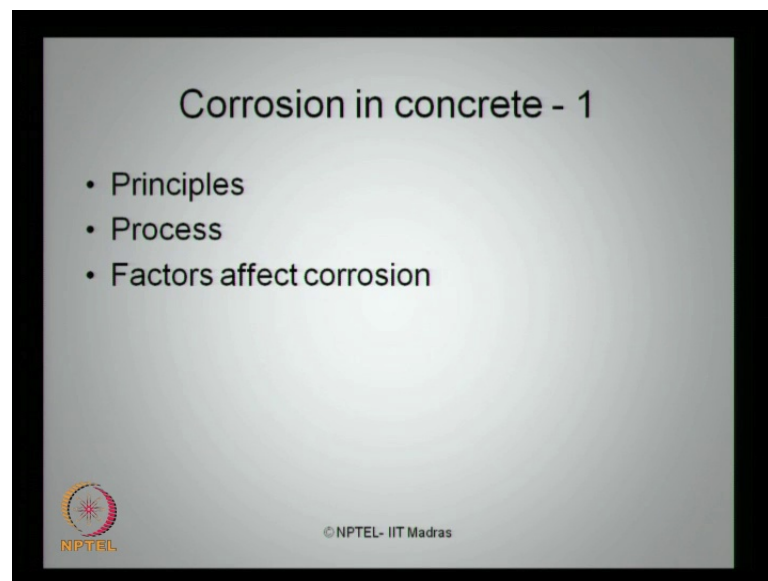


Ocean Structures and Materials
Prof. Dr. Srinivasan Chandrasekaran
Department of Ocean Engineering
Indian Institute of Technology, Madras

Module - 3
Lecture - 6
Corrosion in concrete I

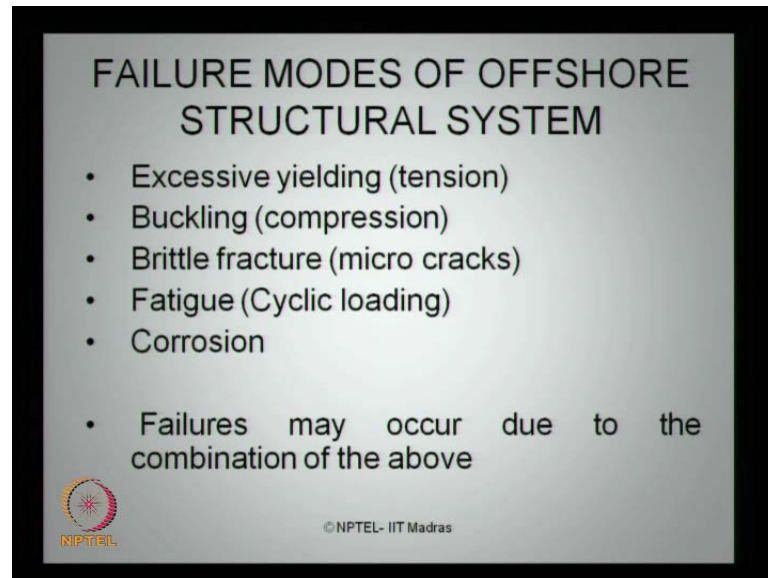
Ladies and gentlemen, welcome to the 6th lecture on module 3 on the virtual course on Ocean Structures and Materials under the braces of NPTEL, IIT Madras. In the last lectures, we discussed about suitability of different kinds of material for offshore application and ocean environment. In the first module, we discussed in detail about different types of coastal structures, offshore structures, and their varied applications and suitability. We will now continue in this lecture to discuss about some of the specific problems associated to material in marine environment. For example, let us take concrete, corrosion is one of the important serious problem associated with concrete. In the last lecture, we discussed about one of the method by which concrete can be protected against corrosion or water proofing what we call crystalline technology. In this lecture, we will discuss about corrosion protection measures.

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So, the lecture is in the series of corrosion in concrete. Lecture number one, we will talk about principles, processes, and what are the factors that affect corrosion in concrete when put in marine environment.

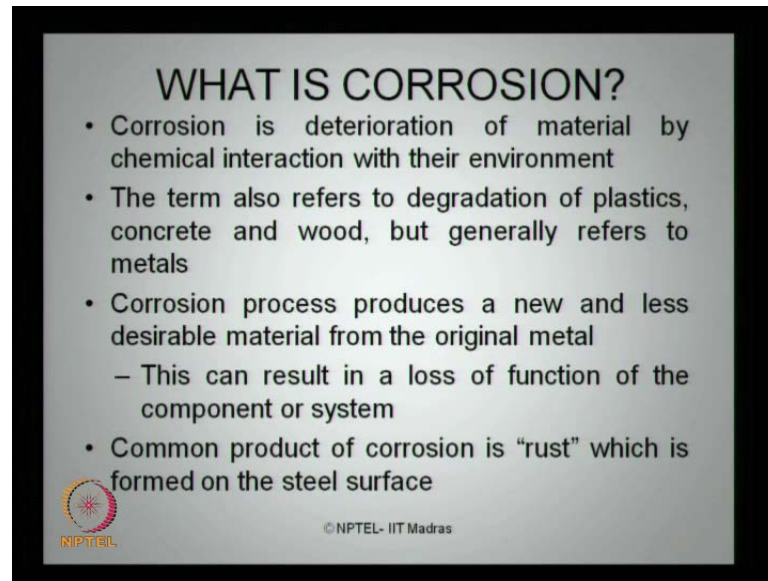
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If you look at the failure modes of different offshore structural systems, it is important for us to understand the failure modes, because they form the basis for treating any material under marine environment. If you look at the failure modes excessive yielding which we call a tension failure is phenomenally a dominant reason for failure modes in offshore structural system. Followed by which is buckling, which results from compressive forces; brittle fracture which develops micro cracks are resulting from the excising of micro cracks in material. Malfunctioning or material manufacturing will result also one of the important failure modes in structural system.


Fatigue results from cyclic loading is an inherent part of loading present in offshore structures, because reversal of loads or combination of loads of different magnitude and direction is an inherent component in forces present in offshore structural systems. Corrosion also falls in the same line as one of the important failure mode of any structural member in offshore structural system. So, if corrosion is adhered to one of the important characteristic of failure for members present in marine environment. Failures may occur, ladies and gentlemen, due to the combination of above or independent of any one of these things.

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WHAT IS CORROSION?

- Corrosion is deterioration of material by chemical interaction with their environment
- The term also refers to degradation of plastics, concrete and wood, but generally refers to metals
- Corrosion process produces a new and less desirable material from the original metal
 - This can result in a loss of function of the component or system
- Common product of corrosion is “rust” which is formed on the steel surface

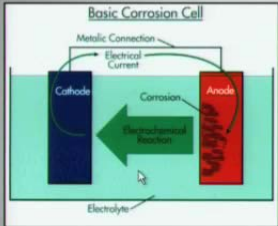
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Let us principally ask a question, what we understand by corrosion. Corrosion is nothing but deterioration of material by chemical interaction with their environment. Now here there are two keywords, which we must understand to realize what corrosion is. One is the environment; other is the chemical interaction with the material and the marine environment. The term also refers to degradation of plastics, concrete, wood, but generally corrosion is a term associated to metals. But, it is not only that metal corrode, any decay of plastics, wood and concrete deterioration is also termed as corrosion in the literature.

