Advance Marine Structures

Prof.Dr. SrinivasanChandrasekaran
Department of Ocean Engineering
Indian Institute of Technology,Madras

Lecture- 2
Fluid structure interaction – II

So, welcome to the second lecture on module 2 on advance marine structures. In lecture one of module 2 we discussed about, what would be the necessity for studying the fluid structure interaction when a member is placed in the fluid flow field. We also saw that, how the member will interfere with the fluid flow field and how the velocity is changed and how the regimes are defined depending upon the Reynolds number as laminar critical, supercritical and transcritical. We also said that, when the member interferes with the flow field then the velocity gets reduced.

So, the reduction of velocity causes increase in forces and distinctly, because of the vortex-induced vibrations, you get two different classical frequencies, one at a very high frequency one ata very low frequency which will cause creating additional forces to the members, and this will cause a resonating response and near resonating response not necessarily when the frequency of the member or the structure matches with these. But even, if they match50 percent to 33 percent of this you get a very high response of large amplitude.

So, we have to understand that wake region is in a very important region where, one should understand how the wakeregion will bestretched when the member is interfered in the fluidfield, and how the velocity is varying for a member placed in fluid field of it is vertical or horizontal.And, we have been focusing our studies only on cylindrical members, because in offshore or in marine structures mostly we used cylindrical members.

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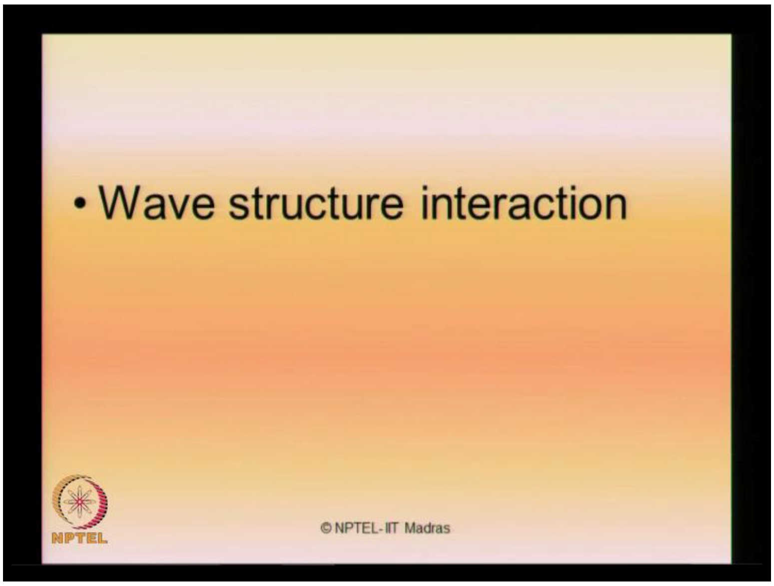

In this lecture, we will talk about wave structure interaction. There is a difference between fluid as a steady-state flow and wave as a varied submerge in effect.Let us see,what is the effect of varied wave structure interaction on members of marine structures.

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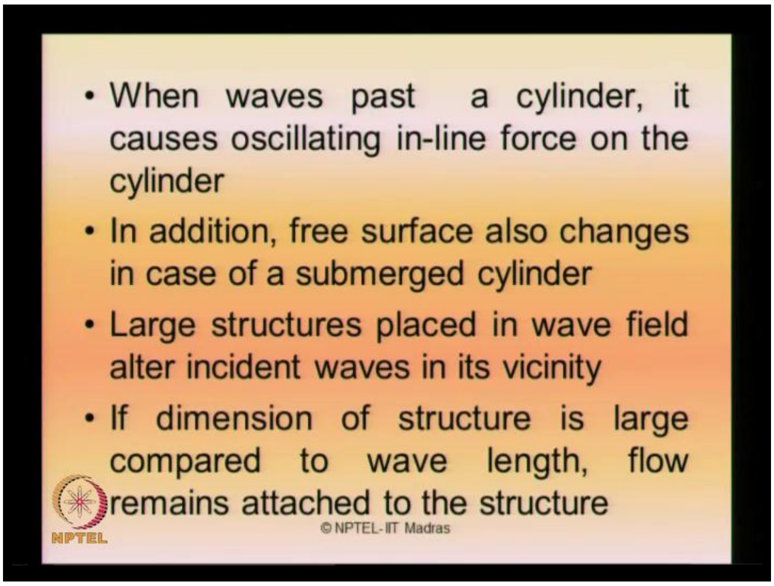

When actually, waves passa cylinder, it causes an oscillation in-line force on the cylinder which we saw in the last lecture as well. In addition, free surface also changes in case of a submerged cylinder. Large structures placed in wave field alter incident waves in its vicinity. So,it is very important to study the region within which these disturbances caused.

Now, if the dimension of this structure or the member is relatively large compared to the wavelength, then the flow remains attached to the structure,that is very important. So when the flow gets detached, then the behavior of the flow field with the interference on the member is different. When the flow gets attached to the structure, then as the structure keeps on movingor reacting to the external forces acting on a member like wave forces and current, then the flow field also get significantly altered along in the same nature as that of the vibration or the moment of the structure.

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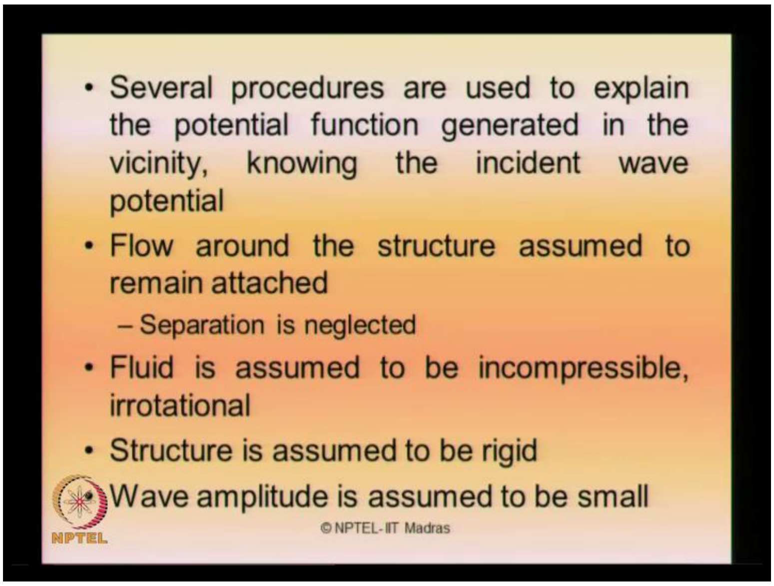

So, there are several procedures available in the literature which is used to explain the potential function generated in the vicinity, knowing the incident wave potential.Flow around the structure is assumed to remain attached. Separation is considered to be neglected in the analysis. Fluid is considered to be incompressible and irrotational and structure is assumed to be rigid.Therefore, the wave amplitude is assumed to be very small in the analysis.

