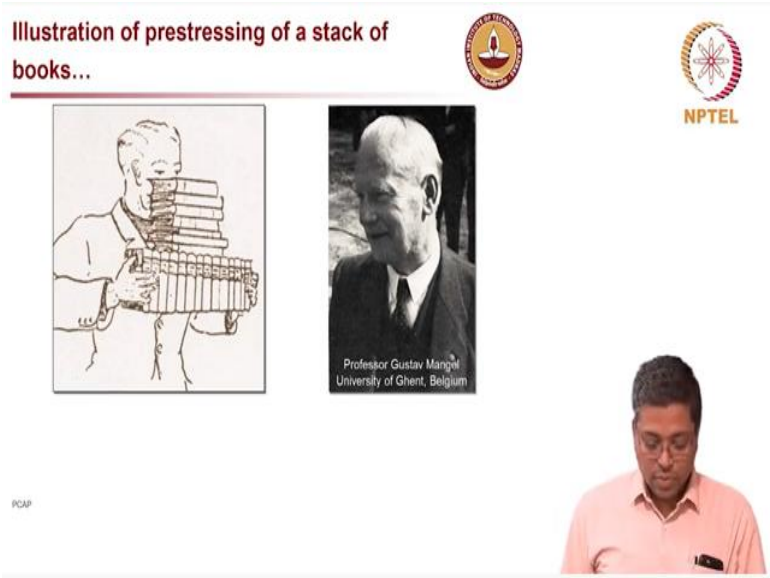
Maintenance and Repair of Concrete Structures
Prof. Radhakrishna G. Pillai
Department of Civil Engineering
Indian Institute of Technology – Madras

Lecture – 07
Corrosion in Prestressed Concrete

(Refer Slide Time: 00:29)

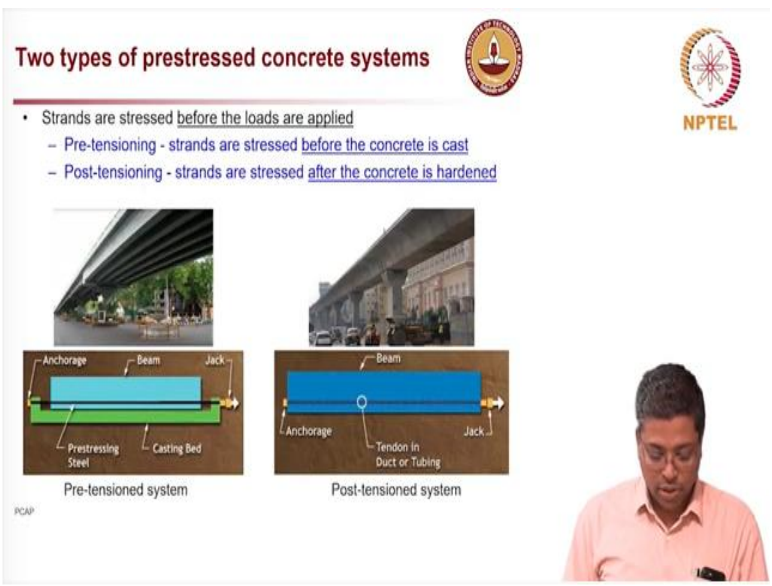
Today in this module on corrosion of embedded metal, we are going to cover corrosion in prestressed concrete systems most of the time there is something special about the corrosion mechanisms in prestressed concrete as compared to the conventional concrete systems.

(Refer Slide Time: 00:32)



I am going to show you very classical illustration of prestressing using some stack of books. You can see this is Professor Gustav Magnel's demonstration. He used to do it in class. Take a stack of books and then press it from the sides so that you can carry more load. So this is the same principle applied for prestressed concrete systems also where you have prestressing.

(Refer Slide Time: 01:06)

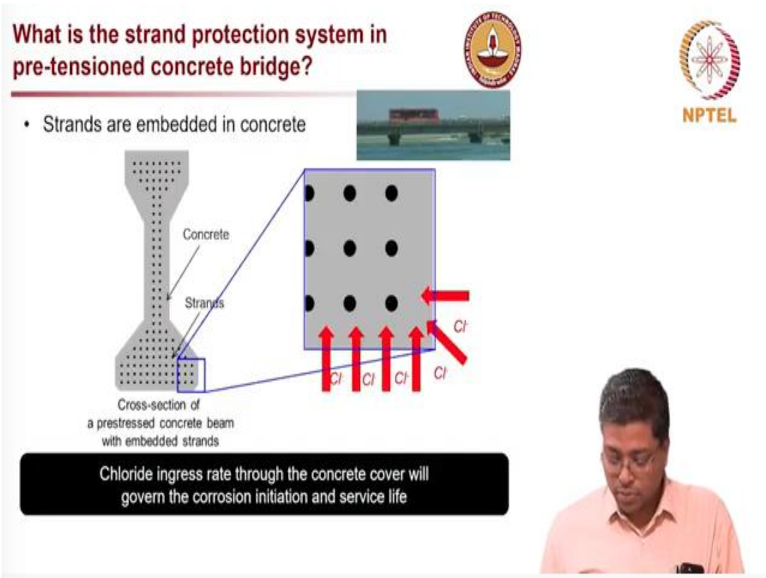


There are two types of prestressed concrete systems, one is pre-tensioned system and the other one is post-tensioned system. The one on the left is a pre-tensioned system.

There are two types of prestressed concrete systems based on the time at which the strands are stressed if it is pretensioned concrete system then the strands are stressed before the concrete is cast. In the post-tensioned concrete system, the strands are actually stressed after the concrete has achieved its strength or after the concrete has hardened.

So, one on the left which you might see these kind of bridges most of the flyovers in the city you might see this kind of systems most of them are actually pre-tensioned concrete. This is a typical metro on the right side. It's a typical metro bridge or elevated metro system where you will mostly see post-tensioned segmental concrete construction. Also I would like to mention if you see an I-girder it is not necessary that it's always like these kind of I-girders. It's not necessary that they are always pre-tensioned but there could also be post-tensioned system.

(Refer Slide Time: 02:29)



So, what is the corrosion protection strategy in the pretension concrete? Here you can see in this close up you have the black dots which are the strands and the grey region represents the concrete. The chlorides penetrate through the concrete cover and reach the steel strand through diffusion or the typical chloride ingress processes which are also present in the conventional reinforced concrete systems.

And then once the chloride builds up to a sufficient level at the steel surface you can say that the corrosion will initiate.

(Refer Slide Time: 03:09)

The pitting corrosion on strands and deformed bars are of 2 types or the type of corrosion which you see in the case of rebars and in the case of strands are little different especially the corrosion cracking patterns. So, for example in the case of typical rebar or a conventional deformed bar like in this case what happens is. You can see that some pits here and there.

