**Maintenance and Repair of Concrete Structures**
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**Module No # 03**
**Lecture No # 12**
**Condition Assessment of Concrete Structures (3/3)**
**(Mechanical and Corrosion Testing of Rebars)**

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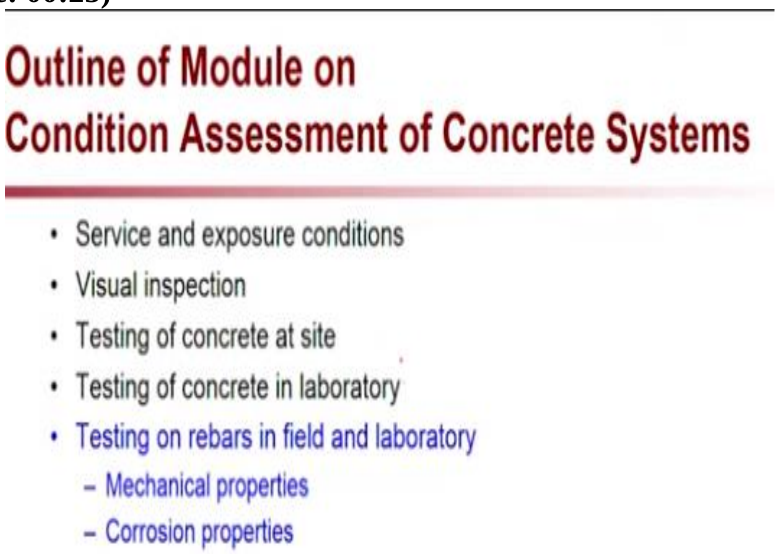


Hi this is the third lecture in the module on condition assessment of concrete structures. In the first lecture we covered service and exposure condition, visual inspection and testing of concrete at site. And in the second lecture we covered testing of concrete in laboratory on both the specimens prepare in lab and obtained from the field. And today in this lecture we will cover testing of rebars in field and laboratory and we look at both mechanical properties and corrosion properties.

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Now before getting into the various tests we will look at what is the need for non-destructive corrosion test and mechanical test. Here in this first picture on the left side, it says concrete wall with no visible corrosion or no stains of corrosion is visible. The same wall after removal of concrete cover, significant corrosion was found in all the rebars which are visible now. And the third photograph is showing a close up view which very clearly shows that almost nothing is left in that particular rebar. So the point here is that even though you may not see corrosion stains on the concrete surface there could be significant amount of corrosion could happening inside the concrete structure or steel might be corroding in a hidden manner. So we need to have techniques which can be utilized to deduct corrosion as early as possible and non-destructive techniques are very much useful in such cases.

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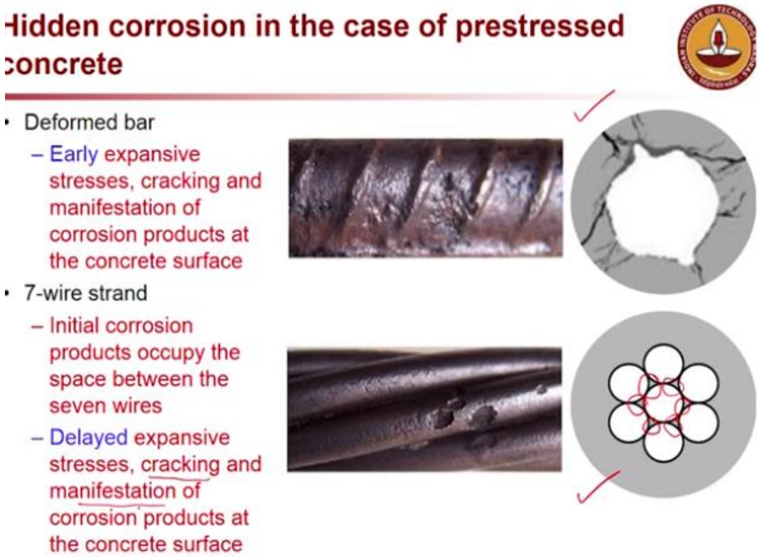


I already discussed this in one of the previous lectures on pre-stress concrete but I just want to recap on that. The first picture is this one it shows how the cracking can happen in case of conventionally reinforced concrete with a solid rebar. And the second one is on how the system is in case of pre-stressing strand. So what happens in case of pre-stressing strand is the initial corrosion products will occupy this triangular space available between the 7 wires and until that space is filled up with corrosion, there won't be significant expansive stress on the surrounding concrete which is not the case of solid reinforcement. So what it means is there could be a significant delay in the generation of expansive stresses, corresponding cracking and manifestation of corrosion product at the concrete surface in case of a pre-stress concrete system.

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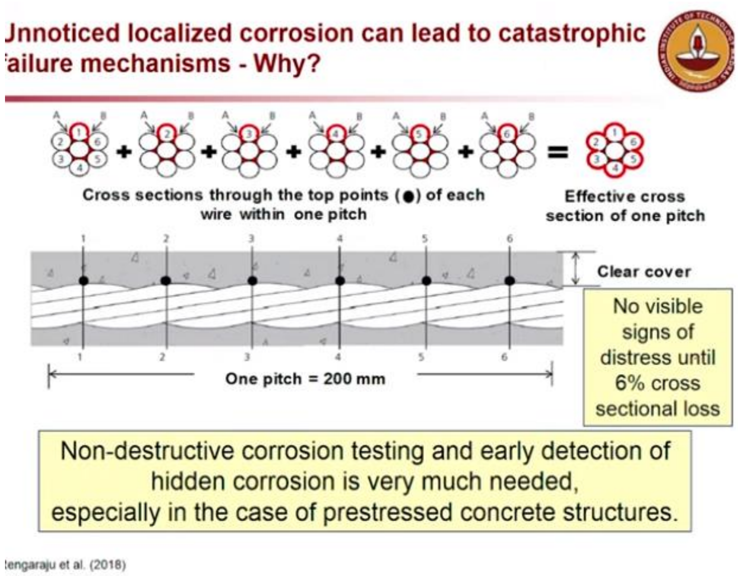

Now this is a again the same slide which was discussed in one of the previous slides. So basically showing a one important aspect that until about 6% of cross sectional loss there may not be significant visible signs on the concrete surface in case of pre-stress concrete. So it is very important for pre-stress concrete to employ non-descriptive testing and detect the corrosion as early as possible because in case of pre-stress concrete once the corrosion starts it is very dangerous. So we have to take a preventive maintenance approach in case of all the structure, we must be able to detect corrosion as early as possible or even before if possible. We should be able to judge when it will start corroding so that we can take preventive measures.

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Now let us say you left the structures without any monitoring and eventually you will reach a stage like severe corrosion and then you will have to assess the residual capacity of this structure. Typical practice is that, if there is about 10% metal loss then we say okay the rebars should be replaced or should be taken up and replace with the new rebar or some kind of major repair or retrofitting has to be done And the point here is the challenge which the engineers are inspector face is, on the document they will say 10% area loss of the rebar but how do we really estimate or measure this 10% reduction? It is very difficult just by looking. You can only say there is significant corrosion but if somebody wants to tell exact amount of percent in a mass loss it is quite difficult, the correctness of the assessment is not well established.

