

Fire Protection, Services and maintenance Management of Building
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Lecture - 52
Carbonation and Chloride measurement

So, we will now look into other test methods, like carbonation test. Which is done, which is a durability related test. You know cement ordinary Portland cement, it is reaction with water produces calcium hydroxide. And it has got some alkalis which are present as you know alkali sodium oxides and potassium oxide that there in the either you know generally as impurities in the system, but they act as flux also, in production of linker reducing down the burning temperature. So, some alkalis would be there in the because sodium is readily soluble, sodium potassiums are readily soluble.

They are salts or oxides and they are available in the world plenty like silica whole of the ocean is full of sodium chloride right. So, there they are abundantly available. So, you find them everywhere. So, this should be in the cement also you find. So, this sodium and potassium they are readily soluble. So, they are highly soluble and calcium hydroxide which is sparingly soluble is formed from the production of hydration product of cement.

So, this maintains, this actually allows for a higher alkalinity of concrete. So, concrete is generally alkaline or cement hydrates are alkaline. So, this alkalinity has got a positive side of it. What is it? The reinforce when the steel as you know iron; iron is not a stable material iron is not a stable material it is actually. Unstable because it is being produced by expense of energy you have stable materials iron oxide or iron sulphide. So, it will try to corrode.

So, it iron will only form oxides, but if the oxide layer is thick and does not allow further oxidation to occur then I am not worried that is called a passive layer, you know in corrosion process corrosion process is aqueous process. Now that kind of oxide formation is favoured at high pH, which are not detrimental or dangerous to iron. We will not talk about that mechanism of corrosion here.

So, that is some time if I you know I would like to know the potential or risk of rebar corrosion initiation, if in terms of it is pH. If the p h is high, it is good corrosion active corrosion will not occur it will there will be a passive layer around rebar which will prevent further corrosion. And if it is less alkaline then I have the chance of active corrosion. Now, when can be there can be less alkalinity.

If the carbon dioxide from the atmosphere reacts with calcium hydroxide, sodium hydroxide, potassium hydroxide alkalis and calcium hydroxide present in the concrete, they will neutralize it. The alkalines alkalinity will be neutralized carbon dioxide with water forming carbonic acid for will finally, form calcium carbonate sodium carbonate etcetera. So, alkaline is will be neutralized that is process we call carbonation process.

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Carbonation Measurement

- Carbonation front measurement by phenolphthalein spray. ✓
- ☎ X-ray diffraction analysis test (XRDA)
- Fourier transformation infrared spectroscopy (FTIR) test ✓
- Thermogravimetric analysis (TGA)** ✓

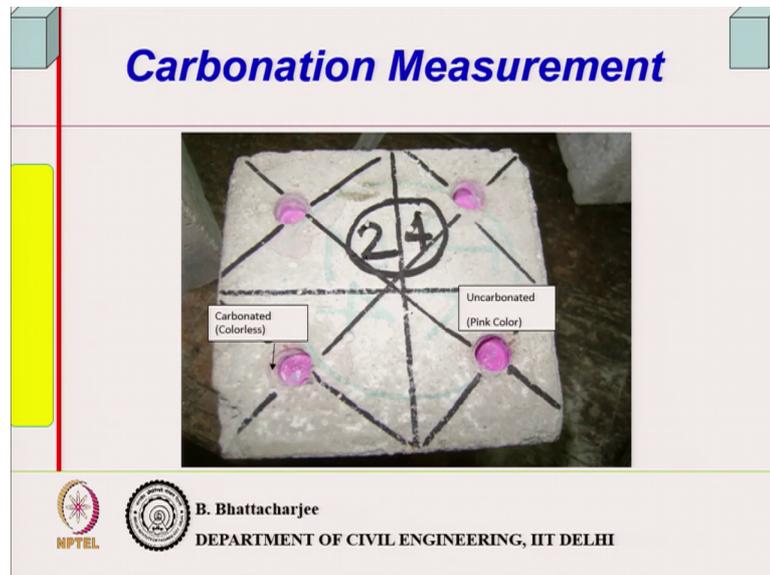
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So, we would like to measure the carbonation front penetration into the concrete. How much this carbonation was occurred this will occur because carbon dioxide is present around 3 percent 3 point 4 percent in the atmosphere all the time.

And moisture if it is available conducive condition is a reaction of carbon dioxide with the concrete at the surface will occur. We do not mind if it goes penetrates, but does not reach up to the enforcement level. It will never occur if there is no moisture. So, carbonation occurs when there is presence of moisture. So, we would know carbonation from measurement therefore, we would like to do.

What do you do is you break the concrete dry and spray phenolphthalein. So, if you spray phenolphthalein, you know it will spray phenolphthalein I suppose there is a colours showing somewhere I should have yes, the colour.

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Spray phenolphthalein if it transferred to pink for example, here it is drill dry in a cube showing dried drilling. And then phenolphthalein has been spread it.

If the colour is pink it means that its pH is still good enough it is not carbonated. If it turns out to be colourless for example, here you can see this the small little bit drilling is colourless. Which means that up to small drill you know small portion this is this is a colour the this is actually the carbonation was occur. So, phenolphthalein spray is done in order to in order to you know find out. So, this is carbonation measurement phenolphthalein spray spraying is done.

