Advance Concrete Technology
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Lecture – 36
Performance based specifications for durable concrete

So in the last class we were talking about how the involvement of water is absolutely essential for the concrete durability problems to happen and the fact that most of the durability problems of concrete were interlinked with permeability of the concrete. So now permeability of concrete obviously depends on the porosity and both these factors depend on the water to cement ratio of the concrete.

We also discussed the fact that in concrete you can divided the section into 2 components one is the cover concrete and the other is the hard concrete. The cover concrete is the one which is subjected to deterioration in case you do not have curing which is done properly for your concrete and if you have any aggressive chemicals which are attacking your concrete from the external environment.

So, the properties of the cover concrete to a large extent determine the overall durability of the concrete.

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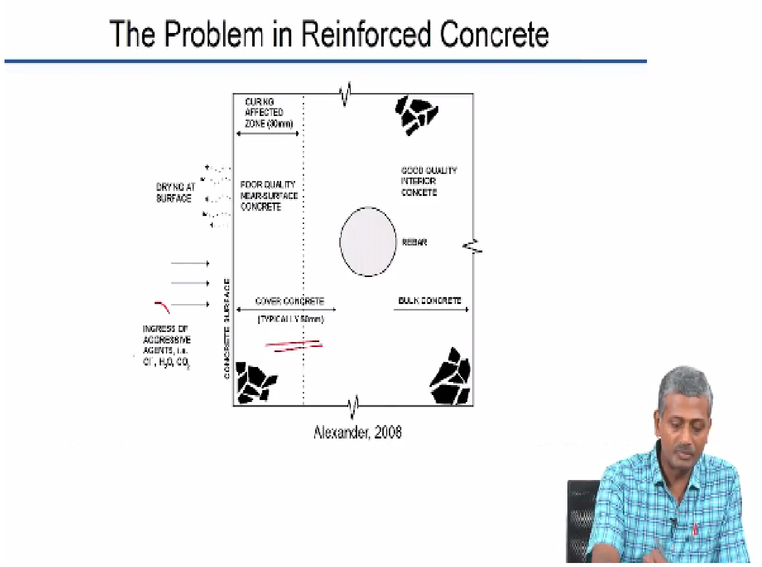

Again this is just depicted once more and this schematic diagram we have of typical reinforce concrete. So as indicated here the cover concrete is what is subjected to ingress of aggressive agents which involves chlorides, carbon dioxide or eve water and generally drying may happen at the surface as we discussed earlier it is difficult for water from more than 30 to 40 millimeter inside the concrete to really dry out of the concrete and in normal drying conditions.

So you can imagine that it is a cover concrete which is primarily subjected to durability related problems and for improving the characteristic of the cover concrete it is within our interest to do curing as long as possible to insure that cement hydration continues and the microstructure of cement develops in a proper manner.

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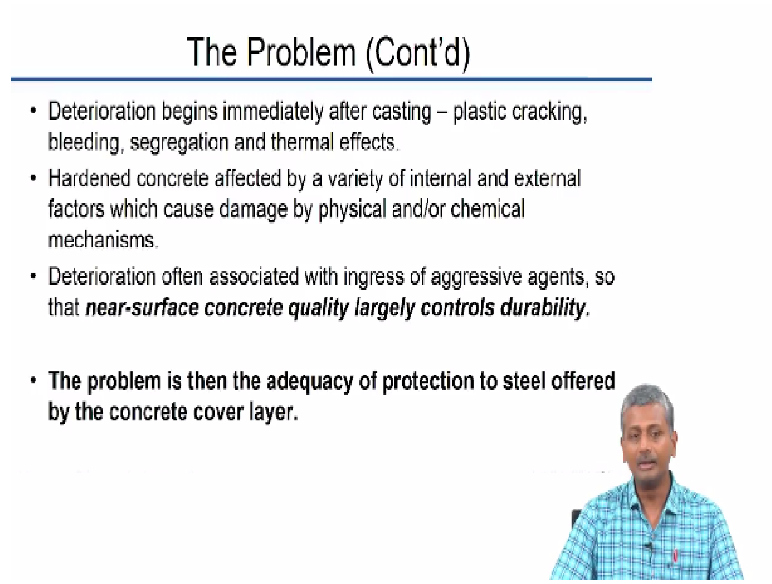

Now in general the problem of durability can be related primarily to the adequacy of protection offered to the steel by the concrete cover layer. So the cover concrete holds the key to durability and this is a concept that you will probably come across in most durability issues. And that primarily because the cover concrete is the one which is protecting the steel from further corrosion and why is the steel corrosion the primary characteristic which we need to worry about?

Primarily because steel corrosion unlike other durability problems in concrete steel corrosion has the ability to reduce the overall load carrying capacity of the concrete structural member. All the other durability related problems of concrete generally tend to deteriorate surface characteristics of the concrete or may be lower the surface hardness of the concrete. But they do not really have a great input towards the overall deterioration of the load carrying capacity of the member.

Whereas corrosion of the reinforce steel can really take that to a new level.

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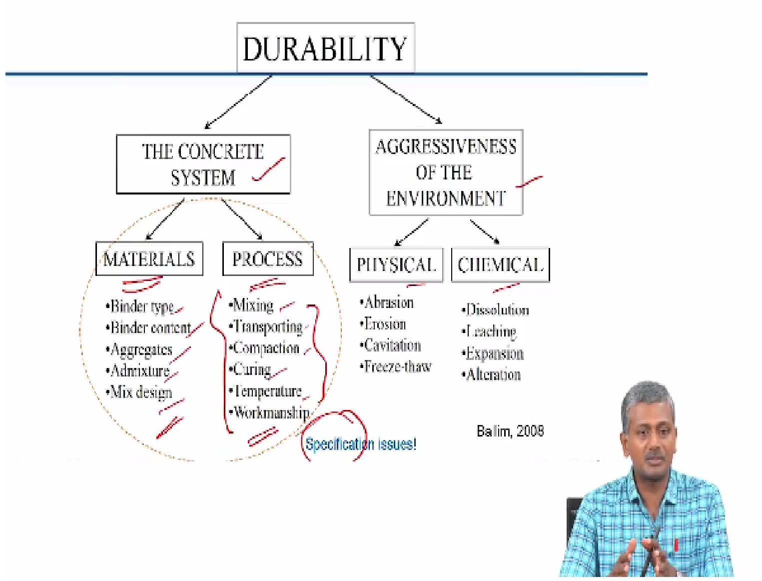

So, having talked about what is the primary reason for durability related problems in concrete let us look at how we can divide durability and look at it from a different perspective. So of course you know that durability is composed of the concrete system and the aggressiveness of the environment. Now we have to design concrete for a specific environment based upon the kind of physical and chemical deterioration mechanisms that are actually acting in that environment.

The requirement for concrete mixed design for a costal environment is obviously different from the requirements for an inland environment. And we have to have some idea about how to do material selection in these conditions. So based on that we workout the requirements of the concrete system itself which are composed of both materials that we use for making concrete including binder type, content of binder, the aggregates, admixtures that are used.

As well as the mix design that we ultimately do in this particular environment. But what we usually do not control in a direct manner is the process of actually putting together the concrete structure. And this process involves the mixing the transportation, compaction, curing, temperature of the concrete and finally the workmanship on the site. So, in another words what we are trying to convey is what is there on paper does not always make it in the structure.

You may always get perfect specimens but the concrete inside the structure may be not be of the same quality as we get in the specimens that are cast and cured in ideal conditions. Because of all these factors that are actually affecting the properties of concrete over and above the actual material that have been selected carefully by a proper mix design. Now how do we address these using specifications that are the primary challenge that we deal with.

As far as controlling concrete quality in actual construction is concerned. So a specification typically tells you what? What is the job specification telling you? When you have a specification let us say for the construction of a foundation for a building with respect to concrete what does the specification tell you? **"Professor - student conversation starts"** What has to be done? How it has to be done?

That is very general term. If you can be more specific, in terms of the methodologies and in terms of the guidelines to be followed what do most specifications end up doing? It will mostly code standards and code or coded requirements will be primarily used to convey the message that this has to be done this particular manner. Now the problem is that the codes are only an enabling document that means the builder can make use of the codes to build.

Something when there is no prior information available on how to build it. The codes are not the end all. There are lot of things a lot of information is actually not there reflecting the codes. Because codes are supposed to be understood at an equal level by all practicing engineers. But to incorporate some of the aspects that define concrete durability. It is not probably not enough to actually just follow the (()) (05:53) requirements.

We will discuss this in more detail later because mostly what happens is 3 is no indication in the codes as to what durability test should I carry out to detect if my concrete is going to be durable or not. It just tells you okay here is a prescription this concrete will be durable in this particular environment if you do all these things right. The problem often is that we do not end up doing all these things right. So how do we address this in the specification?