Corrosion process produces new and less desirable material. So, the difficulty is corrosion creates a new kind of material, which is produced as a byproduct of this process which is caused or which is produced from the original metal, it is less desirable incase of its use. This can result in the loss of function of the component or the entire system. The common product of corrosion is what we address as rust which is formed on the steel surface. It is a brown color product, which is resulting from the metal itself, which forms a powder form, which is coated on the surface of the material or metal, which we address as rust which is form on the steel surface.

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BASIC CORROSION CELL



- There will be a measurable DC voltage which can be read in the metallic path between the anode and the cathode
- When the two are electrically bonded, anode is positively charged and the cathode is negatively charged
- Conventional current flows from positive to negative and thus current discharges from the anode and is picked up at the cathode through the electrolyte
- Current returns from cathode to anode through electrical path
- This flow has a detrimental effect on the anode known as corrosion

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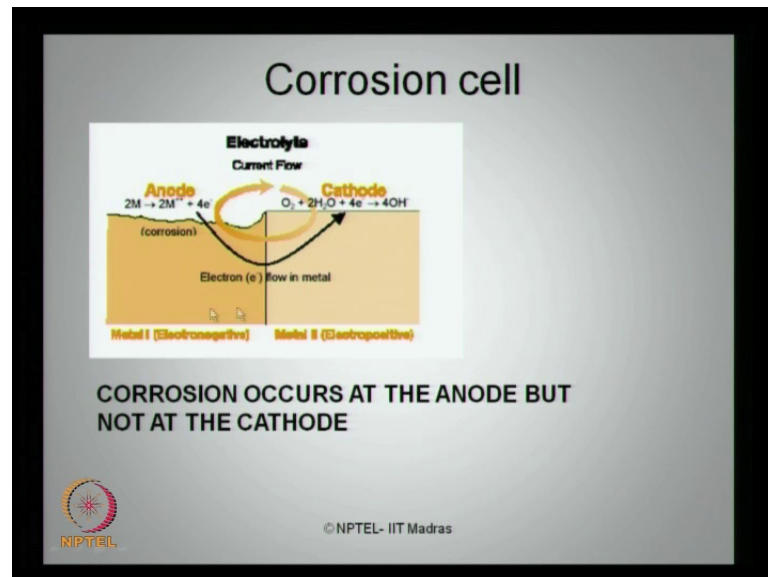
Let us have a look at the basic corrosion cell of what is shown here. The basic corrosion cell needs three components; one is I need to have a anode, I have a metallic component which is a cathode. So, there should be a strong metallic connection which exists between the anode and the cathode. And of course, I require a medium which we call as an electrolyte and all these three are eminently important to activate a basic process what we call corrosion. Therefore, the basic corrosion cell comprises of an anode and a cathode, which are metallically connected and of course, a medium which we call as electrolyte.

There will be a measurable DC voltage which can be read in the metallic path which is connecting anode and the cathode. When the two are electrically bonded, anode becomes positively charged and cathode is negatively charged. The conventional current flows from positive to negative and that is what I have shown here the arrow direction you see here is a flow of current, which flows from anode to cathode or from positive to negative. Therefore, the current discharges from the anode and gets picked up in the cathode through the medium, which we call as an electrolyte. Now this current returns from the cathode to the anode through an electrical path.

So, this flow of current from or pass of irons or electrons from anode to cathode causes serious deterioration or detrimental effect in the anode, therefore corrosion takes place in the anode. The process of deterioration of material or metal component in the anodic part

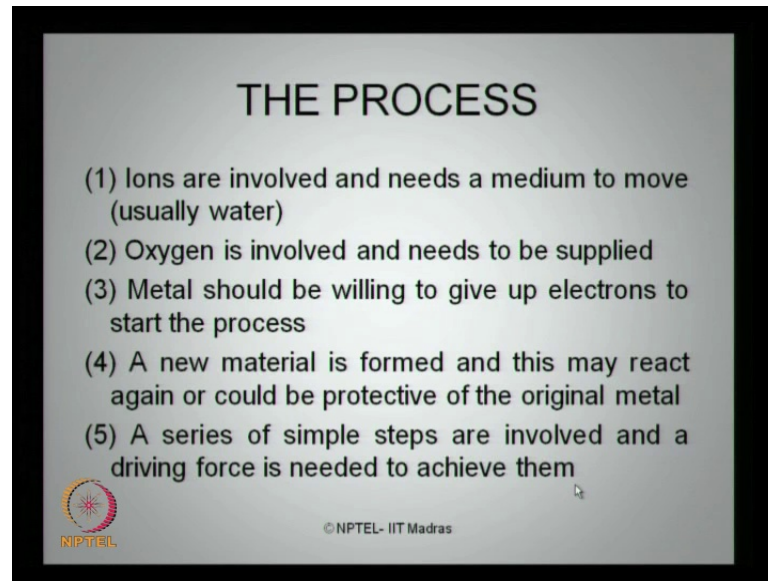
of this connection is what we call as corrosion. So, basic corrosion cell has three vital components - the cathodic part and the anodic part which are metally connected in a component, as well as the medium which can activate the process or the electro chemical reaction which we call as an electrolyte.

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It is very interesting for us to know that anode releases electron and cathode accumulates or gets charged of the electron, therefore they become positively charged and they become negatively charged. And there is a current flow which happens from the cathode to anode, whereas the electron flow occurs from anode to cathode. So, in the whole process, we understand that the corrosion which is nothing but deterioration of metal component occurs in the anode, because electron is being loss from here, but not at the cathode. So, anode gets corroded and not at the cathode.

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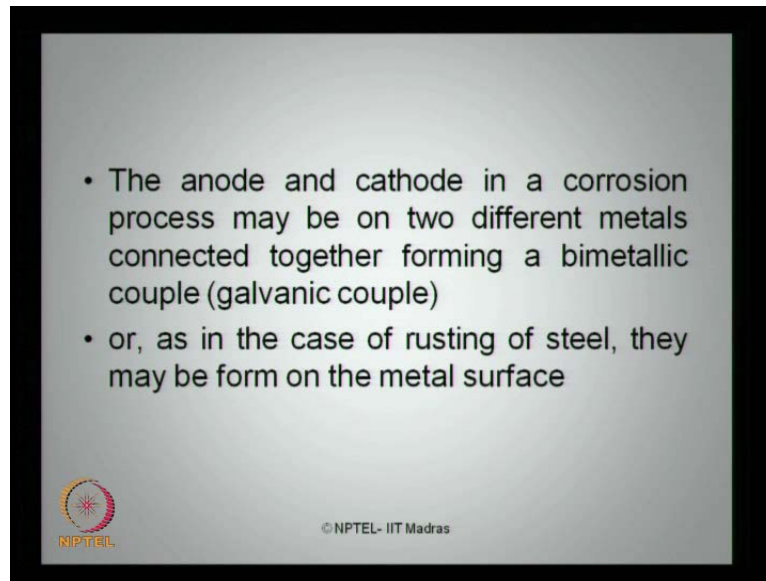
THE PROCESS

- (1) Ions are involved and needs a medium to move (usually water)
- (2) Oxygen is involved and needs to be supplied
- (3) Metal should be willing to give up electrons to start the process
- (4) A new material is formed and this may react again or could be protective of the original metal
- (5) A series of simple steps are involved and a driving force is needed to achieve them

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Let us quickly look at the process in detail. Ions are involved, and therefore it actually needs a medium to move. Usually in the marine environment, you have water as the medium, which enables the movement of ions from anode to cathode. Oxygen is involved, and this is plenty available in abundance in the ocean environment, and this needs to be continuously supply to activate a corrosion process. Of course, metal should be willing to give up electrons to start the process, so anode has to or should have a tendency of loosing electrons; therefore, the corrosion process can be activated. A new metal or material is formed and this may react again, which could be a protective to the original metal. So, the new material which is form as the byproduct of the whole process gets deposited on the material which can be also sometimes form as a protective barrier film on the original metal. The series of simple steps are involved and a driving force of course, is required to achieve them as a corrosion process.