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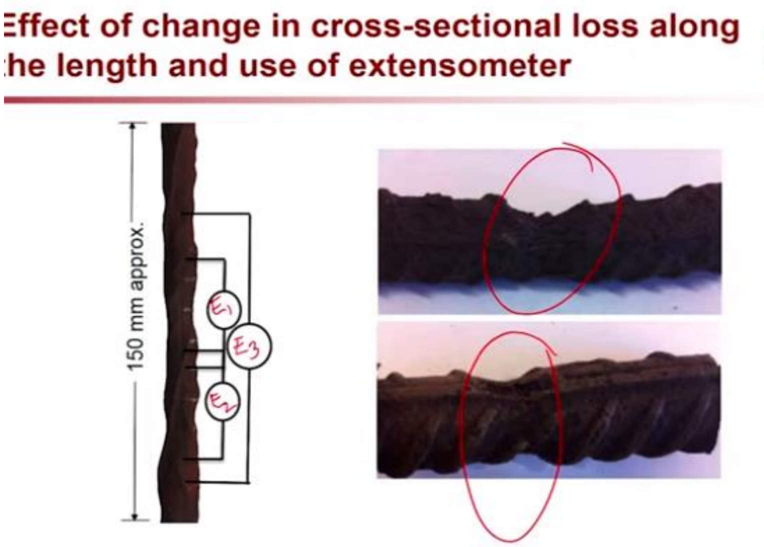


I am going to show you something on what the effect of such change in cross sectional loss on the stress strain measurement which you take is. I am not saying stress strain behavior but I am telling if you take a corroded bar and do a tensile strength stress and get a stress strain behavior, how correct that could be? That is what the idea here, I am not trying to show you that there could be significant changes in the true behavior.

Let us say this bar here, as you see on the bar on the left side there is significant change in the cross sectional along the length. And as you see on the picture on the right side you can see, over here there is a significant loss over here. So definitely when you put axial load on this bar, the stress experience by the region inside the red markings will be much more than the stress experience by the region outside those red marking. So, different point experiences different stress.

Let us say in this bar, if you are actually testing, if you put an extensometer like I showed here, let us say this is E1 I am going to call first extensometer and then another extensometer you put here E2 and then one more if I put E3 okay. So there are 3 extensimeter if I attach to a particular rebar and then do a tension test I will get very different stress strain graph by the data which I procure based on these 3 extensometer.

Basically you are taking an average of the strain within that region. So that leads to a lot of problems, which does not really tell you what is actually happening at various points on the corroded rebar system.

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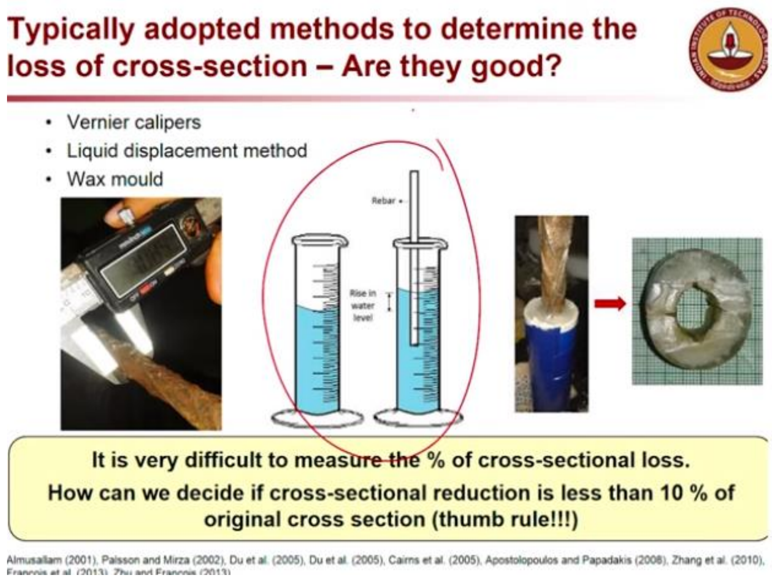


And like I mentioned earlier there is also a difficulty in assessing what is the cross sectional loss? So I am just showing you multiple methods which we ourselves did it in our lab and we found that the most of the methods do not really give a reasonably accurate or sufficiently accurate cross sectional area loss. So first one you can see on the picture on the left side, you have Vernier Caliper you can measure, but imagine it will measure only the diameter not really give you information on how the cross sectional look like. So you cannot even assume a circular shape. I will show you in a next slide that how the shape at various locations of this particular bar. And then the second is method liquid displacement method. Even here what we tried was we put a graduated cylinder then you place solution in that then immerse rebar and then try to see how much dislocation. How much displacement means how much water displaced and even that will not give you much accurate results. Even we tried with kerosene, even that did not help much then we also tried with wax molding, making a mold out of wax and then try to get some idea on how the cross section varies along the length of the rebar. But these are all very difficult to do test and it does really give sufficient accuracy in the readings, it does not really help at the end in estimating how much cross sectional loss.

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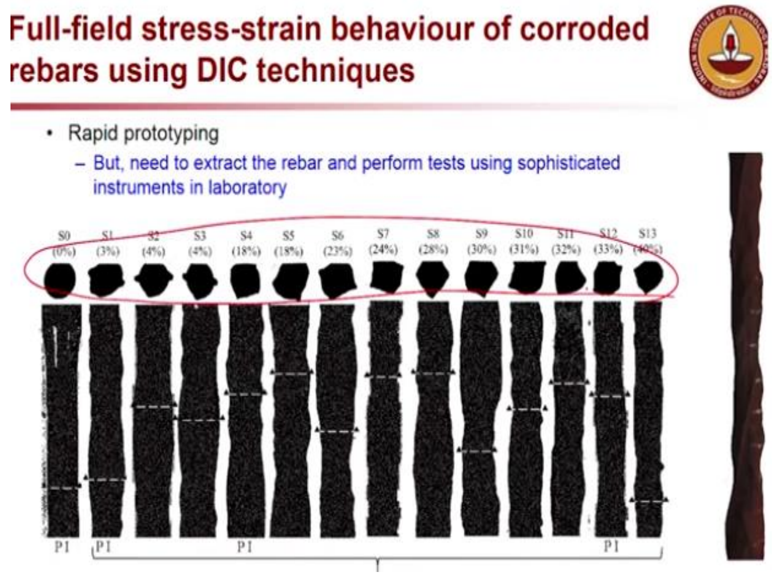


Then for a research purpose we did this study on a particular bar. You can see there are 13 specimens of corroded rebars were collected and then most severely corroded cross sections were selected as see on this white dash lines. The top of this drawing, you can see that how the cross section is, it is never circular in nature; all these are of different shape. So imagine now if you were using a vernier caliper and trying to measure the diameter assuming it to be a circle, how wrong that diameter could be. So bottom line is it is very difficult to measure cross sectional area loss especially over a length of the rebar and in future there may be better way estimating that. But at this moment the rapid prototyping techniques seems to be useful, but the challenge here is we cannot do this site. We have to extract the specimen, bring to the lab and then test, very tedious procedure in getting cross sectional variation along the length.

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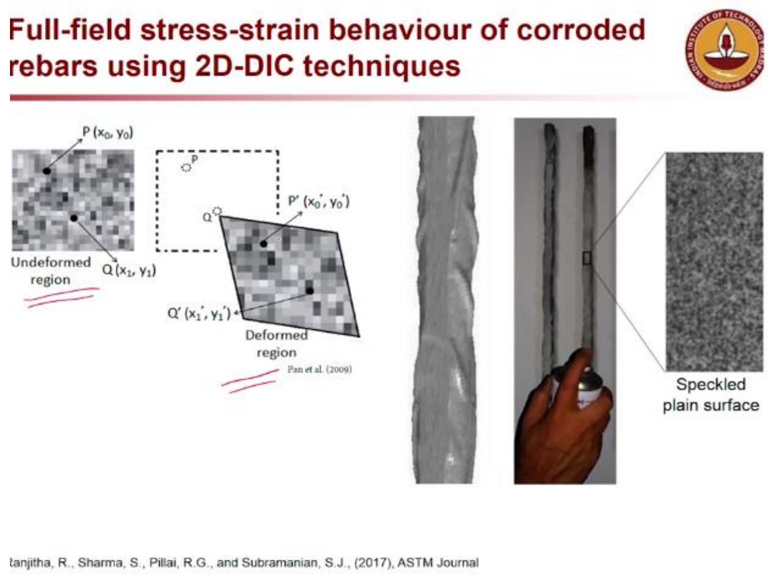


When you talk about a corroded rebar like I mentioned earlier, different points on the rebar might experience different stress depending on the cross sectional at this particular level and so DIC or digital image correlation technique is useful technique which can be utilized to see is the variation in the stress at various points on the rebar at a particular loading condition.