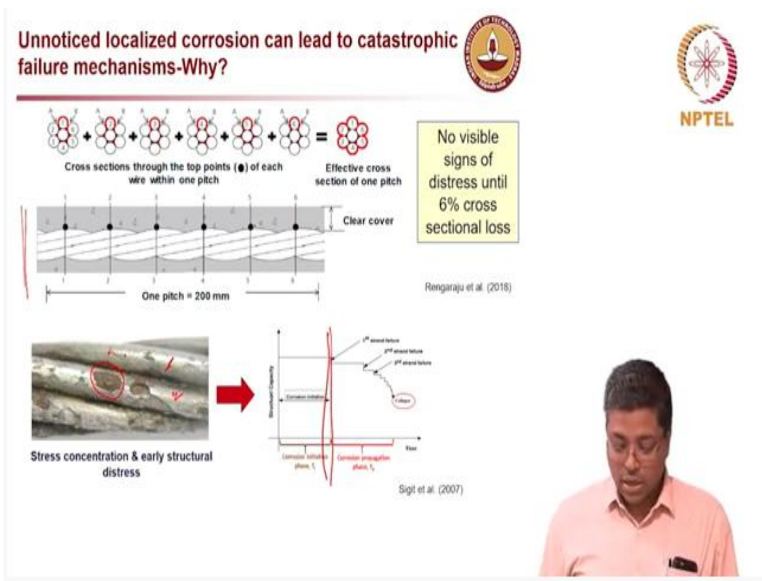
But there are also regions which are not pitted much but the point here is there is no space like in the case of strands. Rebar is a single solid bar and the only surface which is corroding is actually in contact with the concrete. So, whatever the rust is formed it will very fast exert expansive stresses on to the concrete nearby leading to cracking and then followed by the oozing out of this rust through the concrete cover and then you can see that brown stains on the concrete surface.

But in the case of prestressed concrete system it’s a little different what happens is. First because of the stress the pitting can be very significant or much localized and you can see very severe pits whereas some regions are not at all corroding or very limited corrosion. But you can actually have severe pits which might lead to the fracture of that particular wire. Like in this case this particular wire will fracture much earlier than the others which might lead to structural problems.

And also on top of that whatever the rust is formed in the beginning they will occupy these small triangular shape spaces between the 7-wires. Once this space is fully filled with the rust only after that the rust on the strands will actually exert pressure on the surrounding concrete. So because of this what will happen is? There may be prolonged corrosion before you actually see some brown stains.

So, visual observation is not really a good idea when you talk about post tensioned systems. In the case of strands there could be delayed expensive stresses, cracking and manifestation of corrosion products.

(Refer Slide Time: 05:53)



Another thing which can happen in the case of prestressed concrete system is that as you see on this image here or if you take 1 pitch length of the strand that is shown in this picture here. You can see that all the 6 wires are actually getting corroded not only a wire in other words in 1 pitch all the wires at the top surface and those portions are getting corroded.

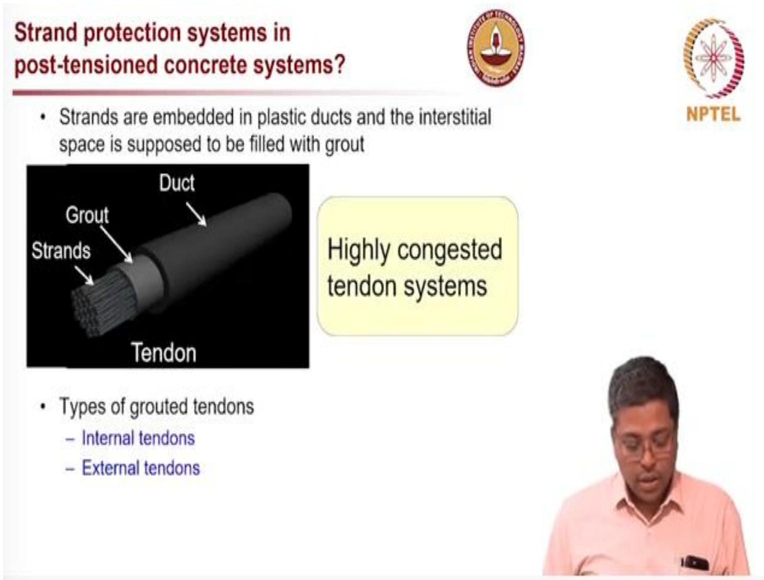
So, effectively what you can see is. When you look at the cross sectional loss over a pitch length it is approximately 6 times the cross sectional loss on 1 wire. So effectively you lose significantly as compared to a rebar. If it is in the case of a rebar let's say you have a rebar like this which is a solid bar only the top portion will be corroding and then this region will not be actually corroding and the picture on the bottom left you can see, severe pitting like this here.

You can see a pit form. So severe pitting whereas some region there is no corrosion at all. Now because of this there will be significant reduction in the structural capacity and that is a significant concern. So actually in this case of prestressed concrete we don't even want to get into the corrosion propagation phase. In fact, we want to enhance or increase the duration of the initiation phase as much as possible. That is because once it starts corroding it becomes very dangerous in the case of prestressed concrete systems.

(Refer Slide Time: 07:40)

Let's look at what is the strand protection strategy or system in post-tensioned segmental concrete. As you see in this sketch here you have several box girders or the segments like in this picture you have 2 diaphragms and then 4 segments just to show but there will be more just to make it clearer to understand I have put it something like this. And then you have tendons which run from 1 pillar to the other. Typical simply supported systems will be something like this.

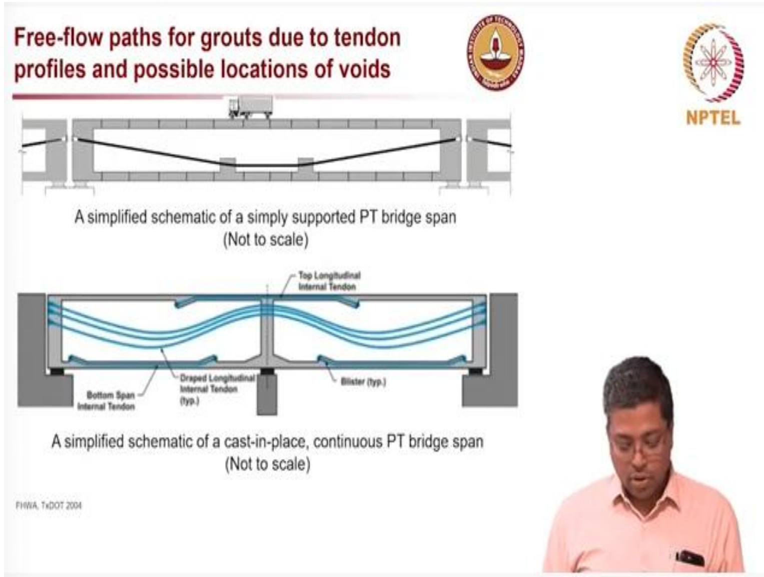
(Refer Slide Time: 08:19)



When you look at the tendon alone, each of the tendon is made of about 19 or depending on the diameter of the tendon you will see multiple strands are placed inside a duct; inside a plastic duct or high density polyethylene duct which is this one and then the space in between the strand and the duct is filled with the cementitious grout. Now, this highly congested strand and that is where the challenge is how to get this space between the strand and the plastic duct filled with cementitious grout properly.

