Concrete Engineering and Technology
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Lecture - 28
Using epoxy-coated bars in concrete structures

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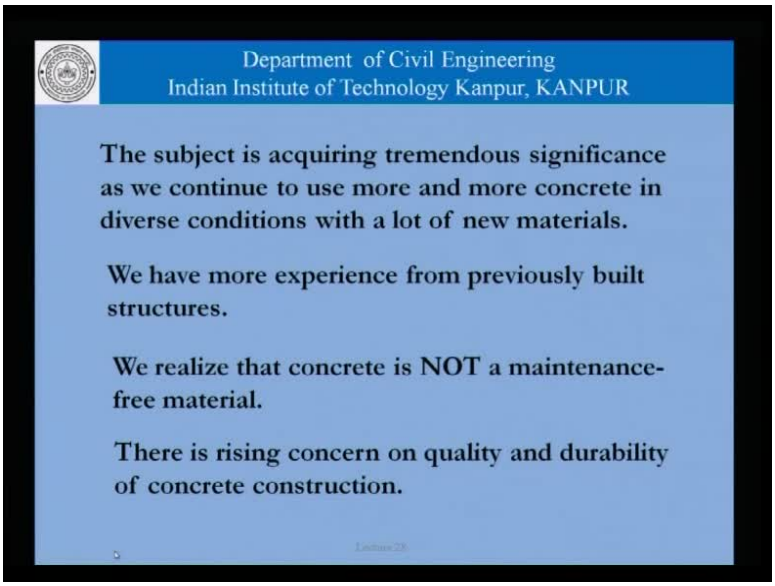

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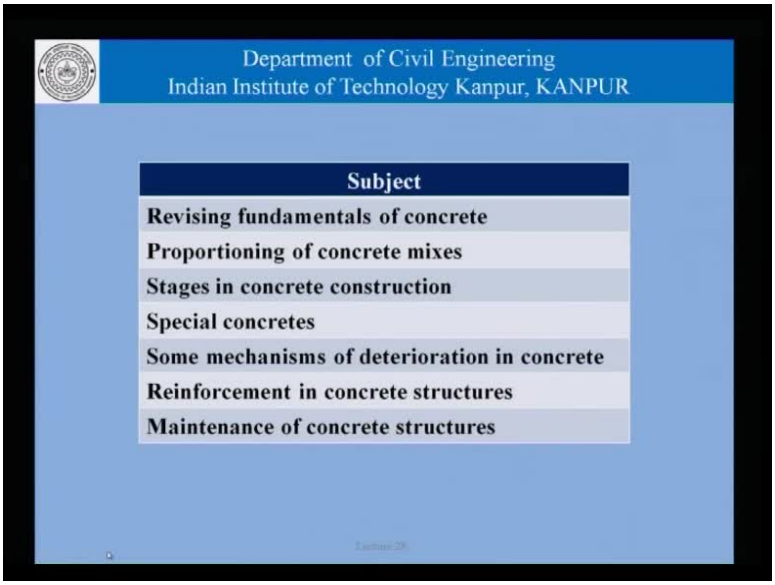

[FL] and welcome back to the series of lectures on concrete engineering and technology, where we are talking of the subject in the context of the importance that it is acquired in

the recent past arising out of increased concern for quality and durability in concrete construction, realization that concrete is not a maintenance free material. And the lot of experience that we have gathered from the performance of existing concrete structures built may be 10, 20, 30, 40 years ago. And we are talking of these different things fundamentals of concrete, proportioning of concrete mixes stages in concrete construction and so on.

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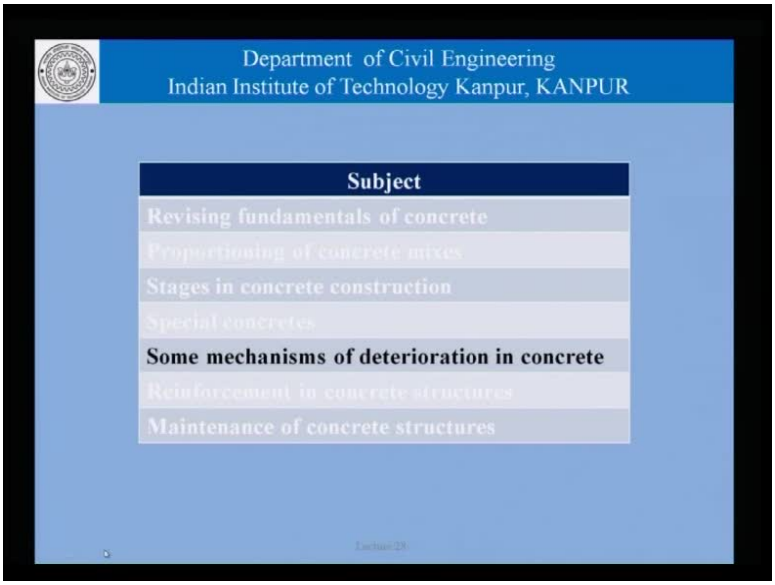

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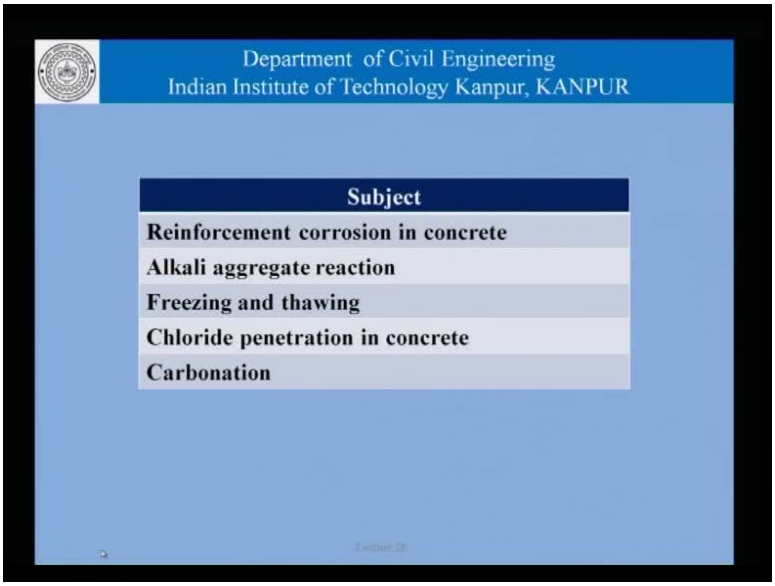

Now in this we are talked of mechanisms of deterioration in concrete structures.

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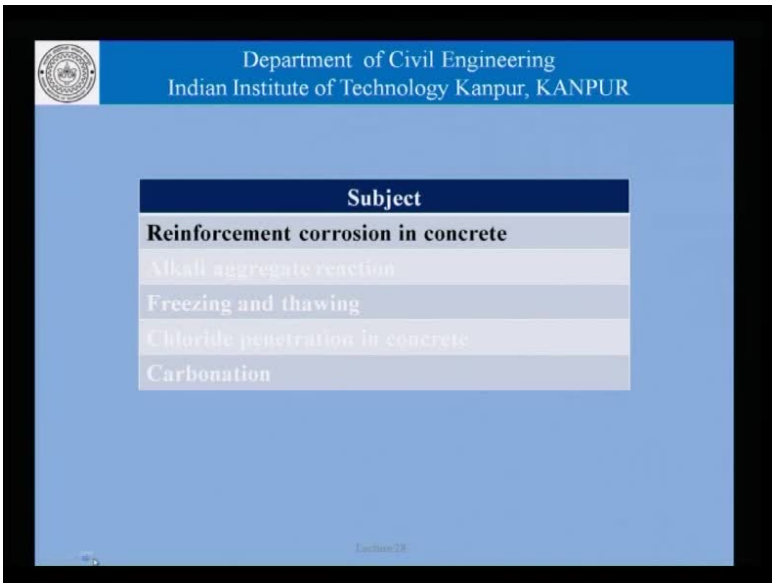

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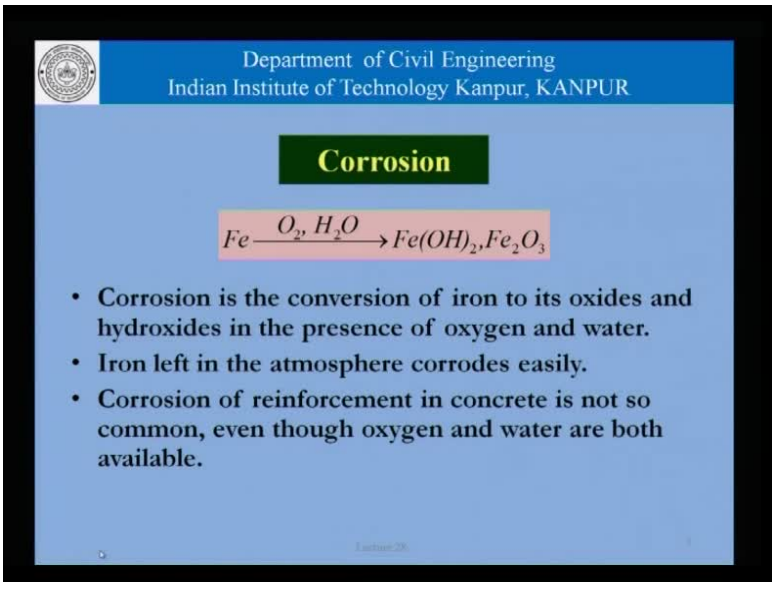

And among in that we had discuss a little bit about reinforcement corrosion in concrete. Now as far as this subject is concerned, we say that correction is basically a process where iron gets converted to iron oxide and iron and iron hydroxide I mean that can be several oxides there can be several hydroxides, but basically it is a processes where iron is converted to oxides in hydroxides of iron in the presence of water and oxygen.

We must remember that iron if it is left in the atmosphere it corrodes pretty easily. And as far as corrosion of reinforcement in concrete is concerned it is not so common, even though we have an ample supply of oxygen and water.