So you can see here digital image correlation, here you have un-deformed region and then the deformed region. So basically the idea is in the un-deformed region before the testing starts you apply black and white the speckles, speckle surface, basically you have a black surface and on top you spray white then take an image and read the pixel by pixel and then during the tensile strength test you can see how each pixel is moving. And then based on that we determine what the local stress strain behavior is.

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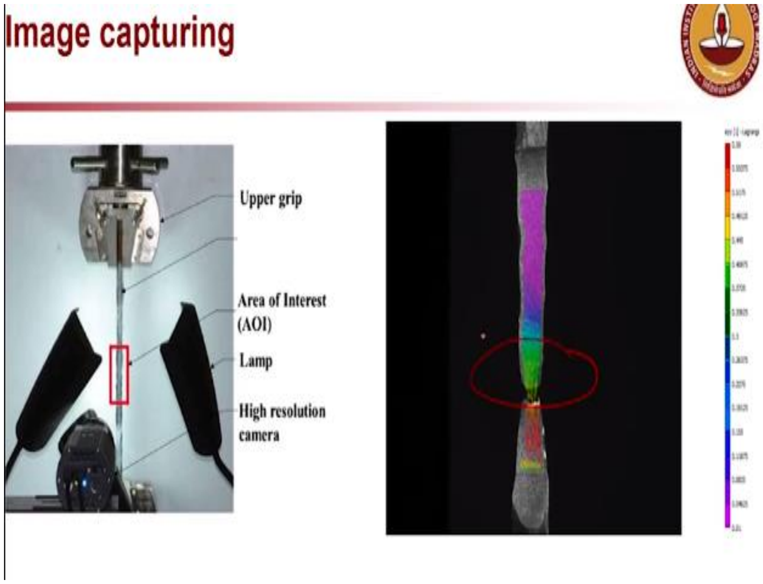


So basically, during the test we capture several images using high resolution camera setup and then post the testing we can analyze the data and then see how the stress strain behavior in different points on the bar. This you can see one example video I am going to show you here, you should look for the change in the color. So more the reddish means higher the stress and then more bluish in color then that region is experiencing less stress. So in this video you will see that the stresses at different points are different and I will take you through until the failure of this specimen.

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And also along the horizontal section itself there is a lot of variation now you can see in some region especially here there is a stress concentration and you will see that the stress at this region is going to build up and eventually it is going to fail. So that is a critical cross sectional which we have to worry, now the specimen as broken.  So how do we get that in the very beginning is very difficult. So rapid prototyping is a good way to really understand what is happening in the steel.

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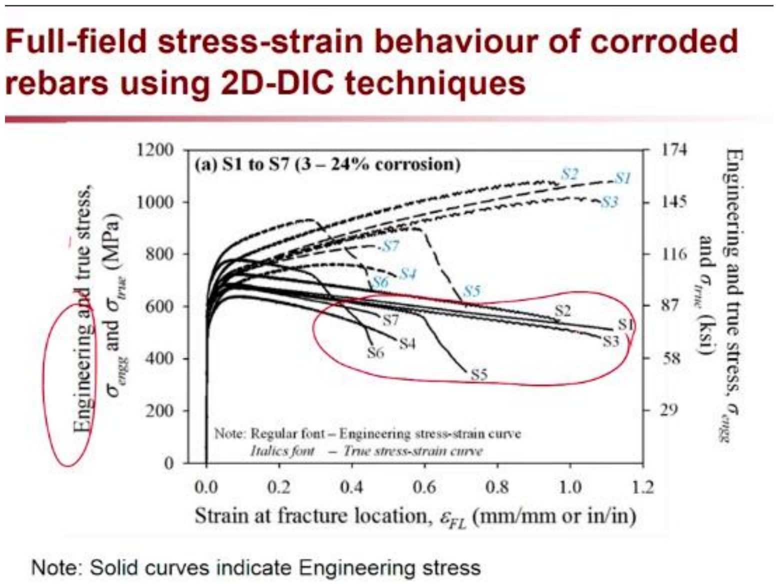


Now here also you can see all these different specimens, look at the solid curve which shows the engineering stress. You can see same rebar but are actually braking at different load conditions and the elongation experienced is also difference. So it is very clear that the stress strain behavior at the different points on the rebar corroded bars.

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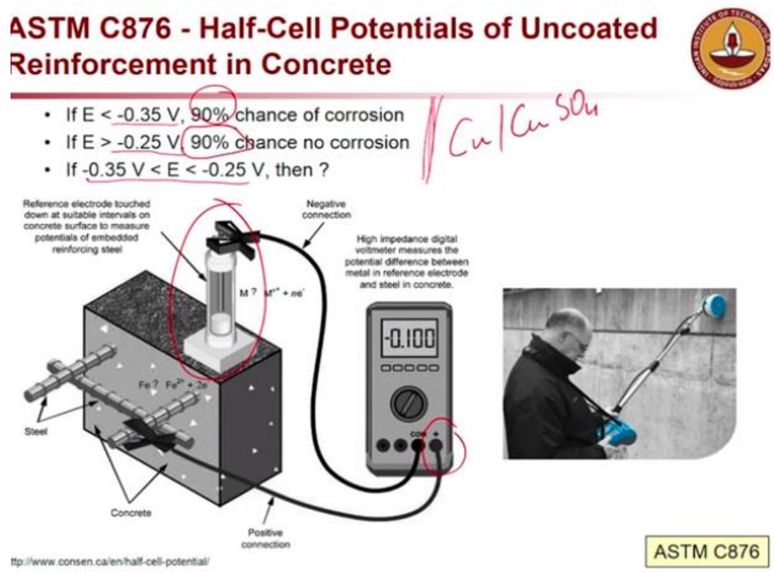


Now ASTM – C876 test is something which is widely used for assessing the probability of corrosion in reinforced concrete system. This method basically relies on the principle that if there is a more negative potential that indicates more or higher probability of corrosion. So you can see here this is a ATSM standard but it says that if the potential is less than -350 millivolt or -0.35 volt then probability of corrosion is about 90%, if the potential is more than -250 millivolt then there is no chance of corrosion, basically 90% chance of no corrosion or 10% chance on corrosion. And if it is something in between then you have to really make your engineering judgment.

So let us look at this sketch at the bottom how it works. You can see the rebars and then with the rebar is directly connected to the positive terminal of the multi meter and the other terminal is connected to the reference electrode. What is a reference electrode? It is an electrode of which the potential is always fixed, it does not change. So wherever you take this particular electrode the electrode has a particular potential. So it is does not matter which electrode you use, all you have to do is you have to make the corresponding adjustments. Electrode mostly people use is copper - copper-sulphate electrode and these numbers are actually based on copper – copper-sulphate electrodes.

Now I will show you this picture, here this man is actually taking measurement using a wheel electrode. Where is the wheel electrode useful? When you have a large surface area to cover then such electrodes are very useful because you do not have to go for point by point, but you can move you now faster along the surface.

