Fire Protection, Services and Maintenance Management of Building

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Lecture – 53
Electrical methods of progress measurement

We will continue on.

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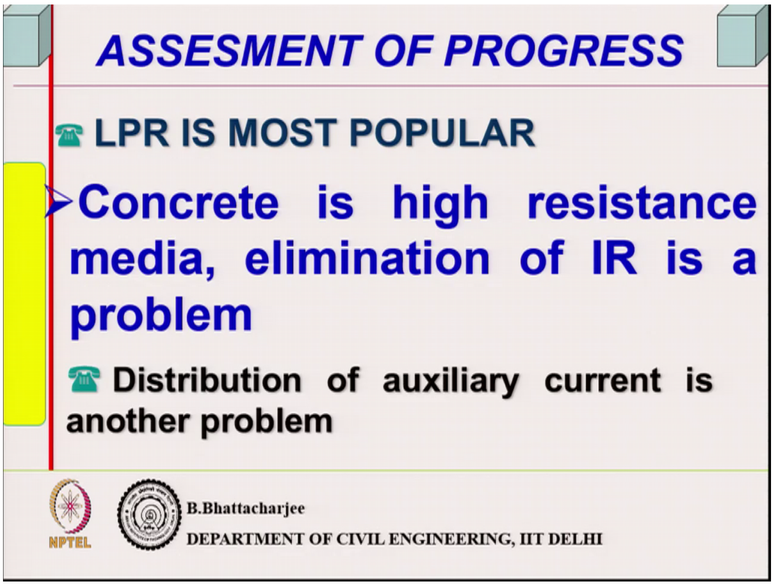

Assessment of progress of corrosion quickly, but we are not going to details of the physics and the chemistry of it So, most popular method is called linear polarization resistance method right. Just quickly without going into much of the you know, electro chemistry and physics behind it. Basically I have a I think I will go to the diagram straightaway.

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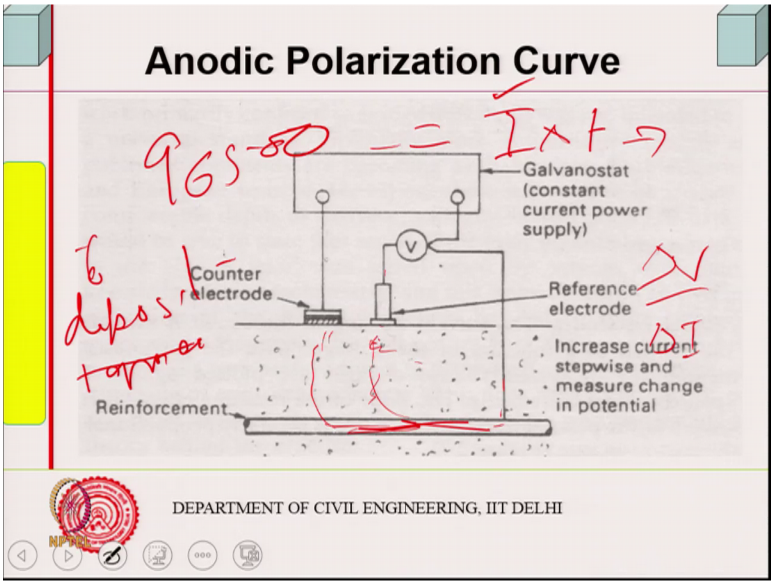

If you look at it here, this diagram will give you something, some idea ok. So, you know if you connect or if you pass current from outside through, the reinforcement supposing I have a source, which can pass current through this. In other words, the corroding electrode or corroding rebar, it is potential can change. I can increase the potential by very small amount; I am talking of the order of millivolts.

So, if I change this potential, what happens is, when I am changing this potential, I find there is a shift in the potential of this rebar from its initial stage. If we recall we had half circle potential measurement, where we connected you know, this is all moist, there is if the connection is through this concrete right. Now this potential now gets shifted because, we have applied current from outside.

The measured potential will get shifted and this shift is proportional to the existing corrosion current density, what you call it rate of corrosion is measured in terms of corrosion current density. Because, it is an electrochemical process. So, we talk in terms of micro amperes, milliamperes, per metre square or the surface area of the reinforcement bar right. So, that is corrosion current density and its proportional to the corrosion current density. Now from faradays law we know, that to deposit 1 gram equivalent of the electrolyte units 96500 coulomb. Approximately 96500 coulomb right, so, 96500 equals to I t. I because current is nothing, but coulomb per second right.

So, charge per unit time flow of charge per unit time, that is current, so, I into t. So, 9650 I t required to deposit, to deposit 1 gram equivalent that is deposit molecular weight, gram molecular weight, divided by valency, divided by number of charges involved in transfer So, deposit one gram equivalent right.

This is what we know. So, that is why corrosion current we measure in terms of corrosion. So, if I am looking at amount of electrolyte that will be deposited per unit area of the reinforcement bar. I will be talking in terms of corrosion current density, corrosion current density. So we talk in terms of corrosion current density one of the ways is to apply current from outside, right current from outside and see the change in the potential, which was already there earlier; half cell potential or rest potential you would have measured and this is this change in potential you know.

So, this is this change in potential delta v by delta I is some sort of a measure of that corrosion rate. We will see that a little bit I am not going to the theory as I said I will not going to the theory So, basically you know this is the most popular method as we call it concrete linear polarization method, one of the most popular, but not very accurate. I will not say it is very accurate. Indirect methods are not very good till date you know like there are other issues involved then I am several issues actually involved there.

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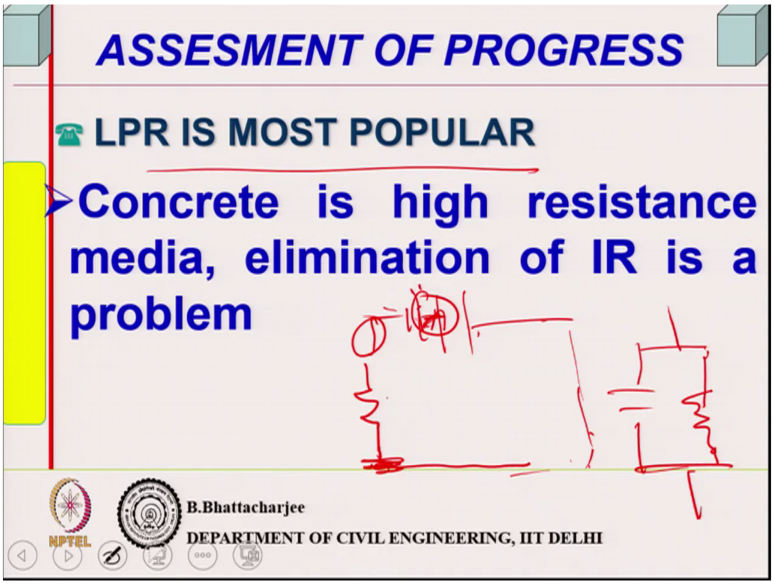

So, concrete also has high resistance. So, actually if you look at the equivalent circuit, you will have concrete resistance, then the reinforcement bar whose resistance is generally neglected, because its conducting compared to concrete. And then you have applied some current here, right some current ampere current you have applied actually some current you have applied here right So, you have applied some current through from dc source, you would have applied current through some dc source. So, there is a current passing through. This is the concrete resistance and this is connected here. Now polarization resistance is the resistance offered at the interface. Because, at the interface you have a capacitor, simplest circuit would be a capacitor because there are two material and a resistor So, this one will have something of this kind. Why capacitor? There is an interface two material dielectric.

So, it can store charges at the interface. So, there is a equivalent capacitor. This is the simplest circuit one can make more complicated, in fact, it reality if you modulate you need to have more component in the circuit. But simplest is that you have a capacitor you know, simplest randles circuit as it is called. So, you have a capacitor at the interface but it also offers resistance when you try to pass current through it.