To go and check whether the concrete quality and structure is to the extent that we want and we had said on the paper itself. Now let me give you an example. Let us say we talk about cover depth so the code says that for a particular service environment you have to have a certain cover depth, minimum cover depth. So, as per that the specification tells you that you should use appropriate cover blocks to get that level of cover.

Now, you use the cover blocks but your process of compaction or vibration is not sufficient and your formwork is not placed properly because of which the cover blocks get dislodged and the actual cover that you get in the structure is much less then what you set out to have in the first place. Now what do you do? You did as per the specifications. You followed the codes but now you actually have the structure where the structure is not meeting the requirement.

So, how can you tailor make the specification to address that requirement? What can you do? **"Professor - student conversation ends".** So there are methodologies for non-destructively measuring the extent of cover to reinforcing bars. So why cannot the specification say okay after the construction is done? Show the measurement of cover on at least 5% or 10% of the locations selected randomly and see whether the cover is actually satisfying the requirement of the design.

And that is why the specification actually can bring out these aspects which cannot be aptly covered by any coded recommendation. The codes can only tell you okay use at least so much cement. Use maximum so powder cement ratio and so on. It cannot tell you that okay after the concrete has been cast do this test to determine whether the actual structures matching the requirements of your design.

And that only can be done with the help of the specifications. So a lot of the control of the durability today is being brought about by the use of appropriate specifications. But the issue of specifications is a complex one we will talk about that about as we go along in this chapter.

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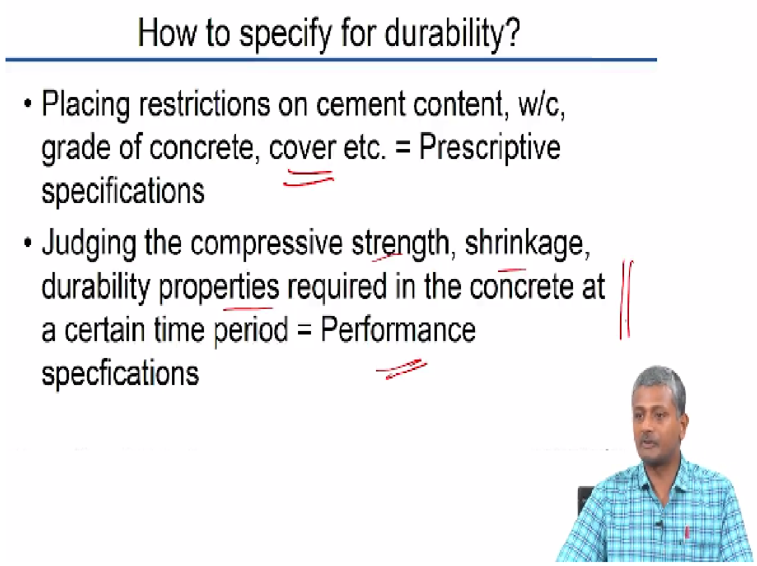

So how do be specify for durability? One way is to simply prescribe or place restrictions on cement content, water to cement ratio, grade of concrete cover and so on. So cover here is a prescriptive requirement because the court says that I need to have so much cover in such an environment. It remains a prescriptive requirement unless you go back and check it in the structure and show that the actual cover is equal to your design cover.

Or at least it is equal to it with some standard deviation which is not too far from the actual cover. So only when you measure it becomes a performance requirement. So judging the compressive strength shrinkage and durability properties required at a certain time period these amount to performance specifications. Even measuring the cover after the construction is done is actually an example of performance specification.

So, specifying for durability can be done in both ways the issue is whether we are able to completely tackle the problems that are associated with performance specifications I will talk about that in some detail now.

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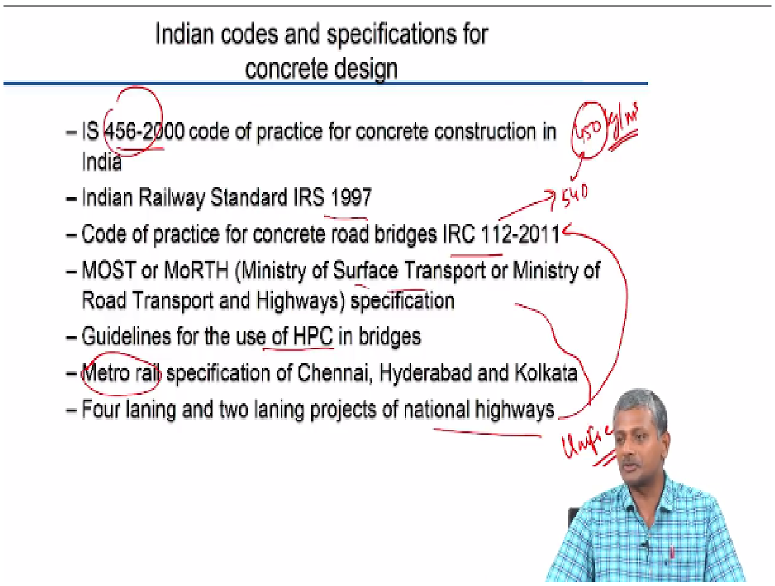

So if you look at Indian codes and specifications for concrete related structures you have the IS 456 that looks at plain and reinforce concrete buildings. You have the Indian Railways Standard IRS 1997. You have the road bridges IRC code 112. You have several specifications from the ministry of road transport and highways as well as the guideline for use of HPC high performance concrete bridges.

You have metro rail specifications which are independently drafted for different cities where the metro rail work is being carried out. And then there is national highway 4 laning work which again comes up with its own specifications for the concrete. Mostly they are linked to the Indian Road Congress because most of the concrete is being used in the bridges and crossing and so on and so forth.

Mostly the structures are built with asphalt concrete but wherever reinforce concrete is used the IRC regulations are probably applying in those specifications. So now we do not really have requirements for concrete set forth in a unified code in our country. And because of that there can be a lot of confusion now just one point of confusion for example in IS 456 the maximum cement content is prescribed for 450 kilogram per cubic meter, maximum cement content.

Why is that prescribed from what perspective? Shrinkage and thermal stresses may be very high when you have too much cement present in your system. So the code tells you that you should restrict your cement to 450 but for the same maximum cement content requirement in IRC 112 is 540. No it is not a misprint. It is 540 its not 450 misprinted as 540. It is 540 and they say that in a bridge structure you can have as much as 540 cement.

Sometimes the demand for strength gains are very high in bridge structures and because of that the IRC is still permitting 540 kilogram of cement per cubic meter. But then the concept is still the same if you have the higher cement content it is obviously going to cause you greater potential for cracking due to thermal and shrinkage effects. So why is not the number the same? Why is there this difference? Where do you apply one or the other?

Obviously, we will choose bridge structures you will be applying IRC but then does not the same logic apply that would fix the cement content automatically at 450. So there is a lot of confusion and especially when you start having these specifications that are made by the highway agencies and by the metro rail agencies. They tend to follow one or the other and it ends up in lot of confusion.

So there is no clear understanding of why this is being done and why we should apply it in the first place so because of that there is a need for a unified code in the country. Unfortunately that will be a dream all the time because most of these (()) (12:09) committees are having their own stalwarts who have been heading these committees for years and years decades. So because of that we will not really see the unifying of all these codes.

Because of which there is still be some confusion in the minds of engineers. Never the less, proceeding forward just looking at the IS-456.

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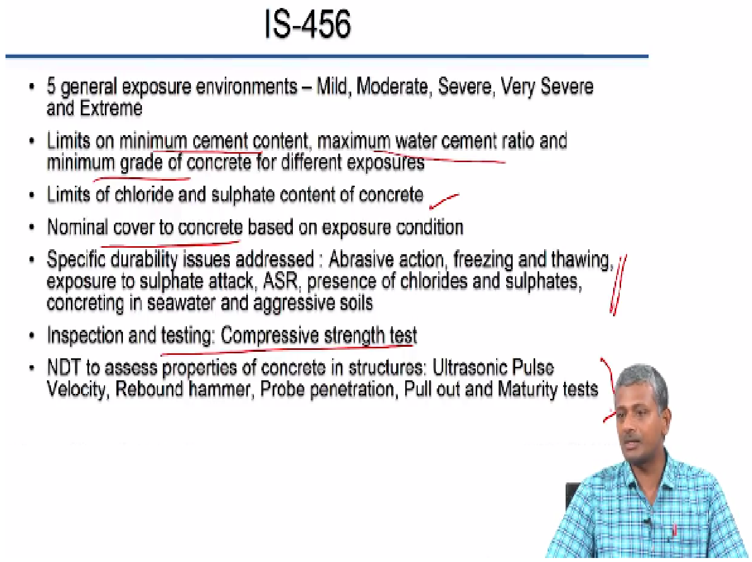

If you look at durability and how it is addressed there are generally 5 exposure environments as far as chloride exposure is concerned you have mild, moderate, severe, very severe and extreme. Generally, what we come across is limitations which are placed on minimum cement content, maximum water to cement ratio and minimum grade of concrete for different exposer conditions. Of course this is an over kill because if you really think about it prescribing 2 of these should be enough.