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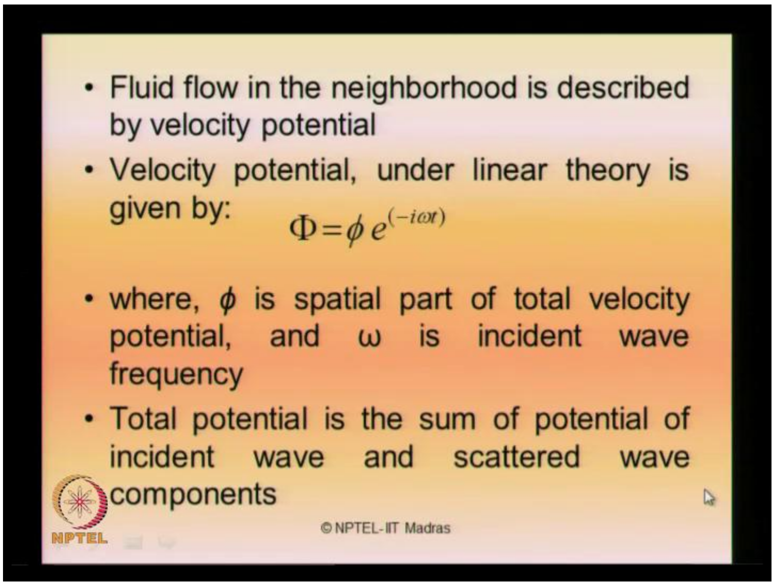

So, look at the fluid flow in the neighborhood which is described by velocity potential given by this equation using the linear theory.In this case phi the equation phidenotes a spatial part of the total velocity potential where, omega is the incident wave frequency. The totalpotential is therefore,a sum of potential of incident wave and the scattered wave components which are applied on a given member which is interfering with the flow field.

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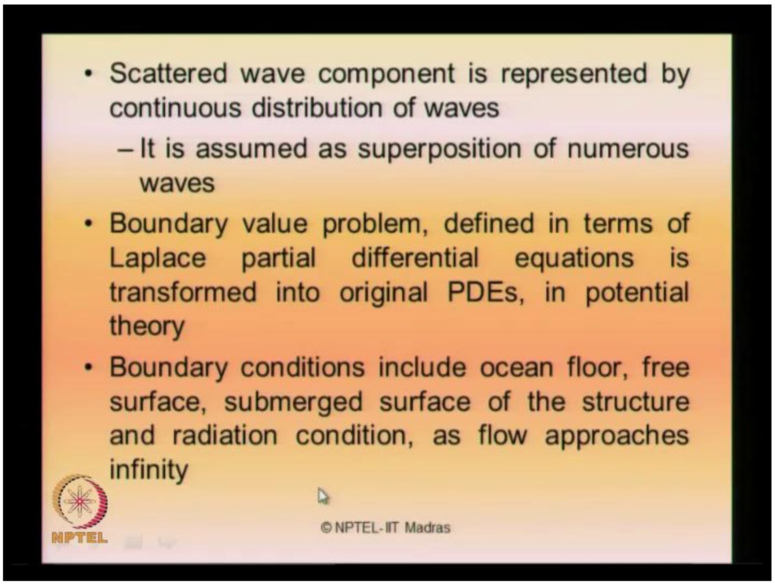

The scattered wave component is represented by a continuous distribution of waves. Itisthereforeassumed to be superposition of numerous waves acting one over the other or one followed by the other. The boundary value problem thereforedefined in terms of Laplace partial differential equation is transformed to the original partial difference equation in the potential theory,that is how the wave structure interaction is handled in the numerical analysis. The boundary conditions include of course the ocean floor, the free surface, the submerged surface of the member, and of course the radiation condition as the flow approaches infinity.

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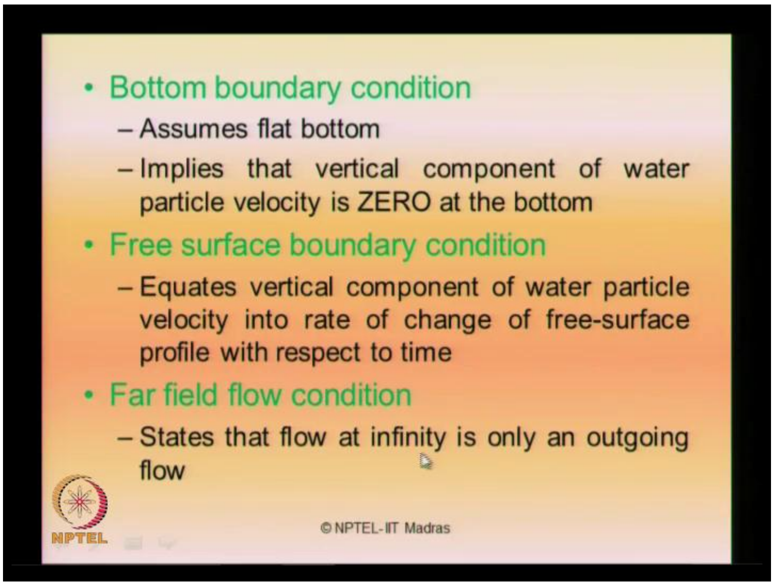

There are different conditions we will now discuss and describe in detail. Let us talk about the bottom boundary condition. The bottom is assumed to be always flat. This implies that, the vertical component of water particle velocity remains practically zero at the bottom. There is no water particle velocity in the vertical direction at the bottom. What we understand by free surface boundary condition? The free surface boundary condition equates the vertical component of the water particle velocity into rate of change of free surface profile with respect to. We talk about the far field flow condition, it states that the flow at infinity long is only an outgoing flow not an incoming flow.

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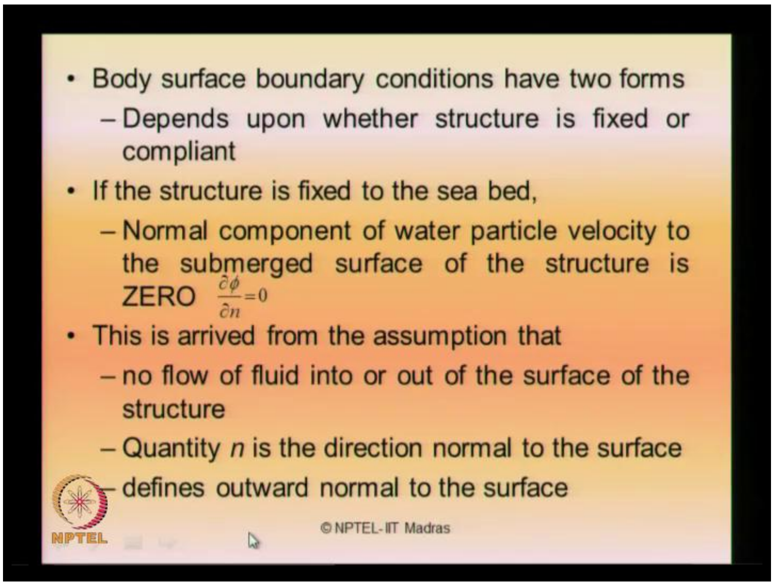

The body surface conditions have two forms, one depends upon whether structure is fixed or compliant. The structure is fixed to the sea bed as in the case of jacket or gravity based structures. The normal component of the water particle velocity to the submerged surface of the structure is taken as zero, that is dou phibydou n is taken as zero.This is arrived from basically from the assumption that no fluid or fluid into or out of the surface of the structure is occurring.The quantityn in this derivative is the direction normal to the surface of the member which is otherwise defined as outward normal to the surface as a vector.

