Advanced Marine Structures
Prof. Dr. Srinivasan Chandrasekaran
Department of Ocean Engineering
Indian Institute of Technology, Madras

Lecture - 6
Environmental Loads - II

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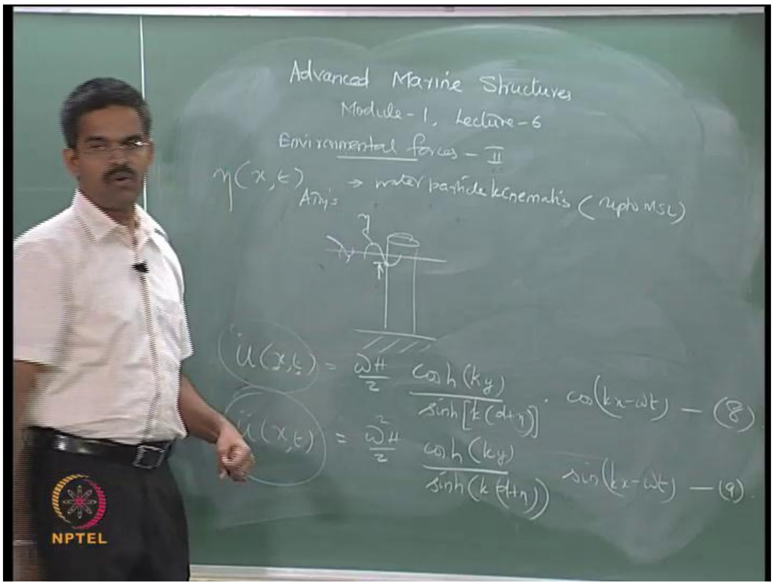

So, we will continue with the lecture on environmental forces, so second lecture on environmental forces. We are talking about the video program, on advanced marine structures. In the last lecture we discussed about, how the sea surface elevation, as a special dependent and time dependent given by aeries theory can be useful to explain the water particle kinematics. And unfortunate part is that the limitation is that, this theory explains water particle kinematics, only up to M S L; that is the mean sea level or still water level, that people have extended this, for submergence effect.

For example, I have got a cylindrical member, it may be fixed to the sea bed or a water wave here, and this is what we called as the crust of the wave, this is what we called as the trough of the wave, when the trough of the wave, touches the body, then the force acting on the member is different, when the crust of the wave touches the force acting on the different, this what we call as submergence effect.

In literature, this is identified as stitching modification, people have given different stitching modification. In the last lecture we discussed about the modification suggested by wheeler, and now we will discuss about the modification, suggested by Chakravarthy. So, the horizontal water particle velocity, and the horizontal water particle acceleration are modified, based on Chakravarthy's specification, as the following equations. This is nothing but the derivative of this, say acceleration. We can see here that, eta which is the sea surface elevation, is also accounted, in the modification suggested by Chakravarthy on the kinematics. So, you call this equation by eight to nine, so one can say that the horizontal water particle velocity in acceleration, are modified, by including the wave elevation effect in to the calculation.

And of course, as we saw in the last lecture, the water particle kinematics, are the wave loading is function of two things; one is the space or special dependent, other is the time dependent. The one more aspect which dependent on, is y, where y is any point of interest, where I want to compute my wave forces. So, it is having special dependence both on two dimensional plain, x as well as y, which is on the vertical. This is what the water depth is small d, is what I am indicating here, this is diameter of the cylinder, and off course h is the wave height, omega is the frequency of the wave, and k is the wave number, and d off course is the water depth, and these are hyperbolic function cos hyperbolic and sin hyperbolic. So, there is no change in these functions, except that the denominator of this argument as we know modified with the addition of eta to it.