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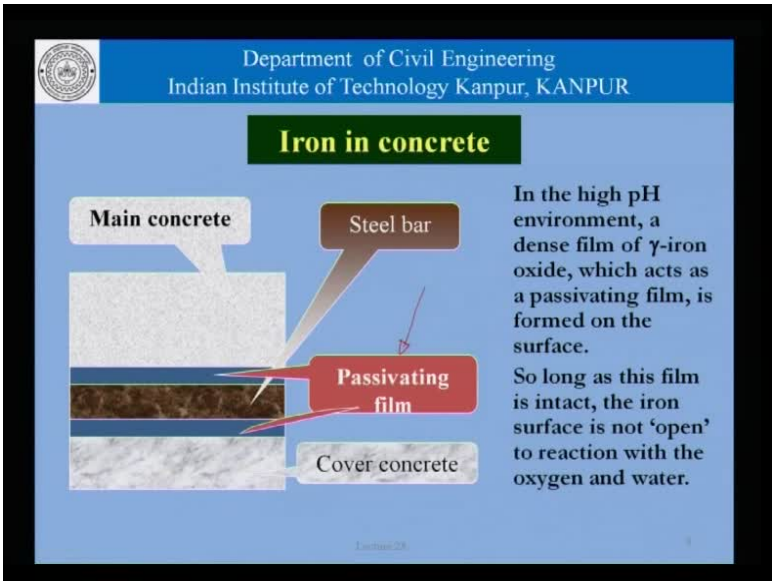

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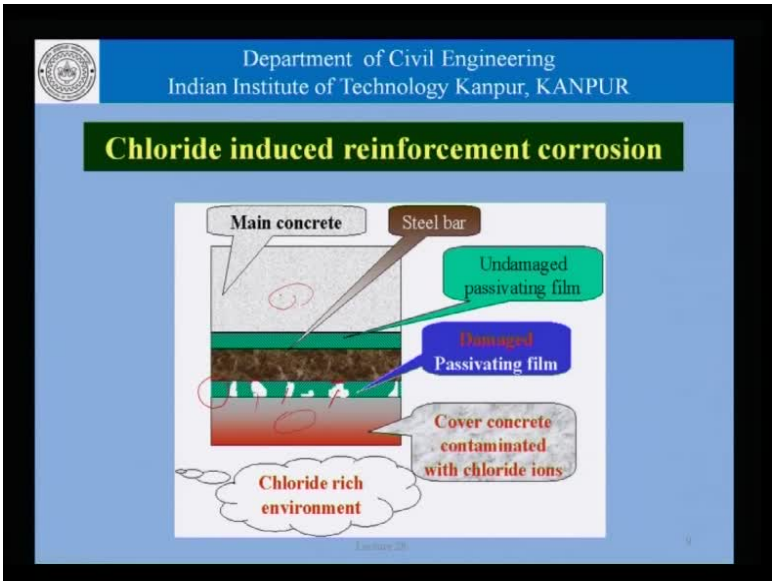

And we talked about the reasons. why that does not happen, the reason is the formation of this passivating film in the neighborhood of the reinforcing bars, because of the high p H of the pore solution and concrete which is a product of the formation of large amounts

of calcium hydroxide on account of large amounts of calcium hydroxide which is formed when cement hydrates.

Now, we have also seen that this passivating film can be damaged as shown here which typically happens. For example, in the case of chloride rich environment and where we have chloride induced reinforcement corrosion, the basic principle there is that in the neighborhood of the reinforcing bar if the chloride concentration exceeds the certain threshold level this film is damaged as shown here.

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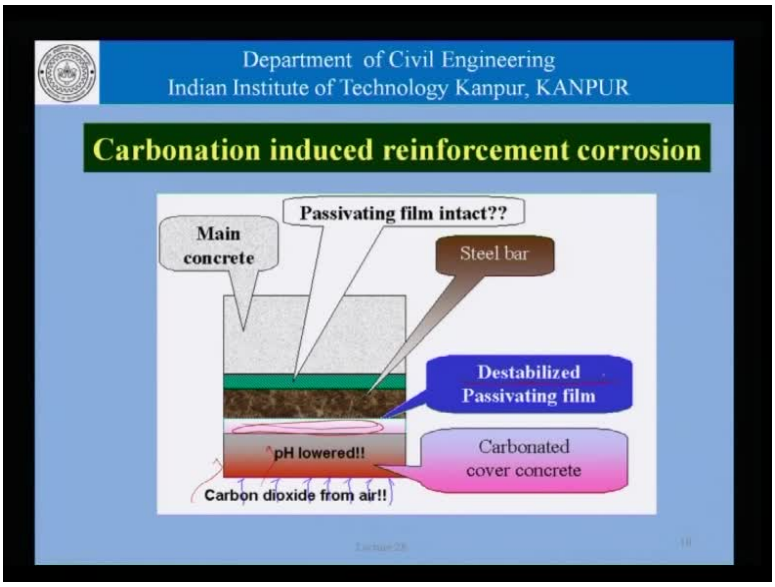

And therefore, the surface of the bar is exposed to the action of oxygen and water which is in abunded supply in the cover concrete or the main body concrete. And that is how corrosion proceeds, it can also happen in the case of carbonation which is the process where carbon dioxide from the atmosphere goes into concrete lowering the p H there, because of the action or the reaction of calcium hydroxide in the pore solution with the penetrating carbon dioxide. As a result of which the p H is reduced and the, this passivating film which was here is destabilized, because of thermo dynamic considerations the p H goes down and the thermo dynamically per stabilizing film or the passivating film is no longer stable.

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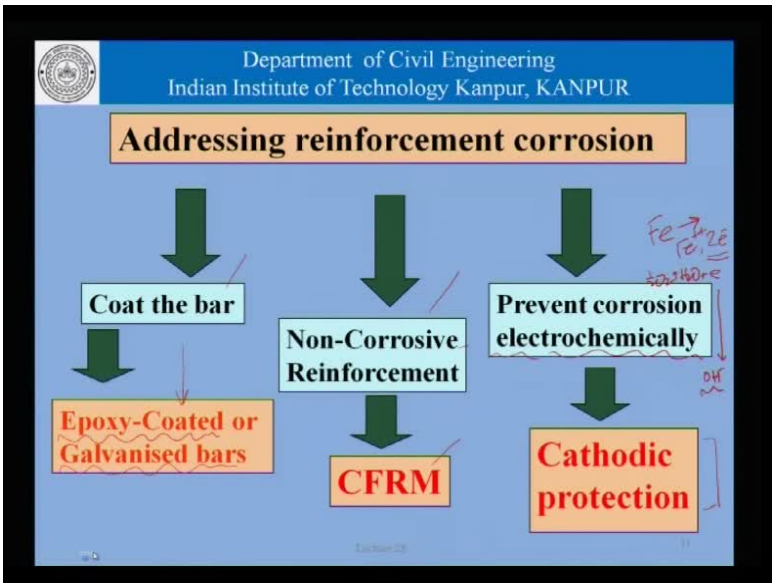

So, in both these conditions we have conditions which are right for corrosion of the reinforcement. Now in order to address this problem of reinforcement corrosion we can follow these three fundamentals step. We can either coat the bar that is we provide physical barrier between the oxygen and water in the concrete and the steel surface or the surface of the iron on the reinforcement surface or we could simply use non corrosive reinforcement. We could use a material that does not corrode or we can do something electrochemically, because we know that corrosion is an electrochemical reaction which involves of the conversion of iron, two iron ions and release of a electrons at the anode. And the consumption of these anodes with oxygen and water which gives you hydroxilines in this reaction taking place at the cathode. So, if for by sound mechanism we are able to control the reaction at the anode or the cathode by some electro chemical means then we can prevent corrosion.

So, these are the basically the three fundamentals steps. Now, as for as coating the reinforcing bar is concerned we could use something like epoxy coated bars or galvanized steel bars and so on which are in this category where we are talking of coating, the reinforcement with the barrier. Non corrosive reinforcement is something like fiber reinforced materials. We will be probably talk about this later on, as for as electro chemical methods for preventing corrosion is concerned. We could consider something like cathodic protection.

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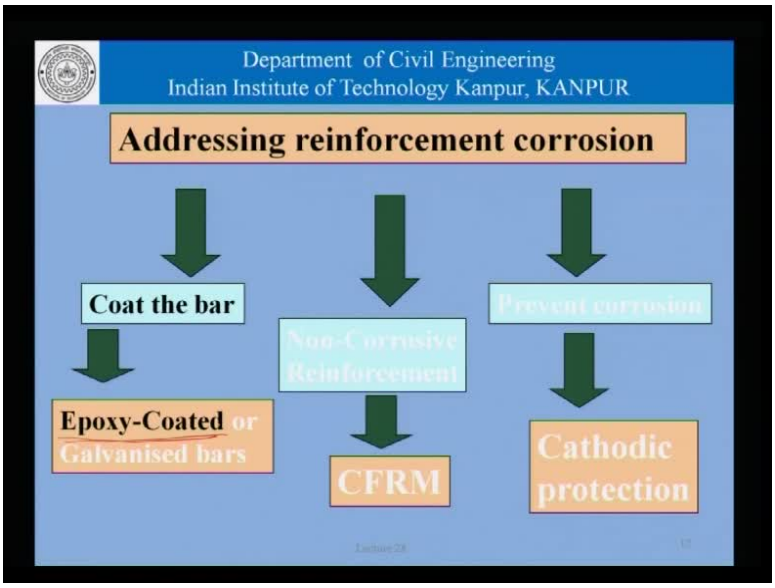

