**Ocean Structures and Materials**

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**Module - 3**
**Lecture - 8**
**Material Sin Repair and Rehabilitation**

. In the first module and the second module we have seen different types of ocean structural systems off shore structures, their applications and different kinds of dredging equipments, which have been used and deployed commonly for coastal protection systems and maintenance. In the third module we have been looking at different kinds of materials, which can be used for construction of ocean structural systems.

In this lecture we will closely see some of the repair methodologies which can be used, which is commonly employed for maintaining and repairing ocean structures. So, we look for materials especially for repair and rehabilitation of ocean structures.

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The moment we talk about material for repair and rehabilitation. Ladies and gentlemen, please underline that there are no standard procedures in international codes, which will suggest and recommend certain classification of material which can be used for repair and rehabilitation.

There are various reasons for this, the foremost reason is that this material can be applied for repair only as case specific, because choice of material to be used for repair and rehabilitation depends on the decision taken by the construction managers and engineer in maintenance in charge of these kind of structural systems. Therefore, in this lecture we will see some of the important techniques, which are generally used for repair and rehabilitation. And of course recent advancements of different material, which are suggested and been commonly used for repair and rehabilitation will also be discussed in detail in the next module.

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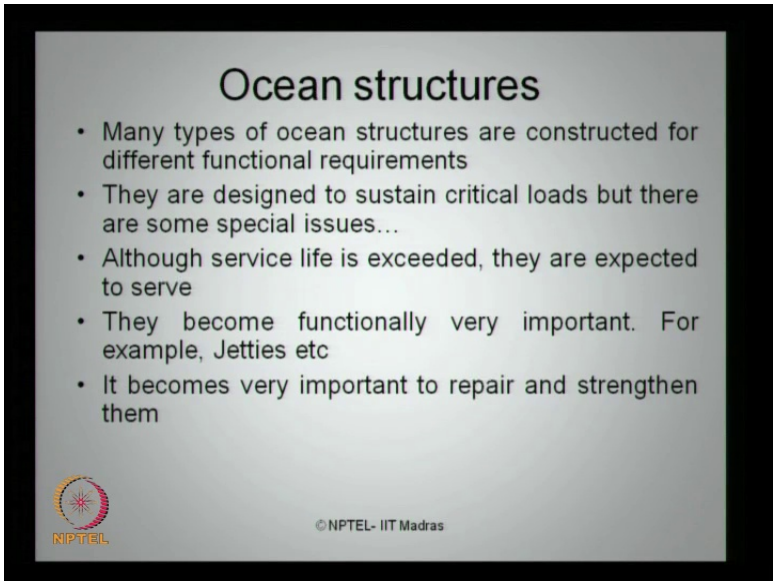


If you look at ocean structures, many types of ocean structural system are generally constructed for various functional requirements, we have seen them in detail. In the previous modules they are generally designed to sustain critical loads, but there are some special issues related to their existence of survivability of service life of this kind of structures. Although, the service life is exceeded, they are expected to serve, which is very critical issue as far as these structural systems are concerned. They become functionally very important and therefore, they cannot be dismantled or reconstructing them.

Once again causes a lot of shut down time, which is not acceptable by the service sector. So, very importantly, ladies and gentlemen, even though ocean structural systems have exceeded the design service life, they are still put to constant use on different functional requirements is very important. I can quote a very simple example, for example offshore jetties are functionally important. Therefore, shut down time for the new construction of the jetty is very difficult and therefore, existing jetties are generally put to use after suitable repair and rehabilitation.

So,herefore ladies and gentlemen, it becomes very important to understand the repair methodologies and techniques to strengthen them. While they are in service, probably ocean structural systems who are one amongst the structural systems, which are generally put to repair and rehabilitation. When they are also in service, interestingly no standard coral regulations specify or recommend any specific type of special repairs applicable to ocean systems.

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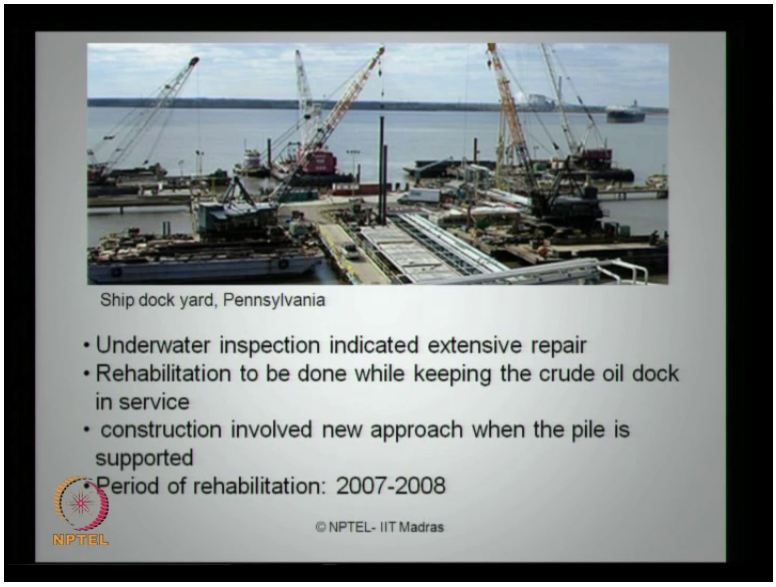


The photograph what you see here is actually a ship dock yard in Pennsylvania. The underwater inspection conducted on this dock yard indicated extensive repair rehabilitation has got to be done while keeping the crude oil dock in service, which is a very important criteria imposed on the maintenance engineer at this juncture. The construction involved actually a new approach when the pile is supported, while the loading is taking place the rehabilitation was done for this job during 2007-2008.

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The other example what you see here, is up gradation of the Cap may in New Jersey to enhance the ferry capacity. New construction with board walks is proposed by the designer, pre stress concrete is used as a new material for enhancing the ferry capacity of this jetty. Bulk heads have state of art composite fender systems, which have been installed all along the surface special feature is a monopole supported fender clusters it, which acting as an energy absorbing piers and dolphins.

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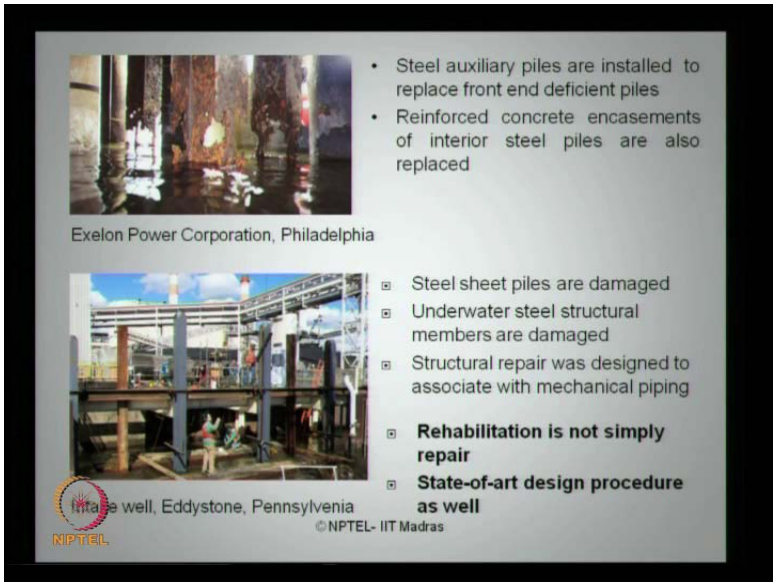


The photograph what you see here is an Exelon power corporation, Philadelphia at the bottom what you see here is an intake system at Eddy stone, Pennsylvania. In case of Exelon power corporation steel

auxiliary piles are installed to replace the front and efficient piles as you see in this photograph here. They reinforce concrete encasements of interior steel pipes are also done. They have been replaced whereas, in Eddy stone Pennsylvania intake well.

The steel sheet piles, which have been used are extensively damaged the underwater steel structural members are also found to be extensively damaged. Structural repair was designed to associate with the mechanical piping system, which in an integral part of the intake well. Therefore, ladies and gentlemen rehabilitation is not simply a repair system it is actually a state of art design procedure as well.

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Another classical example is a bulk material export jetty located in South Iran. The photograph what you see here, is the photograph of the jetty. The berthing structure has jetty to import alumina, a dolphin jetty is also parallelly constructed to export LPG. They are access from the land through breakwaters and bridges as you see in this photograph. Design is special because it has to avoid the impact of two jetties due to lateral loads; the expansion joint is designed in such a manner so that this moment is allowed under the service loads also. Under strong lateral loads, impact energy is dissipated by cylindrical fenders, which have been provided as one of the repair methodology for this kind of jetty at South Iran.

