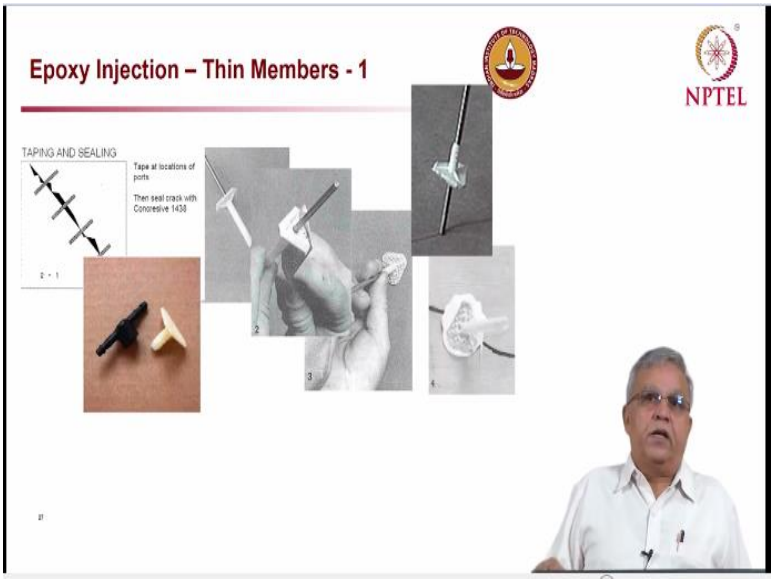

Epoxy injection for a thin member. I told you first we tape it across the crack then you use that white colored one is called an injection port. We insert a rod into the injection port and then apply some bonding edge at the bottom of the injection port the triangular flat bottom and locate it over the crack like this, see the, the pin, the rod which has been inserted through the port that rod is kept on the crack pointed on the crack and this is lowered and then fixed another crack.

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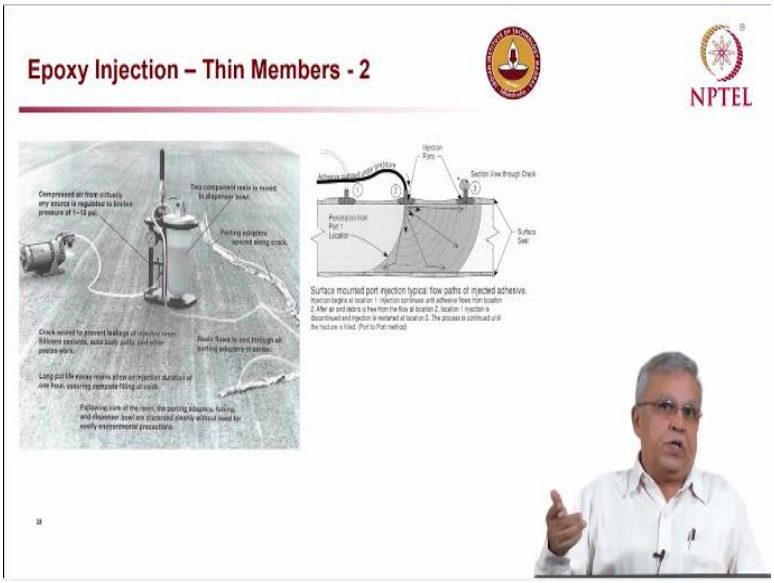

So, this arrangement you see, we saw this picture earlier and you can see the details written in small text there. There is a port, there is a pressure gauge and there is a small pump, air pump. You can also have a paddle pump. And each can develop 2 kg pressure that is good enough and the exit host the transparent polyethylene holes is connected to so many ports which are fixed onto

the crack. How it functions, you see in the extreme left already injection is over and the next port injection is going on, the resin is going in a kind of a radial direction and it starts emitting from next port. You see a small bubble coming up that shows that.

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How do you know whether the injection is done properly or not? You take a core and check, that is the only way you can.

