Retrofitting and Rehabilitation of Civil Infrastructure
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Lecture 03
Materials Related Distresses

Hello friends, welcome to the NPTEL Online Certification Course Retrofitting and Rehabilitation of Civil Infrastructure. Today we will discuss Module-A, the topic for Module-A is Deterioration of Concrete Structures.

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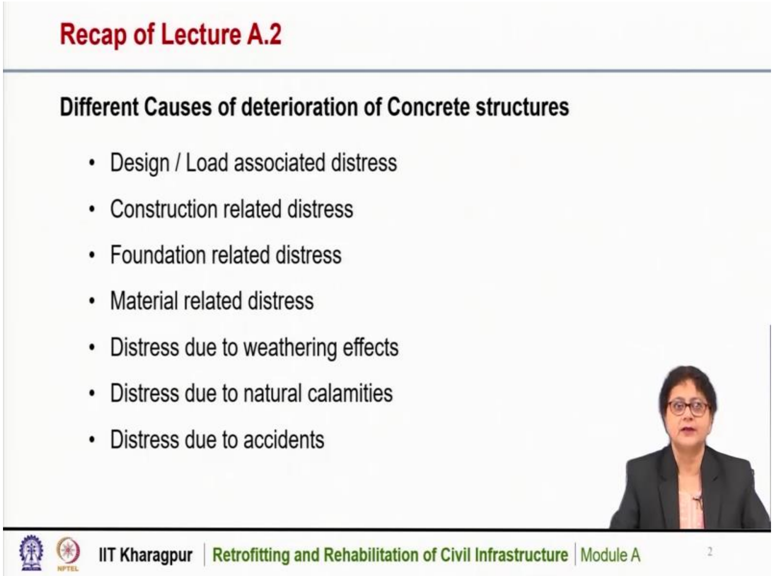

In the previous lecture, we have discussed the different causes of deterioration of concrete structures. Due to the deterioration of concrete structures, the performance and durability of the infrastructure get affected severely. We have seen that there are several reasons for deterioration of structures, it could be due to design or load associated distress, or due to several construction-related issues that may affect the performance of the structure.

Foundation related problems or a number of material-related distress may also affect the structure and deteriorate. Distresses may be due to several weathering effects like freezing and thawing, alternate wetting and drying, and several natural calamities like earthquake or storm may affect the performance of infrastructure. We have also seen that distresses may also be due to several manmade accidents like fire, all these affect the performance of infrastructure and the durability.

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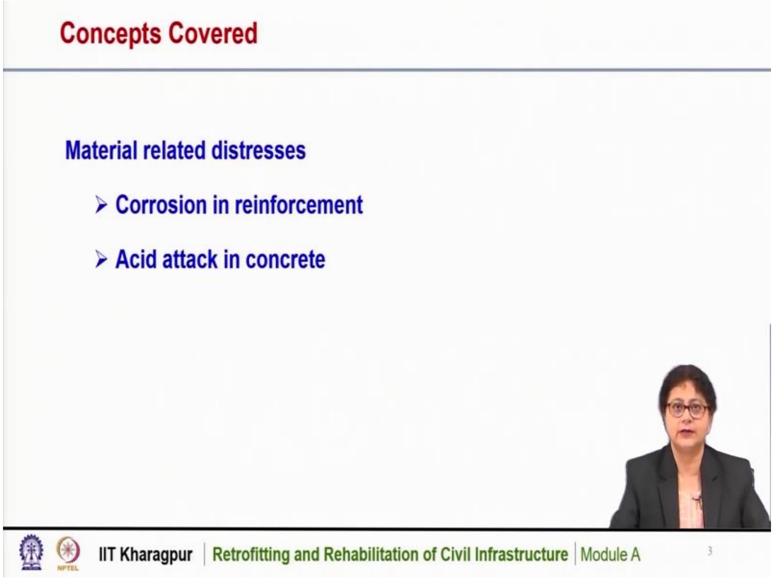

In today's lecture, we will discuss two material related distresses that are found in reinforced concrete structure. One is corrosion in reinforcement and the other is acid attack in concrete.

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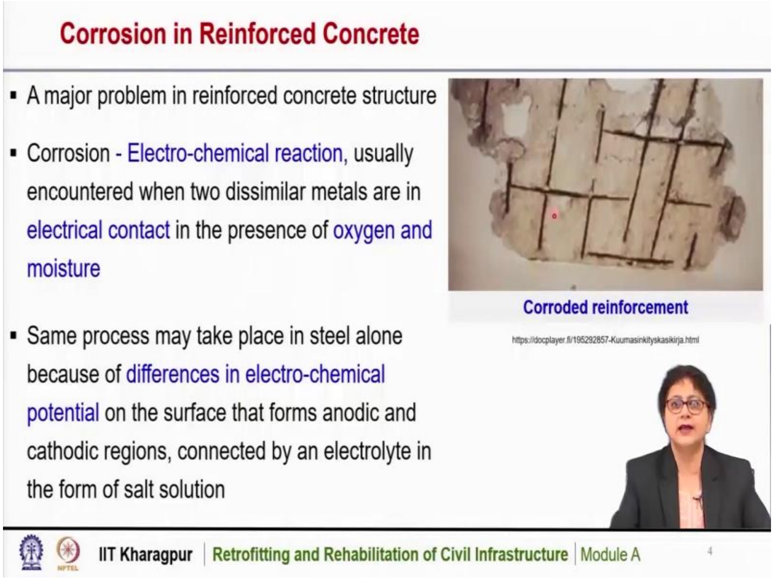

