Ocean structures and materials
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Module - 4
Lecture - 4
Repair and Rehabilitation-Fenders

In this lecture, we will talk about few advance methodologies on repair and rehabilitation of marine structures. We will also talk about some of the important structural components of fenders and sheet piles in this lecture.

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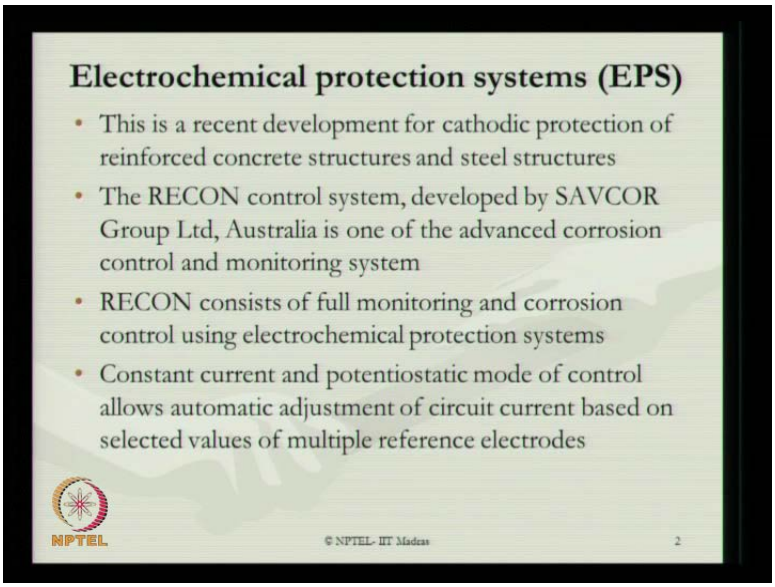

When you talk about concrete structures or steel structures, which are commonly used for marine systems, Electro chemical protection system plays a very important role for protecting them against corrosion. Electro chemical protection system briefly attests as EPS is a recent development for cathodic protection of reinforced concrete structures and steel structures. The RECON control system, developed by SAVCOR group limited, Australia is one of the advanced corrosion control and monitoring system. As we understand, corrosion is one of the major problems in reinforced concrete structures as well as rebars are concerned, and of course, steel structures when we are talk about offshore jackup structures etcetera.

RECON consists of full monitoring corrosion control using a new system process called electro chemical protection systems. So, let us try to understand, how this system actually operates and how it offers protection against corrosion for reinforced concrete structures and steel structures as well. In this methodology, a constant current and potentiostatic mode of control allows automatic adjustment of circuit current based on selected values of multiple reference electrodes.

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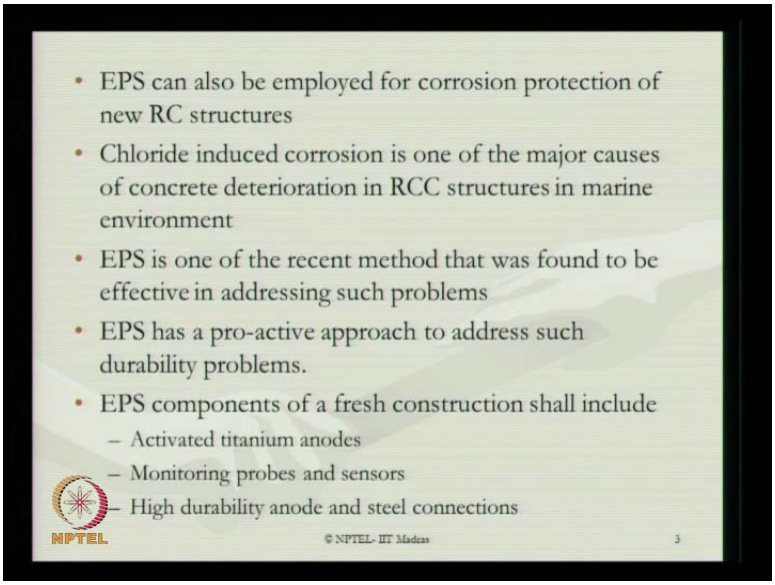

EPS can also be employed for corrosion protection of new reinforced concrete structures. The chloride induced corrosion is one of the major causes of concrete deterioration in reinforced concrete structures in marine environment. EPS is one of the recent methods, that was found to be effective in addressing these problems. EPS has a pro-active approach to address such durability issues. EPS components of a fresh construction shall include activated titanium anodes, monitoring probes and sensors and of course, high durability anode and steel connections.

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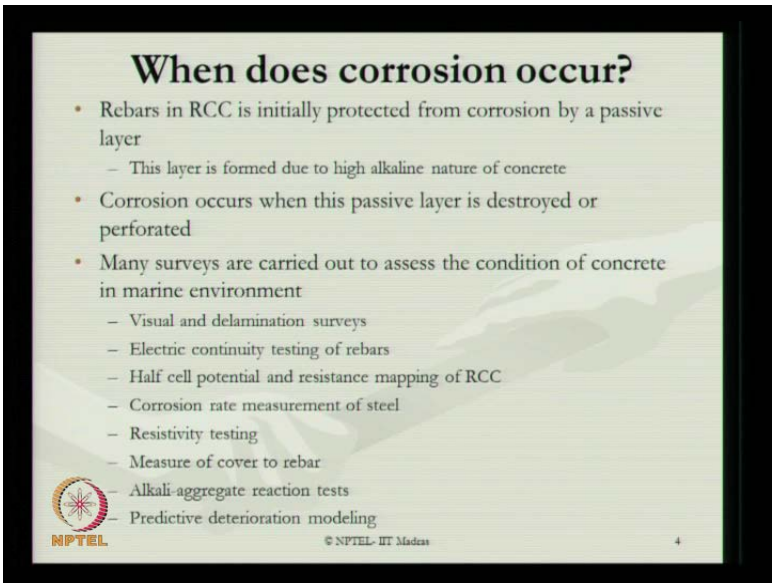

Now the fundamental question comes, before we think of using such EPS systems are when does corrosion occur in reinforced concrete system or in a steel structure. In particular, when you talk about reinforced concrete structures, the reinforcement embedded in concrete is initially protected from corrosion by a passive layer form around them. This layer is formed essentially due to high alkaline nature of concrete.

Now, corrosion occurs when this passive layer is destroyed or perforated. Many surveys are to be carried out to actually assess the condition of concrete in marine environment. Following are the list of surveys which are generally carried out to assess the condition of concrete. Visual and delamination survey, electric continuity testing of rebars, half-cell potential test and resistance mapping of reinforced concrete structures, corrosion rate measurement of steel, resistivity testing, measurement of covering to the rebar, alkali aggregate reaction test, and predictive deterioration modeling. So, these are some of the experimental and analytical tools which are generally carried out for assessing the condition of concrete structures in marine environment.

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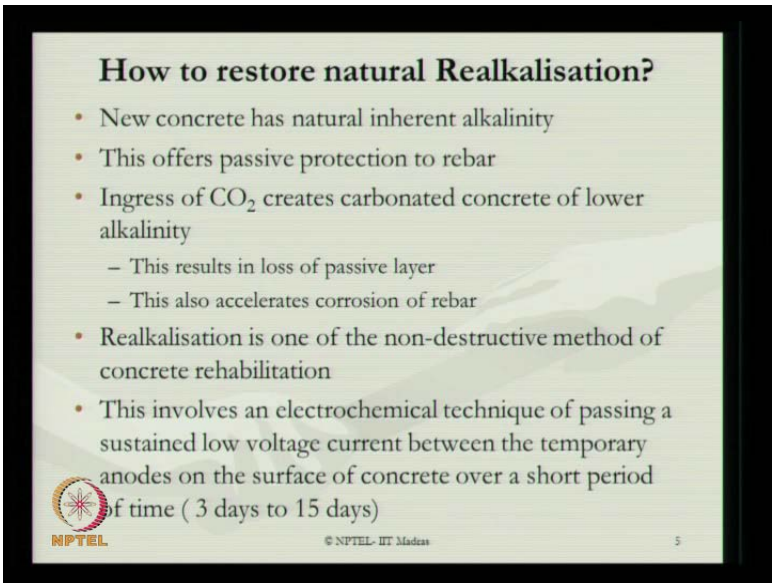

Now the fundamental question comes, corrosion will be activated once the passive layer is destructed or perforated. Now, how to restore the natural Realkalisation of concrete. New concrete has a natural inherent alkalinity, this offers passive protection to the rebar. Now when this passive protection is destructed or destroyed ingression of carbon dioxide creates carbonated concrete of a very low alkalinity. This of course, results in loss of the passive layer, this also accelerates corrosion of reinforced bar in concrete. The Realkalisation, therefore, is one of the famous and common non-destructive methods to counter at concrete rehabilitation. This involves an electrochemical technique of passing a sustained low voltage current between the temporary anodes on the surface of concrete over a short period of time, and this period can vary anywhere from 3 days to 15 days. And this experiment can be repeated in number of cycles in a given period of time.

