Hydration, Porosity and Strength of Cementitious Materials
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Lecture – 39
Durability of Concrete-II-Specifications

Welcome to this lecture 39 in our course on hydration porosity and strength of cementitious materials. And this is the second lecture in the series of durability of concrete and today we will be talking about specifications.

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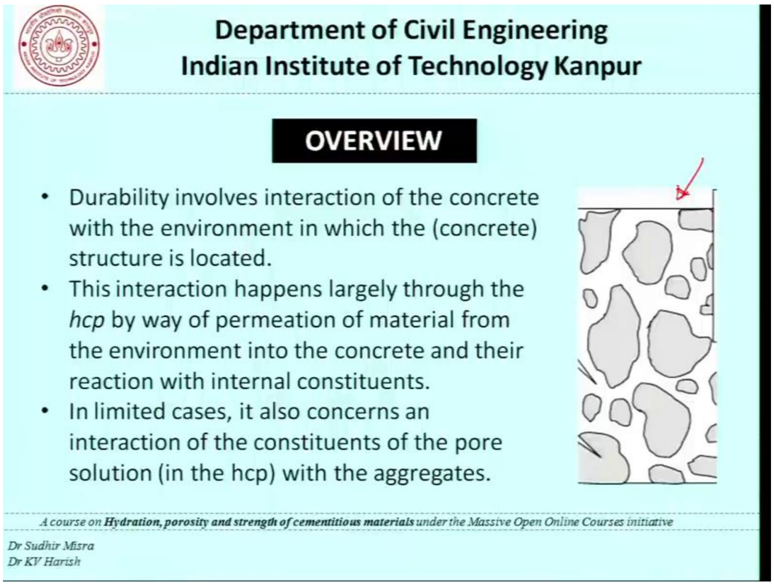

In the last discussion we had discussed this slide where we had looked at. This concrete model and talked in terms of durability involving the interaction of this concrete with the environment in which the structure is located, and this interaction happens largely through the hcp by way of permeation of material from the environment into the concrete and the reaction of these permeating material which could be deleterious at times with the internal constituents.

In limited cases it also concerns the interaction of the constituents of the pore solution within the hcp with the aggregates and it said that this is largely the situation when we are talking about alkali aggregate reaction.

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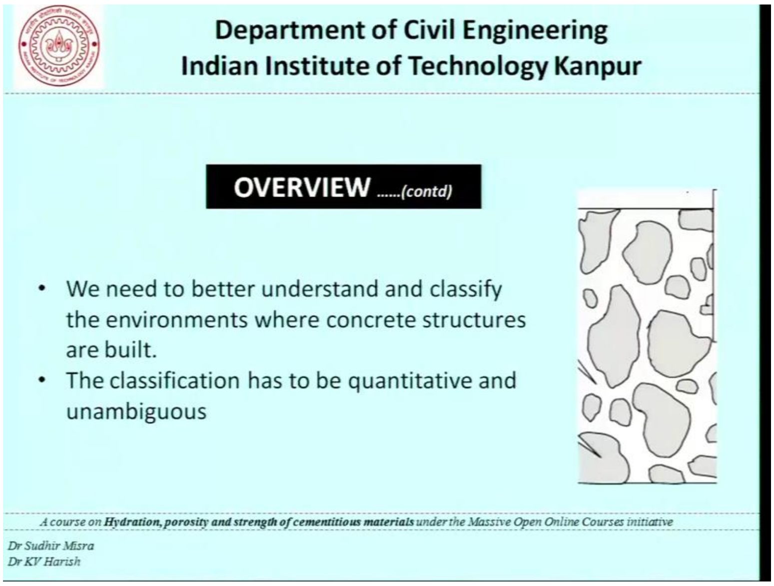

We continue to say that we need to better understand and classify the environments where the concrete structures are built in order to be able to make sure that we are able to impart the necessary durability to them and this classification has to be quantitative and unambiguous.

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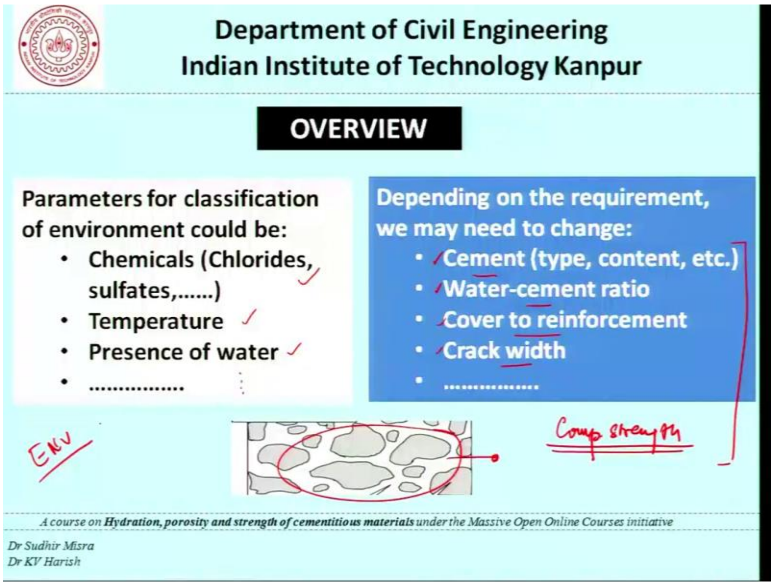

Basically it boils down to the situation which is depicted in this slide. Here we have a concrete which we want to be durable. Now this concrete is located in an environment which can be classified in terms of the chemicals the temperature presence of water and so on.

Now, in order that this concrete is durable we need to specify things like the cement water cement ratio the cover to the reinforcement crack width and so on. So, basically we can model the situation or try to understand the situation in the framework of a demand supply model. Demand is something which the environment the severity of it places on the structure. Now the more severe the environment the higher is the demand. Now how does this concrete structure or the concrete in that structure meet the demand. That is something which is the capacity which this concrete has to resist or to fulfill the demand be imposed. Now we impart this durability or this capacity by way of the cement content the water cement ratio the cover to reinforcement cracked width and also of course, in are good old way the compressive strength.

So, if we are able to ensure the parameters here or within a certain range, then implicitly we try to meet the demand which is being placed on this concrete by the environment.

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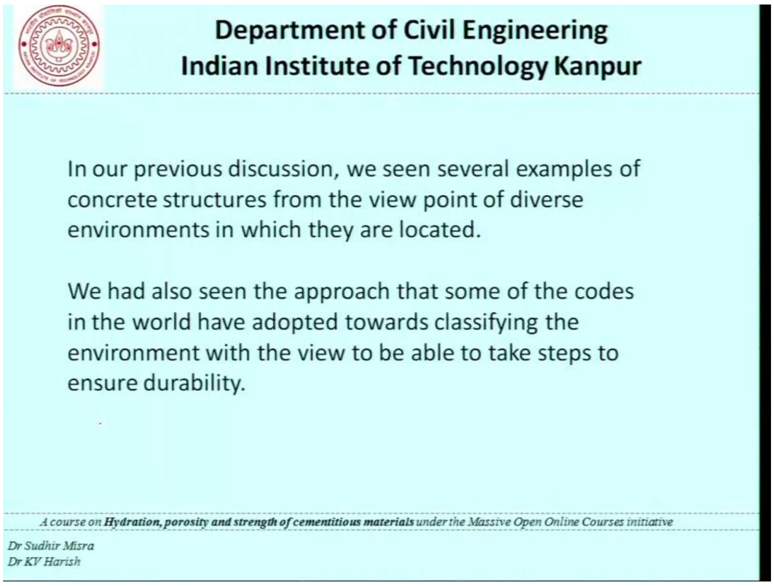

So, moving forward let summarize that in our previous discussion we had seen several examples of concrete structures, from the viewpoint of the diverse environments in which they are located. We had seen bridges we had seen tunnels we had seen buildings we had seen roads railways and so on. All of these are in different environments and we can classify or we can categorize the environments by way of the temperatures the humidity the content of chlorides or sulfates and so on. And we are also seen the approach that some of the course in the world have adopted towards classifying the environment from the view that we are able to take steps to ensure durability.