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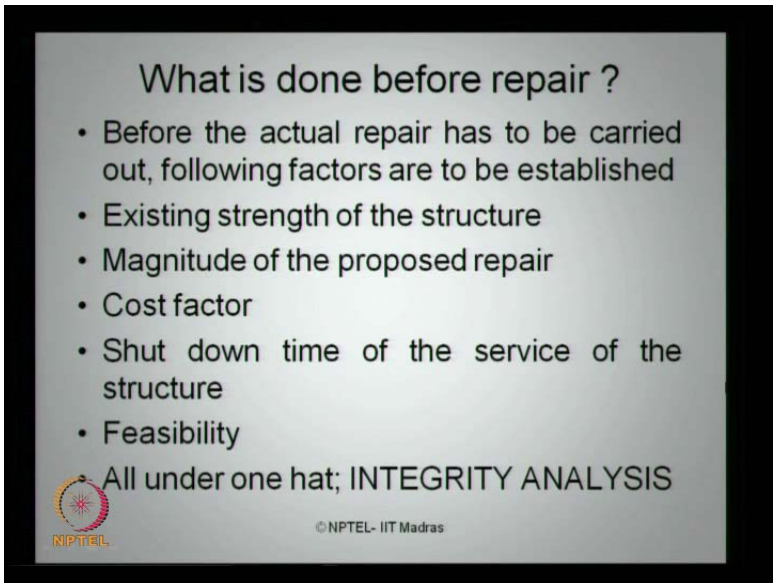


Now, the fundamental question which is being asked in such kind of repair mechanisms is that, what is done before the start of the repair? Before the actual repair has to be carried out, following factors are necessarily to be established; one what is the existing strength of the structure, two what is the magnitude of the proposed repair? In terms of the volume of work the matrix of work to be carried out and of course, the cost involvement and the shutdown time of the proposed structural system.

What could be the important cost factor associated with the repair work and what will be the shutdown time of the service of the structure, which are most important to be considered much before attempting a repair to kind of ocean structural system? Above all interestingly one also looks at what is the feasibility to undergo this kind of repair. And ladies and gentlemen all of them together all under one hat or a single process system this, what we call as integrity analysis of ocean system.

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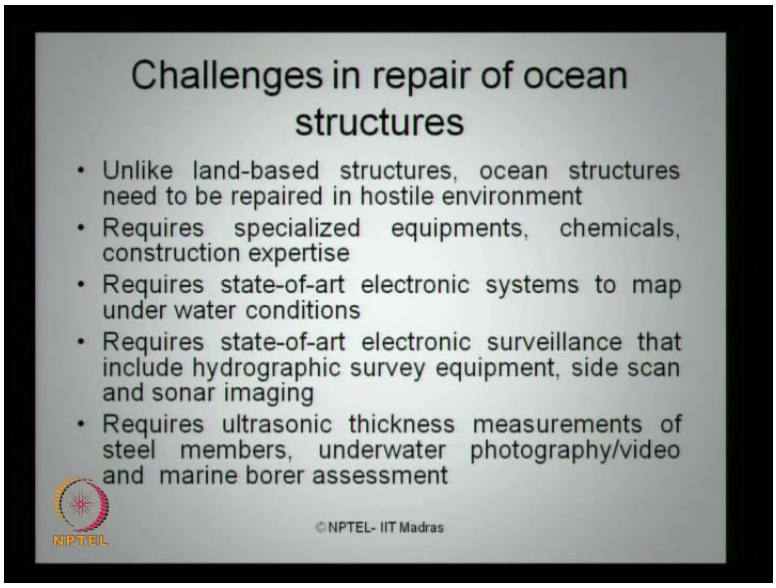


What are the challenges which are generally posted, while you attempt a repair on ocean structure? Unlike land based structures, ocean structures need to be repaired in coastal environment because these kinds of structures mostly have less or remote access to land. It also requires specialized equipments, chemicals and construction expertise to carry out repair with these kinds of structural systems.

It also requires state of art electronic systems to map under water conditions of the existing system because the existing system should be thoroughly examined. And the states of art electronic system should be deployed to understand the asis varies basis of the system. If you really want to propose the appropriate repair methodology for underwater structural members, it also requires state of art electronic surveillance that includes hydrographic survey equipment side scan and sonar imaging while the repair is also in process.

It also requires ultrasonic thickness measurements of steel members because it is very important to assess, the actual thickness of existing members if you want to propose an appropriate repair methodology for these members. Therefore, underwater videography, photography and marine borer assessment technologies are very commonly deployed, when you want really think about repair of ocean structural system. Therefore, ladies and gentlemen, even to attempt the repair in ocean structures is a complex task. It is not an as easy and an as simple as we do for land based structural systems.

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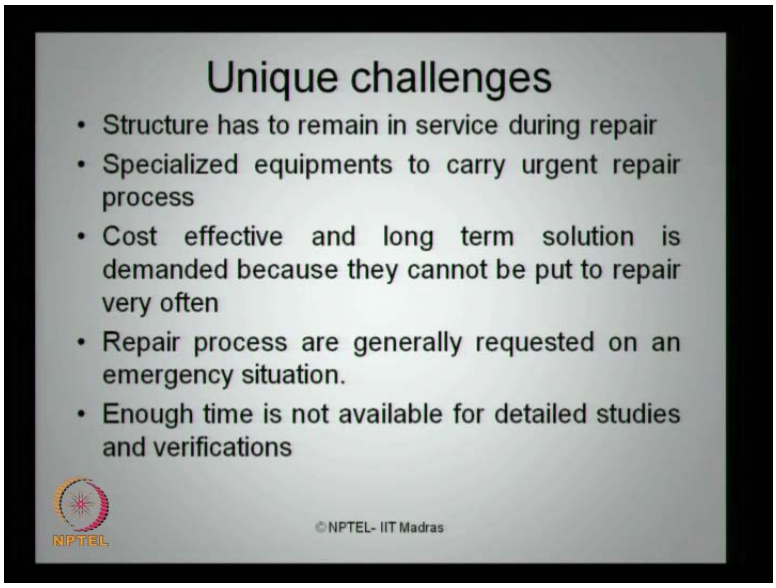


What are the unique challenges, which can be posted on when you attempt to do a repair of ocean structural system? Structure has to remain in service while you are carrying out the repair it is a very interesting task, which is assigned to maintenance or a construction or a rehabilitation engineer who attempts to do a repair on existing structural system. The structure should remain in service when the repair is being carried out. Therefore, the load carrying capacity should not be challenged when you are attempting a repair. Hence, specialized equipments are generally used because of two reasons; one you cannot damage the existing structural system to a greater extent, which affects the load carrying capacity, two the shutdown time to which you are going to carry out the repair is always available to you in a limited point of time.

Therefore, specialized equipments are to be used to carry out urgent repair process and of course, the repair process suggested by you should be cost effective. It should remain as a long term solution because these are two important factors, which are generally demanded by the client, so that they need not have to put the repair very often. Therefore, the shutdown time during the repair of a foreseen system is also limited. Hence, the client is always interested to limit the long term solution of this problem attempted as well as the solution suggested by the consultant or the designer should also be cost effective.

The repair processes as I said are not generally available in the standard literature and are not generally recommended by international codal provisions because the chemical admixtures, which are generally

used for repairs are case specific. Therefore, on any emergency situation one should be aware of understanding the repair methodology, which is generally recommended for this kind of repair.

Hence, one should have a standard of understanding of various repair methodologies and chemicals available to do repair on emergency situation. Enough time is generally not available for the maintenance engineer to carry out repair. Therefore, detailed studies and verifications cannot be carried out at longer time duration because generally repairs are attempted, when there is an emergency call.