And this resistance offer is called polarization resistance and it can be shown that, polarization resistance is a function of the corrosion rate actually which is occurring into the steel bar right. Because you know the state of corrosion is also dependent upon, what is called whether, it is in passive state already there is some slow rate. So, there is a coating on top of the rebar which is, not allowing current to progress fast or if it is allowing active state.

So, therefore, this polarization resistance measurement base is based on this kind of principal.

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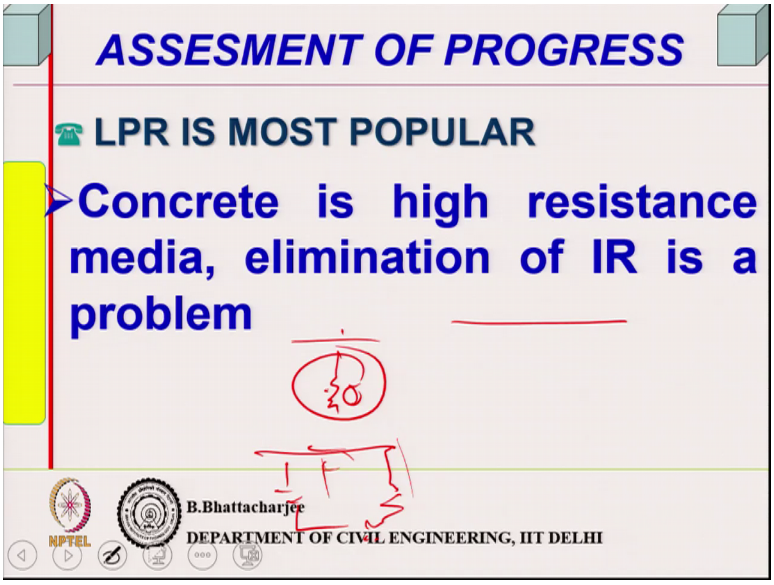

But concrete resistance is very high. So, the resistance that I have showing from the concrete surface to this is very high. So, this has to be eliminated because, polarization resistance is only at the interface, polarization resistance is only at the interface. You know, so this is what I am saying, there is a capacitor and there is another resistance, so equivalent resistance of this part is polarization resistance.

So, but when I am passing a current and measuring current and the potential changes, that is also be involving this resistance; you say high resistive media. So, IR drop across this has to be eliminated. This is done either electronically or theoretically also one can do, plus the way you, know pass the current for example; if you look at it you pass the current through this.

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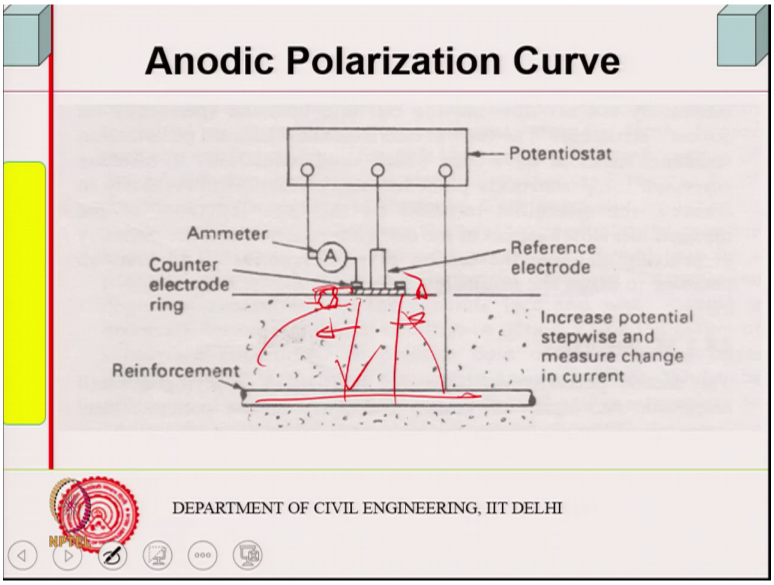

Now if you pass the current its distribution is not uniform, it will not be something like this direct vertical, it will get spreaded.

So, how much area through which is getting polarized, for where your current is going applied current is going, that is again uncertain. So, that is these are the issues. But this is been taken care of by using what is called a guard ring provide another guard another you know, ring sort of a annular electrode there through which same current is passed; such that the you know potential difference along this direction is minimal. So, you want to keep it one membrane, so etcetera, so, there some assumptions. So, these are called polarization curves and you can do it to a using a potential step, which will measure that you know which will actually go on steps of delta v change. And at every step of delta v will be constant and corresponding current it will measure.

Or if it is dynamic that is also in the same manner it goes to given potential what is the current. The others way is galvano static. That means, you increase the current in steps measure the potential right. Both are being used actually ok. There are other issues involved I think I will not going to this. So, this is basically polarization LPR method right.

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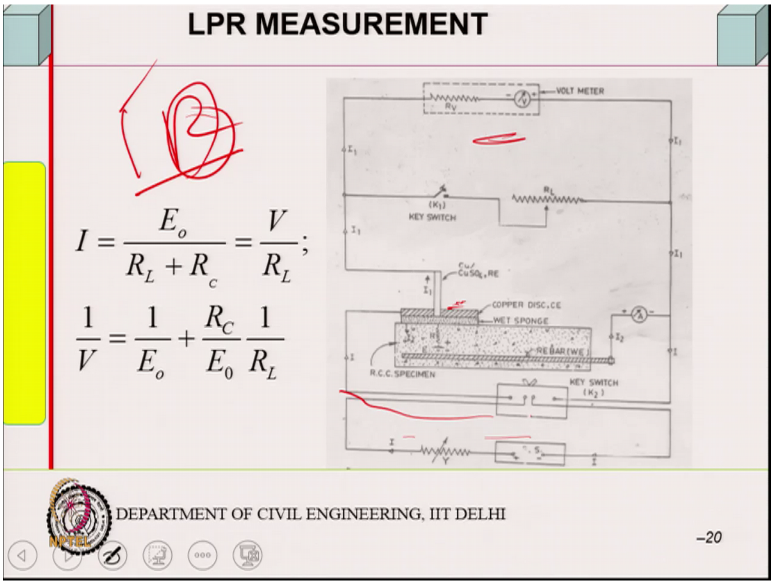

So, one can actually you know this is how the concrete beam for example; in a concrete beam this is how the setup would be. The this is your reference electrode, this is called auxiliary electrode to where you are current passing the current from a source.

Then there is a switch here right, so, constant current sources are there right. There is a through the register you can control the current etcetera etcetera and this is the circuit. So, there is a volt meter here which measures the reference potential changes. One can eliminate out this I R drop; some ways are there algebraically as is shown here, but I think I will not going to that. So, modern instrument can do that, modern instrument will give you how much is a and from that you can also find out the resistivity of concrete, because you find out I R drop. If you know the R I not exactly resistivity, but some relative measure of the resistivity you can find out, because you do not know the area do not know you know there is some confusions related to area uncertains are there related to area.

But relative resistance you can find out. For same current one concrete shows higher I R drop which means, its resistance is more. Another which shows less I R drop, so relative resistivity also you can find out. I think I will not look into this in details the you know how you do eliminate I R.