If you have water cement ratio your strength is anyway automatically sort of fixed and then you have cement content. There is no clear link between cement content and strength but then in general for moderate levels of cements if you increase the cement content the strength usually goes up at a fix water content. So then you have probably specifying all 3 of them is more of an overkill as far as the codes are concerned.

But never the less we have it like that most international code which use prescriptive specification also specify all 3 values. There are limits on chloride and sulphate content of concrete. Of course we do not want internal sources of chloride and sulphates which will create problems. Nominal cover to concrete based on exposure condition as defined and specific durability issues that addressed include abrasive action.

Freezing and thawing, exposure to sulphate attack, alkali silica reactivity, presence of chlorides, concreting in seawater and aggressive soils. So, all these are addressed in one way or the other in the code. But there is no specific way of addressing them there is just general requirement of the concrete which have been defined for these different durability problems. The inspection and testing is based entirely on compressive strength.

There is no mention of conducting any durability related tests to actually ascertain the behaviour in these different environments. And of course they also talk about nondestructive testing to assess properties including ultrasonic pulse velocity, rebound hammer, robe penetration, pulls out and maturity tests. So, several tests are covered but nothing points directly to the durability of the concrete.

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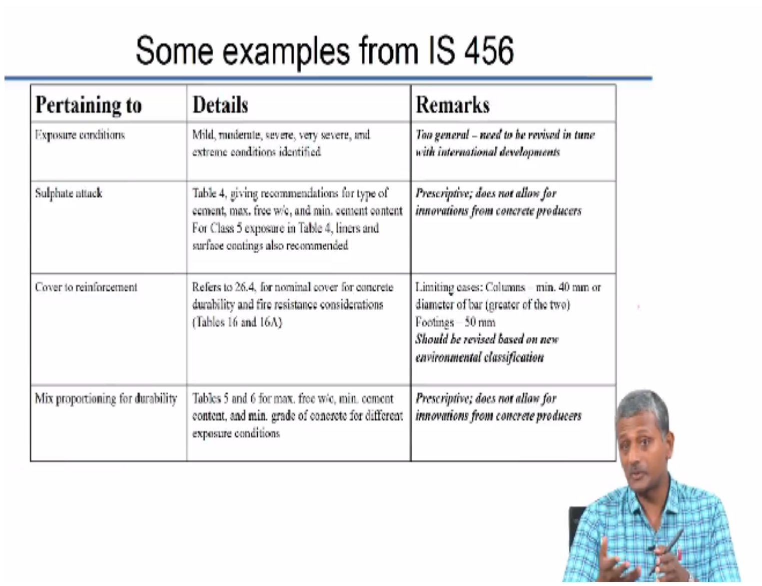

Pertaining to	Details	Remarks
Exposure conditions	Mild, moderate, severe, very severe, and extreme conditions identified	*Too general – need to be revised in tune with international developments*
Sulphate attack	Table 4, giving recommendations for type of cement, max. free w/c, and min. cement content For Class 5 exposure in Table 4, liners and surface coatings also recommended	*Prescriptive; does not allow for innovations from concrete producers*
Cover to reinforcement	Refers to 26.4, for nominal cover for concrete durability and fire resistance considerations (Tables 16 and 16A)	Limiting cases: Columns – min. 40 mm or diameter of bar (greater of the two) Footings – 50 mm *Should be revised based on new environmental classification*
Mix proportioning for durability	Tables 5 and 6 for max. free w/c, min. cement content, and min. grade of concrete for different exposure conditions	*Prescriptive; does not allow for innovations from concrete producers*

Some examples from IS 456 has been captured in the stable and the remarks has been given in terms of trying to assess what is the short coming that need to be addressed to make it little bit better in tune with the current international regulations. IS 456 we know that last it was modified in 2000, 2000 implies that information and IS 456 is possibly from 1995 because it takes a long time to actually write the codes.

So we are still working on information that is derived in 1995 world over specially in Europe the EN 206 the codes for concrete they have been rewritten and adopted by various countries as their national standards and these are more recent and probably a lot more relevant for their respective concrete construction practice. So there are lot of remarks that have been put in the last column here primarily looking at what are the short comings with the kind of durability treatments.

That have been done in IS 456 and what is the way forward. So this is not something which we will discuss in detail please read this on your own.

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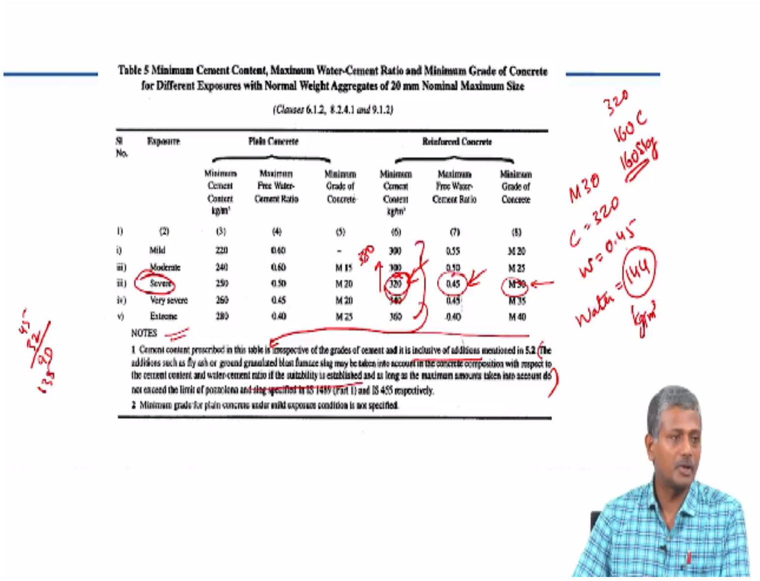

Table 5 Minimum Cement Content, Maximum Water-Cement Ratio and Minimum Grade of Concrete for Different Exposures with Normal Weight Aggregates of 20 mm Nominal Maximum Size

(Clauses 6.1.2, 8.2.4.1 and 9.1.2)

Sl No.	Exposure	Plain Concrete			Reinforced Concrete		
		Minimum Cement Content kg/m³	Maximum Free Water-Cement Ratio	Minimum Grade of Concrete	Minimum Cement Content kg/m³	Maximum Free Water-Cement Ratio	Minimum Grade of Concrete
1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
i)	Mild	220	0.60	-	300	0.55	M 20
ii)	Moderate	240	0.60	M 15	300	0.50	M 25
iii)	Severe	250	0.50	M 20	320	0.45	M 30
iv)	Very severe	260	0.45	M 20	340	0.45	M 35
v)	Extreme	280	0.40	M 25	360	0.40	M 40

NOTES

1 Cement content prescribed in this table is irrespective of the grades of cement and it is inclusive of additions mentioned in 5.2. The additions such as fly ash or ground granulated blast furnace slag may be taken into account in the concrete composition with respect to the cement content and water-cement ratio if the suitability is established and as long as the maximum amounts taken into account do not exceed the limit of pozzolona and slag specified in IS 1489 (Part 1) and IS 455 respectively.

2 Minimum grade for plain concrete under mild exposure condition is not specified.

And I just wanted to you show you this table from IS 456 as far as chloride exposure condition is concerned. So we have 5 different exposure conditions for which the requirement of the water cement ratio, cement content and grad of concrete are given for 5 different environments here. So let us just pick one for example the severe environment and the description of the environment also is given in the codes.

It tells you that severe environment basically is what type? Concrete which is made in the costal environment now what is costal environment? There is no clear definition of that. So we have to assume that it is something which is near the cost. How near? Again its left to interpretation that is not a bad thing we have to make sure that the engineer applies his or her mind to this situation to say whether the current project comes within the coastal zone or not.

But very often it makes sense to actually put a guideline as to what should be considered as the end of the coastal zone. Now CPWD has a nice regulation which say that anything which is 10 kilometer away from the coast or within 10 kilometer from the coast is considered coastal. So let us say that we apply that (()) (16:38) here. The concrete can be designed for any grade that is required for the structure but that grade should be fixed at a minimum of 30 megapascal, M30.

That means when we are in the severe environment we cannot design concrete for buildings which is less then M30 if it is reinforce concrete. Now you go out and see the kind of construction that is happening across the city you will probably find only 10% of the projects actually have a strength grater then M25. Although we are in the sevier environment in Chennai most of Chennai comes within the coastal region even if you take the 10 kilometer distance.

From the coast as a boundary still only about 10% of the structures in the city are probably following this regulation strictly. Because most builders do not really require strength greater then 20, 25 megapascal for the concrete. Concrete is simply sitting there filling the space it is mostly the steel that they put in the structures which take up the structural look. But unfortunately because the concrete is not as the quality that is desired you can lead to durability problems.

