Concrete Technology

Prof. B. Bhattacharjee
Department of Civil Engineering
Indian Institute of Technology, Delhi

Lecture - 35
Durability of Concrete: Rebar Corrosion and General Strategy

Welcome to module 8 lecture 35. This is the last lecture of this module and we will continue with durability of concrete. In this last lecture, we will look at general strategy of course, some issues related to rework corrosion which we shall be looking into.

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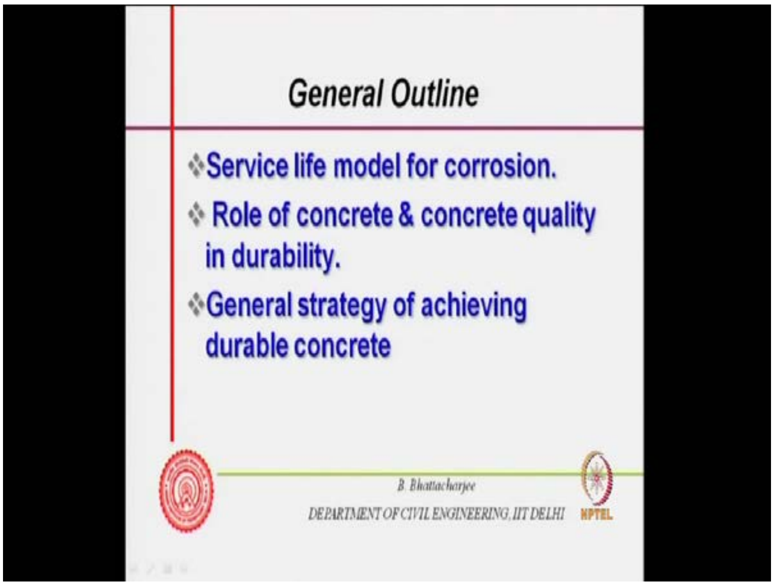

So, first we look into some of the empirical modules which are available for corrosion and then role of concrete and concrete quality in durability, general strategy of achieving durable concrete.

So, in case of corrosion the propagation period, we talked of in the service life, if we recall we talked of service life, there are 2 phase, the simplest module there is a deactivation or initiation phase followed by a propagation a period. So, today we are talking of this, you know this is related to carbonation and all that. So, we are now looking at propagation period which actually is governed by the rate of corrosion of course, which is function of environment etcetera which we have seen earlier.

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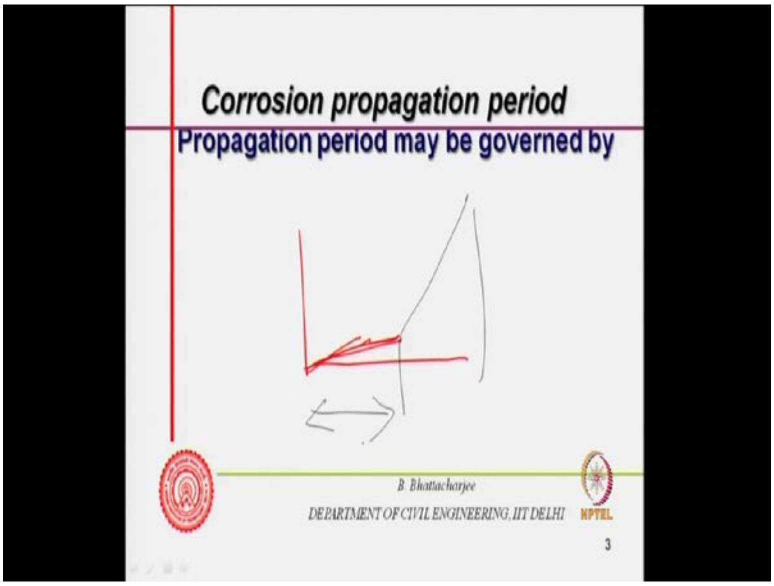

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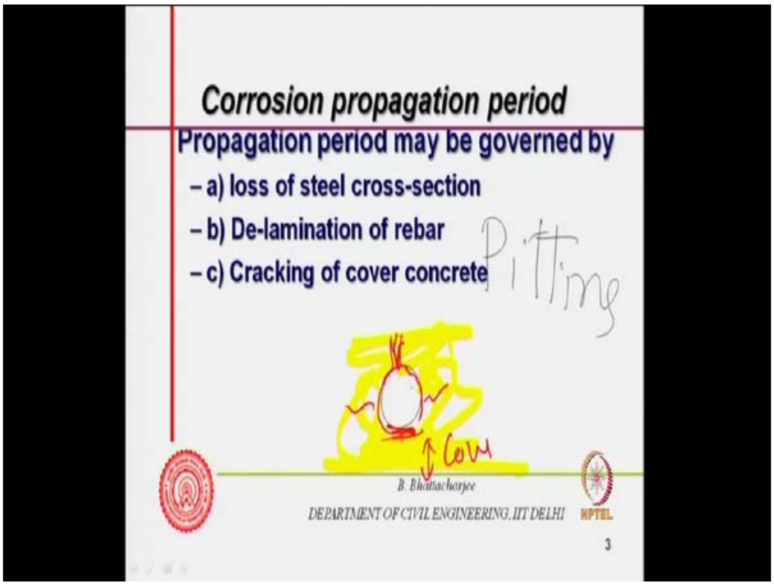

So, some fundamentals we did like look earlier but, the result of corrosion could be loss of steel cross section in some cases. I said especially, in the case of pitting. Pitting you know in case of pitting, it is a loss of steel cross section, second case could be de-lamination of the rebar that is this is your reinforcement bar and the surrounding concrete is here, surrounding concrete is here, surrounding concrete is here.

Now, let us say this is the bottom side and there is a de-lamination from the rebar. So, this is actually gets separated out, bar gets separated out at the, you know bond is lost and it eager's de-lamination so that could be a second sort of scenario and the third scenario is cracking of cover concrete. So, this is most concrete, you know it is quite common of the de-lamination occurs in case of slab, there could be cracks of this form as we have seen, earlier cracks of this form and then there could be de-lamination of the cover, if this is the cover and this you know might fall of completely. So, this could be 3 different cases and let us see what is the empirical model? Some empirical models are available for this.

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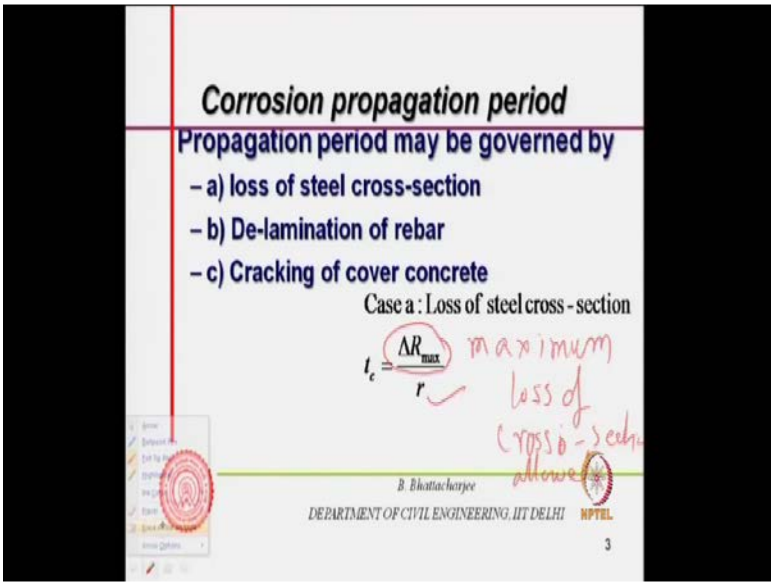

So, case a loss of steel cross section in that case, this is the rate actually and this is the maximum cross section loss allowed, you know delta R max is the maximum loss of cross section allowed, you know delta R max is the maximum loss of cross section allowed, because after that what will happen, if the material is lost significantly then, it may be able to carry the load. So, maximum loss allowed is, it will be related to maximum loss allowed.

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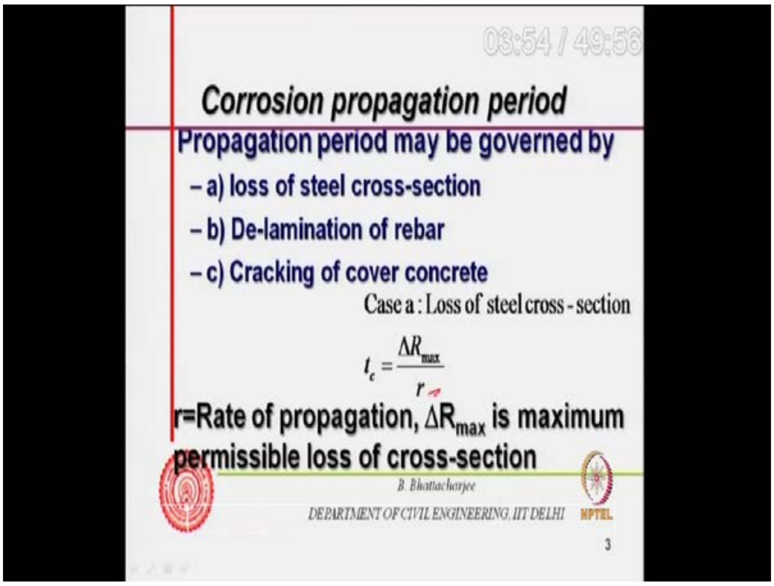

So, rate of propagation here is the maximum permissible loss of cross section. So, if I know rate in some manner and maximum loss then it is possible but, then rate must be expressed in terms of depth of penetration which I said 3.27 etcetera, a formula which we are looked into the last class all right.

