Maintenance and Repair of Concrete Structures

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Lecture No - 17 – Part 2
Galvanic Anode Performance (GAP) Test

Hi, welcome to IIT Madras. This is a video on galvanic anode performance test which we developed here to assess the quality of galvanic anode, which can be used for protecting reinforced concrete structures from corrosion. So, let me give an introduction on this, why there was a need for this type of test? We are facing a lot of challenges nowadays in ensuring that the repair works which are done on reinforced concrete systems are durable.

Most of the time we see that within 5 to 6 years of time we end up going back again to the same site and then keep doing the repair or repeated repair works. So, one technology which is available today to ensure that the repairs are durable is galvanic protection or cathodic protection of concrete structures. Cathodic protection technique involves providing a zinc metal or more active metal and connect that metal to the steel reinforcement.

However, even though this technology is widely used still we see a lot of sites where the poor-quality anodes are being used, which again might lead to perception that this technology is not good. So, there was a need for developing a test method which can help us in assessing the quality of the anodes in short term, because if the anodes are working very good the service life of structures can be enhanced by 20 to 25 years.

However, we cannot wait for that long time. So, there was a need for developing a short-term test method. In other words, in couple of month's period of time, we should be able to tell whether the anodes are going to be good or not. A short-term test method to assess the long-term performance was the need. Considering that we developed method which we are going to call as Galvanic Anode Performance test or in short GAP test. Deepak and Karthikeyan are working on this, they are Ph.D. students here in IIT Madras.

They will explain more details on how the test is to be done. And also, maybe more on why there is a need for such tests in detail.

Hi, my name is Deepak Kamde, I am a Ph.D. student at Department of Civil Engineering, IIT Madras. Today I will be demonstrating you how the galvanic anode performance test can be used to evaluate the performance of the commercially available galvanic anodes.

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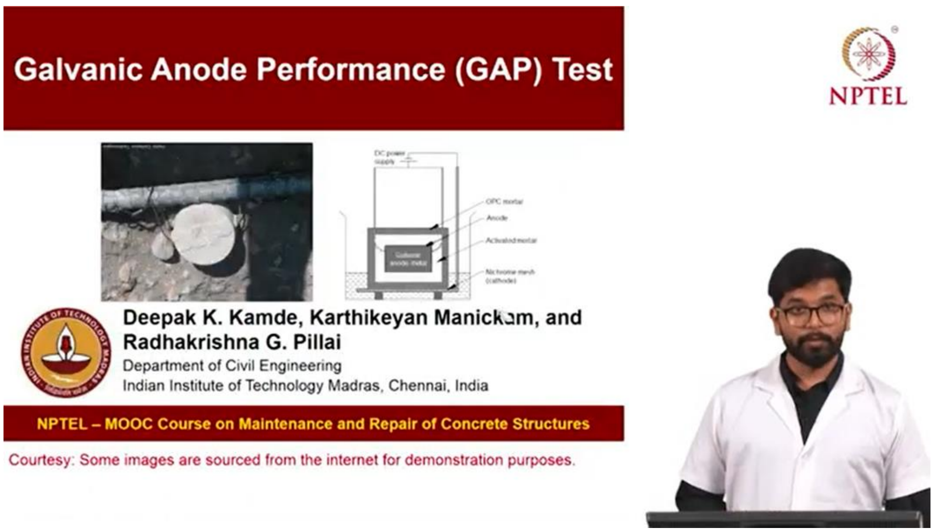

So, on screen you see 2 images; one is from the reinforced concrete structure. On the left side; This one is from the reinforced concrete structure where a rebar is connected to a galvanic anode here. On the right side; a galvanic anode performance test setup which can accelerate the process and tell you how one anode is performing compared to the other anodes and what will be the service life of the anode. We will see in this presentation how to calculate that.

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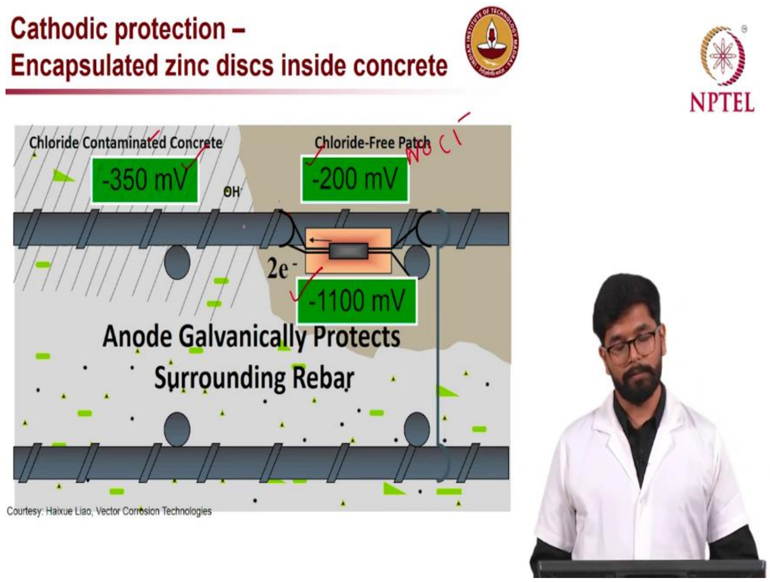

Let us see how the galvanic anode works. To repair a concrete structure, we do the patch work here with a freshly placed concrete in this place there is no chloride in this region and there is more chloride in the remaining portion of the concrete. So, Due to this, we will have difference in the electrochemical potential. The rebar in the freshly placed concrete can have the electrochemical potential of – 200 mV which is relatively positive than the electro chemical potential of the rebar in the parent concrete which is about let us take an example as - 350 mV.

Due to these potential differences, electro chemical cell can form at the interface and corrosion may initiate at the interface here. To avoid this, what we can do is we can connect a sacrificial anode, which you see here; when you connect a sacrificial anode the potential of the sacrificial anode is very negative as compared to any of the potentials I discussed before.

So, the potential of - 1100 mV and these potentials will form a mixed electrochemical cell because of which the sacrificial anode will corrode and the rebar will be protected.

