Concrete Technology
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Lecture - 32

Durability of Concrete: Frost Action & Rebar Corrosion

Welcome to module 8 lecture 2, will continue with durability of concrete, and in this lecture, we look into frost action and introduce rebar corrosion reinforcement corrosion.

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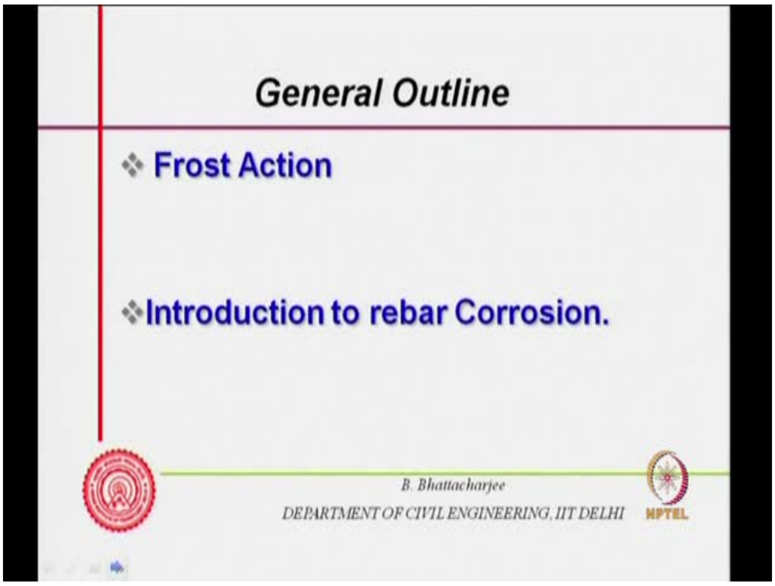

General Outline

- Frost Action
- Introduction to rebar Corrosion.

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So, essentially will look at cross section and will introduce rebar corrosion today. Now, we know frost Action of frost, usually is a more relevant to the cold countries. But in Indian sub continent, Indian scenario, the Himalayan areas are subset able to frost action, freezing and thawing. And you know the problem of freezing and thawing can result in kind of (( )) of concrete. Now, water if present in the concrete can freeze at lower temperature, and you know the ice occupies more volume than the water. Now, presence of this you know freezing point of water is not fixed unless it is distilled water.

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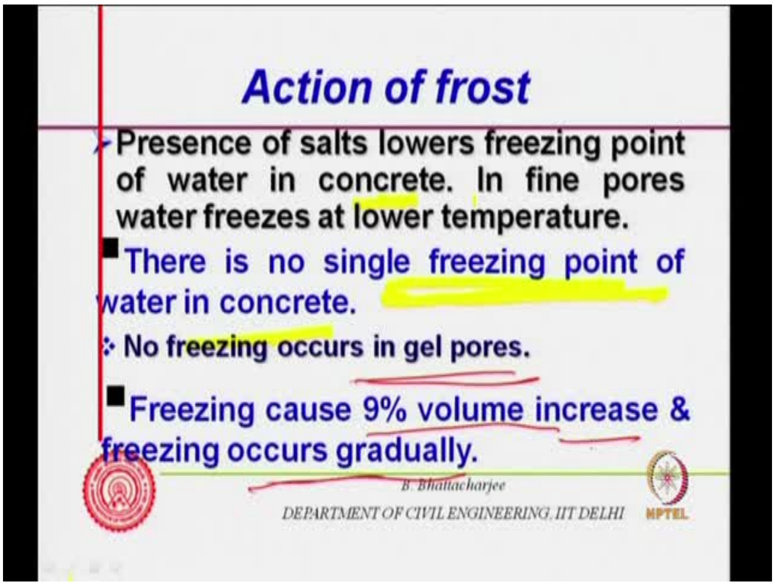

Action of frost

- Presence of salts lowers freezing point of water in concrete. In fine pores water freezes at lower temperature.
- There is no single freezing point of water in concrete.
  - No freezing occurs in gel pores.
- Freezing cause 9% volume increase & freezing occurs gradually.

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We know that depression of freezing point occurs when you have got salts. You know Presence of salts actually lowers the freezing point, salt present lowers the freezing point, and force freezes at lower temperature. So this is one issue. Second issue is since the ferocity force sizes differ, salt concentration would differ at different location in the concrete. There is no single freezing point of water in concrete. So, therefore there is no single freezing point freezing point of water in concrete. And in gel pores gel we hardly any freezing. So, in gel pores there will be no freezing no freezing occurs in gel pores. So, what it means: even the concrete is saturated, all you know and the temperature goes down, freezing will not occur .Simultaneously in all the pores only in some pores freezing will occur depending upon the salt concentration, size of the pore and of course how close you know the approximately to the surface of freezing temperature.

Now, when freezing occurs Freezing cause us 9 percent volume increase and freezing occurs gradually. Because all will not all force will not get you know water in all the force will not get frozen in one row.

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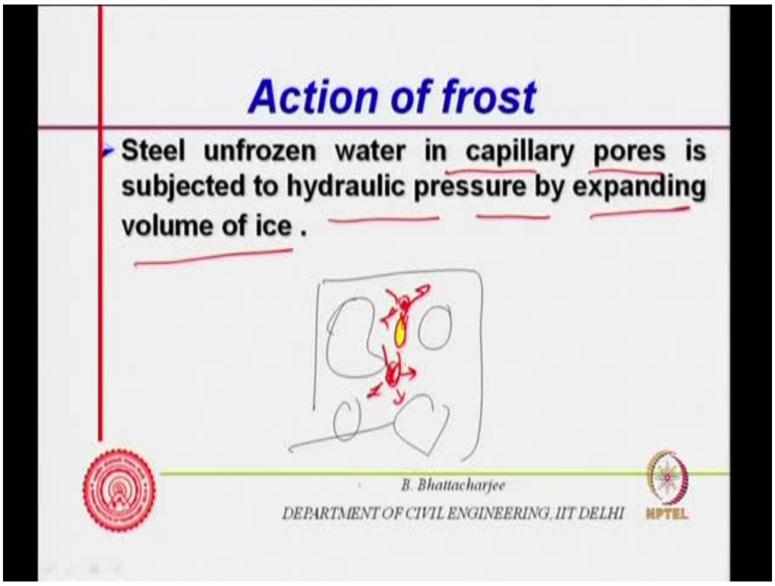

Action of frost

- Steel unfrozen water in capillary pores is subjected to hydraulic pressure by expanding volume of ice .

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So, there is the nine percent volume increase. Now, this volume increase actually causes a kind of an access pressure. So the water in unfrozen capillary is subjected to hydraulic pressure by this expanding volume of ice. So, what you can look into is something like this. You have the concrete the other the aggregates etcetera, and then, you have got force of various kind interconnected system and so on. The water freezes in some of the pores the other courses till free, and the hydraulic pressure in this you know hydraulic pressure in this force would cause an outward pressure on to the concrete. Because, this is frozen water this is just water which is unfrozen and since this is expanding. And this is connected this will actually exert, hydraulic pressure in the surrounding concrete matrix.

So, as a result there is internal pressure generated, this un relief pressure inside induces internal terms and expresses and that can be local failure. So, there can be local failure local failure could occur. And when thawing occurs again and when thawing occurs this wood space. You know for example, if this was your pore space which actually because of hydraulic pressure cracks occurred in this manner.

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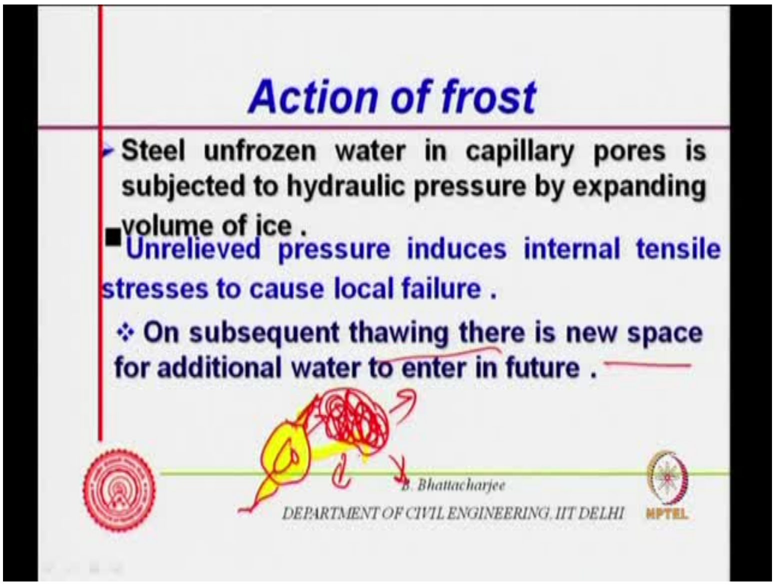

Action of frost

- Steel unfrozen water in capillary pores is subjected to hydraulic pressure by expanding volume of ice .
- Unrelieved pressure induces internal tensile stresses to cause local failure .
- ❖ On subsequent thawing there is new space for additional water to enter in future .

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Now, when actually you know cracks got expanded or something of this kind, now next time when next time when water freezes water will enter into this as well as into the new cracks And freezing action will be there, in this new cracks you know cracked or new, newly formed features or spaces again. So, in other words now this will exert more hydraulic pressure, this will exert. You know this will cause more hydraulic pressure into water where there are. You know this is the water where the force where so this will exert more pressure.

Because more pore space are available which are filled with ice. So, me spaces which are not earlier filled by water now that filled up by water and can get frozen again. And some portion might get frozen again and if they get frozen then really exert pressure outward. And therefore, this process you know the cycle will continue. So, these cycles as it continues the process is you know repeated several times. And then finally the damage to the concrete will occur.

So, thus the Action of frost in on concrete. So, when the radiational additional mechanism when capillary becomes. You know it becomes ice the vapor pressure reduces. So, when capillary pores once ice formation had occurred, the vapor pressure would reduce. So Gel water will move to the capillary So, gel to capillary because you know ice has formed here the ice formation was occurred here.

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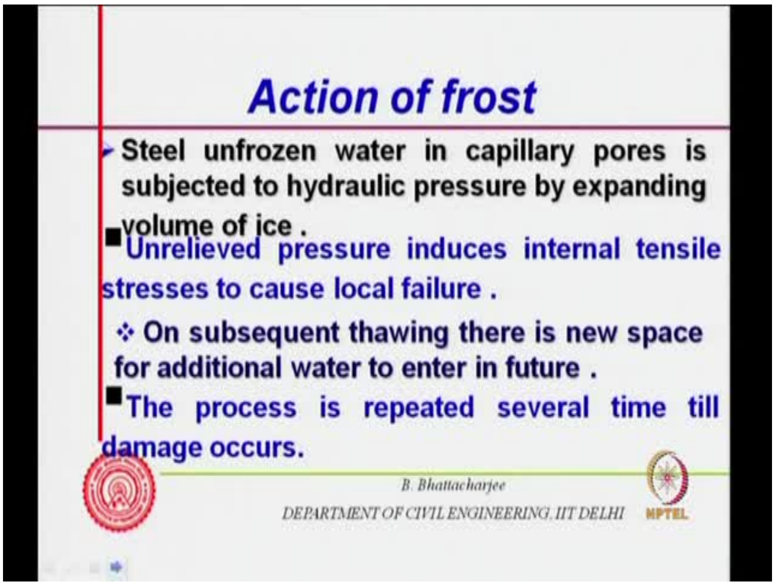

Action of frost

- Steel unfrozen water in capillary pores is subjected to hydraulic pressure by expanding volume of ice .
- Unrelieved pressure induces internal tensile stresses to cause local failure .
- On subsequent thawing there is new space for additional water to enter in future .
- The process is repeated several time till damage occurs.

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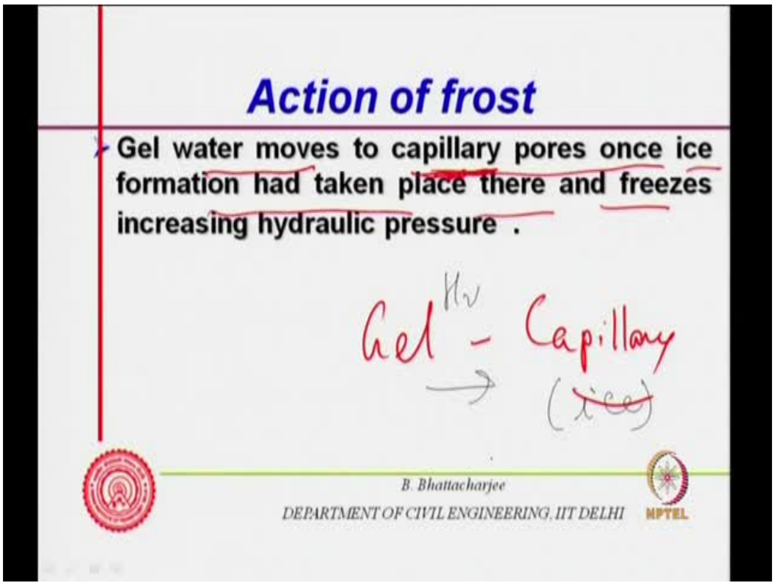

Action of frost

- Gel water moves to capillary pores once ice formation had taken place there and freezes increasing hydraulic pressure .

Gel ^{H_2O} – Capillary

$\rightarrow$

(~~ice~~)

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So, therefore, gel to water will move gel, water will move from gel to capillary, and then again it will get frozen and the hydraulic pressure will increase. So, this is a kind of a, you know kind of a cyclic process repeated repetitive process. I mean, It is sought of cascading effect first you have a some gel formation, some ice formation. In some of the capillaries resulting in access hydraulic pressure, causes cracking and next time those crack or features that has been created will again filled up by water and therefore, additional spaces.