So, that is trend you find out whether how much it is. So, what you do is you break or drill dry spray phenolphthalein if they up to some depth you might find that it is colourless beyond that it is pink colour. So, that depth is a depth of carbonation penetration. You can also do X ray diffraction analysis this is a sample to identify whether calcium you know dried drill out take the powder do X ray diffraction. So, you have to actually take a cores slice it off and grind it and do X ray diffraction to find out calcium carbonate presence is there or calcium hydroxide.

There are you know Fourier transformation infrared spectroscopy FTIR, then T G A thermogravimetric analysis one can do. I might talk about this in connection of a fire if the term time to time permits thermogravimetric analysis can be done to identify presence of calcium hydroxide or calcium carbonate etcetera etcetera.

So, these are instrumental one, but very commonly done is the phenolphthalein test. So, what you do as I said I drill core, I will drill some hole and spray phenolphthalein. And you can see that this colour is turning pink carbonate uncarbonated you know uncarbonated.

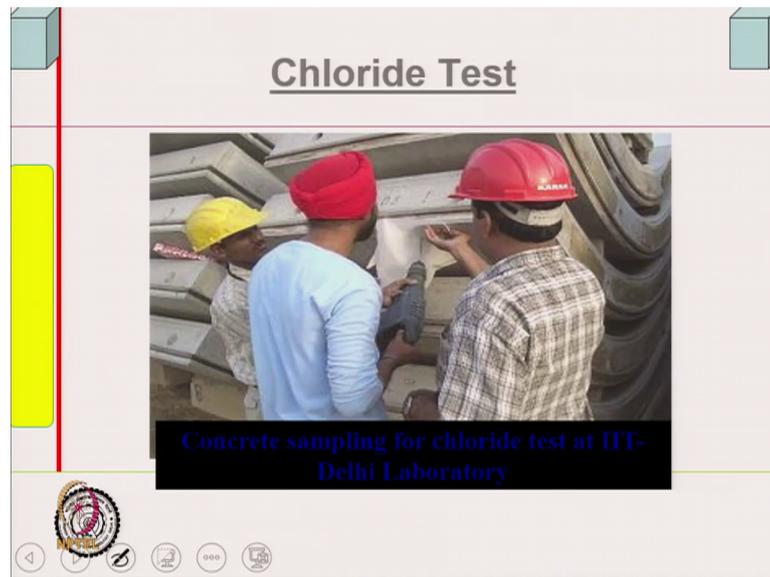
And if surrounding you find that this carbonation is inside carbonated is pink inside, but somewhere around the surrounding the some depth up to which it is a 2 dimensional picture not showing properly up to uncarbonated I mean carbonated because it is colourless. So, one can visually observe colourless or right that is how it is.

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For example, this whole show carbonated these whole show uncarbonated sorry. This is carbonated this is uncarbonated, pink is uncarbonated. And white colour same colour remaining is actually carbonated. So, the depth of this is known, depth of by drill is known. Up to that depth carbonations occurred and when I drill further inside I find that carbonation has not occurred. So, depth of carbonation I can find out by simple measurements right.

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So, this is how it is done. Here for example, you drill the whole dry is showing you have a drill the whole dry in the same once same.

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The slide is titled "Free & Bound chloride" in a blue, italicized font. It contains the following text and chemical equations:

- ▶ Some of the total chloride remain physically and chemically bound with the cement.
- $C_3A + CaCl_2 \rightarrow 3CaO \cdot Al_2O_3 \cdot CaCl_2 \cdot 10H_2O$
- ▶ Higher C_3A improves chloride binding through salts' $3CaO \cdot Al_2O_3 \cdot CaCl_2 \cdot 10H_2O$ (Fridel salt)' & $3CaO \cdot Al_2O_3 \cdot CaCl_2 \cdot 32H_2O$
- Acid (6N HNO_3) soluble chloride indicates total chloride & Water soluble chloride indicates free chloride.
- $AgNO_3$ or $Hg(NO_3)_2$ titration

At the bottom of the slide, there is a circular logo of IIT Delhi, the name "B. Bhattacharjee", and the text "DEPARTMENT OF CIVIL ENGINEERING, IIT DELHI". There are also navigation icons at the bottom left.

Then one others is for any how chloride sometime we would like to find out chloride. Now, chlorides are 2 type free and bound. Because some of the chloride present in concrete can chemically react with tricalcium aluminate or get physically bound. So, what you do is you take sample grind it into powder passing through a specific size see

verify this is 150 micron or whatever it is, dissolve it in water for half an hour in distilled water boil it and filter it right.

So, the precipitative throughout I mean that you know the one on top you throw out and you take the filtrate titrate it for chloride. So, you can find out the chloride concentration. So, basically chemically combined you know some other chlorides are chemically combined.

For example, tricalcium aluminate in cement reacts with calcium chloride forming this salt called creedal you know creedal salts. So, they are chemically combined. So, chemically combined chloride you want to find out you have to dissolve it in 6 normal nitric acid concentrated nitric acid. So, I am not interested in telling why higher chemically bound chloride you know like they have the positive effect because chloride is also responsible for corrosion. Like low pH, active corrosion can occur high chloride concentration active corrosion can occur.

