**Maintenance and Repair of Concrete Structures**
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**Lecture 10**
**Condition Assessment of Concrete Structures (1/3)**
**(Exposure conditions, visual inspection, on-site concrete testing)**

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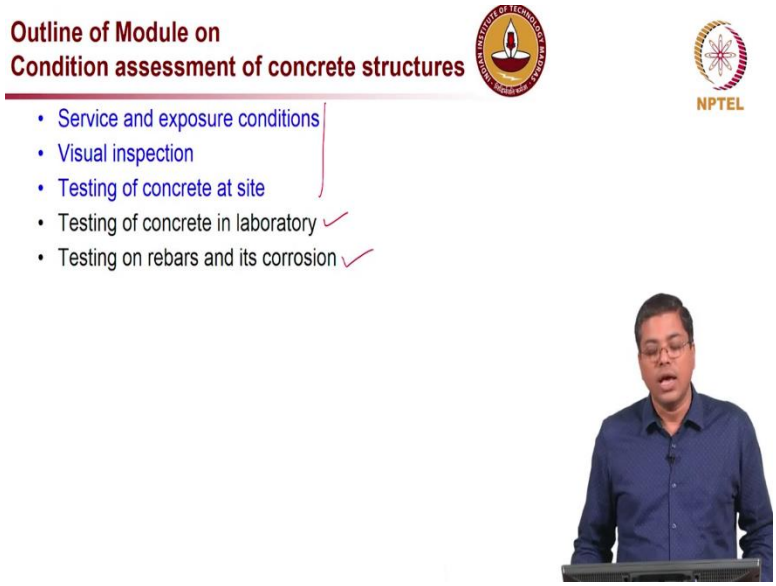


Hi, today we are going to start this module on condition assessment of concrete structures. There will be 3 lectures in this and this is the outline of the module. We will cover service and exposure conditions, visual inspection and testing of concrete at site, which will be in today's lecture and the next 2 lectures we will cover testing of concrete in laboratory and testing of rebars and its corrosion in concrete structures.

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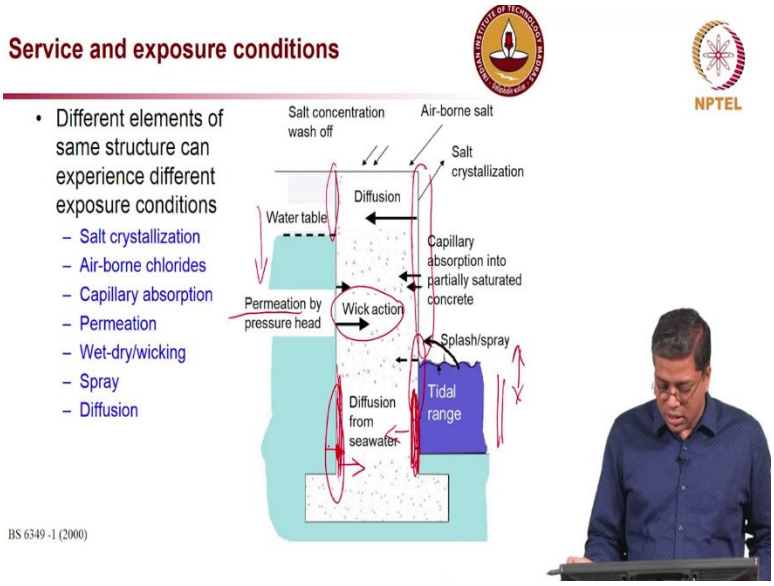


Now, service and exposure conditions, you can see this picture on the right side, where I am showing one concrete element and which is exposed to water on both sides you can see, but you can also notice that some portion of this structure is not exposed to water. For example, this is not directly in contact with the water body, this portion is not in direct contact with water body you have soil, see on this on the left side you have soil and on the right side you have water.

So, here you can see water table so, that means, moist or you know a wet the soil is probably saturated in some time and during the summer season it's water level can go down and that it means basically the X the surface of the concrete is might experience a wetting and drying action which will lead to something called Wick action. And at the same time when the water table is very high, it might experience permeation because of the pressure head and on the right side you see a tidal zone here which the tidal means that water level can increase and decrease.

So, it can go up and then go down sometimes. So, depending on the condition, whether it is in wet condition or a dry condition, this region can also experience wicking action. I will also like to mention that let us say a way bottom over here, if the exposure condition is really wet, you can also have diffusion because once the water or the chloride solution gets into the concrete and then it gets deposited at the near surface of the concrete.

It happens here also. So, once the chloride get deposited on the near surface, then that chloride can diffuse into the concrete surface. So, you are looking at wicking action, diffusion, permeation all these mechanisms can happen on the same structure, but at different locations depending on the type of exposure condition, for which the structure is exposed to.

So, point is, it is not that if you have one concrete structure every element or every portion of that concrete structure is not going to be experiencing same deterioration or same level or same rate of ingress of chlorides but it depends on what is the surface conditions. If it is experiencing wetting and drying, its Wick action if it is experiencing continuous immersion on it is a different mechanism.

You can have permeation because of the pressure head, and once the chloride gets into the concrete then there is also a diffusion action. So, all these have to be considered while evaluating exposure conditions.

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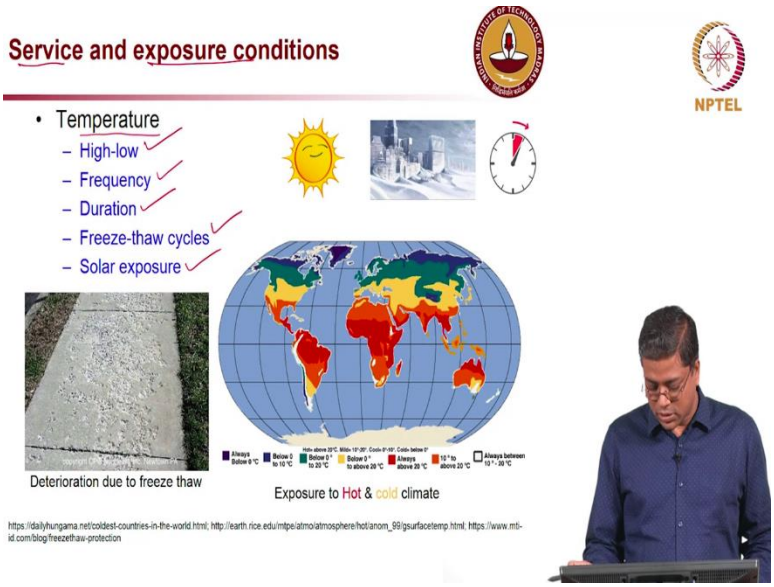


And when you look at temperature you can say like there are various durations depending on the geographical locations, you can have long summer days or sorry long summer period or a long winter. So, this duration of this summer and winter or rainy season, they all really matter in when you talk about temperature, I am going not really including the rainy season we are all only looking at the temperature condition.

So, summer or winter and then what is the frequency? that means the if you are talking about freeze thaw cycles for example, how many freeze thaw cycles you will have and what is the maximum temperature and the minimum temperature the structure is exposed to and duration of that exposure including solar exposure and basically a hot summer season. So, all these have to be looked at or thought through when we evaluate the exposure conditions, which particular structure is experiencing.

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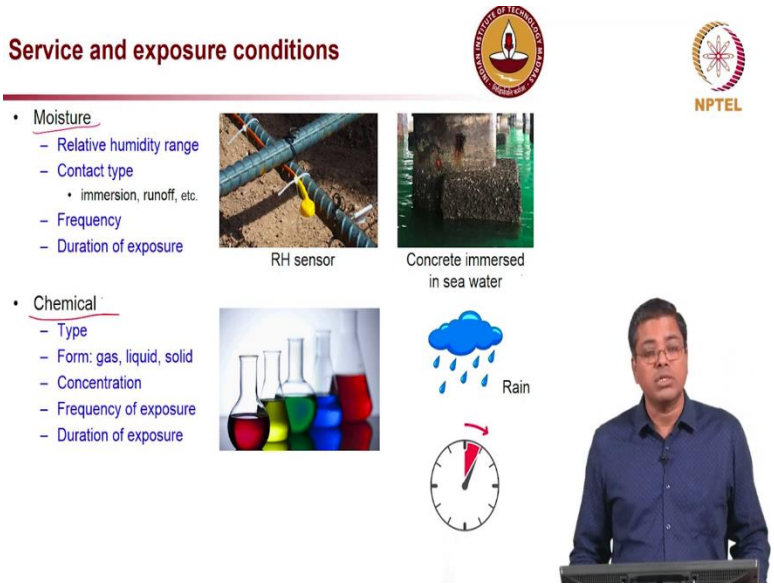


And we also have to look at moisture conditions for example, if as we see in the picture on the top right it is a concrete column which is actually standing in seawater it is a jetty structure. And you can see it is immersed in seawater and also you can have rain, but difference is when you are talking about seawater you might have splash zone so, wetting and drying etc can happen and the same structure which is exposed to rain, after the rainy season is over you might have summer, so you do not have much of humidity.

So, how do we know what is the humidity which the steel inside the concrete is experiencing. So, that is very important to know because corrosion phenomenon depends heavily on the moisture conditions, especially in the cover zone or in particular at the steel concrete interface. So, there are some humidity sensors also available in the market today. So, you can use all that to get an idea

about how much is the humidity level at the steel concrete interface, because most of the corrosion mechanism, moisture condition is very, very important.

