Maintenance and Repair of Concrete Structures
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Module No # 01
Lecture No # 00
Prologue

Hi, welcome to this NPTEL MOOC course on Maintenance and Repair of Concrete Structures. This lecture will give you an intro to the course basically go through why a course like this is important and different modules in this course.

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On the screen the picture which you are seeing is an aerial view of a major construction project and surroundings in Chennai city and the objective of this course is, there are many projects like this in various parts of the country and we need to ensure that these structures don't face much of repair. But, if they need a repair then that repair should also last very long or durable repairs. So, that's the idea of floating a course like this and so we will see more.

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Now India is actually witnessing a construction boom. We are constructing a lot of highways, seaports, airports, residential and commercial buildings both in urban and rural areas. So lot of construction is happening today as you see on the bottom left you can see there is a

single house and another picture on a rural housing and also an urban housing multiple storey apartment complexes etcetera with the aim of giving housing for all Indians.

So, we have lot of these projects going on and if we do not ensure that these projects are built with quality or durability in mind then we will end up in having huge repair and maintenance activities. Sometimes we may not be able to even handle that magnitude of repair works. So that's a real concern and makes this course very important in that way.

So in short, we need to keep these structures safe and usable for long period of time which could be several decades depending on the type of structure and without much maintenance and repair that's a key point. Without much maintenance and repair because if we are thinking about just keep on repairing and maintaining then that is not really a big challenge. So, building structures with durability in mind and ensuring that the repair works are minimal and at the same time if we do repair then make sure that the repair is also lasting for long period of time as beside by various projects. So this is the need for this course.

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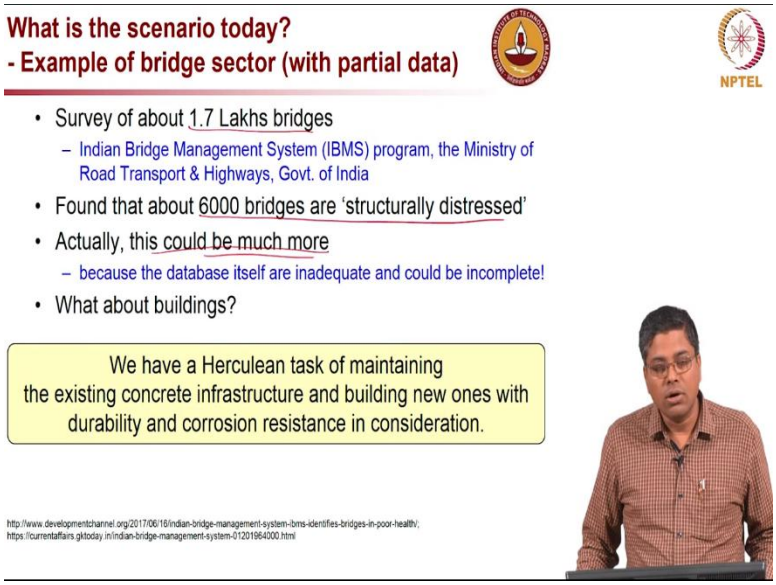

Let's look at what is the scenario today especially for the bridge sector in India. In general bridges, whether they are made of concrete or steel. So, recently the government of India conducted a survey of about 1.7 lakhs of bridges and this was done through the program on Indian Bridge Management System (IBMS) by the ministry of road transport and highways government of India.

They found that 6000 bridges are structurally distressed. For a country like this, I seriously feel the actual number could be much more because sometimes we find it very difficult to get data and even if we get data the quality or correctness of data is another question. So, this covers only bridges. What about buildings? There are so many buildings also in our country which are of different quality and of different age.

We have lot of old buildings and new buildings which are being built today. So, we have a huge task or Herculean task of maintaining the existing concrete infrastructure; not only bridges and buildings but many other and building new ones with durability and corrosion resistance in consideration. Why I say corrosion resistance? Because that is one of the most important deterioration mechanisms which is widely observed in many concrete structures.

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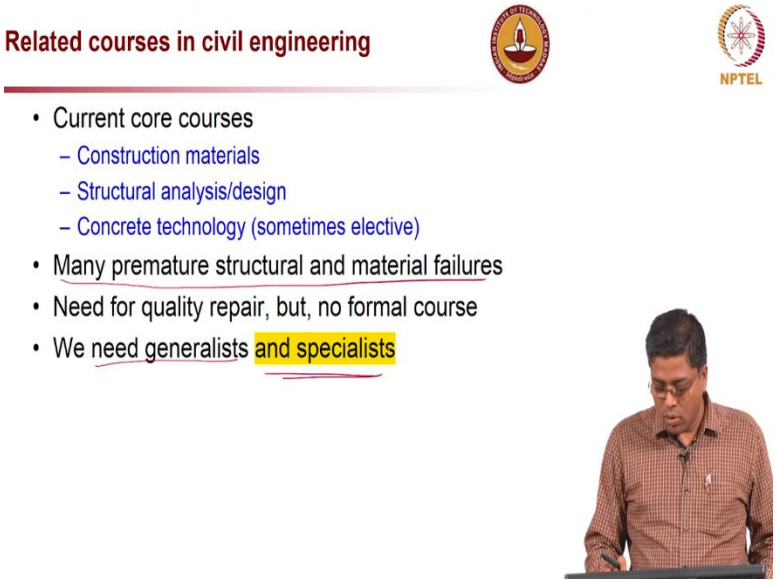

Now, let me tell you again the need for a course like this. Today many civil engineering curriculums have these three courses which are written in blue text. Construction materials, structural analysis and design related courses and also concrete technology which is again sometimes given as an elective course. What I am trying to tell here is the construction materials are not given adequate importance in some of these civil engineering curriculums.

