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

Module - 3
Lecture - 3
Concrete in marine environment

… In the previous two lectures, we discussed different types of material, in general which are applicable for marine environment. We discussed about properties that are exclusively required for material to qualify them to be used in marine environment. In detail, we discussed about steel as one of the important construction material for ocean structures in the last lecture.

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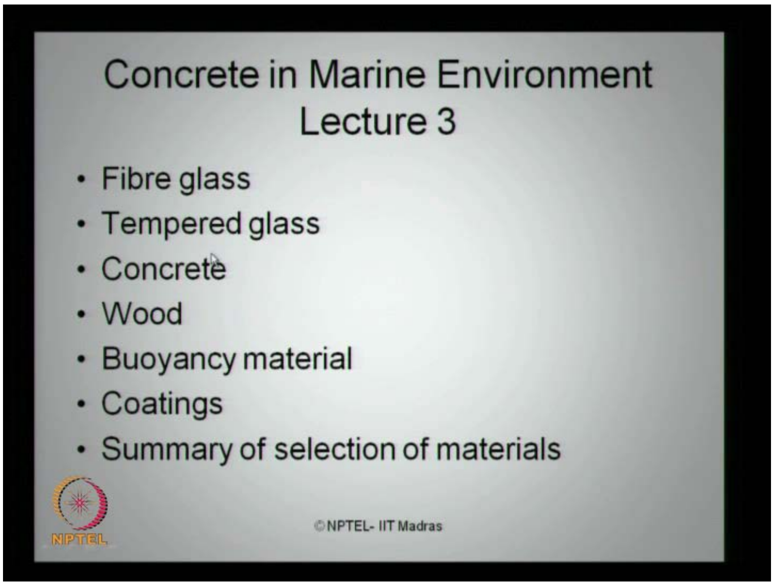

In this lecture, we will discuss about some additional material which can also be used as construction material for offshore structures. So, this lecture will focus on concrete in marine environment. In addition, we will also talk about fiber glass, tempered glass, concrete, wood, buoyancy material, coatings and summary of the selection of material in this lecture. In the next lecture, we will dedicate completely to the response behavior of concrete alone in marine environment. In this lecture, we will however touch concrete as one of the important material for construction along with other material as listed here in this slide.

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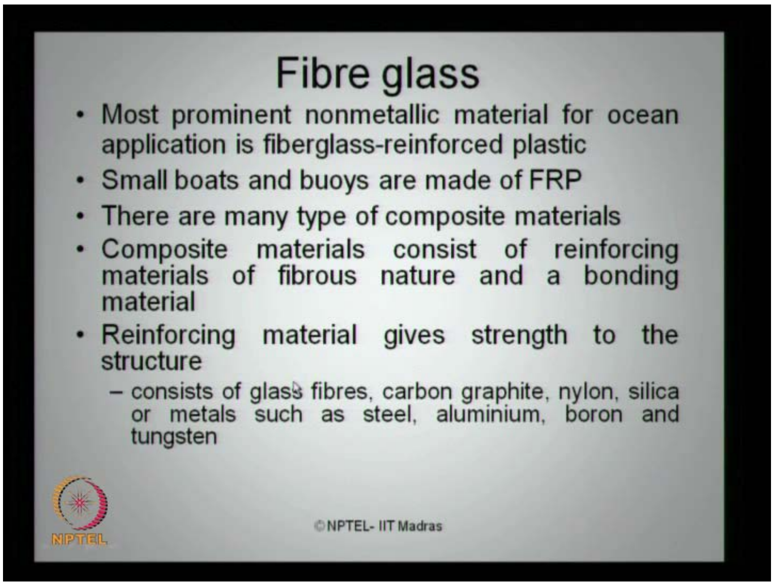

Talk about fiber glass as one of the important construction material used for marine environment. Most prominent non metallic material is a fiber glass, which can be used for ocean application. What we use in ocean application is actually a reinforced fiber glass which is reinforced with plastic. We call this as FGRP or simply FRP. Small boats and buoys are generally made of FRP. There are many types of composite material in fiber glass which are modified constituents which qualify this material for marine environment.

Composite materials consist of reinforcing material fibrous nature and a bonding material which forms on homogeneous mass which can be used as a construction material for marine environment. The reinforcing material to this kind of composite actually gives strength to the structure. Consist of glass fibers, carbon graphite, nylon, silica or sometimes metal wires such as steel, aluminum, boron and tungsten which are actually used as reinforcing material of fibrous in nature which is compiled with the bonding material to form a composite of fiber glass which can be used as one of the important construction material in marine environment.

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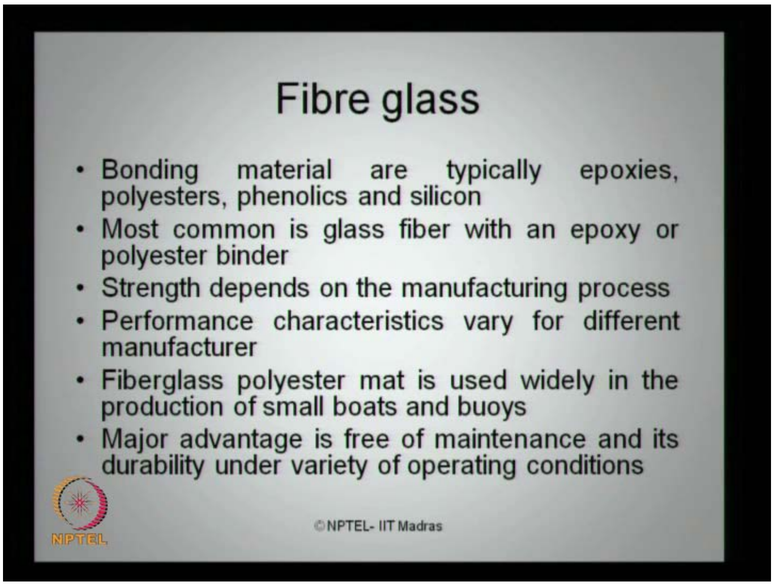

Bonding material are typically epoxies, polyesters, phenolics and silicon. Most common is a glass fiber with an epoxy or a polyester binder. Strength of this kind of composite fiber glass depends on the manufacturing process also. The performance characteristics vary for different manufactures as well. Fiber glass polyester mat is widely used in the protection of small boats and buoys as one of the classical material for construction of these kind of small vessels meant for navigation. The major advantage of fiber glass composite as a construction material in marine environment is free of maintenance, and it is durability under variety of operating conditions.

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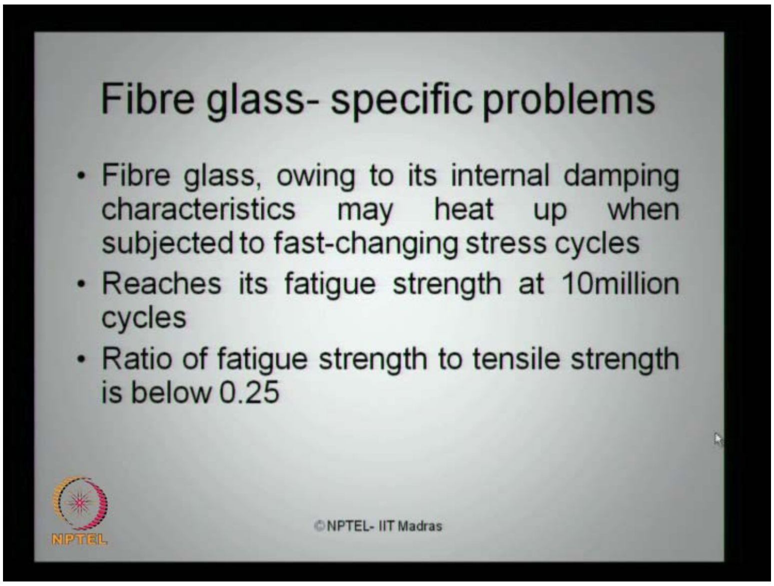

Fiber glass has specific problems which need to be addressed before we recommend this material as one of the construction material in marine environment. Fiber glass actually has a specific problem, owing to its internal damping characteristics, fiber glass generally get heated up when it subjected to fast changing stress cycles - that is one of the important demerits or one of the specific problem what fiber glass has because in offshore structural construction system, you will see there are members which will be subjected to fast changing stress cycles in those criteria situation fiber glass cannot be recommended as one of the important construction material for the systems. Fiber glass reaches its fatigue strength at 10 million cycles. What does it mean for us is that, the ratio of fatigue strength to tensile strength is as low as about 0.25; that means, the fatigue strength of fiber glass even composite is also much lower to that of the tensile strength of this fibers.

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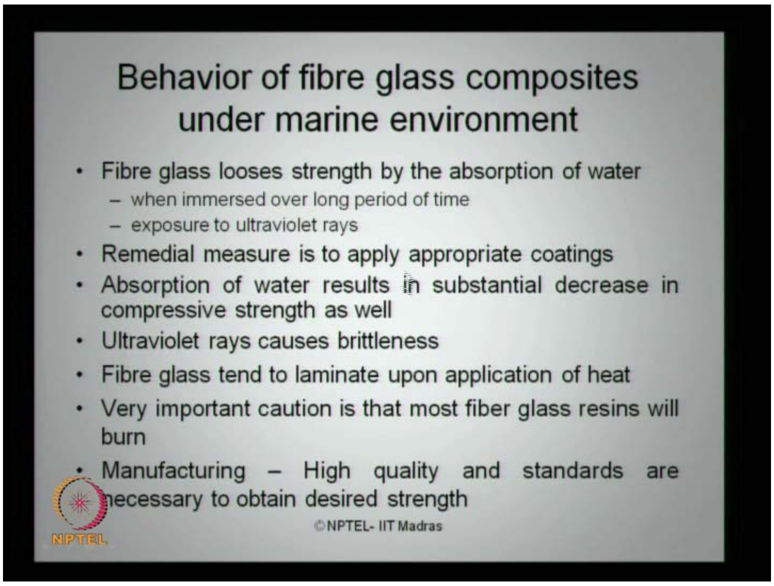

If we look at the behavior of fiber glass composite under marine environment, fiber glass loses its strength by absorption of water - when immersed over long period of time or even when it is exposed to ultraviolet rays. Remedial measure to treat this problem is that to apply appropriate coatings on this. Absorption of water actually results in substantial decrease in compressive strength also. Ultra violet rays causes brittleness to the material. Fiber glass tends to laminate upon the application of heat. Very important caution is that more fiber glass resins will burn at high temperatures. If we look at the manufacturing process, high quality and standards are necessary to obtain the desired strength and of course, the resins which are used in manufacturing fiber glass composites are effectively designed to modify the fundamental characteristics of fiber glass which suits for marine application, which can overcome few of this problems which are listed above in this slide.