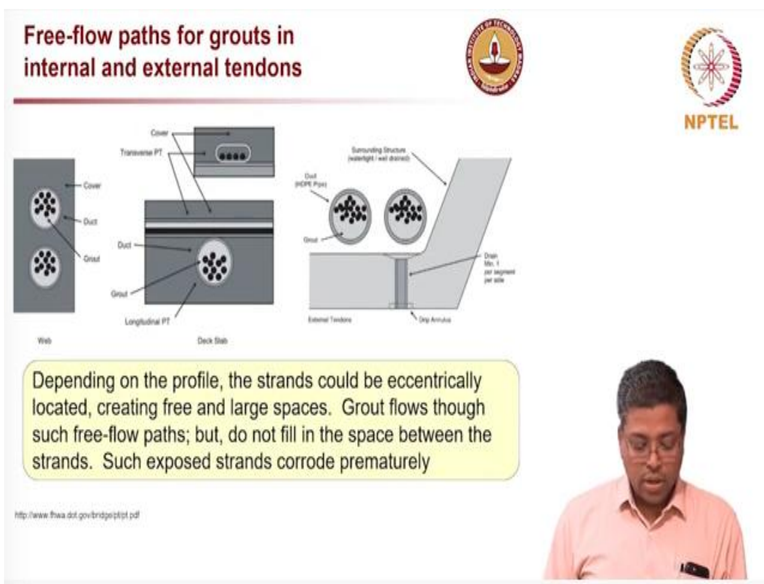
That is the biggest challenge and if it is not filled properly you can actually experience significant amount of corrosion or early corrosion of the system. There are 2 types of tendon systems one is internal and another one is external. The internal is when the duct or the entire tendon is inside the concrete where the external means it is kept outside the concrete.

(Refer Slide Time: 09:26)



Depending on various reasons designers might choose either internal or external tendon system. So here, it shows a typical profile of tendons on the top drawing you can see it is a straight profile like this and then it goes like that. In the bottom one you will see a curved profile mainly because here it is a continuous beam system and in the top one typically when you have simply supported system you go for that kind of profile.

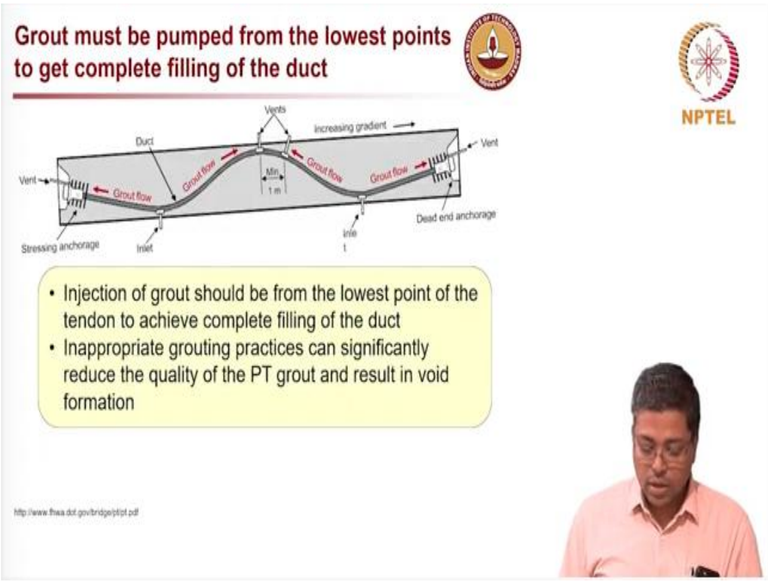
(Refer Slide Time: 10:00)



When you have this profile the strands will not stay at the centre of the duct. When you pull the strands depending on the profile the strand will try to occupy a shortest distance and it will get little bit eccentric to either one of the sides of the duct as you see here on the left image if the strand is pulled then it is moving towards one direction as you see here in both these tendons, the strands are more congested in the top portion of the duct than at the bottom portion.

And in this case over here you can see that strands are pulled towards the bottom. In this case also it is actually at the bottom. Here moving towards the top. So it is not necessary that always the strands to be at the centre. So, because of this what is actually happening is. There is some region here like this as I am drawing where you have less congested region and the grout which you fill flow through that region and then it will reach the other end. Then people generally conclude that if the grout is pumped from one end of the tendon and if it is reaching the other end it is actually completely filled. But that is not the right conclusion to make because you have to really make sure that this congested region like this here is actually filled up that is very important.

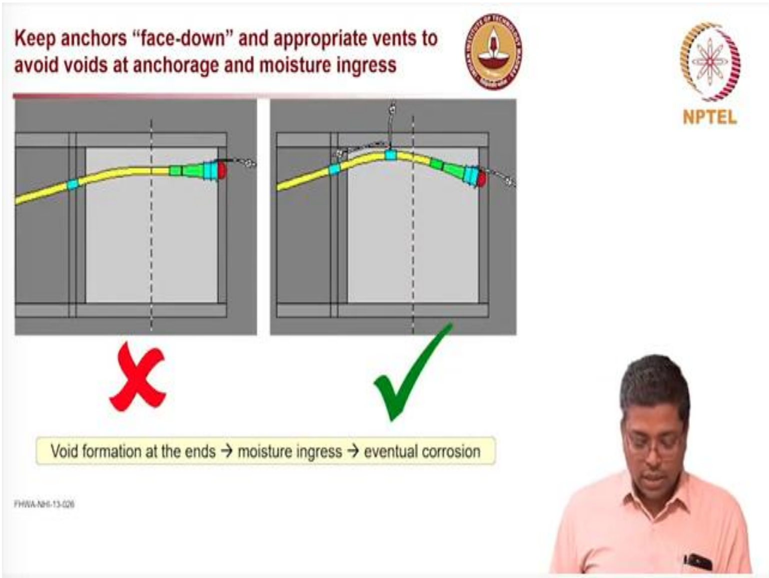
(Refer Slide Time: 11:40)



For achieving that we should a very good grout and also allow enough time for the grout to flow and best way is instead of pumping the grout from one end of the duct to the other end you pick the lowermost points as per the Federal Highway Administration this is the recommendation especially based on a study conducted by Florida Department of Transportation.

