Dynamics of Ocean Structures
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Lecture No – 30
Fluid Structure Interaction- II

Today in the 30th Lecture, in Module 2 we will talk about the Fluid Structure Interaction part 2 where we discussed yesterday something on wave structure interaction.

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So, we must understand and appreciate that looking at a system of this order, where for a given offshore structure the inertia forces are very high across the top side mass of the given system is very high significantly large. And system can either be flexible or stiff enough to re-centre or to enable the re-centre capability by looking at the right hand side of the equation of motion of f of t, where when we say that in a given flow field if member interferes with the flow domain in the vicinity of this member; what would be the consequences occurring because of the fluid interacting with the structure.

More interestingly this has been a very challenging problem in offshore structural design itself right from the beginning. And to avoid and alleviate these kinds of forces effectively people started anchoring this cylinder to the seafloor as a permanent system so that they have a fixed base, so that the response given by the system back to the environment vicinity around the flow field is minimum. There are two kinds of forces coming; one is the vibration induced on the member because of the continuous flow of the water particles which is called the flow field.

The second is secondary vibration or oscillation generated by this system itself even if it is fixed. Of course, in the case of floating of it will anyway happen, even if it is fixed it will have a secondary vibration around the vicinity of this in both the direction, in my flow and the transverse flow both which we saw in the last structure and we will continue to do that Now, we will see some of the important points then we will talk about the summary.

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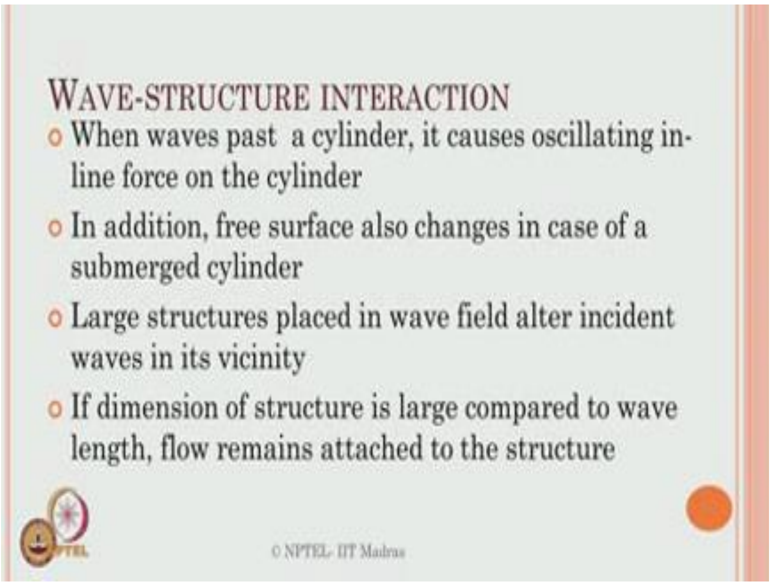

We look at the wave structure interaction. We already said that when waves past a cylinder it cause oscillation in line force on the cylinder. In addition free-surface also changes. In case of a submerged cylinder large structures on the other hand in dimension of the structure with respect to the wave length is compatibly or significantly very large when they are placed in the wave field they alter the instant wave in the vicinity. Please understand they do not alter the wave on the downstream side. There is an upstream side, there is downstream side there is the pressure difference between these two which relates in a differential shear which we saw in the last lecture.

So, near the vicinity the upstream side the way approaches side it has got lot of disturbances created when the cylinder or member interferes with the flow field. However, this interfere will settle after the wave pass the cylinder and the specific length which we call as characteristics length of given problem. This is actually the boundary element of the given analysis which we will talk about this later in the coming lectures in this module. So, beyond which the interference effect on the cylinder on the wave field or the flow field will be not significant at all.

So, if you want to mathematically or numerically model the behavior of fluid structure interaction your domain should encounter or capable of encountering the whole disturbances as in the inline as well as transverse direction, numerically as well as experimentally.

So, that is what the idea we all understand how it is generally done, but still however we must emphasize that large structures are placed in wave field. The wave field the instant wave field in the vicinity is altered significantly and of course the dimension structure is too large compared to the wave length then the flow remains attached to the cylinder, and that becomes the problem. Because, if the cylinder is also oscillating body then it creates vibration automatically because the flow is attached to the cylinder, when the flow separates then you can see effect of separation of the flow field and nullifying effect on the vibration of the system. It will just attach to the structure so it adopts vibration of the structure itself which is very bad.

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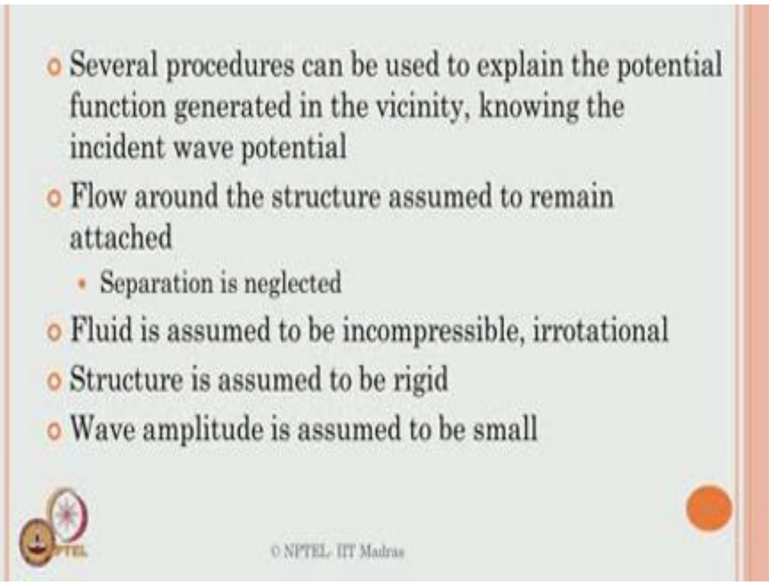

Now, to explain these philosophies there are several procedures available in this literature. One can use the potential function the generated in the vicinity, knowing the incident wave potential. We also agree and understand the flow around the structure is assumed to remain attached, because separation is generally neglected. Fluid is assumed to be incompressible; irrotational that is a standard assumption in the analysis in wave theories. Structure is assumed to be rigid for the time being. Please understand structure assumed to be rigid does not mean the member is fixed at the bottom.

Rigidity can come not only from boundary condition, but also from the (Refer Time: 05:28) ratio that is diameter versus thickness ratio also. The structure or the member can still remain rigid is this d and this is t then for deviating value of specific number which has a categorical number design you can always say that the member is rigid. The rigidity does only come from the boundary condition; of course it also comes from the boundary condition. And more importantly we also assume that the wave amplitude is relatively small.

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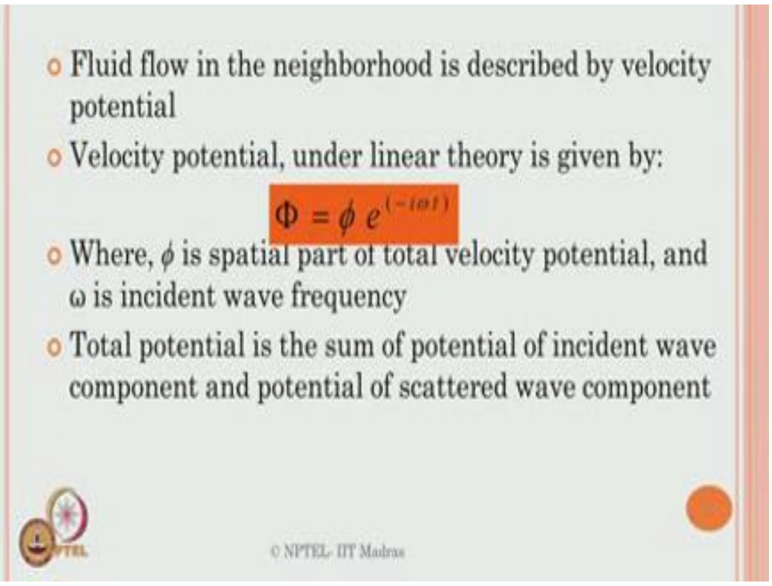

Interestingly, we will go ahead and try to understand that the flow field in the neighborhood is generally described by the velocity potential. Velocity potential under linear wave theory is given by phi which is written over e minus omega t which has got both the components cosine and sin components. Where, phi is the spatial part of total velocity potential and omega of course is the incident wave frequency which generates or hits the member.

Now the total potential of course in this case is going to be sum of potential incident wave component and that of scattered wave component, because on the wave or the wave particles comes and hit the member all the wave particles do not pass the member at all. They also get scattered because of the interference effect. And that scattering or the volume of scattering the extent of scattering of course depends on or the reflection. Depends on what is the characteristics dimension of this member with respect to that of wave length. Because the characteristic of the wave is quantified by two items; one is of course the amplitude, another is of course the wavelength.

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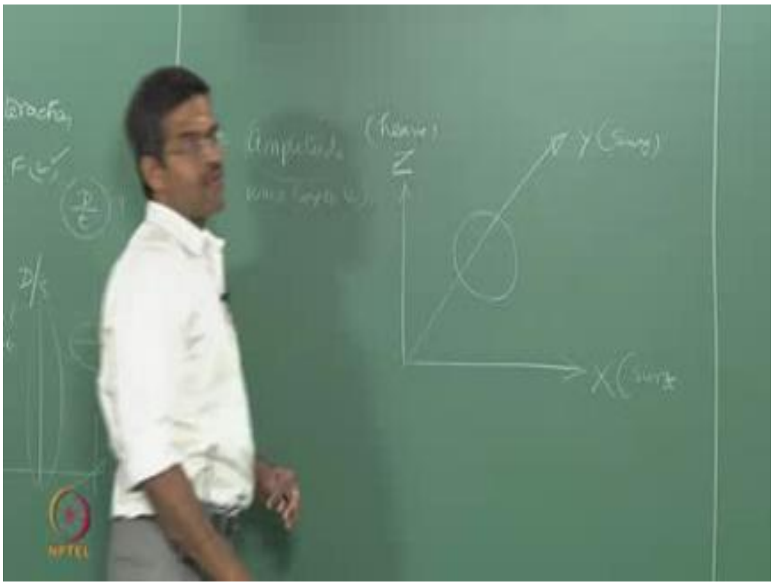

Wavelength in the sense wave period actually as you know wavelength and period are related. One of these two periods we just now said that wave amplitude is relatively small compared to the diameter or characteristic dimension of the member, we do not call this diameter we call this characteristics dimension. Why we call this characteristics dimension, because this is actually the dimension which is fore fronting the wave approach. For example, if we take eclipse major and minor axis characteristics then which will be characteristics dimension depends upon how do you orient the member. If you orient the member this way then this becomes characteristics dimension or vice versa.

So, depending upon the dimension of the characteristics value of the member with respect to that of wave length then the water particle gets also scattered. Now the forces have to be generated by two nodes; one is called the sum of the potential wave component and the other one is the potential of the scattered wave component.

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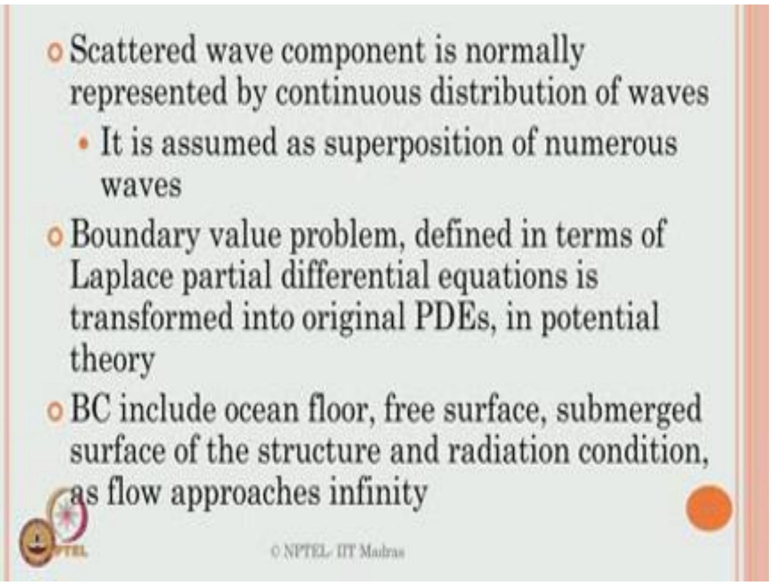

having said this let us closely look at the scattered wave component, because instance wave theory we already have the various theory for example, to explain me the various water body schematics which gives me in turn the forces on the member. The member we fixed, then we have already given the equation yesterday we know how to calculate the forces per unit length you remember. The member is floating we already said yesterday how to calculate using relative velocity component of the member and that of water particle velocity.