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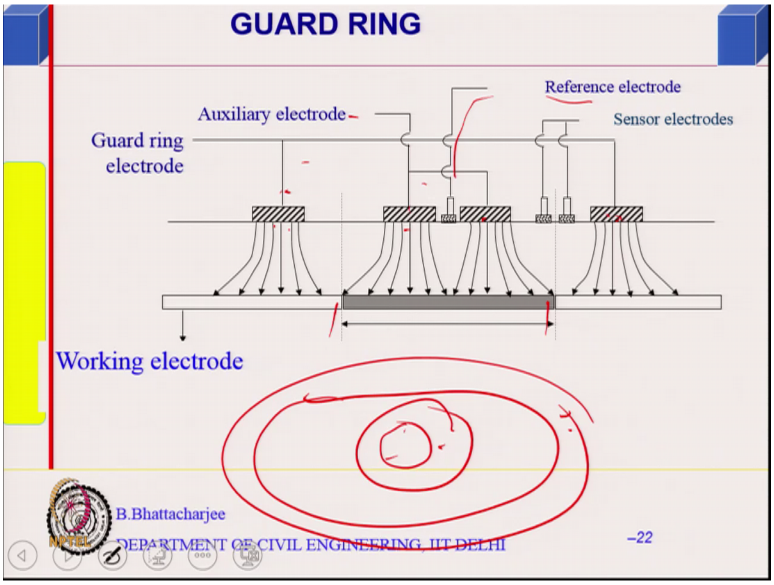

Now, this is the guard ring I was talking about. In a guard ring you have two electrodes through which, you have pass current. This is one electrode, which is annular ring. In plan it will look like a ring and there is another thing right. So, this is a strip, this is outer. These two are at the same potential so that the flow is restricted within this area, flow of current is restricted. So, this is how one takes care and these are reference electrode, whose potential changing you will be measuring. So, you pass current through this and also through this, in order to these are called you know, guard ring and this is either called auxiliary electrode or control electrode; they are called auxiliary electrode or control electrode. So, commercial equipments are available on this line for example; this is one of those Rapicor.

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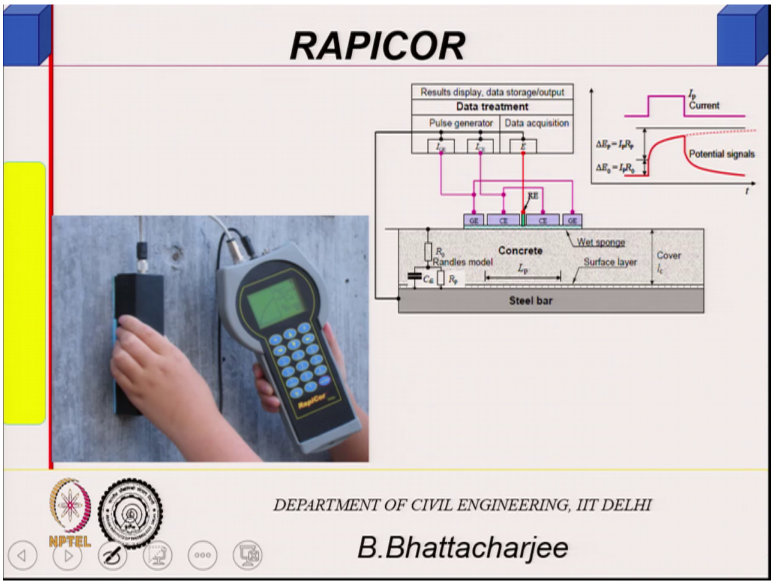

But again reliability of this measurements true corrosion rate what it is rather relative. You can possibly say at a given place the corrosion rate is higher, then another place it is lower. Absolute value validities in the laboratory one can validate them, but actual side validation is not very easy, but people do measure. So, this is the instrument looks like this, rapicor is one of them. There are several such instruments available based on different principles LPR then the rather you send a you know, pulse and things like that So, this is how it looks like you know, it has got a guard ring, same circuit that I have talking about alright.

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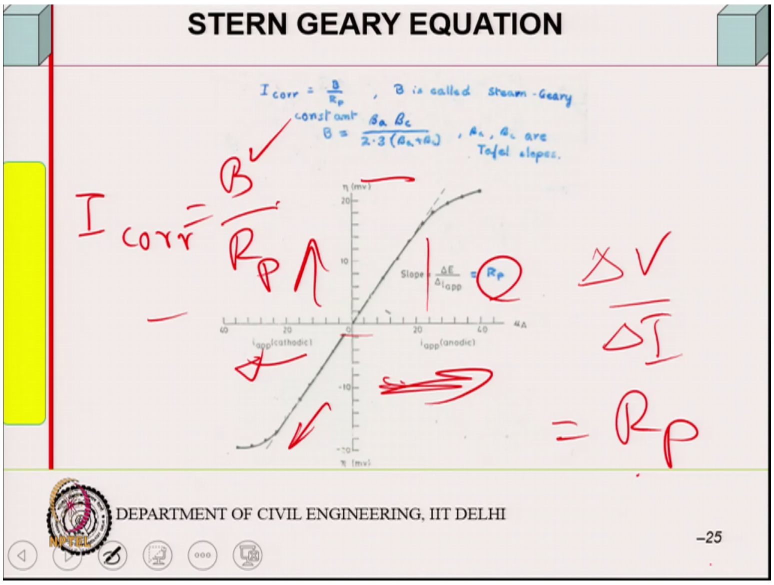

So, I do not think I will go into the electrochemistry of this at all. Stern Geary equation is what is used to find out corrosion current density. Just let me right out what is stern Gearys equation.

If this is the potential you know applied current versus change in the reference potential. You can the change the direction of the current it would be like that. So, slope here delta V over delta I this is a slope, which is called polarization resistance RP. Slope of this one is called R P. you know R P. This R P is related to corrosion current density as B divided by R P, provided you take the area you know in a given area etcetera etcetera. So, what is B? B is called Stern Gearys constant. After the name of the you know, people who gave this, Stern Gearys constant and it is it is it can be found out again. It is it depends upon various factors and these are related to something called tafels constant. Again I am not going into this. So, Stern Gearys equation is I corr is equals to B over R p.

And B is given as beta a beta c divided by 2.3 beta a plus beta c. These are called beta a, beta c these are called anodic and cathodic tafels constant. I do not think I will go into that electrochemistry, but instruments are available that is why I want to tell you.

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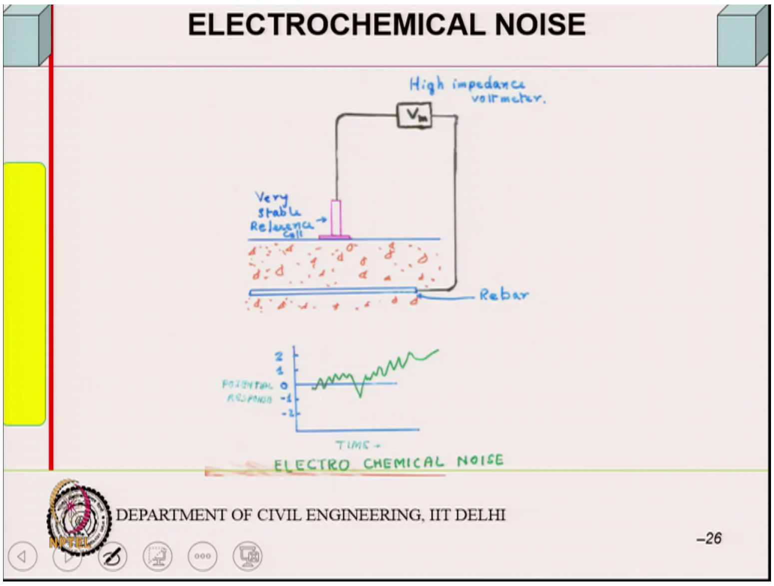

There are some instruments of the kind of electrochemical noise, commercial equipments I have not seen one similarly, a c impedance spectroscopy.

