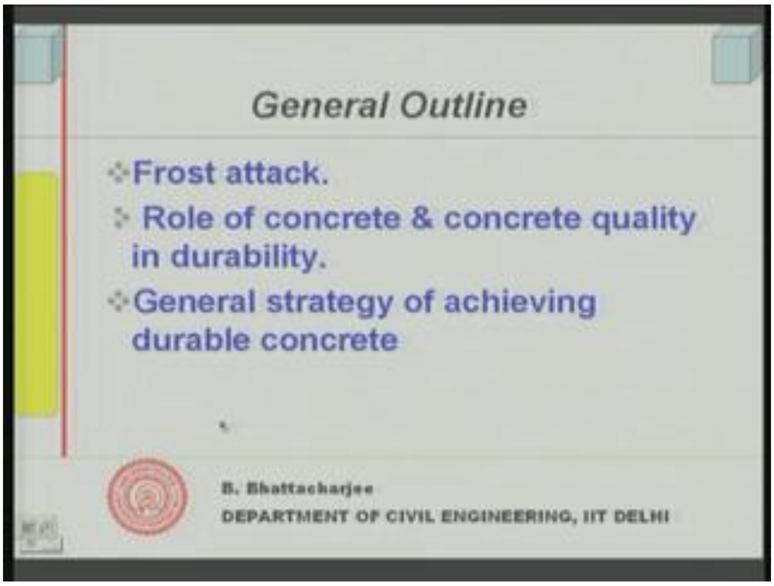
Building Materials and Construction
Prof. Dr. B. Bhattacharjee
Dept of Civil Engineering
Indian Institute of Technology, Delhi

Module - 7
Lecture - 3
Durability of Concrete:
Frost Attack and General Strategy

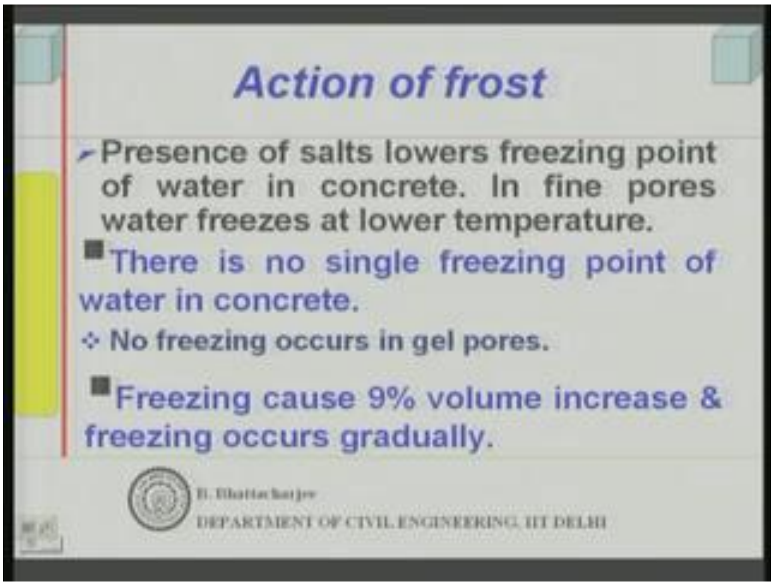
So far we have looked into the chemical degradation process. Now in this lecture, we shall look into one of the physical degradation processes. That is the frost attack and then we will look into general strategy for making durable concrete.

(Refer Slide Time: 01:32)



So, the general outline therefore would be frost attack, followed by role of concrete and concrete quality in durability, and obviously followed from that is general strategy of achieving durable concrete.

(Refer Slide Time: 01:47)



Now, what does frost do? Well this is not a very common phenomena in most of the part of our country, excepting the northern part Himachal Pradesh, Uttaranchal and J and K, because it is a phenomena related to cold climate. So, when ice formation takes place due to freezing of water during the winter season, the frost can actually result in damage to the concrete. So, how does it do? Presence of salt lowers freezing point of water in concrete. Normally the concrete I mean the water has got a freezing point 0. And test broadly before we will look into the details, this water in a saturated concrete when gets frozen, would actually will become ice. And this ice exert pressure onto the concrete inside the concrete, generate some sort of internal pressure within concrete and which causes damage to the concrete in the long run.

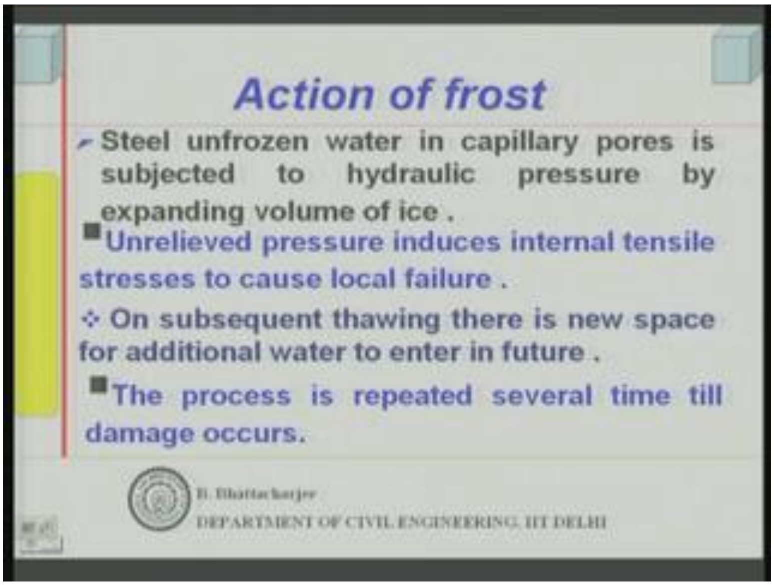
So, that is what is the frost attack, we are trying to look into this. First of all if we look at it, since there are salts present in the pore water of concrete, this salts would lower down the freezing point, you know depression of freezing point by putting some solute into the water. Then also in very fine pores, the water freezes at lower temperature, because the other forces comes in; the surface tension forces and other forces surface forces would come in. And there it freezes at lower temperature.

So, when concrete water does not freeze at 0 degree centigrade, but it freezes at lower temperature and there is no single freezing point of water in the concrete and some portion water, you know all water definitely will not freeze together. If the pores is the concrete saturated water, some portion water will freeze and become ice; other portion still it will remain water, because the freezing point is not same and all water does not become is not frozen together.

So, that is what happens. And when such a thing is occurring, there is some percentage of volume increase in within the volume increase due to the formation of ice. And this ice pressure exerts pressure into the rest of the concrete. Now, 1 important point is that, gel pores are so small that, there no freezing takes place. We have we remember that, there are 2 main types of inherent pores in concrete; the pores coming from hydration of cement. This water fills space which does not get occupied by the hydrates of cement. That we called as capillary pores. And if you remember they are of larger sizes and the other types of pores are gel pores, which are very fine sizes order of Armstrong sizes; 10 to 15 Armstrong sizes.

If you remember you know, so those size such fine pores such very small pores, actually freezing does not occur there at all. So, freezing occurs only in capillary pores. And due to the freezing formation of ice, there is an approximately 9 percent increase in the volume of due to the formation of ice. So, the water which was occupying a volume, now occupy more volume, because of formation of ice and volume increases about 9 percent.

(Refer Slide Time: 05:28)

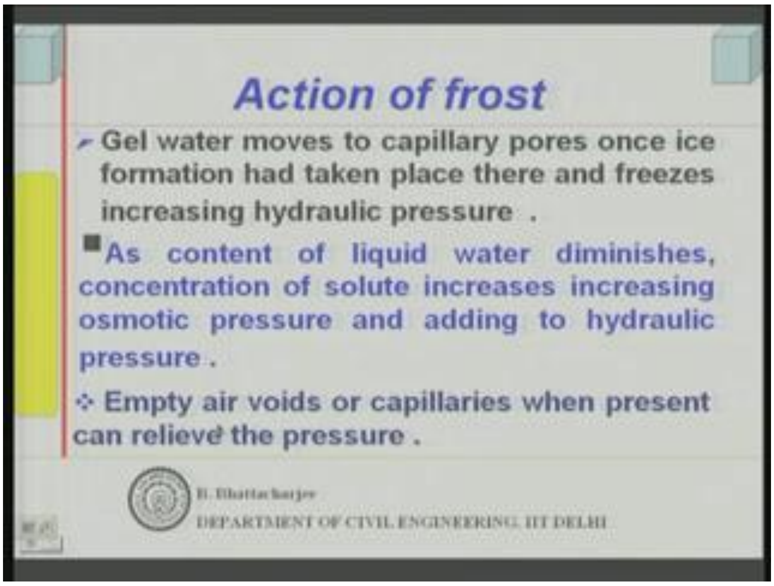


Now, when such 9 percent or some percentage of increase in volume is there, steel unfrozen water in the capillary pores is subjected to hydraulic pressure by expanding volume of the ice. You know you have something like this, let us say water and suddenly there is an ice formation that has taken place. It is all water and suddenly ice formation as taken place. Now, this ice would occupy you know, it will occupy more volume then the original water. You know if this was the original water, ice would occupy now more volume and it will exert pressure; hydraulic pressure in all directions.