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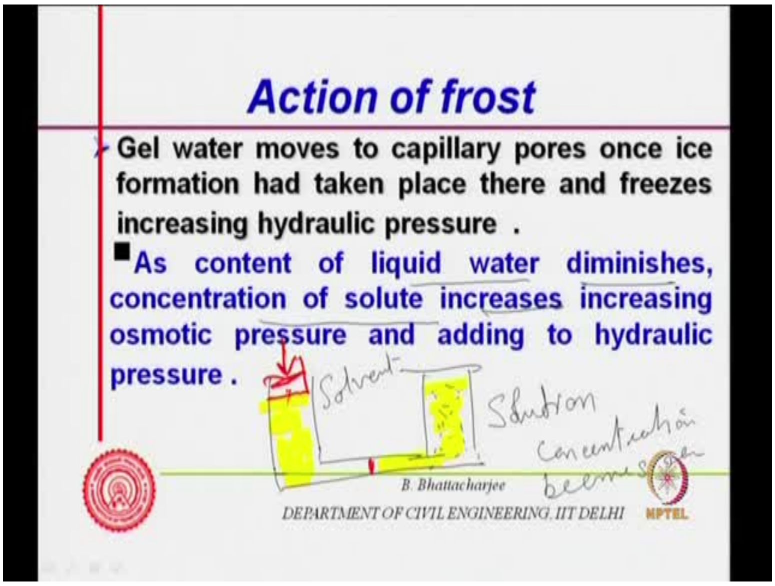

Action of frost

- Gel water moves to capillary pores once ice formation had taken place there and freezes increasing hydraulic pressure .
- As content of liquid water diminishes, concentration of solute increases increasing osmotic pressure and adding to hydraulic pressure .

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Now available, more hydraulic pressure and whenever, there is hydraulic you know there is a ice formation in the capillaries. The vapor pressure reduces and Gel water moves to the capillaries. And again this freezes. And therefore, you know kind of a cascading effect and after number of cycles actually you will find that there is a kind of a dissection of the concrete in so and so forth. Now, this other effect is when liquid water diminishes concentration of solute also increases. And osmotic pressure increases adding to hydraulic pressure.

So, therefore, concentration of the solute which changes you know basically as we said that solute concentration, causes diffusion will look into that a little bit more sometime later on but right. Now we can understand this for example, this phenomena will be something like this suppose in a solute, I have two tanks and there is a semi permeable membrane here. And I have got water here, distilled water and here also distilled water, but with some sought of solute solution present in this.

So, here I have got solution, here. The solvent, after sometime you will find the concentration tend to be a same after some time there you find that. You know after some time one find the concentration become same. So, concentration becomes same But, suppose in you know I put suppose in I put a piston here instead, I put a piston here you know and apply pressure, it will remain same the concentration would not change concentration doesn’t change, if I apply pressure here to a piston. So, this pressure difference is you know is called you know this is this pressure which I have applied, implies. That there is a pressure difference existing between high concentration to low concentration.

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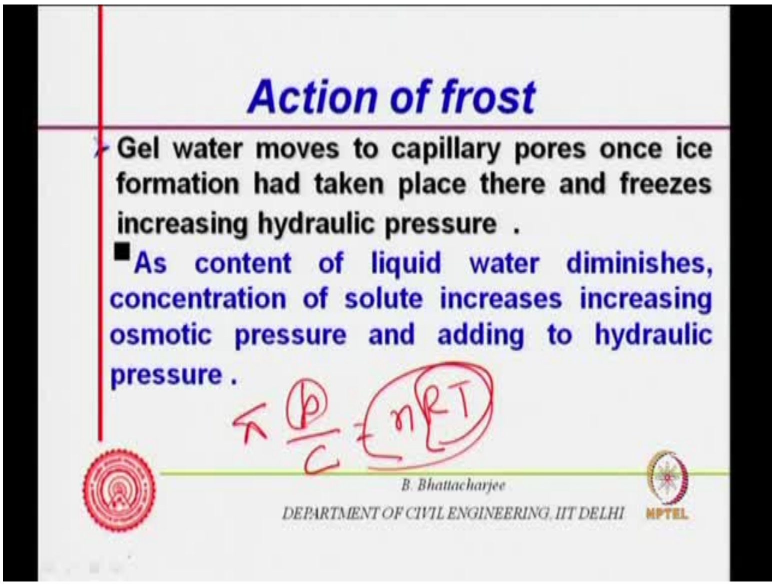

Action of frost

- Gel water moves to capillary pores once ice formation had taken place there and freezes increasing hydraulic pressure .
- As content of liquid water diminishes, concentration of solute increases increasing osmotic pressure and adding to hydraulic pressure .

$\pi \frac{p}{c} = nRT$

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And this is called a osmotic pressure osmotic pressure you know and due to osmotic pressure solute moves from high concentration to low concentration. And in fact it can also be shown that the pressure by concentration is something you know it is proportional to RT. So, you in fact you pressure by concentration volume one by volume is a concentration, so pb. So, its follow almost the you know this pressure or sometime denoted by pie it follows the gas flow itself so ideal gas follow itself. So, this can be related you know so pressure osmotic pressure can be related to the gas so and so forth right. So, that is what it is. So, osmotic pressure the solute concentration being different it can cause actually in osmotic pressure and it can add to the hydraulic pressure.

Empty air voids or capillaries is when present can relieve this pressure. But, suppose in I, have got empty capillaries or empty voids which is not filled with water. And then were hydrostatic pressure is applied, this get ruptured and the water can enter into this one and this can relieve some of this pressure. So, empty air voids if I if present in the system it will cause relieving of the pressure release of the pressure. And thereby you know the dissipation of concrete or detritions of concrete is controlled.

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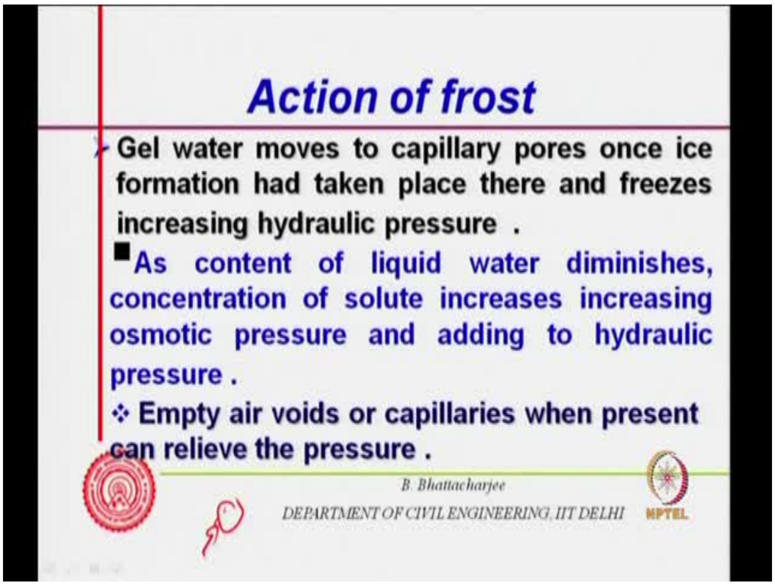

Action of frost

- Gel water moves to capillary pores once ice formation had taken place there and freezes increasing hydraulic pressure .

■ As content of liquid water diminishes, concentration of solute increases increasing osmotic pressure and adding to hydraulic pressure .

❖ Empty air voids or capillaries when present can relieve the pressure .

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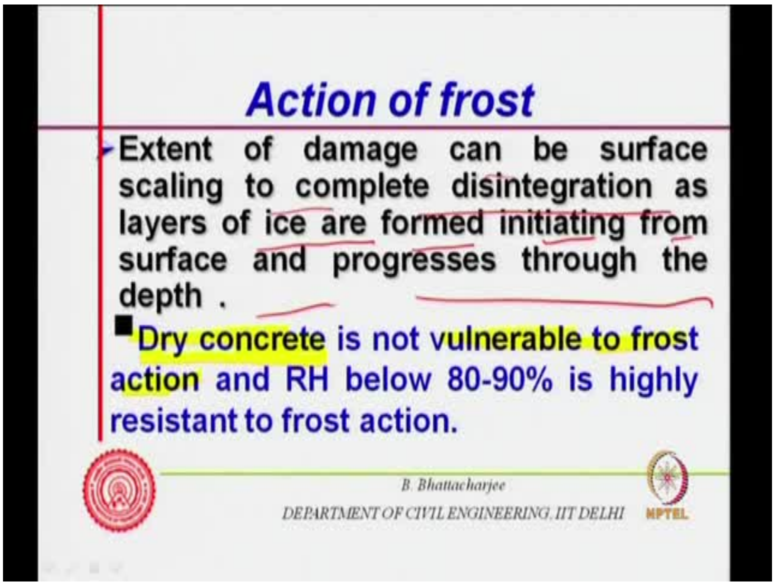

Action of frost

- Extent of damage can be surface scaling to complete disintegration as layers of ice are formed initiating from surface and progresses through the depth .

■ Dry concrete is not vulnerable to frost action and RH below 80-90% is highly resistant to frost action.

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So, extend of damage can be surface scaling to complete this integration as layers of ice are formed initiating from surface and progress to the depth. So, essentially it starts from the surface and penetrates inside and surface scaling sometime constant you know complete disintegration of the concrete from the surface and so on so forth.

After certain number of cycles so it doesn’t occur in one cycle first freezing, then thawing. So, more water comes in next again freezing, and deception, and again thawing. So further more water comes in after certain number of cycles over the years actually you find that surface concrete actually is coming out, popping out or something like that disintegration is occurring. So that is what is action of frost. If the concrete remains dry, it is not vulnerable to frost section. Because rh below eighty to ninety percent is highly resistance to frost action, because water is not there what to freeze. So if the relative humidity is less than 100 percent, less than 90 percent, vapor pressure only vapor should be there, and it will not freeze, since vapors will be there it will not freeze. So, dry concrete is not vulnerable to frost action very important.

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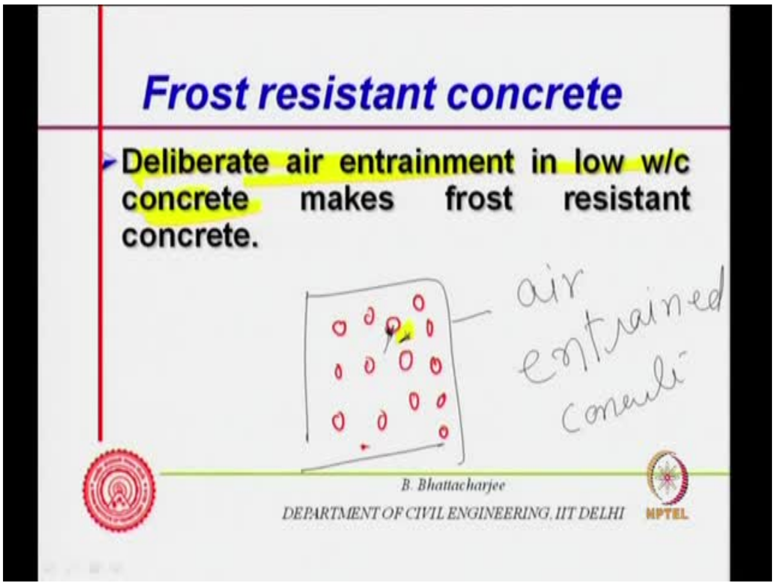

Frost resistant concrete

- Deliberate air entrainment in low w/c concrete makes frost resistant concrete.

air entrained concrete

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Dry concrete is not vulnerable to frost action. So, therefore, again we see if we keep water out everything is fine. If I can keep water out everything is fine. So, therefore, frost resistance concrete one ways to keep it dry but that may become not that, may not be possible all the time. But, what you can do there was another issue you said, if there are empty frost space not filled with water. Where water can enter during you know during the freezing relieve the hydraulic pressure, right. That some or other would be able to extend, the freezing and thawing number of cycles of freezing. And thawing and the durability of the concrete wood increase in other words fort resistance of the concrete will increase.

So, deliberate air entrainment in, low water cement ratio concrete. Now, low water cement ratio concrete will actually allow less water into it. Less water engage in guess less water in guess and if I have air entrainment. Now, what air entrainment will do, it will actually kind of a, this is your concrete creates creative sort of isolated small pore system, spherical. This well distributed small pore system, air entrainment air entrained concrete. So, there well distributed fine pores but closed pores well distributed fine pores but closed pores.

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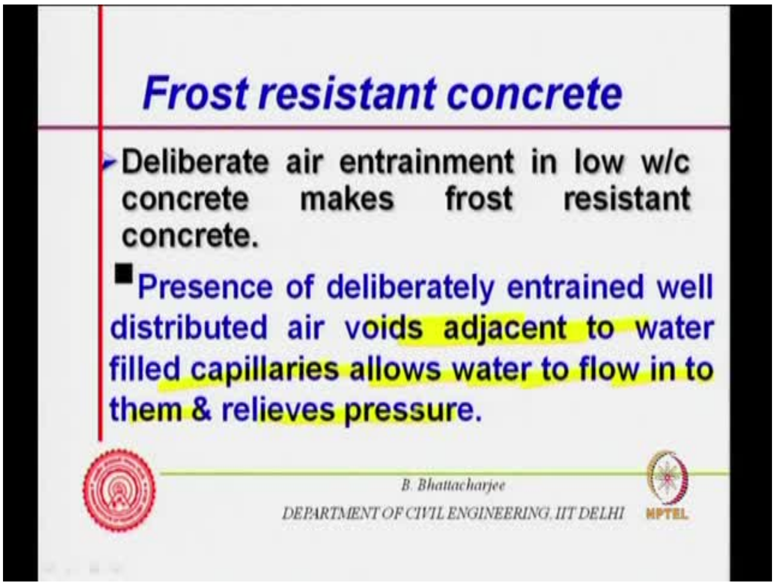

Frost resistant concrete

- Deliberate air entrainment in low w/c concrete makes frost resistant concrete.
- Presence of deliberately entrained well distributed air voids adjacent to water filled capillaries allows water to flow in to them & relieves pressure.

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Now, these pores initially are dry not filled with water. Now, once hydrostatic pressure hydraulic pressure inside the capillaries increase. You know this, pore boundaries might get ruptured and water enters there. Now, where is the water enters pressure is released. And therefore, surrounding concrete is remains intact or unaffected surrounding concrete remains unaffected. This concrete remains unaffected this concrete this concrete remains unaffected. You know concrete here, will remain unaffected. So, deliberate air entrainment actually increases the life. You know presence of deliberately entrained well distributed air voids adjacent to water filled capillaries allows water to flow into them and relieve pressure.