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• The anode and cathode in a corrosion process may be on two different metals connected together forming a bimetallic couple (galvanic couple)

• or, as in the case of rusting of steel, they may be form on the metal surface

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The anode and the cathode in a corrosion process may be on two different metals, which are connected together which can form what we understand as a bimetallic couple, which is otherwise referred as galvanic couple in the literature. Or on the other hand, in the case of rusting of steel, they may be forming on a metal surface itself.

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CORROSION OF STEEL IN SEA WATER

• Steel is the basic material of construction in the offshore industry

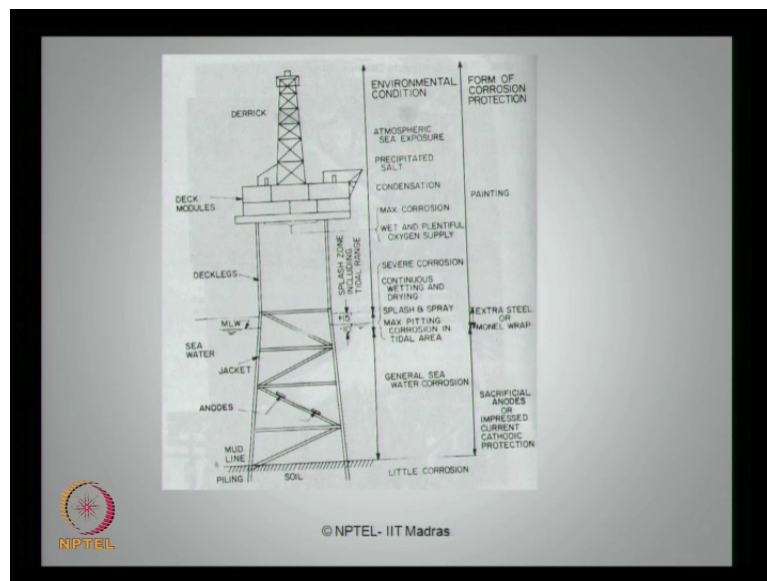
• Corrosion to a large extent governed by the oxygen content of the sea-water

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Corrosion of steel in sea water is a very important aspect to understand thoroughly. Steel is the basic material of construction, which is commonly recommended for offshore industry. We have already seen in module one various type of material which is

generally used and what are the kinds of offshore platforms which are generally constructed. We have already seen in module three different materials out of which steel is recommended as a strongest possible material favorable by many international codes to be used for construction in marine environment. So, steel is accepted as one of the basic material of construction in offshore industry. Corrosion by enlarged is governed by the oxygen content present in seawater.

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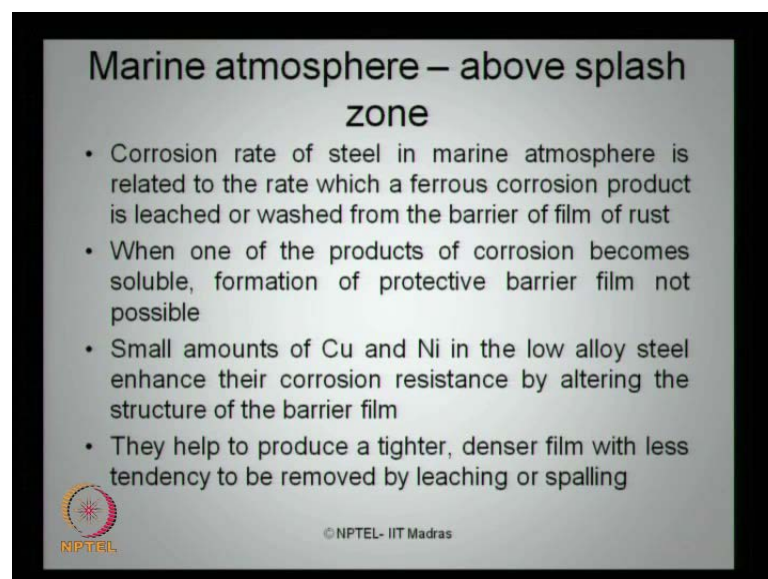
This figure shows you different regions at which the corrosion takes place in a given offshore platform. What are the different forms of corrosion, and what are the different forms of corrosion protection, which are generally advised by the researches and practicing engineers is listed in the same figure. The figure also shows on the left side, a typical scheme diagram of an offshore jacket structure, which is fixed to the seabed. So, you can see from the top the derrick, the deck modules, the deck legs, and then the jacket legs, and of course, the mud line and the piles which is embedded in soil.

If we look at the regions where the environmental conditions are proposed in the figure, the atmospheric sea exposure is always there on the top portion of the top side where we call derrick and deck modules are present. It contains generally precipitated salt and there is a condensation process takes place in this region. And of course, the maximum corrosion occurs at the bottom of the deck slab which you see here, because it is alternate subjected to wet and plentiful of oxygen supply is there in this region. When you move

to the splash zone or the tidal zone, it is a severe corrosion present it is due to the main reason that there is continuous wetting and drying in this area, because of tidal variations in the sea environment. And it is splashes and sprays therefore, it results in what we call maximum pitting corrosion in the tidal area. When you move further down in the deeper areas, where the jackets and the mud lines are present, generally the seawater has a corrosive medium, because of presence of salts and chemicals and that is also corrosion in this region.


If we look at the different forms of corrosion protection as suggested by the literature or by researchers and practicing engineers, you will see that majority of the segment of members, which are presented in atmospheric zone and near tidal zone can be protected by painting;. whereas, in case of splash zone, people generally use extra steel or monal rapping or sheathing to protect members in splash zones. And in immersed zones, people generally use sacrificial anode technique or impressed current cathodic protection methods to protect members from corrosion. Whereas, in the soil or the mud line below, there is a little amount of corrosion, therefore there are no requesting methods recommended by practicing engineers to prevent members from corrosion in these regions. So, ladies and gentlemen, this figure gives you a compressive look out of different segments of corrosion which is happening in various members in a offshore structural member like a typical jacket structure, and what are the recommended corrosion protection measures as a nut shell.

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Marine atmosphere – above splash zone

- Corrosion rate of steel in marine atmosphere is related to the rate which a ferrous corrosion product is leached or washed from the barrier of film of rust
- When one of the products of corrosion becomes soluble, formation of protective barrier film not possible
- Small amounts of Cu and Ni in the low alloy steel enhance their corrosion resistance by altering the structure of the barrier film
- They help to produce a tighter, denser film with less tendency to be removed by leaching or spalling

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If we look at different zones now in order, let us talk about marine atmosphere where we say above splash zone. The corrosion rate of steel in the marine atmosphere is related to the rate at which the ferrous corrosion product is leached off or washed off from the barrier of film or rust. We already said that whenever corrosion process is initiated, a barrier of protection film is being created on the top of the member. If there is a possibility that this barrier film can be leached off or washed off then the corrosion process can be activated. Whereas, in case of atmospheric zone, there is a least possibility that this film can be washed off. When one of the products of corrosion become soluble then the formation of protective barrier film will not become possible. So, in atmosphere zone, by luck this is not happening, therefore the corrosion rate is lowest in the atmospheric zone. Small amounts of copper and nickel in the low alloy steel enhance their corrosion resistance by altering the structure of the barrier film. Therefore, they have been recommended to be used near the splash zone or above splash zone sector in the atmospheric zone. They help to produce a tighter and denser film, which forms a protective barrier on the members with fewer tendencies to be removed by leaching or by spalling.

