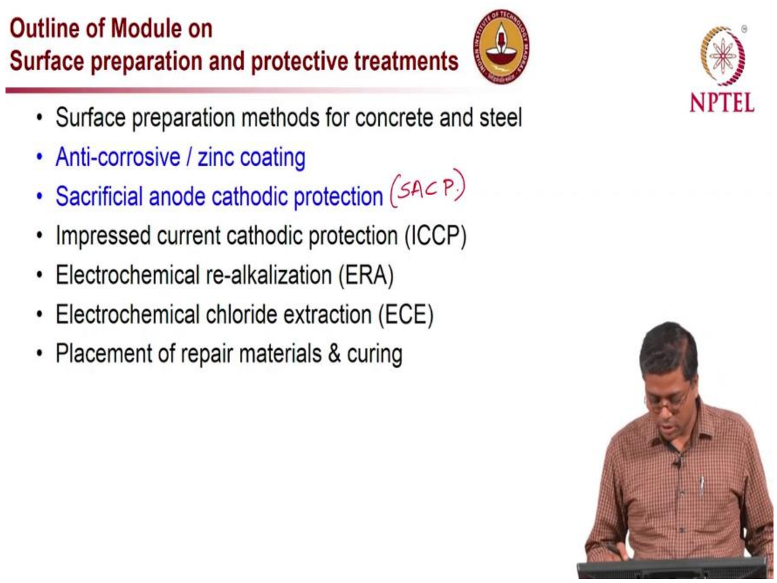
Maintenance and Repair of Concrete Structures

Radhakrishna G. Pillai
Department of Civil Engineering
Indian Institute of Technology-Madras

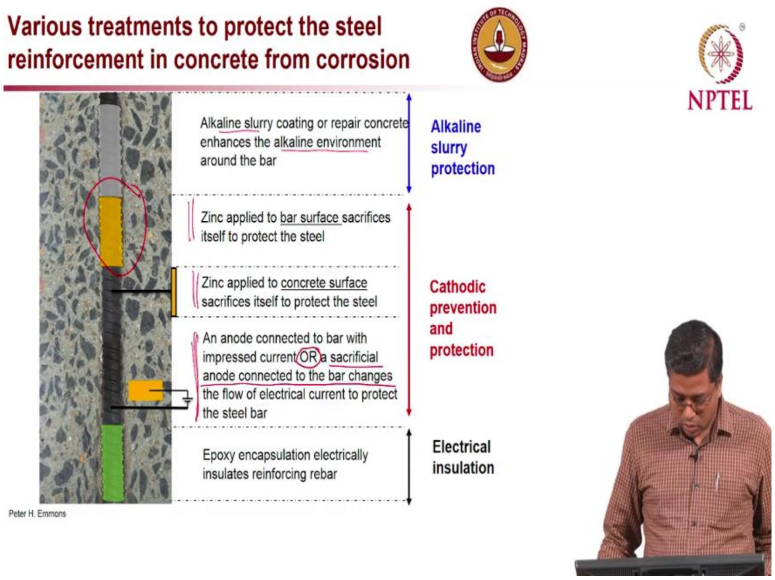
Lecture No. 17 – Part 1
Surface Preparation and Protective Treatments
(Protective treatment for steel reinforcement)

(Refer Slide Time: 00:23)



Hi, in this module on surface preparation and protective treatments, this is the second lecture and in which we will look at the Anti-corrosive or Zinc coating and also look at Sacrificial Anode Cathodic Protection (SACP).

(Refer Slide Time: 00:40)



What are the various treatments available to protect the steel reinforcement? These are the 3 general category you can see alkaline slurry protection and then cathodic prevention and protection. If you are talking about protecting the steel before the steel starts corroding, then we call it cathodic prevention. And if we are applying the same technique to protect a steel which is already started corroded, then we call it cathodic protection.

And then we have an third category which is electrical insulation of the reinforcement. So, in this electrical insulation of the reinforcement we already covered that in our module on coated reinforcement, especially the Nonmetallic coating where we talked about fusion bonded epoxy coated rebars in earlier lecture.

Now, today we will focus on this first two which is alkaline slurry protection and cathodic prevention and cathodic protection. So, in the alkaline slurry protection the main idea is this alkaline slurry which is applied on to the rebar, it provides an alkaline environment and hence gives more protective environment to the steel. In the cathodic prevention and protection case there are 3 major types which we are going to discuss today is first is a Zinc coating is directly applied to the rebar surface or directly applied onto the steel reinforcement which is this case here. So, you can see here the yellowish color, it is indicating that, and then in the second type is where zinc is applied to the concrete surface or a coating of zinc is applied to the concrete surface which sacrifices itself to protect the steel.

And that coating is electrically connected to the steel reinforcement. We will show you the more details later and then a third category is where an anode is connected or more typically a zinc anode is connected to the bar with an impressed current applied, that is one case and also you can see here or it can be either an impressed current technique or a sacrificial anode technique.

So, in this lecture, we are going to focus more on the sacrificial anode connected to the bar, impressed current technique we will talk about that in the next lecture. So, today we are going to cover only this Sacrificial Anode Technique.

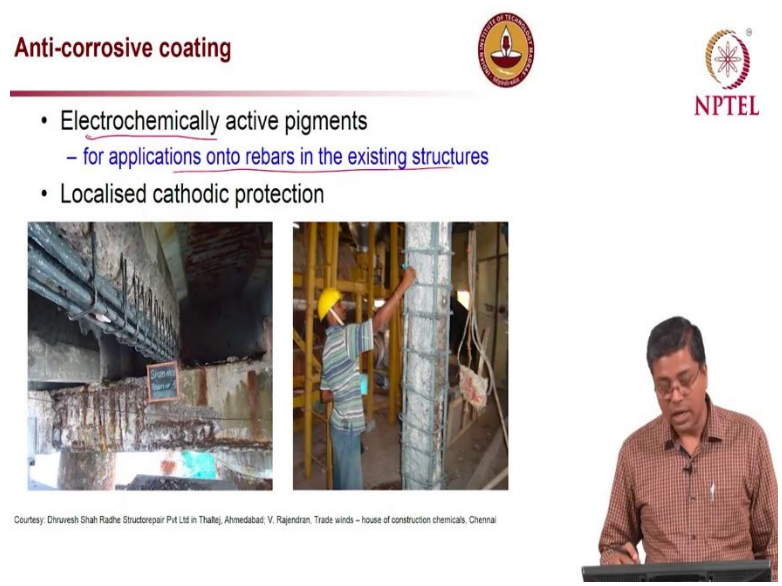
(Refer Slide Time: 03:56)

Now, Alkaline Slurry Coating, you can see the pictures at the bottom. Where a powder is mixed with the cement slurry, where you get at the end very highly alkaline, but cementitious also in nature and then that is applied on to the rebar surface. Which provides an alkaline environment and also a mechanical barrier and at the same time, that way it provides very good resistance against corrosion.

And this is an example bridge on the top right what you are seeing is it is a pile construction for a coastal bridge where this kind of coatings were applied and however, please note that this coating is not adequately applied. So, that is why I put this picture here. So, when you talk about these coatings, if they are not applied properly, then you do not get a good protection, rather it adversely affects the performance of the steel.