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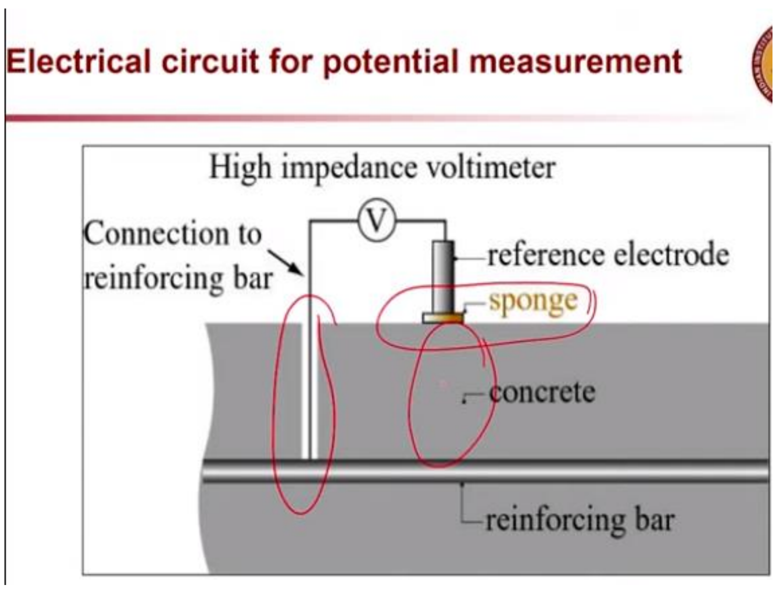


So this is a simplest schematic showing how this particular potential measurement works. One main thing in this you have to really get a actual electrical connection to the rebar, so how we do? We drill a hole at some point on the reinforced concrete structure and connect to the rebar and then the other terminal is connected to the reference electrode and a good contact with the concrete surface is also required. And then you have the concrete here so the moisture condition of the cover concrete plays a significant role in the measurement which you get. So if it is relatively dry you may get very different results as compared to relatively wet concrete cover. So if you are comparing test results, you must ensure that the moisture condition of the concrete cover is also similar range for both the test measurement, otherwise you will get unnecessarily worried about the scatter in the data which is not really what is happening in the concrete structure. So corrosion measurements are very good but you have to interpret and understand the ways which influence the corrosion measurement otherwise it is very difficult to get meaningful information out of it. Understanding on how to interpret and what are the necessary conditions of the steel concrete systems are very important to consider.

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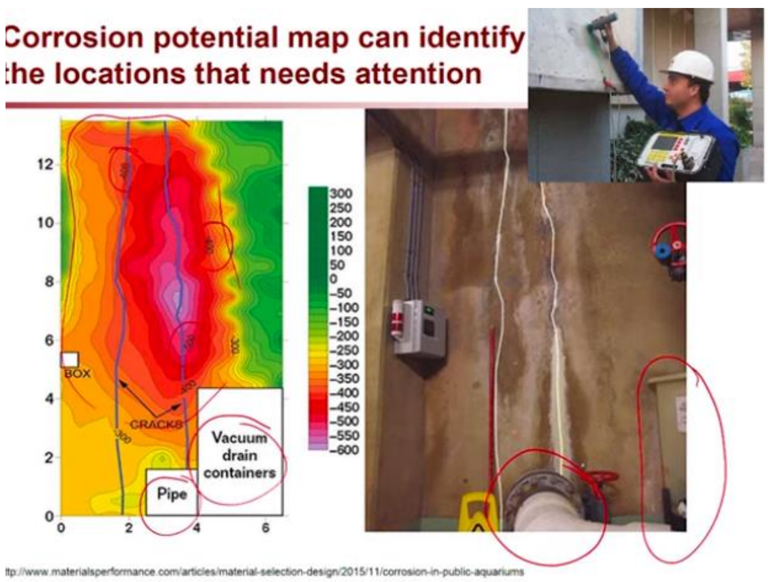


Now here is an example which showing how this particular test can be useful for judging probability of corrosion. You can see here in the photograph on the right side, there is a pipe going here at the bottom and then there is a vacuum drain container. So, these two are shown in the contour map on the left side so that you can easily compare these two. As you see that on the picture on the contour map on the left side that there the red region indicates kind of high probability of corrosion or more negative. If you look at the numbers closely, this is -500 towards that pinkish region and then you have -400 here and -400 here and then as you go towards the green it is more positive or in other words less probability of corrosion. And there is also a blue line which is showing the crack and this crack is reproduce as a white line which is not the sealant or anything they just to show where the crack was.

So these types of test helps you in telling what is a probability of corrosion, but it does not tell you anything about the kinetics of corrosion. It is only thermo dynamics of corrosion and so only probability you will get not the rate of corrosion. So that is something important to remember you get only probability of corrosion and nothing about a time, what is the rate of corrosion because if you want to estimate the service life you need to know the rate of corrosion, that is something different I will show you that later.

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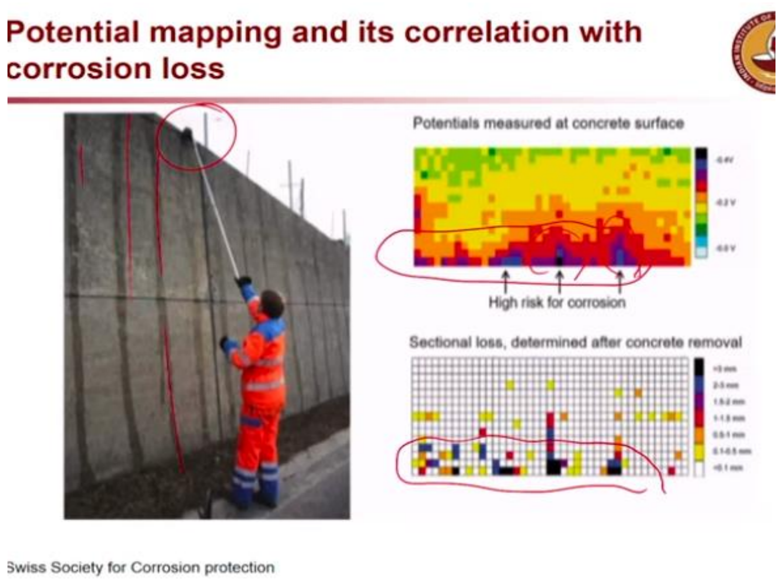


But before that this is another example of potential mapping of large concrete structure, you can see there, again it is actually a wheel electrode, all these vertical wet regions where the potential measurements were taken and map contour map was developed. And after the measurement the concrete was removed and compared with the section loss. The comparison of these two plots is shown on the right side.

If you compare these two plots on right side you will see that wherever there is a high risk mentioned there you have more and more delamination in that region. Here also it is kind of that region is showing higher risk of corrosion and after concrete removal it was proven that this test is actually useful. But one thing is the moisture conditions is something very important. If you maintain an equivalent moisture condition of for all the measurement points then you will be able to get good data and then be able to compare.

It is not just you take this tool and hand the tool and then go to the site and then put it on the concrete surface and take reading and say that this is my corrosion potential measured. And so you may end up in having a lot of scatted data which may not really give you anything useful at the end. So quality control of measurement is very important when you talk about these kind of tests.

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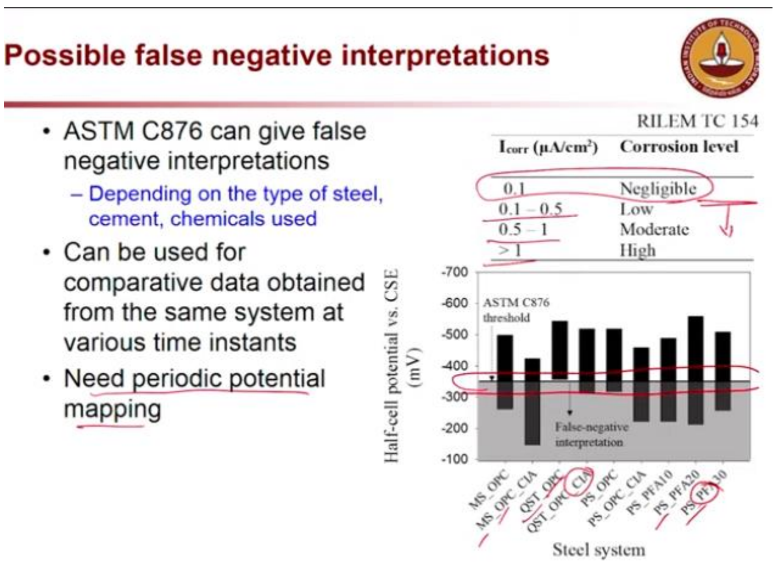


Also an important thing to tell is this particular standard ASTM C876 the values which I showed you earlier, these values -350, -250 and all these criteria or guidelines where developed based on steel and concrete used in 1970’s. But today we have a lot of other types of steel, different type of concrete, different type of chemicals, corrosion inhibitors even we have coated rebars used. So there may all have influence on how to judge or interpret the data because, you cannot use the same criteria given in ASTM C876 apply it on all sorts of steel reinforced concrete systems which will give you very negative interpretation. So as you see on the top right, this is a RILEM recommendation which is telling basically corrosion level can be consider negligible if the corrosion rate is 0.1 micro amps centimeter square 0.1 to 0.5 it can be considered low 0.5 to 1 it can considered moderate and greater than 1 it can be considered as high.