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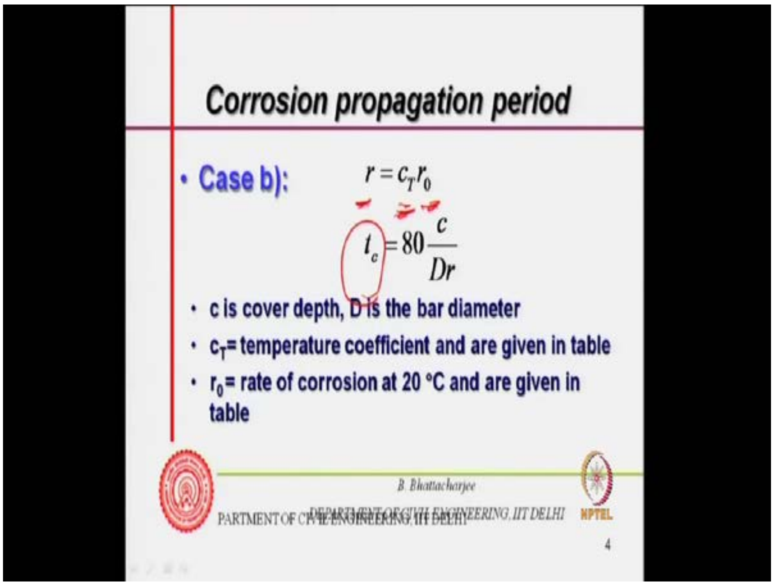

So, this is one way. Case b was related to de-lamination and in this de-lamination, the rate can be related to c T into r 0. In fact, this is empirical. So, this rate can be found out from any case, all of the 3 cases and c T is a factor for temperature we look into this, what are the values of c t? r 0 is we can say reference corrosion rate. So, at standard temperature and at any other temperature this will be given by r and this is the time of corrosion would be 80 c by D r, where D is the bar diameter and c is the cover depth. So, it is de-lamination time right and that is 80 c by D r, where c is the cover depth, D is the bar diameter. So, it is proportional to c by D, r is the rate of corrosion and same earlier also, a rate of corrosion. So, its rate of corrosion is same expressed in terms of depth of penetration.

So, these are actually this it will see this is covered by bar diameter and this is rate of again millimeter or mils per year, I mean will be micrometer per year or whatever it is. So, t c u you will get in terms of time t c of course, you will get it in time. So, 80 D, this is an empirical equation. So, c is the cover depth, d is the bar diameter, c T is the temperature coefficient and this is valid for all 3 models that the empirical, those people who have derived they have given this table for c T, r 0 if rate of corrosion at 20 degree centigrade and again given in a table.

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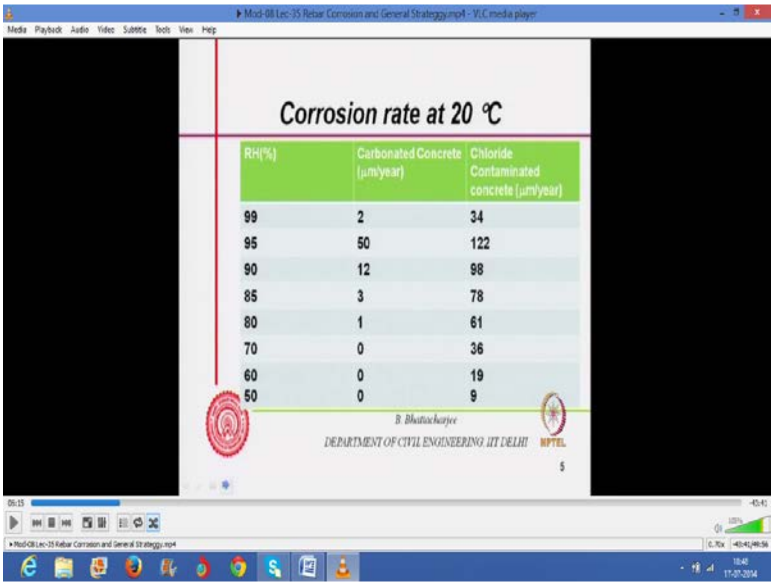

Therefore, for the kind of condition where actually experiments were done, where this empirical module is applicable, do you know you can use this formulae and first find out the r 0 which is given in the table, then if there is a temperature change rate you can determine from this and t c is the time for de-lamination given by this model. This is from this available in a book by Serja and Basketry, “Durability design of concrete”.

So, 20 degree tables, I have just reproduced some of the part of the table is given, if depending upon the relative humidity, high humidity this value is low in carbonated concrete in chloride concrete. So, r value, r 0 value for chloride concrete and carbonated concrete. Now, this is the relative humidity. This is 85, this value fairly high in micrometer per year, when relative humidity is 95 percent; it is carbonation is already occurred, carbonated concrete. This is the guidelines given for you to know the corrosion.

Now, you see if the relative humidity becomes very low, corrosion rate becomes small because corrosion requires presence of moisture as well but, while in chloride still this continues and maximum is again around 95 percent relative humidity. So, 34100 percent relative humidity within the concrete pore or in the condition that has been considered it actually reduces down so, with the relative humidity r 0 values can be obtained at 20 degree centigrade.

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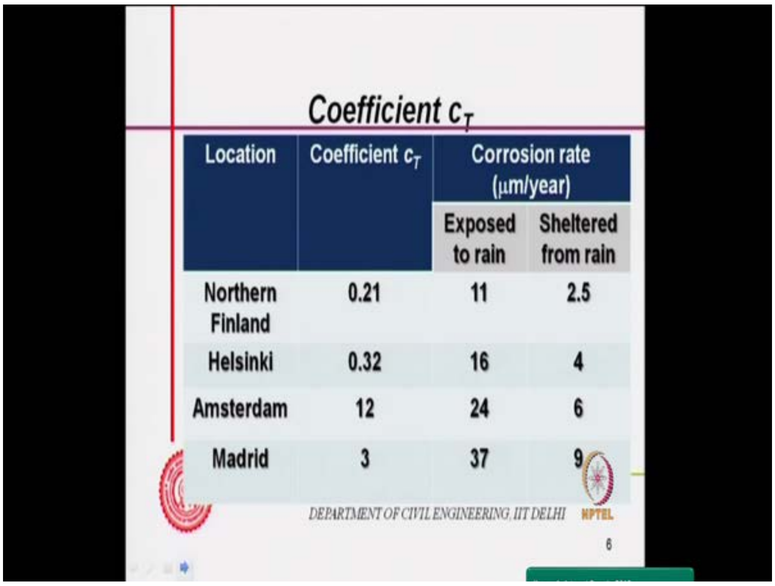

Location	Coefficient c_T	Corrosion rate (μm/year)	
		Exposed to rain	Sheltered from rain
Northern Finland	0.21	11	2.5
Helsinki	0.32	16	4
Amsterdam	12	24	6
Madrid	3	37	9

And CT values one can obtain for different locations, they have given for example, northern Finland very cold so, they have given CT coefficient 0.21 because, this will be less than 20 degree centigrade and Madrid, which is close to 20 degree Amsterdam there this is 3 and Amsterdam 12.

So, the temperature where it is depending upon the temperature these values are changing in case of sheltered or in case of expose to rain. See sheltered from rain this is the scenario exposed rain so, this is our empirical relationship but, it gives you a kind of guideline or understanding sort of you know, what do we understand from this is three cases possible one is de lamination another is you know, loss of the diameter and third is cracking of the cover concrete this three situation possible and all are dependent on r rate of corrosion which again is the function of temperature and also chloride or carbonated concrete relative humidity so, it varies with all that and varies you know varies whether it expose to rain or sheltered from rain and CT values are given here so, this is the function of temperature.

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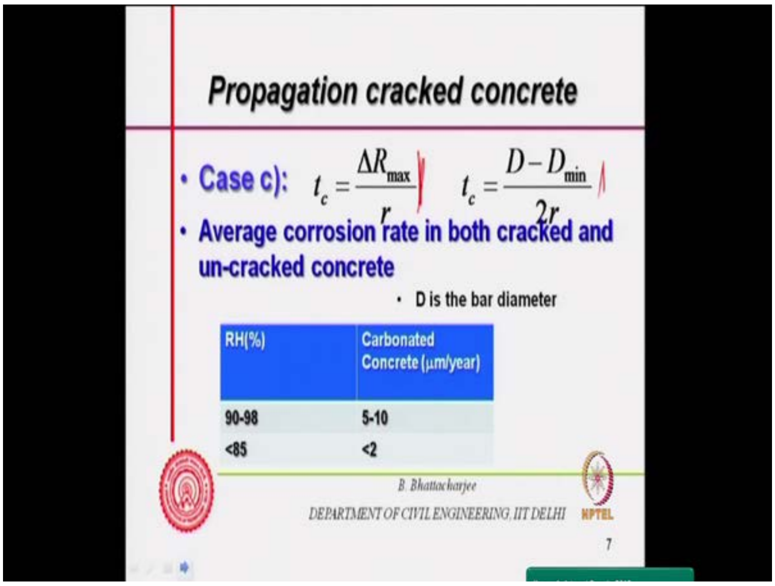

So, case c then the last one the cracking of cover concrete this is given as D minus D min divided by two r t c is d R max that is we have seen earlier now D is the bar diameter and average corrosion rate for both cracked and cracked concrete. So, this is for un- cracked concrete this is for cracked concrete D minus D minimum right divided by 2r where average corrosion rate for both cracked and un- cracked concrete.

So, t c this is given for different relative humidity carbonated concrete then you know this relative humidity carbonated concrete, this rates are given this is less than 2 and D is the bar diameter actually the minimum D that is likely to be there because, Rmax is known so this divided by 2r that will give you the time required for cracking of the cover concrete.

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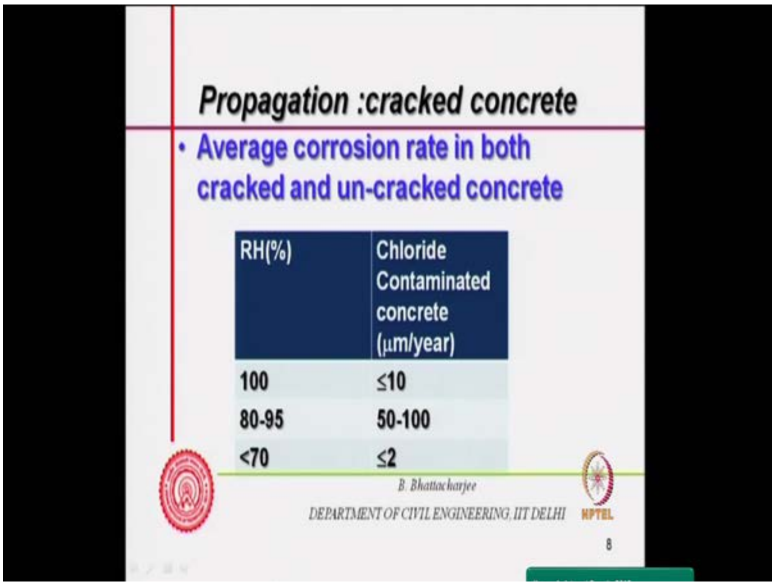

So, this three empirical equations, are given but, let us understand average corrosion rate both cracked and un-cracked concrete for relative chloride contaminated concrete this values are given average corrosion rate so, this is also given in terms of average corrosion rate in carbonated concrete, this is for chloride this is for carbonated situation average corrosion rate is given here and time is given by this formula where r you can determine from this for carbonated concrete for two cases it is shown for other cases this values are available.