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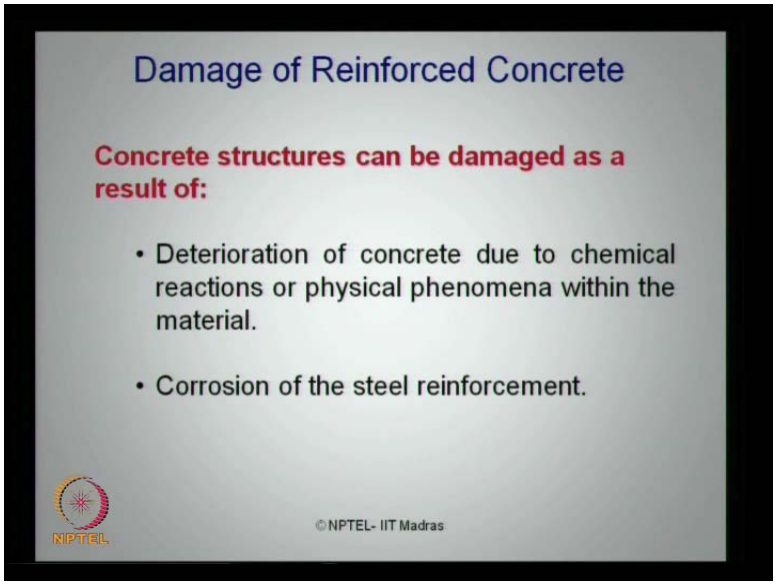


When you talk about damage of reinforced concrete ocean structural systems, there are very interesting points to be understood as far as concrete as a construction material is concerned. Concrete structures can be damaged as a result of either deterioration of concrete due to chemical reactions or physical phenomenon within the material. The second major issue is that the reinforcement, which is embedded in concrete, also receives a corrosive attack, because of the marine environment.

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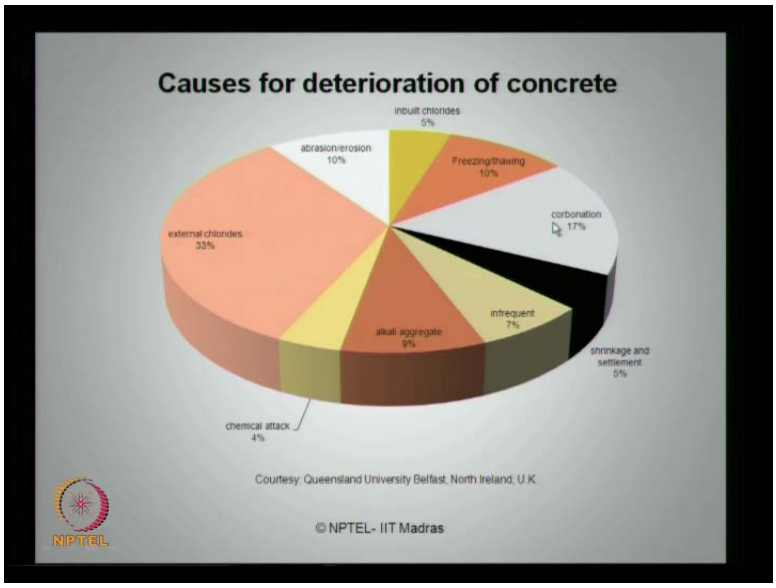


If you look at this chart, which indicates me what are the general causes for deterioration of concrete as studied in Queensland University, North Ireland UK. The majority of people and researchers have spoken saying the reason for deterioration of concrete is from external chlorides. Followed by which put together is an internal or inbuilt chloride system and of course, temperature variation in terms of freezing and thawing also contributes to the deterioration of concrete structures in terms of ocean structural systems. Carbonation and alkali aggregates also contribute about one fourth or 25 percent in total about the deterioration process in together.

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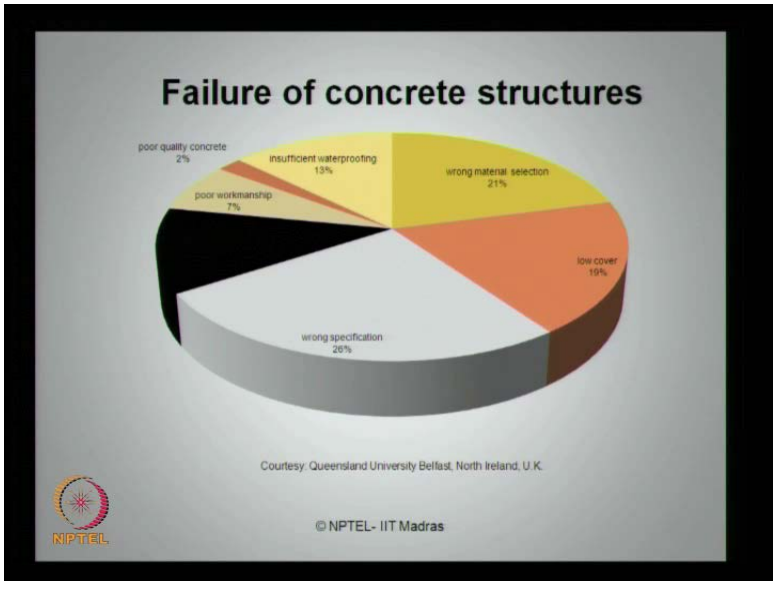

If you also look at the reasons for failure of concrete structures as attempted in ocean structural systems as seen from this chart as occurred to see with Queensland University at U K, poor quality concrete contribute only for about 2 percent. As you see here because enough quality control methods are exercised in terms of construction of ocean structural systems. The majority actually comes mainly from wrong specification, wrong material selection and in sufficient water proofing and very poor cover in terms of design or in terms of construction aspects.

The failure of this kind of structural system generally gets focused upon wrong selection of material as a majority. Therefore, ladies and gentlemen, it is very important for us to understand selection of material plays a very important role when you want to apply this as a construction material for ocean structural systems.

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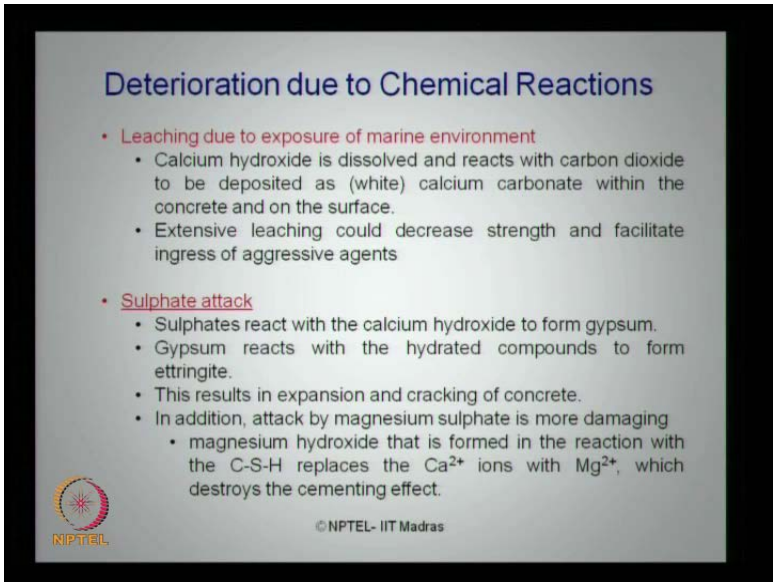


If you look at the process of deterioration of concrete due to chemical reaction, which is a very important task as far as repair is attempted in ocean structural system. Leaching and sulphate attack are considered to be a serious problems as far as concrete under chemical reactions are consist. Calcium hydroxide is dissolved and reacts with carbon dioxide which forms as a deposit, which is white calcium carbonate within the concrete and also on the surface of concrete. Extensive leaching could decrease the strength of concrete and also facilitate ingression of aggressive agents into the concrete, which then further reacts with rebar embedded concrete and causes corrosion.

If you look at the sulphate attack as one of the reasons for chemical reaction, which deteriorates strength of concrete sulphates reacts with calcium hydroxide to form a compound called gypsum.

Gypsum in turn reacts with hydrated compounds to form Ettringite this results in expansion of concrete in manifold volume, which results ultimately in cracking of concrete. Once concrete surface gets cracked it gets exposed to weather and therefore, penetration of chlorides and weather environment then attacks the reinforcement, which results in corrosion.

In addition attack by magnesium sulphate is more damaging because magnesium hydroxide that is formed the reaction between CSH replaces the calcium irons with magnesium irons, which destroys the so called cementing effect in concrete. Also, if you look at the alkali silica reaction as one the important reason for deterioration of concrete.