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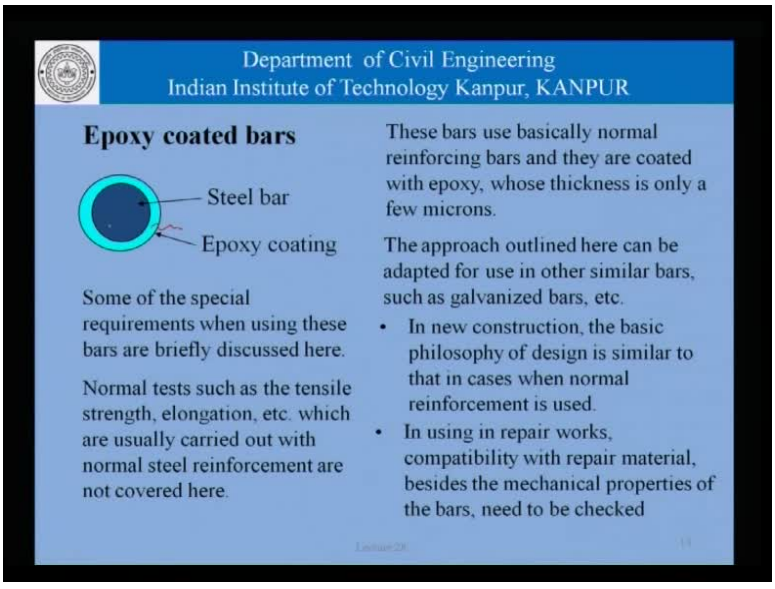

Now, cathodic protection is a standard tool as far as steel structures or pipelines are concerned it is application in the case of concrete structures is rather small. There may be some applications, but by and large we have not too many applications of cathodic protection as a means to prevent or protect reinforcement in a concrete structure. So, our discussion today would be focused on the use of epoxy coated bars, as far as wall of the methods is concerned for prevention of corrosion in the reinforcing steel. Now, what is epoxy coated bar? It is basically a steel bar a normal steel bar which has a very fine coating of epoxy material on it, please remember that this figure is not to scale.

So, if the thickness is very small, now since is basically a normal steel bar most of the considerations that apply for the choice of a reinforcing steel would still apply as far as the use of epoxy coated bars in concrete construction is concerned. And therefore, normal tests such as the tensile strength, elongation etcetera, which are usually carried out for normal steel reinforcement are not going to be talked about here. And we would assume that you already know about them. And the, as for as the coating is concerned I already mention that it is only few microns, they approach adopted here would be similar in case of other bars. For example, galvanized bars or any other coating that we use, because it the principle is the same. In new construction that the basically philosophy design is similar to that of using normal reinforced odd normal reinforcing bars.

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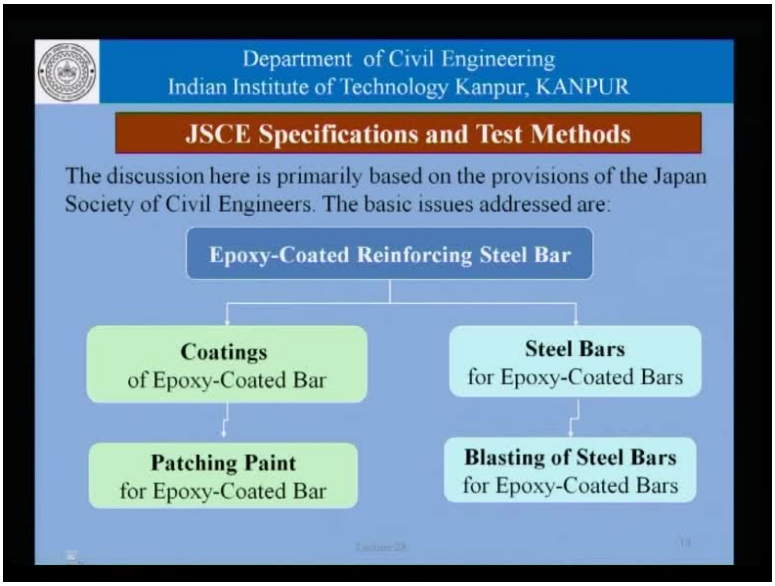

If we are using epoxy coated bars in a repair or rehabilitation job then we have to talk in terms of compatibility. We have to talk a little bit about the issues related to corrosion the electro chemistry and so on. But for the discussion today, you would confine ourselves to using normal epoxy coated bars in concrete construction. And the special tests that need to be carried out when we are using such bars in the concrete construction. The discussion today would largely be based on the provisions of the Japan society of civil engineers applications relating to use of epoxy coated reinforcing steel bars. And we have the issues related to the coating itself then we have some issues related to patch painting that is material that is used in case certain repairs need to be carried out.

Then of course, there are steel bars which are to be used for the manufacture of epoxy coated bars and the basting of steel bars for epoxy coated bars. The blasting refers to sand blasting which should basically means or is a processes by which the normal steel bars are cleaned before they are epoxy coated, though will not cover it in detail. The manufacture of epoxy coated bars essentially involves normal reinforcing bars, heated to a certain temperature, exposed to a powder of epoxy which condenses all the hot surface of the reinforcing bar forming a very tight thin film on the surface of the bar. Let me show you some of these epoxy coated bars, this is an epoxy coated bar. As you can see that it is not really normal steel bar with rims on the surface except that it has a green coating, the color can be vary color that the manufacture decides or it is pleasing to you.

So, there is a color coded so is basically a normal steel bar with the coating of a epoxy these bars come in different diameters. You can have bar which is about 316 m m in diameter there could be a bar which is about 12 m m diameter and so on. If you can closely look at the surface here, you can see that the surface is the same as of a normal steel bar and the coating can hardly be measured in terms of millimeters and so on, because it is really a very thin film.

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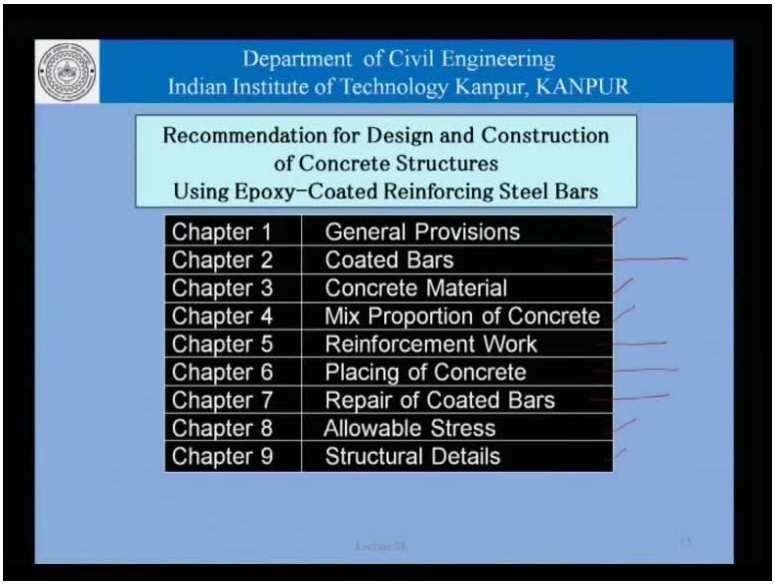

So, we must remember that this is the kind of material that we are talking of when we are using epoxy coated bars in normal reinforce concrete construction or pre stress concrete construction these are the bars which are embedded in concrete. As far as the

recommendations for designing construction of concrete structures using a epoxy coated reinforcing steel bars is concerned which is JC publication which a France society of civil engineers. It means it has 9 chapters general provision, coated bars, concrete materials, mix proportion of concrete reinforcement, work placing of concrete, repair of coated bars, allowable stresses and structural detail. Now, if we look at this closely except for the chapter on coated bars, repair of coated bars. And perhaps some considerations that will apply in terms of placing of concrete, some special consideration that will apply as far as reinforcement work is concerned which means time of reinforcement bending of reinforcement and so on.

The other things are just the same as far as are just the same as in the case of normal concrete construction. The general provisions, the concrete materials, the proportioning of concrete, they allowable stresses in the reinforcement and structural detailing these are really independent of the fact that whether the reinforcing material being used is a normal reinforcement or an epoxy coated reinforcement. In other words, we have to ensure that the coated bar in addition to meeting the requirements of a normal steel bar also satisfies the requirements from the point of view of durability, in terms of the fact that it should not being a damaged coating and so on.

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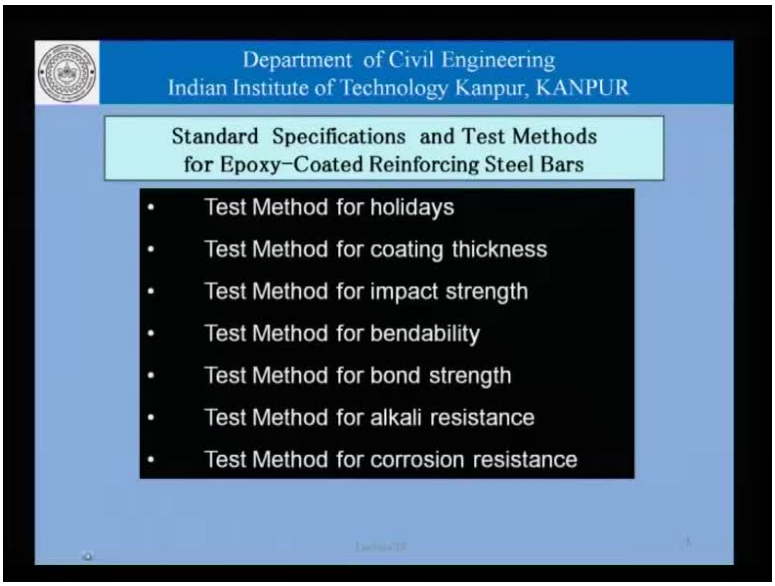

And that is what we will try to study in our discussion today then as for as standard specification test methods for epoxy coated bars is concerned, there are test methods for

holidays which is essentially a pin hold or a small discontinuity in the coating. So, you can imagine that these coatings need not be absolutely continues.