So, whenever we talk about coating, it is always better to provide a good coating and protect the coating from scratching etc. And at the same time when you apply the coating, you should apply it continuously on the steel surface otherwise, they tend to give a negative result or in other words it makes the steel more vulnerable to corrosion.

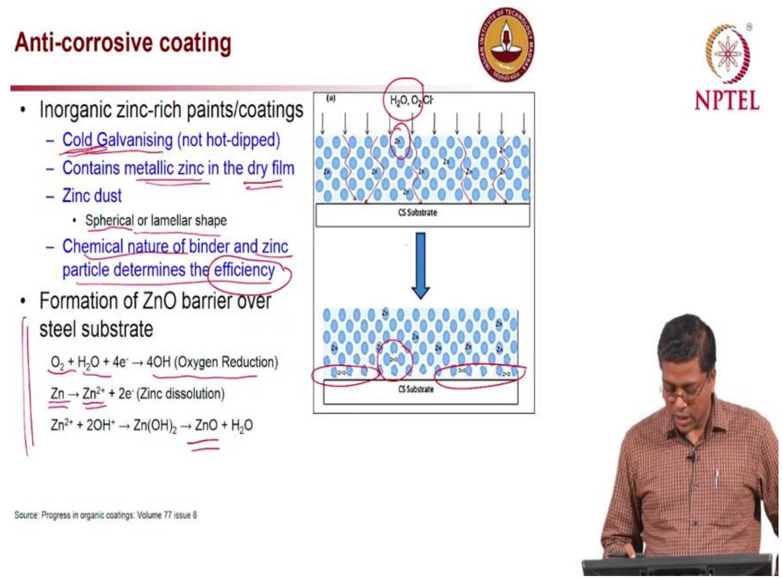
(Refer Slide Time: 05:34)



An Anti-corrosive coating is another category, typically they are also rich in zinc and because of that, they have Electro Chemical action and then typically used for rebars in the existing structures. Typically, when the steel has already started exhibiting some corrosion, we clean the rust from the steel and then protect or coat the steel.

As you can see on the picture on the left side a structure where there was heavy corrosion and then you can see grey color coating applied on to the corroded steel rebar and on the right side also you can see it is being applied on to the corroded steel rebar, but after cleaning the loose rust. And it essentially provides a localized cathodic protection because there is zinc, which is present in the entire chemical or the coating.

(Refer Slide Time: 06:46)



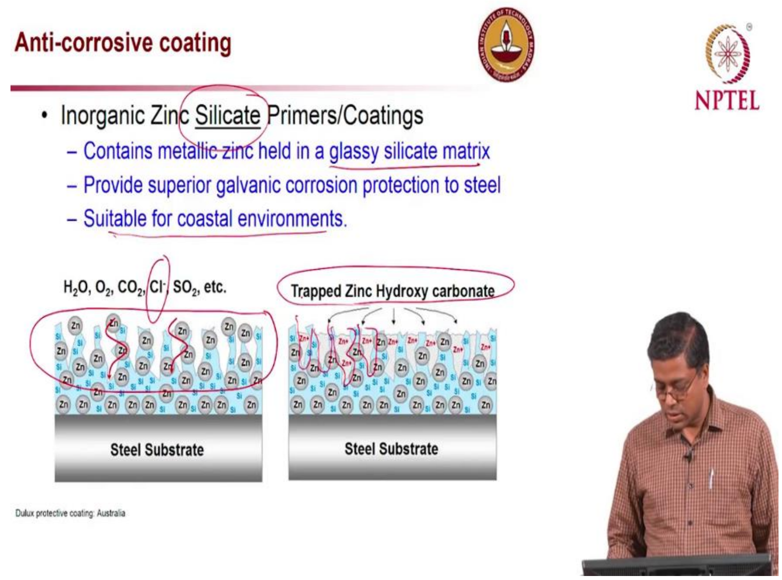
Now, how do they really work? We will see on this; inorganic zinc rich paints or coatings are available. And one point to note here these are not like the galvanized steel where we go for hot dipped, in this case it is a cold galvanization. In other words, the temperature you are directly applying this on to a steel which is kept at an ambient temperature, it is not very high temperature like in the case of hot dipped galvanization.

So, this cold galvanizing is what is being done and the material typically contains Metallic Zinc in the dry film. Zinc dust is in spherical or laminar shape, and the chemical nature of the binder and the zinc particle determines how efficient this will.

So, as you can see in presence of oxygen and moisture you have this oxygen reduction reaction happening and the metallic zinc gets oxidized. And then it becomes zinc 2^+, releasing 2 electrons. As you can see here, metallic zinc here in presence of Oxygen and H_2O and then what eventually happens is you can see zinc Z and O is formed, especially on the surface of the steel or near the steel surface.

So, you can see here in this reaction, you can see the final product is Zinc oxide and that gives this good protection for the steel.

(Refer Slide Time: 08:30)

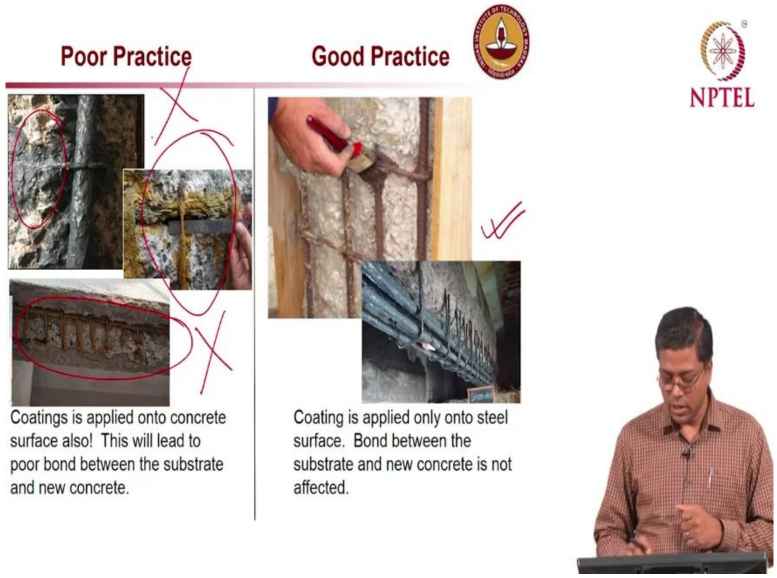


And there is also one more special type of primers available which is actually zinc, which is present in silicate based matrix or glassy silicate matrix and in which this also provides very superior galvanic corrosion protection and because of this superiority it is very good for coastal environment other words, there the expected corrosion rate is typically high.

So, in such cases you will need high performing coatings. So, this is one type of such coating and in the mechanism wise you can see here on the left side the 2 red arrows which are going down that indicate the ingress of the different chemicals from the environment. And you can also see a lot of cracks in that region.

And which are actually filled by Zinc2^{+} or oxidized zinc ions and then that kind of provides the protection from corrosion, Zinc Hydroxy carbonates are formed and or they are trapped inside the layer and which provides this galvanic protection.

(Refer Slide Time: 10:04)



Now, whenever we talk about any of these coatings, one important thing to remember is that this coating is meant for steel and not for the concrete. So, here you can see on the picture on the top left there is a gray color coating which is also accidentally applied on to the concrete surface. Now, imagine how you will get a good bond in this region where the concrete also is covered or coated with this primer.