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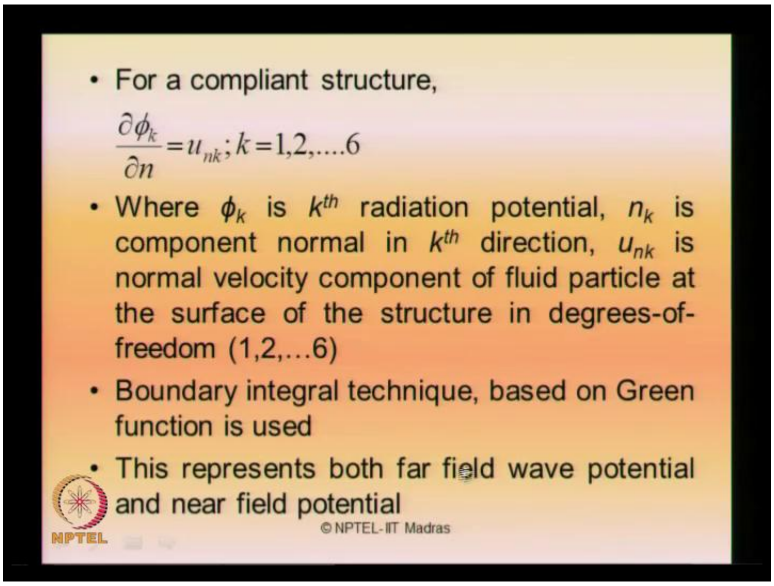

On the other hand, alternatively for a complaint structure,we use this equation to compute the velocity potential where, phi k is the kth radiation potential used in the derivative,nk is the component normal in the kthdirection and U nk is thenormal velocity component of the fluid particle at the surface of the structure where k refers to different degrees-of-freedom where, you are serving of this potential. Then use boundary integral technique which is based on Green function to evaluate this. This represents both the far field wave potential and near field wave potential. This is true for complaint structures.

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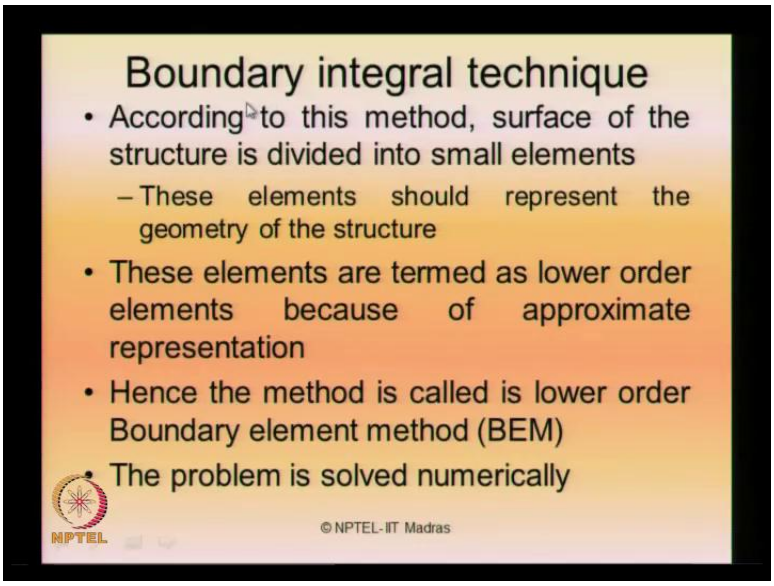

Let us quickly discuss, very briefly what you mean by boundary integral technique. According to this method,the surface of the structure is divided into small elements. Each element is made to ideally represent the geometry of the structure. Then these elements are termed as lower order elements because of approximating in the representation. Hence the method is also otherwisecalled as lower order boundary element method. It is just because the lower order elements are assumed as approximate representation of the members, however please note that, the members or the elements should represent ideally the whole geometric parameter of the structure. Then once the problem is formulated,this problem is then solved numerically.

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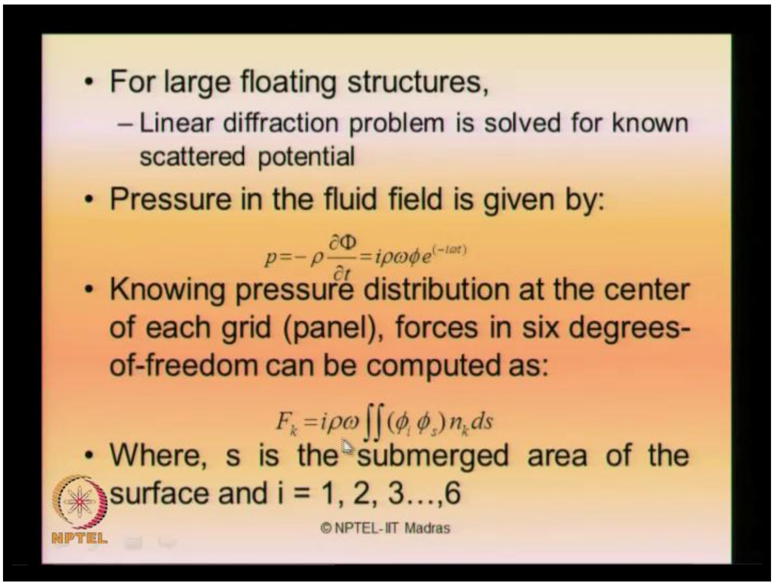

Now, when you start applying this for very large floating structures, then we recommend to use leaner diffraction problem which is solved for the known scattered potential. The pressure in the fluid flow is given by this equation as you see in the slide. Knowing the pressure distribution at the center of each grid, because you are dividing the whole element whole structures or the members into different meshes which we call as grids or panels, now forces in six degrees-of-freedom can be computed using this equation. Because, in this equation you know the velocity of potential phii phi s taken for every n k where k is the degree of freedom submission one to six, s is the submerged area what you see in this of the surface for every degree of freedom one to six.

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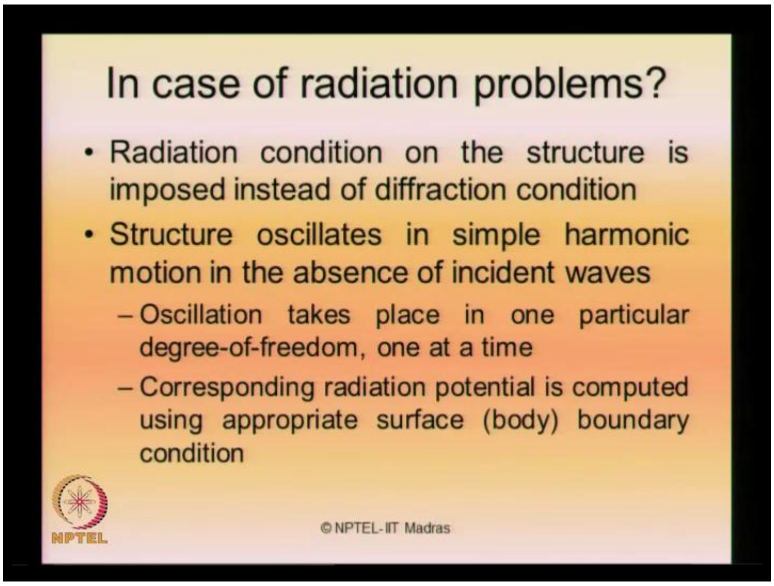

Now, if you are interested in studying the radiation problem, then in that case,the radiation condition on the structure is imposed instead of diffraction condition. The structure oscillates in simple harmonic motion in the absence of incident waves. The oscillation takes place in one particular degree of freedom one at a time. Correspondingto the radiation potential is computed using appropriate surface boundary condition which we call as body boundary condition.