However, for the scattered wave component, generally the scattered wave component is normally represented by continuous distribution. It is generally assumed as superposition of numerous waves. Now then it becomes a boundary value problem. The boundary value problem, defined in terms of Laplace partial differential equations is transformed into original partial differential equation in the potential theory. And the boundary condition now in this case will include ocean floor, free-surface, submerged surface of the cylinder or structure and the radiation condition as the flow approaches infinity. So, there are different conditions you want to specify in a numeric analysis when I start doing the capture the scattered way component effect on the member.

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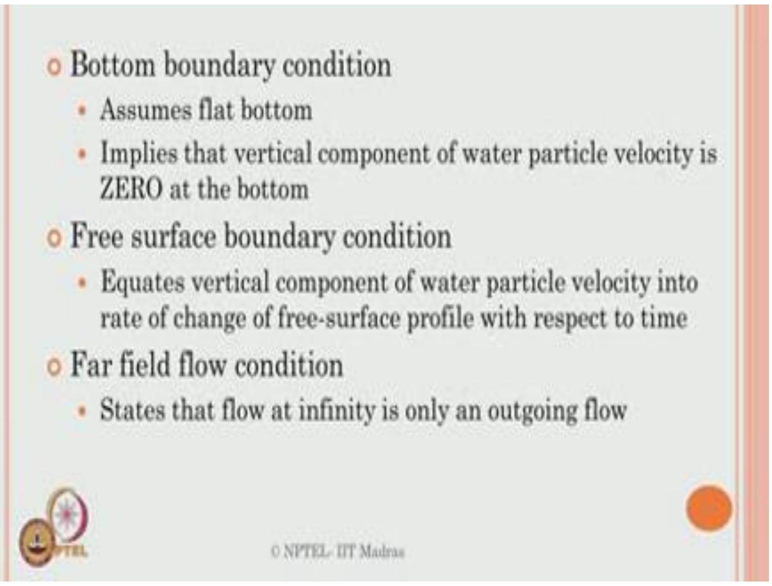

Having said this, let us look at what are those classical boundary conditions which we must use in case of numerical analysis. Let look at the bottom boundary conditions, generally in analysis the bottom is assumed to be flat. However, in ocean bed the flatness is not ensured and roughness is also not ensured, so therefore we assume that the system or the sea bottom remains flat because the distance or the flatness of the surface from that of the edge of the cylinder is very large compared to water depth of the sea bed where the structure is installed. Therefore, the assumption is very much valid we assume the flat bottom for the given sea surface at the bottom sea bed.

It also implies that the vertical component of the velocity now is practically zero at the bottom the moment I say flat. If I say inclined or let us say rough terrain etcetera I will have two components; one is horizontal, other vertical component. To avoid this complexity we assume that bottom is remained flat. Therefore, there is only one component which along the inline force the other one vertical component of the velocity is remaining practically zero.

Now look at the free-surface boundary condition, because we already have three surfaces. Please see here in the slide we already said the boundary value problem or boundary condition for a given problem should include the ocean floor, the free-surface and of course the submerged surface of the member either member is partially submerged now. So, we now just saw the bottom boundary condition we assume it to be flat.

The free-surface boundary condition equates the vertical component of water particle velocity into rate of change of free-surface profile with respect to time. So, I am able to capture or I am attempting to capture the water particle velocity variation in the time domain which will now help me to classify the free-surface condition. It means the free-surface boundary condition alone is capable of giving me the variable submergence effect on the given body, whereas bottom will not give me because bottom is flat.

Now there is something called as far field flow condition. What does it mean is that the body is located here, this is my incident way field, and this is my downstream far. Now, what is the influence of the far field on the body? Will it reflect back on the member, will I have any interference on successive member nearby depending on spacing of the member? I have to capture this also because, if we successive member in one row what we call as group or cluster of cylinders or structure of members then the interference effect on this member will be back on this member also. So, I must always classify what is my far field boundary condition or the flow condition. And it states that the flow at infinity is only at an outgoing flow. That is the general assumption.

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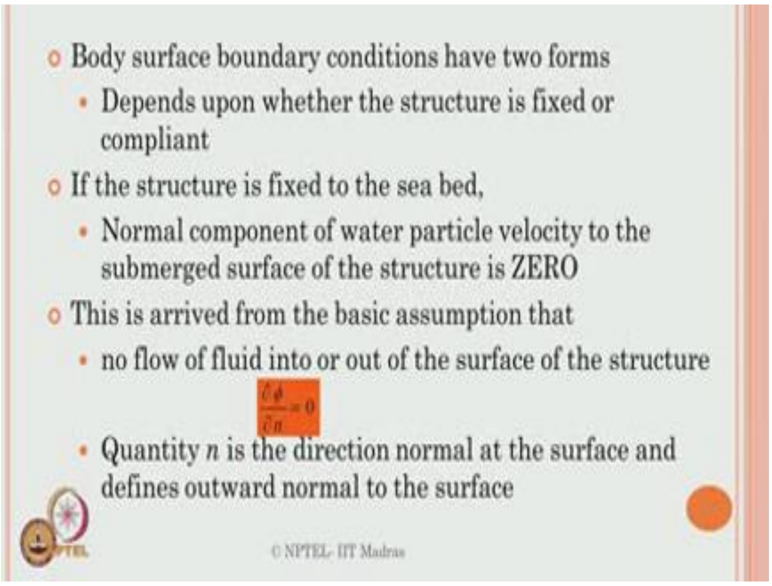

Having said this, now we have to also discuss and define the body surface conditions of these systems. The body surface boundary conditions again we have two forms; it actually depends on whether this is fixed or compliant. Please note it is compliant, compliant means floating flexible.

If the structure is fixed to the sea bed then the normal component already we said is going to remain zero. This is arrived from basic assumption that no flow of fluid into or out of surface structures is possible. Therefore, we say dou phi by dou eta or dou n is normal this is zero the quantity n is the direction normal at the surface and defines outward normal to the surface which is set to zero.

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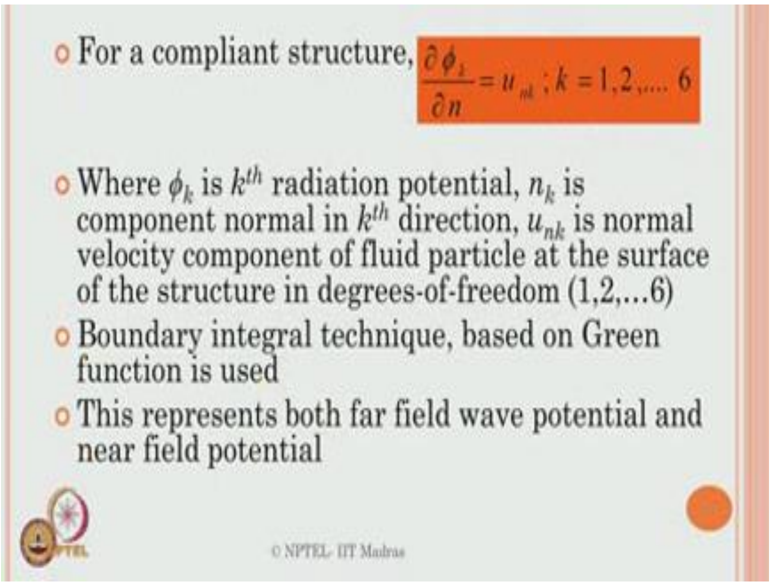

Having said this, now for a compliant structure of course this will have different components in all the directions therefore dou by k by dou n where it is going to be u and k. Where, k can vary from 1 to 6, 1 to 6 are numbers of degrees-of-freedom what this cylinder can. One can ask me why I am limiting to 6 we already know this, but still let us for the benefit of the users let us try to specify this. I have a cylinder in plain let us say I have three axis, so I call this as x axis, this as y axis, this as z axis. I can have displacements along x y and z which we classically call as such as sway, surge and heave along zeta or z axis.

And I also have rotations about this axis, so to indicate rotation direction I normally put my thumb towards the direction. Remaining four fingers will have a specific direction plotted I am marking that here I call this rotation about x axis roll, I put the thumb here I call this as pitch, I put my thumb here I call this my yaw. So, there are only 6 degrees-of-freedom a member can have in offshore structure analysis.

So, we say that phi k will be radiation potential kth value where nk is the component normal in the kth direction and u nk is of course, is the normal velocity component of fluid particle at the surface of the structure. Where, k refers to the degrees-of-freedom varying equal to 6.

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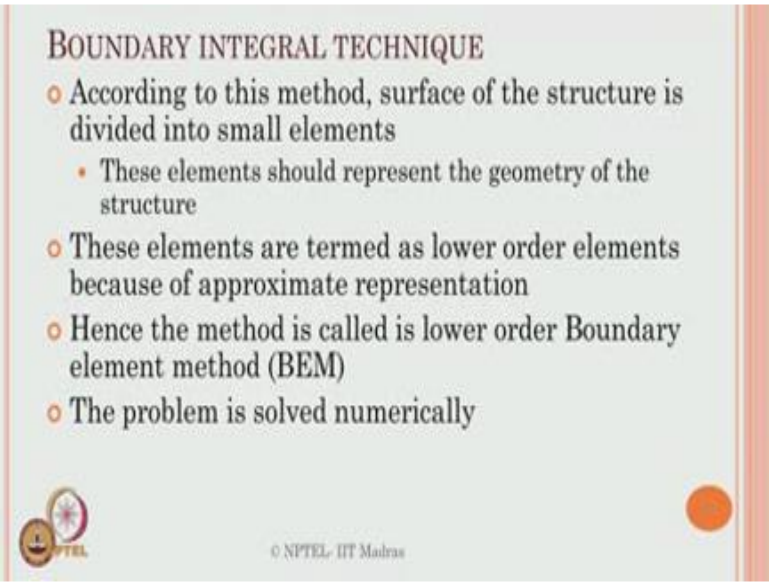

Now, this problem becomes more complex therefore we cannot be solved using conventional partial differential equation techniques. So, we use greens theorem or greens function to solve this boundary value problem or boundary integral technique. This represents both conferences of far field wave potential and near field wave potential. Now let us quickly see what is that so called boundary integral technique? According to this method surface of the structure is divided into small elements. We divide the surface of the member into small segmental elements. Theses element of course should represent true geometry of the structure in its spinal surface.

So, these elements are termed as lower order elements because of approximate representation. Hence the method is also called otherwise as a lower order boundary element method the problem is then solved numerically, so people use this. So, what they do is they will not try to find member force on the entire member they try to divide member surface into small finite elements and try to find out the numerical value of the water particle velocity and the force on this elements, and then integrate it for the entire length of the member to find the total force of the member. And then resolve this force in all equivalent respective degrees-of-freedom to get the force on the member.

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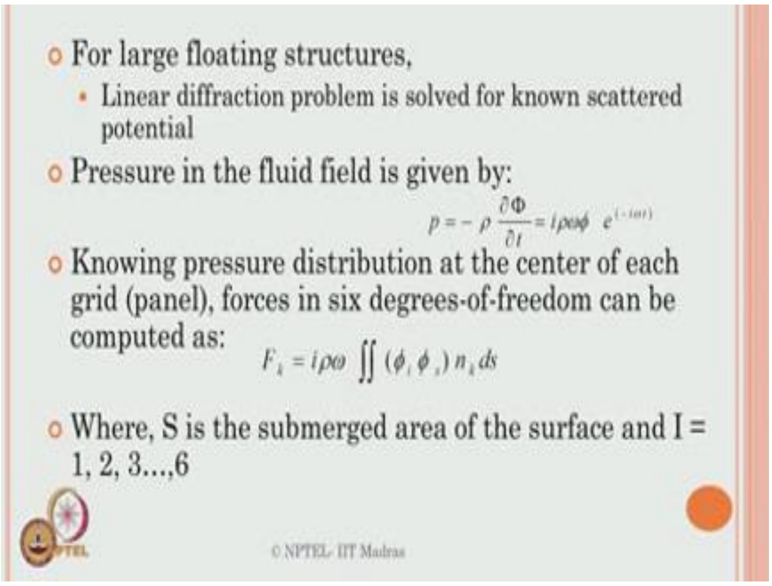

What we call as boundary interval technique or lower order element or lower order boundary element technique. Now on the other hand this is not so because for large floating structures it becomes the problem. Please understand when I say large floating structure it is not largeness because of the diameter of the member, the structure itself is very large. The buoyancy force or the surface area occupied is very very large. For example, FSRU, floating, storage, regasification units they are very large in size 190 meter long 45 meter wide and design draft can be 20 to 25 meters. They are very large floating systems.