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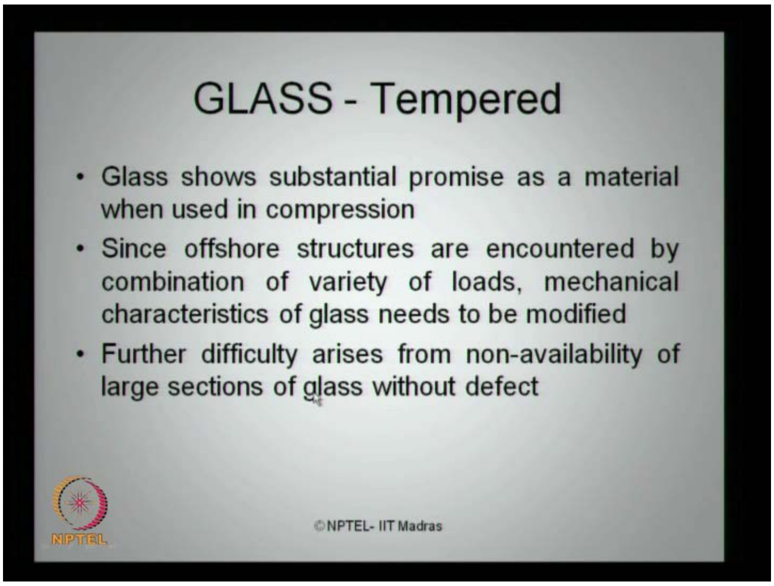

The next material can be instead of a fiber-reinforced glass or a composite we can look for what we call tempered glass. Glass shows a substantial promise as a material when used in compression; however, since offshore structures are encountered by combination of variety of loads, we cannot ensure that the member of structural component in offshore structures is subjected only one classification of loads. Generally they are always in a different combination of loads, and therefore, the mechanical characteristic of glass need to be substantially modified if you have used glass or a tempered glass as one of the construction material in marine environment. Further difficulty arises because of non-availability of glass in large sections without defect, because glass in the manufacturing process has attract, attract a lot of defects during the construction process. So, it is very difficult to have a large section of glass without defect. So, these two limitations pose tempered glass as one of the serious problem which cannot be used as directly as a construction material in marine environment.

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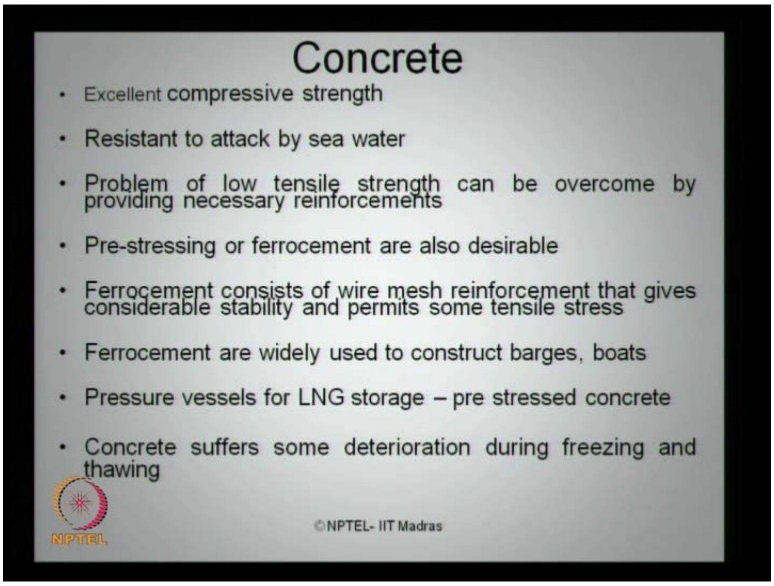

The other material which is very popular in case of, let us say, gravity based structures, in case of top deck sites, in many of the offshore platform systems, is concrete. Concrete has got many advantages, and therefore, strongly recommended as a construction material in the marine environment. It has got excellent compressive strength result resistant to attack by sea water. Problem of low tensile strength which is one of the phenomenal difficulty what concrete has is generally overcome by providing necessary reinforcements to this concrete. Pre-stressing or Ferro cement are also desirable methods of strengthening concrete. Ferro cement actually consist of wire mesh reinforcement that gives considerable stability and permits some tensile stress in concrete. Ferro cement is widely used for construction of barges and boats. Pressure vessels for LNG storage are generally constructed using pre-stressed concrete. Concrete suffers serious deterioration during freezing and thawing and therefore, one has got to be careful in treating this material if it is be used at different temperature gradients in marine environment.

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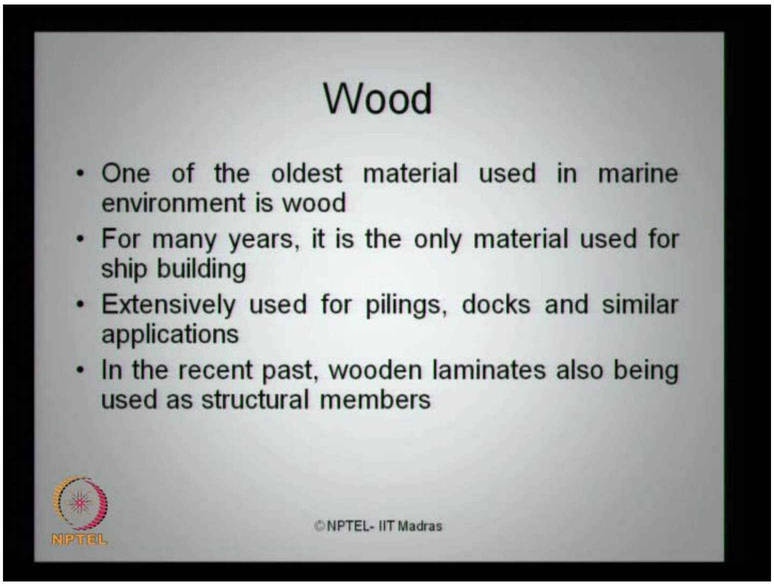

Wood is also one of the interesting and important construction material which is used in marine environment. Ladies and gentlemen, we can easily recollect that until recent times, wood has been one of the non replacement material for construction of ships. It is one of the oldest material used in marine environment. For many years basically it is only material which used for ship building. Extensively used now for pilings, docks and other similar applications in marine environment. In the recent past, wooden laminates also being used as structural members in offshore structures.

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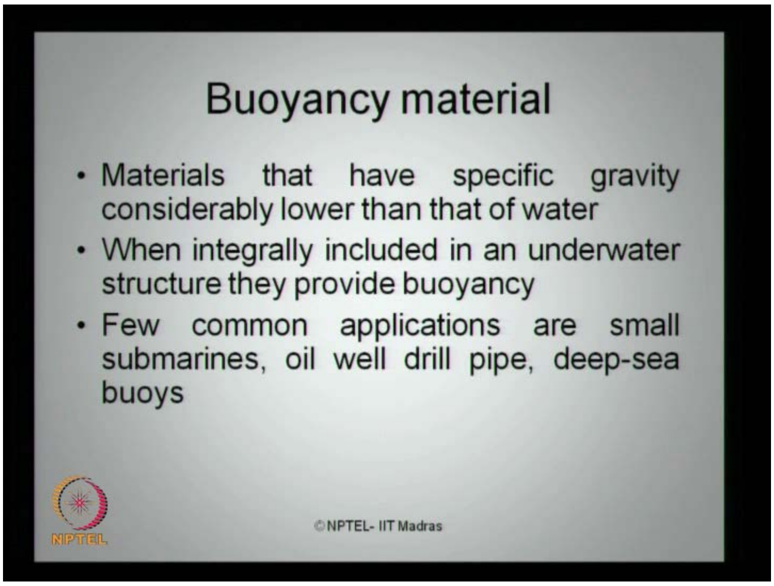

Let us look at some buoyancy material which are also used in offshore construction applications. Materials which have low specific gravity lower than that of water are generally identified as buoyancy materials. When integrally included in underwater structure, they provide enough and required buoyancy to the whole structural system. Few common application areas where buoyancy material can be commonly used are small submarines, oil well drill pipes, and deep-sea buoys.

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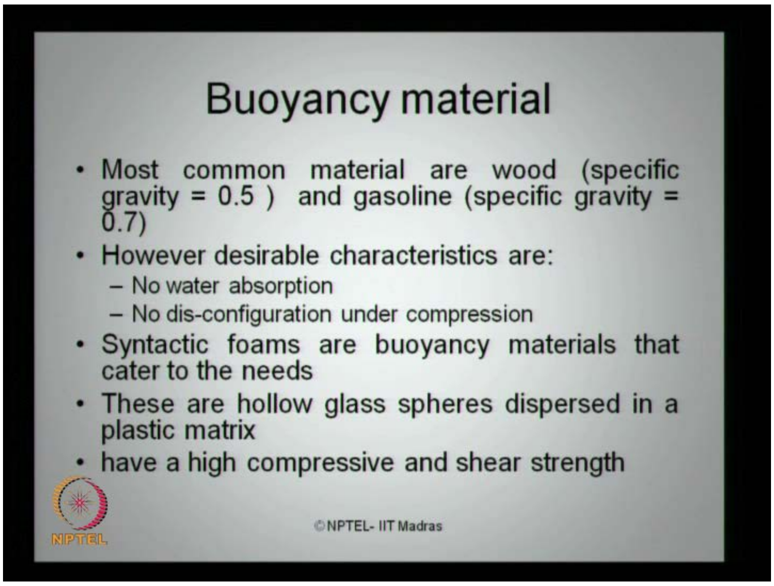

Most common material which is used as a buoyancy material is wood. The specific gravity of wood is approximately equal to 0.5; whereas, one can use gasoline also whose specific gravity is about 0.7. However, there are some desirable characteristics which a buoyancy material should posses, for example, it should have no water absorption, and it should have no dis-configuration under compressive forces. Syntactic foams are also recently being deployed as buoyancy material to cater to the above requirements. These are hollow glass spheres dispersed in a plastic matrix. They have a very high compressive as well as shear strength.

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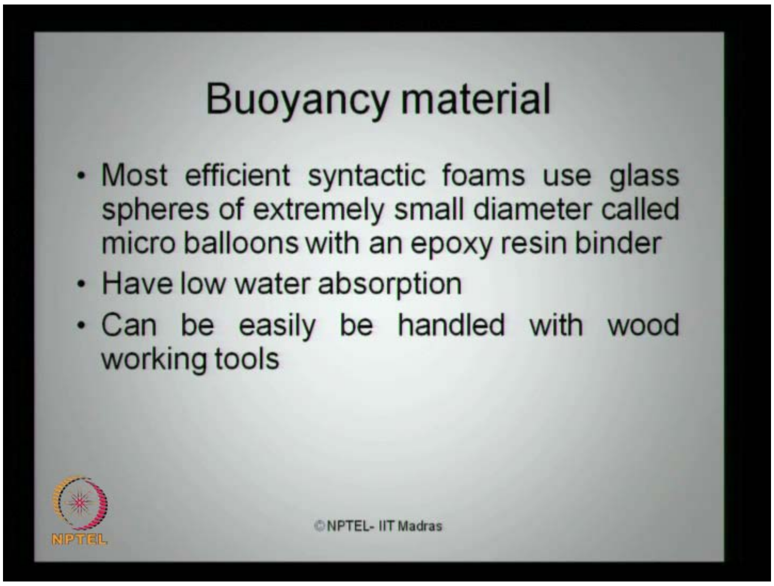

Most efficient syntactic forms use glass spheres are of extremely small diameter, they are identified in a literature as micro balloons, and of course, an epoxy resin binder is being used to form a good binding material of these glass spheres of a very small diameter we call this material as syntactic foams. They have a very low water absorption capacity and they can be easily handled with wood working tools. So, the workability or constructability with respect to this buoyancy material a syntactic forms is as similar to and as easy as that of wood. Therefore, this is one of the popular material which is being used as construction material in offshore structural system.