So, it is not a good idea to apply and also this picture here, I mean this picture is like, you can see that steel is almost corroded, completely lost, probably it is better to provide a new rebar in that case or replace with a new rebar rather than trying to spent money on this coating and applying on that and all the workmanship efforts required to do this job, instead the best thing is to remove that steel and probably provide new rebar because that steel rods are almost corroded, nothing is left.

So, in such cases the engineer should take a better judgment, So that, we don't waste money by just applying chemicals left and right. So, that is something which is very important to note. Like, whenever we talk about these chemicals, you have to also see where you want to apply them, is it really beneficial to do so or is there a better way of doing things.

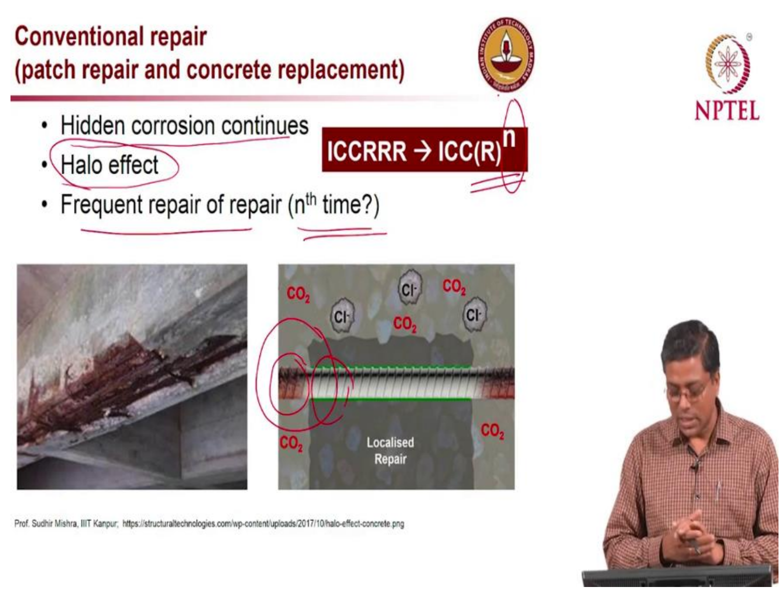
And also, here you can see in this picture, a lot of this yellow color coating is applied on the concrete adjacent to the steel rebar, that is something which we don't want to do. So, and also if you think about the amount of chemical used or wasted by being applied on to the concrete surface, you can just imagine how much is the surface area of the steel and what is the surface area of the surrounding concrete on which this coating is applied, it is just mere waste.

So, we have to, how do we do this? I would say give the workman, a very small brush, which is having a diameter exactly like that of the rebar that will solve the purpose, but these are these are the simple ways by which we can ensure that the work is done in a right way. And also tell them that they did not face this by applying onto the concrete. It is only meant for steel.

And if the workers realize that the by applying this coating onto the concrete surface will actually create more damage or you know create more problem, then most of the workers will not do it, they will be more careful. But in most cases they are not aware of the adverse effect and that is why these kind of things happen, but we must stop it by educating more and more people.

So, I would say we should spend some time in the beginning to educate the skilled labor or working personnel. That is very important, but we sometimes don't do it. Now, on the right side is a good practice where you can see only the reinforcement is having the coating and not the concrete around it. So, this is how it should be done. This is a very good practice and not the one on the left side.

(Refer Slide Time: 13:55)



Now, when we talk about conventional repair, bottom left you can see a rebar which is heavily corroded. So, what we will do? We will usually clean this rebar, apply some coating and then patch it. So, what happens in this typical patch repair is the hidden corrosion still continues to happen, and we call it something called halo effect.

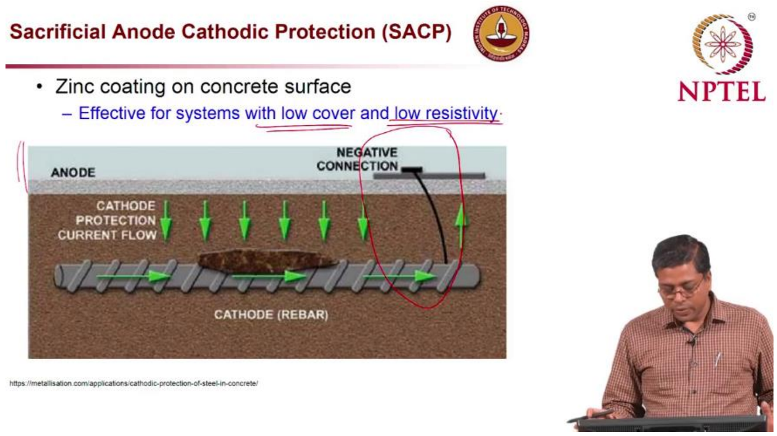
I am going to explain what that halo effect is, as you see on the picture on the bottom right, you can see this region has the concrete. So, the center portion of the image shows the new repair material, which is good quality concrete or new concrete, noted here as localized repair and concrete around it, it is still having some carbon dioxide or carbonated concrete or it has some chlorides in it.

So, in such cases, the steel rebar goes through the two concretes here you can see goes through the old concrete and the new concrete. Now the point is when the same steel rebar goes through the old and new concrete which has different chemistry or the different pH environment then, it automatically creates a battery or a corrosion cell at that interface and which leads to the formation of anode here, and the cathode here.

So, this battery is formed right across the interface between the old and new concrete. So, how do we avoid this corrosion from happening? This corrosion which is occurring in the old concrete after the repair this happens in couple of years, most often you will see that this corrosion happens which we call Halo effect. And this leads to a frequent repair.

I would mention here in one of the international conferences people were even discussing about changing the name of the conference to International Conference on concrete repair rehabilitation to the power n, jokingly, but it is something very serious because we are repairing and we are going again and again and repairing the same portion of the structure, because we are not doing a durable repair or we are not thinking about what will happen after the repair is done. Whether it is going to be really long lasting or not. So, in such cases, what do we do?

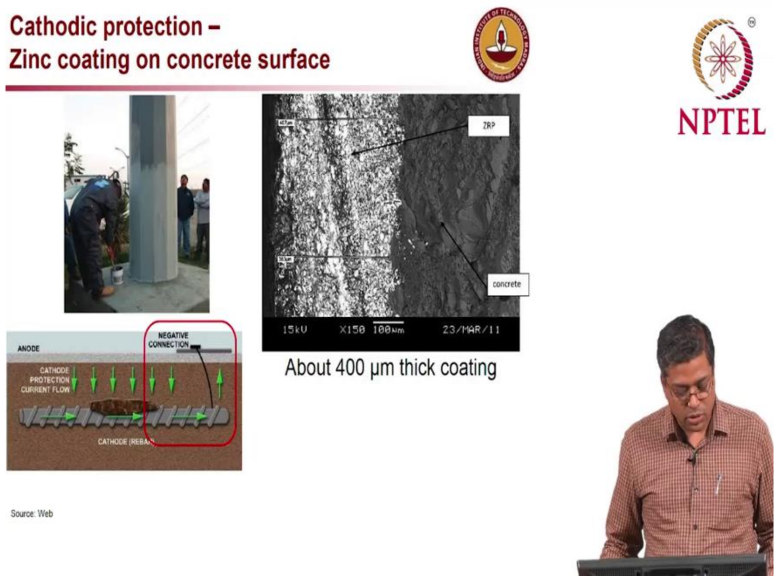
(Refer Slide Time: 16:44)



In this slide, we are showing a Sacrificial Anode Cathodic Protection system or SACP. The first generation of that technique, where you can see a zinc coating is applied on the concrete surface with which is having a rebar embedded and then there is a connection between the steel rebar and the zinc coating, which is also very important to for the system to function. So, it is not like just applying a coating.