So, for large floating structures the linear diffraction problem is solved for known scattered potential. I have an example later I will show you an example how radiation potential the velocity potential are being solved using analytical technique on applied to TLP I will show you later. But, anyway we will try to understand that for large floating structures the linear diffraction problem is solved for known scattered potential. Pressure in the fluid field is given by rho which is as sure as minus sin dou by dou t.

And knowing the pressure distribution centre of each grid are the divided panel then forces in 6 degrees-of-freedom that can resolve using this integration given as f of k, where i rho omega phi a phi s where s is actually talking about the submerged area of the surface and i varies from 1 to 6 being the degrees-of-freedom of given member.

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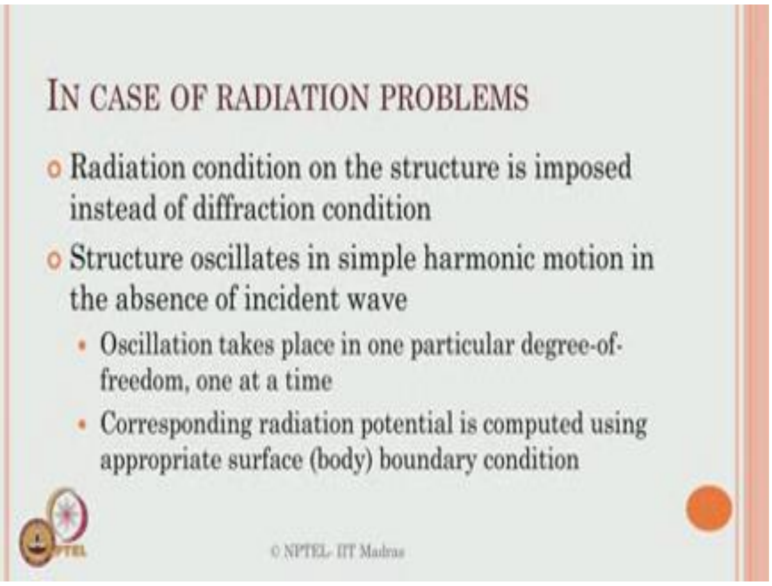

Now in case of radiation problems, because when you have got a large floating system the flow of field will be interpret by the member and result in what we call as radiation potential additional to that of the scattered velocity potential. In case of radiation problems, radiation conditional structure is imposed instead of diffraction condition now. Structure oscillates in simple harmonic motion is an assumption to the absence of incident wave, then oscillation takes place in one particular degree-of-freedom at one time that is ideal session. Corresponding radiation potential is computed using appropriate surface boundary condition given on the system.

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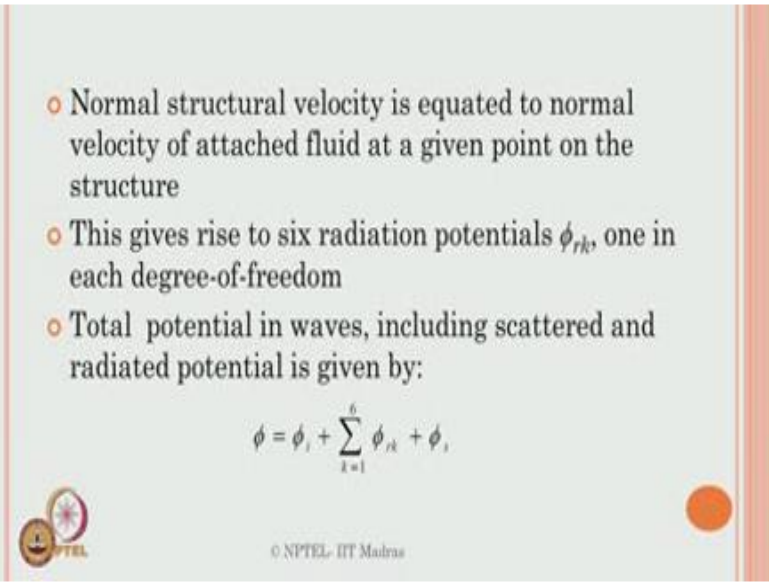

Then the normal structure velocity is equated to normal velocity attached to the fluid particle at the given point of structure. This will now give rise to six radiation potential phi r k. Where, k is varying from 1 to 6 degrees-of-freedom. The total potential in waves now include scattered and radiated.

So, radiation potential is valid only for large floating structures, whereas scatter is valid when the characteristics dimension of system be fixed or floating have got some dimension relationship with that of the wave length of the given body or the flow field. So instant wave, scattered wave, radiated wave, we have got different potential being generated. And forces of course will come it is in all since freedom equal to all of them.

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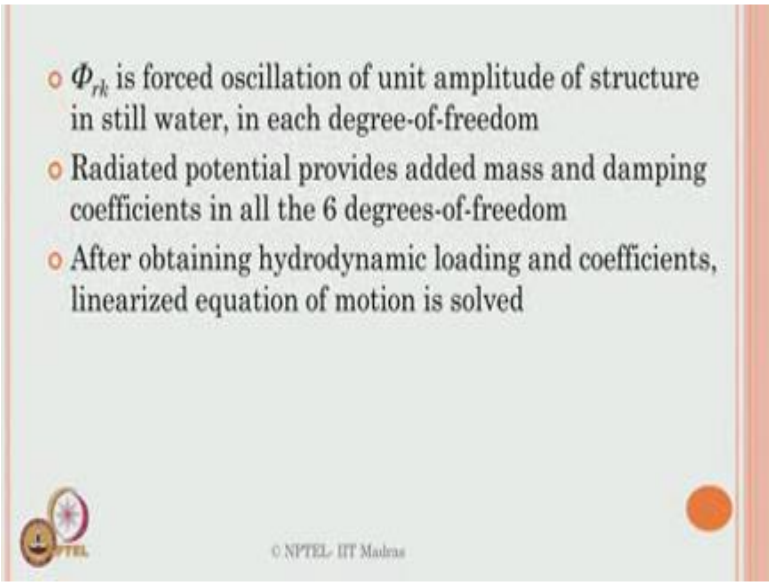

Of course, phi r k is the forced oscillation of unit amplitude of structure in still water in each degree-of-freedom k being the number counted for each degree-of-freedom. Now, radiated potential provides added mass and damping coefficient. Why we say added mass, because added mass is again is a velocity is an oscillation term which comes from the additional oscillation component arising from the oscillation of the body given in the 6 degrees-of-freedom, therefore added mass.

Why damping coefficient, because this will induce and force damping of water body around the vicinity of the member, therefore damping coefficients. Now they all come into play in all 6 degrees-of-freedom resolved accordingly. After obtaining hydrodynamic loading and coefficients the linearized equation of motion is now solved. that is the procedure.

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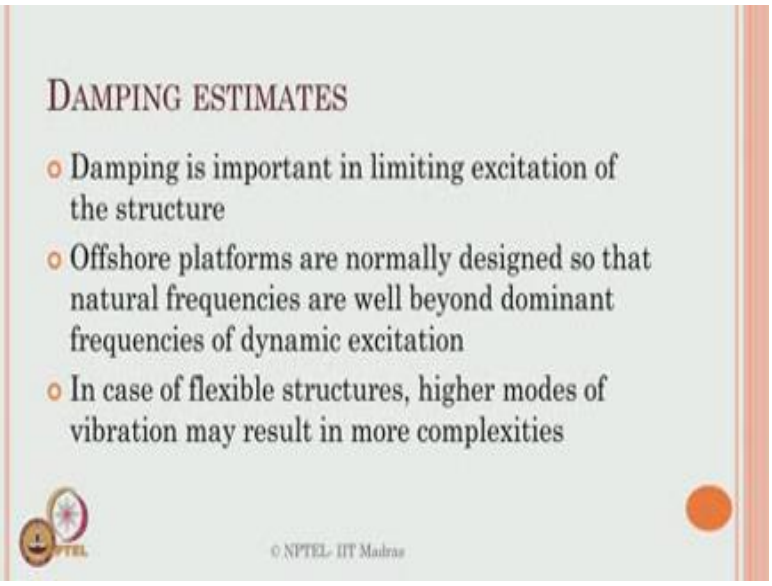

As we said damping in also becomes very important in case of offshore structures, because damping is a very important estimate and dynamic analysis as well. Damping is important in limiting excitation of structures we all know that. Offshore platform is normally designed, so that natural frequency beyond the bandwidth of the dominant frequency of dynamic excitation we know that because we have already seen a curve where the design curve says my dominant frequency is in a specific range, whereas my natural frequency system is classically divided into two components which is either very low or very high from the dominant wave frequency.

In case of flexible structures higher modes of vibration may result in more complexities which need to be handled very carefully, because they will give rise to secondary forces called springing and ringing action in the given flexible systems.

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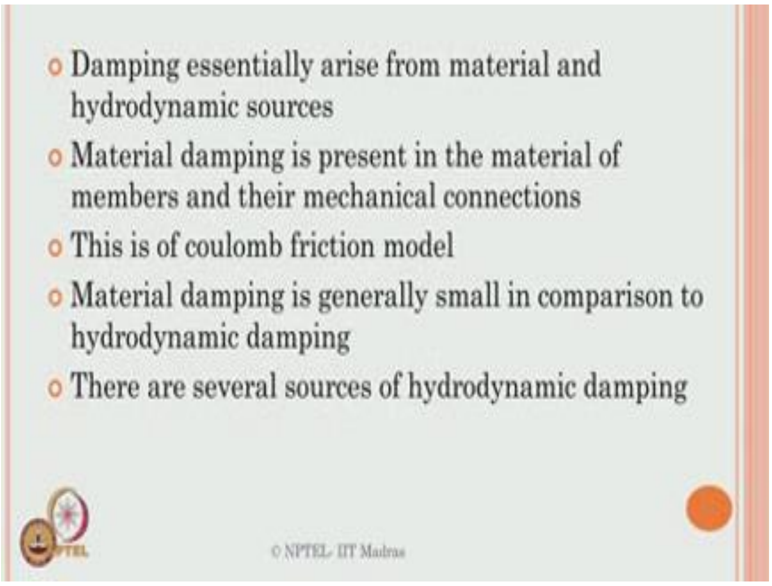

So, we now understand in general damping essentially arise from material, because material degradation will also cause damping. And of course, it comes from hydrodynamic sources, because we are talking about damping. Material damping is present in the material members of the members and the mechanical connections between the members or the joint or connections there is of course the cool infraction model, we already explained this in earlier module. Material damping generally is small in comparison to hydrodynamic damping. There are several sources of hydrodynamic damping which we also said in the first module lectures.

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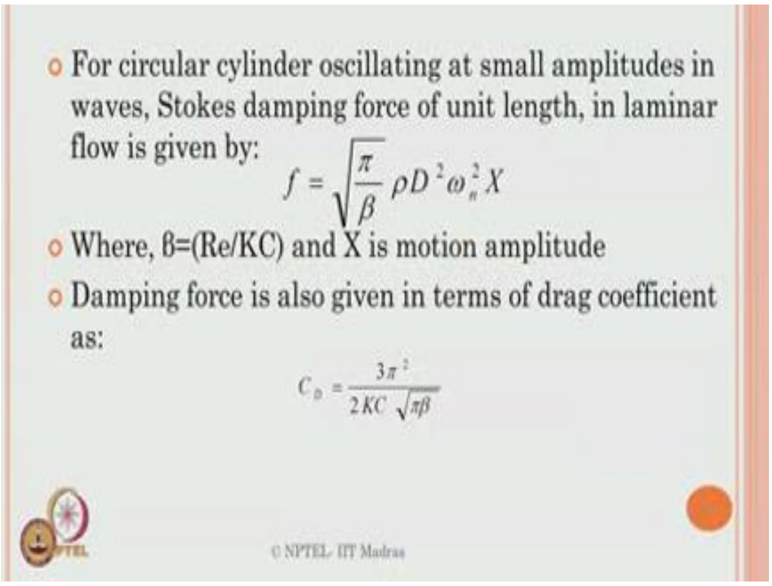

Now there are two equations available on the screen now which will help you to estimate the damping very easily. For circular cylinder oscillating at small amplitudes stokes has given an equivalent damping force which is given by the equation available as here, f is equal to pi d beta rho d square omega n square x. Where, x is the motion amplitude so it is proportionate to motion amplitude, where of course d is the characteristics dimension of the member. I keep on repeating this it is not the diameter of the member; it is member which is normal to the wave front. Diameter of course in cylinder is going to be the diameter, but does not always remain as a diameter it is always called as characteristics dimension of the member, it is not the larger one.

So, d of course rho is the density of the sea water. And omega n is the natural frequency of the member which is vibrating. Whereas, beta of course we have already seen yesterday that instead of explaining only Reynolds number people looked at ratio of Reynolds carpenter number, therefore that is what the design is generally used in analysis and design of offshore structures. Therefore beta has been used here as stokes recommend damping force per unit length of the member is given by this equation.