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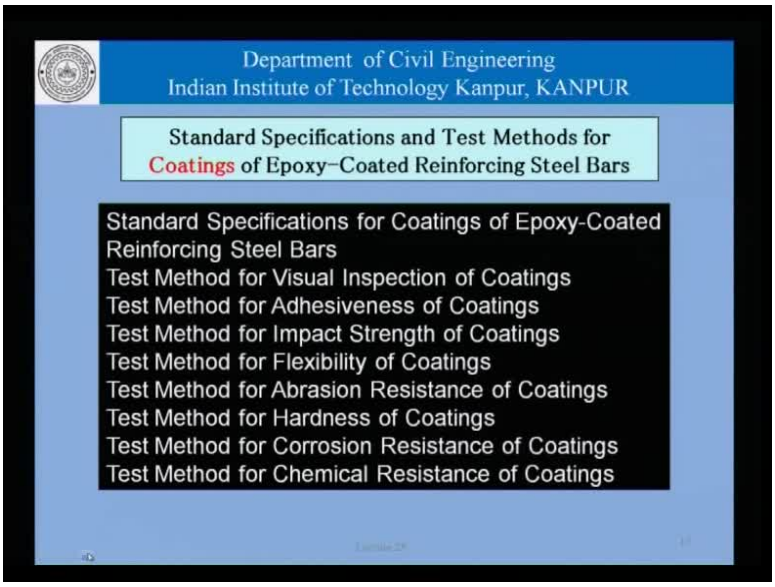

So, there can be a manufacturing defect where in there could be pin holes which have called holidays there could be small discontinuities and so on. And that is what we need to test and find out. There are test for impact strength; there is a test for bendability; there is test for bond strength; there is alkali resistance, corrosion resistance and so on. As far as the specification and test methods for coatings is concerned there are standard specification for this. Then there are test methods for visual inspection of coatings at adhesiveness of coatings, impact strength of the coating, flexibility of the coating, abrasion resistance of coatings, hardness of coatings, corrosion resistance and chemical resistance of coatings.

So, there is a small difference which is made between the characterization of the coatings themselves and the characterization and quality control of the epoxy coated bar. There are standard specifications for steel bars which can be used and that is a more or less the same as the normal standard. And that is more or less the same as that for normal reinforcing bars there is standard specification and test methods of patch painting for repair of epoxy coated bars which could be specification for the patch paint. And there is a test method for the patch paint there is a specifications of blasting which is basically a

processes by which is which is basically a process for cleaning the surface of the bar. To make sure that the coating properly at here is to the surface of the reinforcement.

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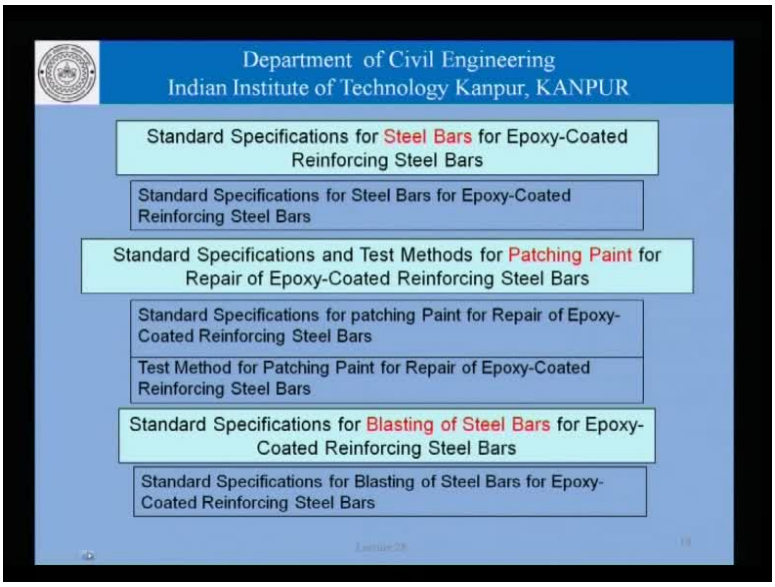

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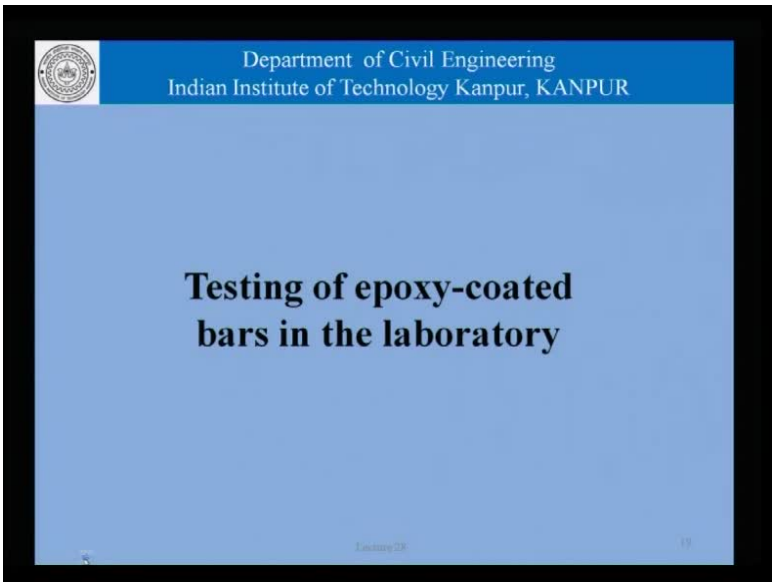

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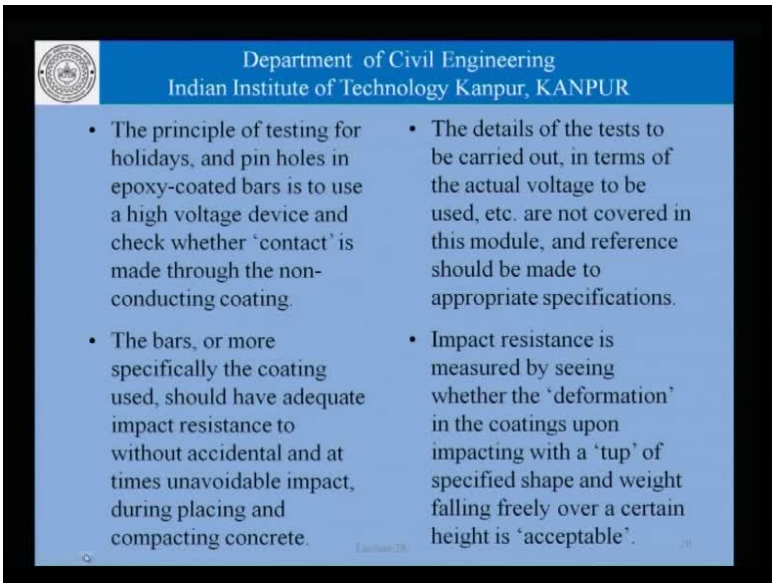

Now, coming to the main discussion that we have for today which is testing of epoxy coated bars in the laboratory. The principle of testing for holidays and pin holes in epoxy coated bars is basically to use a high voltage device and check whether contact, electrical contact is made through the non conducting coating. Second the bars, or more specifically the coatings used should have adequate impact resistance to with stand accidental and at times an avoidable impact, during placing and compacting of concrete.

What this really refers to is the handling of the reinforcing powers, sometimes the reinforcing bars can hit each other by design or sometimes accidently. So, when a power powers another bar the coating on the bars should not get damaged beyond the acceptable limit. And that is what we try to test when we try to determine the impact resistance of a coating in an epoxy coated bar. The same thing happens when we are dealing with compaction using internal vibrators. So, the needle of the internal vibrator unavoidably hits the reinforcement, what we try to do is to make sure that the needle that is used for the vibration is also epoxy coated. And therefore, the kind of impact that it has is not as severe as a normal steel the needle would have.

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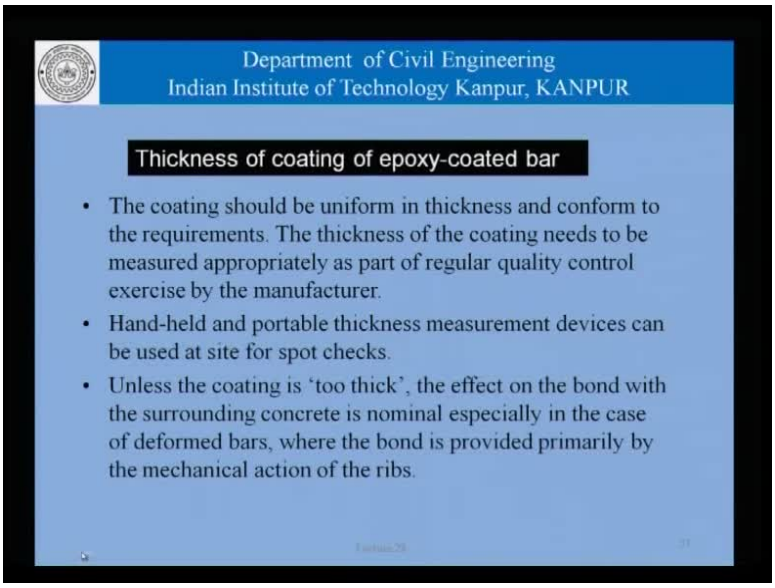

The details of these tests in terms of the actual voltages used and so on are not covered in the discussion today. And I would encourage you to look up appropriate references and test methods from the S T M or any other source, coming to the first order of business which is in terms of the thickness of the coating of the epoxy coated bars. So, if you look at this bar again, what we need to ensure is that the coating thickness of this entire bar should be the same, in principle guess should be the same. But as far as engineering is concerned it will have a certain amount of tolerance and that should be minimal which should be as smallest possible it should be within acceptable limits. And the coating should be uniform in size and conform to the requirements, which is given in terms of the variations at so on.

