Ocean Structures and Materials
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Module - 1
Lecture - 8
Environmental loads II

Ladies and gentlemen, welcome to the eighth lecture on module 1 on ocean structures and materials. In the last lecture we discussed about the different methods by which can compute the water particle kinematics by two different wave theories. We discussed about Airys wave theory as well as Stokes fifth order wave theory.

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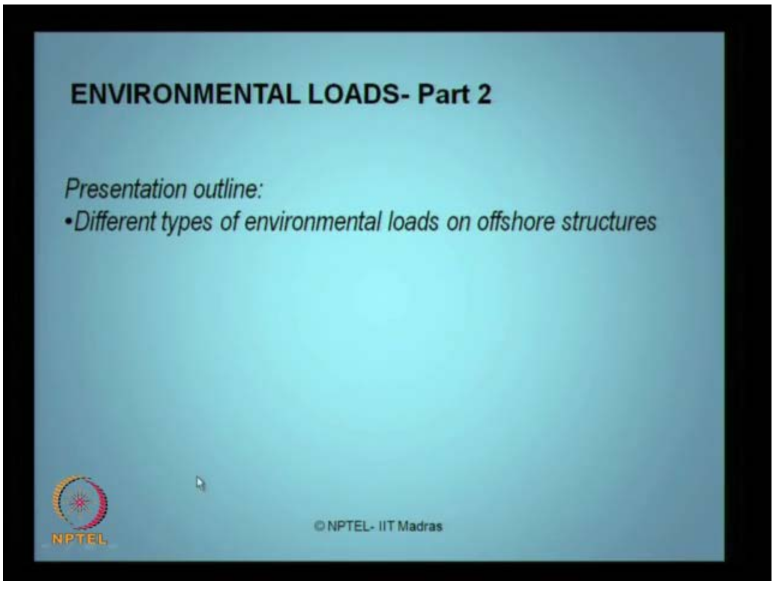

This is in continuation of the last lecture, where we are going to talk about the different types of environmental loads to compute on offshore structures. In the last lecture, we discussed about calculation of wind forces and wave forces.

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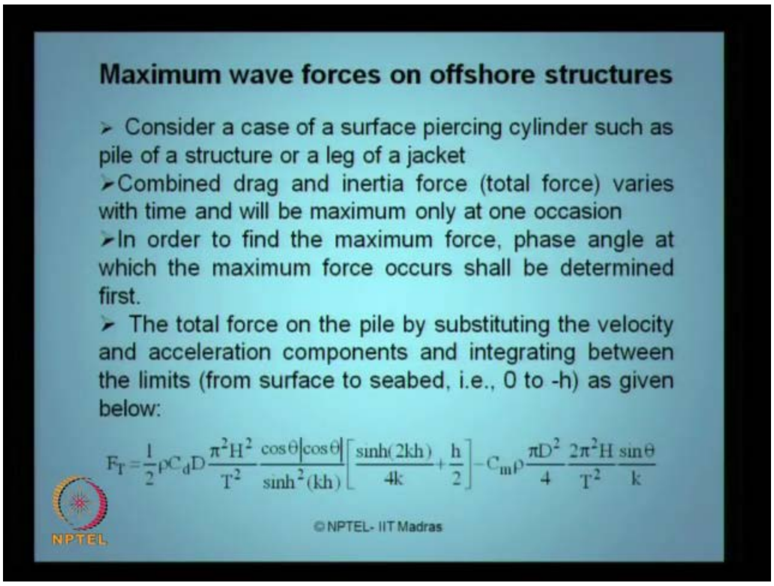

Now, Interestingly we must know how to compute the maximum wave force on an offshore structure. Now, the question comes what do you understand by the maximum wave force? Now, interestingly let us consider a case of a surface piercing cylinder, such as pile of a structure or leg of a jacket platform. The combined drag and inertia force, which we call them as total force varies with respect to time and will be maximum only at one specific occasion. In order to find where the maximum force is, the phase angle at which the maximum force occurs shall be first determined. The total force then on the leg of the structure by substituting the velocity and acceleration component and integrating it from the limits that is from the sea surface bed to the height 0 to minus h, I say minus because h is measured from the mean sea level towards the seabed is given below by this equation. In this equation we will be interested to know what will be the theta value at which this force can be at maximum.

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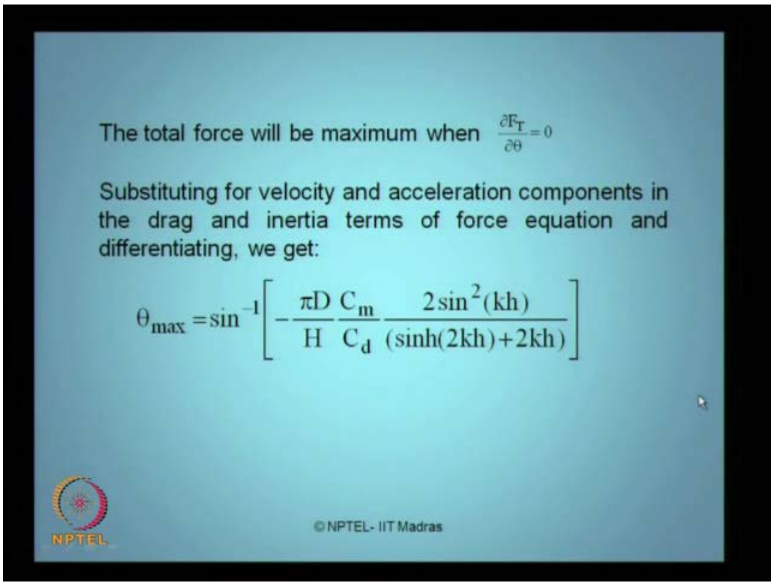

The total force will be given when this equation is satisfied so by substituting the velocity and acceleration components in the drag and inertia terms of the force and differentiating it I can find the maximum angle at which the force can remain at maximum. So, I will compute the maximum angle, substitute this back in the force equation and try to find the maximum force in the given member.

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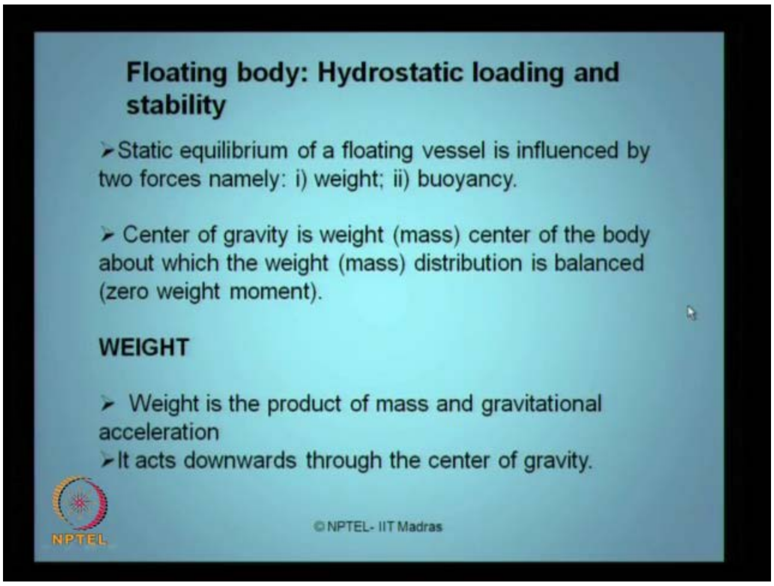

After understanding how to compute the wind forces and wave forces, now let us see how to understand what is the significant of hydrostatic loading and stability of a floating body. The static equilibrium of a floating vessel is influenced by two forces namely weight and buoyancy. The center of gravity is weight or mass center of a body about which the weight distribution or the mass distribution is balanced. We call this as zero weight moment.

Now, what is weight? Weight, as we all understand is simply a product of mass of the body with gravitational acceleration. It always acts downward through the point what we call center of gravity of the system.

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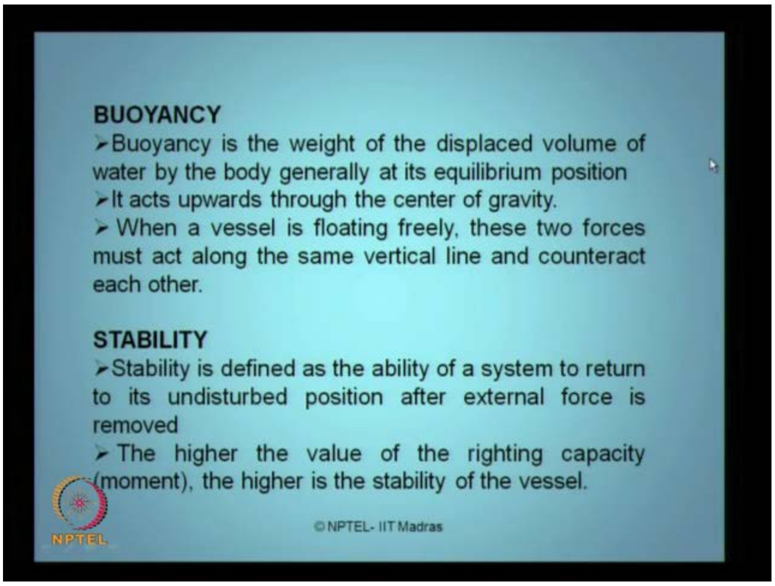

When we talk about buoyancy, buoyancy is also the weight of the displaced volume of water by the body generally at its equilibrium position. It acts upward through the center of gravity when a vessel is floating freely these two forces must act on the same vertical line which is collinear and counteract each other for a perfect equilibrium. Then, what is a question of stability? Stability is defined as the ability of the system to return to its undisturbed position after external force is removed. The higher the value of the righting capacity, higher is the stability of the vessel.