Corrosion is a major problem everywhere in the world in reinforced concrete structures. Every year, millions and millions of dollars are spent to protect the reinforcement and prevent corrosion. Corrosion affects the structure severely. The capacity of the structure, the structural strength reduces significantly due to corrosion of reinforcement and their performance, and the overall durability is reduced significantly.

Corrosion is an electrochemical reaction usually encountered when two dissimilar metals are in electrical contact in the presence of oxygen and moisture. However, the same process may take place in steel alone, because of the difference in electrochemical potential on the surface that forms anodic and cathodic regions, when it is connected by an electrolyte in the form of salt solution.

Here is a typical picture of a corroded reinforcement in a structure, we can see here that the reinforcements are corroded badly and the concrete is spalled out due to the effect of corrosion.

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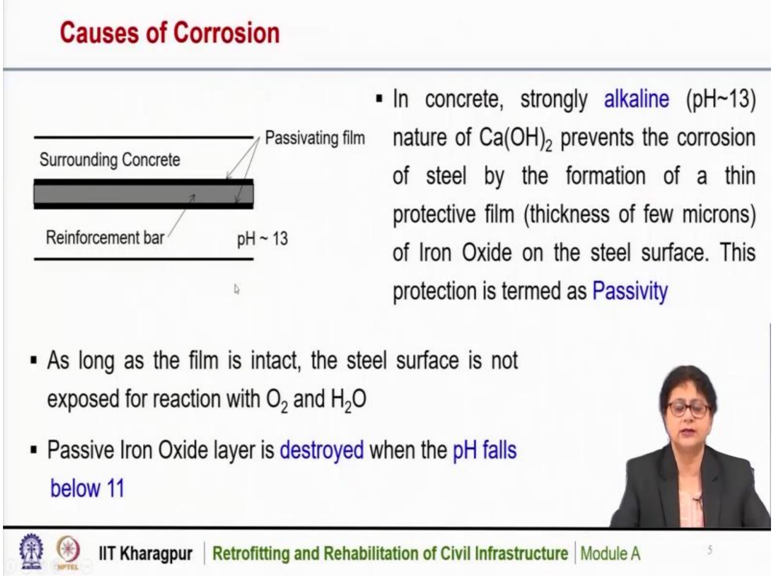

In concrete, the strongly alkaline nature of the calcium hydroxide which is present in concrete as a product of its hydration, prevents the corrosion of steel by the formation of a thin protective fill, this protective film is of iron oxide and that is formed on the steel surface. This protection is termed as passivity.

You can see here that this is schematically shown, that when the reinforcement bar is placed within concrete, a passivating film is formed when the alkalinity is high, alkalinity is in the range of 13. And in this alkaline atmosphere, this passivating film is formed. As long as this film is intact, the steel surface is not exposed for the reaction with oxygen and water.

When this passivating layer is destroyed, this happens when the pH falls below 11. So, a strongly alkaline nature of the concrete helps in the formation of the protective film on the steel surface.

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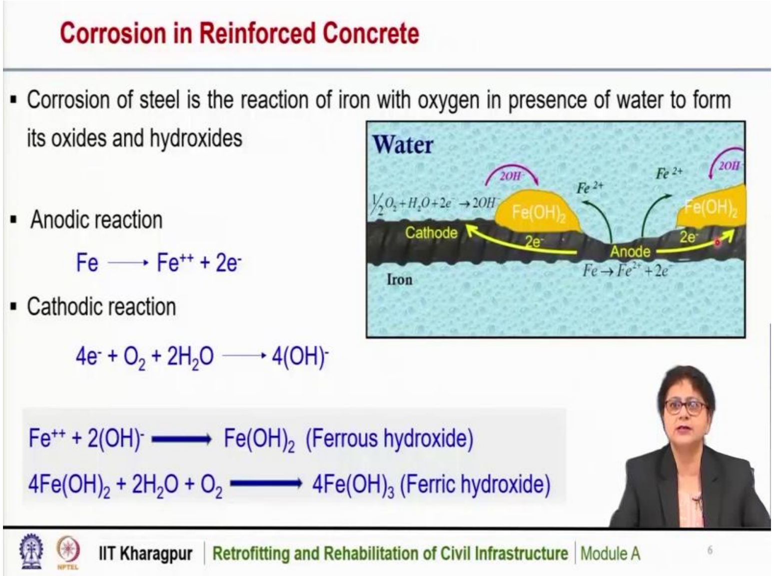

Corrosion of steel is the reaction of iron with oxygen in presence of water to form its oxides and hydroxides. Anodic and cathodic reactions are taking place, where Fe ions are formed, positively charged Fe ions are formed and electrons are released. In the catalytic reaction, these electrons are combined with oxygen and water to form the hydroxide ions, these hydroxide ions are negatively charged and when they combine with the positively charged Fe ions, it forms ferrous hydroxide.