And the coating, this thickness of the coating needs to measured appropriately using a thickness device. And is a part of the normal quality control exercise by the manufacture of course, hand held and portable thickness measurement devices can be used to check the thickness of coatings at site in a spot check. We should remember that unless the coating is simply too thick, the effect of the presence of the coating on the bond with the surrounding concrete is rather nominal especially in the case of deformed bars where the bond is predominantly provided by the mechanical action of the rips. In case of non-deformed bars or M S rounds their I can imagine S if we coated deformed, if we coat A M S round. Then the implication in terms of the bond strength would be much larger, because basically there the friction between they m s round and the surrounding concrete

is the predominant force providing the bottom strength. In this case where deform bars are used and that typically the case, in most of the reinforce concrete construction.

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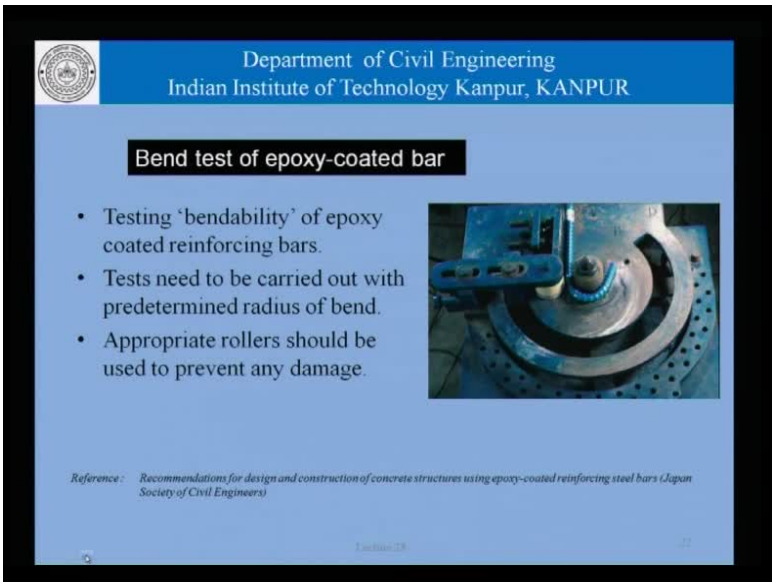

Now, the predominant force as for as bond is concerned is provided by the mechanical action for the rips and the friction per say is a very small component. And therefore, the presence of epoxy coatings on the bars does not really affect the bond strength of course, as matter of completeness we need to do appropriate bond test to ensure that any reduction that the any reduction that happens in the bond strength is within acceptable limits. Coming to the bend test of the approximate coating bar in concrete construction the reinforcement very often needs to be bend and when we bend the reinforcement we need to get a shape which is something like this. So a straight bar is bend around a fulcrum, in order to give a certain shape this can happen and the corners this can happen when we bend the bars from the considerations of shear and so on and so forth.

Now, once we do that what really happens is that the outer surface of the bar is subjected to tensile forces. And if the coating is not the tile enough it will we damaged and that is what we need to ensure that does not happen. And this is why we have to carry out of bend test; obviously, there should be appropriate roller, should be used. So that the contact itself does not damage the bar use coated roller themselves and so on. The details of test such as the actual diameter of the roller which should be used the angle through which the bar should be bend and so on.

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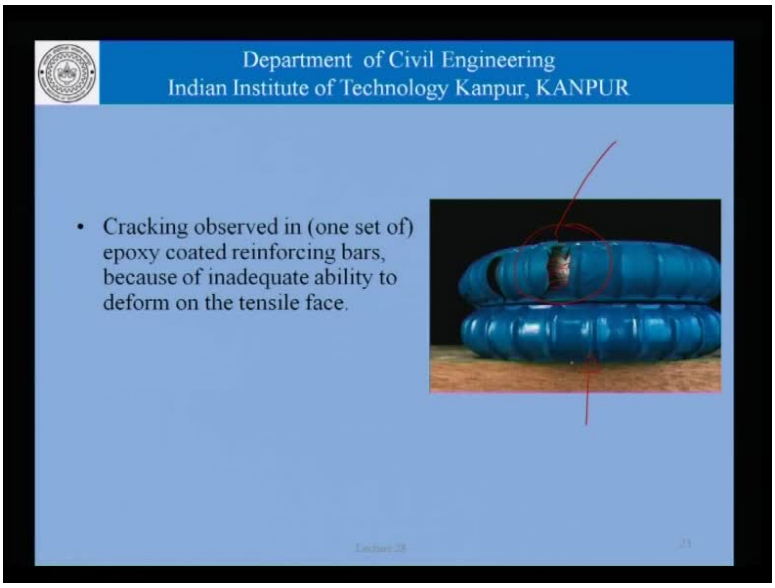

Is being left out from our discussion today, now this picture here shows what happens to a bar which is not good enough. This picture here shows that the cracking; this picture here shows that the coating has cracked it has simply failed it did not have the right amount of flexibility. And when the bar was bend there was a failure at this point compared to the bar shown below.

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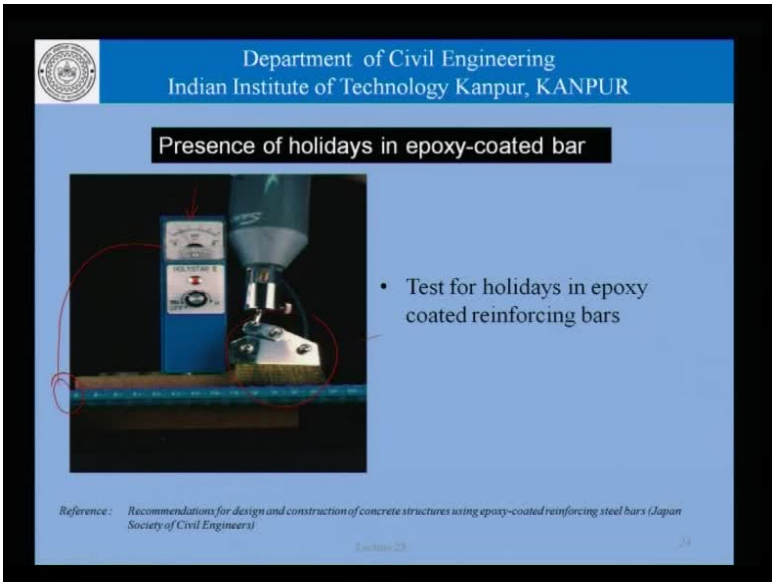

So, this is the bend test for the epoxy coated bars. This device here is used to detect to presence of holidays or pin holes in epoxy coated bars. And as was mentioned earlier

basically the idea is that there is a high voltage applied between sound place here where the coating has been removed and the make it surface of the reinforcement exposed and the power supply here. And this power supply and the contact that we have at the reinforcement the continuities checked, using this kind of an electrode or a brush which is used along the reinforcement.

So, if we have bar like this, what we do is use that brush at different points to check whether they coating is integral. The non conducting nature of the coating, make sure that only at locations where there are pin holes on the epoxy coated bar where they will be a contact. And that can be seen using the multi meter kind of device that we use in the system. As far as specifications are concerned, we can talk in terms of what is the maximum number of pin holes that can be tolerated? Please understand that it is virtually possible to get zero pin holes, a manufacture can target zero pin holes. But they will be some pin holes sometimes and it is up to the client or the user to decide what is an acceptable level of defects? It is much likely characteristics strength of concrete where we say yes we accept 5 percent failure of cubes that is 5 percent failure below the characteristics strength. Of course, from engineering point of view we also impose a limit on what is the minimum acceptable strength regardless of the 5 percent criteria? That is part of quality control of concrete.

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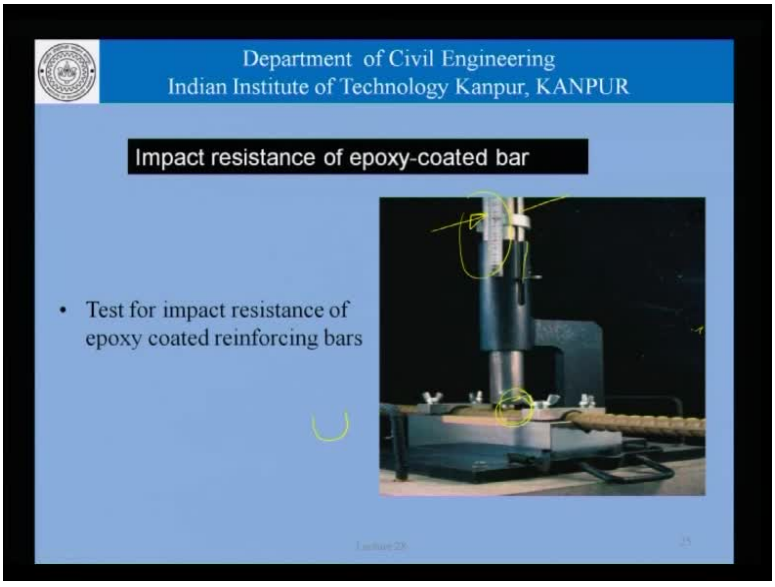

Similarly, here we have to have a specification which sells the 12 in the manufacturing process. We will test the bars with the certain frequency. We will test certain lengths per total length of the powers manufactured, and we will accept the bars provided the number of defects is lower than an accept than a pre-determined number. So that is how we basically go about doing a quality control as far as presence of holidays in epoxy coated bars is concerned. Now, this picture here shows how the impact resistance of the epoxy coated bars is carried out? So, we can see that there is a graduated scale that runs along the pipe which is here. And this here is a tub which is something like this u shape. And this tub is taken up and how high it is gone is measured by this gradually this scale and allowed to fall on to this reinforcing bar here.