So, some guidelines actually gives you right and this is with the chloride situation average corrosion rate are given for different relative to be used in this formula for cracking cracked concrete, the cracked concrete which is already cracked concrete which is already cracked.

Now, basically cracking of cover concrete is an important issue and it can be modeled earlier it was modeled considering thick and thin cylinder situation or by FEM modeling currently people are trying the properties, which are important is modulus of elasticity cover depth tensile strength bar diameter c by D ratio rate of corrosion in terms of penetration and density of rust.

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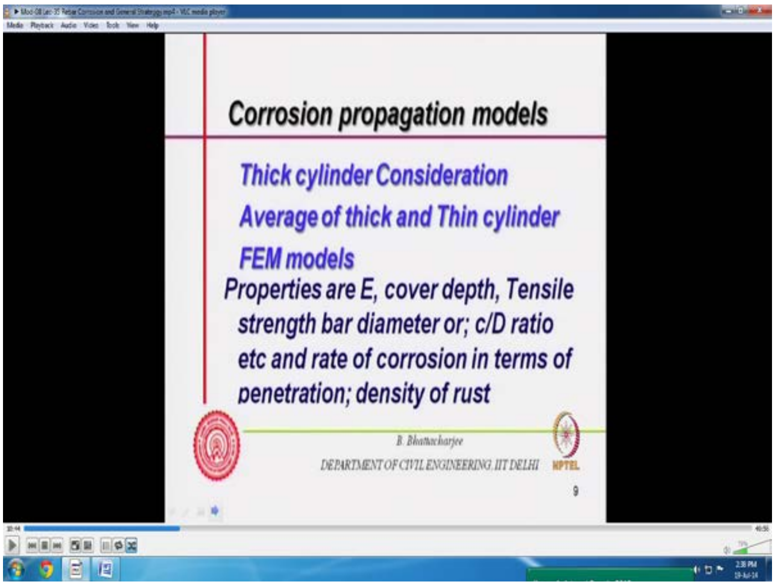

So, all these properties are required if you want to predict the time of cover concrete cracking, that is much relatively more sophisticated then what we just talked about these were empirical models while this what I am talking of right now, is empirical but based on theory of elasticity mechanical model of cracking of the cover concrete. So, if you want to estimate cracking, this is how one can model them.

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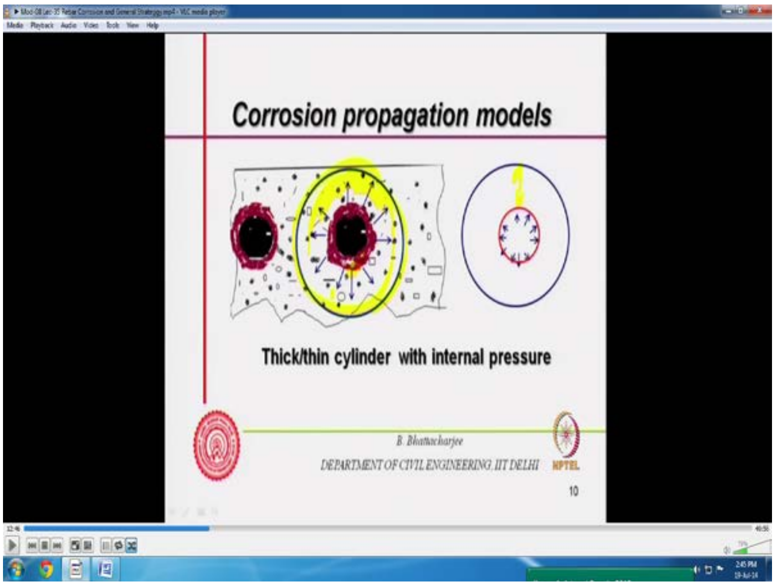

Now the phenomena is looked upon like this is your concrete and this is the rebar so, the corrosion has occurred here, the corrosion has occurred here, red colored so, it is corrosion product has formed now this will exert a kind of pressure. So, this kind we exert a kind of pressure so, those people who use cylinder theories they assume this is your cylinder but, otherwise continuum you can consider and the pressure that will be exerted outside that will cause excess strain in the zones strain as well as stresses in the zone and one can solve the problem of elasticity and find out the time cracking cover concrete.

But lot of work needs to be done here, there has been attempt verification of the models by experimental work is not easy but, thick cylinder could be assumed to be like this thick cylinder scenario, large and thin cylinder you know with this, the pressure is from inside so, the pressure is from inside there is a pressure so, we can consider this thickness being very small.

If it is a thin cylinder consideration apply those models but, one can actually do finite element modeling for the complete thing and then arrive at time but, there has been lot of uncertainties involved in such modeling materiel properties, the how much what is the kind of you know interfacial properties of the interface the porosity in the interface between the steel bar and the concrete because, some rust product will go and get accumulated there.

So, pressure will not increase also the properties of the rust product, their modulus of elasticity and several other situation whether you take it as a you know what kind of a problem you take it plain strain problem and then you take the uniform pressure, varying pressure becomes very difficult. So, you take uniform pressure in the surrounding system or take uniform strain you know deformation.

So, all this are there are complexities involved in this modeling but, this is how one can visualize this what happens and this can result in you know the taking of concrete which is defined as a service layer. So, these are the further more sophisticated theoretical modeling.

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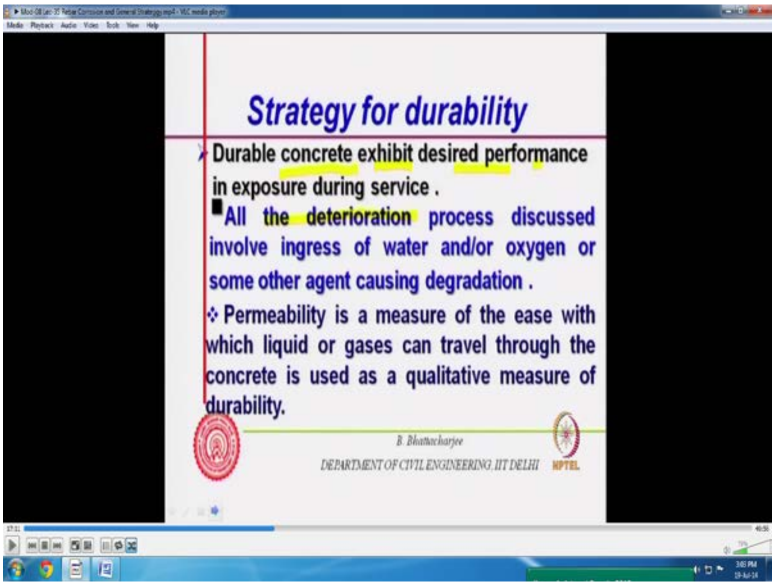

At the moment even those empirical models that I talked about earlier, would be applicable to only those specific conditions but, this gives us some understanding at least that on what factors thus this propagation period depends. So, what we see right now is a propagation period, will actually depend on the environment relative humidity chloride contaminated concrete or carbonated concrete so you know chloride concrete and carbonated concrete and what is more important loss of bar diameter or cracking of the cover concrete whether the concrete is already cracked then situation will be different.

So, all this factors that we have understood from our last couple of slides or last you know discussion that has gone. So with this I think we can close our discussion on corrosion propagation models, can look into strategy for durability and that is what we will look into.

Now strategy for durability that has been so, we have understood you know all the problems deterioration process and their details in last 4 lectures and the part of this lectures as well so, what is the strategy currently what we have understood is our understanding in terms of the physical phenomena and physical you know models for deterioration is really limited very limited.

Possibly carbonation is a function of under root time t time this is experimentally validated, many things would not have been experimentally validated many things would not be experimentally, you know could not be validated because, the long term required accelerated test quite often may not actually represents the real situations so, but we have to have strategy for durability and we had already in place over the years which is improving good lot of it is actually now prescriptive.

So, we look into the prescriptive situation of i s code but, let us say let us see what are the possible strategies and we have got to understand, you know we got in understanding of the difficulties associated with doing mathematically or quantitatively estimating the service life of concrete because, it is dependent on so, many factors environment the materials etcetera and also our lack of understanding in a complex material like concrete which is not a single compound many compounds, how it will react which compound will react under what situation all these complexities are there.

Therefore at the moment prediction of service life, is practically not even in an ascent stage also not in embryo stage because, your mathematical understanding is relatively very limited. So, we cannot you know stoichiometry of the reaction and the product formation and the mechanics of till it cracks or some way we can that is really, that is you know that is an infancy stage, embryo stage if I may put in so, but research around it will improve but, at the moment you got to have some strategy.

So therefore, let us look at the strategy durable concrete exhibits desired performance in exposure during service that is what we said, in the beginning durable concrete must exhibit desired performance in exposure during service. And all the deterioration process that we have discussed actually we have seen that they involve ingress of water or oxygen or carbon dioxide or chloride or something agent causing degradation.

So therefore, since we cannot address specific degradation phenomena what people have done earlier permeability has been considered, you know this ideas is actually borrowed from the soil because, permeability of the soil is well you know application has been well established but, one difference with the soil and the concrete would be you know permeability governs the flow through the soil.

Now, flow through the soil could be quite often, when we were dealing with geotechnical problem or otherwise or trying to look at their permeability you know it is quite often, it could be saturated situation many a time it will be saturated situation therefore, this idea was already available for the soil, this was borrowed here but for concrete remains most of the time unsaturated, you know saturated concrete is only it is a rare thing it is not very often, when we are looking because our concrete will be expose to atmosphere many other cases to wetting and drying plus zone of you know marine environment wave will come and hit so, this is this one may not be able to assume it fully saturated all the time in all the places.

So but, however since the tool was already concept was already available in soil, that was borrowed from the soil early on because permeability is the property which governs the flow of fluid or gases, through this may through porous material. So, this is the measure permeability's of measure of ease with which liquid or gases can travel through the concrete and is used as a qualitative measure of durability has been used. And still use as a qualitative measure of durability I said qualitative because, it cannot give you any quantitative information with regards to concrete service life or anything but, you can relatively compare relatively compare two concrete, more permeable concrete is be less durable than a less permeable concrete but, there are other issues we will come to them soon.