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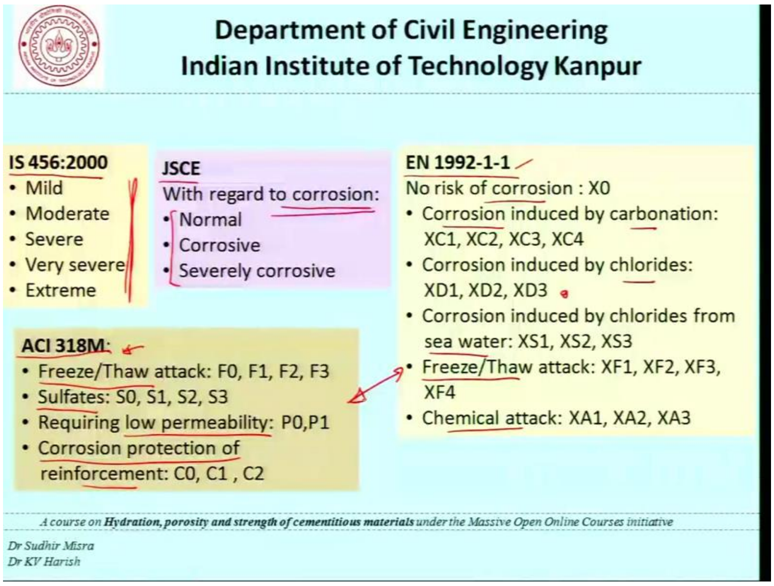

So, now let us take a quick look at that slide once again. Here is the classification in IS 456 japan society of civil engineering from the point of view of corrosion EN 1992 and the ACI 318. So, if we look at this classification for example, basically what is being done is we are saying that there are 5 types of environments, and we have given some words to them mild moderate severe very severe and extreme, and then we try to fit. In the different environments from the point of view of presence of moisture presence of sea water presence of sulfates the temperature variations the rain water into some of these when it came to ACI for example, it is not the environment that we are talking about. The classification is based on the likely mechanism of deterioration. ACI are the there could be structures which are subjected to freeze. And thaw and within freeze and thaw there is a classification depending on the severity of freeze and thaw expected.

Similarly, there is a classification based on sulfates, there is a classification where low permeability of concrete is required. And there is a classification for corrosion protection of reinforcement. So, there is a slight difference in the approach in IS and the ACI the IS 6 to classify the environment whereas, the ACI tries to classify the environment with the viewpoint of mitigating certain mechanisms of deterioration. Similarly, if we look at the

JSCE again we have a target environment in mind we are talking of corrosion and from the point of view of corrosion we could have normal corrosive severely corrosive environments. And similarly as for as the EN is concerned there is the no risk of corrosion the corrosion induced by carbonation or chlorides are get divided into 2 parts chlorides, here and those from sea water and we talk of freezing thawing and chemical attack.

So, there is a little bit of similarity between the approaches here. In both cases it is the mechanism of the deterioration which has been kept in mind when classifying the structures.

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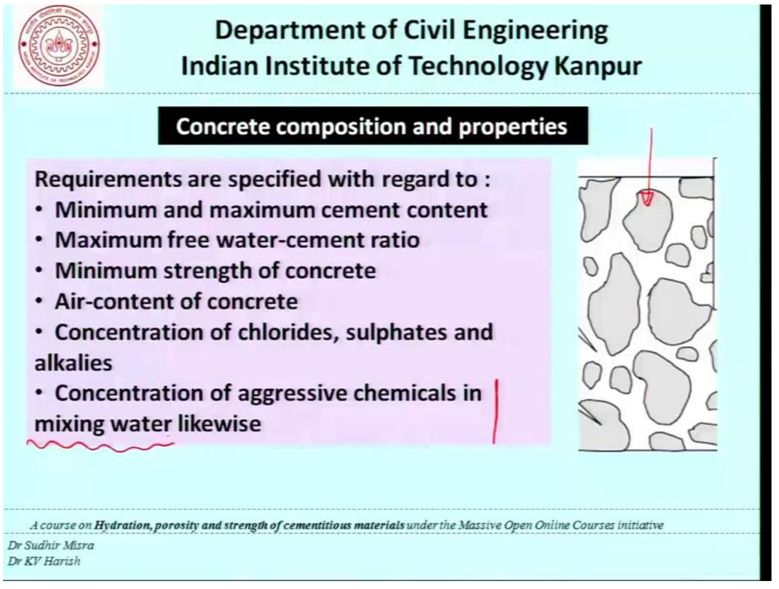

Now, moving forward what do we need to do when it comes to specifications. That is what are the parameters that will help us lay down the guidelines for what kind of concrete is to be used. And that is something which we will be talking about they most of the time one could be the minimum and maximum cement content. It could be the maximum free water cement ratio. It could be the minimum strength of concrete. It could be the air content in concrete or the concentration of chloride sulphate and alkalies or the concentration of aggressive chemicals and mixing water and likewise.

The thing is I would like to draw your special attention to this provision here and especially the term mixing water. What is being said is that the material that we use should have a certain characteristic. It should be for example, free from chlorides. We cannot really control the chlorides that will enter the concrete from outside. And therefore, in order to minimize the total chloride content in the concrete during the service life one of the steps that we can take at the time of building this structure or construction is to ensure that with chloride content in the fresh concrete is kept to a bare minimum there can be a requirement that we will not accept concrete which has more than a certain level of chloride. And this level could be depending on whether we have reinforced concrete or pre stressed concrete or plain concrete and so on.

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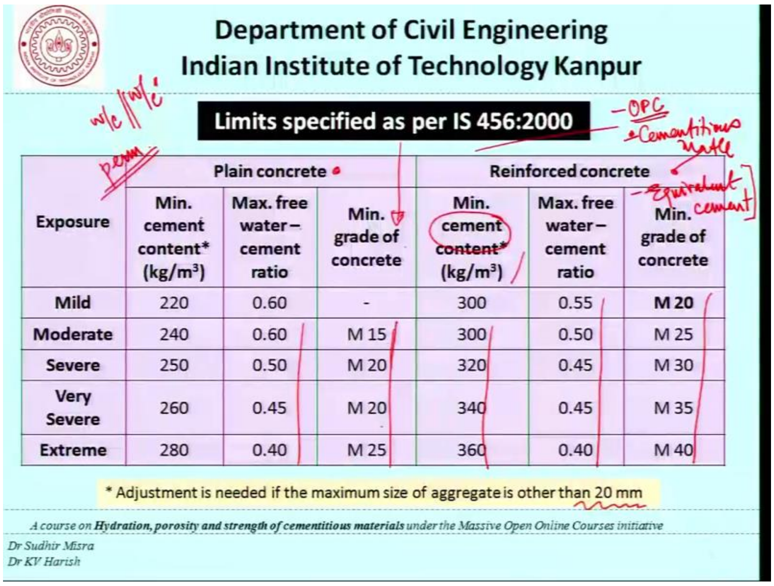

Exposure	Plain concrete			Reinforced concrete		
	Min. cement content* (kg/m³)	Max. free water – cement ratio	Min. grade of concrete	Min. cement content* (kg/m³)	Max. free water – cement ratio	Min. grade of concrete
Mild	220	0.60	-	300	0.55	M 20
Moderate	240	0.60	M 15	300	0.50	M 25
Severe	250	0.50	M 20	320	0.45	M 30
Very Severe	260	0.45	M 20	340	0.45	M 35
Extreme	280	0.40	M 25	360	0.40	M 40

Now, going into the details of these specifications let us look at the limit is which have been prescribed for the minimum cement content the maximum free water cement ratio the minimum grade of concrete for plain concretes and reinforced concretes as for as IS 456 is concerned. So, this table has been taken from the document itself and of course, it also says that we can make an adjustment in the minimum cement content if the aggregate size is more than 20 mm or is other than 20 mm, and we can see that for plain concrete we could use concretes which are in this range as for as the characteristic strength is concerned. Compared this column with respect to this column which is for reinforced concrete and we can see that the grades of concrete are about 10 MPa higher or maybe even 15 MPa higher when it comes to more severe environments.