Damping forces also given by drag coefficient that C d is not the drag coefficient here it is actually the damping coefficient is given by 3 pi square by 2 k c by beta. So, these are two alternative methods by which one can work out damping force per unit length of the given member which it includes the hydrodynamic damping arising from the member.

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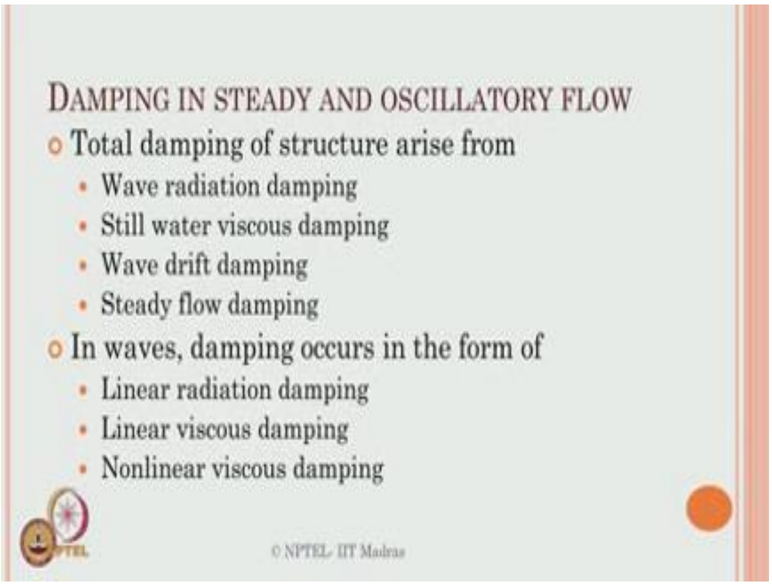

If I talk about damping in steady and oscillatory flow, total damping of structure arise from different sources for example it can be; wave radiation damping, still water viscous damping, it can be wave drift damping, can be steady flow damping. I can give only one example of wave radiation damping.

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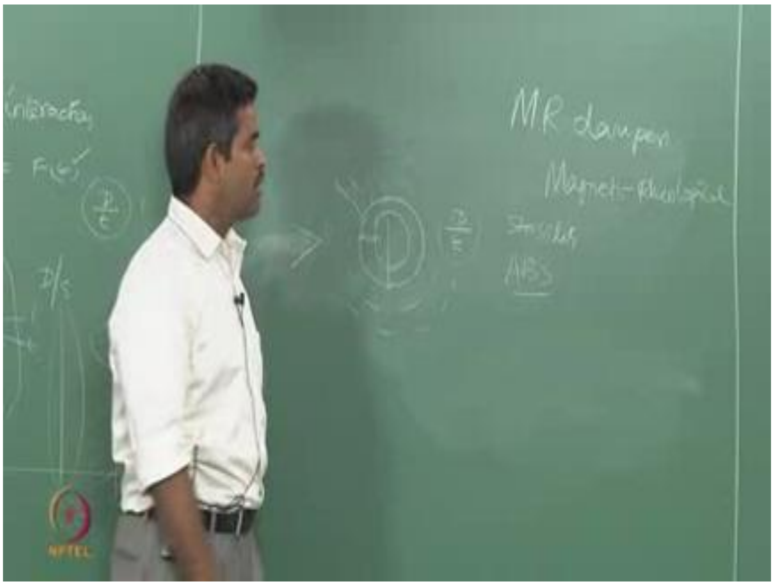

Let us say I have a cylinder whose characteristics dimension is known to me, whose thickness or d by t is significantly the thickness is low compared to the diameter. Of course, we must know that d by t is a very important number based on which the member is checked for stability, you cannot keep the thickness so low compared to the diameter the member look highly flexible so it will not remain stable. So, ABS; American Bureau of Shipping gives us a guideline how to select the member whose d by t will be in a specific range, otherwise before the member fails in axial forces member failing buckling because it will not be stable.

I have got a d by t which is proportionately available and accepted by ABS let us say I have a instant flow field this my inflow direction and when the body interface with the flow dimension of flow field I have radiation potentials passed around. Now, as you keep on seeing here when they are getting radiated away from the source radiated away from the source they will start blocking force or the action of the force on the member. There is always radiation damping cost that is what we say here where radiation damping.

This can be of two forms; one because of the high amplitude motion of the cylinder itself if the cylinder is flexible or because of the rigidity of the member which reflect the member forces or the way particle hitting the member, so can be two forms. Therefore there is one important source of damping. Of course, in terms of ways because they all arise from the structure they also arise from the ways in terms of linear radiation damping, linear viscous damping and non-linear viscous damping. Of course in so called models in the previous modules we have only discussed about the viscous damping is linear.

We have not talked about non-linear viscous damping because then this called Magneto Rheological dampers; MR dampers will talk about this later. In the third module I will talk about we have used MR dampers for one of the structural controls and one of the tall buildings in Europe when we did some research there. I will talk about magneto rheological dampers, they are neither viscous nor friction based, neither (Refer Time: 24:36) model nor viscous damping model. So, combination of both actually is got both the components it.

So, MR damping, so they can also create non-linear damping. Will talk about this later where the useful how they are useful will talk about this talk about circular control in the last module, we will talk about this. So, damping can arise from two sources one from structure itself, one comes from the ways also.

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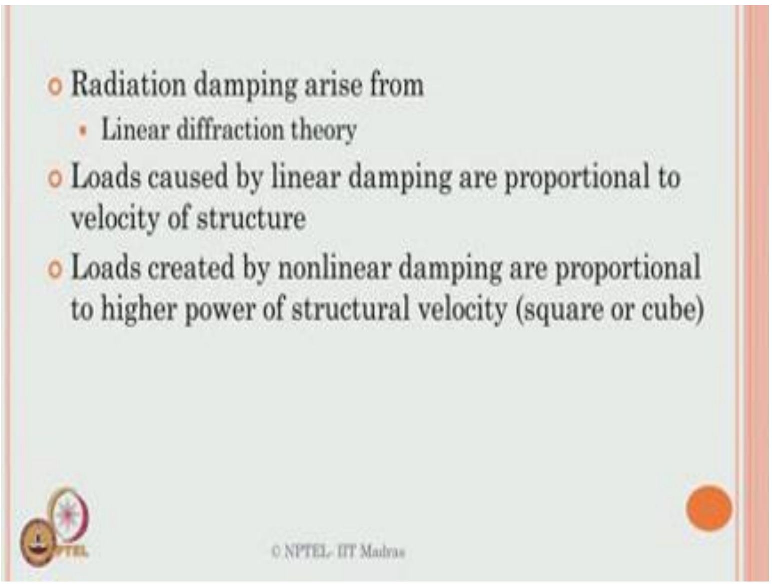

As you just know radiation damping arises from linear diffraction theory. Loads caused by linear damping are proportional to velocity of structure that is why it is called viscous damping related because you are proposition to velocity. Loads created the non-linear damping are propositional to higher power of velocity, that very important. if the velocity is very large for a high flexible member then the damping arising of non-linear component will be very very high, because there will be order 3 or 2.

Having said in both the lectures will talk about quick summary of what we have understood so for from fluid fraction interaction as summery.

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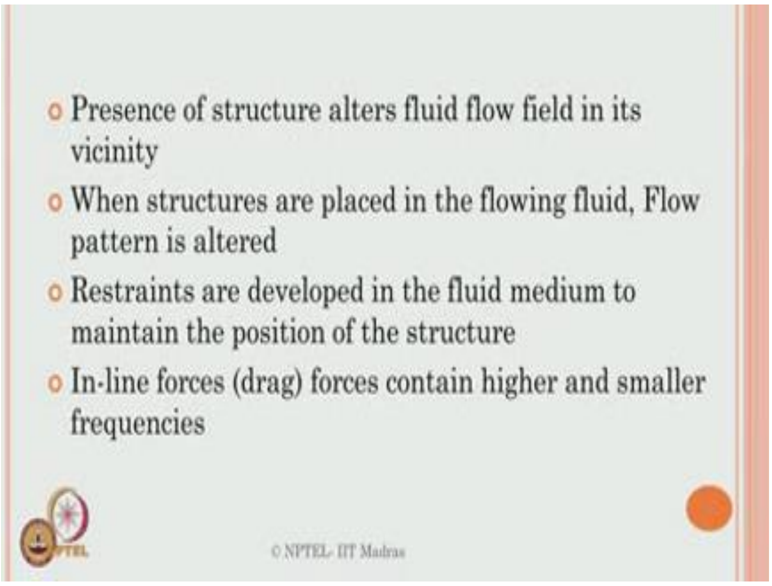

We already said presence of structure alters the fluid flow in vicinity, is very very clear. Please understand the influence of the member on the flow field is limited it is not infinite. That is why we always put word vicinity. The flow field is only influenced by the member interference only around his vicinity beyond that. If you are able to construct one more member that is why you know that is one of the important characteristics dimensions how you place the spacing of the column in a give TLP or place the columns in series of break water structures. What should be the spacing between the piles and the column members?

So, you must always try to find out what would be that distance beyond which the interference of the member or fluid structure interactions becomes (Refer Time: 26:30), otherwise will cause secondary effects on the given member itself which will damage the member. So that is how the spacing is decided as per the design is concerned. Now in structures are placed with the flow in fluid we have understood that the flow pattern is completely altered. We already said as a shear happing special differential happen, so flow field is alter or flow pattern is altered, retains of course a developed in both fluids medium as well as in the structural medium both. And structure tries to get in gain is re centering capability which results in additional force on the given media; that very important. In-line forces what we call drag contain higher and smaller frequencies both should be captured.

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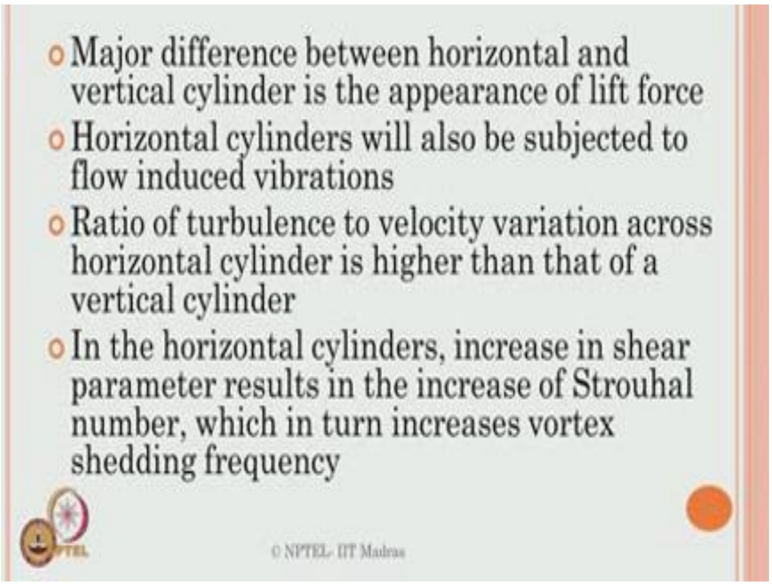

The major difference between horizontal vertical cylinders is in the appearance of lift force itself. In case of horizontal it is very simple where as vertical it is a differential shear happing. Horizontal cylinders will be all subject to flow induced vibration so you have to very careful. In fact, the recent trend is people use this technique to harness wave energy. They keep member horizontal they allow member to vibrate and flow induce vibration caused by the cylinder on the body is captured and they are trying to harness wave energy from this concept.

You will have a very interesting flow induce by vibration characteristics. Ratio of turbulence to velocity variation across the horizontal cylinder is a higher than that of the particular cylinder. We already seen is a last lecture. In horizontal cylinders there is increasing shape parameter which results in increase in Strouhals number, which in turn increases the vortex shedding frequency.

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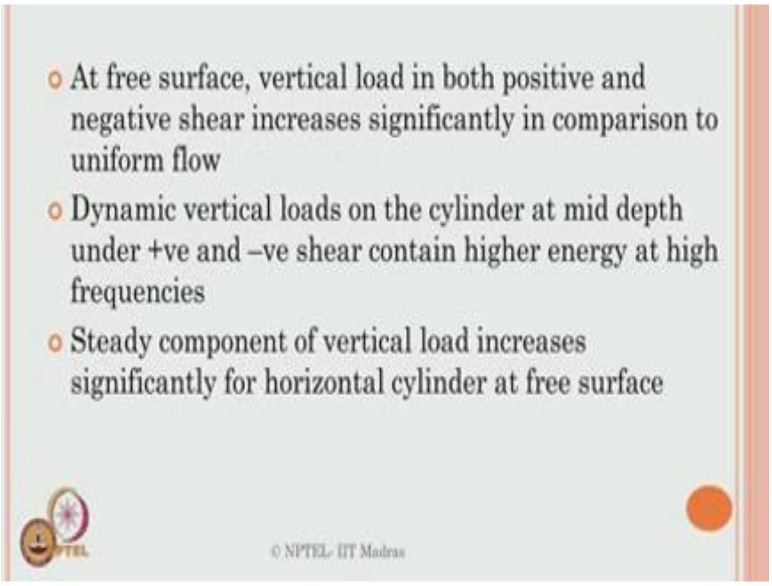

Of course that free-surface, the vertical load in both positive and negative shear increases significantly in comparison uniform flow. The dynamic vertical loads on the cylinder the mid depth under positive and negative shear contain highest possible energy at very high frequencies. The study component of vertical load increases significantly for horizontal cylinder only at the free-surface.