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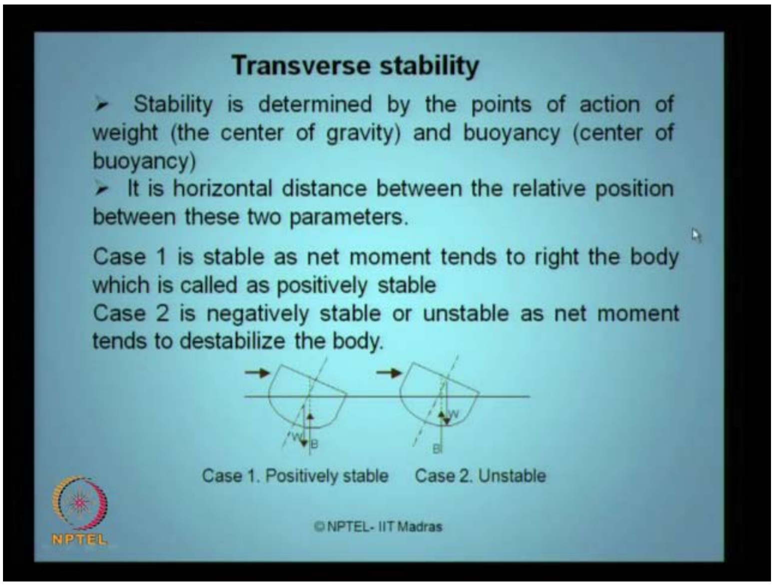

Talk about transverse stability, look at these two figures. As is said stability is determined by the points of action of the weight passing through the center of gravity and the buoyancy passing through the center of buoyancy. It is nothing but the horizontal distance between the relative positions of these two parameters. Let us say for example, this is the point where the weight is acting, that is the point where the buoyancy is acting, it is horizontal distance between these two which will govern the transverse stability.

Let us look at the two cases, case 1 is stable as the net moment tends to right the body. What do you understand by right the body? Let us say for example, the body is subjected to transverse force as shown in this arrow, whereas the moment caused by this couple is counteracting this force, I call this as tends to right the body therefore, I will say if this system exists, then it is positively stable.

Look at the other case where the forces are acting in the same direction, but the couple is also activating the force so that the body becomes unstable. I call this as either negatively stable or unstable because the net moment tries to destabilize the body unlike in the first figure. So, basically the transverses stability depends strongly on the relative position between the center of mass or the mass center and the buoyancy or the buoyancy center.

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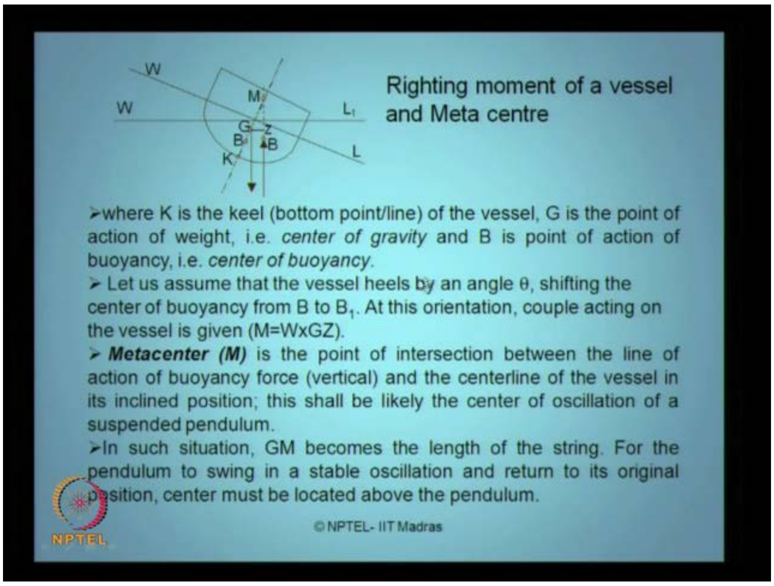

Let us look at what we understand by righting moment of a vessel and the classical explanation for metacentre. Look at this figure; I have a body initially straight. Now, in this figure let us say K is a keel which is the bottom point of the line of the vessel, G is the point where the weight is acting which is call center of gravity and of course B is the point where buoyancy is acting or center of buoyancy. Now, let us assume that the vessel is heel by an angle theta. Initially, it is a vertical like this. Now, the vessel is tilted. Initially, W L 1 was the plane, now, it has turned to W L. Let us say, it is tilted by an angle theta.

Now, it shifts the center of buoyancy from B to B 1. At this orientation the couple acting the vessel will you know given by the W at the weight of the vessel multiplied by the horizontal distance G Z. Now, the meta center can be easily explain with this equation or with this figure. Meta center actually is the geometric intersection between the line of action of buoyancy force which is vertical and the centerline of the vessel in its inclined position. Let us say project this line vertically up and project this line in the inclined position vertically and the same line, the point of intersection of this two will give me what is call meta centre. This is treated as center of oscillation for a suspended pendulum in such situation G M, the distance G M becomes the length is string for the pendulum to swing in a stable oscillation and return to the original position, the center must be located above the pendulum.

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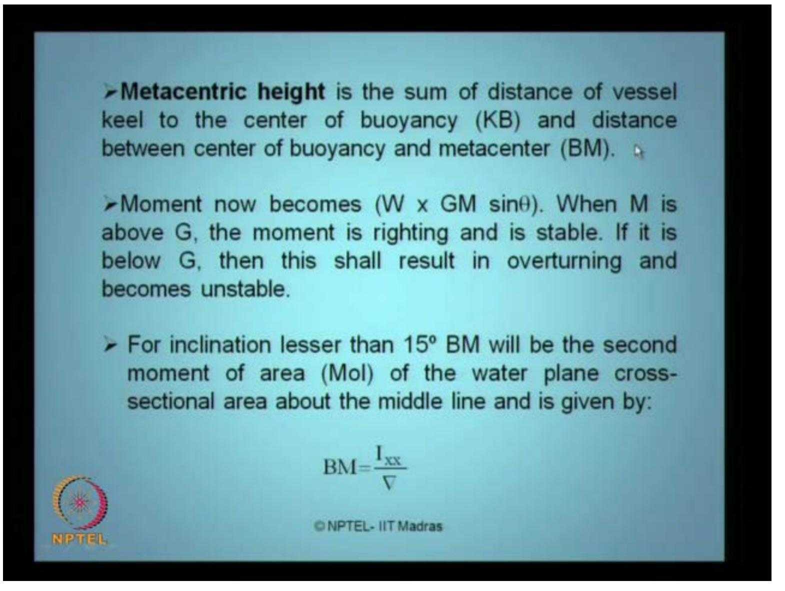

So, what do you understand by meta centric height? Meta centric height classically is the sum of distance of vessel heel the center of buoyancy plus the distance between center of buoyancy and meta center. And the moment now becomes W multiplied by G M sin theta for an inclined vessel of theta, where when the M is above G the moment is righting and it is stable. If it is below G this shall result in instability. So, for an inclination lesser than 15 degrees B M will be the second moment of area which can be computed, they classical equation has given here.