Similarly, the water cement ratio requirements are much more stringent here than here and the minimum cement requirements are also higher. One thing I would like to point out is that we discussed some time though that when we are talking about the cement in this day and age we must also a specify whether we are talking about the OPC content or we are talking of the cementitious material content or we are talking about some kind of an equivalent cement content, where the OPC and a part of this cementitious material depending upon it is efficiency is taken into account. So, this whole idea of specifying a water cement ratio or water to the cementitious material ratio that is something which we need to keep in mind. And it sometimes becomes one of the issues where there is no agreement between that see the contractors and the clients or the owners and so on.

Therefore, it becomes imperative that we pay a greater attention to a specify the grade of concrete or build in the permeability kind of requirement. We say that we want a concrete which has a certain permeability regardless of what kind of cement or what kind of water cement ratio or the water cementitious material ratio has been used.

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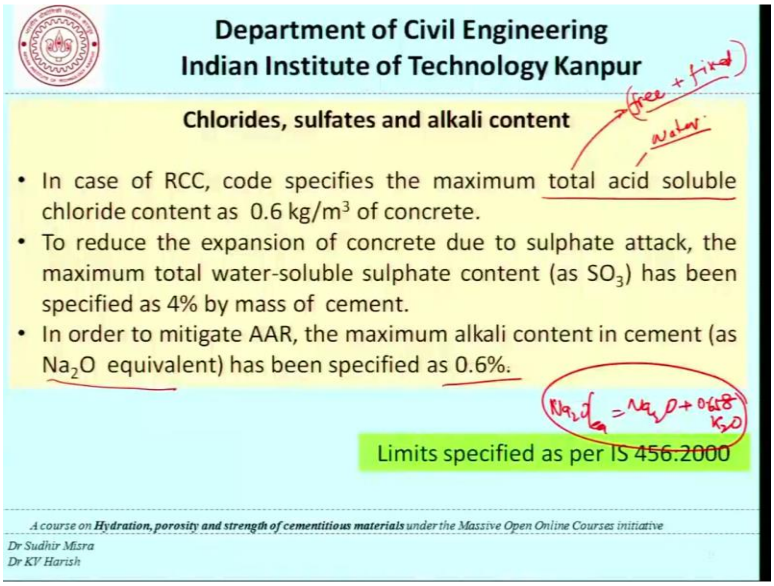

Now, moving forward if you look at the chloride sulphates and alkali content, in the case of RCC the code specifies the maximum total acid soluble chloride content to be 0.6 kg is in a cubic meter of concrete and in order to reduce the expansion of concrete due to sulphate attack the maximum total water soluble sulphate content as a SO3 has been specified as 4 percent by mass of cement.

So, when we talk of total asset soluble of course, it is a matter of detail that in concretes we often talk in terms of acid soluble and water soluble chlorides. As for as the total is concerned if you read literature there will be free chlorides and then there will be bound chlorides or fixed chlorides and this total is actually the sum of these two.

So, without getting into the detail if you are interested of course, you should go back to some of the references that have sited this is what the specification else in order to mitigate the alkali aggregate reaction the maximum alkali content is cement as Na2 equivalent has been a specified as 0.6 percent. And how do we calculate the Na2O equivalent I am. So, if we talked about this before the Na2O equivalent is equal to the Na2O content in the cement plus 0.658 times the K2O content. So, this is how we calculate the equivalent Na2 a content in a cement and that value should be less than 0.6 percent when it comes to cement content as for as IS 456 is concerned and adjustment in the cement content is proposed if the normal size of the aggregates of the nominal maximum size of the aggregate is different from 20 mm that is maybe it is 10 mm or 40 mm recommended adjustments are plus 40 minus 30.

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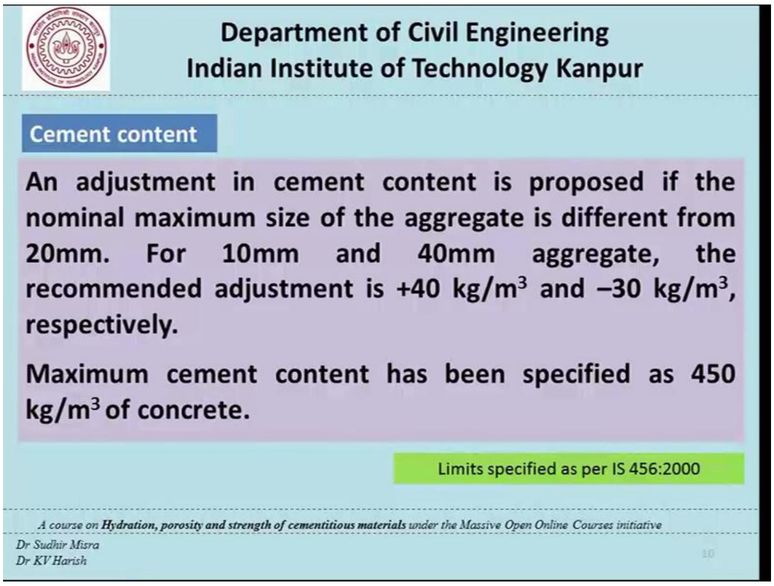

So, the cement content needs to be increased if the nominal maximum size of aggregate is smaller and may be reduced if that size is larger the maximum cement content proposed in IS 456 has been a specified as 450 kg S to a cubic meter of concrete.

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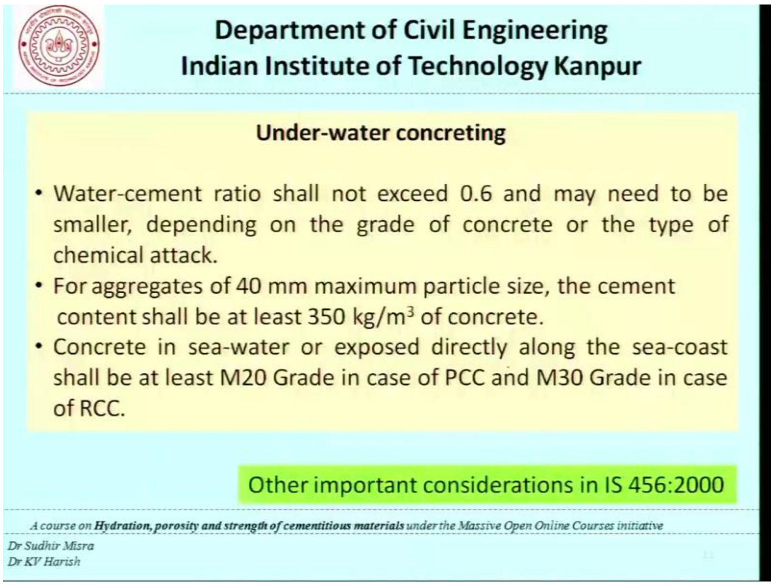

Now, there are special conditions in this document and that requires concrete to have certain special properties. For example, the water cement ratio is not permitted to exceed 0.6 and may need to be smaller depending on the grade of concrete or the type of chemical attack that is expected in the case of underwater concreting, for aggregates of 40 mm maximum particle size the cement content shall be at least 350 kg S concrete in sea water or expose directly along the sea coast shall be at least M20 grade.