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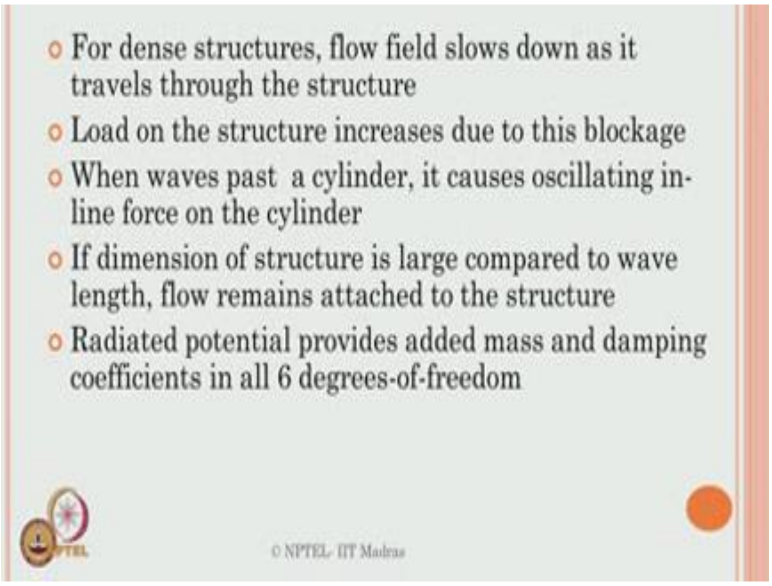

For dense structure which are closely spaced the flow fields close down. We already saw that yesterday as I travel through the structure. Load on structure therefore increases what we calls as a blockage effect we already said what is component of blockage effect. When wave pass the cylinder, it causes oscillation in-line force on the cylinder. If the dimension of the member is large in comparison to the wave length flow remains attached to this cylinder. The radiated potential provides added mass and damping coefficients in all active 6 degrees-of-freedom.

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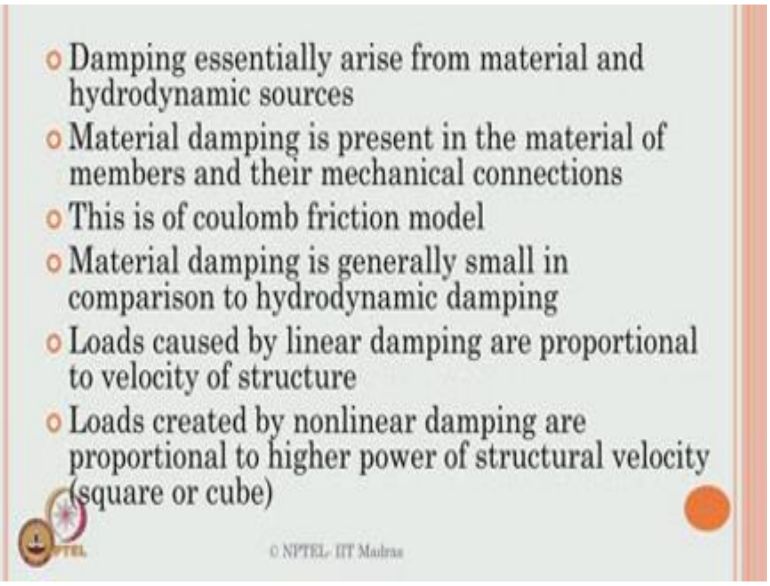

Damping arises essentially from material and hydrodynamic sources; material damping is presented in the material itself, because of mechanical connections these are cool and friction model. Material damping is generally small in comparison hydro dynamic damping. Loads caused by linear damping are proportional to velocity of the structure. However, when the loads are caused because of non-linear damping they will proportional to either square or cube of the velocity of the structure.

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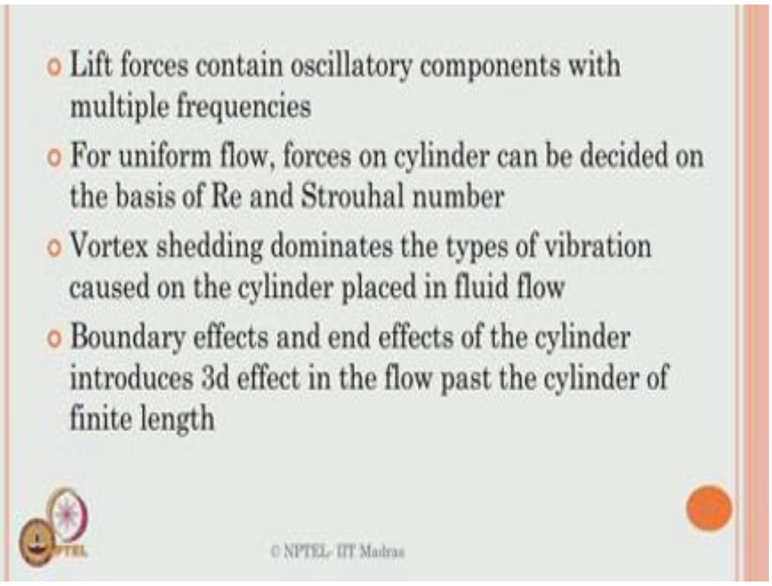

Lift forces contain oscillatory components with multiple frequencies. For uniform flow, forces on cylinder can be decided on basis of either a Reynolds number or Strouhal number. However, people look at the ratio of these two numbers for the design. Votex shedding dominates types of vibration cause by the cylinder placed in the fluid flow. Boundary effects in defects in cylinder introduce 3d effect in the flow passes cylinder for finite length.

So, having understood this brief summary and FSI will start with applying dynamics of dynamic analysis and design for different kinds of structures. In this example class I will take about a fixed type structure. I will touch upon some of the aspects of software application on this how it is been use I will touch upon sacks would is done. So, we will have 10- 15 slide to teach you how fixed type structure generally analyzes statically and then dynamic analysis done. Of course, I will solve it later by using classical equation motion subsequently.

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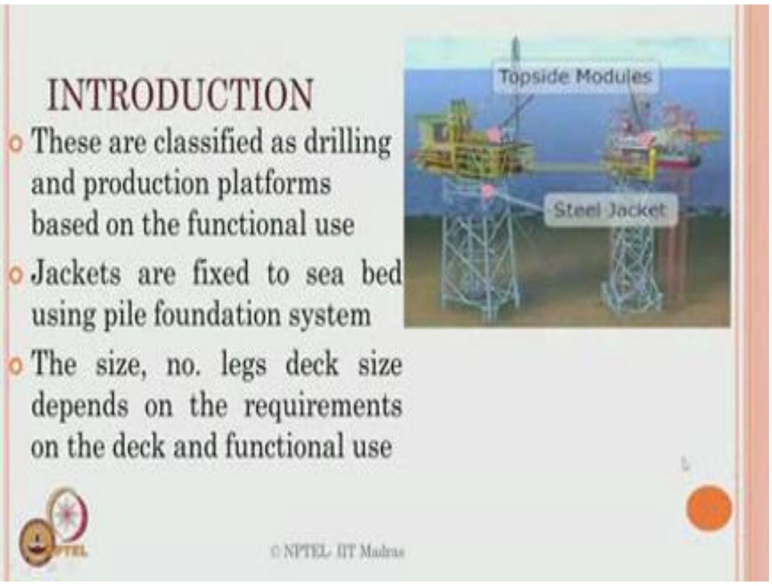

We all know that fixed type structures are classified as drilling and production platforms based on the functional use. Jackets structures are fixed to the sea bed, we already saw in the earlier module. Generally piles are used to hanker them to the sea bed; the size, the number of legs, the deck size depends on requirements of the deck and functional use because they are form dominated or not function dominated. Generally the classical system what you see here is a stress base system which is a transparent system that why call the templates structures. So, that is a steel jacket at the bottom and tops it called the topside module which is modular construction.

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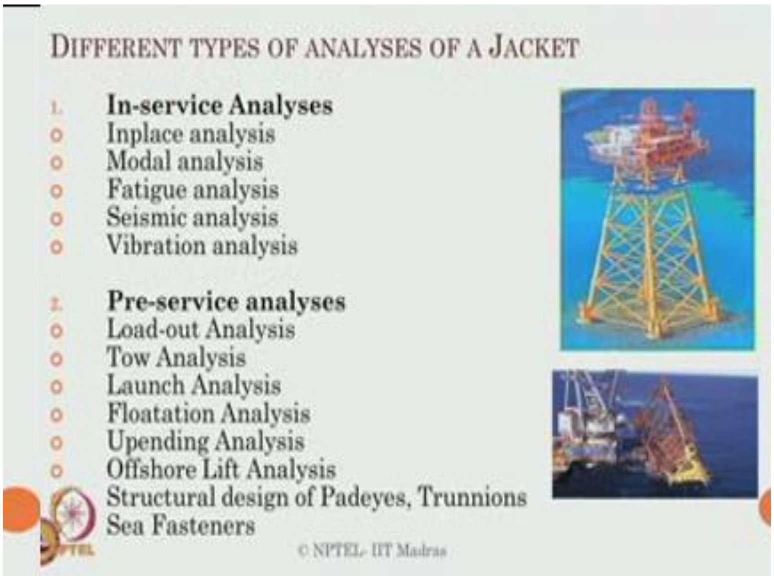

There are different types of analysis you do for a jacket; one is called in-service analysis and other is pre-service analysis. In-service analysis comprises of In-place analysis, modal analysis, fatigue analysis, seismic and vibration analysis. Whereas, pre-service analysis also looks at load-out analysis, tow analysis, and launch analysis, and floatation analysis, are upending analysis, offshore lift analysis, structural design of Padeyes and Trunnions, and of course analysis and design of sea fasteners. So, you can clearly see there are two categories of analysis a set of analysis been done for jacket structures; one is to classify the member dimension, one is to facilitate the construction or erections of the member, both are important.

Friends it is very important for us to realize that the second kind analysis what we do is only and uniquely apply to offshore structures alone. Land base structure offshore structure do not have any complexity on pre-service analysis, because the complexity generally arise in installation and commissioning or decommissioning offshore platform compare to the of design itself. Because the member will fail, may fail when they are being lunched or throwed or analyzed or let us say plotted or upended, is an operational stage in case of installation of jacket structure the slide below shows the figure here shows you one of upending stage of the template leg.

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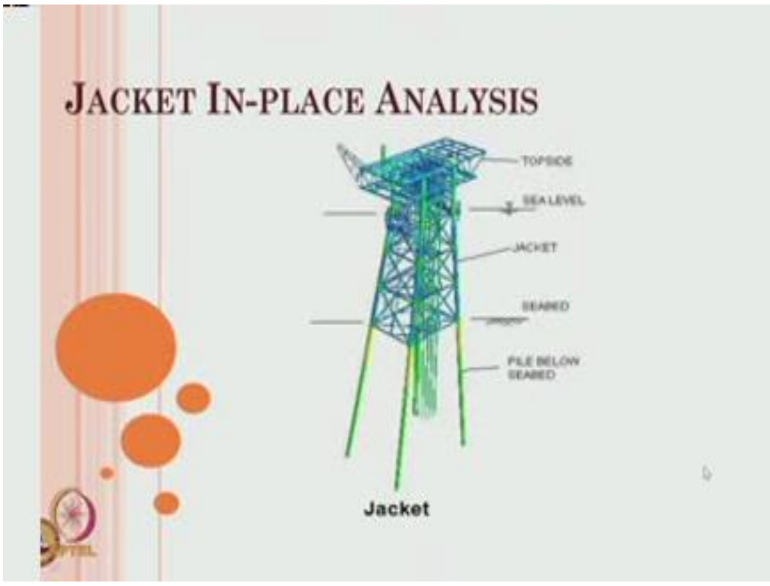

So, talk about one typical analysis which in-place analysis. The symmetric figure of the jacket as generated on software shown here. The topside is again a stress system, the sea bed is mark or the sea level free-surface level is marked. Jacket again is a compression or combination of different members' vertical horizontal and inclined member which are brasses. Sea bed of course, is a fixed plat bottom and of course piles will anchor the fixed the lakes the template structures to the bottom using an anchor connection.

