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

Module - 3
Lecture - 4
Concrete: problems and solutions

Welcome to the lecture 4 on module 3 of ocean structures and materials, a virtual classroom under the braces of NPTEL, IIT Madras. This course had two modules already completed, module one - we discussed about variety of offshore structures and coastal structures, their applicability, suitability for various water types, their applications and their construction form, geometric style, size, dimensions and etcetera. In module number two, we also discussed about various types of construction methods and techniques, methods of laying pipelines. We also discussed about dredging equipments, which are commonly used for coastal structure and cleaning etcetera.

In module three, we will discuss about variety of material, which is actually found suitable for application of marine environment. We discussed about a basic requirements of physical, mechanical and structural properties of material which are required and which are to be fulfilled for qualifying the materials to be used in marine environment. We also discussed about variety of materials like steel, concrete, metal, and nonmetals etcetera. And we saw the few classified recommendations given by various international code based on which an engineer can easily select an appropriate material for construction of offshore structures or coastal structures.

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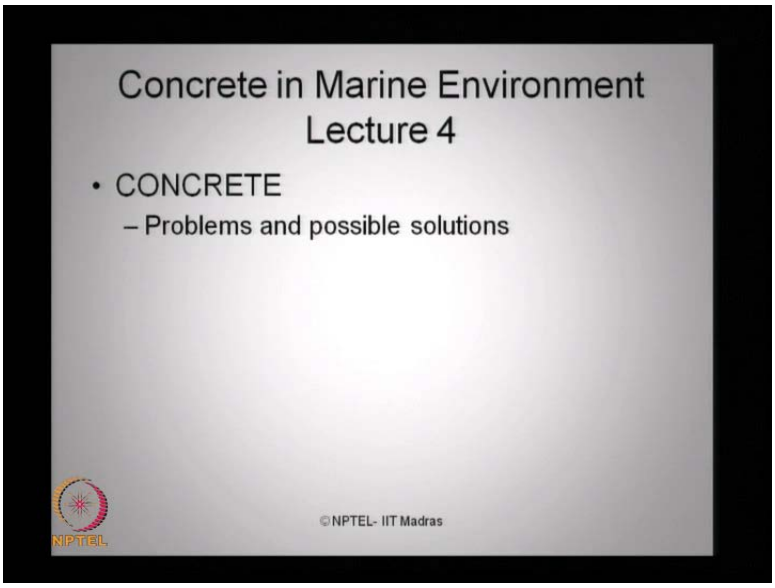

In the current lecture, we will discuss in detail about concrete problems and possible solutions which concrete has in marine environment. In the next lecture also, we will discuss about different adoptable methodology by which performance of concrete can be improved strongly.

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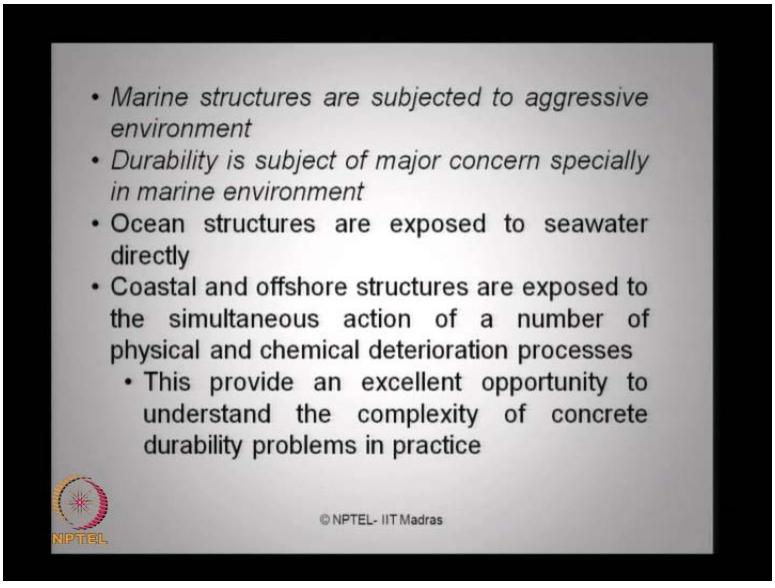

Marine structures are subjected to aggressive environment. Durability is subject of major concern, specially in marine environment. Ocean structure are exposed to seawater directly. Therefore, coastal and offshore structure are exposed of simultaneous action of

a number of physical and chemical deterioration processes. Therefore, this is an excellent opportunity for us to understand, the complexity of concrete durability problems in reality, because the environment under which concrete structure are constructed in marine environment is highly complex. Therefore, durability of concrete remains a major challenge as one of the important construction material in offshore structures. In this lecture, we will discuss about some of the problems and solutions, which can be adopted to improve the performance of concrete to particular to marine environment.

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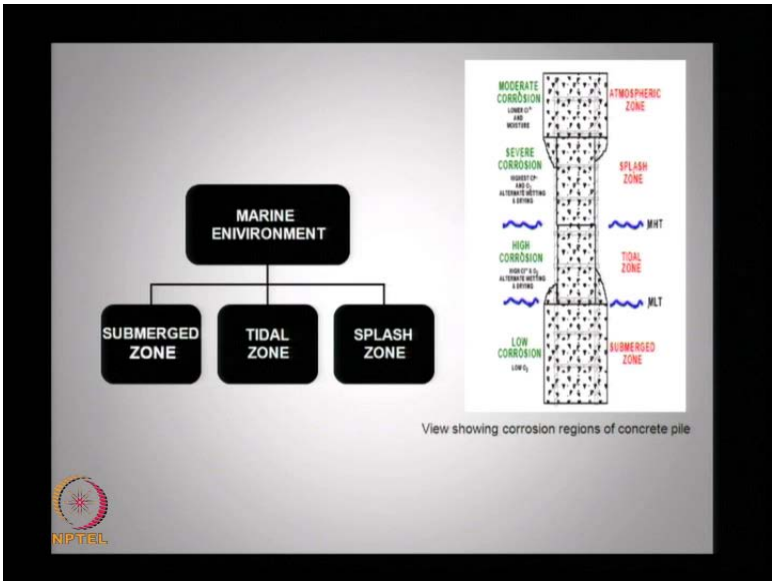

Look at different kinds of corrosion region, which are there in marine sea state. The marine environment has three major zone, which can be classified as corrosion region, or corrosion zone, submerged zone, tidal zone and splash zone. If you look at these zones has applied to single, simple concrete pile as you see in this figure. The atmospheric zone where the corrosion is highly moderate is on the top; the splash zone is the potion, which is highly above the MHT; the high tile and low tile level. And the zone between this two tile level is what I am addressing as tidal zone the one which below this what I am addressing as submerged zone.

So, ladies and gentlemen, three major zones where atmospheric zone, tidal zone and submerged zones are area of concentration where we talk about corrosions and concrete piles. If you look at the atmospheric zone as one of the important aspects, where corrosion can be studied. The corrosion in this zone is highly moderate. The main reason

is the lower chlorine content and presence of moisture. The severe corrosion takes place in splash zone, because the reason of present of Aventine's of oxygen and alternate wetting and drying is take place here.