This ferrous hydroxide further reacts with oxygen and water to form ferric hydroxide which again with oxidation forms the rusting or creates corrosion in reinforcement. So, schematically it is shown here you can see that this anodic and cathodic reaction is taking place in steel reinforcement when there is anode, this region there is release of the electrons, Fe ions are formed and they are going to the cathodic region where it is combined with oxygen and water to form the hydroxide ions.

So, there is a loss of material here and the effective area is also reduced in case of steel reinforcement.

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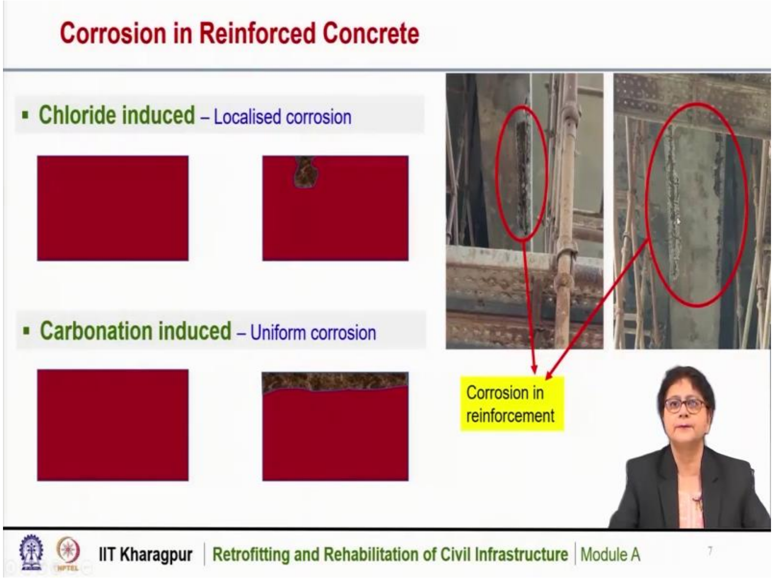

Corrosion in reinforced concrete can be of two types, one is chloride-induced and another is carbonation-induced. Chloride-induced corrosion is due to the effect of chlorides in reinforced concrete. Chloride-induced corrosion is due to the effect of chlorides in reinforced concrete, this is more localized corrosion and it is more intense also.

Whereas carbonation-induced corrosion is due to the effect of atmospheric carbon dioxide, this is more uniform in nature and also slower as compared to the chloride-induced corrosion. You can see here that this is a typical picture of a corroded reinforcement in longitudinal girder of an ROB. A recent project we are doing where it is the ROB is being retrofitted since it is badly damaged, the reinforcements are exposed. Here you can see due to corrosion and they are corroded along its length.

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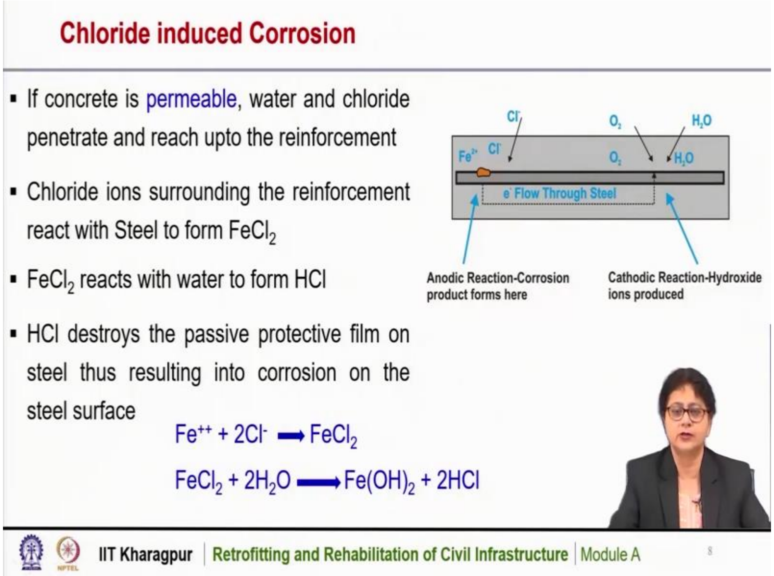

Chloride-induced corrosion is due to the effect of chlorides on concrete. If concrete is permeable with having some cracks on its surface, then water and chloride penetrate through the material and may reach up to the reinforcement. This chloride ions surrounding the reinforcement then react with the steel to form ferrous chloride. Ferrous chloride reacts with water further to form hydrochloric acid.

This hydrochloric acid is responsible for destroying the protective passivating film on the steel reinforcement thus results into corrosion on the steel surface. Here, we can see that this is the anodic and cathodic reaction taking place. The Fe ions are formed, electrons are released and it goes to the cathodic region and chlorides it reacts with the negatively charged chloride ions to form $FeCL_2$ or the ferrous chloride.

