Advanced Topics in the Science and Technology of Concrete
Professor Manu Santhanam
Introduction to Concrete Durability

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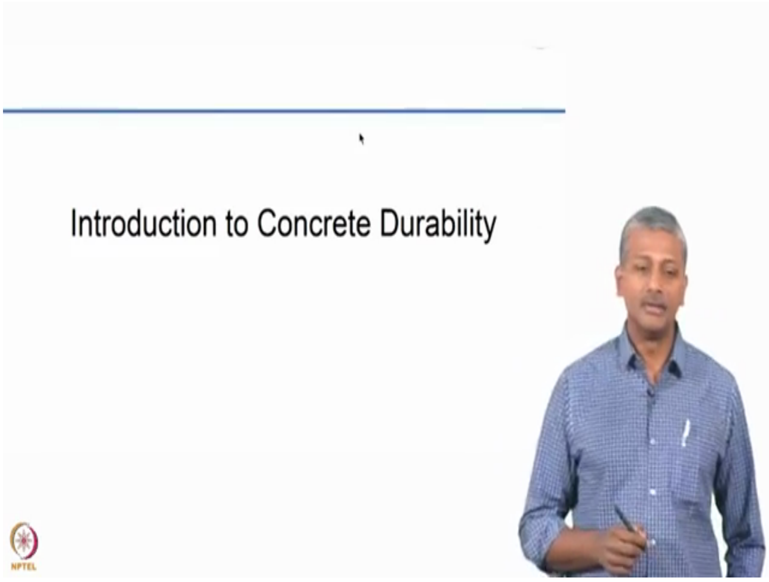

Hello everybody, welcome to this talk on introduction to concrete durability.

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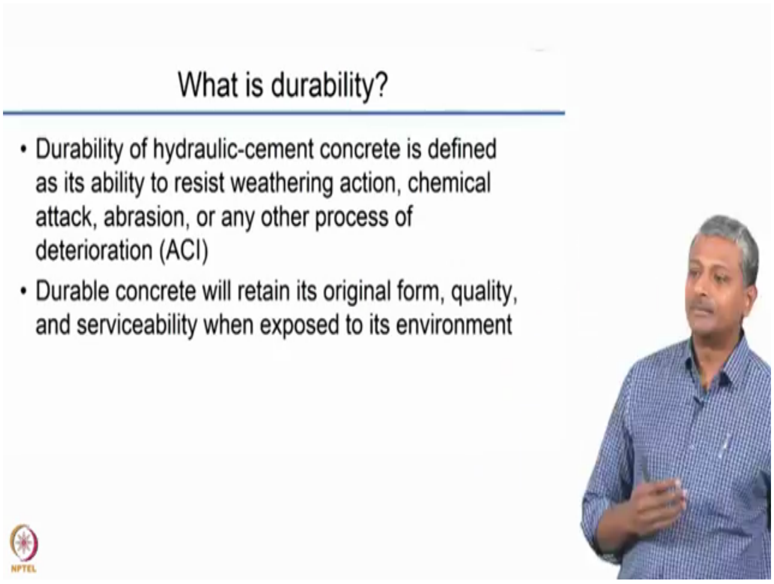

The purpose of this talk is to look at aspects of durability of concrete and try and understand how durability can be actually designed for in concrete construction. So first of all let us take a basic understanding or look at the conventional definitions of durability because as far as the American concrete institute document is concerned they define durability as the ability to resist weathering action, chemical attack, abrasion, or any other process of deterioration.

So there is a lot involved in durability as you will see later in a couple of lectures that are in this course later on you will see different types of durability problems and how they affect to concrete properties. Now of course durable concrete will retain its original form quality and serviceability when exposed to the environment and that is very important for us as far as concrete service is concerned because we want it to be free of any problems during the service life for the structure.

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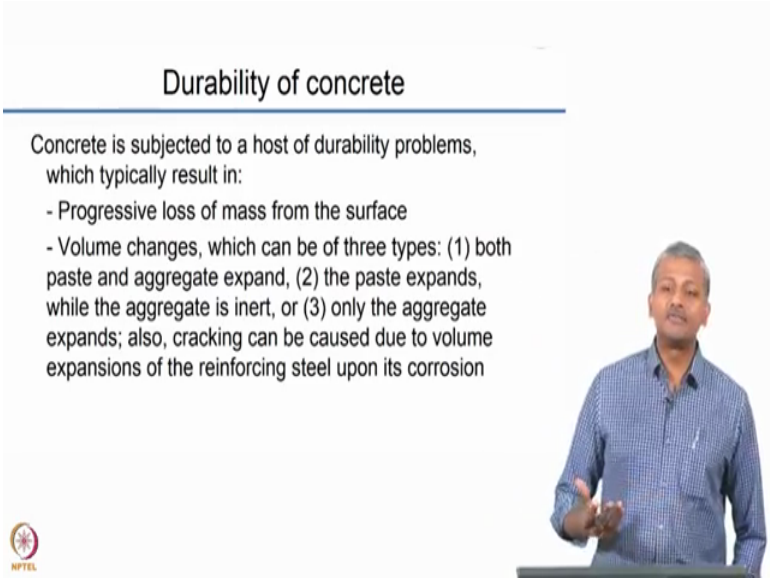

Alright, so there are several different types of durability problems that can happen in concrete, but mostly what you will see is the manifestation of these problems either is in the form of progressive loss of mass from the surface that means there is constant erosion that happens from the surface inverts, or there are volume changes which can happen in several different ways, the paste can expand on its own, the aggregate can expand because of certain issues or both paste and aggregate can actually expand or sometimes the steel expands because of corrosion and resultant stresses in the surrounding concrete.

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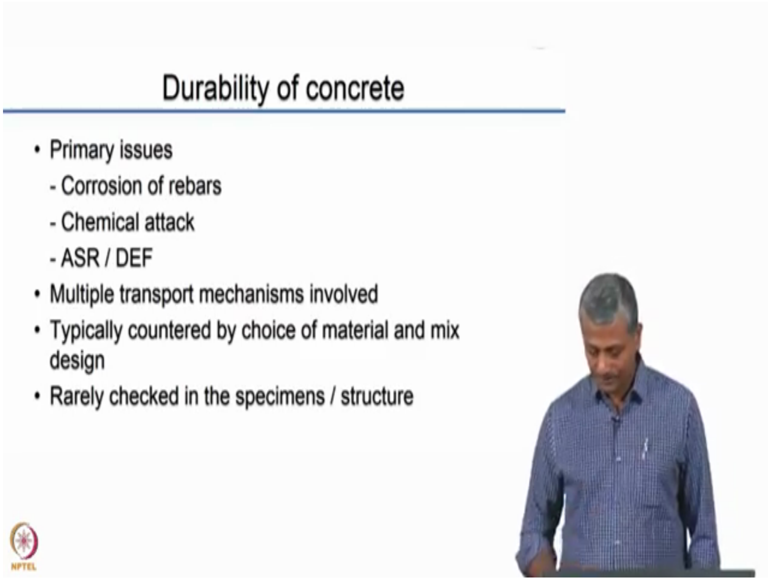

Now as far as the issues concerning concrete are concerned you can look at three issues as being very primary to the concrete structures all over the world the first and foremost issue is the corrosion of reinforcing bars and that is probably the most deleterious problem because ultimately it effects the structural integrity of the concrete structure, then you have in smaller locations around the world you have forms like chemical attack like sulphate attack, acid attack and so on and that may affect to some extent the integrity of the concrete but it does not pose the kind of dangers that corrosion does.

And then you have mode (topic) location specific problems like alkali–silica reactivity which happens only when you have some specific strains of reactive silica and your aggregate which is available in the locality that the concrete has manufactured, we may also have some problems like delayed ettringite formation which is more of a processing related issue where concrete is cured at high temperatures.

Now one the thing that you need to understand is durability is not a simple phenomenon like we studied in the lab, in the field there are multiple transport mechanisms that lead to durability problems. Now transport mechanisms are again a topic of much research because people want to understand how best to reflect durability problems that happen in the field with simulated mechanisms of lack procedures that can actually understand the characteristics of the concrete for enabling durability based design of concrete structures.

Now generally as far as concrete construction is concerned we tackle durability by choice of material in mixed design, we ensure that we are using the right kind of materials, we ensure that the mixed design procedures are proper and we ensure that we are following strictly the code which is actually prescribing various criterion to be looked at with respect to durability. But very rarely we actually check for durability in the structure, we do not really see whether it is actually being met with in the structure, right.

So that is something which we have to look at in more detail to try and understand how we can control the durability of the concrete in the structure.

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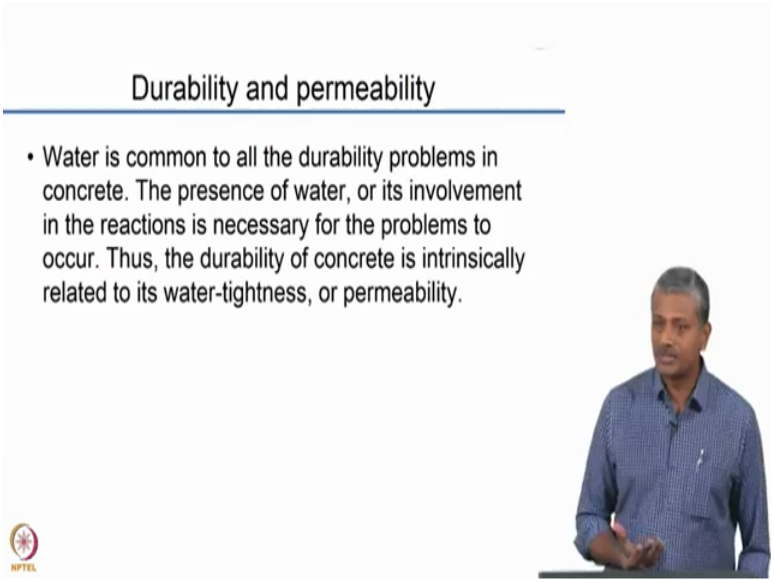

Now one essential component of durability is the water that is present in concrete or which penetrates concrete from the external environment. For all durability problems of concrete which I have talked about in the previous slide corrosion, chemical attack, Alkali–silica reaction, DEF for all these problems to actually get manifested the presence of water is absolutely necessary, without water being there in the system you really will not have any durability problems.

In other words if you maintain concrete in a dry environment you do not really have a major problem with the durability of the concrete or service life of the concrete. So durability is intrinsically related to the water (())(4:27) concrete or the permeability of the concrete, so without water most of these reactions do not occur.

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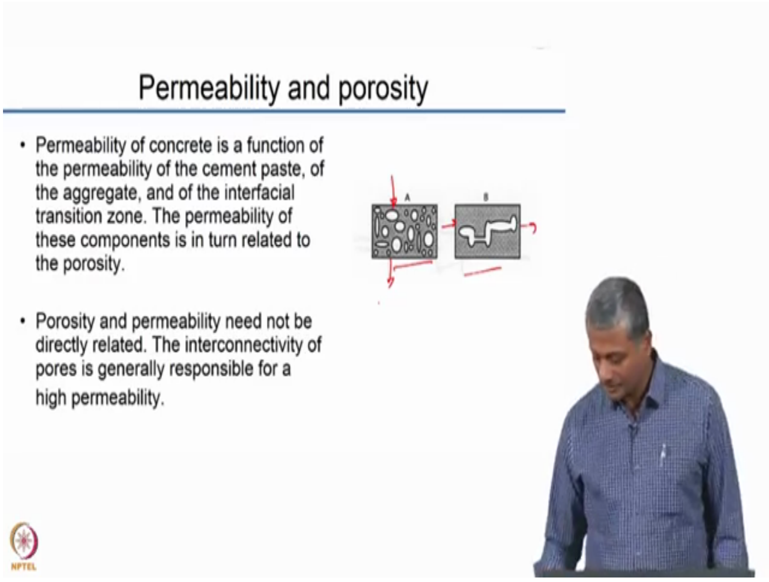

So of course we know that permeability of concrete is related to how interconnected the pore spaces in the concrete are. Now why are pores forming in concrete? If you have understood cement chemistry you know that the reaction of formation of cementitious hydration products from the cementitious components or compounds leads to the generation of pores spaces because you do not have a complete filling of the pores by the hydration products.