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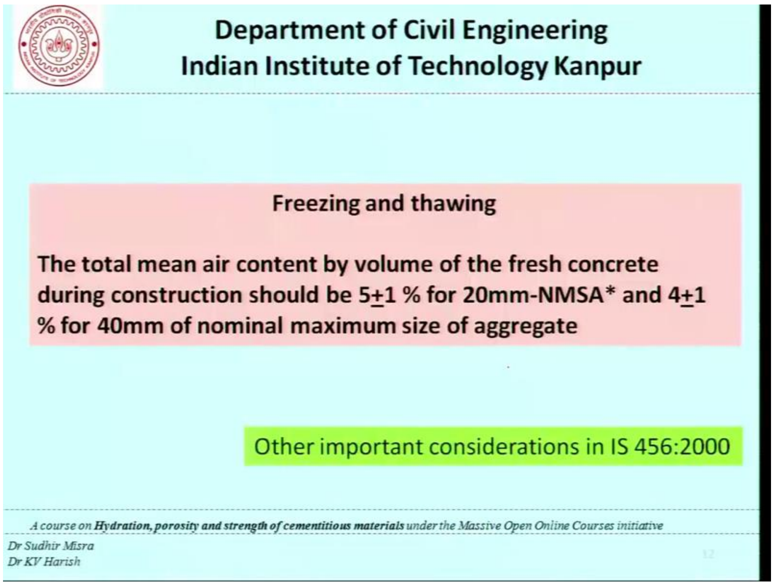

In case of PCC and M30 in the case of RCC as for as freezing and thawing is concerned the total mean a content by volume of the fresh concrete during construction should be about 5 plus minus 1 percent for 20 mm nominal size of aggregate and 4 plus minus 1 percent if then nominal maximum size of aggregate is 40 mm.

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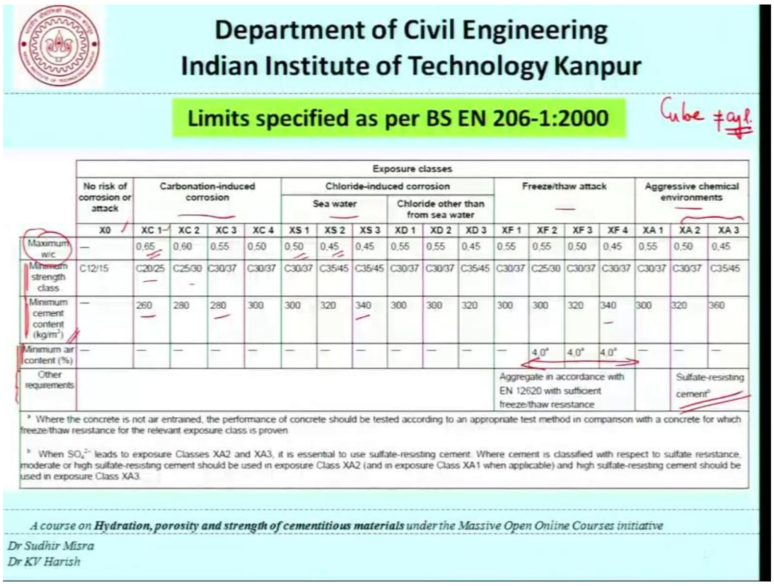

Now, if we come to let us a document like BS EN 2061 of 2000, here are the maximum water cement ratios or the minimum strength class the minimum cement content minimum air content and any other requirements for different types of exposure classes. So, if we can see it ranging from X 0 to X C 1 X C 2 X C 3 4 excess 1 2 3 and so on. The maximum water cement ratio from 0.65 to 0.45 here 0.5 here and so on these are the values which are listed for the different classes of exposure. When it comes to strength we are talking in terms of different strengths classifications, I would like to point out that when we talk in terms of strength classifications and we tried to compare the strength requirements across different codes, we must keep in mind that different codes will specify the characteristic strength of concrete in terms of the kind of specimen that they use and that something which is very important and relevant because the strength of concrete determined using a cube specimen and the cylindrical specimen is not really the same.

So, that something which we must keep in mind the cube strength and the cylinder strength is not equal. And the cylinder strength can be taken to be about 80 percent of the cube strength and that conversion if you do only then we should be able to compare a strength requirement for a given class of exposure across different codes. Now as for as the minimum cement content is concerned again these values are 260 280 340 here and so on as for as air content is concerned you can notice that there is no requirement all the way down except for situations, where we are expecting freeze thaw attack of the severity of except 2 3 and 4.

In the case of aggressive chemical attack in the case of X A 2 X A 3 we require on this code requires the use of sulphate resisting cement.

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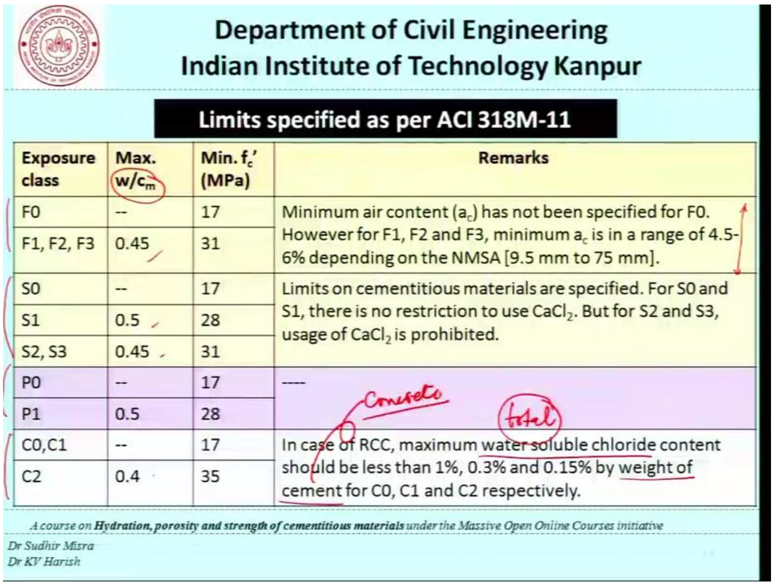

Exposure class	Max. w/c_m	Min. f_c' (MPa)	Remarks
F0	--	17	Minimum air content (a_c) has not been specified for F0. However for F1, F2 and F3, minimum a_c is in a range of 4.5-6% depending on the NMSA [9.5 mm to 75 mm].
F1, F2, F3	0.45	31	
S0	--	17	Limits on cementitious materials are specified. For S0 and S1, there is no restriction to use $CaCl_2$. But for S2 and S3, usage of $CaCl_2$ is prohibited.
S1	0.5	28	
S2, S3	0.45	31	
P0	--	17	----
P1	0.5	28	
C0,C1	--	17	In case of RCC, maximum water soluble chloride content should be less than 1%, 0.3% and 0.15% by weight of cement for C0, C1 and C2 respectively.
C2	0.4	35	

Now, coming to the American concrete institute of the ACI. Here are the exposure classes this is the freezing and thawing the sulphate attack low permeability and the structures requiring protection against carbonation. So, here we have for example, we can notice that, there is a water to cementitious material the specification. And these numbers are essentially pretty close to a kind of numbers that we see in Indian codes. So, maybe even the European codes, but in this case we are really talking about the cementitious material and these are the comments that I have written here explaining or discussing some of the other requirements for example, for F 0 F 1 F 2 F 3 the minimum air content has not been specified for F 0; however, for F 1 F 2 and F 3 the minimum air content is in the range of 4.5 to 6 depending on the nominal maximum size of aggregate from 9.5 to 75 mm.

