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

Lecture - 2
Fluid-structure interaction I

So, we will talk about, the 2nd module lecture 2 where you will again discuss the fluid structure interaction, and in this lecture we will give you some summaryof what is to be the influence of let say, the cylinder horizontal or vertical placed in the fluid medium and what would be the interest porous in dynamics point of view. We will give a summary on FSI related to this in this lecture. So, lecture 2 will again focus on fluid structure interaction as a continue lecture of the last 1 in the 2nd module.

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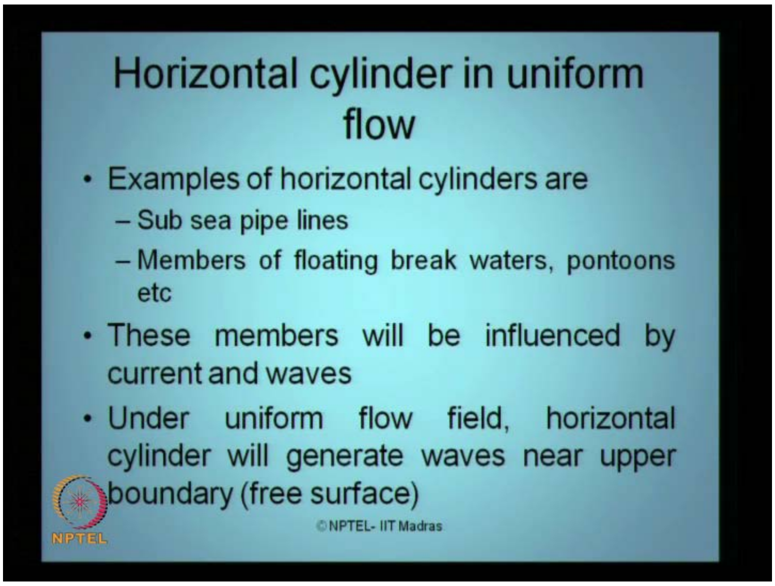

So, already we said that Horizontal cylinder in uniform flow when you place in a horizontal cylinder, because the orientation cylinder the length of the cylinder the boundary condition and the physical location cylinder whether it is nearer to the mean sea level near to the free surface will bother or will affect for influence, the overall fluid field pattern around the cylinder in a vicinity. When we talk about, horizontal cylinder uniform flow. So, this will going to affect significantly the fluid flow let us 1st look at the examples of the horizontal cylinders kept or in the sea water or in let say marine conditions can have subsea pipe lines, it can also have members of floating break waters, pontoons, etceteras which are horizontal members for example, TLPS vertical columns as well as horizontal members. So, horizontal members are called as pontoons.

So these members are generally influenced by the presence of wave and current and uniform and the uniformed flow field, the Horizontal cylinder will generates waves near the boundary only near the free surface generates waves, as said goes deeper and deeper the effect will not be there when the cylinder is horizontally placed.

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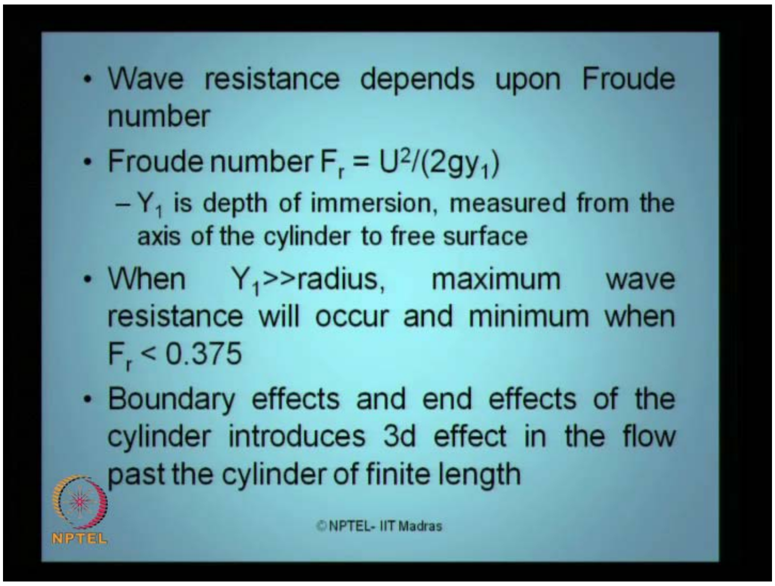

So, Waves resistance interestingly depends on the Froude number, obvious which is given by a simple expression U square by 2 gy 1 where y 1 is the depth of immersion, measured form the axis of the cylinder to the free surface and of course, g stands for gravitational value which is 9.81 meter per 2nd square. So, when the depth of emersion measured from the axis of the cylinder to the free surface is phenomenally high compare to the radius of the member or the cylinder then, the maximum Wave resistance will occur. It means the cylinder will resist the waves to its maximum and this resistance will occur to minimums when the Froude number is less than the number value of point 375 as seen in the literature the reference of these are all given at the end of the slide. So, you will understand where it has been borrowed from.

So, if the Froude number if the radius is lower compare to that of the depth of the immersion measured from the axis of the cylinder to the free surface, and if that value is very large compare to the radius of the member, the resistance offered with the cylinder for the wave action will be the maximum. So, the boundary effect and end effects if you talk about, the length of the cylinder covering the ends of the cylinder etceteras will induce what we called 3d effect to the fluid flow in the vicinity of the cylinder.

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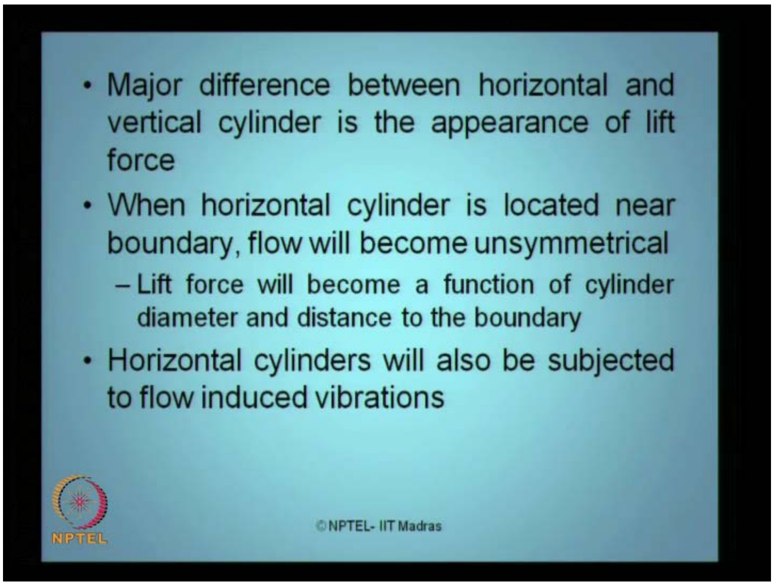

If the cylinder is of finite length, the same story happens in case of vertical cylinder also in horizontal cylinder the story is again same. So, the major difference between horizontal and vertical cylinder is in the appearance of the lift force how the lift forces are appearing in the whole fluid system interaction is the reference. Now, between the horizon vertical and cylinder when Horizontal cylinder is located near the boundary, the flow will become unsymmetrical that is very important it will not be symmetric in nature non symmetric. The lift forces are essentially now will become the function of cylinder diameter and the distance of the cylinder from the boundary.

So, as a diameter is larger and larger the lift forces will become higher and higher. In addition horizontal cylinder will also be subjected to what we called flow induced vibration a classical example is VAV which is vertex induced vibration.

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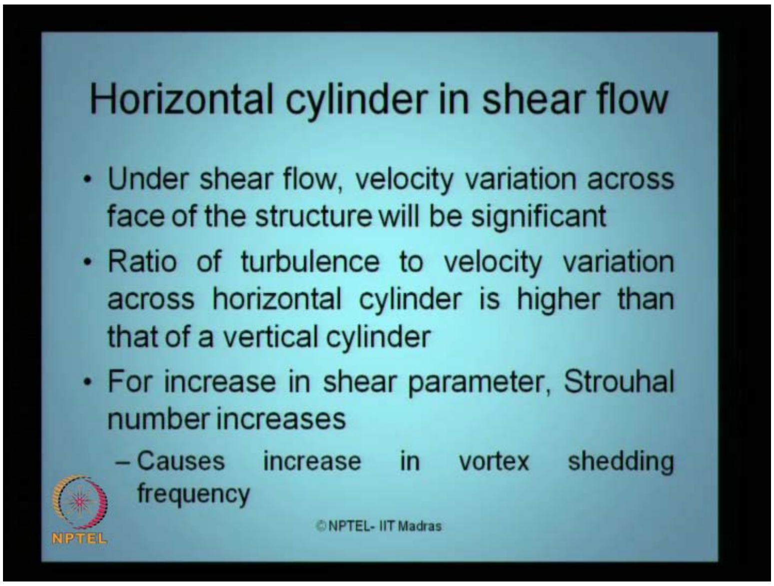

So, they will also be subjected to flow induced vibration in addition to the inline and transverse vibrations happening because of the wave interaction. If I talk about, the horizontal flow cylinders in a shear flow because we saw in the vertical cylinder in the shear flow.

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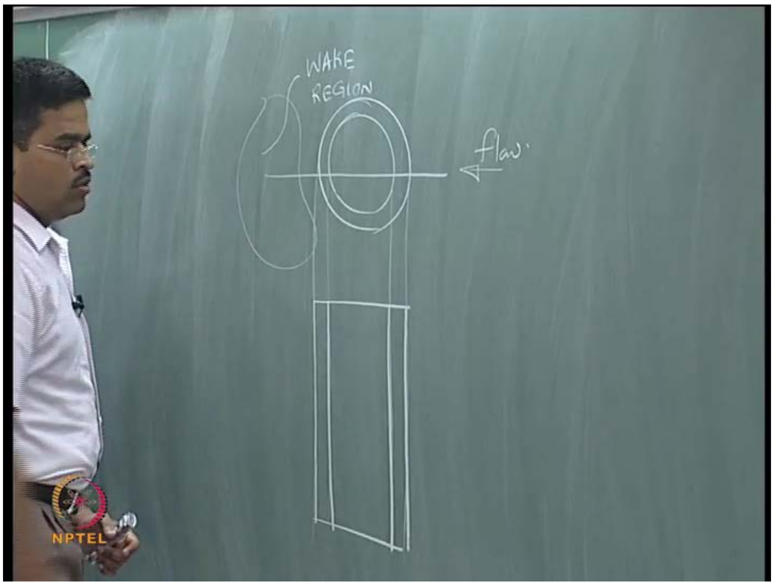

If you keep a vertical cylinder in a shear flow, this becomes the flow direction and this is what I called as a wake region you will see, there is going to be a downward flow here, there is going to be upward flow here, near the wake region as per the cylinder remains vertical. In case of a shear flow, because the presence of cylinder in a fluid medium actually shares the flow. So, this some downward and upwards share of the flow that is why it is called the shear flow it shears of the flow actually because of the presence of the vertical cylinder.

Similarly, let us look at the horizontal cylinder in the shear flow the velocity variation across the face structure will now become significantly important when you talk about, the horizontal cylinder in a shear flow. Now, interestingly the ratio of turbulence to the velocity variation cross the cylinder is higher than that of vertical cylinder. So, the ratio of the turbulence value to the velocity which will vary across the horizontal cylinder is now becoming higher and higher in compare to the vertical cylinder. So, therefore, if you got an off shore structure member which is an assembly of horizontal vertical cylinders then, the vibrations induced because of the flow field on the member interference because, of the vertical cylinder and horizontal cylinder will have a different domain of vibrations as well as, the effects on horizontal cylinder are going to be different near the free surface compare to with the depth located form the free surface.