So, for example the concrete technology which is coming as an elective. Maybe it is time for us to rethink on this. We need to be like a civil engineer when they graduate if they are going

for construction sector. They should know what the concrete is? & what the construction materials are? So, we end up in having premature structural and material failures because adequate importance is not given for the materials which are sometimes used.

We need to have a next generation of engineers with adequate knowledge on what can go wrong in concrete structures and then if they go wrong how to repair them with good quality. Also when we say quality repair but there are no formal courses available for understanding repair of concrete structures. There are documents and information available but no formal courses available in many institutes.

So, I think this course will also help to fill that gap. Now another thing is we need general civil engineers for sure, but we also need specialist or repair specialist that's very important. By the end of this course you will know that there are many things which need to be taken care while designing a repair for a concrete structure. So, we really need specialists who are trained and skilled to take up a repair work.

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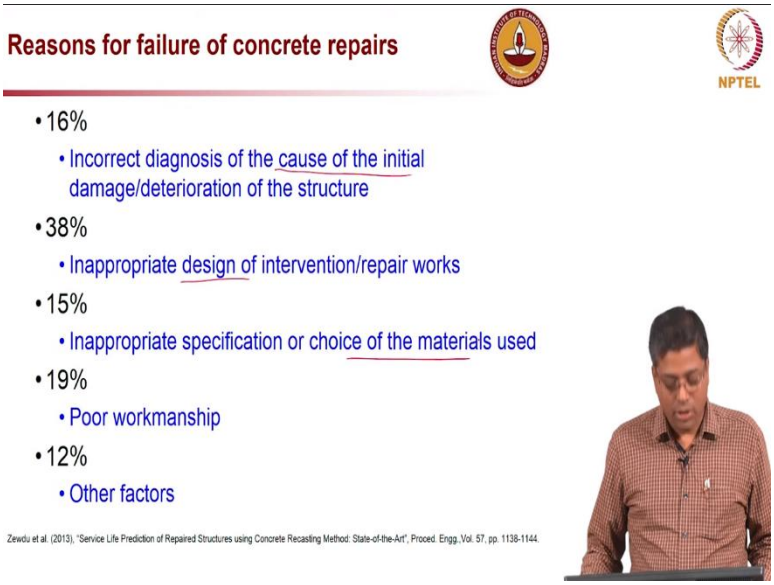

What are the reasons for failure of repairs? It is not failure of the concrete structures from the beginning but the failure of the repair which was undertaken on the structures. So you can see that about 16% of repair failures happened because of incorrect diagnosis or in other words without really understanding the root cause of the problem or original problem. So that led to the failure of the repair.

About 38% of the failure of repair happened because of inappropriate design of the repair work. About 15% of repair failed because of inappropriate specification or inappropriate choice of materials. About 19% of the failure of repair happened because of poor workmanship and 12% for other factors. So definitely the first three if you see that is something which is very important and poor workmanship is also equally important.

So definitely we need to know what is a root cause of the initial damage and then proper design of repair and appropriate choice of specification and materials. So design of specifications and materials. So, all these are very important. Definitely poor workmanship need to be enhanced.

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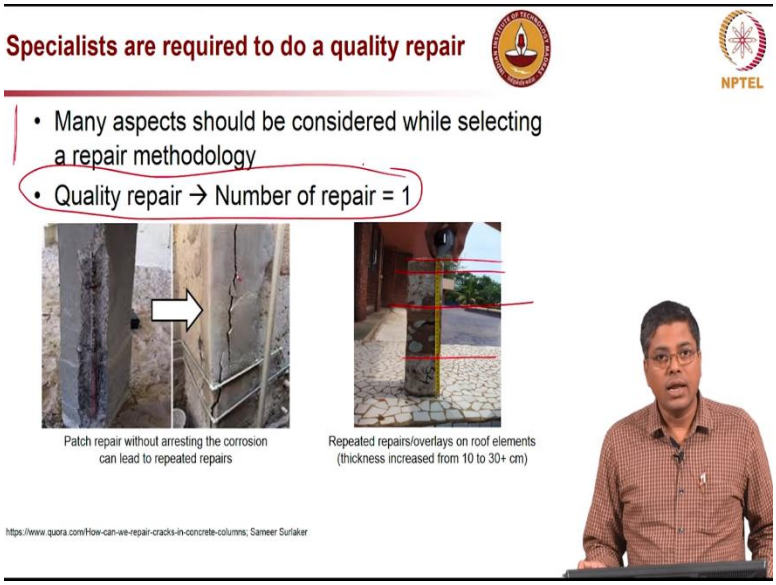

In 2 slides before; I said specialists are required to do a quality repair. These are some of the examples I am going to show you where it was done by generalist and then repair itself failed very fast. So one thing when we talk about repair is that many aspects should be considered while selecting a repair methodology or a repair technique or repair material or the way in which it is repaired.