So, that’s the idea adjacent to the water filled capillaries allows water to flow into them and relieves pressure. so pressure is relieved actually. So, therefore, the skeleton of the matrix solid matrix, solid skeleton, remains unaffected you know. So, therefore, it can last but then the deliberate entrained voids which are there once, there water enters there that becomes part of the interconnected pore system. So, next thawing cycle during the next thawing, the water will penetrate into it. And then again it’s also part of a whole system. But, all the air voids will not be filled in 1 row, so some will get actually filled in by water. You know they will come into the permeable or interconnected permeable pore speeds.

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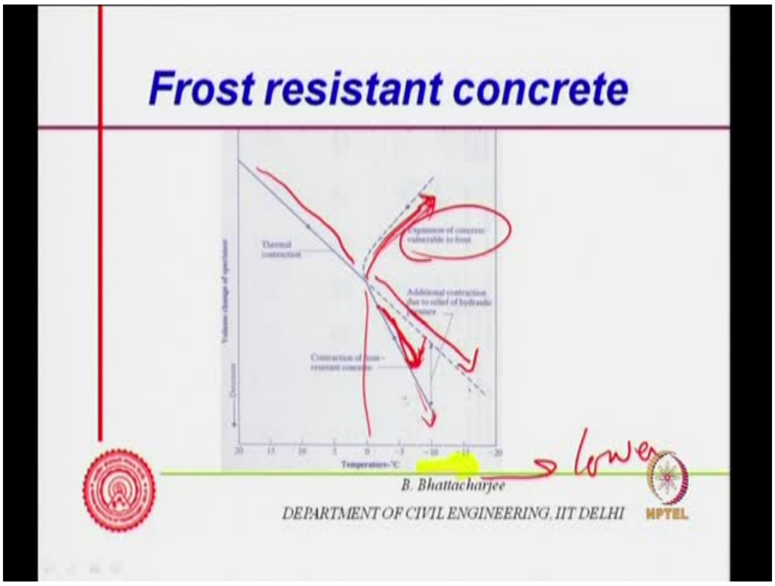

Frost resistant concrete

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But, some will still remain, for the next cycle and for the next cycle and so on so forth. So, therefore, number of cycles the near intend concrete with stand, is much higher than non air entrant concrete, and this can be seen from this diagram. You will see when temperature is going down this is the lower temperature. Lower temperature is lower, this thermal contraction of the concrete, and if thermal contraction would have continued after 0 degree centigrade. It would have gone like this, parallel to this but what happens is if I look at the bulk bulk look at the bulk behavior.

Then from this point its starts expanding actually why? If it is not here entrained its starts expanding, because the hydraulic pressure causes the whole thing to hydraulic pressure of the freezing. You know because of the ice being formed inside it causes it to sort of access. You know internal pressure, and that causes a kind of expansion till it fails till the surface concrete goes out while if I have entrained concrete, the pressure is relieved and has the pressure is relieved, contrast skeleton is. You know it gets contracted, because of the thermal contraction effect. And this all together you know there is actually a reduction in the volume event more than thermal contraction.. So, it is not only frost resistance air entrained concrete not only exhibit a kind of reduction in reduction in then you know thermal contraction affect. But, it also shows further reduction in the volume of the whole system.

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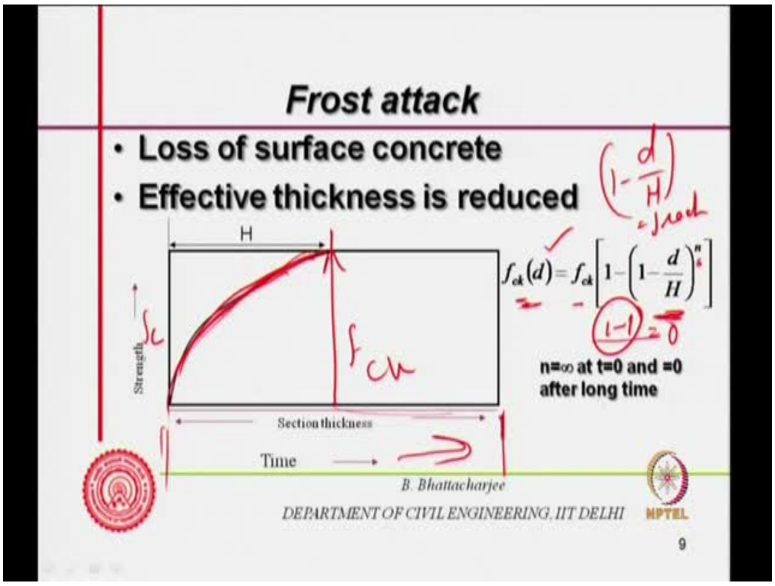

Frost attack

- Loss of surface concrete
- Effective thickness is reduced

$$f_{ck}(d) = f_{ck}\left[1-\left(1-\frac{d}{H}\right)^{n}\right]$$

n=∞ at t=0 and =0 after long time

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Because the pressure that was that would have been created hydraulically would have been released somewhere else. And the contraction is even more in this particular case. So, additional contraction this is because of the relief of the hydraulic pressure. So, this hydraulic pressure that is that gets released in a way there is no pressure some pores will be filled with ice. And contraction of ice will also you know it will also takes place. This, all results in volume contraction instead of volume expansion of air and trained concrete. So, that is that is actually a protection from frost attack. Essentially the effect is loss of surface concrete, effective thickness can be reduced when frost attack is occurring.

And some sort of empirical formulations are there, so one can conceive actually, with time this is my section thickness, which time the strength will reduce from the surface to inside. So, this is my design strength and this point f ck but the strength will be lower which time. So, if it is at very large time or infinite time H is a let us say H is a at infinite time H is a you know h is a depth up to which the strength reduction occurs, because there is a freezing cycle and a thawing cycle. So, most I will get in during thawing, frozen. And during once cooled again you know the it would some of it will come out. So, finally the water will again get in. So, there is a waiting drying scenario. And normally there is a depth of influence, beyond which no freezing action will be freezing action or frost action will not be seen.

So, effective in this one therefore, since f ck is only available up to this, in fact one can concede, that affective thickness is reduced. And someone empirical formula is available the number of them in fact this is 1 of them, f ck at a distance d is given by f ck multiplied by 1 1 d by H into n. Now, what is d? d is the depth and n is a n depends upon number of cycles, n is a depth of influence maximum depth. So, when you know when t is equal to 0, everywhere it will be fc k, so this value should turn out to be 0. So, this value you know it will be H by d is a depth. And this to the power very large value makes this value altogether small.

Because, this value will be fraction, d by H is a fraction, 1 minus d by h is also a fraction, and fraction to the power large value tend to make it very small. So, when t is equal to 0 f this value will be f ck everywhere. Now, when t is equal to infinity after very long time this is equals to 0. So, this 0 means this is 0 means this is equal to 1. So, f ck at d and this is valid up to the depth of h, beyond H is not valid. So, any depth up to the you know, this value at t is equal to infinity this value will tend to be t n will tend to be 0. So, this anything to the power 0 is equal to 1.

So, 1 minus 1 is equal to 0. So, if you know this value would tend to be at a depth this will be this will tend to be f 0 only small you know at over a very long period of time. All you know f ck value will tend to be 0 that what this equation says alright. But, then this is t is infinity so this is one empirical equation through which one can actually get some idea. One can get some idea that this is how the strength changes so this is fc. So fc would change fuel strength will change like this parabolic ally in this manner. And you know quite and one can fit an equation to this particular one right so that is what it is. So this is you know since its empirical I have just taken part of it and to explain the scenario.

There is similar other empirical model, for example, if you consider rate of d r as a rate of disintegration, one can assume step variation like this, step variation like this. So, first cycle you know this is a depth of disintegration this exceeds the depth of disintegration, this is time. Second cycle there is more and so on so forth and you can actually approximate.

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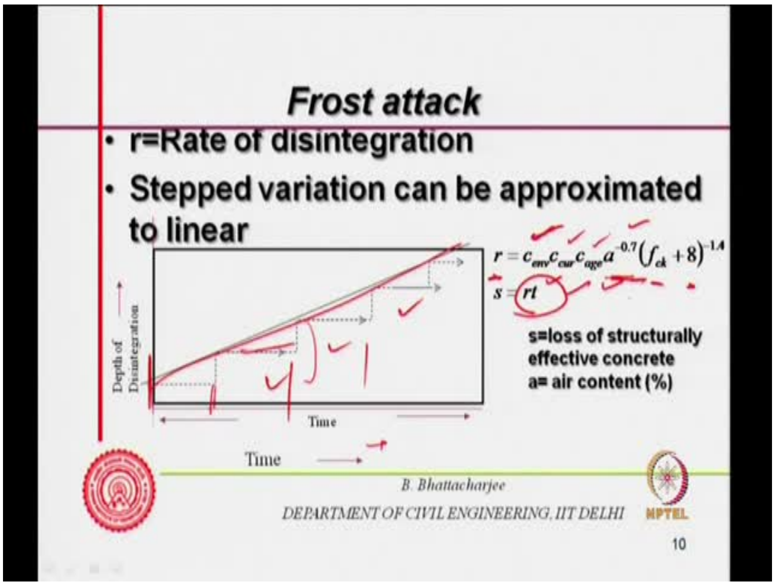

Frost attack

- r=Rate of disintegration
- Stepped variation can be approximated to linear

$r = c_{env} c_{cur} c_{age} a^{-0.7} (f_{ck} + 8)^{-1.4}$

$s = rt$

s=loss of structurally effective concrete
a= air content (%)

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So, this are each cycle, every cycle there is some depth of penetration increases, and you can actually linear lipid this. So, depth of penetration can be linearly related to time. In other words the rate can be one can find out the rate which will be slope of this line, would be the rate. So, rate is given by another formula empirical formula f coefficient called c environmental, c and v securing c age. A constant to the power point 7 and f ck plus 8 to the power minus 1 point 4 now S is a. You know loss of structural effective concrete is a function of rate into time. So, rate of structurally effective concrete loss of structural effective concrete is given by this which is a slope of this line and you know structural effective.

So, this depth represents the depth of disintegration. So, equals to r into t now, how c environmental c curing and c h c environmental is related to the environment of exposer, c curing is related to the curing condition. And at age after you know this are constant. So, now this are given in the next slide c curing is given as 0.85 plus point 0.17 log d where is d is the curing days. So, you have higher curing days C curing will be less in fact rate will be less. So, you see you can see the factors which effects the frost attack S age. So, if the age is more, obviously this value should be less but this will also depend upon the supplementary cementious material or fosslonic material. That you where using for example, P sf stands for the proportion of you know percentage of silica fume.

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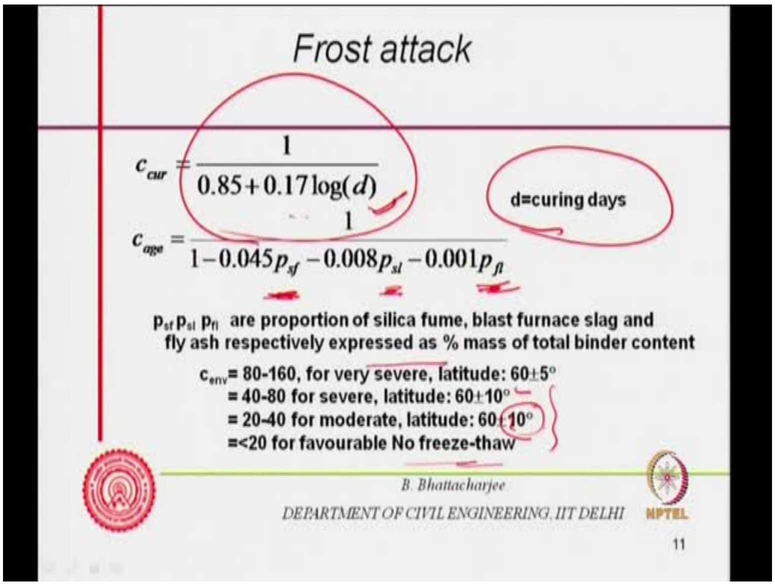

Frost attack

$$c_{cur} = \frac{1}{0.85 + 0.17\log(d)}$$

d=curing days

$$c_{age} = \frac{1}{1 - 0.045p_{sf} - 0.008p_{sl} - 0.001p_{fl}}$$

p_{sf} p_{sl} p_{fl} are proportion of silica fume, blast furnace slag and fly ash respectively expressed as % mass of total binder content

c_{env}= 80-160, for very severe, latitude: 60±5°
= 40-80 for severe, latitude: 60±10°
= 20-40 for moderate, latitude: 60±10°
=<20 for favourable No freeze-thaw

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Percentage of slag, percentage of fly ash, p that etcetera proportional silica fumes blast furnace slag. And fly ash respectively expresses, percentage of mass of total blinder content. So, if you use slag, fly ash, and silica fume this effect of age will be less. Because, this value will be so large values of this one, this tends to be smaller value this you know 1 minus this higher value this smaller value. So, this will become 1 minus this. So, this will become larger you know so this is something to with the effective field. C environment is given as 80 to 164 very severe condition latitude 60 plus minus 5 that is you know sub tropical climate, 40 to 80 for severe latitude 60 plus minus 10 and 20 to 40 for moderate and for favorable no freeze thaw. So, depending upon the situation one can choose this environmental condition.

I think this is the something wrong this is not correct this would be twenty possible. So, whatever it is. So, environmental condition depending upon environmental condition moderate condition or severe exposer condition or very severe exposer condition. This value of c depend, and therefore you can obtain the rate, from this expression f ck stands for the characteristics strain. 8 is taken as 1 point 6 5 sigma, in other words this represents a kind of mean strength. So, larger the strength r will be smaller, larger the strength more than that will the grade of concrete r will be smaller. And a, is effective you know as a constant depending upon s into t is a total time actually s is a, s into t is a time.