So, we would like to find out chloride concentration some time. So, therefore, 6 normal acid soluble is 6 normal nitric acid soluble chloride. So, you dissolve it now in nitric acid grind the concrete dissolved it in nitric acid, and then you titrate then you find total chloride. You dissolve it in water boil it actually for half an hour then you find out the chloride content by titration that you call free chloride or water soluble chloride.

Then titrate with silver nitrate or mercury nitrate right. So, these days you do not have to really worry if you have not seen this titration you have automatic titrater, electrochemical card fisher titration and all other no electrochemical process. So, what is that is you pour your material press the switch and little bit of you know it will should display you the chloride concentration little bit of inputs you will have to give in terms of satin constants and things like that. So, automatically if there is a motor which will drop no puppet burette business.

I mean; obviously, puppet burette is more accurate, but you need skill passing for that. So, if a skilled chemistry is doing because here the person has to actually visualize the colour changes going from, because endpoint is decided by change in colour. Now, if you are not experienced, you would not be able to judge you know like if you have done it in the school days remember the colour changes, it vanishes shows the colour vanishes

keep on shaking etcetera etcetera, but the electrochemical automatic titrater they find it out on their own.

Accuracy might be slightly less than visual, but visual needs lot more skilled people. So, anyway so, this titration is done. So, this is another measurement for chloride measurement.

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RESISTIVITY TEST

$$\rho = 2\pi S R = 2\pi S \frac{V}{I} \quad \left(\frac{\text{Volts}/\text{cm}}{\text{Amps}} \right)$$

Resistivity measurements with four equally spaced electrodes set in holes drilled in the concrete (Wenner method)

RESISTIVITY (Ohm-cm)	LIKELY HOOD OF SIGNIFICANT CORROSION
$\rho < 5000$	Very High
5000 - 10000	High
10000 - 20000	Low / Moderate
$\rho > 20000$	Low

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The other measurement related to durabilities resistivity measurement. Resistivity because, corrosion is an electrochemical process current passes so, high resistance concrete is better.

So, you measure resistivity of concrete by this 4 probe method. Van der methods actually. So, you have actually you just place that one onto the concrete. Now there are 2 probes here stays at s and 2 more probes placed at s. Actually, what you do you pass a current through this alternating current through this and measure the voltage in the inner one.

Now, the instrument is automatic. You do not have to do much. This is automatic and it will tell you what is the resistivity of concrete. The formula is something like this, resistivity is given as twice pi S is the spacing v over I twice pi S where S is the spacing S into V by I. So, V is the measured voltage across these 2, I is the current you have passed from that you can derive this, but in this class I am not interested in deriving this.

If the resistivity is very low less than 5000ohm centimetre you say that you know resistivity is low means current can pass. So, risk of corrosion is high, very high. If the resistivity is very high more than 20000very low, possibility of resistivity you know corrosion to occur. So, high low risk of corrosion high risk of corrosion depending upon the resistivity well.

So, what you can do? You can actually measure it over large grid over a slab bridge deck or buildings roof or floor and then you can plot contours of high resistivity area and low resistivity area. So, you can demarcate the areas of high risk corrosion risk areas and low risk corrosion areas. So, this is what is used for actually demarcating areas of high risk of corrosion and low.

You can do further testing. You might even break to see whether actual rusting has occurred or not then, but first you do demarcate this area. So, this is van der proof method the you know the potential between C and D is measured.

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RESISTIVITY

Potential difference between C & D is measured, ϕ from C to D due to I entering at A & B is calculated and difference calculated

$$\frac{d\phi}{dr} = \frac{I\rho}{2\pi r^2}$$

$$\Delta\phi = \int_{r_1}^{r_2} \frac{I\rho}{2\pi r^2} dr = \frac{-I\rho}{2\pi} \left(\frac{1}{r_2} - \frac{1}{r_1} \right)$$

$$\Delta\phi_1 = \frac{-I\rho}{2\pi} \left(\frac{1}{2a} - \frac{1}{a} \right) = \frac{I\rho}{4\pi a}$$

$$\Delta\phi_{total} = \Delta\phi_1 + \Delta\phi_2 = \frac{I\rho}{2\pi a} \quad \text{or} \quad \rho = 2\pi a \frac{\Delta\phi}{I}$$

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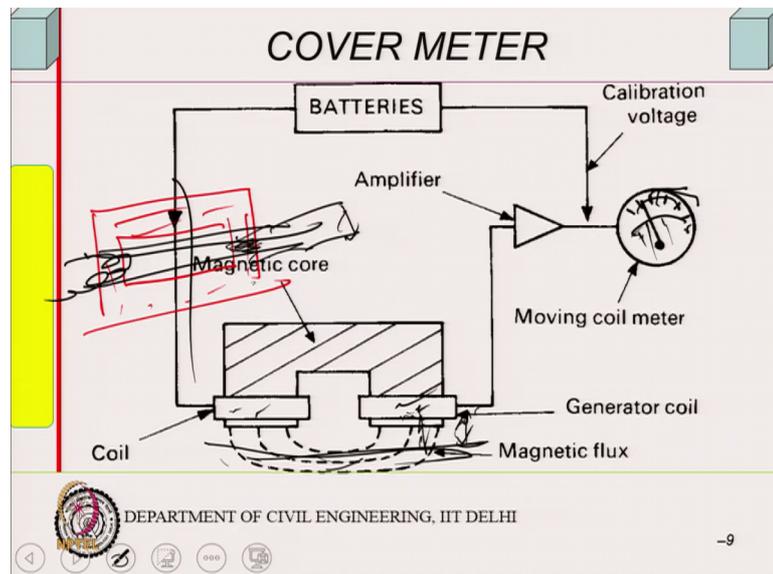
5 from C D is due to you know a current I entering, this is a current well this is showing d c alternating current can be used there is no problem, A at A is these calculate you know A at current entering at A and B and calculated that you know basically one can derive this formula. Because current entering spreading it will go like this lines, equi potential lines right it will spread along this direction.