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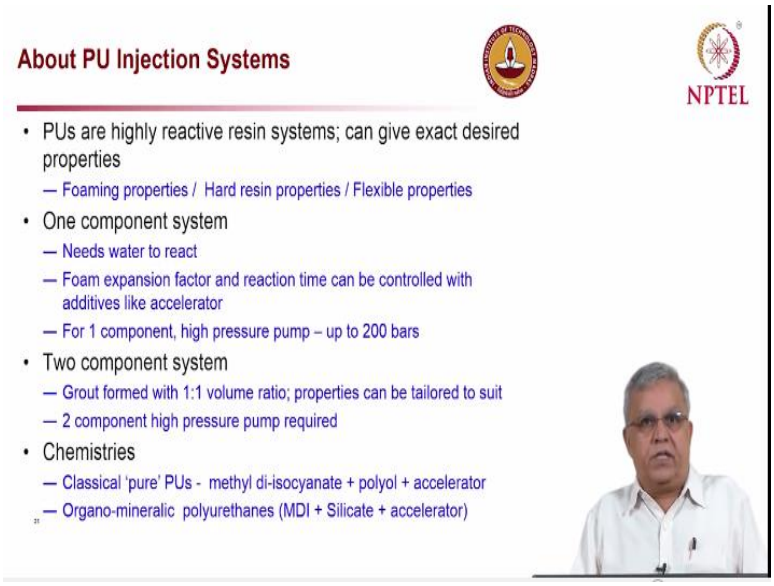

So, this is about PU injection systems. PU – Polyurethanes are very highly reactive resistance it can give exact decided property you can formulate it to that whether it is a foaming property or hard resin property or flexible property you can get it done through formulation. It can be one

component system which needs only water to react. And foam expansion factor and the reaction time can be controlled with some additives like accelerator.

So, some places say there was a case wherein some 600-700 liters of water was leaking out from a single point and tried to be stopped, we need to have a very quick expansion factor and as well as very quick huge expansion factor. So, for 1 component we need a high-pressure pump, one component polyurethane up to 200 bars. And then two component systems, it is grout is formed with 1:1 volume ratio we saw earlier some video; properties can be tailored to suit.

What properties, whether; how hard the foam should be and so on and 2 component high pressure injection machines are required. The chemistries are very simple; I will not go into too much of chemistry except to say that, there is what is called as a classical pure polyurethane which has got methyl di-isocyanate plus a polyol plus an accelerator; there is another modern highly versatile system called organo-mineral polyurethanes which has got a MDI that is methyl di-isocyanate plus silicate plus accelerator.

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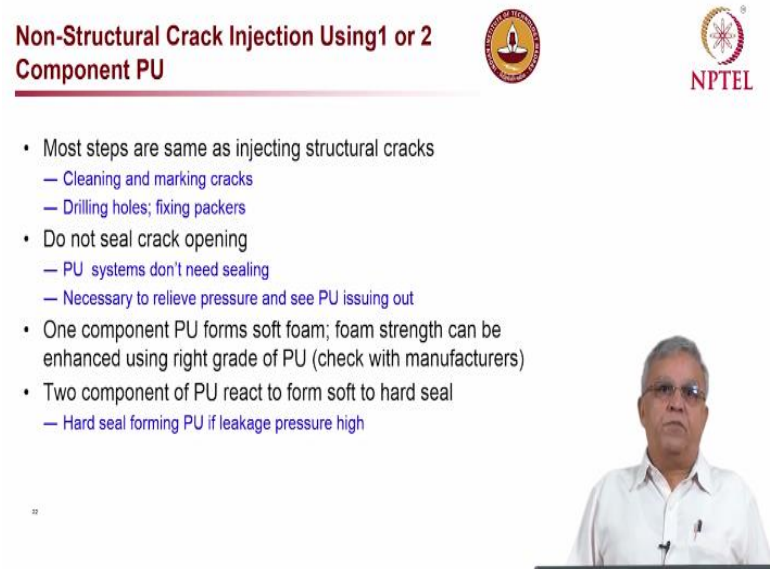

Now, non-structural crack injection using 1 or 2 component PU, most of the steps are same as injecting structural cracks, that is why I do not want to repeat them here except cleaning and marking of cracks. You need to clean and mark the cracks I mean the same thing, drilling of holes,

fixing of packers. But in the case of PU we do not seal the crack opening. In the case of epoxy, we seal the crack opening, okay.