These pores spaces as progressive hydration happens tend to become smaller and smaller as the pores spaces become smaller their interconnectivity also reduces. So in other words the ease with which the water or any other aggressive chemical can penetrate the concrete will reduce with respect to progressive hydration. But then in some instances you may have the porosity not directly being linked to the permeability.

For example if you have (())(5:22) systems which have a lot of voids by these voids need not be essentially connected in the same way as we expected for a high water to cement ratio concrete. In a high water cement ratio concrete we have a lot of porosity which is going to be highly interconnected, but in (())(5:38) system need not be like that. So what I am trying to get that your porosity and permeability need not be directly interlinked for all kinds of cementitious systems, but for the most part we are fairly closely interlinked, okay.

So interconnectivity of the pores is the question. For example if you look at these two systems A and B in A you have lot of porosity but this porosity is not really interconnected. In B you do not have so many discrete pores but then whatever pores are there are fairly well connected because of which the permeation of a liquid through the B system will be much easier than the permeation through the A system you can clearly imagine that.

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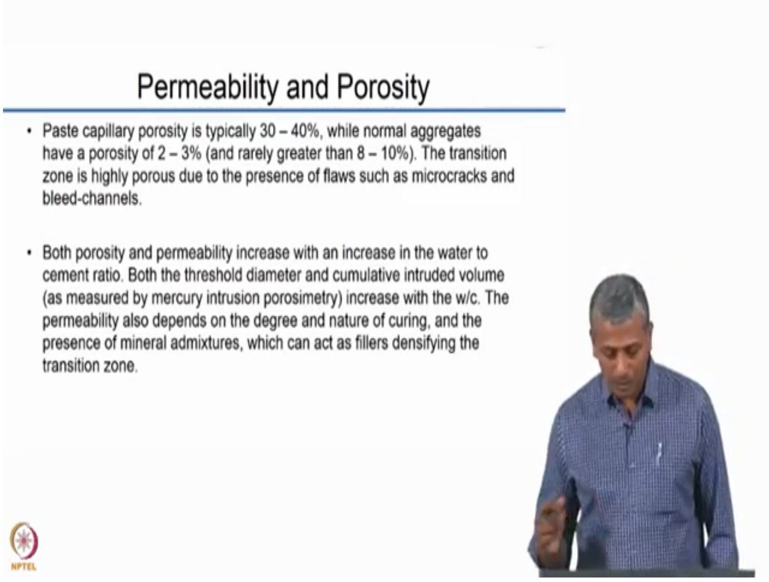

So as far as permeability and porosity is concerned in concrete you can divide concrete into various phases, you have the paste, you have the aggregate paste and then you have the interfacial zone between the paste and the aggregate, okay. The paste itself has a very high porosity, okay but then again these pores are essentially at a very small size scale, but when you go to the interfacial transition zone it gives you a completely different and much (()) (6:43) scale of porosity which makes it the preferred path of transport of liquids through the concrete, okay.

So again cracks and interfacial transition zone, presence of micro cracks and the higher porosity around the interfacial transition zone are the primary reasons why most concrete becomes quite permeable to water and other aggressive chemicals, okay. Now there are various ways of understanding of what porosity is and how to actually study the permeability of the systems in concrete, but one of the common methods of understanding porosity and the distribution of the pores size is mercury intrusion porosimetry.

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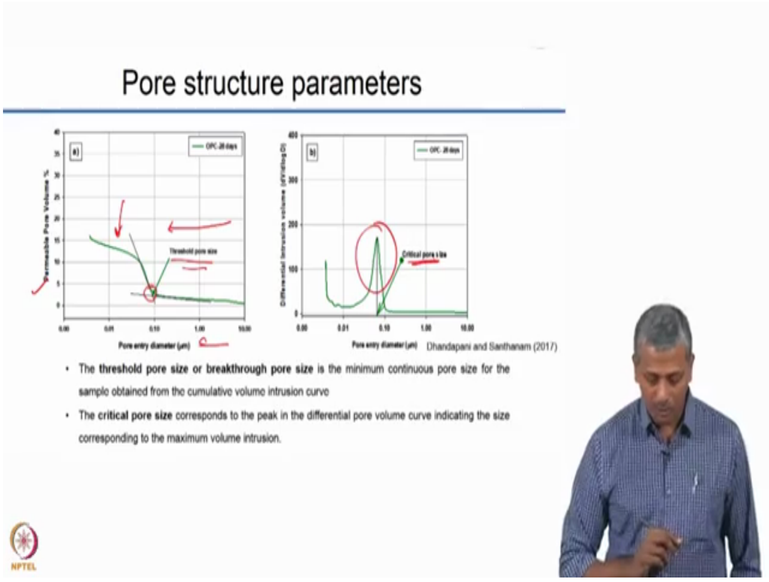

So let us look at some data from mercury intrusion porosimetry, if you look at the plot the typical plot that is produced as a result of this experiment and the pore entry diameter. So as the pore entry diameter become smaller and smaller you need to increase the pressure at which mercury will intrude these pores, okay. So as the pressure increases more and more mercury intrudes the pores and at a certain point you will see that there is a sudden increase in the levels of intrusion of the mercury and that point in general terminology with respect to cementitious materials is called the threshold pore size.

So in other words it is the maximum size that needs to be overcome for the mercury to actually completely flood the porous system in the concrete, okay so the threshold pore size is of great importance because that often defines what is the available size which the incoming fluid has to overcome in order to penetrate the material, okay so this threshold pore size as you can readily imagine reduces when you reduce the water cement ratio of the system.

In other words when the existing porosity in the system keeps on reducing because of reduction of water cement ratio the threshold pore size also reduces, there is another parameter in mercury intrusion porosimetry that is called the critical pore size, if you take a differential of this plot you ultimately end up with the distribution of the pore sizes the most likely pore size that you have in a system is otherwise known as a critical pore size in the system, of course this terminology is not always consistent people sometimes use threshold and critical interchangeably but they are not exactly the same with respect to the plots that I am showing you here.

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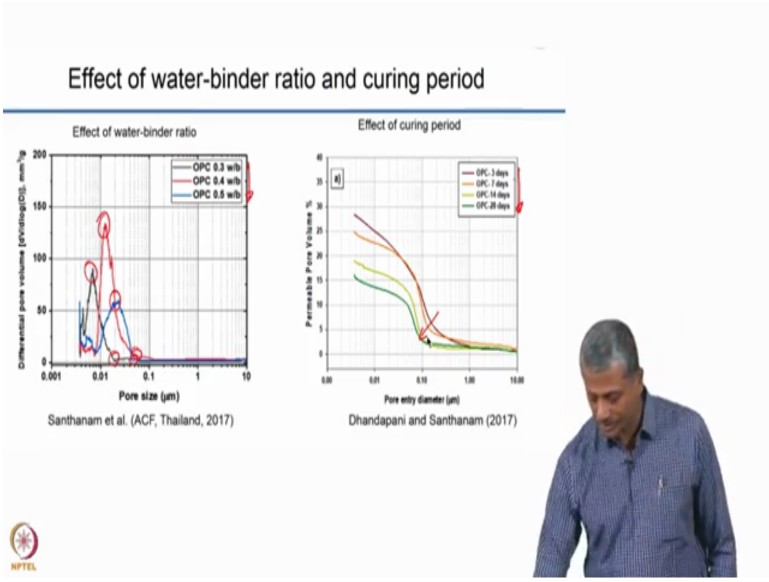

Alright, so let us look at some effects here of mix design on these pore sizes. So as I said earlier when you increase the water-binder ratio when you are going from the black to the red to the blue line what you are essentially doing is you are changing your pore entry diameter, so this is of course presented in terms of the differential pore volume. So if you look at the pore entry diameter you are talking about diameters close to 0.1 micron for the case of black system that is in the case of the 0.3 water binder ratio system your pore entry diameter is close to about 0.02 micron, whereas for the 0.4 water binder ratio system that is the red system it is about 0.07 or 08 microns and again for the 0.5 water binder ratio system or the blue system it is also somewhere in the same range.

So essentially what has happened is when you are trying to reduce the water cement ratio your pore entry diameters are reduced and your distribution of the pores around this critical pore size are also different for example at 0.5 you are here that is your critical pore size, at 0.4 you are somewhere here that is 0.01 and at 0.3 you are further refining the pores by pushing it down to less than 0.01. So again the effect of the water binder ratio can be clearly observed in the mercury intrusion porosimetry curves.

Similarly as I said earlier when you extend the degree of hydration you are also expecting a shift in the pore sizes of the systems to more finer progressively finer pore sizes. So as you can see from 3 to 28 days this is only with ordinary portland cement system, the pore size distribution curves are shifting progressively towards the left, in other words the pore sizes have become much and much much more finer as you increase the degree of hydration.

Now similarly when you consider the impact of mineral additives like fly ash, or silica fume or limestone calcined clay systems you will expect a change in your pore size distribution towards finer and finer pore sizes and that has to be reflected ultimately in your durability parameters or durability which is measured as a level of resistance to the permeation of liquids like water or other aggressive chemicals.

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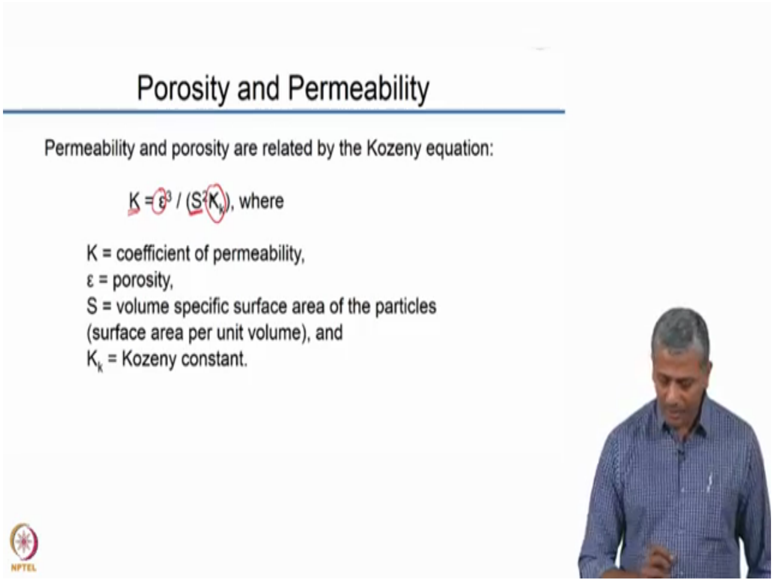

Now very often there are relationships which are available in literature which link the porosity and the permeability one such relationship is the Kozeny relationship or Kozeny equation, here the coefficient of permeability is linked to the porosity and the specific surface area of the particles which are involved in the system, this is only an approximate equation because it makes you something called the Kozeny constant K k, okay. So once you do the porosity of the system you can sort of work out the theoretical permeability value of the fluid through the system.