Similarly, in the case of sulphate attack there is no limit on cementitious material specified for S 0 and S one in the case of corrosive environments in the case of r C the maximum water soluble chloride content should be less than 1 percent point 3 percent and 0.15 percentage by weight of cement for C 0, C 1 and C 2 respectively. So, if we read this a specification a talks of the water soluble fluoride content and it is given in terms of weight of cement. So, these are the kind of details which are different in different codes.

We notice that as for as IS codes are concerned there was the specification on the total chloride content and it was in terms of concrete and not cement. So, when we are comparing different codes trying to understand which code is more stringent than the other and that something which is becoming more and more important in this day and age when we are talking of engineers from one country or companies from one country trying to do their work in other countries. That is when we need to compare the specifications in different countries and try to work depending on whatever specification is applicable for a particular construction.

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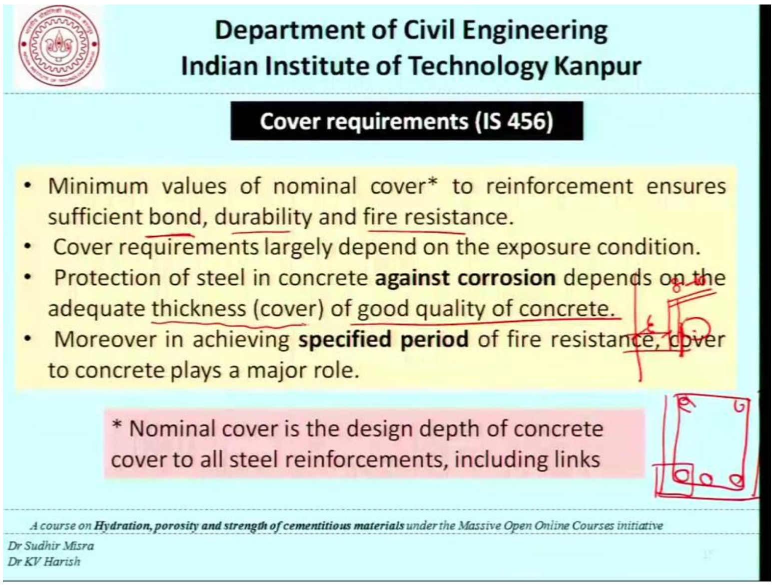

Now, moving on from the specifications for the concrete we go to cover requirements now cover as we have discussed before is basically the thickness of concrete that is available to us after the reinforcement to the surface of the environment. So, this cover thickness again is our shield to protect the reinforcement against corrosion or any other effects. The minimum value for nominal cover to reinforcement ensures sufficient bond durability and fire resistance. So, this cover thickness is actually determined based on a structural consideration that is bond. Durability considerations that is the ingress of deleterious material and fire resistance in the case when this environment here would become extremely hot and the steel needs to be protected against an unacceptable rise in temperature.

This nominal cover is the design depth of concrete cover to all reinforcement including links. Now when we are talking about the cover we should also remember that if for example, we have a reinforcement concrete beam like this there is reinforcement here and then there is a stirrup. Now if we draw this picture a little more in detail we will realize that there is a main reinforcement and there is a stirrup and this is this surface of the concrete. So, the cover is not really to the main reinforcement which is this much, but the reinforcement in the stirrup. So, there is this difference between the cover to the main reinforcing parts of a member and the cover to the nearest steel surface.

So, even though it may be just about 8 to 10 millimeters, but that is something which is important when we come to the cover because the total values itself are just about 30 to 40 millimeters has we will see. Of course, cover requirements largely depend on the exposure condition and protection of steel in concrete against corrosion depends on the adequate thickness of good quality concrete. Now this good quality of concrete is something which we have already talked about a little earlier when we are trying to restrict or try to specify the maximum water cement ratio the minimum strength and that cement content and so on. And with thickness is what we are talking about in this slide.

Moreover, in achieving the specified period of fire resistance cover of concrete place a major role. So, indeed there is a fire in the room or there is a design requirement that steel should be protected against any unacceptable temperature rise then we need to provide a certain amount of cover from that point of view.

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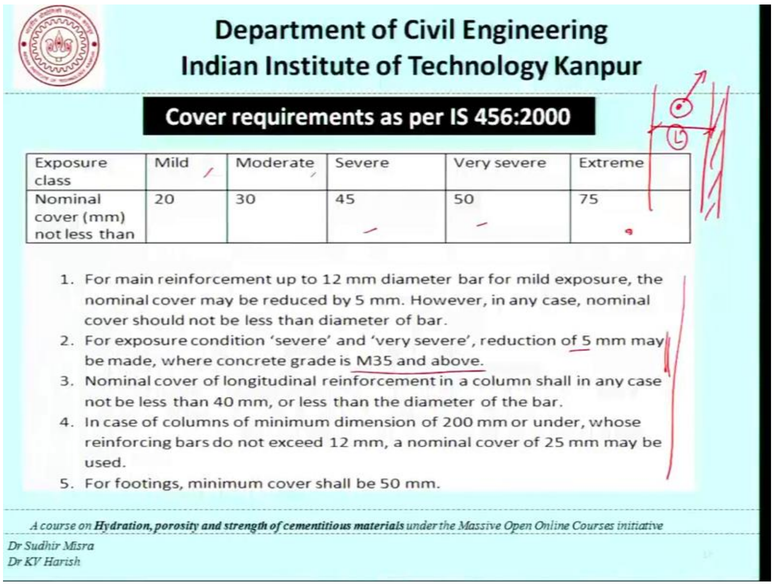

Now, as for as the durability requirements are concerned and in this document IS 456 for the 5 classifications that is mild moderate severe very severe and extreme the nominal cover should not be less than 20 30 45 50 and 75 millimeters. Now having a specified these nominal covers there are these esplanade feed notes for the main reinforcement up to 12 millimeters diameter for mild exposure the nominal cover may be reduced by 5 millimeters how in any case the nominal cover should not be less than the diameter of the bar.

Number 2 for exposure condition severe and very severe are reduction of 5 millimeters may be made where the concrete grade is M35 and above. Now let me explain this part a little bit whatever essential objective is that this reinforcement should be protected. And the amount of protection depends on the quality of concrete and the length. So, if the quality is improved there is an intuitive reason to say that this length can be reduced and this is what is being stated here that for these 2 conditions that is very severe and severe if we are using M35 or higher grades of concrete we may reduce the cover by 5 millimeters, but this is not available for extreme conditions. For nominal cover for longitudinal reinforcement in a column shall in any case not be less than 40 millimeters or the diameter of the bar in case of columns of minimum dimensions of 200 or under goes reinforcing bars do not exceed 12 millimeters and nominal cover of 25 millimeters maybe used.