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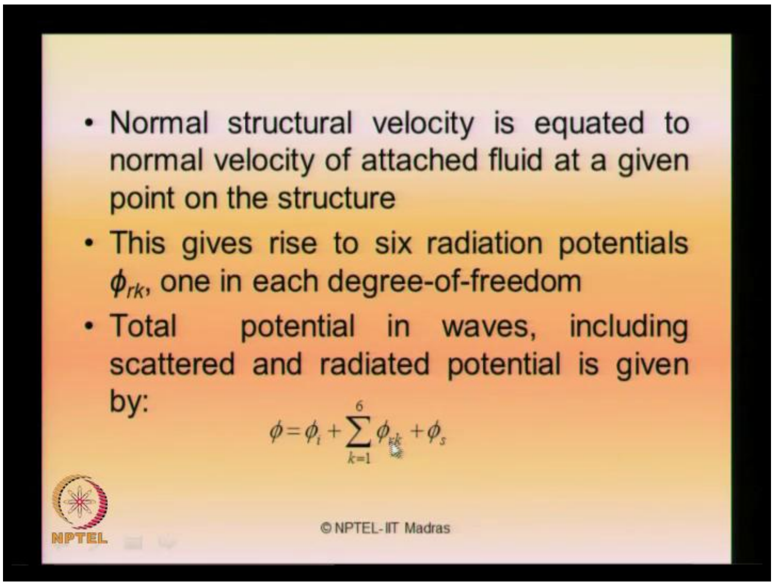

Then subsequently, the normal structure velocity is equated to the normal velocity of the attached fluid at any given point on the structural member. This gives rise,of courseto six radiation potentials phi r k, one in each degree-of-freedom where, k stands for the degree-of-freedom one to six. Then the total potential in waves including scattered and radiated potential is given by the summation ofphii and phirk where, phi i is what we have already computed and phirk is what we get from radiation potential.So i stand for incident waves and r stands for radiation waves.

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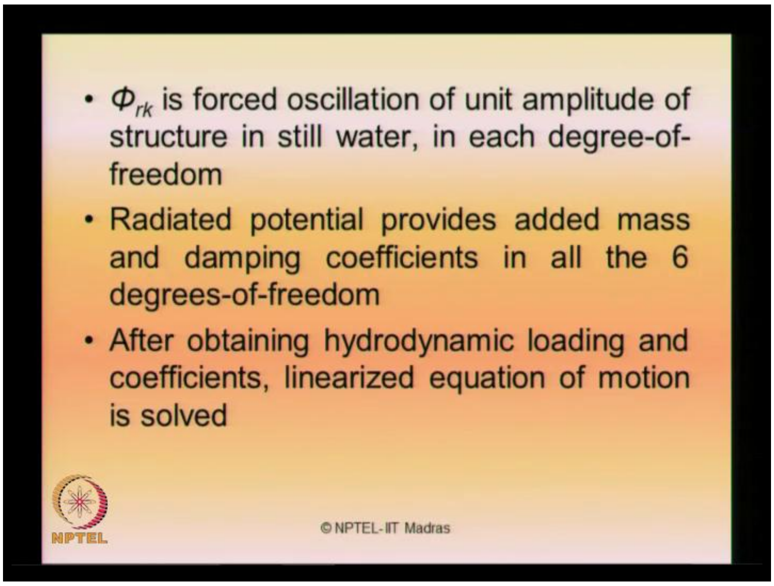

Phirk of course is the forced oscillation of unit amplitude of structure in still water in each degree-of-freedom. The radiated potential provides added mass also and the damping coefficients in all six degrees-of-freedom. After obtaining hydrodynamic loading and coefficients, linearized equation of motion is subsequently solved using numerical or analytical technique.

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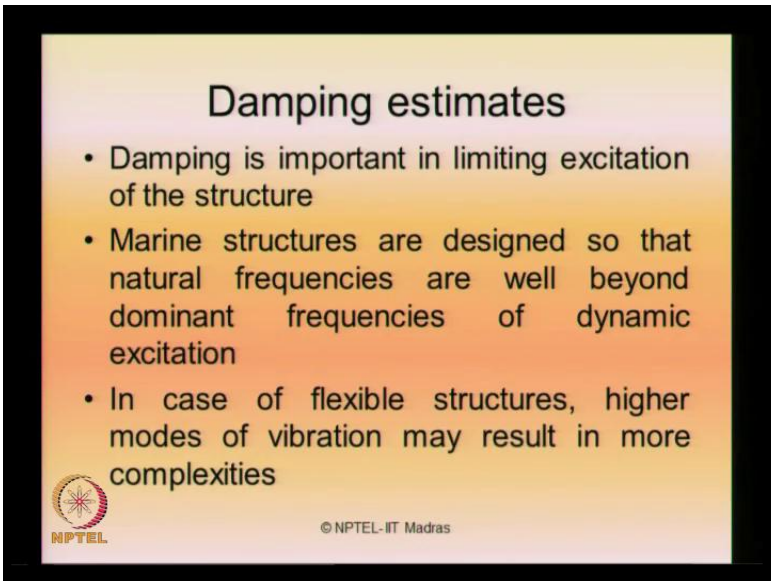

Most importantly, one should also know how to do a damping estimates because hydrodynamic damping is playing a very important role when we consider fluid structure interaction. This is in addition to the structural damping which is happening on the member. There can be damping caused because of material deterioration which is also accounted in addition to what we are talking about hydrodynamic damping. Damping is an important criterion in limiting excitation of the structure because we really talk aboutresponse control of structures one can aim of going for a higher damping or reduced response in terms of behavioral structure. Because you cannot release the loads from the structure, we can only work on either material damping or structural damping or hydrodynamic aspectsof damping.

Marine structures are designed so that natural frequencies are well beyond the dominant frequencies of the dynamic excitation.I think, we all understand this because the fundamental requests or requirement for designing a dynamic, let us say the marine structure, is that the fundamental frequency of the structural system should be far scattered away from the dominant wave period or wave period of the structure. So we do not invoke resonance response in the structure at all because resonating response or the band near the resonance will cause damage which is not expected to happen in the marine structures.

So, incase of flexible structures,higher modes of vibration may result in more complexities because you understand that the structure will also oscillate in its own frequency which is caused by low amplitude of waves itself.Because structure itself is moving and the motion of the structure will also cause self-excited vibration in the system,therefore, floating structures or flexible structures on the other hand complain structures will create more complexities because they include higher modes of vibration also interfere, otherwise fundamentally first or few earlier modes will be sufficient enough to do dynamic analysis for fixed type of structures.