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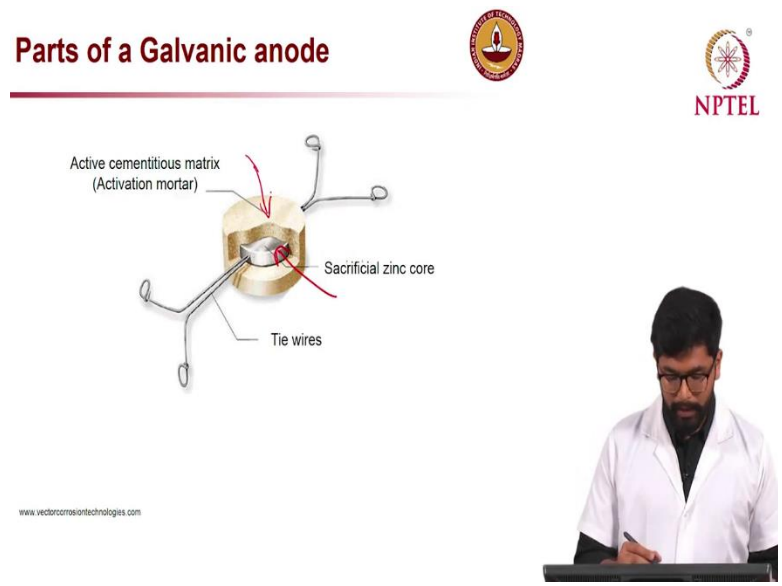

Now, let us see what is there inside a galvanic anode. So, there is a zinc metal piece in the center and cementitious metrics surrounding to that which is also called the activation motor, which keeps the zinc metal active for corrosion and you have a tie wires here which will be finally connected to the rebar. So, this is how a sacrificial anode looks like.

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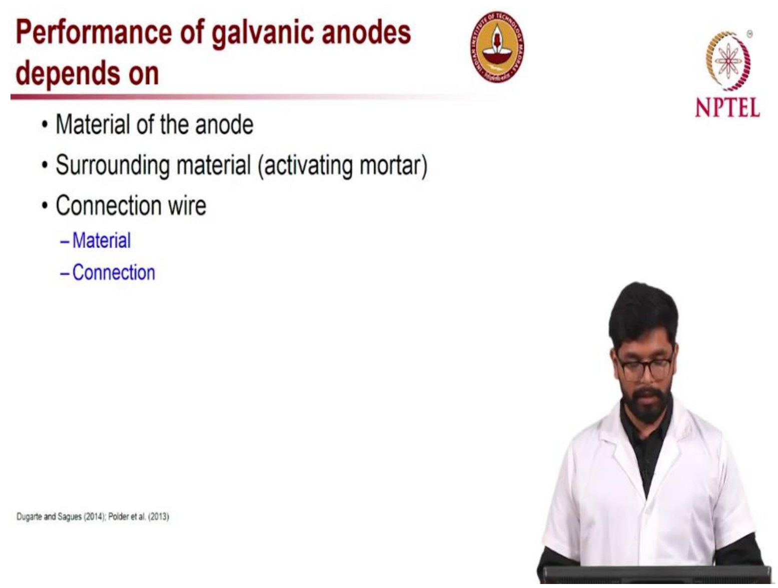

And the performance of the sacrificial anode will also depend on these materials. So, material of the anode that is the zinc metal, surrounding material that is the activation motor and the connection wire, and how do you connect it to the rebar. The whole performance of galvanic anode system will depend on these properties.

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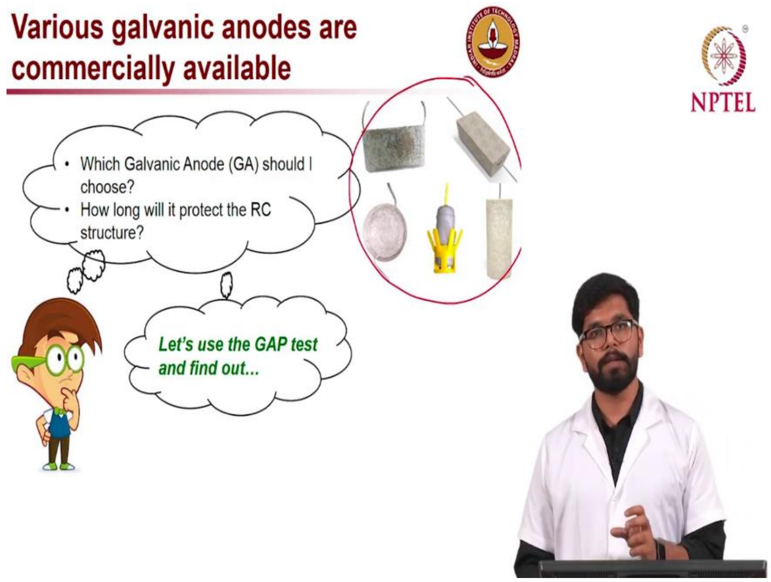

Commercially there are various sacrificial anodes available. Here you see a lot of examples are given here, they are available in various shapes and size. When we want to use these anodes, we need to know which anode performs better for that, and also, we want to know how long these anodes will be able to protect our reinforced concrete structures. How do we choose these anodes? We cannot go for trial and error method because the life of the sacrificial anodes which we are looking at is about 20 to 25 years.

So, we need to know the performance of these anodes in very short time. So, we have developed a short-term test method, we call it as Galvanic Anode Performance test or GAP test. That is what I will discuss after this.