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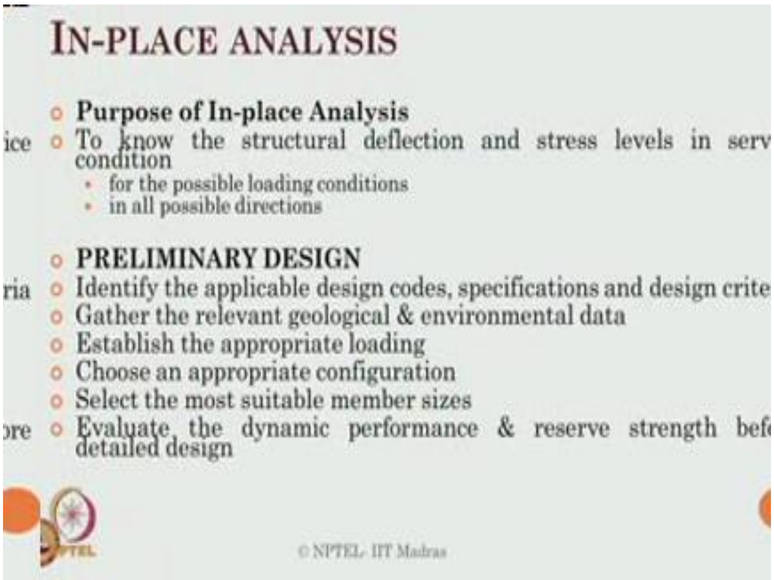

The purpose of in-place analysis is to know the structural deflection and stress levels in the service condition. So, it does not do any dynamic analysis in general it wants to know what would be the structural deflection and stress levels in service condition. So, it does not do any dynamic analysis in general it wants know what would be the structural deflection criteria is it going to be very large or very small, insignificant and what would be the stress generated because of the displacements caused on the member by the forces acting on the member. Why we want to find out this because two reasons; one to find out the favorable possible loading conditions or what the possible directions are where you can orient the members when you are analyzing or when you are installed.

So, you do preliminary design based on this because you are member or the structure should not fail when you install then decommission them. You do a preliminary design you identify the application applicable design codes specification are design criteria. Gather the relevant geological data then establish appropriate loading conditions. Choose an appropriate configuration of the member. Select the most suitable members' sizes. Evaluate the dynamic performance the reserve strength.

Generally the most important consideration in static analysis and jacket structures is what we called unitary check. We will talk about slightly in the next slide I will show you that.

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So, different design course available which you can also read from other parallel courses where people teach design of offshore structures; API-RP2A, AISC, DNV rules, AWS rules for welding course and DOS, offshore installation guidance on design construction and certification.

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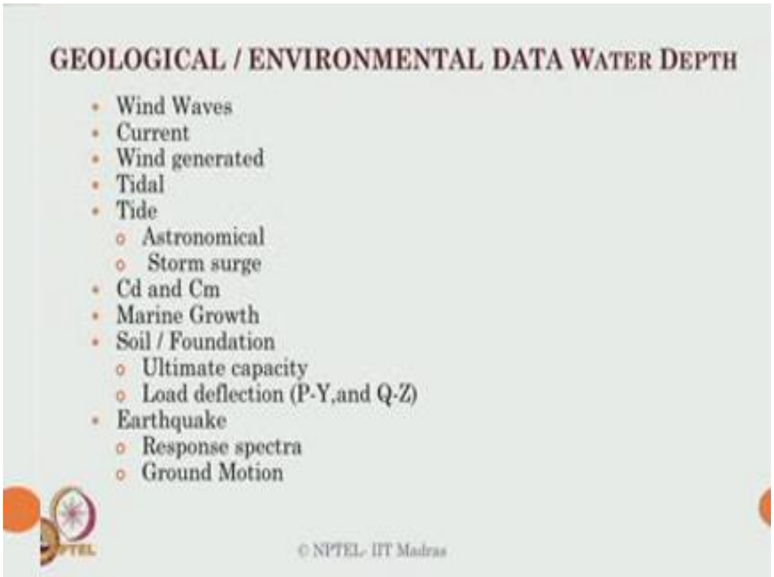

Let us quickly see what are those environmental data related to water depth which we must collect if you want to do an analysis for offshore structures systems. Wind waves, current, wind generated waves, and tidal, and tide. Tide will have both astronomical and storm surge part, of course the drag inertia coefficient given the specific area. Marine growth intensity, soil and foundation categories in terms of an ultimate capacity and load deflection criteria for a given pile design. Of course, the earthquakes available in the specific sector which will result may be a response spectra or at least ground motion or p ground acceleration times tree should be available to me as an input data which are geological and environmental data available to me for a given water depth where the system will be installed.

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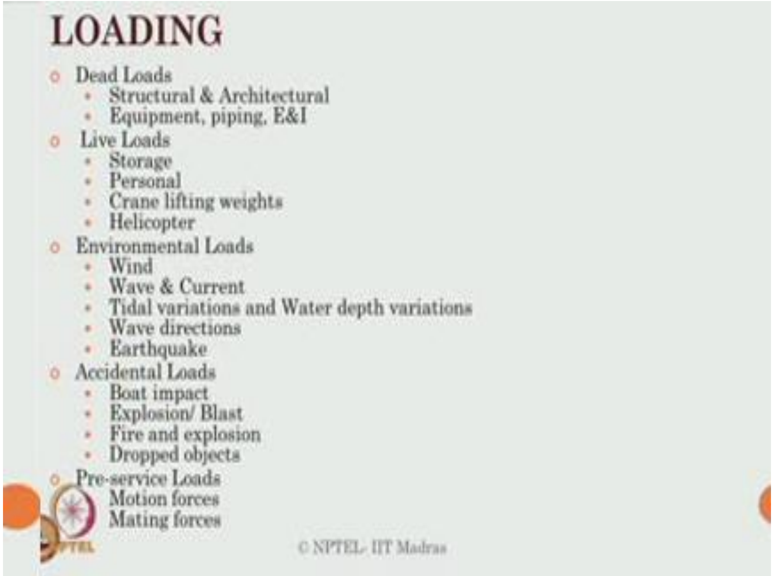

What are different kinds of loading? We already saw that in the last lecture f of t, in the last module but still let us focus back again. Dead loads can be structural architectural, equipment piping and erection and commissioning. Live loads - storage, personal or people, crane lifting weights, and helicopter; Environmental loads - wind, wave current, tidal variations, wave directions and earthquake; Accidental loads - boat impact, explosion blast loads, fire and explosion and draft objects; that very important; Pre-service loads like, motion force and mating forces.

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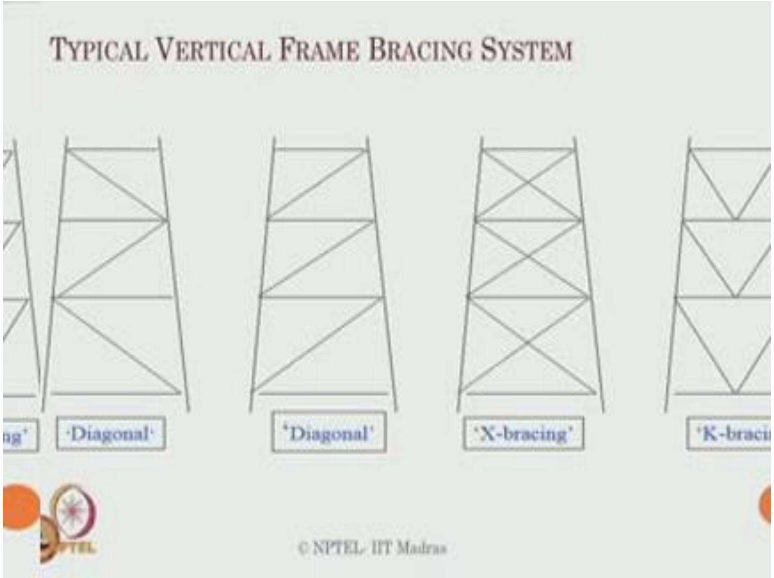

Now, to ensure that the stress system remains stable we go for different kinds of bracing systems. Is the typical brace system adopted in case of jacket structures? The diagonal basic system this also a diagonal bracing system in the only difference in these two cases is that this mirror reflects of the other, this is unidirectional; this one all unidirectional oriented where as this mirror.

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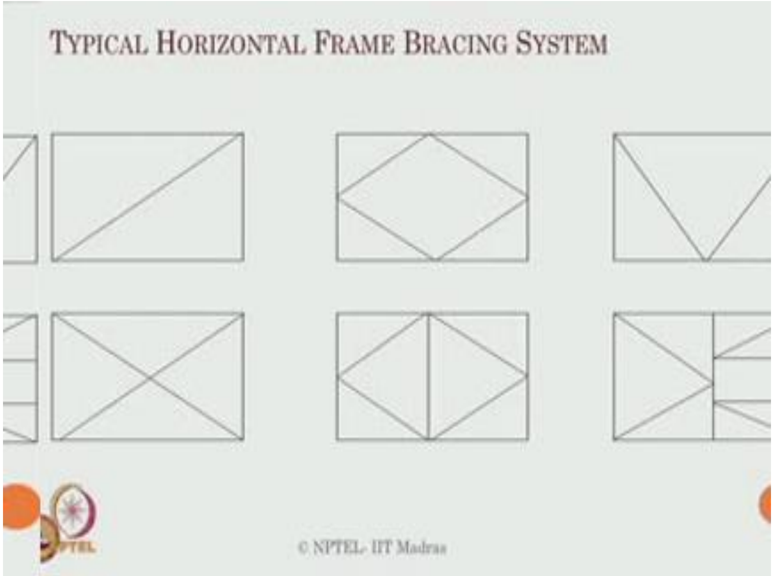

The other one is a x bracing which one see the shape is x in the other one is the k bracing. It looks like v actually it is a k look at this is the k. This is a member and (Refer

Time: 36:13) this k that is why its k function. Typical horizontal frame bracing is also available on the deck, diagonal, crombush, v x etcetera.

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GUIDELINES ON PRELIMINARY TUBULAR MEMBER SIZING

Parameter	Range	Typical application	Remarks
Kl/r	<100	Primary braces	
	100-120	Secondary braces	
D/t	16-20	Joint cans	Not recommended (rolli practicality)
	20-30	Joint cans	
	30-60	Braces	
	60-90	Legs/Piles	Local buckling to be investigated

K = effective length factor; l = un-braced length; r = radius of gyration; D= outside diameter; t= thickness

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Now, there are some guidelines available for finding out the minimum sizing. Please understand offshore structural design is more or less predefined by the codes. We do not have choice of selecting a member or diameter thickness as member choice, more or less they are pre defined depending upon the k l by r ratio which is the deflection pre parameter or the stability parameter other is as he said that d by t value. It is very important. So, both on based on the two parameters depending upon the range available for k being effective length factor, l being un-braced length and of course radius gyration is represent r.

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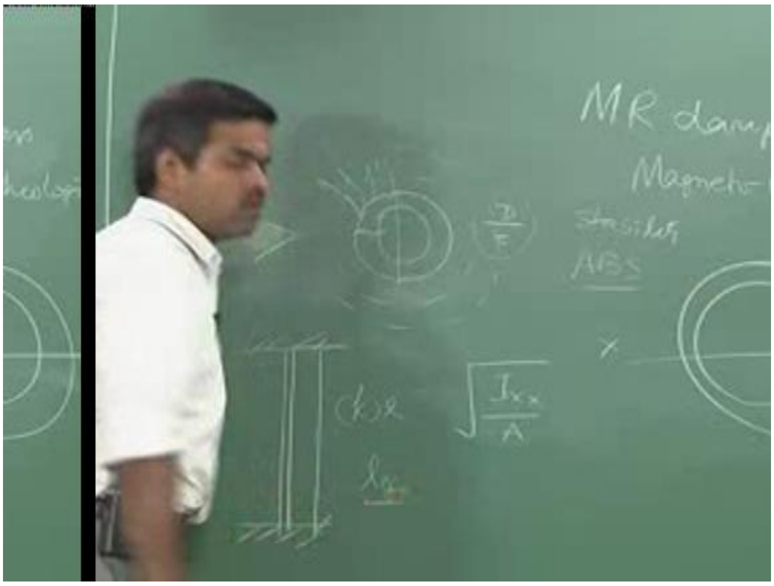

We all know this how to compute them because they are basically part of fundamental mechanics for a given member, which is tubular member for any dominant direction. Let us say x x or y y, I must compute the moment of inertia, I must know cross section area, I will get the radius of variation in the direction not necessarily least I am talking about I value or r value. And of course if this member is having connections in the top and bottom which are both in fixed. Let us say and I have a member I should be able to compute what is unsupported link. Please do not multiply any factor here, do not try to work out l effective try only the unsupported length that is connection form the top to the bottom.