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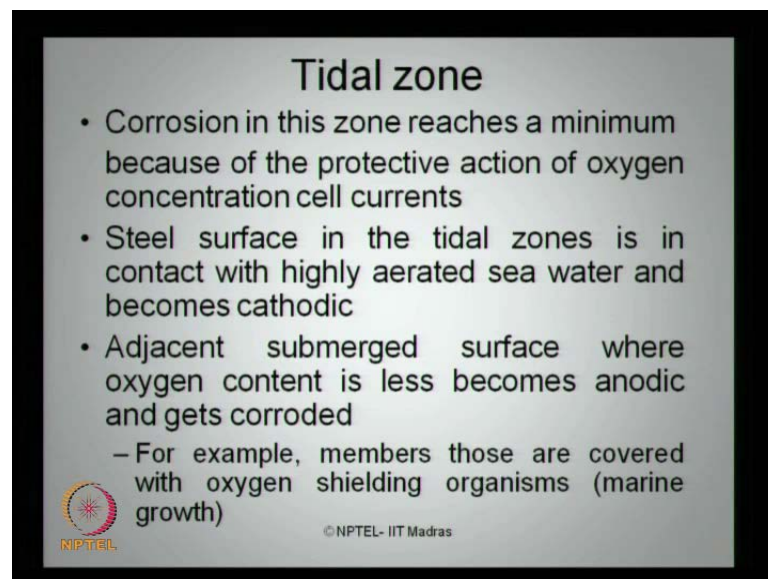


If we look at the splash zone in closer look, the rust films in this zone have a little opportunity to become dry, because this zone is subjected to alternate wetting and drying continuously. Therefore, members in the zone have a very little possibility that they may become dry. So, they are constantly wet, therefore, they do not develop any protective

properties even though the rust films may be formed, because once they are formed, they will be leached off automatically. This is aggravated, because of the presence of abundant oxygen content in this region, that is one of the main culprits why the corrosion takes place in this splash zone to be the maximum.


The rate of corrosion in this splash zone is several times greater than that of the continuous immersion part of the member. Unfortunately, ladies and gentlemen, the same member passes through different regions of corrosion, therefore the same member develops a bimetallic couple, whereas one part of the member becomes anodic and other part of the member become cathodic, and therefore the presence of electro light enables the corrosion process very fast. Therefore, the rate of corrosion in this region is seen as several times higher than that of the other regions, which is continuously immersed in seawater.

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Tidal zone

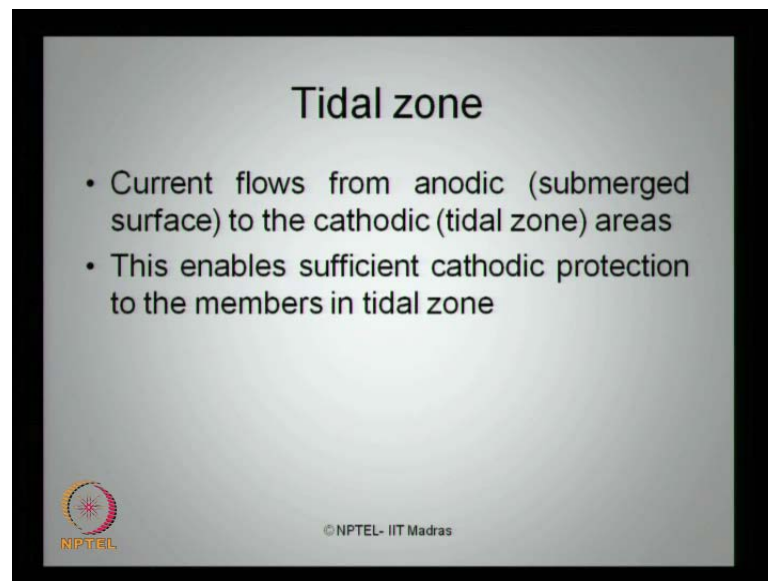
- Corrosion in this zone reaches a minimum because of the protective action of oxygen concentration cell currents
- Steel surface in the tidal zones is in contact with highly aerated sea water and becomes cathodic
- Adjacent submerged surface where oxygen content is less becomes anodic and gets corroded
 - For example, members those are covered with oxygen shielding organisms (marine growth)

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If we look at the tidal zone, corrosion in this zone reaches a minimum, because of the protective action of oxygen concentration cell currents present in this region. The steel surface in a tidal zone is in contact with highly aerated seawater, and therefore, they become cathodic. Ladies and gentlemen, you can now realize that cathodic part of the member does not corrode; only the anodic part of the member which loses electrons or removal of ions gets corroded. The member in this tidal zone becomes cathodic, because the steel surface in this zone has contact with highly aerated seawater, therefore, they do

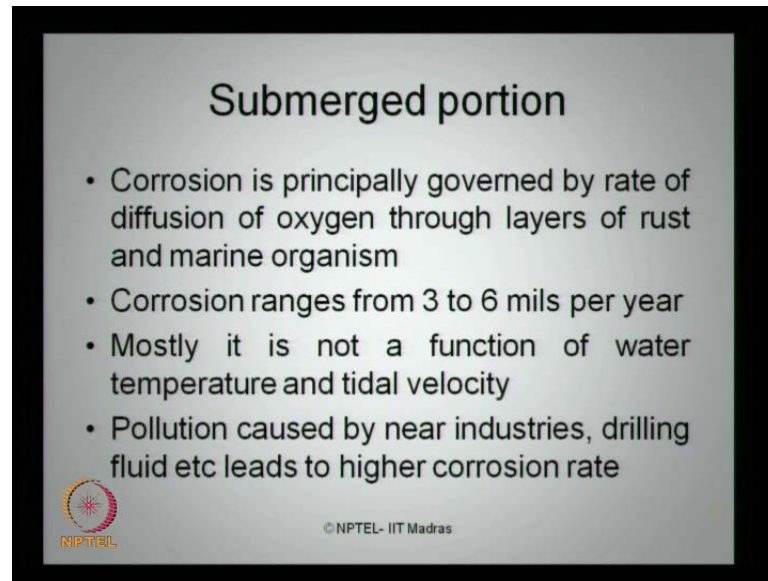
not get corroded it pass on this problem to the adjacent areas. Therefore, the adjacent submerged surface where the oxygen content is less becomes anodic, and therefore, they gets corroded severely. For example, members those are covered with oxygen shielding organisms like marine growth may get or may received lesser oxygen content on the surface and they become anodic, and because of this reason they get corroded faster than the members present in the tidal zone.

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Current flows from anodic, which is submerged surface to the cathodic which is tidal zone in this areas in sea environment. This enables sufficient cathodic protection to the members in tidal zone automatically. This is caused, ladies and gentlemen, because the differential aeration present or because of formation of marine growth in the regions which are immersed below and not in the regions where as a tidal zone.