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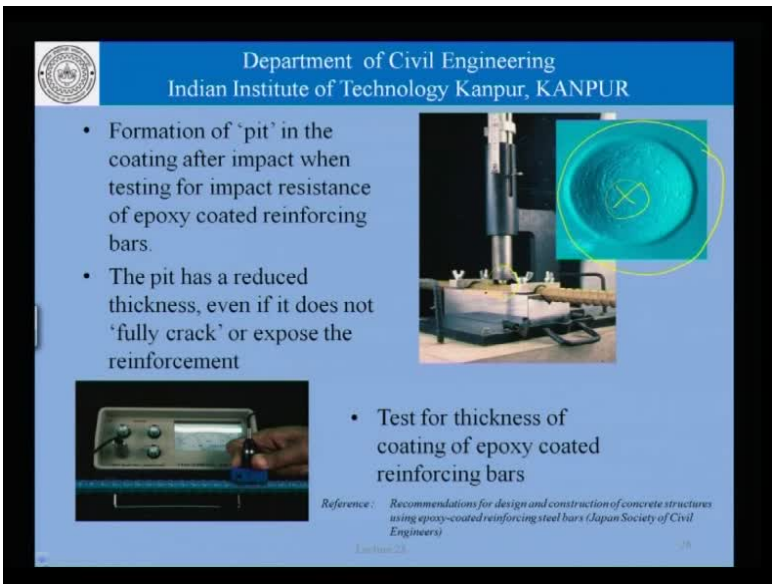

Once it falls on the reinforcing bar what we need to see is whether the coating has been damaged or not. And that is something which is shown here that once the tub falls on the reinforcing bar here what happens in this shown here that is the up kind of pit is formed. And that pit, if now depending on the properties of the coating, this pit may have an unacceptable or a very thin thickness or a very small thickness here or it may even simply break. And that again can be seen in terms of a device, now whether or not this pit that has formed has actually resulted in the formation of a unacceptably thin film or has resulted in an unacceptable level of damage to the film can again we checked using a device something like this. And we use the same device to check whether the coating that has that the pit that has formed or that this deformation that as occurred in the

coating is a acceptable or not. Needless to say the specifications that we used in terms of the voltage used for a impact test and so on need not really be the same as that for used in the case of determination of pin holes in the epoxy coated bars.

Now, coming to the thickness of course, we have seen that there are devices which will tell us how the thickness is or what is the variation of the thickness along the length q. And their again we need to have specification which we tell us what is the amount of variation that we will accept? As far as the mean value is concerned what is the minimum thickness that we will accept? As far as the mean value is concerned what is the minimum thickness that we will accept and so on? Now, as far as the impact resistance of the epoxy coated bar is concerned, the weight of the tub is standardized. And therefore, the impact resistance has to be measured in terms of the height through which it can fall and still not damage the coating. Now, how do we go about determining this height?

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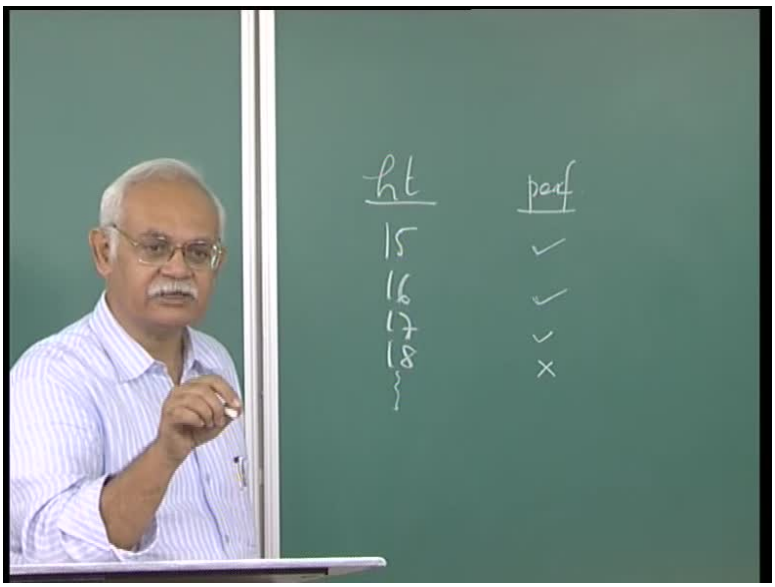

So, let us go through a small example and see how this can actually be determined if we have the height of fall to be 15 centimeter 16 centimeter 17 and 18 and so on we keep increasing it, what we really doing is we are increasing the height through which the tub is allowed to fall by 1 centimeter. And as for as the performance of the coating is concerned which is measured in terms of, whether the coating is damaged or not when the tub is allowed to fall from that height.

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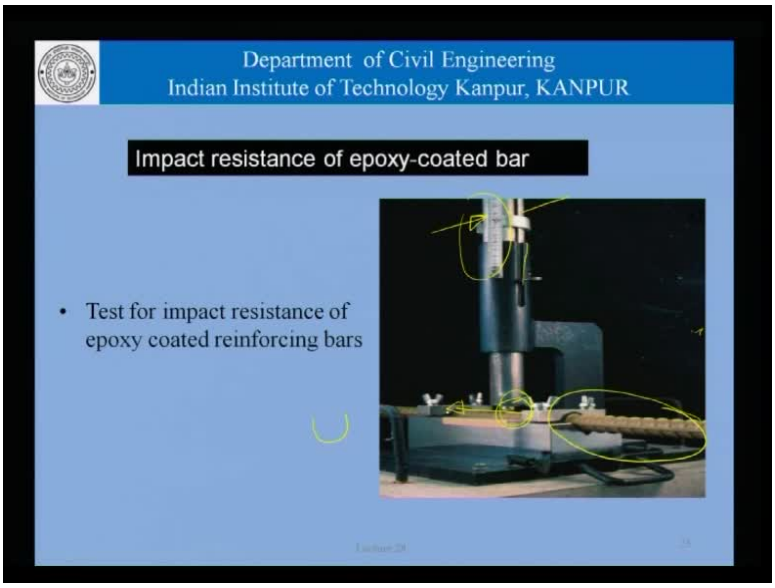

Let us say that it 15 centimeters the performance is acceptable that is the coating does not get damaged, at 16 centimeters again it is acceptable so long as it is acceptable. We increase the height to determine what happens at that next stage? So for example, it is 17 is also acceptable. But at 18 the performances not acceptable, what is done actually is that we need to keep changing the location as well, what we need to do is to keep changing the location at which the straight occurs.

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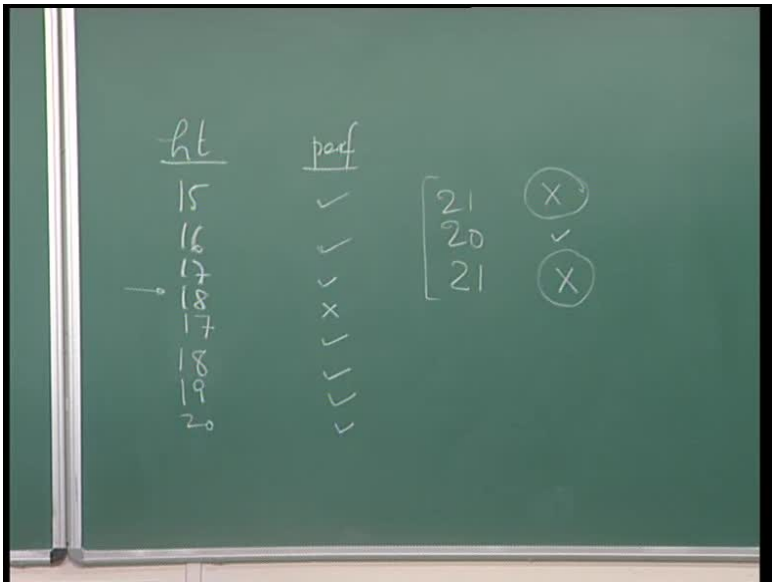

So, this bar here is shifted by a unit, every time we to the test. So, if we look at the bar, the first step backed is let say carried out here and the bar is moved; the next impact is carried out here and the bar is moved and so on and so forth. So, it is important to ensure that at no place the bar is actually struck toys.

So having said that now if the coating fills if it is dropped from 18 centimeters, the procedure would say that you go back to 17 and find out if the coatings is still intact. And if it is intact then you go back to 18 and it might happen that in this time the coating performs alright, because as a matter of manufacturing it is possible that only at that location where the first 18 was struck there was a small problem. And therefore, the coating field when the we move the bar to 17 and the next location and go back to 18 at the next location as we keep moving the bar, at that new location where the next 18 was a struck the coating performed alright.

And therefore, we are allowed to go to 19 and see how it performs go to 20 how it performs and so on, may be a 21 it fails and if it fails a 21. Then we go back to 20 and it passes we go back to 21 and it face again. Now this here is an indication now that the bar is such that it is not able to take a 21 centimeter fall and can take a 20 centimeter fall. And this kind of a process if we say this happening toys in a row is unacceptable then we have a situation that we have determined that the impact resistance of that particular bar is 20 centimeters.

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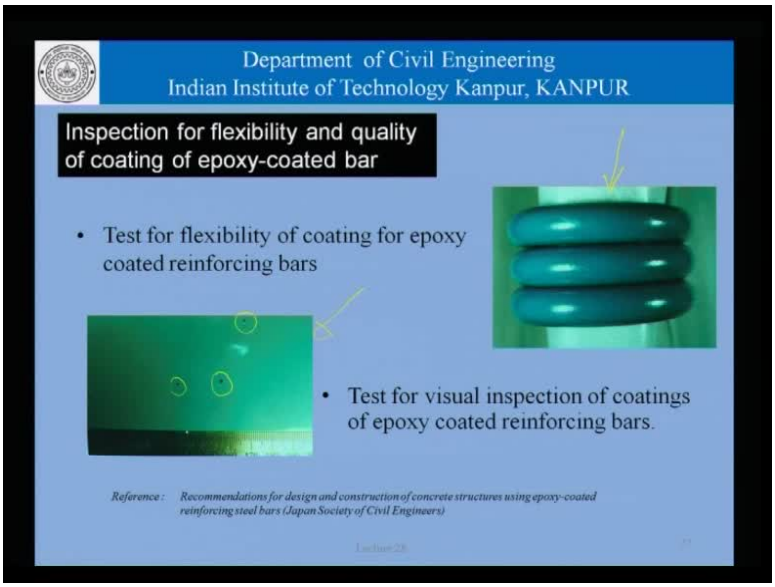

So, at the end of end the cost is very important parameter that we must in mind when we are using any new material. Coming to other methods there are test for flexibility and quality of coating of epoxy coated bars. So, this picture here is that for flexibility of a coating, whereas this picture here is a visual inspection of the coating on the reinforcement bar.