This ferrous chloride when reacts with water present in it and that water may come also from the outside environment through the cracks or some water may be present also within the concrete and with this reaction ferrous hydroxide and hydrochloric acid is formed. This hydrochloric acid destroys the protective film. Thus, corrosion can take place.

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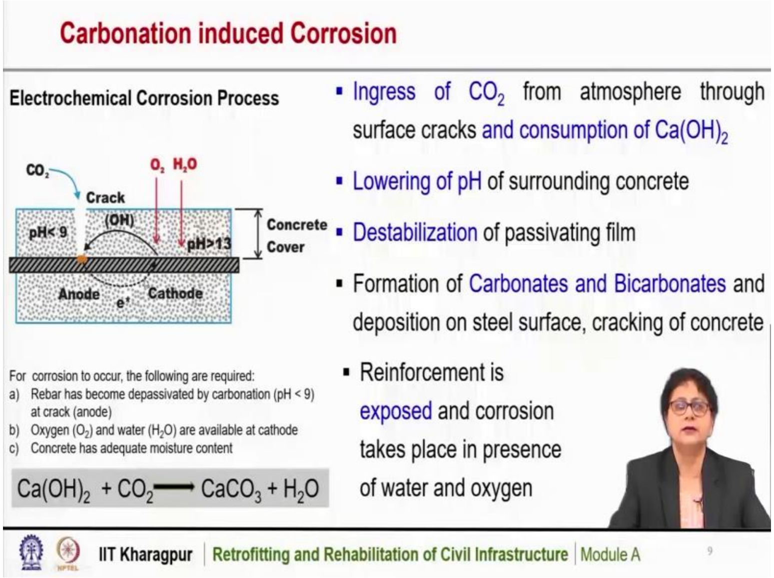

In carbonation-induced corrosion, it is due to the increase of carbon dioxide from atmosphere through surface cracks and consumption of calcium hydroxide, this carbon dioxide reacts with the calcium hydroxide present in concrete, and carbonates are formed, calcium carbonate. You can see here that this reaction that is taking place due to carbonation induced corrosion and carbonate and bicarbonate are formed and are deposited on the steel surface.

Due to this, there may be cracking of concrete because concrete experiences expensive pressure due to the formation of this product that causes destabilization of the passivating film. Thus, reinforcements are exposed and corrosion takes place in presence of water and oxygen.

So, here also we can see that, in this picture, schematic diagram, you can see that when the pH level is lower than 13, it is in the range of 9 and if the surface has cracks, so the carbon dioxide from atmosphere can come and may reach to the reinforcement. So, the anodic and cathodic reaction can take place and then the reinforcements are exposed and the bars are corroded.

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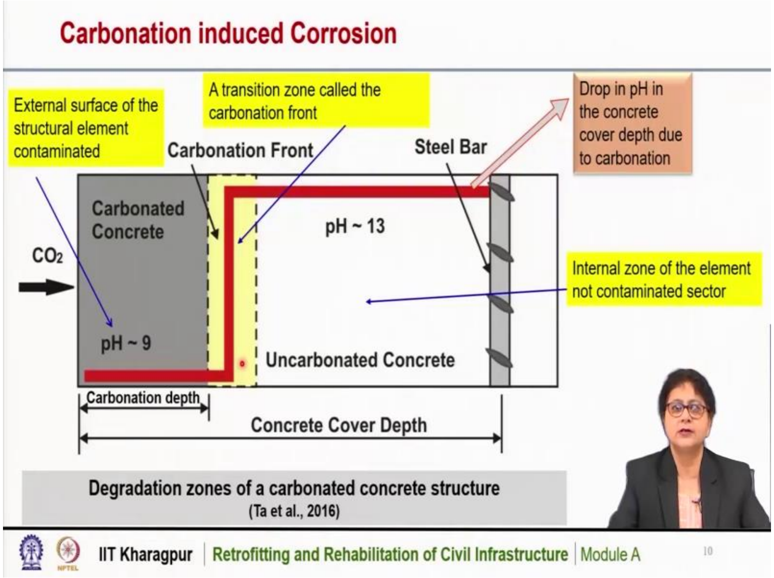

This is a schematic diagram that shows the degradation zone of a carbonated concrete structure. Here it is shown schematically that this is the reinforcement within concrete and this is the cover depth. Now, if carbon dioxide can enter through the material, through some cracks, some portion of the concrete may get carbonated. So, this portion the pH level is also low and this portion is carbonated and this is the carbonation depth.

The external surface of the structural element is contaminated in this region. This region it is protected and not contaminated. Also, the pH level is high in this region, so there is no carbonation. So, the reinforcement is also protected. However, there is a transition zone between this too where the pH level varies. So, in this region, it is also called the carbonation front where the pH level actually varies.

So, with time, this carbonation depth increases and it may reach up to the reinforcement and when it reaches up to the reinforcement, corrosion may take place.