In the case of rebar, when you apply a zinc coating onto the steel rebar directly there is an electrical connection, but in this case when you apply the zinc coating on the concrete surface, then you have to actually connect that coating material to the steel rebar, an electrical connection is required. And this type of system used to work very well for low cover and low resistive concretes which are the type of concrete which were used probably couple of decades earlier. So, in such cases it used to work very well.

(Refer Slide Time: 17:53)



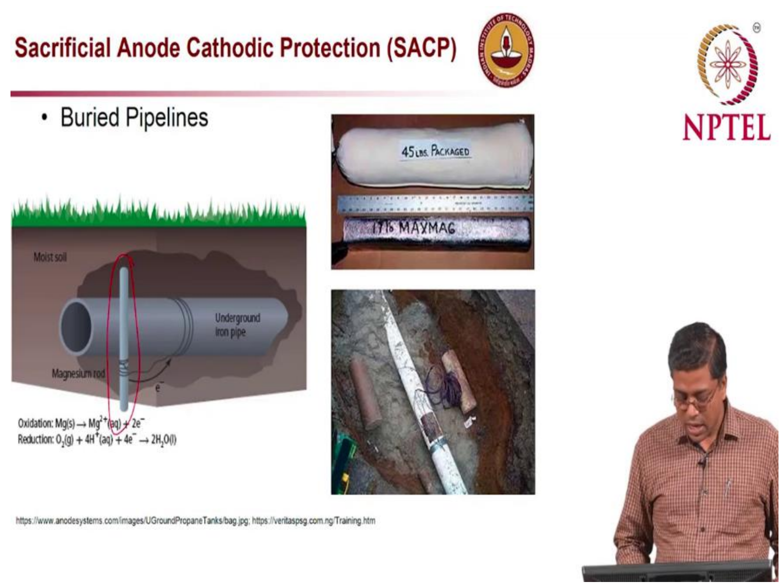
I will show you some examples. This is an example where you can see such coating applied when the cover concrete was relatively less, and the concrete was also relatively porous in nature, and you can see the thickness of the coating applied in this particular case, this is a bridge column is about 400 micron thick and you can see this, I got this picture from Dr. Sergi of Vector Corrosion Technologies.

(Refer Slide Time: 18:30)

And you can see that another example here again this is a bridge in Paris and one another bridge in Texas. You can see significant cracking on this girder here and here also there are a lot of cracking on this girder and then which were addressed or the corrosion was arrested by applying zinc coating which is electrically connected to the steel reinforcement inside. Now, the positive thing about this technique is that that does not really create much of disturbance to the traffic.

You can apply this overnight and then get the job done. And then long-term protection is provided, but when the cover depth increases or when the resistivity of the concrete increases, then this technique does not work very well. So, I have shown that in the red text in this yellow box, so, when you have a larger cover or a highly resistive concrete then this may not be really a good technique to go for.

(Refer Slide Time: 19:31)



So, in such cases, we actually borrowed some ideas which were already in practice in other fields. So, this is one example where sacrificial anode system is used for protecting buried pipelines where you have an anode system which is electrically connected to the underground pipe and depending on the resistivity of the soil you can really protect this buried concrete.

(Refer Slide Time: 20:04)

And another area where this Sacrificial anodes are widely used is ocean or offshore structures, where you can see in this particular example, which is a Riser of an offshore platform, you can see all these are the anodes which are connected and how the electrical circuit is completed in this case is because these structures are immersed into the seawater. So, the seawater itself helps in completing the electrical circuit. So, that is why you will see that in concrete structures, we have to have the circuit completed.

We cannot put an anode on the surface of the concrete and expect it to perform, it is not going to work very well you have to have actually embed the anode or it should be completely in contact with the concrete. So that the electrical circuit is completed, because I have seen examples where anodes are just connected to the concrete surface and they actually staying in air, which is not a good practice and it will not function.

(Refer Slide Time: 21:16)

So, we have to actually embed the anodes when you talk about concrete structures. Like you see here, you can see on the picture on the bottom right there are rebars and then the concrete cover is removed and the anodes are embedded inside. And bottom right image also shows the, same thing and this is how it is connected. So, you can see a typical anode system, where you have a zinc disc at the center.

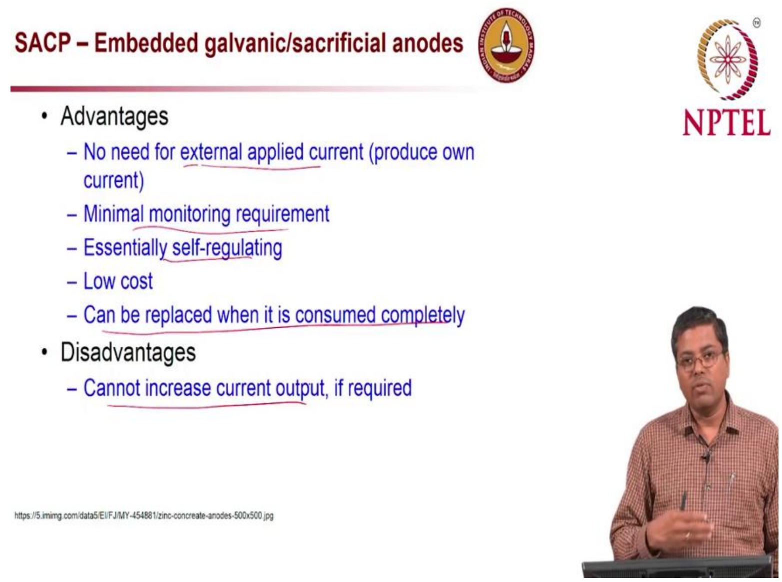
And which is covered by encapsulating mortar, which is not just cement. Because why I am saying this is there are a lot of anodes available in the market, which are just some cement packed around the zinc disk. It does not work and why it does not work? I will cover that later, but you had to really think about these are not just a zinc plate connected to a tie wire and then put it in mortar that is not how it is.

So, this encapsulating mortar has to have an active cementitious metrics, what it means is that the zinc element meets a pH of about 13+, pH should be greater than 13, if the pH is greater than 13 then zinc corrodes. So, for the zinc anode to corrode, you should ensure that the surrounding material is having a very high pH for the entire life of the structure. If you are designing this repair for let us say 20 or 25 years for that entire period the zinc has to have high pH around it.

Otherwise it will not corrode and it the system will not function. And also, this tie wire should not corrode because we have also seen cases where tie wire gets corroded and it gets disconnected from the zinc anode, then also the system does not work. So, it is and on one more thing is when you talk about the zinc corrosion, it also has some expensive property but not like the steel. But a little bit and then that the end this encapsulating mortar should have sufficient air voids or void space to accommodate to all the zinc when it corrodes.

So that it does not crack and creates other problems. So, these are all considered while designing a good quality, sacrificial anode system. But unfortunately, in the market, there are many things, many anodes which are of poor quality and one should be very careful while choosing these anodes otherwise you will be spending a lot of money and then you won't get the return.