And how long I mean, then if you look at the chemical attack or exposure conditions for example, if you are talking about Chemical Plant where if it is made out of reinforced concrete structure reinforced concrete elements. So let us say you are talking about the plant which is making hydrochloric acid, so, the entire local environment will be rich in HCL or chloride is abundantly available, or depending on type, if you are talking about sulfuric acid then maybe you will have to think about sulfate exposure or sulfate attack.

So, this again the local environmental condition, and what chemicals are present, what temperature and what moisture conditions are there and what chemical conditions are there, all these have to be really assessed before we go for further details on the condition assessment. So, these are all background information, which are necessary.

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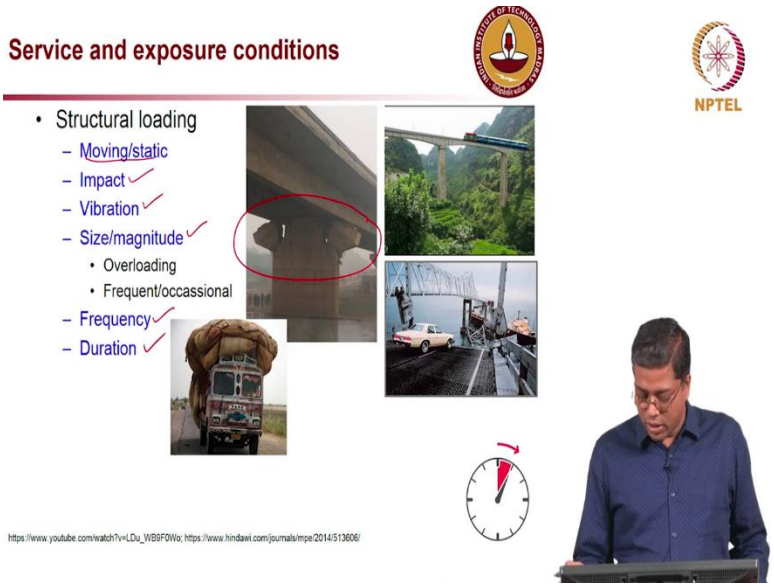


Now, when you talk about service condition, which is essentially the structural loading conditions, you can have moving loads or static loads, dead and live loads and then you can have impact load, vibration, depending on structure, if you are talking about a bridge structure, you can have vibration and there are also examples of impact where the flyovers gets impacted by, as you see

on the picture on the bottom right, you can see it is actually a bridge in Florida, which was impacted the column was hit by a ship.

So, such impact load even though very rare, you can actually have them and especially on bridge structures, and then looking at the size and magnitude if we are talking about overloading, how much over loading and was that overloading very frequent or it was just occasional. Such information on history of loading also is very important to get you can look at this bridge element, I mean, preliminary investigations were saying that this is because of overloading but I still do not have more details on this recent incident, this particular bridge failure.

So, and also frequency and duration of such loading. That is what I mean by how frequent and how much occasion, I mean is it very rare incident or very frequent overloading all these information on such things have to be collected before we go for further detailed inspections.

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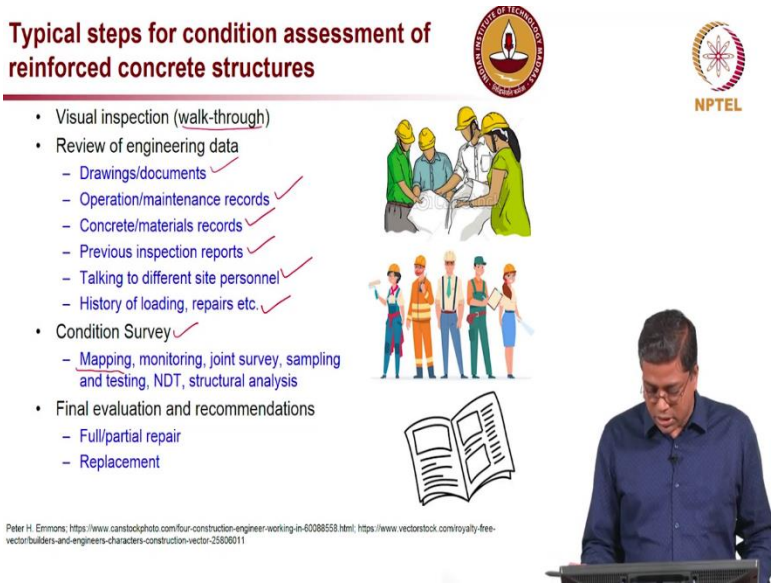


Now, when you talk about condition assessment, globally, you can say these are the steps which we have to follow, the first thing to do is have a visual inspection, mainly walkthrough or you to really feel the structure, what is the type of damage, because if you are depending on the information given by others, sometimes knowingly or unknowingly, you might not get full information. So, it is always better to ask for visual inspection.

And you must visually inspect the structure before going for detail or before making opinions on details. Otherwise, you must say that these opinions which I am giving is actually without having a visual inspection. So, the reader of your report can also make judgments on that.

Now, reviewing of engineering data, sometimes you have to collect all the construction drawings, but in most cases, you may not have these drawings that is also important to note. So, if you do not have, then you try to prepare, or get whatever documents are available and then make meaning out of them. And then you have to have operation and maintenance records, and then concrete and what type of materials were used, or test data during construction. But again, let me tell that most cases, because when you are talking about repair, you are talking about old structures. And at that time maybe people might not have saved all the data.

So, you may sometimes you have to work with what you have, so it's also reality is probably different from the ideal cases I am explaining here what all you should have. But if you do not have then you have to make your own engineering judgments. Then previous inspection reports if available and talking to different site person, this is very important because when you go to a site if you can actually talk to the people there, you might get much more information than what is actually available on the reports etc.

So, which could really give you an insight into the problem and history of loading and repair etc. I already told these are also very, very important. Even if some excessing loading happened just once, that might have induced some cracks or some deformation etc. which are very important to know. Now condition survey, you have to actually go to the structure and then survey the structure. You can make maps on various properties along the structural element.

One example I can tell is, let's say if you are talking about delamination for example, you can actually map the entire surface of the concrete and on concrete surface and then say this region has more delamination than this region, these all will help in avoiding unnecessary repairs and at the same time ensuring that repair is done at right place and in the right way. And then based on all these we can give final evaluation and recommendations on to go for whether a partial repair or a full repair or it is better to actually replace the structure, demolish and then replace or reconstruct.

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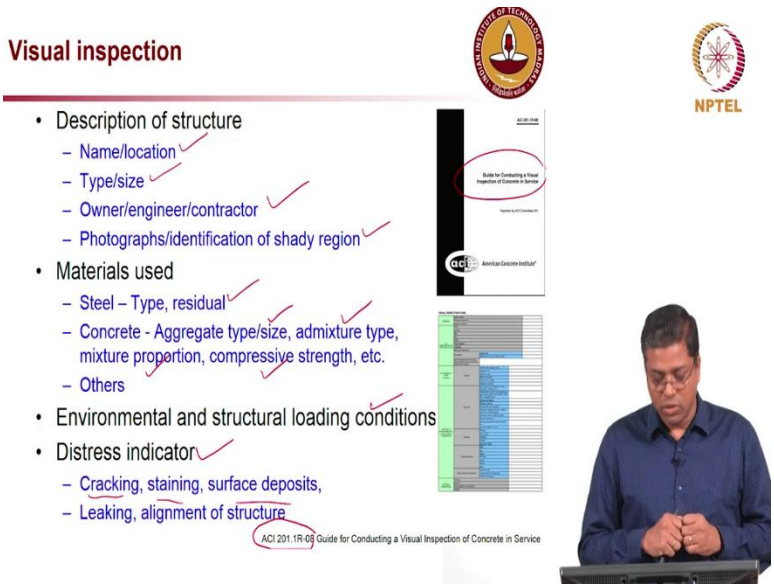


Now, in more detail on visual inspection, first what all things we have to really look for when you go for visual inspection. First thing is even if possible before itself you have to get the where you are and this information should be also recorded. And there is a nice ACI guideline available on how to conduct with visual inspection in concrete structures, ACI 201.1R-08. You can look for guide for conducting a visual inspection.

Now, description of structure and then type and size of the structure. Who is the owner, who is the engineer, who is the contractor, sometimes you might also say that there are multiple contractors are involved because maybe the first contracted contractor started the work and something happened they walked out and then a new contractor came in so, all these information is also very, very important when we talk about what all information have to be collected.

And then photos and identification of specific regions in the structure which is experiencing distress and also the main information on what type of material is used? steel, even the type of steel, is the steel already corroded? What is the residual strength possible or how much steel has been corroded I know it is very difficult to estimate a cross section loss, but getting some photographs etc. would help in making engineering judgments later on.

And then concrete and aggregate type what type of aggregate is used, what type of admixtures were used, mixture proportion, compressive strength and other properties. So, whatever the materials are used, we also need to know more details about the materials used, and environmental and structural loading and what are the indicators of the distress. So, all these have to be documented. It is not just talking to people and then gaining information.

But at the same time, we have to document it maybe for your own future assessment or for somebody else. If they are coming on board, they can you can pass on the information much easier. So, ordered collection of information is also very, very important. So, I would say before going for visual inspection, you need to know what you want to inspect for that is very, important to know. Some idea on what to inspect for must be there before you go for inspection.