So, therefore, if you talk about increase in shear parameter if the shear parameter in a given flow increases then the Strouhal number will guide or govern the behavior of the cylinder in the fluid flow. So, the Strouhal number increase will cause it increase in vortex shedding frequency.

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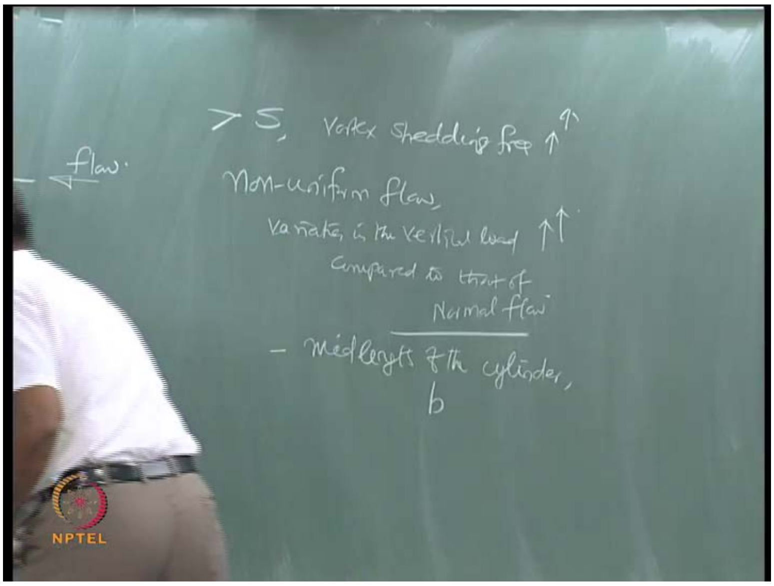

The vortex increase frequency for higher Strouhal number the vortex shedding frequency will become high for a horizontal cylinder in a shear flow. Whereas, in vertical cylinder we have already seen the domain where the velocity reduction happens and sometime inline flow vibration becomes important whereas, sometime transverse vibration becomes important in certain case of Reynolds number and Strouhal number you will see that the inline flow, that is the drag vibration will occur at the toes of the frequency of the transverse vibration the frequency content will be different.

So, the presence of drag will also be there plus again the secondary vibration cause because at the frequency at which double of the transverse vibration or the lift force vibration also occur a presence in a vertical cylinder.

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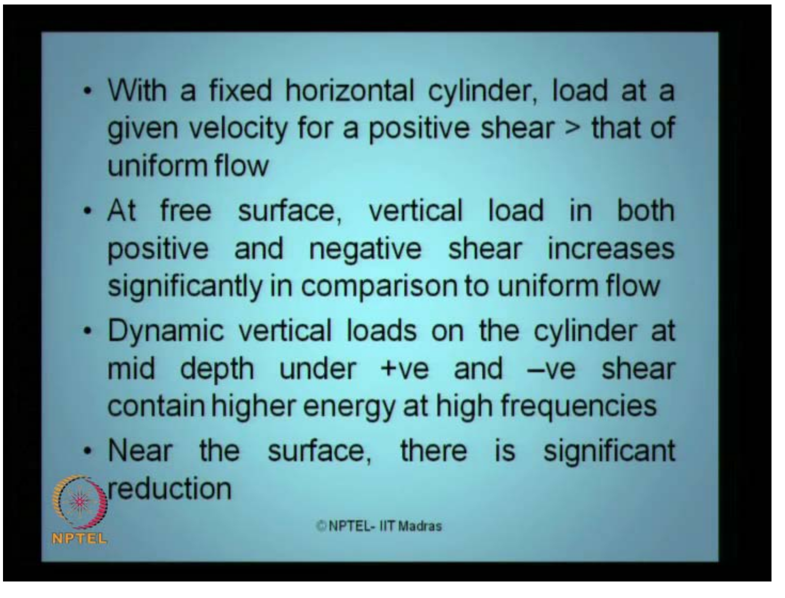

So, when fixed horizontal cylinders load at a given velocity for a higher positive shear. So, the velocity variation because of the positive shear is much more in a shear flow compare to the uniform flow which has been also absorbed in a vertical cylinder. So, of course, at a free surface the vertical load in both positive and negative shear increases significantly, in comparison to uniform flow that is the difference there for, if you have got a non uniform flow then the variation in the vertical is high in compare to in comparison to that of been normal flow.

So, the dynamic vertical loads on the cylinder at the depth or at the middle of the cylinder because of the positive and negative shear will have frequencies at an higher level with energy contain large, the band of the frequency bit will be higher. So, at the mid length of the cylinder the energy content will be also higher and it will occur, at a higher frequency of course, near the surface there is a significant reduction any question here.

Student: Sir, what is vortex sediment or frequency?

You want the number or phenomena explain of course, in the case of horizontal cylinder near the free surface there is a significant suppress of eddy and wake formation. Wake formation has not occurred in horizontal cylinder near the surface whereas, in vertical cylinder it is significant.

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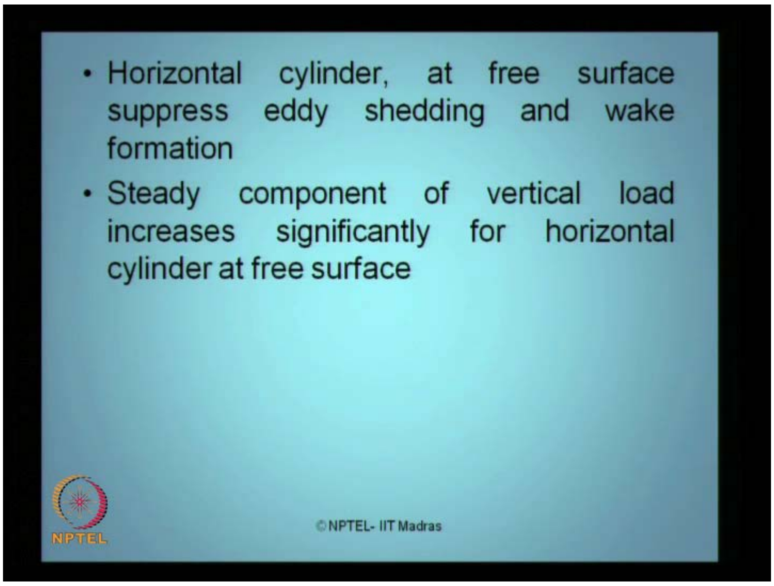

Whereas, in horizontal cylinder it is not there is suppression of the eddy formation and of course, it is a big reason and this happens near the free surface. So, the location horizontal cylinder is very important as far as the vibration phenomena are concerned when you talk about, fluid in interaction for an horizontal cylinder. Say there is steady component on the vertical load which increases significantly at the free surface.

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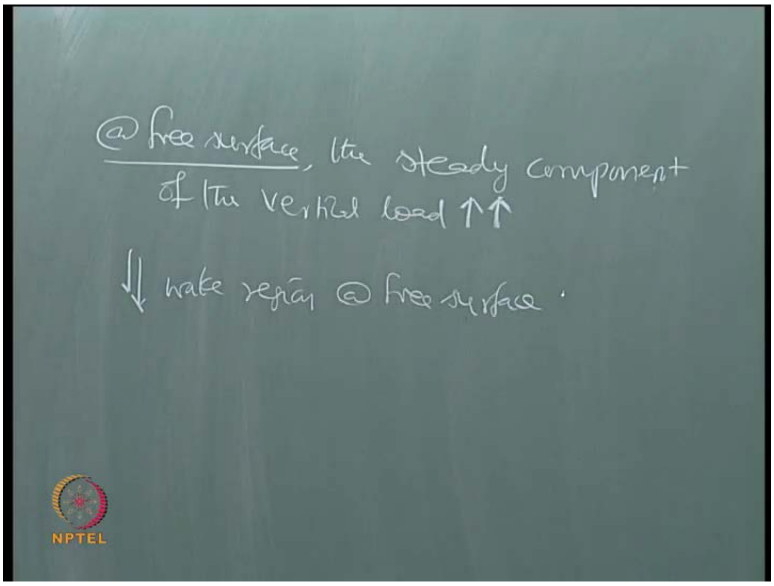

So, at the free surface the steady component keeps increasing significantly. So, what the free surface. The steady component of the vertical load increases, at the free surface where as there is a significant reduction of the wake formation at the free surface.

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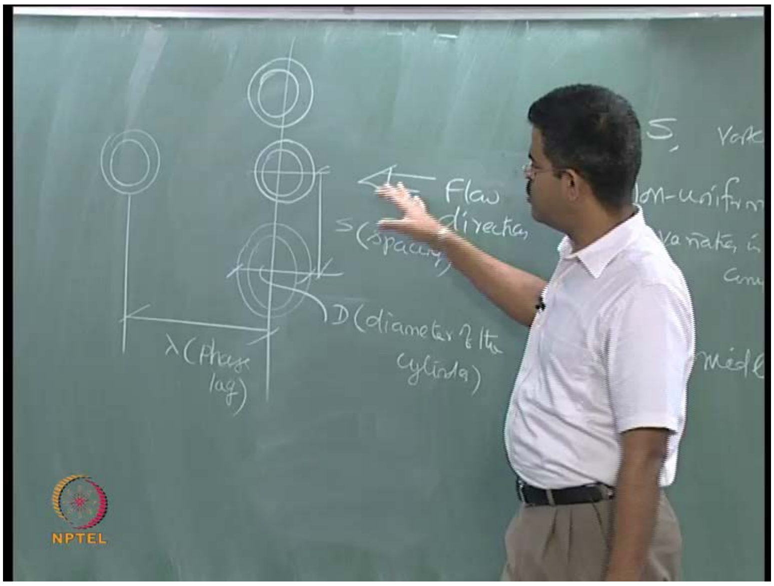

So now we talk about, cylinders or members which is in groups when this is my flow direction is the 1 cylinder I talk about, group of cylinders. I can also talk about, group of cylinders in a specific arrangement with a phase lag and of course, this is spacing and of course, this is the diameter. So when we talk about, the interference of group of cylinders in flow field then it almost to what we called blockage because, the flow field or the velocity of the flow pass the cylinder which is the group they get reduced. And we already saw, in the last lecture in case of reduction in velocity there will be different kinds of vibration set in the cylinder itself.

So, when there is velocity reduces there is different kind of vibration for a specific range of 1, 2, and 3 the vibration set on the cylinder will be of a deafen mode sometime it is in drag or inline effect sometime it is in transverse effect. We have seen in the last lecture you can look at the table later. So, when we talk about group of cylinders which is encountering the fluid flow it reduces the velocity significantly and this causes what we called blockage.

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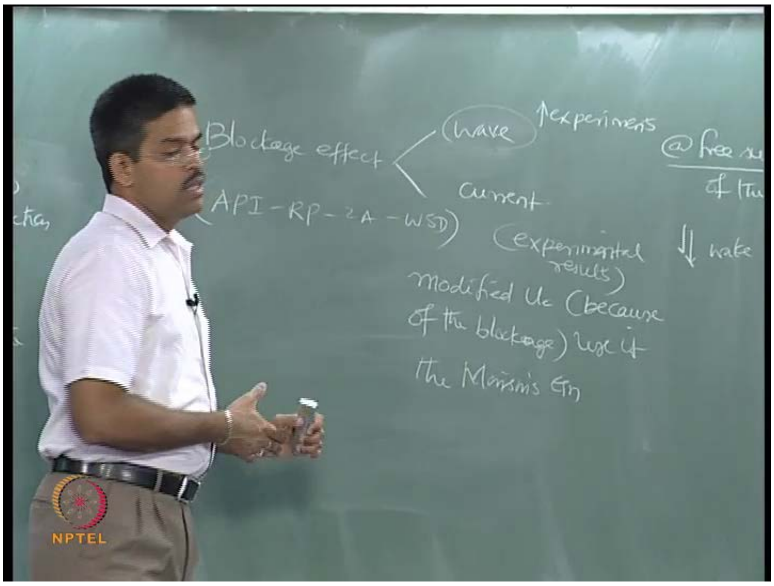

This is at distance API very interestingly on two parts, the blockage effect can be on wave. The blockage effect can be on the wave loading can be on the current as well, in case of waves there are no enough evidence, this is API recommended practice 2A-WSD in case of wave there are very few experiments which verify this fact, but analytically it is not verified therefore, as far as blockage effect and wave loading is concern people do not account for the increase in force because of blockage effect on waves, where as in case of blockage effect in current there has been very good experimental results available in the literature therefore, people say that find the modified current velocity because of the blockage, and use it in the Morison sea that is what EPA recommends in case of blockage effect for current velocity is concerned.