Now if we consider this 0.1 and above act like an active corrosion and less than 0.1 micro amp per centimeter square we say it is no corrosion happening. So we did some test in our laboratory with mild steel with OPC concrete and TMT or QST steel with OPC concrete and also with corrosion inhibitors and pre-stressing steel with fly ash of different dosage. So different type of SCM's, corrosion inhibitors and two types of steel all these were looked at and then we found that there could be significant misleading information if you blindly follow ASTM C876. We cannot blindly follow ASTM C876 because C876 says that if the potential, this is the critical potential let us say that -350 millivolt, below that then there is 90% of corrosion but what we found is it is not really the case with all the steel rebars.

So you have to really have different ranges for different steel concrete systems. That is still not available and we are working on it. But the thing is at this moment what we should do is, if you are given a structure how do we use this technique of potential mapping? Instead of blindly looking at this -350 millivolt as criteria what you have to do is develop a contour map and then say that the more negative regions are having more probability of corrosion than the more positive regions. I think that we should do at this time instead of blindly looking for this -350, it is not a good approach. So we have to really go for a comparison between various points on the structure which are made of same steel concrete system.

And another thing is if you make periodic measurements, let us say after every couple of years, we are making potential measurements depending on the importance of the structure, then we can say from the previous data that now the potential has changed to this much so there is something different happening, like during the previous inspection there was no corrosion and now there is corrosion.

So this is something very important about this potential mapping, we have to be very careful in using this numbers and this criteria of -350 millivolt should not be blindly used we should rely on comparative measurements and looking at which area is more positive and which area is more negative and then say that more negative region has higher probability of corrosion.

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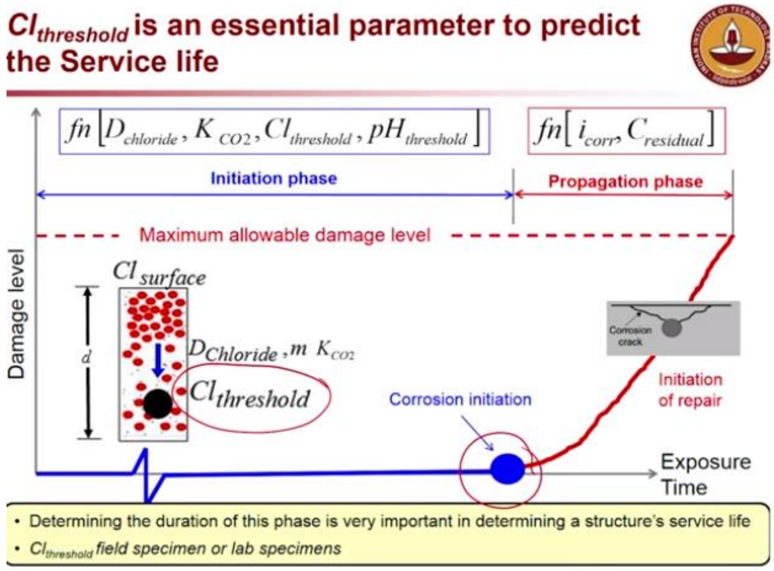


Now let us get into another very important parameter which is chloride threshold. We already discussed this slide and we are talking about chloride threshold which is a crucial factor for the initiation of corrosion.

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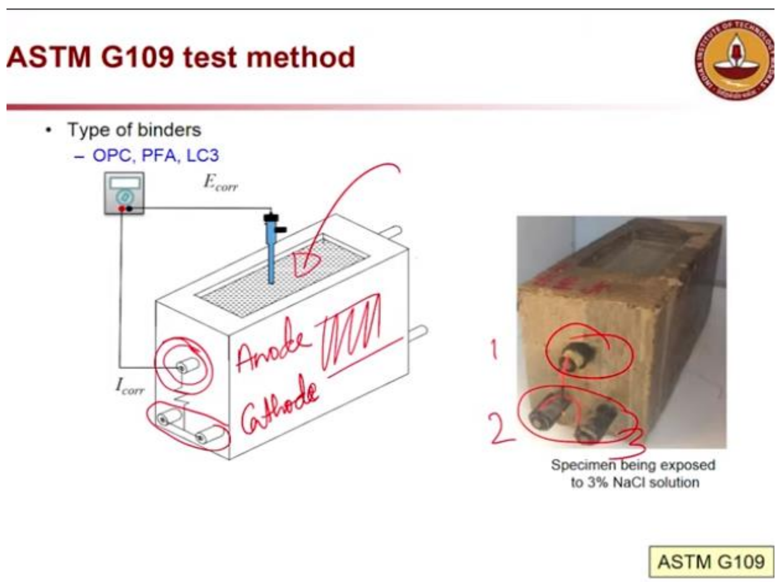


Now one widely used test method is ASTM G109. The test method itself does not say that it can used for chloride threshold, but people have started using it for determining chloride threshold based on the time of initiation or whenever the readings showed initiation of corrosion. And this is heavily dependent on the macro cell corrosion between the top rebar and the bottom rebar.

So you can see 3 rebars on this specimen 1, 2 and 3 so the 2 and 3 are connected together and the top rebar is the one which is expected to corrode and here is the reservoir where you will place the chloride solution and then chloride solution penetrates into the concrete and reaches the first rebar or this top rebar and that rebar will start corroding.

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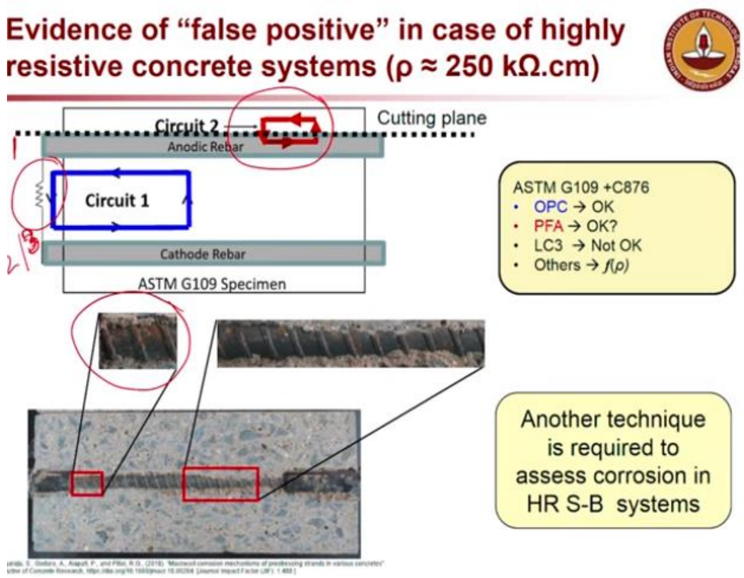


The electrical circuit I will show here you can see here the circuit 1 which is happening in most of the experiments with the relatively older concrete with more porous micro structure and you can see here this is the anodic bar at the top this is bar number 1 and this is bar number 2 and bar number 3 as I showed in the previous slide. So the circuit 1 between the anodic rebar at the top and the cathodic rebars at the bottom is what is usually happening in this kind of testing.