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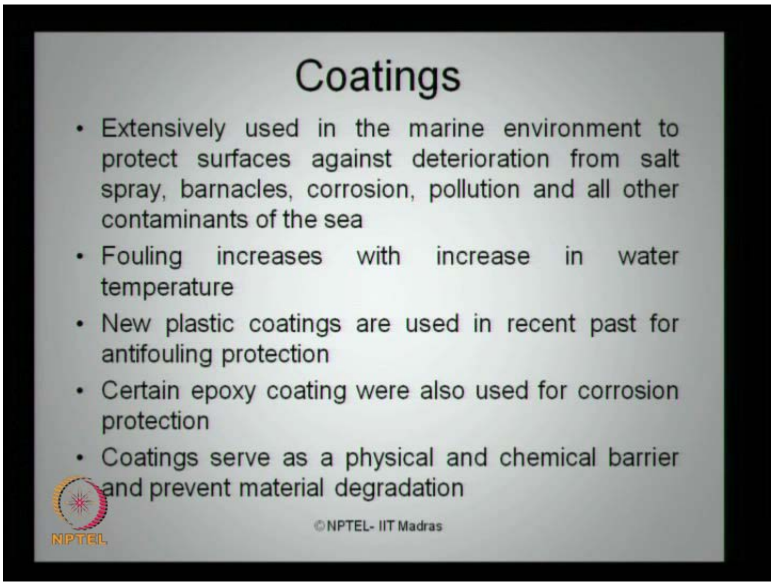

Next that comes in the list is different kinds of coatings. Ladies and gentlemen, we must understand the importance of coatings in marine environment. Coatings are extensively used in marine environment to protect surface against deterioration from salt spray, barnacles, corrosion prevention, pollution and all other contaminants which are present in seawater. The fouling increases with increase in water temperature now plastic coatings which are new recently in the literature are being used recent past for antifouling protection. Certain epoxy coatings are also used for corrosion protection as well in some of the members in offshore structural systems. Coatings actually serve as a physical and a chemical barrier and prevent material degradation in the moment they are applied in a proper format.

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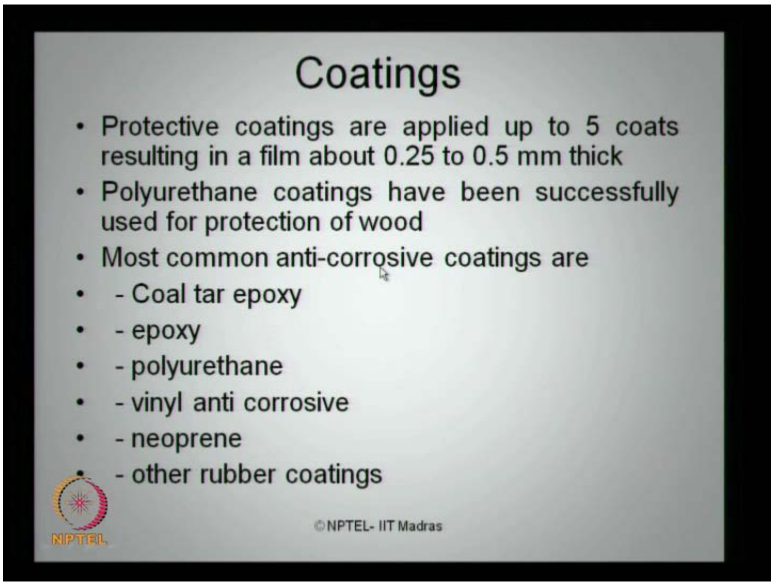

Now, what is that proper format which we must apply coatings on the members? Protective coatings are generally applied up to 5 coats resulting in a film of over 0.25 to 0.5 millimeter thick in total. Polyurethane coatings have been successfully used for protection of wood also in case of marine applications. Most common anti corrosive coatings which you can seen in the literature are listed as follows. You can say coal tar epoxy is one of the common anti corrosive coating which is being used. You can also use epoxy, polyurethane, vinyl anti corrosive coatings or neoprene coating and other rubber coatings which are found in the literature as recommended strongly as one of the possible anti corrosive agents which can be applied on members of offshore structural members to prevent it basically from action of corrosion.

Ladies and gentlemen, we will discuss the corrosion process phenomenally in detail in few lectures down the line in the same module. We will also talk about another material with an important application of offshore sector which is GRP. GRP is essentially used as one of the interesting and recommended material for construction of life boats. They are self righting, totally enclosed, motor propelled, survival crafts which are used in offshore oil industry which are manufactured using glass reinforced plastic which we call them as GRP. One important property what the GRP attains is fire retardant resins.

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The craft range of 6.2 to 8.75 meter in length which can carry about 21 to over 66 people are generally used or generally constructed using GRP as a material. The survival craft which is required to withstand about 30 meters high kerosene flames and temperature about 1150 degree Celsius are all essentially fabricated using GRP as one of the important construction material.

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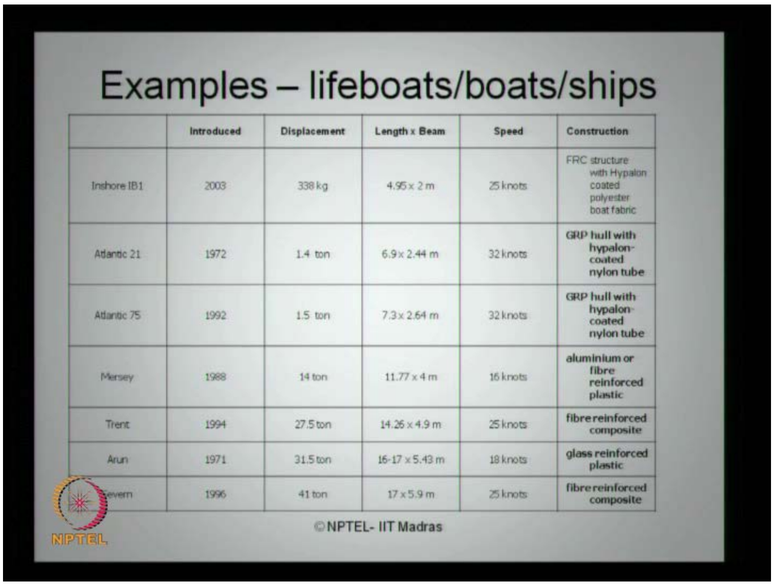

	Introduced	Displacement	Length x Beam	Speed	Construction
Inshore IB1	2003	338 kg	4.95 x 2 m	25 knots	FRC structure with Hypalon coated polyester boat fabric
Atlantic 21	1972	1.4 ton	6.9 x 2.44 m	32 knots	GRP hull with hypalon-coated nylon tube
Atlantic 75	1992	1.5 ton	7.3 x 2.64 m	32 knots	GRP hull with hypalon-coated nylon tube
Mersey	1988	14 ton	11.77 x 4 m	16 knots	aluminium or fibre reinforced plastic
Trent	1994	27.5 ton	14.26 x 4.9 m	25 knots	fibre reinforced composite
Arun	1971	31.5 ton	16-17 x 5.43 m	18 knots	glass reinforced plastic
Severn	1996	41 ton	17 x 5.9 m	25 knots	fibre reinforced composite

There are some few life boats, boats and ships given as examples in this table. For example, inshore IB 1, Atlantic 21, Atlantic 75, Mersey, Trent, Arun, Severn are some of the important names of the life boats and ships which has been used as survival craft in offshore industry. They are introduced in different years as you see here as old as 1971 to as new as 2003. They have a displacement value or weight as stating a slow as 338 kilogram to as high as even 27 or 31 or even up to a displacement of 41 tones. The size of these life crafts or life boats vary anywhere from 4.952 meter to as large as 17 to about 16 meter, 6 meter as well. They can travel in various speeds varying from 16 knots to as high as double of this which is 32 knots speed. The essential material which has been used for construction or you can see here essentially GRP are fiber reinforced composites, you also use FRC which called fiber reinforced composites which has been used essentially as one of the important construction material for construction of survival crafts or life boats and ships.

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Here is a photograph you see is the ship built with monolithic GRP, which displacement 460 tons and about 46.3 meter long.

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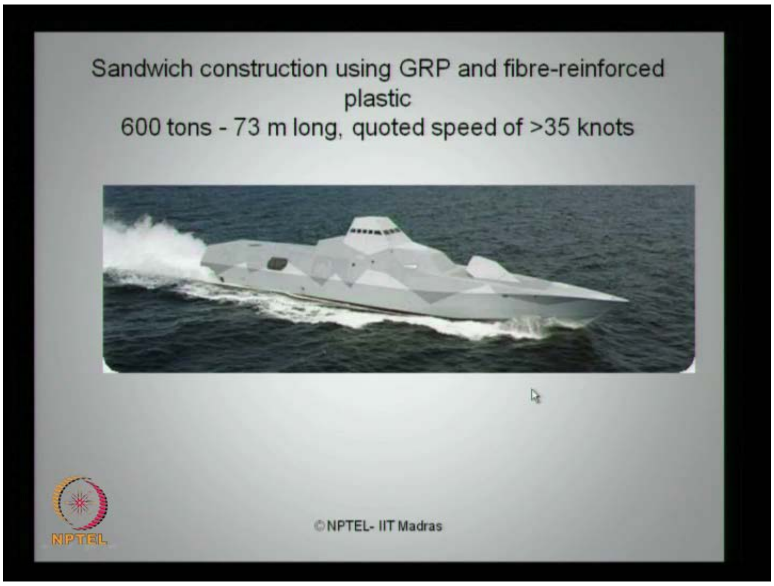

It is the another photograph a sandwich construction of GRP and fiber reinforced plastic. The displacement is about 600 tons and the length of the ship of the boat is about 73 meter long, and the quoted speed of this is about 35 knots. Ladies and gentlemen, we are strategically hiding the name of these vessels because of important naval importance, which we done in the literature.