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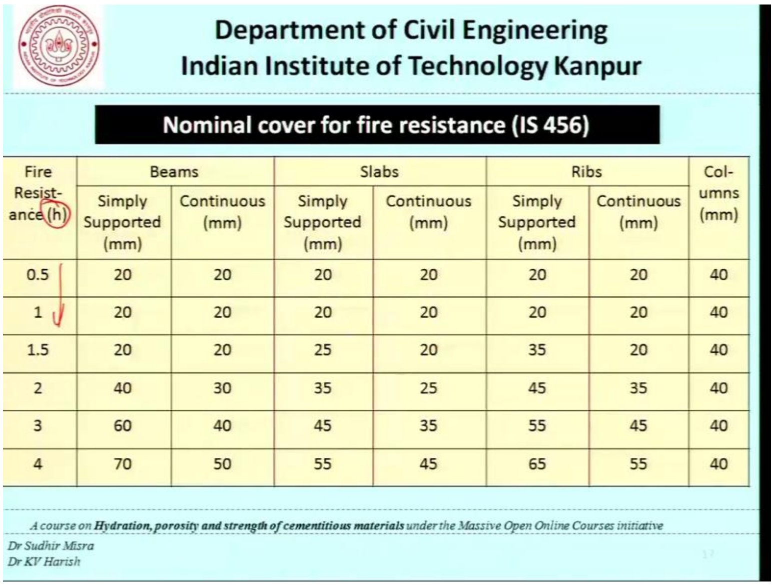

Fire Resistance (h)	Beams		Slabs		Ribs		Columns (mm)
	Simply Supported (mm)	Continuous (mm)	Simply Supported (mm)	Continuous (mm)	Simply Supported (mm)	Continuous (mm)	
0.5	20	20	20	20	20	20	40
1	20	20	20	20	20	20	40
1.5	20	20	25	20	35	20	40
2	40	30	35	25	45	35	40
3	60	40	45	35	55	45	40
4	70	50	55	45	65	55	40

For footings the minimum cover shall be 50 mm. So, these are kind of fine print when we read a document and try to implement it in a drawing or in actual construction. This table here gives you the nominal cover for fire resistance. And of course, the fire resistance would depend on what is the time for which the fire resistance is required. So, if there is half an hour to 4 hours so; obviously, if the time of the design fire is increased they cover requirement should be increased we would need a higher amount of concrete to be able to protect the reinforcement against the fire for a longer duration. And without getting into the details this time here in the first column depends on what is the kind of a structure that we are talking about what is it is functional use what is the amount of combustible material likely to be stored and so on. And we can see that the cover depends on not only the time of this fire, but also the members the beams the slabs the ribs in the columns and what are the support conditions.

So, this is governed largely from structural considerations and the fact that we want to protect the reinforcement against and then acceptable temperature rise.

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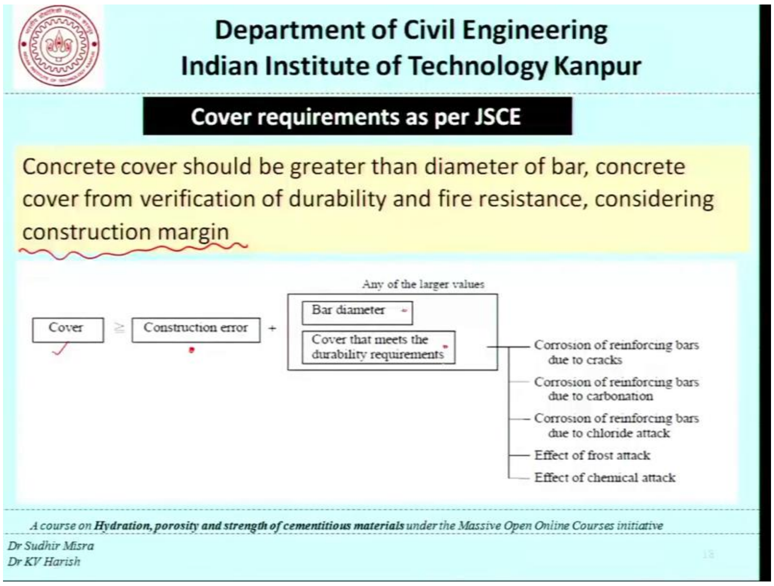

Now, coming to the cover requirements in some other codes let us look at what the JSCE is (Refer Time: 24:41) civil engineers as the cover concretes shall be greater than the diameter of the bar the concrete cover from verification of durability and fire resistance considering the construction margin. So, here we are invoking or including the concept of construction margin. That is, we know that even though the designer may specify a certain cover whether it is 40 mm or 40 5 mm or 50 mm, when working at site depending on the kind of quality control that is used that cover maybe different and that is what is the construction error. So, what it said is the cover should would be greater than the sum of the construction error expected plus the bar diameter or the cover that is required from the durability point of view and as for as the cover from the durability requirements is concerned it could be corrosion of reinforcing bar due to cracks corrosion of reinforcing bar due to carbonation decoration of reinforcing bars due to chloride attack the effect of frost attack and the effect of chemical attack.

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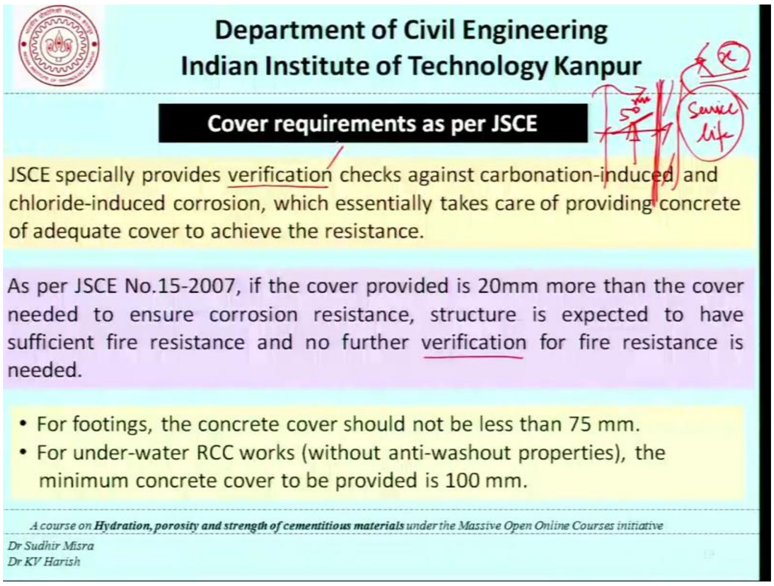

Now, talking a little bit more about these requirement, the JSCE especially provides verification checks against the carbonation induced and the chloride induced corrosion which essentially take care of the providing of concrete of adequate cover to achieve this resistance. And as per JSCE number 15 2007 if the cover provided is 20 millimeters more than the cover needed to ensure corrosion resistance the structure is expected to have sufficient fire resistance, and no further verification for fire resistance is needed. For footings the concrete cover should be not less than 75 millimeters for underwater RCC works without anti washout properties of the concrete the minimum concrete cover provided is one hundred millimeters.

So, without getting into the details involved this slide has the word verification. Now what this verification part means is that we say that well we will provide a certain amount of cover let say 50 millimeters or whatever it is and then verify whether this is sufficient to meet a well-defined condition. For example, we may say that the chloride concentration at this level should be less than X. And now in order that the chloride concentration at the surface of this reinforcing bar is less than X we need to put in place a certain cover and also certain type of concrete. Now based on a model which talks in terms of the diffusion of chlorides into this concrete, it can be verified if the concentration at the reinforcing bar location at the end of service life. This should be less than this x. So, we are not getting into the modeling of that, but that is what is the verification statement being made.

So, there is no prescriptive requirement of cover, but a more phenomenon based that is more mechanism based discussion where we say that the minimum cover provided should meet a certain functional or a functional requirement.