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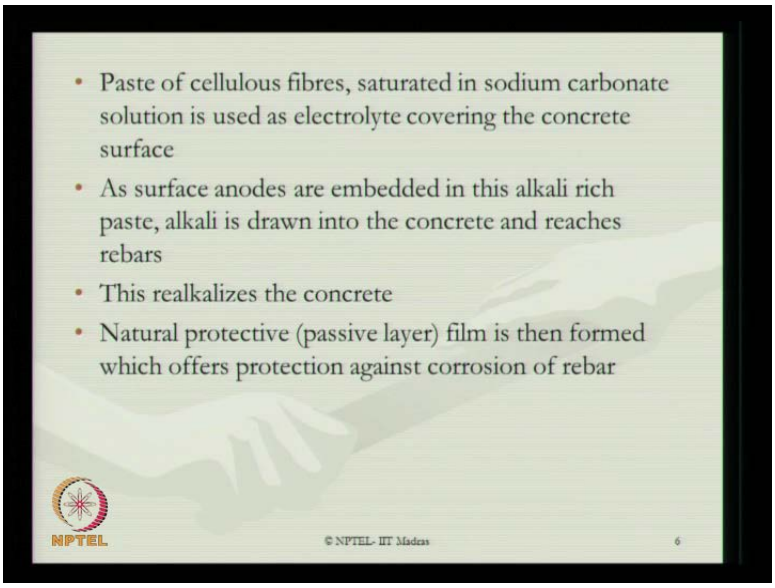

Paste of cellulous fibres which are saturated in sodium carbonate solution is generally used as an electrolyte covering the concrete surface. As surface anodes are embedded in this alkali, alkalai is drawn into the concrete and reaches the rebars. This realkalizes the concrete in totality. Natural protective - passive layer, is then formed which offers protection against corrosion of this rebar.

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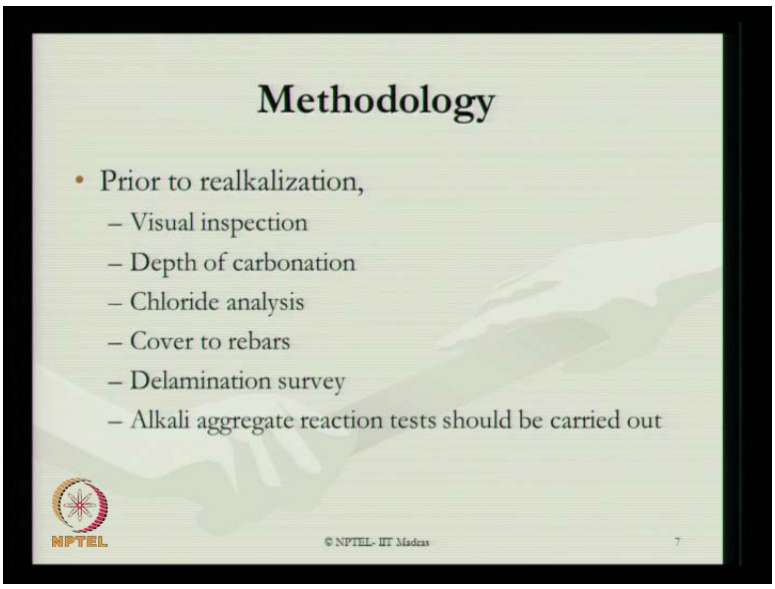

Let us quickly see, what is the methodology at which this can be applied. Before you apply realkalization techniques to any reinforced concrete systems, the following

inspections are to be carried out. One should carry all visual inspection, depth of carbonation to be as a time. The chloride analysis test to be carried out and then cover to rebars to be assessed very carefully, and one has to conduct delamination survey to understand the integrity of concrete in situ and of course, one should also study alkali aggregate reaction through experimental investigations before realkalisation is attempted in concrete structures.

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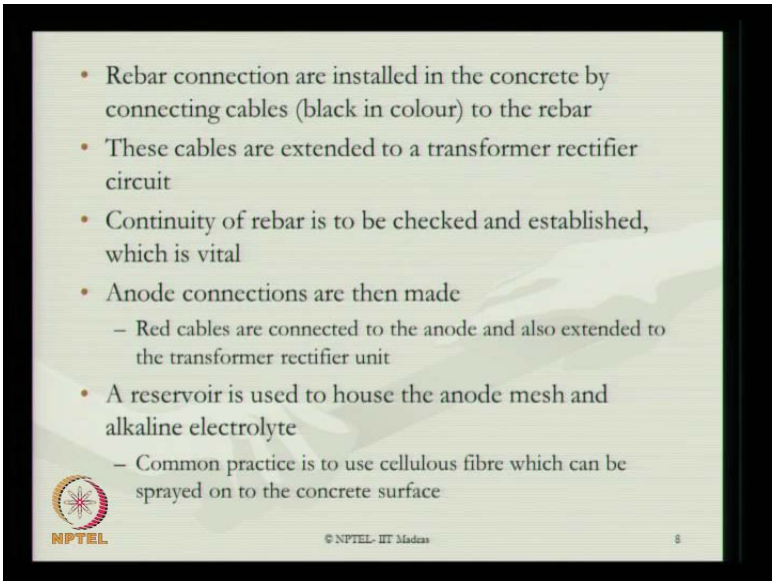

The rebar connections are installed in the concrete by connecting cables. Let say these cables are generally black in color. These cables are extended to a transformer rectifier circuit in the outside. The continuity of the rebar has to be certain and checked before this test is conducted. Anode connections are then made; red cables are connected to the anode and also extended to the same transformer circuit, rectifier unit. Now a reservoir is used to house the anode mesh and alkaline electrolyte. The common practice is to use cellulous Fibre, which can be sprayed on the concrete surface which will act as an electrolyte medium.