So as you see here they pick the lowermost points on the profile and then try to pump in. This is the inlet, pump the grout into the duct and then the grout is allowed to flow upward and through this vent it is supposed to come out and then vents here also. So the filling from the bottom most point let the grout flow upward and that is how it is supposed that will actually ensure much better filling than filling from one end and letting the grout flow downward etc.

(Refer Slide Time: 12:43)



Now other thing is to prevent the void formation at the end or the anchorage. You can also do a little bit to prevent the void formation and entry of moisture. You can see that slight inclination of the tendon profile at the end can also so, for example if this is the end of the anchorage zone if water is coming through like this it will never go upward like this. But in this case you may see that water going like this. So that is kind of this is not good and this is good practice to follow slight change in the profile.

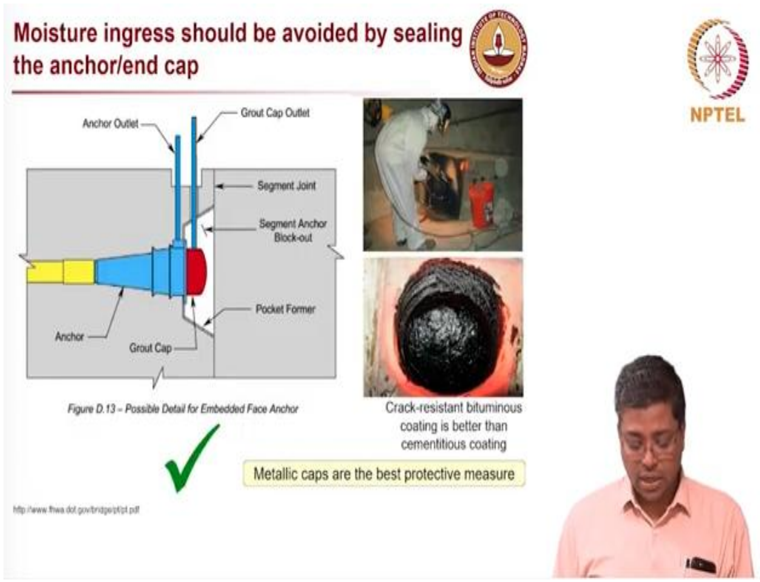
(Refer Slide Time: 13:25)

Nowadays, you will see that most of the tendon systems you have this cementitious cap like this. What is happening in this is? Cement has an inherent property of absorbing moisture, it is hydrophilic in nature. So, it will absorb the moisture and then if that anchorage region has sufficient moisture. Definitely it is going to lead to corrosion of the strands at the near anchorage zones.

And you might see strands corroding something like this in very short period of time which is not really a good thing to happen. Especially when we think that these types of structures are supposed to last for 100 years or more. Now, recently people are also practicing to put some kind of polymeric coating on this like water proofing coating.

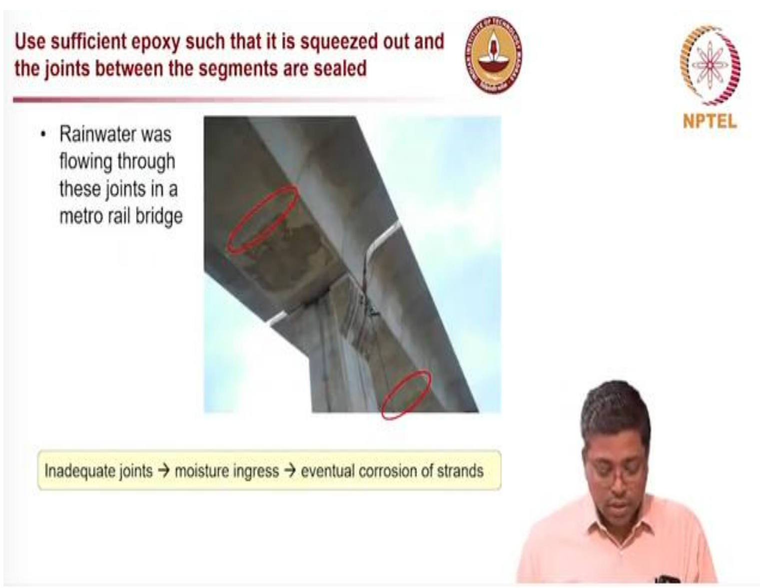
But remember that these structures when they are exposed to sunlight these polymeric coating might actually degrade in very short period of time maybe few years down the line they might degrade unless it is prevented or protected from sunlight. So I would say the metallic caps are the best preventive measure for these kinds of systems.

(Refer Slide Time: 14:50)



And on top of the metallic cap you also should have very good concrete element which will protect it. You need to really take care of the anchorage zones otherwise these structures will have severe corrosion problem in very short period of time.

(Refer Slide Time: 15:10)

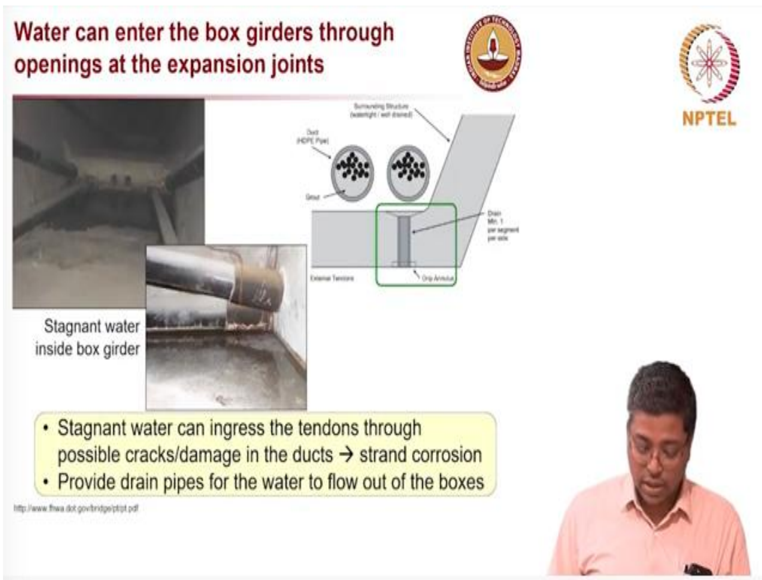


Now, these are the segmental joints, the joints we can see here. So these joints usually are supposed to be filled. Earlier few decades ago people used to go for dry joints means there is nothing in between the 2 segments. You just keep the 2 segments together and then you know press it or due to the prestressing action itself and then rely on the shear keys for the resistance.

However, later on people found that it leads to severe corrosion because through this dry joint oxygen and moisture can penetrate and will lead to localized corrosion of the strands which are going like this. So this region will actually corrode. So, to prevent that recently people are actually using epoxy joints. That means you put epoxy on the facing surface of both the segments and then push them together and squeeze it.