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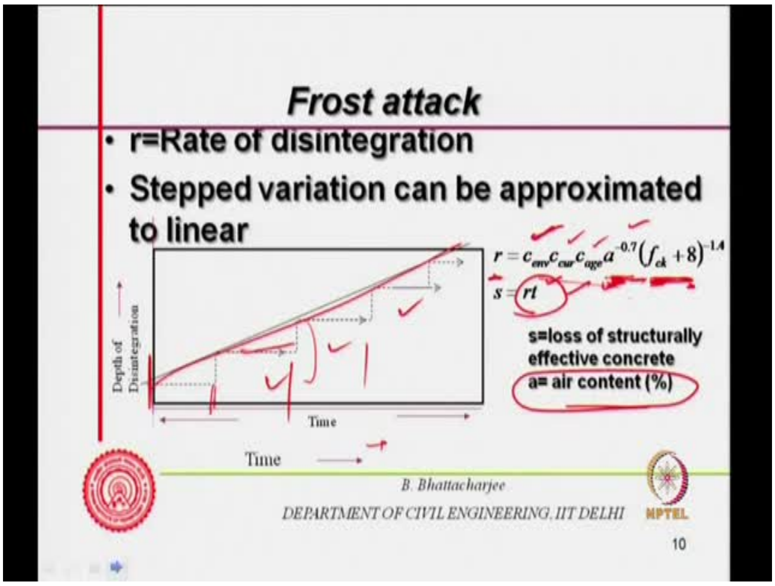

Frost attack

- r=Rate of disintegration
- Stepped variation can be approximated to linear

$r = c_{env} c_{cur} c_{age} a^{-0.7} (f_{ck} + 8)^{-1.4}$

$s = rt$

s=loss of structurally effective concrete

a= air content (%)

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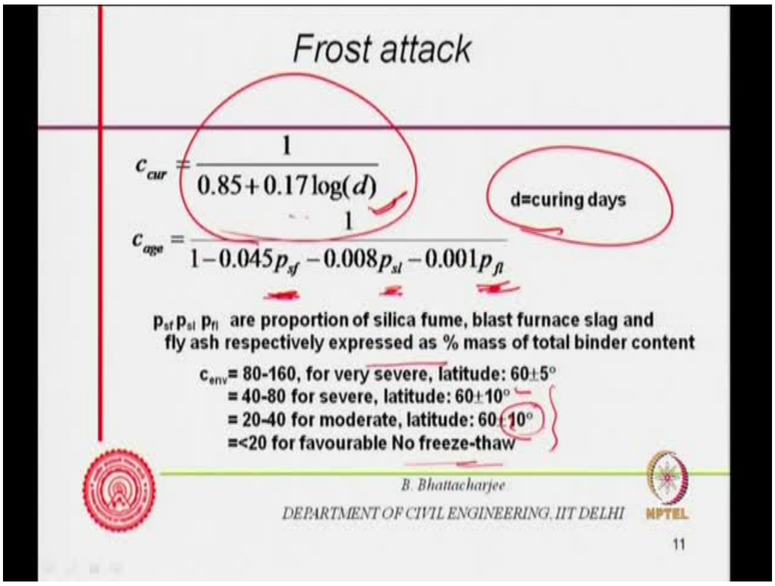

Frost attack

$c_{cur} = \frac{1}{0.85 + 0.17\log(d)}$

d=curing days

$c_{age} = \frac{1}{1 - 0.045 p_{sf} - 0.008 p_{sl} - 0.001 p_{fl}}$

p_{sf} p_{sl} p_{fl} are proportion of silica fume, blast furnace slag and fly ash respectively expressed as % mass of total binder content

c_{env}= 80-160, for very severe, latitude: 60±5°
= 40-80 for severe, latitude: 60±10°
= 20-40 for moderate, latitude: 60±10°
=<20 for favourable No freeze-thaw

So, what we have seen is a, is a constant, depending upon air content so you have high air content there will be reduction. So, a is a factor or constant depending upon air content higher the air content less will be the rate. And therefore, s will be you know s is since s is r into t right. So, r less that means or you know loss of structure concrete would be slower process. So, it can last for longer period, so that is related to frost attack and a surface deterioration by leaching that occurs in some of those. You know many places exposed to water.

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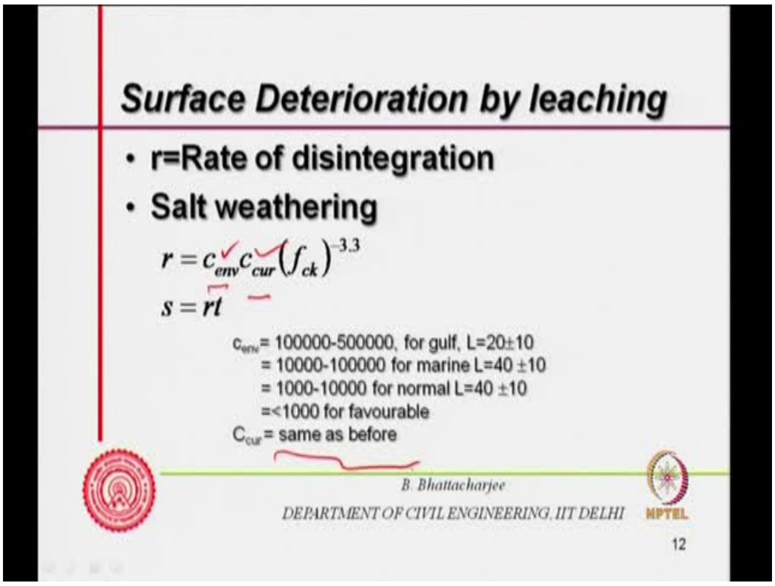

Surface Deterioration by leaching

- r=Rate of disintegration
- Salt weathering

$$r = c_{env} c_{cur} (f_{ck})^{-3.3}$$

$$s = rt$$

C_{env} = 100000-500000, for gulf, L=20±10
= 10000-100000 for marine L=40 ±10
= 1000-10000 for normal L=40 ±10
=<1000 for favourable
C_{cur} = same as before

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So, rate of disintegration for salt weathering situation is given by again a formula of the similar kind C is an empirical formula, but although the values may not applicable universally but it tell us.

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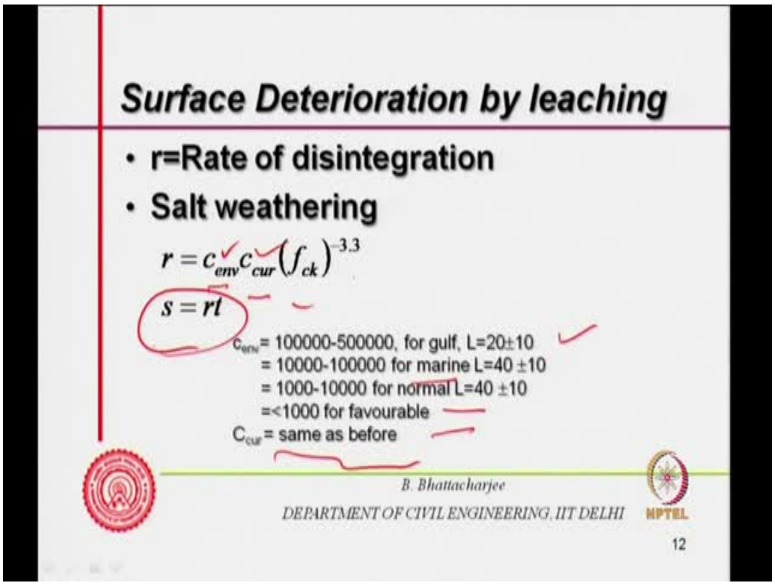

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What are the factors which governs this in other words? In case of frost action it is governed by the air content, a to the power minus 7 the strength of the concrete or grade of the concrete. And it also depends upon the environmental curing and age, which again in terms depends upon fly air, slag. And you know silica fume content, all right.

Similarly, a leaching would depend upon C environment. And C curing, the C curing is same as before curing it will depend upon curing age, f ck. You know the formula was if you can see that if you can remember the formulas point 0.85 plus point 0.17 log of d. So, d is a curing age so larger the curing age c cure is less right larger the curing is less C cure is less and so and so fore so forth. So, C environment is given for the gulf condition, for marine condition. And for normal condition, this is for favorable condition f ck to the power 3 point 3.

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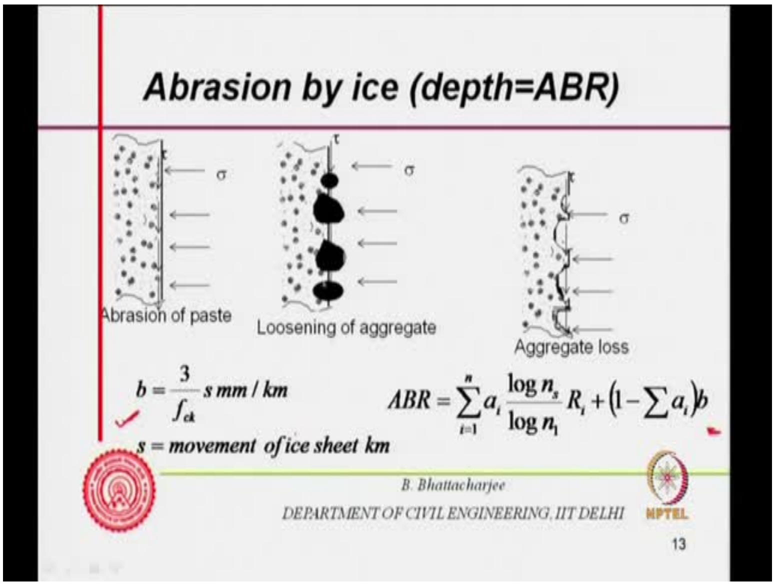

Abrasion by ice (depth=ABR)

$$b = \frac{3}{f_{ck}} s \ mm/km$$

s = movement of ice sheet km

$$ABR = \sum_{i=1}^{n} a_i \frac{\log n_s}{\log n_1} R_i + \left(1 - \sum a_i\right) b$$

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So, that means it is a curing condition is important, say in more the curing condition C cure will be less, environment depends upon marine environment gulf condition the leaching. Because, as we you remember we talked of sea water retire we said, that and you know the calcium sulfate which are formed, are leached out. So, this leaching rate is given by this formula. And s gives you the structurally disintegrated concrete r into t. So, this gives us third one is related to abrasion of ice, and the similar sought of situation when there is a marine environment or environment. Where there is water and you have ice bonding. So, abrasion depth ABR can be formed. Now, the phenomena is like this, you have a ice comes and heats it, and you have a two way section. You know there is a thaw acting there thaw shear stress and also a sigma normal stress.

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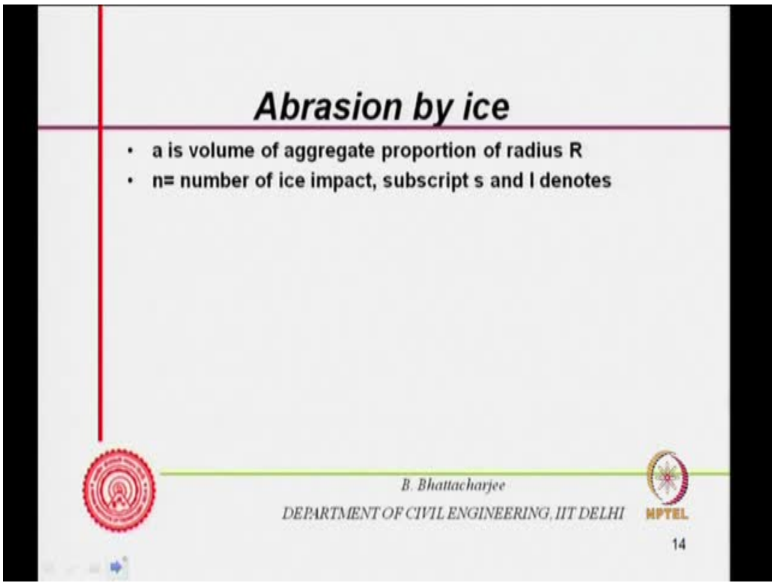

Abrasion by ice

- a is volume of aggregate proportion of radius R
- n= number of ice impact, subscript s and l denotes

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So, both sigma shear stress because it would heat at an angle and you will have both, you know shear stress. And sigma the normal stress acting on to it, and this causes aggression of the pace. So, the pace goes out first and then exposes the aggregate and when we have further shear stress coming and heating the aggregate. And the normal stress is coming and heating the pace, if the aggregate gets loosens.

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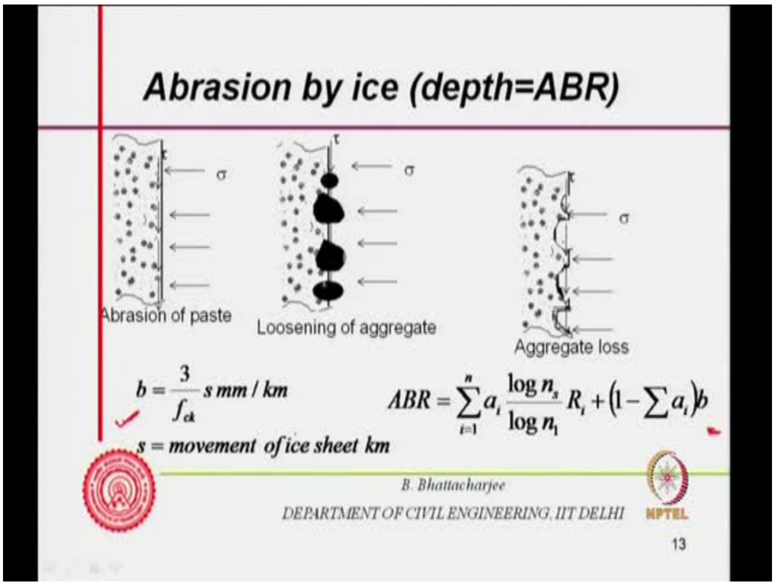

Abrasion by ice (depth=ABR)

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$$ABR = \sum_{i=1}^{n} a_i \frac{\log n_s}{\log n_1} R_i + \left(1 - \sum a_i\right) b$$

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So, loosening of the aggregate would occur and finally, the aggregate will go out, and then further shear stress. And the normal stress will be acting and this phenomena may continue depending upon how the ice heats. And this scenario you know this causes aggregate loss, and structural disintegrated concrete. So, s is a movement of ice heating kilometer the formula given is something like this, the depth of aggression. Due to ice is given by a I log n I n 2 by ns by n 1 Ri. And 1 minus a I into b. So, b is given by this b is related to strength s is the movement of I sheet in kilometer and n etcetera will just defined. So, when ice comes in heat the behavior is something like this.