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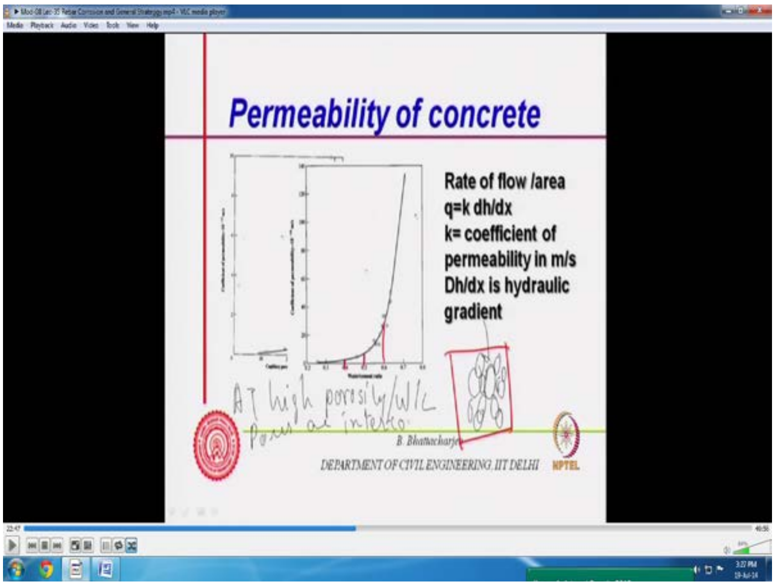

So, rate of flow a flow per unit area under steady state condition, is defined as the you know is defined as the rate of flow under steady state condition is defined as it is for unit hydraulic radiant, we call it permeability. So k is the this should be small d this should be small d this should be small d, d x you know this is d h d x D h d x is the hydraulic radiant.

So, the flow takes place because there is a hydraulic radiant existing that means if this is my specimen there is a head here delta h is the head here you know delta h is here or d h is the here and this is the x thickness so, if I maintain if it is saturated and this d h d x is constant, under this the flow through this one q is proportional to d h d x like any other flow heat flow and similar equations this is Darcy’s equation q is equals to k d h d x and this is coefficient of permeability. So, permeability is defined as that property which governs basically, flow it is something analogical to thermal conductivity or conductivity of you know conductivity thermal conductivity of similar one.

So, basically what diffusion coefficient that we talked about in case of steady condition so, this is coefficient of permeability therefore, for a given hydraulic radiant flow is proportional to k. So, more k means more flow less k means less flow, now it has been observed that k is a function of capillary porosity so, as your capillary porosity this is about 30 percent 20 percent this is about 30 percent 20 percent 30 percent 20 percent 10 percent and this is coefficient of permeability, 10 to the power minus 12 13 you know large value 10 to the power 12 or so, this is the capillary porosity increases certainly there is a maculation threshold above which it increases significantly below this values are small certainly from this point it starts increasing.

Now, why such a thing happen, well when the capillary porosity is large I mean the interconnectivity pores or pores are important but, any way before I come to this, therefore, since capillary it is related to capillary porosity in this manner it should be related to water cement ratio in this manner as well so, in the water cement ratio this is water to cement ration 0.5 here 0.6 here 0.4 here and it increases suddenly it increases so, it is a function of water cement ratio.

As the water cement ratio increases beyond 0.5 suddenly it starts increasing say exponentially increases, the reason being basically earlier you know capillary porosity being, if it is high supposing this is my material and these are my capillary pores are here, now if I have low porosity they will be isolated when the porosities are high they likely to be all interconnected. So, flow through interconnected system is likely to be more so there will be interconnected at high porosity, capillary porosity oblique water cement ratio pores becomes interconnected pores are interconnected.

So therefore, their permeability increases so that, is the percolation threshold something like 0.5 after which all pores tends to be interconnected connected and there is a tendency for permeability increase so, you can see the porosity interconnectivity of those pores this is an important issue as regard to permeability.

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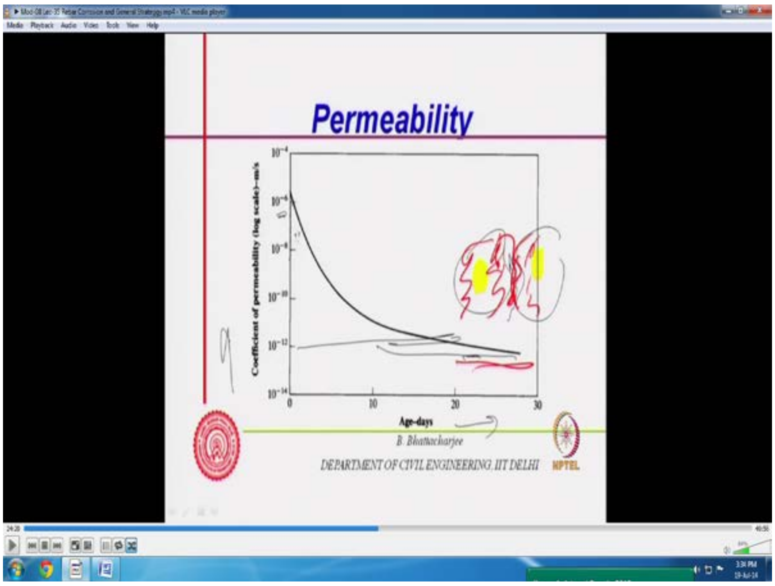

Its reduces will the age as your age in days reduces, permeability coefficient of permeability reduces here 10 to the power minus 6 log scale this is plotted in log scale but, with higher the you know it reduces so, 10 to the power minus 12 so, it is 10 to the power minus 6 so, all it goes to 10 to the power minus 12 in meter per second. So, with age it reduces and we can understand hydration, will progress capillaries will get segmented, you know capillaries which you are interconnected so, this is our if you recall this is our cement particle, this is our cement particle and this is the hydrated cement this is the hydrated cement around hydrated cement around and if you more hydrated cement around and this was the water originally this was the water originally this was the water fill space as the hydration progresses this would go and reach their capillary will get segmented.

And we talked of capillary segmentation earlier therefore, interconnectivity will reduced so, this is related to more hydration, capillary gets first total capillary will reduce and segmentation will increase they will be less interconnected therefore, you know permeability tends to reduce.

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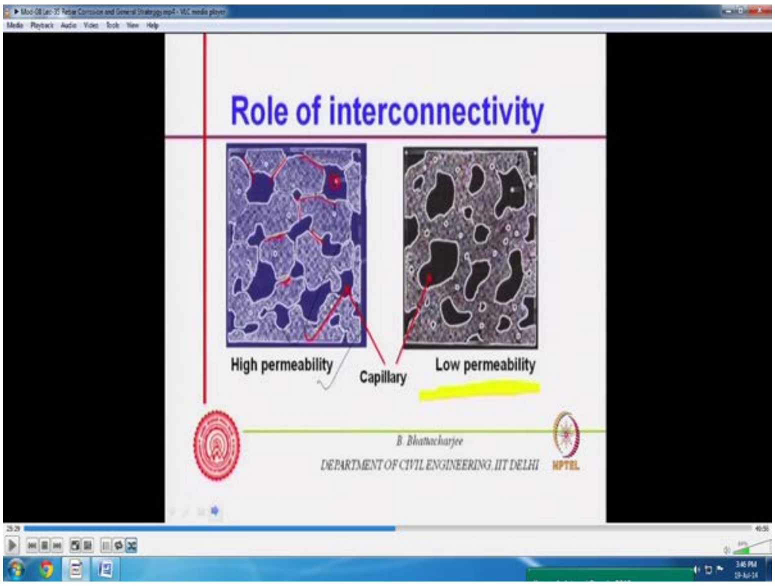

So, what we have seen so far permeability is a function of porosity water cement ratio, obviously capillary porosity and with age it reduces, it is also function of age because of the segmentation, with this we can understand from this diagram for example, consider this one this is the pores are all interconnected through this ones, they are through this one's interconnected you know capillary pores are all interconnected these are your capillary pores they are interconnected.

So, this if I have low porosity system, you know that is low permeability system, there disconnected, there is no interconnection between these two now, this interconnections are lost therefore, this will be a low permeability system compare to this one this one which is high permeability system. So, compare to this one this is high permeability system, it should be low permeability system, this will be a low permeability system.

So, you can see capillaries there the segmented capillaries and un-segmented capillaries therefore, the curing must also play a role because, if you do not do the curing capillaries will not be segmented I mentioned this, when we are talking of curing. So, capillaries will not be segmented if we do not do, you know minimum curing has to be done related to capillary segmentation. So, this gives us certain understanding related to permeability.

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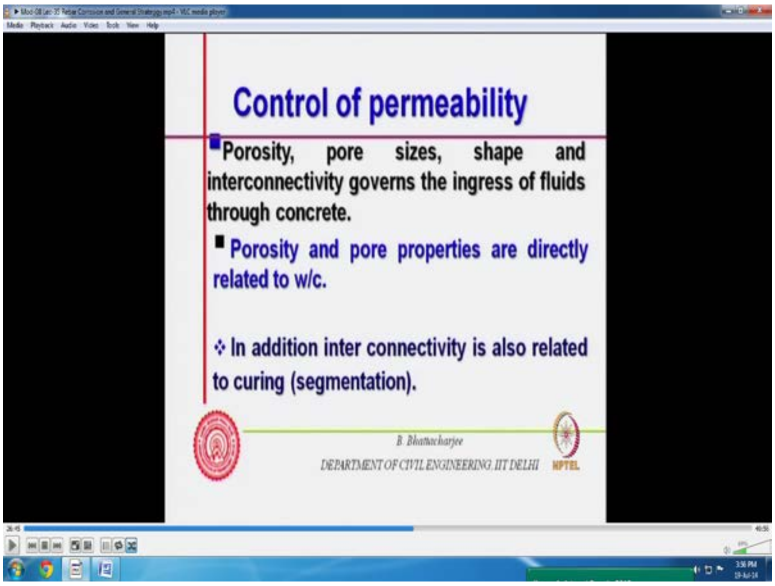

So, what we have seen so, far we have seen that you know the permeability depends upon porosity pore sizes, shapes interconnectivity and this all governs the ingress of fluid through the concrete alright. So, if we want to conclude the permeability well we have to actually look into this issues now porosity and pore properties are directly related to water cement ratio that is what also we have seen and curing also plays an important role because, it causes segmentation therefore, we control water cement ratio and curing these are very important issues with regard to strategy for durability. So, interconnectivity also relates means also related to curing that is segmentation.