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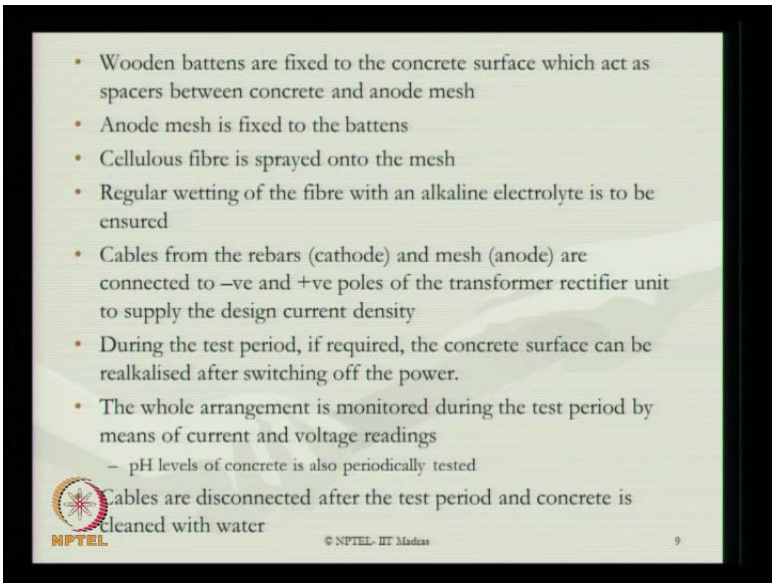

Wooden battens are then fixed to the concrete surface, which act as spacers between concrete and the anode mesh. Anode mesh is then fixed to these battens. The cellulous fiber is sprayed on the mesh. Regular wetting of the fibre can also be done as an electron alkaline electrolyte is to be ensured. Cables from the rebar which we called cathode which are generally black in color and mesh which be called anode which are generally red in color are connected respectively to the negative and positive poles of the transformer rectifier unit to supply the design current in density. During the test period, if required the concrete surface can be realkalised after switching off the power, if you see the electrolyte is getting dried of because a weather conditions. The whole arrangement is then subsequently monitored during the test period by means of current and voltage readings. The pH levels of concrete is also periodically inspected and tested. Cables are then disconnected after the test period is over and the concrete is cleaned with water, now the concrete is completely realkalised and the passive layer will be formed, so that corrosion on the rebar will not occur further. This test and this procedure, be repeated at cause and intervals may be at a cycle of 3 to 6 months gap depends upon the marine environment where the jetties or structures are placed.

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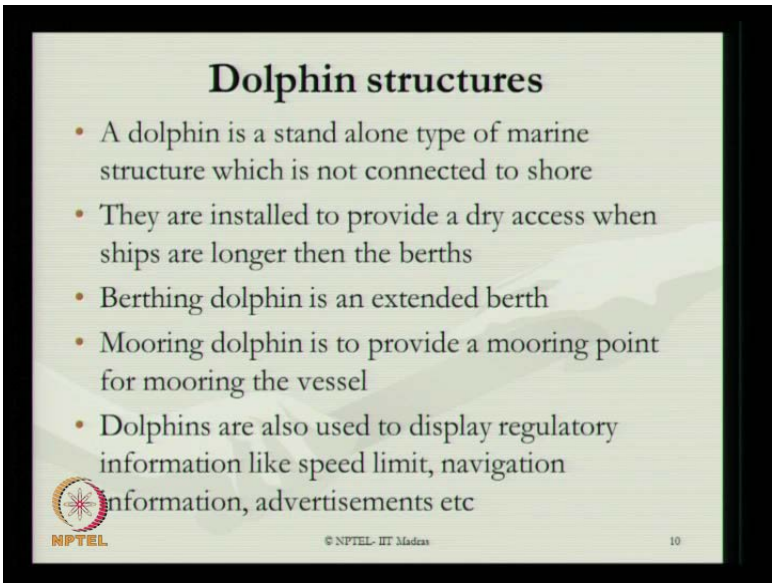

Before we look into other kind of system, let us talk about rehabilitation more in detail in terms of how to compute the reaction of corrosion time or initiation of corrosion from the equations.

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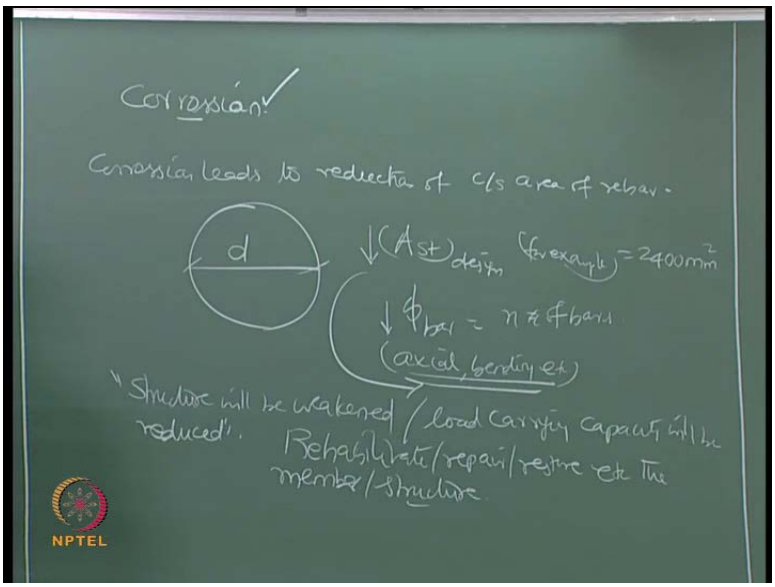

So, ladies and gentlemen, we will talk about corrosion as a big process. Corrosion actually leads to reduction of cross sectional area of the rebar. For example, in the design, I have got area of steel whose diameter is d and of course, I have got the design value of AST, for example, as 2400 mm square. So, depending upon the diameter of the

bar, I will get n number of bars to be placed in position to take care of the design loads - it can be axial, it can be bending, etcetera. On reduction of this diameter of the bar, because of corrosion there is reduction in area of steel, which will directly affect the load carrying capacity of the structure. It means the structure will be weakened or the load carrying capacity will be reduced. So, to improve the capacity I have got to rehabilitate or repair or restore etcetera the member or the structure.

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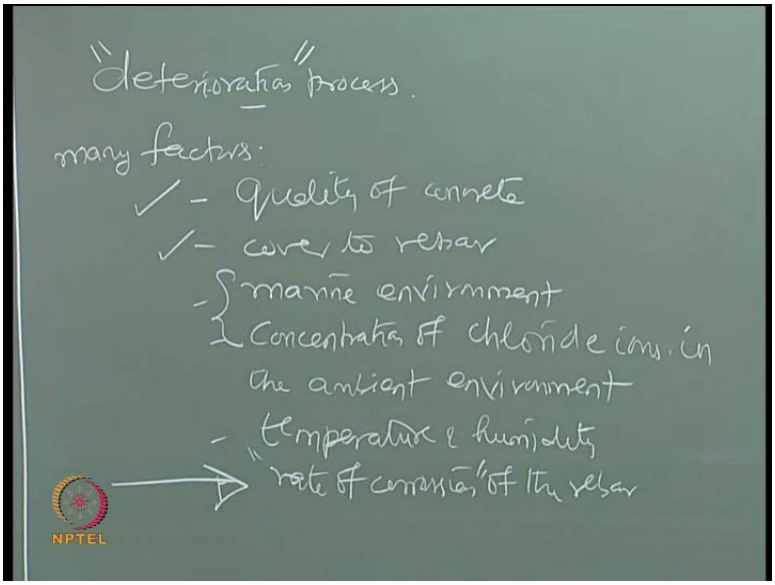

Now let us quickly understand, what is the primary reason for reduction of diameter bar, because of corrosion. So if we look at deterioration process as a whole, it depends on many factors as you see in the bottom. Quality of concrete, cover to the rebar, marine environment, concentration of chloride irons in the ambient environment, temperature and humidity of course, the rate of corrosion of the rebar. So, looking at all these factors which contribute to the quality deterioration of the member or the structure, of course, one can easily control the quality of concrete by proper inspection and placing of concrete, one can ensure from the proper construction methodology that the cover to rebar is ensured properly as per the design requirements. Now one can take care of the marine environment and chloride concentration by external protection methodologies, whereas if you were to talk about the rate of corrosions just becomes one of the important parameter, which directly is related to the deterioration mechanism of member or concrete structures.