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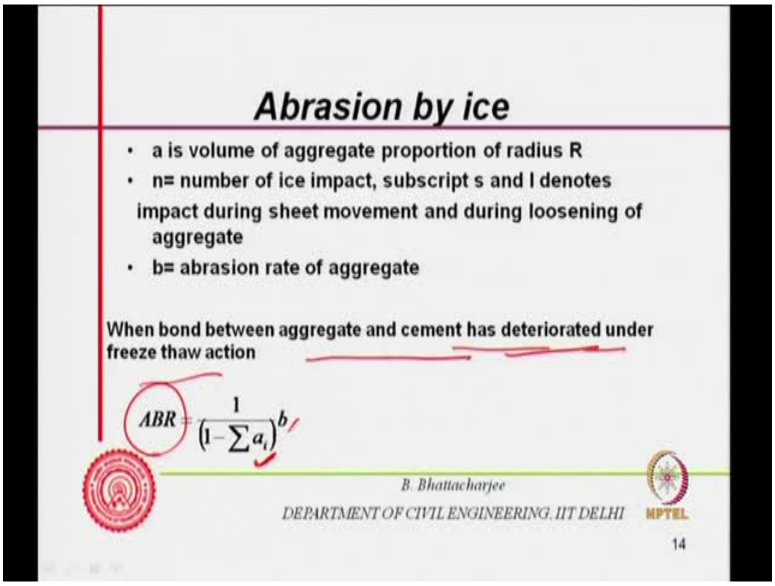

Abrasion by ice

- a is volume of aggregate proportion of radius R
- n= number of ice impact, subscript s and l denotes impact during sheet movement and during loosening of aggregate
- b= abrasion rate of aggregate

When bond between aggregate and cement has deteriorated under freeze thaw action

$$ABR = \frac{1}{\left(1-\sum a_i\right)^b}$$

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So, a is the volume of aggregate proportion of radius r. Now, you see this is in this 1 r i there is a same going from n to 1. So, Sa is the you know volume proportion of aggregate of size r larger the size it would depend upon the size larger. And some total for all sizes should be taken into account b is related to strands n is a number of ice impacts subscript s. And l I denotes impact during sheet movement and during loosening of a aggregate. So first is a sheet movement is this first one.

You know s and you know S in movement in kilometer n S and n l ns stands for number of heat during the initial pace. And S stands for later on for loosening, after loosening of the aggregate, S is the kilometer movement of the ice, b is an abrasion rate of aggregate and ABR is given by this formula. When bond between aggregate and cement has disintegrated under freeze thaw action ABR could be one part. This was the earlier formula. And this is the case when bond has cement and a aggregate has deteriorated under freeze thaw action already. So, that means previous one was before so there is no freeze thaw action. But, once the freeze thaw action was occurred this depth of aggression is given by this.

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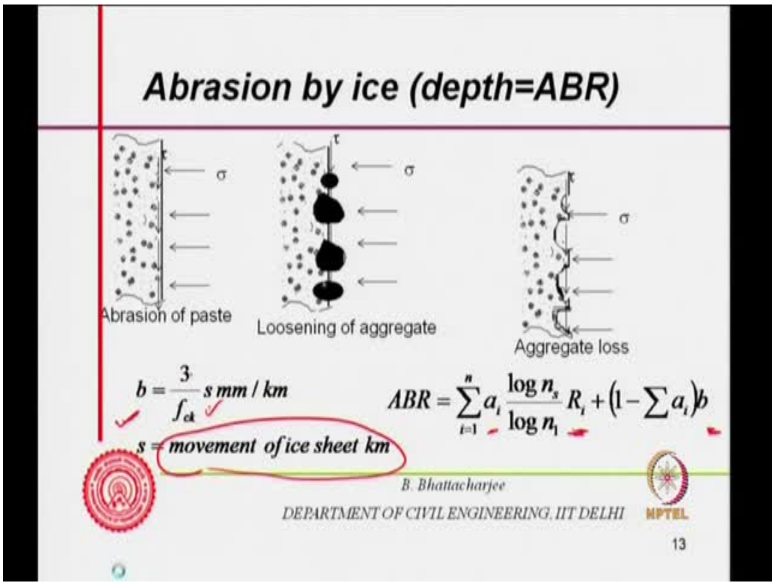

Abrasion by ice (depth=ABR)

$b = \frac{3}{f_{ck}} s \ mm/km$

s = movement of ice sheet km

$$ABR = \sum_{i=1}^{n} a_i \frac{\log n_s}{\log n_l} R_i + \left(1 - \sum a_i\right) b$$

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You know this equation which is more simple a is stands for the aggregate of size. volume proportion of the aggregate of size I x size, and b is of course, strength one over strength you know 3 divided by 3 point three divided by strength. So, is an empirical formula into S stands for movement of the ice sheet, so three by f c k into s millimeter per kilometer. So, movement of ice in kilometer, so that what it is?

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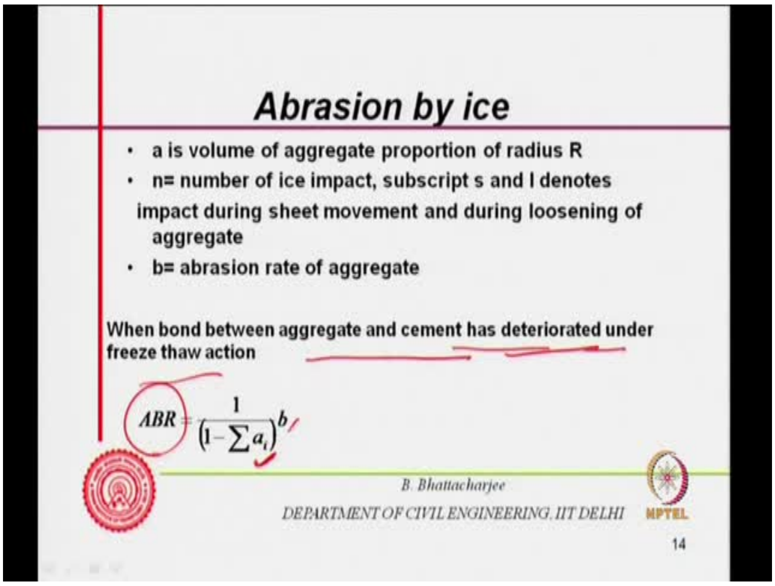

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$$ABR = \frac{1}{\left(1 - \sum a_i\right)} b$$

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So, there is there is an empirical formula again gives you abrasion by ice. Now, what is the ways what are the ways actually. We know what are the ways actually we protect against this kind of scenario. We have seen one is a low water cement ratio, the distends should be good higher the strength. All this cases of frost action, aggression by ice etcetera or any leaching even in marine environment and this would be less.

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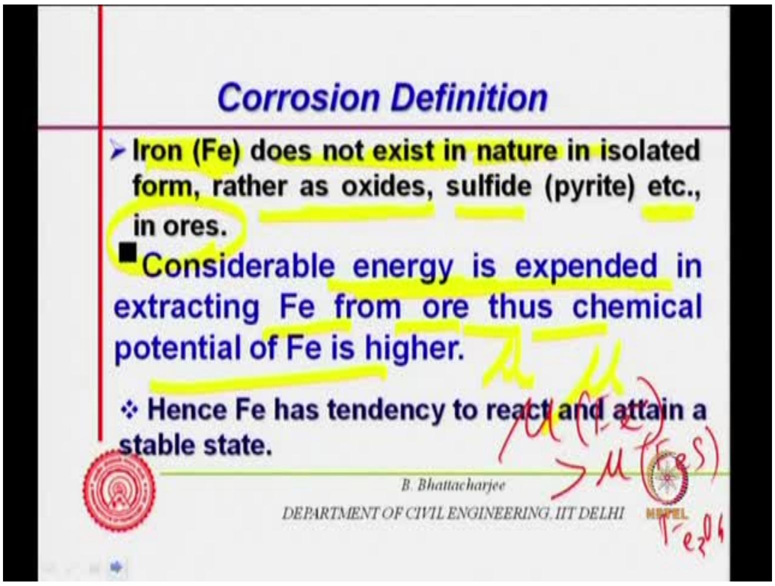

Corrosion Definition

- Iron (Fe) does not exist in nature in isolated form, rather as oxides, sulfide (pyrite) etc., in ores.

■ Considerable energy is expended in extracting Fe from ore thus chemical potential of Fe is higher.

❖ Hence Fe has tendency to react and attain a stable state.

$\mu \quad \mu$

$\mu(Fe) > \mu(FeS)$

Fe_2O_4

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So, one is the strength, in case of frost action it is air entrainment, if you have air entrainment this will pop up better. And curing condition age etcetera so the factors you have seen so protection should be low water cement ratio, air entrainment. Now, air entrainment reduces a strength a little bit. Because, you are introducing new force that will gives us strength somewhat. Essentially air entrainment air entertaining admixtures will define when you talked of you know admixtures. So, air entertaining admixtures can be added but they will have small extent. You know slight reduction in the strength as well. So that is the protection against frost section, high water cement ratio, good curing as well as air entertaining air entrain. Now, let’s look into the introduced corrosion one of the major problem the most common problem is the corrosion of rebar, rebar corrosion is one of the major problem, in r c c and even in p p s c p structure concrete corrosion is the major problem.

you know worldwide corrosion is a big problem for metals, lot of loss or money goes in repair due to corrosion. So, let’s define corrosion first of all we must understand, iron like we talked of concrete of the day, which are that you know f e does not exist in nature in isolated form, rather it exist as oxide, sulfide, etcetera and in ores, so in ores minerals in minute and extracted. So, the minerals in which iron is contained it exist in oxides, sulfide, etcetera. Therefore, iron is not a natural material, now how do I get iron out of it, I extend accounts considerable energy in extracting f e from ore, thus mu chemical potential that the other due we talked about, mu you know the chemical potential we talked about mu of f e will be higher than f e s because you have given a lot of energy.

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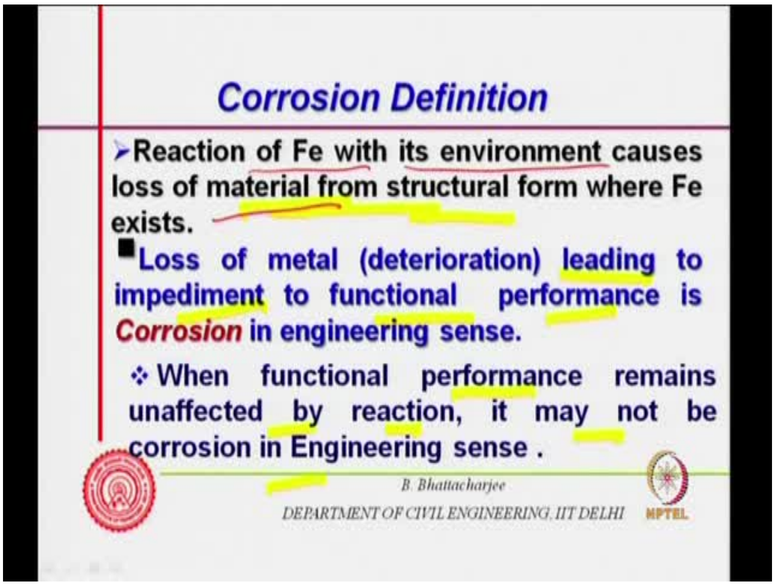

Corrosion Definition

- Reaction of Fe with its environment causes loss of material from structural form where Fe exists.
  - Loss of metal (deterioration) leading to impediment to functional performance is *Corrosion* in engineering sense.
    - When functional performance remains unaffected by reaction, it may not be corrosion in Engineering sense .

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So, mu of f e would be definitely greater than mu of you know Fe s or Fe o Fe 3 o 4 etcetera magnetite, hematite. Whatever you call it so actually given energy so therefore, it will have an tendency to come to a natural state. Hence, Fe has a tendency, to react and attain a stable state. Therefore, it has a tendency thermodynamic tendency because you have its potential chemical potential is higher. F reaction of Fe with its environment causes loss of material from structural from where f e exists. For example, you have a, structural steel corrosion, which cause reduction from the steel member or in case of enforcement.

They to loss of material but then loss of material might manifest itself in different manner in case of enforce concrete. And in structural system so enforce concrete it might manifest itself by kind of expansion will come to that later on. So, but loss of Fe with its environment causes loss of the material, you know it causes loss of the material from the structural for example, reinforcement might lose this material, and if this loss of material metal which we are calling as deterioration of the metal, if it leads to impediment of functional performance. That is not able to do the functional performance any more, that is corrosion. So, therefore, functional performance is important a little bit of loss of metal. If does not create any problem as far as my functional performance is concerned; I would not call it corrosion in engineering times. So, when functional performance remains and effected by reaction it may not be corrosion in engineering sense.