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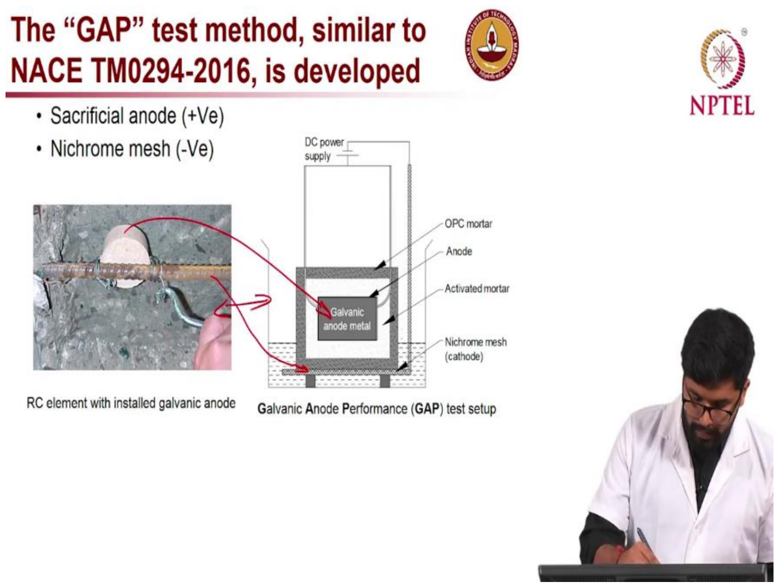

So, here you see on the left side we are replicating the same thing from field to the lab. You have a anode here, which is anode over here, then this rebar is replicated with the nichrome mesh here, this nichrome mesh is placed at the bottom which is behaving as the rebar in the structures and surrounding to that we place this cementitious system which is replicating the concrete in the reinforced concrete structure.

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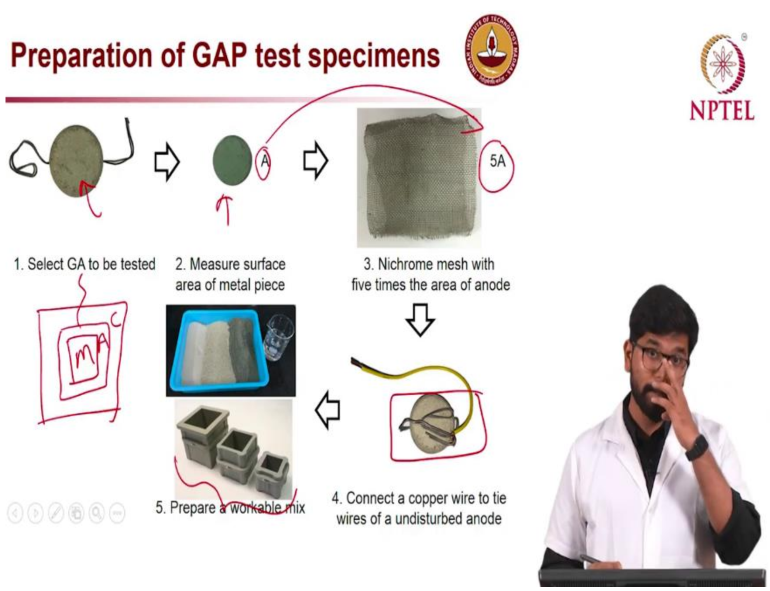

So, how do we prepare this test specimen for GAP test is we take a galvanic anode, whichever you want to test, what is the performance of that or what is the life if you want to evaluate the life of that anode. Take the galvanic anode, remove the activation motor, this is the metal piece inside this activation motor and measure the area of the galvanic anode. Let us say the area A is taken.

Nichrome mesh is a corrosion resistance material, you can take any corrosion resistant material, we have taken the nichrome mesh. Area of the nichrome mesh should be 5 times the area of the metal piece. Then take the freshly undisturbed galvanic anode and connect a copper wire or any wire you can take connect to that.

And prepare a workable cementitious mix using sand, cement and water and then place it any in any of the mold whichever is to the size of the anode. Our aim here is to keep the cover to 5 mm surrounding to the whole system. So, only this connection wire will come out. So, ultimately this GAP test specimen will look like this, you will have metal piece inside activation motor surrounding to that, one wire coming out this is how the GAP test specimen will look like. So, this is how one of the example of the GAP test specimen is here.

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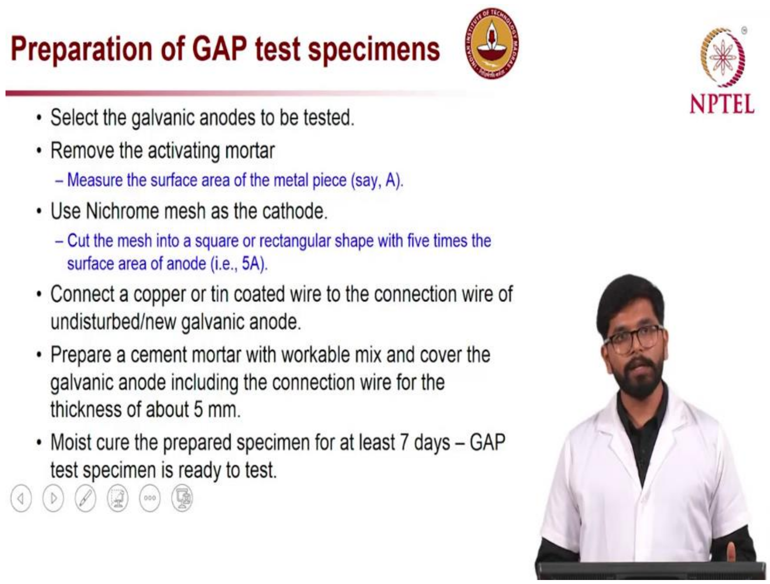

This is a detailed procedure for preparing a GAP test specimen you can read this and prepare your own get GAP test specimen. So, after casting, we cure it for 7 days.