So, in whichever pore since the pores are interconnected, wherever actually some ice formation as taken place; that will exert pressure into the pore water: hydraulic pressure into the pore water right, because of the volume expansion of the ice. If this pressure remains, it is not relived by some means, the water pressure hydraulic pressure. Then this induces internal tensile stresses and it can cause local failure.

Now what happens next? After the 1 cycle of freezing, there will be toeing. Now, since the crack should have developed over you know some since the unrelieved pressure was there, that would have cost some new cracks. And those spaces which you have created additional space created, due to by the unrelieved pressure, now, they will be also available those spaces also will be available for water to enter. First t takes place, so ice melts into water. And subsequently additional water can also enter into that new space that has been created by cracks. And what will happen next time? They 2 will you know will contribute to the overall pore space, where this would be released, where hydraulic pressure will increase. And if this process continuous continues continuous for several cycles, damages would be absorbed into the concrete. So, concrete get damaged after several cycles.

(Refer Slide Time: 07:52)



The gel water does not … You know there is no ice formation in gel water. When ice formation takes place in capillary pores, the gel water then there is a you know sort of gradient existing. There are some water in the gel, gel water is there, it has got you know the absorbed water is there and there is ice less reduction in water. And possibly if it is all ice formation has taken place, the drying of the gel will actually get water you know gel pores would take place. Some gel water will come into the capillary pores. So, the drying actions could be there. In fact, gel water can move to capillary pores once ice formation has taken place and thus again freezes.

So, water actually gel water also moves to the capillary. So, already capillary water which has become ice, further gel water tends to move there and then it tries to actually cause excess pressure there. So, it increases the hydraulic pressure. If eventually it is able to move, it will become ice. Some excess pressure would be created. So, hydraulic pressure would increase.

Finally as content of liquid water decreases diminishes, concentration of solute also increases. Now, in the same pore, if this was my pore, this was my pore, now, some portion as become ice, some portion some ice formation as taken place actually. Some portion as become let us say ice, this portion as become ice. Now, the water as decreased by, but my solutes which were there earlier, solutes which were present earlier, they were already there. Their content they did not contribute to the ice formation. They have not got inside gone inside the ice; it is only water which has got converted into ice.

So, concentration of this solid will now increase inside this pore. Now, this concentration increase will actually result in osmotic pressure and adding to the hydraulic pressure. So, concentration change, because osmotic pressure is related to the concentration, so osmotic pressure would actually all add to the hydraulic pressure. So, therefore, what we see is; this is a progressive process or it is a process 1 link to the other sort of cascading effect. First water in the capillary is becoming ice, because the no single freezing point.

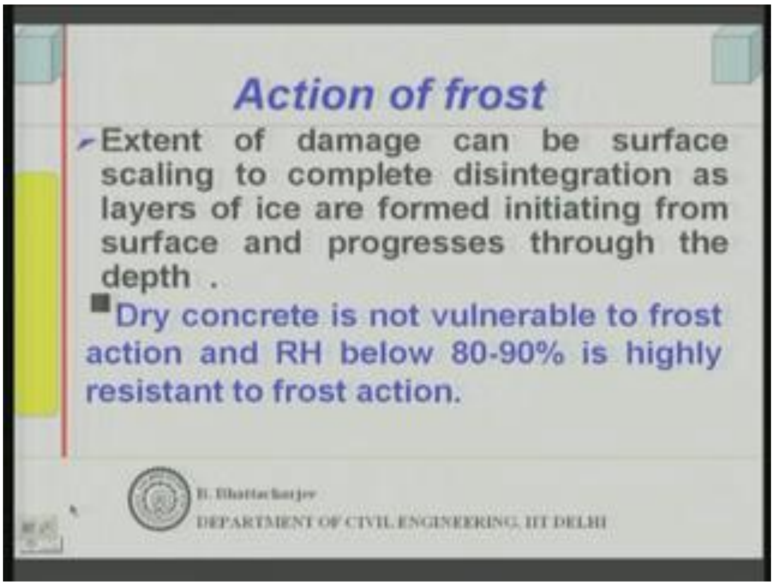
Now, the ice some water becoming ice. Gel water will tend to move. Also since some waters in the capillaries have become ice, solute concentration there would increase. And the solution will become more saturated, exerting more osmotic pressure. In the net some total is increase pressure into the internal pressure within the concrete. And that is the mechanism of frost. So, that is how it will be. When it exerts, it will actually cause cracking of the faintly surrounding concrete.

In fact, it is observed at the surface first why, because water would surface water you know surface water is water enters into the surface, maybe everything within the depth of the concrete is not saturated and then surface would get cooled first surface and ice formation will take place there and it will penetrate inside gradually. And in the long run, surface concrete starts cracking and actually … So, there will be some cracking and spooling of the concrete in form of removal of concrete from the surface.

So, loss of concrete from the surface takes place after several cycles of freezing. But 1 interesting point is if you have some empty voids which are not actually available to water, you know some empty capillaries are there which are not available to the water initially. And when pressure exerts, when hydraulic pressure increases, this pressure can you know this exertion of this can result in penetration into those capillaries. The water will go there and the pressure will be relieved.

So, if I have some reserved cap pore spaces, which are not which are airfield and not occupied by air. When water exerts hydraulic pressure due to freezing action, the pressure can be relieved through those spaces. And if this becomes possible, the effect of freezing can be reduced. And that is the idea against protection. That is the idea of protection against frost.

(Refer Slide Time: 12:37)



So, generally extent of damage starts from surface scaling, as we said from surface scaling right to complete disintegration as layers of ice are formed, initiating from surface and progresses through the depth. So, it starts from the surface and goes through the depth. Most important again, dry concrete is not vulnerable to frost action and R H below 80 to 90 percent. 80 to 90 percent is highly resistant to frost action.

So, this is a physical phenomenon; it is no longer chemical, it is a physical phenomena and water is again the main agent. If you can keep it dry this phenomena wouldn’t occur. So, that is what it is. Very important, nothing should penetrate into the concrete from outside, especially water penetration that should be stopped.

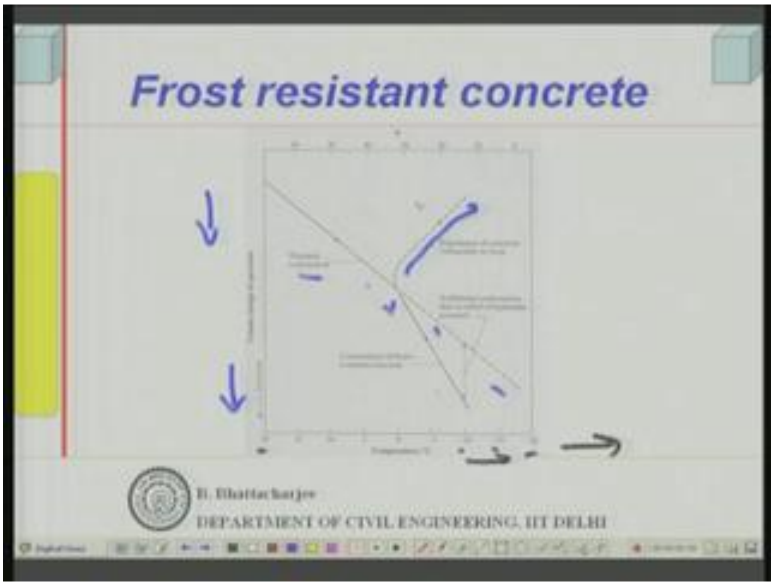
(Refer Slide Time: 13:47)

Major way how it is protected makes frost resistant concrete is deliberate, air entertainment in low water cement ratio concrete. So, we enter the air, air enter agents are used in cold climate. This is almost a regulation practice for exposed concrete, because this deliberately enter air pockets, which are uniformly distributed through the concretes struck, you know concrete material which is very uniformly distributed and the- will be fine pores. These pores are not actually accessible to the water in the beginning, but they can serve as reserved pore spaces, which can allow pressure to be relived, because when the water exert pressure that can enter into those pores break the boundaries of those pores and enter into them.