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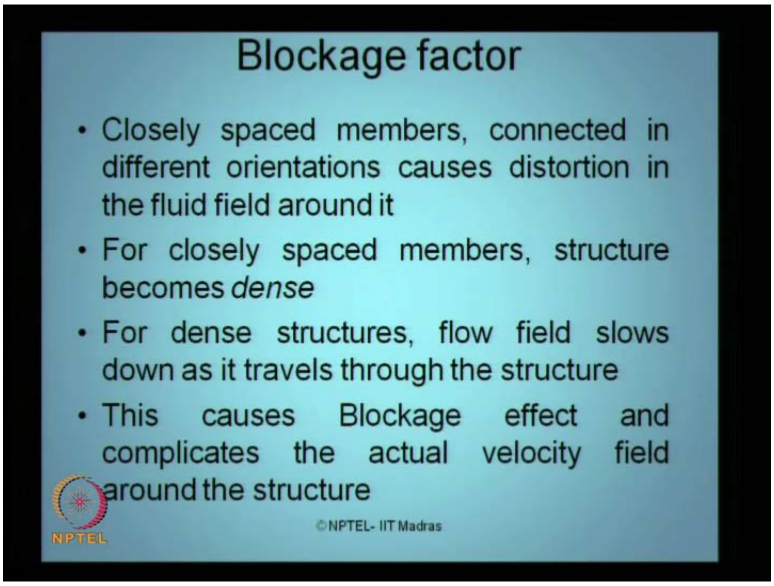

So, let us quickly look at, what is the blockage factor? I would compute this. So, as just now said, closely spaced members connected in different orientation can be 1 on a transpose direction can be 1 on the inline direction of the fluid flow, closely spaced members when they are connected each other remember they are all connected they are independent in such no they are all interconnected when they are connected together it causes distortion in the fluid flow around it in the vicinity. So, the structure is considered as dense in it is terminally the structures becomes dense because of the group of cylinders therefore, the flow fluid retards or slows down as it, pass the cylinder or the structure. So, this causes what we technically called as blockage, and it complicates the velocity in the vicinity of the structure.

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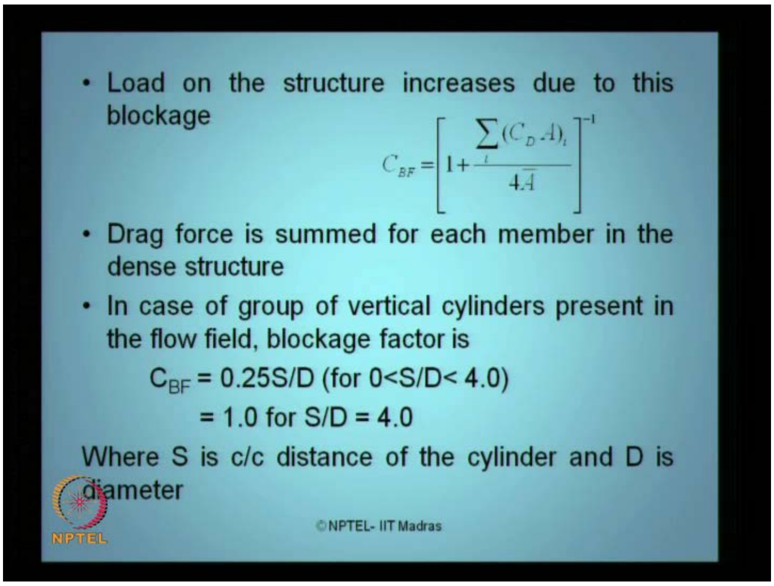

So, load on structure increases because of this reduced velocity due to this blockage, and we compute this blockage factor as CBF as given in this expression where the drag force on each member is summed up separately and then arrived at, for the influence of blockage factor on the structures.

So, the blockage factor will enable enhance the load because the wave action, but there are no experimental evidences though enough we verify this fact therefore, this is not accounted in the design at present. On the other hand we can also look, at blockage factor for group of vertical cylinders in the other format which is a function of spacing and the diameter. If, the spacing versus diameter ratio is less than 4.0 then, you can simply use a blockage factor as 0.25 S by S if this value is exactly equal to 4 then, you can use blockage factor as 1. Of course, this done for each and every cylinder separate and summed up for finding out the drag force on the members. So, this what we already said yes the spacing of the cylinder D is the diameter of the cylinder. Say an actual blockage or any group of structure are cylinders kept in a specific orientation if they are inter connected they are called the dense structures. The dense structure will retard the fluid flow, the retardation on the velocity reduction will increase the force on the member.

There are experimental evidences which conforms this for wave action, but not been recommended for current action yes, it is recommended indirectly by finding out the modified current velocity because, of the blockage effect then used that modified value in the Morison equation for finding the drag force on the member .

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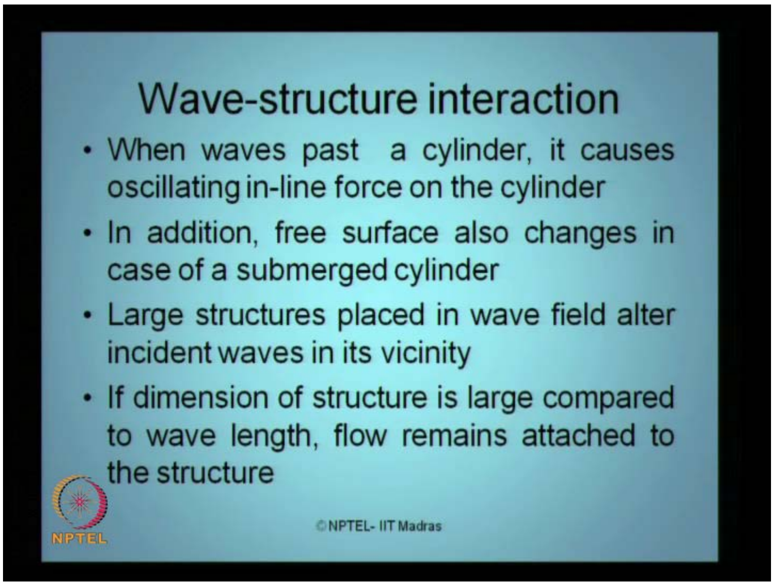

We will talk about Wave structure interaction quickly. So, as we saw whether the cylinders are placed vertical or horizontal when the wave or the flow action passes though the cylinder, it oscillates or creates the oscillation the in-line direction or the flow direction, which cause oscillating force on the in-line direction of the flow. In addition the free surface also changes which introduces the additional buoyancy or the submerged effect on the cylinder. If you talk about, large structures placed in the wave field they alter the instance wave itself, in the vicinity of the structure. So, these are all statement qualitative which I have, taken away from different research finding the various papers which are referred back at the end of the presentation.

So, on the other hand, if the dimension of the structure is very large compared to the wave length as you understand the flow remains attached with the cylinder that is the very important factor which is been used for finding out the forces on the member using the Morison equation. So, the flow remains attached. So, that is one of the interesting assumption must be made, in case of estimating forces on the members. So, this is 2 1 when the dimension of the structures is very large compare to its wave length.

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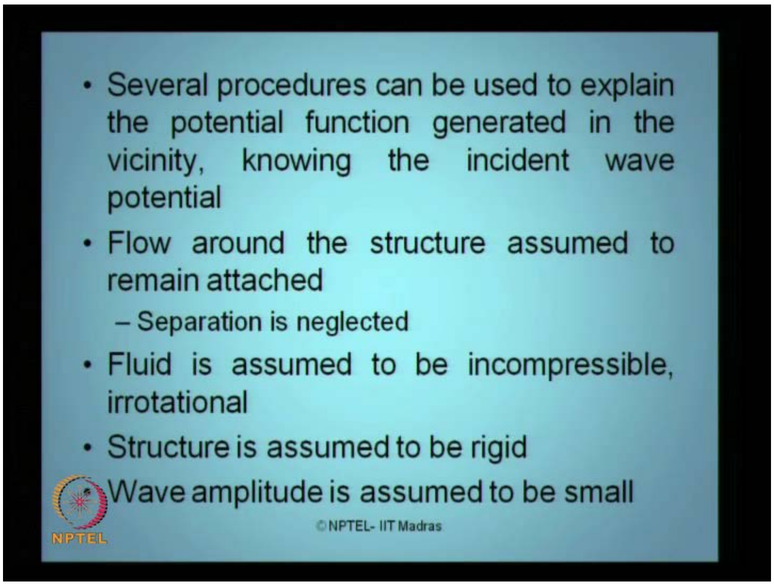

So, several procedures are actually used to explain the potential function generated on the vicinity. If you know, the instance wave potential for example, Flow around the structure is assumed to remain attached. I said it is a large structure the separation is neglected and Fluid is assumed to be incompressible and irrotational for our potential flow theory. Therefore, the structure is also assumed to remain rigid for it is action and of course, we do this analysis only for small wave amplitudes.

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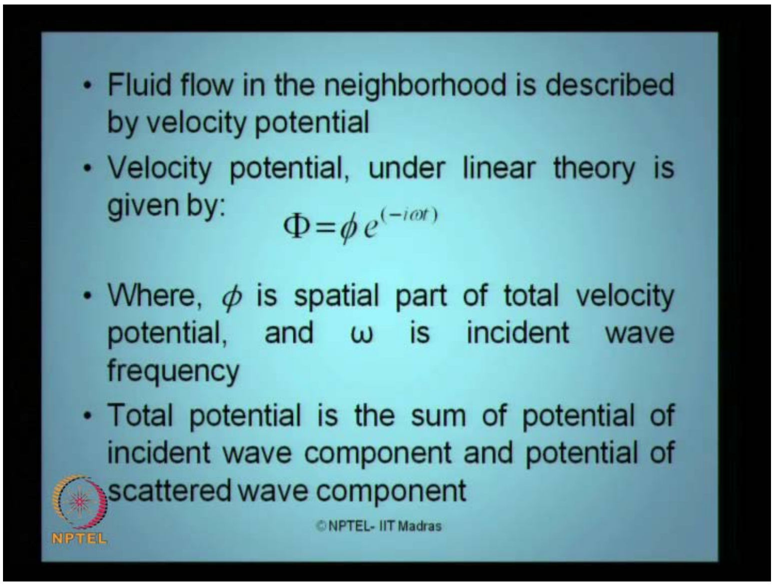

So, the fluid flowing the neighborhood is described a Velocity potential as given in this expression under linear theory, where in this case phi is the special part of the Total velocity potential the special variation created in the velocity potential where is omega is the frequency of the instance wave which you already know, what is fitting or what is encountering the vessel or the cylinder.