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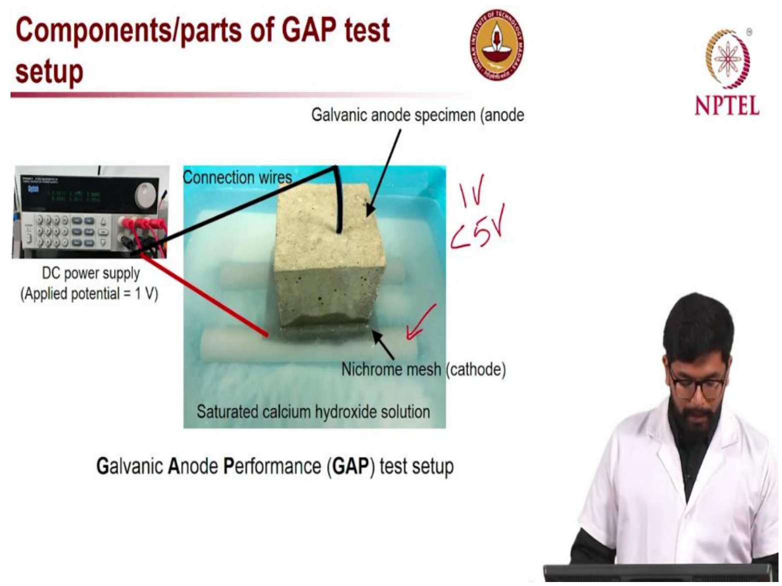

What you see here is the GAP test setup. In this at the base we placed a nonmetallic stand to raise the level of the GAP specimen. Why are we doing that is to provide sufficient oxygen to the cathode which is our nichrome mesh which is placed in the bottom of the specimen, and then the GAP specimen which I explained is placed on top of the nichrome mesh and that is connected to the positive terminal of the power DC power supply.

And the nichrome mesh is connected to the negative terminal of the DC power supply and then we apply a potential difference of one volt. We can apply a potential difference less than 5 volts. But we are restricting it to 1 volt which can be very close to the real scenario and based on this we will be able to capture very close response of a galvanic anode in the real scenario.

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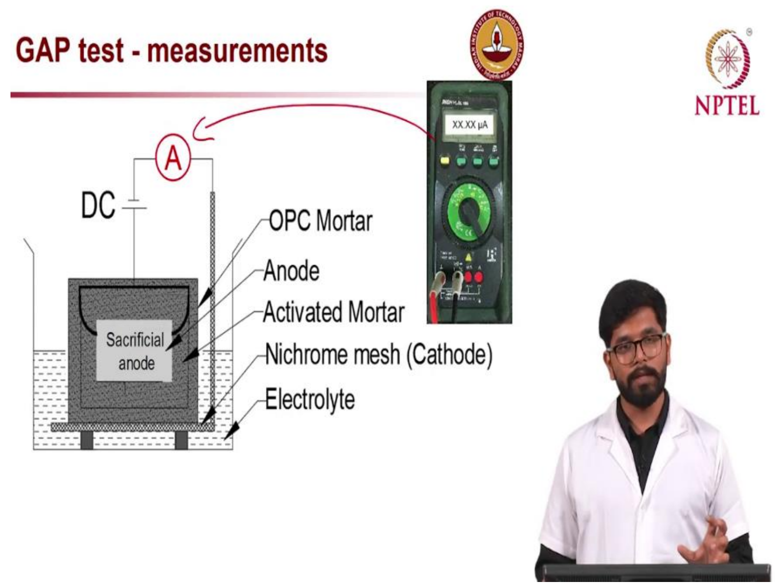

To evaluate the performance of galvanic anode, we measure the output current from the GAP test specimen. We connect the multimeter in series between the anode and the cathode and measure how much current is coming out of the GAP test specimen. These measurements have to be done every alternate day to capture when exactly is the GAP test specimen failing to provide the sufficient output current.

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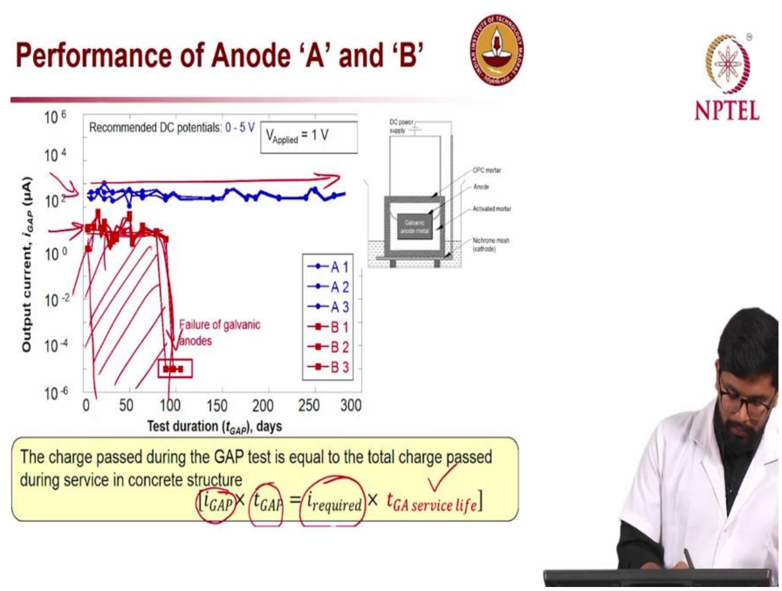

Here is an example of the measurements taken form two commercially available galvanic anodes. And what we see here is anode 'A' was able to supply a current of about 20 micro amperes and the anode 'B' was able to supply a current of about 150 micro amperes. Based on this what we can see is anode A is performing better than anode B because the output current from the anode B is less than anode A.

This measurement has been taken continuously for a period of 300 days. What we see is anode B failed after about 100 days and the output current from the anode was about 0. Whereas, the anode A is able to perform for very long term. So, this shows the anode A performs better than anode B. Based on this, how can we calculate the service life also? Now, here the total charge pass during the GAP test should be equal to the total charge pass during the service life of the concrete structure.

So, what you see here is this the area below the curve during the testing should be equal to the area below the curve when it is actually done on a RC element. So, how can we calculate that, let's say you know the how much current is required for protecting a reinforced concrete structure. So, we do this test and we know what is the current coming from the GAP test, this is the current which is coming from the GAP test.

That is 'i' GAP. time of the GAP test you know at what time the anode is failing, it is about 90 days. So, this is this also we know. We know how much is current required to protect the reinforced concrete structure, but we do not know how long it is going to work.

$$i_{GAP} * t_{GAP} = i_{required} * t_{GA\ service\ life}$$

So, using this equation, we can calculate how much time the galvanic anode is going to actually protect the reinforced concrete structure. This looks very easy here, but you will have to integrate each part here. The integration of each section will give you the accurate or near to the accurate service life of the galvanic anode.