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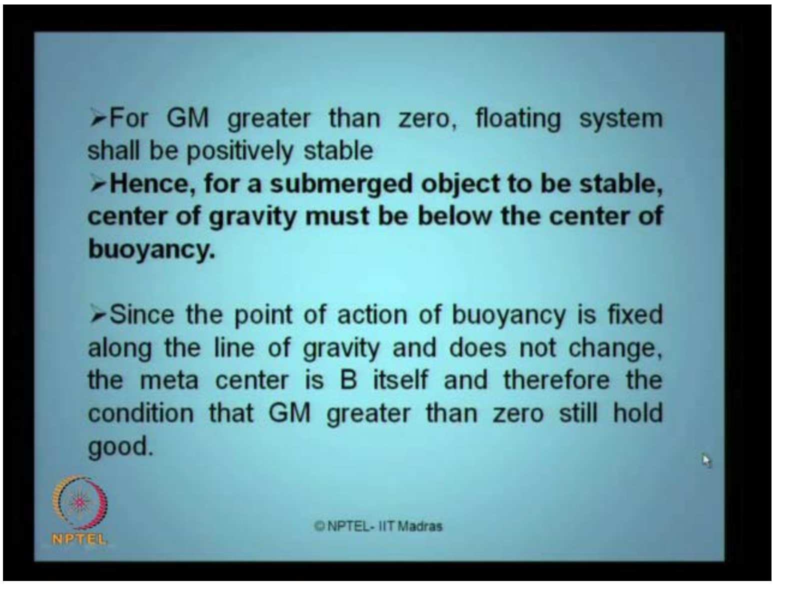

For G M greater than zero, the floating system shall be positively stable. Hence, it is very simple to summarize for a submerged object to be remain stable the center of gravity must lie below the center of buoyancy. Since, the point of action of buoyancy is fixed along the line of gravity and does not change the meta center is B itself and therefore, the condition that G M greater than zero still holds good in our argument.

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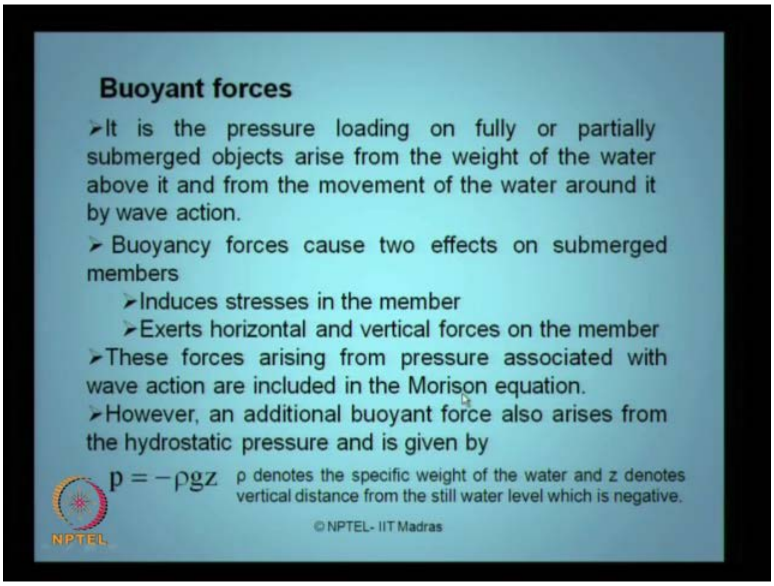

Let us look into the other type of force what we call buoyant forces. It is the pressure loading on fully or partially submerged objects arise from the weight of water above it and from them moment of water around it around it by wave action. Buoyancy forces cause two effects on submerged members. One, it induces stressin the member, two it exerts horizontal and vertical forces on the member.

Now, these forces arising from pressure associated with wave action are already included in the Morison equation. However, there can be an additional buoyant force which can arise from the hydrostatic pressure. Now, this is given by the following equation where rho specifies the specific weight of water and z denotes the vertical distance from the still water level which is negative, which is why the term negative and negative will give you the positive value of the pressure value.

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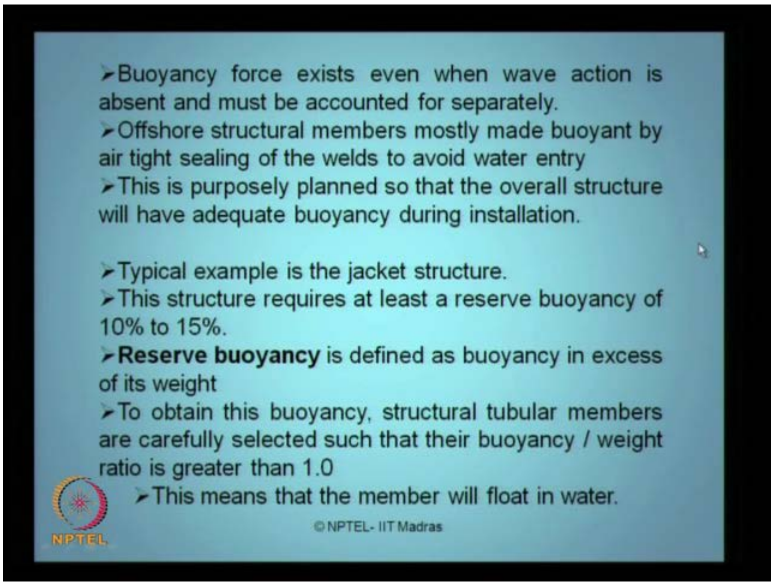

Now, the buoyancy force exists even when the wave action is absent and therefore, the ladies and gentlemen it is very important that we must account for it separate. Offshore structural members mostly made buoyant by air tight sealing of the welds to avoid the water entry. This is purposely planned so the overall structure will remain adequate buoyant during installation. Because that is very important, we have to install the structure in a given site location. Let us take a typical example of a jacket structure. The jacket structure requires at least a reserve buoyancy of about 10 to 15 percent.

Now, the question comes what do you understand by reserve buoyancy? Reserve buoyancy is defined as the buoyancy in excess of its weight. To obtain this buoyancy structural tubular members are carefully selected such that the buoyancy by weight ratio is always greater than 1, it means buoyancy will be always greater than weight, you must select the tubular member such a fashion that the displays volume of this member compared to its weight of the member with respect to its cross sectional dimension and thickness will always satisfy that the buoyancy will exceed its weight. This is what we call the reserve buoyancy. If we have the member of the nature, then this will enable the member to float in water during installation.

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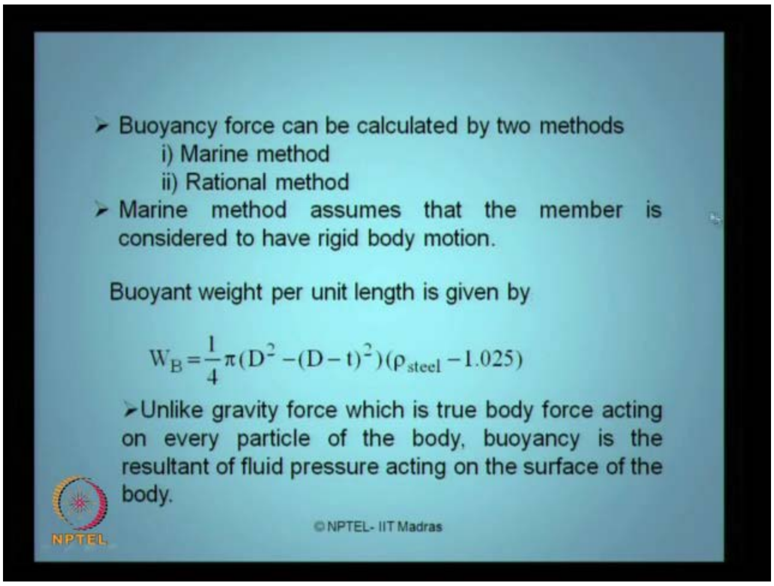

The buoyancy force can be computed by two methods. One is what we call as a marine method; other is what we call as a rational method. The marine method assumes that the member is considered to have rigid body motion. In that case the buoyant weight per unit length of the member is given by this equation. Unlike the gravity force which is truly a body force acting on every particle of the body, buoyancy is resultant of fluid pressure acting on the surface of the body.

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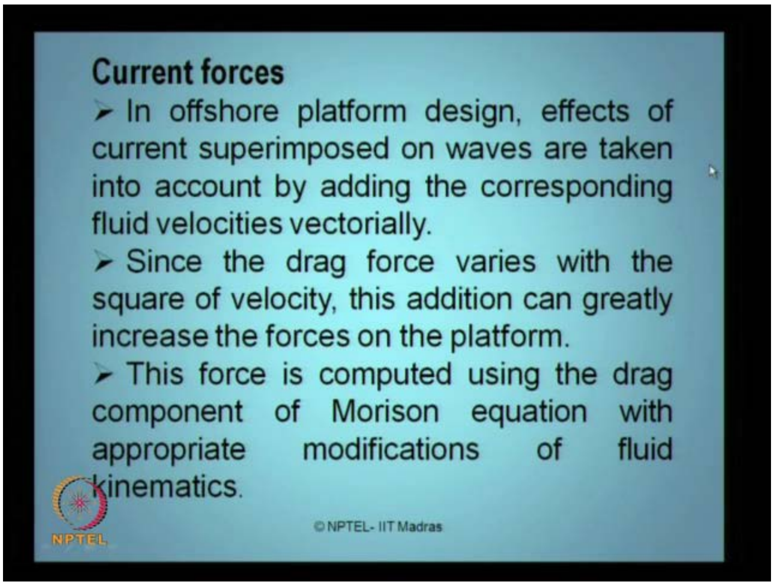

Let us look at the second classification of the forces which follows this, which is called current forces. In the offshore platform design effects of current superimposed on waves are taken into account by adding the corresponding fluid velocities vectorially. Since, the drag force varies with the square of velocity as you saw in the Morison equation; this addition can greatly increase the forces on the platform. So, this fore is computed using the drag component of the Morison equation with appropriate modifications done on the fluid kinematics.