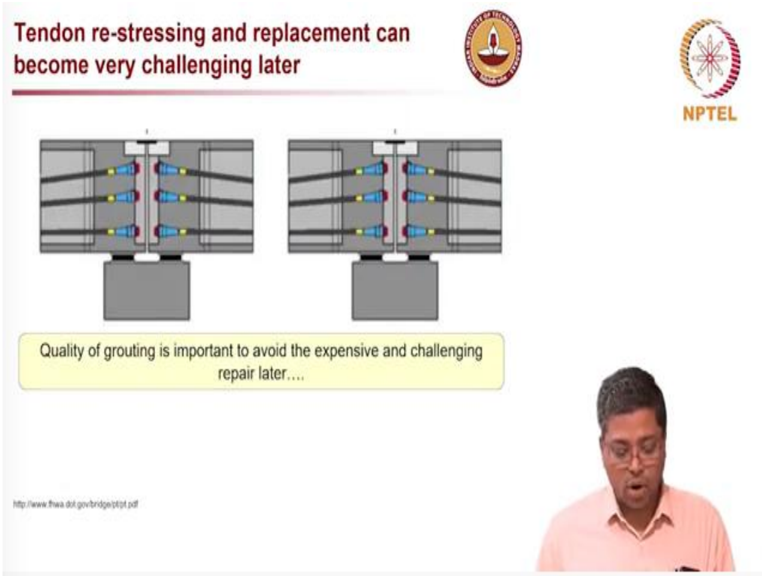
Because of prestressing it will get squeezed and it is supposed to fill the entire region and to prevent the entry of moisture and oxygen it is very important. But we have seen if you do not really put a good amount of epoxy it will actually lead to further leakage and corrosion later on.

(Refer Slide Time: 16:36)



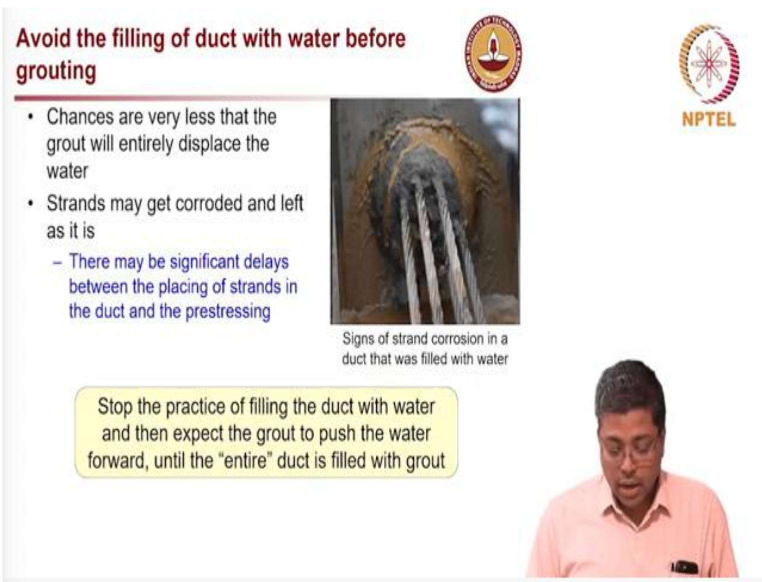
This is an example showing that inside the duct you can actually have stagnant water and it is very important to make sure that these kinds of things don’t happen. This is not good for the strands. So how do we prevent that? There is a design procedure where they suggest to provide a drain hole, I mean hole on the segment for draining the water. Whatever possible water stagnation it will drain and then let the water out. It is very important to keep these systems away from water.

(Refer Slide Time: 17:17)



This is an example; I want to show where the water can come in. This is an expansion joint and 2 girders. Water can come in and then enter here to this way and this way. So this is a severe issue. So this must be avoided by making sure that there is a very good protection mechanism to prevent the entry of water.

(Refer Slide Time: 17:44)



There used to be a practice of filling the duct with water before the grout is filled in and then expecting that the grout will actually displace the water and prevent the formation of air void. This was the idea for going for practicing filling the duct with water. But it is not really a good idea because the strands might get corroded and the type of water which you use if it has a lot of chlorides that might also affect.

So, because of this nowadays it is not recommended to fill the duct with water before filling the grout, okay. So you can see here this picture was taken from one of the sites where this was actually practiced as you see here the colour of this grout it is not grey, it has a lot of rust getting mixed with it. So it is a proof that the strand inside has corroded to some extent. So that is something which needs to be avoided.

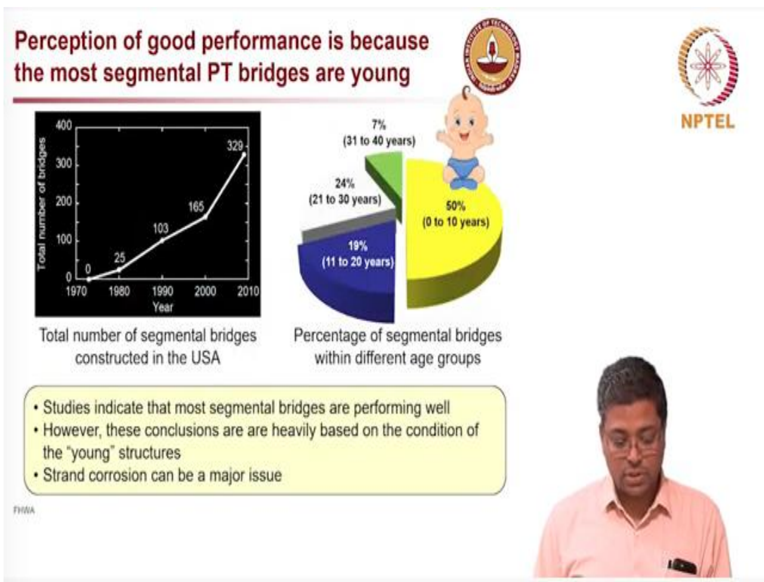
(Refer Slide Time: 18:51)

Also we should have a good number of inspectors and qualified persons at the site. This is a picture taken almost 9 years ago but what you can see is there is no inspector at this site when the bridge was being grouted. Because the grouting in essence is not given sufficient importance and that is where the problem lies I think.

(Refer Slide Time: 19:20)

And then also the shear keys it is leading to this you can see an example where a shear key is lost and you know it does not really have a good shear resistance, this might really affect the shear capacity of this.