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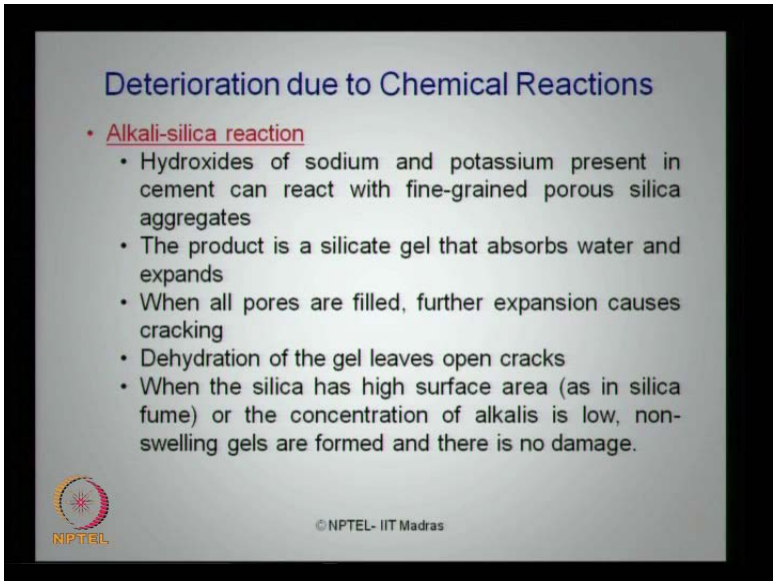


Hydroxides of sodium and potassium that are present in cement can react with fine grained porous silica aggregates a product what is called is a silica gel is formed is absorbs water and as a result this expands. When all the pores all filled further expansion causes cracking of concrete dehydration of the gel leads the cracks open. When the silica has high surface area as in case of silica fume, which is commonly used or concentration of alkalis is low, then non-swelling gels are formed which of course results no damage.

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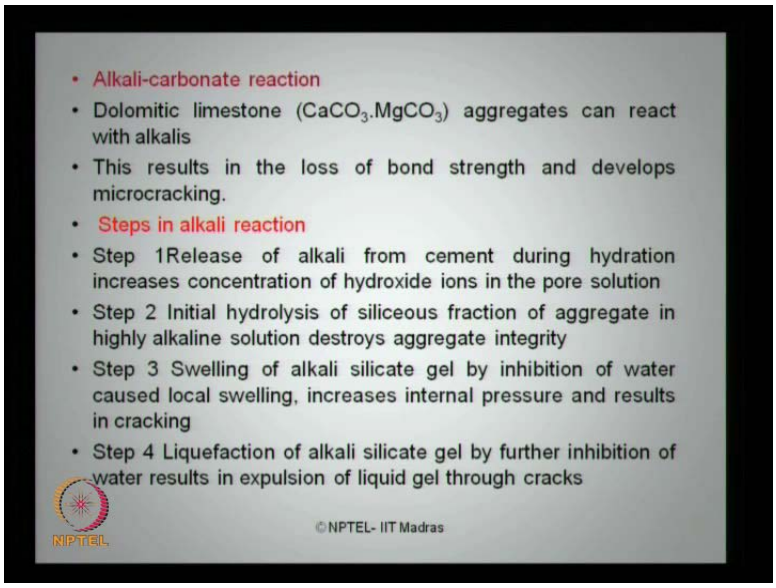


If you look at the alkali carbonate reaction present in concrete which is subjected to marine environment, the dolomitic lime stone aggregates can react with alkaline. This results in the loss of bond strength and develops what we call micro cracking in the concrete structure. The steps in alkali reaction can be seen as follows; as a first step release of alkali from cement during hydration increases concentration of hydroxide ions in the pore solution.

In the second step initial hydrolysis of siliceous fraction of aggregate in highly alkaline solution destroys the aggregate integrity completely, followed by which swelling of alkali silicate gel by inhibition of water cost local swelling, increases internal pressure and this result in cracking of concrete. As a last step liquefaction of alkali silicate gel takes place the further inhibition of water this results in the expulsion liquid gel through cracks.

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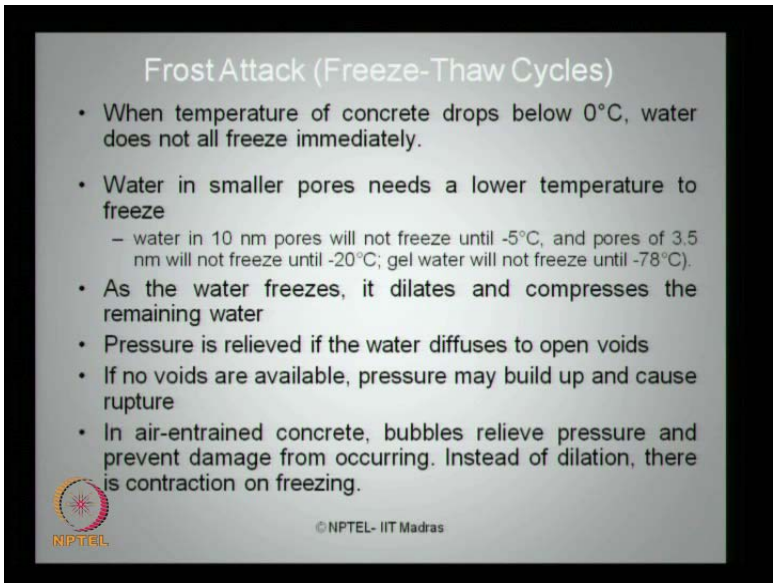


As you understand sometimes ocean structures are also subjected to reversal of time in terms of temperature like Freeze Thaw cycles, what we call as Frost attack in literature. When the temperature of concrete drops below 0 degrees, water actually immediately does not freeze, water in smaller pores needs a lower temperature below 0 to get frozen. So, water in 10 nanometer pores will not freeze until minus 5 degrees is reached and pores of 3 point 5 nanometer will not freeze until minus 20 degree is reached. So, gel water will not freeze until minus 78 degrees Celsius is reached.

So, water does not freeze immediately as soon as temperature drops down to 0 as the water freezes it dilutes and compresses the remaining water. Pressure is relieved if the water diffuses to open the voids, if voids are not available then pressure may build up and it causes rupture in concrete. If the air entrained concrete, bubbles relieve the pressure and prevent damages from occurring instead of dilation there is contraction on freezing.

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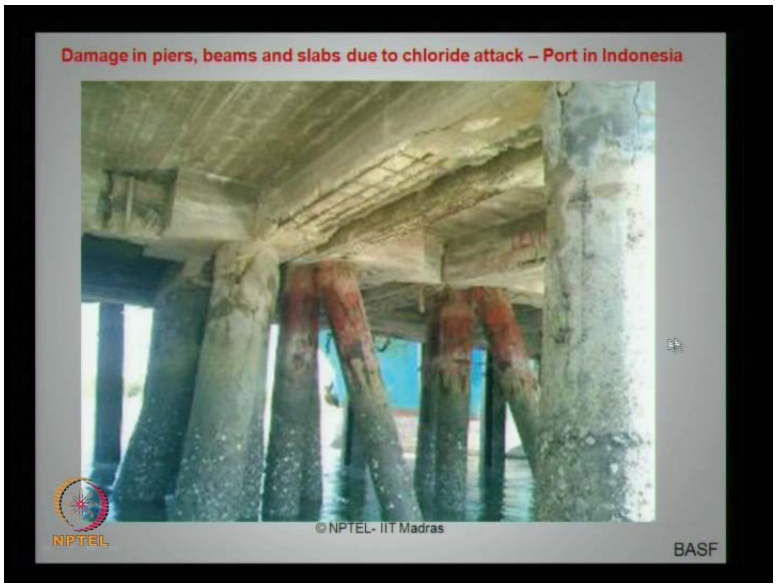


Ladies and gentlemen, it is a very interesting picture showing the damage in piers beams and socket of the slab, which are primarily due to the chlorine attack which is a port in Indonesia. You can see the socket of the beams, which are extensively corroded even the surface of the columns which are corroded and spoiling of concrete takes places, which exposes the reinforcement not only on the side faces of the beam as well as the main reinforcement in the bottom face of the beam as well.

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If you look at the damage picture of the jetty due to sea water exposure, again you can see here the bottom surface of the slab is also getting exposed, whereas the reinforcement is getting exposed to a severe attack of chemical environment in marine sea state.

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Also the jetty fenders get deteriorated due to chloride attack and mechanical action. You can see here the deteriorated jetty fenders, where the steel is getting exposed thoroughly and some repairs being attempted using a specific specification of the chemical and the concrete, which will be discussed in the next part.