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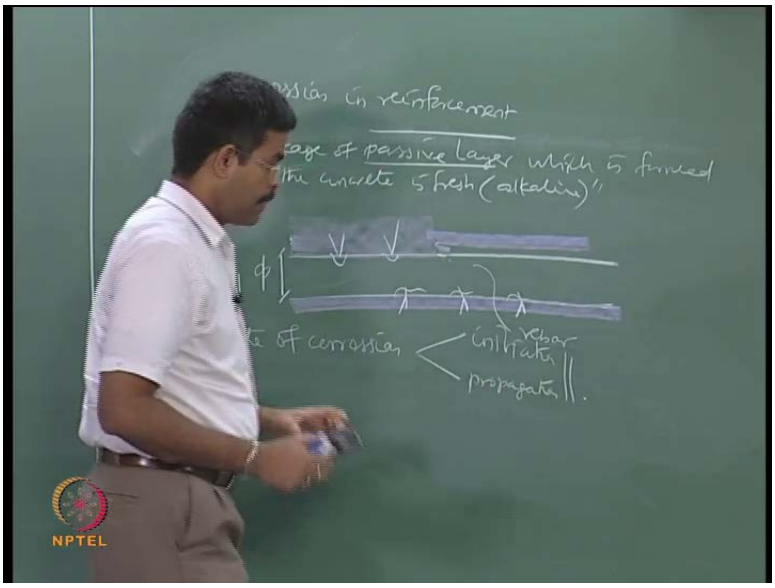

So, let us talk about how to estimate rate of corrosions, quickly, using values available in the literature. So, as we understand corrosion in reinforcement is essentially cost, because of the fundamental reason is breakage of the passive layer which is formed when the concrete is fresh, I should say alkaline. When the concrete is fresh, I have got a passive layer formed, and when this passive layer is broken or perforated, when it is not continuous then on those segments were the passive layer is not continuous. Then say this is my rebar, this is my passive layer, whenever I have got any cracks or any perforations in the passive layer, because of carbon dioxide ingression etcetera. So, these areas or these locations are the points were the rebar will start getting corroded. So, as a result of which there is a net effective reductions in the diameter of the bar, which affects the load carrying capacity of the whole member.

There has been detailed studies conducted by professor Sengupta, Avalon Sengupta and professor Devadoss Menon in Civil engineering department, IIT Madras. So, I am going to just give glimpse of the approach what these people are carried out to estimate empirically how corrosion rate can be actually calculated. So, corrosion rate or let say rate of corrosion has got two processes; one is what I called initiation, other is called propagation.

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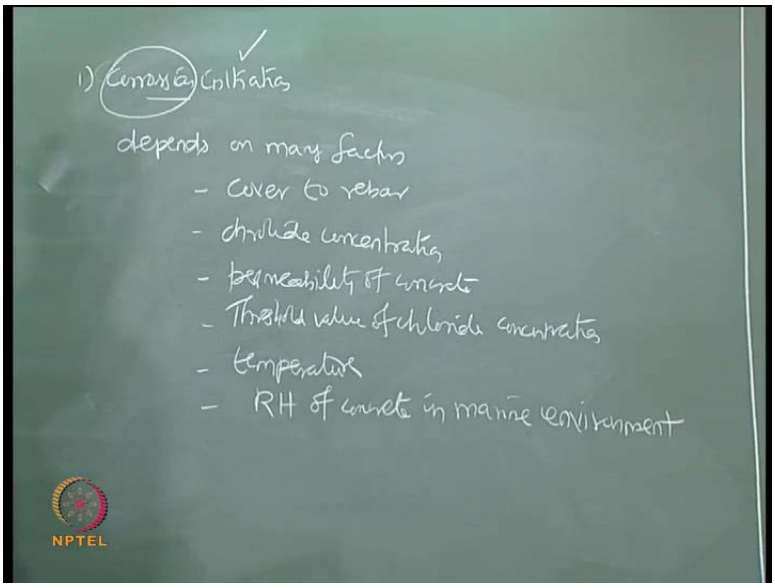

Let us talk about corrosion initiation. Corrosion initiation depends on many parameters cover to rebar, chloride concentration, permeability, threshold value of chloride concentration, temperature and relative humidity of concrete in marine environment. So, there are many factors which affect or contribute to the initiation process of corrosion.

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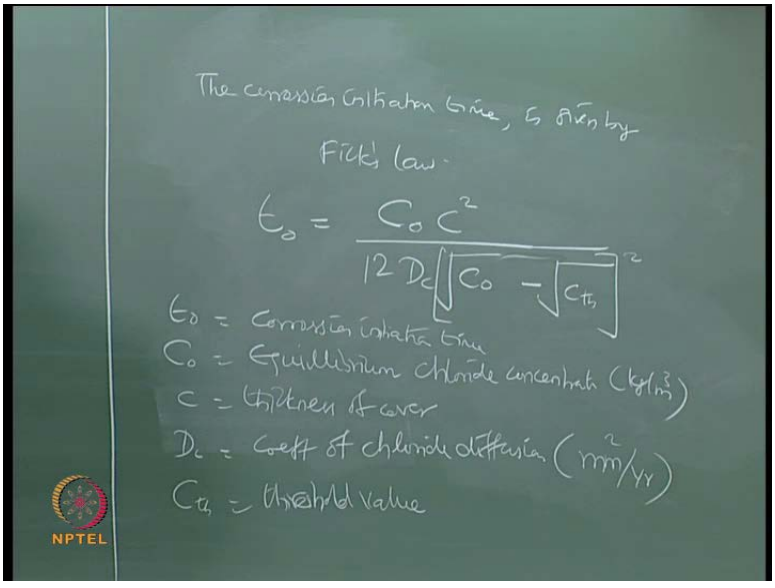

The corrosion initiation time is given by Flicks law, Fick's law, which says t naught is C naught C square 12 D c square root of C naught C threshold value. Where t naught indicates the corrosion initiation time, C naught indicates equilibrium chloride

concentration given in kg per cubic meter, and D c is a cover depth or thickness of cover. C is thickness of cover, D c coefficient of chloride diffusion, which is millimeter square per year, and C t h is the threshold value.

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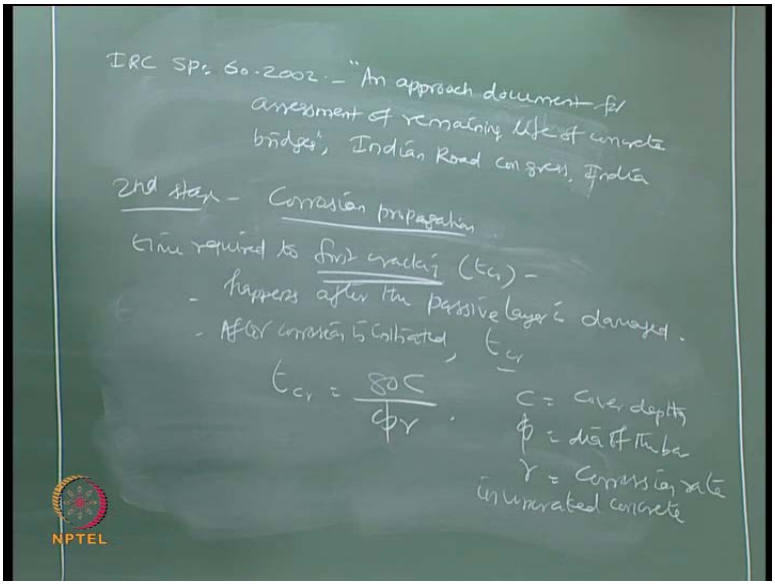

So, the reference can be seen from IRC SP -60-2002, IRC SP-2002, is an approach document for assessment of remaining life concrete bridges, Indian road congress, India. The second stage is what we call is corrosion propagation. The time required to first cracking, which we call as t c r, which happens generally, which happens after the passive layer is damaged - that is after corrosion is initiated. Then what shouldbe the time at which the first crack would occur, which can be given by where c is the cover depth, phi is diameter of the bar, and r - corrosion rate in uncracked concrete.