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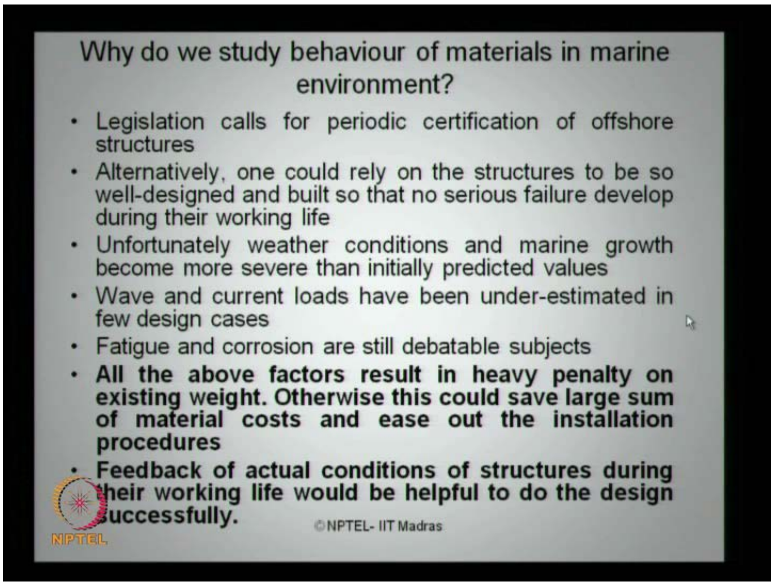

Now the fundamental question comes to our mind is why do we study behavior of materials in marine environment. What is the necessity to understand behavior of material in marine environment. Most importantly legislation calls for a periodic certification of offshore structures is very important that every offshore structure should be periodically certified for its survivability in the given sea state or in the given sea environment. Alternatively, one can rely on the structures so well designed and are built, so that no serious failure can develop during their working life. However unfortunately, the weather conditions and marine growth become more severe than initially predicted values in the design, and therefore, waves and current loads are also been under estimated in the few design cases.

Fatigue and corrosion are still a debatable subjects, which are very essential problems as well as structures in marine environment is concern. All the above factors result in heavy penalty on the existing weight of the structural system; otherwise, if we are able to predict all of them in a proper format, one can save large sum of material cost and that can be even easiness in the installation procedures as well. But since we are unable to predict all the above factors in a very high precision manner we have got account for this correction factors in the material only. Therefore, it is very essential that we must study the behavior of materials in marine environment. So feedback of actual condition of structures during their working life will be a very helpful tool to do the design successfully for structures to be design in marine environment.

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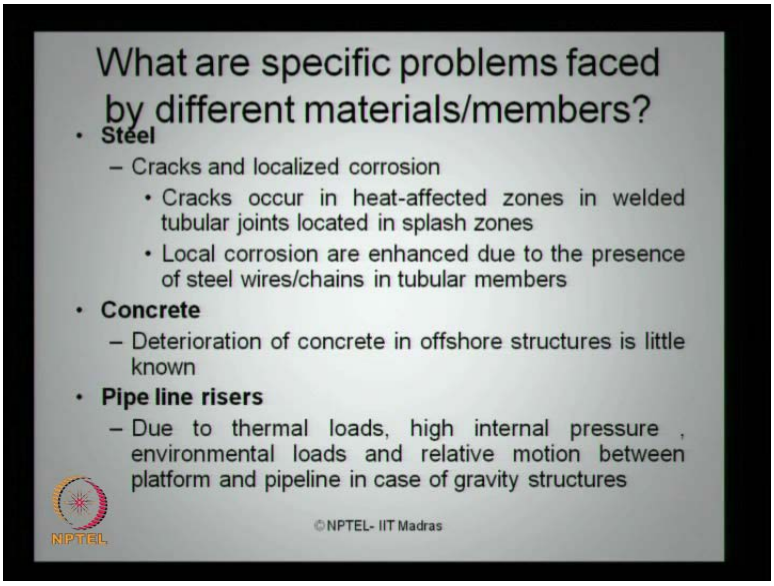

Now, the question follows is what are those specific problems which are faced by different materials or structural members, when they are put in ocean environment. It is a very interesting question which we would like to answer before we understand the variety of material which has being used or recommended for ocean environment. Let us look at steel as one of the important material, which has been very commonly applied and used in ocean environment. Steel develops cracks and it is susceptible to localized corrosion effects. Cracks occur in heat affected zones in the welded tubular joints which are located in splash zones. The local corrosion enhanced due to the presence of steel wires or chains the tubular members.

If you look at concrete as an alternate construction material for steel in marine environment, then concrete has a problem because the deterioration phenomena of concrete in offshore environment is very little known in the literature. If we look at pipe line rises as one of the important material which is being used or the member which is being applied in offshore structural system. Due to thermal variations high internal pressure in the pipe lines, environmental loads acting on the pipe line and relative motion between the platform and pipeline in case of gravity structures, they are subjected to combination of different variety of loads which are specifically not to be understood because the problem is still the research updates us the behavior of these structural members under the combination of these kinds of loads. Therefore, it becomes very critical for us to understand the material behavior under this combination of loads for any structural member for example, pipeline rises.

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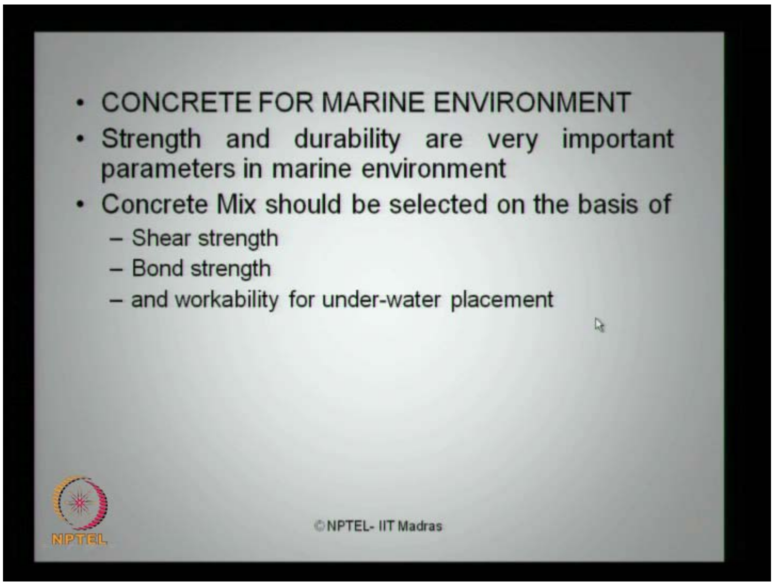

If you look at concrete for marine environment, strength and durability are very important parameters of concrete in marine environment. The concrete mix should be carefully selected on the basis of its shear strength, bond strength and workability because under water placement is one of the important criteria which we consider in mind when we select concrete for marine environment applications.

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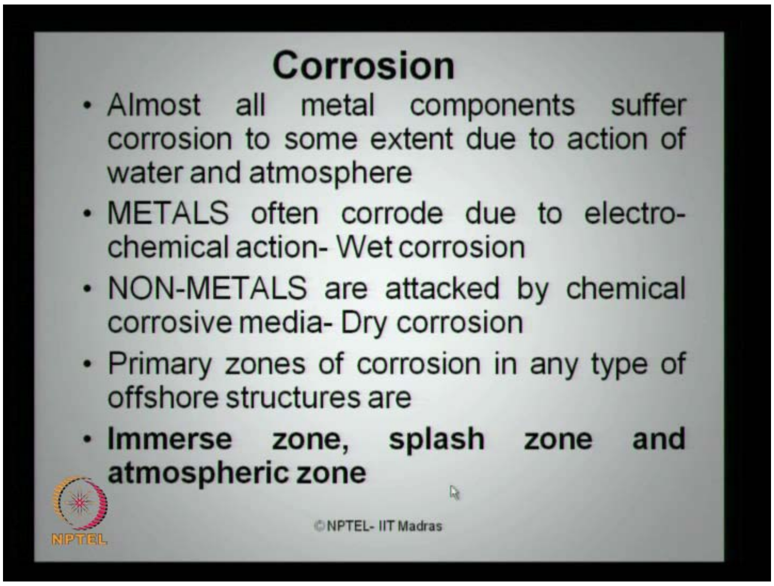

Corrosion is another phenomenal problem what the material has; essentially all metal components suffer corrosion to some extent because of action of water and environmental effects on this material. Metals often corrode due to electrochemical action what we call them as wet corrosion. Non-metals are attacked by chemical corrosive media which we call them as dry corrosion. So, corrosion is an inherent process which is present in the ocean environment, therefore effect of corrosion on metal as well as non-metallic components are always present and the effect causes a very serious problem to these materials and of course to the members made up of these materials. The primary zones of corrosion in any type of offshore structures can be the following. Immerse zone, splash zone and atmospheric zone.

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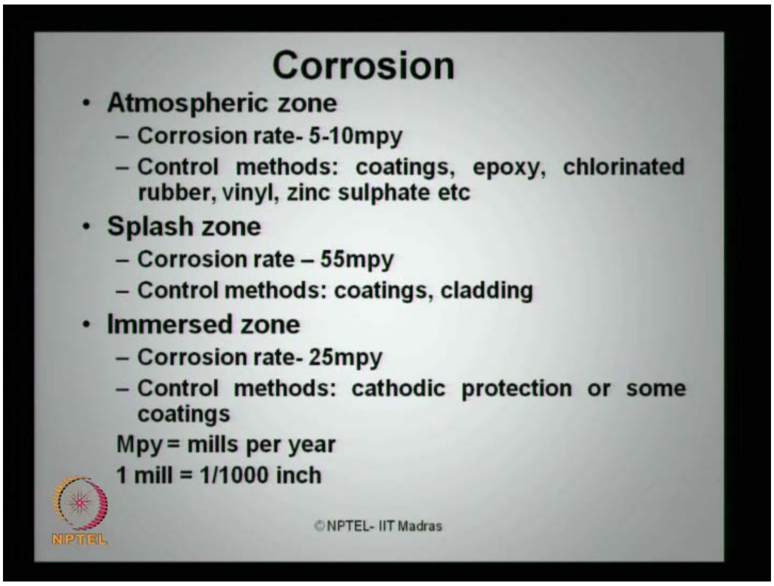

Atmospheric zone is the upper most zone layer which has got the corrosion rate however 5 to ten10 mpy that is mills per year. The control methods which are generally employed to protect or to prevent or to retard corrosion in the atmospheric zone, yes we can apply coatings, can use epoxy based resins, can use chlorinated rubber vinyl zinc sulphate etcetera. If we look at the splash zone, the corrosion rate is very high practically about five to ten times as that of atmospheric zone, so 55 mills per year. Generally the control methods are coatings and provide additional cladding. If we look at the immersed zone, the corrosion rate is half that you have in the splash zone is about 25 mpy, the control methods are generally cathodic protection or some coatings. Now in the whole literature, you will see mpy stands for mills per year and one mill is about 1 by 1000 of an inch.