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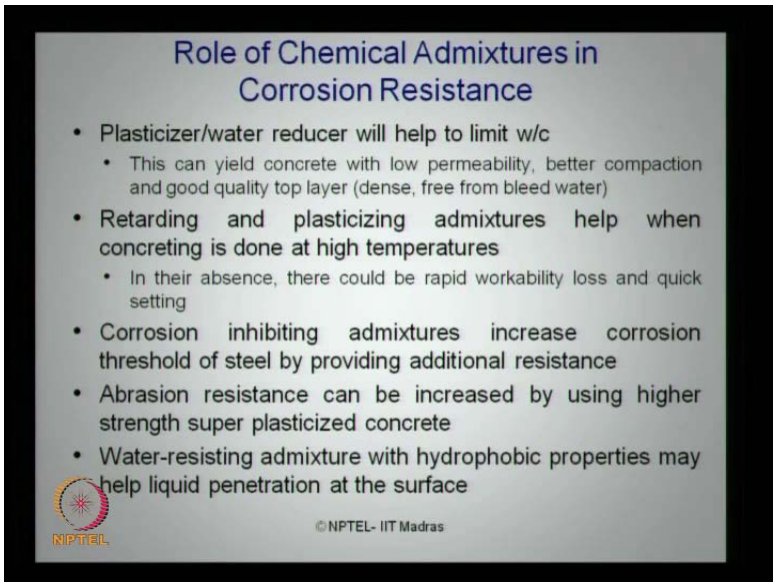

Now, as we understand, looking at these examples, we see that role of admixtures play a very important role in inculcating corrosion resistance to the reinforcement embedded in concrete. As I said, these admixtures have different roles to play as case specific. Therefore, no international codes clearly recommend certain set of chemicals it all depends on experience site engineers and maintenance engineers to recommend certain admixtures and chemical treatment to protect ocean structures or systems from further corrosion.

This is the process what we call repair and rehabilitation. You can use plasticizers or water reducers, which will help to limit the water cement ratio. This can yield concrete with low permeability better contraction and good quality top layer. The top layer will remain dense and will free from bleeding waters. The retarding and plasticizing admixtures will help, when concreting is done at higher temperatures in their absence there could be rapid work ability loss and it will result in quick setting, which is not desirable as far as ocean structural construction is concerned.

Corrosion inhibiting admixtures increases corrosion threshold of steel by providing additional resistance to rebar can also add admixtures, which improve abrasion resistance. This can be increased by using higher strength super plasticized concrete. Water resisting admixtures can also be used with hydrophobic properties which may help liquid penetration at the surface.

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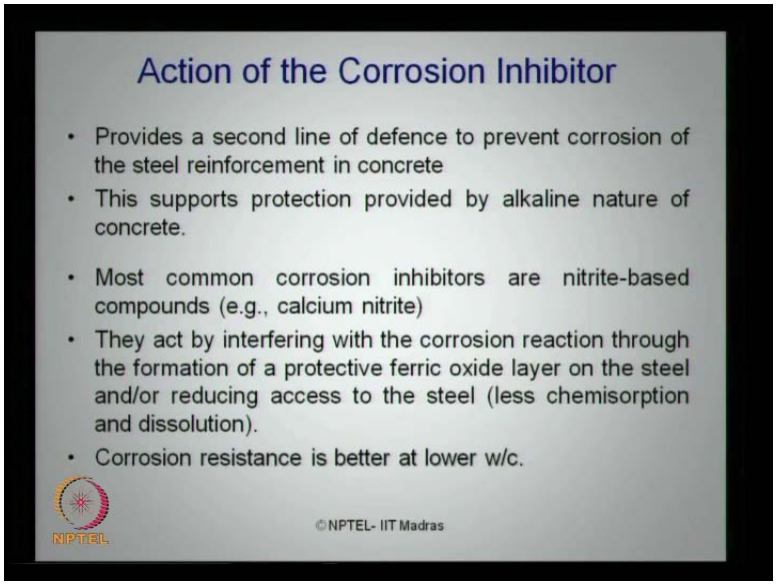


If you look at the action of corrosion inhibitor in detail, it provides a second line of defense to prevent corrosion of steel reinforcement which is embedded in concrete. This supports a protection provided by alkaline nature of concrete, most commonly used corrosion inhibitors are nitrite based compounds. I

can give an example calcium nitrite is a compound, which is being used as a common corrosion inhibitor. They give a second line of defense to prevent corrosion to the steel reinforcement. They act by interfering in the corrosion reaction to the formation of protective ferric oxide layer on steel or by reducing access to steel, which is less Chemisorption or dissolution, corrosion resistance is better off course at lower water cement ratio.

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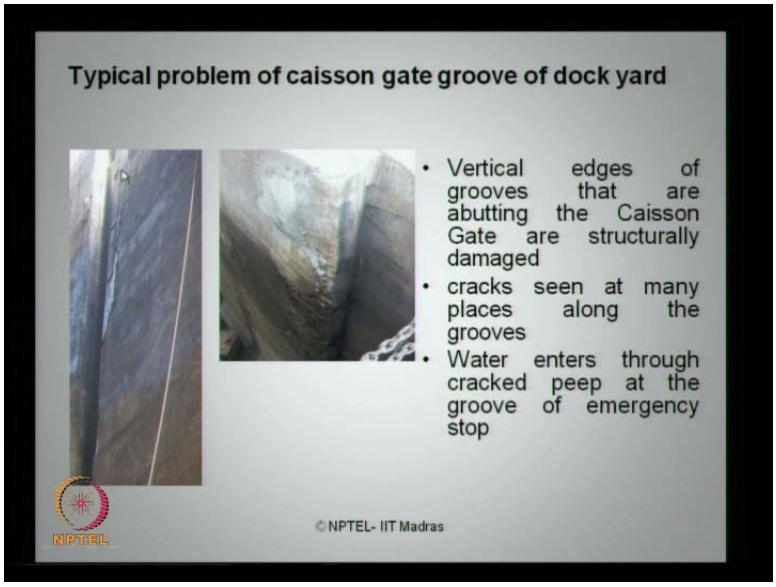


If you look at the typical case example of the caisson gate group of a dock yard, which we examined, the picture shows you the dock yard gate the caisson gate which is damaged, the vertical edges of the groove as you see here. These are the vertical edges of the caisson gate groove, which are extensively damaged because of the impact caused by the caisson gate. The vertical edges of the groove are abetting the caisson gate are seemed to be structurally damaged, cracks are seen at many places you can see on the surface as well as here along the grooves water therefore, enters through the crack the peep at the groove at the emergency stop as you see from here.

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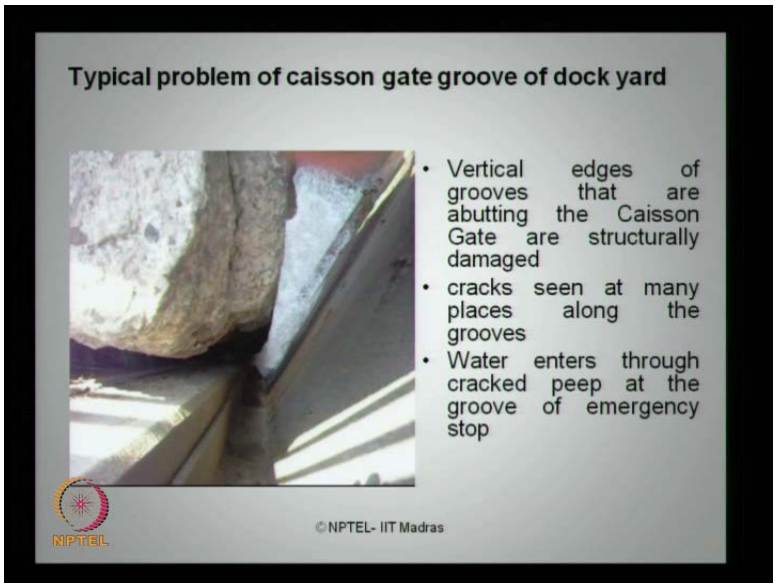


There is a damage caused therefore, waters enters through these the gates does not remain water tight. So, what would be the method to attempt a repair for this kind of treatment.

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If you look at the preparation action for repair the concrete has to be completely chipped of in stages and the steel has got to be completely exposed.