The total potential which is present now in the flow field is sum of the instance wave component what you already know, and the potential scattered wave component both has got to be added together to find out the instantaneous potential at the specific flow field present at the time.

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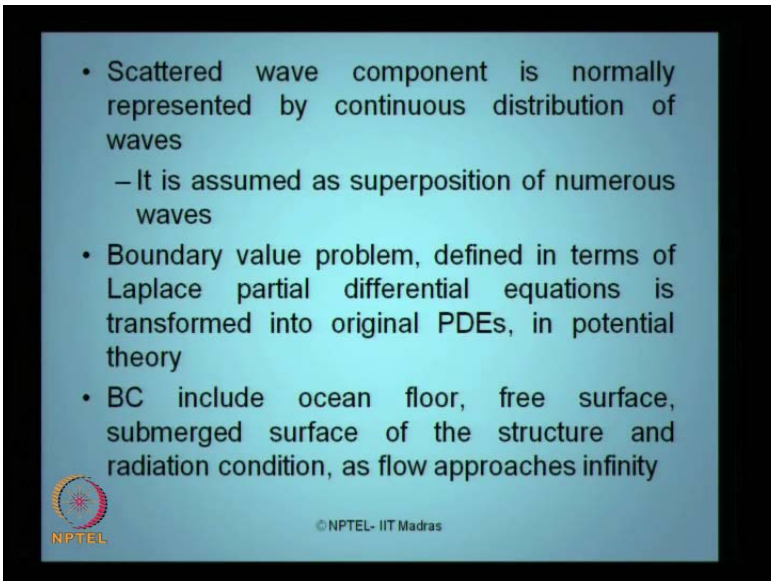

The scattered wave component is generally represented by continuous distribution of waves, because it keeps on scattering all directions as far as instance wave is concerned when it encounter cylinder, but it is assumed to be superposition of numerous waves using a specific theory.

So, it now terms to be a boundary value problem which is defined in terms of Laplace partial differential equation, which is conventionally transformed when original partial differential equation in potential flow theory. Now the question here is where are the boundary conditions? The boundary conditions include the ocean flow, the free surface, the submerged surface, of the structure and the radiation condition as the flow approaches infinity. These are the boundary condition what we apply or what are used for solving a potential flow theory.

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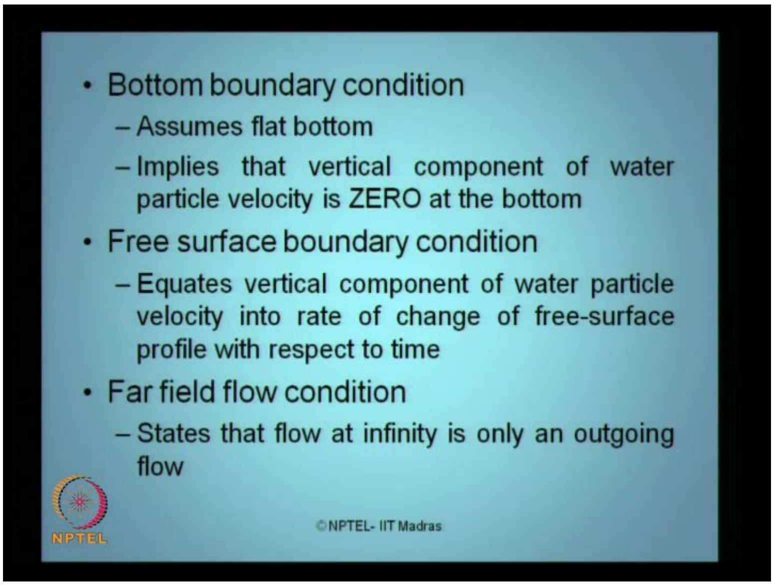

So, if you look at the Bottom boundary condition separately it assumes the flat bottom, and it implies the vertical component of the water particle velocity remains 0 at the bottom if you look at, the free surface boundary condition it equates the vertical component of water particle velocity again, into the rate of change of free surface profile with respect to time. When we look at the far free flow condition, then it states that the float infinity is only an outgoing flow there is no incoming flow to the system. The velocity derivatives only any outgoing direction.

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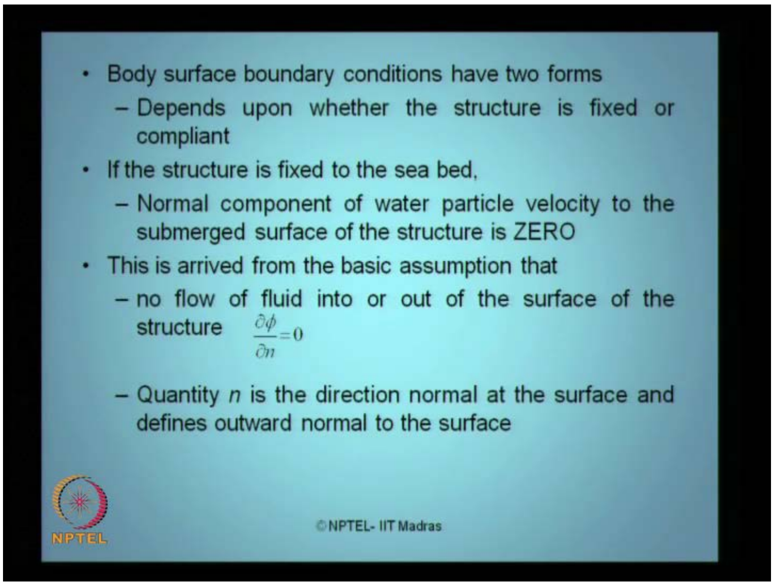

So, now the body surface Boundary condition has two forms which depends slowly, on the structure where the fixed or compliant we will see both the case of now. When the structure is fixed to the sea bed the normal component as you just saw, of the water particle velocity to the submerged surface of the structure remain 0. So, this arrived in the basic assumption that the derivative of the potential with respect to the directionality normal remain 0.

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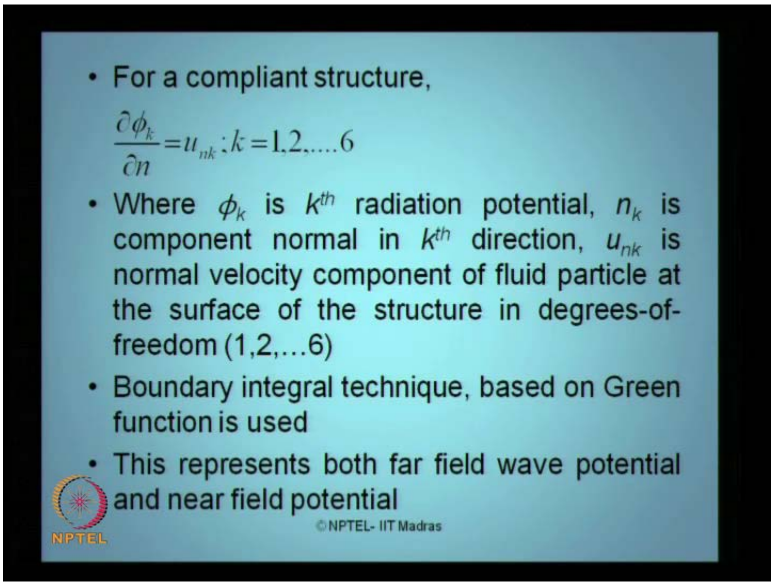

When we talk about, compliant structures then in this case the equation given by as it is been shown that that the phi kth is the radiation potential where n k is the component normal of the potential in kth direction and whereas u nk is the normal velocity component of the fluid particle in all degrees of freedom what a calculating the forces at for example, now case is going to be 6 degrees of freedom. So, the Boundary integral technique based on green function will be used to solve this potential of theory this represent both the far field wave potential near field wave potential both. According to this method the surface of the structure is divided into small parts.

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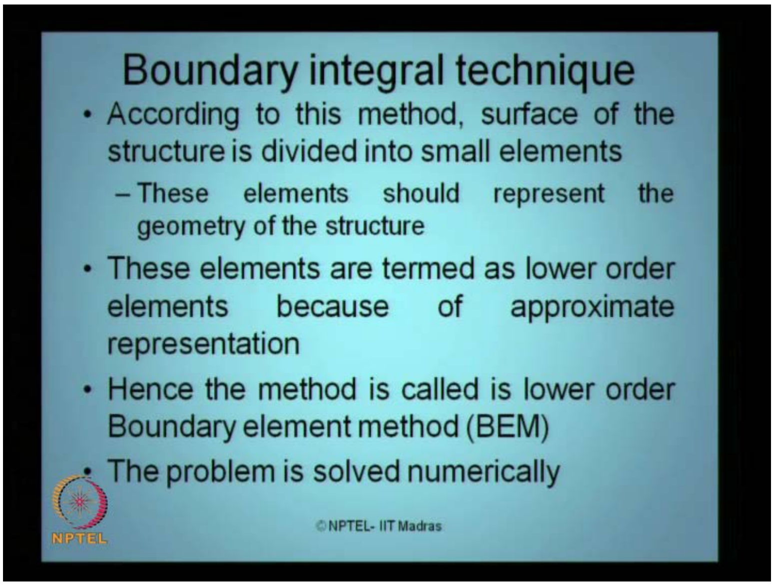

These elements should represent however, the original geometry of the structure has no change in this. If that is the case these sediments are then termed as lower order elements because of the approximation that is why this theory or this method I called lower order boundary element method, the lower order in the sense I am dividing the whole structure into small components whose geometric characteristics remains absolutely similar to the whole structure. That is why this is called as lower order boundary element method.

Of course the problem solve numerically, then where is numerical technique been used to solve this potential theory problem using BEM which were not discussing in this particular course, but anyway there is a directionality of your understanding that what actually the waves such interaction induced in the structure and how do you handle the problem, how do you formulate the problem how do you handle the problem, how do you solve by what technique they are just taking u only under part of understanding this.

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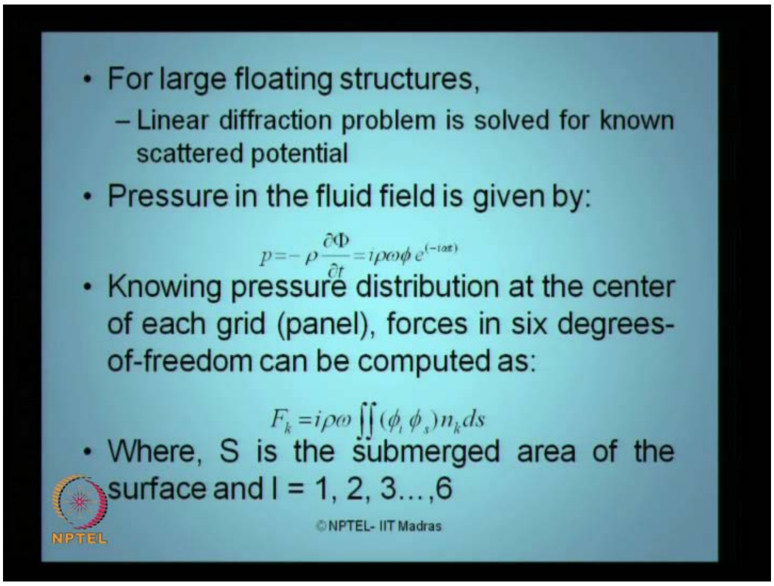

If you talk about, large floating structure where again we have an example in dynamics the Linear diffraction problem is solved for known scattered potential now the pressure in the flow field is given by this expression as you see in this slide now, where S is actually submerged area of the surface in all degrees of freedom. So, what you got to do is, you have to find out the pressure distribution at center which grid. So, call elements what you have divided the whole structure into and find out the pressure distribution in all degrees of freedom independently at each component. So, we are working out the pressure in the fluid flow as given with equation for I, is for every degree of freedom independently.