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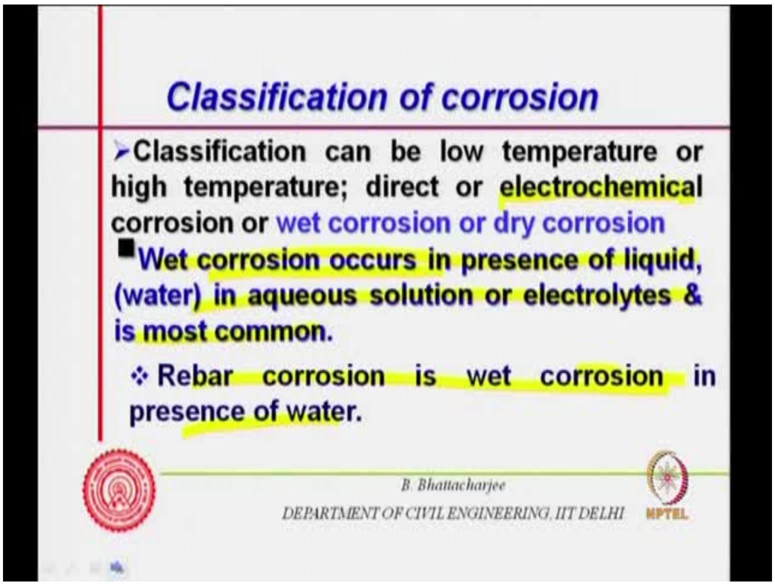

Classification of corrosion

- Classification can be low temperature or high temperature; direct or electrochemical corrosion or wet corrosion or dry corrosion
  - Wet corrosion occurs in presence of liquid, (water) in aqueous solution or electrolytes & is most common.
    - Rebar corrosion is wet corrosion in presence of water.

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Some loss very loss, little loss rate of loss very loss small, slow loss. If that is occurring I may not call it really a corrosion process, Corrosion process is important. When there is a loss of there is a loss in the, you know loss in the functional performance. So that is how we define corrosion process, and if we classify the corrosion, classification can be low temperature or high temperature. You know corrosion is generally referred to metal but then corrosion also exists for many other items even might find some book of corrosion of concrete. So, although this is basically deterioration we are talking about. But, here we are specifically we are mentioning about metal or rather reinforcement or rebar. We are looking at rebar corrosion. So, classification of corrosion in metal can be low temperature corrosion. Or high temperature corrosion, or you can classify in terms of direct or electro chemical corrosion.

Some may be simply oxidized. For example, there is a hot iron high temperature corrosion we put in oxygen. Just you know blow oxygen over high temperature at high temperature it might get oxidize. So, high temperature corrosion and it is a direct corrosion but otherwise there can be corrosion which is electrochemical corrosion. But, a better way to classify corrosion will be wet corrosion and dry corrosion. So, direct corrosion wet dry corrosion using may be direct corrosion. But, wet corrosion is largely electrochemical in nature, it is electrochemical in nature. And occurs in presence of liquid, quite often it is bottom in aqueous solution Or electrolytes in presence of electrolytes and this is the most common. So, wet corrosion occurs in presence of liquid in aqueous solution or electrolytes in presence of common and rebar corrosion is wet corrosion in presence of water.

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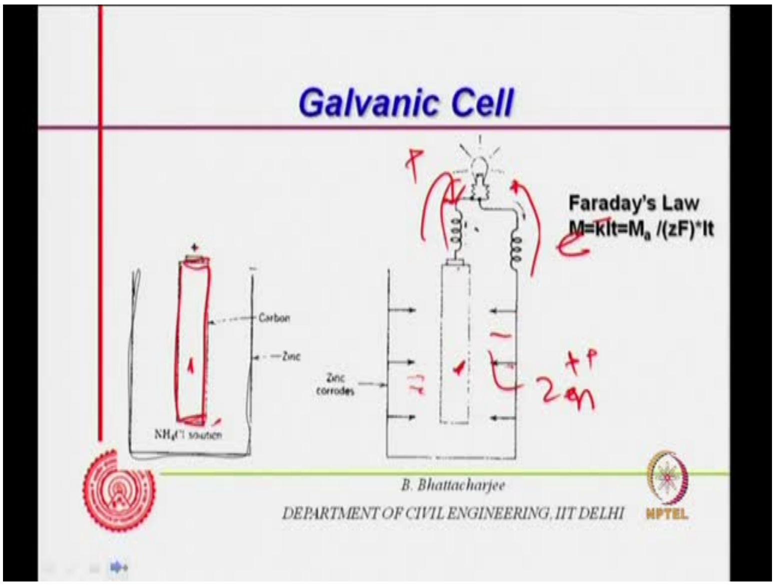

Galvanic Cell

Faraday's Law

$M=kIt=M_a/(zF)*It$

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Because, enforcement is not subjected to high temperature most of them, because of a cover concrete, even in case of fire it takes time for heat to reach their. And oxidation is the secondary aspects that not but within the enforcement. When water penetrates electro chemical corrosion can occurs. So, therefore, rebar corrosion is gradually wet corrosion and electro chemical corrosion. So, it is largely wet and electrochemical corrosion right largely wet an electro chemical corrosion. The two understand corrosion you might understand, What is a galvanic cell? You know we are familiar with battery. So, this is my zinc cell dry cell and this is my graphite or carbon and other electrode.

So, there are two electrodes, carbon and this is zinc. Now, if I connect a battery this is positive terminal and this is negative terminal. So, if I connect a battery through this, what happens is light glows. And we know this is phenomena is electrolysis essentially ammonium chloride solution is here could be if it is ammonium chloride molten, fuse form. Or whatever it could be there what happens is zinc iron actually moves out of it, zinc iron moves out of it right. And basically electron moves in this direction electron moves along this direction. So my positive current movement is along this direction positive current direction is along this direction. So, zinc iron moves along this direction and electron moves along this direction.

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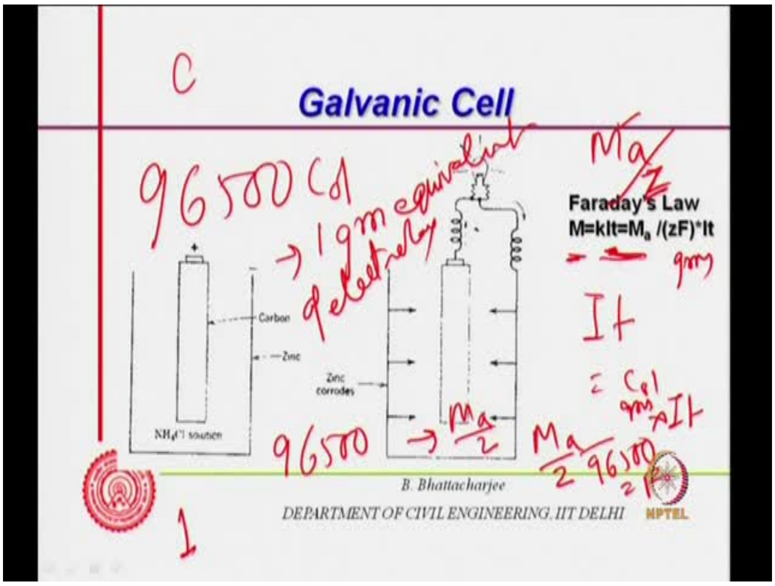

Galvanic Cell

Faraday's Law

$M=kIt=M_a/(zF)*It$

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So, my positive iron for current movement is along this direction. So, this is my positive electrode, so this is my cathode. And this is my anode, that is a galvanic cell we know that you know battery we use all of them. So, whenever we connect a kind of load to a battery. And this is governed by the you know the zinc that will get dissolved the amount of zinc that will get dissolved is governed by faradays law, which says that mass of the metal dissolved is proportional to current into time or the charge I into t thus colon. You know so that, much charge it will proportional to charge. Now, this constant it can be written as you know in fact it can be stated in another manner you need 96500 colon right or faradays constant.

So, 996500 colon is required to deposit one gram equivalent, of electrolyte. So, if the metals atomic weight is m a it is balance c or electrons that it can lose is z, 2 electron it can lose. So, therefore, it is equivalent gram equivalent will be molecular weight express in gram divided by z. So, 96500 colon will actually deposit, you know this much colon will deposit m a by z. So, 1 colon will deposit m a by z into 96500 which is you know grams that faradays constant and it colon will deposit that many grams so this is f faradays constant.

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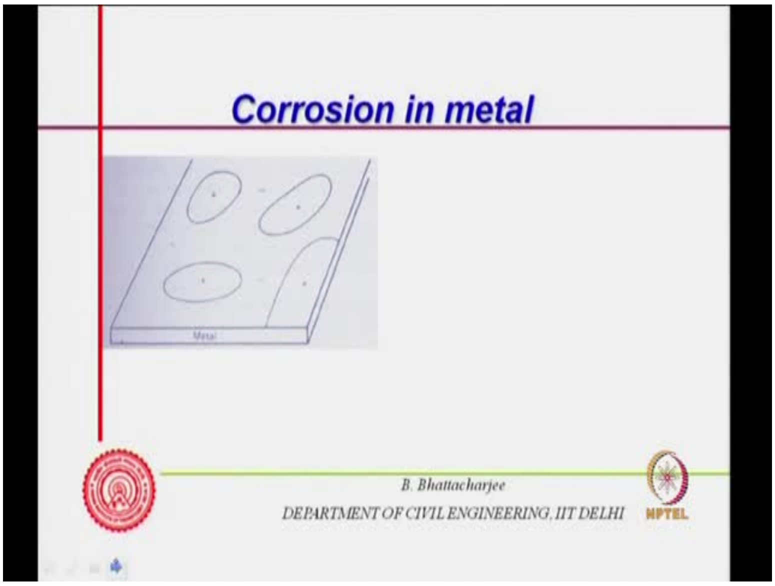

Corrosion in metal

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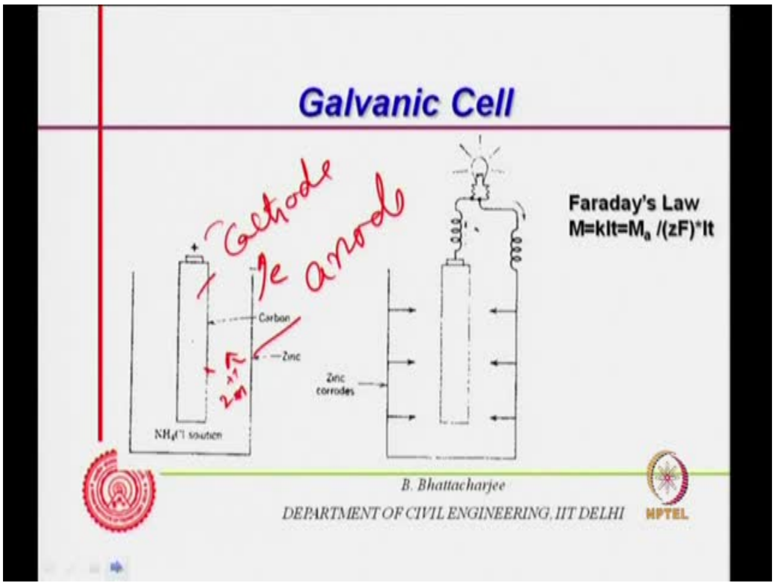

Galvanic Cell

Faraday's Law

$M=kIt=M_a/(zF)*It$

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So m a by you know this is given by this is a faradays law. The mass of metal deposited or metal dissolved zinc would whatever metal is proportional to the charge your passing through or I into t and is given ma divided by z f into It.

So, that is a galvanic cell when you have two separate electrodes here. So that is called a galvanic cell right from where you can derive current. A corrosion cell is formed in the same metal anodes and cathodes are formed. And if you see this you have anode, and you have cathode. From anode metal moves along this direction zinc iron was moving along this direction zinc iron was moving along this direction. And electron was moving along this direction.

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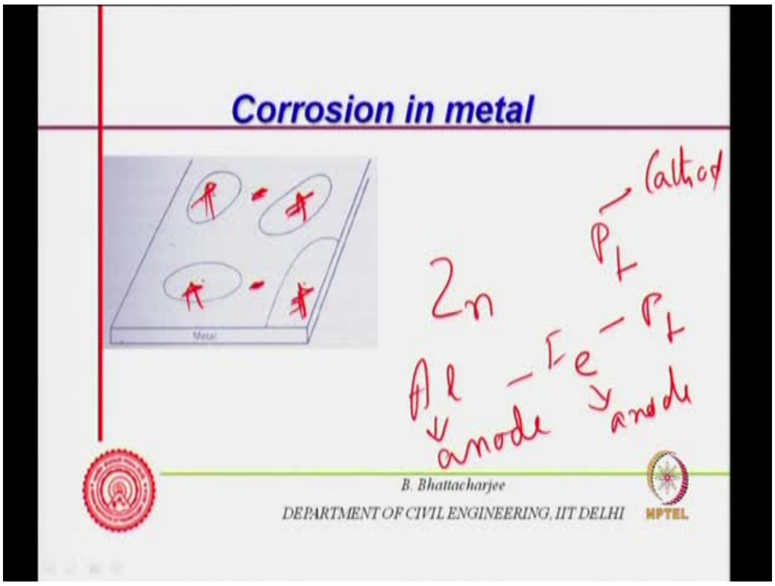

Corrosion in metal

Cathod

Pt

Zn

Al – Fe – Pt

anode

anode

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And at that cathode you know zinc iron was reaching there, and electron was you know electron was passing in this manner. So, at anode actually metal dissolution occurs and at cathode of course, other cathodic reaction would occur. So, you can have some negative anode and cathode formation in the metal itself. For example, this is positive, this is positive this is positive. So, two electrodes itself might formed in the metal itself depending upon composition, because that means variation in composition and all metal for example. If I connect zinc with platinum zinc and platinum, obviously this will always be cathode, aluminum with iron. This will be anode, where as iron with platinum this will be anode.