Now, distress cracking, staining, surface deposits, leaking, alignment of structure, all these things, you should have an idea on. These are the things I should look for, which are indicators of something which is happening inside the concrete or inside the structure. So, it is very important to have a good understanding of the material deterioration mechanisms, which we had detailed modules on that on both steel and concrete. So, once you know the deterioration mechanisms or the corrosion mechanisms, then you can actually have an idea on what to look for when you go for visual inspection.

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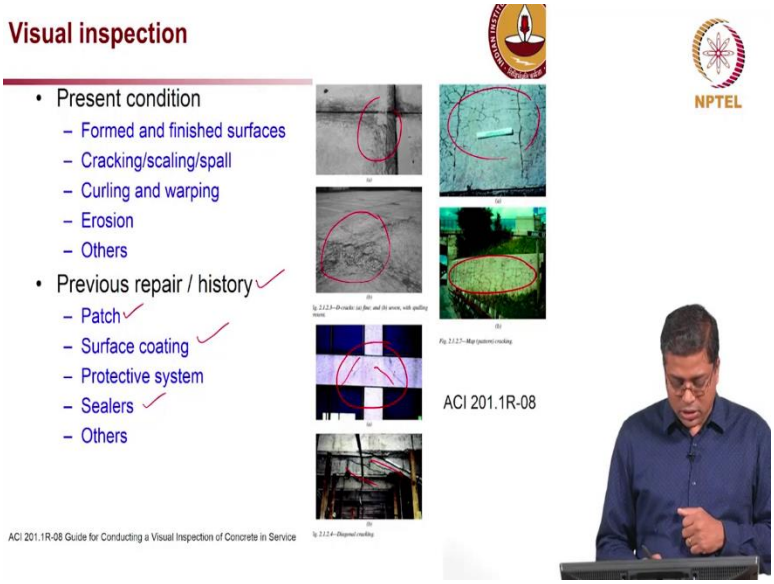

And also, what is a present condition like this particular guideline which I was talking ACI 201.1R-08 provides representative images of different type of damage or deterioration which concrete structures can experience. As you can see here in these pictures, you can see a lot of this deep cracking which we discussed in freeze thaw. And this a significant cracking here you can see an ASR type cracking map cracking pattern.

And here you can see a shear failure and diagonal cracks. So, this document is a very good source for looking for getting an idea on what to look for when we go for visual inspection on various types of structures. Now, also I talked about previous repair if something was done earlier what was done, whether it was just patch repair or something else was also done, did whether a surface coating was provided or sealers.

So, what type of repair work was done already and then how many times they were doing; they did all those repair work. So, again, you have to collect a history of repair works also history of construction, history of loading, history of exposure conditions and history of what repair has been already done on the concrete structures all these are very important.

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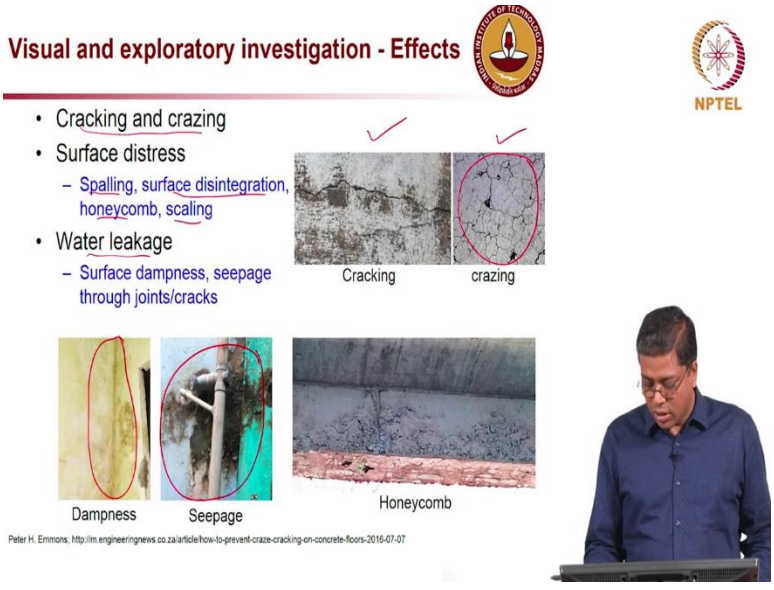


Now, visual and exploratory in what are the effects, which we have to look at cracking and crazing. And this is a picture how the different cracking is, maybe you will have a deep crack. If you are talking about crazing, it is very fine crack that is what the major difference between cracking and

crazing. Crazing means fine cracks and network of fine cracks, as you see in the picture here, and then surface distress. You can look for spalling you can look for disintegration of the concrete cover.

And then you can look for probably honeycomb and scaling all these examples I am showing on the picture here and again water leakage. If you are talking about dampness you can see on this wall inside the house and then here it is an exterior element where pipeline coming from the restrooms or bathrooms, and the nearby regions are somehow getting the moisture from these pipes. So, that is also not a good thing.

So, these all are indicators or manifestations of something which is happening inside the concrete. Because if you have moisture, then you can say some other problems will occur if you have crack then you can say something wrong happened even structurally sometimes in this structure, and if you are saying honeycomb, then you can say of course, that has to be filled up with something so, this will help in taking actions.

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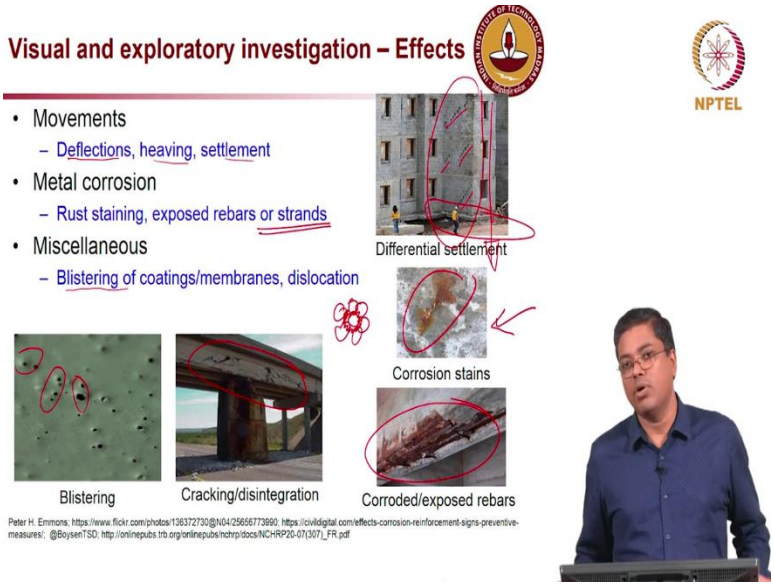


So, some more effects or demonstrations or manifestation of something happening inside the concrete. So, if you are talking structural, you can say there could be deflections, heaving or settlement. You can see in this nice picture (picture on the top right corner), nice picture but the building is not good. You can see here the inclined cracks on the building, which is definitely an

indicator that this right end of this building is actually settling down or this particular slab over there is not able to take that cantilever load which is acting on it.

And then metal corrosion rust staining as here you can see that the brown stains which is a very good indicator for detecting corrosion or to confirm that corrosion is happening inside. But I must say one thing here, when we are talking about prestress concrete structure, we will have a separate lecture on that we already covered, basically saying that the idea of looking at rust stain as an indicator for corrosion is not really good for pretension concrete structures. Because by the time the rust stains from the strand due to the strand corrosion reaches the concrete surface it will be too late because, as we discussed already the 7 wires which are there in a strand, you have a space in between in between the 7 wires, that space gets filled up first and then only it will exert pressure on to the surrounding concrete.

So, the rust straining is not a good indicator for prestress concrete structures. For other conventional concrete structures, we can say that is a good indicator but not for the prestress concrete structures. Because by the time rust shows up on the concrete surface it will be too late. So, this I would say for the strands, we should not look for we have to go for other techniques to detect corrosion or we should not even allow corrosion to happen in pretension concrete structures.

Now, other miscellaneous, blistering if you are talking about coatings, then you if you have these blisters like this, then effectively these coatings are of no use. And then disintegration you can see here severe damage and this is like point of no return where even the entire rebar is completely exposed we can actually see what type of rebar is used, what is the spacing, all the detailing can be understood without any non-destructive equipment. But that is not something which we want to reach so, all these a visual inspection everything we should think about doing it early enough so that we do not reach this point of severe corrosion.

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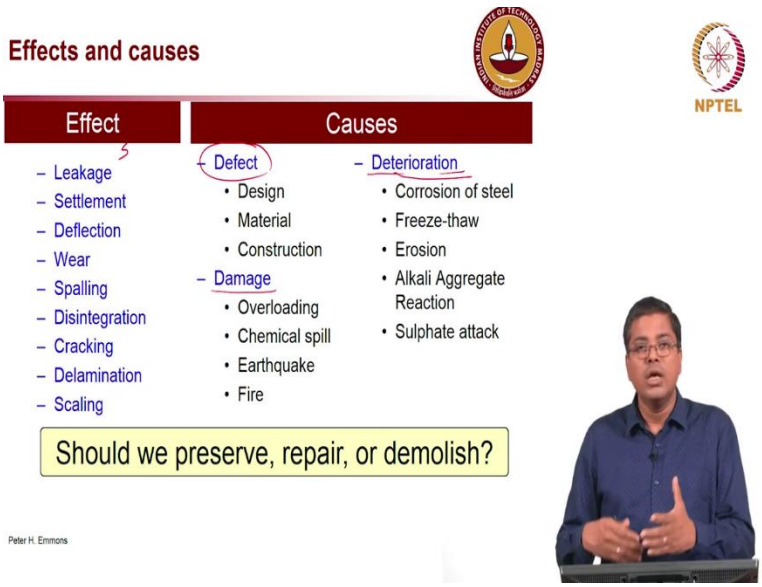


Now, this just summarizing, or listing all the different type of effects and causes for those, so if you are talking about defect, we are looking at mainly what are the design problems or material, not meeting adequate requirements and then sometimes also construction, poor construction practices all this can lead to defects in concrete structures when you talk about damage.