Whereas, in tidal zone high corrosion is take place of course, it is slightly lower than that of happening as splash zone, but the corrosion is higher because the presence of chlorine and oxygen and alternate wetting and drying process. Whereas the corrosion is much lower in the submerged zone because of depletion of oxygen as you go deeper and deeper. So, a single concrete pile is subjected to variety of corrosion ranges within specific areas which is a complex problem as per as any membrane is concern concrete put to this and use has to meet lot of challenges so that improvement and performance of concrete is one of the major focus what we people address in the recent literature.

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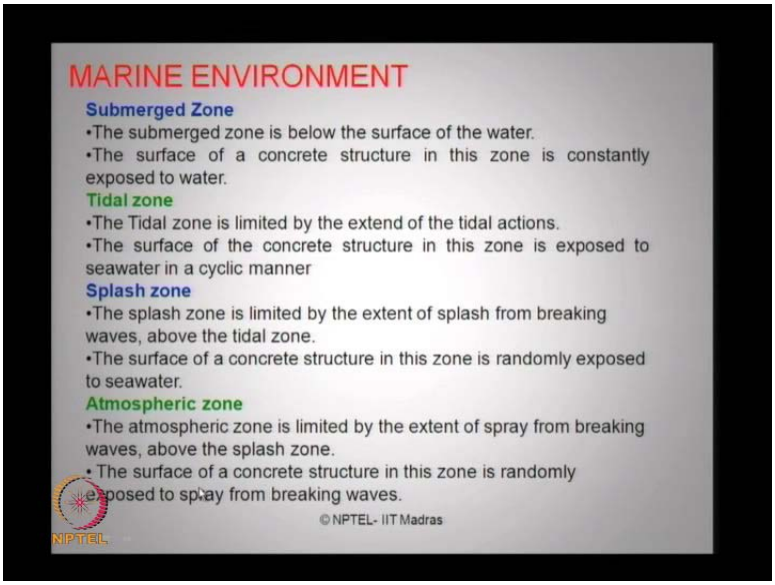

Marine environment can be discussed in different zones, can be separated or classified in different zones as you see in the current slide. We talk about submerged zones, tidal zone, splash zone, and atmospheric zone. The submerged zone is below the surface of the water. The surface of a concrete structure in this zone is constantly exposed to water; whereas in tidal zone, it is limited by the extent of the tidal actions only; it is site specific depends on the sea state in a specific site where the structure is being executed. The surface of the concrete structure in this zone are exposed to seawater in a very interesting

manner cyclic manner. Therefore, the alternate wetting and drying is take place in this zone, which is more very dangerous for concrete performance in such an environment.

When we talk about splash zone, splash zone are limited by the extent of splash from breaking waves above the tidal zone. The surface of a concrete structure in this zone are randomly exposed to seawater, because it is dependent on what is the extent of splash you have from the breaking wave above the tidal zone. Whereas in atmospheric zone, it is limited by the extent of spray from breaking waves, above the splash zone the highly limited the surface of a concrete structure in this zone is randomly exposed to spray from breaking waves therefore, the corrosion in this region is far lesser compared to that of splash zone and tidal zones. However, the corrosion in submerged zone is further lesser, because presence depletion of oxygen in this segment.

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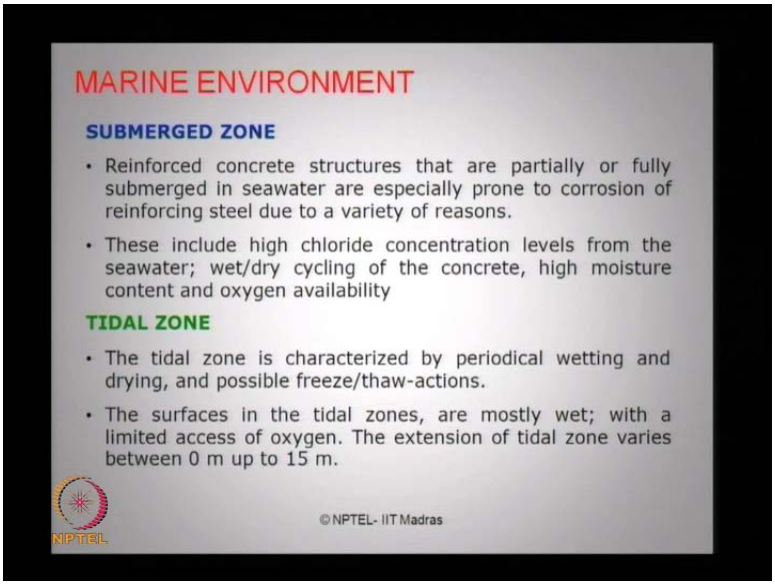

We will attend submerged zone in detai;l reinforced concrete structures are partially or fully submerged in seawater or especially prone to corrosion of reinforcing steel due to a variety of reasons. These include high chloride concentration present in deep waters, wet and dry cycling of the concrete, high moisture content and oxygen availability. There are many factors, which will contribute to corrosion, even submerged zone, where concrete is partially or fully submerged. If we talk about tidal zone, tidal zone is characterized by periodical wetting and drying and there is a possibility of freezing and thaw depending upon the region where the structure exists. The surface in the tidal zones are mostly wet

with a limited access of oxygen, the extension of tidal zone varies approximately ladies and gentlemen from 0 meters practically to 15 meters (( )) that.

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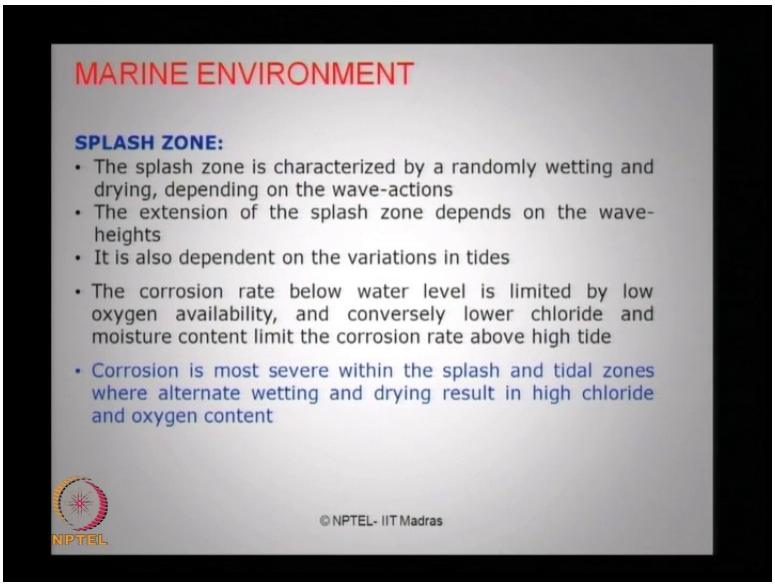

If you look at the splash zone, the splash zone are characterized by a randomly wetting and drying process. It of course, depends on the cyclic actions of waves. The extension of the splash zone depends on the wave – heights at a specific sea site, it depends on what is a wave height at which the operational design as we done for the platform. It is also dependent on the variation of tides in specific sea state. The corrosion rate below the water level is limited by low oxygen availability and conversely lower chloride and moisture content limits the corrosion rate above high tide zones. Ladies and gentlemen, the corrosion is therefore, most severe within the splash zone and tidal zone, where alternative drying and wetting take place, this result is high in chloride and oxygen concentration, which is one of the primary factor which activates corrosion in reinforce concrete especially in concrete as construction material for ocean structure.