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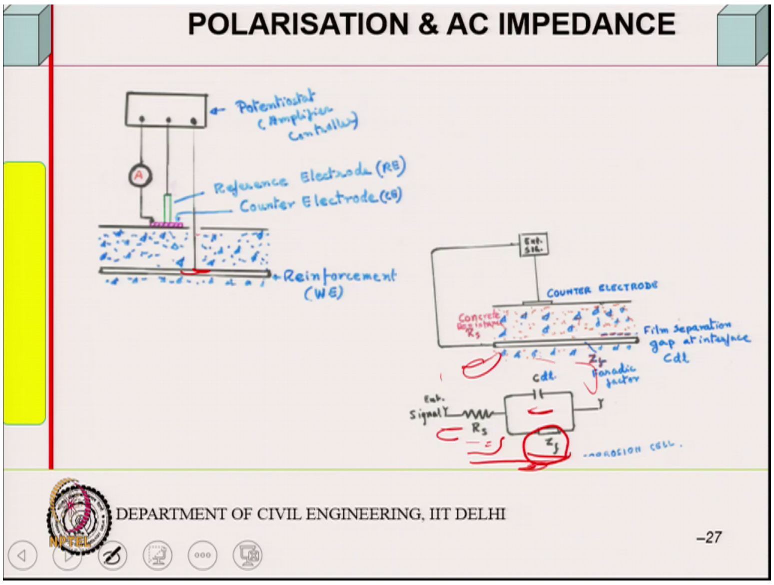

But this is not yet gone to the field not yet to go to the field. It is almost similar to our you know you know is similar to linear LPR instrument. Only thing you do is, now you pass alternating current rather than direct current at different frequencies. Now the capacitance I said that, equivalent circuit was something like this simple equivalent circuit, you are saying there is a capacitance, there is a resistance, resistance of the concrete right resistance of the concrete.

So, you send the signal or you know this is connected send the. So, impedance of this one would change with frequency. What is impedance? You know resistance is for direct current only resistance will be there. So, you have when you have a directional current; current pass through conductors, which offers some resistances and we know its related by Ohms law. And this r is related to resistivity of the metal or material conductor concrete (Refer Time: 15:21) even concrete length over a that we know. I am not you know going further into that.

So, there is some resistance of the concrete at the end at the interface, there will be some resistance offered by concrete in the interface. Now interface has got a capacitor. what is the capacitor, it stores the charge if, you pass a direct current through it, it will store the charge, one of the plate will be at higher charge another will be at lower charge you know current will finally, flow. But if it is alternating current, one time it will be positive next time it will be negative. So, the alternating current actually flow takes place or vibration of the electron about their mean position equilibrium is not disturbed by putting a capacitor. Only thing what happens is it store some of this energy.

And that one derives and because it stores some, that means, it offers some kind of an you know disturbance to the flow path. So, that is basically the reactance of the capacitance. I will not give you the equation of the reactance and all that you might have done it in somewhere in electrical technology. And when you have combine this reactance and resistance together in a you know series circuit, parallel circuits, in general you call it impedance. Impedance is you know disturbance is offered to flow of the current alternating current by any combination of capacitor, inductor etcetera etcetera you know resistance and so on. So, a c apacitors will provide capacitor will provide reactance and inductance so.

Now, this the reactance of a capacitor is the function of the frequency. Like we have 50 cycles, but supposing I change the frequency it is a function of the frequency. So, one state is you know dc current, where there is frequency 0 and you can vary the frequency. So, if you vary the frequency, from there you assuming typical you know kind of circuits, various kind of circuits for circuit model for your concrete interface concrete reinforcement bar interface plus the additional concrete etcetera, you can actually find out again polarization resistance. Because this is polarization resistance, this component is a polarization resistance. So, from this measurement you can find it polarization resistance.

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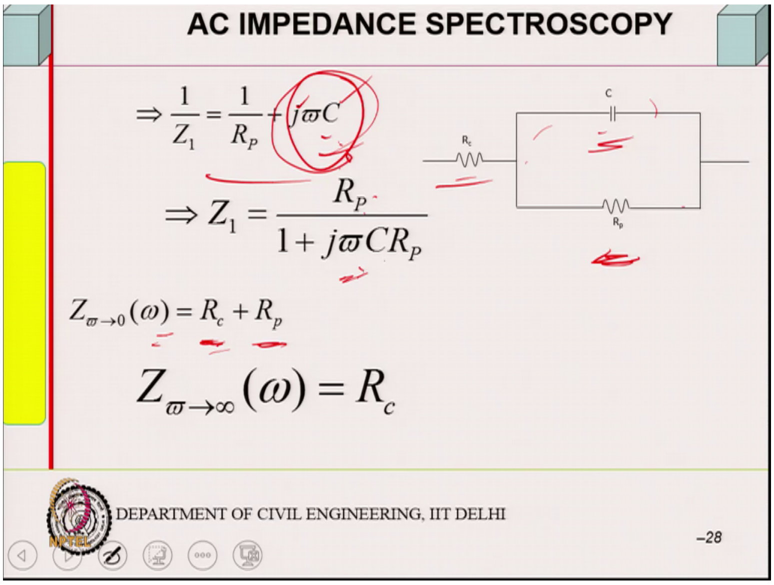

But this is not in suit technique as yet not very successfully in suit technique that is what I talking about, the circuit equivalent circuit.

And one can have you know the impedance of this portion 1 by R P. This is the polarization resistance and it is minus you know its imaginary because we use complex algebra to model this mathematically model them. Because current you know peak of the current and peak of the voltage they are not in the they do not occur same time in case of a capacitors, because it will store then release. In case of resistance it is same, whenever you have a peak of the current peak of the voltage will be same. In case of capacitor, actually it will store and then release. So, there is a phase difference, what we call there is a phase difference 90 degree phase difference and they follow complex algebra I will show you.

This is how this is a j, omega stands for the angular frequency twice pi f and C is the capacitance equivalent capacitance of the interface. So, you can write it like this and overall Z 11 can then write I am not interested in writing, but I am just. So, you see if you measure the complete circuit, you know complete circuit impedance, you can give make you know get an expression for complete impedance circuit.

So, impedance of resistance of the circuit will be R c plus R p because they are series. So, when you are it is dc current 0 omega is equals to 0, omega tends to 0 you get equivalent impedance is this and when omega tends to infinity, when omega tends to infinity because this is you know, omega tends to infinity means this part will be very large right, this part will be very large. So, nothing will flow through this. Actually everything will flow through, everything you know like nothing will like is as if, you know this the sorry everything will flow through this.

There is a current short circuit, you can show that. When omega is very large this part is 0, so, it simply R P. Omega is sorry R C is simply R P if I divide by R P, I get 1 by R P, you know no omega is infinity, overall you know from the circuit it, it will turn out to be R C, it will turn out to be R C actually. You can calculate the equivalent circuit and use omega being very large, so, it will turn out to be R C. This was for Z 1 only this part.

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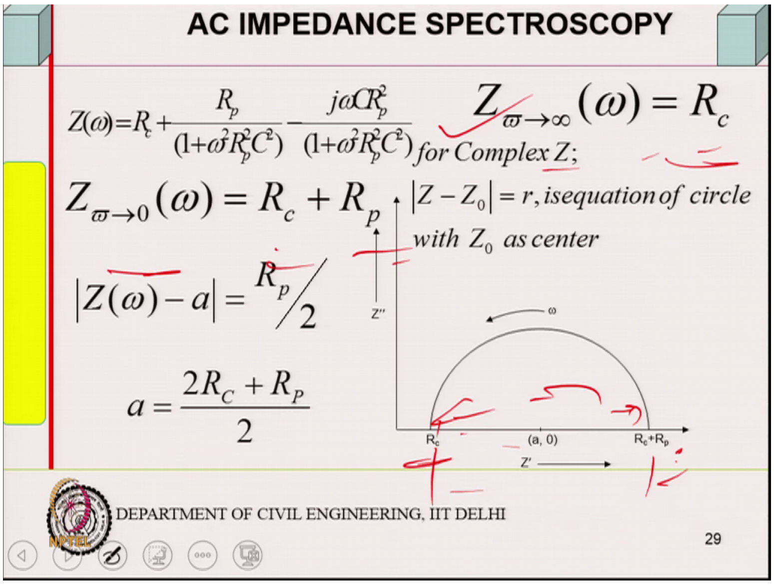

So, no one can calculate this out, this is the formula actually. So, I do not think I will going into the derivation of this. So, one can show that when omega tends to 0 this is R C plus R P, when omega tends to infinity it is RC. So, if you plot if you measure it at different frequencies, very high frequencies equivalent impedance is R C and very low frequencies are 0 it is R C plus R P difference of this gives you R P.