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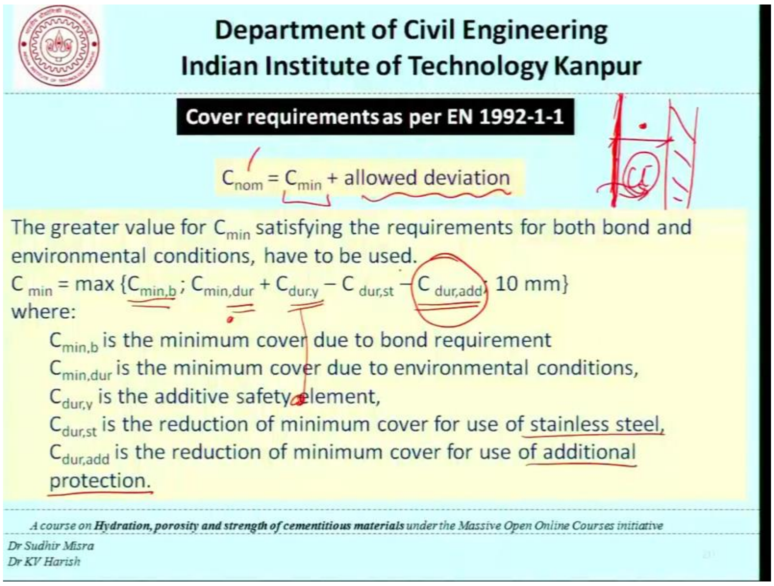

Now, coming to EN 1992 the nominal cover here also is the minimum cover plus allowed deviation. So, this document also talks in terms of a requirement based on or inclusive of allowed deviations. So, the greater value of C min satisfying the requirements for both bond and environmental conditions have to be used and therefore, C minimum should be the maximum of the C minimum which is required or the C minimum from the durability point of view plus the C durability minus the terms which is given here or 10 mm where C minimum b is the minimum requirement of cover based on bond.

C minimum durability is the minimum requirement of cover based on environmental conditions which is this term here. C durability y here this is the added safety element to account for the deviations. This is the reduction in the cover which is allowed if we are using stainless steel or non corrosive steels and there is another reduction which is permitted if we are using any additional protection. Now what these additional protections could be that on the surface of concrete we apply a coating. So, that the reinforcement here is protected against chloride attack. So, the chloride attack in this case is not only being addressed by the concrete here, but also by providing any impervious coating all using a certain special type of homework and so on. So, indeed stands to reason that this cover requirement can be revisited and in fact, reduced. So, that is what is being allowed here by adding this term C durability additional steps.

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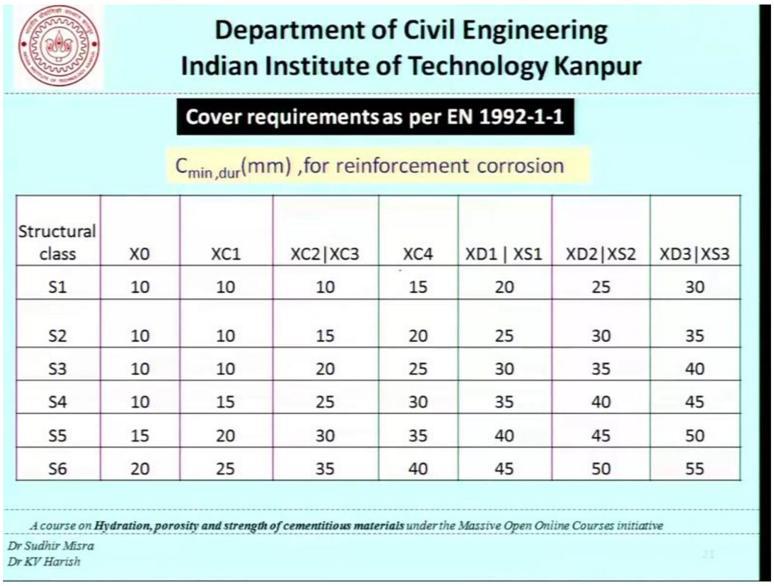

Now, from the durability considerations this is the kind of table which tells us for different classes of structures what are the minimum requirements for cover.

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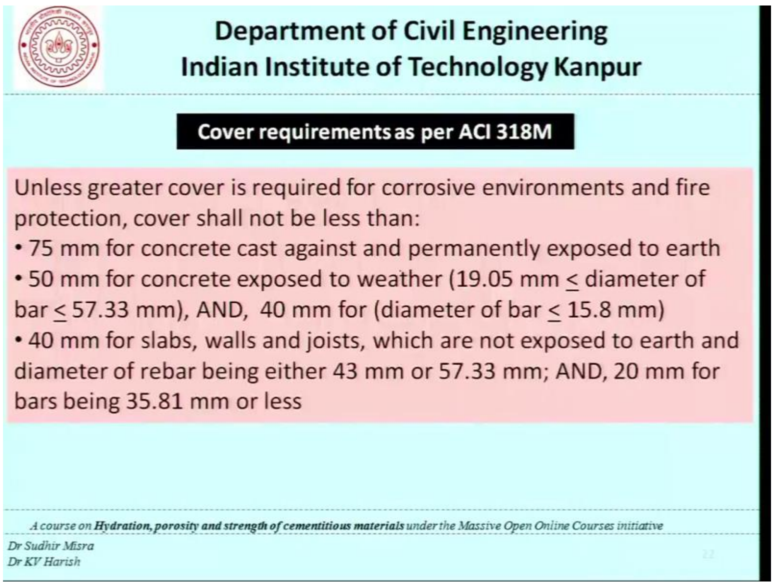

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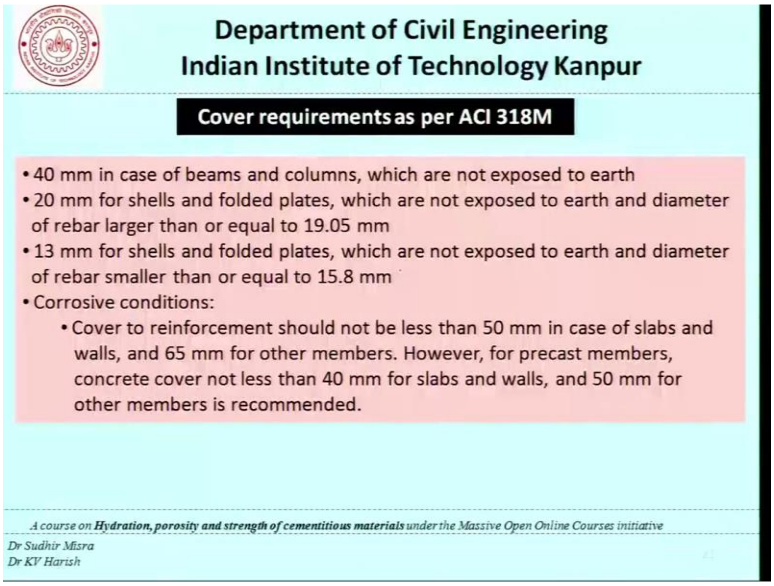

And similarly we have the requirements given in ACI 318 in this slide and the next one which is this.

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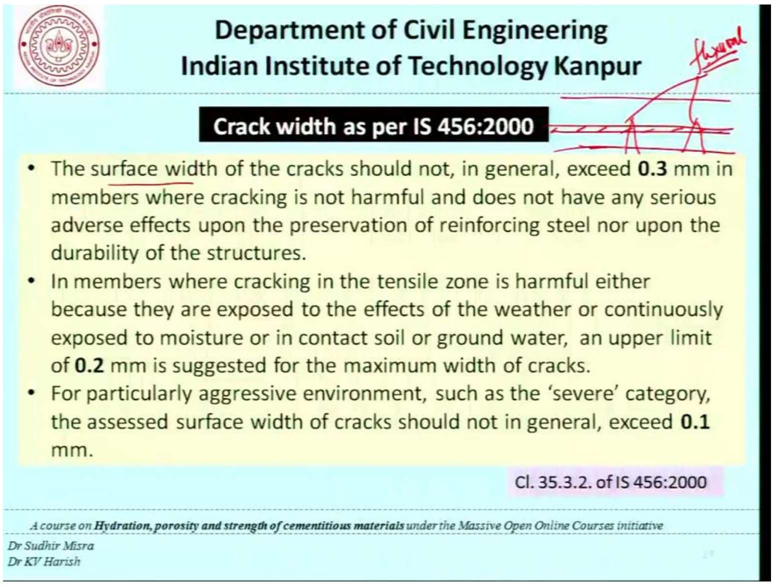

And the last thing that we need to talk about is the crack width that is the flexural track width in most cases we must remember that as for as concrete structures are concerned specially effects of beam there is always a possibility. In fact, reinforce concrete structures are designed with that possibility, that if there is an application of load we will have certain cracks and these are the flexural cracks that we expect.