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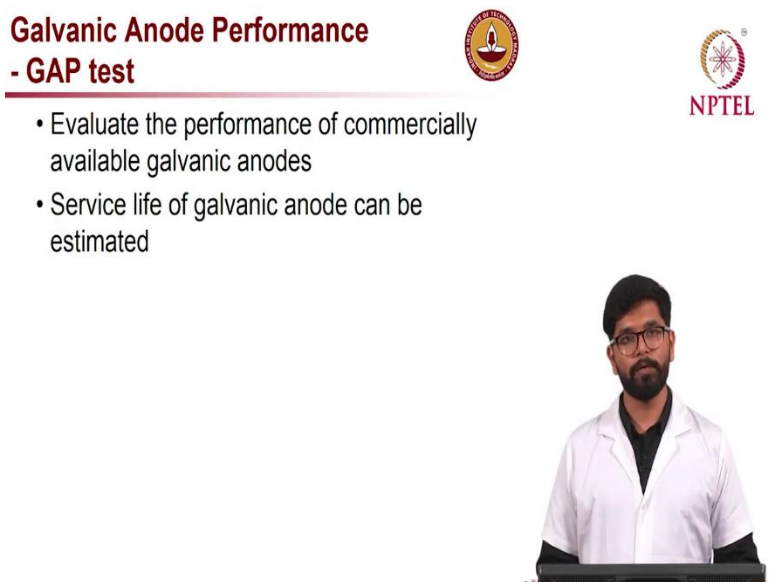

Using GAP test, we can evaluate the performance of commercially available galvanic anodes. And also we can evaluate or estimate the service life of galvanic anodes which are available in the market. Then choose which anode has to be used in the reinforced concrete structure for repair. And we can estimate what is the expected life of the repair we are looking for based on that we can choose the anode which fits better for the life we are looking for and the performance, which we are looking for.

Now, Karthikeyan will demonstrate how the measurement should be done from GAP test specimen. Thank you.

Hello all, I am Karthikeyan, I am a Ph.D. student from the Department of Civil Engineering, IIT Madras. Now I am going to demonstrate you how to take measurements from the GAP specimens.

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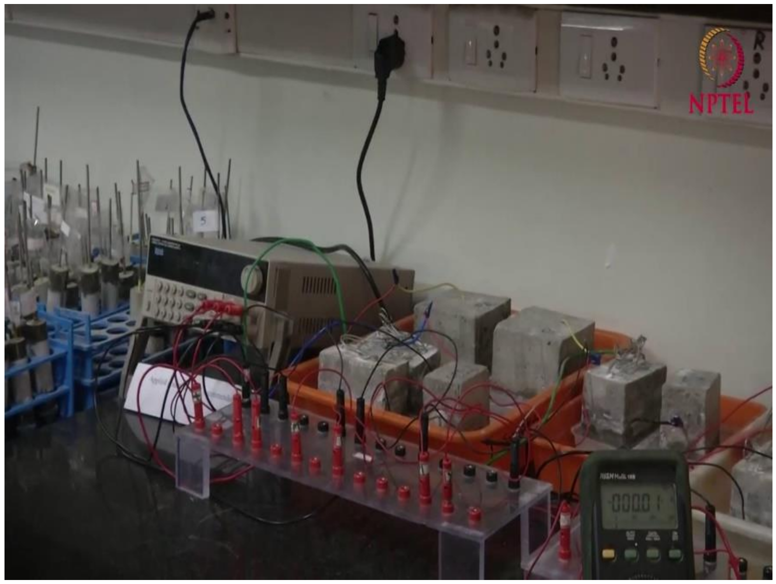

Here we can see specimens made from different commercially available anodes are being tested. So, here we can see that the red wire is coming from the anode which is going to the DC power supply and it is connected back to the cathode which is the nichrome mesh through the black cable. The objective of the GAP test is to measure the output current which is coming from the anode. To achieve that, we have to place a multimeter in series between the anode and the cathode to measure the output current that is coming from the anode.

Now I am going to demonstrate to you how to take measurements from 2 anode specimens which are made from two different commercially available anodes. We can see that we are placing a multimeter in series between the anode and the cathode and the current output which is coming from the anode is around 41 micro amps.

This is the current output from another GAP specimen which was made from a different commercially available anode. So, the output current we can see is almost around 1.14 micro amps, we have to carry out these current measurements on every alternate day till the output current from the anode drops to 0. That point marks the end of the service life of the anode.

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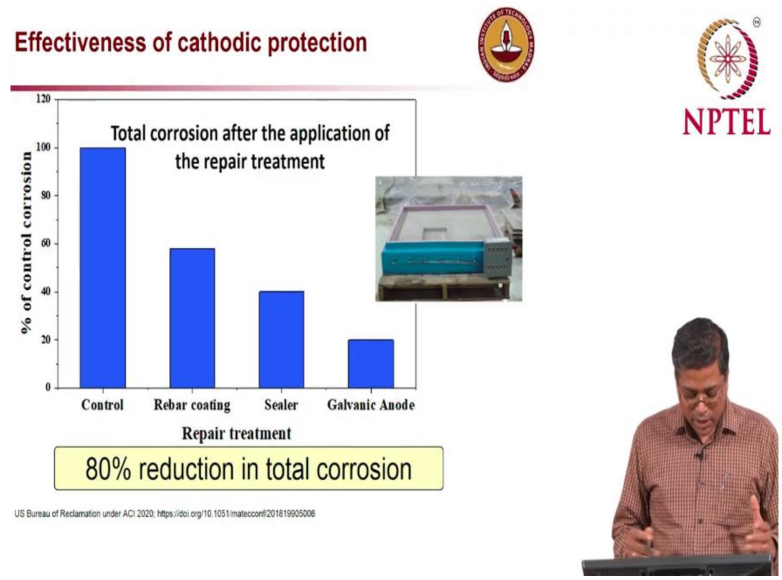

Now, there is some case studies I am going to show you other parts of the world; they have experience on the performance of anodes and effectiveness of cathodic protection you can see if you don't provide any protection and the case with galvanic anode protection, there is significant reduction in the total corrosion. This is an experiment done in Kansas and where you can see the 80% reduction in the amount of corrosion compared with the control.