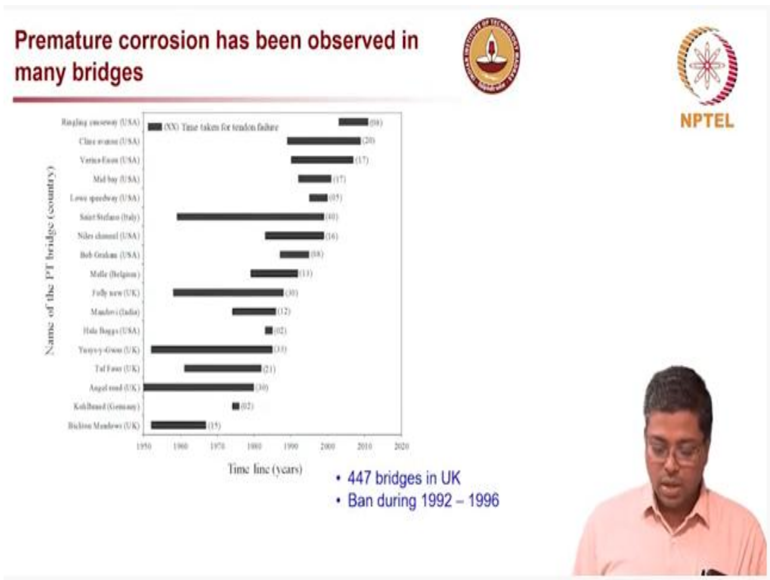
(Refer Slide Time: 19:36)



We generally think that the post-tensioned concrete bridges are performing well. Why we have this feeling is? Mainly because most of the structures which we see around are less than 10 years old or they are very young. Babies always look good so that is one reason why we are having general feeling that all these post-tensioned structures or prestressed concrete structures are of good quality.

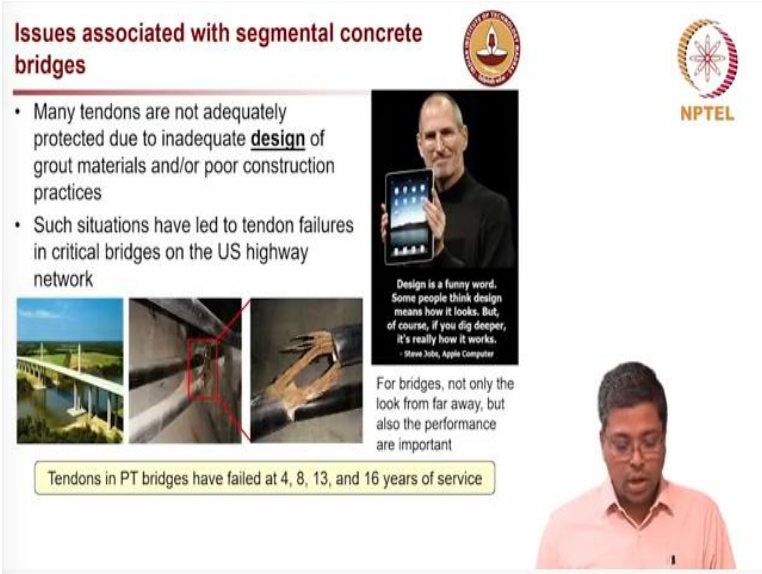
But as time passes we will see that the size of this yellow region is going to reduce and then the green, white and blue it is going to increase. So, I mean this is also a pie chart here. So let us not judge the long term performance of these structures based on the short term performance. It is very important to understand this and we really have to do things. So that, these young structures will actually last as long as they are decided to last. So the protection of strands from corrosion is very important.

(Refer Slide Time: 20:57)



So this is a bar chart showing the premature corrosion on post-tensioned bridges. So the numbers in the parenthesis show the number of years before they shown corrosion.

(Refer Slide Time: 21:15)



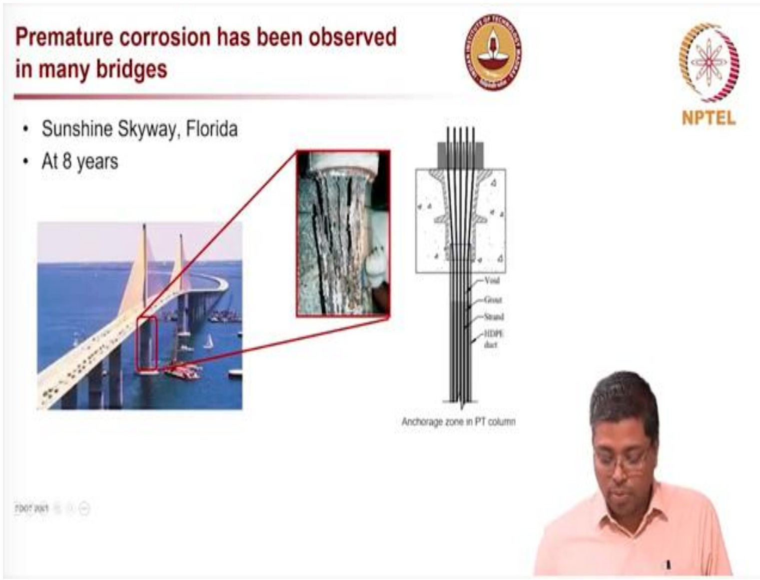
What are the issues? Mainly the tendons are inadequately grouted and hence they corrode prematurely. In this picture here this bridge actually failed after the tendons were refilled with grout and in a very short period you can see here within about 15 years they started experiencing corrosion which is not at all expected in these kinds of bridges which are designed for 100+ years.

(Refer Slide Time: 21:47)

Now, where is the corrosion actually happening? You see the profile here and then what is happening is, the cement in the grout will segregate, cement will move downward and water will move upward. So cement will move downward; water will move upward and then basically it segregates and then you see lot of bleed water will form at the top portion of the tendon like it is shown in this close up.

Then eventually that bleed water will evaporate. So you can see this unshaded or the white region is supposed to be filled with grout but it is not. So that will lead to additional problems.

(Refer Slide Time: 22:33)

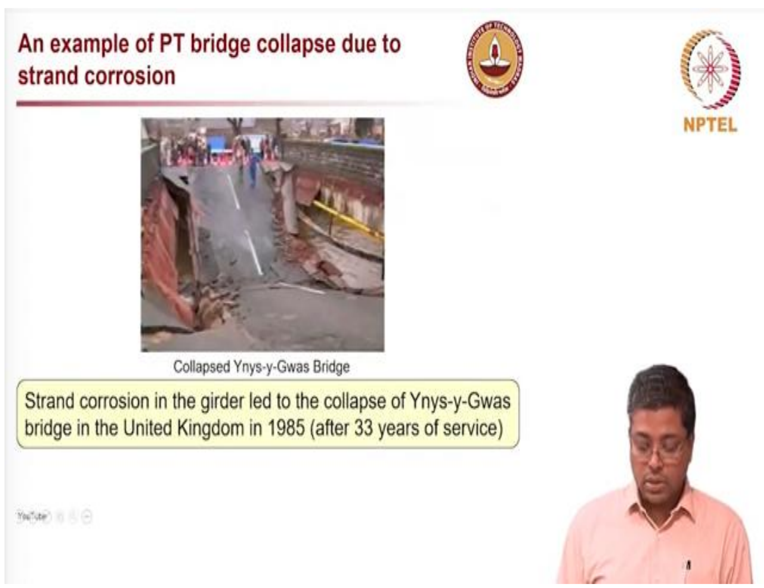


This is another bridge where you can see a vertical tendon like in this pillar where this portion here is not at all grouted. So that is also leading to severe corrosion as it was visible in about 8 years this strand system completely corroded which is again very early corrosion.