So, when you are in the severe environment M30 is the minimum that you need to have. Of course once you decide that and you fix your water to cement ratio as less than .45 then this cement content requirement usually goes out of the window because very few builders or very few concrete producers will actually produce this grade of concrete with as low a cement as 320. Now there are practical implications.

Let us say I am designing M30 concrete and I want to keep my cement content to the bare minimum prescribed by the code. I say I am using M30 have the cement content of 320. I have a water cement ratio I am maximizing it at .45 so what is my water content? .45 multiplied by 320 how much is that? 144. Now at 144 kilogram per cubic meter of water unless you use a very high range water reducer like a PC based superplasticizer, you are not going to get any workability.

If you add water you already disqualify the concrete from this requirement. So you have to have a water reducer. Now that means you cannot keep this level of cement in your system. So you automatically have to up the cement content probably you may go up to 380 when you go up to 380 at this water cement ratio you will probably have enough water to work with a lower grade superplasticizer like an S and F and even if you go for 400 cement.

You probably will have enough water to not use any admixture which is what is there in most specifications that is used in residential concrete construction. In those case people do not even use admixtures. When they are using RMC or ready mix concrete obviously they are using concrete with admixtures which is probably optimized with respect to cement content and so on. But people who are mixing on site most of them are not using any admixtures.

They may be using 400 kilogram per cubic meter of cement which makes it 180 kilograms of water probably with sufficient to give you the required workability. But then what are you doing when you are changing he mix like that you are probably not having an optimal concrete mix at all for a grade of 30 megapascal you have used 400 kilograms of cements probably overshooting your cement requirement by several 10 of kilograms.

So, what I am trying to say is this guideline is taken on a face value by the construction agencies. What you also need to understand is that the cement content is inclusive, is irrespective of the grade. So whether it is 43 or 33 or 53 the same number applies and as inclusive of addition mentioned in clause 5.2 of the IS 456. Now inclusion mentioned in 5.2 include slag, fossil and fly ash (()) (20:47).

So that means you can use any of these materials as a replacement for your cement and bring down the extent of cement actually that is being consumed at this project. So you can actually make this 320 with 160 cement and 160 slag that is perfectly allowed as per you course. Only thing is often people who do not believe in alternative materials start talking about this next line that is written addition such as fly ash or GBS may be taken into account.

In the concrete composition with respect to cement content and water cement ratio. If the suitability is established and as long as the maximum amount is taken into account do not exceed the limits specified in their individual course. That is okay that means for fly ash we cannot go more than 35%, for slag we cannot go more than 70% but then how do you establish suitability? What is the test method with which you establish suitability nothing?

As far as the code is concerned it is only the strength and the workability so how do you establish suitability for durability in a severe environment with just the help of prescriptive specification. You cannot. So obviously there is a need here to specify okay if you want to establish suitability to this test and show that your value is coming within this limit and then you concrete can be deemed to be (()) (22:10).

So that is what is lacking in the code. It does not really tell us as to how we can establish the suitability. It gives us a way forward for using metal admixtures but it does not clearly tell us how best to adjudge whether the concrete quality will be as good as the one with plain portland cement.

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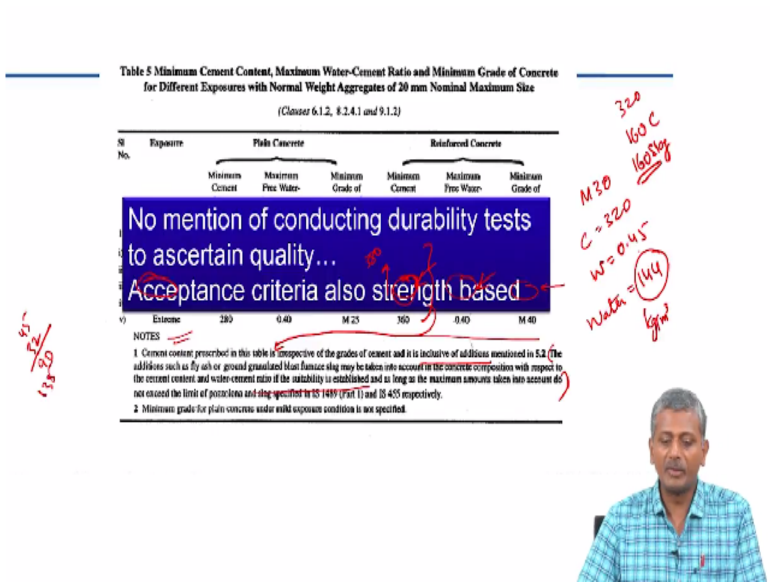

So there is no mention of conducting durability test to certain quality acceptance criteria as I said before is just based on compressive strength.

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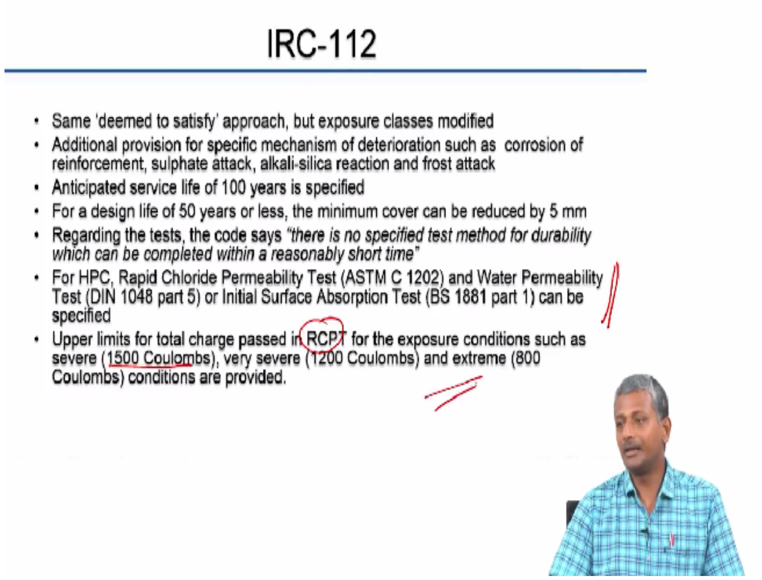

IRC 112 goes one step forward because it is meant to be that design guideline for concrete for bridges where generally higher performance concrete is used. So here they do have a specification in terms of RCPT, water permissibility and initial surface absorption test. They give values for is acceptable what is not. For example, if you look at RCPT, rapid chloride penetration test.

The values specified in the IRC codes say that for a severe condition your concrete should not exceed 1500 Coulombs of charge that is passing through the system. Of course we will discuss what this test is all about little bit later. So it gives you these values but there are no guidelines as to how we can achieve these values. For example, if the code says or if the specification does not allow you the use of fly ash.

Or slag or silica fume as a cement replacement you can never get these good values unless you are overshooting on the strength requirement of the concrete. Now, I have told you about the example where fly ash was used not as a cement replacement but as a fly and aggregate replacement. Because the contractor wanted to make use of fly ash to bring down the RCPT value to a controllable level but they were not permitted to replace cement.

So, they use it as an extra filler as part of the aggregate. So there is no guideline given in IRC as to how we can achieve these values.

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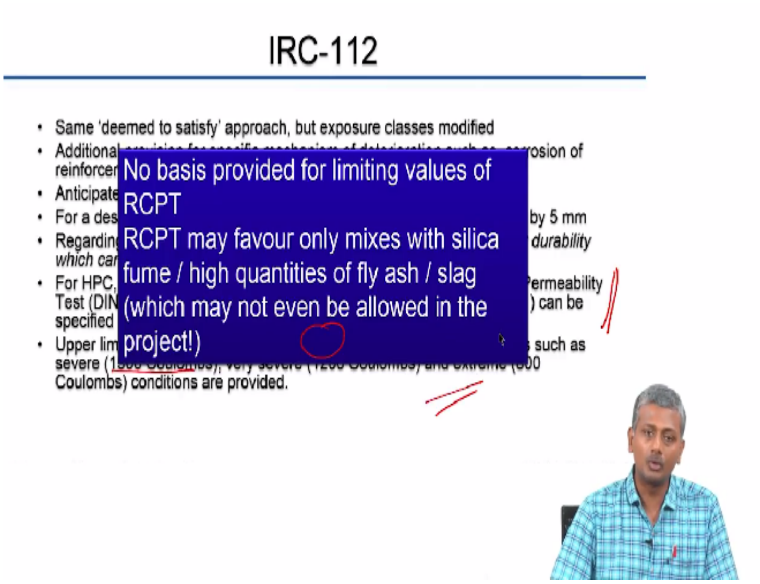

RCPT may end up as we discussed earlier favouring mixtures with silica fume or the once which have reactive silica which may not be even allowed in the project. In some cases, you may not be allowed to use these materials in the project. So the specification has to be anticipate this and address that carefully. So that is how a performance specification should be drawn based on the requirement of the code and how well we can apply it to the given construction project.