So, actually $d\phi/dr$ you can actually derive, but I think for this class I will leave it at this stage. The formula, I have given you, it can be shown that $\Delta\phi$ is given by this I the current entering ρ divided by 2π by r_2 minus r_1 and from this one can derive this equation $\Delta\phi$ is equal to you know $I\rho$ by $4\pi a$ where a is this spacing same thing what I have showed earlier.

And total $\Delta\phi$ because of 2 such things acting will be $\Delta\phi_1$ plus $\Delta\phi_2$ which will be measured between the potential difference between C and D and it works out to be the derivation of this formula is given twice $\pi a I$ I said that you know root wise π yes I was saying earlier notation.

So, since s is same as a actually $\Delta\phi$ is nothing but v measure v divided by I . So, you find out values. You do not have to do all that modern machines they will record it and give you a control after that. Because the digital electronics you know it you go on moving it from place to place record only the coordinates and later on you will get the contour plot demarcating high resistive areas to low resistive area, low resistive area means high risk of corrosion and it will might even tell you in red colour that is the high risk of corrosion.

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Measuring cover, cover depth as well as bar location. Now this was the very conventional way, you know if you recollect how does a transformer work, transformer will have a magnetic core like this right. Magnetic core transformer will have magnetic

core and then you will have a primary coil here right and a secondary coil there. So, as you have alternating current or dI you know the change in current is occurring, the magnetic field here will change. And you know you alternating voltage is supply to this magnetic field will change magnetic it will generate actually magnetic circuit will complete through this magnetic core.

At this magnetic flux or magnetic field, you know change in magnetic field will induce current or you know potential you know the $V I$. So, generally $V I$ is equals to constant in a transformer that is what is done. Now supposing I cut this take half transformer this is what is done. So, it is cut this side secondary is not, secondary is here primary is here, but it is cut like this you know this portion is not there.

So, you have a primary coil and the secondary coil. You pass a current through this pass a current through this, now it will the magnetic circuit will not be complete if it is here, but you have a reinforcement bar then through that magnetic circuit will be complete and you will get a signal in the secondary.

So, it is actually a half transformer core is cut the primary is there secondary is there, but the magnetic circuit will not get completed unless you have a magnetic material. So, you have a rebar, magnet magnetic circuit will get completed, and you will get the signal there that is amplified and when this is pick now you can this is simply a handle device.

You can go on shifting it and see the deflection here. Wherever the deflection is maximum; that means, the distance is least; that means, you are right on top of the reinforcement bar. You know on a slab you gone moving it and you measure the so, look at the signal when the signal is maximum; that means, you are right on top of the rebar. So, you can actually locate the rebar and it does it quiet accurately.

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So in fact, you can get you can get actually complete you can get like this you know locate the rebar shift it wherever you find peak and along this direction you go on shifting it you can locate the rebar easily and today modern system it can actually give you the total diagram of the rebar layout, but it does something more also. Not so, accurately because the cover distance 2 things are now unknown to me. I have located the rebar one is unknown is how much is this distance. And second thing unknown is the what is the bar diameter?

Now, it is related empirically you know intensity of this current can be related to the bar diameter and cover depth through empirical relationship. Somewhere it is some cube relation cubic relationships are there 2 variables are there. So, accuracy is a problem, but what is normally done is you do a calibration on the same concrete for example, you know 12 mm bar you find out for different covers what is the value here or reading here.

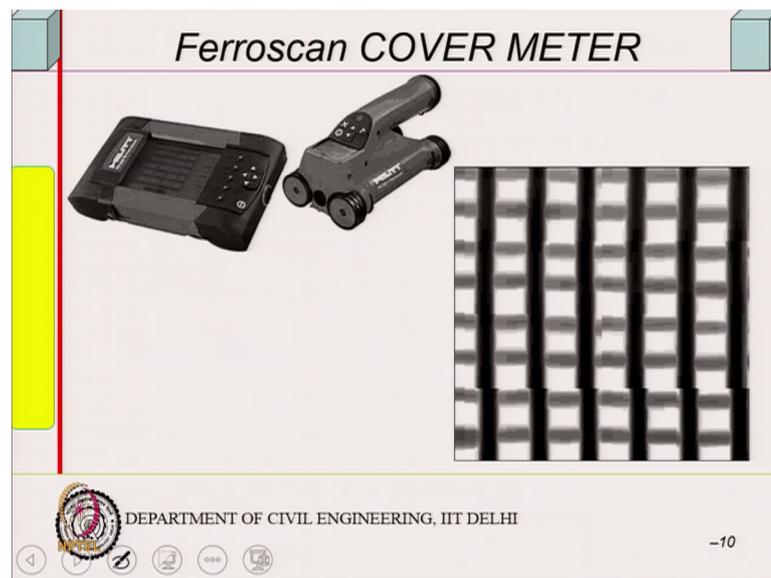
You can do your own calibration and then go to actual size. So, make same concrete, same cover depth you vary do a calibration manufacturers provide calibration accuracy is relatively less, but it locates the bar very accurately there is not problem about location.