Now, these cracks have varying debts as we move from the surface of the concrete inside, and what we are talked about here is the surface width of these cracks and this is what is not allowed to exceed point 3 millimeters. And more details are given on this slide and you can refer to them as we move forward as for as the JSCE is concerned.

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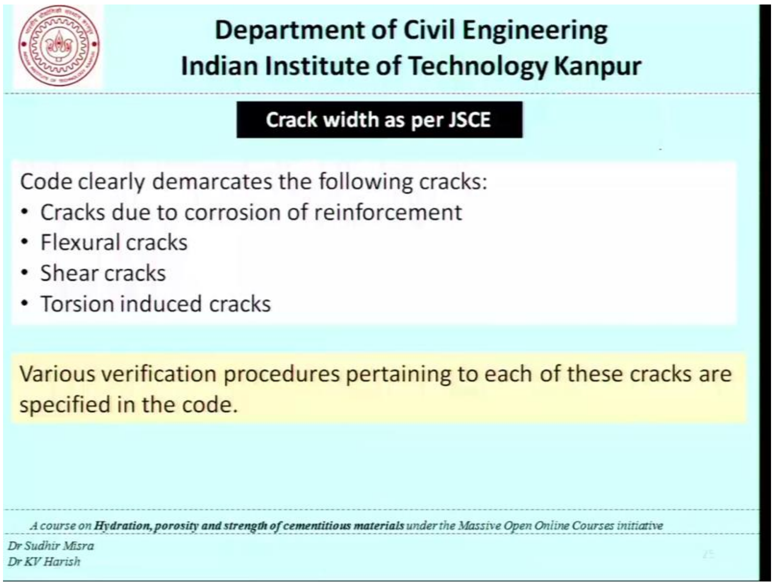

The code clearly demarcates the following cracks that is cracks due to corrosion of reinforcement flexural cracks shear and torsion and various verification procedures pertaining to each of these cracks have been specified in the code.

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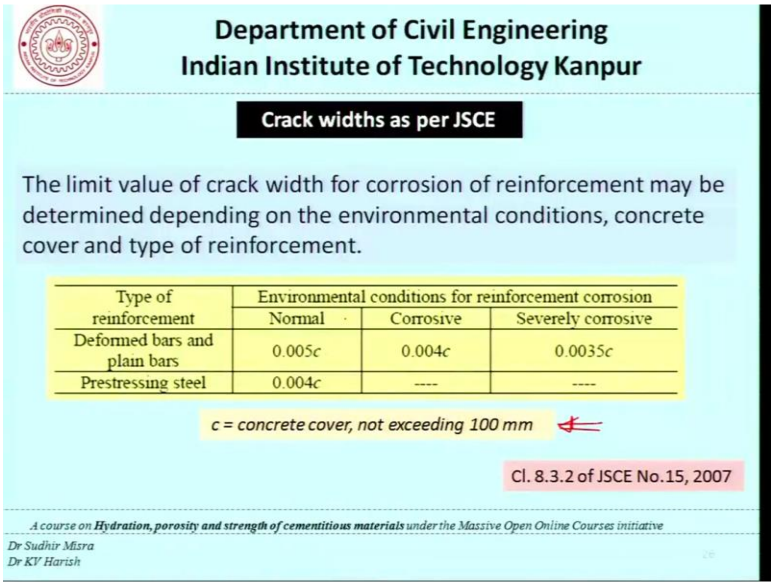

And the crack widths given or listed in this table for different types of reinforcement that is used, and the environmental condition you will recall that this normal corrosive and very severe is exactly the kind of 3 classifications of structures that we talked about from the point of view of corrosion.

But we must remember that there is a maximum stipulation as for as the cover is concerned the concrete cover should not exceed hundred millimeters.

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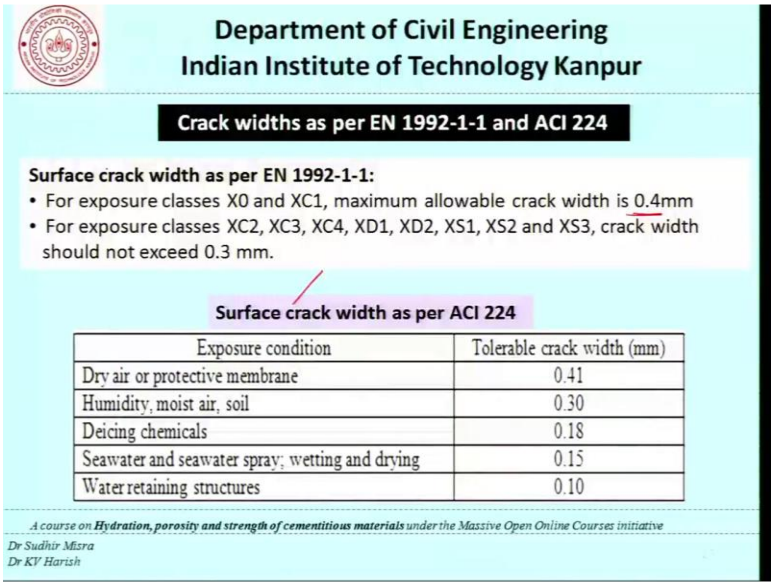

Crack widths as for as EN 1992 and ACI 224 is concerned this table here gives you the different numbers and we can see that you are talking in terms of crack widths of the order of about 0.4 and in the case of ACI 224 also it is the surface crack width that we are talking about and that is given to be 0.4 millimeters and so on depending on the different exposure conditions.

So, today we have tried to talk in terms of the specifications as to how to get durable concrete. In terms of the cement the water cement ratio the strength and so on the requirements on the concrete itself. And then we spend some time talking about the requirements on the cover. That is the length of concrete or the amount of concrete beyond the reinforcing bar which is preventing any deleterious action from the environment to reach the reinforcement location and also the crack width in RC members.

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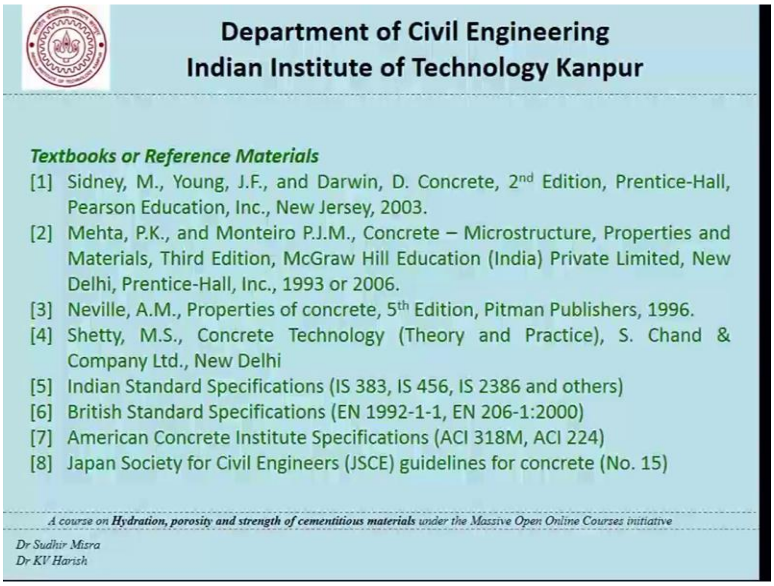

So, with this we come to an end of the discussion today this slide gives you the reference material which can help you better understand the subject matter covered.

Thank you.