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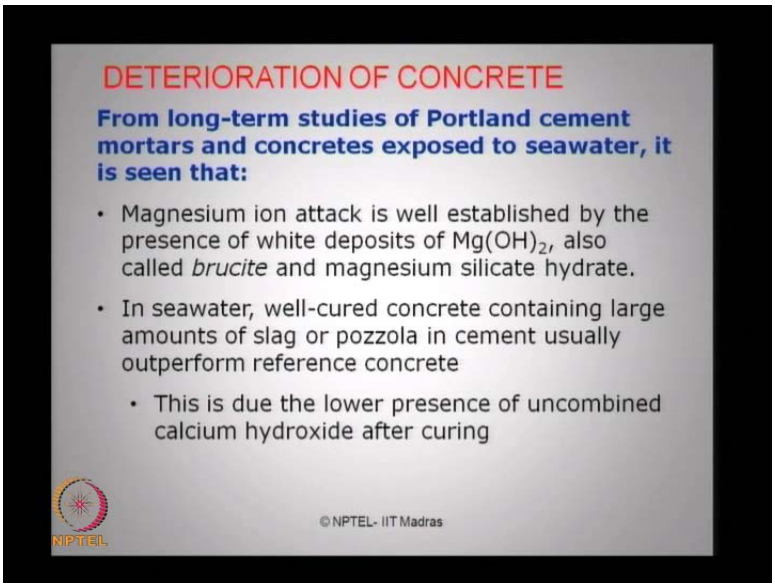

If you look at the deterioration of concrete as one of the important event, which is interesting for us to know, what are those reasons why concrete should deteriorate under marine environment? For long-time studies of Portland cement, mortars and concrete exposed to seawater, literature very clearly shows that the magnesium ion attack is well established by the presence of white deposits of magnesium hydroxide which is also called as brucite and magnesium silicate hydrates. So, the research can conducted on different white deposits, which has happen on long term expose of seawater, which clearly shows the presence of magnesium hydroxide or brucite and magnesium silicates hydrate. In sea water, a well-cured concrete containing large amounts of slag or pozzola in cement usually outperform the reference concrete that is basic reason for this. The essentially reason for this is due the lower presence of uncombined calcium hydroxide which is there after curing of concrete.

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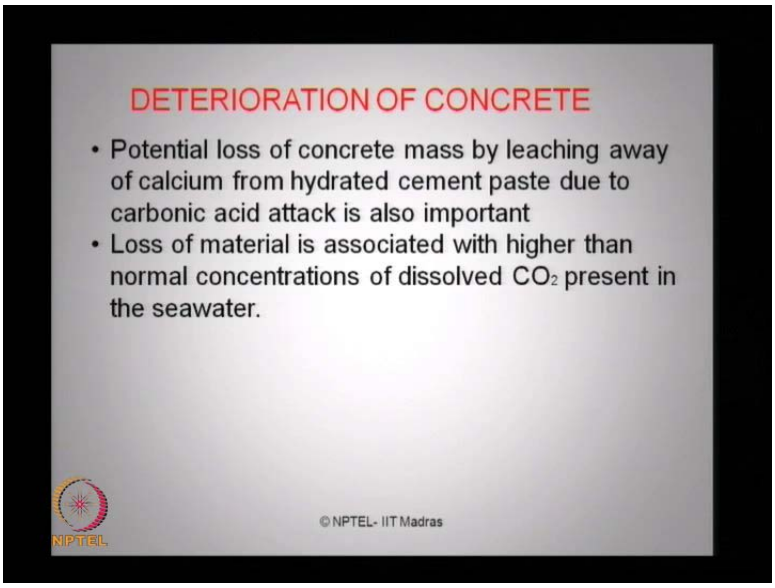

There is a potential loss of concrete mass by leaching away of calcium from hydrated cement paste due to carbonic acid attack which is also important. The dissolved carbon dioxide content any seawater is not a major concern for much chemical analysis, but that is the one of the reason, why, the potential loss of concrete mass by leaching away. The loss of material in concrete is associated with higher than normal concentration of dissolved carbon dioxide present in seawater. So one of the important factor why concrete present in the seawater has got loss of concrete mass by leaching away of calcium from hydrated cement paste.

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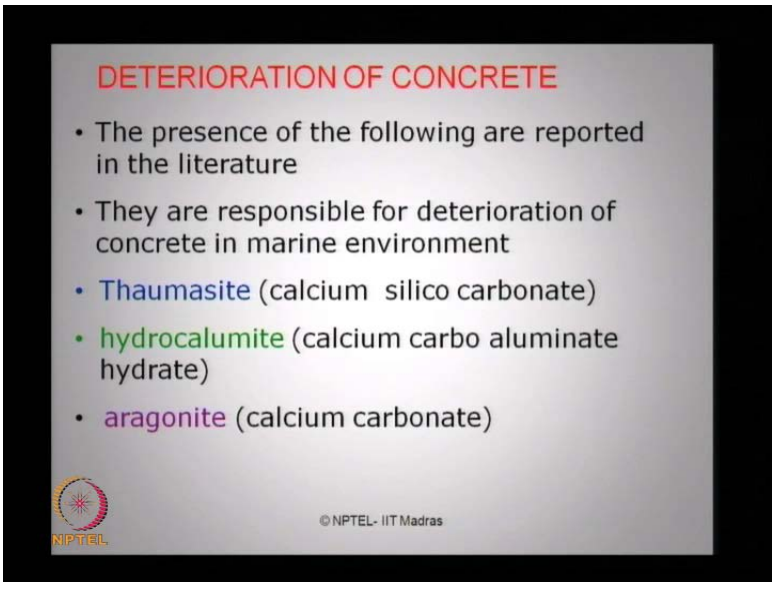

If you look at the deterioration of concrete, further in details, the presence of the following is reported in the literature. They are responsible for deterioration of concrete in marine environment. Thaumasite, which is calcium silico carbonate; hydrocalumite, which is calcium carbo aluminate hydrate; and aragonite which is calcium carbonate. Ladies and gentlemen, the presence of these three components in cement are on the surface of members exposed seawater constantly, clearly shows major reason and major concern for deterioration strength of concrete durability of concrete when the exposure to seawater.