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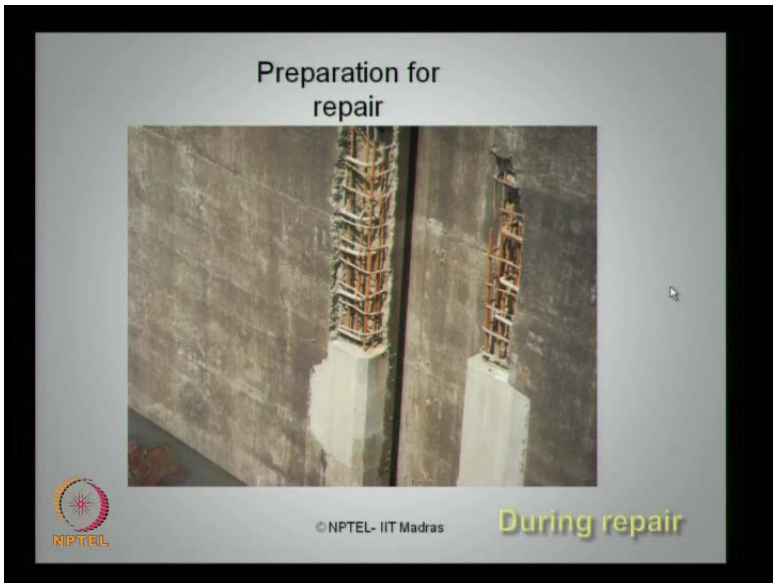


As you see in this photograph during repair you got to do a proper water proof shuttering, and keep on doing micro plating whose specifications are discussed in the next slide.

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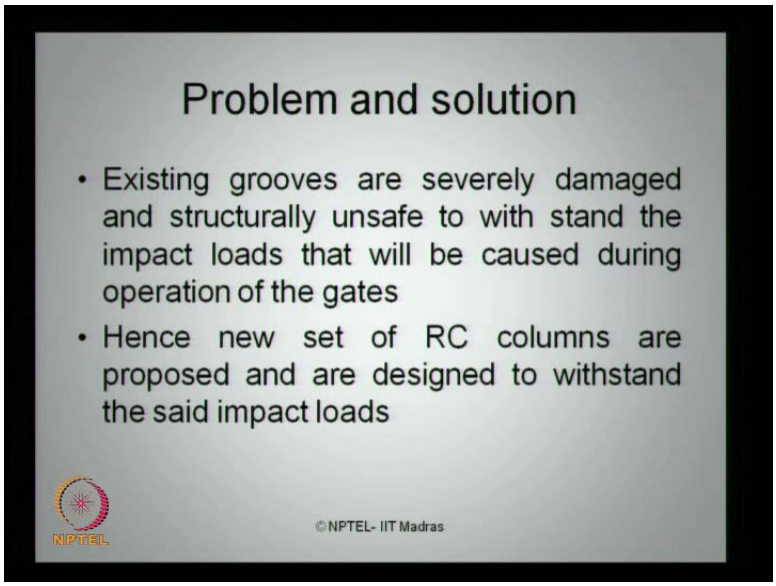


So, the problem what you just now saw is existing grooves are severely damaged and they seems to be structurally unsafe because they cannot withstand the impact loads, which are posed by the gate when the gate is being under operation. Hence, new set of reinforced concrete columns are propose in the design and the design to withstand the said impact loads caused by the gates.

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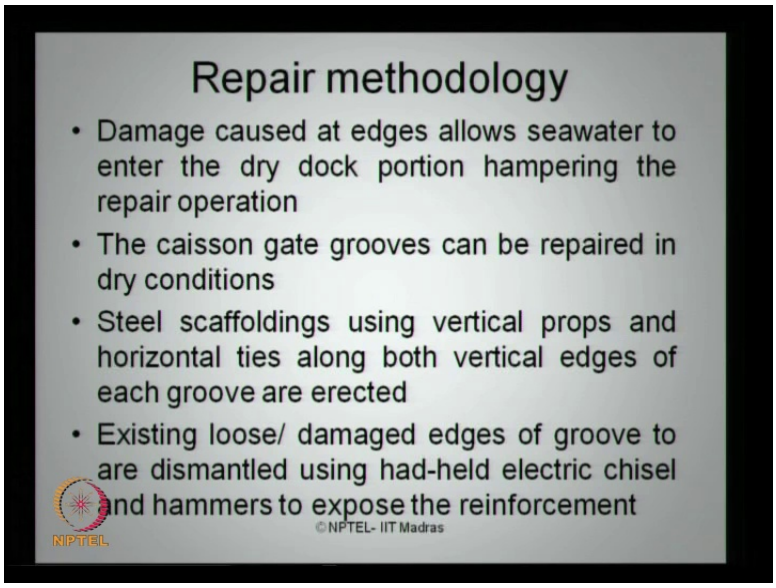


What is the repair methodology? Damage caused at the edges allows the seawater to enter the die dock position, which is hampering the repair operation of the dock. The caisson gate grooves can be repaired only in the dry condition. Therefore, you have got to shut down the dock for service ability for some time. Steel scaffoldings are used using vertical props and horizontal ties both for vertical edges of each group and they are erected as straight as possible. Existing loose or damaged edges of grooves are cleaned thoroughly; they are completely dismantled using hand held electrical chisel and hammers to expose the reinforcement.

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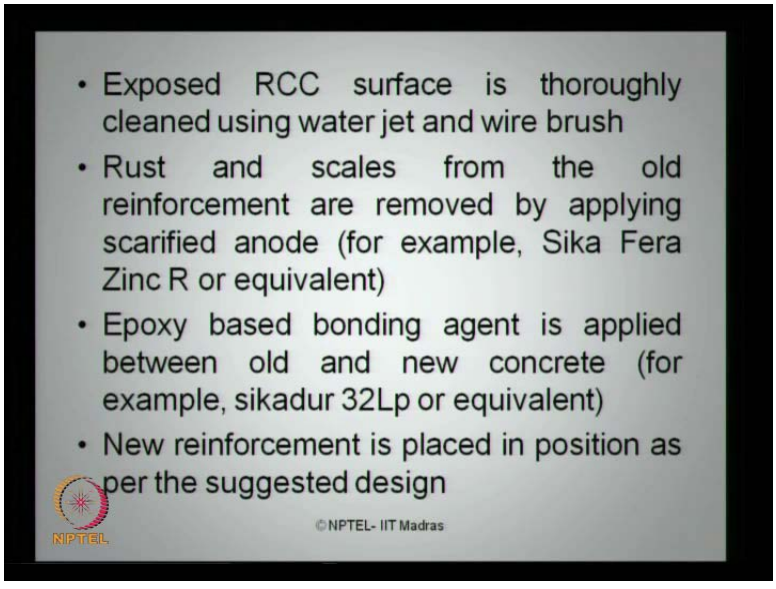

The exposed RCC surface is then thoroughly cleaned using water jet and the wire brush. Rust and scales from the old reinforcement are removed by applying scarified anode, which is for example, can be a Sika Fera Zinc R chemical compound or equivalent. Epoxy based bonding agent is then applied between the old and new concrete for example, Sikadur 32 Lp or equivalent can be used for such kind of applications. New reinforcement is now placed in position as per the suggested design.

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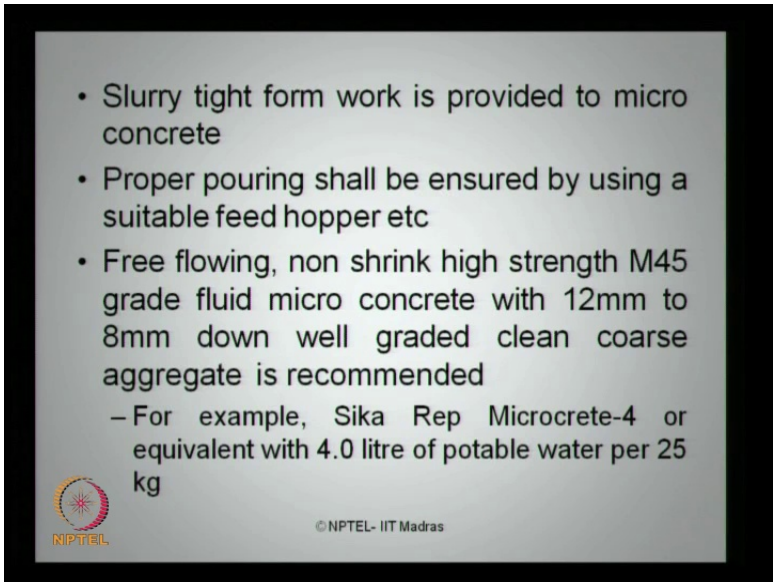


The slurry tide form work is then erected to provide microcrete concrete, proper poring shall be ensured by using a suitable feed hopper mechanism. Free flowing, non-shrink high strength M45 grade was designed for this application, which should be a fluid micro concrete with 12mm to 8mm down well graded clean coarse aggregate is recommended for this application. For example, Sika Rep microcrete 4 or equivalent with 4 liter of water for 25kg is recommended as a mixture of micro concrete, which can be poured in the water tight slurry for repairing this gate groove.