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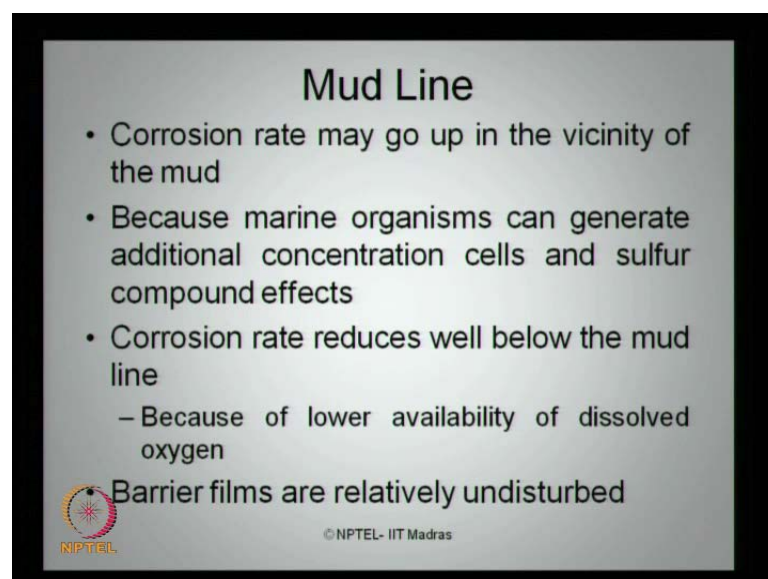
Submerged portion

- Corrosion is principally governed by rate of diffusion of oxygen through layers of rust and marine organism
- Corrosion ranges from 3 to 6 mils per year
- Mostly it is not a function of water temperature and tidal velocity
- Pollution caused by near industries, drilling fluid etc leads to higher corrosion rate

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If we look at the submerged portion of the offshore member in the seawater, corrosion is principally governed in this region by the rate of diffusion of oxygen through layers of rust and marine organisms. Corrosion ranges from 3 to 6 mils per year, I would request you to understand the units of corrosion which has been explained in the previous slides on the previous modules of lectures. Mostly corrosion rate is not a function of water temperature and tidal velocity; we must remember this point very carefully. Pollution caused by near industries, drilling fluids etcetera also contaminate the seawater, which are responsible for higher rate of corrosion in the marine environment.

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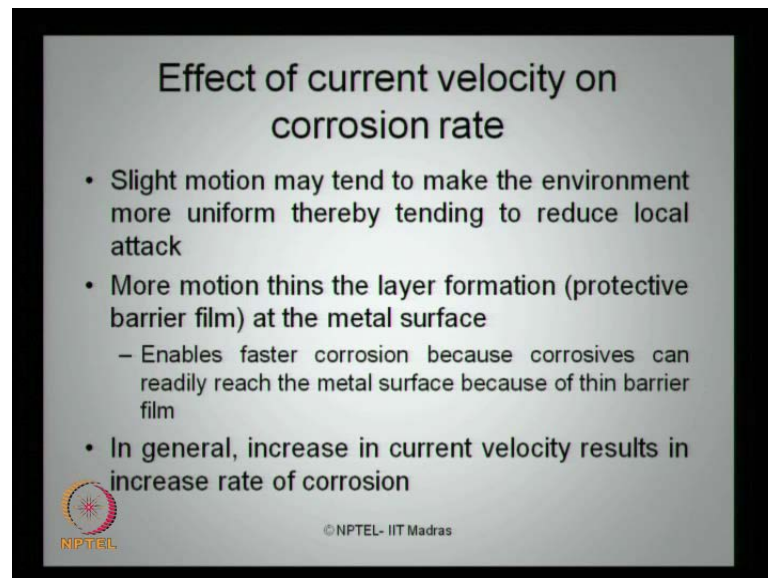
Mud Line

- Corrosion rate may go up in the vicinity of the mud
- Because marine organisms can generate additional concentration cells and sulfur compound effects
- Corrosion rate reduces well below the mud line
 - Because of lower availability of dissolved oxygen
- Barrier films are relatively undisturbed

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If you look at the mud line, where the piles have been installed or driven into sea which is forming support to bottom founded offshore structures, the corrosion rate may go up in the vicinity of the mud line, but further down they are very less. Because a marine organisms, which can generate additional concentration cells and sulfur compound effects in the vicinity of the mud line, there is a possibility that the corrosion rate may become high, because they become anodic compared to the remaining part. The corrosion rate reduces well below the mud line because of lower availability of what we called dissolved oxygen content. The barrier films, once they are formed in this region are relatively undisturbed, therefore they form a protective coating automatically and that protects the members in this region.

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Effect of current velocity on corrosion rate

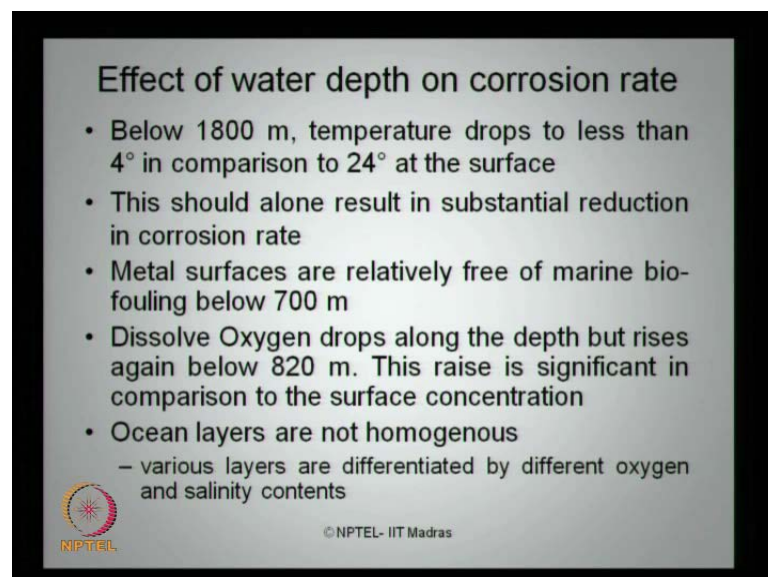
- Slight motion may tend to make the environment more uniform thereby tending to reduce local attack
- More motion thins the layer formation (protective barrier film) at the metal surface
 - Enables faster corrosion because corrosives can readily reach the metal surface because of thin barrier film
- In general, increase in current velocity results in increase rate of corrosion

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Now, let us look at various factors that are influencing corrosion members of offshore structures, which are driven or present in the sea environment. First let us look at the effect of current velocity on corrosion rate. Ladies and gentlemen, we understand that any slight motion may tend to make the environment more uniform, and thereby it has a tendency to reduce the local attack on the barrier film, which is formed on the member which protects the member. So, any gentle motion will not affect or disturb the formation of this protective barrier members, which is formed on the members or on the structural members, therefore, they offer protection against corrosion.


When this motion is increased the layer formation, becomes thinner that results in very thin formation of the layer of the protective barrier film, therefore, it enables faster corrosion, because corrosives can readily reach the metal surface because of thin barrier film being formed on the surface of the members. Therefore, current velocity plays a very important role in accelerating the corrosion rate. If the current velocity is high then the thin protective barrier films are formed, which enables the corrosives to reach the metal component. If the velocity is low, this so called film formed on the metal surface is remaining unaffected, therefore the corrosion rate depletes in this region. In general, increase in current velocity results in increase in rate of corrosion.