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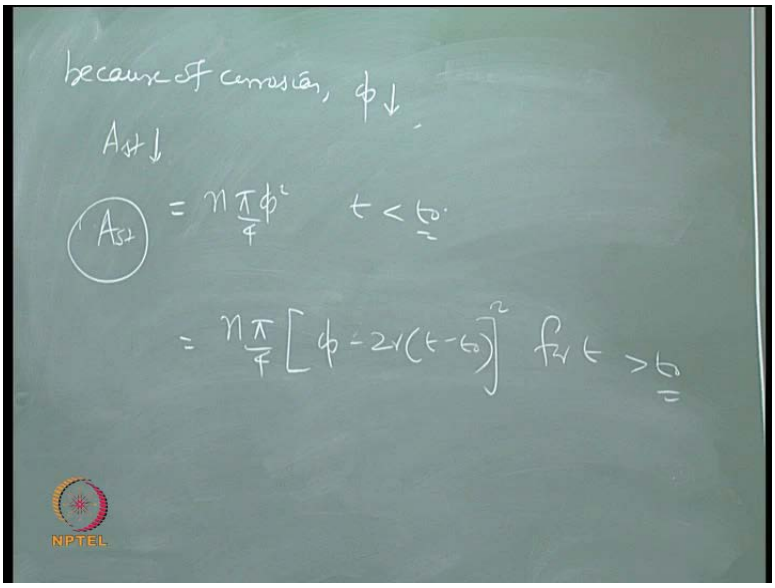

So, once corrosion initiated and propagated, because of corrosion, the diameter gets reduced and area of steel gets reduced. There is a reduction in area of steel or net area of steel is getting reduced. So, this can be computed by two equations n pi square by 4, when t is less than t naught. n pi by 4 phi minus t minus t naught the whole square, when t greater than t naught. And t naught already they are given in equation how to compute the initiation time at which the corrosion will start happen. So, from this expression, I will be able to find out the net reduction in area of steel which will affect the ultimately load carrying capacity of the member.

So, ladies and gentlemen, we discussed about how to estimate the rate of corrosion, corrosion initialization and corrosion propagation, and therefore we will now understand how to estimate the net reduction area of steel, because of corrosion happening in rebar in reinforced concrete members in marine structures or in marine environment. So, this is one of the interesting methodologies or one of the advanced techniques where one estimates the lifetime or expected lifetime a service life of a structure where we decide whether the structure is got to be restore or rehabilitated. So, it is very important to understand what is the remaining lifetime of the structure, before we decide whether structure should be repaired, rehabilitated or retrofitted.

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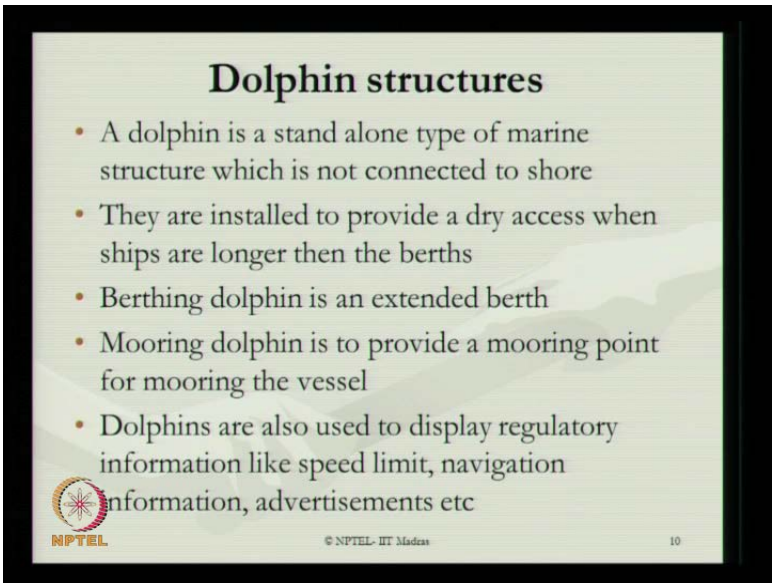

Now, down the line further, we will discuss about dolphin structures. A dolphin structure is actually a standalone type of marine structure, which is not connected to the shore. They are installed to provide a dry access when ships are longer then the berths. Berthing dolphin is an extended berth which houses vessels which are longer than the berth itself. Of course, mooring dolphins are provided as a mooring point for mooring the vessels in position. Dolphins are also used to display regulatory information like speed limits, navigation information advertisements etcetera in the sea front.

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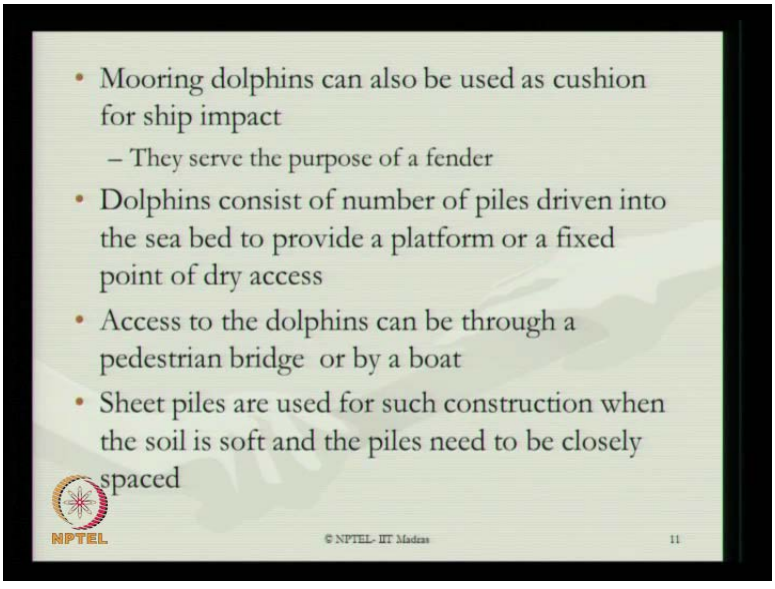

Mooring dolphins can also be used as a cushion for ship impacts; they serve the purpose of a fender. Dolphins consist of number of piles driven into seabed to provide a platform or a fixed point of dry. Access to the dolphins can be either through a pedestrian bridge or usually by a boat. Therefore, sheet piles are generally used for such construction when the soil is soft and the foundation necessarily to be deeper. Now let us talk about different type of sheet piles, which are used for such kind of foundations of dolphin structures where the soil is soft and that foundation is got to be deeper.

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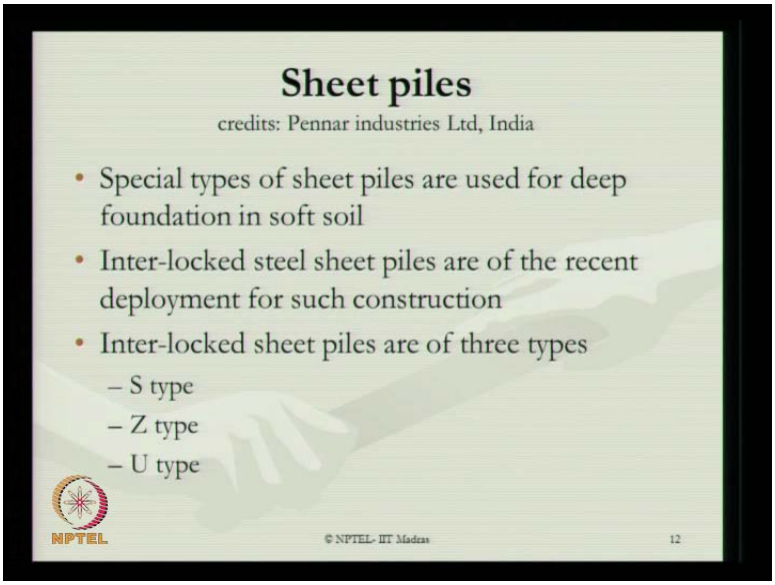

Sheet piles or special types of sheet piles, are used for deep foundation in soft soil. There are inter- locked steel sheet piles which are generally available which are one of the reason deployment of such construction. Inter locked sheet piles is essentially are of three types S type, Z type, and U type.