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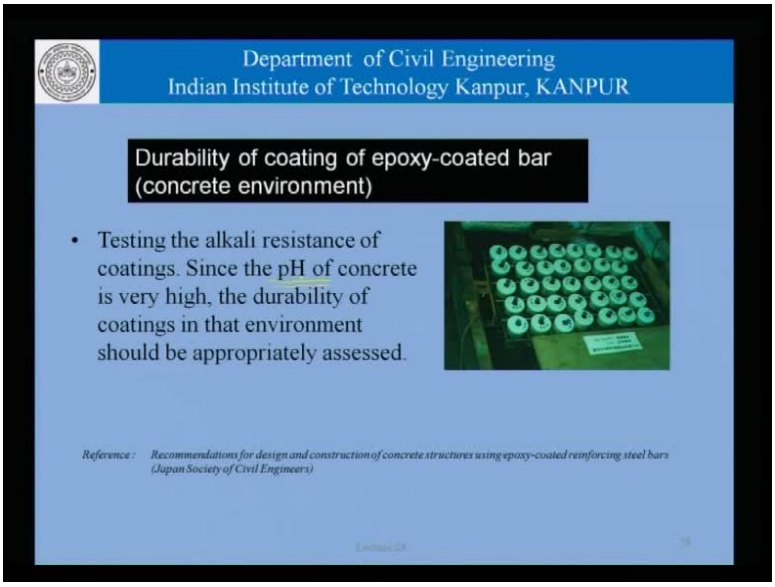

So, if we look closely at a coated surface we might find small droplets much like that droplets that we see in case of a painted surface, and the presence of these is an unacceptable sign as for as the quality of the epoxy coated bar is concerned. Now, let us come to the durability of the coat, a coated bar is very good as far as its action, in terms of prevention of corrosion is concerned. However, we need to ensure that the coating itself is durable in the, is specific environment that it is located and this specification environment we are talking about is that of concrete which has a high p H. And therefore, the coating should be such that it is durable in high p H.

Now, these tests when it comes to testing of coated bars on the coatings in concrete is concerned they can be carried out either by buying these bars in the concrete. So that we know that they are being buried in an actual environment and there is no simulation involved and we get the performance of the coated bar from this test.

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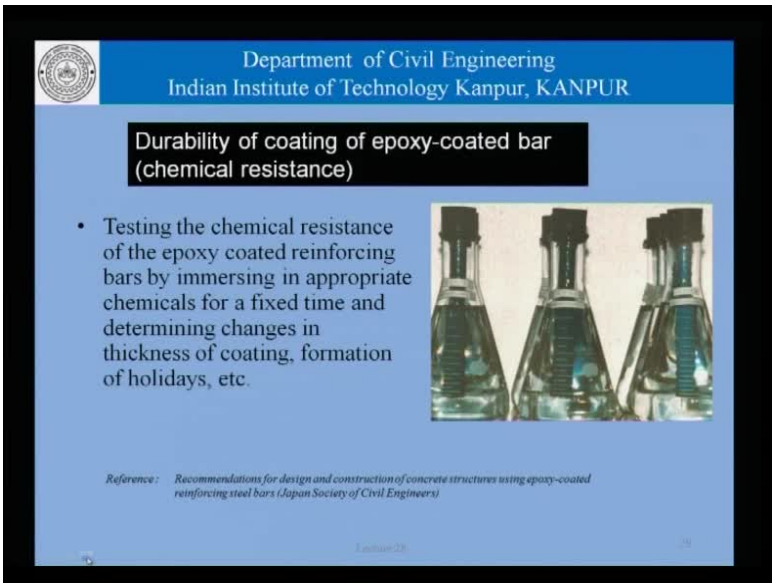

If we are using these tests as a quality control measure for the acceptance of epoxy coated bars. Then the test method should clearly specify what kind of concrete the bar should be embedded in, how long will they exposure test we carried out and what we will be the method adopted to evaluate the bars once they are extracted from the concrete specimen? Another way of doing the test is by simply putting the bars in a simulated in environment of concrete. And we have often talked about saturated solution of calcium hydroxide being a very good substitute as far as concrete is concerned. A saturated solution of calcium hydroxide simulates the high p H.

The advantage of carrying out test like this when we expose the bars or immerse the bars in a saturated solution of calcium hydroxide with whatever other chemicals that we when we need to add or we may want to add. They advantage of that is that we can actually see and monitor the deterioration if at all it is occurring in terms of loss of thickness formation of holidays, crimpling and so on and so forth.

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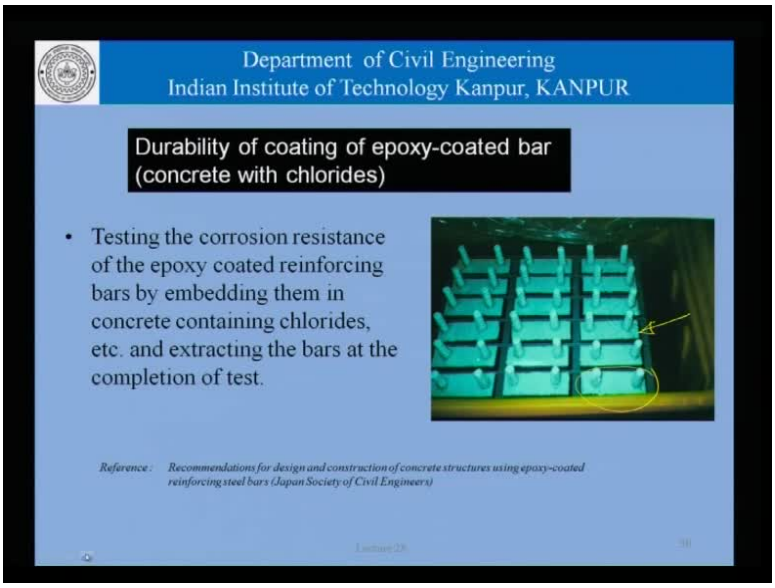

The disadvantage of working like this is that it the end of it, it is not the real environment it is only the simulated environment. Continuing with tests on durability of coatings of epoxy coated bars. And example could be chlorides we could embed these bars in concrete contaminated with chlorides. And see how they perform over a period of time and these specimens of concrete reinforced with epoxy coated bars can be expose to environment such as cyclic wetting and trying with salt water with plane water, elevated temperature and so on.

And the kind of test method that we follow depends on whether we are testing the bars from the point of view acceptance and quality control or we are testing the performance of bars in an actual environment. In the form of case, most of the parameters that we need in terms of concrete used the chloride environment the environment in which the concrete should be exposed duration and so on. All those have to be fixed and we should only try to see that under those fixed conditions of standard testing, what is the performance of the bar?

However, in case, the target or the objective is to determine the performance of a coated. The objective is to determine the performance or study the performance of a coated bar in a certain environment. Then the test conditions have to be suitable quantified so that we are testing the bar in an appropriate environment. And therefore, we need to have another regime by which that evaluation will be carried out, but at the end of it they

evaluation is all in terms of formation of holidays, the continuing the loss in continuity of the coating trampling of the coating damage to the coating and so on and so forth.

We should also remember that compared to as the epoxy coated bar which will be extracted out of a concrete specimen which is shown here or a bar which is going to be extracted out of a solution which has been in which it has been embedded. They will be big difference as far as how it appears, as far as the bar which is exposed to solution in this concerned it will be much easier to study that bar in terms of what the coating looks like and so on and so forth. Whereas a bar which is extracted out of concrete here would have cement particles may be send particle some times and hearing to the surface of the bar. And though a those particles can sometimes not be easily removed, because any attempt to remove those particles could also damage the coating which is not part of the testing procedure. These things are these things need to be kept at the back of the mind when we decide on a testing regime for the epoxy coated bars when use in concrete construction.

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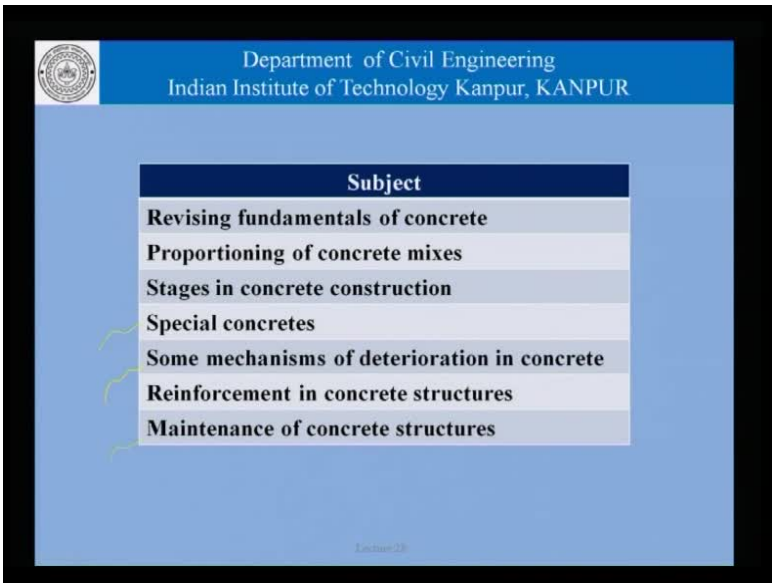

Now, if we look at the discussion today in the context of what the cores, what the other subjects in this simple, in this module deal with? It could be a situation where we talking of special concretes, because here we have using a special material as for a reinforcement is concerned, we have addressed reinforcement corrosion. And therefore, the discussion is part of some kind of deterioration process in reinforced concrete construction. Then

we have addressed issues which are related to the maintenance of concrete structures in slightly convoluted way but yes there are relevant from that point of view is well.