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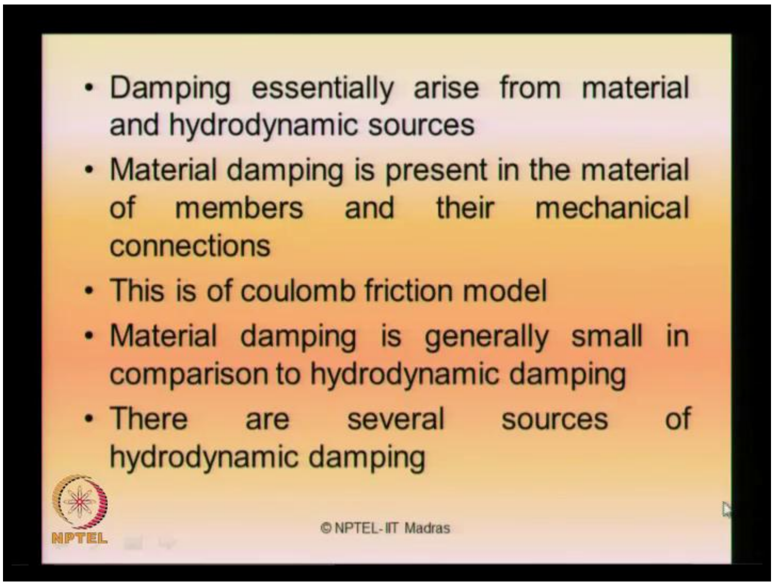

Therefore, one can clearly summarize here the damping essentially arise from material and hydrodynamic sources. Material damping is present in the material of members and their mechanical connections, this is very important. Deliberately in certain design,we introduce this connection or this kind of damping,for example, you can put a hinged joint are a boil joint or absorb dynamic vibration absorber which can connect the deck and the leg. There are examples where these kinds of studies have been attempted in land base structure.

There are examples, where, people have attempted this in off floor and marine structures where one classical example what, people attempted is in articulated legplatform ALPs or MLATs multileg articulated towers where,articulation is deliberately introduced at the bottom point where the tower is attached to the foundation of the sea bed through a hinge. So material damping can also be considered as an important aspect of presentation in the material and then mechanical connections as well. Of course this is handled is a coulomb friction model in the analysis. Material damping is generally given small in comparison to hydrodynamic damping because hydrodynamic damping effects can be very large significantly compared to that of material damping.Now there are various several sources of hydrodynamic damping.

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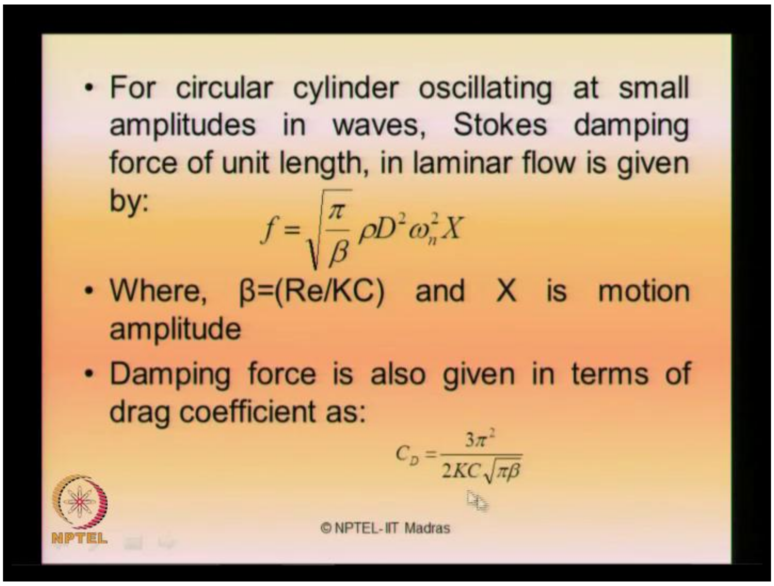

For circular cylinder oscillating at small amplitude in waves, Stokes damping force of unit length in laminar flow is given by a simple equation like this, where beta is a ratio of Reynolds number toKeulegan-Carpenter number and of course x is the motion amplitude. Other researchers a set of people also handle dampingforce in terms of drag coefficient. You can also modify the drag coefficient which can include partially the hydrodynamic damping which comes from thewater or the fluid medium. So, they modify the damping force in terms of drag coefficient as you see in this equation here where,KC again is aKeulegan-Carpenter number and beta stands for a ratio of Reynolds number to Keulegan-Carpenter number.

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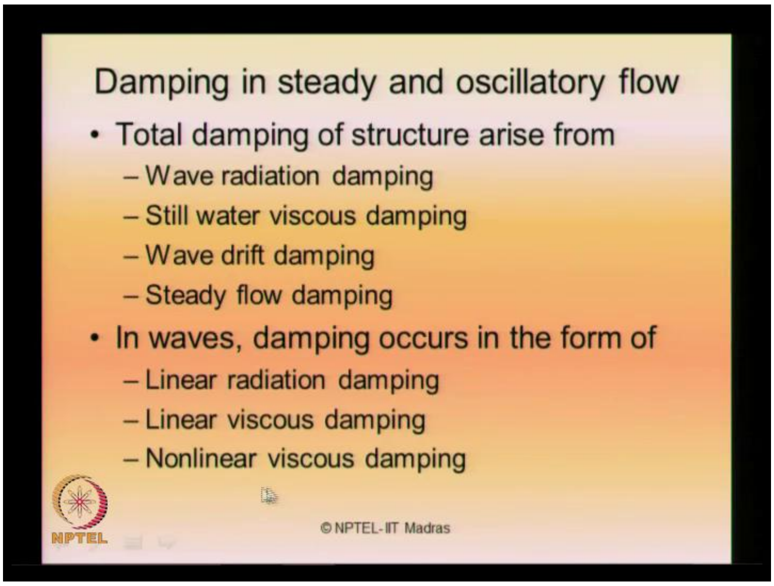

If you look at detail more in damping in steady andoscillatory flow, then the total damping of structure arises from many sources. There can be wave, radiation damping, when the wave comes and hits the structure because of the interference of the member in the fluid flow, the waves get radiated, they also cause damping. Still water causes viscous damping because viscosity is essentially a characteristic of the fluid. Wave can also callwhat is called drift damping because structures canalso get drifted and there can be something called steady flow damping.

So hydrodynamic damping which is occurring on the structure arises from various sources. It is very difficult to distinctly quantify all of them because all of them do not have or do not pose a distinct regime where, they can be estimated correctly. So the total damping occur can be a mixtureof all the four,therefore, it is very difficult to quantifyindependently how you get these values buthowever, there are methods to overallquantifythe hydrodynamic damping effect in addition to what the structure is damping.There can be distinctly methods and research papers which can show you what is the effect of structural damping, and what is the contribution of hydrodynamic damping in a given structural form.

In waves, essentially damping occurs in the form,it can be a linear radiation damping, it can be a linear viscous damping, it can be ofcourse a nonlinear viscous damping.So depending upon what kind of damping you are addressing,the dampers are otherwise called as nonlinear viscous dampers, linear viscous dampers, etcwhich you would see in the literature which are generally studied generally deployed for land based structures butrecent reference have been made byresearchers to deploy them even in offshore structure as well.