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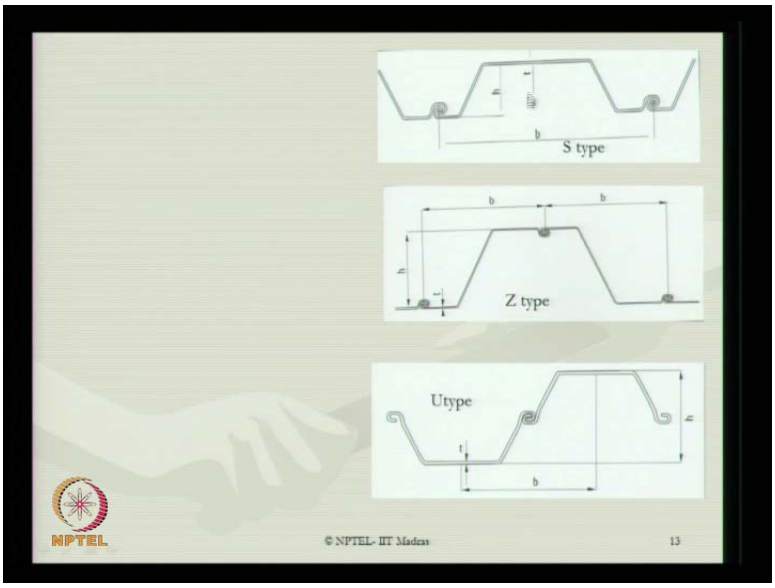

The pictures what you see now will be of different configurations geometrically. The one on the top is an S type, Z type and U type. The variables as you see in the diagram are let say for example, d, h and t.

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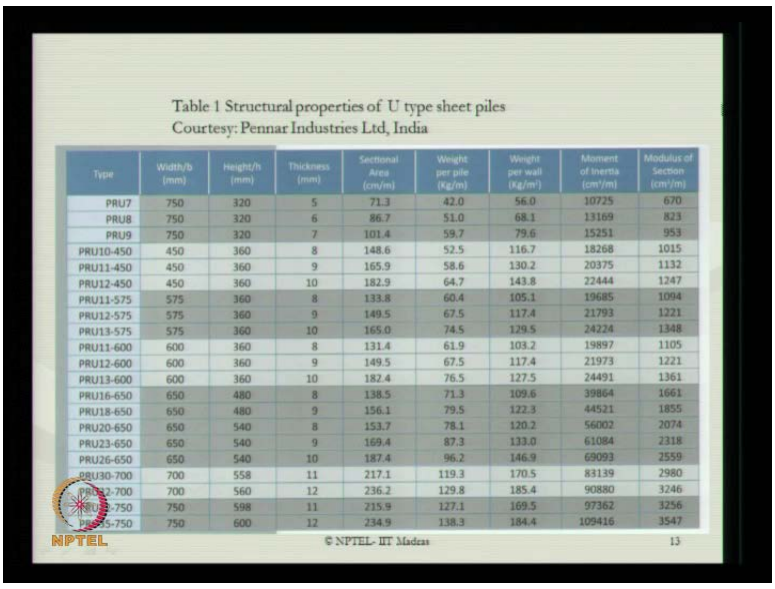

Type	Width/b (mm)	Height/h (mm)	Thickness (mm)	Sectional Area (cm/m)	Weight per pile (Kg/m)	Weight per wall (Kg/m²)	Moment of Inertia (cm⁴/m)	Modulus of Section (cm³/m)
PRU7	750	320	5	71.3	42.0	56.0	10725	670
PRU8	750	320	6	86.7	51.0	68.1	13169	823
PRU9	750	320	7	101.4	59.7	79.6	15251	953
PRU10-450	450	360	8	148.6	52.5	116.7	18268	1015
PRU11-450	450	360	9	165.9	58.6	130.2	20375	1132
PRU12-450	450	360	10	182.9	64.7	143.8	22444	1247
PRU11-575	575	360	8	133.8	60.4	105.1	19685	1094
PRU12-575	575	360	9	149.5	67.5	117.4	21793	1221
PRU13-575	575	360	10	165.0	74.5	129.5	24224	1348
PRU11-600	600	360	8	131.4	61.9	103.2	19897	1105
PRU12-600	600	360	9	149.5	67.5	117.4	21973	1221
PRU13-600	600	360	10	182.4	76.5	127.5	24491	1361
PRU16-650	650	480	8	138.5	71.3	109.6	39864	1661
PRU18-650	650	480	9	156.1	79.5	122.3	44521	1855
PRU20-650	650	540	8	153.7	78.1	120.2	56002	2074
PRU23-650	650	540	9	169.4	87.3	133.0	61084	2318
PRU26-650	650	540	10	187.4	96.2	146.9	69093	2559
PRU30-700	700	558	11	217.1	119.3	170.5	83139	2980
PRU12-700	700	560	12	236.2	129.8	185.4	90880	3246
PRU11-750	750	598	11	215.9	127.1	169.5	97362	3256
PRU12-750	750	600	12	234.9	138.3	184.4	109416	3547

So, depending upon the type of the sheet pile then the variety of these dimensions are available in the literature given by Pennar Industries Limited, India, which are one of the leading manufacturers of these kinds of sheet piles used for marine application. For example, depending upon the configuration as assessed by use chance for U type piles,

which is U type sheet piles, and different numbers are the configurations as assessed along with a specific dimension breadth, height and thickness. Of course, for a suitable chosen configuration of a sheet pile of U type shape, there are other properties available readily from the manufacturer like sectional area, weight per pile per an in meter and weight per wall per square meter area. And of course, a moment of inertia and modulus of section which are available per meter run or per meter length of the piles.

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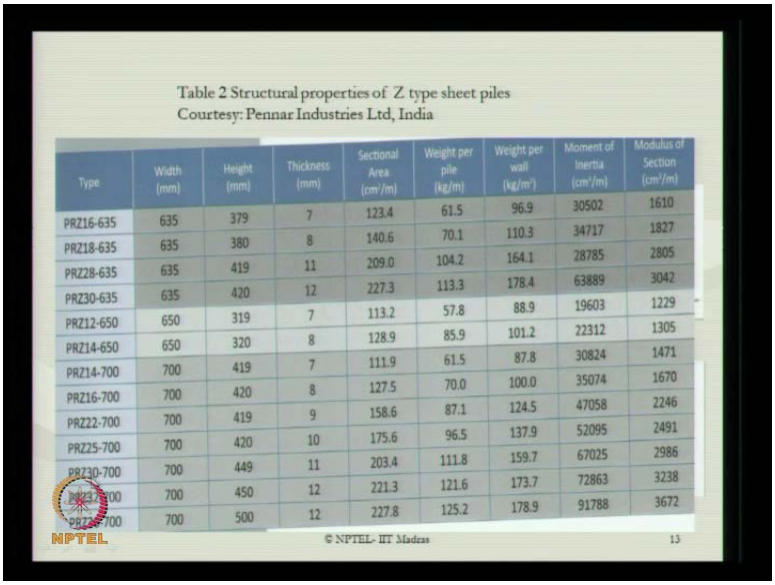

The second type of pile what we have the Z type sheet piles. Again the variables of breadth, height and thickness, and the structural characteristics of these kinds are available for different configurations as given by the manufacturer.

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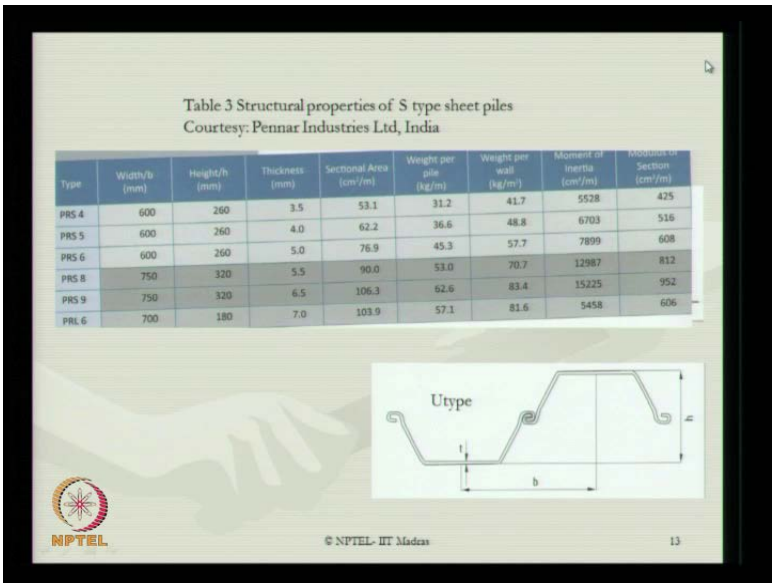

We also have these properties available for S type sheet piles available for different configurations, for different structural characteristics as given by the manufacturer.