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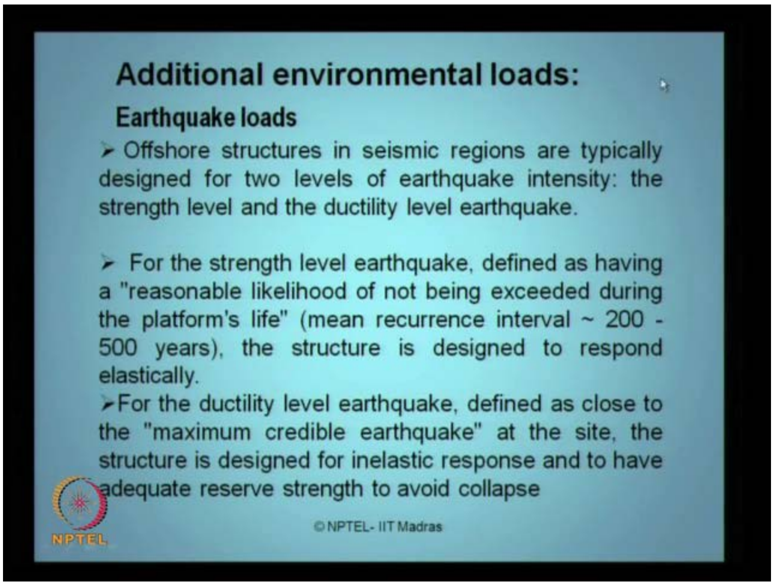

Let us now look at what are the different additional environmental loads coming out to the system. If we look at the earthquake loads as I said, this is one of the predominant loads acting on a offshore structure, offshore structures in seismic regions are typically designed for two levels of earthquake intensity. The strength level and the ductility level earthquakes. For the strength level earthquake it is defined as having a reasonable likelihood of not being exceeded during the platform life, the mean recurrence interval is approximately above 200 to 500 years. The structure is designed to respond elastically, can also have the other level of the designed what we call the ductility level earthquake. For ductility level earthquake is defined as close to the maximum credible earthquake which you call literature as MCE. The structure is designed for inelastic response and to have adequate reserve strength to avoid collapse under this action of forces.

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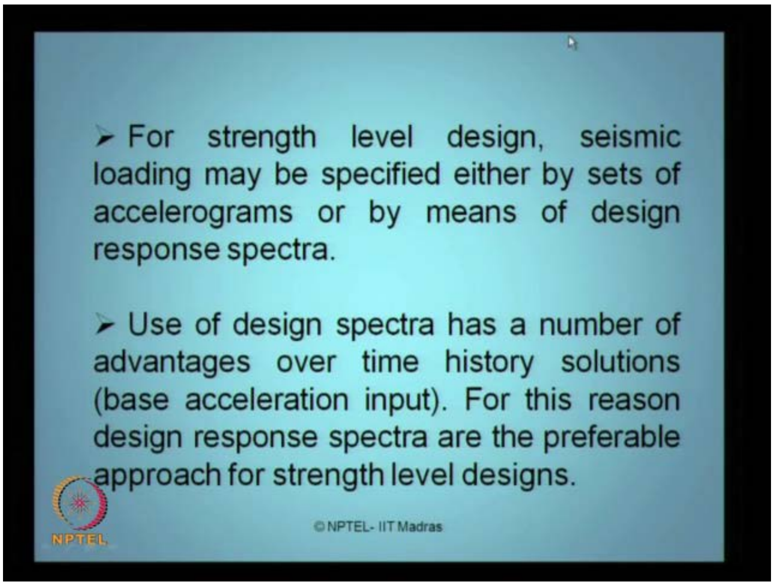

For the strength level design, seismic loading may be specified either by sets of accelerograms or by means of design response spectra. The use of design response spectra has a number of advantages over the time history solutions which is based on the base acceleration input. For this reason the design spectra are generally preferred for strength level designs in offshore structural designs.

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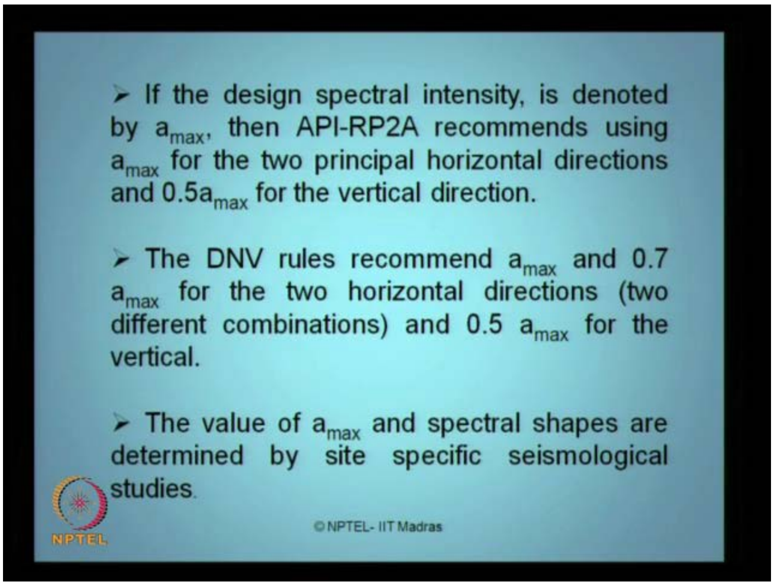

In the design spectral intensity is denoted by a max then international codes like APRP2A recommends using a max for two principal horizontal directions and 0.5 of a max for the vertical direction, whereas the DNV rule recommends a max and 0.7 a max for two horizontal directions that is two different combinations and of course, half of this a max for vertical direction. And the value of the a max and the spectral shapes are actually obtained by site specific seismological studies.

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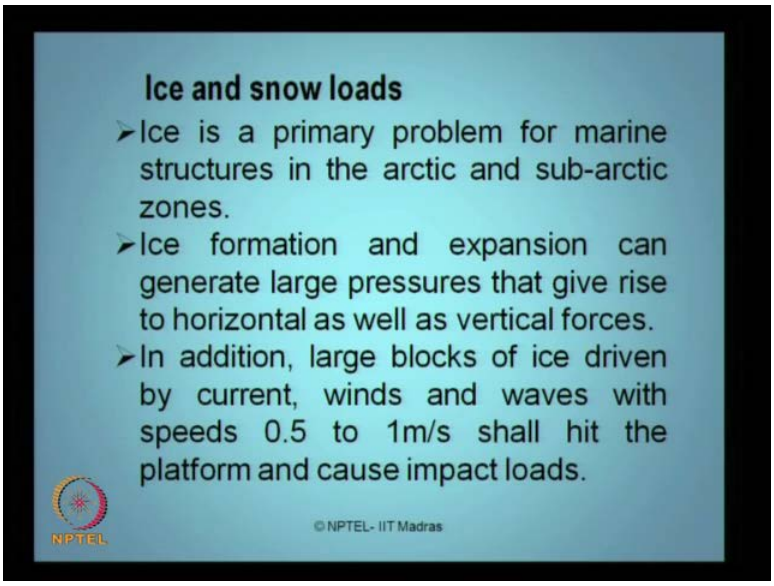

The other classificant load which comes on offshore structure is ice and snow loads. Now, ice is the primary problem for marine structures in the arctic and sub arctic zones. Ice formation and expansion can generate large pressure that gives rise to horizontal as well as vertical forces on offshore members in addition large blocks of ice driven by current wind and waves with the speed of 0.5 to 1 meter per second can come and hit the platform, this can cause ladies and gentleman very severe impact loads on the members. Therefore, ice loads are also critically important not only for the location otherwise they can also cause impact loads which can cause serious damage to the members of offshore structures.