You can see on the picture on the left side there is a column which has spalled it's not the same column but I just wanted to show you this to convey the message. This is again a picture I got from the website. You can see that on the right side, this portion is actually repaired; patch

repaired but again it cracked right along the rebar. That means for this particular repair the corrosion which is happening in the steel inside the concrete structure was not arrested.

It was just a cosmetic repair, just covering it up that is not really going to solve the problem. And in this type of cases what usually happens is you will go back to the same structure again in about 4 to 5 years and then by that time again it cracks and then you will keep on doing this repair. So for a small element you might not realize the cost implications. But when you talk about large structures definitely it really influences the life cycle cost of the structure.

So we have to keep the life cycle cost to be minimal that means the quality of repair should be very good and it should address the root cause of the problem. On the right side you see the picture which is a core taken from roof of a building and you can see there is one layer, second layer, third, fourth and so many layers of water proofing because water was keep on leaking and it was failing. And then you see the thickness of the roof element increase from about 10 centimeter from the beginning to about 30 + centimeter which is really not a good practice.

The repair work again was not good in the first case when this started leaking they put another overlay again an overlay so multiple overlays were kept on this structure. And by doing this it's actually increasing the dead load on the structure. May be you should check many structures are out there which are something like this. So we keep on adding dead load and then that put more stress on the columns and the beams below.

So this again an inappropriate way of repairing we should remove the unwanted concrete and put new layer. So that's so all these will be discussed in this course how we should really handle the repair work. So that you don't really create additional distress to the structure and you are actually helping the structure to survive better. Now, one other important point is this, when I say quality repair what I mean is, the number of repair should be one for the entire life of the structure because we already have some structures and we have to fix them and after that we should not end up in repairing it again and again. So this should be the target. If you ever have a repair work make sure that we don't go back to the structure again to do the same repair.

Which is very challenging for which you need to really understand the root cause of the problem and scientifically address the problem rather than just getting some material and then patch up and then just doing a cosmetic repair.

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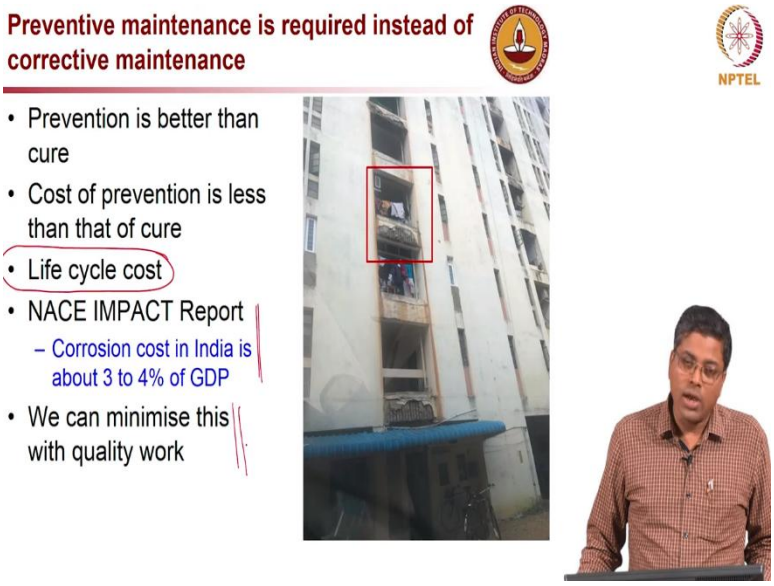
This is another example where I wanted to show, you can see on the left side you have a building where the clothes are being dried and the water from the cloth is dripping on to the beams below you can see in that little red box. So the beams near the staircase that is getting corroded and it was left like that unattended for long time allowing the corrosion to happen for long time. And then eventually I noticed that after few months when this was there and then they repaired it; just a patch repair, just covering up with. They removed the old concrete cover and then fill up that space with new concrete without really addressing the root cause. You can see on the picture on the right also you still have a lot of clothes which are being dried. That means the water from the cloth is dripping on to the beams and steel inside those beams get sufficient moisture to continue corrosion.

So, we should address these things either by making sure that there is a water proofing layer around the beams. So that water really doesn't get into the beam and corrode the steel surface. So if you tell the people not to dry clothes there, they may not agree with it. But you have to find an engineering solution, so that we can still practice what we do but at the same time not really harm the concrete structures. So that's how the approach should be or repair methodology should be chosen. **(Refer Slide Time 13:57)**



So this is that picture again little bigger you can see how badly those beams are corroded. Now, prevention is definitely better than cure and it will cost you much less when you compare that with the cost for curing in other words here curing is like repairing the structure. So if we can actually prevent this water from getting into the concrete beam and then reaching the steel that is the prevention which we are talking about so that the beam doesn't corrode and there is no need for corrosion repair.

Now, this will enhance the life cycle cost if you actually take preventive measures over the life of the structure the total cost will be less. That is the life cycle cost I think we need to start thinking about not only the capital investment but also the life cycle cost of buildings. So this is in next lecture also I will cover this NACE IMPACT Report the cost of corrosion is very high. It's about 3 to 4% of GDP.

So objective is how can we minimize this cost of corrosion? Can we do some quality repair work and quality construction like new construction? and the repair of existing structures. So that we can minimize the cost of corrosion in our country so that's the objective.