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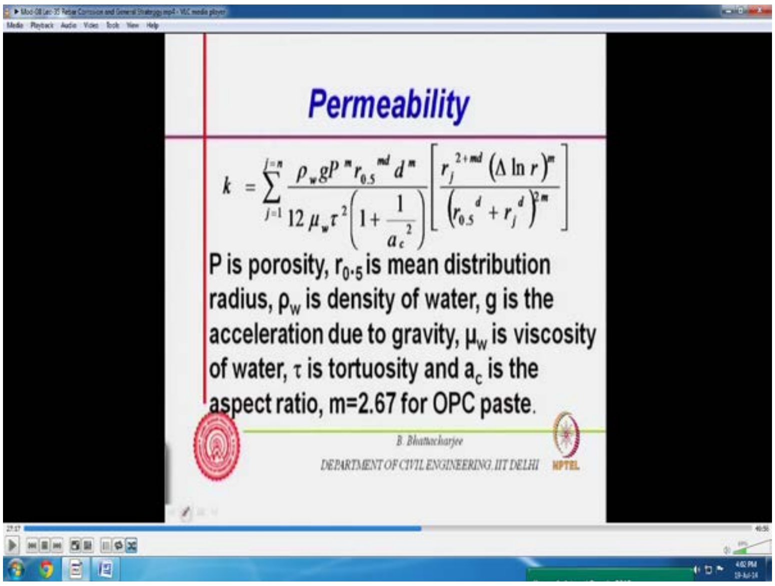

So, let us see something more related to this permeability well a mathematical relationship of can be of this kind for permeability related to pores sizes my idea is to give you show you what are the kind of properties of the you know system that will go under permeability of let us say cement pay system.

Now, in this one k stands for permeability k stands for permeability here k stands for permeability k stands for permeability, rho is the you know this equation is theoretically derived based on results of intrusion poro symmetry, whereby interconnected pores one can determined porosities. So, depends upon density of water this is acceleration due to gravity p is the porosity, this is what is called mean distribution radius or median pore m is the factor exponent, which is 2.67 for OPC paste might vary from material to material and d is the dispersion of the pores that is if I plot log of, if I plot you know pore size distribution volume of pores, let us say and if put log of pore size then I will get this sort of a relationship.

So, this dispersion of pore the minimum size, to the maximum size, minimum to maximum size, maximum size of pore so that, d is related to that so d is related to dispersion of pores d is related to pore dispersion right so this is mean distribution radius d is related to pore dispersion rho is density of water this is dispersion as i said this is dispersion and this is j going from one to n that means there are several pore sizes which you can divide into number of groups say, n groups number of you know number of groups, n groups you can divide them into n groups and each group delta l n r gives you the you know small, d r values or you know r 1 r 2 minus r 1 so, in log terms so, l n r 2 minus l n r 1 that is delta l n r m is the exponent I already said, d is the dispersion r j is the jth pore size average jth pore and this is for any pore size.

So, r j stands for jth pore size so, a c stands for aspect ratio of the pore, which you can take it depending upon the type of pore shape, of the pore for example, aspect ratio if it is you know cylindrical would be 1 because, pore size will be circular cross section of the pore. So, it is the aspect ratio of the cross sectional pore for elliptic pores, this will depend upon the major axis minor axis of the ellipse this is tortuosity of the pore, so this can be determined for some of the material, some are available but, I am not interested in how to determine estimate k from all these factor now mu is the viscosity of water.

Now, this can be determined from powers model as we have seen earlier at 0.5 and d we said that it could be because, you know porosity can be related to this can be also related to water cement ratio, this can also be related to water cement ratio and particle size of the cement particle, size of the cement particle, water cement ratio age degree of hydration that is age all this the d and r 0.5 can be related to those and we have shown some relationship earlier when we are talking of strength but, one can relate to this.

So, in nut shell what we see? we see that k depends upon pore size distribution as many number of size, you have k will vary according to that so, also depends upon dispersion of the pores and mean radius now all this and p itself depends on water cement ratio average particle size of cement or particle size distribution of the cement may be h then it depends upon tortuosity which also can be related to you know, the material the kind of age etcetera viscosity of water and so on. So, forth aspect ratio pores which in the simplest k can be 1 for circle.

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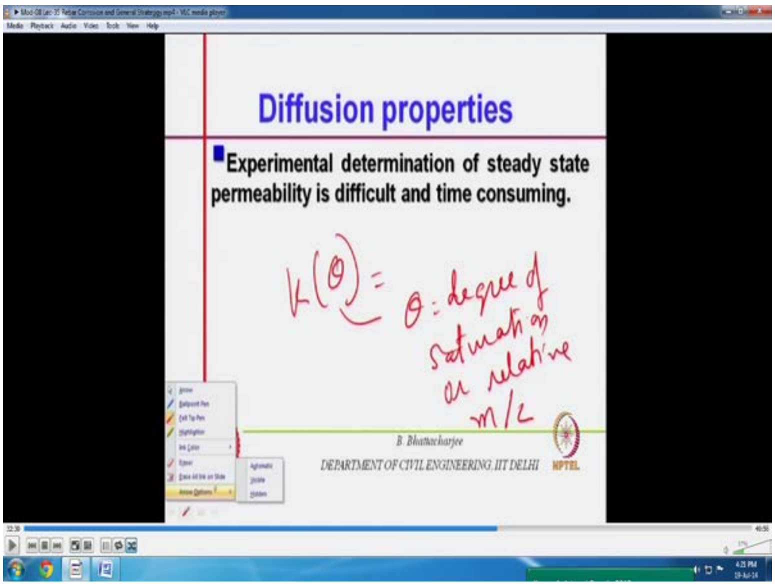

So, these are the factors on which permeability's depends on them but, you see experimental determination of steady state permeability is difficult and time consuming. In fact unsteady state it will vary with the degree of saturation, so k in unsaturated state can be a function of theta while theta is degree of saturation or relative moisture content. So, this will but, then k generally we determined for, you know we determined for saturated condition. So, to achieve the saturated condition statistic situation takes very long time in concrete because, permeation permeability is very low so, it is difficult and time consuming very long time it takes and it is not easy to do so, this is one thing.

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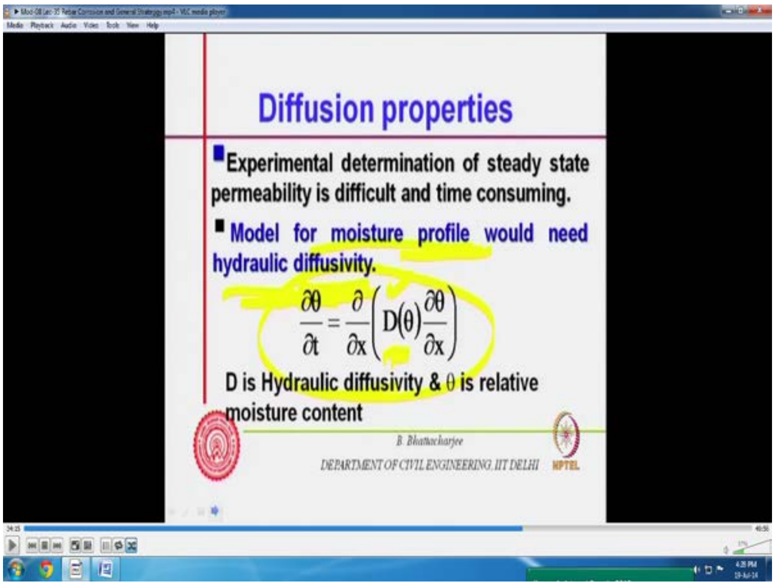

Second aspect, with permeability is, permeability cannot be used for modeling moisture profile or you know amount of carbon dioxide that will penetrate or oxygen that will penetrate so, oxygen permeability or carbon dioxide permeability they are all related to saturated condition, in fact un saturated situation will be more you know, it is easily easy to model through diffusivity.

So, diffusion properties are diffusivity also they are not necessarily diffusion as we understood, from fixed that is concentration dependent diffusion but, they are you know concentration where diffusion which you know is a function of the concentration because, of the concentration gradient but, here the diffusion of oxygen carbon dioxide all this they will be concentrated dependent but, water diffusion or hydraulic diffusivity it is you know, it is not exactly diffusion but, it flows under capillary section or under vapor pressure gradient. So, for water situation hydraulic diffusivity one can use and the equation that governs this liquid water flow or similar equation governs even vapor flow is called Richard's equation.

So, d theta is the function of the degree of itself this comes under extended Darcy's law I am trying to tell you only the importance of this, one here rather than permeability if you want to find out numerically model, the flow or ingress into moisture ingress into material concrete. So, this Hydraulic diffusivity theta is relative moisture content.

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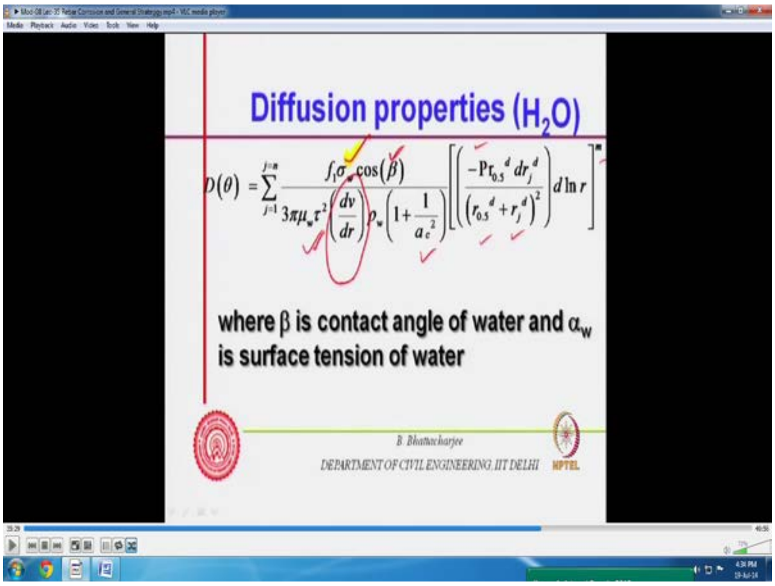

So, you see diffusion properties are important similarly, carbon you know this is diffusivity of this Hydraulic diffusivity, can be expressed in the similar manner for from pore size distribution, using this equation all the things are same except that here this is the surface tension property, then this is surface tension properties of water and f1 relates to aspect ratio, actually this relates to aspect ratio, f1 is another property which is related, you know is another relative to a pore size distribution algorithm, d v d r is the rate of change of pore volume with radius and tortuosity viscosity are 0.5 r j etcetera of porosity all this comes into picture, m which was there in exponent that will come.