Finding out diameter, it gives you calibration curve of various diameter, what is the cover depth? You know signal if you get a given signal given signal given value the cover for there will be 3 4 curves here. In fact, in this one this will be 3 4 curves right.

So, in this curves there will be in this one the bar diameter for this bar diameter another bar diameter and what is a cover depth will be in this scale. So, one can actually measure

this. So, this is a traditional instruments were there today we have digital instrument some if it is whether if you can feed your own calibration curves it can give you. Otherwise accuracy is relatively less, but it will give you the good bar layout. So, this instruments are available now.

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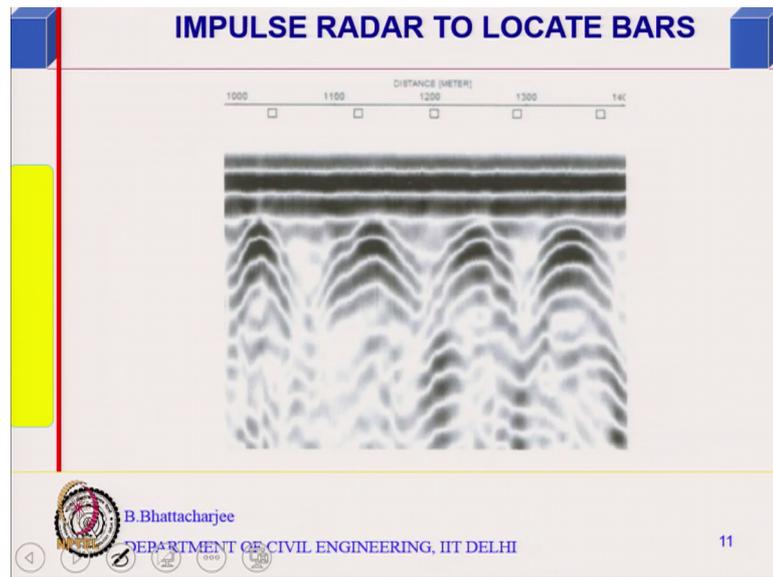


This something like this one will and things like that. So, this is what is a ferrosan cover meter, it will go and it will give you something of this sort of bar layout and all you can get right.

Diameter is usually a problem, but if you know the diameter supposing I drill hole and find out the diameter. So, diameter is known only cover is unknown. Use a calibration to find out cover, but supposing I make mistake of one millimetre even that can make a difference. Because my specification could be 25 mm cover. Actually it is 25 I measured 23 or 24, 2 millimetre for a difference that itself may not be acceptable to me. So, the accuracy level that is there is not you know cover depth problem may come, but layout is very easily found out and you can avoid location of use this instrument avoid locations for drilling core.

You do not want to drill through that relative bar. So, you identify those do not want to do re bound ultrasonic test though rebar. So, first find out the rebar locations and then do other test where rebar can interfere with your test results also.

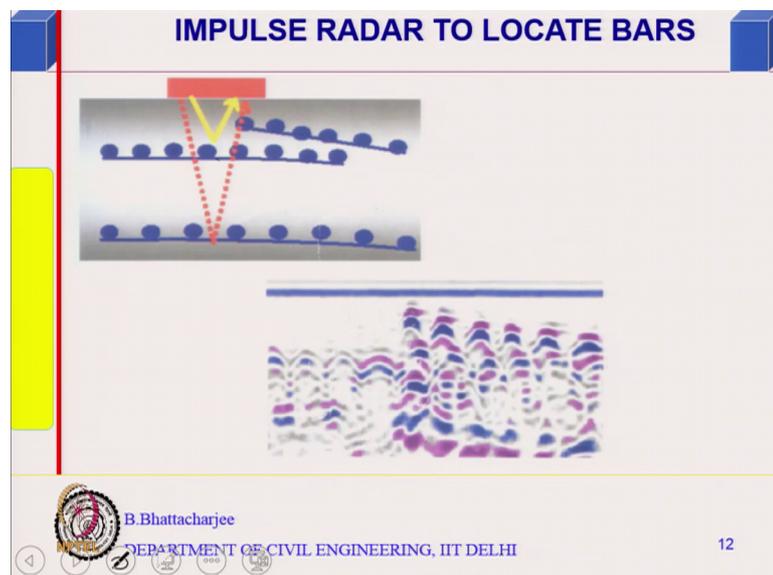
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So, that is cover meter, but today you can have impulse radar techniques. Here the interpretation is a problem you must be next part to it to do an interpretation. For example, impulse radar would send signal and images you will get something like this. Something like this or of images you will get if there is a rebar.

So, from the kind of images one can actually find out idea about rebar or whether they have been placed correctly or not. So, impulse or the radar technique one is a magnetic type others is a impulse radar type and something like this it can locate.

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For example, if you have a poor bar detailing. What does the radar do signal is send them it is reflected back and you trace the time of arrival of the reflected way you know reflected signal from that you can find out the distance. So, if this was your bar layout the impulse radar signal would come something like this.