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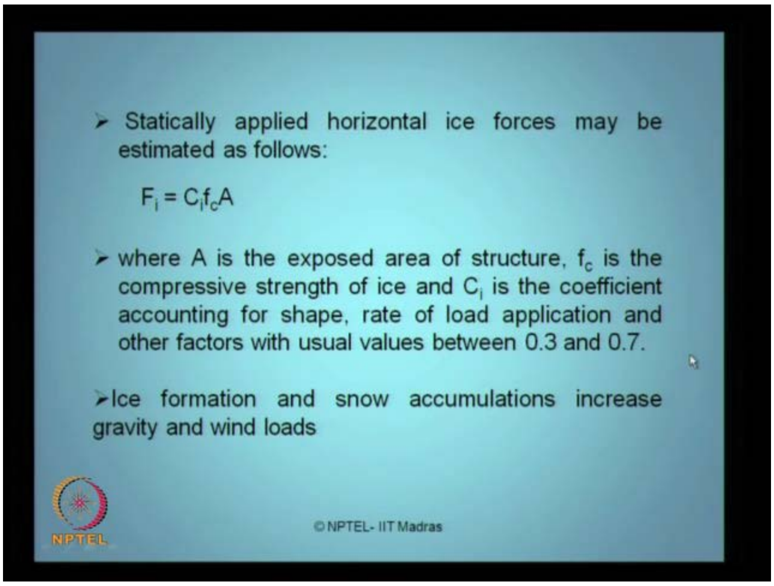

Statically applied horizontal ice force may be estimated from the given equation given here, where in this equation A is exposed area of structure, Fc is the compressive strength of ice and Ci is the coefficient accounting for shape, rate of loading application and other factors with usual values between 0.3 to 0.7 as seen in the literature. The ice formation and snow accumulations increase gravity as well as wind loads coming on the offshore platform.

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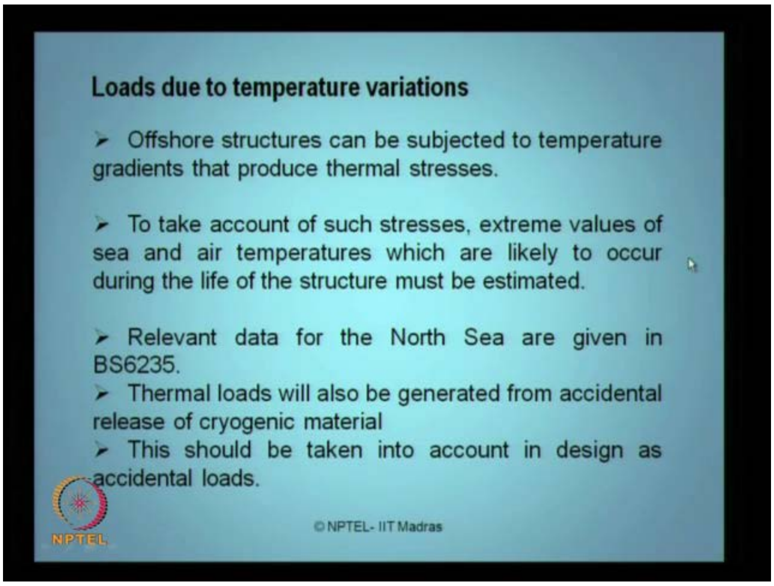

The other kind of load what we see in offshore structure is loads due to temperature variations. Offshore structures can be subjected to temperature gradients that produce what we call thermal stresses. To account for such stresses, extreme values of sea and air temperatures are important, which are likely to occur during the life time of the structure they must be estimated in advance.

The relevant data for the North Sea are available in BS6235, the thermal loads will also be generated form accidental releases of cryogenic materials. This should be taken into account the design as accidental loads in designing members of offshore structures.

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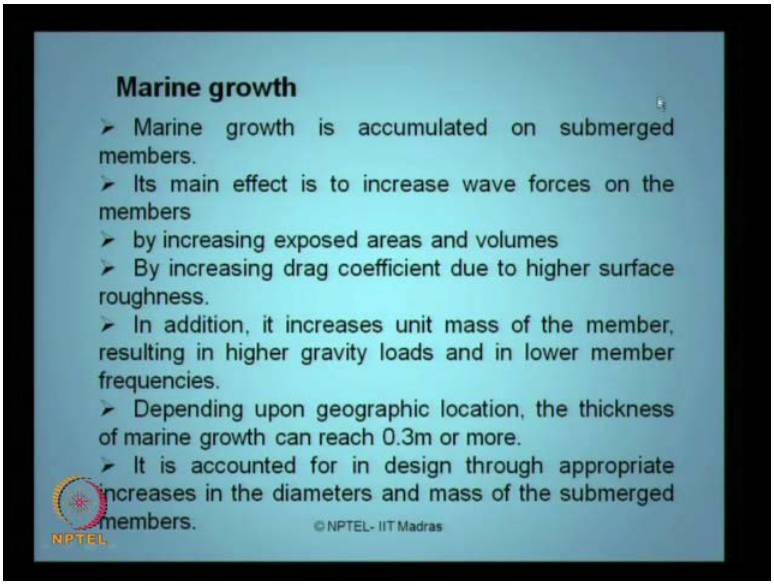

The most important thing as I said in the series of loading acting on offshore structure is what we call marine growth. Now, marine growth is nothing but an accumulation of marine organism on the submerge members. The main effect of this marine growth is nothing but increase the wave forces on the members. We may wonder how a marine organism deposit on the circumference of the member can increase the wave forces. Ladies and gentlemen, if we look at the Morison equation expression, the Morison equation force per unit length depends on diameter of the member which is indicated as capital D in the expression.

Now, when this capital D is increased because of marine accumulation or biological organisms surrounding this member by increasing the diameter of the member obviously you will see the force per unit length of the member increases. So, this is causes essentially the increase in the exposed area and the volume and also it increases the drag coefficient due to high surface roughness. Ladies and gentlemen, as you all understand drag force coefficient depends on roughness of the surface of the member. In addition, when the diameter is increased then there is a marine growth deposit around the circumference of the member, the mass of the member is also changed. It further increases. So, this results in higher gravity loads and lower member frequencies. So, marine growth has got many direct and indirect implications.

One, marine growth has the direct implication that covers the circumference surface of the member for the members are non-detectable in case of inspection for any maintenance. That is a direct impact of the marine growth on the members, whereas indirectly the marine growth increases the exposed area, increases the submerged volume, increases the mass, increases the weight of the structure, changes its frequency, lowers the member frequency and it has got many indirect impact.

Now, depending upon a geographic location the marine growth thickness can be as highest 300 mille meters that is 0.3 meter, can be more event in certain instances. Now, the fundamental questions comes how do you account for this marine growth in the design of members? It is accounted in the design through appropriate increase in the diameters and the mass of the submerged members. So, indirectly you increase the diameter of the member and increase the mass of the submerged member and account for approximately for the expected marine growth in service life of the offshore structure.

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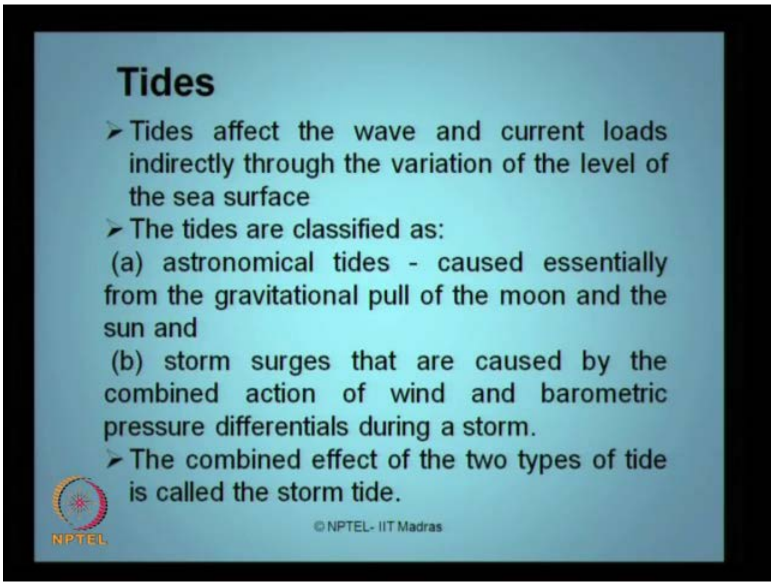

The next effect which comes on structures or the members of the offshore platform is tide effects. Tides affect the wave and current loads indirectly through the variation of level of sea surface. Now, the tides are classified as astronomical tides and storm surges. Now, astronomical tides are caused essentially from the gravitation pull of the moon and the sun.

While the storm surges are caused by the combined action of wind and the barometric pressure difference during a storm. The combined effect of these two types of tide is what we call a storm tide.