So, they are not initially water not available to the interconnected porosity. But some of it actually gets you know it becomes available or gets converted into interconnected porosity in 1 cycle of freezing. But there will be still some more left, in the next cycle of freezing there will be more of such pores, which will be brought into the interconnected porosity through pressure release. Pressure will get released and the water will enter into those air enter pores deliberately air enter- pores. So, this process continuous, every year some amount of air enter pore will be used up in relieving the pressure. And what you find; the number of cycles and non air enter concrete can withstand. Number of using time cycles and non air enter concrete can withstand is much less compared to air enter concrete, which can withstand much higher number of larger number of freezing cycles.

So, this is 1 of the ways of making frost resistance concrete right. They are well distributed air voids adjacent to water filled capillaries, allow water to flow into them and relieve pressure. That is the basic idea; that is what they do.

(Refer Slide Time: 16:05)



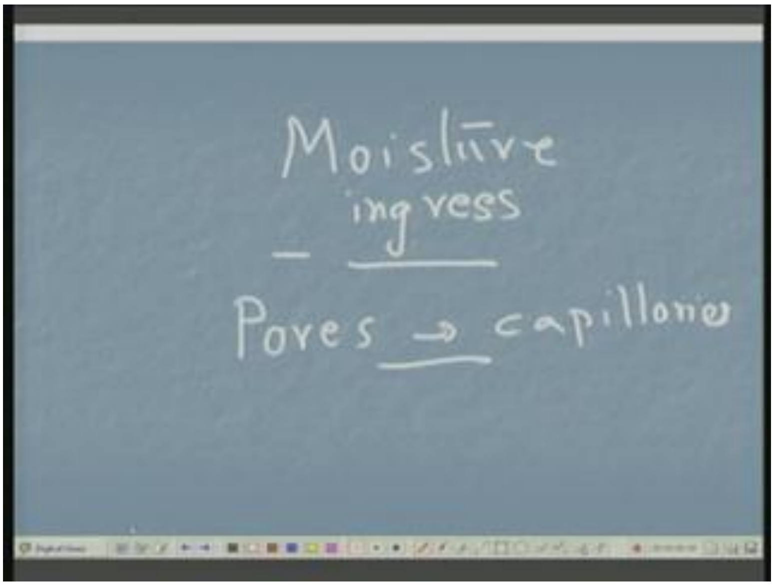
And if you see this diagram, this will make it somewhat clear what happens. You see when actually when temple is this side, you see you can see the lower temperature here; minus 20 minus 15 etcetera to upto plus 20. So, when temperature is reduced you know along this direction, reduce reduction of temperature takes place actually, temperature is reduced and we can see the volume of concrete specimen. Now, there will be some amount of contractions. So, people have started contraction and therefore, the normal contraction should have followed thermal contraction which is there. Actually thermal contraction the volume is decreasing. Volume decreased along this direction. So, this is the normal thermal contraction that should have followed.

But when you go below 0 degree centigrade, if you do not have an air enter concrete what happens; is there is an expansion along this direction. And this expansion is because of this freezing effect. What it does? It actually causes expansion due to formation of ice which exerts pressure and there is of the concrete, overall concrete gets expanded. So, overall volume increase in concrete takes place.

But if you have used air enter or air enter agent in production of the concrete and enter air into the concrete, then the path followed is this. In fact, you will have more contraction then the thermal contraction; so additional contraction due to relieve of this pressure. So, what will happen; this pressure release allows you thermal contraction plus additional contraction also takes place and that is how actually frost produced. Frost and concrete is produced right. So, that is what the action of frost is.

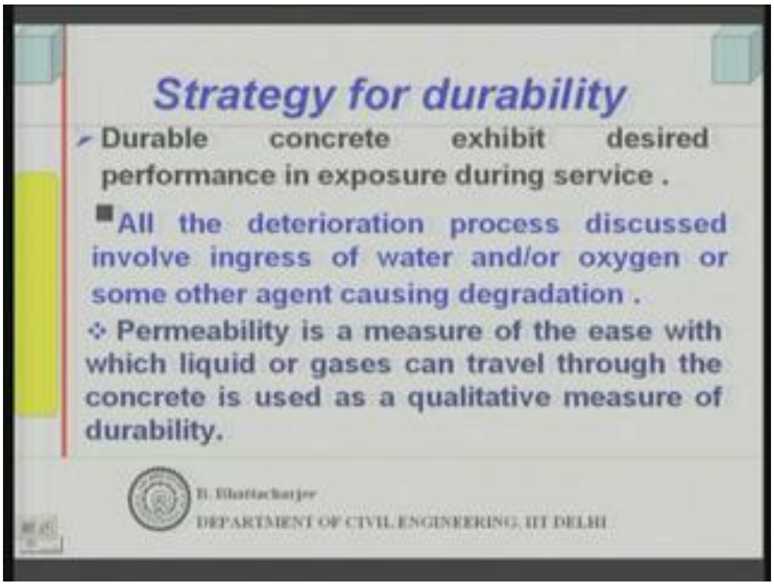
So, then now we have so far we have discussed all the types of possible degradation mechanism in concrete. There can be some more but major ones we have covered; the chemical ones and the physical 1; that is a frost. Although: frost is not very common in larger part of this country, but this phenomenon tells us all, you know discussion of this tells us; how what are the what are the mechanisms of physical, even physical deterioration process. One thing found common in all cases is the presence of moisture. In all cases we have found the presence of moisture is the main cause of deterioration.

(Refer Slide Time: 18:39)



You know presence of moisture is a basically it is moisture. This point must be noted down. And ingress, it comes from outside. Moisture ingress is the main; that is the main thing. And how does it in how does it come in? Through the pores; mainly the capillary pores. So, this is 1 thing we have found common in all cases. We have said that, if you can keep the water away well, the durability of the concrete will be achieved. So, that is the first fundamental that, how durability of the concrete should be achieved.

(Refer Slide Time: 19:17)



Strategy for durability and that is what our discussion now would focus around this. Well let us just re-look into the definition. What we said durable concrete should exhibit desired performance in exposure during service. That is what a durable concrete is. Durable concrete should exhibit desired performance or performance in the environmental exposure during its service. Whatever exposure it is for the time, whatever we have specified.

And the point that I would like to again is all the deterioration process discussed; involve ingress of water and in some cases of course, oxygen or carbon dioxide or some other fluid causing the degradation. So it is the ingress of material which is important; ingress of fluids. And therefore, the property that was historically the property that was that 1 looked into is the permeability. Just going back a little bit to the history, you see initially people thought initial research in concrete durability was very little, because it was thought that concrete is highly durable. It is definitely more durable than many other materials, not readily reacting like iron in steel.

So, people thought its 1 of the structural material, it is very durable. But after all you produce it with a expensive energy. So, therefore, it will have tendency to react. Therefore it cannot be infinite durability. So, by you know as the concrete structures, their use became more popular in aggressive environments like tropical countries, in offshore, 1 started finding that after all concrete is not really of infinite durability. So, 1 got to look into the durability of concrete.

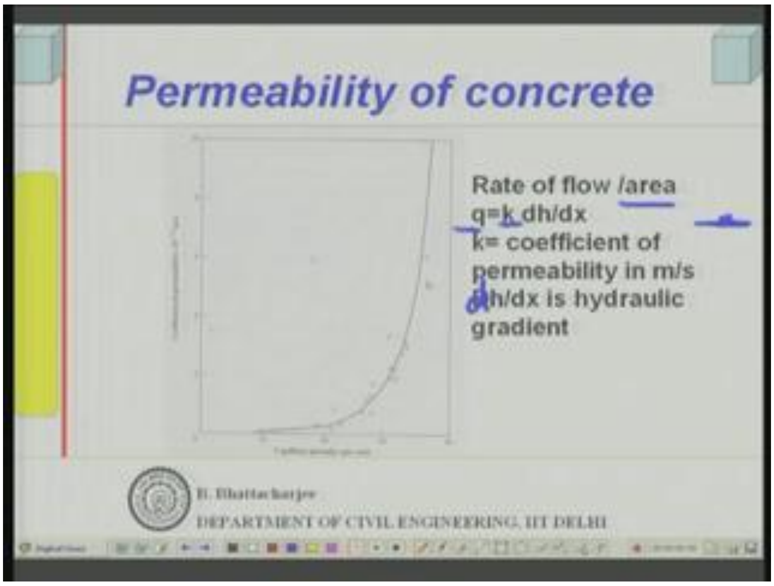
Now, how do we see? What thing is it was understood is it is water, which is the sole agent which causes the durability problem or oxygen or something of that kind. Now, how to study this? What should be the parameter? In soil 1 uses permeability that is its law. We will just present this 1. So, this concept was borrowed. You know in pores media, 1 of the simplest parameter material property, what 1 which 1 can look into is the permeability.