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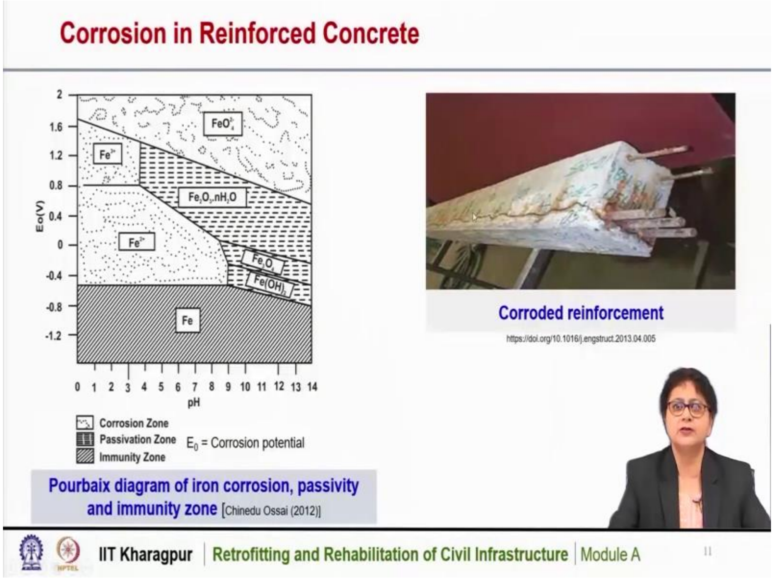

This is a Pourbaix diagram, schematically shown it is the relation between the pH and the corrosion potential of the steel reinforcement. Here it shows a region of corrosion zone, passivation zone, and immunity zone. This is depending on the pH level as well as the corrosion potential. In the immunity zone, the reinforcement is protected completely.

So, there is no chance of corrosion. In the passivating zone, this portion is the passivating zone, where the reinforcements are stable, so there is much less chance of corrosion because the passivating film is still protected. And this region is the region where it is the corrosion zone. So, with this diagram, we can show that which portion maybe may get affected at what level of pH or corrosion potential.

This is a typical corroded reinforcement. This is a typical picture of a corroded reinforcement. You can see here the reinforcements are exposed and it is corroded and cracks have been developed on the surface.

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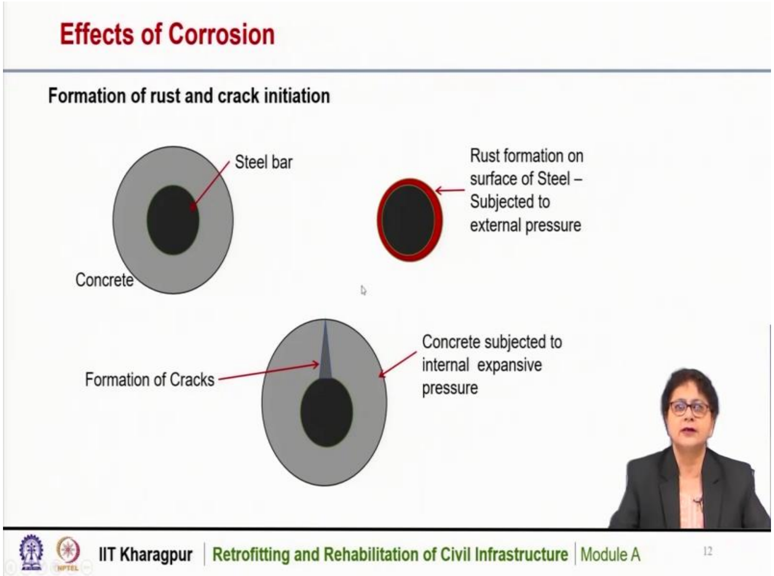

Effects of corrosion is shown in here in this schematic diagram. Formation of rust and crack initiation. Initially, the steel bar is placed within the concrete and they are properly placed and no chemical reaction is taking place. However, when corrosion starts, there is a formation of rust on the surface of steel and it is deposited around the reinforcement, due to which there is an external pressure experienced by the reinforcement.

Surrounding concrete, whenever it is experiencing internal expansive pressure and due to which crack starts from here. So, this crack may propagate within the material and there may be even more cracking and spalling of concrete.

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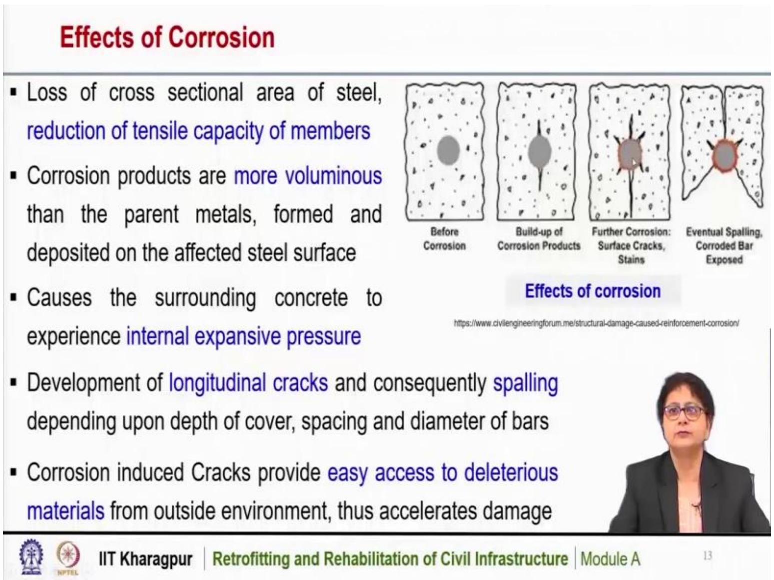