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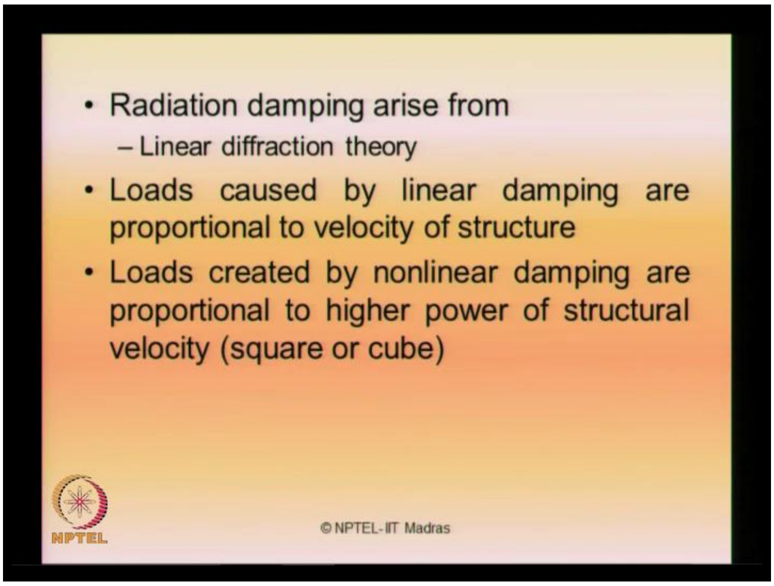

If you look at radiation damping, essentially radiation damping arise from linear diffraction theory, loads caused by the linear damping are proportional to or taken to be proportional to velocity of the structure,because structure is complaint in nature. The loads created by nonlinear damping are proportional to higher power of structural velocities may be either square or cubical powers.

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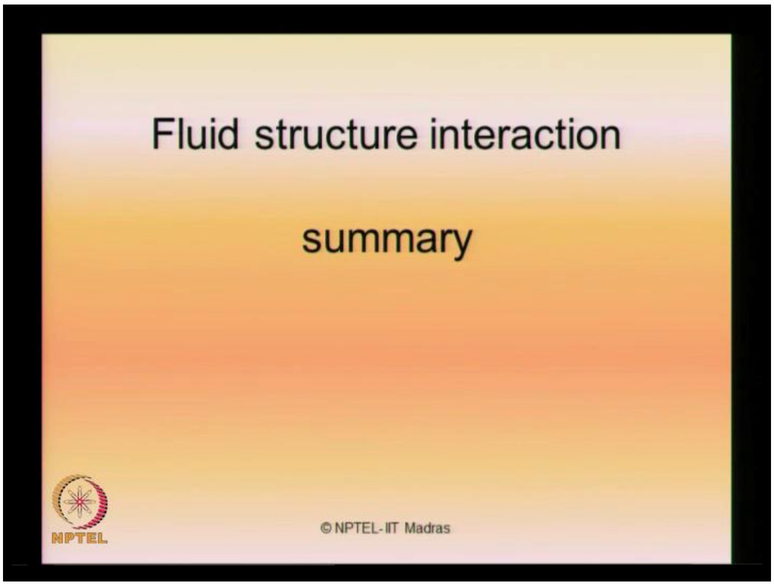

So, these are basics which we have introduced to you in terms of fluid structure interaction and wave structure interaction. We will quickly look at the summary, the important points which we must remember as a designer to address when we talk about wave structure interaction. Because I am going to use these concepts in the next lecturesto talk about how,the responses from the fluid interaction can be reduced by placing a porous media, by using a perforated column, by using VIV spoilers what we call vortex-induced vibrations spoilers etcwhich have been attemptedbyrecent researchers on offshore structures or marine structures.

So we will have a summary here. As I told you in the beginning of this lecture, our focus is not on establishing the hydrodynamic concepts of how, the fluid flow is getting varied in the presence of members. We are talking about how the fluid flow variation influences the forces on the member, the damping forces on the member, the response of the member and an of course how the vibration characteristics of that member or the structure gets disturbed because it gets influenced because of presence of or consideration of fluid structure interaction.That is what the focus is, ok.

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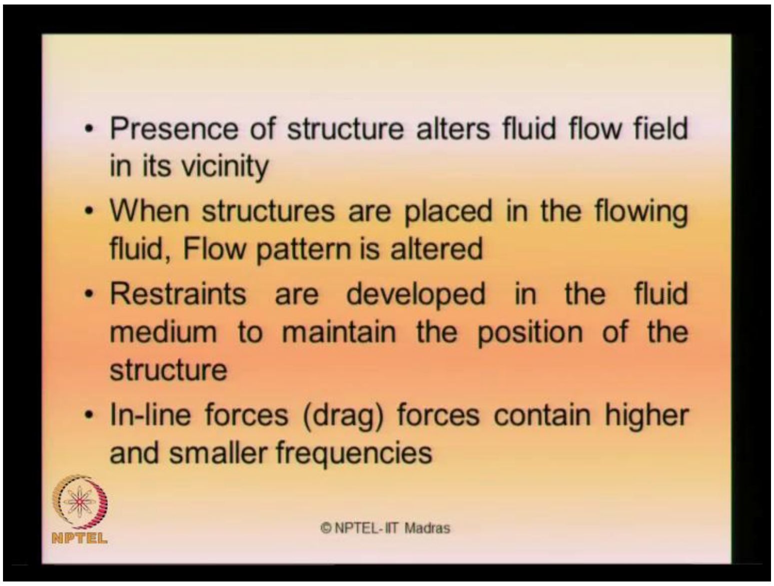

Let us look at the summary here interestingly. The presence of structure alters fluid flow in its vicinity. So we are not talking about far field boundaries, we are talking about what is the disturbance caused by the member in its vicinity what we call as awake region. When structures are placed in the flowing fluid, it is definitely understood that flow pattern is altered. Restraints are developedin the fluid medium to maintain the position of the structure because the structure as got and need to be placed in position if the structure is for example fixed platform. If the structure is complaint, still it cannot move for an infinite distance.

There isa relative distance beyond which the structure cannot move.Therefore, there are restrings developed in the medium to maintain the position of the structure. These are nothing butthe restrain forces which are opposing the applied forces on the member which causes vibrations to the structure in the near vicinity. The in-line forces what we otherwise call as drag forces contain higher and smaller frequencies. Understand, this is very important because drag forces contain two distinct set of frequencies; one can be higher, one can be lower.

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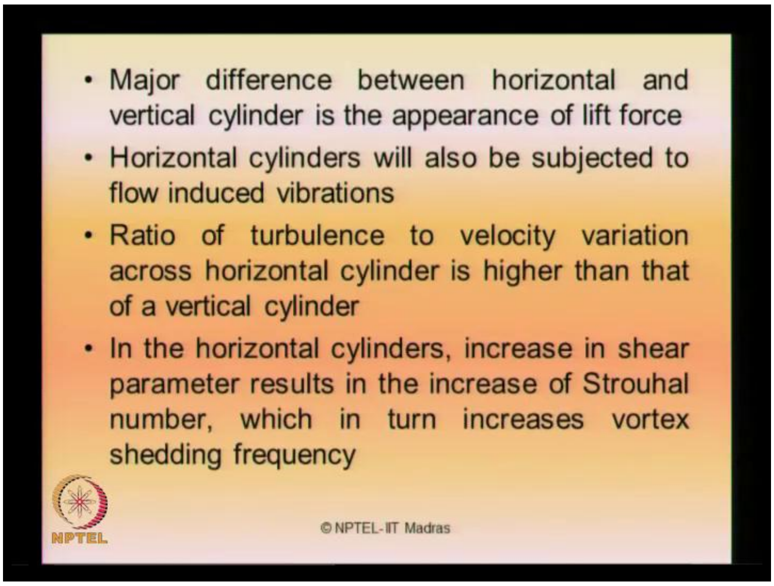

The major difference between the horizontal and vertical cylinder is the appearance of the lift force.The horizontal cylinders will be subjected to flow induced vibration. The ratio of turbulence to velocity variation across a horizontal cylinder is much higher compared to that of a vertical cylinder. In horizontal cylinders, increase in shear parameter results in increase of Strouhal number which in turn increases vortex shedding frequency. There is a danger associated with this frequency because these frequency if it matches with half or one-third of the fundamental frequency of the member, itcan result in high amplitude of vibration.