So this bar corrodes and this is the cathode, top is the anode the bottom is the cathode. And so the resistivity of the concrete in this region plays significant role in completing this electrical circuit, the circuit 1 which was in the blue color in the other slide which is showed. So if you have a very high quality concrete what will really happen? When I say high quality highly durable very dense metrics or compact micro structure then what will happen is that the corrosion circuit is something different than the blue circuit which is across the top and bottom rebar. So what will happen in such case is there might be corrosion but you will not notice that in the type based on the type of measurements you are taking.

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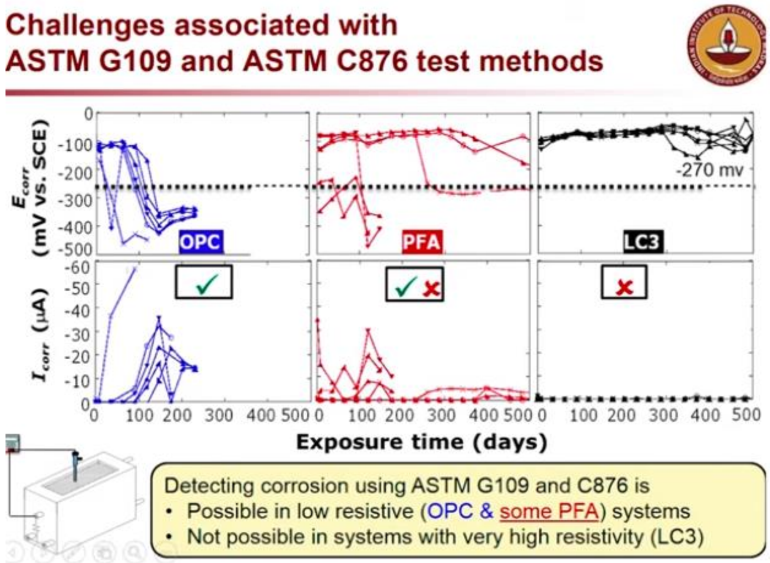


So as it was very clear from this more than a year testing of different type samples, you can see on the first two blue graphs is of OPC, the red is for fly ash base system and black one is a very highly resistive LC3 concrete system. We did this testing and then found that when the resistivity is very high, the corrosion indicated by the measurement which you are taking is very low and how do we take the measurement? We take this $I_{corr}$ and we measure the current between the top and bottom rebar and that is very low. So but is that okay to conclude that the system is performing well? May be not always because what is happening is in this particular test we usually measure the current in the circuit 1 which is the blue circuit, corrosion is happening with both anode and cathode formed on the same top rebar, which is the circuit 2.

So corrosion is happening on the top rebar itself but when you take measurement across the resistor between the top and bottom you cannot really make any judgment on that. So it really again gives you a false reading and how we proved when you open the specimen we could see that it is already corroding, you can see the close up here there is already rust on that but the measurement taken across the resistor is not all reliable.

So these type of test are very good for OPC type concrete but not good for some of the fly ash based concrete with very low water cement ratio or any other the higher resistive concrete system like LC3. So more the resistivity of the concrete, less the reliability of this type of ASTM G109 test testing.

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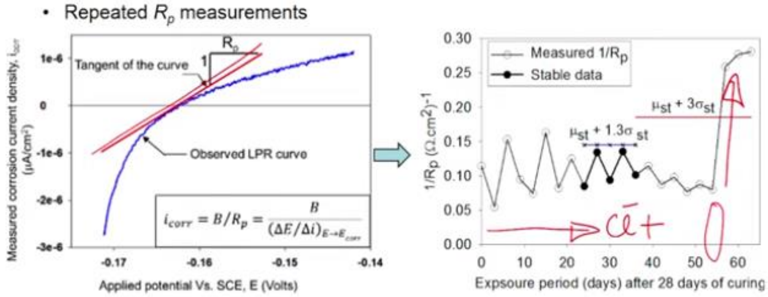
## Linear polarization resistance (LPR) - principles

- Linear polarization resistance (Rp)
- Repeated $R_p$ measurements




The **LPR test** method consists of applying small voltage variations (typically less than 30 mV) above and below its open circuit potential of the rebar. The **polarization resistance** (Rp) is defined as the slope of this current–potential curve, when it crosses the zero current line.

Now in the previous case we found that the corrosion is happening like this circuit 2. So, one rebar is enough to determine or to study the corrosion performance of the concrete system. So how can we develop a test method or something? So there are another techniques which are available which can provide instantaneous corrosion rate or basically linear polarization resistance test can be done.

It is basically what it does is gives a very small voltage or perturbance to the steel surface which is embedded in the concrete and then it measures the current associated with it. And then the slope when it crosses that 0 current access is measured and higher the slope it means higher the corrosion lower the slope it means lower the corrosion rate. So and then we take multiple corrosion rate measurements and then try to determine the time at which there is an increase in corrosion rate and then at that time we can autopsy the specimen and then determine what is the amount of chloride at that particular moment.

So as you see from here to here the chloride concentration keep on increasing, we are exposing this specimen to more and more chlorides and at one particular time the amount of chloride good enough or it is equivalent to the chloride threshold and at that moment there is an increase in the corrosion rate and that is how chloride threshold can be determined.

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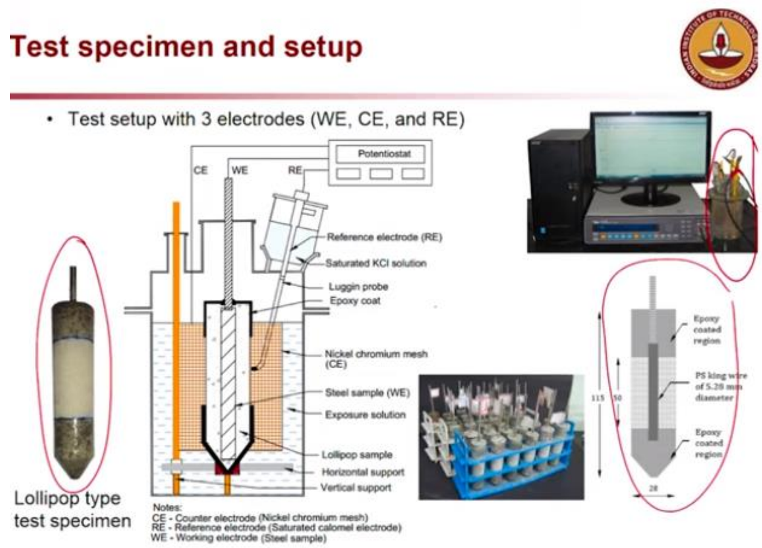


This is the typical test setup for doing this type of test with once rebar like you see in the diagram there one rebar embedded inside and this is how the specimen looks like, we call it lolly pop type specimen and it is kept in a small beaker you can see that here and multiple testing. So this is a typical corrosions cell test set up and we need a potential stat to take the measurements.