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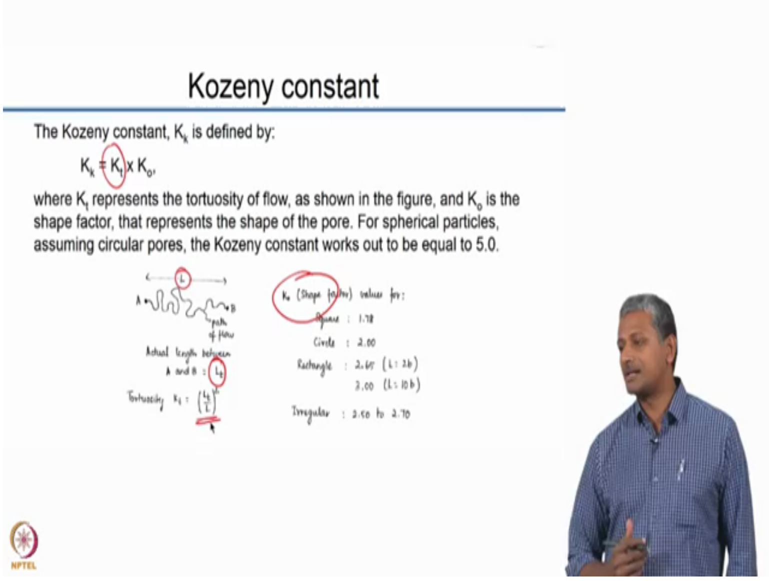

Now this Kozeny constant interestingly looks at two characteristics, one is the shape of the pore there is the shape factor that means depending upon the shape of the pore with the circular, rectangular, square, irregular the flow will be quite different. The other parameter is the tortuosity parameter which reflects the actual path length of the fluid between two points inside the porous system, okay the most obvious path length is the direct path between two points which is marked here A and B so that is L with the actual path flow is L t the length of flow is actually L t and this tortuosity coefficient can be measured as a square of L t divided by L.

Now of course this is one way of defining the tortuosity parameters, people have also attempted other approaches for example using electrical impedance spectroscopy you can also measure tortuosity but that again is not the real tortuosity it is called the electrical tortuosity it represents some degree of electrical connectivity of the pores and that also depends a lot on the degree of saturation of course but here this is an approximate methodology to understand what permeability is once you understand the porosity of the system.

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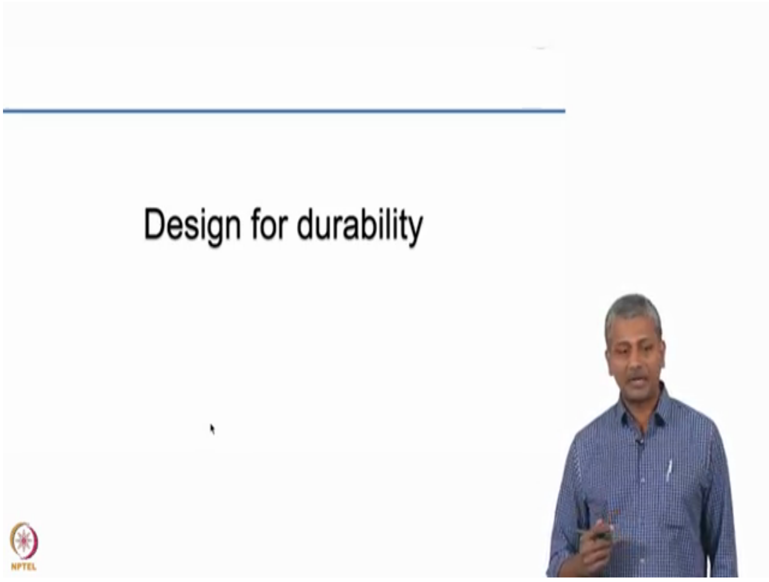

Okay, so having looked at some basic idea about what durability is and the fact that the control of water permeability is critical as far as durability is concerned. Let us look at some aspects on design for durability, how can we actually design for durability and achieve the kind of service that we expect in concrete structures.

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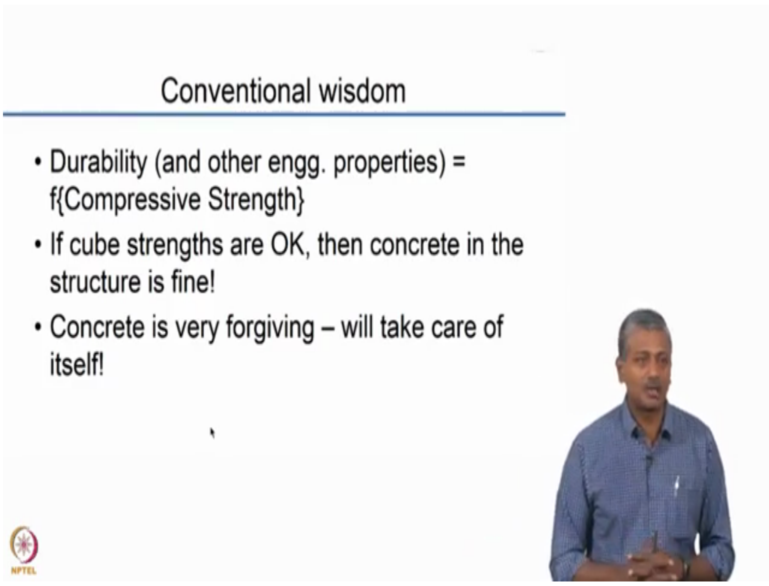

Now the conventional wisdom as we follow in most construction sites is that all engineering properties of the concrete including durability are just a function of the compressive strength. So if you go to a typical job site, what is typically done is they prepare cubes from the sample of concrete that is taken from every so many cubic meters of the concrete delivered to the job site and these cubes are stored in the ideal conditions and broken at 28 days and we get an estimate of 28 day compressive strength and mostly that is taken to be an indicator of everything that is good about the concrete, the 28 days strength requirements are met then we assume that all other requirements are automatically going to be met.

So if the cube strengths are okay, then concrete in the structure is fine is the general belief in the concrete community, another aspect is concrete is very forgiving and it will take care of itself, so it does not matter what practise we do on the site ultimately the concrete is just concrete it should work whichever way we wanted to work, but we know that this is not really true.

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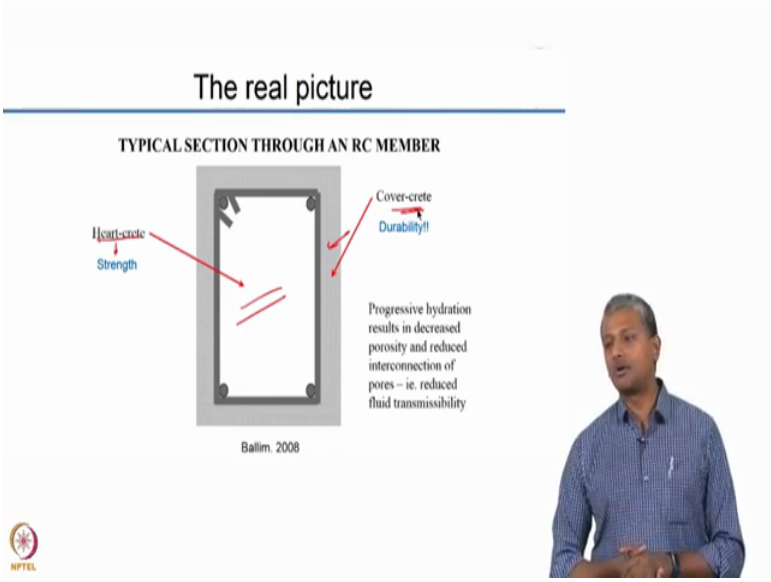

If you take a look at typical structure a (concrete) compression structure made with concrete, so you have your reinforcement here for example this is a section through a column so you have your primary reinforcement longitudinal reinforcement of the four corners, you have the tie bars surrounding the reinforcement, you have the cover concrete which is surrounding this reinforcement further.

Now just imagine a scenario in which you construct this concrete column and forget to do any curing, you just simply forget to do any curing. So what will happen now is the concrete that is in the centre that is entrapped between the reinforcement that is still about 30 to 40 millimetres away from the exterior surface. So you can imagine that the lack of curing or the drying of the concrete is not really going to impact that part of the concrete which is within these four longitudinal bars that is which is encased within the tie bars. In other words the concrete which is in the heart or heart-crete is not really going to be effected by the lack of curing, okay.

On the other hand if you consider this concrete that is outside that is cover-crete if you do not hydrate this concrete well enough you can directly then link it back to the fact that when you do not hydrate the pores do not get filled up and if the pores are not getting filled up your permeability is going to be severely affected. In other words you will end up producing a highly permeable system in the cover zone of the concrete, if you do not do a proper job of curing.

So essentially your heart-crete which is the bulk of your concrete obviously is contributing a lot to the strength whereas the cover-crete is highly responsible for the durability of the concrete in general the entire structural durability is taking care of by the cover concrete that you provide. So if you do not pay attention to the quality of cover concrete you are likely to get a poor service life.

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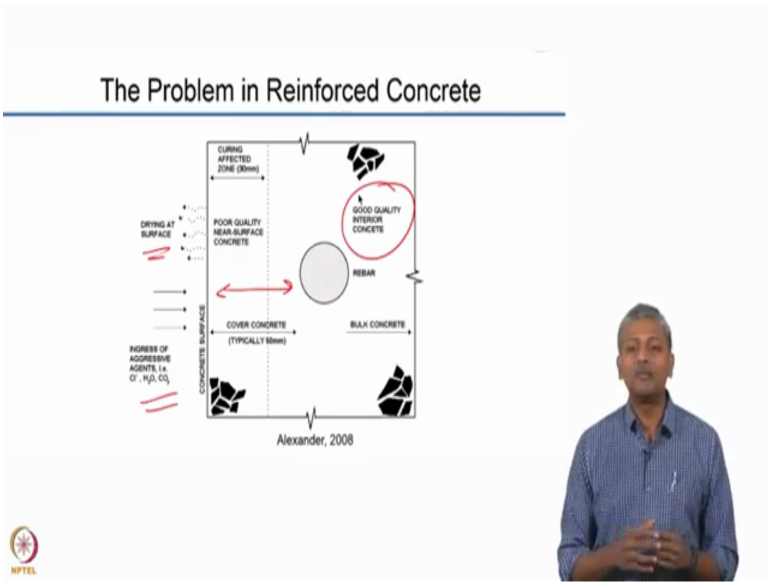

Now again just to put this in perspective just showing you the problem in reinforced concrete you have the surface concrete on top of the reinforcing bar, this concrete is the one which is facing the effects of drying, it is also facing the effects of ingress of aggressive agents like chlorides and carbon di oxide, whereas you have concrete in the interior which is relatively free from all these problems.

And in general if you think about it the way that concrete construction is done the concrete quality near the surface is generally poorer as compared to the concrete quality in the interior just think about something like a slab for instance when you do the vibration of the concrete in the slab the water which is free inside the concrete will tend to move up and the water cement ratio that is at the surface will generally be greater than the water to cement ratio in the interior of the concrete.

Similarly in a column also when you vibrate the free water will generally tend to go towards the sides and the exterior surface of the concrete will tend to have a slightly higher water content as oppose to what you have in the bulk of the concrete. So do cover concrete is already in a poorer condition, if you do not do a good job of curing you are going to be making it worst.