So, in fact Hydraulic diffusivity can be also expressed in the similar manner from pore size distribution, beta is a contact angle of water which will be one foremost in the cases cos beta will be 1 beta is 0 so, cos beta will be equals to 1.

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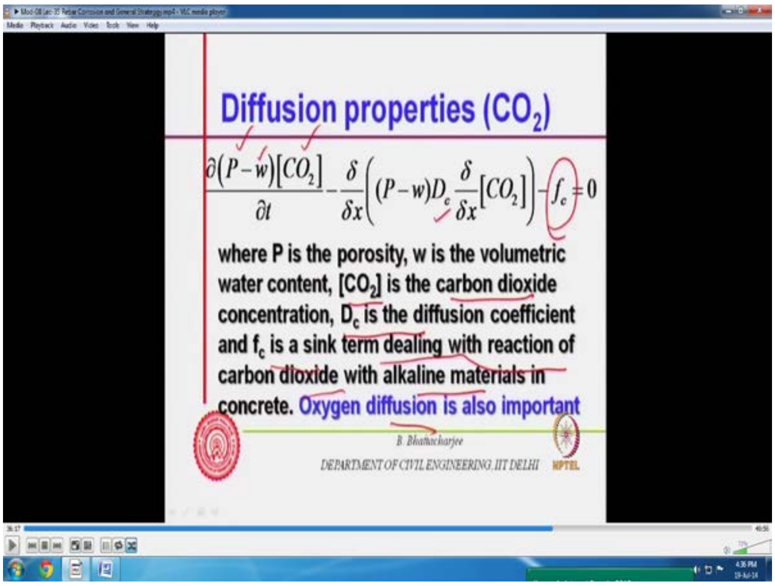

One can actually relate this properties, to you know pore size distribution similarly, carbon dioxide diffusion and the modeling of flow carbon dioxide flow can be through diffusion properties for example, this is porosity this is the water filled space or water content carbon dioxide concentration and diffusion of carbon dioxide coefficient this is a sink that is all alkali content related to the alkali content of the concrete.

So, where P is the porosity w is the volumetric water, content carbon dioxide is the carbon dioxide concentration d is the diffusion coefficient, this is the sink term dealing with reaction of carbon dioxide with alkaline material in concrete oxygen diffusion is also important. So, what we see if we want to actually model this flow or profile within the material how much carbon dioxide, how does the carbon dioxide concentration varies with time and space, within concrete then I got to solve this kind of equation and diffusion coefficient corresponding carbon dioxide diffusion coefficient important where, we have seen the chloride diffusion equation generalized class, sometime in 3 lecture you know so, 2 or 3 or 4 lecture in fact 3 lecture we looked into in this one.

So, what we see is the diffusion properties are important, if you are trying to model them permeability can only give you qualitative information a better concrete and a poor concrete but, there are lot of work to be done here, research is to be done here in order that you know one can actually use them for practical purposes. The equations the material properties solving them may not be a big problem, with the kind of numerical methods and computers that is available today but, not easy to find out the coefficient in the coefficients in the equation so, that's it.

Similarly, oxygen diffusion is important if you are trying to model let us say corrosion process but, corrosion there are much more complexity if one wants to model for rate of corrosion, there will be so, many equations involving so, many diffusion process so, many processes also charged balance will be there.

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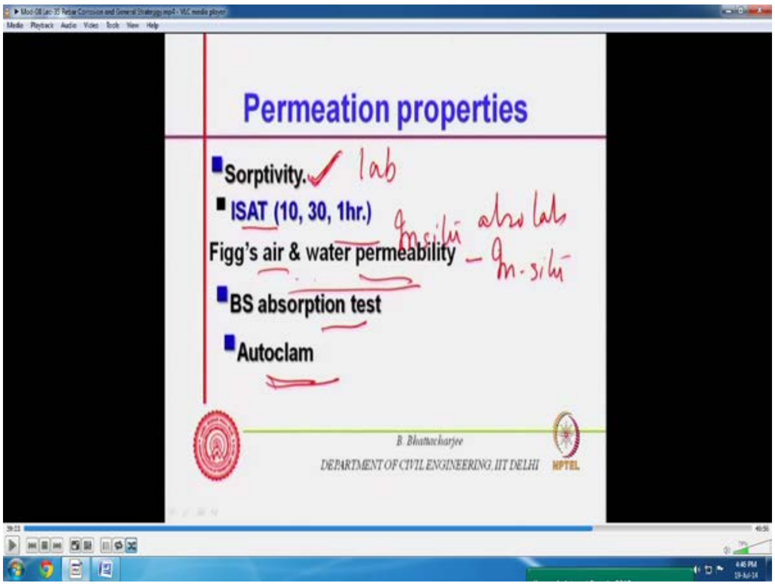

So, these are the complications involved in modeling and predicting service life, however we have to we can compare and sometime we might have to judge performance of materials, insitu so, certain permeation properties permeability measurement is difficult in insitu it will be even more difficult. So, certain tests have been devised namely, Sorptivity is a property initial surface absorption test Sorptivity for lab specimen, laboratory specimen, this can be done insitu Figg's air and water permeability, insitu as well as in the lab, both then also lab laboratory, B S absorption test take a core specimen and do absorption test.

Now, this all gives us what is called permeation properties Auto clam and there are many more there are number of them, you know series of them have been developed at different places like this, is in Bell pass this is BS absorption test this is also BS test, Sorptivity originally by hall and etcetera these are all several other properties there is one in the Switzerland, some modification of this one, modification of this one, because this requires bake home application. So, without the bake home application so, there are several of them which are there and some of them can be used insitu not on the lab specimen so that, we can find out the performance of durability performance of concrete in structure.

So, permeability is difficult to determine but, this ones will be relatively easier but, with this one you can actually compare two different but, cannot predict really much, not you know they are not predictive but, you can tell you about which is better concrete, which is poor concrete.

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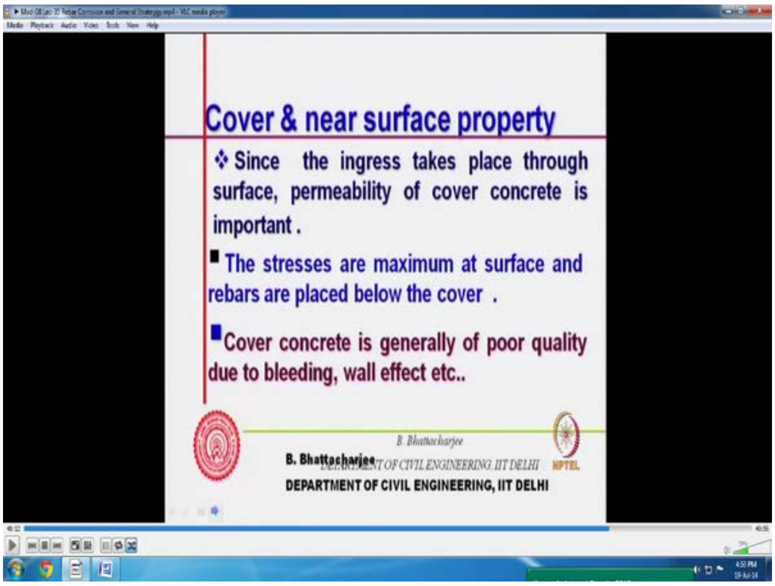

Anyway, this is the situation but, one more important issue is, for durability cover concrete is most important because, ingress takes place through surface. So, permeability or permeation property of the cover concrete is important and all insitu measurement of course, looks into the cover measurement in cover because, that is approachable. But you see the stresses or maximum stresses are maximum at the surface and reverse are placed also below the curve so, cover importance of cover concrete is very very important cover concrete is generally poor quality, due to bleeding wall effect etcetera, etcetera.

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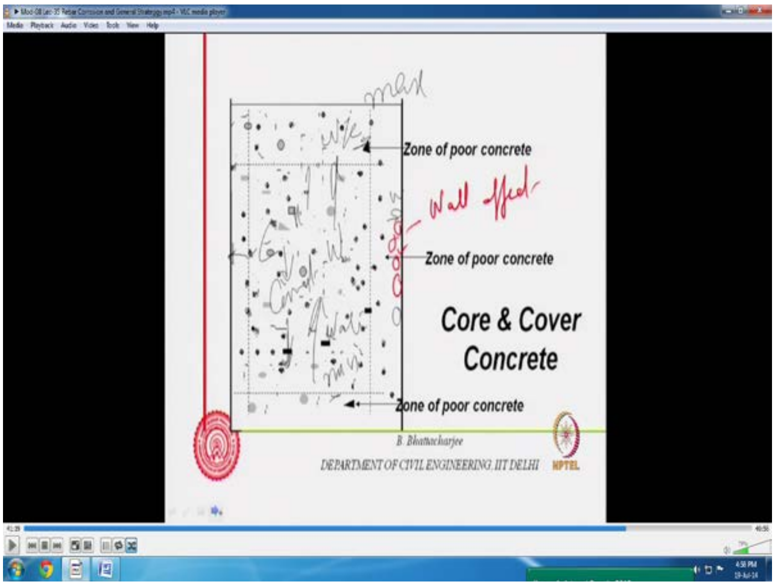

Let us look at this cover concrete, you see if this is your concrete this will be the zone of poor concrete why? Because wall effect packing of aggregates are not very good here, wall effect remember wall effect and this could actually result in more porosity here so, this concrete here is not very good, water has a tendency to go up, water has a tendency to go up so maximum water saving ratio maximum, bleed bleeding would occur here even when you do vibration, water has a tendency to come here therefore, this zone of poor concrete and water cement ratio maximum here, cement will tendency cement comes down, cement has a tendency cement has a tendency to come down water has a tendency to go up.

So, c comes down, h goes up maximum water cement ratio minimum, water cement ratio therefore, what will happen you know you will have poorest concrete up there poorest concrete is up there because maximum water cement ratio is there will be evaporation shrinking and all those effect therefore, zone of good concrete is somewhere here, zone of good concrete is somewhere here and zone of poor concrete is there and poorest concrete is there but, this is the most trussed these are the most trussed areas because, flexural stresses are maximum here depending upon of course, the kind of structure you have flexural compression is maximum here, tensile is maximum here so, tensile cracking will any way occur torsion, is maximum at the periphery stresses are maximum at the periphery and penetration do occur from outside. So therefore, cover concrete is most important but, that is poorest durability is governed by so, one must put in lot more effort on the cover concrete.