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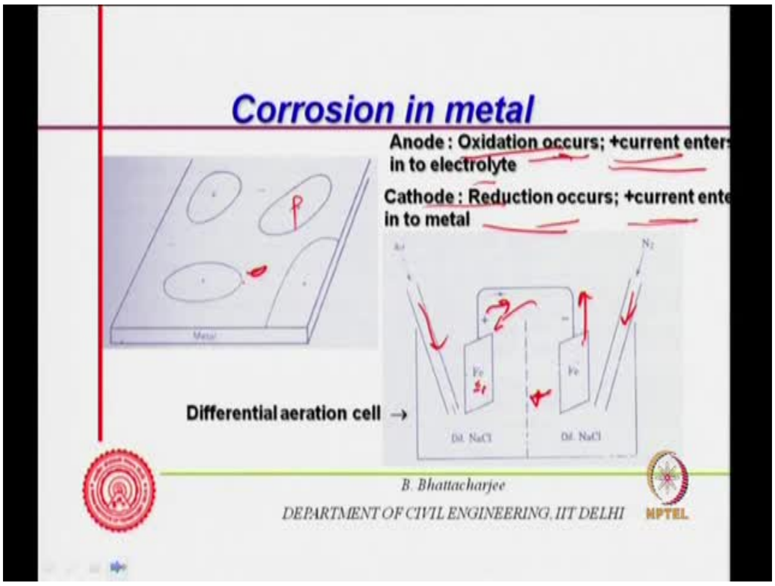

Corrosion in metal

Anode : Oxidation occurs; +current enter in to electrolyte

Cathode : Reduction occurs; +current ente in to metal

Differential aeration cell →

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So, it depends upon the tendency of the metal to lose electron, and this also depends upon its composition metal or alloy, it could be right, how easily it can lose. So this is this will discuss sometime later on. So, ions you know positive cathodes and anodes can form in the same metal itself. So, when you are looking at wet corrosion or equals corrosion positive in its electrochemical. And at anode and cathode can form in the same metal itself because its composition will differ from time to time. And also the concentration of the electrolyte outside may differ. So, all this factor put together you cannot have a identical kind of a metal. Or alloy suppose in you consider a rebar it will not be exactly same throughout. So, some portion will be higher tendency to lose electron some portion will not be. Where it will have tendency to lose electron that will act like an anode other places it may look it may you know. So, at anode actually oxidation occurs.

And current enter into electrolyte, like I said zinc at cathode reduction occurs current enter into the metal right current into the enter into the metal. So, positive ion will enter into the electrolyte, it at cathode positive ion will enter into the metal itself. So, here the difference is corrosion cell you have both anode and cathode in the same metal. Even in same Fe. If you see the outside concentration effect as I am saying the metal you know composition may not be exactly same in this negative zone. And positive zone, but suppose in I pass in the same dilute sodium chloride ion to ion electrodes are there I pass l here. And I pass nitrogen here, see not here oxygen, so you will find that actually this will act like a you know here, it will act like an anode. Where you know and this other place it will act like a so positive ion moves out of this one right.

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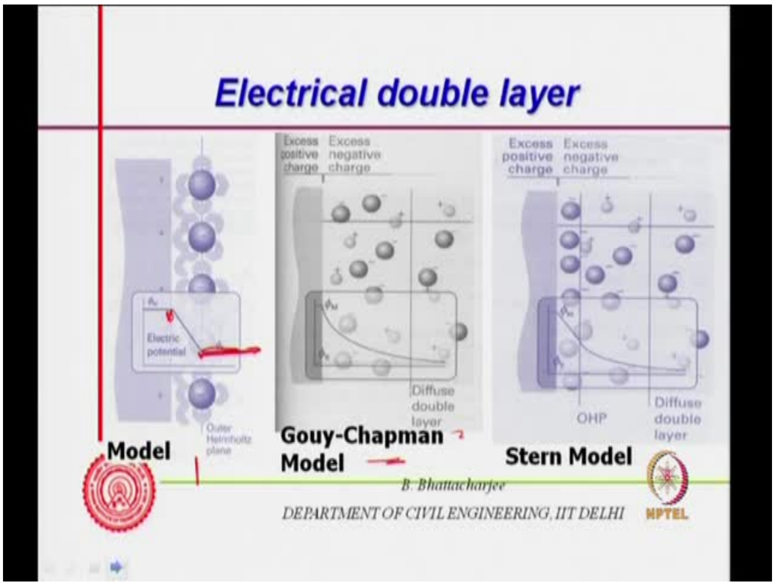

Electrical double layer

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In other words electron moves in this direction so this is acting as anode. And this is acting as cathode, so this is acting as anode, where this nitrogen I pass will act as anode compare to this 1. So, it also depends upon concentration of then you know concentration of the metal in the solution. So, this is nitrogenated I have pass nitrogen from outside so that oxygen is given out here I pass oxygen, and one of them we have same material will act like anode and cathode. So, two issues, one composition of the metals are not same even concentration of the electrolyte may not be same. And therefore, anode and cathode formation can take place within the metal itself. And that forms a corrosion cell. So, differential aeration cell as we call it so it forms a corrosion cell and a at the anode or cathode at then you know there is there is a metal.

There is an electrical double layer, so this (( )) model, which is been later on so the charge in a, if you see the potential there is a double layer exists. And potential here and in the bulk electrolyte there is a difference, initially it was considered as linear levering. And the point where it becomes potential doesn't change anymore that's called outer (( )) pain plain. That then there is a defused layer then consumed conceived called Gouy Chapman model. And then you have got stern mo stern model there is a diffused layer which is extending and then there is a constant.

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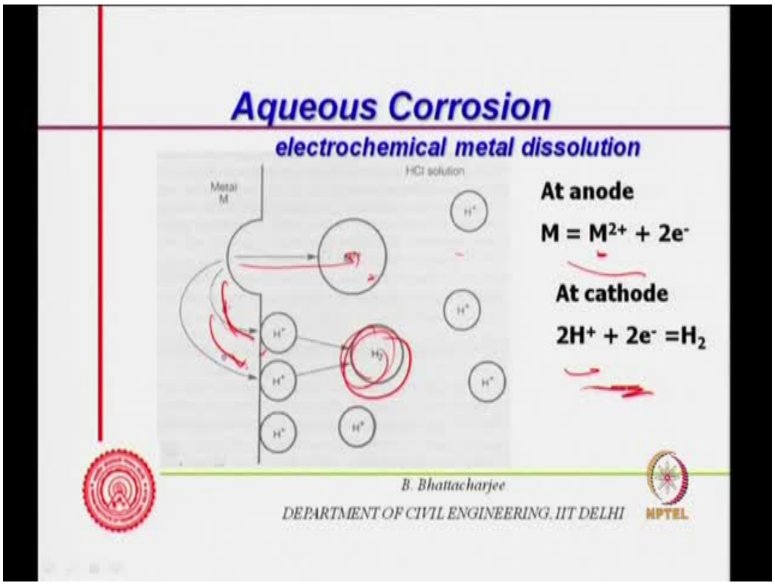

Aqueous Corrosion

electrochemical metal dissolution

At anode

$M = M^{2+} + 2e^-$

At cathode

$2H^+ + 2e^- = H_2$

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So, basically electrical double layer formation that occur in the metal. Well I think will not go into details of this at the moment we might come back or discuss this sometime later on. So, basically, at the anode metal will come out of this. And metal will come out and at that cathode actually hydrogen reaction can occur it’s an example not necessary.

Always hydrogen reaction will occur it would depend upon the composition of the electrolyte itself. So, for example, here water is there and reaction of water with oxygen etcetera if it liberate out hydrogen, at the cathode. Then two hydrogen can form hydrogen molecule in let us say metal in a HCI solution. So, this could be one of the cases where hydrogen evolution is actually occurring right so but metal comes out. So, here the other reaction, so at the cathode actually h two generate and at the anode metal will go on. So, that shows and the electron will move like this that again show a corrosion cell likewise corrosion cell. So, electrochemical metal dissolution that is what it shows. So, at anode metal gets dissolved and it loses it becomes iron loses to electron moves along this direction. At cathode to hydrogen accepts electron. But, this is not the all the common reaction in some cases this occurs in enforcement.

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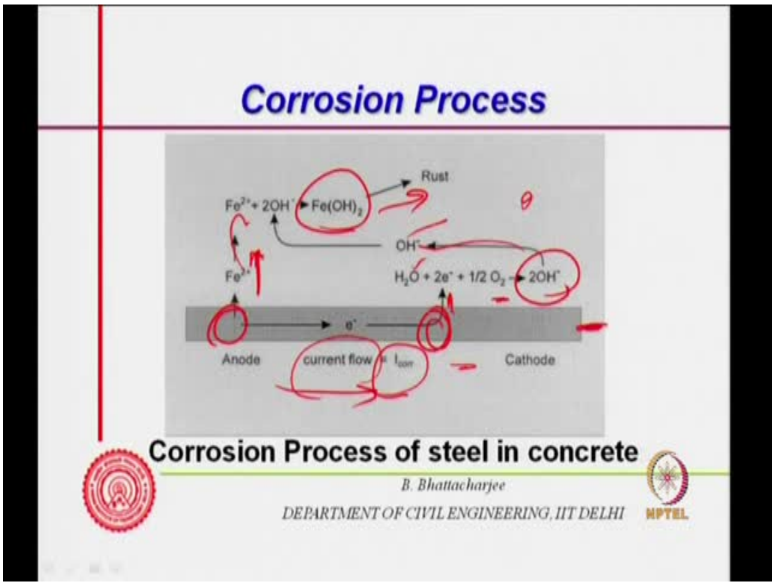

Corrosion Process

Corrosion Process of steel in concrete

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This is not very common but except in certain cases we shall see that later. So, in rebar corrosion if this is your enforcement bar. There will be anode somewhere there will be cathode somewhere and at anode iron will dissolve. I mean got into the solution Fe 2 plus, electron will move along this direction. And the current flow rate if I call it density. As I corr. and at cathode actually this electron will come out react with water and oxygen to form hydroxyl iron. This hydroxyl iron can further reacts with this Fe to from Fe OH 2 which may not be, which is usually not stable and can lead to rust formation depending upon the situation or you know environmental.

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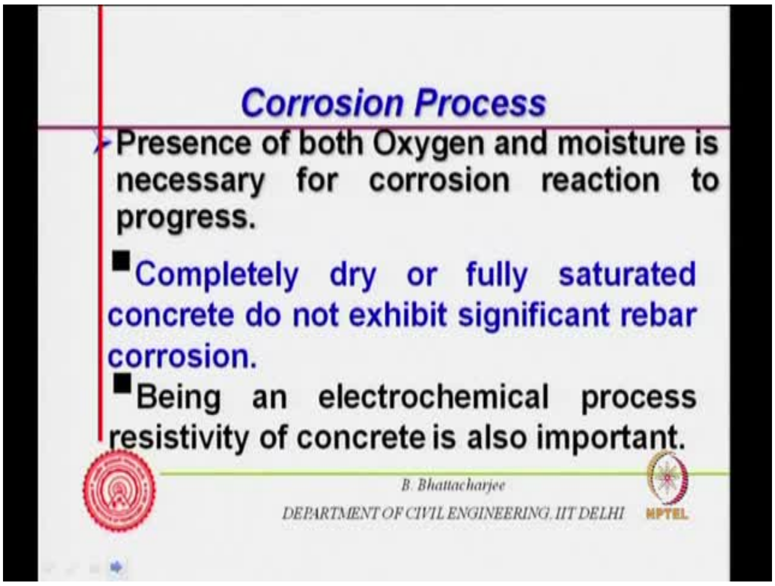

Corrosion Process

- Presence of both Oxygen and moisture is necessary for corrosion reaction to progress.
  - Completely dry or fully saturated concrete do not exhibit significant rebar corrosion.
  - Being an electrochemical process resistivity of concrete is also important.

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Let us say condition of the electrolyte itself. So what forms what kind of rust forms will depend upon the environmental you know electrolyte condition. Presence of oxygen and moister therefore, is necessary for corrosion reaction to progress and rebar completely dry or fully saturated concrete do not exhibit significant rebar corrosion, being. And electrochemical process concrete resistivity will also play an important role and will see this later on, will come back to corrosion again.

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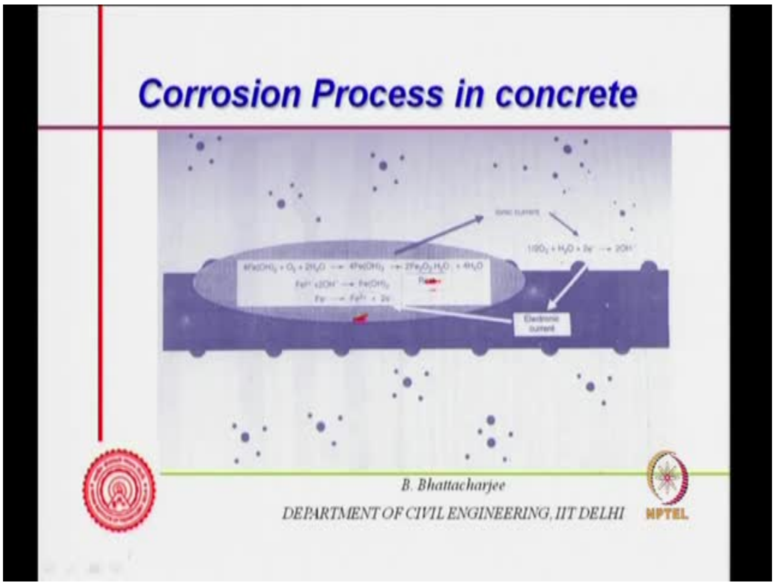

Corrosion Process in concrete

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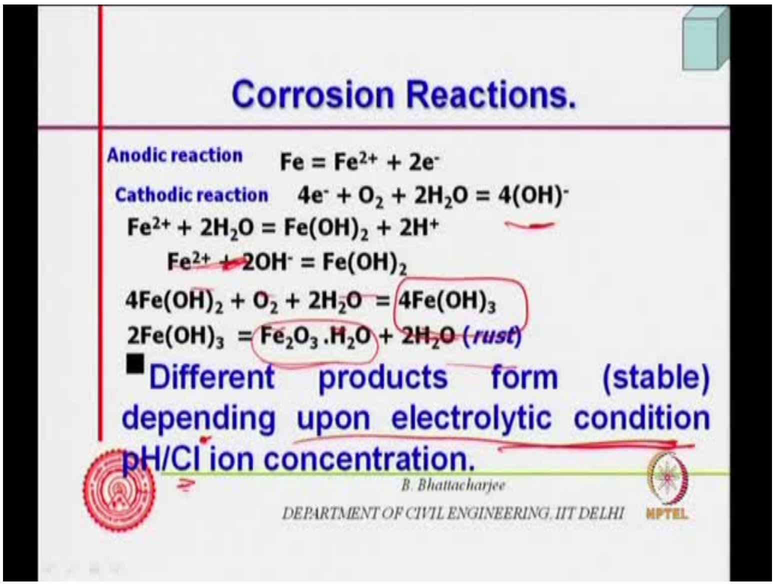

Corrosion Reactions.