So, if you compute for example, ten mills per year you will see what would be the thickness in terms of millimeter of the corrosion. So, corrosion actually eats away the parent material in terms of its thickness. As we all understand, once the designated thickness of a material in a tubular joint is lost, the member also substantially loses its strength or the member degrades from its functional purpose for which it is being designed. So, corrosion as a deteriorated process should be addressed very carefully, we a have a dedicated lecture explaining corrosion and protection measures on corrosion subsequently down the line in the same module.

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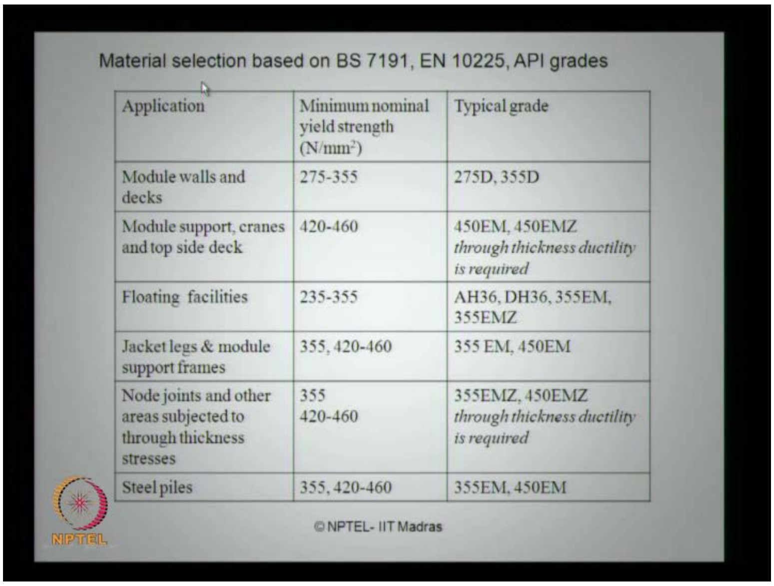
Material selection based on BS 7191, EN 10225, API grades

Application	Minimum nominal yield strength (N/mm^2)	Typical grade
Module walls and decks	275-355	275D, 355D
Module support, cranes and top side deck	420-460	450EM, 450EMZ *through thickness ductility is required*
Floating facilities	235-355	AH36, DH36, 355EM, 355EMZ
Jacket legs & module support frames	355, 420-460	355 EM, 450EM
Node joints and other areas subjected to through thickness stresses	355 420-460	355EMZ, 450EMZ *through thickness ductility is required*
Steel piles	355, 420-460	355EM, 450EM

If we look at the material selection, which is being advised by different codes based on BS 7191, EN 10225 or API grades. I have put a brief summary of different kinds of recommendations made by this international codes on material selection for different typical grades. Module walls and decks - if you look at this as one of the important application area the minimum nominal yield strength recommended by these codes vary from 275 mega pascal to 355 mega pascal. The typical grade recommended by these kinds of codes goes as 275 d to 355 d, and these numbers exactly reflect the same strength which is suggested by these codes, so 275 stands for a grade of steel which has got a minimum nominal yield strength of about 275 Newton per mm square.

If we look at different kinds of members varying from modulus supports, cranes and top side deck members then they require the higher grade of yield strength, therefore, people recommend yield strength with 420 to 460 mega pascal. Therefore, we have got these kind of grades recommended by different international codes, and of course, most important requirement suggested by these codes is that through thickness ductility is demanded from these material when they are being used for these kind of specific application. If we look at floating facilities like buoy semi-submersible etcetera, then the nominal yield strength required for the material to be used for floating facility can vary as low as 235 to 355 mega pascal. The different grades of steel recommended by these codes are listed here.

If we look at the jacket legs and module support frames in a jack up legs are in case of jacket platforms the new required yield strength steel varying from 355 to as say as 460. If we look at the nodal joints and other areas subjected to through thickness stresses then you require again yield strength as high as 460, of course, additional requirements suggested by the code is through thickness ductility is ensured or should be checked, so that they can survive the specific condition for which the stress are subjected too. If we look at the steel piles has one of the important members of offshore structural system then they require yield strength varying from 355 to 460. So, ladies and gentlemen, this table gives you comprehensive look out of how international codes recommend material for different kinds of application as a summary here.

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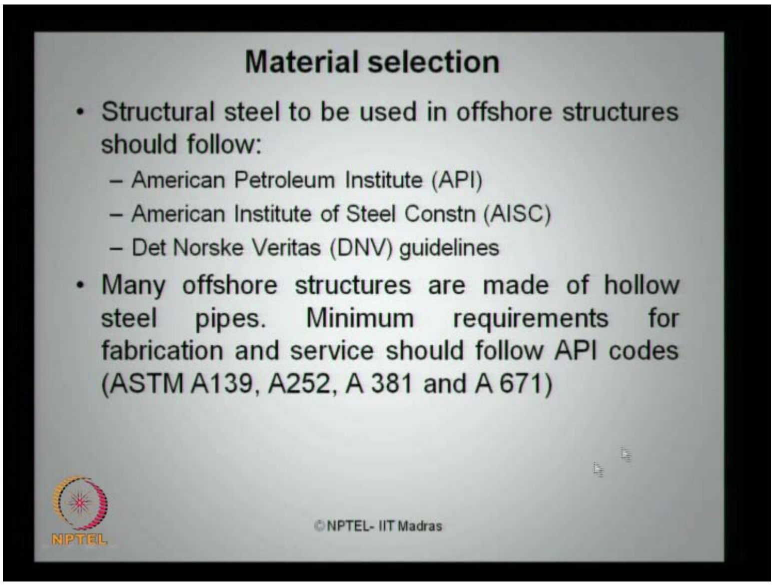

If we look at material selection as one of the important criteria in offshore structures. Structural steel if we are used in a offshore structure should follow essentially recommendations made by API or AISC or DNV guidelines. Many offshore structures are made of hollow steel tubes, the minimum requirements of fabrication service should follow API codes as ASTM A 139, A 252, A 381 and A 671 mandatory requirements to qualify them to be used in offshore structures.

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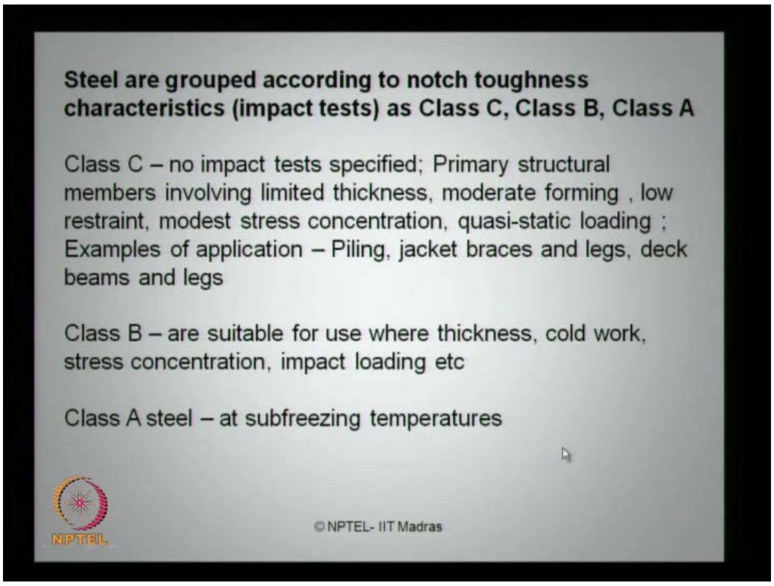

Steel are also grouped according to the notch toughness, characteristics as important in impact tests. We have already discussed in the last lecture, I want it to strike to elaborate more on the notch toughness specified by different test. As we see steel can be grouped as class C, class B and class A; A is applicable at subfreezing temperature; B is applicable for material where the thickness cold work stress concentration impact loading can be overseen in the design. Whereas, class C is applied only when no impact tests are specified, it is used for primary structural members involving limited thickness, moderate forming, low restraint modest stress concentration and quasi static loading. The example can be a piling or a jacket braces and legs, deck beams and legs etcetera. So, you will see in case of selection of steel or grouping of steel being international codes notch toughness are impact test serves an very important purpose I will come to that in the next slide.

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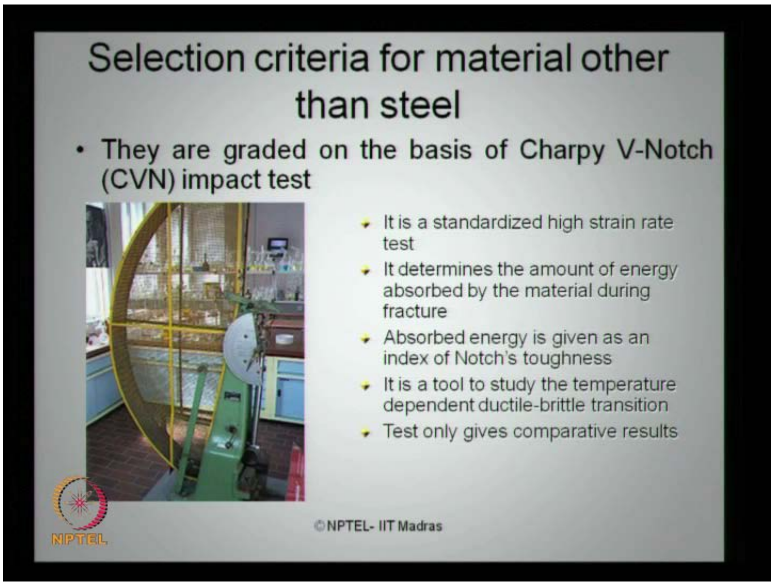

So, selection of material other than steel is insisted based on Charpy V Notch test which we called CVN impact test. CVN impact test is a very simple experiment conducted in the laboratory to understand the impact strength of any material. So, it is standardized high strain rate test which you seen in the standard test procedures. It determines the amount of energy absorbed by the material during fracture; absorbed energy is given as an index of notch toughness of the material, it is a tool to study the temperature dependent, ductile brittle transition. The test unfortunately gives only comparative results.

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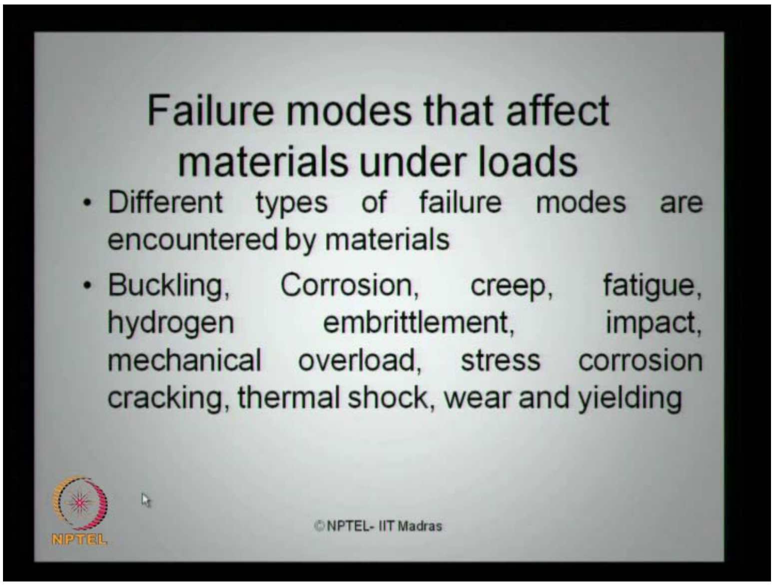

If we look at the different failure modes that affect material under loads, different types of failure modes are encountered by the material when they are exposed to offshore structures. For example, buckling, corrosion, creep, fatigue, hydrogen, embrittlement, impact, mechanical overload, stress concentration, cracking, thermal shocks, wear and yielding are very interestingly a wide variety of failure modes, which happens on material when they have been used in structural members in offshore structural systems.