And one component PU forms soft foam; the foam strength can be enhanced using right grade of polyurethane. You need to check with manufactures and the two components of PU react to form soft to hard seal, different degrees of hardness and hard seal forming polyurethane is require if the leakage pressure is high.

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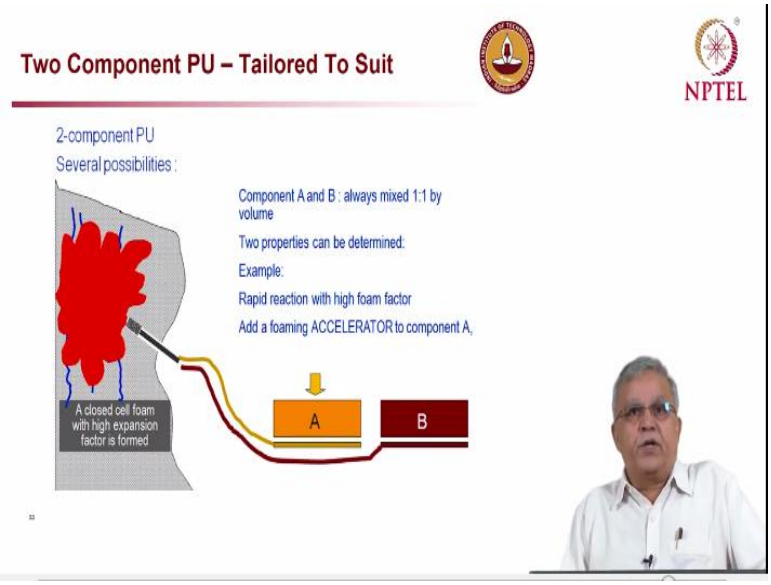

I am just showing you; this is an example of how you can tailor the two-component polyurethane system to meet a particular purpose. Here what we require was rapid reaction with high foaming factor to stop high leakage, so this was used.

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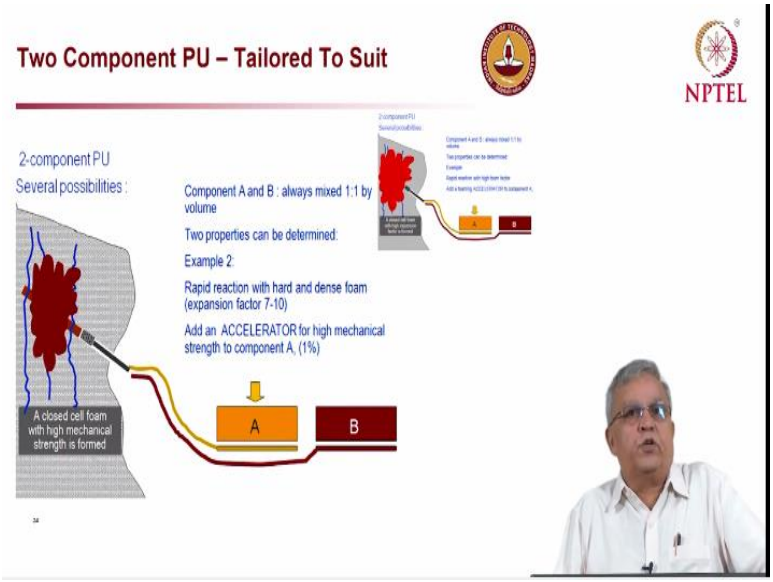

There can also be another case wherein a dense foam is required. It is not just rapid reaction but will also need a dense; hard and dense foam so you need something else. These two illustrations are just to show that you can tailor two component PU to suit the actual requirement.

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And these are two examples of machines. There are many different types of machines used.

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And the point of injection; I mentioned to you this is important where the nozzle or lance we call it as a lance for injecting. The assembly various different components you see two different components coming, there is a pressure gauge and so on just to give a feel of it.