So, l is a un-braced or unsupported link. Of course, a k factor is an effective length factor depending upon the boundary condition which can be imposed on your multiplier. So, you have a range depending upon that also depends on what application look at. Primary braces, secondary braces, joint cans, legs and piles. What should be the kind of member sizing a preliminary tubular available for a given system is available in generally in the design codes

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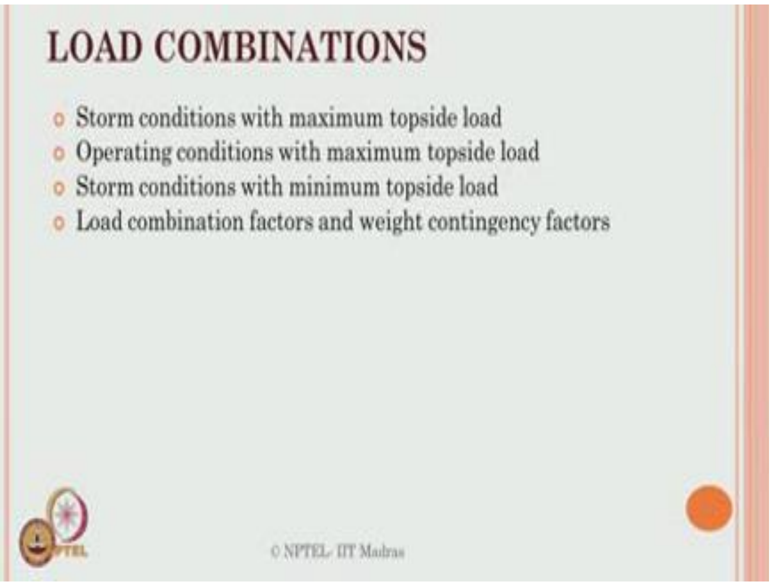

There are different load combinations people use to design the system for storm condition maximum topside load that is one worst combination. The other combination can be operating conditions with maximum topside load. Third could be storm condition with minimum storm topside load. And forth can be load combination factor and weight contingency effects on the given system. These are different combinations apart from dead live load window or combination etcetera which are discussed abbreviated in the previous model lectures.

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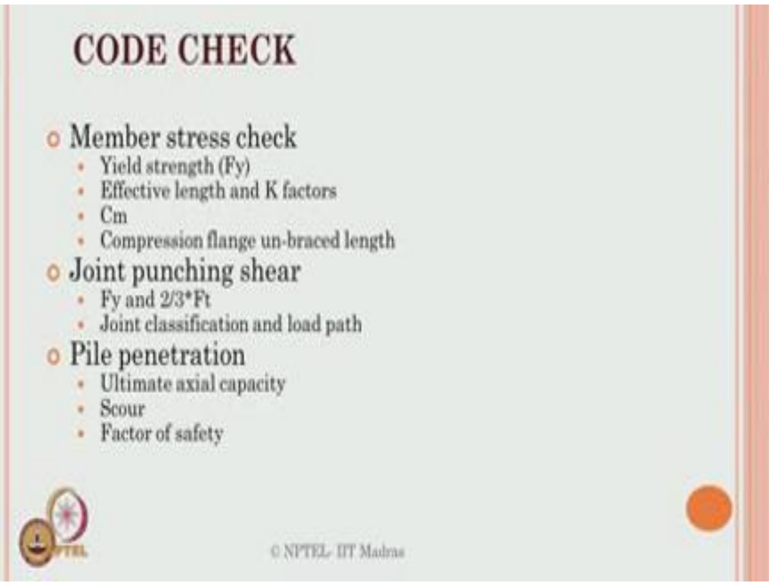

Generally, code recommends a unitary check which is said few minutes back. Member should be check for the stresses depending upon the yield strength, effective length and k factors, C m value and compression flange un-braced length. There also check for joint punching shear because you have got k connections check connections etcetera in braces. One check for the joint punching shear where you look at the yield strength and two third of the (Refer Time: 39:16) strength of the member. And joint classification and the load path. You can also look at the pile penetration where we check the ultimate axial capacity of the pile, the scour depth, and the factor of safety for which the pile resists the lateral loads coming on the system.

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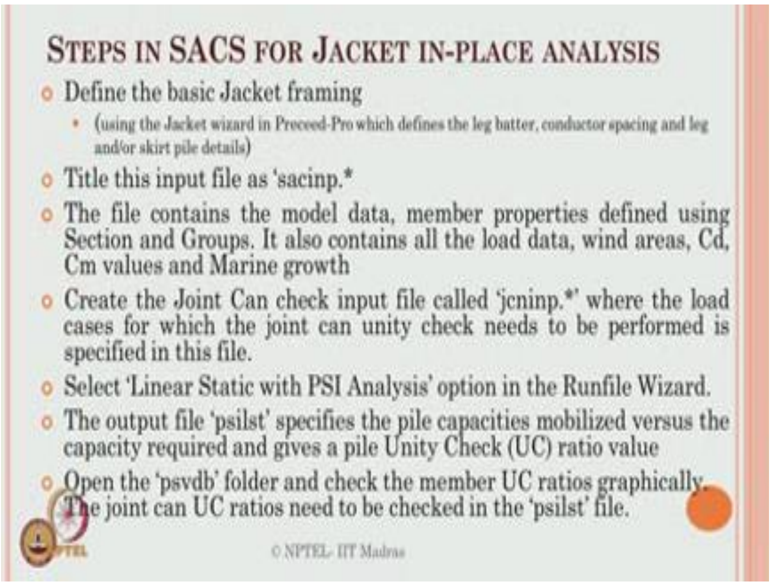

Let us quickly see what are those steps in a jacket modeling in sacs in general for in-place analysis define the basic jacket framing use the jacket wizard in precede pro in sacs module which defines, the leg batter, the conductor spacing and leg and a skirt file details title. This fire as an input as INP dot star, the file contains the model data, the member property is the C d C m value, the wind area and the low data marine growth etcetera.

You can also group them you can also section them. Create a joint can check input file called "jcninp", it is a standard modules available in sacs where the load cases for which joint unit check needs to performed. Select linear static with PSI analysis option in the Runfile Wizard. Now, please understand here I am talking about a static analysis which is also linear. The output file specifies the pile capacity mobilized versus the required giving a unitary check for your value. Open the “psvdb” folder and check the member UC ratios graphically.

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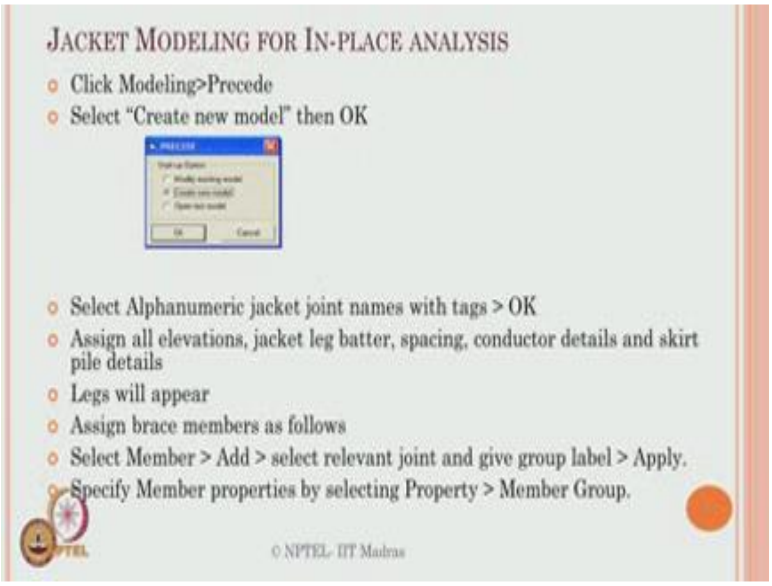

One typical plot is available now in the second slide. So, these are typical screen capture available for creating a new module. You can add the member as you see from here.

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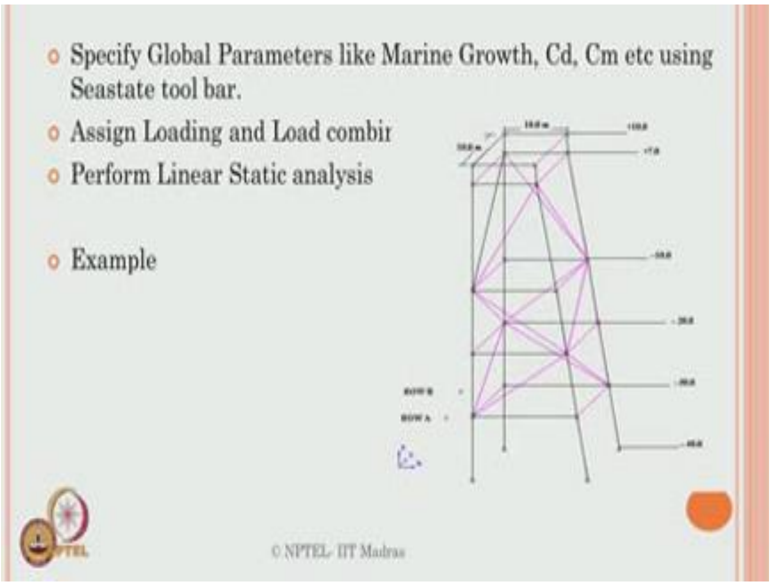

Then a typical result is available as an example here, jacket has been created with the r l of minus 42 plus 10 about 50 meter rho and rho b are the 2 rho’s of piles available or the jacket lake is available. At different levels as minus 10 minus 20 minus 30 the points are connected in the analysis. The deck is about 10 meters 10 meters square.

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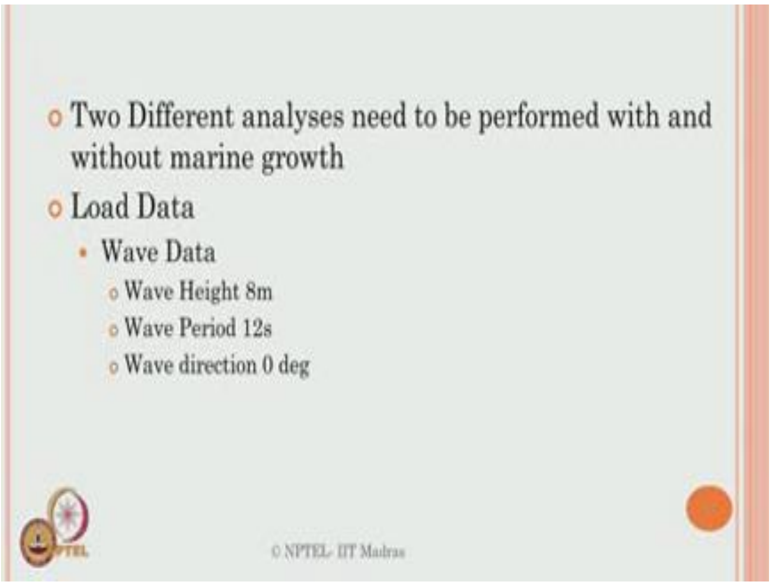

The load data is be used as wave data significant wave height 8 meter and wave period 12 seconds and wave direction is 0.

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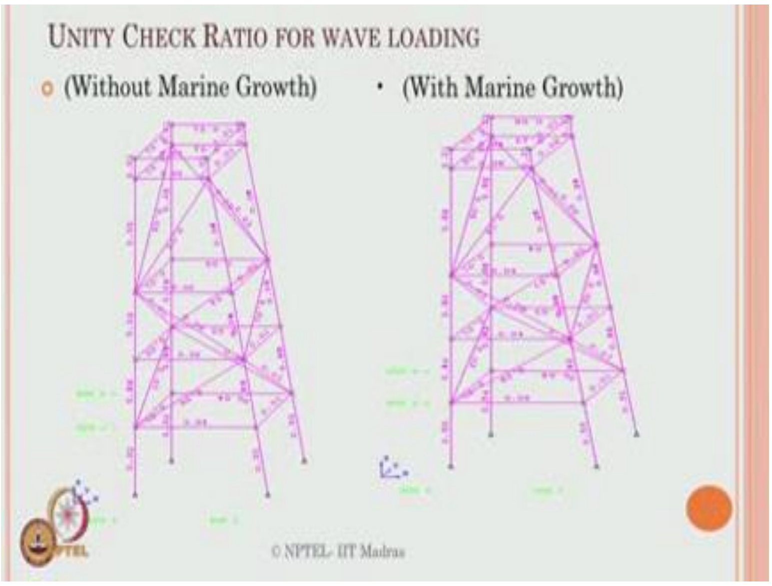

Then unitary check with and without marine growth is been done. And you will see for example, look at the specific member; this member is a having the number of 0.04 is an unitary check it is safe it means the number does not exceed one it is safe. We can check for every member this member is having 0.32 which may be one of the critical members. Other all other members practically close to 0.