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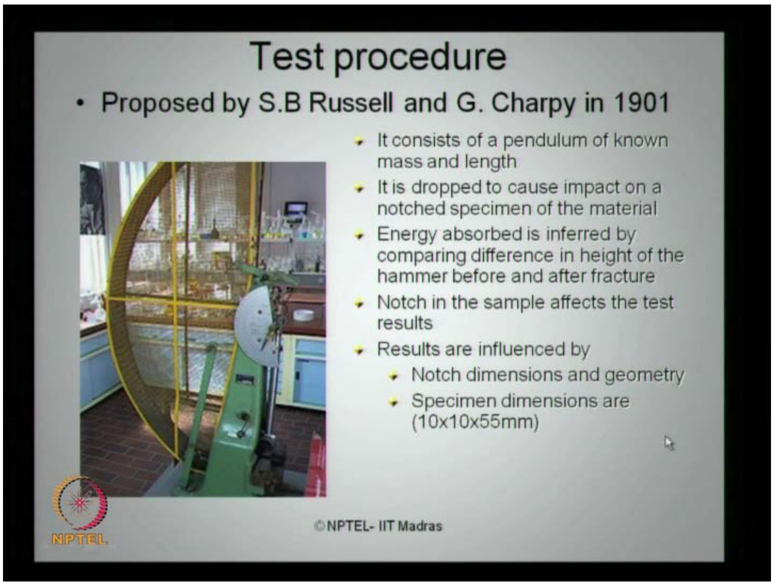

We look at the test procedures of impact test suggested by Russell and Charpy in 1901. It consists of a simple pendulum of a known mass and length, it is dropped to cause an impact on specimen of the material. Energy absorbed is inferred by comparing difference in height of the hammer before and after fracture. Notch in the simple affects the test results; results are influenced by the notch dimensions geometry the specimen dimension recommended for the stress are 10 by 10 by 55 millimeters.

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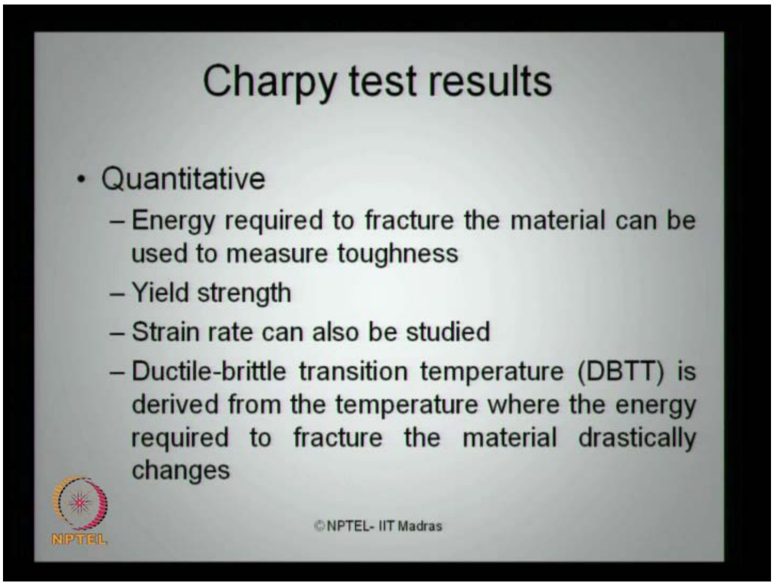

These tests provide me quantitative and qualitative comparative results. If we look at the quantitative values given by this Charpy test results, the energy required to fracture the material can be used to measure the toughness of the material. It is speak about the yield strength of the material, the strain rate can also be studied at which the material fails. Importantly the test gives me ductile brittle transition temperature; this temperature derive where the energy is required to fracture the material drastically changes, when the test is being conducted.

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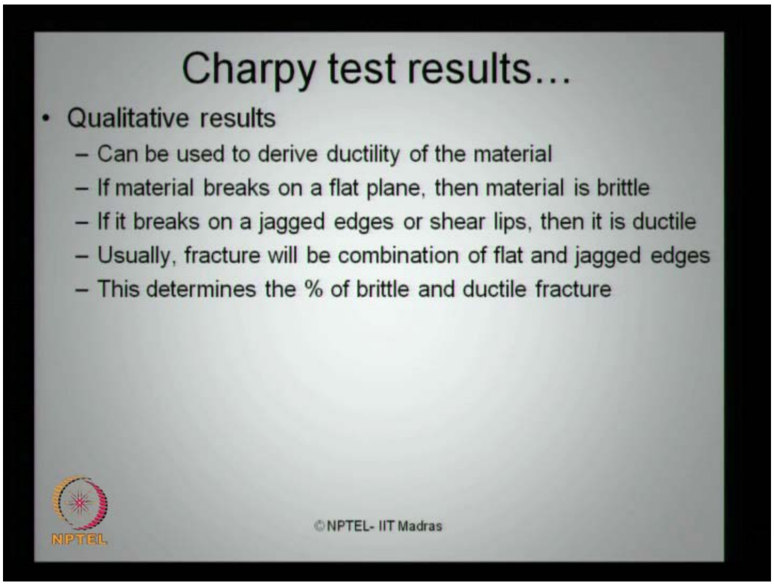

The test also gives me some qualitative results. It can be used to derive ductility of the material indirectly. The material breaks on a flat plan then the material is consider to be brittle. If the material breaks on a jagged edge or shear lips, then the material is consider to be a ductile material; usually fracture will be a combination of flat and jagged edges. So, this determines what is the percentage of brittleness and ductile failure or fracture in that specific result.

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Material Selection Requirements for ABS Ordinary and Higher Strength Steels

Numbers in table are maximum thicknesses in mm (in.)

Blank areas indicate no application

Grade	Service Temperature °C (°F)																	
	Secondary Applications						Primary Applications						Special Applications					
	0 (32)	−10 (14)	−20 (−4)	−30 (−22)	−40* (−40)*	−50* (−58)*	0 (32)	−10 (14)	−20 (−4)	−30 (−22)	−40* (−40)*	−50* (−58)*	0 (32)	−10 (14)	−20 (−4)	−30 (−22)	−40* (−22)	−50* (−58)*
A	51 (2.00)	19 (0.75)	12.5 (0.50)	—	—	—	19 (0.75)	12.5 (0.50)	—	—	—	—	—	—	—	—	—	—
B	51 (2.00)	25.5 (1.00)	19 (0.75)	12.5 (0.50)	—	—	25.5 (1.00)	19 (0.75)	12.5 (0.50)	—	—	—	16 (0.63)	—	—	—	—	—
D, DS	51 (2.00)	35 (1.375)	35 (1.375)	22.5 (0.89)	12.5 (0.50)	—	35 (1.375)	35 (1.375)	22.5 (0.89)	12.5 (0.50)	—	—	22.5 (0.89)	16 (0.63)	—	—	—	—
DN	51 (2.00)	51 (2.00)	51 (2.00)	27.5 (1.08)	22.5 (0.89)	16 (0.63)	51 (2.00)	51 (2.00)	27.5 (1.08)	22.5 (0.89)	16 (0.63)	—	27.5 (1.08)	22.5 (0.89)	16 (0.63)	—	—	—
CS, E	51 (2.00)	51 (2.00)	51 (2.00)	51 (2.00)	51 (2.00)	27.5 (1.08)	51 (2.00)	51 (2.00)	51 (2.00)	51 (2.00)	27.5 (1.08)	16 (0.63)	51 (2.00)	51 (2.00)	27.5 (1.08)	16 (0.63)	12.5 (0.50)	
AH	51 (2.00)	25.5 (1.00)	19 (0.75)	12.5 (0.50)	—	—	19 (0.75)	19 (0.75)	12.5 (0.50)	—	—	—	19 (0.75)	—	—	—	—	—
DH	51 (2.00)	51 (2.00)	51 (2.00)	19 (0.75)	12.5 (0.50)	—	51 (2.00)	51 (2.00)	19 (0.75)	12.5 (0.50)	—	—	19 (0.75)	16 (0.63)	—	—	—	—
DHN	51 (2.00)	51 (2.00)	51 (2.00)	27.5 (1.08)	22.5 (0.89)	16 (0.63)	51 (2.00)	51 (2.00)	27.5 (1.08)	22.5 (0.89)	16 (0.63)	—	27.5 (1.08)	22.5 (0.89)	16 (0.63)	—	—	—
EH	51 (2.00)	51 (2.00)	51 (2.00)	51 (2.00)	51 (2.00)	27.5 (1.08)	51 (2.00)	51 (2.00)	51 (2.00)	51 (2.00)	27.5 (1.08)	16 (0.63)	51 (2.00)	51 (2.00)	27.5 (1.08)	16 (0.63)	12.5 (0.50)	—

* −40°C and −50°C (−40°F and −58°F) service temperatures are listed for guidance only.

This table gives me a comprehensive comparison of material selection requirements based on ABS requirements as given here. This gives me different grade steel being used for secondary, primary and special applications in different service temperatures both given in Celsius as well as in Fahrenheit. So, interestingly ABS designate steel grades based on their applications as you also saw in API and British standards and DNB rules.