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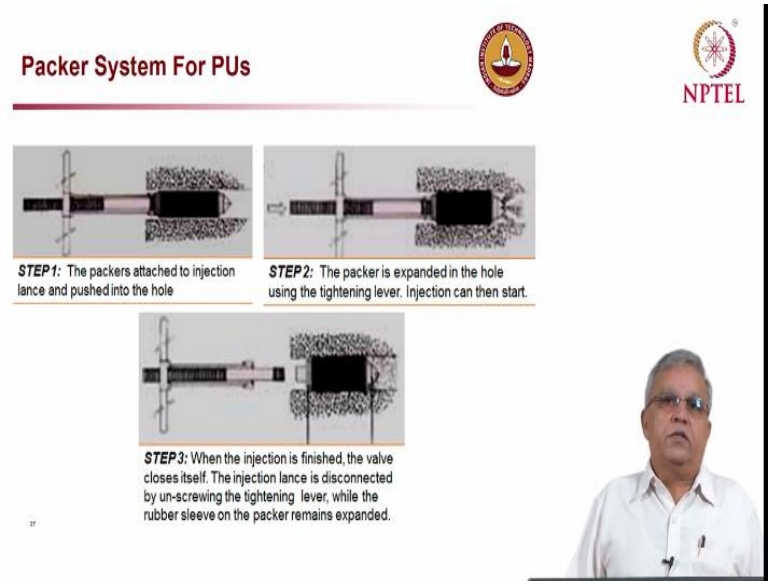

So you; when you are fixing a packer first you fix a packer, the packers are attached to a drilling lance and inserted into the hole and there you see a liver that liver is tighten turned clockwise then inside you see the rubber has bloated you can see that and that bloating of the rubber holds it into the hold without slipping even in a pressure. Then after the all the injection is over automatically the valve closes then we can turn it anti-clockwise you know, unscrew it and remove it. But we have to leave the packer; we have sacrifice it.

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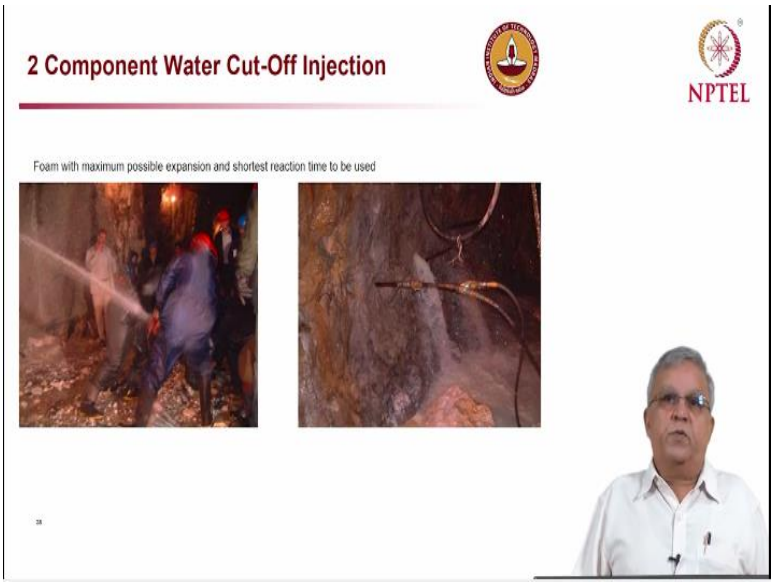

This is a picture of a water cut-off injection; water is leaking through a tunnel valve and two component system is used; you can see water is still flowing and gradually it comes to an end. I do not want to show a video because it is a long video taking long time.

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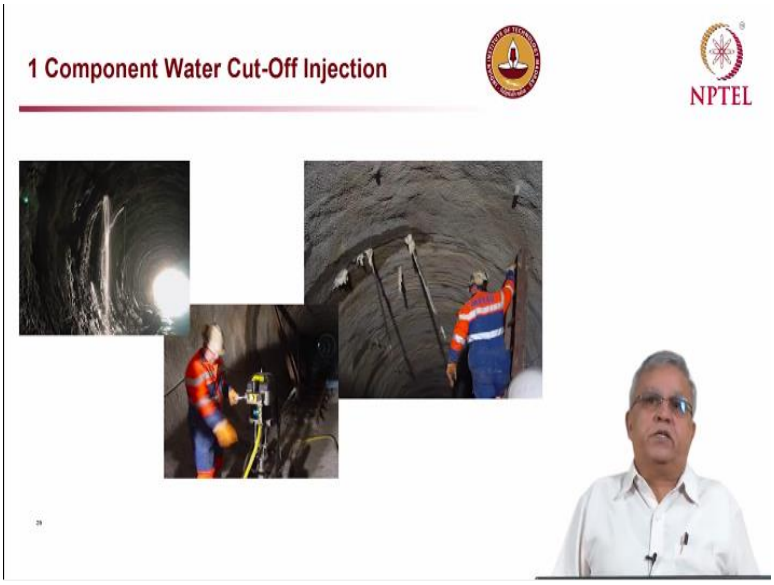