So, permeability is the measure, of the ease with which liquid or gas can travel through the concrete. And this has been used as a qualitative measure of durability. Why qualitative, because quantitative the permeability alone is not sufficient. You see if you remember; we looked into permeability in case of soil saturated permeability. Permeability in saturated state when it is water saturated. Now, this cannot be a quantitative measure, because concrete is rarely saturated, most of the time it is unsaturated. Concrete is very rarely saturated unless it is submerged concrete.

In submerged concrete problem of durability is much less, because those degradation process which requires oxygen or carbon dioxide would not be there. Some other we have seen that, you know although the boys chapter and some moisture will be there, but some other some other reactions which can go in which requires presence of air, they would not go. So, they are relatively less prone then areas where actually goes on. Anyway coming back to the permeability; why it cannot be a qualitative measure quantitative measure, because unsaturated concrete the permeability is function of the moisture content itself and 1 has to look into extended law for unsaturated flow and more complex things.

But at the moment, one is not interested in the modeling or calculating the service life. In fact, we do not have reliable model for such a thing. So, what we do, we measure qualitatively and compare, you know permeability is used or similar per qualities. There are other absorption test etcetera, which are used as qualitative measure for comparing 2 concretes for their durability. So, we will now focus our discussion on permeability itself.

(Refer Slide Time: 23:36)



Now, permeability is defined if you remember from d law. From d law it is defined like this. Rate of flow per unit area if it is q, q is a rate of flow in meter cube per meter square; meter cube is a flow per unit time per second. So, q will have a unit of meter cube per meter square per second. In other words it is meter per seconds. And this is been from d- laws, this is proportional to k and it is a constant of a material for saturated permeability. This we are talking of only saturated permeability at the moment.

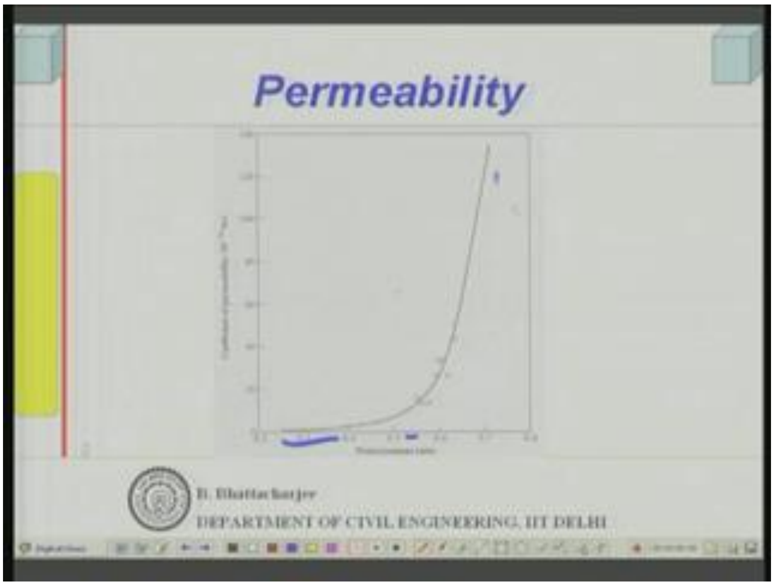
So, its constant for the material saturated permeability is equal to into d h d x, rate of change of hydraulic gradient with x or pressure, you can relate it to d p d x as well whatever it is this is defined, this is the conventional w- designing. This is called d h d x is called hydraulic gradient. This should be written as d. So, d h d x is hydraulic gradient. So, rate of flow per unit area is proportional to hydraulic gradient and the constant of proportionality, we call as coefficient of permeability and its unit is meter per seconds. You can see that, d h d x is unit less if it is head in meter and x is also in meter. So, its unit less, so k would be meter per seconds.

So, people try to measure coefficient of permeability for cement paste. This is for cement paste or even you can measure for concrete, but it is a very tedious process, because unlike soil, concrete is relatively impervious and it takes months to arrive at the steady state and measure it, but people have done this measurement. And interesting to see that, permeability is a function of capillary porosity, so as your capillary porosity percent increases, it actually increases. Permeability increases and you can see the order, you know 10 to the power minus 13 meter per seconds. You can see the order actually very small permeability.

So, as your capillary porosity increases it increases, but beyond a particular porosity which could be a percolation threshold. I will just discuss this, what it is. Suddenly the permeability increases significantly. What is this? Why does it do this way? You see initially pores are all, if you have low capillary porosity, pores will be possibly isolated very little interconnected. But as the porosity increases, the point comes when all the pores becomes interconnected. That means that is a percolation threshold, above which all pores becomes interconnected.

So, when you have large amount of interconnected pores, you know permeability increases significantly. So, permeability; there is a threshold above which actually, threshold capillary porosity, above which permeability increases significant.

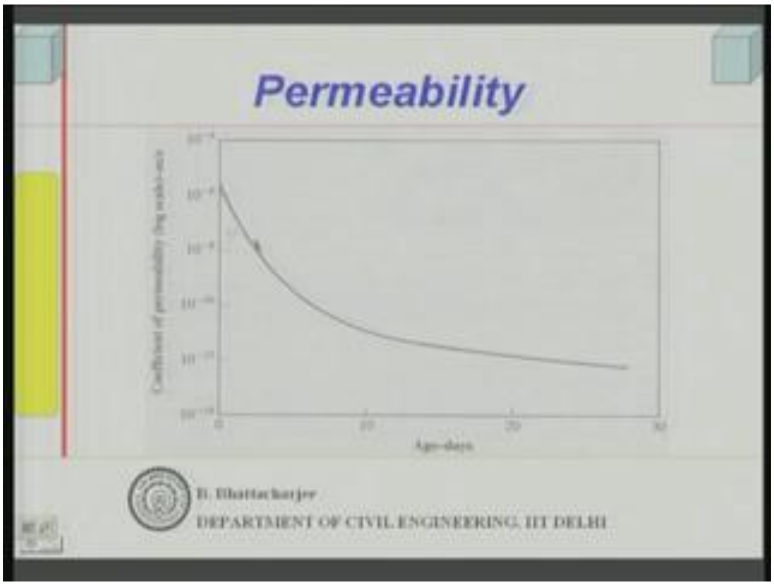
(Refer Slide Time: 26:45)



So, if you have looked into the capillary porosity and we know the capillary porosity is a function of the water cement ratio, then why not look into water cement ratio. And similarly, it would be seen the water cement ratio and capillary permeability as got the similar kind of relationship; 10 to the minus 14 meter per second and water cement ratio. And it has been observed that, at low water cement ratio, permeability is small. And you have suddenly above 0.5 water cement ratio, permeability become very high, because above 0.5 water cement ratio, you have now sufficient capillary pores. The capillary porosity is sufficiently large and they all get interconnected.

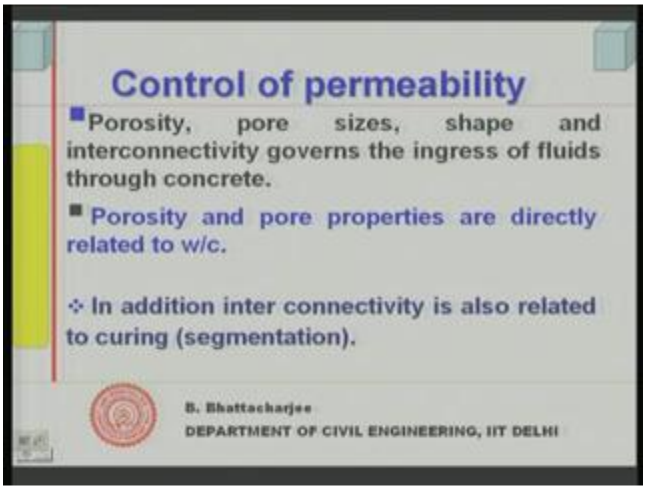
So, therefore, water cement ratio controls the durability as well. We have seen that, water cement ratio controls the strength, it controls the durability as well, because durability's or moisture ingress which is the primary factor towards durability is dependent on the capillary porosity, which in turn is dependent on the water cement ratio. So, that is what it is. Water cement ratio is very important from durability as well. We shall see some more things related to this.

(Refer Slide Time: 27:57)



It has been observed that, with age the permeability would decrease. You know permeability coefficient of permeability in concrete decreases with age. This with concrete, that was with the you know this, I mean this cement paste. And similar all cement paste materials that behave in the similar manner. So, this is in log scale. It is actually it as the age increases.