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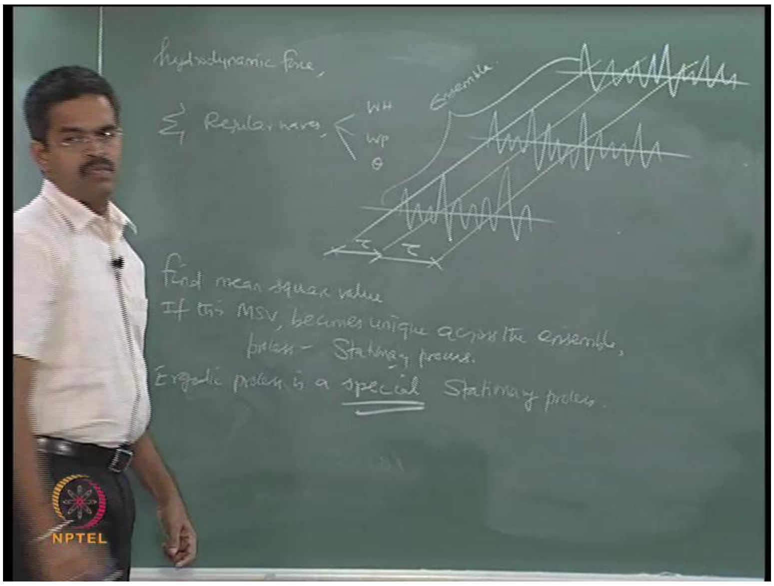

Now, having said this, now if you want really compute the wave force, or the hydrodynamic force on any marine structural member, one has got actually identify the wave profile. So, we already said in the beginning that, waves are nothing but summation of n number of regular waves, this n can be finite number, n can be infinite number which will have the summation of three components of a regular wave, I should say regular waves. The components are the wave amplitude can be different, the wave period can be different, and off course the wave direction can be different. If you put all of them together, then you will be able to really simulate a original wind driven open sea state, to which a marine structure is exposed to. So, I am trying to draw series of regular waves, as see in this picture here.

I have taken three examples, three waves of different waveguide wave period and theta, but I am summing them up all, so I will get a individual irregular wave in every time. So, let us say this is my, where as I am trying to sum up different components here, getting irregular wave. May be I have another record, what it do here is, I pick up a time line, or timelines at equal intervals, let the interval be tau. Now, I find the mean square value of the record, these records or what we call as ensemble, I try to find the mean square value of these records. If this mean square value becomes unique, across the ensemble, if it becomes unique across entire ensemble, then I, call this process, as stationary process, the process becomes stationary. Now, ergodic process is a special stationary process. Now, what is the specialty in the stationary process, which is identified as an ergodic process. Let us take a simple example.

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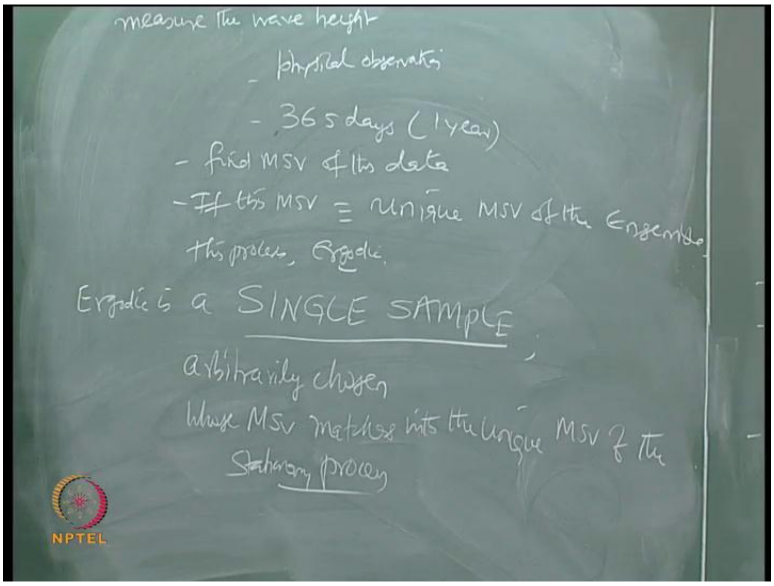

measure the wave height
- physical observation
- 365 days (1 year)
- find MSV of this data
- If this MSV $\equiv$ unique MSV of the Ensemble
this process, Ergodic.

Ergodic is a SINGLE SAMPLE,
arbitrarily chosen
whose MSV matches with the unique MSV of the
Stationary process

Now, I am trying to measure the wave height, wave height can be measure in open sea in many manners. Let say I take a physical observation, physical observation I guess, I do this for let us say 365 days throughout the full one year, every day at a specific time, morning 8 o clock, I keep on observing the wave height, keep on recording it, I have 365 data with me. Now, find the mean square value of this data, if this mean square value, is exactly equal to the unique mean square value of the ensemble, then this process becomes ergodic. So, shortly, ergodic is a single sample, it is not a set of records, so single sample, which is arbitrarily chosen, whose mean square value matches with the unique mean square value of the stationary process.