1 Component water cut-off injection, you can see in a tunnel a lot of water leaking points are there and then one component PU is injected. Here so much water is there, a huge foaming factor as well as rapid reaction is required and finally it is all stopped. You can see, where the water was leaking it has all stopped.

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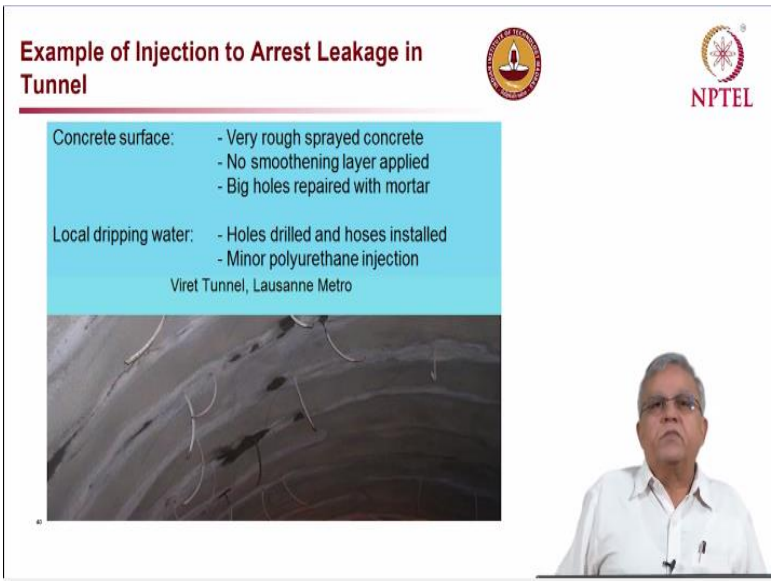

So, there are quite a few example, example of injection to arrest leakage in tunnel. See this a place called Viret Tunnel in Lausanne Metro construction and what you see here is in the concrete lining and the roof corrode lining you see in the drill hole, it is not the stiff steel packers that is used it is a rubber host.

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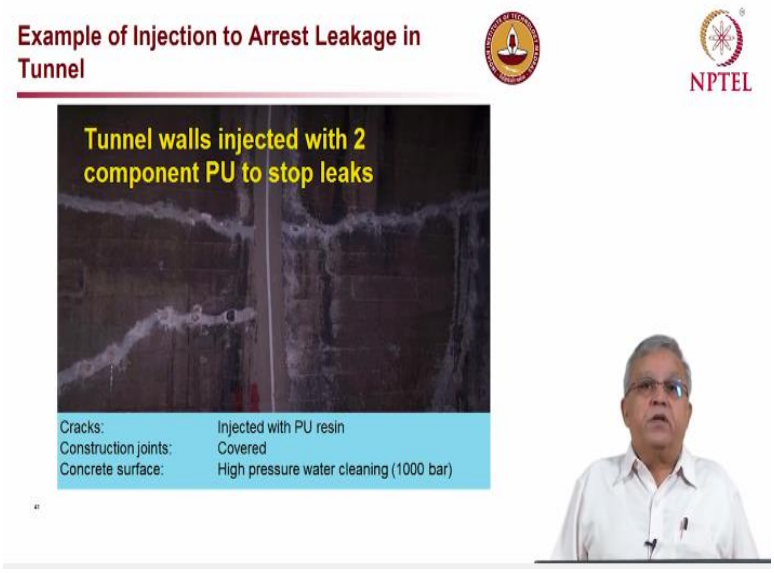

And this another case wherein a tunnel walls were injected with 2 component PU to stop leaks and a high-pressure water cleaning has done.