(Refer Slide Time: 24:06)



Now, what are the advantages of this? There is no need for externally applied current, because it is you are putting a zinc into the concrete and then expecting that zinc to react as and when it is based on the corrosion current or based on the environment if it is a more let us say you have a same system during the rainy season maybe because of the more high moisture condition you will have a higher demand.

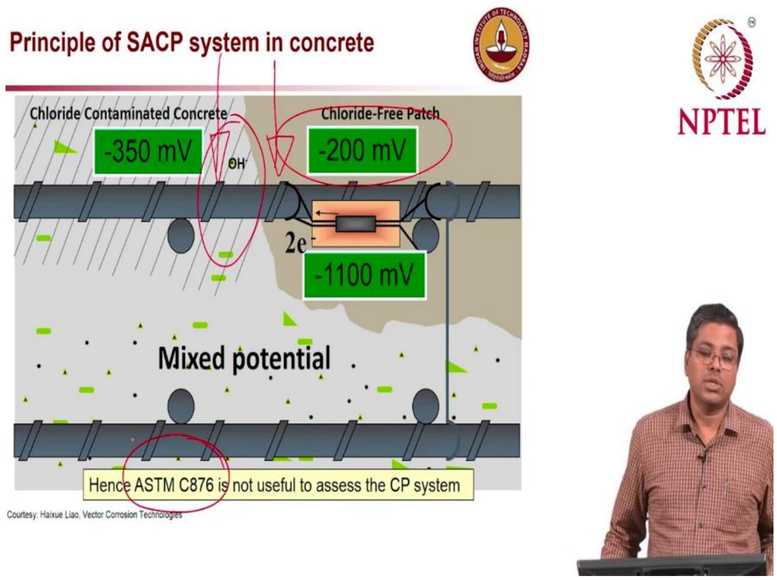
While the same concrete during summer, the demand will be less but the good thing about this sacrificial anode system is they will supply the current based on what is the demand from the steel and hence protecting the steel from further corrosion which does not really happen when you did not have these kinds of systems. And so, if you are just covering up with patch material, it does not really give you long life.

But with the sacrificial anode systems, you can really get or extend the life by about 20, 25 years. And at that time, we can also replace, let us say the system consumes the entire anode in about 25 years, you know exactly where the anodes are placed and you can take it and then put new anodes replaced without really damaging the entire structure. So, we really can extend the life of the concrete structure significantly.

And so self-regulating, I have already explained and minimal monitoring say once it is connected and the beginning it is insured, then maybe every 5 years to go back and just check whether it is functioning or not. And one negative thing about is once you install these anodes, you cannot really increase the demand which is a good thing in case of ICCP system or impress current system.

Where if you have much higher corrosion happening, much higher demand for current output from these anodes. In the case of ICCP system, which I am going to discuss in the next lecture, where you have a control on how much current you can apply, but in this, you don’t have a control. So, if you have, if you end up in something like that, you add more anodes that is the only option at that time, but that is not something which is very bad, because you can always design for what based on the current demand.

(Refer Slide Time: 26:36)



Now, how this works? So, until now I told generally what is the benefit of doing using these anodes, so how they work? So, you can see on the top right in this image, you have a chloride free patch or the new concrete. And reinforcement was actually corroding when you put this chloride free patch, the reinforcement in this region is now an exposed to a good quality concrete so it does not corrode.

But the reinforcement over here, which is now in the old concrete, it because of the halo effect, which we discussed earlier, this region will tend to corrode and that is why it is showing - 350 millivolts on the steel in the left side, which is chloride contaminated concrete. Now, when you connect this anode to the steel, what happens is the steel potential changes and then you can see that the potential of the corroding zinc is -1100 millivolt.

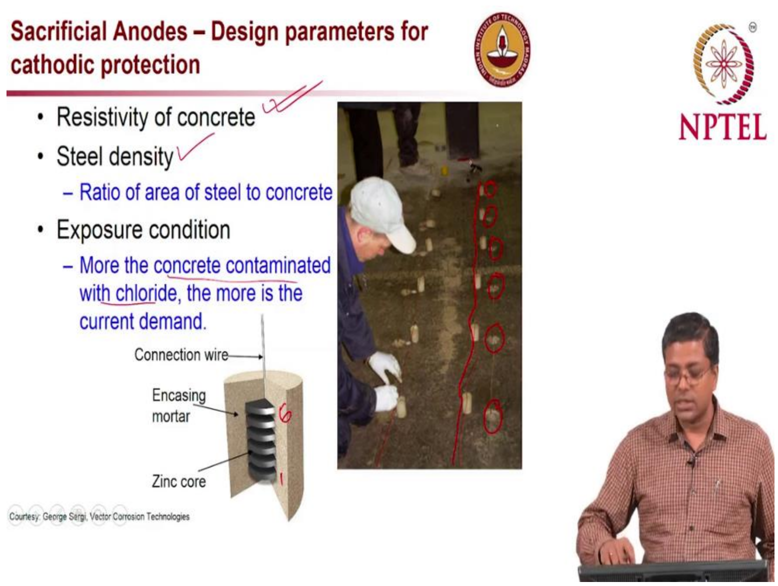
So, now, the there is a flow of electron from the zinc to the steel and so, the steel is protected and the zinc is corroding and then essentially you have more positive potential for the steel and then we can say the steel is actually protected because of the electrical connection to the zinc. So, that is something and one more thing is very important here is if you put potential measurement unit like any copper sulphate electrodes or any of so those electrodes which we typically use for half-cell potential measurement.

If you put those instruments on this, measure the potential which you are measuring is not the potential of the steel, but it is the mixed potential of the steel-zinc connected system. So, we should not adopt this as ASTM C876 criteria of - 350 millivolt or - 250 millivolt, that criteria which we discussed in an earlier slide or earlier lecture, that criteria cannot be adopted.

So, all this if you adopt it you are actually not really measuring what you want to measure because that criteria is the ASTM C876 criteria is meant for the steel potential, but when you measure the potential of a rebar system, where the galvanic anodes are also connected, you are measuring the mixed potential of both the steel and zinc and not the potential of only the steel.

Hence, the criteria given in ASTM C876 cannot be applied to the, galvanically protected reinforced concrete system. It is very important to tell this because many places people still adopt that and which is then they say that is minus more than negative than -350. So, system is corroding but it is not true.

(Refer Slide Time: 29:58)



Now, what are the design parameters when you talk about sacrificial anodes? We need to know what is the resistivity of the concrete. So, if you have a highly resistive concrete maybe you will need more anodes because the current which is supplied by the anode has to pass through this concrete to reach the steel. So, that is also something, the ionic current I am talking. So, the resistivity of the concrete is very important.

Steel density, how much steel is there? So, if for one anode; or one anode can protect a particular area or surface area of the steel and in this vicinity if you have more steel than you will need, more anode to protect that steel provided the corrosion rate is similar and then exposure condition. So, the more the chloride the more the contamination, the more is the current demand. That means the more is the amount of anode required when I say amount of anode it's also important to think about this surface area of the anode. It is not just the mass but surface area of the anode.

So, you can see here on the picture at the bottom where about 6 discs. 1 to 6 discs of zinc is placed, they are all connected together and so, that has more surface area to supply sufficient electrons to the steel reinforcement nearby. This picture over here shows an example where there you can see here small holes are drilled and these anodes are all getting connected.