Effect of corrosion are significant. There is loss of cross-sectional area of steel that results into reduction of the tensile capacity of the member. Corrosion products are more voluminous than the parent metals and it is formed and deposited on the affected steel surface. We have seen in this previous slide that they are deposited around the reinforcement. Here also we can see that they are deposited, this causes the surrounding concrete to experience internal expansive pressure and that results into the development of longitudinal cracks.

So, here also crack starts and it reaches up to the surface, consequently spalling occurs and how much will be the spalling that depends on the cover depth, also it depends on the spacing and diameter of the reinforcement bars. Corrosion induces cracks provide easy access to the deleterious materials from outside environment, thus, further accelerates the damage.

So, here we can see that schematically it is shown that when there is no corrosion, the reinforcement is placed like this, after that, a corrosion starts, and crack also initiated. Here that crack propagates and reaches up to the surface, many more cracks reach to the surface, there is the spalling of the concrete in that region.

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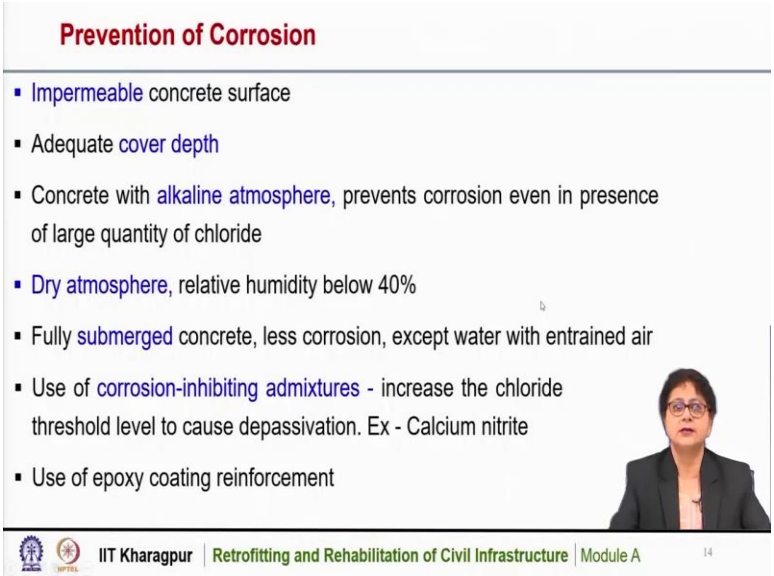

How can we prevent corrosion? It is very, very challenging to prevent corrosion in reinforced concrete structures. Concrete surface should be impermeable and that is an important consideration to prevent corrosion. It should not have cracks on it. The cover depth should be adequate so that reinforcements are protected. An alkaline atmosphere prevents corrosion even if there is a presence of large amount of chloride, but the alkaline atmosphere is very effective in preventing corrosion.

A dry atmosphere also is helpful in preventing corrosion when the relative humidity is below 40% or so. A fully submerge concrete is also much better and less corrosion may take place if water does not contain entrained air because corrosion is the chemical reaction in presence of water and oxygen. So, if oxygen is not present within water, then the submerged concrete is also in a better state to prevent corrosion.

Use of corrosion inhibiting in admixtures that is effective in reducing corrosion and epoxy coating reinforcement is also quite effective in preventing corrosion of reinforcement.

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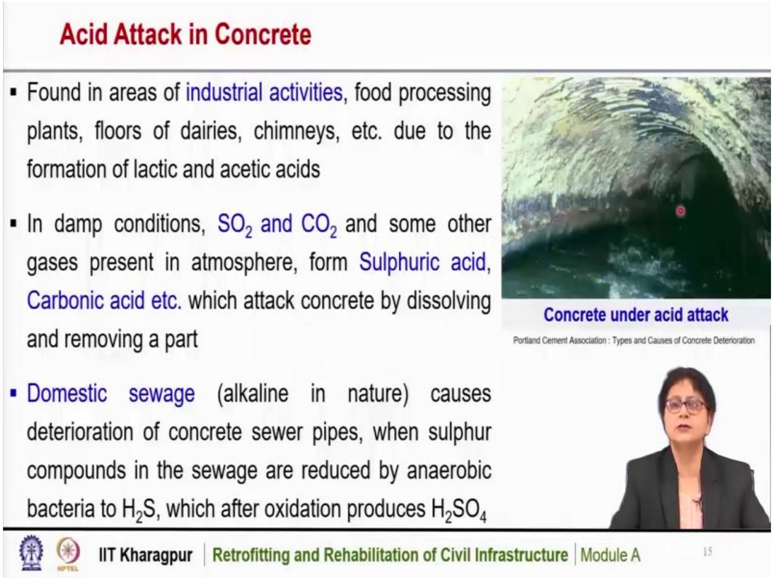

After discussing corrosion of reinforcement, we will discuss another material related distress in concrete which is acid attack. This type of distress by acid are found in the areas of industrial activities like food processing plants, floors of dairies, chimneys, etcetera. Due to which the formation of lactic acids and acetic acids are produced.