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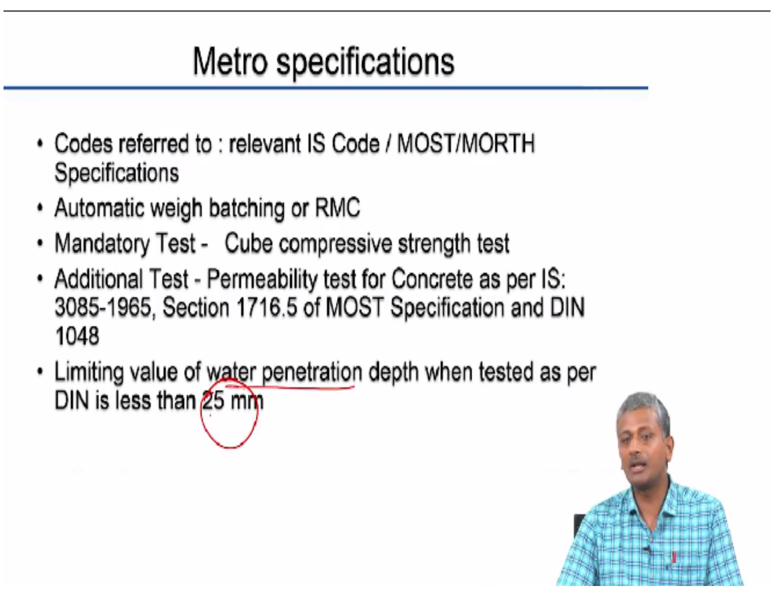

Now metro specifications of course draw a different IS codes or the ministry of Road Transport or Rail specifications. Now here they have actually called for durability testing also to be done and when we were looking at Chennai metro the concrete that way designed for the metro had to pass not just strength and workability requirement but also some minimum requirements for the respected durability tests.

So, again they were looking mostly at the water penetration test where water penetrate with concrete after being applied under pressure and then you determine the depth of penetration with water into the concrete. So, the metro spec relayed on some measurement being done on the actual concrete which was used for the construction project. And that brought about a slightly better control on the quality of the concrete that was supplied for the project.

So that way that is the step in the positive direction. However even the metro project does not clearly link as to what this value of 25 millimeters actually means as far as the service life of the concrete is concerned. Does this means that my concrete will be durable for 50 years, 100 years or what? We have not really used any models to bring that to light.

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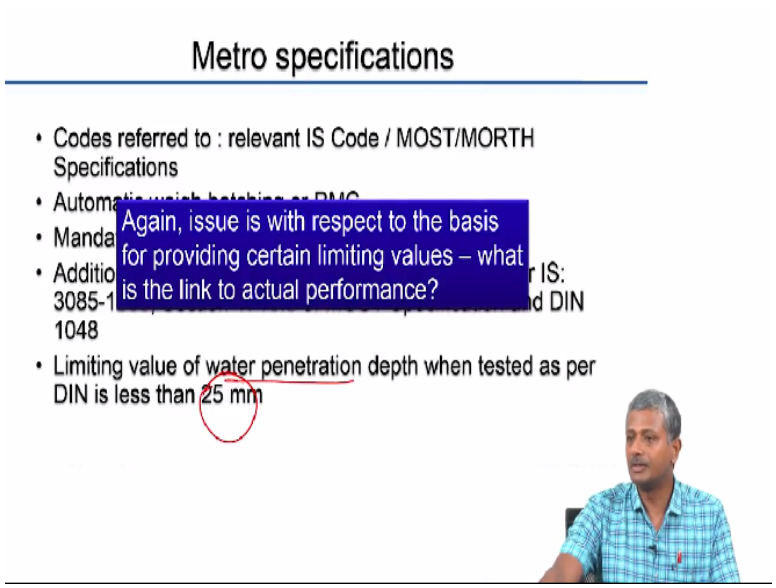

So again what is the link to actual performances something which is missing in this.

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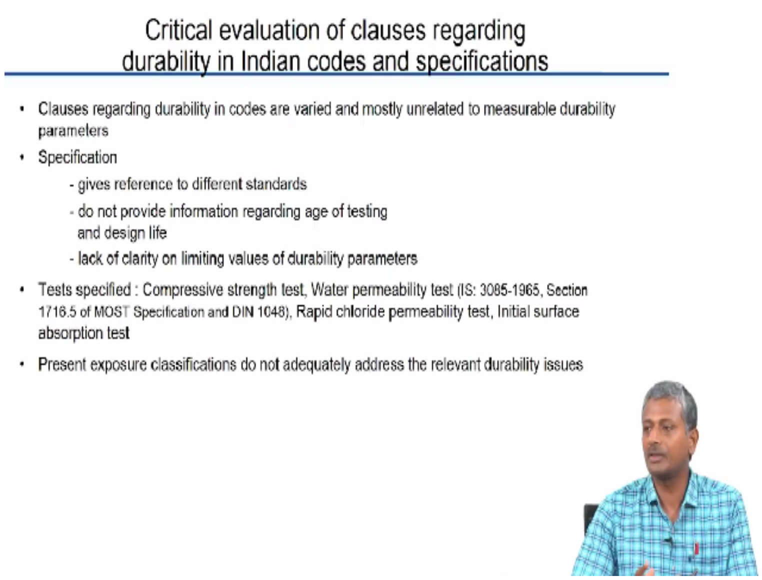

So critically what can be said is the specifications give reference to the different standards to be followed and they do not provide any information regarding the age of testing and the design life. And there is lack of clarity on limiting values of durability parameters as to how much is good, 1000 is good, 1500 is good. Why is it good? How does it like to the actual service life? All that needs to be worked out in more detail.

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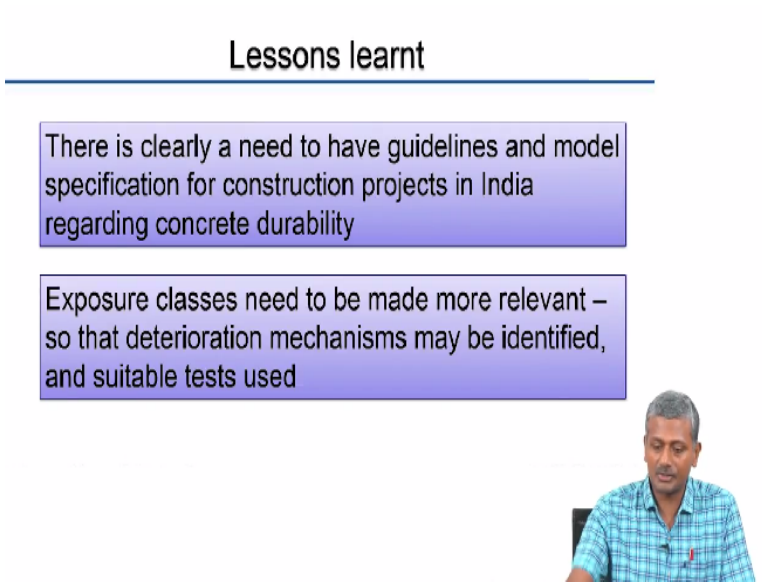

So the lessons that we have learnt from a perusal of in Indian standards as well as the practices as far as concrete construction in the industry are, one there is clearly a need to have guidelines and model specification for construction projects in India regarding concrete durability. And this is something which is a work in progress actually the Indian Concrete Institute has come up with the technical committee that works on identifying various aspects of concrete durability.

And finding the relevance of durability specifications in construction projects. So that is something that is a document which will be in the hands of all practicing engineers who are also ICI members. So exposure classes need to made more relevant. For example, we show in the severe exposure class talk about corrosion or it talks about chloride related corrosion but there are several other types of durability problems that are actually missing.

For example, carbonation related durability is not addressed in the Indian standard codes. So deterioration mechanisms had to be accurately modeled using the exposure classifications and that is something which is still missing.