In series, you can see there is a little red wire which goes and which are all connecting all the anodes and then these are anodes are embedded into these drilled holes and protect the reinforcement in the vicinity.

(Refer Slide Time: 31:57)

Now, these are some different types of anodes available with comes in various shapes but the point here main thing to note, I just want to say here is that these are the original type where they embed the anode and you can actually reach as close as possible to the steel rebar that is the idea of giving or coming up with these embedded type anodes rather than an anode, which is applied on the surface.

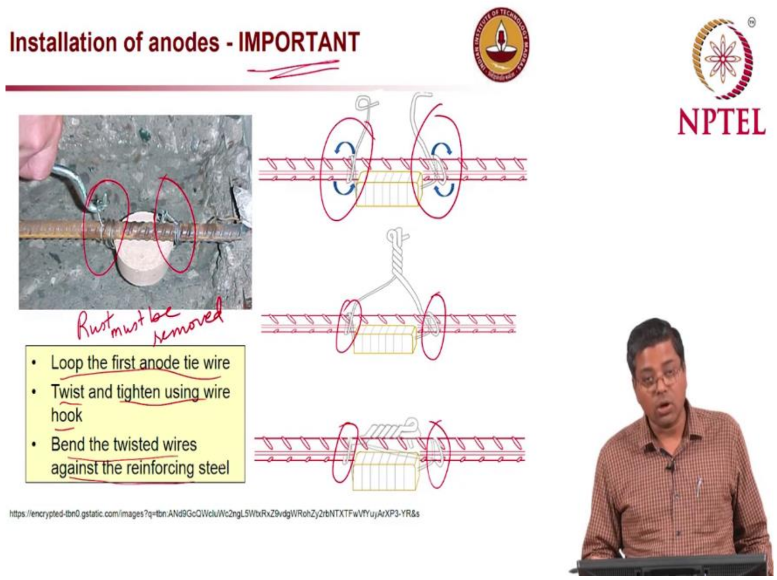
So, typically when we talk about impressed current technique, then we put the anode on the surface of the concrete. That is how usually it is done, whether maybe specific cases but in general, and in the case of sacrificial anode system, these anodes are embedded into the concrete and then covered so that after the work is over, people would not even know that there is some type of repair being done or some kind of electrochemical activities happening.

But in the case of impress current you will see this boxes where rectifiers where and then where the current is being controlled and which need to be protected from vandalism etc. So, in case of galvanic anode protection system or sacrificial anode protection system, you did not have to worry about those vandalism that which is very important.

So, and this on the left side you can see some of these discreet anodes which can be installed in drilled holes at various locations in the concrete structure. On the right side you can see distributed anodes which are connected or to the rebar and then kept parallel to the rebar and this works very well when you talk about coated rebar system because it is something where, you don't know where the damage is and then so.

And wherever there is a damage you have to protect them. So, you can see that kind of system also works very well this long anode it is not stripped, but it is like a long piece which can be installed and the structure can be protected for a long term.

(Refer Slide Time: 34:15)



Now some tip is very important because, most often when you have any new technology that technology gets killed if the application or implementation is not done properly. So, it is very important to know how that system works. What are the essential things for that system to work? And are we actually doing all that while installing, but if you don't do all that, then we cannot blame the system or the technology but you have only blame the workmanship.

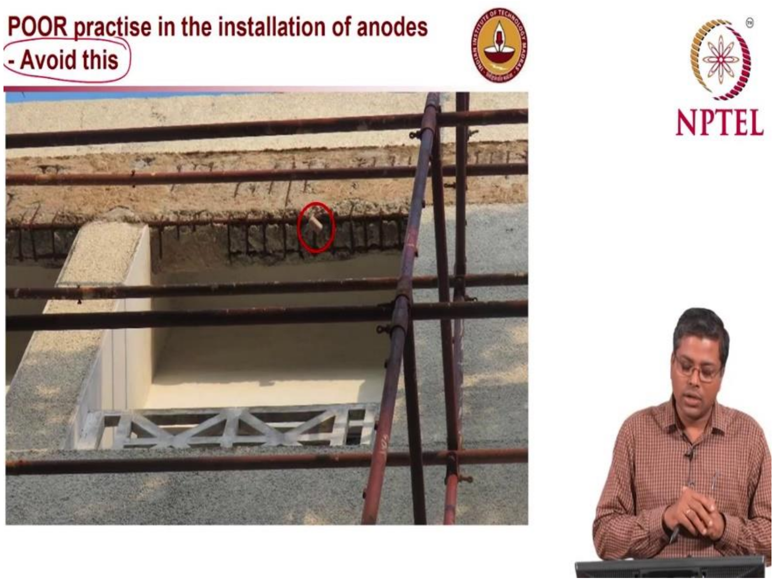
So here is something which is very important when you talk about these anodes. So, you have to really connect these anodes. If the tie wire which comes out of the anode, you have to really make sure that it is tied very well and as you see on this photograph on the top left I just marked that it is very well tied. Now imagine you have this rebar which is heavily corroded. Imagine a case, and you tight it very well.

So you have to, wherever you tie the anode must ensure that rust is removed. This rust must be removed because rust is an insulator rust must be removed, and then we will check the electrical connection, I will show that in the next slide. So, this is how an anode is connected. So, you have to tie this very well, tie around and tighten it very nicely and then you can see how it is connected over here. So tightening is very important.

So the tie wire should be electrically connected to the rebar and then there should not be any possibility of the repair material getting in between, if you don't tie them very tightly, what will happen is when you place the repair material, they can actually get into the space between the tie wire and the steel rebar, and then you lose the electrical connection? So that is not something which is favorable. So you have to really tie them very well.

Now, loop the first anode tie wire, Twist and tighten using hook and then Bend their twisted wires against the reinforcing steel. My student made this nice drawing sketch here, Very Good. So, this is something which is very important when we talk about galvanic anodes and their insulation.

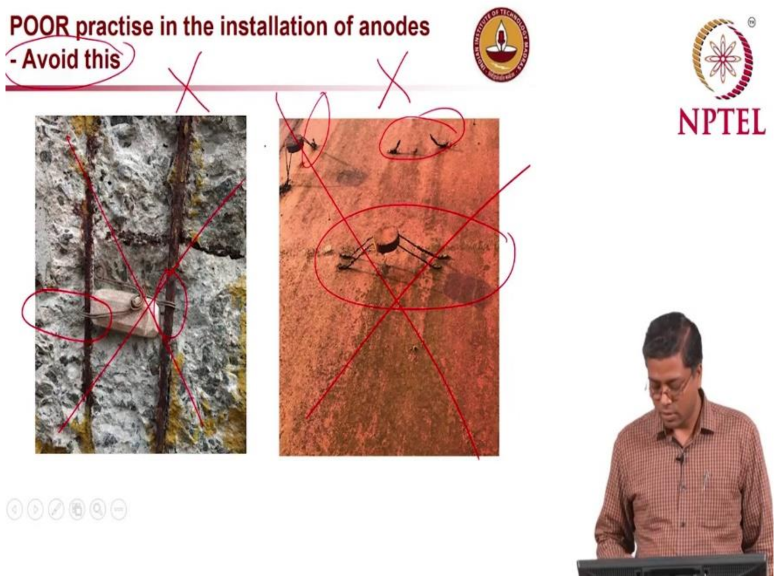
(Refer Slide Time: 36:44)



This is a poor practice we must avoid this. So, we must go for very tight good electrical connection. So as you can see here, there is an anode hanging from the beam where it was installed, I only took this picture. So, you can see that it is not a good practice and then we enforce that this is really tied it very well otherwise eventually what will happen is after a few years, this anode is not working.