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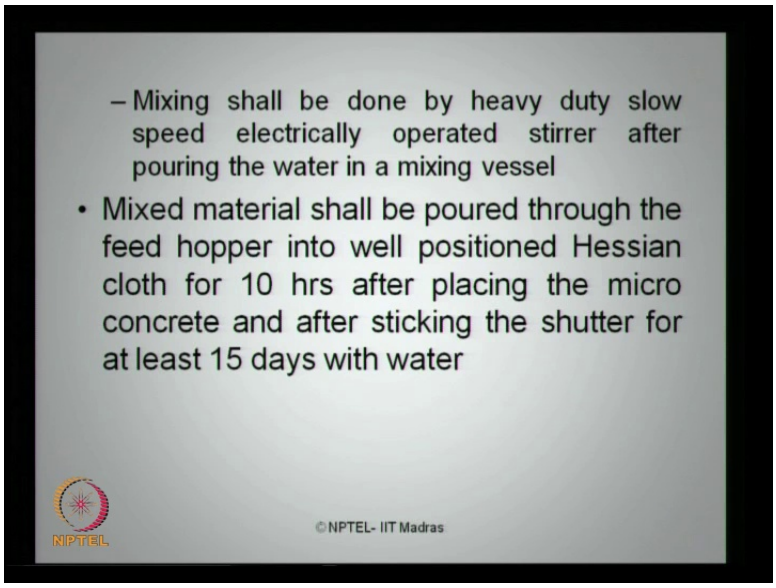


Mixing should be done by heavy duty, slow speed, electrically operated stirrer after pouring the water in the mixing vessel. Mixed material should be poured through feed hopper system into the well position hessian cloth for 10 hours after placing the micro concrete and after sticking the shutter for at least 15 days with water.

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If you look at the advanced materials, which are used for repair…

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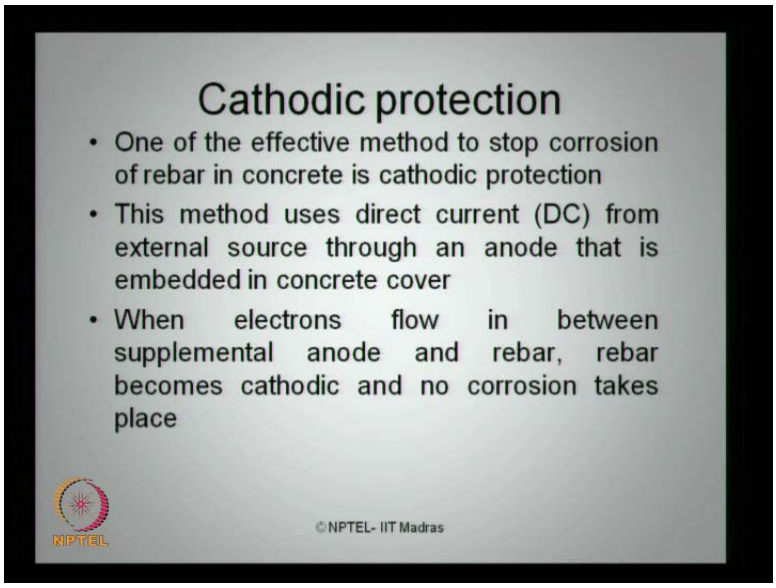


Cathodic protection forms a very major role in such kind of treatment, one of the effective methods to stop corrosion of reinforcement bar in concrete is cathodic protection. This method uses direct current from external source through anode that is embedded in concrete cover. When the electrons flow in between the supplemental anode and rebar, rebar becomes cathodic and therefore, it is protected because no corrosion takes place in the reinforcing bar.

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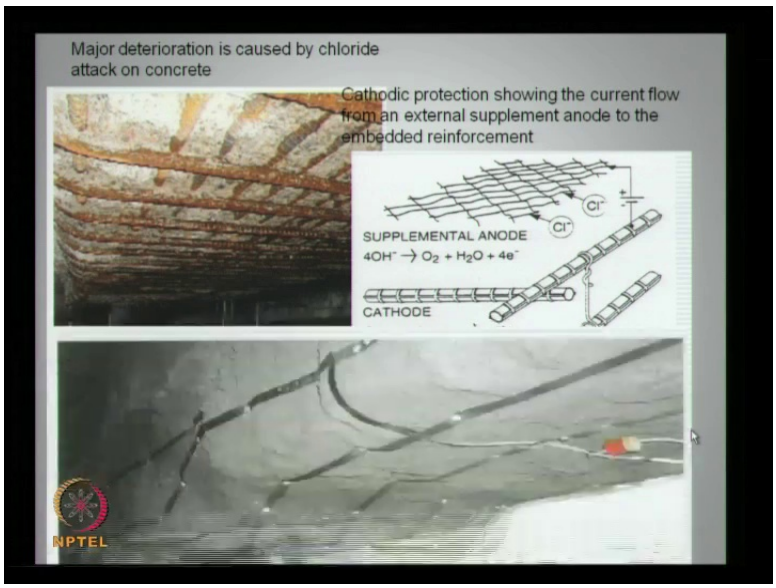


If you look at one of the examples again, where the major deterioration is caused by chloride attack on concrete. As you see here the cathodic protection which is being prepared shows a current flow from an

external supplement node, which is acting as anode to the embedded reinforcement. So, the supplemented anode is being connected to existing rebar, which are corroded which is becoming the cathode that is why we call this as a cathodic protection.

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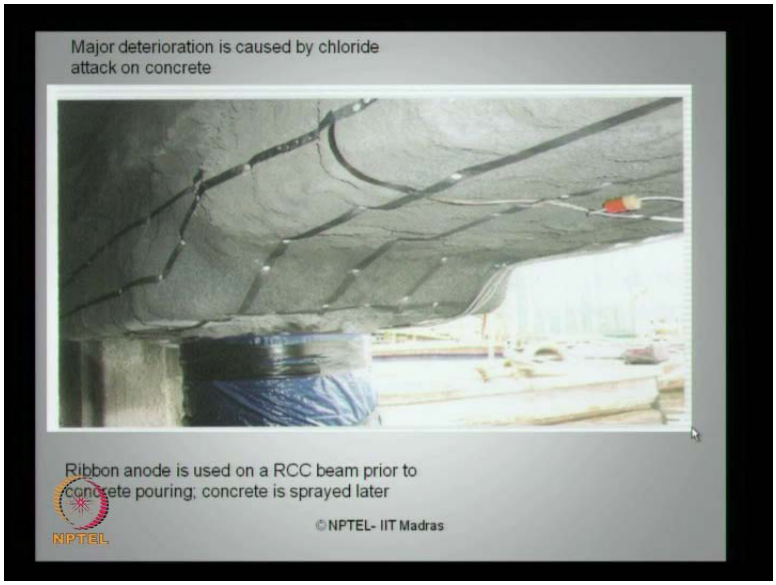


The ribbon anode is also used in RCC been prior to concrete as you see in this photograph. These are all ribbon anodes which have been used. Therefore, they are allowed to corrode whereas, the rebar inside embedded inside does not corrode because it becomes cathodic.

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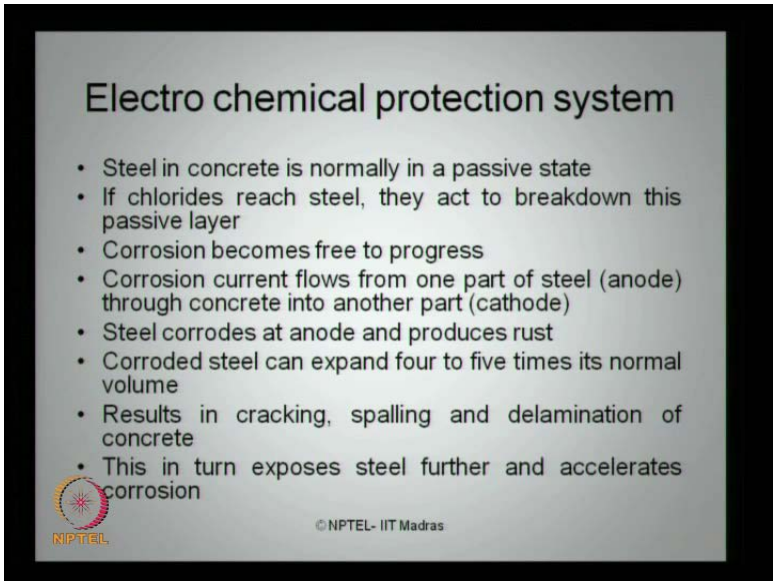

If you look at electro chemical protection systems further as an advance method for protecting this kind of structural systems. Steel concrete remains normally in a passive state, if chlorides reach steel they act to break down this passive layer. So, corrosion becomes free to progress therefore, corrosion current flows from one part of steel, which becomes anode through concrete into another part which becomes cathode. So, steel corrodes at anode and produces rust, corroded steel then can expand four to five times of its normal volume, which cracks concrete and also results in spoiling and delamination of concrete. This in turn exposes the steel further and accelerates the corrosion process.