Now, interestingly hydrodynamic force, acting on the member, will come from the waves. Waves or series and summation of regular number of waves, of infinite number, which has got different wave wide, wave period, and direction. Out of this complexity I am able to pick up at random, one specific signal, which is got a mean square value, for example of the wave height, which is equal to the unique mean square value of the whole ensemble. Now, I am considering only one wave, or one signal, instead of considering n number of signals. So, I have now reduced the problem of considering n number of signals to one, signal which is ergodic and a stationary process.

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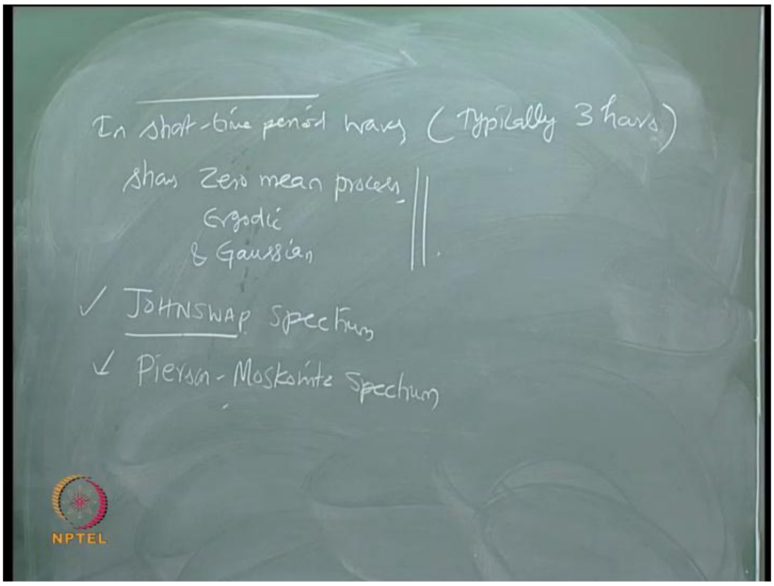

In short-time period waves (Typically 3 hours)
shows Zero mean process
Ergodic
& Gaussian

✓ JOHNSWAP Spectrum

✓ Pierson - Moskowitz Spectrum

When the question comes why are we interested, in identifying a single ergodic process or a single sample, because in short time period waves, the moment is say short time period, now I should define the period, this typically three hours. So, I take a wave record for three hours, and try to use this process, and pick up a sample, I call that as a short time period wave, shows a zero mean process is ergodic, and Gaussian, this has been shown in the literature.

Now, to understand why or what do we mean by ergodic, we have given this explanation. So, I picked up a single sample, which has got a mean square value, which is more or less matching, with the mean square value of the whole stationary process on an ensemble, and that is the data what you have with me, and generally that data has got a zero mean process, and it is a Gaussian process. In such case to find out the forces, people use John Swap spectrum. Now John Swap spectrum is further modified, and people also use what we call Pierson Moskowitz spectrum, we will talk about the spectrums now. So for a short time period wave, in an open sea state these spectrums are valid, when you talk about long period waves.

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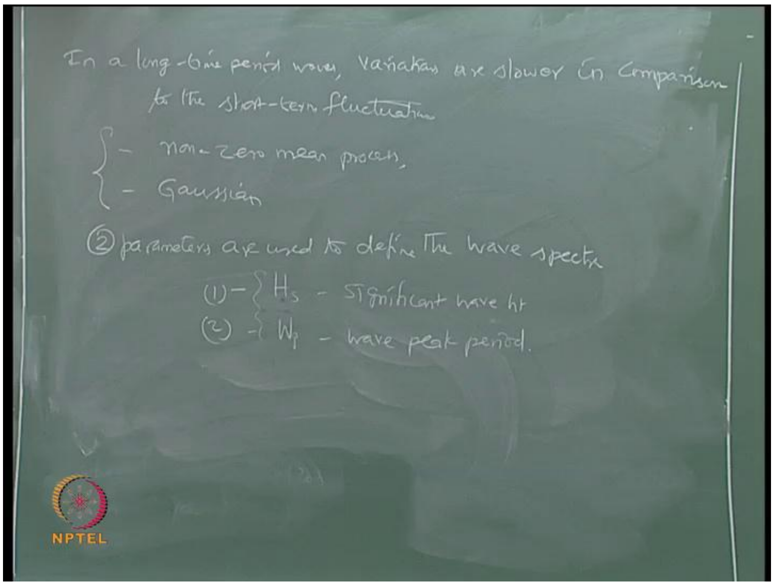

In a long-time period waves, variations are slower in comparison to the short-term fluctuations

- non-zero mean process,
- Gaussian

② parameters are used to define the wave spectra

(1) – H_s – significant wave ht

(2) – W_p – wave peak period.