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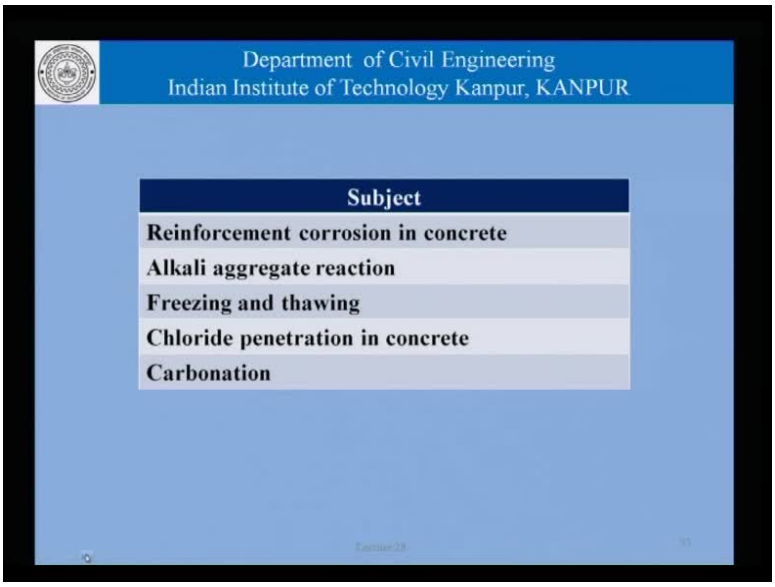

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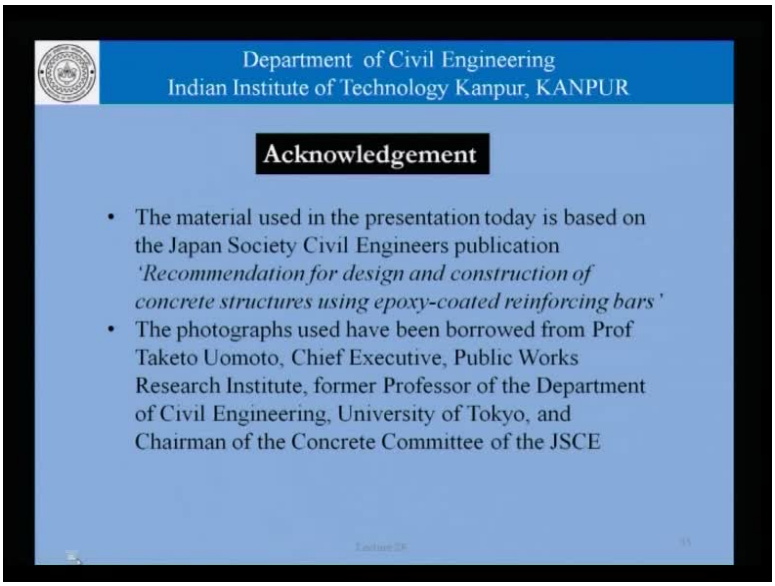

So, the idea is let often times it is not possible to classify a discussion very strictly into one or the other compartment, and that something which you can keep at the back of your mind, as we go along these cores. So to the discussion for example, today is relevant from the point of view of reinforcement corrosion in concrete it is relevant from the point of view of chloride penetration in concrete and also carbonation I would like to

thank the Japan society of civil engineers and the publication recommendations for design construction of concretes structures using epoxy coated reinforcement bars which is the bases for most of the material that we discussed today and the photographs which are been borrowed from professor Uomoto, the chief executive public works research institute Japan, and former the professor of the department of civil engineering university of Tokyo, and chairman of concrete committee of the JSCE.

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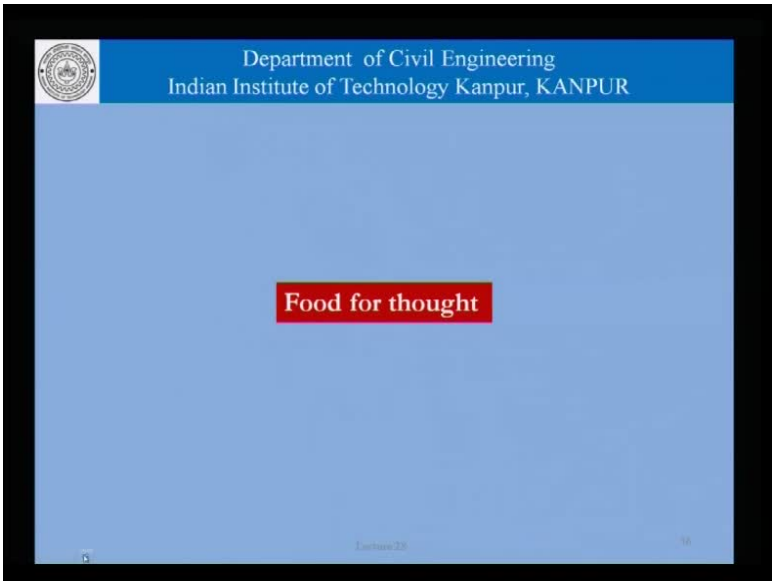

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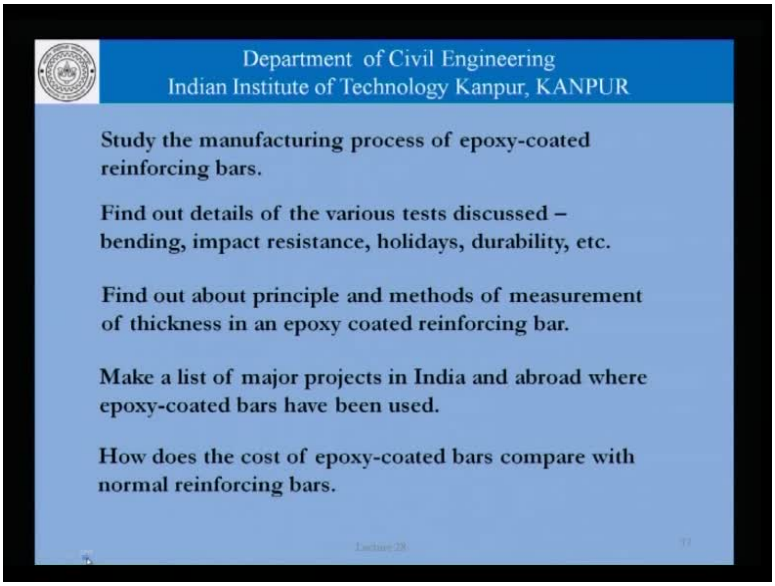

Now, before we close as usual let us go through a couple of questions which will help us understand the subject better. We should study a little bit more about the manufacturing processes of the epoxy coated reinforcing bars, because once we do that we will understand what can be the causes for the problems or issues relating to quality as far as epoxy coated bars is concerned. For example, one issue could be the temperature at which the epoxy is deposited on the bars. The duration for which the bar is allowed to stand in that chamber, the rate of cooling of those bars and so on. It will be good if you find out the details respective bending, impact resistance, holiday's in durability. We just discuss the principles of the test, we did not discuss the specific issues as the, what kind of concrete, what kind of solution, how long, what temperature and so on? For the exposure of the these test.

We know it will be good to know little bit more about the principle and the methods of measurement of thickness in epoxy coated reinforcing bars that something which civil engineers often do not encounter, because very few of us actually use epoxy coated bars. And unless we use a epoxy coated bars we will not need to measure the thickness of a coating which is very small that something which civil engineers often to do in case of steel structures, yes of course, when we paint steel structures again from the point of view of corrosion protection there is a need to determine or measure the thickness of the coating. So that something which is slightly different from using a epoxy coated bars in R C construction or pre stress concrete construction. Making a list of major projects in India broad where epoxy coated bars have been used would again be a very informative and instructive exercise.

And finally, better understanding of the cost of epoxy coated bars so that we have in perspective as to what is the financial implication of using a material which is more durable. Yes what at the end of it what is the kind of cost involved? And whether we want to investment additional amount of cost would depend on what kind of a structure we are building? If we are building a structure which is very normal or may be temporarily then one may decide that we will not need to use of, we need not use epoxy coated bar, because of the additional investment involved. Whereas if you are using or whereas if we are building as structure like a nuclear plant or a bridge a critical structure, industrial structure and so on where we would like the structure to be actually durable or

to have no size of deterioration, the reinforcement not to corrode there one message that the investment is justified.

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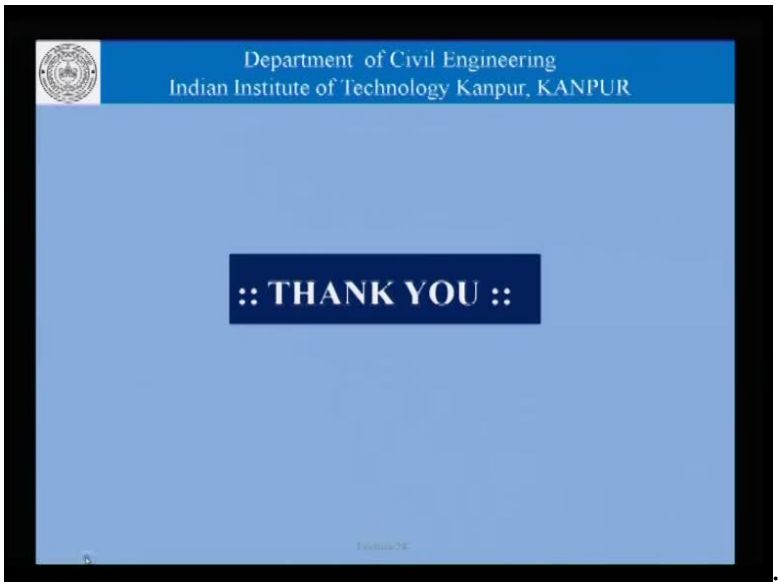

And with these are like to thank you.