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Effect of water depth on corrosion rate

- Below 1800 m, temperature drops to less than 4° in comparison to 24° at the surface
- This should alone result in substantial reduction in corrosion rate
- Metal surfaces are relatively free of marine bio-fouling below 700 m
- Dissolve Oxygen drops along the depth but rises again below 820 m. This raise is significant in comparison to the surface concentration
- Ocean layers are not homogenous
 - various layers are differentiated by different oxygen and salinity contents

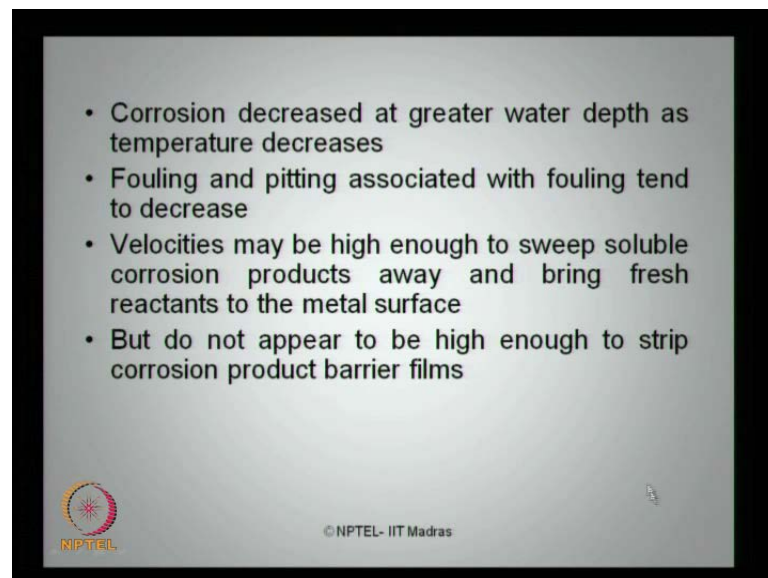
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The next factor, which affects the rate of corrosion is the water depth. Let us see, what the effect of water depth on corrosion rate is. As we all understand presence of dissolved oxygen content is very important for accelerating a corrosion mechanism. So, let us try to understand what is the oxygen level concentration at deep of waters. Below 1800 meter approximately, the temperature drops to a number is about 4 degree centigrade in comparison to about 24 degrees at the surface. So, there is a tremendous temperature gradient which happens on the same member because of the increase in water depth. This should alone result in substantial reduction in corrosion rate. Ladies and gentlemen, this decrease in temperature results in reduction in corrosion rate in the members. Metal surfaces are relatively free of marine bio-fouling, practically below 700 meters; it has been statically seen in many research papers that the bio fouling effect

caused by the marine organisms are relatively not affecting the metal surface when the depth is larger than about 700 meters.

So, dissolved oxygen content drops along the depth, but it rises below 820 meters approximately. So, the dissolved oxygen content drops down up to depth of over 750 to 800 meters then further it gets increased. So, this raises a significant in comparison to the surface concentration. Therefore, the ocean layers, ladies and gentlemen are not homogeneous; various layers are differentiated by different oxygen and salinity contents as seen in different bullet points in this slide. And these are the reasons, why the effect of water depth plays a very important role in accelerating or decelerating the corrosion rate on members in deep water structures located in sea environment.

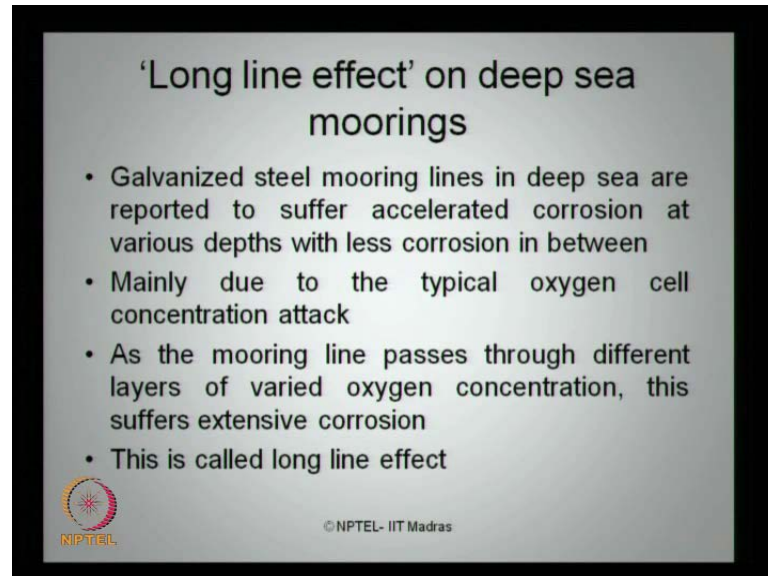
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Corrosion decreased at greater water depths as a temperature decreases that is one of the main reason. Fouling and pitting associated with fouling tend to decrease or higher water depths. Velocities may be high enough to sweep the soluble corrosion products away; therefore they bring fresh reactants to the metal surface, which increases the corrosion rate. Therefore, the velocity of current, the water depth and the presence of dissolve oxygen content are all responsible factors for either accelerating or decelerating the corrosion rate at different regions of the same member present in ocean environment. But they do not appear to be high enough to strip corrosion product of barrier films, because


a velocity may not be sufficient enough at deeper water depths, which can disturb the so called barrier films which are once formed on the metal surface.

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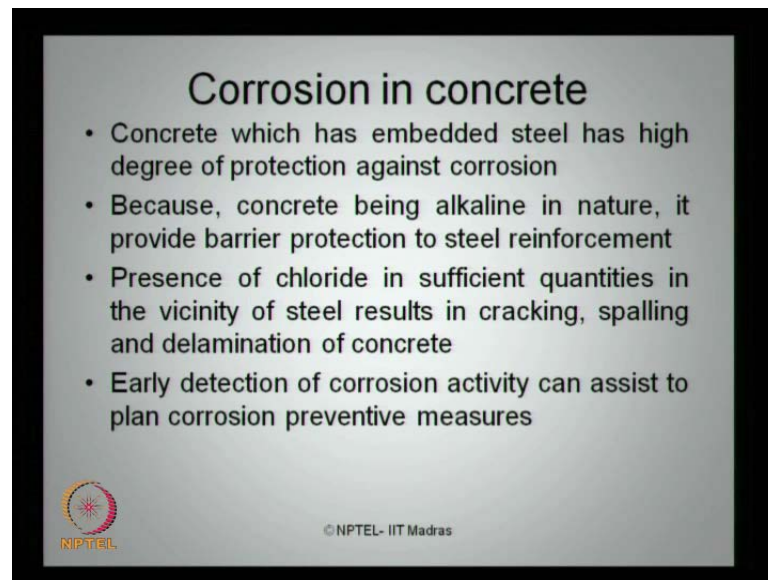
'Long line effect' on deep sea moorings

- Galvanized steel mooring lines in deep sea are reported to suffer accelerated corrosion at various depths with less corrosion in between
- Mainly due to the typical oxygen cell concentration attack
- As the mooring line passes through different layers of varied oxygen concentration, this suffers extensive corrosion
- This is called long line effect

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Ladies and gentlemen, very importantly on deep-sea moorings, there is an effect called long line effect present on moorings. Let us see what you understand by a long line effect on deep-sea moorings. The galvanized steel mooring lines which are present in deep-sea are reported to suffer accelerated corrosion at various depths with less corrosion in between. It is very important for us to understand the same mooring line, which has got differential aeration levels because of water depth increase in different segments is subjected to different levels of corrosion, so that is what we call as a long line effect. Mainly due to the typical oxygen cell concentration attack, the long length of these mooring lines are subjected to different layers of varied oxygen concentration that alters the rate of corrosion in different segments along the length of the mooring line, and this effect is referred as long line effect in the mooring line system.