It is mainly something which happens immediately, like overloading of a structure or a chemical spill. Let us say you have a tanker which is going on bridge, and then spills all the chemicals. There are cases like that, very rarely, but it can happen. An earthquake fire these are all immediate effects. When you talk about deterioration, it is mainly a long-term process, which is corrosion of steel freeze thaw it again takes time, erosion, it takes time, then alkali aggregate reaction or ASR it also takes time, sulfate attack these are all long-term deterioration mechanisms.

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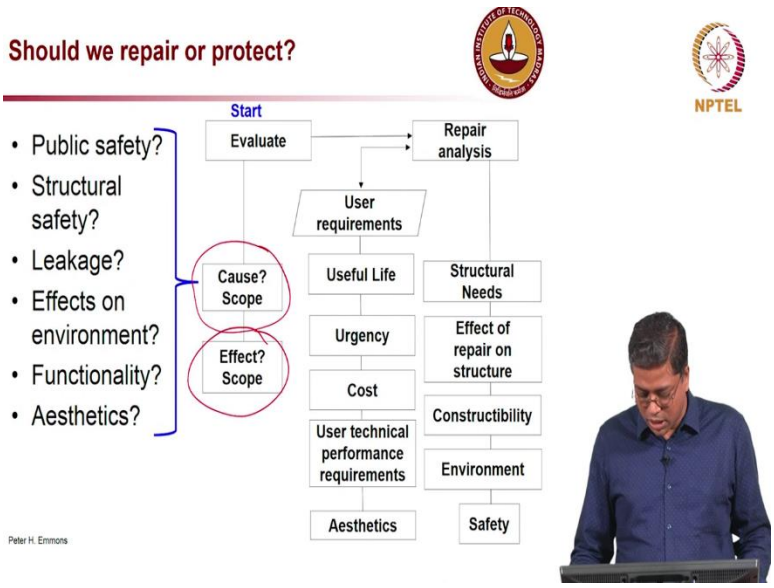


Now, should we repair or protect? This is a big question because money is involved in this and so, how do we decide? you are to first look at public safety and then safety of the structure itself and then leakage whether there is significant leakage or if there is a small leakage which is leading to a large problem, then we can just arrest the leakage and that will take care of the or that will prevent further damage to the structure then effects on environment.

And then functionality and aesthetics all these you have to ask questions and then you have to see what is important for you and then accordingly you have to decide whether we need to protect the structure, or repair the structure or it is better to demolish and reconstruct another structure. Of course, money is also an important factor. So, this is just a flowchart, looking at this so these questions which are put on the left side, you can say, these are the causes and then look at what is the effect.

See you have to define the scope of the work is very important because that sets the boundary to work. Like if you are talking about a large bridge structure, you have to say, I am going to take this portion alone, and then look at it. Sometimes you have to go for a pilot work and then see whether that repair work, which you are suggesting is actually good for the entire structure and then go for a larger portion of the structure. So, it is all that time consuming processes but judicious judgment have to be made.

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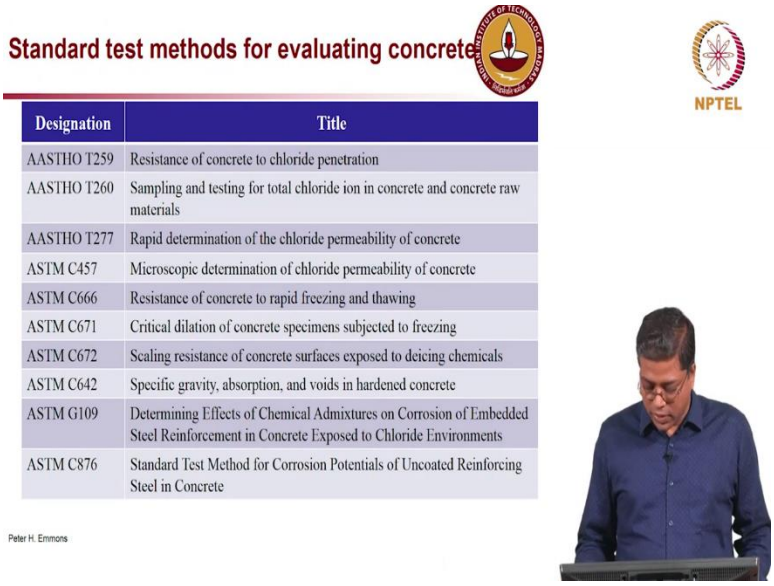


This is a list of various test methods available for evaluation or condition assessment of reinforced concrete system plain and systems with steel in it, you can just go through this list later and this is also some more list on such various test methods available.

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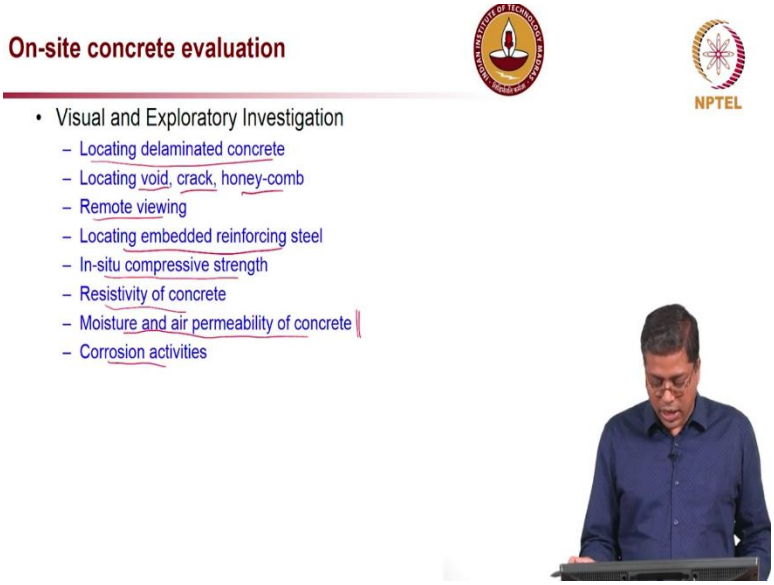


Now, what are the different types of tests which we can do on site. I mean go to the site and do the tests right then and there. So, in case of visual and exploratory investigation, visual means you just look through walkthrough inspection and the exploratory means you take sometimes, some small specimens from the field.

Or you remove some concrete so that you can see what is inside, things like that. But it does not really involve laboratory tests I am talking. Basically, in this particular lecture, we are going to look at things which we can do at site.

Now, locating delaminated concrete, so, that is 1 major task and locating voids, cracks, honeycombs, etc. and remote viewing. Remote viewing means, if you have a structure where you want to see what is happening inside the structure like a tendon if you have on a bridge element, what is you know what happens inside tendon. So, you can put some camera which can go through like endoscopic technology, and then you can see what is happening inside. Then locating embedded reinforcing steel, where is the reinforcing steel is what is probably the diameter of the steel, what is the spacing of the steel. So, that is also sometimes very important. In-situ compressive strength; not the test results which you get from testing cubes, but what is actually the type of the strength of the concrete which is used on the concrete structure.

And then resistivity of the concrete and the moisture and air permeability of the concrete and then corrosion activity. So, these are all different type of tests, which we can do at site.

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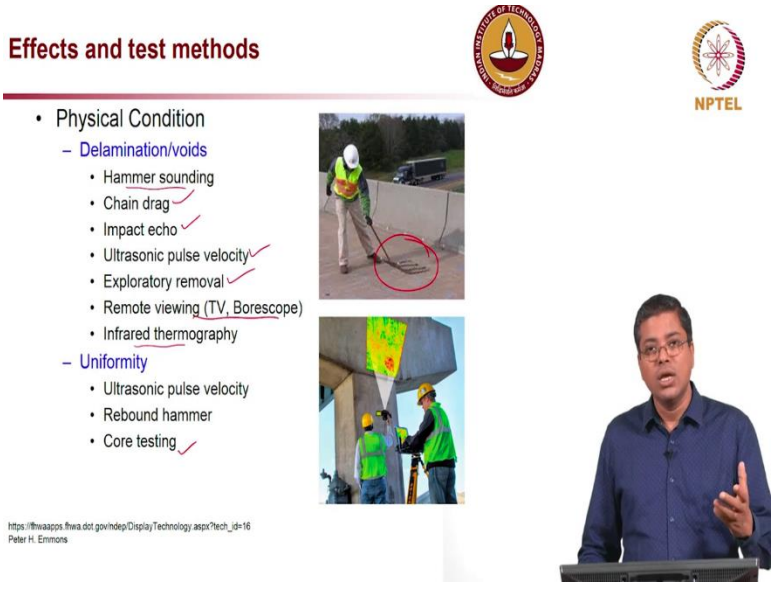


Now, physical condition. If you are talking about delamination and voids, if you want to detect that, these are different things. Hammer sounding because by looking at the type of sound, if it is a metallic sound which is coming, then you can say there is no delamination if it is a hollow sound

by hearing you can whether there is any delamination or not. But again, this depends on the person who is listening. That is also something important to consider. Chain drag is an old technique. You can see in this picture here, there is 4 chains there so they are actually dragging it by hearing the sound, they will decide whether the region is delaminated or not.