(Refer Slide Time: 28:25)



As the age increases proficient of permeability reduces down, because hydration takes place and capillary pores are reduced with hydration capillary pores are reduced. Remember the equation for capillary porosity, it involve age degree of hydration. Higher the degree of hydration, capillary porosity will be low and therefore, permeability reduces. But beyond a point capillary porosity does not reduce and that is why this became straight line.

How can we can control the permeability, let us see. Or permeation let me call it, because permeability is a relative measure. You can compare permeability of 2 concrete; whichever has got lower permeability is more durable. But permeation property let me see. This permeation property is a function of porosity, because larger the porosity flow path the area available. You know constructional area available for flow to take place would be more. But it is also important the pore sizes, because you know the flow is a function of the pore sizes r, the radius of the pore or diameter of the pore sizes are important.

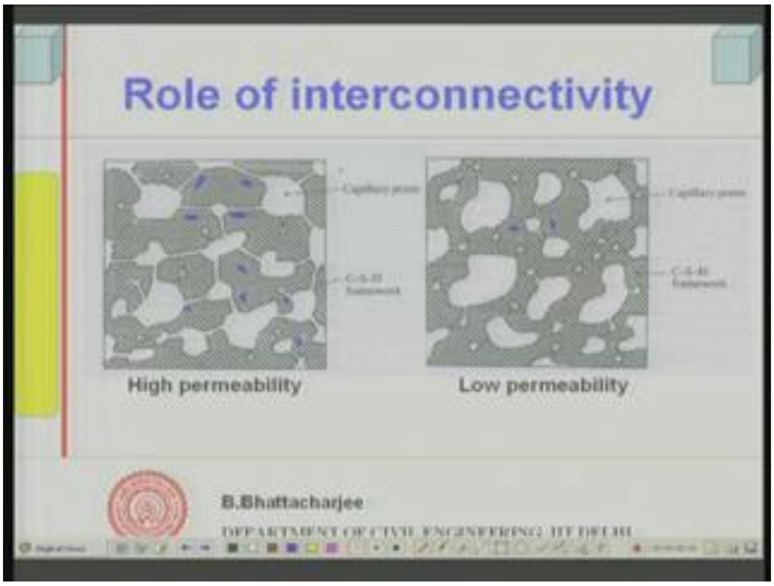
So, Sizes are important in strength also, because we have seen that strength is inversely proportional to large size, critical stress was inversely proportion to size. So, it is also important here, sizes are important. Then the shape should also be important here, because you know the flow would also depend upon this. But more important is interconnectivity, because pores in concrete are, you know their paths are. So, we talk in terms of, this is the L and actual L is- for example, L actual let me call it. So, tow would be L a divided by L.

So, this is also important, how long the path is right. So, this porosity, pore size, shape interconnectivity etcetera, actually they govern the ingress of fluids through the concrete. Therefore, these are important parameters.

Porosity is again the important parameter as far as durability is concerned. So, pore properties and porosity if they are directly related to water to cement ratio. In fact, pore sizes their interconnectivity, they are all related to water to cement ratio. And that is why 1 should control the water cement ratio to get better durability. Now there is additional thing. If you remember when we talked about curing, we said that curing results in segmenting the capillary porosity. I mean in other words, if you do not do the curing properly, pores may not be segmented. There are minimum number of days require to segment, minimum number of days of curing required to ensure segmented capillary system.

If you remember; 0.4 water cement ratio requires 3 days. And we said that, if the water cement ratio is more than 0.7, even if you do water curing for 1 year, well it is not going to segment the pores. You know segmentation of the pores will not be achieved. So, curing days and low water cement ratio, you know sufficient adequate number of curing days. If you do not cure, the capillary will not be segmented even though you have got low water cement ratio. So, this is what is observed in the next diagram.

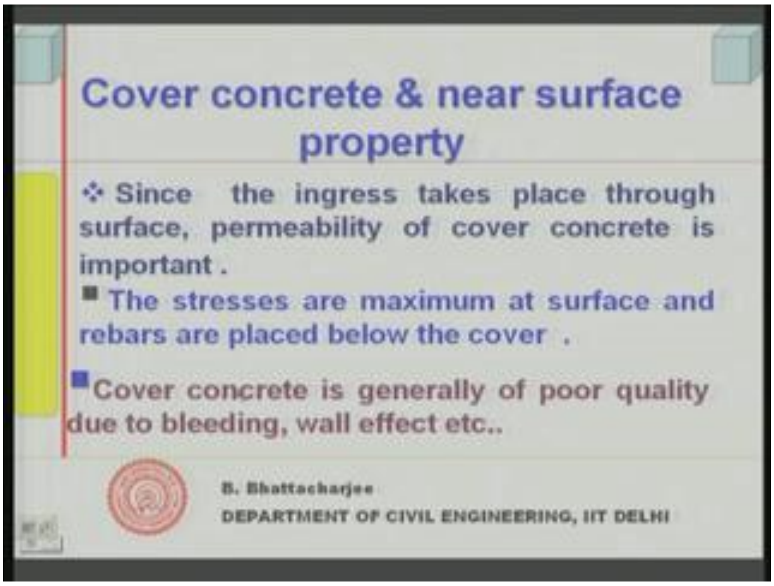
(Refer Slide Time: 31:56)



As you can see you know this 2 diagram shows pores having t pore systems having similar porosity. They have porosity values not largely different. But in this case they are all connected porosity. There is interconnectivity, they are not segmented pores. These are all actually here you can see they are segmented. This has become smaller and this has become smaller, so, some pores have reduced. And in other words it has got segmented, some of the pores are just finishing. All the total porosity by and large will be same.

So, this will be much low permeability then high permeability. This actually tells us the importance of curing with respect to durability as well. So, if, you do not do proper curing, the durability cannot be ensured, because segmentation of the capillaries would not be there. So, this is what it is role of interconnectivity.

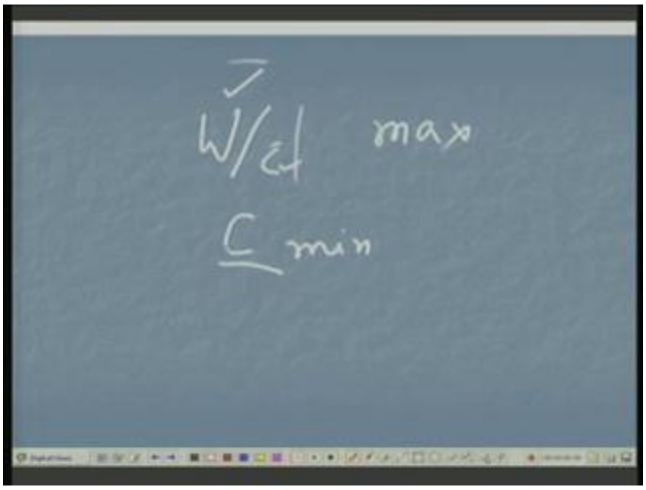
(Refer Slide Time: 32:47)



So, what we have seen that, water cement ratio plays a major role. But 1 point we did not mention actually is the cement content, because cement content ensures proper compaction. In case of Sulphate attack, it has been found that higher cement content shows better resistances to our Sulphate attack. In other words high cement content you may talk about, high fine, amount of fines, fines of the cement size they ensure better compaction. They also ensure release of right kind of say alkalis in case of p H etcetera. But more important is the compaction part of it.

So, cement content is also important from compaction point of view or cement content that should be. So, they are important from and second issue is; when you have minimum cement content for normal mixtures, workable mixtures ensuring a water cement ratio and the minimum cement content ensures sufficient amount of water content as well.

(Refer Slide Time: 34:01)

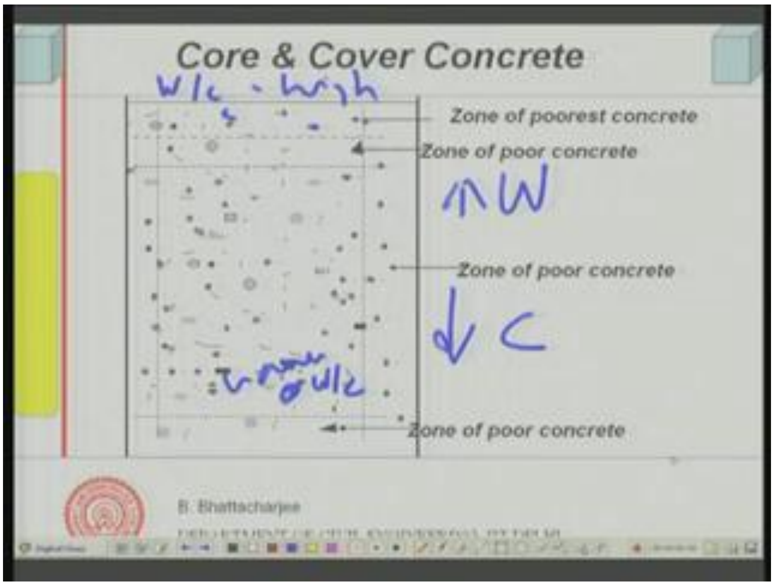


Because if I am fixing up water to cement ratio minimum, maximum. This I am fixing up a maximum, you know water to cement ratio max I am fixing up and a C minimum I am fixing up. So, I will ensure sufficient amount of water as well, because this maximum is fixed into some value and this minimum is fixed at some value. So, I will have minimum cement correspondingly, I can you know the amount of water is also ensured for and compaction is ensured by total minimum quantity of C.