(Refer Slide Time: 22:54)

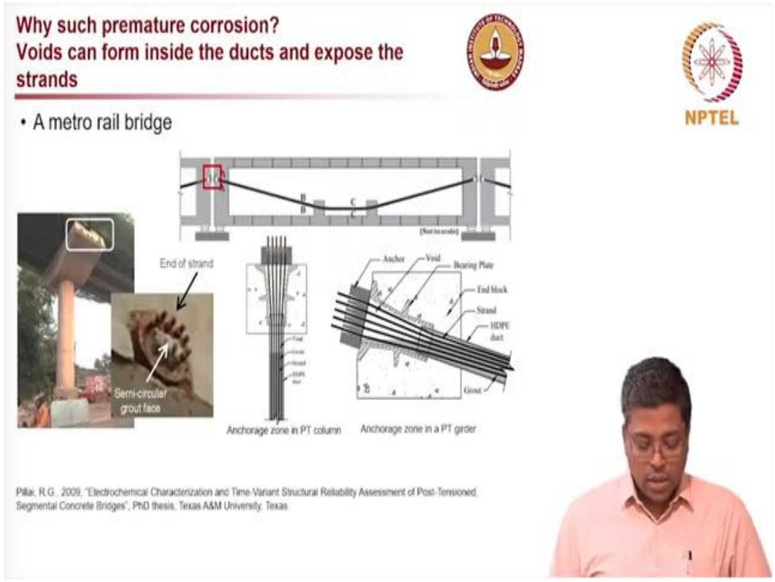
Other kind of problems which can be observed is the broken ducts. If the plastic is not of high quality then broken ducts problem may be seen, lot of voids in tendons present and then water stagnation and then even there are regions where there is no grout at all. This is a picture taken from the center span. But there is very clear indication that there was no grout reached at this location.

(Refer Slide Time: 23:24)



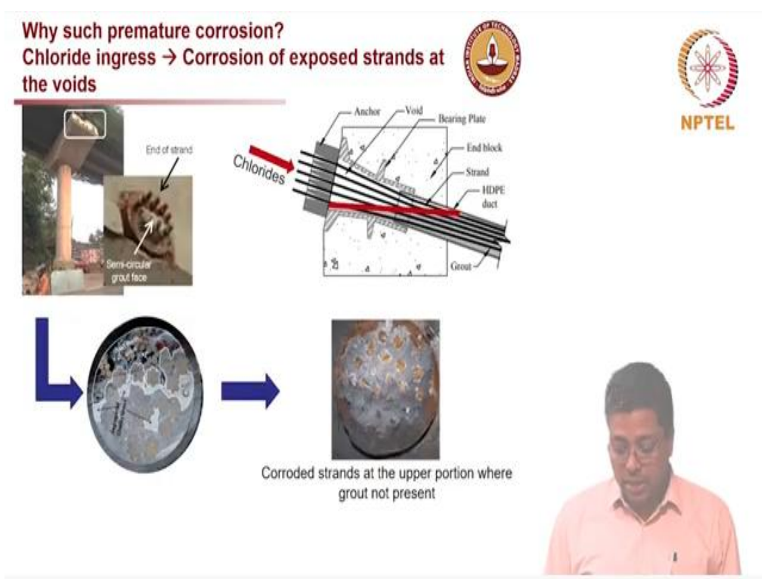
This is another failure which happened in just 33 years due to poor grouting.

(Refer Slide Time: 23:34)



This is another demonstration of poor grouting being done. As you see in this bridge here, on this end you can see a semi-circular region of grout. If the tendon was completely filled; the tendon goes like this, horizontal tendon on this girder, the pier cap if it goes, if it is not filled properly you will see the semi-circular or partially filled region. If it is properly filled with grout it should be a perfect circle and which is not visible it is very clear that the grout is not properly filled.

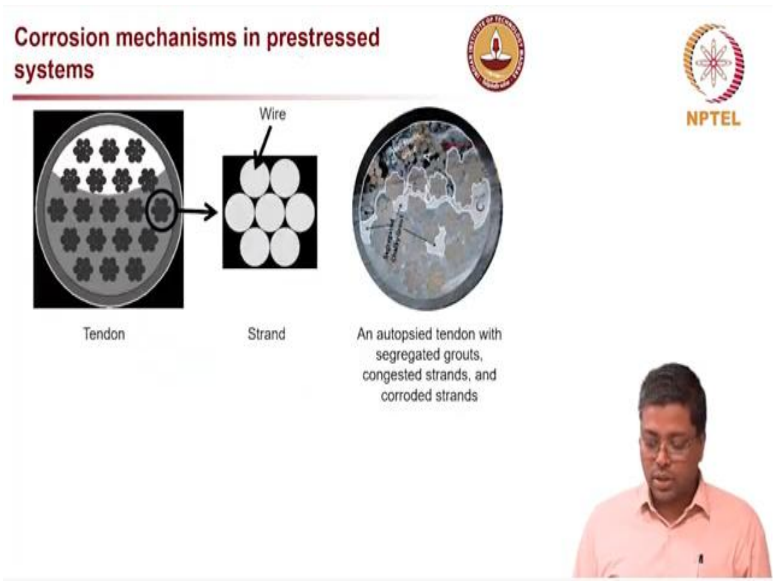
(Refer Slide Time: 24:16)



What is the problem with this is that after some time as you see here if there are regions with no grout and with grout. The top portion of this grout indicated by this horizontal red line, the top portion will get very easily carbonated. Now when you have carbonation like that and chlorides can enter and CO_2 can also enter through this and it will carbonate this region.