This is one of the ways of finding, this is found out through what is called you know these are I mean one can derive. This is actually the two diagrams Nequist and boards diagram. So, from those plots you can actually find out typically this is what is shown in something like this omega increasing R C R C plus R P. So, this is nothing, but, if you subtract R P, you know this will be simply this portion will be simply R P, this portion will be simply R P. So, you can find it out from this kind of measurements ok.

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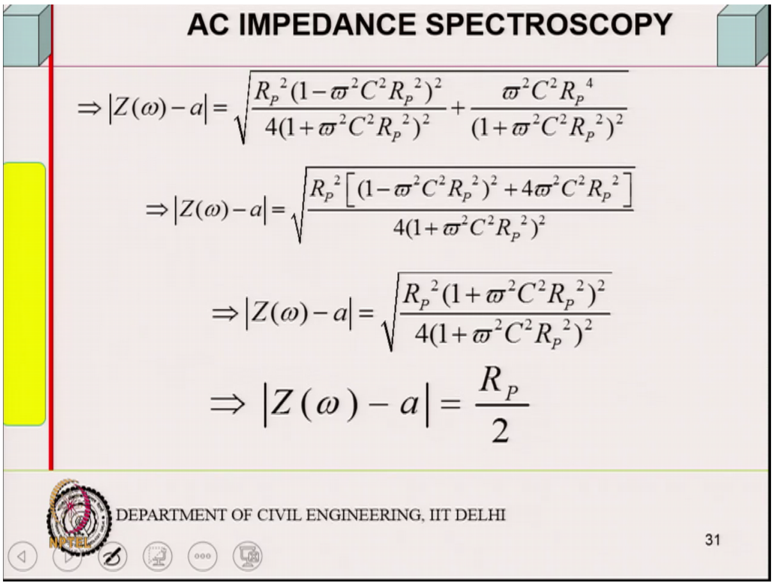

This derivation I think I am not interested in this one can show that R P by 2 will be the radius.

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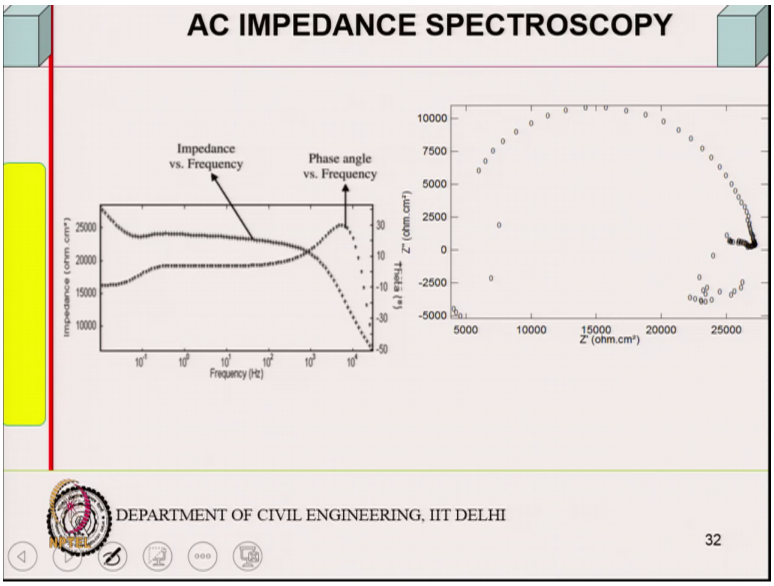

So, people plot different types of diagrams and from that actually obtain the polarization resistance and one can ok. But this is still till date it is more of a laboratory based technique rather than into the actual site you know.

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So, that is what it is. Other way of measuring is simply measure by mass laws. So, what you do, in from actual structure, where it has corroded at a given time, take out a small piece of bar. And if it is laboratory type, then it is this one has got corroded just make it to fail, you know the bar make it to fail there is a reinforcement bar, which has corroded. You can see it is covered here, so, that no corrosion can come from outside it was corroding from inside. So, once corroded you might get something like this.

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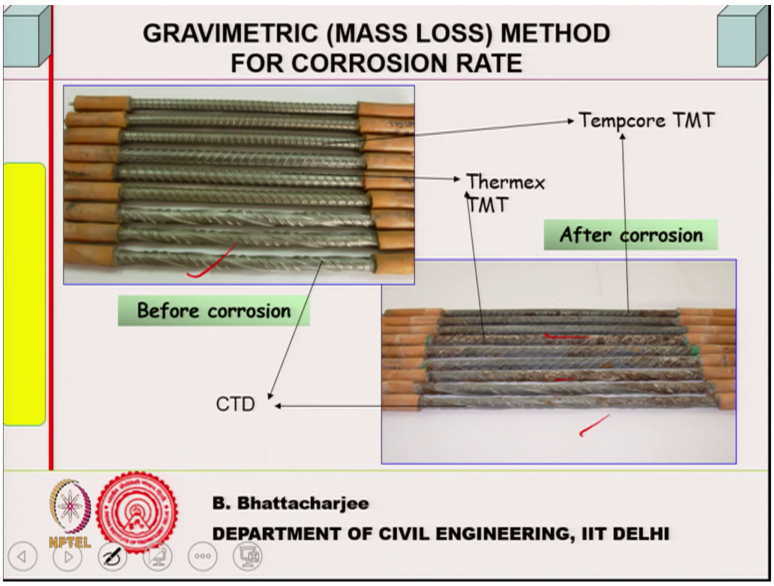

This is before corrosion, after corrosion, bar will look like this. You can say this is corroded, this is corroded right. Then you wash it off and find out the original mass is known to you, you find out the remaining mass. And if you found out the area here then you can find the corrosion current density.

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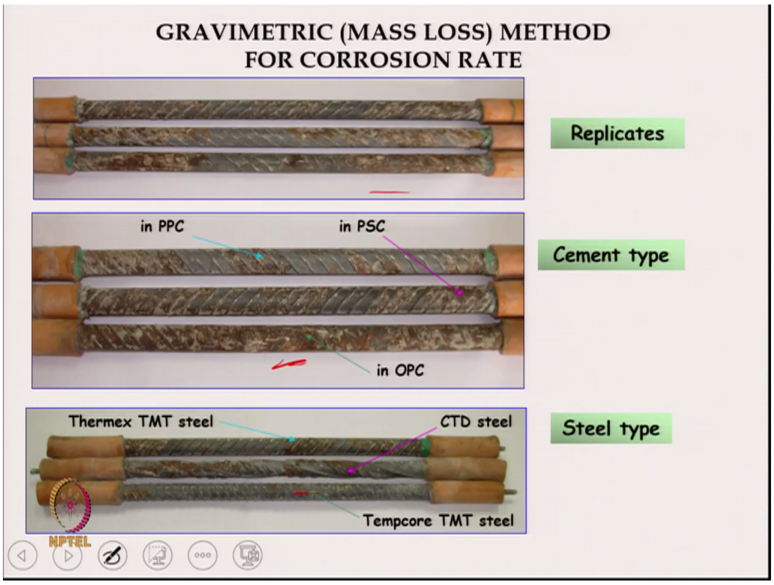

So, this can happen for various steel types you can find out etcetera etcetera. I think I am not interested, I am just showing this is corroded, this is corroded, highly corroded, highly corroded, something is less corroded. So, this is gravimetric thing you can do in the liberty to test, but actual site if you are doing you unless you have done it at number of time, you will not able to know whether what is happening rate; because you got to know at a different types. But at given time you want to find out cut a piece of steel bar, cut a piece of steel bar clean it with either here are you know there is basically it is done with 2 source of solution: One is hexamethylene tetramine or Clarkes solution right. So, Clarke solution is basically, stannous chloride antimony chloride in let us it is a so on so we know that.