So, you must know how to inter do an interpretation they are red coloured blue coloured and all that, this is actually for this. So, somebody has to be trained, the trained person can do this, but this can this is this can give you better idea if you know you know if some the properly interpretation is done it can give you.

So, this cover this is how you find out cover, first you said that how you find out the cover using conventional cover metres magnetic type and this is impulse radar technique or other way. So, you can find out cover. In fact, GPRs as you know I will come to that GPR as you know it can find out the foundation depth; depth of foundation you can find out not, you know profiling you can do you send the signal to the ground reflected signal comes back from the time you can find out. So, actually boundary of the boundary of the foundations you can find out.

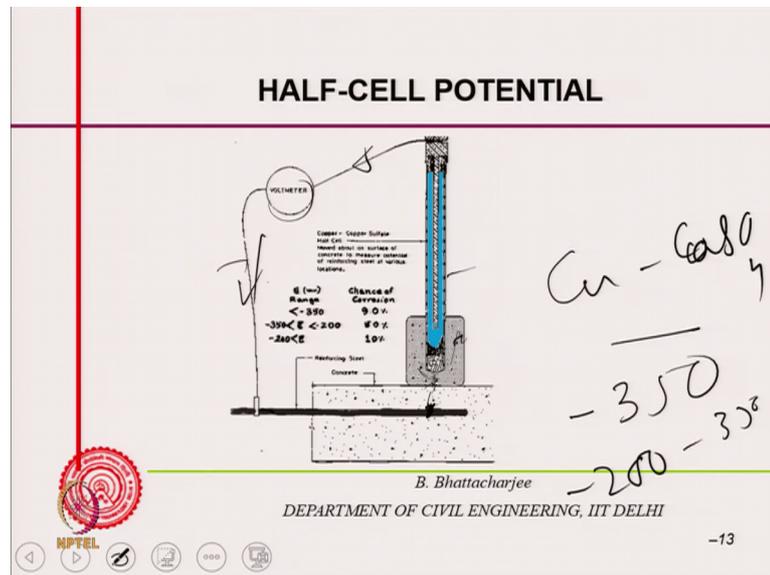
You know archaeological survey is using this, I know that it was used in that kedarnath temple after the plant. You know it is somebody whom I know he did that actually. So, you have to have that instruments. So, they found out the rock is still intake foundation on which the temple was temple was built is built on rock, hard rock goes fell down below.

So, that is why nothing has happened to the temple rest of the recent all hotels and all they vanished away because they are you know there is hardly any genius staff. This was done at the purpose to last for very long time by those people from their empirical knowledge. And this he found out the you know the rock profile and all that you found out. So, that is what it is.

This test is half-cell potentially done test is done again to demarcate the area of high risk corrosion compared to low released reinforcement corrosion. We have seen resistivity I can use right, low resistivity means high risk of corrosion and half-cell potential is another one.

Because corrosion is an electrochemical process so, by measuring some potential I can say what is my risk of corrosion. Particularly if it is chloride induced, it is when you use extensively on bridges and buildings.

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So, the American society of testing material 876 gives you this kind of a setup where you have got you know a copper rod in a which acts as an electrode in a saturated copper sulphate solution.

So, you dissolve copper sulphate in distilled water saturated and the copper rod is here. And you can see that you know there is crystals of copper sulphate; crystals of copper sulphate they should be there ensuring that it is saturated. So, you should have sufficient copper sulphate and then you should be able to see that.

So, that you ensure that it is saturated right. And this is sponge, in order to make contact with the concrete. Now this is sponge soaked in soap solution such that electrical contact is built and here there is a porous plug. So, you say a tube with a bottom open there is a porous plug through which this copper sulphate solution is actually is all moist, all saturated with water. So, this is all conductive.

So, this sort of you know it is conductive and there is a voltmeter here usually voltmeter have high resistance. Because through the voltmeter current does not pass is not supposed to pass you measure the potential difference. In ammeters or current measuring

devices resistance is very low because current should be passing and that should cause actually any deflection or any kind of analogue or digital you know display. So, voltmeter resistance is usually very high. This has specifically no current should passed through this; no current should pass through this right no current should passed through this once.

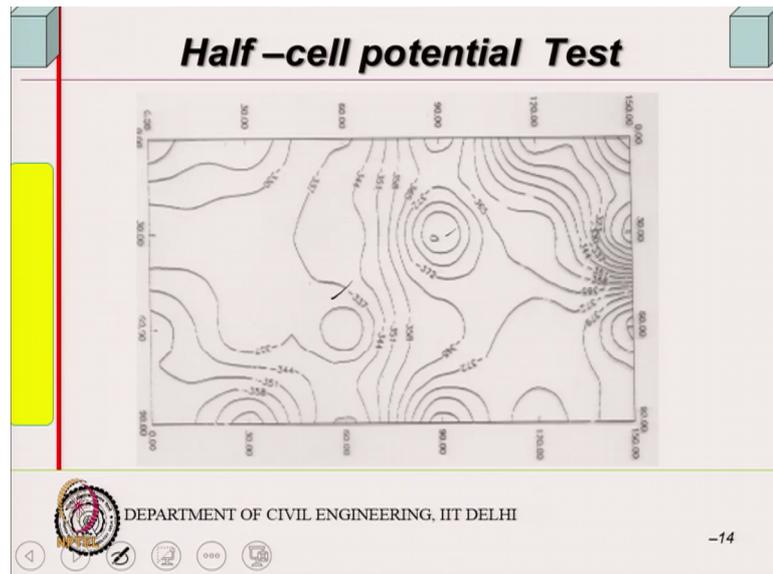
So, this is connected to the reinforcement bar. So, you have to expose the reinforcement bar. Maybe drill through the concrete and use a crocodile clip or something to connect it right. Crocodile clip or something to connect it and this is a voltmeter now you measure simply the potential. So, it measure the potential of the bar some where there, because this is the nearest distance of the bar this is conductive so, potential difference between this. Now this is what is called a reference electrode standard reference electrode.