Impact echo. It is more sophisticated instrument. But for special cases that could be useful. And then UPV or ultrasonic pulse velocity which kind of tells you whether the concrete is integral or not. And then or if there is a crack inside the concrete, I will cover that in detail later.

And exploratory removal, you remove the concrete just to see what is inside. And remote viewing, which is mainly by inserting a camera or something into a small hole and then see what is inside. Not a full-scale damage, but just a small hole to see what is inside the concrete element. And infrared thermography that is something which is very useful to see where the moisture is and basically idea is here to look at the temperature profile on the structure.

And then based on that you make judgments and uniformity in an ultra-sonic pulse velocity can also be used for essentially to look at the integrity of the structure. So, for what it means is if you have air voids or something inside or if you have a honeycomb that test can tell you that the concrete is not really same everywhere, because if you look do the same test at different locations, based on the test results which you get you can say whether the uniformity of the concrete how good it is across the surface.

And core testing if you do large number of cores from various locations on the concrete structure then you can actually see what is a scatter in the test results and then that will indicate the quality of the material, quality in terms of uniformity also or consistency across the structure.

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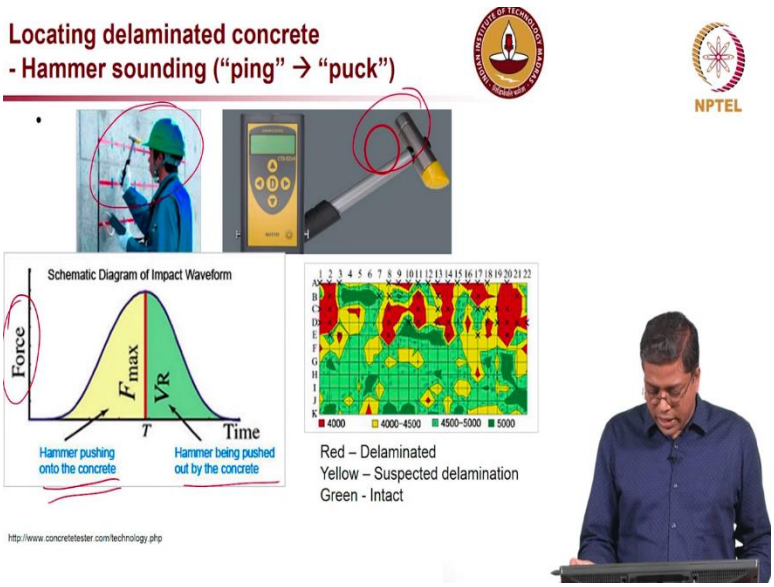


Now, let us go through one by one, I am not covering all the tests, which we said but some of the tests we can cover.

Locating the delaminated concrete, how do we locate? So, this is an instrumented hammer, which can be hammered onto the concrete surface, as you see here, this person is hammering it on to the concrete surface. And you can determine whether there is the delamination or not by looking at the force the hammer pushing on to the concrete. How much is the force and the hammer being pushed out so when you hit it how is the reflection from the concrete surface. Or by looking at mainly on the force calculation that instrumented hammer it will calculate the force acting and then if the graph which you see over here on the bottom left, if it is a skewed graph, then you can say it is kind of there is the sign of delamination.

And so, based on this force which we measure, we can actually develop a contour plot as you see on the bottom right. So, you can see all these red regions are be laminated and the yellow regions are about to get or there is a doubt whether it is delaminated or not and the green regions you can say it is clear or intact surfaces and then the next step could be to go and do a detailed inspection on the delaminated region or you can remove the delaminated region alone, instead of removing the entire concrete stuff surface so, that is the idea here.

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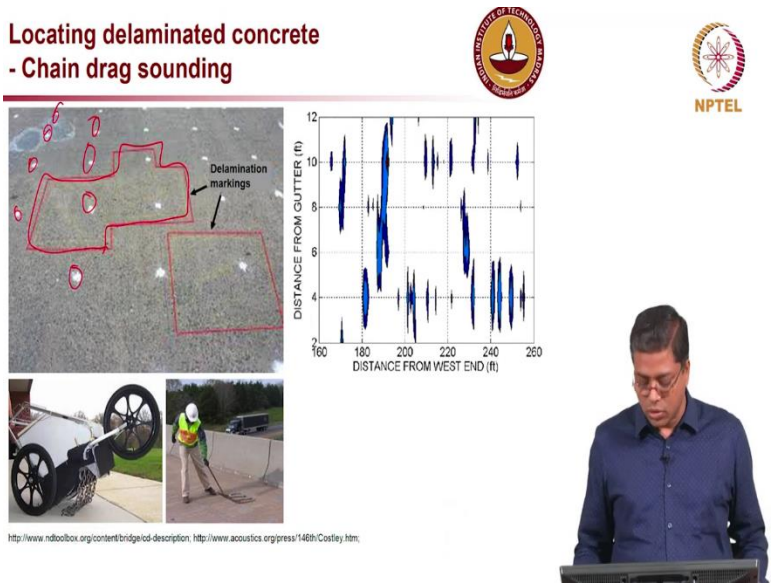


And then this is the old technology the chain dragging. Once you drag the chain you can see there are grids marked first here, all these white spots are grids. And then after that, you drag the chain and then mark the region with which indicates delamination. And then you can again create a contour map like this, which is shown on the right side and then decide what to do next.

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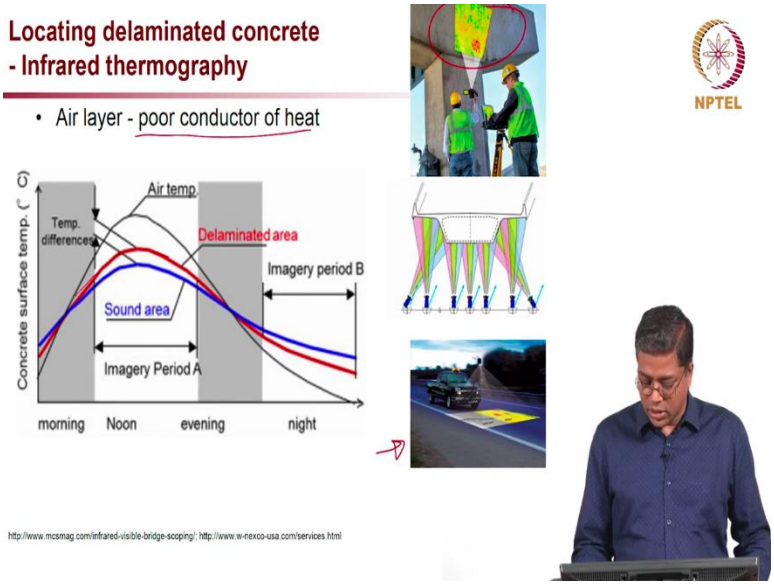


Another way of locating the laminated concrete let's say you are talking about a structural element, where you cannot really reach or it is too far away like the picture on the top right, you can see that it is very difficult to reach to the top of that bridge. So, if you can have a camera which will take image of the concrete surface with standing in a remote place.

You can take these images of various concrete surfaces. And then look at the image, the image itself is very clear here you can see some region is red, some yellow, some green. So, that will kind of tell you which region is delaminated and which is not delaminated. It is working on the principle that if there is a delamination then you have an air layer between the surface concrete and the substrate. So, this air layer is essentially a poor conductor of heat.

So, that will give you a different curve than the region with intact concrete. So, you can see in the graph here the blue curve indicates the good quality concrete or sound region and where the delaminated region is indicated by the red curve and then you compare this for different locations and then see how different it is and that will kind of give you an idea of which region on the surface is delaminated and which is not delaminated.

And very useful for large structures like bridges where otherwise you will have to have a lot of manpower and the time required will also be very long. Bottom you can see a infrared camera fitted on a car or a pickup truck, then you can actually ride on entire road surface, it can be mapped and you can do this in the morning in the noon, evening, night and then collect the data and then have an analysis and then see which region is actually delaminated.

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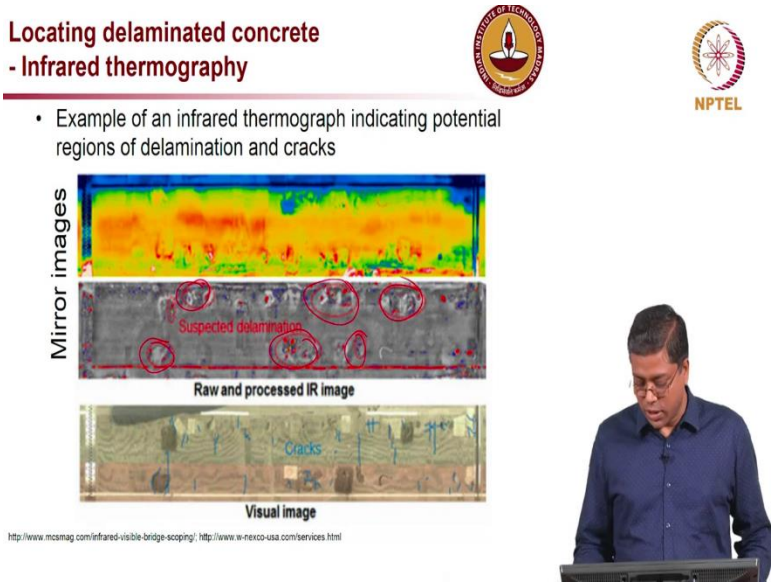


Now, this is a contour map which can be used later. So, you can see here, these circle regions are all indicating some kind of suspicion on whether there is the delamination or not. And so, these

images can be created and which is very useful especially when you talk about very large surfaces for inspection.