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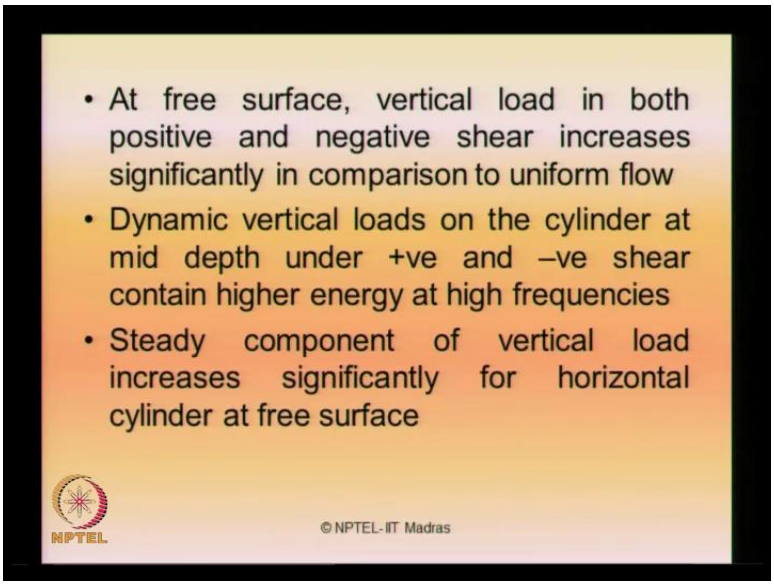

At free surface, vertical load in both positive and negative shear increases significantly in comparison uniform flow. The dynamic vertical loads on the cylinder at the middledepth are our concentration under positive and negative shear, because at middle depth or middle section of the member, they contain higher energyat various frequencies. Steady component of vertical load increases significantly for horizontal cylindersat free surface.

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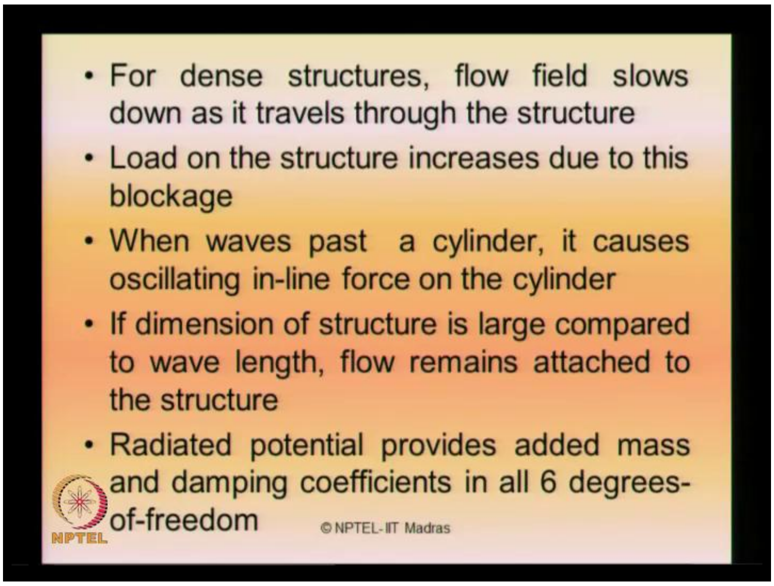

For dense structures, the flow field slows down as it travels through the structures.This is again a dangerous aspect, because the velocity retardation or reduction increases forces in the member. Load on the structure therefore,increases due to this blockage. This is identified as blockage factor which is taken as an increased factor in the loads on the members which are clusters or group of members. When waves past a cylinder, it causes oscillating in-line forces on the cylinder. If the dimension of the structure is very large compared to the wave length, then the flow remains attached to the cylinder. Radiated potentialprovides added mass and damping coefficients in all six degrees offreedom.

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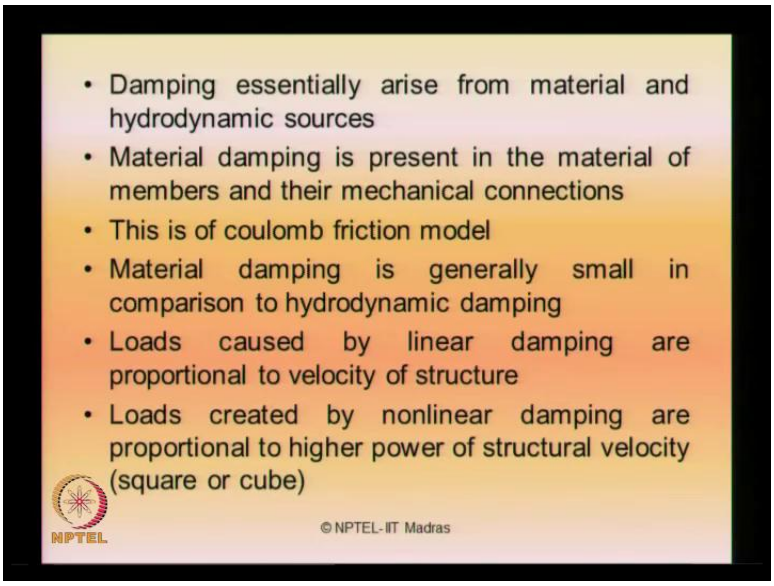

Damping essentially arises from material and hydrodynamic sources. Material damping is present in the material of members and their mechanical connections, of course they are modeled as coulomb friction model dampers. Material damping however is generally small compared that of hydrodynamic damping. The loads caused by linear damping are proportional to velocity of the structure which is viscous dampers. Loads created by nonlinear damping are proportional to higher power of structure velocity may be second order or third order.

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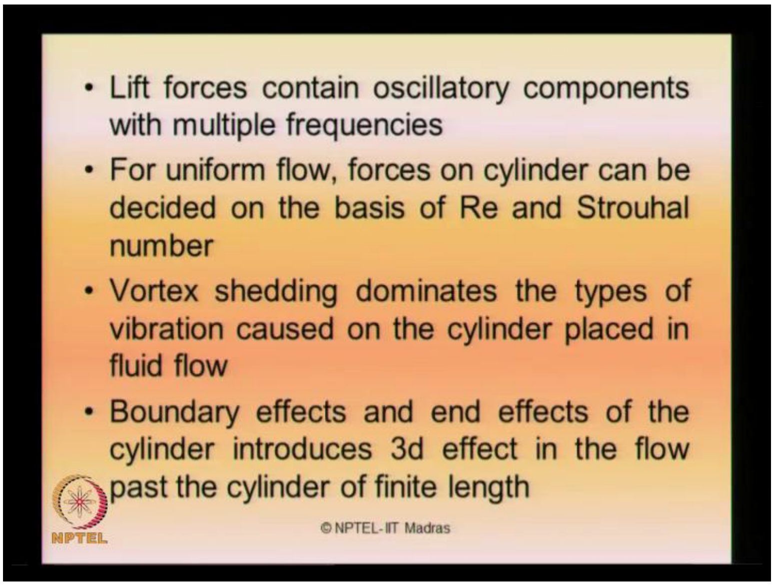

The lift forces contain oscillatory components with multiple frequencies is important because the drag forces have distinct set of frequencies where you can always either mitigate or handle in the design, where as lift forces have a cluster frequencies which are spread for a wide band, so the structure may get affected by lift forces if not by the drag design components. For uniform flow, forces on cylinder can be decided on the bases of Reynolds number and Strouhalnumber.