It means it is a very rigid and very safe, this member is having 0.36 is not 0.36, 0.08, 0.20, 0.51, 0.02 etcetera they have very nominal. This is 0.06 do not read as 90.0, this written in the other way 0.06 and so on. That is how it can be easily done and generated from the software itself directly. So, essential check for stability or in-place analysis in service analysis is that unitary check which essentially checks the clear of the members of the stress levels.

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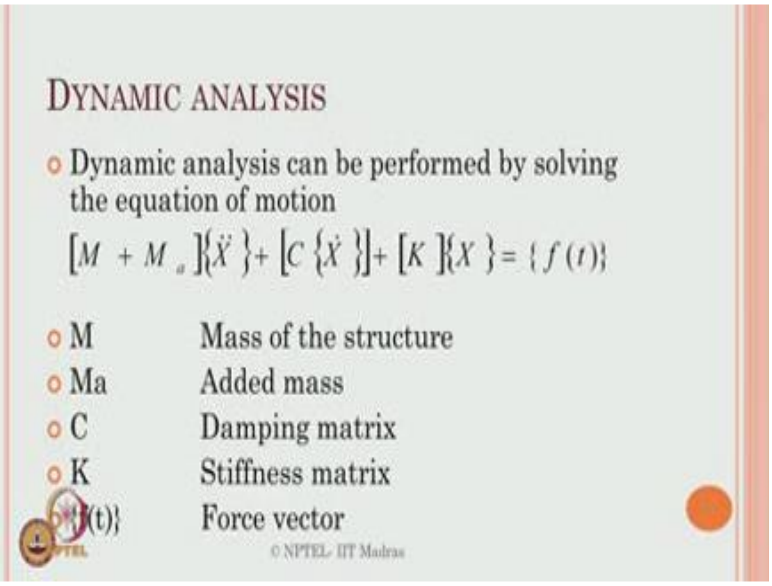

Once it is done for static analysis you go for dynamic analysis. So, the standard equation portion is very familiar to all of us we know that. Now the only term which we do not know which is very very specific an offshore structure is Ma. We added mass term, how do we get this term. So, will take up an example and arrive or derive this added mass for different systems I will show you how it is done. Otherwise, all other terminology very familiar to us f of t k C Ma or M etcetera we know the classical equation of motion.

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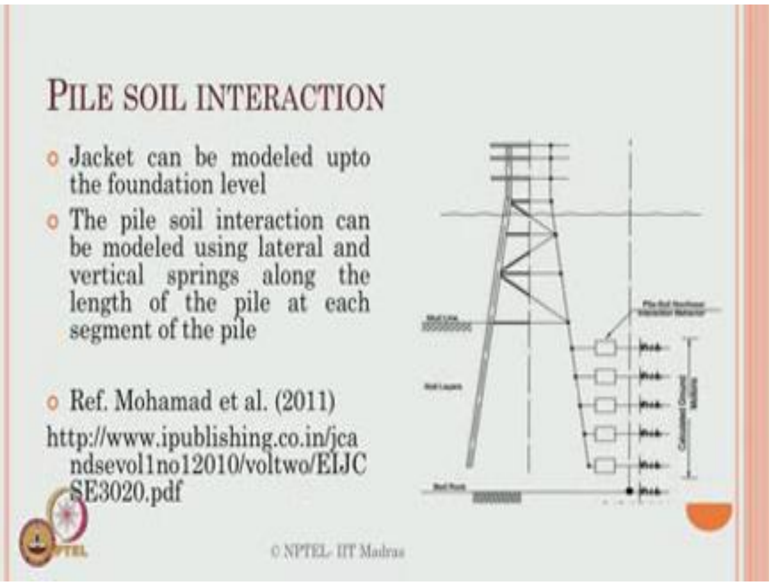

We also do pile soil interaction for jackets because they are embedded on sea bed. Jacket can be modeled up to the foundation level. The pile soil interaction is generally model using a lateral and vertical springs. That is the general procedure what people do along the length of the pile at each segment of the pile this will supported by Mohamad et al. in 2011 reference is available there directly from the EIJC journal directly at indicator there in 2011. So, pile is a generally modeled as lateral vertical springs and RT the actions are transferred to then pile system for analysis and design.

So, this is what we are going to summarize now in fluid structure interaction in this class and we will talk about the different applications. I will classically introduce one important application now which will discuss in the next lecture of course.

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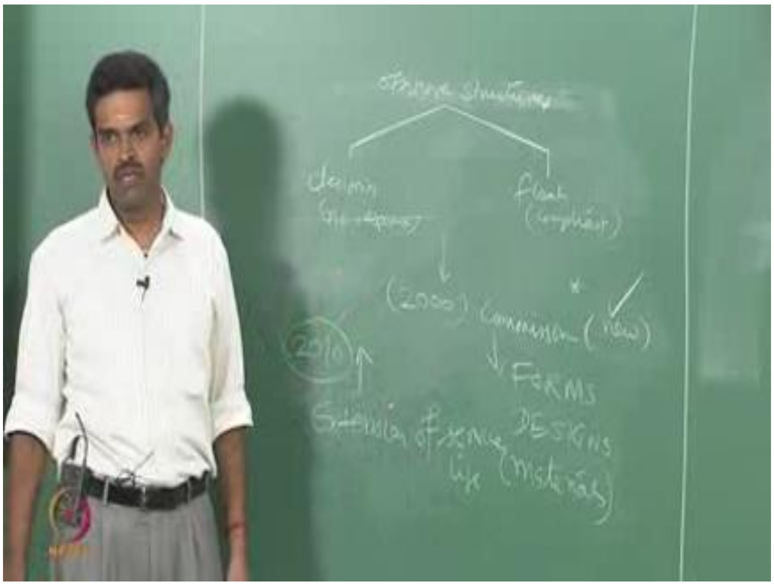

See we will talk about let us say the offshore structure. People initially started designing them for no response; maybe jacket structure, fixed base, water base, GBS, etcetera. Subsequently, people said this is of no use because a highly economical and decommissioning them installation lot of time return time available on terms of economics very low, so you do not want this. And people said you design them remain as floating or what we call as compliant. So, today I have a system at location a, I have no oil at a remove it from bring it to b I want a negative completely versatile. In fact, people (Refer Time: 44:28) interested to know can I have a ship or floating system where keep on exploring oil continuously along x and y kilometer area for a given a day, so that is the hypothetical thing so compliant systems.

In both this cases may be still 2000, I can say that year 2000 people having only commissioning new systems and installing new. So, the focus was essentially on structural forms and new designs structural design, and of course new material there is no doubt about it new materials for topside bottom side etcetera.

Now, the present trend from 2010 onwards the present trend is people are not interested in actually investing more a new structural forms being floating be fixed, they are not interested. What they want to know is extension of service life of the existing platforms because right from 70 still 2000 about 30-30 as bracket people have constructed more than 1500 platforms elsewhere Gulf or Mexico. Now people cannot or need not and should not abundant all of them because some of them be useful. So, they you cannot abundant all of them, because decommissioning and abounding them is also caused.

Therefore, people are interested to know can be extend a service life. So, now the important focus which is in drifted in offshore structural engineering now and we all agree and you also study economic you know that. Now, the oil phase being very very high, now there is lot of retrenchment happening in oil industry in terms recruitment. There are no new projects and new investments being happening in oil industry for the past may be one year close. How long will continue nobody knows.

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Now, the basic reason is you cannot keep on investing a new forms and designs and keep on exploring at great water depth, because greater water depth greater exploration will cost you more or more there is no guarantee of the return back again. Therefore people are interested. Can he extend the existing form to some more years so that I need have to invest much more, but I can still draw some money? Therefore, rehabilitation has become a very hyper (Refer Time: 43:53) now in offshore engineering. The people wanted to know really can he strengthen the existing members. Generally if we look at this two words as a coin people generally say I have a system, maybe a cylindrical member a system a block subjected to force the block responds; the block becomes weak, force does not become weak force is getting intensified force keep on changing there is no weakness. Block becomes weak because material degradation, what we call ageing effect; ageing effect it becomes weak, so generally it becomes weak.

Generally retrofitty is always focusing to strengthening the member. How do they do it? There are many techniques available to be very rough and crew to say that try to put a cover over this and then strengthen them. Now to do strengthening of member you have got a shut down the member or shut down the platform for some time. The movement you shut down the platform the whole exercise of economy will be question, so you cannot do that. And strengthening of member is a very important idea which is in applied to many members offshore and onshore, but now the latest trend is do not strengthen the member let the member be as it is reduce the force on the member.

Now the best part is you this environmental factor you cannot reduce a force actually by any technique. So, what they do is you have member, you put a cover over the member, and protect the member and sacrifices the cover and keep on changing the cover, because cover is not to be put for the entire length or the entire depth of the member; because member will not is not uniformly damaged for the entire height of the member is only partial damages are happening. Even if you look at this strengthening part people do not strengthen the entire member, they only strengthen possibly the joint of the connections. Only few points they will strengthen. So, those points which are weak in strength point of view only protect them.

So, one can ask me question by protecting this by putting a cover this how the force are reduced, because I am not doing anything with the force. If I put any external agency reduce the current velocity reduce the water particle velocity it is fine. But, I am only putting the cover. These are very interesting appreciation idea which is generally used for plotting temporary structures, because plotting temporary structure which are generally use for navel application. For example, let us say I have (Refer Time: 49:29) summering I want to repair Sumerian, it is caps is completely I have a platform, I have a j t, I have a vessel, I have cargo which is very important statistically just has been cap sized. I want to repair it instantaneously service it. So, I have to create a temporary platform. There I can imagine of going for any kind of this system where I invest on very huge type of form based designs and construct a platform then repair the vessel. Vessel go out platform remain there what to do with the platform, so we cannot do that four to do that.

So, what people do is they go for plotting temporary connections. Any plotting temporary connections which are complained in nature should attract fewer forces; otherwise the plotting system will be get on plotting you cannot do any repair operation at all. There should be technique available to reduce the force. So, people have attempted this first time this was attempted and understood at tension like platform which is mass (Refer Time: 50:29) spoil this mass platform completely it was put down for operation for 2 years, there where in a production is platform.

So, people attempted this they hypnotically though can I reduce force they put cover then they left it conceptualized that is all. So, research has taken place in different trends this component of reducing force is a new idea for offshore structure, but (Refer Time: 50:50) very common area in all coastal structures, wherever coastal structures there people use this for many years, ekofisk is one example. Ekofisk form one classical example where people use to translate members to reduce the force on the coastal j t people is using this. But in offshore structures for strength protection point of view people have never attempted this at all, but only they gave an idea mass TLP can do this an experimental study.

So, in the next lecture we have got a very interesting the study done for the one of the important government agency in India where we attempted to classify this some important study. We will discuss partly about that the technique available and one interestingly results where we will show you how numerically step by step this study can be done. How experimentally step by step study can be done. What do you get from the outcome of the study? Is of course, a hydrodynamic analysis is not purely a dynamic analysis because I am taking about fluid structural analysis interaction, hydrodynamic analysis which will be discussed in the next lecture tomorrow. We will talk about then 45 minutes. So, some results will be given to you.

And more interestingly the design eights and developed which give me directly used if you want really design an outer cover for damage number directly. In one lick you can design the system select the outer cover place it over the member the member will get rid of the forces coming on the system is readily available. Of course, the outcome of the design is depending upon the (Refer Time: 52:22) numerical analysis which is valuated, experimentally, analytically, and numerically accepted published and patented more than about two international journals.

So, will talk about that tomorrow in one of the important study that will be very interesting part to make you understand believe that hydrodynamic can be or dynamic analysis tool can be useful in a practical application like this which is a hot spot area of application now in ocean engineering or offshore engineering. Do you have any question here now?

So, we stop here I have given you some preamble about analysis take up different forms of off shore structures TLP etcetera in subsequent lectures in this module. We will talk about detail dynamic analysis step by step in all this cases you the equation motion derived from stiffness matrix here. We will of course solve them in the numerical method I will give you results only because a algorithm will given to you numerical analysis given here I will give the results directly refer into the published papers where you can read the paper and understand how they have been represented. That is the idea in this model. So, it start with the (Refer Time: 53:26) part tomorrow then will go ahead with this.

Thank you.