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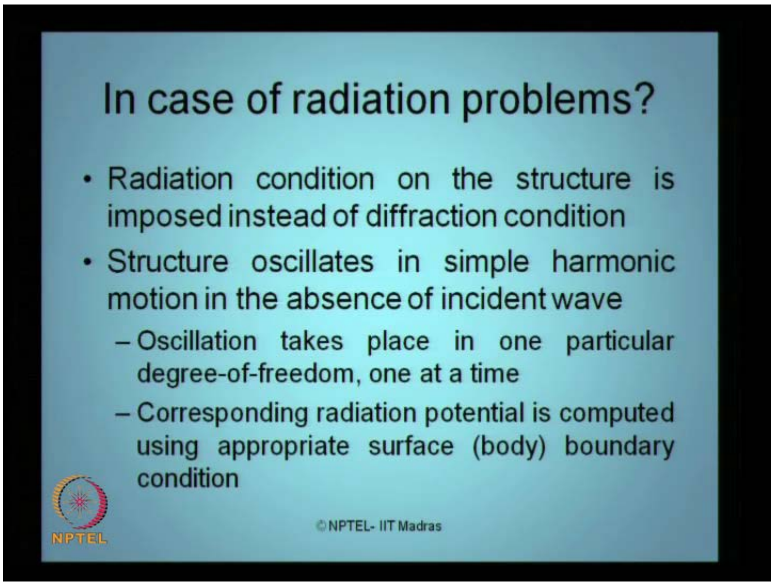

So, once you know that the radiation condition is imposed instead of diffraction condition now, for your solving the problem. The structure oscillates or constructive oscillate in simple harmonic motion, in the absence of incident waves now oscillation takes place only in 1 degree of freedom at a time. So, that is what your ideal decision is the corresponding radiation potential is now, calculated using boundary condition which is appropriated for a given cylinder or given structure in a free state.

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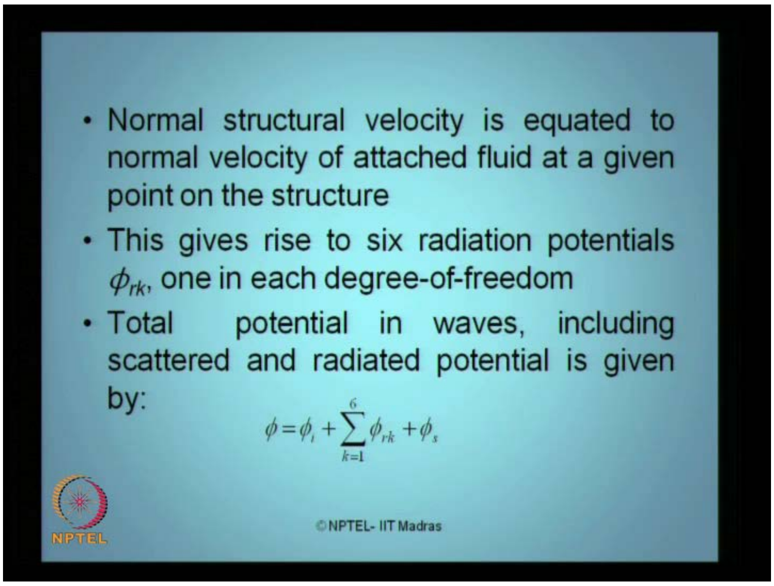

So, Normal structure velocity is now, calculate in all degrees of freedom as you see this expression here, which is included the scattered potential and radiated potential both are and s as well. So, phi rk what is see here, is a force oscillation of unit amplitude which is worked out for every degree freedom where k is the each degree of freedom separately.

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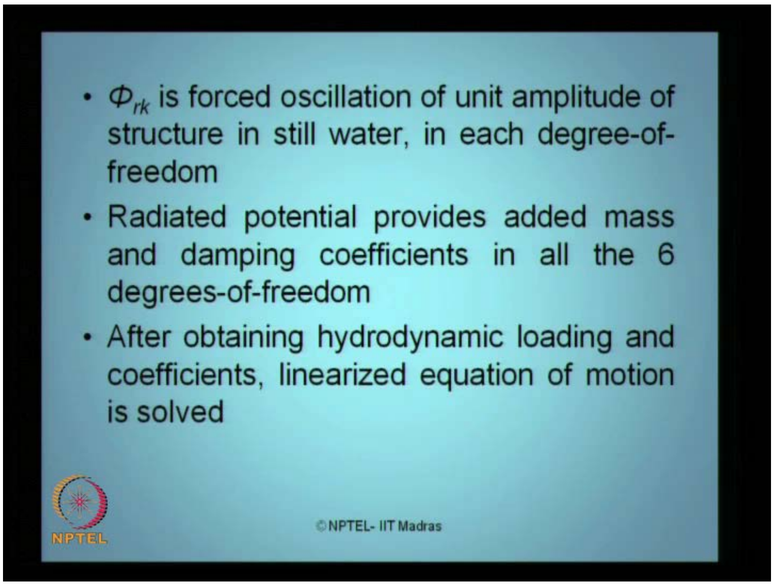

So, radiated potential provides added mass and damping coefficient for my analysis in all the 6 degrees-of-freedom separately. So, after obtained hydrodynamic loading obtained in the member, linear equation of motion which is been solved using different techniques either in time domain or in frequency domain. That is how, my dynamic analysis of incorporating the FSI in structural problem where this cylinder is fixed or it is a large in diameter or this floating.

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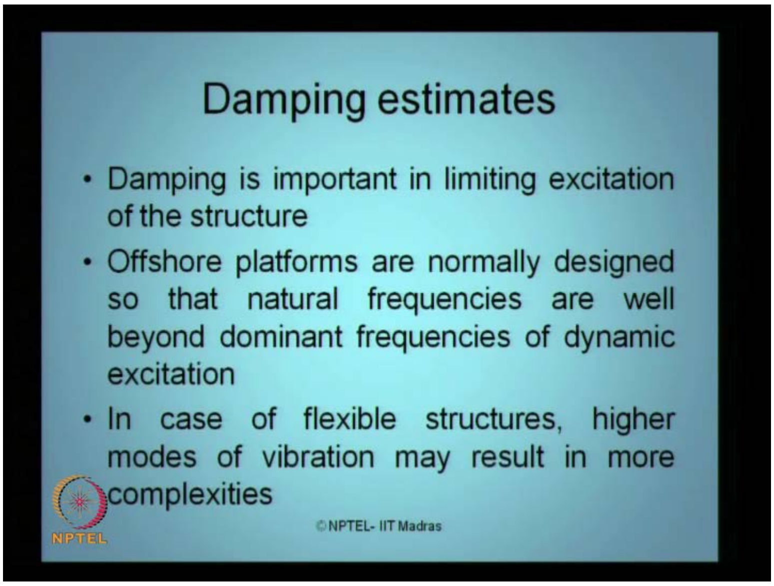

Where, the surface of the cylinder is closer to the free surface or mean sea level. Interestingly as we also saw damping place a very important role as far as hydrodynamic let say, housing structure are concern. Let us talk about, the Damping estimate very quickly now, damping is very important when you excite the structure for a limiting frequency that is very important. Offshore platform are generally design not have the natural frequency well within the domain of the excitation frequency that is the general design concept what we have in offshore structures. However, in case of flexible structures more interestingly the higher modes of vibration play a role in the finding out the response which will add more complexity to the dynamic analysis.

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So, we should use what we called modern response method, or flexible structures or I should say Compliant. We look about an example how do tranquil the modes etceteras? Later, but we should use this algorithm if you are talking about, compliant structure because higher modes will not participate in the overall response of the structure.

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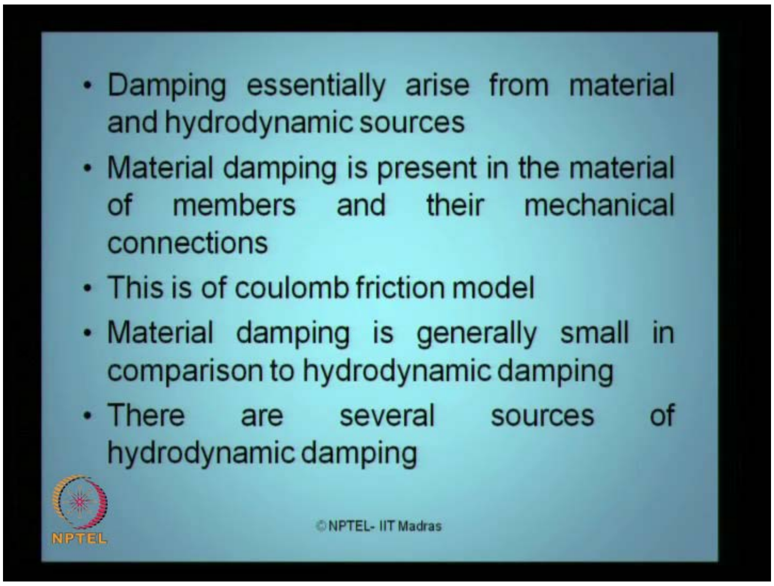

So, damping essentially comes from two structures one is material other is hydrodynamic. So, there are two Sources of damping one is from the material itself other is from hydrodynamic. The material can also come from the surface of the material or the material characteristics as well as, from the joints or connections can come from the members, in come from connections. So, they will result in a friction model which is expressed by coulombs model. So, it can come from the material of the member as well as, the mechanical connections.

So, this is basically a friction model which is given by the coulomb theorem whereas, the hydrodynamic damping will come from the viscous model which will see in the subsequently slide. But, interestingly people are founded form the experimental investigation is that, the damping which comes from source of the material is for inferior lesser compare to the hydrodynamic damping as well as oceans structure are concern. So, generally they are very small the material damping is very small. Therefore, if you look at non-linear dynamic analysis where the non-linearity essentially comes from the material, this is not a significant application to offshore structures. If, the non-linearity comes from the forcing function for example, from the drag for example, form the variable submergence for example, form the system non-linearity that is because of the stiffness and the mass then this is significant people do not talk about, non-linearity in terms of material here, they talk about in term of essentially on the loading component or any system geometry itself. So, talking about flexible systems or complaints structures you would have system non-linearity.

Talking about, large diameter structures where we use Morgan equation talk about, drag non-linearity. So, the material damping is generally a less compare of the hydrodynamic damping because these are the two sources from which damping in come in motional structure. So, now, let us quickly look at the hydrodynamic damping there are several sources from where these damping can arise.

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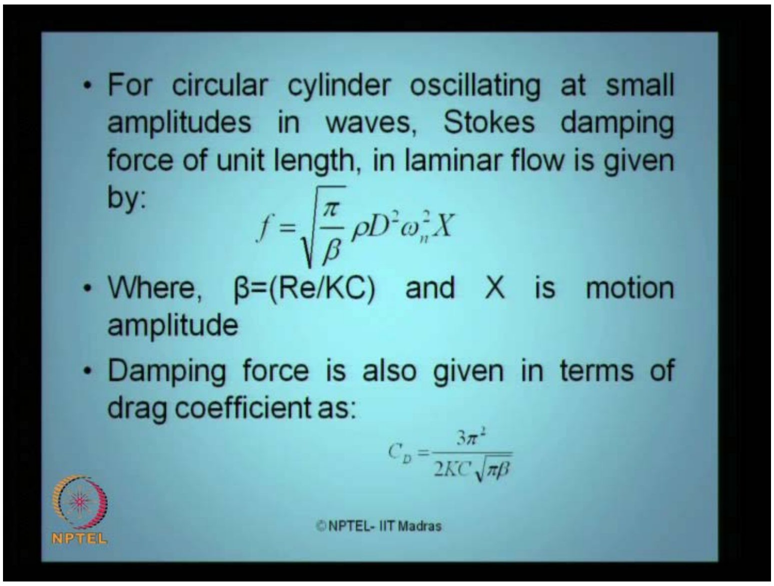

For circular cylinder oscillating in waves which has smaller in amplitude, in the stock damping per unit length of the member in a laminar steady state flow can be given by this expression where, the beta values here is nothing, but the ratio of the 2t number which is Reynolds number and kiloton carpenter number based on this value depending upon the amplitude of the response of the system can easily find the stocks damping per unit length of the member, which can also come from a import sources of hydrodynamic damping. We can also find out damping in terms of varying drag co-efficient as given by this expression here, which is also available in the literature as an alternative method of computing damping in terms of its drag co-efficient you can use the modified drag co-efficient. Which can account for hydrodynamic damping in a given system, which is given by the plane expression where Cd is given by 3 pi square by KC stands for kiloton carpenter number here.