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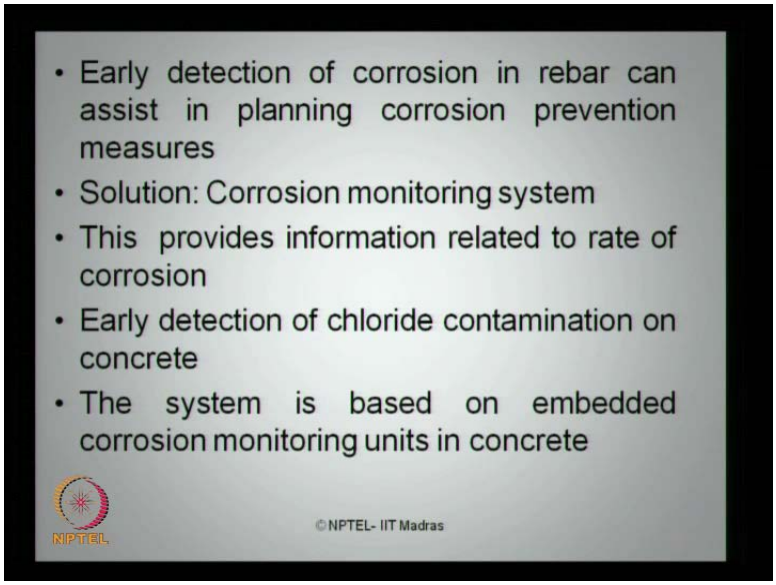


Early detection of corrosion therefore, is a very important stage in planning the corrosion prevention measures, the solution could be what we call corrosion monitoring system; we will discuss this system in detail and as applied to various examples in the fourth module. However, now will see very briefly what is a corrosion monitoring system? This provides information to the rate of corrosion at which the rebar is being corroded. Early detection of chloride contamination of concrete is also an integral part of this corrosion monitoring system. This system is based on embedded corrosion monitoring units in concrete itself.

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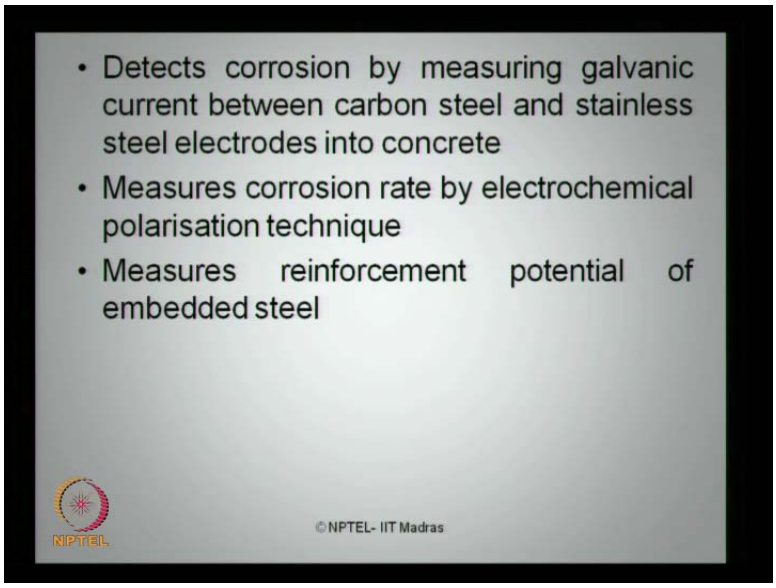


It detects corrosion by measuring the galvanic current between carbon steel and stainless steel electrodes with their embedded into concrete, it measures the corrosion rate by electro chemical polarization technique, it measures the reinforcement potential of the embedded steel.

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If you look at the recent advancements available in the literature as one of the important case, study has been done for improving corrosion resistance to steel.

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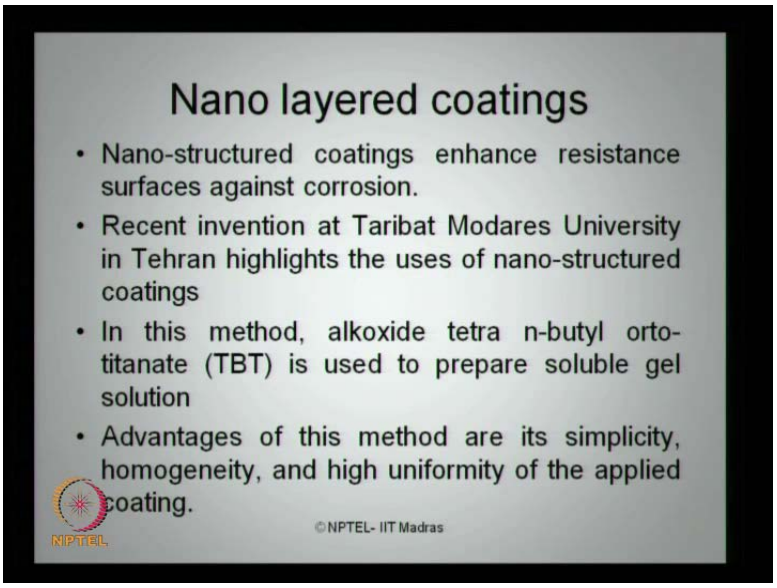


Ladies and gentlemen, so very recent advancement had been done by using Nano layered coatings. Nano structured coatings enhance the resistance surface against corrosion. The recent invention in Taribat Modares University in Tehran highlights the use of Nano structured coatings, which I will discuss very briefly now in two slides. In this method, alkoxide tetra butyl ortotitanate, which is abbreviated as TBT is used to prepare a soluble gel solution. The advantages of this method are its simplicity, homogeneity and high uniformity of the applied coating, which is very thin, therefore this is called Nano layered coating.

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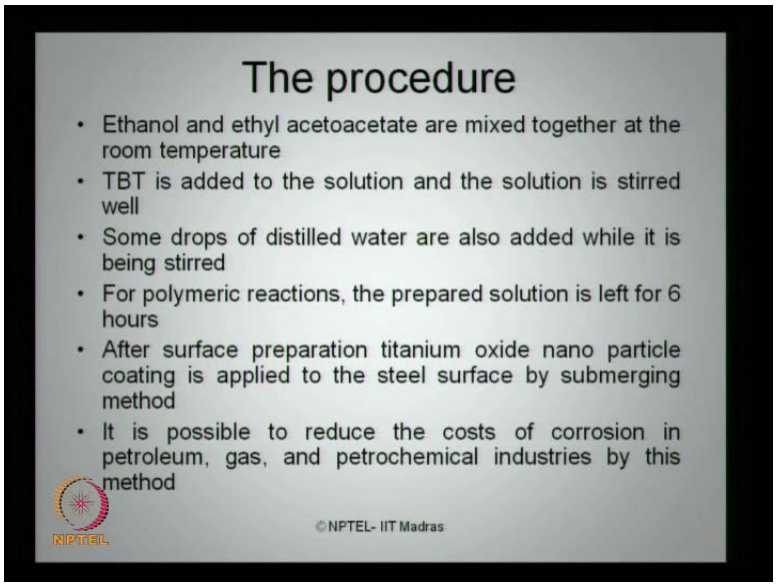

How this is done? Ethanol and ethyl acetoacetate are mixed together at room temperature, TBT added to the solution and the solution is stirred well. While stirring taking place some drops of distilled water is also added during this process, for polymeric reactions the prepared reaction is then left for about 6 hours. After surface preparation is done using titanium oxide Nano coating is then applied on the surface of steel by submerging method. It is possible to reduce the causes of corrosion in petroleum gas and petrochemical industries by applying simply a Nano coating on the steel surface by submerging method, which is one of the recent advancements done in Tehran.

So, ladies and gentlemen, in this lecture we discussed about the repair methodologies and rehabilitation techniques, which are commonly adopted. We also discussed few case sheets where these methods were attempted successfully for repair and rehabilitation. So, the construction materials chemical admixtures, which are commonly used for repair and rehabilitation are really challenging because no standard international procedures are recommended by the codes to follow any repair schemes because these repair schemes are generally case to case basis. We will discuss more about these schemes in the next module. Thank you very much for listening to this lecture.