Even if you provide a sealer, it doesn't it is not that effective. So, among the systems like rebar coating or a sealer and galvanic, it was very clear that the anode systems perform very well. And, it helps in reducing the corrosion significantly, much better than or much more than the efficiency of rebar coating, or a sealer.

So, this is I think the way to go for when you talk about repair of concrete structures, especially when you want it for lasting for 20 to 25 years without any additional intervention.

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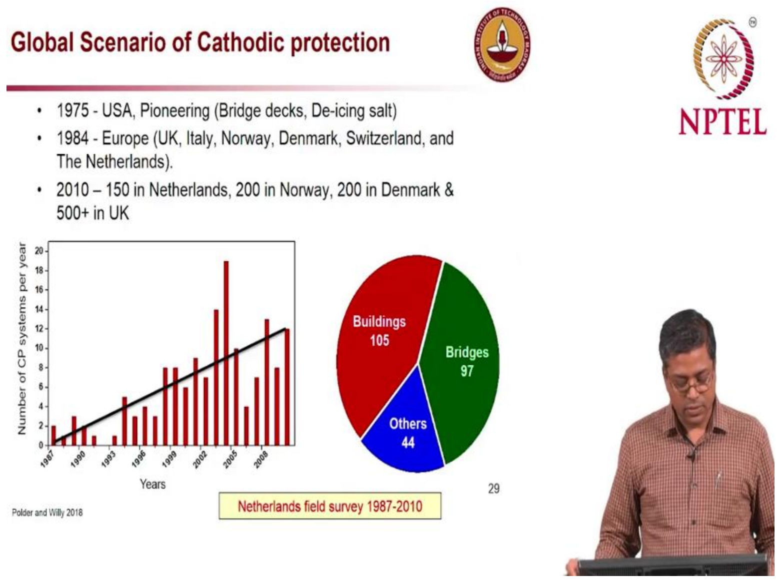

Now, this is a global scenario where we can see this, statistics on number of CP systems. This is why I am showing this, globally people have tried and they have proven that this works really well for concrete structures and it is high time that we also increase the number of such applications in our concrete structures, which are experiencing severe corrosion. And also, other important structures, which we do not want to corrode, so that is cathodic prevention.

If we know that the structure is really not going to meet the design life or if it is about to corrode, then it is better to install the systems before they start corroding. That way, the work itself is easier, and also you save a lot of money because once it starts corroding things are going to be very, very difficult as the age-old statement prevention is better than cure. So, cathodic prevention is better than to cathodic protection. Cathodic prevention is better than wait until the steel corrodes and then go for cathodic protection which is more expensive.

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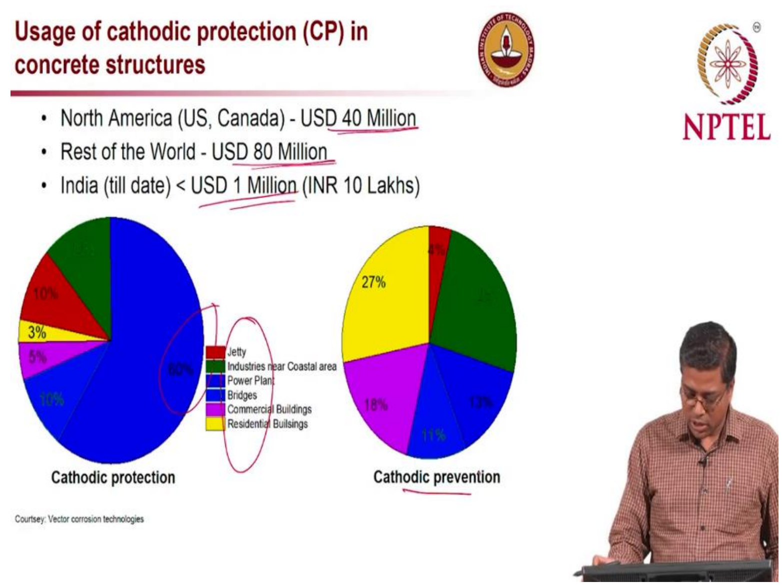

This is in US; they spend about 40 million rupees on cathodic protection rest of the world is 80 million where you can see India statistics just 1 million. But if you look at the amount of concrete structures which are in distress, we also have very large number. So, it is definitely a strategy which is very good at technology which is very widely applied elsewhere in the world.

And it is high time that we must also take this very seriously. You see the type of structures jetty industries, near coastal area, power plant, bridges, commercial, all sorts of structures are there. And then if you look at Indian case only 60%, the power plants, especially the cooling towers, there are a lot of cooling towers, which you see water and then they have started exhibiting corrosion much earlier and people have tried to protect such structures with cathodic protection.

Again, I must tell you this data I got from one of my friends in vector corrosion technologies, Dhruvesh Shah. But we have to see that this may not be an exact number when we consider the entire country. This is just based on one particular manufacturer, but there are many other manufacturers or products available in the market. So, if you really look at the distribution of where the cathodic protection systems are used, and how much cathodic prevention systems are used, we can study that and then we need to really increase because as I talk, there are a lot of structures which are corroding and we want to arrest the corrosion in such structures by cathodic protection system. And there is a lot of room for doing better quality repair by the use of cathodic protection.