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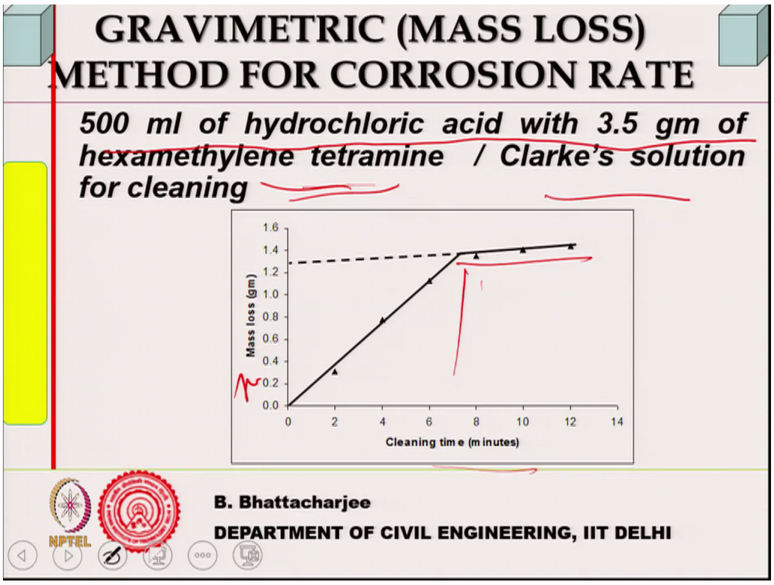

And this is hexamethyl tetramine. So, you dissolve them, first you brush it off, then you know apply this solution on top of this rebar, all the rust will get dissolved and intact iron will remain as it is. So, you can find out the mass. So, this is prepared by 500 ml hydrochloric acid with 3.5 grams of this. This solution if you apply at the surface, rust get dissolved steel remains as it is So, what done is on this number of cleaning actually, cleaning time and then after certain period of time you find that mass law is not change in mass is very little. So, initial mass you find out how much is the mass? 0 mass loss in the beginning then some which time, so about you know it is something of around 8 10 minutes you have to do that, cleaning keep it in that water, so, that then it goes.

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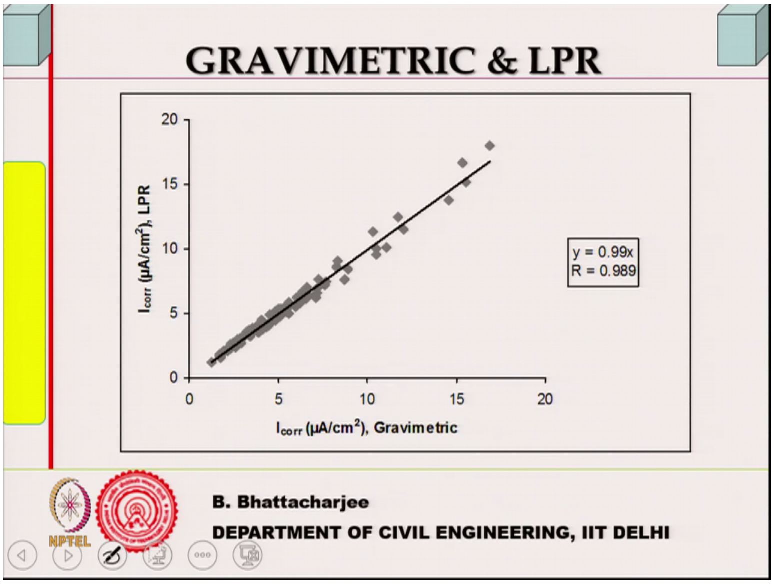

So, that is it. People one can compare ac impedance spectroscopy and LPR by the same instrument this is possible. Gravimetric laboratory you can compare, but actual site doing LPR and then doing gravimetric, then gravimetric you have to do over the years, many time to find out the rate. So, that kind of validation has not been really done much.

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I said you know this is one of the measurements like rapicor measurement I was telling you So, commercial instruments are very much there.

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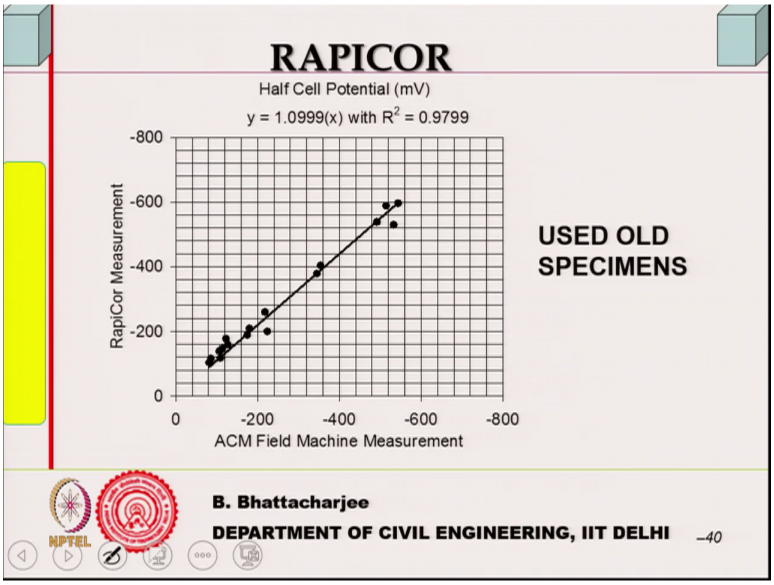

And one can you know use them ok.

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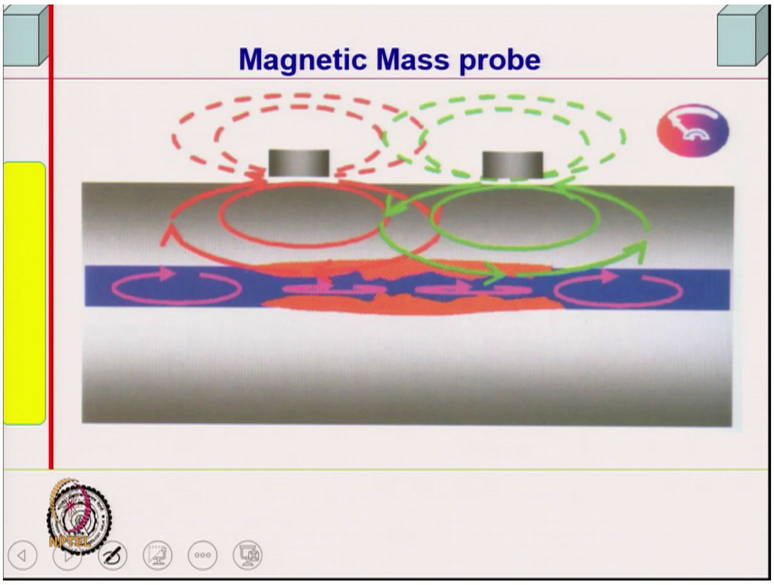

Now, let us look at magnetic mass probe. It can actually tell you, how much is the quantum of rust at any point of time So, basically this is the probes actually and you can see that the image that you get, that will tell you how much is the, because modern instruments they can actually bring out using softwares.

So, how much is the amount of rust and how much is remaining. So, this is a technique used to find out the quantum of rust, but then this is very costly instrument not very easy not very not very cheap right. So, things like impulse radar technique magnetic mass probe they can give you lot more information, in addition to whatever conventional entities are done.