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Corrosion in concrete

- Concrete which has embedded steel has high degree of protection against corrosion
- Because, concrete being alkaline in nature, it provide barrier protection to steel reinforcement
- Presence of chloride in sufficient quantities in the vicinity of steel results in cracking, spalling and delamination of concrete
- Early detection of corrosion activity can assist to plan corrosion preventive measures

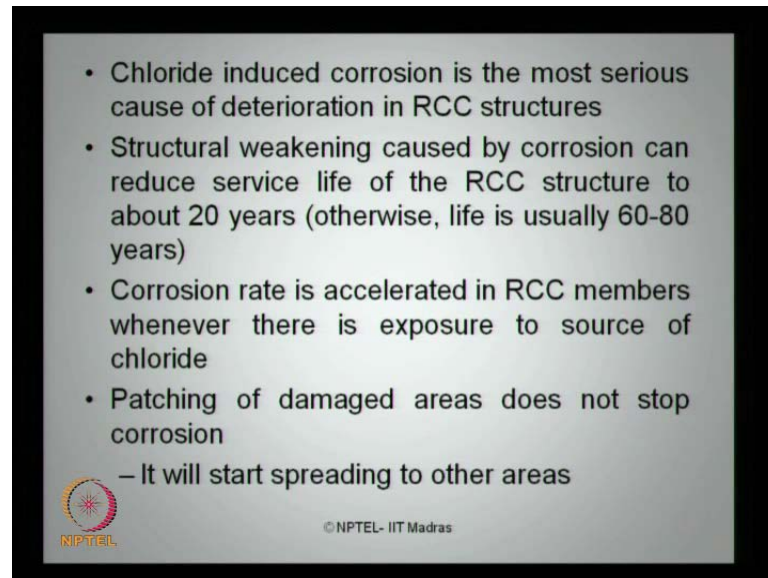
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Let us look at the corrosion in concrete, because concrete is also equally important material for construction in offshore structures in deep-sea environment. In that case, let us study what are the effects of corrosion in the reinforcing bar present in concrete. Ladies and gentlemen, as we all understand concrete cannot take tensile forces and to make it adaptable to take tension, we have got a reinforced concrete with steel reinforcement. Now the embedded steel is actually the component, which is corroded. Concrete which has got embedded steel has high degree of protection against corrosion. Generally, the protection is there, because a cover offers very good protective layer for the steel which is embedded inside concrete. Because concrete being alkaline in nature, it provides barrier protection to steel reinforcement, there is absolutely no doubt in this philosophy that concrete is being strongly recommended for marine environment.

Now the problems are very simple. The presence of chlorides in sufficient quantities in seawater, which is available near the vicinity of steel results in cracking of this cover layer of concrete, it results also in what we call spalling of cover layer which delaminates concrete from the reinforcement. Once the delamination or spalling occurs, the cover is completely released from the concrete, which exposes the reinforced steel to a severe environment. So, chloride attack or the chlorides present in the sea salt or sea water are essentially responsible for this kind of attack which is happening on concrete. I results in spalling, cracking and ultimately delamination of cover from the steel reinforcement. Ladies and gentlemen, early detection of corrosion activity can assist to plan corrosion

preventive measures very easily. We will discuss the methods of various corrosion protection techniques as advanced repair and rehabilitation techniques in the fourth module.

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• Chloride induced corrosion is the most serious cause of deterioration in RCC structures

• Structural weakening caused by corrosion can reduce service life of the RCC structure to about 20 years (otherwise, life is usually 60-80 years)

• Corrosion rate is accelerated in RCC members whenever there is exposure to source of chloride

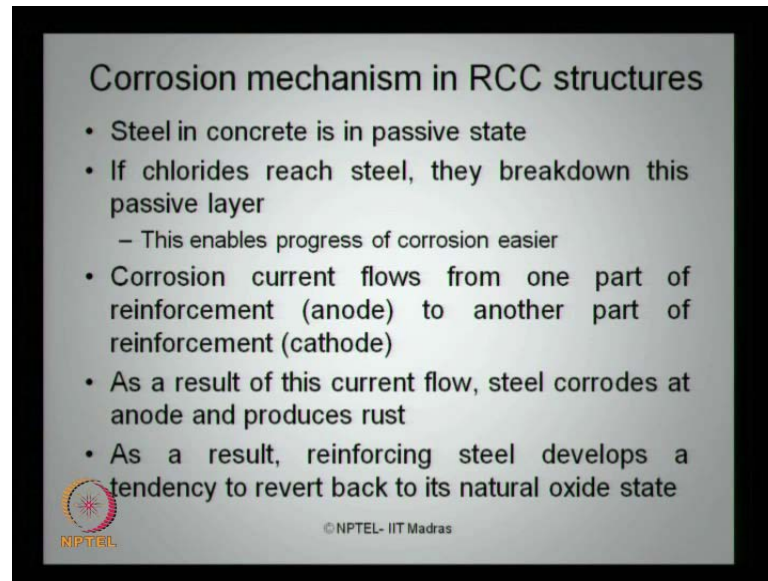
• Patching of damaged areas does not stop corrosion

– It will start spreading to other areas

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Chloride induced corrosion is considered as one of the most serious cause of deterioration of RCC structures in marine environment. Structural weakening caused by corrosion can reduce its service life to about 20 years; otherwise, they have a service life usually varied from 60 to 80 years. Corrosion rate is accelerated in RCC members whenever they are exposed to source of chloride. It is very important that the chlorides which are available the near vicinity of sea reinforcement results in delamination of cover from concrete, and that exposes steel to a larger extend which results in corrosion of steel in RCC. The patching of damaged areas which generally attempted by research engineers or by practicing engineers is not helpful, because the patched area is stopped, but the remaining areas will be affected by corrosion.

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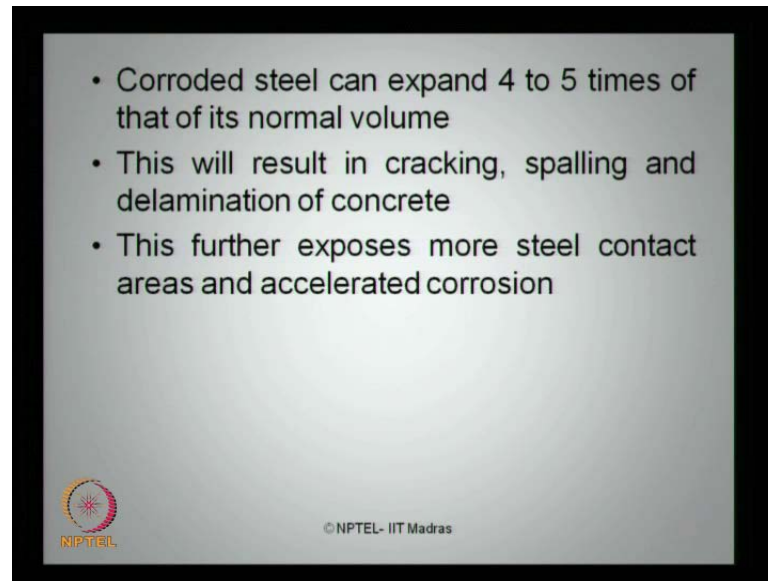
Corrosion mechanism in RCC structures

- Steel in concrete is in passive state
- If chlorides reach steel, they breakdown this passive layer
 - This enables progress of corrosion easier
- Corrosion current flows from one part of reinforcement (anode) to another part of reinforcement (cathode)
- As a result of this current flow, steel corrodes at anode and produces rust
- As a result, reinforcing steel develops a tendency to revert back to its natural oxide state

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Now let us look at the corrosion mechanism in RCC structures more in detail. Steel in concrete remains what we call as a passive state. If chlorides reach steel, they breakdown this passive layer; this enables progress of corrosion much faster, because the passive layer is broke down by presence of chloride. The corrosion current flows from one part of the reinforcement, which becomes anode to another part of the reinforcement which becomes cathode. Ladies and gentlemen, there is a bimetallic coupling happening within the reinforcement itself. One segment or one length of reinforcement, which becomes a differential part, gets anodic or becomes anodic and their get starts getting corroded compared to the other part of the same reinforcement, which becomes cathodic. As a result of which this current flow, steel corrodes at a faster rate in anode and start producing a component which we call as a powder or brown rust. As a result, reinforcing steel develops a tendency to revert back to its natural oxide state which is ferric oxide.