So, they will come back and tell you that the cathodic protection technology itself is bad, but what is bad is not the technology, but the way it is implemented. So, tying of the anode to the reinforcement and getting a very good electrical connection is important. So, you have to remove the rust from the steel surface.

(Refer Slide Time: 37:37)



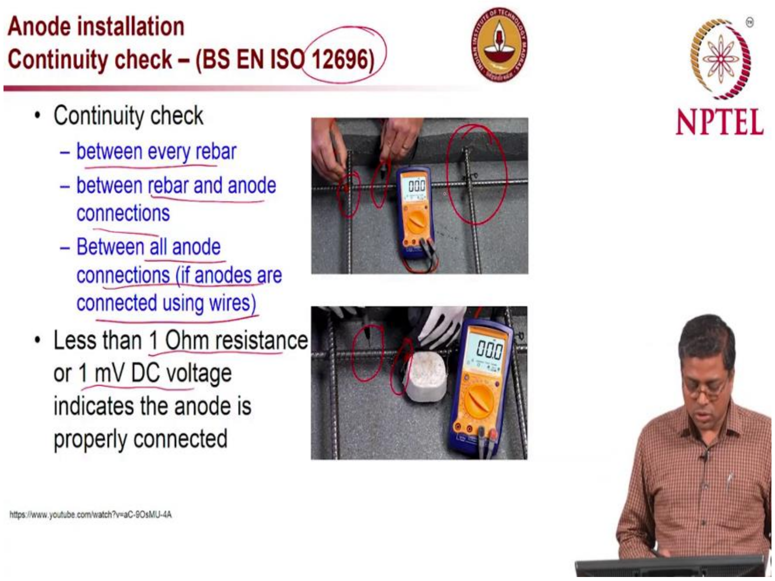
This is another example you can see here is very loosely tied. This also very loosely tied. So, earlier I was telling the concrete can or the repair material can get into the space between the tie bar as you see here, this circle right here if you see, you can see that the there is some space between the tie wire you have to look very closely to the image there is some space between the tie wire and the corroded rebar and the rebar also is full of rust.

So, even in this case unless you really remove the rust where the tie wire is, you will not get proper electrical connection and then the anode will not work and the steel will continue to corrode and then after a few years you say that anode is not working that is not right. So, the implementation is very, very important and crucial. Here is another example where this is a picture from a bridge structure.

Now they expect this anode to function, how is it going to function? there is no electrical circuit completed, the electrical circuit is not complete, So eventually what happened is you see that all the tie wires corroded. This zinc which is inside this circular disk is not helping in protecting the system below. So, this is not how an anode should be connected. You have to ensure that the electrical circuit is very good.

So, understanding how our system works and then only we should apply. So, in this cases, it is very clear that the engineer did not understand the mechanism or even the people at site or even the suppliers of the anode should ensure that it is installed properly. Otherwise, the system is not going to work and eventually we will all blame the technology but this kind of things should not be practiced.

(Refer Slide Time: 39:52)



Now, how do we check that the anode will actually work? So first thing is checking the electrical connectivity so you can refer this ISO standard 12696. As you see in this picture here, this person is connecting the one probe of the multimeter and other to the transfers bar. So, the 2 rebars and you see whether the connectivity is very good or not and between the rebar and the anode connections also.

So, you can see here on the bottom picture, he is connecting one terminal to the rebar, and the another terminal is connected to the tie wire which is coming out of the anode. So, and if you see that the resistivity is very low when you take these measurements as it is seen on the multimeter the resistivity is almost 0. When you say that resistivity is or resistance is 0, that means there is a very good electrical connection between these various points we talked about.

So, in this case, this anode at the bottom that will be able to protect both the rebars in perpendicular directions. So that is our idea, it is not just to protect the rebar to which it is connected but to protect the rebar mat or the entire rebar system. So, between all connections if the anodes are connected using the tie wires, very well cleaned tie wire also should be clean and made sure that there is no rust on the tie wire because if you buy the anode and after some time you connect it there are possibilities that the tie wire also have some corrosion so all that makes sure that there is no rust at the time of installation both on the steel and on the anode. Now if the resistance is less than 1 Ohm, we can say that it is very low resistivity and then connection is very good.

If it is less than 1 millivolt potential difference, then also we can say it is very good electrical connection between the rebars and also good electrical connection between the anode and the rebar. This becomes very important when you talk about very heavily corroded structure.

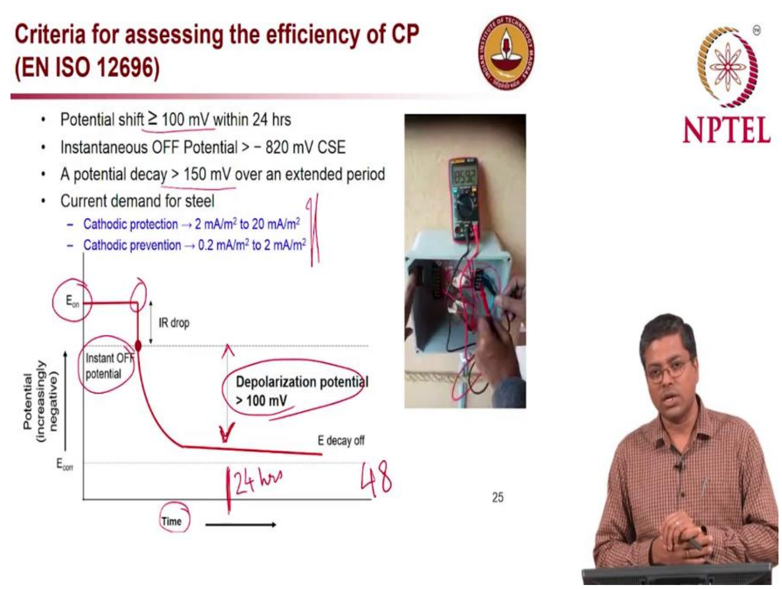
What will happen is the rust will get trapped in between the 2 rebars and you will not have a good connection. So you may have to actually provide another tie wire in that case and clean the surface of the rebar and make sure that there is a good electrical connection between the, between all the reinforced steel reinforcement, it’s very, very important sure to ensure that the connectivity between the systems are very good then only all this galvanic anode systems will work.

(Refer Slide Time: 43:11)

Now, this is an example where it is about 3, 4 storey building and you can see at the bottom of this column and many of the columns in this line, were actually having this corrosion at the bottom point and this is a close up here you can see the stirrups are getting corroded why because, this column is actually absorbing or sucking all the water from the ground because of capillary action and reinforcement at the bottom is exposed to that moist environment throughout the year.

Except maybe, whenever it gets exposed to this and then it contains that concrete around works like a water sink, and then the rate of corrosion is higher in this case, as opposed to the other regions on the same column. So how do we protect this because, if one way is by injecting some chemicals into the bottom of the column, where we work on the pore structure of the column. And prevent the entry of moisture from ground and at the same time if you can actually provide cathodic protection, we can stop the corrosion from happening.