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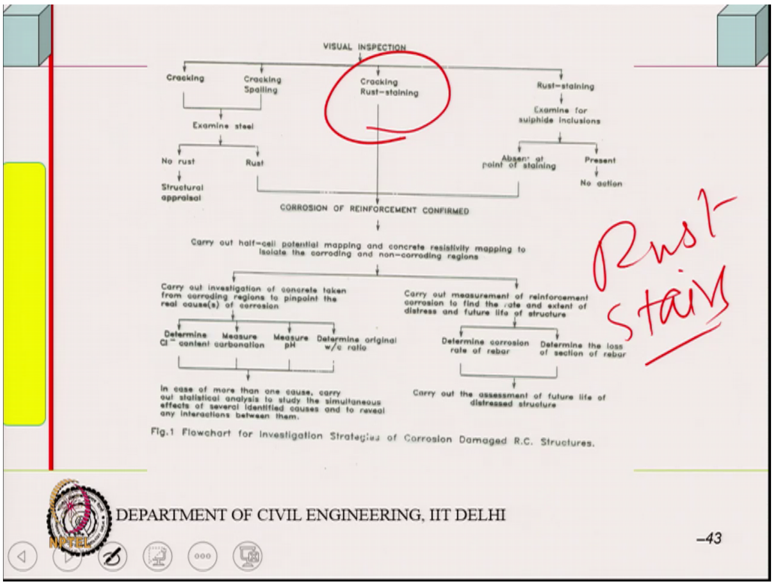

So, if you look at corrosion you know corrosion, actually if you look at it, it would be first you have some visual survey, you will get rust staining. So, if you get rust staining, rust stains. Then you know corrosion is occurring right or cracks spalling break it and see. Then you can do some chemical test onto the concrete, whether chloride is there, carbonation is there. And you can do some test on the structure itself and D t to demark it those areas, which are potentially high risky because half cell potential or resistivity test will tell you that. Now do some rate testing there, do corrosion rate testing and those locations, where you have you have already found out demarcated using you know other techniques.

Or even if you can break even if it is already damage cracked, you can break and see how much is the mass loss. At different places you do there is of course, the other statistical aspects and quantification of the total mass loss potential etcetera etcetera you can find out, so this is how it is done. So basically, you know if you do a number of case studies which are being reported here.

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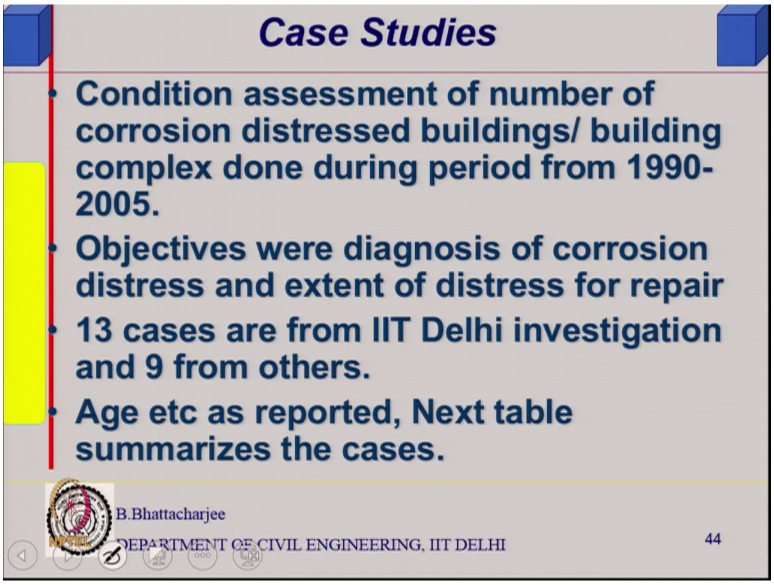

But one thing is found out, most of the cases diagnosis was done and it was formed corrosion and many of them are our own investigation actually.

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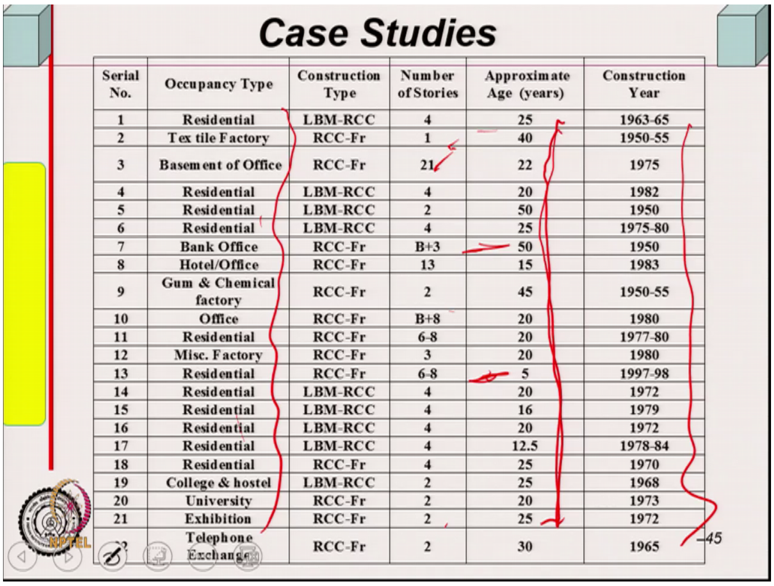

Serial No.	Occupancy Type	Construction Type	Number of Stories	Approximate Age (years)	Construction Year
1	Residential	LBM-RCC	4	25	1963-65
2	Tex tile Factory	RCC-Fr	1	40	1950-55
3	Basement of Office	RCC-Fr	21	22	1975
4	Residential	LBM-RCC	4	20	1982
5	Residential	LBM-RCC	2	50	1950
6	Residential	LBM-RCC	4	25	1975-80
7	Bank Office	RCC-Fr	B+3	50	1950
8	Hotel/Office	RCC-Fr	13	15	1983
9	Gum & Chemical factory	RCC-Fr	2	45	1950-55
10	Office	RCC-Fr	B+8	20	1980
11	Residential	RCC-Fr	6-8	20	1977-80
12	Misc. Factory	RCC-Fr	3	20	1980
13	Residential	RCC-Fr	6-8	5	1997-98
14	Residential	LBM-RCC	4	20	1972
15	Residential	LBM-RCC	4	16	1979
16	Residential	LBM-RCC	4	20	1972
17	Residential	LBM-RCC	4	12.5	1978-84
18	Residential	RCC-Fr	4	25	1970
19	College & hostel	LBM-RCC	2	25	1968
20	University	RCC-Fr	2	20	1973
21	Exhibition	RCC-Fr	2	25	1972
22	Telephone Exchange	RCC-Fr	2	30	1965

So, what we find is, you know if you see this table different types of buildings right residential textile factory, residential office, etcetera etcetera.

And construction is either R C C or load bearing machinery and R C C slab. Because, many of the old low rise buildings are load bearing machinery with R C C slab on top. And when they came for investigation was taken, because people do not investigate in between. Once they face the problem, when you need extensive repair then only you come and investigation. So, age at which investigation was done is approximate, you know age will say. This varies from 5 years to somewhere, we will see 5 that is the minimum and maximum will be somewhere 50 or so. Some building showed excessive corrosion distress after 5 years and some show after 50 years. So, you know it is a; but, major factor, so you can see the construction here also is noted in your slides you will find. Obviously, this was done in 1990s or around 2000. So, this is this is you know related to the 50 years means 1950 or 48, 1948 those kind of things.

And their heights where one of the building was 28 story, 21 and others are less single 2 story even single story. What is major one finds, what is the cause.