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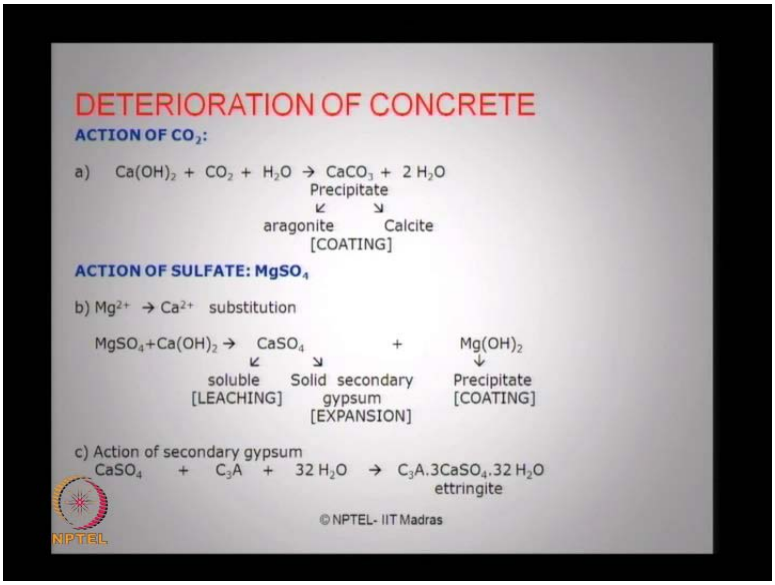

We will look quickly at the action of carbon dioxide and magnesium sulfate now in this slide. If you look at the action of carbon dioxide presence in deterioration of concrete, calcium hydroxide plus presence of carbon dioxide with water forms what we call as precipitate powder, which is calcium carbonate, is component of aragonite and calcite. They appear as the surface coating on the member, which is wet. If you look at the action of sulfates, which is magnesium sulfate, magnesium gives you calcium as substitution magnesium sulfate plus calcium hydra oxide forms as soluble leaching powder which is calcium sulfate which also forms a solid secondary gypsum which is essentially responsible for expansion of concrete in case when they subjected to seawater. Magnesium hydroxide forms the precipitate, which appears as the coating over the members on the surface. If you look at the action of secondary gypsum calcium sulfate

plus secondary gypsum in the presence of water of moisture causes what we call a ettringite as a component is outcome of the chemical reaction.

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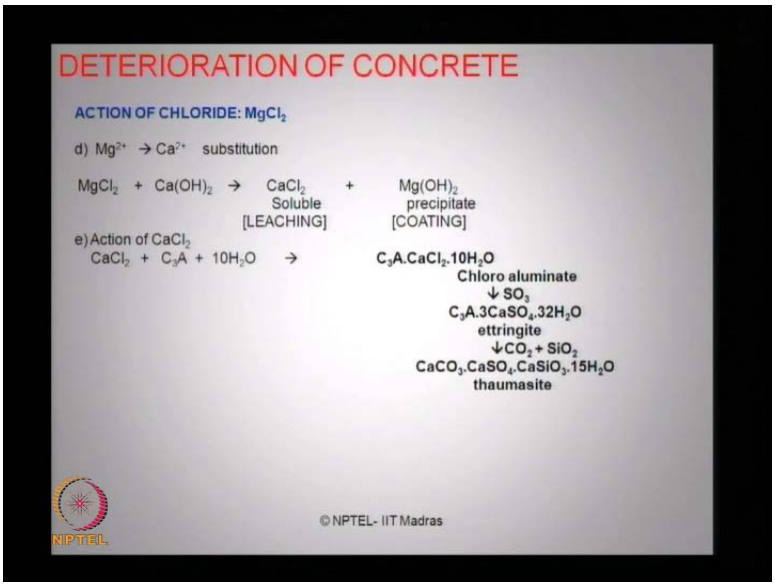

If you look at the action of chloride, it is also responsible for deterioration of concrete. Magnesium plus gives you calcium plus substitution, the magnesium chloride in the presence of calcium hydra oxide forms what we call as leaching component which is calcium chloride as well as magnesium hydra oxide which becomes a precipitate powder which appears coating over the surface. If you look at the action of calcium chloride alone, which is responsible also for deterioration of concrete, then calcium chloride in the presence of moisture, gives you chloro aluminate further added to S O 3, which gives you what we call a ettringite component which also results in thaumasite component which are highly responsible for deterioration of strength and loss of durability of concrete in marine environment.

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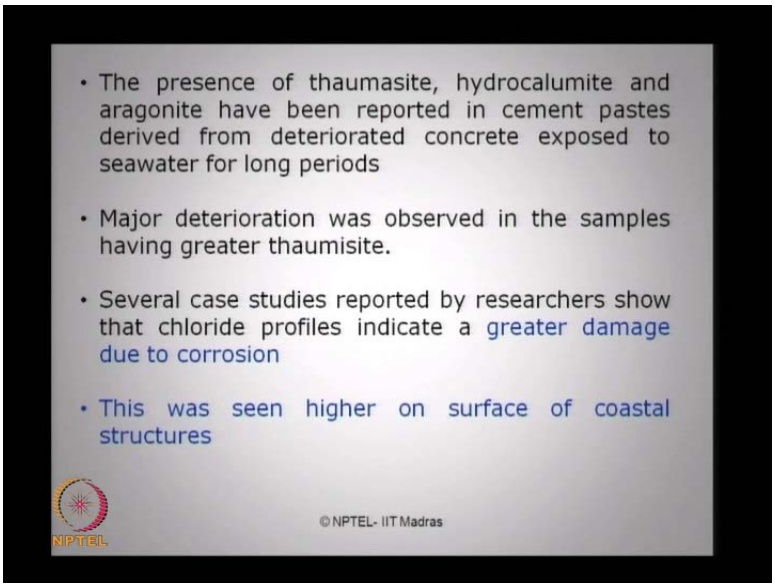

Therefore, ladies and gentlemen, the presence of thaumasite, hydrocalumite and aragonite have been reported in cement pastes derived from deteriorated concrete exposed to seawater for long periods. The major deterioration, was observed in the samples having greater thaumisite. Several case studies reported in the literature by researchers, show that the chloride profiles indicate a greater damage due to the presence of corrosion. This was seen higher on the surface of coastal structures present in the literature. All the references relevant to your studies are available in the list of research paper advice to you in the website of NPTEL, IIT Madras under the course of Ocean Structures and Materials.