Anodic reaction $Fe = Fe^{2+} + 2e^-$

Cathodic reaction $4e^- + O_2 + 2H_2O = 4(OH)^-$

$Fe^{2+} + 2H_2O = Fe(OH)_2 + 2H^+$

$Fe^{2+} + 2OH^- = Fe(OH)_2$

$4Fe(OH)_2 + O_2 + 2H_2O = 4Fe(OH)_3$

$2Fe(OH)_3 = Fe_2O_3.H_2O + 2H_2O$ (*rust*)

- Different products form (stable) depending upon electrolytic condition pH/Cl ion concentration.

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So this is again shows the corrosion process in concrete. But, the reaction shown are different reaction actually hydroxyl iron then iron. And they together might form f e two o three but may form something else. Also let us see the next reaction, anodic reaction is common cathodic reaction either could be this is the, and this may react with. You know the Fe may itself react with water forming to hydrogen.

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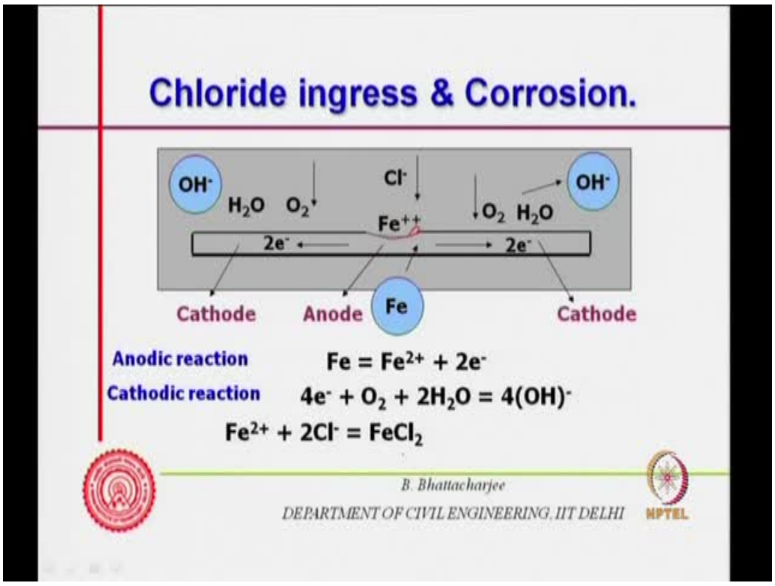

Chloride ingress & Corrosion.

Anodic reaction $Fe = Fe^{2+} + 2e^-$

Cathodic reaction $4e^- + O_2 + 2H_2O = 4(OH)^-$

$Fe^{2+} + 2Cl^- = FeCl_2$

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And these two hydrogen can receive electron and form h2 or Fe can reacts with Fe o h2 or Fe o h2 can react with oxygen and water forming Fe o h3. So, what we see is there can be different reactions possible. Once there are different reactions possible Fe o h3 can break down into Ffe2 o3 Ferric oxide. And water rust. So, there are different kinds of reaction and different kinds of product are possible, so different form products form or remains stable depending upon electrolytic condition, namely ph or chloride and concentration chloride and concentration ph or chloride, and concentration when we are saying depending upon electrolytic condition. The environment electrolyte environment mainly it is ph and chloride and concentration go once this electrolytic condition. So, different products can form. Now, some products are no so dangerous, you know for example, in case of chloride there could be some sought of loss in the metal, this reaction can take place cathodic reaction could be this, and finally Fe plus can reactive this.

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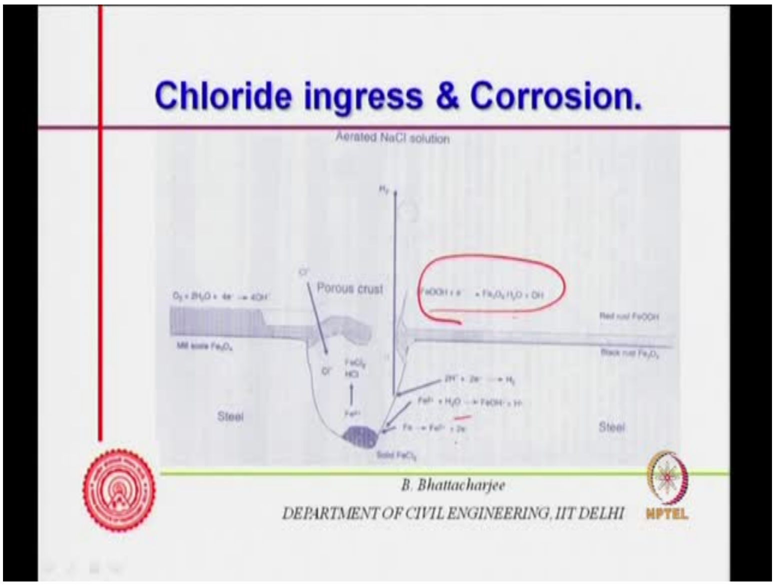

Chloride ingress & Corrosion.

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So, if it is chloride is there without chloride you have seen the reaction and this may form even the kind of pit Fe c l 2 creates some kind of rust. And finally, some sort of product like, this is formed. There are various kinds of products form we will come back to it sometime later on. But, what we are trying to say is depending upon the environment different types of product formation can take place.

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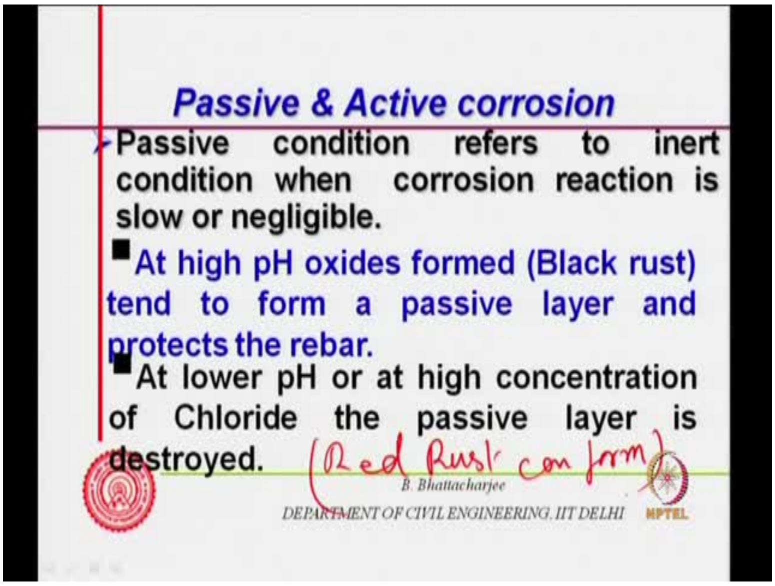

Passive & Active corrosion

- Passive condition refers to inert condition when corrosion reaction is slow or negligible.
- At high pH oxides formed (Black rust) tend to form a passive layer and protects the rebar.
- At lower pH or at high concentration of Chloride the passive layer is destroyed. (Red Rust can form)

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We, refer some condition called passive condition, were its near to inert condition when corrosion reaction is slow or negligible, at high p h oxides form Fe 2 o3 or Fe 3 or 4 tends to form a passive layer. And protects the rebar, that is why I am saying at high ph Ffe 3o 4 or some black rust as we call it some products are stable while at low ph Fe three Fe oh3 of some form we will come to that some time later..

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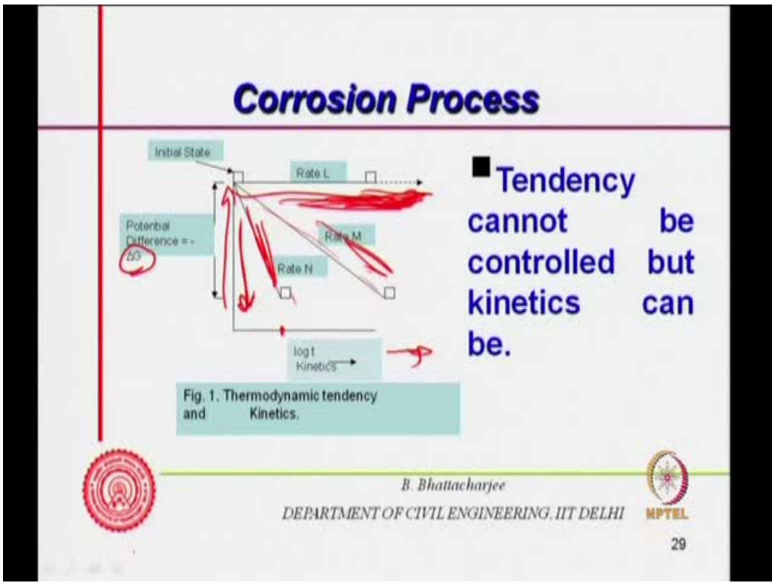

Corrosion Process

Fig. 1. Thermodynamic tendency and Kinetics.

- Tendency cannot be controlled but kinetics can be.

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On that is stable which you call as red rust. So, at lower ph high concentration of chloride passive layer get destroyed. And the stable material is and the stable material is just let me put is stable material is red rust, red rust can form. So, you see under different condition different products can form, red rust can form or black rust can form. Now, an analogy is actually the steel. If you look at it when I have produced steel I have created in delta g is a potential difference free energy I have changed. Now, if black rust is forming it may be very slow rate if red rust in forming it may be faster rate.

And if I have provided a full protection coated it may not you know the rate would because very small. So, they all cases there is a tendency of this to come out log t but the tendency is what you call potential thermodynamic tendency. But, the kinetic switch governs the rate log t versus you know the falling rate which log t rate. At which it come back to this demonstrate they might differ.

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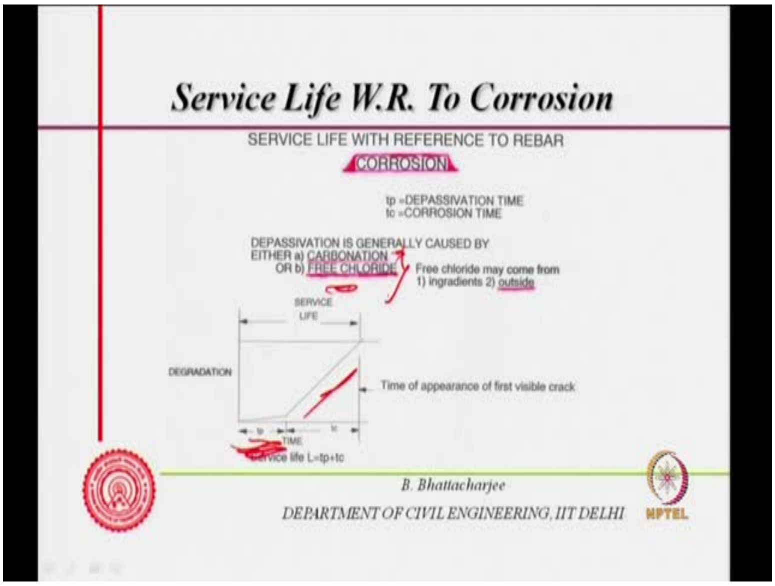

Service Life W.R. To Corrosion

SERVICE LIFE WITH REFERENCE TO REBAR CORROSION

tp =DEPASSIVATION TIME
tc =CORROSION TIME

DEPASSIVATION IS GENERALLY CAUSED BY
EITHER a) CARBONATION
OR b) FREE CHLORIDE

Free chloride may come from
1) ingradients 2) outside

Service life L=tp+tc

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So, in a passive state depending upon passive state it might because somewhere there. And with a coating complete coating protection 100 percent no water almost 0z water it might be something like this. But, in a contusive condition the rate will because higher. So rate is the function of all this and therefore, tendency cannot be controlled but kinetic be controlled. So, service life with respect to corrosion we defined is it concrete is initially is passive.

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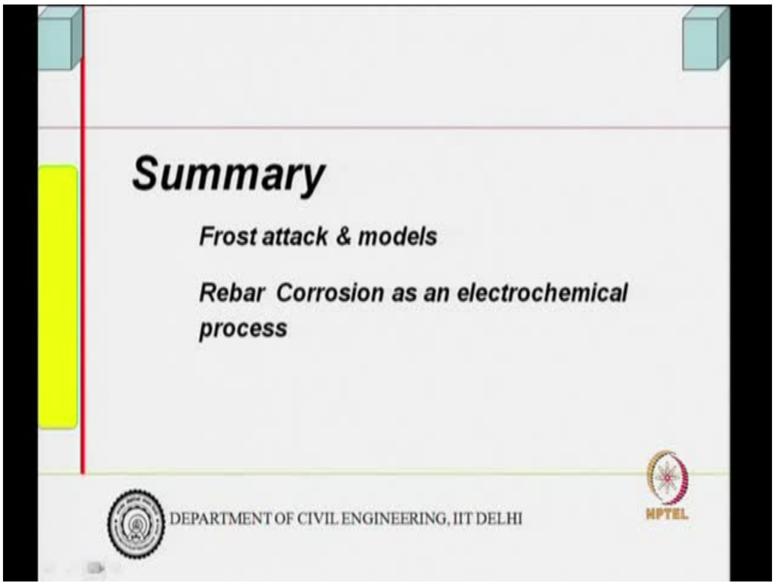

Summary

Frost attack & models

Rebar Corrosion as an electrochemical process

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But, it can loses its passivity it can lose its passivity due to p h reduction, or chloride coming in from outside. So, therefore, this we call as depassivation time, and this is the corrosion time. So the two things which causes this are carbonation and chloride. So, therefore, first we will look into carbonation and chloride. And then there in ways and their effect, and then we will look into corrosion. So, this is summary is our discussion today we will looked into frost attack and the relative models. Then, we introduced rebar corrosion and we said that normally it can be passive. But carbonation and chloride can actually be passivity.