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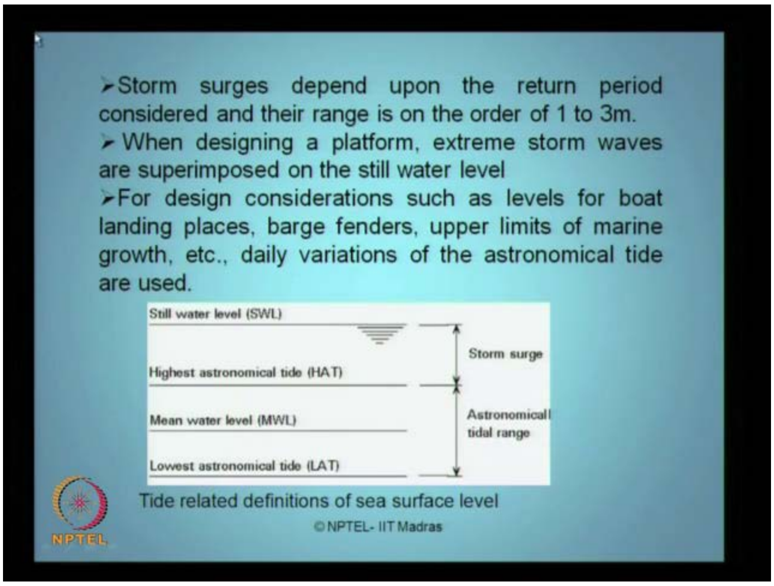

The storm surge depends on the return period which is considered and their range is on the order of 1 to 3 meter, whereas while designing the platform the extreme storm waves are actually superimposed on the still water level. Ladies and gentlemen, this figure gives a tide related definition on the sea surface level. Look at these three levels which is usually measured are mentioned in the literature what we call still water level, highest astronomical tide level, mean water level. Remember, these values are not and these levels are not same. There is small confusion in many of the literature given, still water level and astronomical tide level are varied by what we call as a storm surge, can be as highest 1 to 3 meters.

Whereas, still water level and mean water level differ by a different value which is an added to the storm surge and the affect of astronomical tidal range on this. So, depending upon what is the lowest and highest astronomical tide, your astronomical tide range will be fixed and the mean value of this added to the storm surge will be the difference between the mean water level and the still water level. So, what we talking about in the offshore design is the mean water level. So, when designing the platform extreme storm waves are actually superimposed on the still water level, for design considerations such as levels for boats landing places, barge fenders, upper limits of marine growth etcetera astronomical tide values are used.

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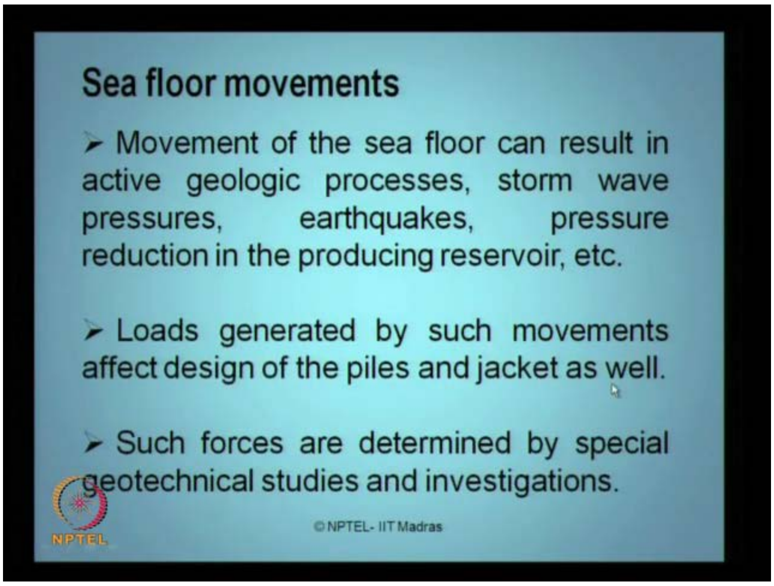

The other kind of force which acts on members of offshore is sea floor movement. The movement of the sea floor can result in active geologic processes, can activate storm wave pressures, it can cause what we call earthquakes, it cause pressure reduction in producing reservoir etcetera. Then the loads generated by such moments after the design of the piles and jackets of offshore structures. Such forces are determined by special geotechnical studies and investigations.

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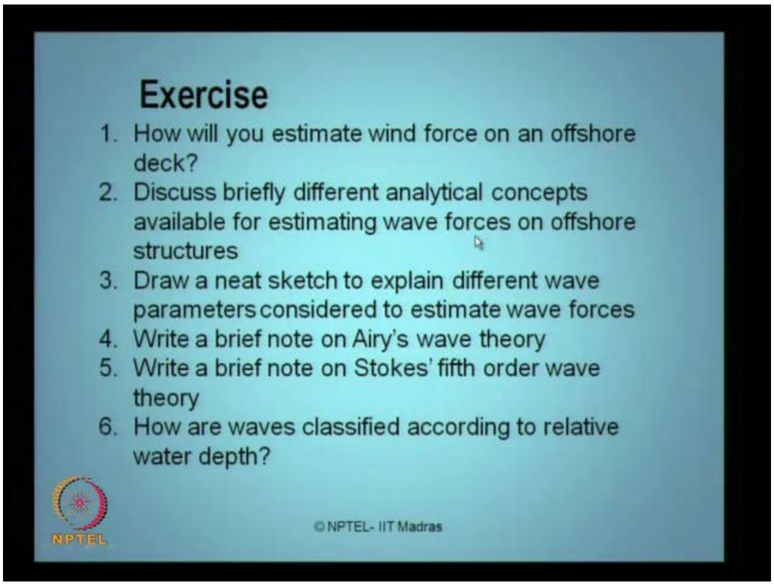

Now, based on these two lectures I want you to give a very brief exercise. I want you to sincerely attempt this exercise so that you understand thoroughly what has been discussed in the previous lectures. So, let us quickly take a summary of what we have discussed so far. We have discussed different types of offshore structures depending upon at what depth they can be installed, at what geographical location they can be installed, where they are located around the world, how the history of offshore industry started and keep on changing, what are the latest developments happening in offshore industry and why this platforms specially constructed and what locations they are constructed. So, we have seen different classified platforms.

Now, I have a small exercise for you which I want to you to answer based on the presentation shown to you till now. How will you estimate wind forces on an offshore deck? We discussed this in detail in the previous lecture. Discuss very briefly the different analytical concepts available for estimating wave forces on offshore members? We discussed two different theories one is Airys wave theory and another is Stokes fifth order wave theory. Draw a neat sketch to explain different wave parameters considered to estimate wave forces? I show you a figure in the previous slide. Write a brief note on classical Airys linear wave theory? Write also a brief note on Stokes fifth order wave theory? We have explained vary detail about this. How are waves classified related to water depth? We have made a comparison to show you how the waves can be classified.

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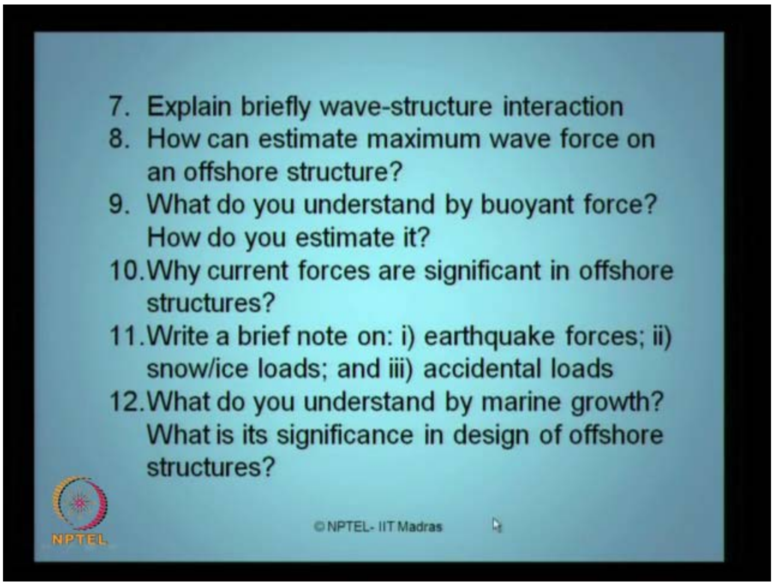

Now, explain briefly what we understand by the term wave structure interaction? How can we estimate maximum wave forces on an offshore structure? What we understand by what we call a buoyant force, how to estimate it for a given member? Now, tell me why current forces significant in offshore structures? I want you to write a brief note on earthquake forces, ice and snow loads, and accidental loads acting on offshore structures? What do you understand by marine growth? What is its significance in the design of offshore structures?

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I have few tutorials for you which are given as problems on as applied to offshore structures. The solutions for these tutorials are available, you can fully write to me at NPTEL IIT Madras, we will try to give the solution for this tutorial, but I want you to attempt this tutorial first at your own level by understanding the lectures delivered to you.