Vertex shedding dominates the types of vibration caused on the cylinder placed in a fluid flow, we already saw that. The boundary effects and end effects of the cylinder introduces 3d effects in the fluid flow domain. If the ends are finite, the ends are closed,then instead of 2d, it creates a 3dimensional variation when the fluid passes the cylinder of a finite length.So these are the summaries of points which we must remember when you talk about wave structure or fluid structure interaction when the member interferes with the fluid domain.There are interesting references for this specific lecture.

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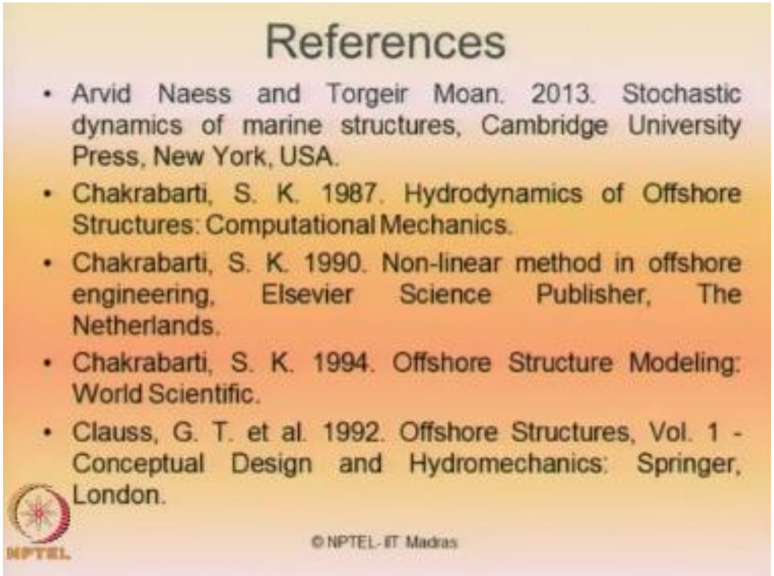

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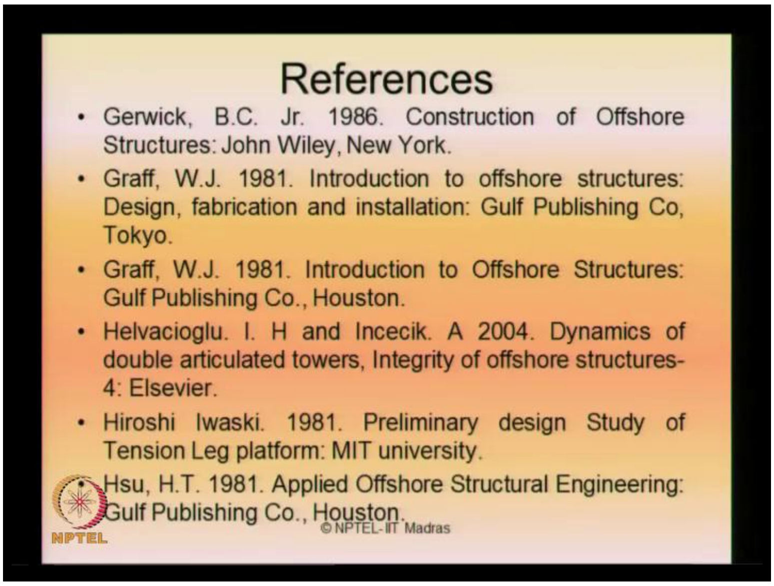

I request the viewers to go through them in detail.

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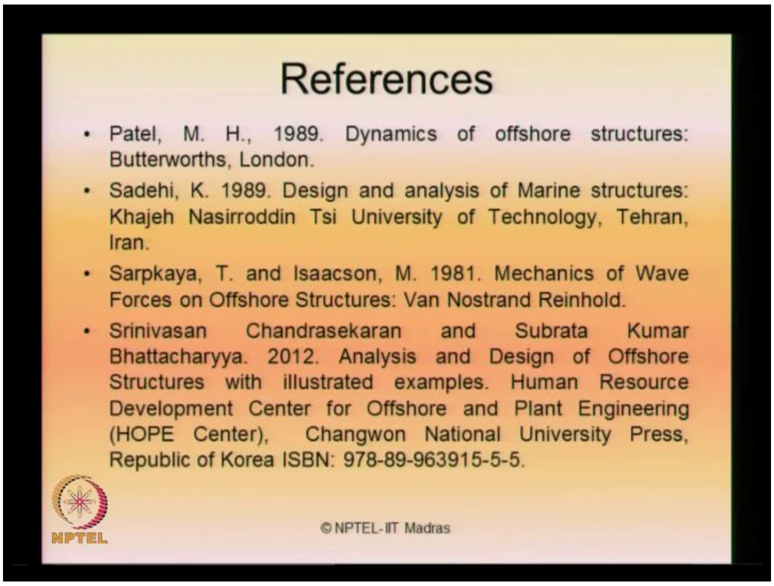

They are available in standard text books in all international libraries.In the next lecture, we will discuss about the case studywhere we are talking about use of perforations, flow-induced vibrations, how to mitigate flow-induced vibrations in given marine structures as example applications. There are experimental, numerical and analyticalstudies conducted on using perforated members on marine structures where,we will show you some examples in some studies and some useful inferenceshow the fluid structure interaction concepts has been handled more effectively to mitigate the forceson the members.

So our focus in the lecture through and through in this module would be how to design a given structural system for additional forces which are sensitively created on the member in its vicinity because of member interfering with the flow field. The same conceptsdefinitely are applicable when the member interferes with the wind velocity.Of course in this lecture, we are talking about flow field means only fluid structure interaction. We have discussed partially about the wind structure interaction using aerodynamic admittance function in the first module.I request the viewers tolook into the firstmodule lectures where, this has been handled intelligently by addressing this issue using aerodynamic admittance functions.

So with this we complete this lecture and we have understood that FSI is important, wave structure interaction creates sensitive effects and influences the structural response of the members whether they are individual,placedhorizontal,placedvertical and placed in groups. Because there are sensitive issues where the drag can have different distinct frequencies, the lift forces can have multiple wide range of frequencies and as well as the vortex-induced vibrations can cause high amplitude response on the members or high amplitude forceson the structuralmembers even at a frequency which is half or one-third of the fundamental frequency of the member. So with this we complete this lecture.

Thank you very much.

Wewill have the class tomorrow morning 9 to 10.