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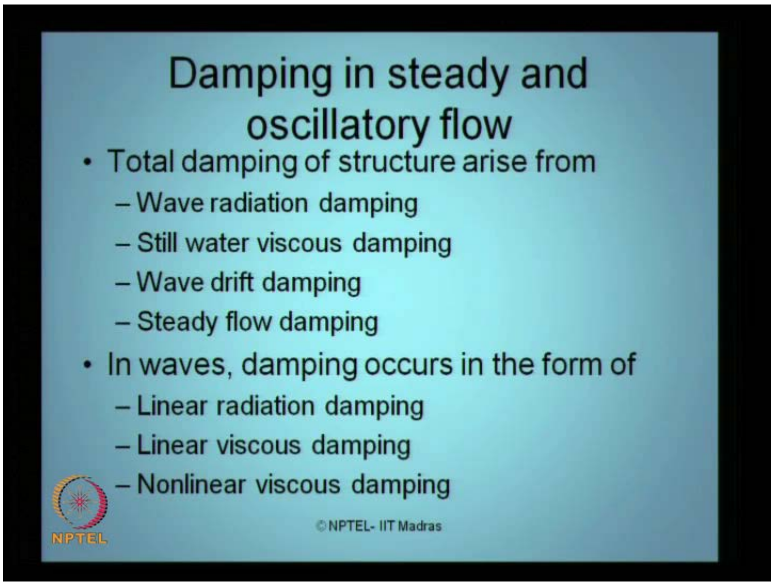

We look at, damping in steady and oscillatory flow because, that was a laminar flow the previous one was the laminar flow it is a laminar flow here, when look at oscillatory or steady state flow then, the damping of the structure arrived from the four different sources it comes from wave radiation damping in come from silt water, viscous damping, comes from wave drift damping, and steady flow damping which all will be function of velocity. Damping and also occur in the form of linear radiation damping, linear viscous, and non-linear viscous damping which are all function of velocity of the motion of the structural system. So, radiation damping actually arrived form linear diffraction theory, the low cost on a linear damping as proportional to the velocity of the structure as I just said.

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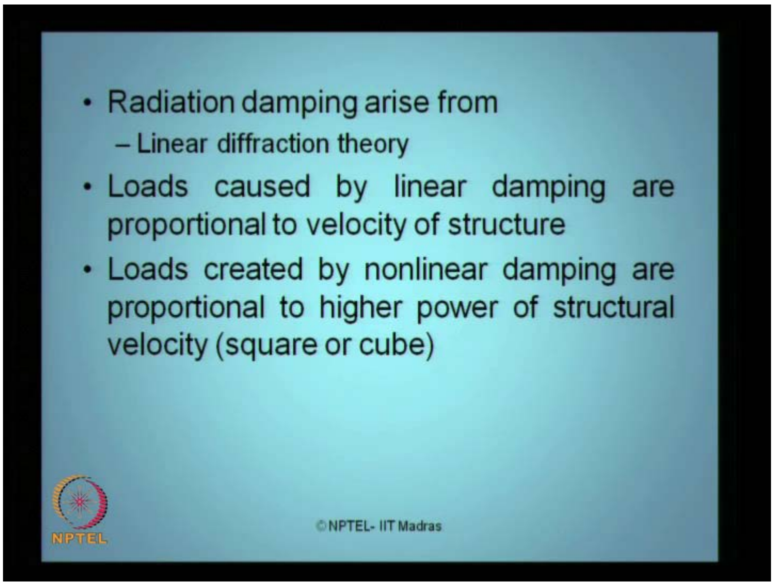

Now, the loads created by non-linear damping are proportional to the higher powers of the structural velocity. So, they are also component of or a function of such a velocity. But, often higher power not a linear. So, the difference source of damping which comes on a offshore structure, when it is steady and oscillating flow, arise from wave radiation, still water viscous damping, wave drift damping, and slow steady flow damping which are essentially a viscous flow damping models which have been used for our analysis in general because, they are either function or proportional to velocity in linear terms or in terms of higher powers of the structural velocity.

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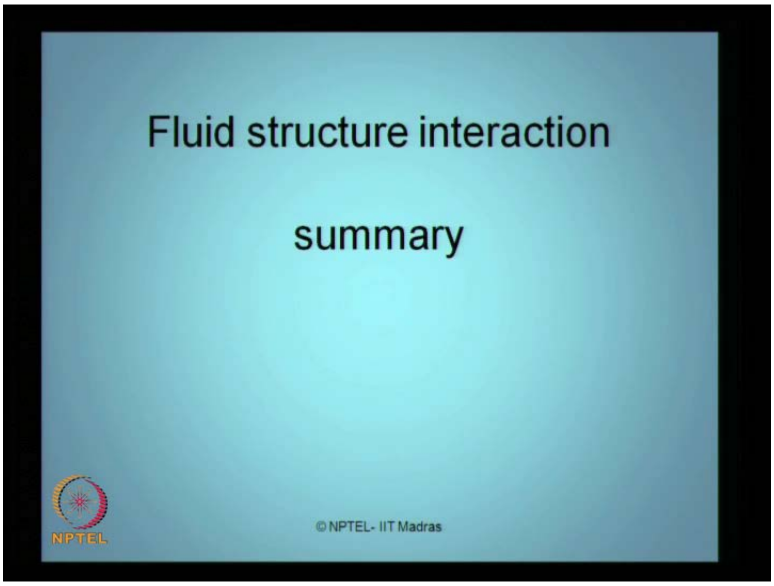

So, in a very brief summary we have picked up two example where. we have got one horizontal and one vertical cylinder we made the flow field pass the cylinder sometimes we also discussed about group of cylinders and see what is the effect of these cylinders? Depending upon the orientation, depending upon it is finite of length, depending upon the boundary condition whether the ends are closed or open, and depending upon the physical location whether it is closer to the boundary or closer to the sea bed. What would be the significant alteration of the flow field and how do you handle this in a classical potential theory? As explained in the literature, and how to transform these forces in terms of dynamics importance in Fluid structure interaction and wave structural interaction that is what we have seen in the two lectures we quickly summarized now, what we have seen.

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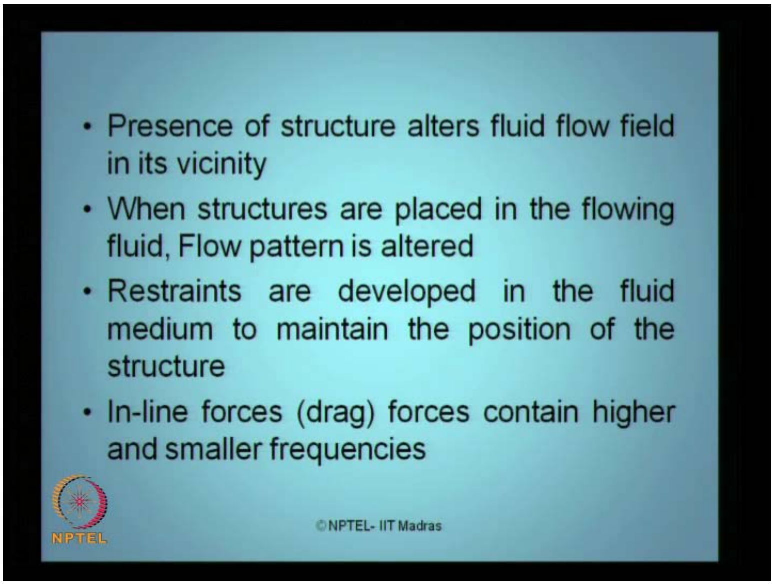

So, far it is very important for us to understand it is all these statements are qualitative of course, it will quantify them later by picking up examples on different kinds of structure. They are very important it is a very interesting summary given by the various researchers, which will show you in the next slide on ward the references.

So, essentially we can understand that the Presence of structure certainly alters the fluid flow field in this vicinity. One important aspect is, when the cylinder is vertically place it is creates a weak region with shear of the flow depending upon the flow field in its vicinity. So, it disturbs the vicinity when the structure is placed in the flowing field the flow pattern is what people say is altered qualitatively. The restraints are developed in the fluid medium to maintain the position of the structure that is very important the structure does not want to move or wants to move in a specific manner it develops the strains in the wave field what we are trying to measure, and response are crated because of this kind of restraints developed by the structure on a flow field. So, inline forces what we are addresses is drag forces contain both frequencies higher and lower depending upon what is the Reynolds number and what is a corresponding Strouhal number.

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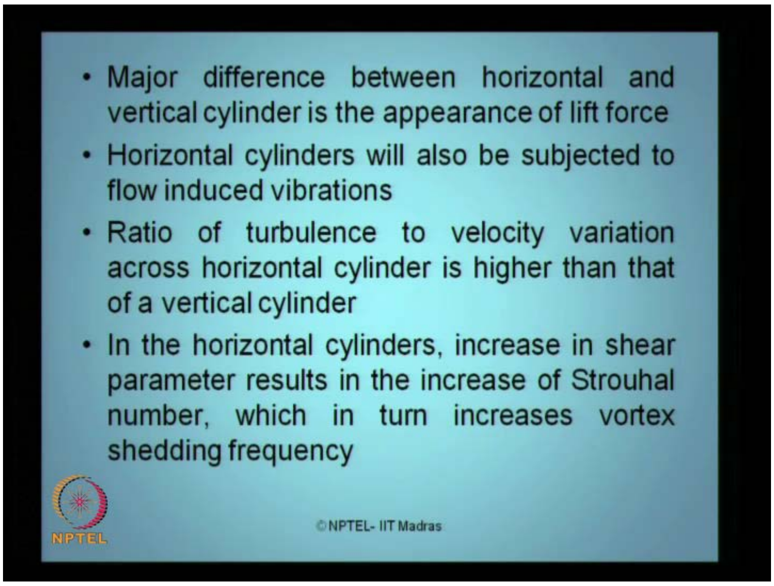

The Major difference actually comes in the lift force in it is appearance between the horizontal vertical cylinder where does it occur, Horizontal cylinder are also subjected to fluid induced vibrations for example, vortex induced vibration VIVs importantly the ratio of turbulence velocity variation across the horizontal cylinder is higher, than that of vertical cylinder. In a horizontal cylinder increase in shear parameter results in increase in Strouhal number which intern increases vortex shedding frequency that is what the answer is. The vortex shedding frequency quantitatively will be enhanced by increasing the Strouhal numbers which happens essentially in a horizontal cylinders not in vertical cylinders. So, orientation of the cinder will matter whether cause VIV or not.