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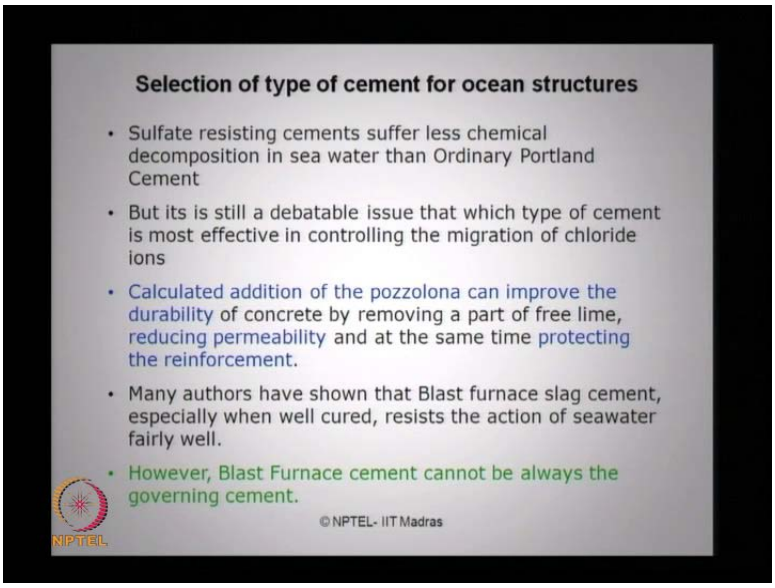

Now the question comes, as to how we understand concrete has a specific problem related to strength and durability. Can we have some guidelines related to how you select type of cement for ocean structures, because selection of important ingredient in concrete which is cement which maters much in terms of durability and strength. Let see can we have some guidelines by which I can select appropriate type or quality or variety of cement, which can be used in ocean structures. Researchers' advice sulfate resisting cements, which suffer less chemical decomposition in seawater when compared to ordinary portland cement which referred as OBC in the literature. Still it is debatable subject, because which type of cement to be used effectively in control because still the study can able to strength because the appropriate selection of cement for sea environment.

Calculated addition of the pozzolona can improve the durability of concrete; researchers have said that durability of concrete can be improved by presence of pozzolonic content provided the addition of pozzolonic content is properly calculated and then added to cement. Therefore, this calculated addition of pozzolona can improve the durability of concrete by removing a part of free lime from concrete. It reduces permeability to very high accident and at the same time protects the reinforcement to the phenomenal level. Many author and researchers have shown that the blast furnace slag cement what we call as BFC also can be used when well cured, resist the action of seawater which is fairly

well. However, blast furnace cement cannot be a only alternative cement which can be suggest for coastal structures and ocean structures.

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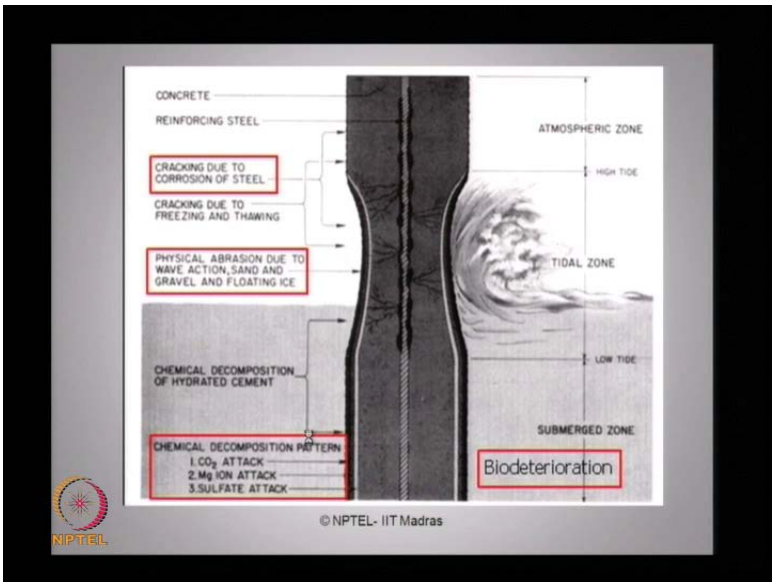

If you look at the figure, which shows be different areas where I can talk about the reasons why the corrosion or deterioration of concrete take place in the atmospheric zone, in the tidal zone, and submerged zone. Let us look at the attention of a single pile with reinforcement schematically shown the concrete cover and the reinforcing steel is what you see in the picture here. There can be cracking which can be due to the corrosion of steel in these zone which is essentially happens closer to atmospheric zone and high tide zone. Cracking can also be due to alternative freezing and thawing which can happen in certain artic regions where these structures are constructed.

Therefore, these are fundamental reasons why, they have deterioration of concrete in atmospheric and upper high tidal zone. The physical abrasion due to wave action, sand, and gravel and floating ice can be reason where we see extensive corrosion or extensive deterioration of strength and durability of concrete in the tidal zone. When we talk about the submerged zone, the chemical decomposition of hydrated cement happen in this area, the chemical decomposition pattern can be resulting in carbon dioxide attack, magnesium ion attack and sulfate attack.

So, in different region, ladies and gentlemen, we can see that how the concrete strength and durability is deteriorating due to the corrosive action presents, because of the

chemical available in seawater. This is what we call bio-deterioration instead of chemical degradation; a new name is available in this literature, because this is present in the concept of biological degradation along with the chemical present in the seawater.

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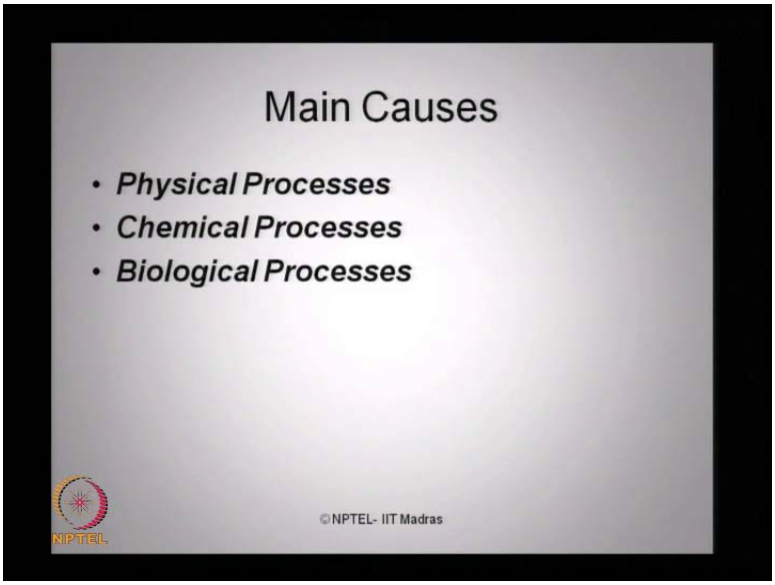

Let us look at the main causes, why this kind of deterioration happens. There can be physical processes, which are responsible for this kind of chemical attack or this kind of strength deterioration. There can be chemical process, which involve in the strength degradation of concrete when used under marine environment. There can be of course, biological processes, which are responsible for this kind of strength deterioration and durability loss.