So, you know the electrical potential that would be generated between the copper bar and copper sulphate and the difference between this is measured by this voltmeter. Standard electrode used in electrochemistry standard hydrogen electrode where your platinum rod right, but I think I am not interested in telling details of an hydrogen electrode. So, you have varieties of reference electrode. And their potential is measured with respect to standard hydrogen electrode whose potential is assumed to be 0. So, this has got a standard copper, copper sulphate electrode, copper rod copper sulphate. So, that is called $Cu / CuSO_4$ electrode right.

So, that is used and that is been found to be more suitable there can be other reference electrode. So, ASTM suggests this. And you measure the potential and if it is less than minus negative you know more negative then minus 350 milli volt chance of corrosion is 90 percent. That is empirically observed by measurement in lot of bridges in North America.

So, ASTM is actually is classified this. If you find between this potential between minus 200 to minus 350 between this you, know then you say the chance of corrosion is 50. I mean it may be corroding may not be corroding. And if it is more positive then minus 200 that is minus 100 and 50 or something no corrosion is occurring. So, you can actually demarcate the areas of active corrosion from less corrosion yeah. So, risk of corrosion you can demarcate it right.

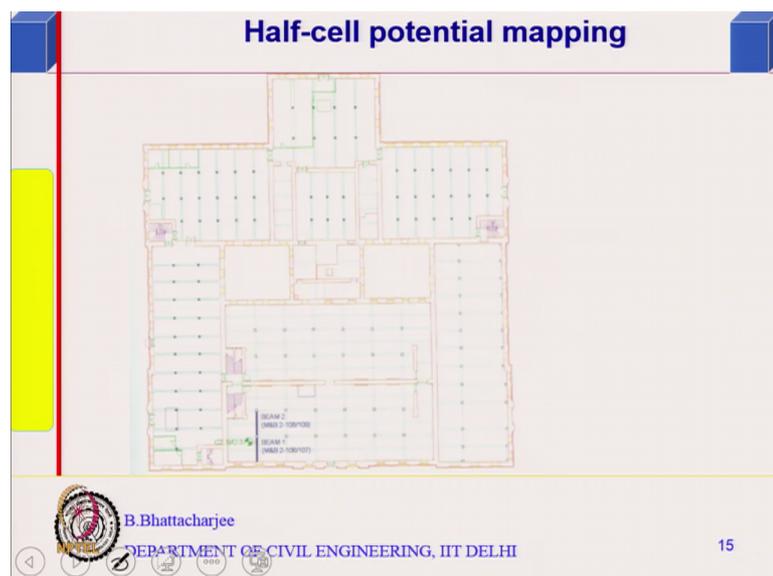
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So, this is how one can actually plot the contour. So, this is actually by such device which you fabricated ourselves long back. Commercial equipments are not available and in a slab in IT where they are demolishing it we obtain this contour plot.

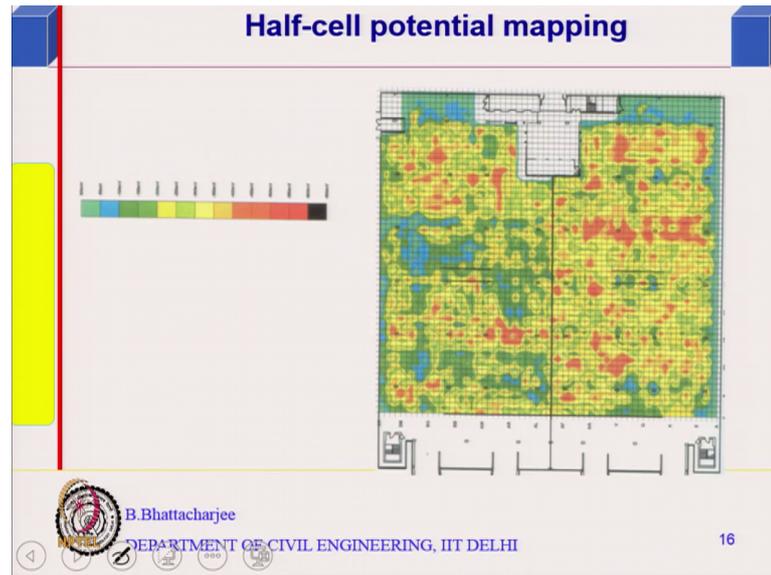
By plotting and different point take that data put it in a software those days called sulphur and which will plot contour for you. So, this lines are you can see that some will be 227 negative potential line somewhere you. So, demarcate the areas of high risk corrosion to low risk corrosion in the slab.