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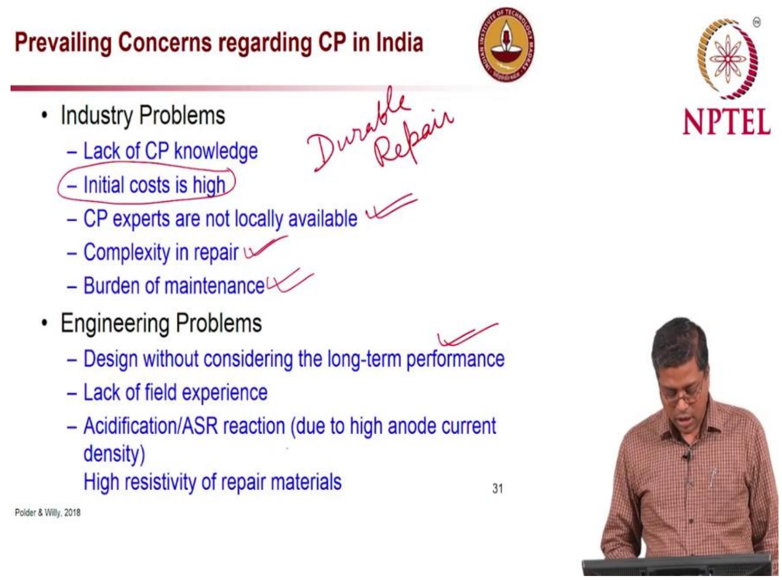

And what are the problems or why we are seeing difficulties in penetrating into the market. I mean, I have been working in this area for last couple of years and then these are some of the tips which I got why industry is not picking up this technology much in India. One is the lack of knowledge about this technology among the concrete engineers or repair personnel. And also, there is a myth that the initial cost is high, so I will show you some data on that also.

And there are not many experts available in this area and complexity is there. And then there is a burden of maintenance. But these are not always correct. If you do a good, very good job you do, it is a very good technology. And if anybody interested, we can talk about it. And then engineering problems design without considering the long-term performance. Most of the repair work, they say, we repair and then there is a hidden expectation that they will come back in 5 years and again, do the repair.

I have seen many cases like that. So, on an average, if you repair, do a patch repair, without this cathodic protection system, you can expect that corrosion will continue to happen because of the halo effect. And then in about 5 to 6 years, you will end up in redoing the repair. So, this is a general law. Most experienced engineers know this, in 5 to 6 years you go back to the same site and do the repairs. So that is something which we want to avoid, so that we get long life for the repair or we achieve the target of durable repair.

Lack of field experience, and then acidification or ASR reaction due to high anode current density that is, if the design is over designed, and then high resistivity of repair materials, that is also a challenge, sometimes, but in such cases, you do not expect much of corrosion. So that is a different story.

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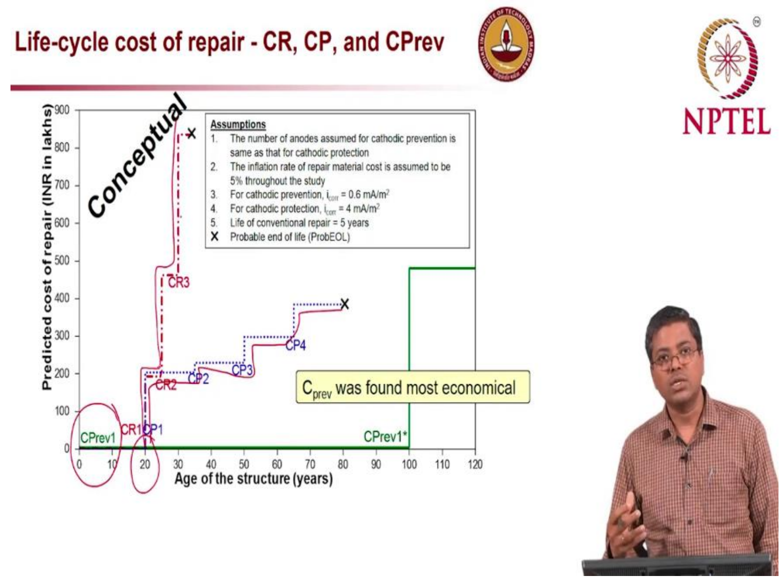

Now, lifecycle cost. This is a comparison where we are showing cathodic prevention is really, really very good when you talk about very long life. So, if you are talking about cathodic protection, that is, let us say in this case at the year of year 20, you see a corrosion damage. And then if we just do a patch repair, you go with this red line and then costs keep on increasing. And then you do that every 5, 6 years the costs keep on increasing.

But if you go for cathodic protection, which is the blue curve here, you can see this step going, some replacement after some time and still you are able to achieve 8 years of life without much, without much cost implications as it is shown in this red curve. Again, let me tell that this is a conceptual graph, just to show you how cathodic prevention is better than cathodic protection and how cathodic protection is better than a conventional repair without galvanic protection, galvanic anodes.

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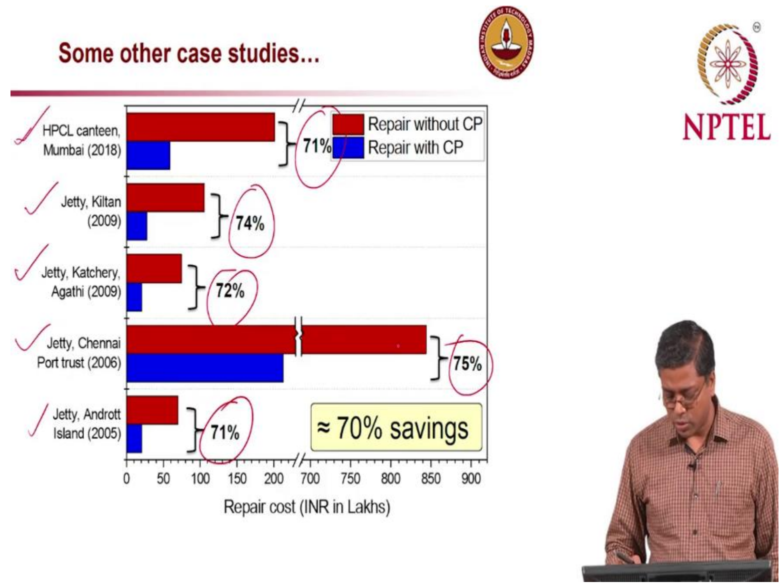

This is some statistics again collected from the field, you can see here works on a canteen in Mumbai, which is again HPCL. It is very close to the seashore a jetty structure. All these are coastal structures, where they had to go for this kind of repair because the other repairs were not working and they found that the savings is in the range of 70%, which is very, very high as compared to conventional patch repair and once you do this, there is no more interventions required for 20 to 25 years.