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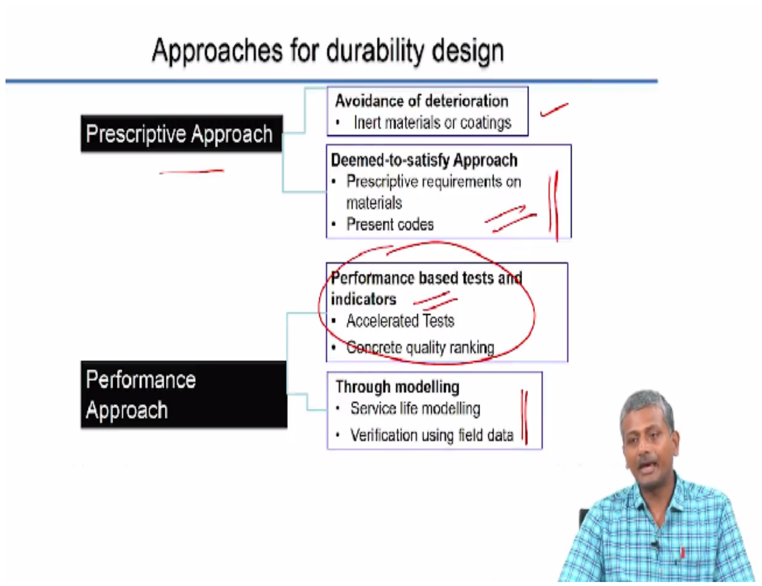

Again to recapitulate the approaches for durability design you have a prescriptive approach which can have 2 components either avoidance of deterioration that means for a project instead of regular reinforcing steel as specified stainless steel because stainless steel will not corrode in the (()) (27:24) service life of the structure. So I say that I choose a material that is not going to be deteriorating. So avoid deteriorating altogether.

But we know that is not really a cost effective solution. So we have deemed-to-satisfy approach where we say that if we use so much of this so much of that and do this mixing in this particular manner assuming that we do everything on the field right we will get durable concrete and that is the kind of approach that is done in the current codes, prescriptive specifications based on requirements of materials.

The performance approach links to either the use of performance based tests and indicators. For example the use of shrinkage test, rapid chloride test, water absorption test, and so on to specify the quality of concrete in structure or through modeling. Supposing we have some inputs of the concrete available with us can be use suitable models to establish what would be the service for the concrete in this specific environment.

So there are models available but the problem with models are there are several models available and no 2 researcher seem to agree on which is the better model to suit the durability requirements for concrete in the specific construction scenario or service environments? So, models we still have not been sufficient level of confidence with or agreement with as far as research is concerned.

So right most efforts are (()) (28:49) are based on performance testing and using that to actually concluded the durability of concrete in the field.

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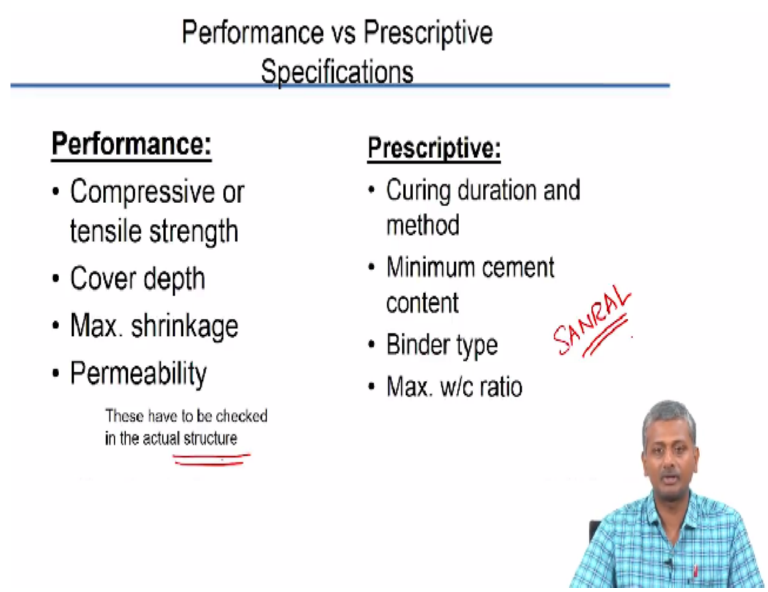

So just again this is showing you the examples of performance and prescriptive specification again I am just not going to repeat that. So the idea is that most of these are to be checked on the concrete that is supplied for the actual structure and not just stablish on concrete specimens that have been prepared using laboratory based (()) (29:12). So when concrete is supplied to the structure you either take concrete for testing directly from the structure.

Or from the specimens that have been subjected to exactly the same conditions that your structural concrete is subjected. Well otherwise when you are brining specimen back to your lab you are curing them in ideal conditions you never know whether the results you are capturing are reflective of what is actually there in structure. So, as far as possible performance requirement should be tested on the concrete in the actual structure.

How do we do that? If you make a column you want to test the durability of concrete in that column after 28 days. Can you go and start extracting a code from that column? Is everything is all right with the strength no will not allow you to touch the column to extract the code. So what do you do? You have to make specimens and cure them in exactly the same condition. Alternatively, you can make up structures which are standing in the same conditions.

Because in a cube we will never be able to simulate the effect of the reinforcement. So, if you make a mock up structure where you actually have the reinforcement in place also then subject that mock up structure to the same kind of curing that is being done in the actual structure then you can draw your specimen from that and do the tests. And this indeed is being taken up by the South African National Road Agency, SANRAL.

And they are able to implement that kind of a specification on highway construction projects especially for bridges where concrete is being used. They are actually mandating the contractor to put up concrete slabs which are basically mockup structures which are subjected to the same kind of environment as the actual structure and then specimens are drawn from that structure, measurements are done on those specimens with respect to durability indicators.

And the numbers are compared with what is obtained from laboratory specimens just to see the degree of control that the contractor has gotten for the concrete quality on site. Now based on the difference from the lab controlled specimen the contractor is either penalized for a poor quality or given a bonus for exceeding the level of quality that is expected in the field. Now that is the way that we need to approach implementing the durability specifications.

If there is no clearly in the spec as to what will happen if the numbers are not okay. So I pull out a code from my concrete at 28 days and I realize that my durability requirement is not being met. So, there has to be some way forward I cannot say just say okay not met bring down the structure that is not going to happen. I need to have directly in my specifications earlier that if the durability is low first there is a financial penalty for the contractor.

Second there are remedial measures that have already been identified that need to be properly executed by the contractor on site that probably is an extra cost for the contractor. So, from the beginning the contractor will know that the quality of concrete to be delivered in the structure has to meet a certain requirement. So automatically the level of concrete construction will shoot up.

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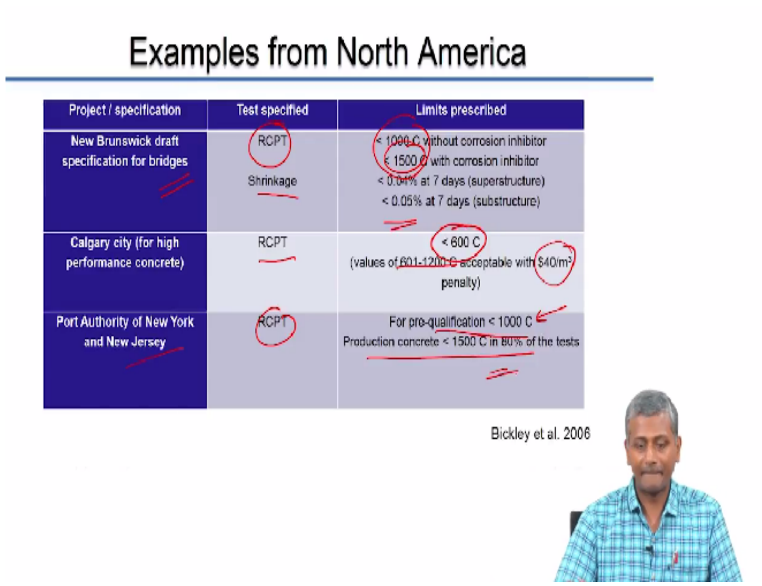

So this is how we see examples from North America where they use a lot of this rapid chloride penetration test and they specified it for bridges in certain states. For example, here the bridges it says very clearly that the chloride permeability should be less than 1000 Coulomb's when you do not have corrosion inhibitor on your concrete and less than 1500 Coulomb's when you have a corrosion inhibitor in a concrete.

Now why does this distinction come about? The presence of corrosion inhibitor may contribute some iron species to your material which many end up increasing the conductivity. So that affect is being captured in this issue of increasing the requirement for the concrete to the corrosion inhibitors. That means you are slackening the requirement for that. It also tells you the shrinkage should be less than .04% at 7 days for the superstructure and then .05% for the substructure.

Again these are very clearly specified values that can be checked by the concrete supplier in the laboratory to get the mixed prequalified to insure that the concrete is accepted for the job. And once the concrete is supplied for the job random sampling can be done and the same can be tested in the laboratory. Calgary city for high performance concrete uses RCPT as a requirement and says that your concrete should have less than 600 Coulomb's.

Or it tells you that if you are having 600 to 12,000 you pay 40 dollars per cubic meter penalty on it. Again very clearly specified all these things will not be there in any code but the specification tells you clearly. So specification is the main guideline which should be used for the construction not the code. Again port authority of New York and New Jersey uses RCPT for prequalification. It says that the concrete mix for prequalification should satisfy less than 1000 Coulomb's requirement.