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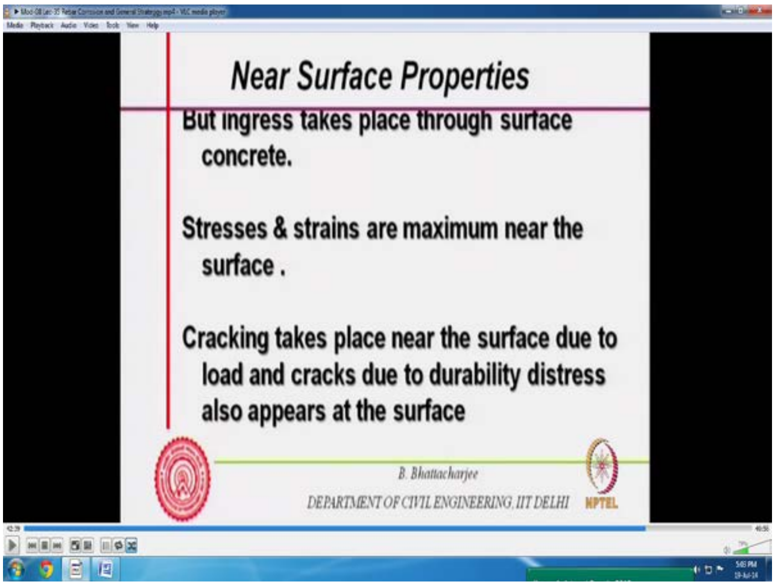

So, good concrete is only in the core so, ingress is takes place through the cover concrete stress and strains are maximum, at the cover concrete and cracking also first takes place in the cover concrete even of if it takes place inside does not matter but, when it comes to the surface, it would actually cause more penetration of more harmful ingredients and therefore, durability problem will be enhanced further.

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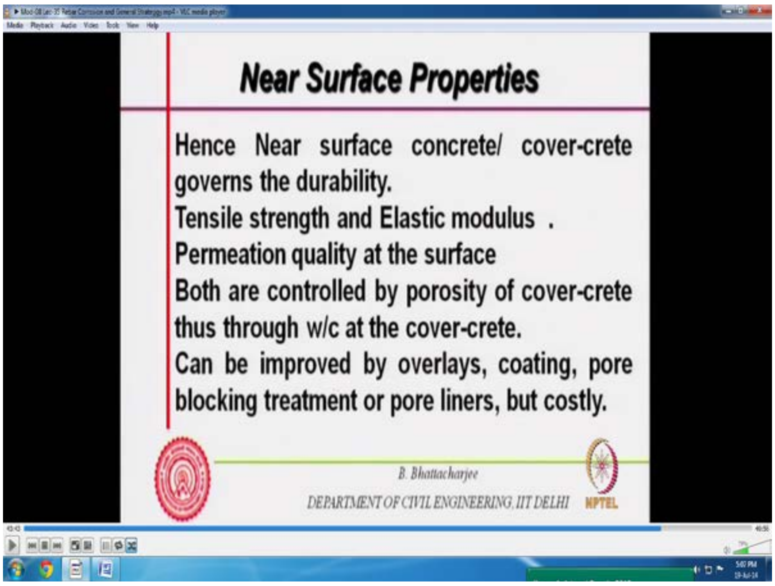

So, near surface this is what governs the you know governs, the durability is there a way well there is possibly some way but, at the moment you know this is inherent in concrete so, we may have to keep water cement ratio, somewhat higher put have one lay may be we will see that of course, tensile strength and elastic modulus of cover concrete is important because, this governs cracking this governs strains, from the stresses that is applied permeation quality at the surface, this is most important.

And both are controlled by property of cover property of porosity of cover-Crete and through water cement ratio of cover-Crete but, we have no way to really cover control the water cement ratio of cover-Crete just like that, there is something which we can do I will just come to that but, we can actually do what we can improve the cover concrete by overlays, put a thick layer you know this is your concrete layer, say this is your concrete this is your original concrete, put a layer here so that, is overlay.

Put a coating here just a coating pore blocking treatment, by you know pore blocking treatment or pore liners actually water proofing treatment, these are I might have an water proofing admixtures into the concrete also, I can put in some material which I can brush application, I can do here I can do brush application on to the concrete surface I can do brush application on to the concrete surface and this material penetrates. Inside some of them reacts with substrate, some of them reacts with the substrate to block, the pore some might act in the you know at the at the at the boundary of the capillary react and just get at a adsorbed there reactor gets adsorbed there and in the process they change the contact angle of water inside.

Since most of the ingresses through water it will not allow water to come in. So, this pore liners pore blocking treatment these are actually water proofing treatment and if water do not go in, then obviously durability will be enhanced. So, cover concrete can be improved by this sort of situation but, then at the moment of course, we do talk in terms of water cement ratio and cement concrete but, some of them could be costly for example, overlays could be costly, coating could be costly, because you may have to repeat them over a period of time, as we have seen earlier that you may have to you know there is service life for this one also and it may have to you know go on changing them from time to time. So therefore, if you change them from time to time, there is a recurring cost involved, lifecycle cost will increase.

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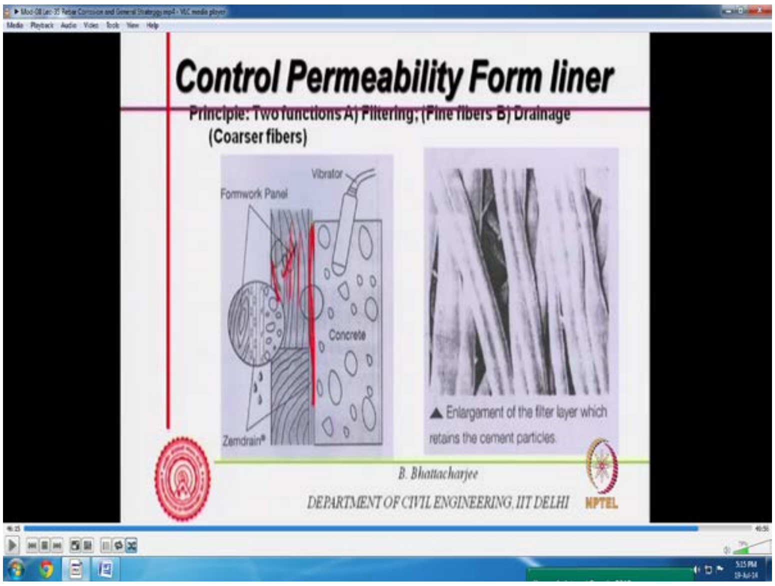

So, these are this could be there but, then one way is to use a control permeability form liner, this is actually a material something like this, you know this let us say this is a material, it has got a core liner it is essentially a thick thin material put in on to the formwork, this is the thin material this is the formwork form or let me write this form formwork, on that I put a liner, thin liner now this liner is a porous material it is a porous material the porosity of course varies so, it has it has got a filtering effect and then there is a drainage so, inner side it allows water to come in but, no solid no cement particle can enter here and its back side it has got a kind of a drainage, it can allow the water to come in and water can drain below down below.

So, when you are vibrating the water tends to move this side air tends to move this side so, it will actually take out the air and water and allow it to drain out so, there is a first phase you know. First phase first is it is a thin material it is a thin material it has got two layers actually front layer, this is a filter layer. So, it is a filter so, polymeric composite material filter and back layer is actually back layer is a porous layer so, it has got the function to drain function of drainage this is called function of filtering so, a is here b is here so, cement particle or you know this materiel material moves along this direction water etcetera water moves along this direction but, cement particles are blocked here

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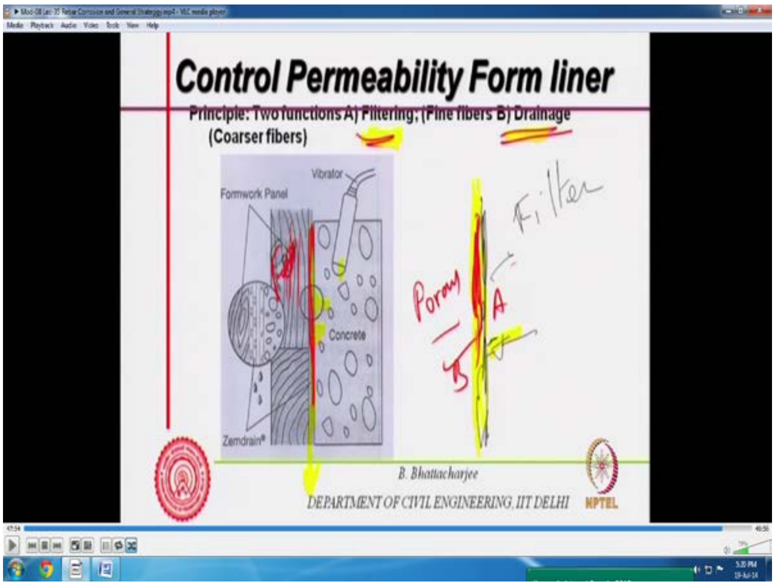

So, water moves along this direction comes here and gets drain here so result is low water cement ratio at the surface result is low water cement ratio at the surface result is low water cement ratio at the low result is low water cement ratio at the surface result is low water cement ratio is the surface result is low water cement ratio is the surface.

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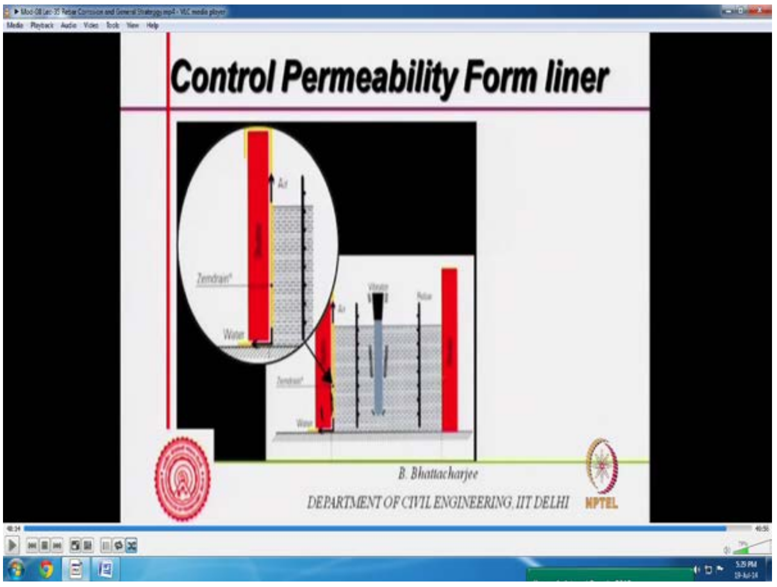

So, you see this is the lining material so, when you vibrate this is the lining material this is your formwork, this is the lining material.