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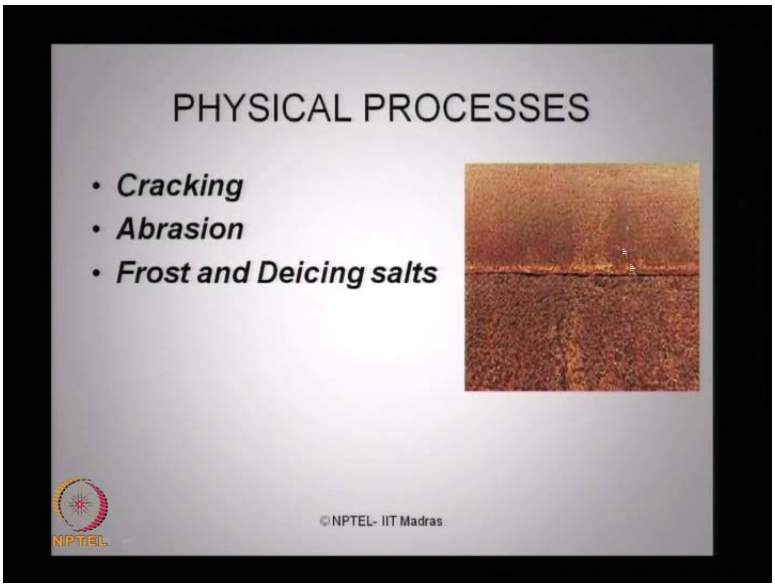

If you look at the physical processes much closer, the photograph shows you here is result of cracking, abrasion, frost and deicing salts, which are appear surface of concrete member as you see here.

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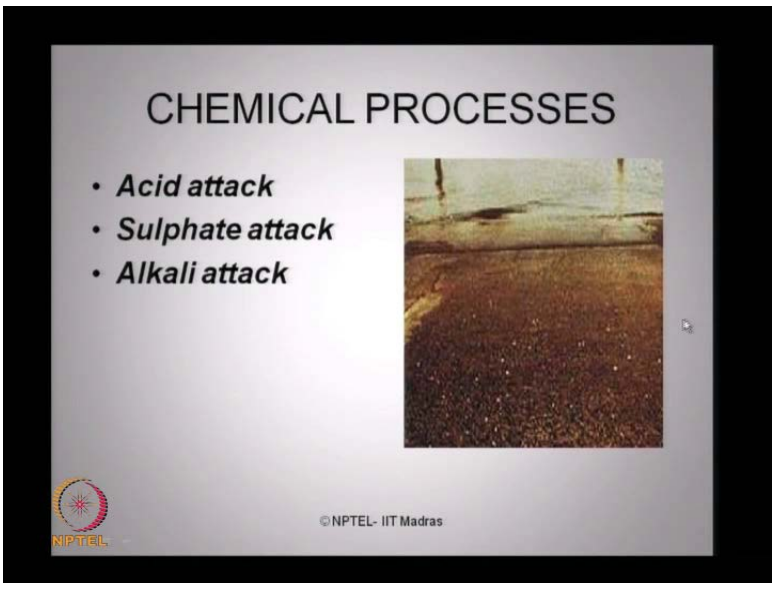

Chemical process can be resulting from acid attack, can be a sulfate attack, or can be a alkali attack, which forms a white component of white surface on the surface area of the concrete as well as parches which is having brownish and white component on the surface.

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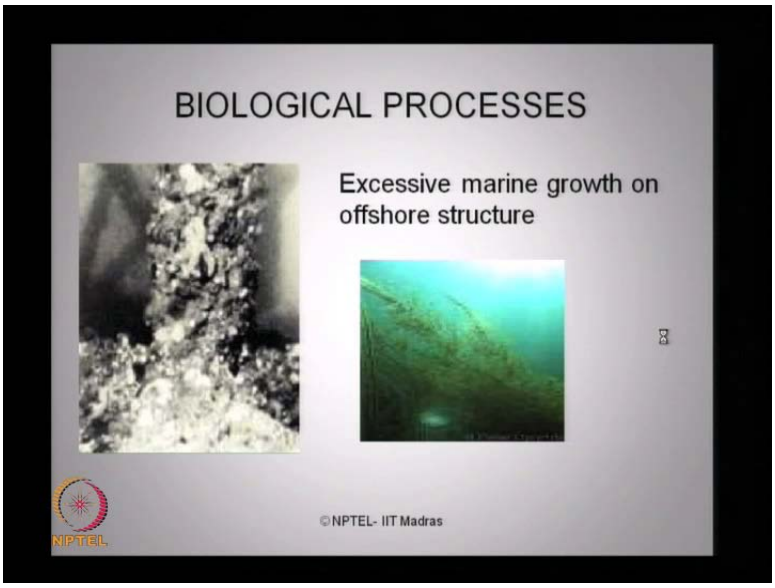

If you look at the biological process, excessive marine growth are considered to be responsible element for strength deterioration of concrete in submerged zone in particular. Excessive marine growth can be a thick as closed about 10 to 15 centimeters, which improve the diameter of the member as well, which improves specific gravity and weight and mass of the structure as well as it denies access to the concrete member for inspection and repair. So the photograph, shown to you here is the marine growth or extensive marine growth which has happen in submerged zone on along the column or along the pile of concrete members.

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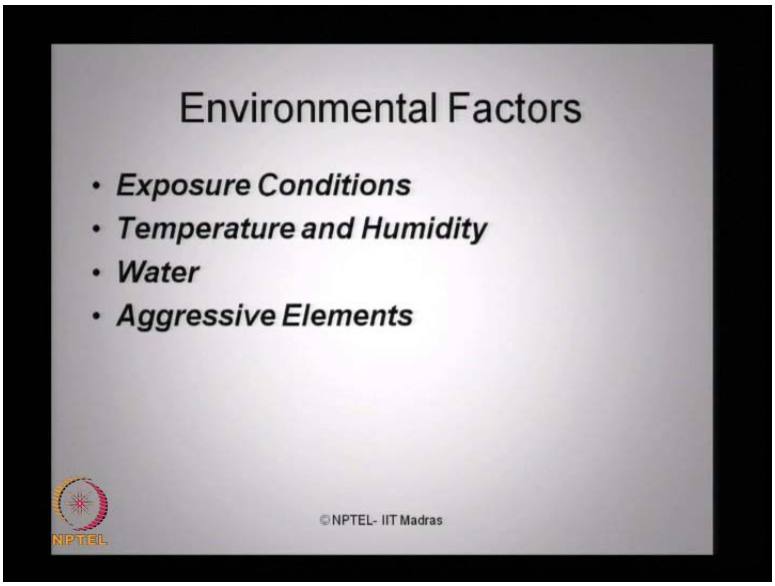

Ladies and gentlemen, now let us look at the environmental factors that are responsible for concrete deterioration or loss of strength of concrete in due (( )) of time when exposed to sea environment. If you look at the various conditions, which are responsible for this strength deterioration, one can see the exposure conditions, which are responsible for the strength deterioration. The varying temperature range which happens in sea environment and presence of humidity which also alter from the atmospheric zone till the submerged zone, it is also responsible for corrosion and other deterioration effect on concrete in sea environment. Of course, the quality of water, the chemical composition, the biodegradable mass present in water - in seawater in particular is also responsible for strength deterioration of concrete. The aggressive elements, which are chemical component presence in seawater or the chemical component, which is released during the drilling process etcetera can also be equally responsible for strength degradation of concrete, when used in marine environment.