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Now sheet piles are used in different applications as see in the photograph here. This one is of the berthing structure where sheet piles has been used in strategic application. These are the stack of sheet piles which are to be installed an available on stock as an inventory data. This is the one picture, which shows the location of sheet piles where there have

been embedded in sea, and they have been projected above the mean sea level at the low tide areas.

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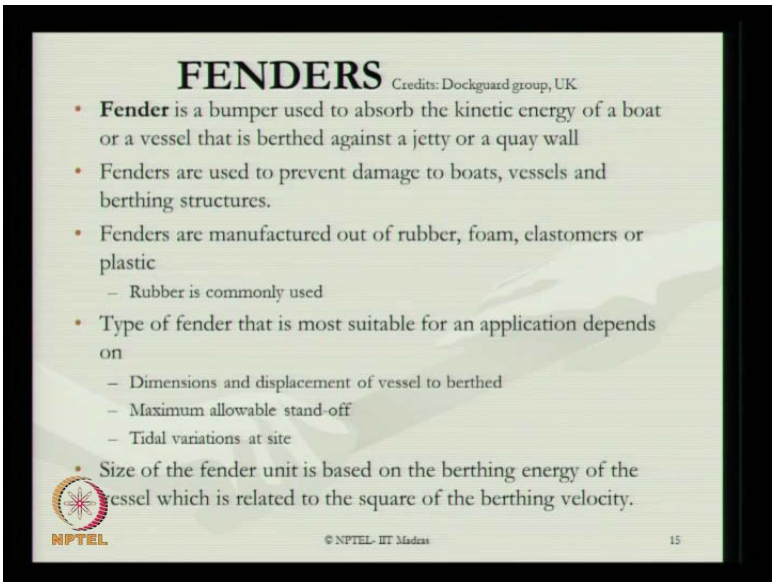

The second application, what we want to discuss it also very interestingly a replacing member in off shore structures or essentially fenders. Fender is actually a bumper which is used to absorb the kinetic energy of a boat or a vessel that is berthed against a jetty or a quay wall. Fenders are used essentially to prevent damage to the boats, vessels and berthing structures. Fenders are manufactured essentially out of rubber, foam, elastomers or plastics. Usually a rubber is a very common material used for manufacturing fenders. Type of fender that is most suitable for an application actually depends on dimensions and displacement of the vessels to be berthed, maximum allowable standoff time and tidal variations at a specific site. The size of the fender unit is based on the berthing energy of the vessel, which is related to the square of the berthing velocity.

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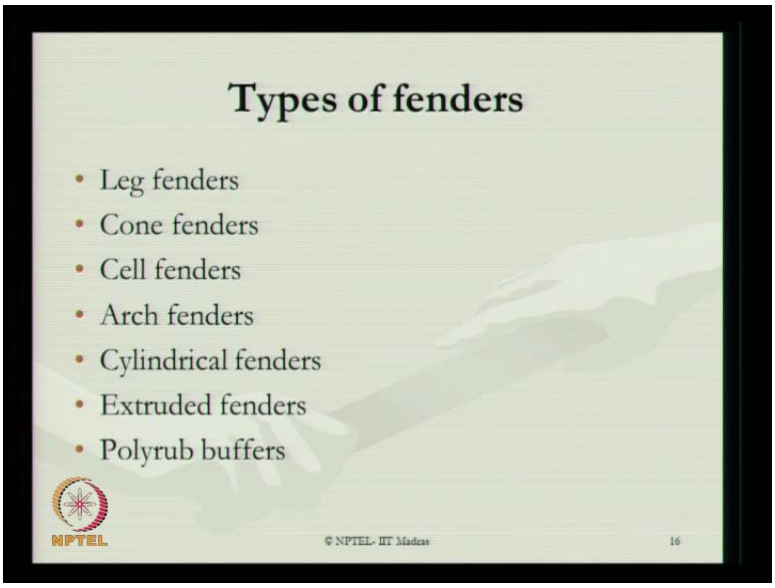

There are different types of fenders manufactured by different manufacturers in the world, leg fenders, cone fenders, cell fenders, arch fenders, cylindrical fenders, extruded fenders and polyrub buffers.

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These are the photographs where different kinds of fenders have been used in reality. You can see this is my berthing structures, in berthing face this one of the fender. Again there is a berthing face, this is another series of fenders being connected and used along

the berthing site. There is again another type of fender being used for the quay walls. These are another type of fenders, which are used in series along the berthing structure.

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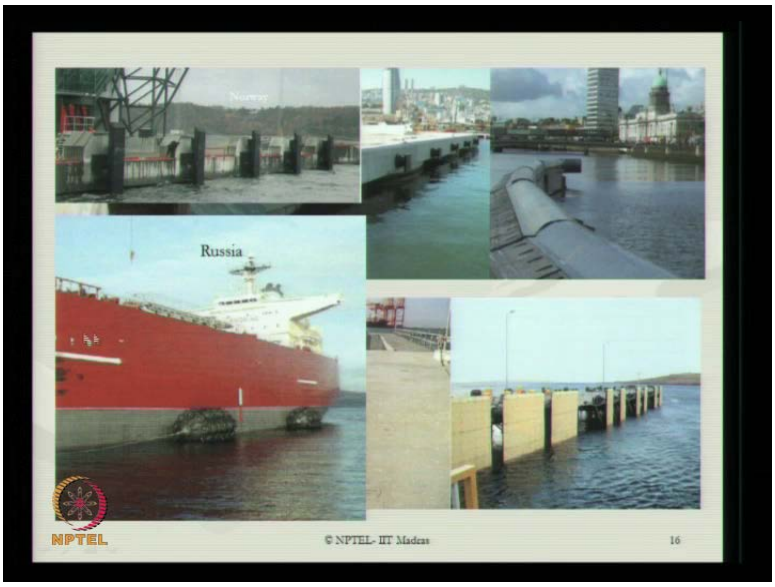

There are some classical examples where different types of fenders are also used around the world. You can see the berthing structure, where the fenders are attached to the berthing structure in Norway is one of the berthing elements. Of course, you have cylindrical type of berthing, cylindrical type of fenders used in Russia for a vessel.

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There are different kinds of fenders being used in UK, in Norway, in UK again, in UAE and of course in Italy. Therefore, fenders are of available different dimensions, different sizes, they are generally provided at intermittence spacing or sometimes they have provided continuously different shape, essentially the material what we have to see here will be either elastomer or rubber.