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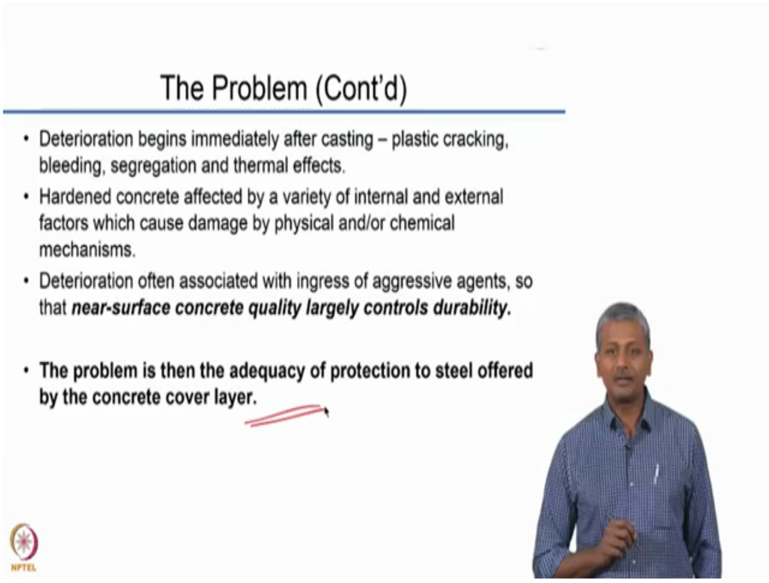

So again as many researchers have pointed out multiple number of times the adequacy of protection to steel offered by concrete in the cover layer is the key to obtaining durable concrete structures.

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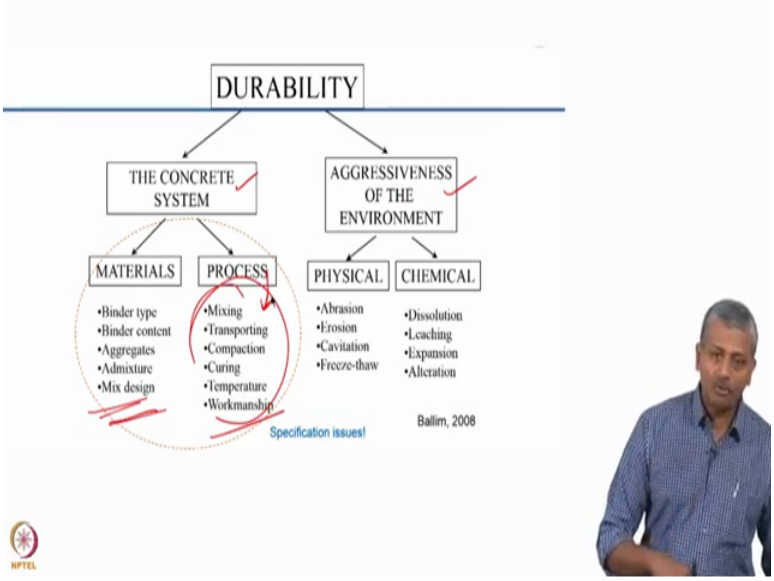

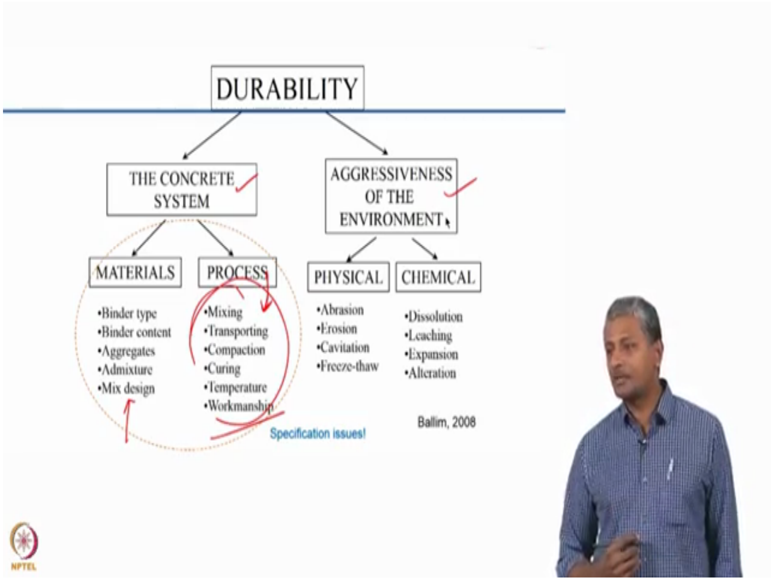

So let us now think about what can be done to really control this, how can we actually specify the control the concrete cover. So if you think about durability it is made up of two distinct components one is the concrete system itself and the other is the aggressiveness of the environment. The concrete system is composed of the materials that go into making the concrete as well as the processes, the materials are obviously the ones that you make a choice of as far as the codes and specifications are concerned, it tells you that okay if you are in a chloride environment ensure that you are using slag based cement, ensure that you are not using a water to cement ratio of more than 0.4 and so on and so forth, okay.

So you are deciding up on the material characteristics that go into designing concrete for a particular environment, then you have the process which includes mixing, transportation, compaction, curing, temperature of the concrete and ultimately the workmanship which actually is resulting in the performance of the concrete in the long term.

Now all these are not easily covered by most concrete specifications, so how do we actually ensure that we bring these into the specification, how do we bring in concrete quality or for example quality of the workmanship into the specification, okay just to give you an example I am specifying the cover, okay I am specifying the materials to be used in the cover concrete, I am also specifying that the cover should be 40 millimetres.

But then how do I bring in the effect of process on the cover? Unless I really go back to the structure after construction and actually measure the cover that has been provided, how do I know that my cover requirement which was on paper has been satisfied by the concrete and the structure? So there should be some ways of bringing in these processing characteristics also into the specifications and that is where we need to ensure that we are allowing for some degree of testing to be included apart from the specification of the materials which is quite commonly done in most construction projects.

So essentially we are adding a layer of additional specifications that ensures that we are able to test the concrete quality in the structure rather than just relying on prescriptions for a good quality construction, of course the other part is the aggressiveness of the environment and we essentially understand what are the problems which happen in specific environments and make appropriate choices of the materials and methods to ensure that we are meeting up the requirements of the environment.

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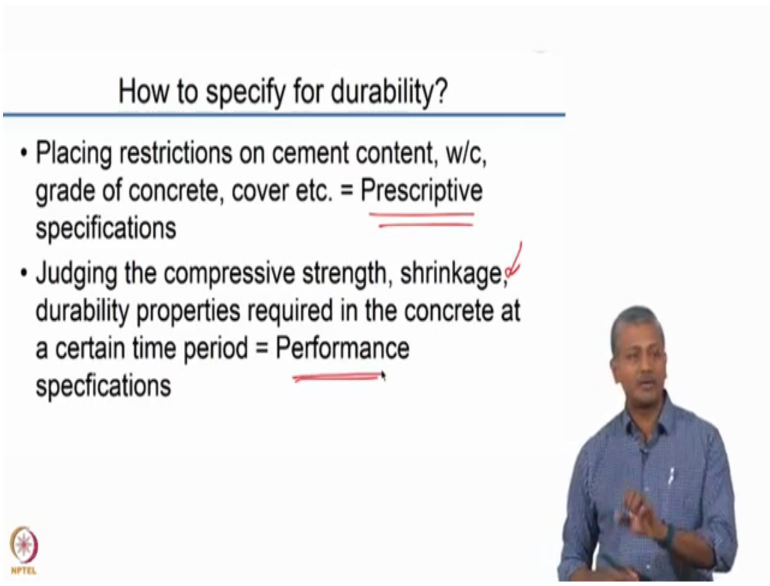

So how to specify for durability? Again just looking just looking at placing restrictions on the cement content, water to cement ratio, grade of concrete, cover and all that that is basically what is known as a prescriptive specification and it is like giving a medicine for an ailment we are saying that okay you put this medicine into the concrete it should be durable for its service life.

But then if we start specifying what this medicine should do at distinct intervals of time, how do we choose the material so that you get a specific performance at distinct intervals of time and that is called performance specifications. So increasingly the world over people are trying to move towards performance based design of concrete because ultimately that will help you get the required characteristics of the concrete in the structure.

Just to put things in a simple manner when you go an electrical shop and buy an electric bulb, the shopkeeper gives you the bulb only after checking it whether it works in the holder or not but in concrete we do not have any such guarantees we just prepares these cubes you do not know what concrete that cube is from and what concrete actually goes with the structure. So how well does a cube reflect what is there in the structure that is the big challenge in concrete. So once you call for performance specifications you will then be able to assert in whether the concrete quality in the structure is also being met properly or not.

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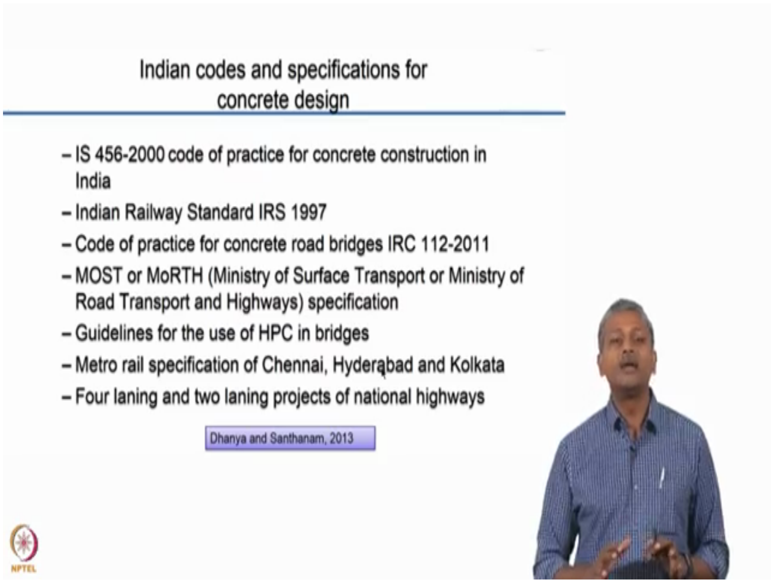

So there are several Indian codes and specifications that look at concrete design, of course if you look at the list of codes inspects it is massive specification for concrete construction with

IAS, with IRC, with IRS, with MOST and then there are guidelines and specifications drawn up by various metro construction projects and highway construction projects and so on.

The only problem is very many times we have find most of these codes are not very well (()) (21:32) with each other, there are several clauses which are in one way in one code but they are not present in same way in the other code. So there is a lot of confusion as far as understanding durability is concerned and how to achieve this durability?

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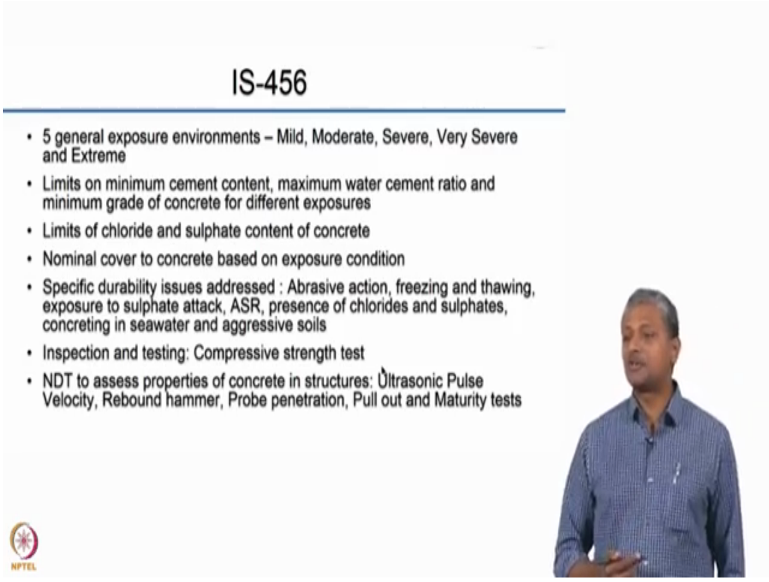

Some aspects from the Indian standards IS-456 which is basically pertaining to reinforce concrete construction for buildings with respect to durability they have been given here, I am not going to go into the details the idea is that there are several issues that are pledging our standards at this point of time we have not really (())(22:03) with the international developments for example when you look at EN 206 which is the euro norm standard or Aci 318, they have been able to implement a lot more of the understanding on durability that has been generated over the last few years.