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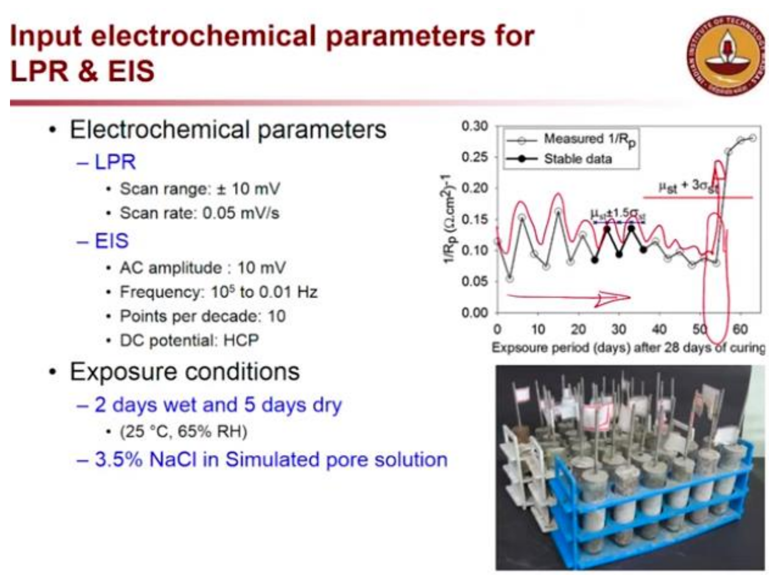


And these are more details on this test is for both linear polarization test and also electro chemical impedance spectroscopy because for systems like coated rebars and highly resistive concrete systems, LPR may not be a good choice. In such cases EIS or electro chemical impedance spectroscopy would be a better choice.

But whatever be the case the bottom line principle of this test method is that you expose the specimen at through wetting and drying and to chlorides, incrementally chloride concentration at the steel surface keep on increasing and correspondingly you measure the corrosion rate at every cycle and then find that one point there is statistically significant increase in the corrosion rate and that is the time when the passive state changes to the active state of corrosion. So we can say at this point corrosion initiated then at that point we open or break the specimen and see what is that amount of chloride at the steel concrete interface by doing chemical test and then you can easily determine. And that particular chloride concentration is equal or defined as the chloride threshold.

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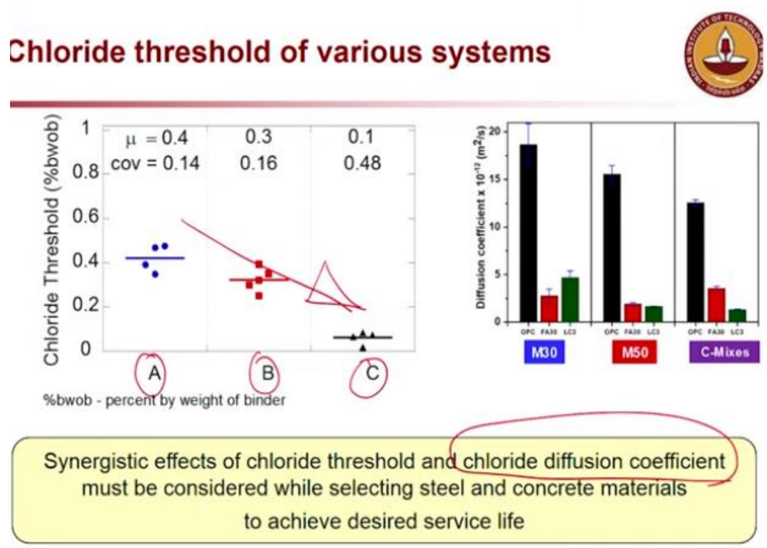


Now you can see the chloride threshold is not just a function of the steel it is also has a function of the type of the cementious system used. As you see here there about 3 systems used A, B, C, we can very clearly see there is a reduction in the chloride threshold as a function of the type of cementious system. So if the chloride threshold is not just a function of steel but for each steel concrete system you have to determine chloride threshold and then we have to combine that chloride threshold result with the chloride diffusion coefficient results which we discussed in the previous lecture.

So the combined effect or synergistic effect of chloride threshold and diffusion coefficient both are required to assess that which steel concrete materials system can used. For example to think about our balanced approach which we talk in the very few early lectures, both the qualities are the quality of both steel and concrete are important. You have to combine effect of both these and then determine the service life and then choose a steel concrete system which will actually give you the desired service life.

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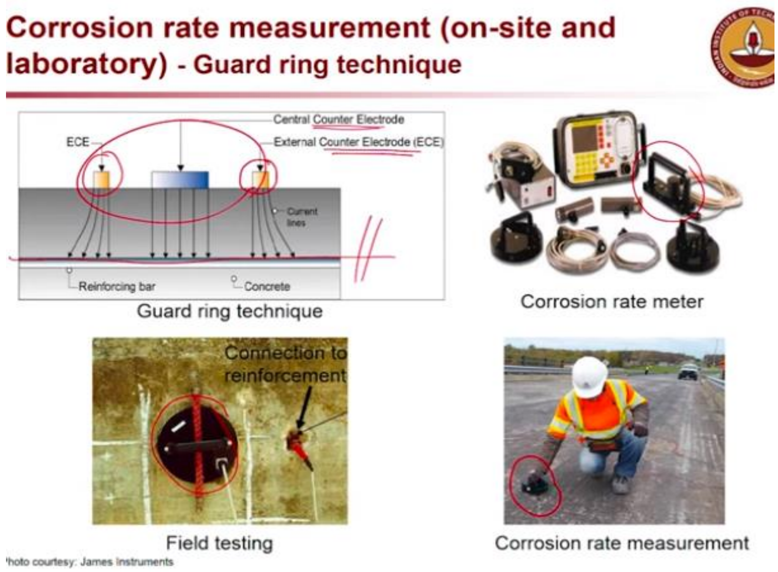


Now once the corrosion starts and then there is something called propagation phase which we discussed earlier. Here you can see this red region here that is the propagation phase. So there it is very important for us to know how much is the residual service life. Like let us say the corrosion already started, now the next step the engineers wants to know or the owner wants to know is that how long I have before the reinforcement lose let us say it is 10% of cross section area.

So we need to know what the rate of corrosion is. So how do we determine the rate of corrosion? So these are some of the technique available to determine the corrosion rate and most of the available instruments are based on this guard ring technique where the area of measurement as you see on the bottom picture you can see a circular you now electrode and you can see in the person on the bottom right he is actually putting the similar type of another electrode on the road surface.

And then you take the measurement so there are instruments with direct contact is available and also the non-contact instruments are available but again you have to really look at the reliability of these different type of instruments based on some pilot studies. Anyway the idea is you confine a small region on the reinforced concrete system that is the region just below this circular electrode, as you see here. There are rectangular type electrodes also.

But the point is that just area below the electrode you have to confine and then take the measurement only in that region. So that is this guard ring technologies. So as you can see here this is the rebar and then you have counter electrode over here and another counter electrode, the center counter electrode and then you take the measurement. So this is the circular counter electrode so both this and this are same piece, so this is the circular counter electrode and then you have another counter electrode at the center.

And then you take the measurement then may be able to determine what is the rate of corrosion and once the rate of corrosion either by assuming an uniform constant corrosion for the wet period and then for dry period some other rate and then you can actually determine how long it will take for the reinforcement to lose x amount of cross section. And then that will help to budget money for that particular repair work if necessary.

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Acceptance/rejection criteria and penalty for inadequate performance on site - SANRAL 2008

| | OPI (log scale) | Payment (%) |
|---|---|---|
| Full acceptance | > 9.70 | 100% |
| Conditional acceptance | > 9.25 ≤ 9.70 | 85% |
| Conditional acceptance | ≥ 8.75 ≤ 9.25 | 70% |
| Rejection | < 8.75 | Not applicable |

Now we discussed various test for concrete durability and then various test for steel. How do we ensure the quality of a new construction or a repair work? This is one way and which was proven to be very successful that is a criterion which was written in the contract document itself. You will have a contract document whether it is for new construction or for a repair project in that you see some criteria, this is an example with oxygen permeability index criteria, but you can develop similar criteria based on other test also. So here the idea was if the OPI, oxygen permeability index the what the owner told to the contractor that after the construction is over, we will do a performance test at random locations on the constructed facility and if the oxygen permeability index is greater than 9.70 then the contractor will get 100% payment, if it is between 9.25 and 9.70 then the contractor will get only 85%, that is 15% penalty, if the OPI is between 8.75 and 9.25 then there is 30% penalty and if it is less than 8.75 then the concrete is or that particular structure element is not acceptable means no payment.