So, when this, this all this put together actually ensures that, I have sufficient compaction achieved into the concrete. So, this is what it is. So, we can ensure that, there is sufficient amount of compaction achieved into the concrete when you have minimum cement content and also maximum water cement ratio. But 1 more important issue is surface concrete. Surface concrete is not at the same, is not same as the other concrete, because you see first thing ingress takes place through the surface and also stresses are maximum at the surface, because you know bending stresses will be maximum at the surface. That is what we have seen. When a beam bends, bending of the beam takes place. Let us say when a beam bends if you are looking at bending of a beam right. So, after bending the beam would be something like this. And bending stresses; tension is maximum here compression is maximum here. So, stresses are maximum at the surface.

Similarly, t stresses will also will be maximum at the surface. So, whenever you have non-uniform stresses; stresses are maximum at the surface and concrete cover is also there. Concrete cover is also you know, I mean the reinforcement is also there. So, what we see ingress takes place through the surface and permeability of cover concrete is important. The stresses are maximum at the surface and rebars are placed below the cover. So, therefore, cover concrete is very, very important, but cover concrete is not generally good, it is somewhat poor quality, because of bleeding wall effect etcetera. Let us see in the next diagram.

(Refer Slide Time: 36:29)



We can see if this is my concrete, this concretes these are the zone of poor concrete why, because this places the wall effect etcetera comes into picture. So, concrete is not compacted as well as this. Similarly, this zone again concrete will not be as good as well packed compact will let us say this point. But another issue is there; obviously, water cement ratio will be minimum here, because cement will have a tendency to come down and water tendency to come up.

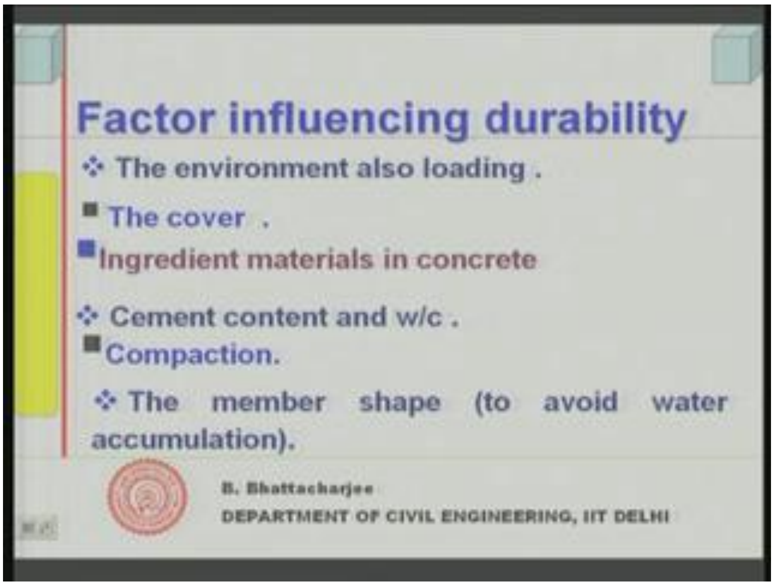
So, this results in formation of further zone of vast concrete, because zone of vast concrete comes up here at the top portion. Since the water as a tendency to move up, water and cement as a tendency to move down, these places will have higher you know lower water cement ratio lower water cement ratio water to cement and this will have highest W by C high.

So, therefore, I will have this is inherent in concrete. I mean I can reduce it down, but this is generally inherent in concrete. I can reduce them all. And this we have discussed in connection with non destructive testing also. So, water will have a tendency to come up. So, this is a zone of poorest concrete, these are the zone of poor concrete and what are the zone of good concrete.

Let us see the zone of good concrete is somewhere here. So, zone of good concrete is somewhere here. So, we see that concrete you know properties are poorer in the surface. However this surface concrete is the most important concrete for durability. This is poorer you know poorer concrete you see in the surface. But the surface concrete is the most important for durability.

So, whenever we are talking of water cement ratio for durability, we can just talk about the surface concrete. So, if you have means for improving surface concrete, then that would serve a better purpose. In fact, modern day we have- some sort of means called control permeability former c, which can actually improve the water cement ratio, reduce down the water cement ratio of the surface concrete. Anyway that is that is not part of our discussion at the moment, but that is what it is…

(Refer Slide Time: 38:42)



So, so far then we have seen the surface concrete effects. That is 1 thing we have seen, but we have seen more importantly the porosity, pore interconnectivity and pore properties control the concrete durability and this can be controlled through water cement ratio and also through somewhat through cement minimum cement content.

Now, what are the factors which affect the durability? First of all environment and sometime loading also, environment means if you are in exposure to marine environment; obviously they are you have got to take more care because it will not be, just any concrete will not be durable; you have to have specific concrete there. Also loading; although loading is not much discussed, but you see fatigue loading is more problematic than static loading. You know concrete when concrete is exposed to a fatigue loading repetitive loading, then cracks can come at much lower stresses. And therefore, in such exposure condition 1 as to take extra care, because concrete may be cracked.

So, fatigue loading is an important issue. Static loading is gets dangerous and environment of course, is very important. The cover is very, very important. Concrete quality is one thing, but the cover is very, very important. The depth of the cover, the quality of the cover; both are important. Then: ingredients materials in concrete. Now ingredients should not have any material, which can cause durability problem. I mentioned about presence of chloride in concrete. So, chloride should not be present in concrete from the ingredients or any other material which can create problem. For example, aggregate prone to potentially prone to alkali aggregate reactivity should be there.

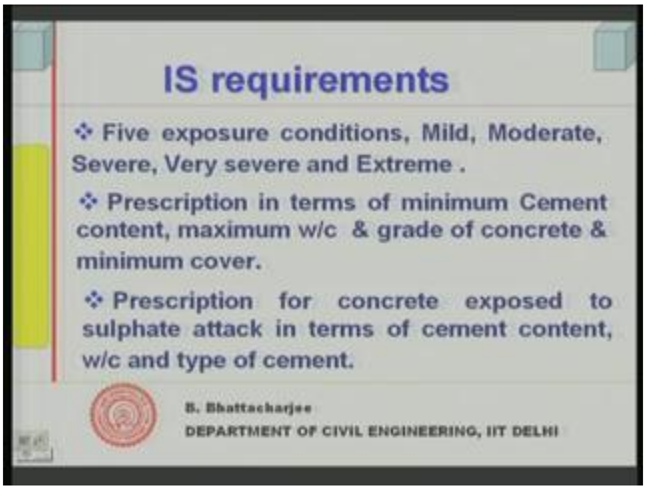
So, ingredient itself should be first of all proper so that, you know it should become a durable concrete. But then you can use additional ingredients like cements. You can use appropriate cement for the appropriate environment. So, ingredients materials in concrete they do affect the durability of concrete, you can choose them accordingly or reject whatever is not desirable. Obviously we have seen the most important parameter is cement content and water cement ratio. And finally, the compaction of the concrete achieved at site.

The member shape is somewhat important, because it should not allow for you know avoid water accumulation because; what we have seen is it is the water which is the main culprit as far as durability of concrete is concerned. If, the water cannot penetrate into the concrete no durability problem will be there. Main thing is ingress of water in whichever form. Now, this ingress since concrete is you know unless it is a very high strength concrete and very low porosity concrete. If, it is continuously let us say in contact with water, there would be tendency for water to penetrate into the concrete, because there is a constant hydraulic pressure unless you have specifically taken care of that hydraulic pressure. For example in hydraulic structures, you specifically take care of that you know make the concrete in such a manner that even in presence of water the moisture ingress to it will be much less, so that is why designed.