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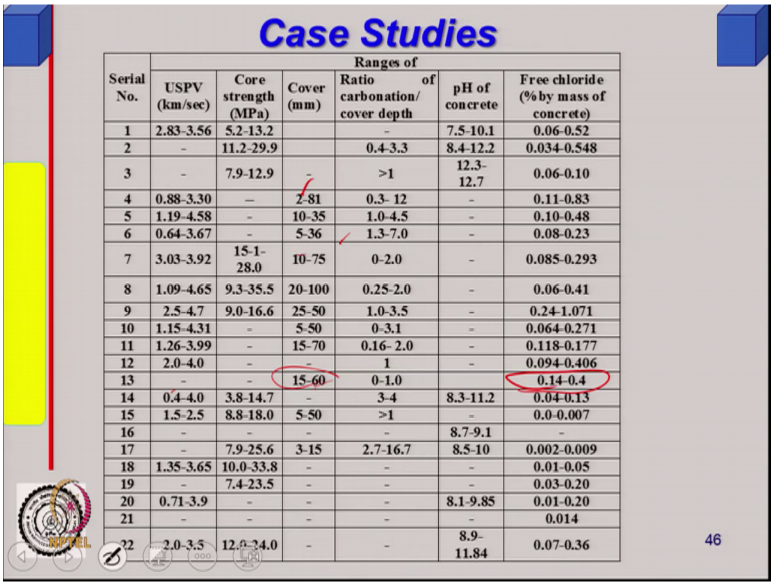

Serial No.	Ranges of					
	USPV (km/sec)	Core strength (MPa)	Cover (mm)	Ratio of carbonation/ cover depth	pH of concrete	Free chloride (% by mass of concrete)
1	2.83-3.56	5.2-13.2		-	7.5-10.1	0.06-0.52
2	-	11.2-29.9		0.4-3.3	8.4-12.2	0.034-0.548
3	-	7.9-12.9	-	>1	12.3-12.7	0.06-0.10
4	0.88-3.30	–	2-81	0.3- 12	-	0.11-0.83
5	1.19-4.58	-	10-35	1.0-4.5	-	0.10-0.48
6	0.64-3.67	-	5-36	1.3-7.0	-	0.08-0.23
7	3.03-3.92	15-1-28.0	10-75	0-2.0	-	0.085-0.293
8	1.09-4.65	9.3-35.5	20-100	0.25-2.0	-	0.06-0.41
9	2.5-4.7	9.0-16.6	25-50	1.0-3.5	-	0.24-1.071
10	1.15-4.31	-	5-50	0-3.1	-	0.064-0.271
11	1.26-3.99	-	15-70	0.16- 2.0	-	0.118-0.177
12	2.0-4.0	-	-	1	-	0.094-0.406
13	-	-	15-60	0-1.0		0.14-0.4
14	0.4-4.0	3.8-14.7	-	3-4	8.3-11.2	0.04-0.13
15	1.5-2.5	8.8-18.0	5-50	>1	-	0.0-0.007
16	-	-	-	-	8.7-9.1	-
17	-	7.9-25.6	3-15	2.7-16.7	8.5-10	0.002-0.009
18	1.35-3.65	10.0-33.8	-	-	-	0.01-0.05
19	-	7.4-23.5	-	-	-	0.03-0.20
20	0.71-3.9	-	-	-	8.1-9.85	0.01-0.20
21	-	-	-	-	-	0.014
22	2.0-3.5	12.0-24.0	-	-	8.9-11.84	0.07-0.36

This essentially people one would find that cover depths, where very low at many places. At particularly which has survived only 5 years you know the 5 years, the one which has survived 5 years is number 13. And if you see number 13 here its coverage these are good, cover when your cover was good, but many other places the covers are not good; 2 millimetre to 81, 5 to 36 and all. These are cover, but this is other problem chloride. This is high chloride, relatively much higher chloride. Then most of them up going up to 0.4 percentage by mass of concrete 4.4 actually 0.015 or .025. Beyond that risk of corrosion becomes very very high.

Percentage by mass of concrete not percentage by mass of cement; there are other ways people talk in terms of percentage mass of cement. But then you have to find out what is the cement content. In all concrete it is difficult to find out what is the cement content. So, it is much better to express them in percentage of concrete. So, this is this is one thing was found. Then p H of a concretes are looked into some cases p H value. But this since this is in northern India majority of them showed actually chloride coming now chloride would have come from the ingredients here.

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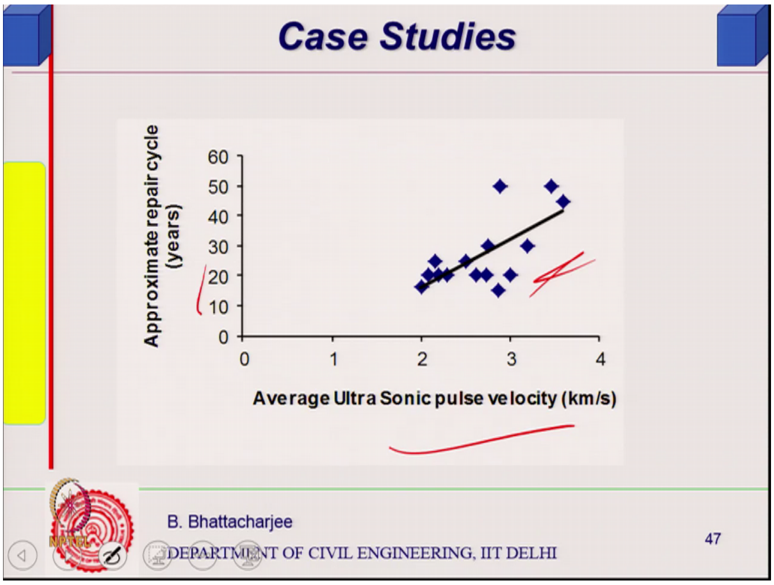

Because there is no seashore, so, some correlation was obtained quality of concrete ultrasonic pulse velocity if, where pulse velocity is high approximate year of repair cycle was also higher; that means, good quality concretes survived for longer years, good quality concrete. So, one thing is one should actually look into this and other thing was cover was a factor.

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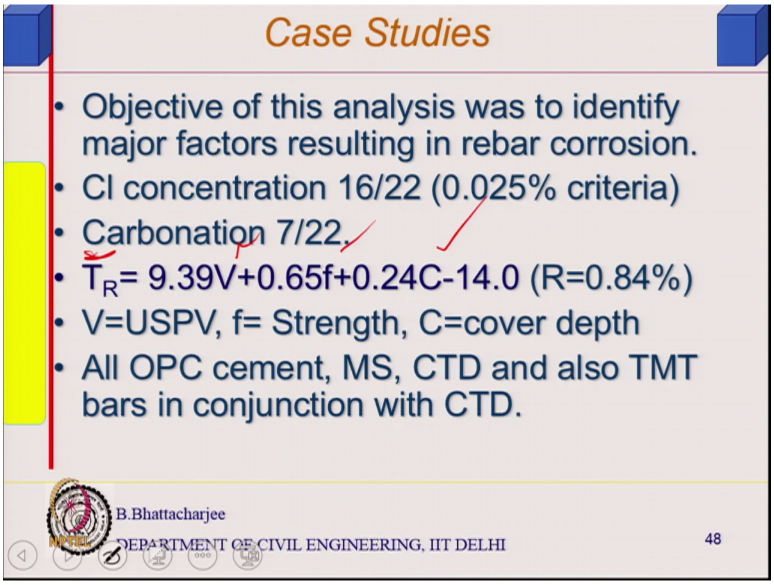

Chloride concentration was more than that cause (Refer Time: 31:11) in 16 out of 22 cases. There 22 cases 16 cases chlorides were high. And carbonation was high in 7 out of 22. So, one can actually using this actual data measure data where, large number of v s simple regression would give you something like time of repair as a function of ultrasonic pulse velocity the strength the cover depth right.

Strength and cover depth some are good cover some are bad So, what we what one finds is, if your concrete is generally good first level, you might require longer time repair cycle will be longer that is, one aspect the cover is other aspect. Generally good means both in terms of soundness in terms of ultrasonic pulse velocity, but it should not be contaminated.

These are all contaminated ones; these are all contaminated with chloride. Majority 20 to 16 out of 22 are contaminated. 16 out of 22 are contaminated. So, if it is contaminated then also good concrete relatively higher resistance etcetera etcetera. So, concrete quality is major factor and contamination should be avoided fully. Steel bars different types of all had actually coal to say deform bars. So, major you know one know the thing was there.