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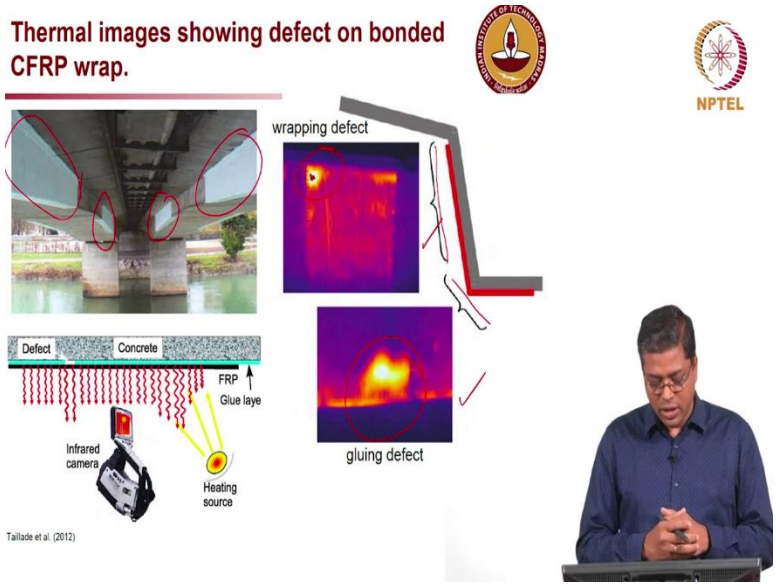


Now, if you are talking about large structures, you can see here on this bridge, you can see here the laminates are applied this here and you these this IR images or infrared images. And that will tell you which location as you see on the pictures on the right side for this portion is that this is the image and for this corner, this is the image and definitely in this corner here, there is some problem in this corner here, it kind of tells you that the gluing is not really well done.

So, this can be brought into the contract documents itself that you will do this test after the work is over. And so, if there is some percentage area if it is delaminated, you can give penalty and if it is all well done, you give bonus. So, definitely the quality of work will be much better.

In such case always you have to incorporate, some kind of post installation inspection that is very, very important and then only we can really improve the quality of the repair work.

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Now, again, looking at other techniques, there are GPR systems, ground penetrating radar systems, which comes in different frequencies. So, when you talk about this kind of tools, It is very important to look at, whether that particular structure or the thickness or the cover concrete of the particular structure, whether the particular instrument is able to measure take good measurements on the particular structure looking at the thickness of the structure so that is very important.

So, it is not that all GPR system will work for all concrete structures. So, you have to really look at the thickness and then have a judgment on ask this question very specifically when somebody says GPR based measurements. All these non-destructive type measurements you should ask this question very specifically to the instrument manufacturer that whether this will give you a good high-resolution image on this particular type of structures given the exposure conditions, etc. That is very important question before just buying an equipment.

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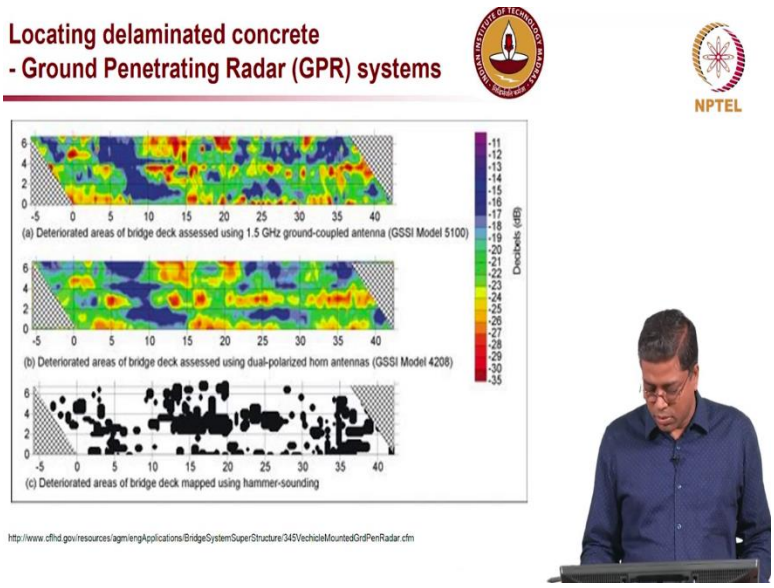


Now here also another contour map showing different regions made with the GPR. You can see that areas of a bridge deck, you can see very clearly only some regions have problem. So, when you talk about replacement of the cover concrete and relaying new concrete, you do not really have to do it on the entire bridge, that that will save a lot of money. So, you these are very good tools, when you talk about large structures, very good tools to help reduce the amount of repair work and that amount of money spent also.

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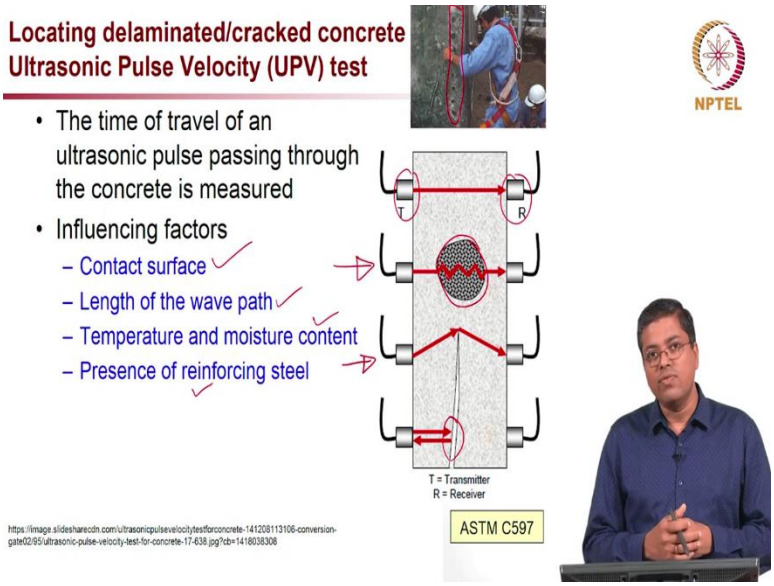


Now, if you are talking about crack or some kind of integrity related issues in concrete, ultrasonic pulse velocity test is a very good one. As you see on the picture here on the right side, you can see there is a transmitter and a receiver. So the wave is going through the concrete and then you look

at basically how long it takes to pass through the concrete if there is a honeycomb or a void something inside the concrete, it is going to take long.

Because the paths of the concrete as you see here, the path of that concrete is not straight line anymore. And if you have a crack again as you see here, there is a deviation in the path of the waves and if it is right at the crack, if the wave hits, it reflects back and it does not even reach the receiver. So, all this kind of gives an indication on the integrity of the or the general quality of the concrete structure or concrete element and what are the factors which influence the quality of the measurements.

So, coating contact surface is very, very important. You have to prepare the surface very well and the transmitter and the receiver should be in good contact with the surface. So, usually we provide a gel, that is what you see on the photograph on the top right, you can see this these markings, which are nothing but the gel, they are not holes drilled or anything they are just that gel, silicone gel, which is provided to ensure continuous wave propagation.

And then length of the path, the longer the length it takes more time for the way to reach from transmitter to the receiver, and temperature and moisture content that will change the rate at which the wave propagates through the concrete and then presence of reinforcing steel that will also affect because if it is going through the steel, there is an interface between the steel and the concrete and if the interface has some air then there could be reflection and so that will also influence the type of readings which you get.

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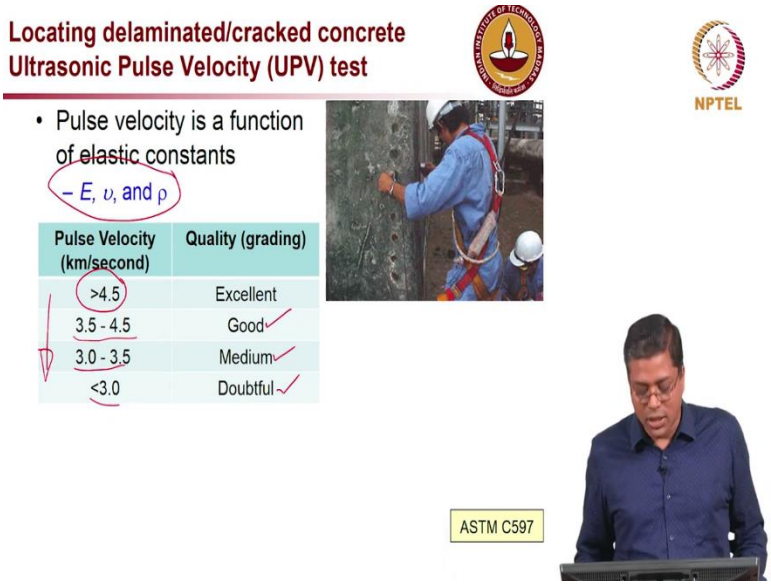


Now, how do we assess this? So before assessing, this pulse velocity is function of elastic constants of the material through which it passes, and then how do we assess if we say that those pulse velocity or the velocity by which the wave is passing through if it is greater than 4.5 generally we can say it is very good or excellent and as the speed of the wave reduces, then you kind of tend to say that the concrete is of not that good quality.