And in this case, maybe if the corrosion rate is high, we know exactly where the anodes are placed. And let us say after 20 years, you take the anode and put a new anode in same place. So this is something very easy to do. And without really waiting for long term for this column to lose all its capacity, so by that time, it will be too late. So this is where we say cathodic prevention technique becomes very important and less expensive than cathodic protection. **(Refer Slide Time: 45:02)**



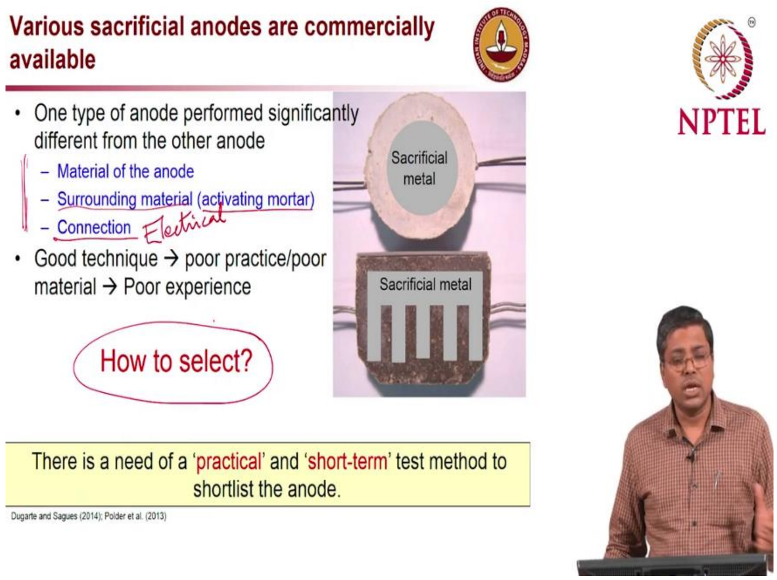
Now, this criteria on checking when you install a cathodic protection system or install an anode, how do we check whether it is working or not? So, one widely used technique is this, we look for shift in the potential if that shift is greater than 100 millivolt in 24 hours, like you say here follow this graph. So, this is the E_{on} that means the potential when the anode is connected to the system and at this moment we disconnect the anode.

So, after that anode there will be a potential drop and so we call that Instant OFF Potential and then after that there will be a decay in the potential and we after 24 hours, we check this potential so, let us say here it is 24 hours. Timescale at the bottom so, this is 24 hours time. At that time if the potential is greater the difference is greater than 100 millivolt or the shift is greater than 100 millivolt.

If the shift is greater than 100 millivolts then we say that the system is working very good. And also, Instantaneous OFF Potential, if it is less than - 820 millivolt versus the copper sulphate electrode then also it is good and then a decay of 150 millivolts over an extended period of time. So, different techniques are have been worked on, because in some cases people also say you cannot measure on 24 hour basis you may have to go for longer period and then measure, maybe 48 hours in some cases.

We have done in one of our projects where we checked this at 48 hours, and we could see that there is a decay in the potential and then based on that we decide okay whether the anode is working or not. Now, these are the typical ranges of current demand, which you can expect when you are talking about cathodic prevention or cathodic protection, you can very clearly see that in the case of cathodic prevention. The current demand is less than 2 milliamp per meter square.

Whereas in the case of cathodic protection, there is a higher demand that means the rate of consumption of anodes will be higher in cathodic protection. So, it is always better to install the anode before the corrosion starts and so that there is no issues with electrical connectivity also. So, as we design the structures, if we can provide the anodes at the critical locations where we expect corrosion, we can also delay the onset of corrosion and really protect the structure for a long time.
(Refer Slide Time: 47:52)



Now, various types of anodes are available. I discussed this briefly a little bit earlier but let me tell this once more. The one type of anode performing significantly different than the other anode. The reason for these difference in performances are mainly the material of the anode, The zinc itself, or the metal itself and the surrounding material or we call it activating mortar or encapsulating mortar different names, but essentially the idea of that mortar is there are 2 roles for that mortar around the anode.

One is because you have zinc metal, the zinc metal needs high pH typically 13+ for it to corrode and the system to work the zinc has to corrode then only it can protect the steel. So, you have to have a mortar which can always provide 13+ pH, for the zinc that is one thing. Now, if the zinc is corroding what will happen this corroded zinc has to occupy some space there is a little bit of expansion happening not like the steel rebar, but a little bit expansion.

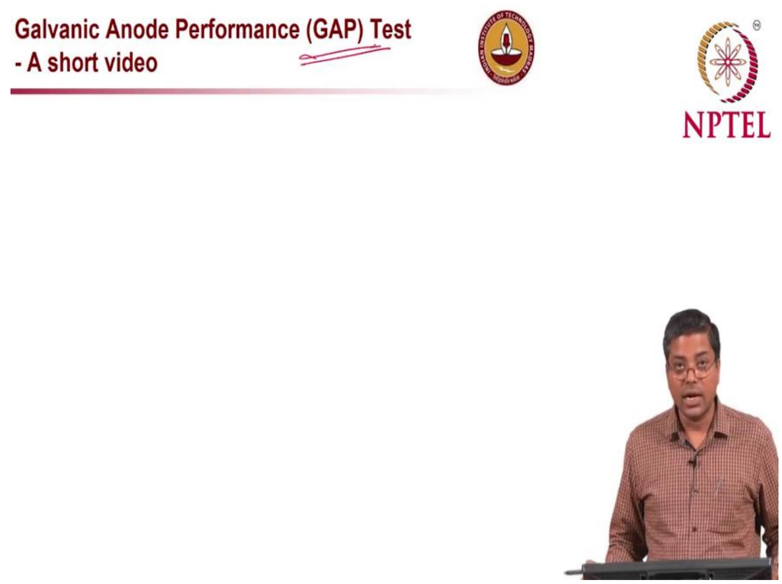
So, where the zinc dust will go it has to get into the pores around so, that the new surface which is exposed new surface of the zinc which is exposed, also get the high pH environment so, it is a very complex system and you have to provide the high pH for the entire design life of the anode which could be about 20 years or 25 years. So, these are the different shapes whatever be it, we have to have a high pH environment for the entire design life of the anode.

So, the activating mortar should provide that for long term not for just few years from the installation, but for long term. So, that is where the difficulties in design comes and there are products available in the market which actually meets those requirements, and also the electrical connection between the anode and the rebar. If they are not electrically connected, then it is not like just visual, I am saying, make it very clear that electrical connectivity is very important. Okay.

So, there must be checked before you cover the anode with mortar, before covering the anodes with mortar, every single anode must be checked for electrical connectivity and that or resistance value must be recorded. Otherwise, we cannot expect the system to work very well. If you do good care in doing all these things, then definitely the structure will last as designed.

Now, how do we select these different types of anodes which are available in the market? there are some test methods available which are meant for ICCP system. So, taking the ideas from that we have actually developed a short-term test method.

(Refer Slide Time: 51:10)



For sacrificial anodes and we call it GAP test, which is Galvanic Anode Performance test, I thought this gap test is sounds nice. So, we are going to call this GAP test. So, this is a short video which shows how the test can be conducted and the significance of this test and what are the things which by which the, we can detect a particular anode is better than the other anode or whether it will be able to give the desired life or extension of the life for the structure.