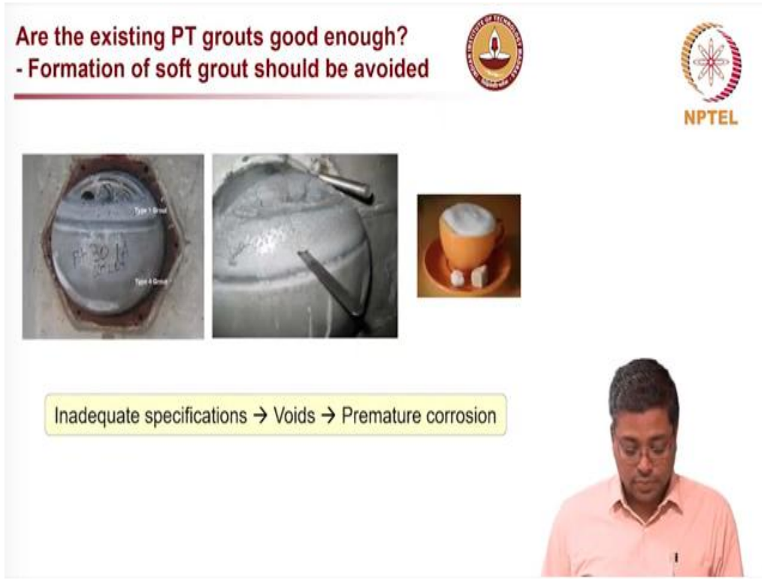
Now you have a strand which is passing through a good grout and it is exposed to a highly carbonated grout. That leads to accelerated corrosion of the strands and this is also an example picture here which says that partially filled region and in this picture if you look very carefully you can see that the top portion is actually showing more corrosion than the bottom portion.

(Refer Slide Time: 25:20)



These are all evidences showing that very severe strand corrosion due to inadequate grouting.

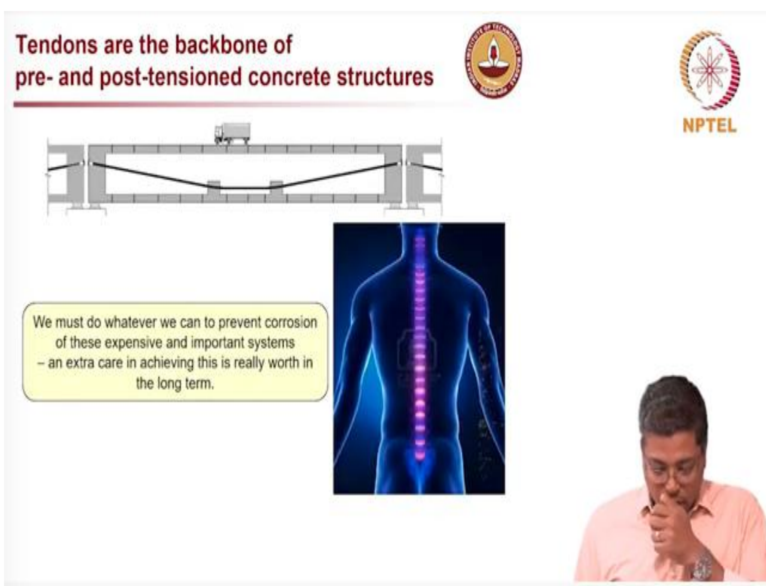
(Refer Slide Time: 25:28)



Now in the market today due to the significant void formation people have worked on developing better quality grouts. Better quality means grouts which can actually fill the tendons much better. But even in some of those grouts we see a new type of problem which is the soft grout formation where the inert materials which are used in this grouts were floating and it forms this soft grout as you see here very porous in nature and which can actually absorb the moisture and keep it there.

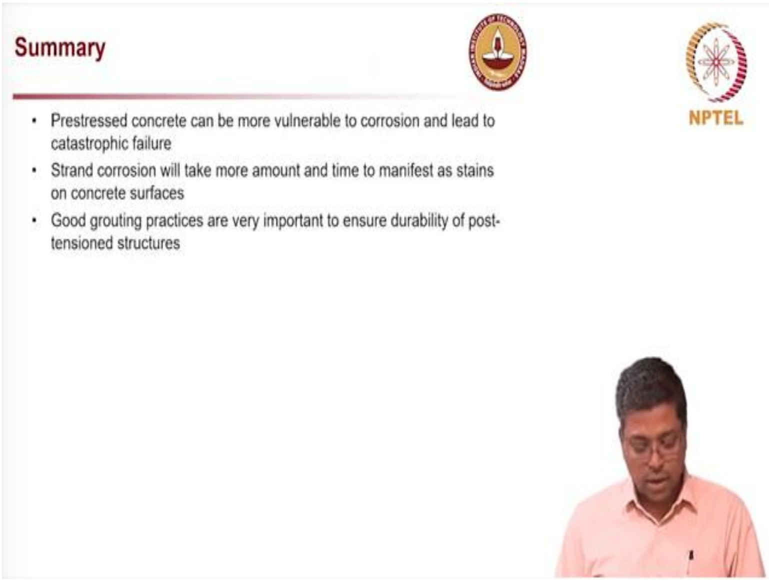
So it is like froth in a coffee cup. I mean on top of the coffee very porous, very low strength which can absorb moisture keep it there and then lead to corrosion of the strand.

(Refer Slide Time: 26:23)



The tendons are really the backbone of post-tensioned systems and it is very essential to make sure that they are protected well from corrosion otherwise we will have severe strand corrosion related issues.

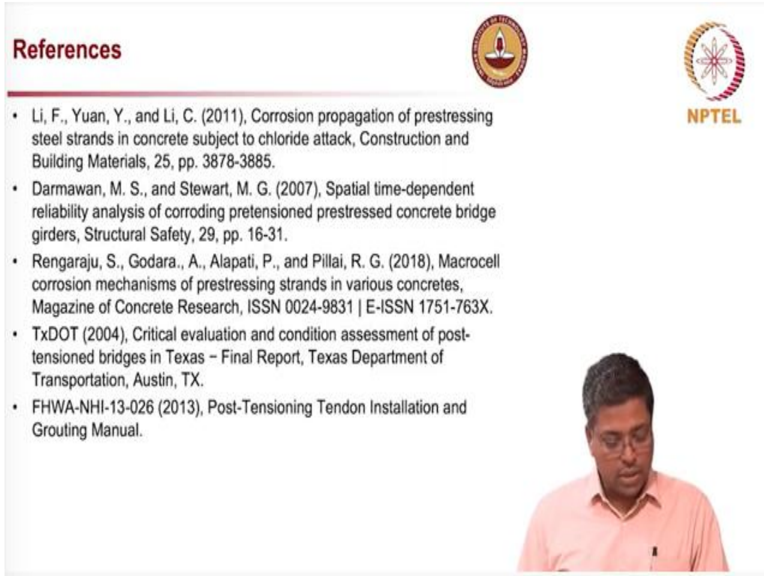
(Refer Slide Time: 26:38)



So we looked at prestressed concrete system and they can be vulnerable. How they corrode? We should not rely on the visual inspection or visual manifestation of the rust on the concrete surface that is not a good idea. And that in the pre-tensioned and post-tensioned concrete systems the corrosion mechanisms are different rather the mechanism leading to corrosion is different.

In the case of pre-tension system, it is mainly through the chloride diffusion through the cover whereas in the post-tension system it is the inadequate grouting is something which leads to premature corrosion.

(Refer Slide Time: 27:30)



This is the list of all the references used in this presentation.