But supposing consider a roof slab or something of that kind, its shape is such that it always cause accumulation of water or even you know improper construction which allows water to accumulate because the slope has not been proper, the draining is not proper, say in case of where you know domestic toilet or bath, where if the slopes are not along the right direction, not along the direction of the track so that the water actually drains off, it can result in water accumulation. And subsequently since the concrete used there is not very high, you cannot use that way because it will be very costly. So, the water would penetrate into the concrete and making it susceptible to various kind of degradation process.

So, shape of the member, their construction practices; they are very, very important, from that point of view so that water does not accumulate. This strategy for durability; obviously, as to be cost effective, you know that we can make the surface impervious by means of coating, by putting various kinds of coating, by putting possibly extra layer of different layer of concrete, but the economics may not justify this. Best way is to make a good concrete ensure the concrete as per our co-practice which has come from experience, ensure that has been adaptive properly and that would make durable concrete. So, this is the basic overall structure.

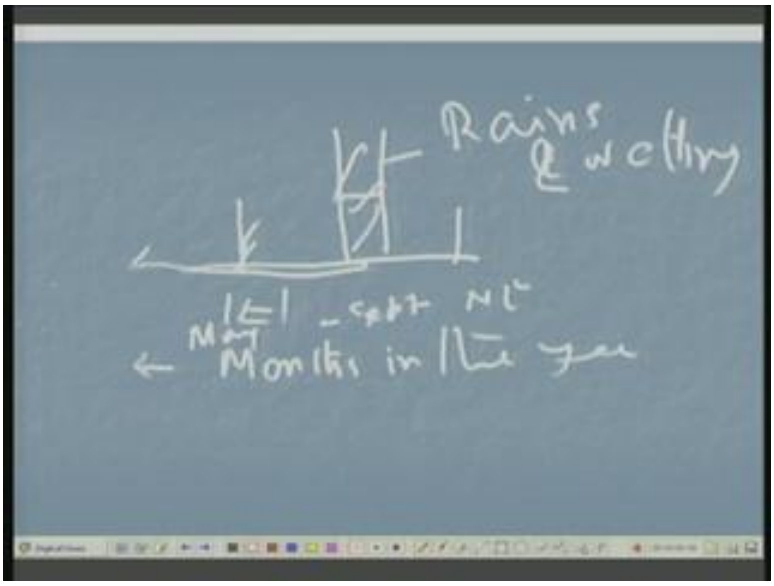
(Refer Slide Time: 43:44)



Now, that is why the Indian standard code of practice what it does. It has actually classified the conditions. I said the environment affects the durability. Since the environment affects the durability, the environment has been classified into 5 exposure condition. That is mild, moderate, severe, very severe and extreme. We will try to define them somewhat. But this is as been you know this has been taken actually from international experience. Generally the exposure condition that would be encountered in a tropical climate is 1 can define them in terms of the climatic condition, because mainly know again the water and possibly the environment like marine environment and so on.

For example wetting drying plays a big role in case of in case of durability. Now, that would depend upon the rainfall pattern. So, the classification of course, is valid for those sort of situation also an exposed structure, continuously exposed to wetting and drying, but again just wetting drying; the wetting drying cycle in details. If, 1 looks into the details, wetting drying cycle would be quite different in different places. For example I will just give the example before we come back to the details of the highest code requirement.

(Refer Slide Time: 45:29)



Say cycle of wetting drying that 1 would encounter in say north east of the country you will have you can have, if this is the concrete surface, you will have large period of waiting, you know large, because monsoon period if this is the months in the year. The monsoon months are much larger in north east; you know it will be all this would be monsoon months say starting from May to September would be monsoon months in north east.

But if you come to let us say in composite monsoon climate, it will be only small portion. So, in composite monsoon climate say Delhi it will be only small portion, where you will have rains wetting and wetting rains and wetting. So, depending upon the climate rains and wetting depending upon the climate, depending upon the climatic condition, the wetting drying cycle varies. So, 1 when 1 looks at details of this 1, then this classification can be even made into wider classification. But at the moment, since it is all prescriptive measures we do not have way to model durability problem. I cannot calculate very easily the service life. There are some empirical models for certain situations, But they are validity of them are not yet, you know they are not calibrated against real life experiences many of them.

So, therefore, we do not really calculate service life at the moment. But we have some sort of prescriptive measures. We say that you do not do this or do this and that kind of thing, so which we call prescriptive recommendation. And most of the codes all over the world go for prescriptive based recommendation and so does IS code as well.

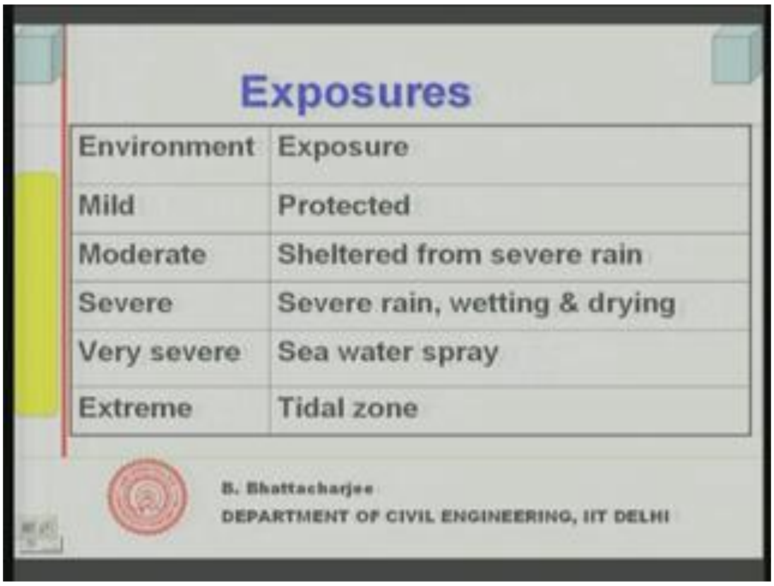
And that is why we have some prescription in terms of minimum cement content maximum water cement ratio and grade of concrete and minimum cover right, so the prescriptions are there. Similarly, if you have Sulphate, you know like- Sulphate environment with Sulphate, we have what type of forms of cement. What types of cement we should use in specific environment, what possible types; these are given.

So, codes at the moment are all prescriptive. Most of the codes in the you know with reference to durability are prescriptive, they are not performance based, because our understanding of the durability problem is relatively less as far as concrete is concerned. So, therefore, code provides prescriptions and we have definitions of exposure conditions like I said mild, I said mild moderate, you know mild moderate or very severe exposure or extreme exposure condition etcetera. And the prescriptions are given in terms of minimum cement content maximum water ratio.

But I would like to discuss a little bit about grade of concrete, because grade of concrete means when you have higher grade of concrete, obviously you are automatically ensuring the low water cement ratio and sufficiently high cement content. For a given workability, you are assuming a sufficient cement content. So, these are double check for low water cement ratio and cement content. Second way of looking at it the same grade of concrete could be different. Since you have already low water cement ratio you cannot get a low strength concrete, automatically you will get high relatively high strength concrete.

So, why not use higher grade of concrete, because otherwise 1 can use let us say M 20 grade of concrete in an severe condition. Supposing this clause you know this prescription was not there. This prescription was not there. So, in very severe you end up using let us say low grade of concrete, because in buildings you can do that and say M 20 grade of concrete, but your maximum water cement ratio is very low. Such low that automatically you will get the strength of concrete M 30, equivalent of M 30. So, then why use low grade cement. You know low I mean low concrete grade concrete; you use the grade of concrete also high. You can economize on the whole thing, so considering all these aspect, grade of concrete as been prescribed. Let us see what are the exposure condition and what are their prescription now.

(Refer Slide Time: 49:41)

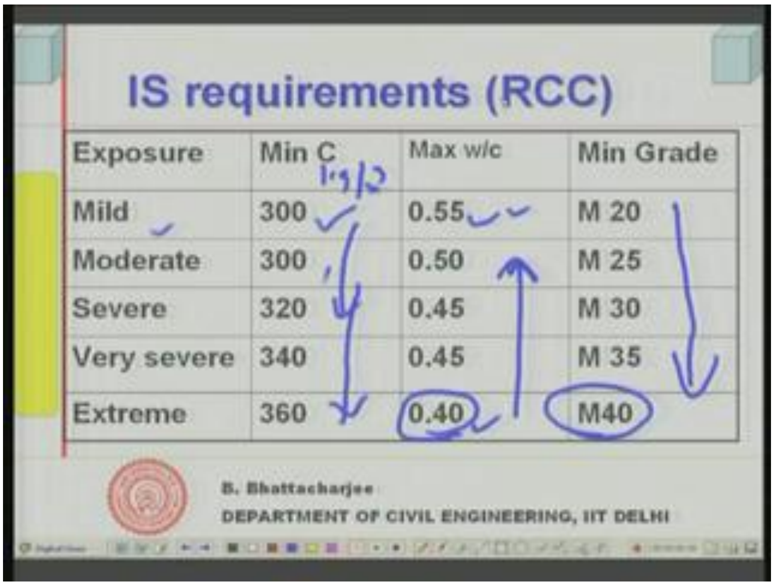


The exposures those are defined are some part of the exposures I have picked up and I am giving you just as an example. For example, the mild represents mild exposure is nothing but it is protected. Mild means it is protected, you know this is protected. So, its protected not exposed that is a mild exposure; obviously, you require, you can use low pretty low cement, you can go for highest water cement ratio here. And then moderate is sheltered from severe rain, not exposed to severe rain and more other conditions are also given.