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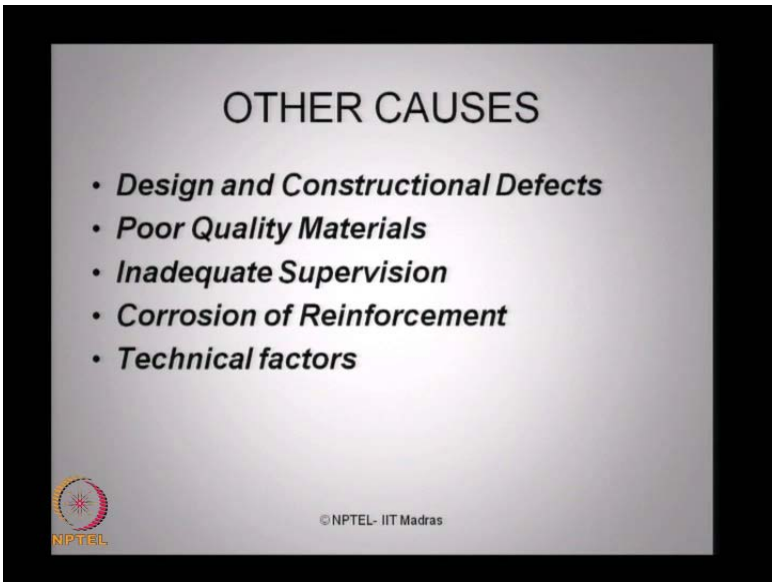

There are other causes and concrete alone cannot be blamed for loss of strength and durability. You can also have basic false in design and there can be some constructional defects, which is also equally responsible for strength loss in concrete members when exposed to sea environment. There can be poor quality material which has been used in construction, this can also be a over side in particular when you talk about the coastal structures. The reason is while using massive concrete in the water and quality control during concreting may not be effrective as good as what we do in land base structure.

So, the poor quality material can also be one of the fundamental reason why concrete degrades its strength much faster than land based structures when put under water. However, very important factor, which people have now started pay attention more in term of concrete structure in sea environment is inadequate supervision. When the super vision is not properly and technically carried out, for the construction of offshore coastal structure, ladies and gentlemen, we must agree this also lead to one of the factor, which degrades the function of concrete in marine environment.

So concrete as a material cannot be blamed alone for its strength degradation. There are many other physical factor, for example - design fault, for example - construction defects, can be poor quality materials, can be inadequate supervision, there can be corrosion of reinforcement as well. Therefore, there are all added reasons or added cause which adds to strength degradation of concrete especially in marine environment. There can be other technical factors, which can also result to or which can lead to the durability problem related concrete in marine environment.

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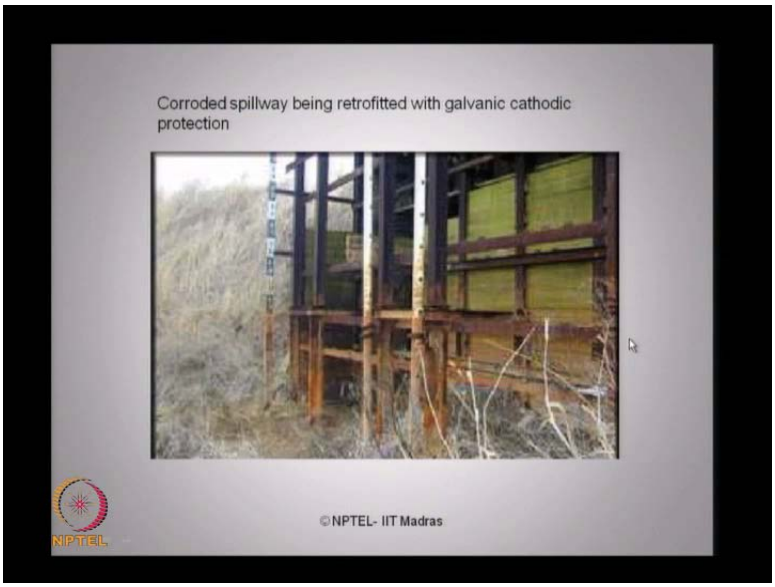

Here is a photograph what you see is a corroded spillway, which has being retrofitted with galvanic cathodic protection. So, we will talk about corrosion in detail in the following lecture, where will talk about what is the corrosion process, what are the different methods by which can be protect corrosion. Ladies and gentlemen, as we all agree, corrosion cannot be prevented, it is very difficult, because it has inherently present

in the sea environment. Of course, corrosion, can be retarded, can be slowed down or can be corrected or can be protected. So one such methodology, that has been used for corroded spillway using a galvanic cathodic protection is what you see in this photograph.

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The next important feeling what people have in terms of improving strength of concrete or performance of concrete members in sea environment is type of inspection that has to be carried out to constantly monitor the strength of concrete and durability and its performance in the progressive manner. and keep on correcting it, before it degrade much beyond the accessible level. Visual inspection is foremost redline in the inspection methodologies, what we do we will talking about this in next module - that is module four where we will talk about non-destructive testing technique in detail. We will also talk about various methods of rehabilitation and retrofitting of concrete, other type of structure in sea environment. Then we will talk about these kinds of inspection methodology much in detail.

So, visual inspection is top line redline talking about inspections. Cracking conditions exposed metal components can also be examine by different methodology by which inspection could be done. The condition of foundation is a very important aspect where I can study to improve the performance of concrete under specific environment. Amount of marine growth, ladies and gentlemen, is very dangerous phenomena where the

strength of concrete member in particular is seriously affected, because marine growth prevents and accessibility to the deteriorate surface, therefore correction, inspection, other things cannot be done.

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If you talk about a brief idea on repairs and repairs methodology of concrete. Removal of deteriorated concrete is one of the important suggestions given by people in the researches which has been practically used in many of the marine and coastal structures. Sealing of cracks using different chemical components is also been attempted by various engineers in different capacities, all over the world to provide or to improve or to establish a stable performance of concrete member especially in sea environment. Replacement of concrete, of course, a good alternative but as expensive as constructing a new structure, so rehabilitation of cause of this suggestion can be even higher than the original principal structure.

The surface treatment is a cosmetic repair what people normally do for attempting to this problem for short span of time to improve the service ability to the basic acceptable level. So surface treatment can be vapour permeable coatings or vapour barrier coatings. I am not degrading the type of surface treatments be done with the practicing engineers to protect marine structures, they are all periodic maintenance. If these maintenance of surface treatment are done essentially when you want to improve the quality control of concrete or to improve the degraded concrete is not a good idea. So, vapour permeable

coating can only allow you to give strength on a superficial site, whereas the internal integrity of these members would have been loss because of strength degradation. So it is very important for us to understand what is the level of strength degradation, before you go for any rehabilitation method which will be discussing in the fourth module of this course on ocean structures and materials. People also talk about restoration of structure where we talk about realkalisation and desalination.