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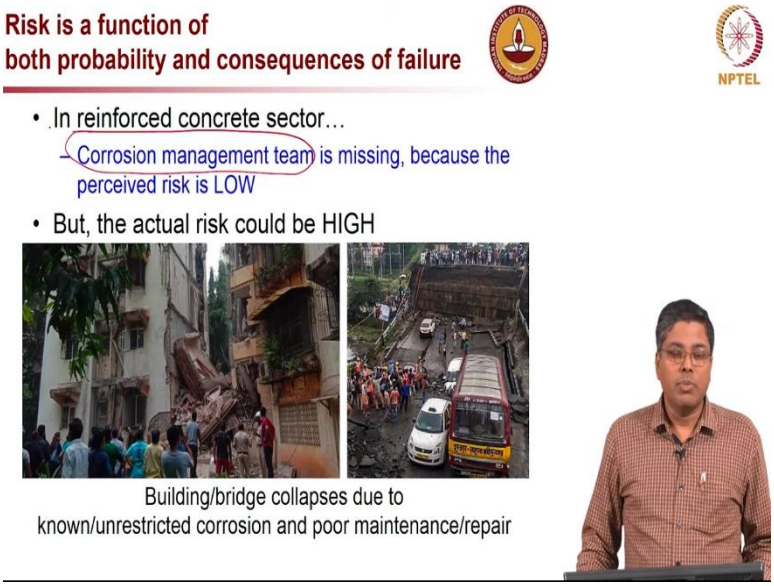

Now, in the previous picture I showed that there was a building apartment complex where you are let allowing the corrosion to continue. What is the reason why we are allowing this to continue? May be this is because of the perceived risk associated with civil engineering structures. Now before talking about that what is risk? Risk is a function of both the probability of failure and the consequence of failure.

So, if you are talking about consequence of failure for example the picture on the bottom you can see the one on the left side there is a building collapsed many people died in that accident. And on the right side it's actually a bridge collapsed. So again, many people died in that accident also. So you can see these kinds so how do we rate the consequence of failure? It all depends on what type of structure you are talking.

So definitely, we have a lot of structures where the consequence of failure can be significantly high. And however in general, there is a different perception. The perception is that there is no significant risk associated with civil engineering structure. And that is the reason why we don't have this corrosion management team in many of the companies we talk about. So I think at least after this course people should actually have corrosion management team. At least one person per company who will really think about preventive maintenance and look for potential problems and then address things way before. So that we can prevent the corrosion from happening and then give longer life for the structures.

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Now, let me show you other sectors where for example offshore platform or manufacturing units or chemical plants or oil and gas pipelines. So all these structures if there is corrosion on these pipelines and then the liquid leak through these pipelines then the risk is very high because the consequence of that failure is very high. Again it is attached with the money involved there. So, again in these sectors because it is attached with the money there is a perception that the consequence is very high and also the actual risk is very high.

In the case of civil structures, the perception is that the risk is very low but the actually there could be significantly high risk. So we need to sensitize engineers on this factor. And not only engineers, the higher-level managers, decision makers who actually allocate funds for maintenance of projects or the structures. See most of the time that is what happened we don't have enough money to maintain the structure or enough money is not allotted to maintain the structure and to repair the structure.

So, we keep on extending or delaying the repair practices and then eventually we end up in situations like this which is not acceptable or not favorable. So, we need to stop corrosion in these structures or take adequate measures so that both the structure and the users are really safe.

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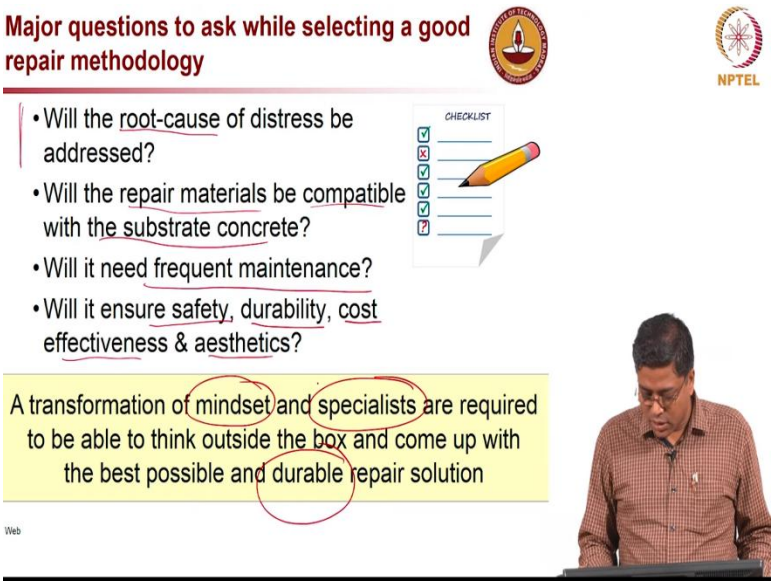

Now, what are the questions we need to ask while selecting a good repair methodology? First thing is, will the root cause of the distress; root cause that's very important of the distress be addressed? Now will the repair materials be compatible with the substrate concrete? And then will it need frequent maintenance? that means more and more money required. Now will it ensure safety, durability, cost effectiveness and aesthetics?

So, all these are important questions to be asked while we choose a repair methodology. And if you get a favorable answer for these questions from that particular repair methodology then we can go ahead. If not, we need to relook at what repair methodology need to be adopted. Now a big message is that we need a transformation of our mindset and we need repair specialist who can actually think outside the box and come up with the best possible and when I say best possible there is also another term which is durable best possible and durable repair solution.