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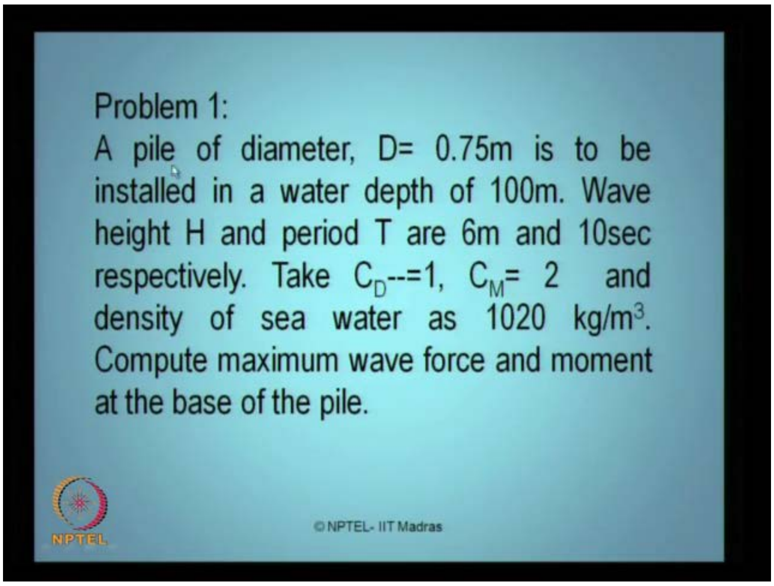

Let say problem number 1 I have a pile of diameter 0.75 meter which is to be installed at a water depth of 100 meters, the wave height and the wave period are taken as 6 meter and 10 second respectively. Take C D and C M as 1 and 2 respectively and take the density of sea water as 1020 kg per cubic meter. What I want you is very simple, compute the maximum wave force and the moment at the base of this pile?

We have expressions given to you for computing the maximum wave force. Ladies and gentlemen kindly remember the references and research papers which are cited in the NPTEL website for this course are to be cleanly studied and understood. We want the answer this tutorial. Please do not only depend on the lecture material which I am giving to you through the slides. I strongly encourage that you must refer back to the original literature as shown in the references and try to read them, if you have any queries, any doubts, please write to me at dr(( ))@iitm.ac.in.

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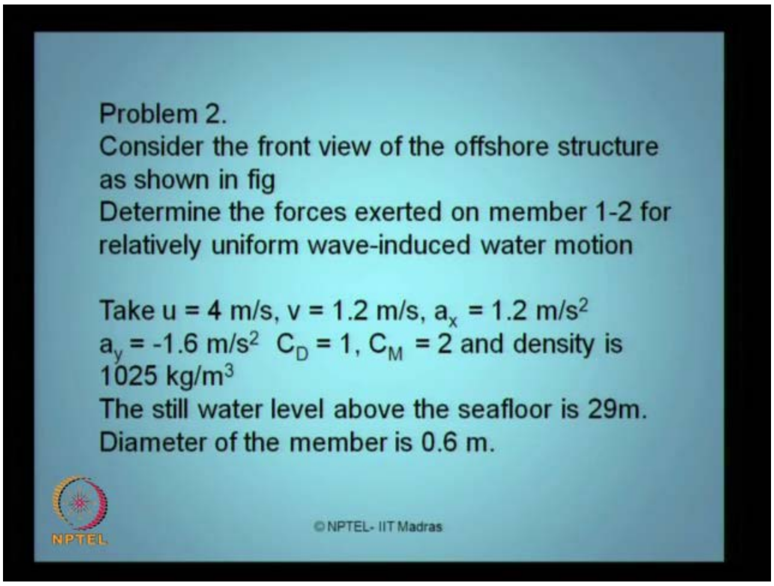

Let us have a second problem. Consider the front view of the offshore structure given to you in the figure as shown in the figure in next slide. I want you determine forces exerted on the member 1 and 2 for relative uniform wave induced water motion. You can take the horizontal water particle velocity as 4 meter per second, vertical as 1.2 meter per second, horizontal acceleration is 1.2 and vertical acceleration is minus 1.6 meter per second square C D and C M are given as it is, density can be given. The still water level above the seafloor is 29 meter, diameter of the member is 0.6 meters.

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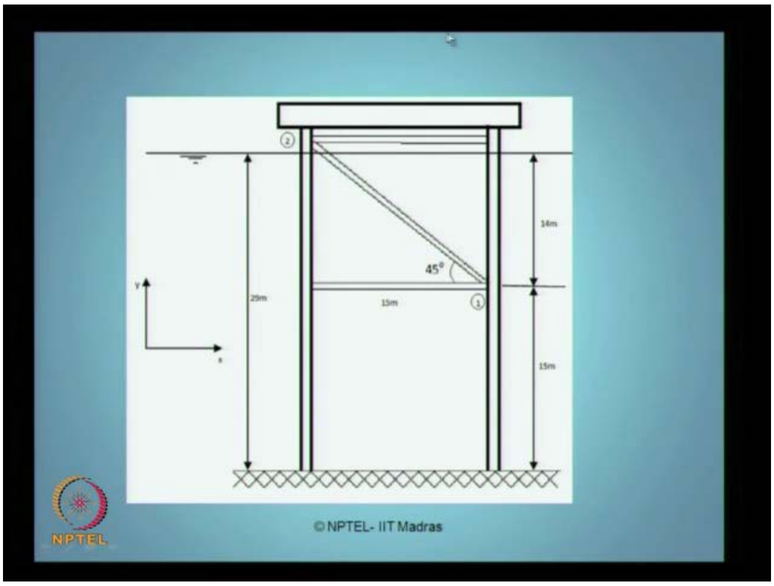

This is the figure, this the member 1 and member 2. I want you to determine the force on the diagonal member 1 2. So, I given all the dimensions of the member, the water depth, the water (( )), estimate the forces. I think you will be able to solve this problem with the help of equations given to you. We can use any appropriated wave theory, there is no problem.

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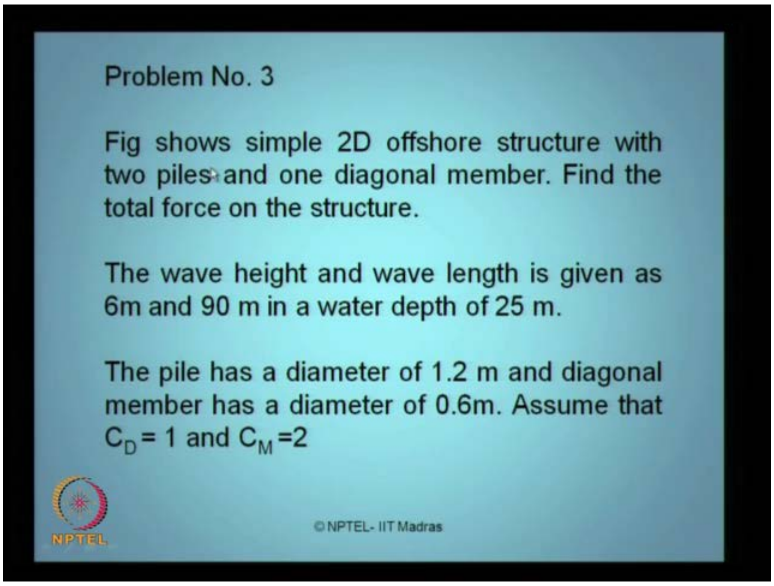

Let us see problem number 3. Again, there is a figure shown of a two dimensional offshore structure with 2 piles and 1 diagonal member, find the total force on the structure, the wave height and wave length are given as below, the pilled diameter has a member of about 1.2 and the diagonal member has a diameter of 0.6 meter.

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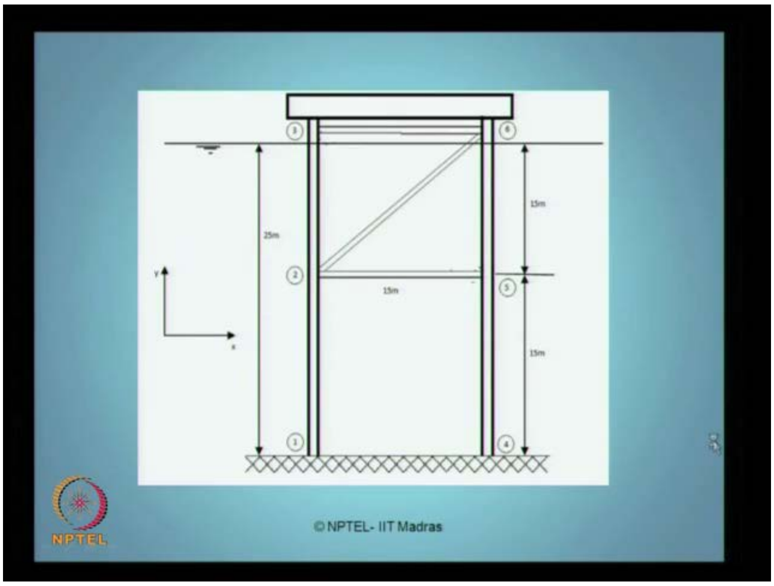

C D C M are shown here so I want different designation in the members, compute the member forces in all the members by using any desired theory as suggested by you.