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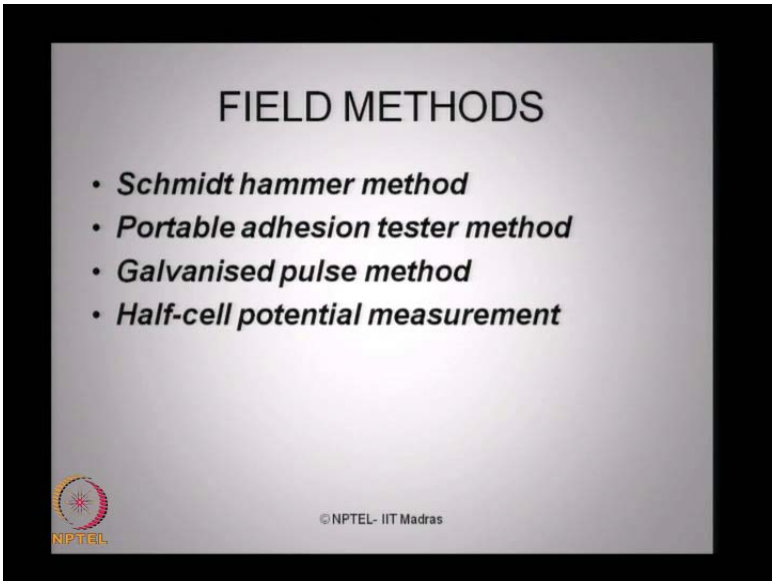

Talk about some of the field methods, which are used for instruction and improving strength and grade of concrete for marine environment. Schmidt hammer method is one of the very important technique which people commonly use. In addition to that people use portable adhesion tester method, people use galvanized pulse method and half-cell potential measurement to qualify the suitability of concrete (( )) and then recommend as appropriate treatments or appropriate methodology of repair which can be then practiced on these members with advised given to them by an experts technical board.

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Schmidt hammer method, I am sure engineers would have heard about this, civil engineer and structure engineer are use this method is very simple equipment, which (( )) strength on the surface essentially.

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Galvanic pulse method is anothertechnique, which can be used to identify the strength of concrete.

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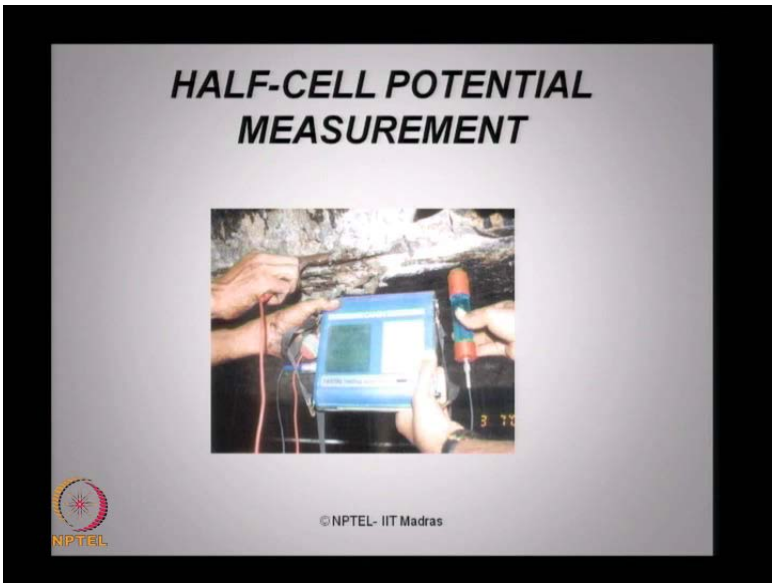

Half-cell potential measurement talks about the penetration of chlorides, which is responsible for corrosion of reinforcement.

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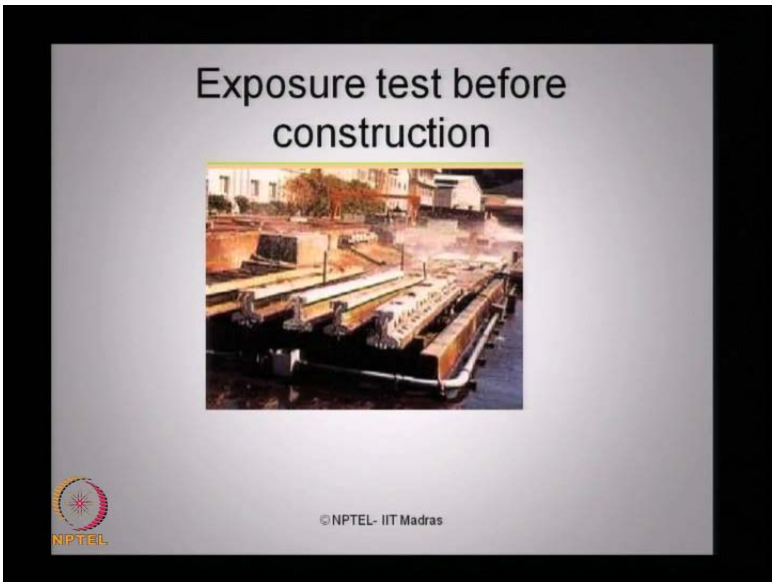

And of course, exposure test before construction is very practical method by which I tried to keep concrete members in the same environment as they will be subjected to in due course of time. Say very physical and practical method by which people will generally do these for adopting concrete in specific environment which they will be used

later. In timber or wood, we call seasoning of wood similar to that seasoning of concrete is nothing but exposing it before construction.

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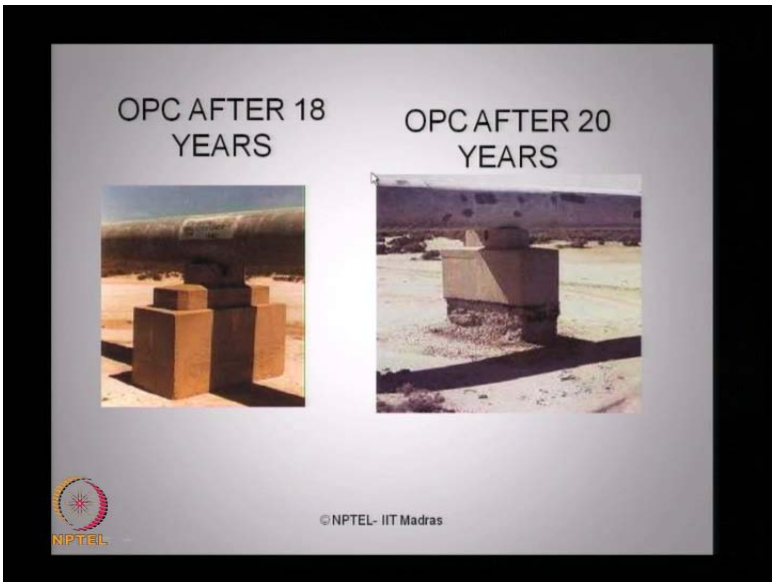

Here is the photograph, which shows you ordinary Portland cement members after 18 years and after 20 years. You see within a span of just two years, you can see lot of packets of deterioration happening, a lot of surface patterning has been attempted. So, ladies and gentlemen, with this slide, we will be closing this lecture when we are talking about concrete is one of the important materials, which can be used for marine structures and coastal applications. However, concrete has specific problem, degradation of strength and durability, which can be addressed by different techniques and methods. In the next lecture, we talk about new technique with recent advancement happen in United State talk about crystalline method of strengthening concrete.

Thank you very much.