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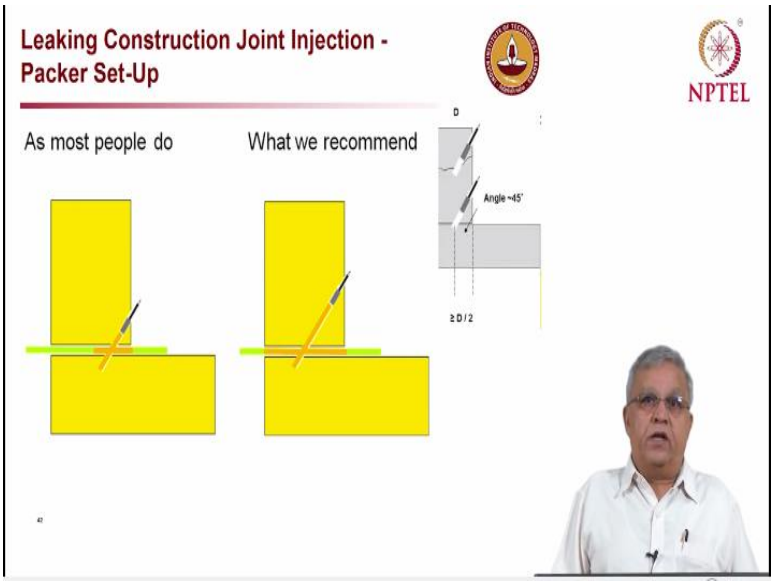

Now, the same technology can be use for leaking construction joint injection. But here please note that we have to choose the resin very carefully where we are injecting, where we are drilling a hole the angle of drilling a hole. It should ideally be in the middle of it, middle of the section.

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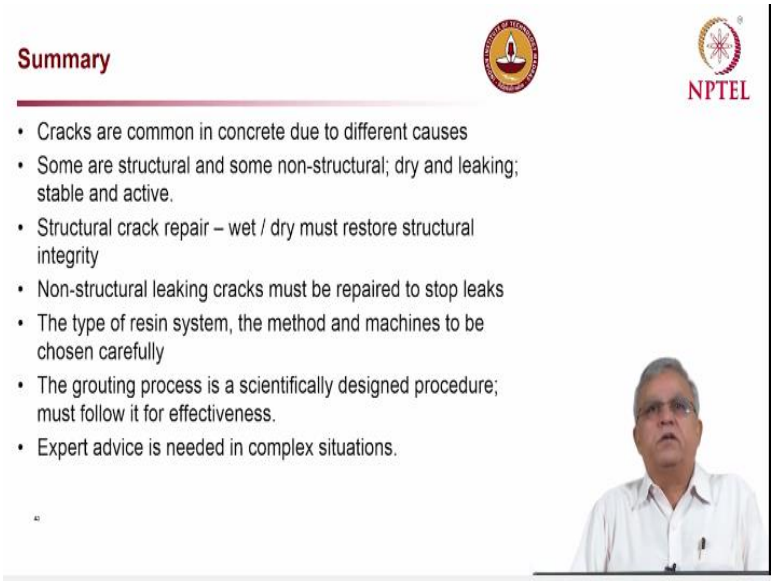

I will not go through the join injection in detail because it is all similar to whatever we talked over crack injection. But just to summarize this session, the cracks are common in concrete due to different causes we discussed. Some of the structural cracks and some are non-structural, some are dry, and some are leaking crack, some cracks are stable, and some are still active, so systems have to be chosen accordingly.

Structural crack repair wet and dry whether it is wet or dry it must restore the structural integrity that is the key requirement. And non-structural cracks leaking cracks it must be repaired to stop leaks. And the type of resin system, the method and machines to be chosen carefully to suit the job, we discussed all these. And the grouting process is a very scientifically designed process, procedure.

It must be followed for effectiveness; I mean I have come across many people taking shortcuts and finally; I mean they keep doing it repeatedly. So, there are some complex situations wherein expert advice is required; this kind of lecture alone is not sufficient amount of reading, guidelines and all that, they may not be sufficient, you need to have an expert advice. So, thank you very much for all the patience listening.