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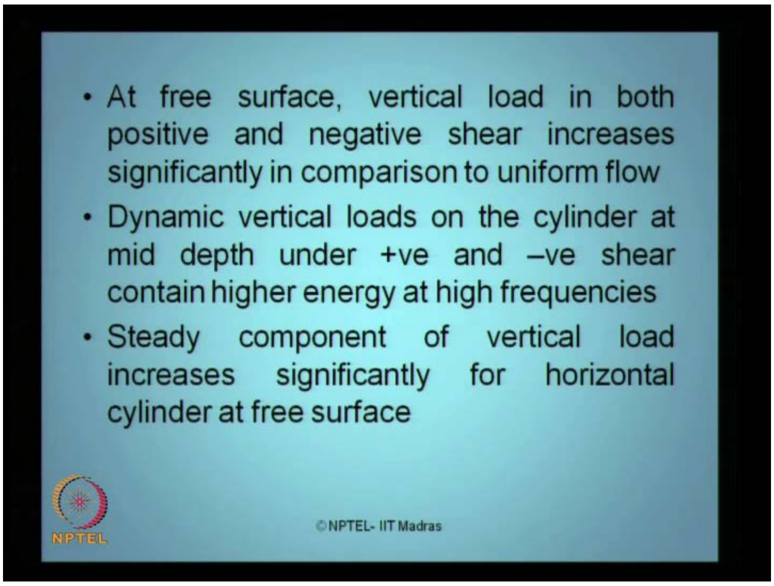

So, at the free surface we look at the free surface bit horizontal cylinder the vertical load in both positive and negative shear increases significantly when we compare it with the uniform flow. The dynamic vertical loads on the cylinder at the middle depth both because of positive and negative shear contain higher energy at very high frequencies. The frequencies are very high and the energy contained it means it is broad banded wave energy is larger at middle of the section. The middle depth of the cylinder.

Steady component of vertical load increase significantly where horizontal cylinder at free surface where is the basin component dies away the eddies and break region are not present in horizontal cylinder near the free surface. When you have dense structure when there are series of cylinders which are kept in flow direction parallel and normal to the direction of flow they cause what we call interference of the fluid flow which is called blockage factor because of the fluid flows slows down the velocity decrease retards it enhances.

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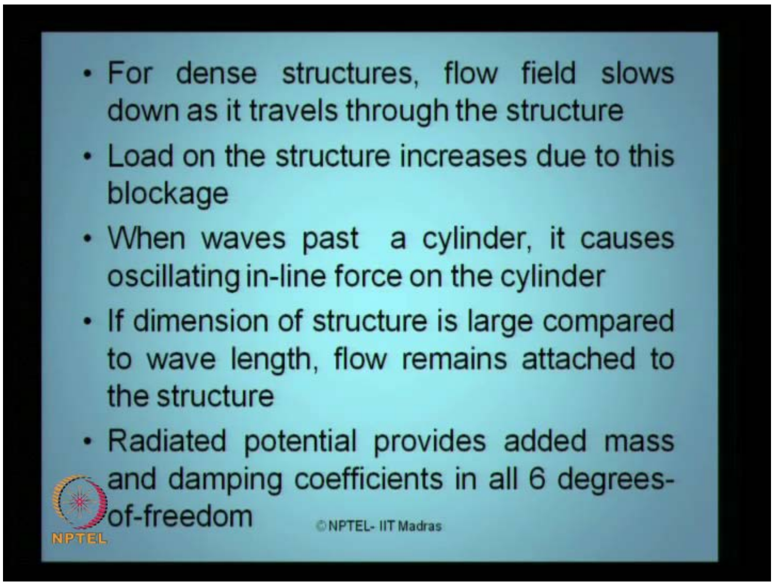

The forcesof the load on the structure increase due to this blockage when wave past a cylinder it causes oscillating inline force on the cylinder that is very important that is why you are looking at the vibration point of view if, the dimension of the structure is very large compare to the wave length the flow remains attached to the structures. So, the assumption of flow not getting separated from the cylinder is very important only for large diameter structures where the diameter has compare to be large to this wave length of the approaching wave. The radiated potential provides added mass of damping co-efficient from a analysis in all 6 degrees are freedom independently I can find out them.

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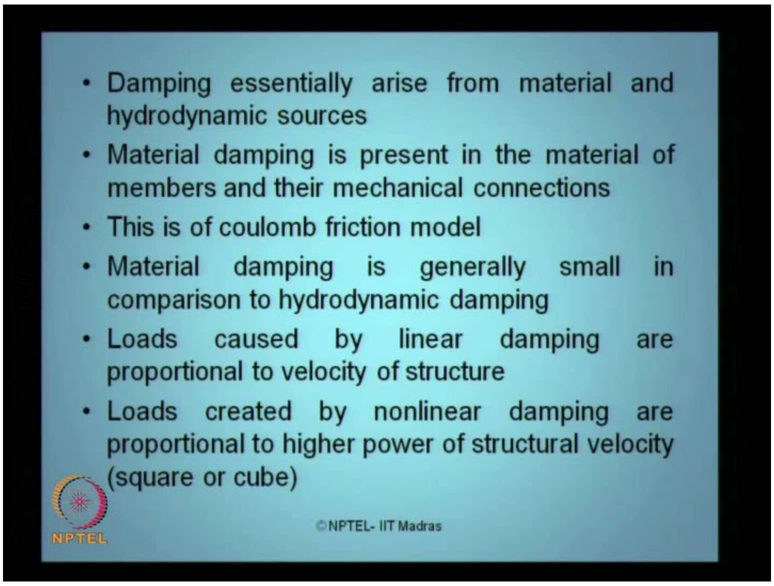

Damping essentially arise from two sources one is material other is hydrodynamic of course, that arise from the material is essentially lower, in its value compare to the hydrodynamic. Therefore, talk about non-linear dynamic analysis the focus is essential non-linearity arising from the forcing function or form the system non-linearity not essentially from the non-linearity arising from the material properties of course, it is also present, but we not look at this in the coastal structures, predominantly and significantly it will not get reported. Essentially non-linearity place an important load majority from the form f which is compliant or from the load which is handled appropriately in the analysis, because people always find equaling linearised drag instead of non-linear drag. You can find litterateur where people use equal linearized drag instead of non-linear drag system component in the forcing function. So, damping essential comes from two sources material hydrodynamic sources of course, material essentially talks about, the friction model where as hydrodynamic essentially talks about, the velocity model which is essentially important for us because our whole analysis depends on c is as function of proportional to its velocity.

So, material damping is generally smaller as just we said, the load caused with the linear damping are proportional to the velocity it can be linear it can be of a higher order as well.

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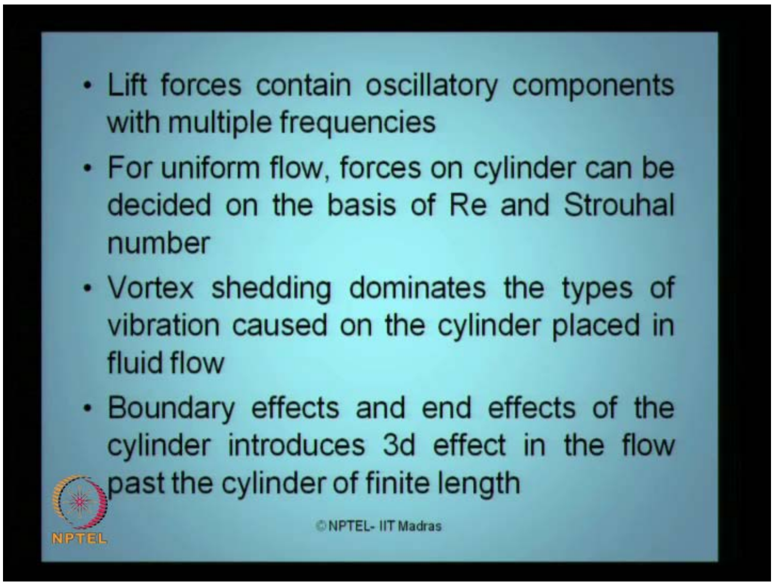

The lift forces contain oscillating components with multiple frequencies that is very important because the frequencies bands are different as we discussed in the last lecture.

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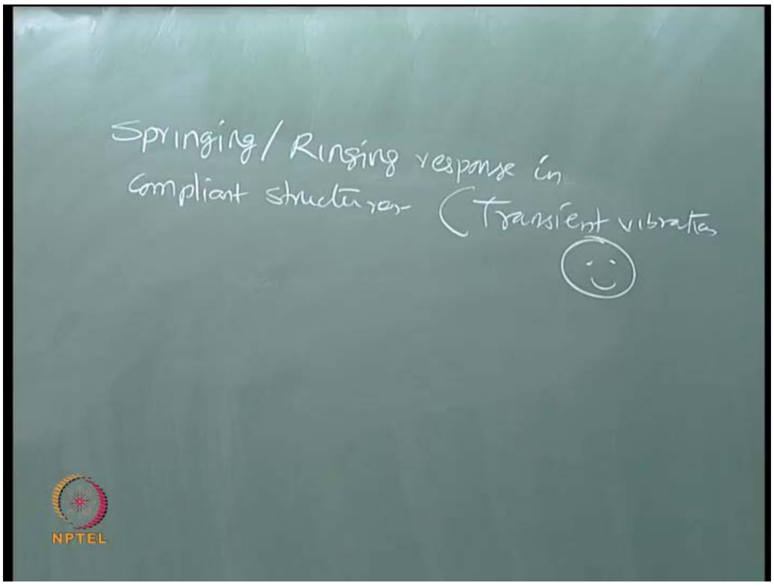

There are something called Spring and Ringing response in complaints structures, where Transient vibration also becomes important. Generally people ignore this, but in this case it will become important I will show you in one of the case studies we will take out in next lectures and show you how Ringing response and springing response can become phenomenally high in compliant structures because there will be only address to the system non-linearity coming from the geometry not for factious structures. So, people have seen this kind of studies report to the litterateur which we will show you and discuss you in the subsequent lectures in this model.

So, for uniform flow forces are essentially governed to the Reynolds number and to some extent Strouhal number as well because we will talk about, what frequency the drag component will appear depending upon the Strouhal number Vortex shedding dominate the type of vibration caused on the cylinder in a fluid flow of course, if it is activated depending upon the reduction in the velocity. The velocity is reduced in the range of 1, 2, 3 as we discussed in the last lecture in the type of vibration imposed in the cylinder varies. The boundary effect in end effects, if it is introduced for a finite length of the cylinder will cause a 3 dimensional effect on the fluid flow if the cylinders are of a finite length and boundary conditions are essentially controlled by either placed in ends of the cylinder or placing them to the vicinity of the main sea or vicinity of the sea surface or the sea wall.

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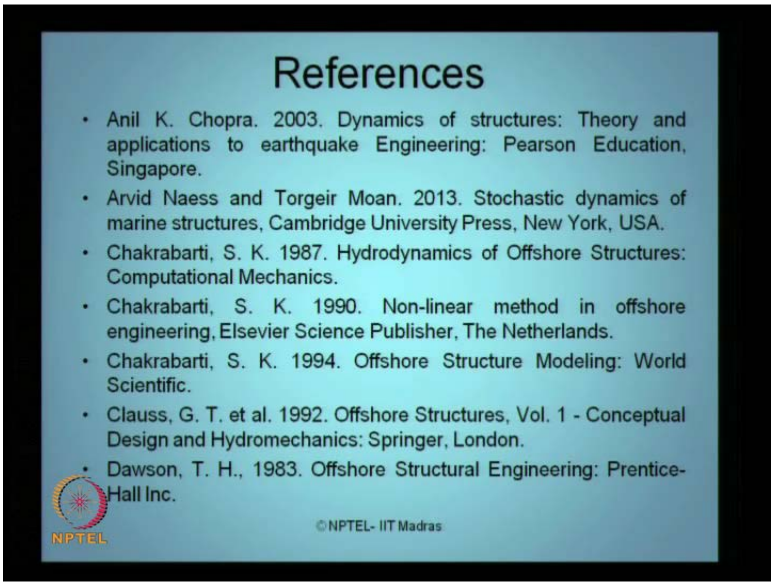

So, there are interesting references these are available in NPTEL site itself just for completion sake acknowledging the authors, and different researchers that we run this slide very quickly. So, majority of this vessels are taken from Chakrabarti and Naess and Torgeir Moan of course, you have interesting material available in Dawson in 1983 of a structural engineering is a very interesting book if anybody wants to really understand fundamental of Offshore structural engineering in terms of engineering coastal engineering perspective please read this book very interesting, very simple given in a very simple format whereas, one look at the hydrodynamic component of your analysis then look at the different books it does not mean Dawson does not address components, but address the whole issue in structural engineering perspective its very interesting its available in our library.