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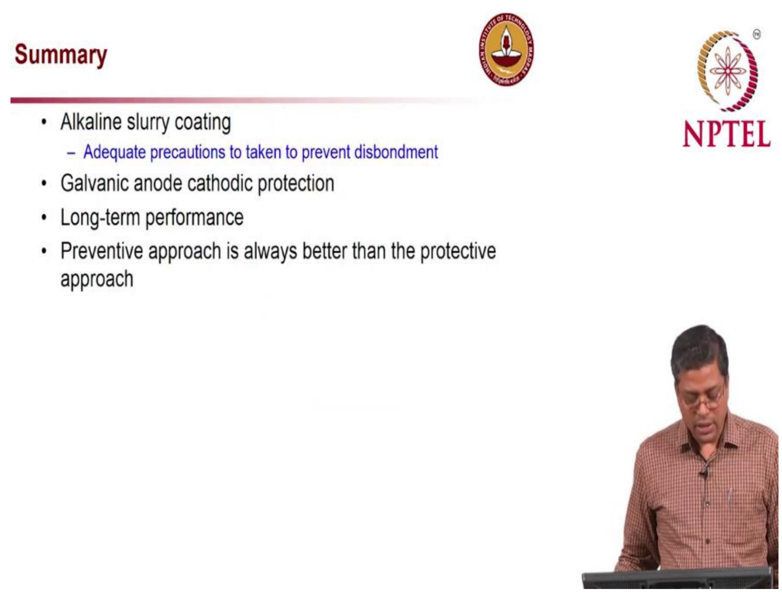

So, to summarize, we talked about alkaline slurry coating adequate precautions to be taken to prevent disbondment and for the coating to work very well. And then again, the coating to work very well the application should be very nicely done it should be done on a clean surface, clean rebar surface. Then we talked about galvanic anode cathodic protection or sacrificial anode cathodic protection SACP and then we also looked at how to ensure that anodes which you select are of good quality.

We introduced the GAP test Galvanic Anode Performance test and then also looked at various features that an anode should have like the connectivity between the rebar and the tie wire and the connectivity between the tie rebar and the rebar like within the wherever they repair region. And then we also talked about how porous the encapsulating motor or the activating mortar should be, it should provide high PH for the zinc to corrode 13+ for the entire design life.

So, if the system is, if the particular anode is not able to provide that anode will not work for long term. So, all these must be considered while thinking about implementing cathodic protection systems or cathodic prevention which is better than cathodic protection. So, lifecycle cost is going to be much lower if you go for cathodic prevention and lifecycle cost is going to be much lower even if you go for cathodic protection also, when you compare that to a conventional repair without any anode system.

So, that once repaired, we can forget for at least 20 to 25 years and that is a very good relief for the field engineers or the decision makers. So that, that money can be used for other construction activities or for other use.

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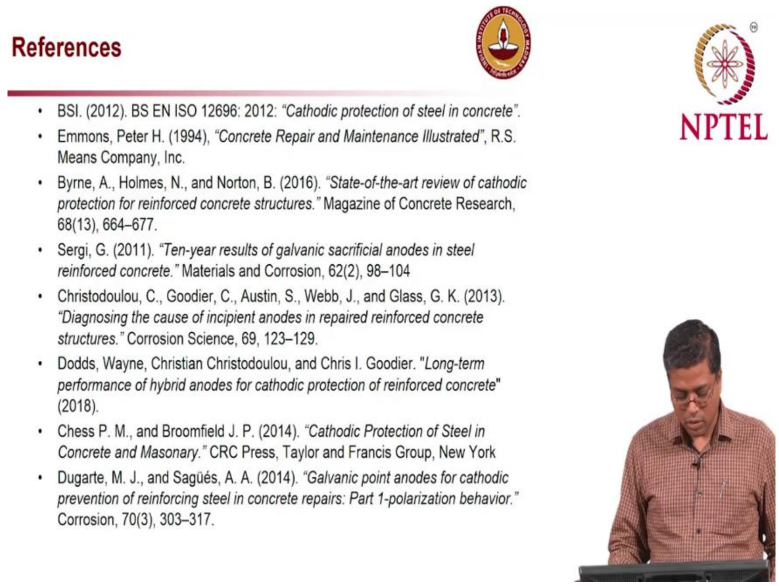

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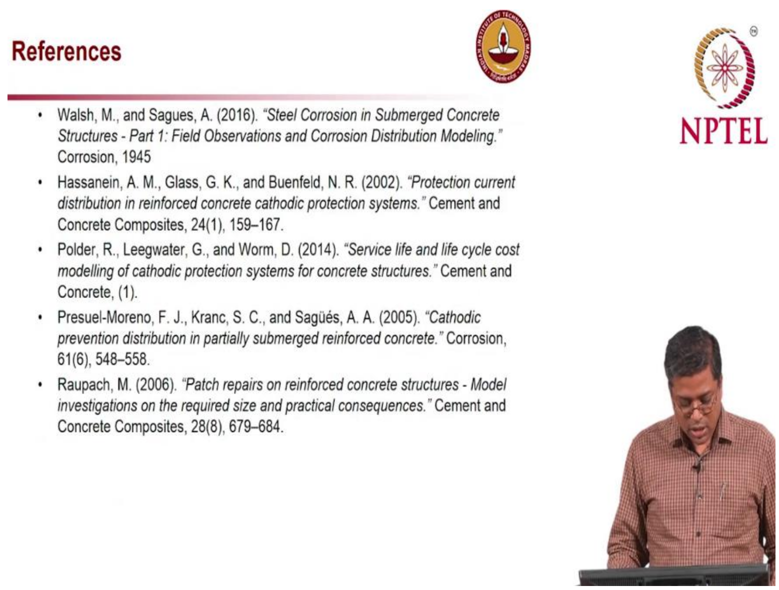

Thank you these are the references which we used for making this lecture. Thank you.