So, just as an example it is taken to see that how it tends to change from protected you know mild to extreme. So, where as mild is protected, this is sheltered from severe rain This is exposed to severe rain and wetting and drying. This is exposed to sea water spray- spray and this is tidal zone, because wetting drying as got more effect as I mentioned. All processes some of the processes particular chloride ingress, wetting and drying plays much bigger role, because while wetting the solution also goes in and chloride is deposited there, while drying this chloride remains there and next wetting again chloride concentration increases.

So, wetting and drying plays more stronger role then simply continuously wet condition actually there will be there will be no carbonation and corrosion process also cannot proceed if it is fully saturated. If it is partially saturated then only all these things happen, corrosion can proceed in partially saturated concrete. So, that way if you have a submerged concrete R C C structure; that is less prone to corrosion compared to the place where actually wetting and drying takes place. That is why tidal zone is in the extreme as sea water spray which takes place in structure that is very severe. So, these are example from going from protected to the tidal zone very severe condition, you know extreme conditions and protection measures are defined accordingly, right.

(Refer Slide Time: 51:43)



This just as an example the elaborate actually code is quite elaborate onto that and 1 can look into the refer to the code table 5 of IS 456 2000 to see this sort of requirements that is given. Table 4 possibly or 3 defines the exposure condition and table 5 gives you this. Now in table 5 is given in this table is given the prescriptive recommendation. You see it says that, if you have a mild condition exposure condition, the minimum cement you should use is 300 kg per meter cube. Units are not given here; this is kg per meter cube. And maximum water cement ratio is 0.55.

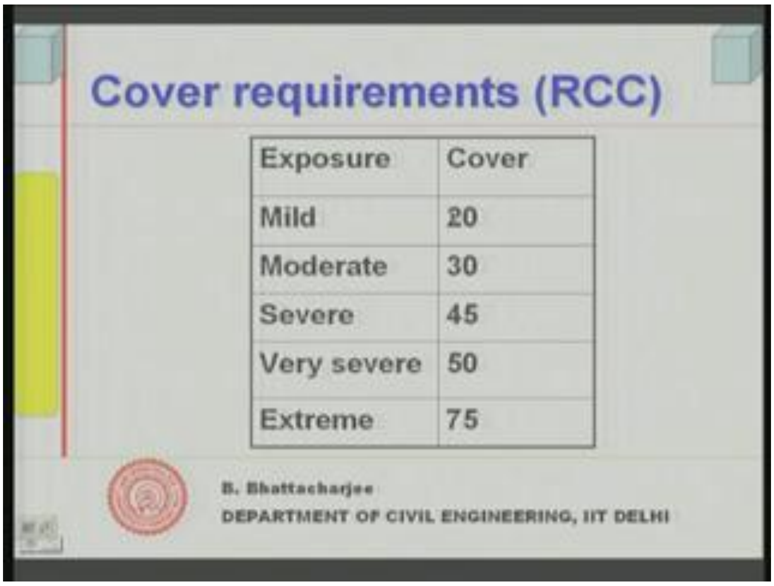
The minimum grade of concrete that you can use is M 20, moderate 300. So, you go this side, minimum cement content increases along this direction and water cement ratio increases along this direction. This is the least and this is the highest. And as I was telling you, if you have any way the maximum water cement ratio is 0.4, possibly the strength greater the cement, I mean you cannot you will not have the strength or the greater the concrete as M 20, you will automatically reach close to M 40. So, therefore, why not use the minimum grade M 40. This will ensure that you use this water cement ratio and possibly the cement content nothing less than that and you can use this in structured design and economize it also.

So, the grade you can see is increasing along this direction. The cement content increasing this direction whereas; water cement ratio is increasing along this direction. So, this is the recommendation of the code; Indian standard code I S 456 2000 as far as minimum cement content water cement ratio and minimum grade of concrete is concerned. But this is actually meant for ordinary cement. These ones are meant for ordinary cement. When it comes to cement and blended cement, you can use the total quantity towards the cement, it is not only the you know total cement you will consider, the p plus the cement, the slag plus the OPC content.

So, both can be used, but only with the restriction of to the fact that, the you can supposing you have added 50 percent all this 50 percent cannot be counted towards this cement minimum cement content, only that allowed in the relevant I S code, for example in case of it is 1429. I S 1429 which says that the what is the permissible amount of fly ash in cement so only that much. Quantity you can take for calculating the water cement ratio or minimum cement content.

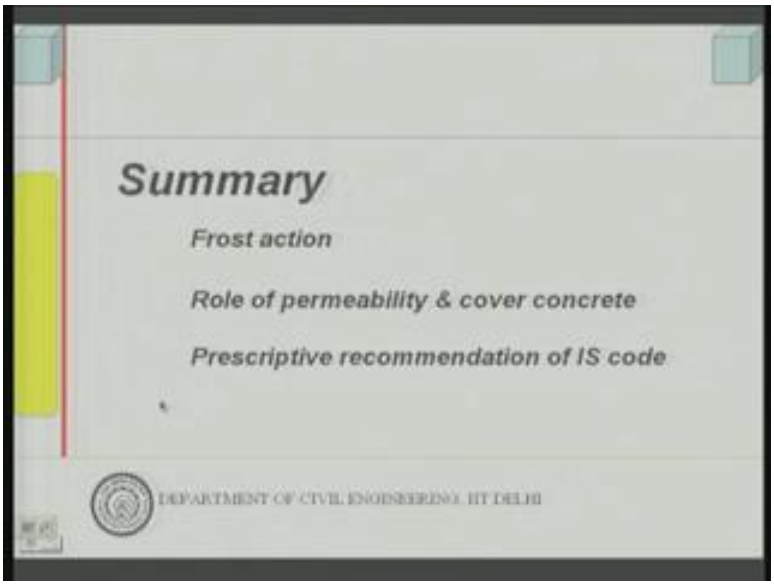
So, in calculation of minimum cement content, you can add up the ordinary cement content plus the content, subject to the condition the content should not exceed the maximum permissible in the relevant code. Similarly, GBFS generated blast furnace slag; you can take in this calculation, but subject to the condition that the maximum GBFS you are taking in calculating minimum cement is doesn’t exceed that permitted in the relevant code, that is, 455 I S 455. And this is the water cement ratio; in this calculation similarly you can take the cement content; cement plus the slag or depending, but and the slag content not exceeding the maximum permissible in their relevant code. So, that is what it is. That is what is the prescription prescriptive recommendation 456? The cover that is prescribed is minimum cover. For mild condition; minimum cover is general for durability.

(Refer Slide Time: 55:40)



Covers are also specified for fire protection etcetera. In column minimum cover of course, should be minimum 40 or it is related to the diameter of the bar also. But from durability the minimum cover required for service life, you know adequate service life is 20, moderate is 30 and as you go, this increases as we go downward. And this is understandable, because in a severe environment you must provide higher cover to the reinforcement bar; otherwise it would be affected by reinforcement corrosion. So, this is the prescription given in the code.

(Refer Slide Time: 56:22)



And we can now gradually summarize. The discussion on durability; similar table is also available for Sulphate, you know Sulphate environment where it prescribes the cement content minimum water cement ratio, maximum water cement ratio and minimum cement content. I just show it, because it is all available in the code. So, these are prescriptive recommendation, they are given in the code and in an environment given environment 1 must follow that. That is the current strategy for durable concrete.

Well, summarizing the durability therefore, this actually completes our discussion on durability of concrete. Today of course, we have looked into frost action, role of permeability and cover concrete and then prescriptive recommendation of I S 456. But you know durability still I would say in not complete in his research and requires lot of research. Overall discuss summarizing overall durability, we have looked into defined the parameters like service life durability etcetera. Then we have looked into all the degradation process. And then lastly we have looked into the durability strategy that is given in the code. And I think with this we end our discussion on durability of concrete.

Thank you. Thank you for being with us.