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• Corroded steel can expand 4 to 5 times of that of its normal volume

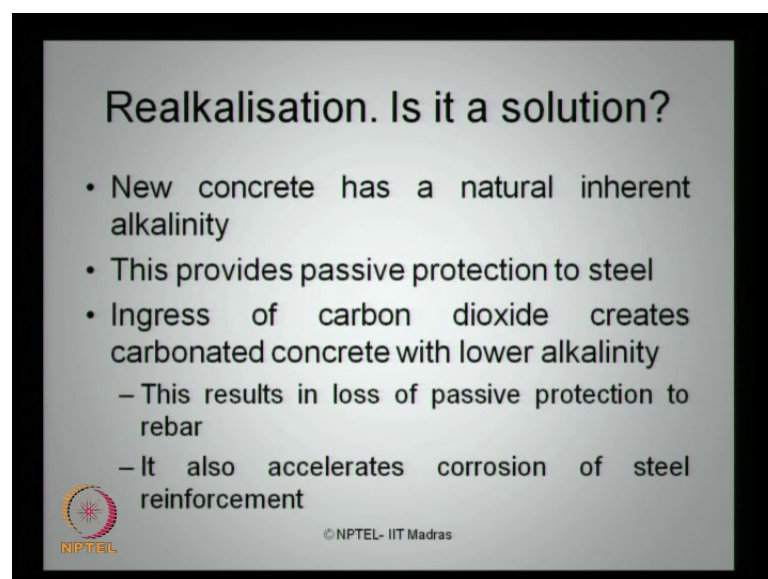
• This will result in cracking, spalling and delamination of concrete

• This further exposes more steel contact areas and accelerated corrosion

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Corroded steel has a specific problem; it can expand to about 4 to 5 times of its normal volume - that is one of the disasters which happens to reinforce concrete structures in marine environment. Once steel is getting corroded, can expand to a very large volume, this will result in cracking, spalling and delamination of concrete. Once the concrete get delaminated and the cover is removed off, steel will get more and more exposed to sea environment and the corrosion will get accelerated. So, therefore, this further exposes more steel in contact to the sea environment, and therefore the accelerated corrosion takes place.

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Realkalisation. Is it a solution?

• New concrete has a natural inherent alkalinity

• This provides passive protection to steel

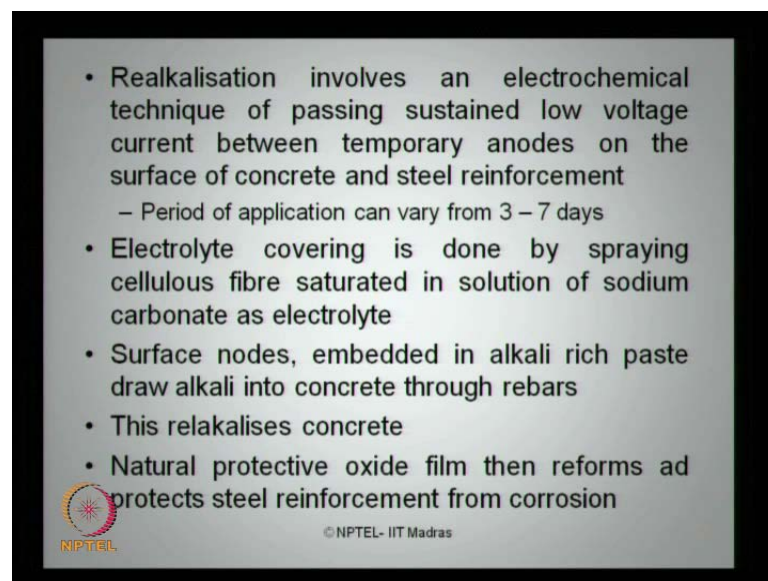
• Ingress of carbon dioxide creates carbonated concrete with lower alkalinity

- This results in loss of passive protection to rebar
- It also accelerates corrosion of steel reinforcement

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There is another interesting solution to protect steel from corrosion which is embedded what we call realkalisation. Is realkalisation really a solution, which can protect members from corrosion? The new concrete has a natural inherent alkalinity, which is present. This provides a passive protection to steel. The ingress of carbon dioxide creates carbonated concrete which tips down the alkalinity, which is already existing in concrete. Therefore, the presence of ingressed carbon dioxide results in loss of passive protection to rebar which is a reinforced bar present in reinforced concrete structures in marine environment. It also accelerates corrosion of steel reinforcement in much faster rate.

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Therefore, realkalisation involves an electrochemical technique of passing sustained low voltage current between the temporary anodes on the surface of concrete and the steel reinforcement. Ladies and gentleman, it is a nothing but an artificial technique by which you pass a low voltage current, you create a temporary anode on the surface of concrete and then also on the steel reinforcement. Usually this is applied for the period varied from 3 to 7 days of duration. The electrolyte covering is done by spraying cellulosic fiber which is nothing but a saturated solution of sodium carbonate which is considered as an electrolyte in this whole process.

The surface nodes, which are now embedded in alkali rich paste draw alkali into concrete through rebars, because you have created a difference on the surface one becomes an anode other becomes a cathode. The surface of concrete now which is embedded in the

rich alkali paste draws alkali into concrete make it alkaline more, therefore the acidic environment which is responsible for corrosion is now being deactivated because of the improve alkalinity in the concrete, this what we call as realkalisation of concrete. This can be an easy process by which you pass a low voltage current on the temporary anodes and the surface of concrete in reinforcement for a period of 3 to 7 days, which can prevent or which can at least retard the acceleration of corrosion on the rebars. So, therefore, this whole process realkalises concrete and that is how the rebar can be protected from corrosion and this we call as realkalisation of concrete.

So, ladies and gentlemen, in this lecture, we discussed very briefly as the first part how to protect metal and concrete from corrosion as a process or as a problem. What is a corrosion process, how does it affects metal or metal surfaces in sea environment, what are the different factors which are responsible for accelerating corrosion rate in sea environment. If concrete or steel is preferred as an advantageous material in marine environment, how they can be protected, what are the various regions at which the corrosion rate varies in the same member in a sea environment? How they are generally protected and what is the realkalisation which is a very important technique which can also protect concrete or the reinforcement embedded in concrete to your great extend. So, natural protective oxide films then reforms and protect steel reinforcement from corrosion what we call as a realkalisation process. In the next lecture, we will talk about more and the corrosion process and corrosion protection measures on concrete.

Thank you.