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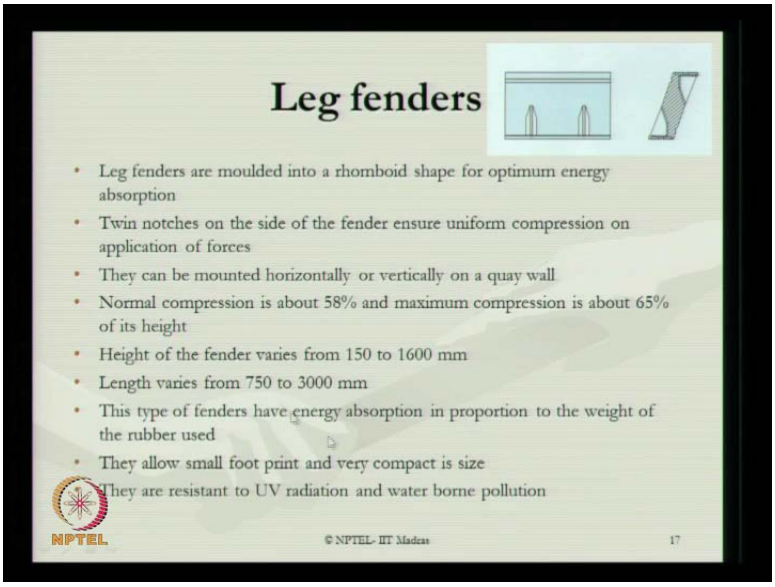

Amongst the type of venders used for berthing structures in offshore facilities, leg fenders are more common. Leg fenders are molded into a rhomboid shape for optimizing the energy absorption. Twin notches as you see in this figure or on the side of the fender to ensure uniform compression on application of forces. They can be mounted either horizontally or vertically on a quay wall. The normal compression is about 58 percent and the maximum compression is about 65 percent of that of its height. The height of the fenders vary anywhere from 150 millimeter to 1600 millimeter. The length of the fenders varies from 750 to 3 meters. These type of fenders have very high energy absorption in proportion to the weight of the rubber being used. They allow small foot prints and they are very compact in size, and they are of course, resistant to ultra violet radiation and water borne pollution. And they find very common application in most of the berthing structures.

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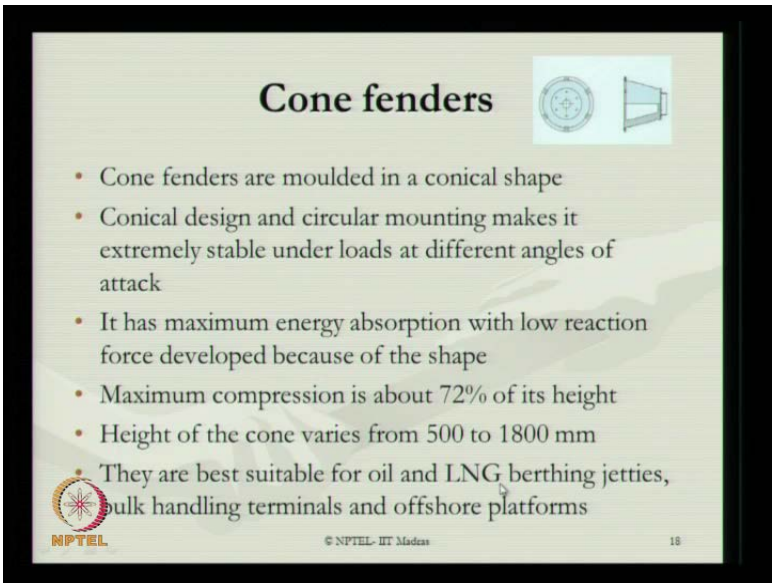

The other type of fender what we see commonly applied is cone fenders. The cross sectional dimensions is shown in the picture here. Cone fenders are molded in a conical shape as seen in the side elevation. The conical design and circular mounting makes it extremely stable under loads at different angles of attack is very important. It has maximum energy absorption with low reaction force developed, because of the shape. The maximum compression of these kinds of fenders is about 72 percent of its height. The height of the cone varies from 500 to 1800 millimeter that is this dimensions varies from 500 to 1.8 meters. These kinds of fenders are best suitable for oil and LNG berthing jetties, bulk handling terminals, and offshore platforms.

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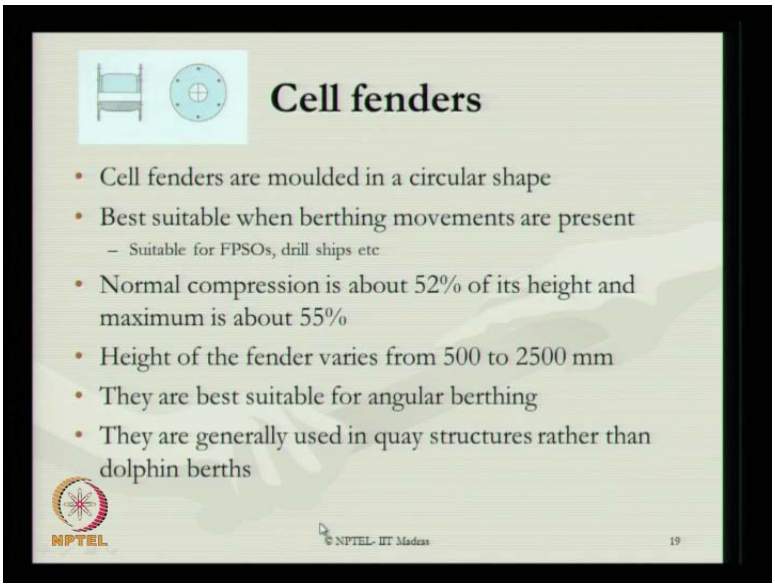

The other type of fender, which is commonly applied and used, is cell fenders. Cell fenders are molded purely in a circular shape as see in the figure here. They are best suitable when berthing movements are present. They are suitable and applicable for FPSO, drill ships, etcetera. The normal compression is about 52 percent whereas the maximum is about 55 percent of its height. The height of the fender essentially varies from 500 millimeters to 2.5 meters. These types of fenders are best suitable for angular berthing, they are generally used in quay structures rather than dolphin berths.

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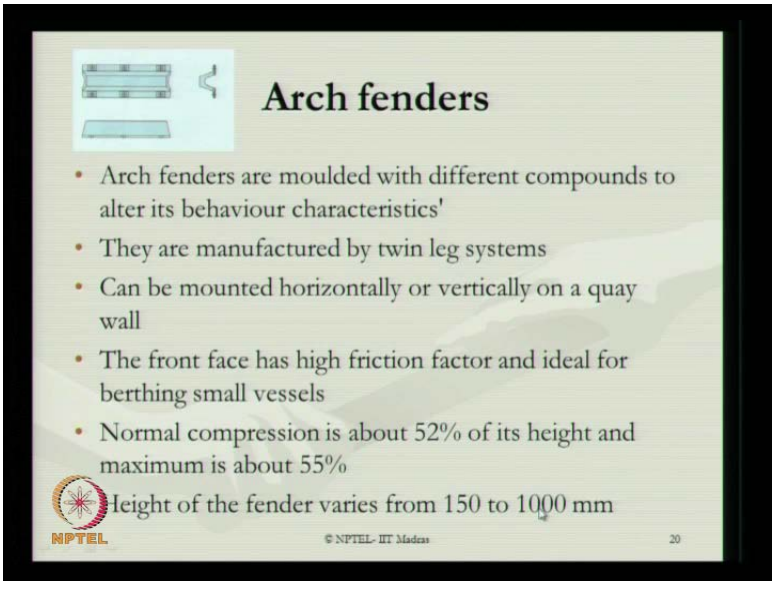

Arch fenders are also molded with different compounds to alter its behavior characteristics. They are manufactured by twin leg systems. They can be mounted horizontally or vertically on a quay wall. The front face high friction factor, which is consider as one of the major advantages of these kind of fenders and it is ideally suitable for berthing small vessels. The normal compression of these kinds of fenders varies from 52 percent of its height to the maximum of 55 percent of its height. The height of the fenders varies from 150 millimeter to 1000 meter.

So, in this lecture, we have summarized different kinds of dolphin structures, different types of sheet piles, different varieties of fenders which are all used for repair and rehabilitation of offshore structures. We also discussed different methodologies and techniques and estimating corrosion propagation and initiation parameters which essential and responsible for corrosion of rebars presented in reinforce concrete structures. So, all the modules put together module one, module two, module three and module four will help you to understand very briefly the course on ocean structures and materials. Any questions available on this course can be addressed to me at NPTEL at IIT Madras. We will happy to receive the questions and give you support externally. The website of NPTEL on this course also has test papers and tutorials, which I wish the listeners, should solve them. And any confusion arising from these questions and the key required for the questions can be always access by direct email to me at NPTEL, IIT Madras

Thank you very much for participating in this course. Thank you and best of luck.