So, in those areas, where there is the formation of acids, the concrete structures, which are situated in those areas may get affected by those acids. In damp conditions, sulphur dioxide and carbon dioxide, and some other gases present in the atmosphere form sulfuric acid, carbonic acid, etcetera, which may attack concrete by dissolving and removing a part of the material.

Domestic sewage which is actually alkaline in nature, but it causes deterioration of concrete sewer pipes, when sulphur compounds in the sewage which is present in the sewage are reduced by anaerobic bacteria to hydrogen sulphide and which after oxidation produces sulfuric acid, and this sulfuric acid may attack concrete and damages the surface.

Look at this picture, this is a typical picture of a sewer pipe, a concrete sewer pipe and it is badly affected due to acids, you can see the surface is disintegrated. And because of this disintegration, there is reduction in the thickness of the material and the concrete is affected and its performance is also reduced.

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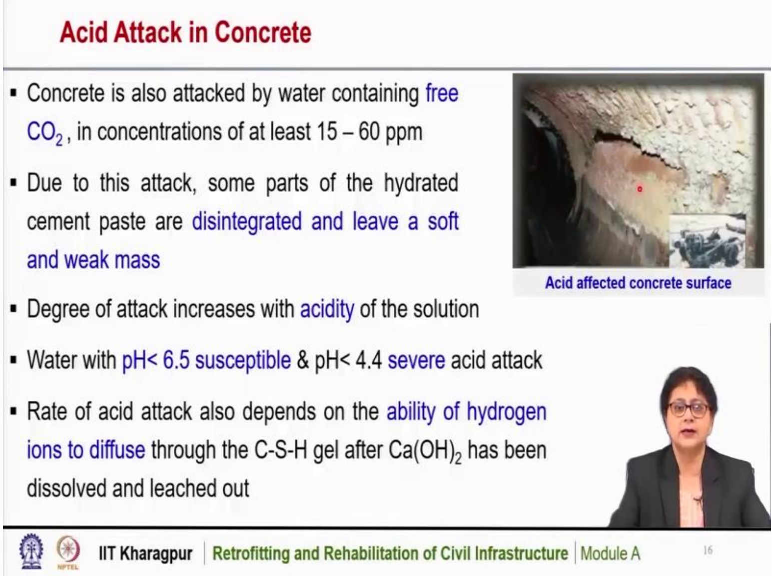

Concrete is also attacked by water containing free carbon dioxide, when the concentration of at least 15 to 60 ppm then concrete may also be get attacked by carbon dioxide. Due to this attack, some parts of the hydrogen cement paste are disintegrated and leave a soft and weak mass. Look at this picture, this is a typical acid-affected concrete surface and because of the acid attack, the surface is disintegrated and a soft mass is also deposited on the surface and that affect the performance of the member.

Degree of acid attack increases when the acidity of the solution increases. Where water with pH level is less than 6.5, the concrete structure which is coming into contact with that type of water or solution is very susceptible to acid attack. And when pH level is below 4.4, it is a condition for severe acid attack. Rate of acid attack also depends on the ability of hydrogen ions to diffuse through the C-S-H gel after calcium hydroxide has been dissolved and leached out.

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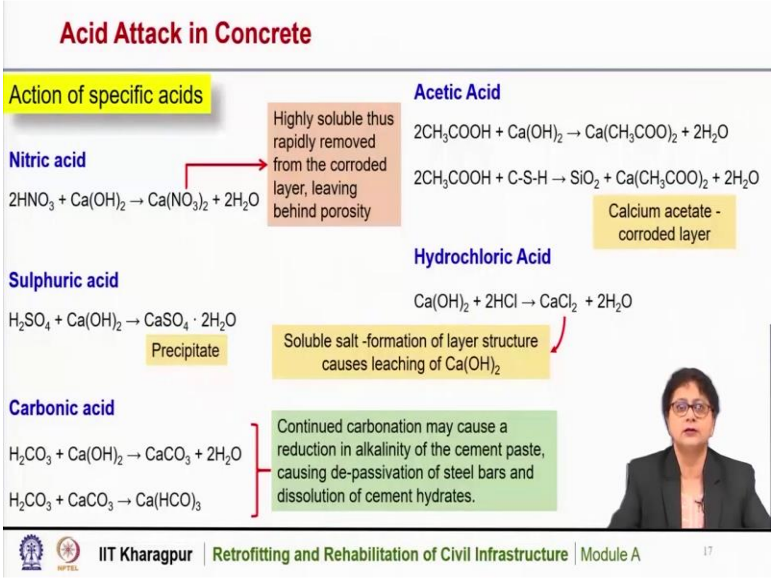

In acid attack, there are chemical reactions taking place due to the action of several acids. The concrete may get affected due to the action of nitric acid, sulfuric acid, carbonic acid, acetic acid, or hydrochloric acid, etcetera, due to which performance is reduced. When nitric acid reacts with calcium hydroxide, calcium nitride is formed and this is highly soluble, thus rapidly removed from the corroded layer leaving behind the porosity.