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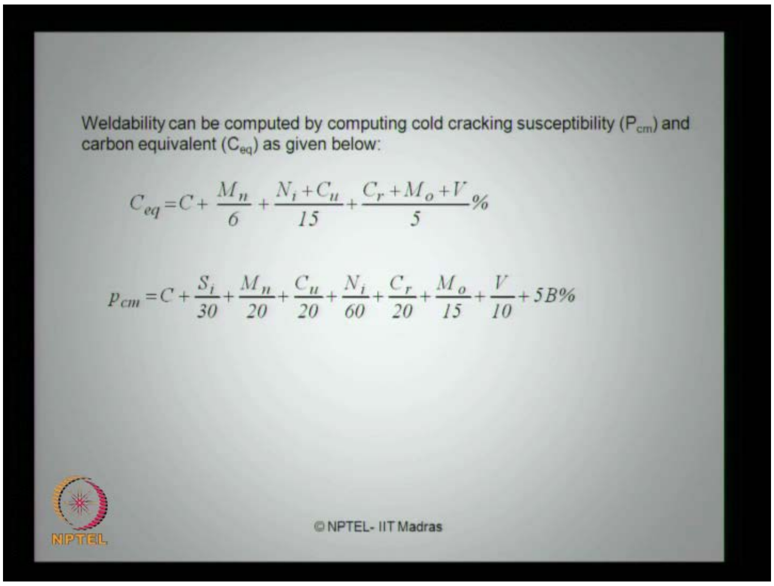

Generally, weld ability is a very important characteristic, which is a requirement for an offshore structural member. So, weld ability can be computed by computing the cold cracking susceptibility and carbon equivalency as given in the following two equations. If you know the carbon, manganese, nickel, copper, chromium, molybdenum and vanadium composition in a given material in percentage you can easily find out what we call carbon equivalency and cold cracking susceptibility. For a given material may be steel which having chemical composition of a different nature, these percentage of composition are available in the standard literature. So, for any specific grade of steel you can always find out the weld ability based on the P C M value and C equivalent value as seen in this slide.

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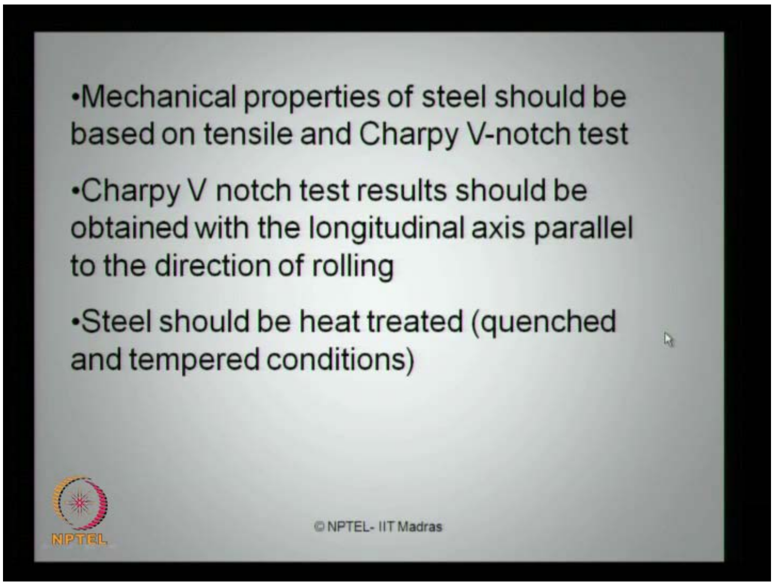

So, ladies and gentlemen, mechanical properties of steel should be based on tensile test as well as Charpy's V notch test. These are the two recommendations made by international codes for people to understand how do we select material for offshore application. Charpy's v notch test results should be obtain with longitudinal axis parallel to the direction of rolling; steel should be heat treated as far as they have been used or recommended to be use in offshore application.

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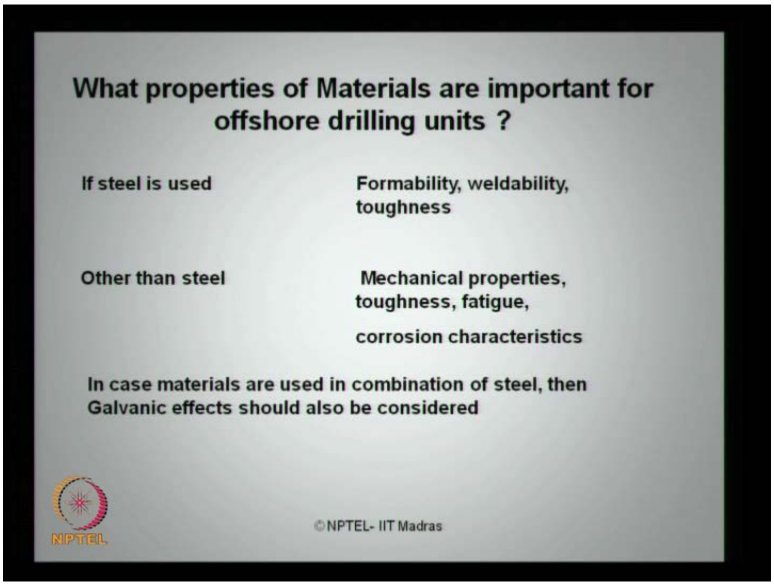

If you want to use steel as a material for offshore drilling unit then steel should be used as a material. In such cases, formability, weld ability and toughness are important criteria be checked for recommending steel for offshore application in case of drilling units. If we want to recommend material other than steel for drilling units then you must focus on mechanical properties, toughness, fatigue and corrosion characteristics. In case, materials are used in combination of steel then you must also check for the galvanic effects which should be considered before you select that material for offshore drilling units. Now ladies and gentlemen, we will give you a very brief summary of different kind of material which have been recommended for offshore application. We have seen them in the past three lectures, now the down the slides few slides will give you a very brief summary of all the material which has been discussed in this three lectures for your apprehensive knowledge on material selection in offshore applications.

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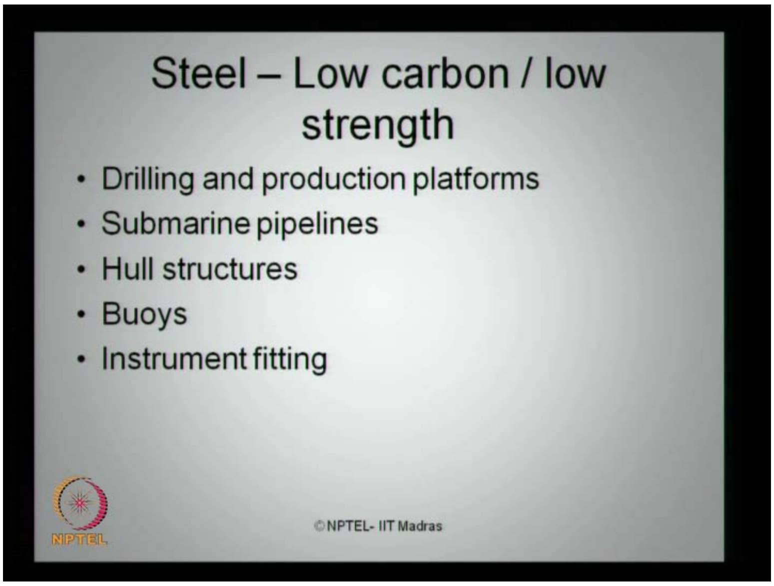

Steel - we can use low carbon low strength steel it is essentially used for drilling and production platforms, submarine pipe lines, hull structures, buoys and instrument fitting as well.

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If we look at medium strength steel can use it for a buoys and icebreakers, use it for submarines, can use it for pressure vessels, storage tanks and merchant ships etcetera.

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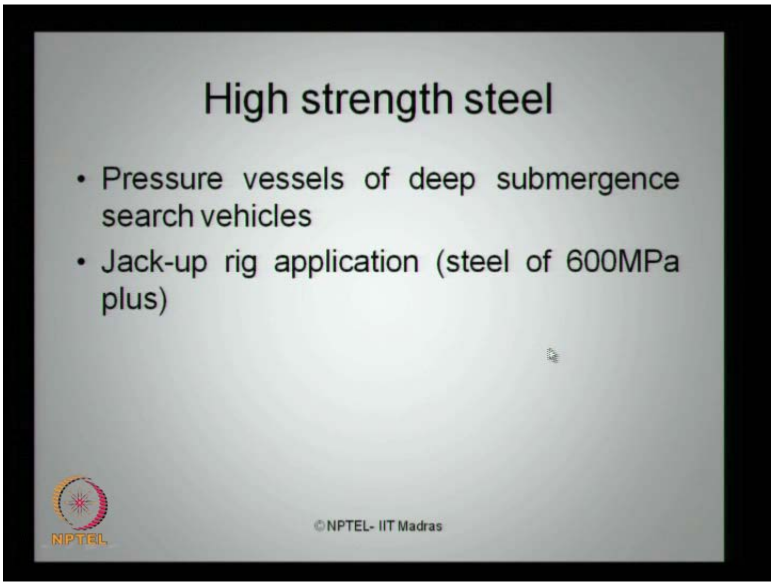

If we look at high strength steel then you can use it for pressure vessels of deep submergence search vehicles, can use it recommended strongly for jack up rig application, because you require steel whose strength is as high as 600 mega pascal plus for jack up rigs.

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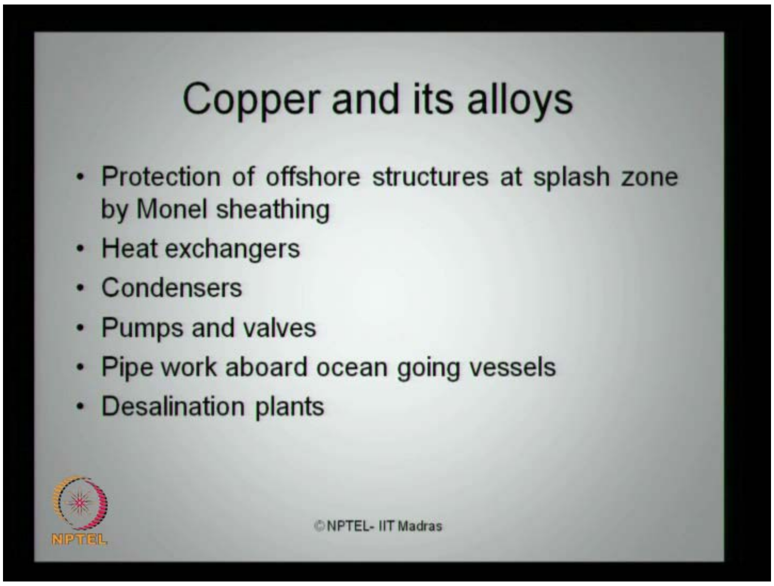

If we look at copper and its alloys as construction material for offshore structures or marine application protection of offshore structures splash zone is generally done by monel sheathing which is an copper alloy. It can be used for heat exchangers, can be used in condensers, used in pumps and valves in top sites, can be used in pipe works aboard ocean going vessels can be used in desalination plants as well.