So, 3.5 to 4.5 we can say it is good, 3 to 3.5 medium and less than 3 it is doubtful there are some serious problems with the structure that could be cracked that could be honeycomb or some external materials also I have seen even cases where bricks are there inside a concrete. So, you know, depending on the quality of construction and the inspection which was carried out.

So, all these you have to think or there could be some, if you are talking about elements which are very large these are very useful information to give you an also to sensitize people at site that you will do all this. So, they have to make sure that the quality is very good. This should be told to the people who are actually doing the work so that they know that if there is some problem, if there will be honeycomb then they will be questioned later.

So, this kind of watchdog approach would really help and we have to be upfront we have to tell the contractors that we will actually have these kinds of inspections. Even for repair work we will have these kinds of inspections later on. So, if you have a good job will give you bonus or if you

do a bad job, then there will be penalties. So, those kinds of statements can be brought into the contract documents. Once you put statements like that, then definitely it is going to really sensitize the workers, engineers and they will do a much better job.

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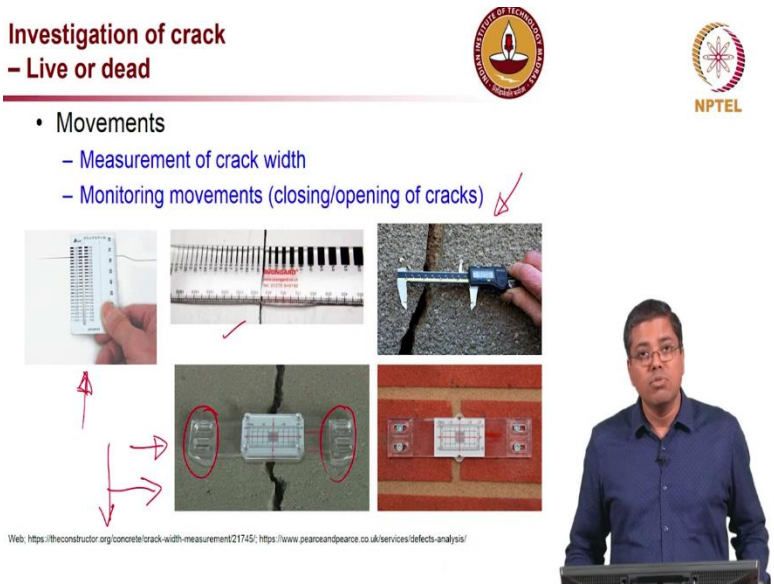


It becomes important to investigate whether a crack is a dead crack or a live crack. Because that will change the way you repair the structure also. And so, one example here is first thing is we will have to measure the crack width, so this is a crack card which is available to it is just like a credit card, which has already different markings with different crack of different width so, all these black lines which you see has different thicknesses.

And then you place this card on the crack and then you can actually measure what is the crack width. And this is a crack scale. And then you can also measure depending on the size if you can also use a Vernier caliper to measure the crack. And also, there are tools available where you can look at both the movement see this way, if you install this on the structure, so, this is glued here and then glued here so, as the crack moves, then there will be movement inside. There are some systems which come with a gauge is fixed on one side, the other side it is free to move and also there are gauges which are available where you can look at both the movement in both directions like perpendicular directions, let us say x and y. So, a movement in this direction and at the same time movement in this direction which will also give you significant information on what type of damage mechanism or what type of movements are happening in the structure.

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Now, we mentioned a little bit about remote viewing, these are some equipment's available where an articulated camera can be used to see what is happening. I will show the examples images on the next side slide. So, basically these cameras you can look at what is in front of the camera what is on the side of the camera and at any angle. So, very useful tools especially for inspection of very important structure.

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So, first 3 images are images taken on pipes or tendons where there were voids inside the tendons and you can see that very clearly. You drill a small hole and put this endoscopic camera into the hole and then look at what is the condition inside and if you see voids maybe it is not good always

or whatever is inside you can actually see this picture shows here on the left bottom left that this kind of things can also be used for inspecting.

If you know what is happening inside the wall because sometimes you have the walls with panels, where there is a space in between the inside and the façade elements. So, you can drill the hole and see, what is the condition inside.

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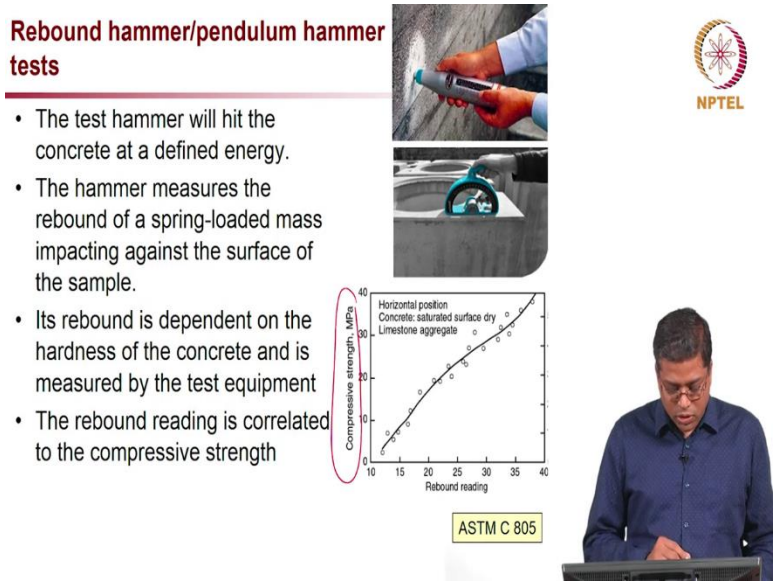


Now rebound hammer, widely used equipment which can be used for testing in getting an assessment of the compressive strength. But I must tell that this is very sensitive to the surface because it essentially depends on the quality of the near surface, based on the quality of the near surface you get a particular reading and then you correlate that reading to the compresses strength.

So, if you have a dust particle on the surface, it will give you very low strength even for a very good quality concrete. So, you have to make sure that the surface is very well cleaned and your tool is kept perpendicular to the surface. If you tilt it is probably going to give you a very different result. So, all these have to be taken care. Make sure that the surface is very clean and smooth and clean while you test this, and also at the same time, the correlations are rightly used.

So, you should not blindly use these numbers that is one thing which I would like to tell you how to really also see where that give, make sure that you have photographs at the time of testing. So,

that will probably give you a hint where the quality of testing. Because it is sometimes you might get numbers which are not really good, but the concrete is actually good, but because of the poor testing procedures, you do not want to say that concrete is of bad quality.

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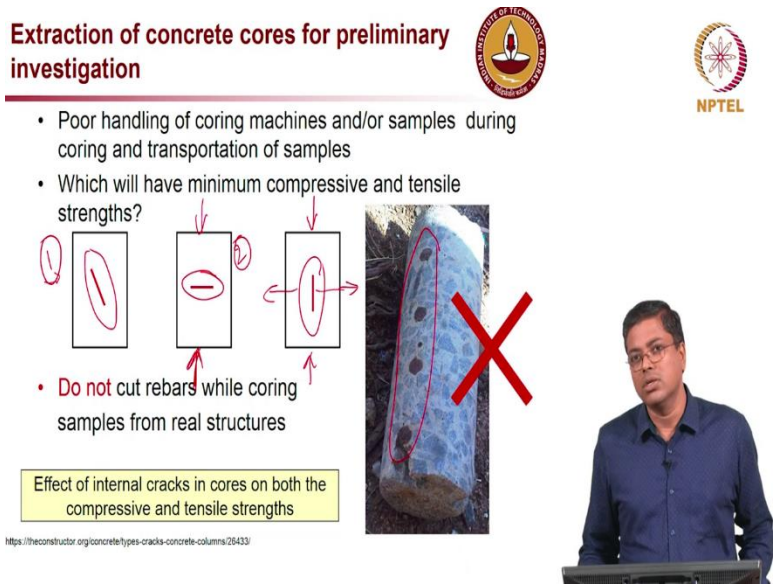


Now, extraction of core, for preliminary investigation. Make sure you use a good coring bit, because if the coring bit is not good, if it is worn out, it will really induce a lot of vibration and then that might also induce cracks in the concrete core which you are collecting. That is also not good idea so good use good tools. That is very, important. Sometimes we tend to keep on using the same tool.

Even if it is worn out, we still tend to use the same tool, but what really happens is you waste a lot of time. When you get the specimen, it is of bad quality because of some cracks which we induce just because of the poor-quality tool. So, having good tools is very, essential, if you want to do a good inspection or good condition assessment. Now, if there are cracks in the core, there if you have this kind of crack or if you have this kind of horizontal crack or if you have this kind of vertical crack.