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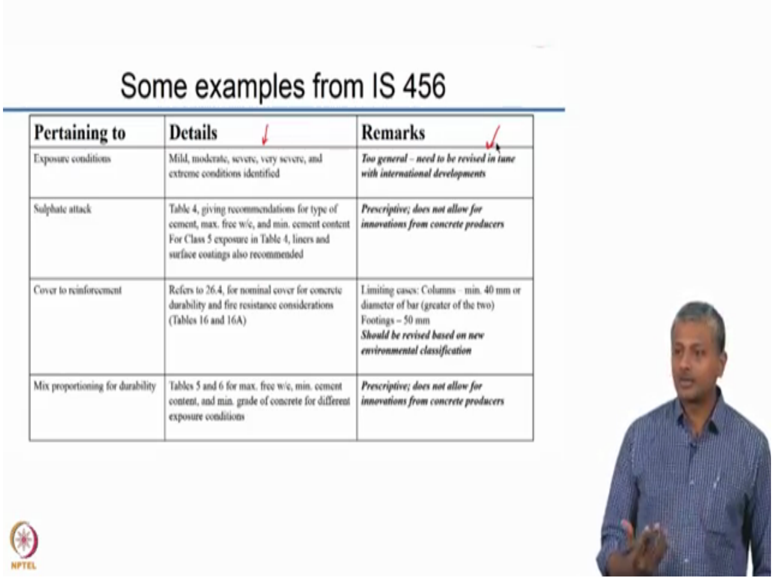

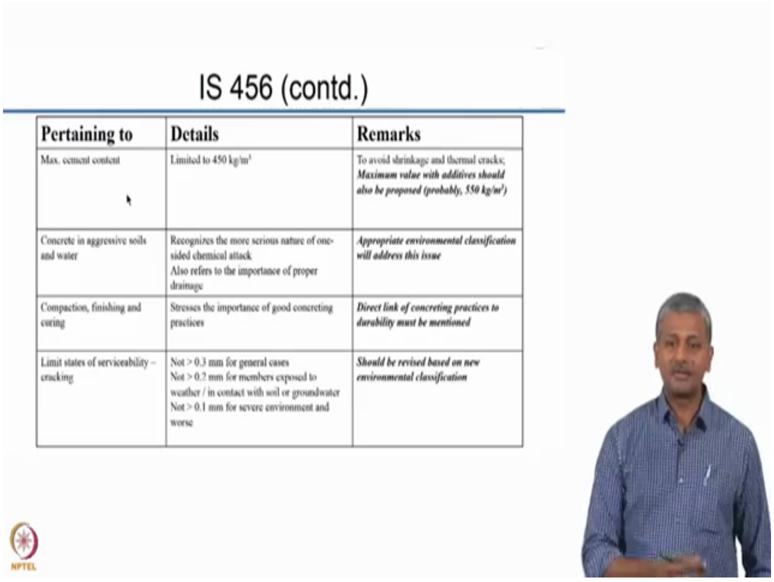

I have also placed some clauses from IS 456 not really going to the details here but the idea is that we have outline some details of these clauses and what is needed with respect to actually improving these clauses in the Indian (specific). Again this is regarding various different aspects which are presented in this code I am not really going into the details of this.

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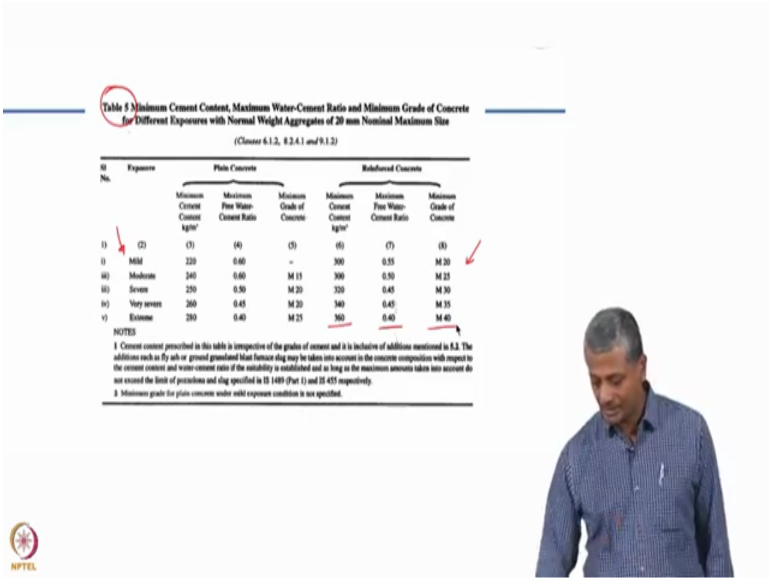

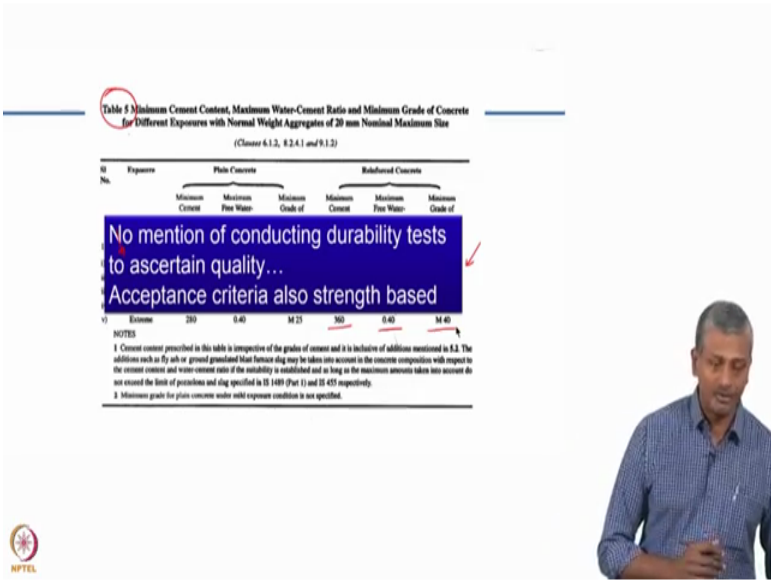

Just to give you one example for instance when we go into the understanding of the prescription for concrete construction or durability of concrete in a chloride based environment these values are given in a table, table 5 in IS 456 which lists 5 different classes of chloride environments mild, moderate, severe, very severe and extreme and it places requirements on the minimum cement content, maximum water cement ratio and minimum grade of concrete.

Now if you really look at this code and want to design a structure in the beginning you may think that okay if I satisfy all these criteria I will automatically get something which is durable. The problem unfortunate part is the code really does not call upon a clear understanding of the test to be performed to assert in whether after choosing these materials are you able to get the required service life or are you able to get the required durability indices or parameters which are present in the concrete, okay. So there is no call for testing as far as this code is concerned.

So there is no mention of conducting durability test or certain quality and the acceptance criteria which need to be followed are only defined for strength, so you do not really know what will happen when you are actually producing concrete and supplying it on the field, how do we actually assert in the acceptance of the concrete in the field.

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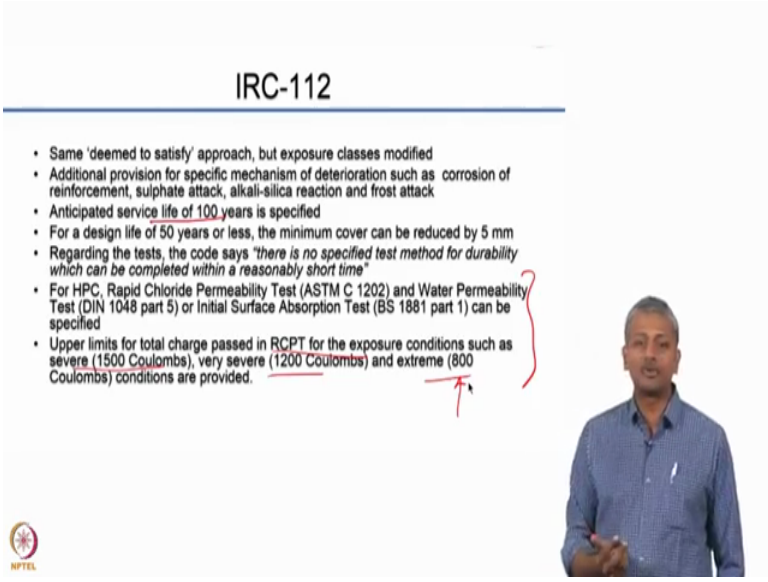

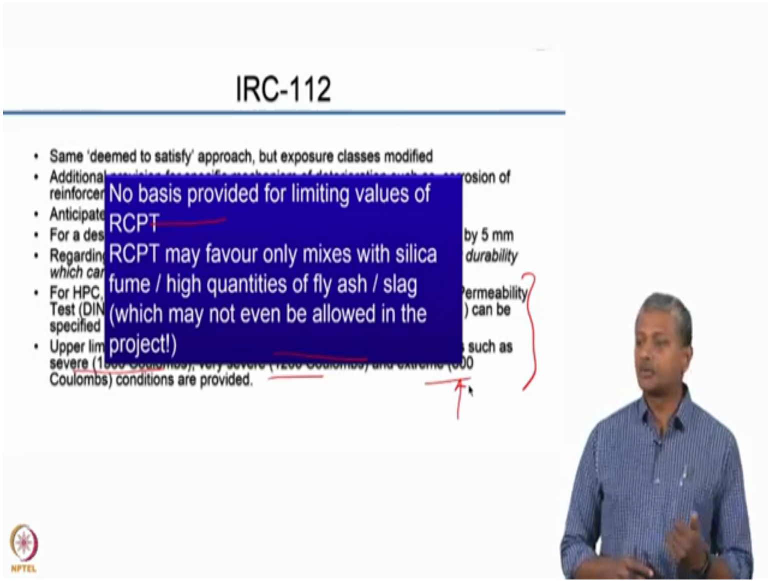

There are some improved standards for example you have the Indian Roads Congress code 112 specification sorry not a code, again here they are talking about anticipated service life of 100 years and again for this what they state is there are very clear cut guidelines that say that your concrete should be defined by certain durability characteristics for example the Rapid Chloride Penetration Test has been specified in some of the cases where they say that for severe condition your concrete should satisfy 1500 columns as a maximum RCPT value and for very severe 1200 and for extreme 800 columns.

Now of course there is no guideline as to how to achieve these values in real construction because such low values like 800 columns can only be achieved when you have a significant proportion of mineral additives in your system or you have some fine mineral additives like silica fume and metakaolin present in the system so there is no guideline given for these limiting values as to why these are specifically chosen and what way are they related to service life, what is the basis of actually providing these values.

Again there is no basis on understanding what combination of materials should be used to actually get these values and sometimes the project specification may not be even allowing such mineral additives to be used in the construction.