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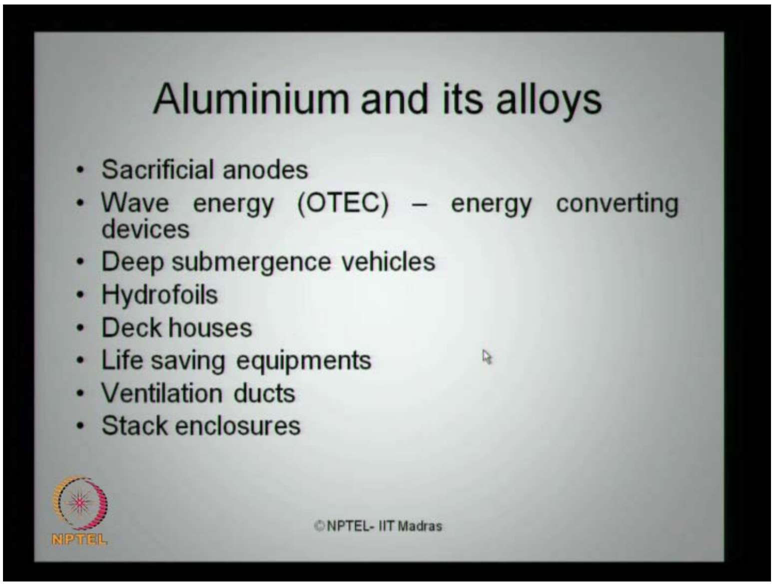

If we look at aluminium and its alloys as one of the construction material for marine application, it can be used for sacrificial anodes; it can be used for wave energy that is ocean OTEC wave energy converting devices. It can be used in deep submergence vehicles you can used in hydrofoils, deck houses, life saving equipments, ventilation ducts and stack enclosures as one of the important application.

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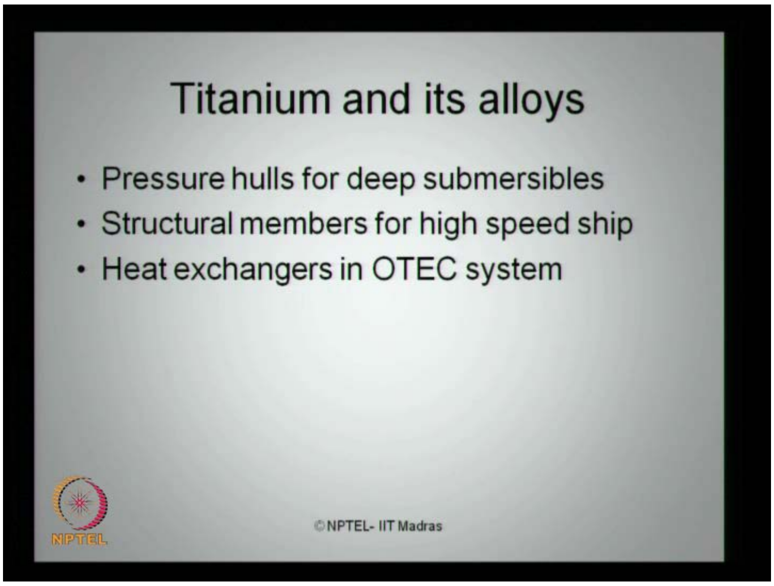

If we look at titanium and its alloys as material for marine environment, then we can use pressure hulls for deep submersibles, structural members for high-speed ships, heat exchangers in OTEC system.

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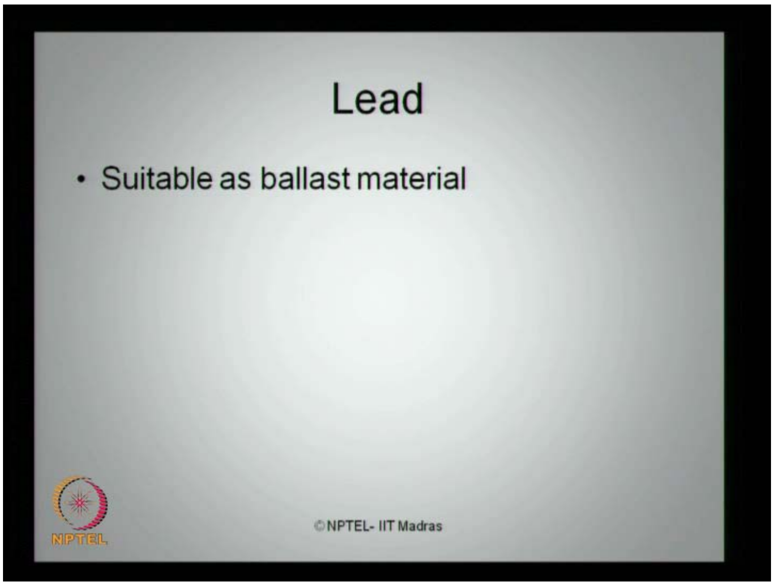

If we look at led as one of the material, it is the most suitable material for ballasting.

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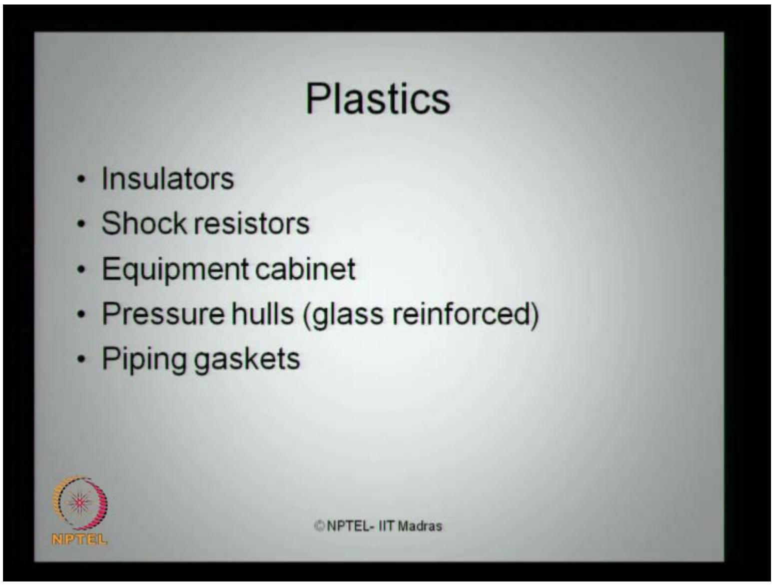

If we look at plastics it can be used for insulators, shock resistors, equipment cabinets pressure hulls which is glass reinforced plastics which we call as GRP, piping gaskets etcetera.

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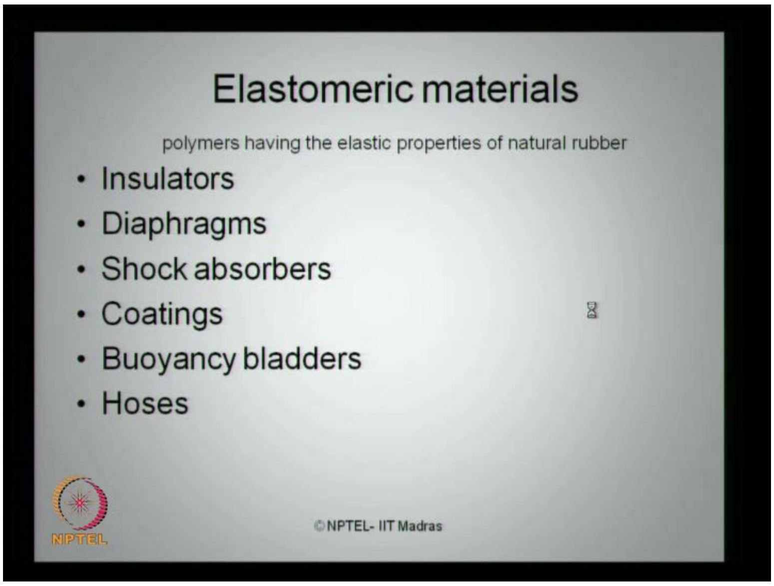

If we look at elastomeric material, polymers having elastic properties of natural rubber are what we call elastomeric material. Then they can be used as insulators, diaphragms, shock absorbers, coatings, buoyancy bladders and hoses etcetera.

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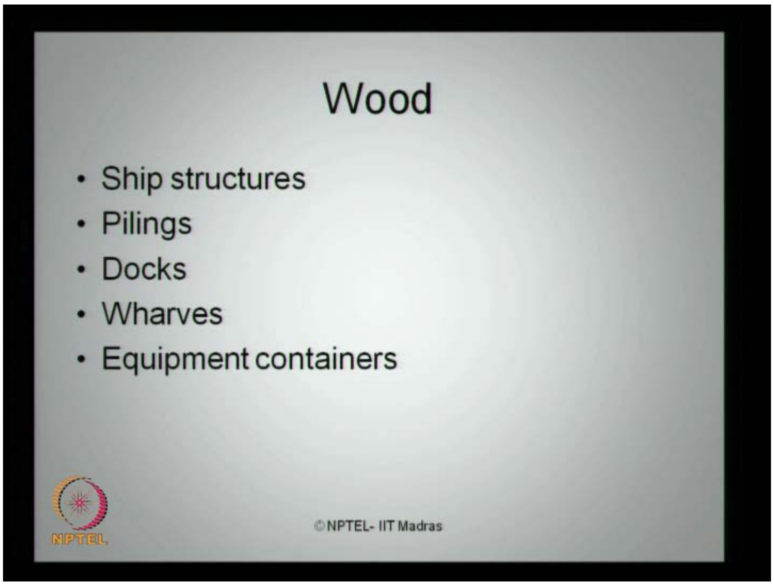

If we look at wood as a construction material in marine application, most commonly used for ship structures pilings, docks, wharves, equipment containers as well.

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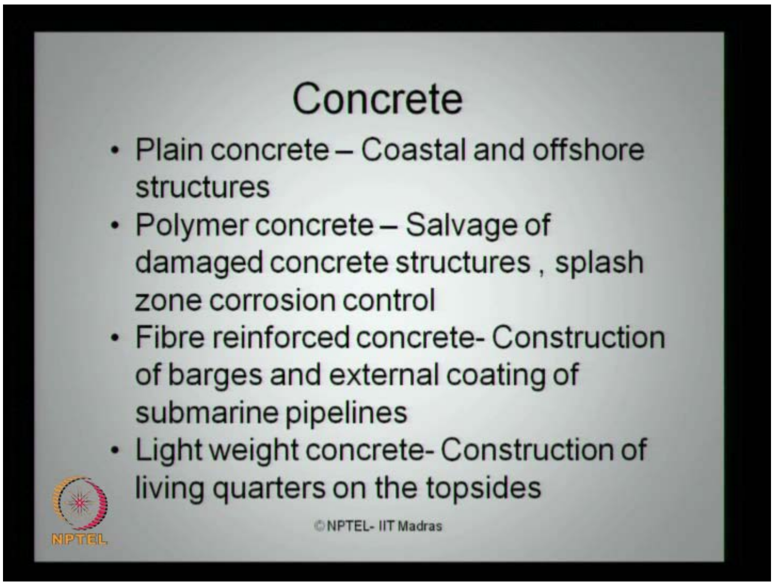

If we look at concrete as one of the most preferred material in marine application, plain concrete can be used for coastal and ocean structure or offshore structures. Polymer concrete can be used salvage of damaged concrete structures in splash zone and zone control corrosion concretes. Fiber reinforced concrete can be used for construction of barges and external coating of submarine pipelines, whereas lightweight concrete can be used for construction of living quarters on the top sides of the platform.

Thank you very much.

We will see in the next lecture concrete as one of the important construction material, and the problems faced by concrete in marine environment.

Thank you very much.