So when you put conditions like this or attach durability to the money, the payment then definitely it is like a watchdog, the person at work will definitely know that if I do a good job I will get quick money or there will be no delay in the payment or no reduction in the payment but if I if the performance of the concrete is not that good then there will be some impact on the payment.

This particular projects which was done in South Africa and what they found is almost all the concrete elements where having an OPI or greater than 9.7 that means no issue and at the same time the concrete structure also was found to be highly durable in nature. So this is one way of ensuring that durability for either for new construction or for repair.

So all you have to do is you have to define a particular performance indicator or a performance test and then put it in the contract that post construction or post repair that this particular type of test will be conducted at random locations and then based on that only payment will be released. So if that kind of contractual agreement is made then definitely we will see much more durable concrete structure and much more durable repairs also.

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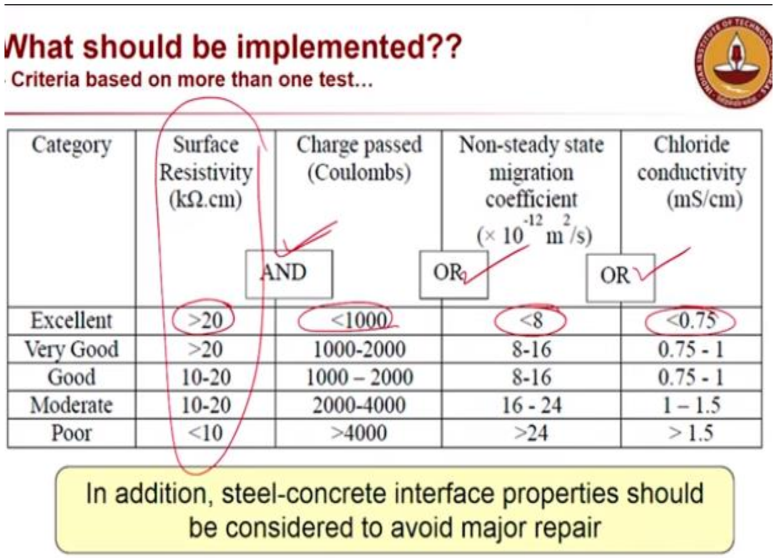


| Category | Surface Resistivity (kΩ.cm) | Charge passed (Coulombs) | Non-steady state migration coefficient (× $10^{-12}$ $m^2$/s) | Chloride conductivity (mS/cm) |
|---|---|---|---|---|
| Excellent | >20 | <1000 | <8 | <0.75 |
| Very Good | >20 | 1000-2000 | 8-16 | 0.75 - 1 |
| Good | 10-20 | 1000 – 2000 | 8-16 | 0.75 - 1 |
| Moderate | 10-20 | 2000-4000 | 16 - 24 | 1 – 1.5 |
| Poor | <10 | >4000 | >24 | > 1.5 |

So this is how we look at different test and a combination of the test parameter. So for example here this is one case, if the surface resistivity is greater than 20 and the RCPT charge passed in the RCPT test is less than 1000 and then any of these three. So what we can do is we can come up with a combined conditions, a combination of different test result and see if a particular combination if it is met then classify the concrete according to that rather than just looking at one particular test method.

In the recent past we have seen that more and more structure people are actually getting more and more serious about doing durability test. Not only compressive strength test but also other test are becoming more and more popular and the main reason is that we are seeing more and more failure of our structure much before the design life is achieved and that is a big concern for everyone. Because as we build more and more structures we have to ensure that they will also achieve their design life and not experience pre mature corrosion. So it is very important to adopt durability based testing and come up with performance based specification in the contract document itself and if we can connect then to the payment then it will be really great. Yes it is very difficult but somewhere we have to start thinking in that way.

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And also preventive maintenance approach is very important. As you see in this building on the left side you can see there is lot of damage and lot of small trees are actually growing, a tree growing on top of a chimney. So what is the engineer who was in charge of this building doing, who is responsible? So we need to really have preventive maintenance strategy, we do not want this tree growing on top of the chimney for any reason I think. So we really have to stop these things from happening or routine maintenance is very important and preventive maintenance. What it means is maintain the structure and do things by seeing what will happen in future and do things to prevent those deterioration mechanisms from happening.

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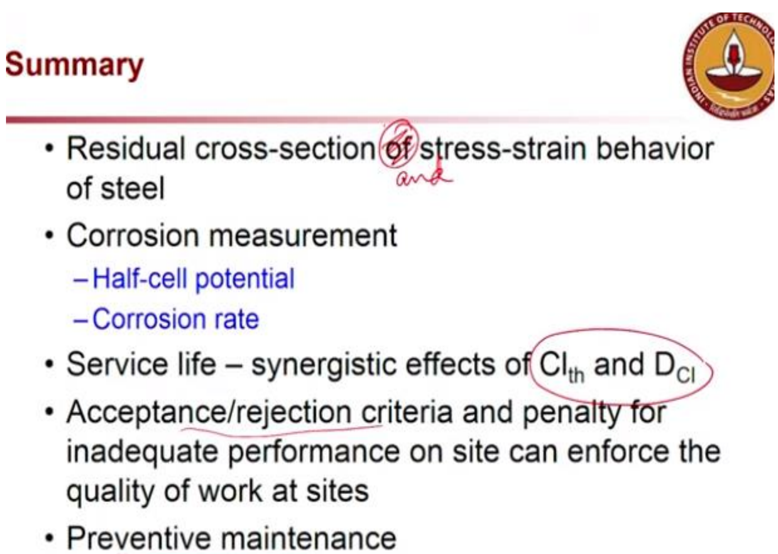

So to summarize we today we discussed about residual cross section and stress strain behavior of steel. And then we also looked at how to measure half-cell potential and corrosion rate and how they can help in determining the probability of corrosion and also the remaining service life respectively. And then service life when you estimate we must look at both chloride threshold and diffusion coefficient. Do not make judgment or selection of materials based on one of them you have to really look at both chloride threshold and diffusion coefficient and see how the combination influences the service life and then choose appropriately. And then acceptance and rejection criteria, connecting money or the payment to the performance indicators and that will be something very useful to ensure that this structure which we built and the repairs which we need are actually going to be long lasting.

And finally we discussed about preventive maintenance there is nothing is better than preventive maintenance. So that will really save a lot of money in future because corrective maintenance is usually much more expensive than preventive maintenance, it is similar to prevent prevention is better than cure which we all know.

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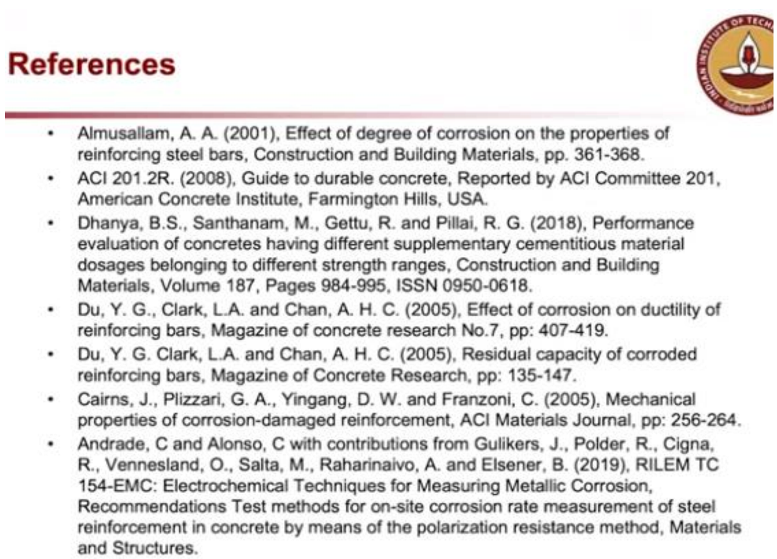


And this are the references used for this presentation. And this will end the module on this condition assessment and next we will start looking at various repair strategies.