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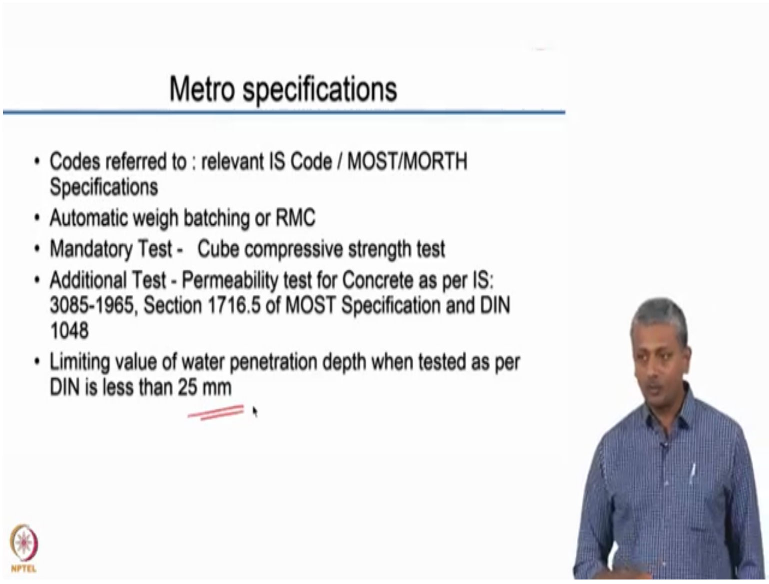

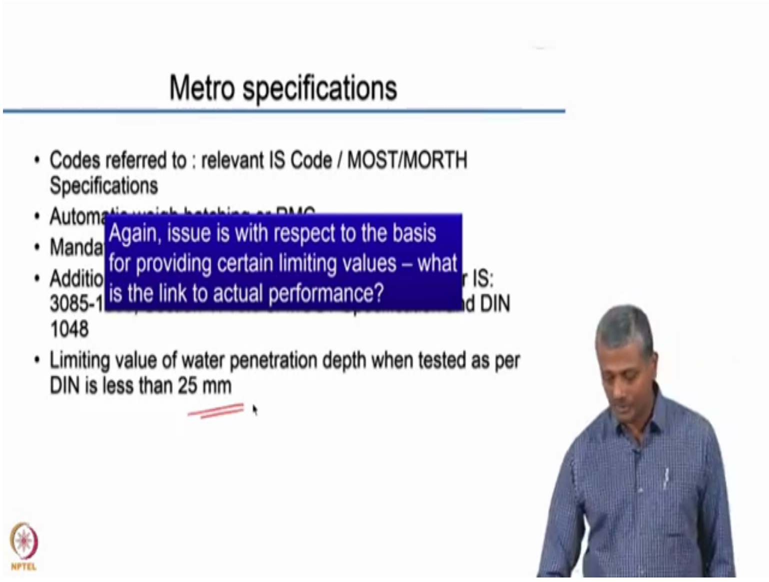

There are of course other specifications like metro specifications in Chennai and other parts of the country where you have water penetration and RCPT specified once again, there are limiting values specified without really any clear basis for what these limiting values pertain to in terms of the actual performance of the structure.

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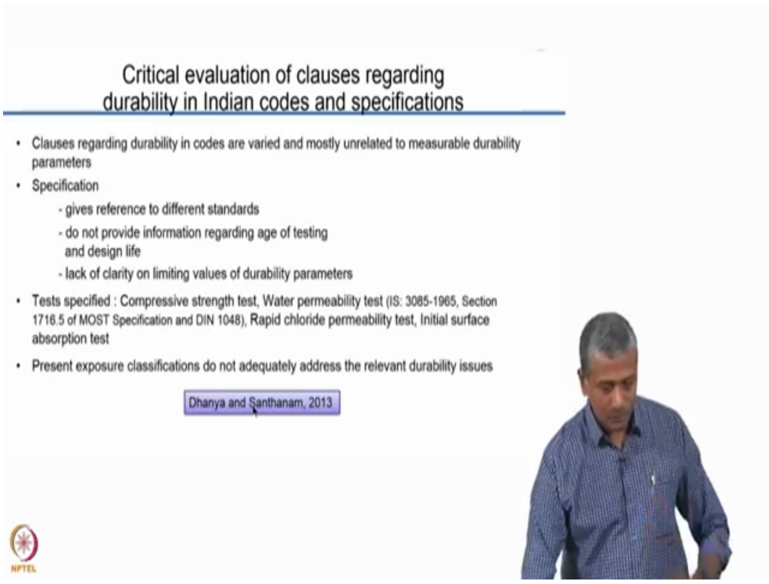

So again there are several issues pledging our current specifications and the need is there to really bring in more and more understanding of different tests that we can use to specify durability in the structure, okay. So you can go over these details by looking at the paper that I have looked at I have specified there.

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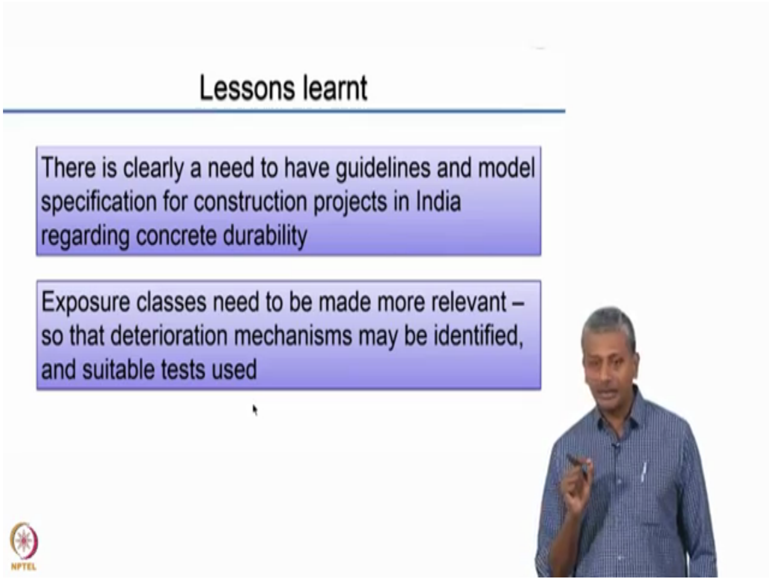

So the lessons that we have been learnt from Indian construction scenario is there is a clear need to have guidelines in model specification for construction projects in India regarding durability, there is of course a need to understand how to redefine our exposure classes because there is a lot of international literature in this which has come out in the last 10, 15 years and we have to start reflecting these in our standards also, idea is to essentially link the exposure classes to the actual deterioration mechanisms that affect the concrete in those kinds of exposure environments.

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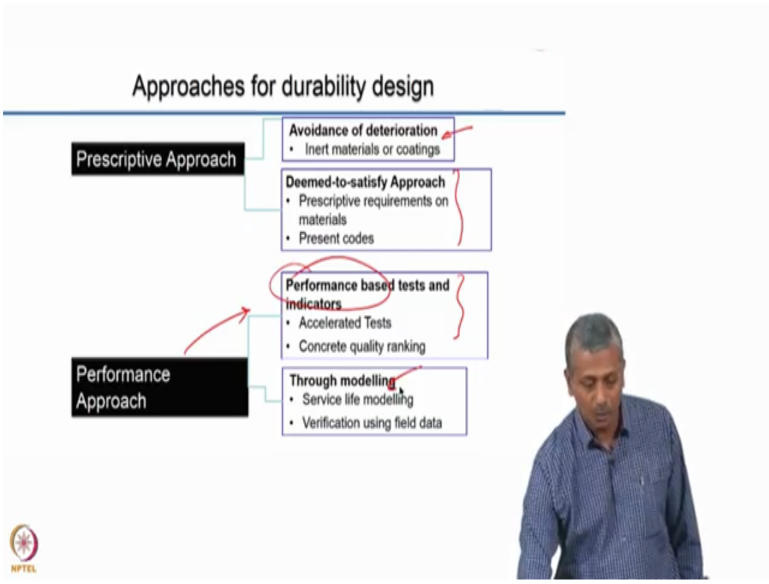

So again jus to summarize the durability design approaches you have the prescriptive approach which can be either use of coatings or inert materials that can totally avoid the deterioration, now that is something which you can imagine that is going to be not very cost effective, it is going to be expensive for example the use of stainless steel instead of reinforcing steel is one of the avoidance of deterioration approaches but that is probably not going to be practical in several scenarios.

And then you have the current way of doing durability design that is providing prescriptive requirements on materials and adopting these practices directly in the construction industry that is basically your present coddle system, then you have the performance based tests and indicators that relates to the performance approach here we define that the concrete characteristics can be measured with the help of accelerated tests before the construction project actually commences and some of these tests can actually be used to monitor the progress of the project and monitor the concrete quality that is happening in the construction project also that is basically your performance based design by using tests and indicators for concrete quality.

And finally of course performance design can be based accomplished through modelling once we get confidence with the use of these tests and understand the significance of the limiting values that we get from these tests, we can actually start doing modelling and then design concrete for certain specific service life with just the modelling approach, but right now I do not think that is sufficient information for us to really go forward with that.

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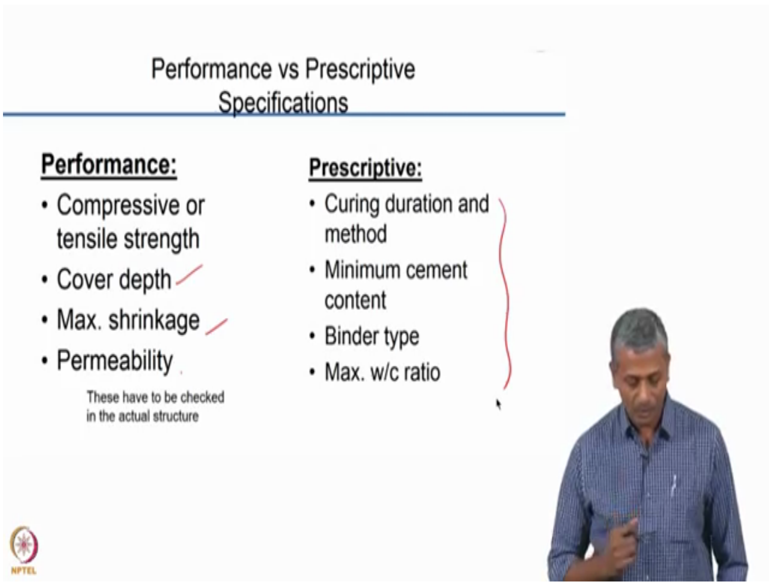

So again just to put this in perspective again the performance specifications could be your compressive or tensile strength, the cover depth which is actually measured in the structure, your shrinkage or permeability, whereas your prescriptive specifications are what are currently specified in your codes in terms of the curing duration method, minimum cement content, the type of binder to be used in your construction project and the maximum water to cement ratio.