So this is very important and we need to change our mindset and we also need specialist. It is very important because why I say mindset is we think that here is the perception of that risk which I discussed 2 slides ago that's very important. We also have very high risk associated with civil engineering structures.

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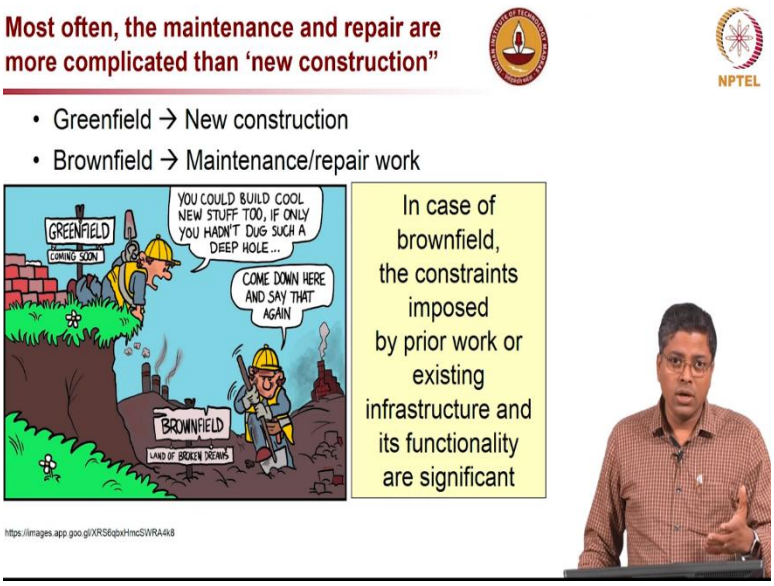

Now, another thing to look at is, how complicated when you talk about a repair work and new construction work. So there are two types of field. One is green field which indicates a new construction and a brown field which indicates a maintenance or a repair work. So as you see on this cartoon here on the bottom left you can see the guy at the construction site he feels that everything is easy because for his side there are no constraints.

But in the brown field he is struggling to do the repair because he has to work around the constraints. So that's very important and very challenging. The repair works are very challenging compared to new construction works because you don't have free space available. You have to work around the system and you have to deliver as fast as possible because when you talk about repair you are already creating trouble for the functionality or stopping the functionality of the structure. So you need to do the work and get out very fast from the site.

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Now, let me now go into what is actually in this course. Until now I was talking about; why this course and what is the importance of this course. How you will think differently once this course is done and then now let's talk about different modules in this course. We have split the course into about 8 modules. First we will talk about corrosion of steel in concrete. I will go through details on these eight modules in the coming slides.

So, let me just read through this, Embedded metal corrosion is one module. Module 2 on Deterioration of cementitious system, Module 3 on Condition assessment of structures. Module 4 will be on Strategies and materials for surface repair and Module 5 is on Surface preparation and protective treatments. Module 6 on Water proofing techniques and Module 7 on Concepts on structural repair and in that we will talk only about the concepts not really detailed analysis. And the Module 8 which is a short module on how to design good tender documents. So how to develop or document tender specifications so that you get durable repair and also we show some case studies on repair projects.

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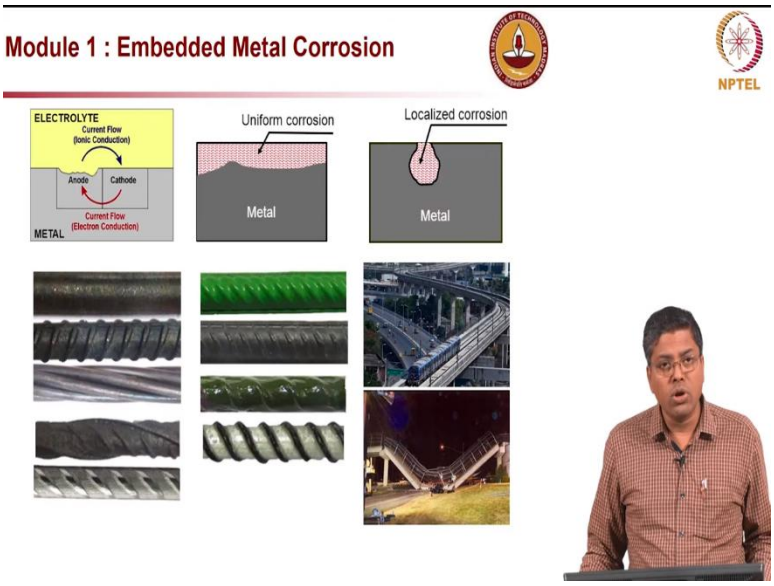

In Module 1 we will talk about Embedded metal corrosion, first in the lecture 1 we will talk what is corrosion? How it happens? and then we will slowly move into what type of corrosion happens in concrete structures? which is carbonation induced corrosion and chloride induced corrosion. Then also we look at different type of re-bars which are available in the market and how different the corrosion mechanisms in these re-bars are? and also whether the coated re-bars are actually good or not. Especially the non-metallic coatings which are widely used today. You will see in these lectures that they are really not good considering the way in which those rebars are used in construction today.