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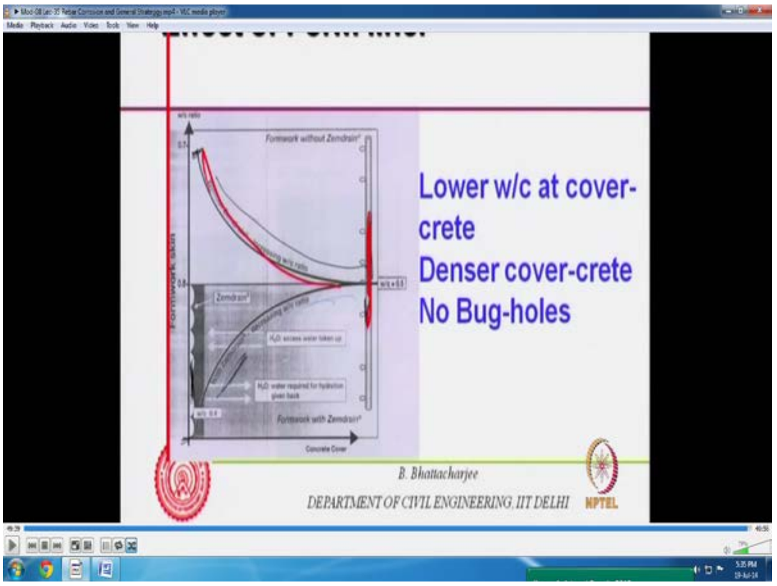

And water and air will have a tendency to move, you know towards the outer periphery and when you have this material, what happens is water cement ratio here reduces significantly. So, if you have original water cement ratio was somewhere around 0.7 without the liner with liner, it might go even to 0.4 where here it is 0.5 this is the reinforcement bar. So, reinforcement bar is here, without the liner water cement ratio is vary like this with liner water cement ratio might vary, like this with liner water cement ratio might vary like this with liner water cement ratio might vary in this manner, water with liner it can vary like this.

So therefore, what we see is lower water cement ratio is the cover-Crete denser cover Crete but, no bug holes it gives you a fantastic finish but, unfortunately it is extremely costly, it is very costly and has not been popular at all because, of its cost and also application difficulty because, you have to put it over the formwork apply toward the formwork and you know fix it over the using a depth and since it is you know like by reducing I mean you cannot demonstrate quantitatively, how much will be the advantage of the moment I have then qualitative advantage. So, this kind of system might work later, on or come may be developed later on but, at the moment if this is costly it is not reduced as much.

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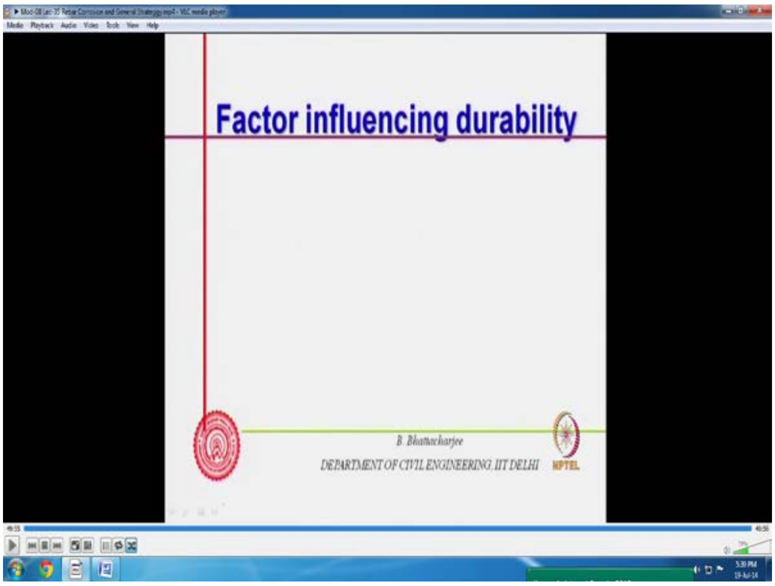

So, this is what we have seen, you know how we can control the durability by control the cover concrete but, at the moment we are at a stage where, you know this is all qualitative our understanding are not very clear as far as the deterioration or degradation mechanisms are concerned and service like prediction is almost I mean mathematical service like prediction, it could be the error could be anything 50 60 100 percent it is because the phenomena is not explained properly.

So, this issues are very much there therefore, we have to do something but, then we cannot wait for knowledge to develop so, now the strategies of the most of the code are of course, to have a kind of prescriptive or some coarse are starting with performance based you know durability requirements now it is but, we must not forget some other factors like loading, we discuss this earlier little bit but, you see fatigue loading will cause earlier then static loading.

So, environment is important loading is also important so, your why your loading is fatigue you better take of durability take more care of durability the crack can come at the surface cover concrete and therefore, one has to be careful more careful about this so, more careful about this, the cover is very very important the ingredients materials in concretes are very very important and cement content and water cement ratio has been used as a prescriptive measure.

So, at the moment cover concrete and as far as ingredients in the concretes are concerned type of cement would be used in depending upon the situation may be binary ternary blends which are coming up for you know blended cement ternary blends composite cements these are coming up, which we discussed in the first module. So, they are coming up from durability concerns but, at the moment water cement ratios are controlled and cement control is controlled by.

But some of the research have shown that it is not important to actually control the cement content, you know the durability of even low cement content but, sufficient fine material in the system you must have good amount of paste in the system not really not necessarily cement but, most of the core prescribes minimum cement content is inputting you know today but, paste content is what is more important water cement ratio is very much important. So, this what has been used as prescriptive methods and compaction is definitely important but, there is no way to really check it directly for durability use unless you have seen some insitu testing and performance measures rather than prescriptive measures but, compaction will also governed because, of porosity will be you know honey concrete will be more less durable, obviously the membership to avoid water accumulation this is the practical scenario.

I can just tell you some cases for example, if this is the balcony you know this is the balcony slab and this is the, this is there is a sort of balcony slab, there is a finish here small parapet sort of thing small Facia beam sort of thing. Now you have a spout hole to drain out water, now this spout hole should be somehow there, quite often you might find it there so, water accumulation can takes place in this.

So, if the water accumulates or you know in sun shade essentially a sun shade is something like this but, we have a drip core so, in a sun shade if the dip course is missing or the slope is other way around slope of the sun shade is downward here water accumulation will occur the dip course is not there, water will not water accumulation could be there it will just flow through this.

So therefore, detail construction to avoid water membership and detail this is very important because, most of the time the water logging starts from water issues is related to details in drawing as well as construction execution of the construction. So, these details are very very important. It is not only the shape but, also you know details of construction so, the shape is important details are very very important to avoid water accumulation this is most important you must avoid this that will improve.

Let us see what is the is code requirement at the end is code classifies is a prescriptive requirement you know is 456 2000, at the moment it gives you prescriptive requirement and this prescriptive requirements, first what it does it classified exposure conditions 5 mild moderate severe very severe and extreme so, it actually classifies exposure condition in 5 mild moderate severe, very severe and extreme and defines them what they are.

For example, mild you know the condition mild is ordinary condition not expose to anything severe will be extreme would be expose to all kind of degradation possibility, plus zone in marine environment so, it classifies them and it is also matching with the erstwhile BS 8 1 1 0, then it gives you prescription in terms of minimum cement content, maximum water cement ratio and grade of concrete and minimum cover this 3 are given in a single table 5 of its 4 5 6 and some of the part of the table as actually referred to introduce for your purpose for understanding prescription of concrete exposed to sulfate attack in terms of type of cement, water cement ratio and other you know type of cement and water cement these also given in separate table. So, certain other tables are there this table 5 specific to deterioration these are given maximum chloride content that is prescribed so, all these prescriptions are there.

So, we look in to table 5 now the table 5 gives you well exposure mild, this is protected just part of the definitions I have just picked up, they are more detailed definition available in the code moderate is sheltered from severe rain, wetting and drying this severe environment, very severe sea water spray extreme is tidal zone that is what I am saying. So, sea water spray you know 5 10 kilometers 5 kilometers within marine sources, there can be chloride accumulation because, sulformation can occur at the crest of the wheel peek, of the wheel the salt can go into the air and due to wind it might migrate inside and some zone close to the sea shore will be quite severe. If there is a water spray simultaneously protected is space where humidity is high within the built in etcetera and now change sheltered from severe rain this rain may be expose to rain but, severe rain.

For example if you have north east exposed column that will be exposed to severe rain wetting and drying is the scenario but, even in composite bounds in climate some columns will be exposed to wetting and drying but, may not be of long spell. So, it will depend upon climatic situation like Delhi I said is composite monsoon climate north east is climate etcetera.

So, this is the classification details you can have in the code itself and then it tells you the minimum cement content, maximum water cement ratio and minimum grade of concrete now water cement ratio is linked to this strain, you can see because, with 0.55 water cement ratio you know 0.4 water cement ratio you are if you designed for m 20 then that will be a bad design, we will end up using lot more cement.

Therefore, this is actually sort of compatible with each other and minimum water cement ratio is 0.45 they have grade of concrete should be m 35 and that will ensure that you are actually not designing the concrete less than 0.45 I mean more than 0.45 water so, this is the prescriptive table given in is code and that is how actually is code controls then covered requirements are given here for mild for let us say, it is i think for minimum cover requirement for certain members, these values are given detail elaborate cover requirements are given in a code also cover requirements are given for fire in case of beam and slab etcetera but, minimum cover for mild is this extreme is 75 for you know in this situation.

So, cover requirement cement content, water cement ratio and grade of concrete these are the prescription that is given in is 456 2000 that is for general concrete but, if you have sulfate or similar other situation rules are also be there maximum chloride content is given type of water, you should use that is also given so, if one adheres to them by enlarge of course, the concrete will be given I think with this with this we would like to summarize our discussion, summarize our discussion of today corrosion propagation models, we have looked onto we have looked into role of permeability and cover concrete diffusivity and then we looked into prescriptive recommendation of is code.

So, this concludes our discussion, on module 8 which was related to durability and lastly what we have understood is how to protect concrete from durability we have looked into the degradation phenomena and also the strategies of v p r and those you know why concrete requires degrades and many definitions, we looked in the beginning then we looked into the degradation phenomena, some module, some service life issues and things like that and finally, of course the current prescript with recommendation performance base recommendation, will come sooner or later but, at the moment this is like this so with this we conclude module 5.

Thank you very much.