But the same concrete mix when it is supplied on the site where you expect greater variability they allow up to 1,500 Coulomb's in 80% of the tests. That means 20% of the test can fail no problem. So that means they have built in some acceptance criteria for the concrete that is supplied to the job site. These prequalification criteria are the laboratory criteria based on which your concrete mix gets accepted for the job.

But once it is accepted it is supplied to the job we expect that day to day there may be variabilities because of that this allowance is given.

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So, there are distinct benefits when you use performance specifications there is scope of innovation for example now there is no body to tell you that you have to use 300 kilogram cement. You have to use 150 kilogram of fly ash. No, you can use what you want provided you are meeting all these preference characteristics. So there are possibilities of increased use of supplementary cementing materials.

So, obviously we have some positive contribution in respect towards sustainability. Client is obviously requiring a good final product. So as long as you are getting good durability in the concrete you are assuring the client good final product. And then people understand their roles in the process much better than if they are relaying entirely on prescriptions.

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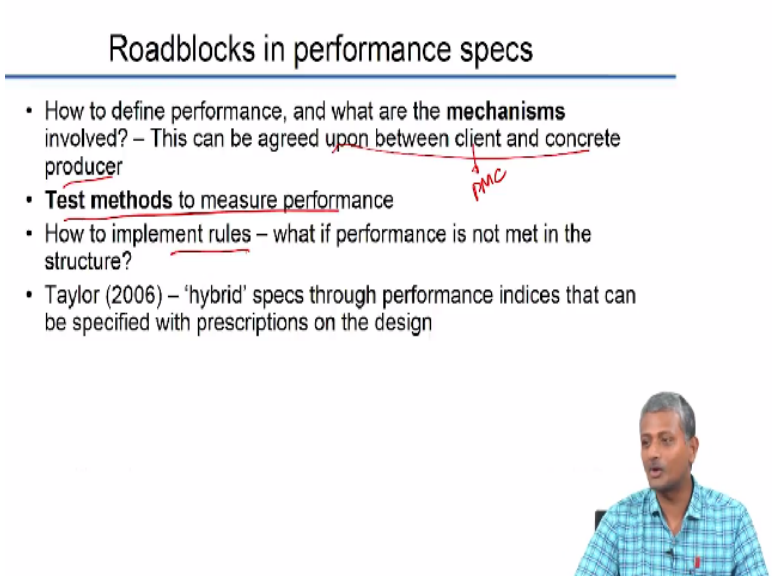

Of course the main issues that we need to tackle as far as performance requirement is concerned is how do we define the mechanisms which are defining performance on a particular concrete construction project. So this has to be agreed upon between the client and the concrete producer or the cline PMC and the concrete producer before the concrete is supplied for the project. Because only then if you arrive at a clear understanding of what should be the requirement of the concrete.

The concrete producer can then go ahead with the design of the concrete. Test methods to measure performance now you will see later based on the types of test method available people often are confused about what test methods are ideal to suit for a particular construction project. How do we make a selection of the test method and how to implement rules that is the most important problem? What if performance is not met in the structure?

And that has to be clearly written in the specification as to what are the penalties for nonconformance? And what are the remedial measures to be taken to ensure that all this comes up to the level that is desired in the structure. The problem there is we are assuming that both the client and the contractor or the client PMC and the contractor will have people who have sufficient knowledge of the material rated issues.

And characteristics to be able to come up with all these requirements well in advance. But the truth of the matter is very few of our companies actually have a concrete technology mostly they rely on the concrete suppliers to directly do the design. Concrete suppliers are not really interested in work durability. They only have to design the concrete to specify the strength and workability so that does not get rejected when it goes to the site.

So what does it tells you? All construction companies should invest in concrete technologies. So there is lot of scope in fact lot of companies look for concrete technologies because they really have anybody to solve their problems. The other issue that is often bogging people down in the construction industry is that the clients have an automatic distrust of the contractor. They think the contractor is in the job only to make money.

So, there are several projects in which I have been involved in which I have been called as an expert to give an opinion on some problem or the other which could be easily sorted out by the contractors staff themselves. The third party is simply called because the client has no belief in what the contractor says. So, there are projects in which we have been approached to do concrete mix designs for M30 concrete, M40 concrete.

These are some things that students can do sitting in the laboratory why do you need an IIT to come up with the design for M30 concrete. That is just because the client does not trust the contractor. A contractor has sufficient number of people who can do this design. The contractors know they have been doing concreting for like years and years. For example, even L&T for instance so when you take up the job as a contractor the client simply does not trust you.

To do the mix design yourself and you have to approach IIT"s who would probably not able to do the design because it is not suited in their best interest to be doing designs for run of the mill types jobs. We do not typically do mix designs for external producers unless the government themselves mandates that the design has to be done by IIT. So what I was trying to say is several issues can be tackled by a better understanding of concrete technology.

And if that understanding of concrete technology is there in the clients or the clients PMC they can certainly trust the decisions made by the contractor to select the kind of materials and mix design required to put the concrete together for the project. Only in very specific cases we need to do additional investigations involving not just one lab probably multiple labs to insure that we are getting the right quality of concrete for the project.

But in most cases the contractor personal, contractor laboratories are enough to carry out that kind of work that is required to produce the quality of concrete design. So again these are issues that we need to overcome in our industry. Work towards a much better harmony amongst people with respect to understanding material characteristics and that is only possible if each side has a concrete technologist. I am just creating more jobs for you.

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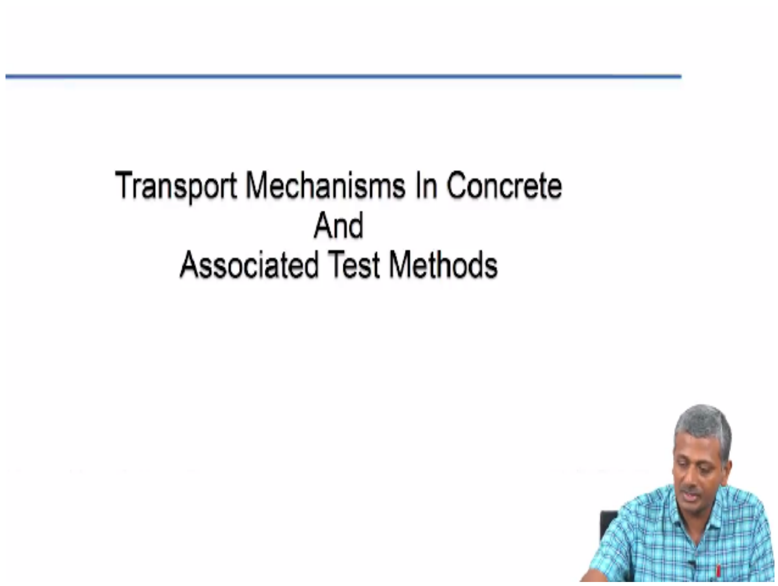

So we will introduce the subject today and continue this tomorrow. Primarily, we will talk about transport mechanism in concrete as to how aggressive agents are transported into the concrete and how do we define these characteristic with the help of test methods. How do we ascertain these characteristic of concrete with the help of relevant test method in the laboratory?

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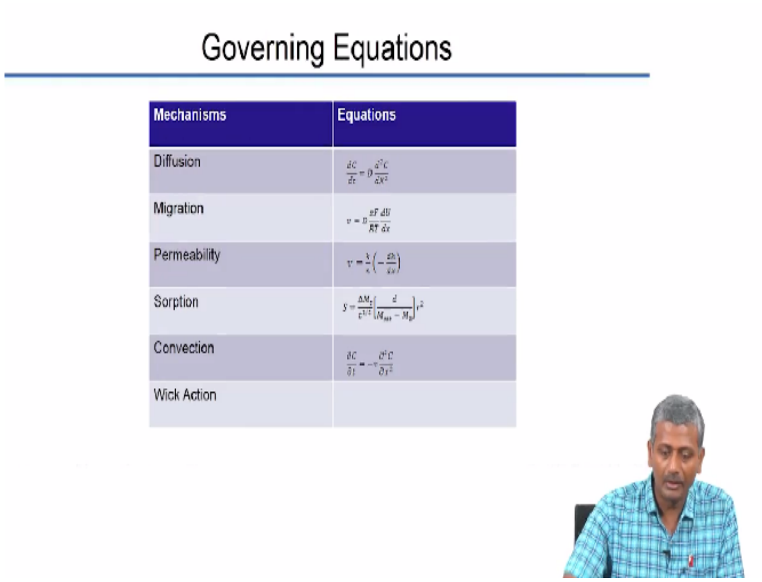

So, I mean of course I do not want to scare you with equations at this stage but the idea is that each of these mechanisms are usually quite well defined with the help of well- known physics based equations. So you have diffusion which is one of the primary mechanisms. You have migration, permeability, sorption, convection and wick action. So all of these or a combination of these can act in any given service environment.