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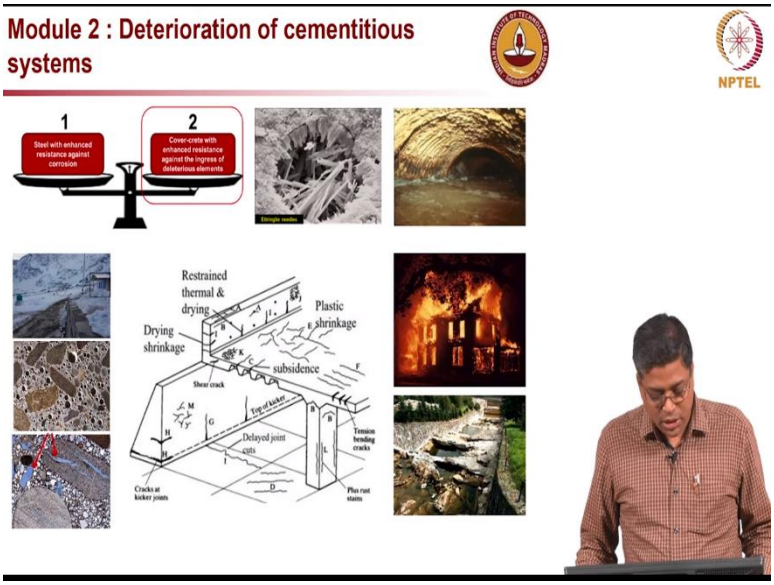

Module 2 is on Deterioration of cementitious system. We will look at various chemistry, chemical aspects & what kind of chemical reaction goes on in concrete structures in long term. We will talk both about shrinkage something which will happen in the very early stage and also looking at delayed ettringite formation or reaction between the cement paste and sulphates and then looking at aggregates also how reactive they are.

We will also discuss, what can go wrong in concrete when there is a fire attack and how these different types of chemical reactions damage the concretes all that will be looking at. In this module we will not talk about steel, we will focus purely on concrete system or cementitious system. And understanding what can go wrong in the concrete part of it?

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In Module 3 we will look at Condition assessment of concrete structures. And here we will talk about how in the laboratory we can test the quality of the concrete and also how in the field we can test the quality of concrete. Also looking at different test methods that are for checking the quality of steel and concrete. For both steel and concrete and reinforced concrete system. So we will look at these different test methods available in the market.

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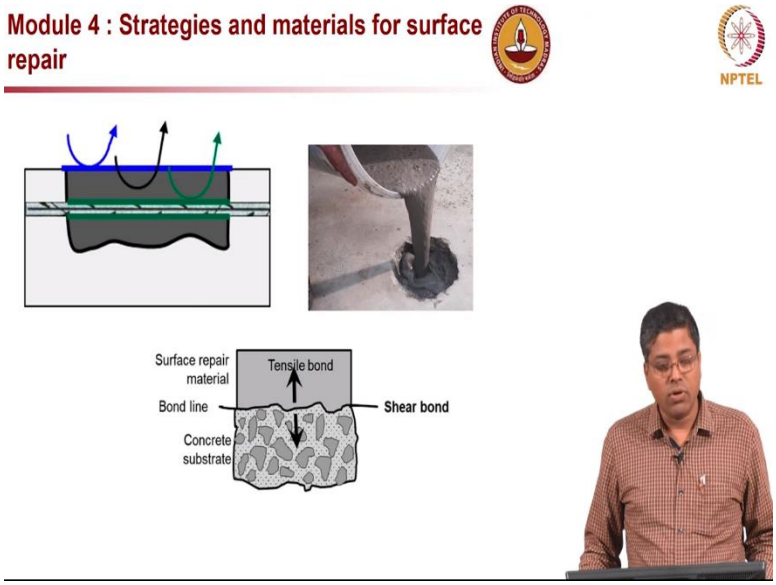

In Module 4, we will talk about Strategies and materials for surface repair or near surface repair. You can see in the pictures here where the blue over there indicates type of coating which you apply on the concrete surface or on the surface of the repair. And the green color indicates things which we do on the steel surface for protecting the steel. And the grey part or the black

arrow indicates how we design the concrete or the repair material itself that should have good flow properties; it should have good elastic behavior all these both fresh and long term performance properties and also how well they can bond with the substrate. So, all this we will look at and how to choose the materials, so that's idea in this module.

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Module 5 is on Surface preparation and protective treatments. So, when you talk about repair, once you understand what the root cause is and then when you are going to repair the structure with some new materials and before you apply these new materials you should ensure that the surface of the concrete is also really treated well. Treated well means let's say you imagine, you are sticking a Cello tape on some surface. If there is a dust on that surface, the tape is not going to stick very well to the surface.

So, like that when you place repair material to the concrete surface you need to actually clean the concrete surface first and then only you should apply new materials. What are the techniques available to clean? and how to ensure that the repair is durable? and also at the same time looking at how to protect the steel from corrosion? Techniques like cathodic protection and different types of cathodic protection and how can we remove chlorides from the concrete? and how can we realkalize the concrete? all these will be discussed in this module.

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In Module 6 we will talk about Water proofing of concrete. I already discussed this picture on the left side. You can see multiple layers of roof overlay on this particular structure which is not really a good idea it is actually adding more weight to the structure. Which induce or which lead to more distress and how do we prevent water from entering the structure that is one thing.

And what are the basic principles of water proofing especially for both old and new construction. When we talk about joints, what are the new techniques available to prevent leakage through the joints? All these will be discussed in this module on water proofing.