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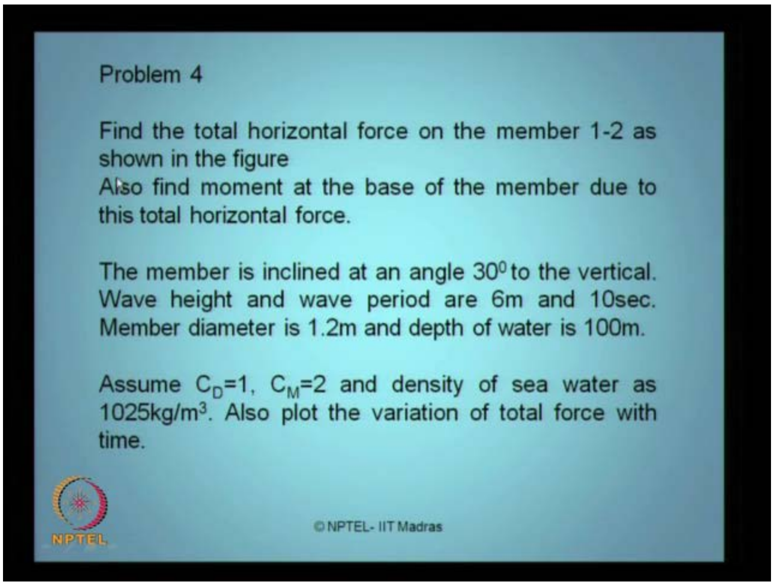

The fourth problem is find the total horizontal force on member 2 as shown in the figure, also find the moment at the base of the member due to this horizontal force. The member is inclined 30 degree to the vertical. Now, the wave height and wave period are given to you which is deep water case is 100 meters and so on. Assume C D and C M, density is given. Now, I want to you plot the variation of total force with time. That is the interesting catch in this problem.

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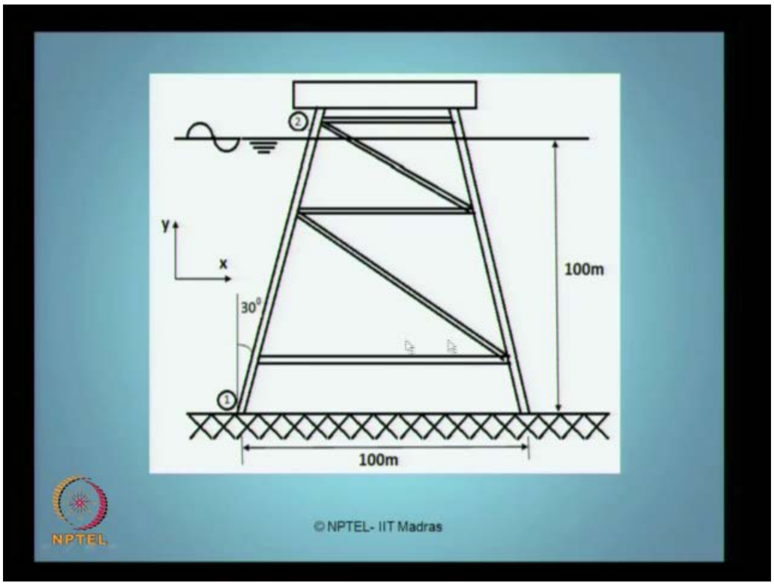

This is the problem where awarded, inclined member, the member is inclined 30 degree to the vertical, this is 100 meters. So, I want you so find out the forces of the member 1 2 as shown in the figure here.

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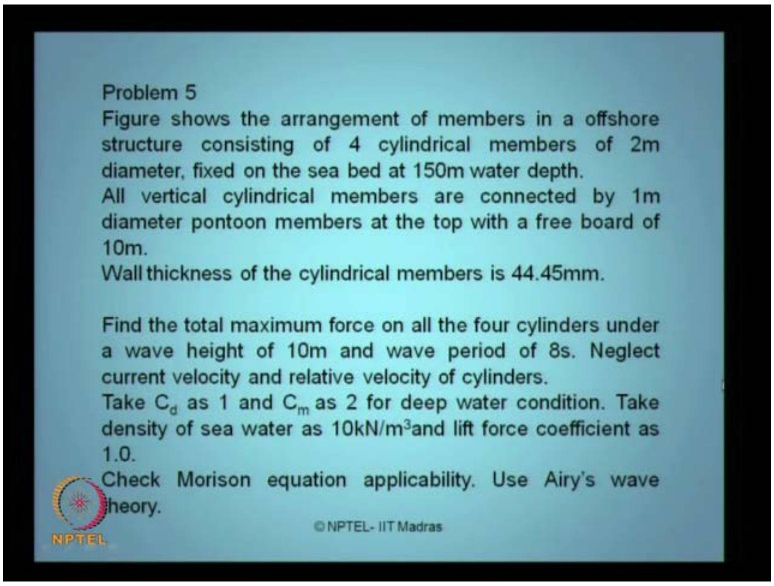

Problem number 5 shows the arrangement of the members in an offshore structure consisting of 4 cylindrical members of 2 meter diameter fixed on the sea bed at 150 meter water depth. All the vertical cylindrical members are connected by 1 meter diameter pontoon members with a free board of 10 meters, wall thickness is given as 44.5 millimeter, find the total maximum force on all the 4 cylindrical members, under the wave height of so much and wave period of so much. Neglect the current velocity and the relative velocity of the cylinders. Take C D C M and density as given here. Take the Morison equation applicability, use specifically Airys wave theory. There is a catch in this problem.

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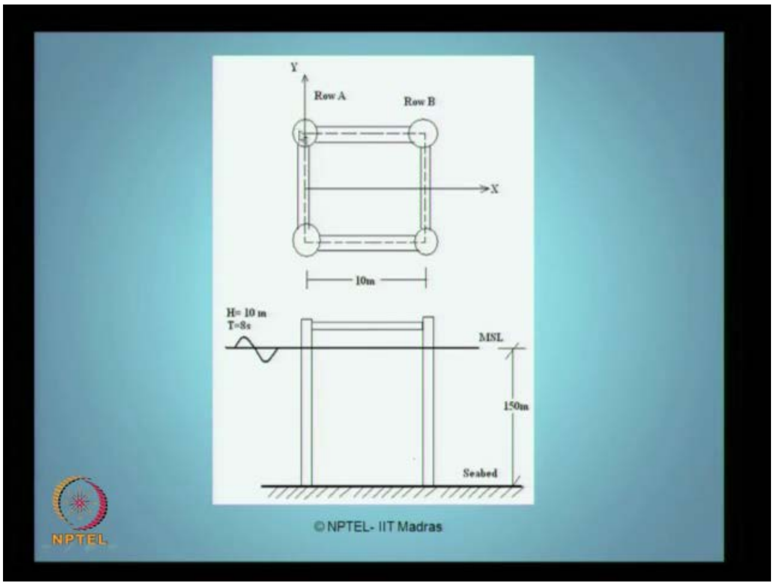

So, you got 4 members, cylindrical members and 4 quantum members, which are spaced 10 meter interval both along X and along Y. So, the depth is 150 meter water depth. So, I want you to compute the forces on all the members using Airys linear wave theory.

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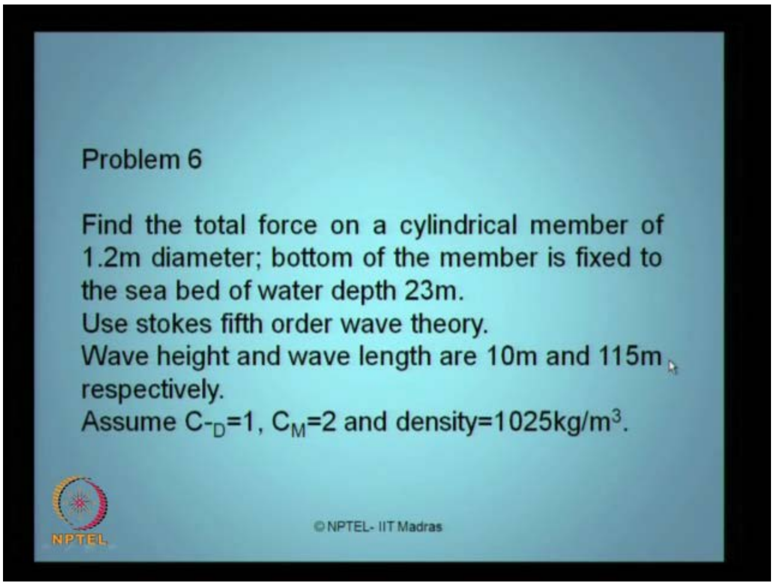

Now, the sixth problem is to find the total force on a cylindrical member of diameter 1.2 meter, the bottom of the member is fixed to the seabed. Use Stokes fifth order wave theory to estimate this; wave height and wave lengths are given, C D and C M are known to me. So, we have discussed how to estimate wave forces, how to estimate wind forces, current, ice load, buoyancy loads, earthquake forces etcetera on members. We have also discussed, what the different types of offshore structures are in brief; so this gives a very brief introduction about different platform types, forces acting on the platforms etcetera in this module. Thank you very much. We will continue forward for the next lecture.