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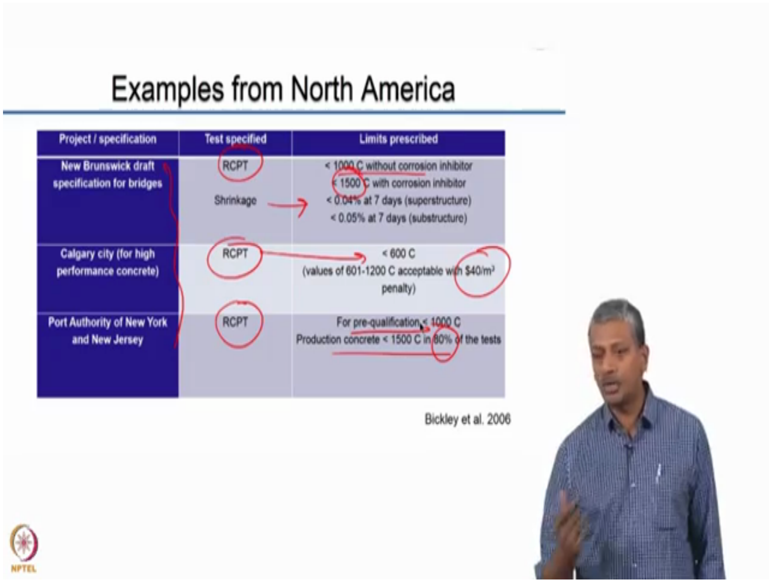

Now just an examples of performance specifications from North America, so you have here several different specifications for bridges and tunnels and so on very high profile structure. So here you have RCPT values being specified by the New Brunswick draft specification for bridges which says that RCPT should be less than 1000 columns without corrosion inhibitor and less than 1500 with corrosion inhibitor and of course taking into consideration of the fact that when you use specialized admixtures like corrosion inhibitors, you can increase the ionic concentrations of your concrete systems that may lead to more conduction that is what a higher limit is provided for concrete with corrosion inhibitors.

The specification also has a limit on shrinkage at 7 days defined separately for the super structure on the sub structure. An interesting part is this Calgary city specification for high performance concrete where it specifies an RCPT value of less than 600 columns but then it says with a clause that you can also have 601 to 1200 columns provided you are willing to pay a penalty of 40 Dollars per cubic meter.

The advantage here is that the contractor or the concrete supplier now has a clear understanding of what criteria needs to be met. For example if the cost for him to provide concrete that achieves a durability of less than 600 columns is much higher than the penalty that it is going to pay for 601 to 1200 columns it may be a worthwhile proposition to actually pay the penalty and go with a different characteristic of the concrete.

So again such criteria need to be made available to the contractor or concrete producer well in advance by a proper arrangement between the client and the contractor so that these characteristics can be worked out in the specification, again here one more Port Authority of New York and New Jersey says that RCPT for pre-qualification that means for ascertaining that the mix is good enough for construction should be less than 1000 columns but when the same mix is specified on site or is supplied on site on a day to day basis for the production concrete you allow a slightly higher deviation you say that you are okay with less than 1500 columns in 80 percent of the tests.

That means you can deviate to even more than 1500 and 20 percent of the tests because you know that in field you can expect a lot more variation than what you have in the laboratory environment.

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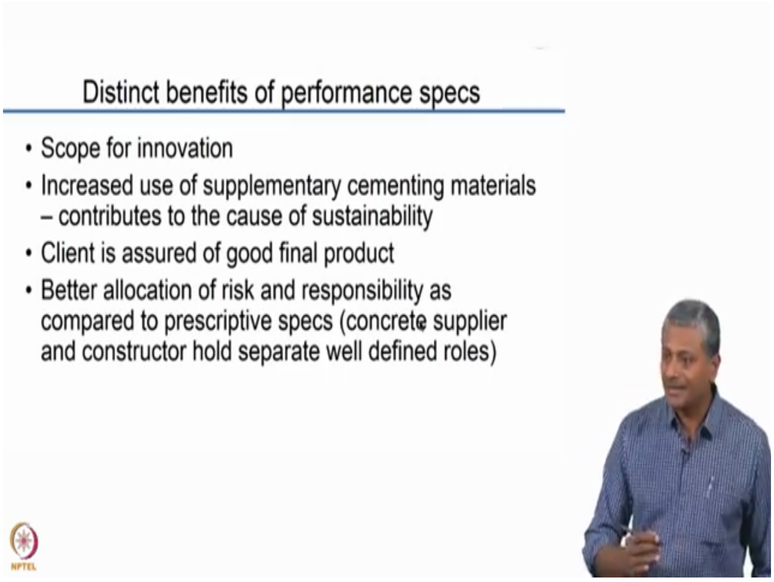

So of course distinct benefits are there, there is scope for innovation and increased use of supplementary cementing materials right now the prescriptive say that you can only use so much percentage of this, so much percentage of that. Now in a performance specification we do not have to worry about what ingredients make our concrete, we only have to worry about what performance we can actually achieve from the concrete and essentially, ultimately the client is assured of a good final product and people understand their roles in the process much more clearly.

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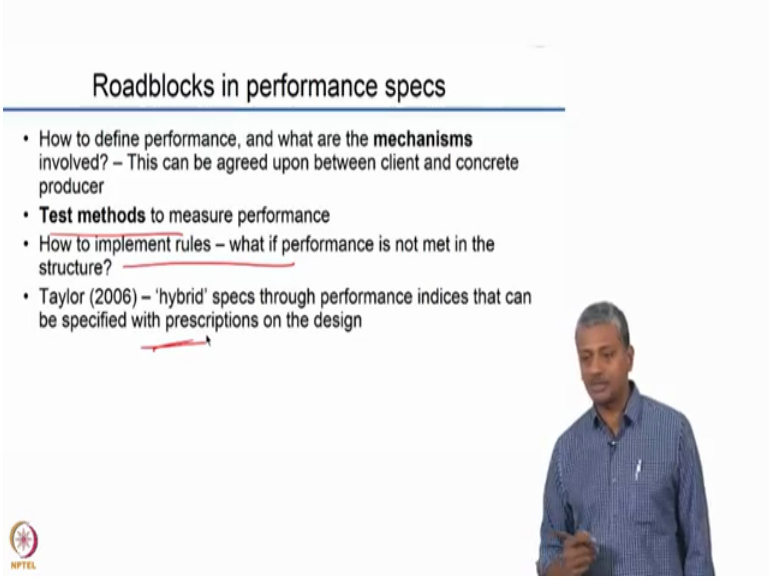

Now of course there are lot of roadblocks as far as successful implementation or performance specification is concerned, how can we define a performance and what are the mechanisms involved? Again this has to be agreed upon between the client and the concrete producer because if the project starts something is then the specification, the concrete producer is not able to make it, it is going to be quite a daisy situation.

For example in one of the construction projects that has recently started in neighbouring state Andhra Pradesh, there is something in the specification which says that the durability test should be carried out for every 100 cubic meters of concrete supplied. Now the concrete construction projects starts with massive piles about 1.5 meter diameter piles which are nearly 40 meters deep.

So for each pile you need upwards of 500 cubic meters, okay. So while they are supplying the concrete and filling up one pile imagine that you need to pull out 5 different samples for durability tests. Now that is not going to be easy, right because they might be doing more than one pile in a day and imagine having to do continuously do durability tests for so many different piles on one particular day, it is not very easy, first of all durability tests are expensive they are not as easy to set up as compressive strength tests, so you need to ensure that you understand how these tests can be implemented on site by taking into account the characteristics of the concrete constructional site.

The other part is what are the test methods that should be used to measure performance, now you see very often that we are randomly using in many of our construction projects rapid chloride penetration test as an indicator of durability, now if you really think about it this mechanism may not really reflect the kind of durability problem that you expect to happen in your specific service environment, in some cases gas permeability or water permeability maybe a lot more interesting to look at rather than the chloride penetration characteristics.

Then major problem is how do we implement the rules? What if performance is not met within the structure? So how do we actually bring that into the specification? For example if I 28 days I do not make the permeability values satisfactorily the structure is already been build, what do you do with it? You cannot obviously bring it down, what are the remedial measures that you need to take up?

So all those aspects need to be thought of well in advance at the time of designing the specification, now we know very well in most of our construction projects that you never have so much time to work with the concrete usually in concrete construction projects in India atleast we have concrete mixed designs that probably the concrete producer gets hardly a month to prepare, but if you really have to work through these durability specifications and understand how to implement them in a regular construction project you need anywhere between 4 to 6 months to really work out something reasonable and the requirements may be for much greater amounts of time if you have special characteristics also and that need to be worked out.

So people have tried to address this issue of implementation by saying that we can try and look at hybrid specifications, for example partly prescriptive and partly performance based in terms of atleast having some sort of a minimum cement contents specified so that we can assert in some level of performance in the structure, at the same time added with the actual tests for the durability to be carried out on the concrete either in specimens or in structures.

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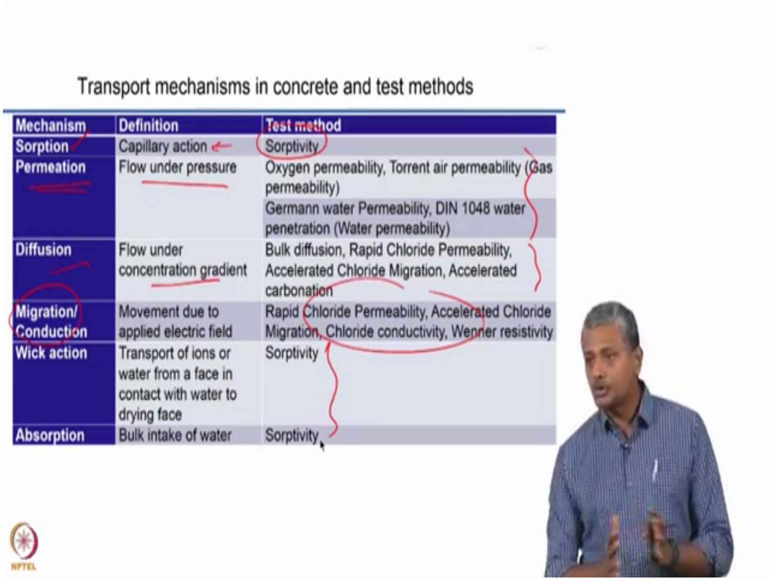

So just to give you some perspective of the transport mechanisms that are involved and the tests methods that actually relate to those mechanisms, so here you have for example sorption which basically is capillary suction. So for example you have a foundation standing in under the ground and you have capillary suction of the water from the external environment and test method that reflects that is sorptivity test which is again a standardized method as far as ASTM in the South African durability index procedures are concerned. You have permeation which is basically flow under pressure and there are several different tests that can actually address this, some are related to gas permeation, some are related to water permeation.

You have diffusion which can happen when the flow of ions happens under concentration gradient and there are several different tests that can actually address diffusion and then another associated form of this test is called the migration test where you apply an electrical potential to presumably increase the level of diffusion sometimes that does not happen, you actually end up testing the conductivity of the concrete but there are several different methods there too.

And then again you have wick action and absorption which can be also reflected by the sorptivity test. So as I had indicated earlier the choice of the test method has to reflect the transport mechanisms that lead to a particular durability problem. For example if I am talking about corrosion of reinforcing steel in concrete there are several different factors that may affect that. For example in a chloride environment you will have diffusion, you will have permeation, you will have some sorption and associated effects.

So the test methods you choose for a chloride environment have to be based on these primary transport mechanisms. For a concrete which is subjected to carbonation you have gas permeation, you have water sorption as the primary effects and any test that you define for the concrete construction should take into account those specific transport mechanisms.

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So just to put things in perspective what are the challenges that we face with concrete construction in India possibly the supplies to most emerging economies?