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In Module 7, will talk about Concepts on structural repair whether can we actually repair the concrete structure by adding additional structural elements or by modifying the existing structural element or by strengthening the existing structural element either by adding more reinforcement or by adding more concrete around like enlarging the size or by wrapping the elements with fibers.

All these will be discussed which are the better techniques for different cases. And also some precautions to be taken while we do this so that eventually the structural repair will actually perform very well.

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I feel this module 8 is very important which is on How to design tender specifications or contracts. Because many people when we ask about quality they say this is not available, that is not available. But, I believe that sometimes the reason is that we don't do enough homework in really thinking about the root cause and making sure that the proper choice of materials and design etcetera of repair is in place.

So, we need to really make sure that we do a very good process of decision making. So that when you make decisions on this type of repair and this type of materials need to be used we need to really know what goes wrong. And the specification should be able to address those things. It's not just when you talk about repair material get a concrete of this much strength. If it is actually a durability problem, we should really have those parameters included in the specifications or contract documents.

So that, we can ensure that the repair is actually durable. And also there is a concern, sometime people think whatever given in the codes we have to follow and sometimes we find that the codes are not really updated. So, as a responsible engineer you can actually look for codes from other countries also and pick the best possible procedure and if you get into the contract then there is no harm or issue in following that code which is available, the reason why a specialist is required is exactly this.

Only a specialist will be able to select the right code, right material, right design etc., for the repair. And also take enough codes most of the codes are actually regulatory document. Why I wanted to mention this is because until few years ago I was also thinking that all these codes are actually mandatory document but they are not. They are only regulatory documents. Engineers have enough power and they should take responsibility in looking at better practices and try to adopt those practices in our country. Let's build good quality structures and make sure they are durable also.

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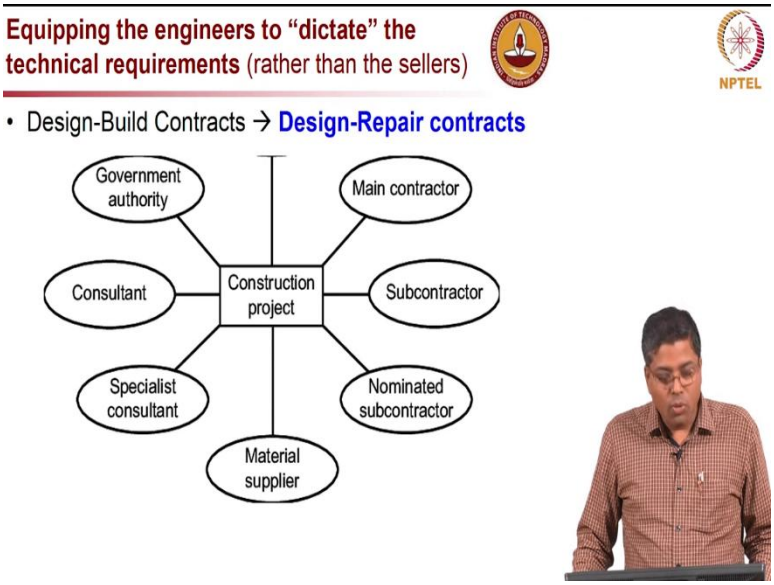

One way to get there is by practicing something called design repair contracts where both the design and the actual work is actually done by the same person. Because in the construction sector you have this multiple stake holders. So, when something goes wrong they start blaming each other. So, blame game happens. So, how can we minimize that? So you keep one person as a responsible person and you let that person or a company to do both the design and repair.

With design repair contracts, we will avoid this blame games and also we need to know what the responsibility of each of the stake holders is. On this chart here you can see government authority, consultant, specialist consultant. So again here specialist that's a key person there and material supplier, nominated subcontractor, another subcontractor and main contractor.

So, lot of stake holders are there, all have responsibilities but there should be one person who will communicate to each of this stake holder and will be responsible. So that person will

ensure that the repair is durable. Now, again one more thing very important is this course will equip the engineers to dictate the technical requirements. Equipping engineers most of the time you will see that engineers really don't know what a material is and what the properties of a material are.

So, it is very important when you talk about complex repair practices we need to really know what happened to the structure. The root cause and what type of loads are acting? both mechanical and environmental loads and then how to address them. And how do we choose a good material like system to address those. Let's not purely depend on the sellers of the material or the suppliers of the material.

But we should be looking at manufacturers and then demanding the manufacturers that I need a material like this which has these target properties and then let the manufacturers, they are capable enough to provide you what you want. But most of the time engineers don't ask we just choose from what is available in the field. Sometimes we have to also demand for better quality and better practices.