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But modern instruments might give you something like this. You know modern instrument might give you something like this. you can see this is the slab lot of measurements have been taken if the who will mounted 5 6 electrode or 5 6 probe together and finally, you get something of this kind something of this kind, you know this kind of plot you get you get something of this kind.

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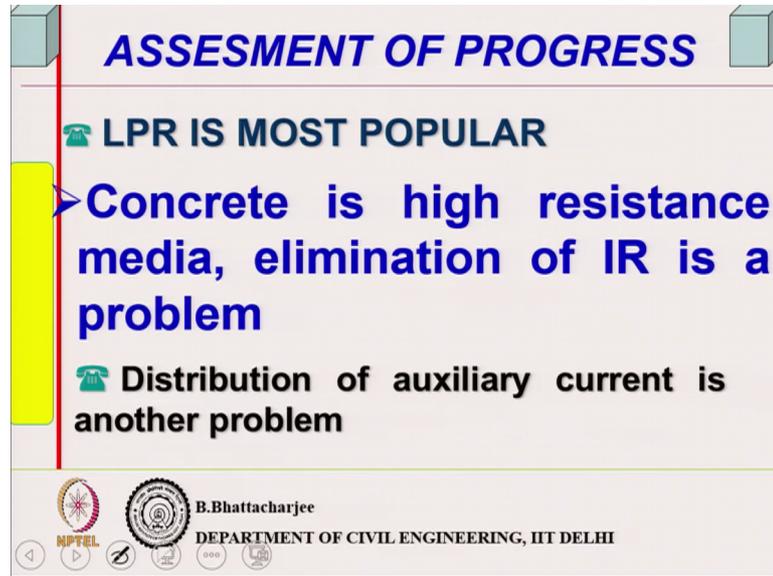
So, modern instruments where there will be some 6 reference electrode or probes simultaneously you just roll it over, is who will mounted. So, we can place shift from 1 place to another measure 6 points shift it measure another 6 point.

And you locate those points digitally they you know there is a I mean this is all microprocessor or computer based. So, you simply input the location according to a coordinate system and later on gives you this kind of area. So, where it is red these are high risk zone where it is green low risk low risk. So, you can actually determine. So, half-cell potential mapping can be done in this manner. Other methods are of course; rate of corrosion measurement, these are all the durability test method.

So, there are instruments now through which we can find out if corrosion is occurring. So, first you do what? I will come to this method possibly a little bit later maybe in the next class, but just before that if you first find out the demarcate the area, where the corrosion risk is very high or resistivity is low. Then now in those location you might do corrosion rate measurement because after all measurement will cost you money.

So, first you demarcate high risk area and then once you are demarcated them you know additional test you do there and if requirement break it and see. So, this is the whole thing right.

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ASSESSMENT OF PROGRESS

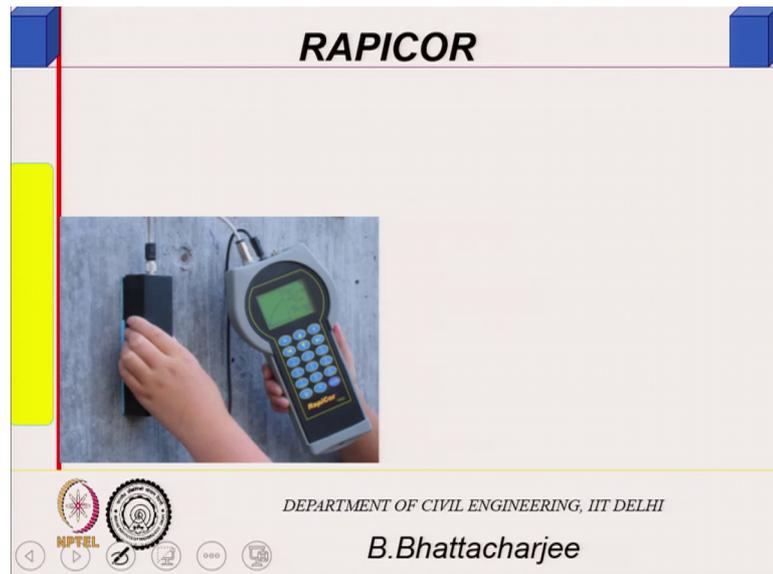
- ☎ **LPR IS MOST POPULAR**
- ▶ **Concrete is high resistance media, elimination of IR is a problem**
- ☎ **Distribution of auxiliary current is another problem**

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So, linear polarization method is one of them, which I will talk about it later on in the next class right. So, this is a kind of an instrument that would be there. But modern instruments you do not see all those. You just see a probe or something like that you put handle device you just place it something like this possibly, something like this I am not going to show right now I will yeah.

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Something like photograph something like this. You know something like this a just handle device right. This is not a very robust instrument, but there robust instrument. In fact, one in the laboratory is for field measurement also, but I think I do not have that photograph of that. This is also there in our lab, but there is a no I do not think I have.

So, this is this I just talked about that in the next class, linear polarization method measurement. There are other methods, but in-situ methods they are still deviated you know they are people are developing them, their a c impedance spectroscopy, colostatic methods galbapals, there are several instruments are available to measure the corrosion rate in actual structure. Now this is important because lot of maintenance cost goes with the river corrosion all right.