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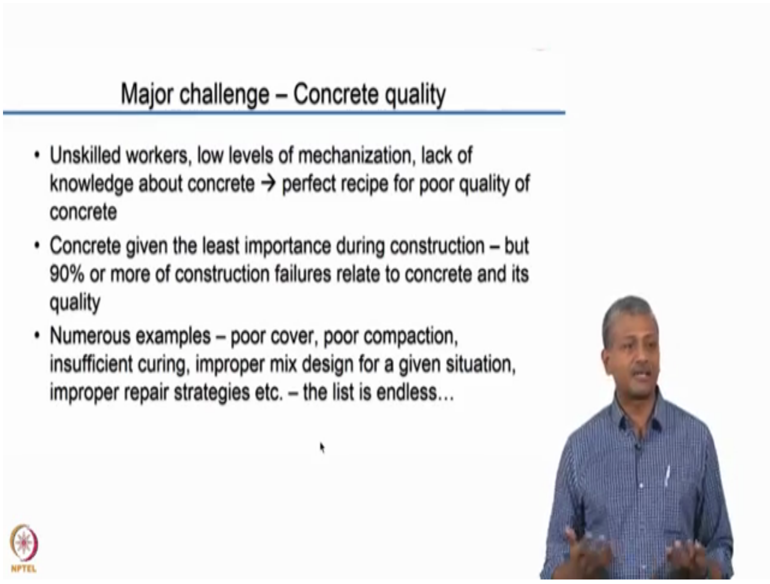

One major aspect is we have unskilled workers and we have very low levels of mechanization, there is also lack of knowledge about concrete on the site very often you find that there is not even 1 percent who understands concrete technology on the site this is obviously going to be a perfect recipe for poor quality of concrete. Again concrete has given very little importance during construction I was telling the example of the time allocated for mixed design, very often you find that the real control of concrete quality the field is also left to people like foremen or workers who really do not understand what the significants or the concrete characteristics are.

So poor cover, poor compaction, insufficient curing, improper mixed design, improper repair strategies and also there is endless list of problems that can actually happen on site.

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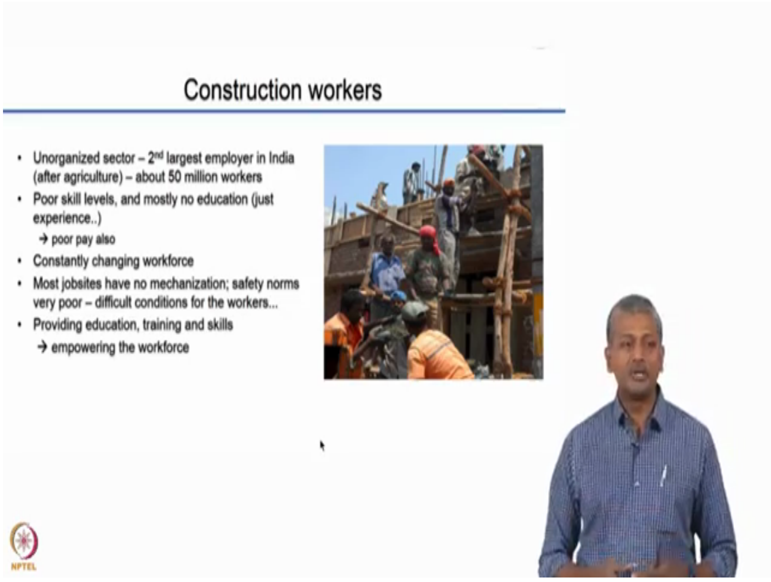

So construction workers obviously form the second largest sector in India after agriculture 50 million workers, poor skill levels and mostly no education, they just gain experience and with that they move from site to site, we have a constantly changing workforce. So ensuring concrete quality is a big challenge because the moment you train a certain set of personnel they probably move on to the next project, they do not stay too long in one project obviously because the pay is low they always seek locations where they can get paid more and more, okay. Now obviously empowering the workforce and providing education to them is absolutely necessary to really get an improvement in the concrete quality.

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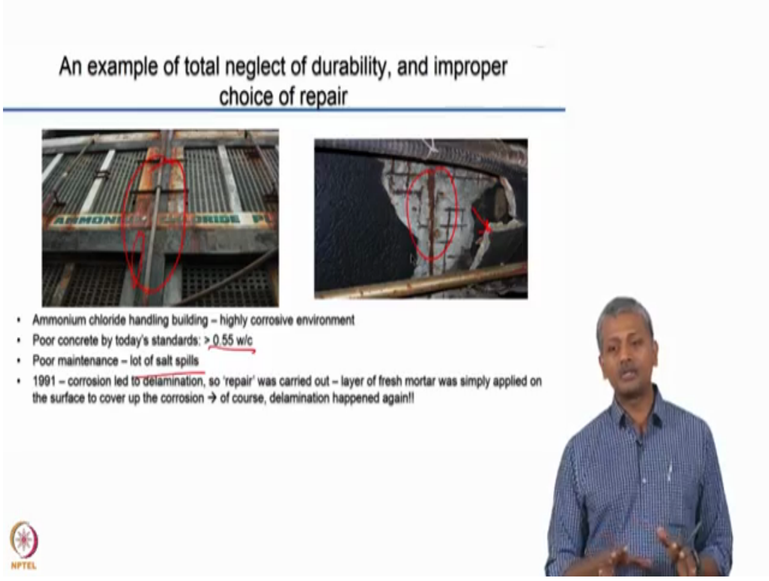

Sometimes we come across situations where people do not apply repair principles properly and end up producing more durability problems. For example this is ammonium chloride handling building which is basically you can imagine ammonium chloride can produce a very highly corrosive environment, this building was constructed in 1960's so obviously at that time there was no real understanding of durability, it was designed with concrete of more than 0.55 water to cement ratio.

Now obviously when you are designing concrete like this atleast you should take care of the maintenance, there is a lot of salt spills that happened in the structure, obviously maintenance was very poor. So all the salt ended up deteriorating the concrete you can see the column itself is showing severe signs of cracking and that is not very good for a structure and the repair strategy that was adopted was to simply use a patching mortar to cover up the concrete corrosion, they did not really repair the corrosion problem but they simply covered it up with the patching mortar.

Now obviously after sometime the corrosion continued and the patching mortar simply fell apart, it came out. So there is an improper application here of an understanding of a problem like corrosion and trying to cover up the problem rather than propose a solution to the problem itself, so very often this is a kind of situation that we see in most of our construction projects.

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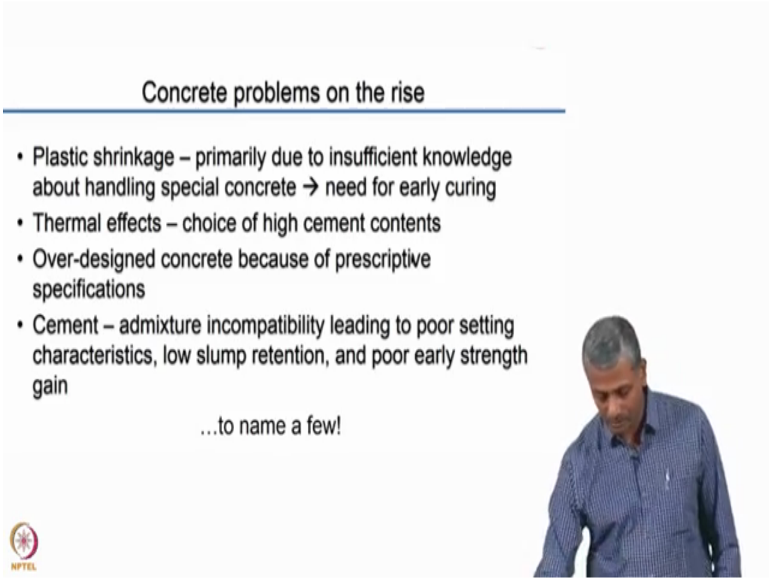

There are other issues also that are on the rise like plastic shrinkage, we are increasingly using supplementary cementing additives in the concrete and if we do not take care of concrete during the early hours we can have plastic shrinkage cracking, thermal effects when you have very high cementitious contents because today needs for strength are very high and over designed concrete because of prescriptive specifications. Sometimes you see if you go to job sites M20, M25 concrete can sometimes have cement contents upwards of 400 kilo grams cubic meter you can imagine that is a complete waste of cement.

And cement admixture incompatibility is again a major issue because very often we have vast differences in the performance between different brands of cement which can actually be pertaining to the same grade itself and you have large range of additives which are available sometimes you have to really test these properly before you can use them well in the concrete.

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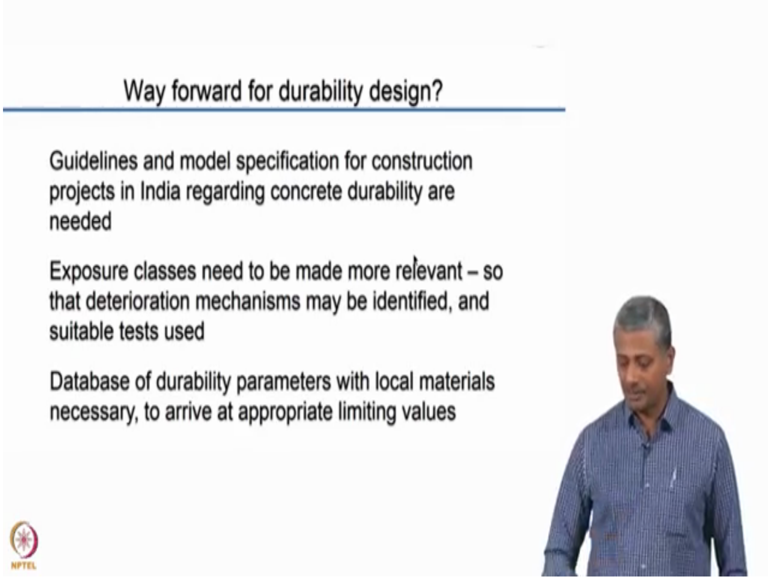

So what are the way forward for durability design? Obviously need guidelines and model specification for construction projects in India regarding durability and exposure classes have to be made more relevant and finally the database of durability parameters with local materials is necessary because ultimately understanding what these limiting values mean for the actual performance of the structure will be only possible when you have a large database with the existing materials that we have in our country.

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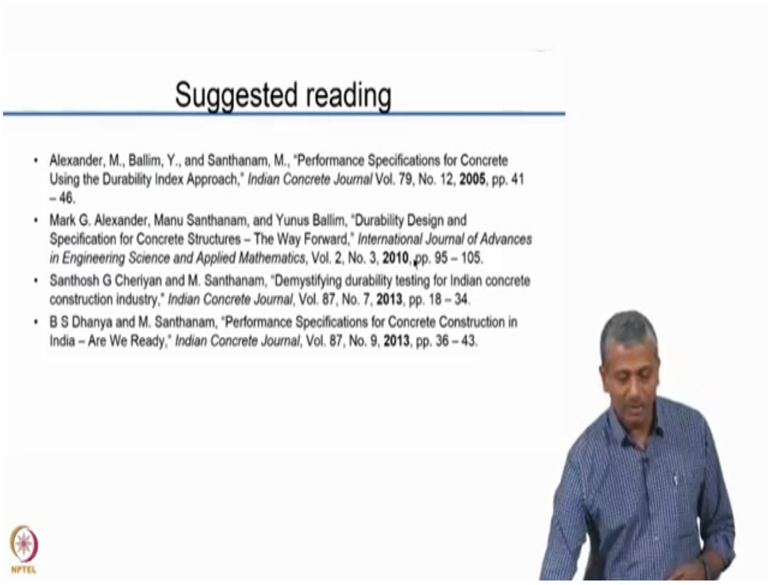

So there is a lot of papers that can be read further for more information on the subject you will see that the content that I have covered here in terms of permeability and its role in defining concrete durability will be critical in understanding other durability problems like sulphate attack, corrosion and so on which will come across later in this course. So thank you all very much for your attention, thank you.