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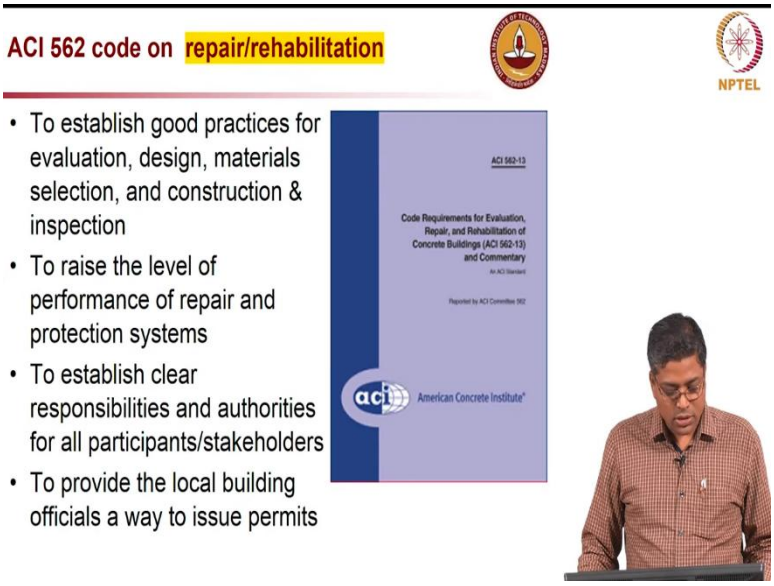

Now, with all these in mind ACI 562 committee has developed a code, on repair and rehabilitation. And this is the front screen of that document and the major objective of this code was to establish good practices for evaluation, design, selection of material and construction and inspection of repairs. Another objective is to raise the level of performance or to enhance the

quality of repair and to establish clear responsibilities and authorities for all participants and stake holders.

So, if you are talking about let's say one example you have a repair project going on, there is a designer and then another company who is doing the repair work like actual implementation. If something goes wrong the person who is implementing will start blaming the designer and designer will say that they didn't implement this properly. So this should not happen.

So, we need to be very careful in assigning the responsibilities to all the stake holders. And designers also should think about how constructible the particular design which they are coming up with is and are they feasible for the particular field conditions. So they have to also think about it and then make sure that feasible solutions are provided. Now, also to provide the local building officials the way to issue permits or select who could be a good person or a company or a firm to do the actual repair work.

What are the criteria by which you can actually select a team for repair work.

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Now, some other important things which I emphasize heavily is. Let's say we know all the technical aspects but unless we are able to communicate that properly to the others or your colleagues. It will be very difficult to practice and communication is very important. So, I

suggest learning how to effectively communicate technical stuff. So there is a very good book which I found by oxford publishers “Effective technical communication a guide for scientists and engineers” specially made for the scientists and engineers. This was written by Professor Barun K Mitra in IIT Kharagpur. I feel it’s a very good book, very crisply written and to the point book. So you will really enjoy it’s not a very big book and not that expensive also. So this is something which I would suggest you to buy and read and then practice. Also many of us don’t give enough importance to drawing; even in some curriculum nowadays engineering drawing is being removed. So, that’s not something which is good and yes we have AutoCAD and various softwares available.

But we need to learn really how to visualize things and then convert them into simple drawings. So that you can explain your ideas and concepts to other engineers working with you and also to the field workers. So it makes it very easy to communicate if you can actually draw very well. So it is something very important to be able to communicate properly and if you can communicate by drawing that’s also very good. So, enhance this quality on how to draw and communicate things.

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Now, this course when I started teaching in IIT madras, Professor Mathews was teaching this course before me. He suggested me to use this book; very good book; very well structured book. So, I really appreciate Mr. Peter H Emmons to write this book. He has put a lot of real

field application examples of field repairs. And I suggest if you can buy this book it will give, you know much better insight into this problem.

So this is the book based on which this whole course is developed. Of course, there are lots of additions to the course but you can really see this is the photograph which we took with Peter H Emmons when he was in India on a conference in Mumbai.

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Now, there are some people who really influenced my carrier significantly this is my PhD and masters guide or advisor, Professor David Trejo. And also Professor Ravindra Gettu and Professor Manu Santhanam at IIT Madras with whom we actually developed one of the best concrete materials lab in the country and also all my other teachers who have helped me in learning many things.

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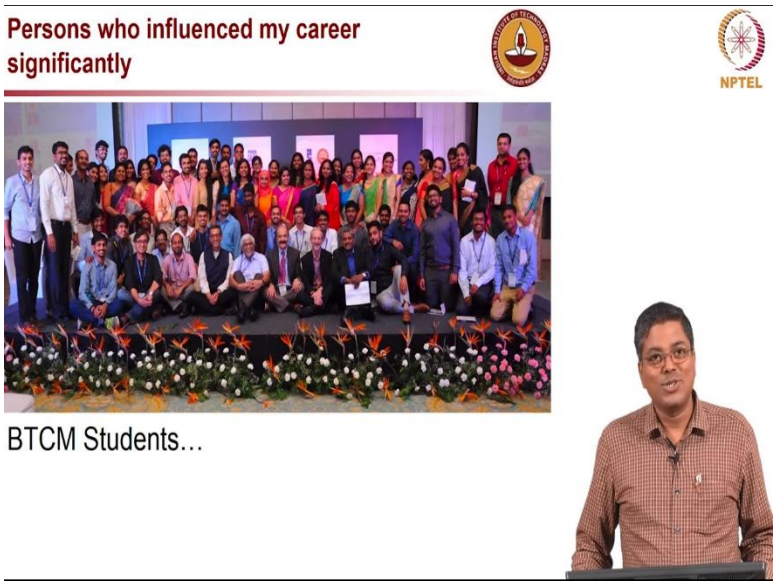

Finally, the BTCM students, one of the largest material groups. Of course, this has people from other parts also. But thanks to everyone and we will see you in class. So we have very informative and educative course which is developed. So see you in class, thank you.