So, because of this reaction, and the product is highly soluble, it corrodes the surface and that causes porosity of the member. When acetic acid reacts with calcium hydroxide, calcium acetate is formed, and this also affects the surface, a corroded layer is formed and it affects the surface and disintegrate it. Sulfuric acid when it reacts with calcium hydroxide, calcium sulphate is formed, which is precipitated on the material and that is deposited also.

When hydrochloric acid reacts with calcium hydroxide, a soluble salt formation of layer structure is there and it causes leaching of the calcium hydroxide. It is similar way when carbonic acid combined with calcium hydroxide, calcium carbonate, and bicarbonate are formed. This continued carbonation may cause the reduction in the alkalinity of the cement paste and it also causes the de-passivation of the steel bars like that carbonation corrosion and due to this de-passivation, there is dissolution of the cement hydrates and further damage accelerates.

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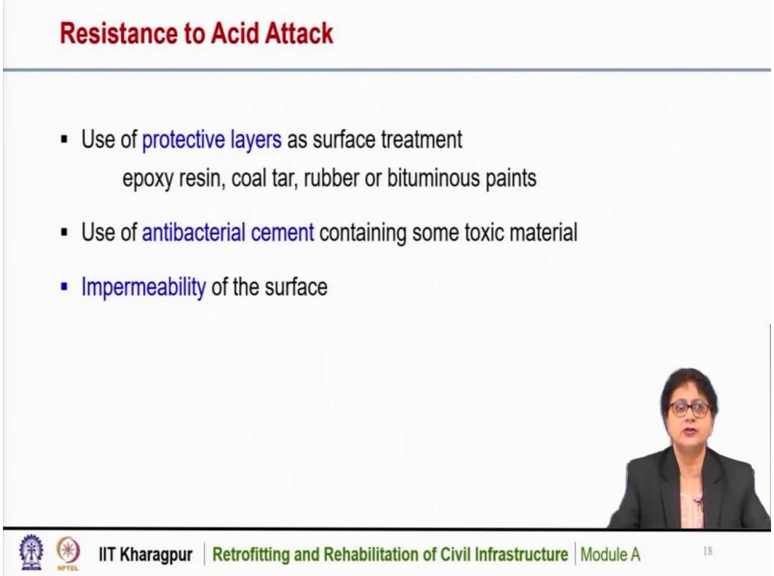

How we can resist acid attack in concrete? We can use a protective layer as surface treatment like epoxy resin, coal tar, rubber, or bituminous paints on the surface of the concrete when there is a chance of concrete to get attacked by several acids as the by-product of industrial activities. Use of antibacterial cement that may contain some toxic material that may also be used to prevent acid attack in concrete and impermeability of the surface is always beneficial and that may also help in resisting acid attack in concrete.

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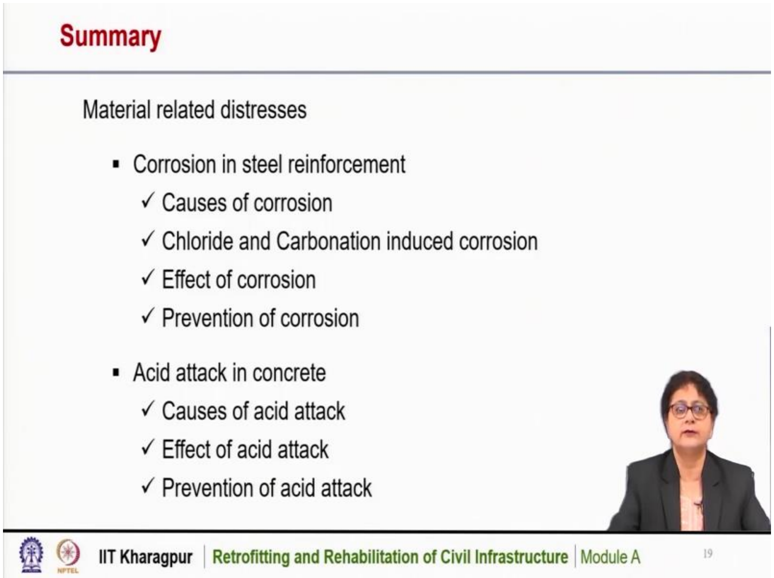

So, to summarize, we have discussed two material-related distresses in concrete, one is corrosion in steel reinforcement and another is acid attack in concrete. In corrosion of steel reinforcement, we have discussed the causes of corrosion, the chloride and carbonation induced corrosion, and how it is taking place that we have discussed.

We have discussed the effects of corrosion and how we can prevent corrosion or in what atmosphere, in what condition corrosion can be prevented. In acid attack in concrete, we have discussed the reasons for acid attack of concrete, the effects of acid attack, and its prevention. Thank you.