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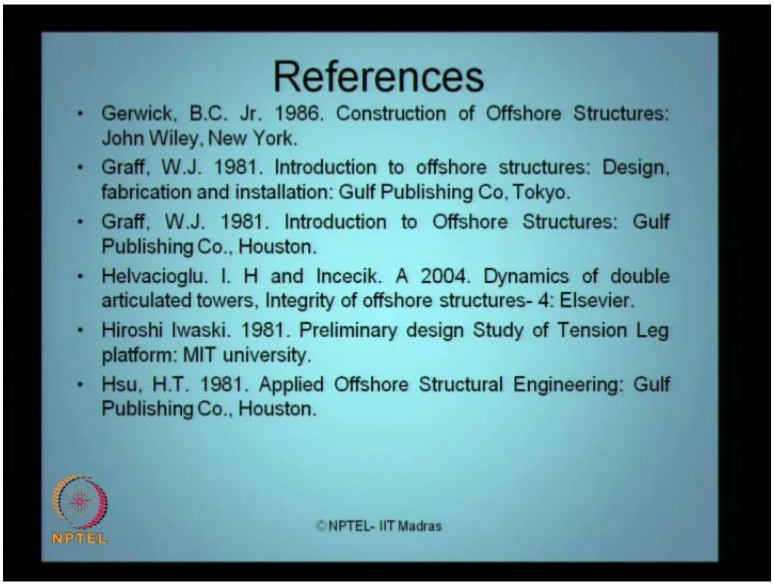

You can see this book of course, the construction aspects which we discussed in the last module as well as present module which you are going to discuss or available in Gerwick and Graff of course, some of the response control of systems which we will discuss in the lectures will be available from Incecick and Helvacioglu.

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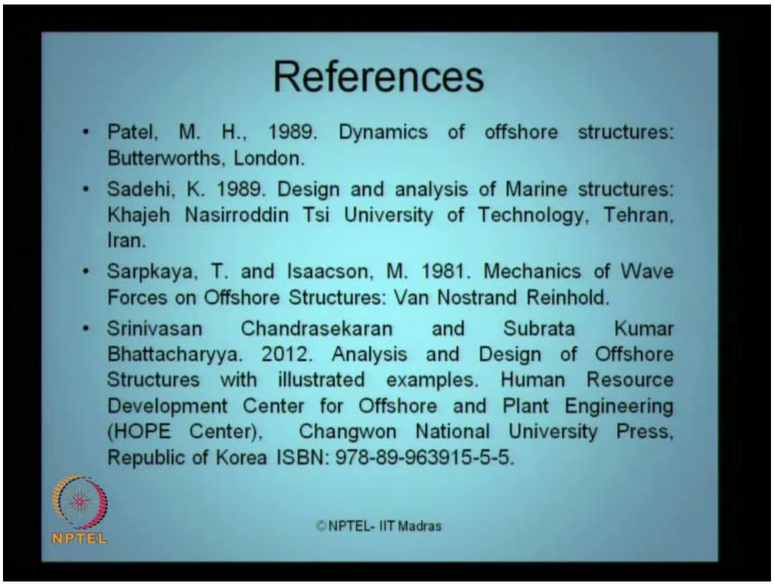

Interesting studies are also referred form Patel and Sadehi and of course, we have also a book written on dynamic analysis where address some of the important components what we have discussed in.

So, far if you have any question this will close. So, in this lecture we have quickly seen how the interface between the fluid and the wave or the fluid and the structure will impart additional forces in terms of force magnitude, in terms of its frequency content, in terms of energy presences, in terms of the orientation of the cylinder length of the cylinder, then how the flow field is altered significantly where the drag forces or lift forces are occurred at a specific frequency which are the ways does not get reported. How vortex shedding frequency will activate the response of the structure, when it is been interfere with the wave or with the fluid flow. If the structures are in the groups then what will happen to the structural system? What effect it cause in the fluid flow as a blockage factor? How it enhances my force coming on the system? whether the force variation is very high near the surface and as it dies on as it go below the bottom I mean towards the mean sea level why does not happen we have discussed in very brief and we have given an idea how one can handle qualitatively FSI in the dynamic analysis. How to quantify this? Is depending upon how do you arrive of F of T on your right hand side of equation of motion which we will keep on seeing now onwards in all example problems what I will take in the next modules or in the next lectures in the same module.

So, qualitatively we understood how FSI is important quantitatively how they are carried away in terms. So, different non-linearity is present in the system. How do you solve the equation of motion? andhow do you know the system have been designed? So, that the frequency of the system is kept off band form the wave frequency, and why the response are still important in a specific degrees of freedom only, which we will discuss in different examples.

So, dynamic analysis of motion systems will become interesting only when we starts understanding in the varying different literature parallely as people address this problem in different domain of interest, all authors, all researchers will not unfortunately or fortunately follow same style of addressing the problem. You will find majority paper at problems in time domain few of them address in frequency domain some of them give time history responses, some of them response amplitude operators, some of them talk about, shed response some of them speak about transient response, some of them talk about application fix structure or fixture platform, some of them isolated only on compliant structure, some of them talk about, compliant structures of large diameter.

So, you have to have an access to different kinds of papers on dynamic analysis of motions structures to understand really on what domain how people use this as a tool to express ultimately the response they gave of system in a given flow field. So, I am not interested estimating the forces remember it is very important. What is the fundamental difference between dynamic analysis of motion structures and non based structures is that in land based structures stress and force are important where as in Offshore structures we are talking about, the response. You may wonder why? Can you tell me why it is so?

Of course moments and forces stress are important, but most importantly or my responses. Can you give me very different statement why this is important? Why this address in dynamic analysis of motion why not the forces? No I mean there is I want a very briefing replacement why one is worried about, the responses of course, one is wonder about the forces you cannot design the system I agree, but the focus on the responses whereas the focus is never on responses when we talk about, land base structures for example, building, bridges people talk about, deflection, but they equally talk about moments and shear forces also here it, predominantly talk about responses why

Student: (( )) functional aspects (( ))

So, if response will be high we can drill all the other function cannot be.

So the functional characteristics or performance characteristic cannot be achieved the response are undesirable. 1, 2 that is one agreed statement two see I want to make the system compliant as I want to take it deeper waters and the deeper water the where I get I had to link it these. The moment I said, the system is remaining compliant I am not bothered about the forces I am bother about the responses.

So dynamic analysis of motion structures in the present scenario will focus essentially on, responses and of course, when we talk about floating structures or let say complaint systems stability also present in it, has got to be negatively buoyant or positively buoyant. Structure stability is equally important, but people are more worried about the responses in complaint degree, because the structures need to be floating or flexible. You want to take it to deep waters. So, forces may not be that important compare to the responses of course, if do not have the forces stress you cannot design it right.

So, you need that, but the focus is on the responses that is why generally in dynamic motion system you will see, the paper address 99 percent the responses not forces that is the focus why it is been dynamics. And there are very interesting example I will give you the questions; there is the very interesting question ;let me see who is able to reply this in a defending manner again.

Say I have two comparisons, one I have a land based structure which is very tall, and land based structure founded in soil. This is soil this is founded in soil very tall the moment the structure becomes very tall, height is very large the structure is flexible there is no doubt on this.

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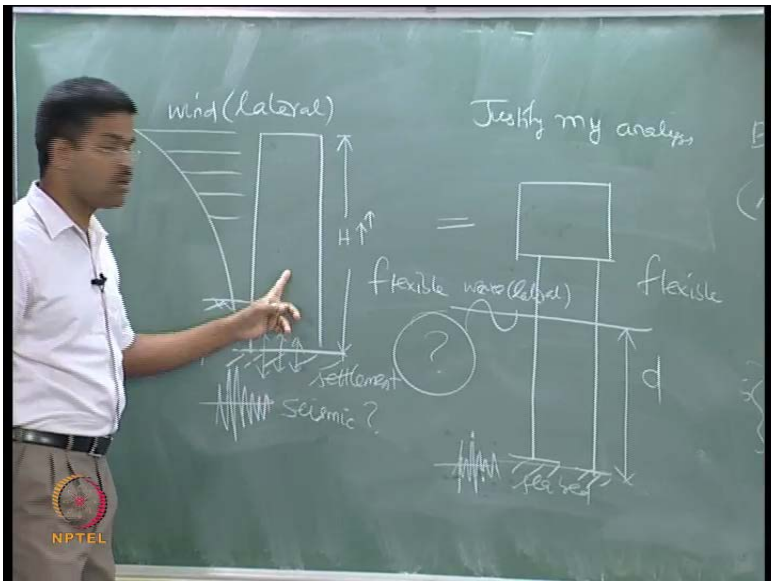

So, I am taking the example of flexible system right compare this with the flexible system like for example, at DLB which is again founded to the sea bed of course, in the water bed is again flexible. Now, I can design the system for wind loading which is one of the lateral load which is governing the system design because it is tall I have designed this for wave loading which is again a lateral loading which, is one of the governing load for the system for design agreed. Now, the question is when in impose any settlement because of geotechnical problems when I impose a seismic excitation. Since the structure is resting in the founded in the soil, the whole force is getting transfer to the members therefore, it can become critical now seismic action can also happen on the sea bed there is no guarantee that they have happen only on land can happen sea bed also right.

Now, one can wonder that when the seismic action happens in the sea bed, because of enormous water depth available here, they make an suppress and therefore, my body will not be effected by the sea or by the (Refer Time: 54:10) but there are interesting studies where seismic excitation can also cause a serious problem to this superstructure. So, my question is not, how and why this is causing? My question is if you want to high equate these both analysis here the force are superimposed of the member because they are connected, but here my superstructure is not connected except to the (Refer Time: 54:33) How do I actually do? Or how do we justify my analysis? Because of a force which is not happening on the system, say here the forces is happening on the system I can justify here is the force not happening on the system at all except that I disconnected by a cable or a (Refer Time: 54:57) how we justify energies?

It is a very interesting problem it is a very interesting problem. How the analysis is justified? I am talking about, justification only the methodology you understand the problem the crooks is the super structure. So, call loading it is not resting on a system where excitation is given. Here I justify fine, but here is not. Secondly, that is the enormous damping happening because of increase water depth therefore, the signal is supposed to die down as it reaches here.

So, should I really consider this? If at all I considered why? and how comes (Refer Time: 55:45) first is why? and then how? So, look at this problem and see whether this can be also answered and addressed or people have done this kind of work for Offshore structure. I am not talking about, structures which are resting on floor, sea floor, like gravity based structure, or jacket structure because then the problem is equal I have no difficulty in justifying it, because the member or the superstructure rest on the sea floor you can always supply the seismic action no problem, Talking about the flexible system which is equivalent to this which is not resting, but still is it important or not justify the analysis that is the question asked.