To transport the external fluids into the concrete which can lead to a deterioration of the concrete properties. Now let us look at what happens when each of these acts on its own.

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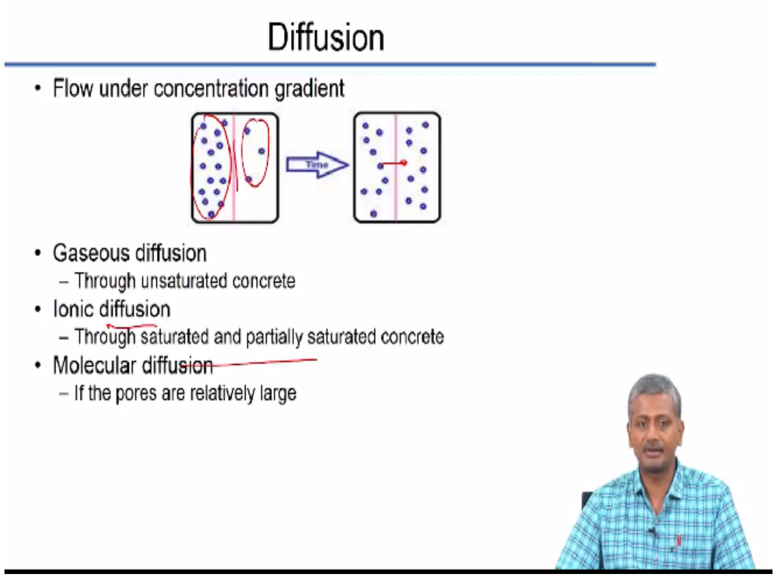

Now diffusion is a mechanism which defines the flow of ionic species under concentration gradient. For example, this is a barrier here, you have higher concentration here and lesser concentration of the ions here. With time the ionic species will tend to move across the barrier to the other side until there is some sort of equilibrium attained in the concentration. So if you can think of semipermeable barrier this sort of diffusion will happen over time.

Now, a steady state diffusion condition is one where this diffusion process is controlled by just the diffusion of the ionic species without a change in the properties of your material in which this diffusion is actually happening. So gaseous diffusion in concrete happens in unsaturated condition because of the concrete is saturated, if the cores are filled with water gasses cannot penetrate unless they dissolve completely in water.

Most gasses do not dissolve more than a certain extent in water so they cannot penetrate if the concrete is saturated. Ionic diffusion generally happens through saturated and partially saturated concrete. For example, chlorides generally will tend to diffuse through saturated concrete. Whereas carbon dioxide will go through unsaturated concrete which does not have moisture blocking all the porosity.

Molecular diffusion can happen if the pours are relatively large so water penetration through the system will happen if the pours are relatively large to allow the molecules of water to penetrate the system.

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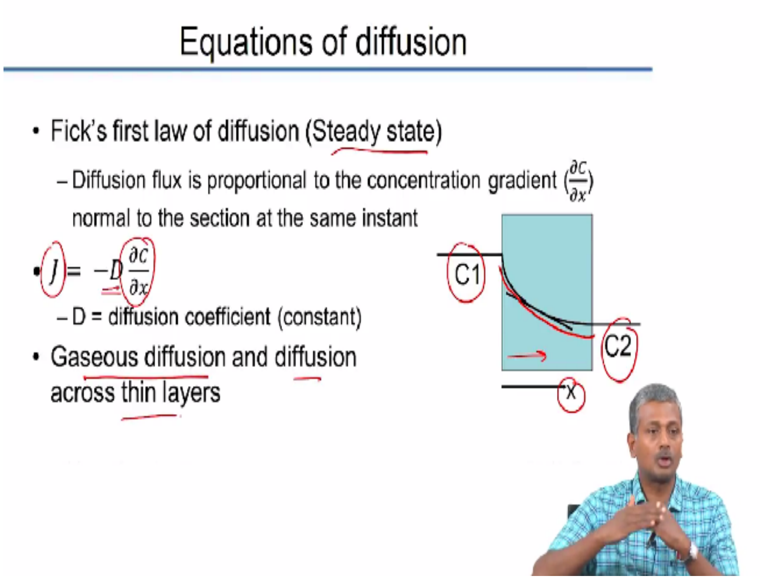

So there are 2 equation of diffusion one is the fixed first law of diffusion which is steady state diffusion and the second one is the fixed second law which is non steady state. This is related to what I was telling about earlier diffusion happens in a material where the properties do not change with respect to time. When the properties of the material do not change with respect to time I can apply the steady state diffusion characteristics.

Here the flux is related with the diffusion coefficient and is the function of the concentration gradient across the system. So this is your material here. X is representing the depth into material. C1 and C2 are the concentrations on the upstream and the downstream phases. So a steady state condition is one where you will always have the same plot maintained for the diffusion process.

That means the material characteristics are not changing with respect to time. So the concentration has the same gradient with respect to depth throughout the life cycle of the material. Now is concrete a material like that? Obviously not we expect that with time concrete characteristics will undergo a change primarily concrete will get more and more densified as the number of days progress.

So, what will happen to this concentration gradient with respect to time? You may have a change in the gradient with respect to time. So that means your concrete characteristics are changing that means you cannot be applying the steady state condition anymore. So here this primarily applies to gaseous diffusion and diffusion across thin layers like membrane like if you have a coating on the concrete surface for instance you can apply the first lay of diffusion.

But if you are looking at diffusion through concrete as a material itself.

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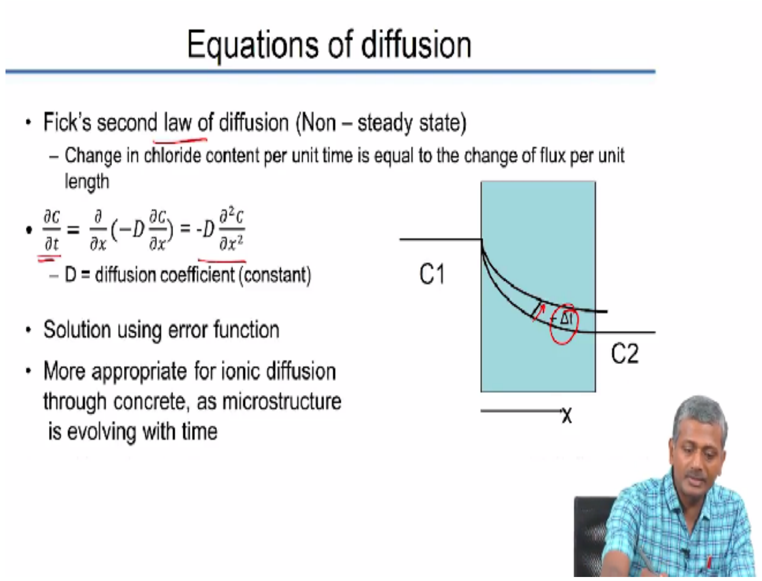

You need to apply the second law in which the concentration gradient with respect to time is written as a function of the diffusion coefficient and the concentration gradient with respect to the depth of the concrete. So here with additional time your gradient is actually changing because the characteristics of material are going to be changing. So here this equation does not have a direct solution.

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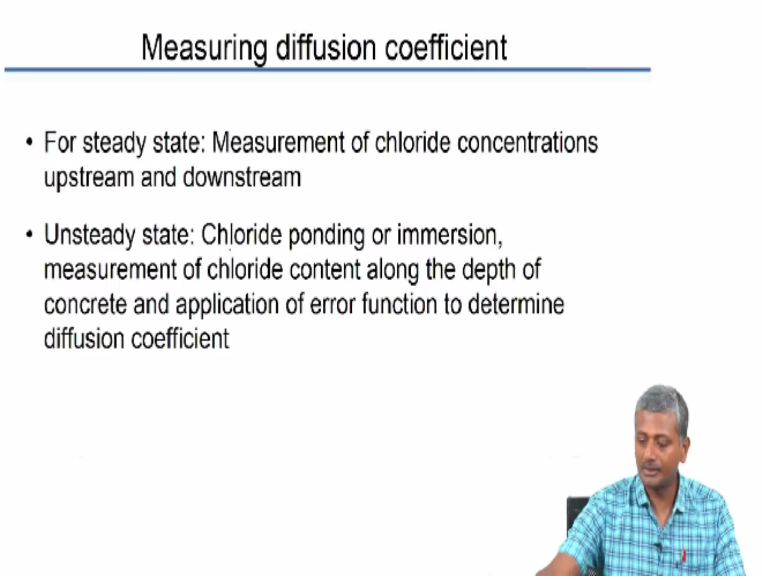

It needs to be solved using a function called the error function. The other previous equation was a direct differential equation which can be solved directly but here this is a second order partial differential equation which needs the error function for the solution. There are error function solutions available directly. So I will talk about how this is actually applied to measurement of chloride diffusion in the next class. Thank you.