You have to really think how these cracks will actually influence the test result which you are going to get if this is the in the first case here, there will be influence, because as you compress the core, this crack might open up in the second case number 2 here, this, this is first case, in which

you have an incline crack. In the second case, you have a horizontal crack or a perpendicular to the direction of application of the force or in a compression load during the testing that will close the crack.

So, it will not really affect that test result. In this case, when you apply something like this, this crack is going to open up this crack is going to open up and that will really influence the test results. So, you have to really look at all these before taking a testing the cores you have to see if there is any cracks on the core specimens also another most important very important thing is you have to avoid cutting the steel rebars concrete the coring is done to actually assess this condition of the structure.

And you should not do something which will actually damage the structure cutting the rebar is essentially damaging the structure. But yes I understand in some cases the rebars are so congested that you may not be able to avoid cutting this rebar but again that must be done with thinking whether you really want to do that do cutting or you want to go for other non-destructive techniques in such cases.

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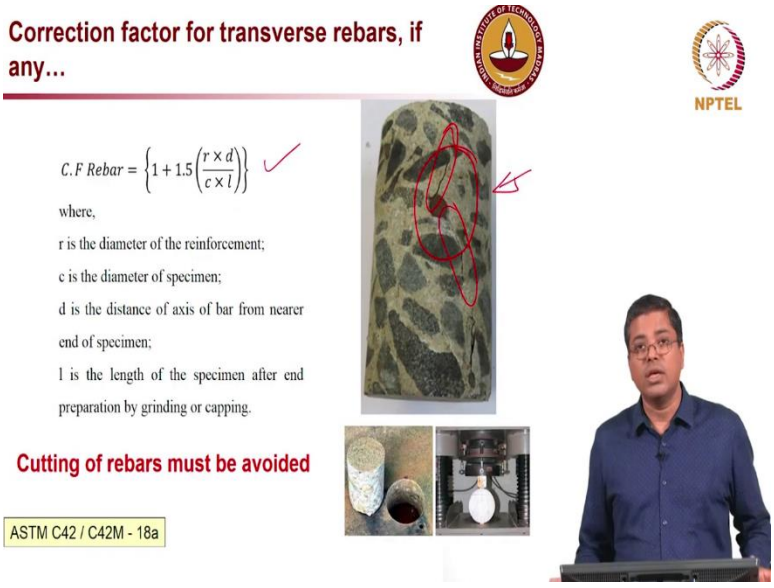


Now, if you have happened to have a concrete core which already has a rebar here as you see here, in this picture, you can see there is a rebar and now very clearly when we tested this specimen, you can see that the crack initiates right here, where the rips of the bar is you can see here there is

a crack initiation and here also that the both these cracks are initiating right at the rebar, which might tell you wrong lower strength than the actual strength of the concrete.

So, there are some correction factors available, which can be adopted before we conclude on the test results. And also, when you have rebars it is important to avoid this cutting of the rebars.

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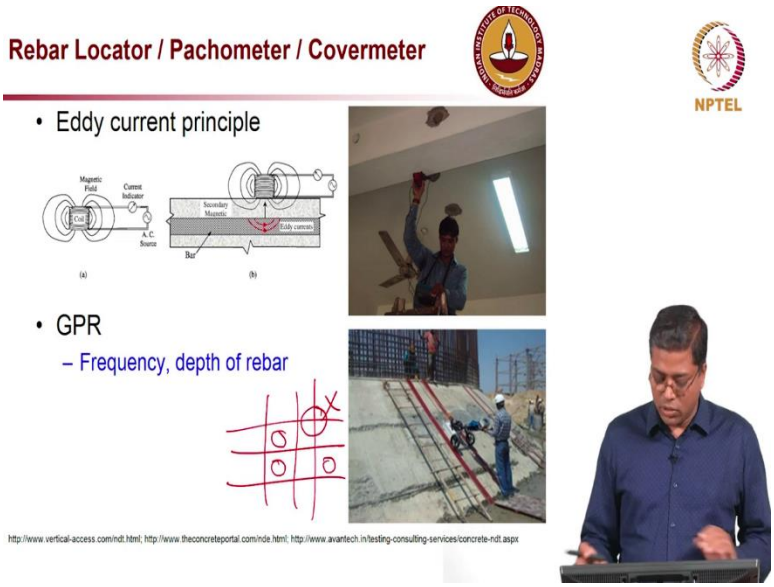


There are instruments available which can detect the location of the rebar and even there are instruments which can tell you what is the approximate diameter of the rebar. So, these kinds of instruments which some of them are based on eddy current principle and some of them are based on ground penetrating radar systems. So, you can use these types of tools to see where the rebar is and make sure that you are not coring at that location you are coring or taking the core from a location away from the rebar.

So, if you have a grid like this, if you have a rebar grid like this make sure that you are coring something like this, these are the locations where you can core and not something like this is not a good idea okay. So, you should not cut the rebar while trying to inspect the concrete structures.

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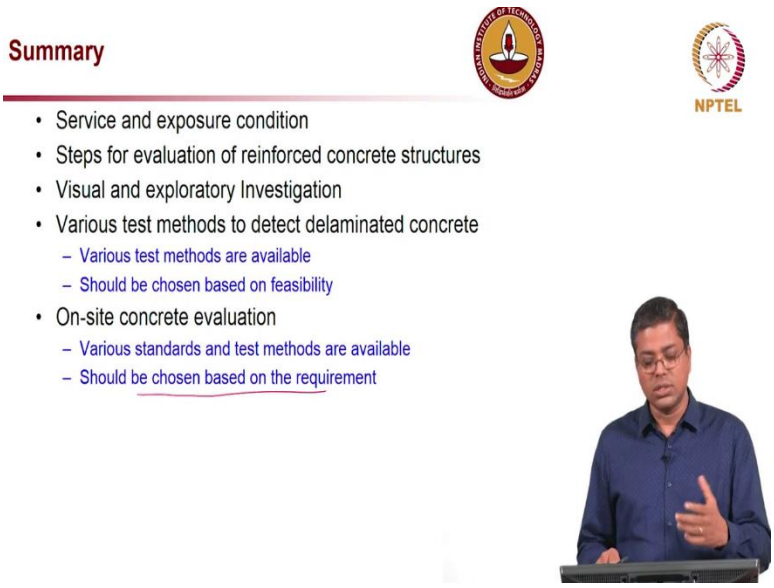


To summarize, we looked at different exposure conditions and different load conditions also, especially overloading whether it is frequent overloading or occasional overloading, and different type of exposure condition looking at temperature moisture, chemical attack etc. and then what are the steps for evaluation or condition assessment, generic steps which we can adopt visual inspection then getting the available documents, maximum information on the structure, history of the loading etc.

How do we collect this information and then how do we record this information, and then also looked at different test methods to detect the delaminated concrete and how we can minimize the amount of work. If you get let us say large structure how these instruments can help in getting a contour plot indicating delaminated region, which can later on help in reducing the amount of repair work. For example, instead of repairing the entire structure, you can say only these 20% of the area is delaminated.

You can actually go and do a repair in only those regions, and then we also looked at various on-site concrete evaluation techniques and what some standard test method I gave you a list of that and should be chosen based on the requirement. It is not that all and non-destructive testing techniques are good for everywhere in order also the type of instrument which we select should be able to give you reasonably sufficient resolution of the images for that particular.

For example, if you are talking about a very thin element, some instrument may not work, so, you have to really look at for the specific applications or specific structural element, size and shape or exposure condition, whether it is wet condition, dry conditions, such cases, which instrument will work, and that is very, very important to see rather than going and doing all sorts of testing on the concrete.

So, a judicious selection of the test methods or testing instruments is very, very important. Because that will definitely reduce the amount of money to be spent on inspection. It is very, very important because many places people do all sorts of tests, which are not really required. So, this I would say that it is very important to select what type of test you need to do so that or you need to know what type of information you want first, and then do a specific test for that information.

Thank you. I think we will cover 2 more lectures on this, we will be looking at laboratory test also, and for both concrete and then looking at corrosion test on steel. Thank you.

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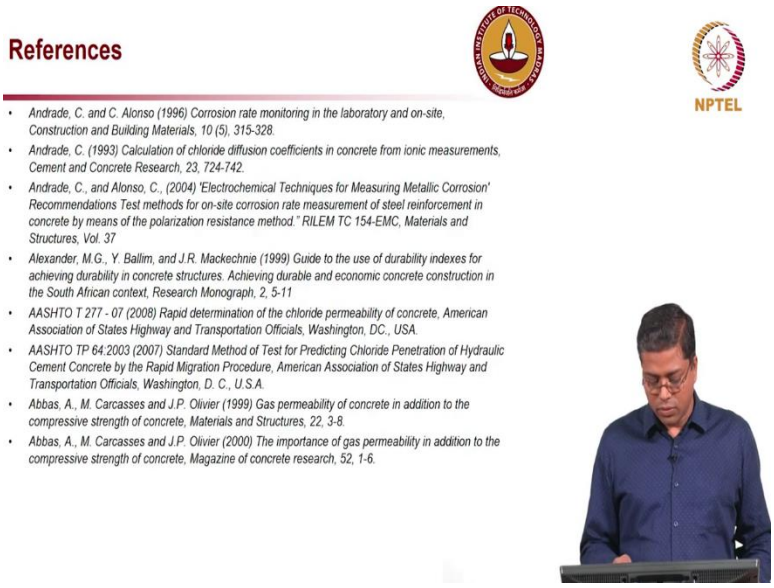


These are the list of the references.