In a long time period waves; that is the duration of the sample is more than three hours. The variations are slower, in comparison to the short term fluctuations, and people have seen that this becomes a non zero mean process and it remains Gaussian, and it cannot be ergodic. In such cases, two parameters are used, to define the wave spectrum; one is, the significant wave height, the other is, wave peak period. So, for long period waves, people use these two parameters to define the wave spectrum.

Now, the question comes, for a short period wave, where Pierson Moskowitz is applicable, though people require these two data, to define the wave spectrum. The answer is partially yes, partially no, whether a modified versions of p m spectrum, where people use h s, as one of the data. The original p m spectrum does not use h s. It uses only one parameter which is the frequency. So, we will speak, we will talk both the spectrums now to understand, because once you know the spectrum, then you will know how to compute the forces from the spectrum.

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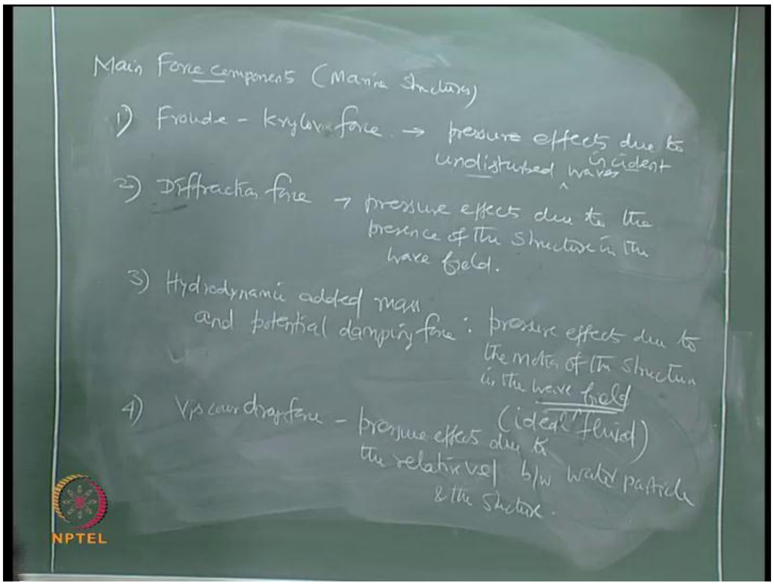

Main Force components (Marine Structures)

1) Froude - Krylov force → pressure effects due to undisturbed incident waves

2) Diffraction force → pressure effects due to the presence of the Structure in the wave field.

3) Hydrodynamic added mass and potential damping force : pressure effects due to the motion of the Structure in the wave field ("ideal" fluid)

4) Viscous drag force - pressure effects due to the relative vel b/w water particle & the Structure.

Before we speak about the spectrums, or different spectra used for computing forces in marine structures, we will talk about what are the force components, which act on marine structures, I should rather say main force components. There are four main force components. Froude Krylor force, which actually originates from pressure effects, due to undisturbed waves, in fact I should say undisturbed incident waves. The second one, is the diffraction force, which results from the pressure effects, due to the presence of the structure in the wave field, it is called diffraction force. The third can be hydrodynamic added mass, and potential damping force. They essentially come from the pressure effects, due to the motion of the structure in the wave field.

We consider the wave field as an ideal fluid, and therefore, we say the hydrodynamic added mass and the potential damming force are, consequences of the pressure effects caused, due to the motion of the structure in the ideal fluid. The fourth could be, the viscous drag force, which is due to the pressure effects, due to the relative velocity, between water particle, and the structure. So, this is very much true in case of complain structures. So, these are main force components, which act on a marine structural member; one is arising from the undisturbed wave, one is coming, because of the structure interference with the wave, other is coming because of the motion of the structure in the wave, and other is because of the relative movement of the structure in the wave field.

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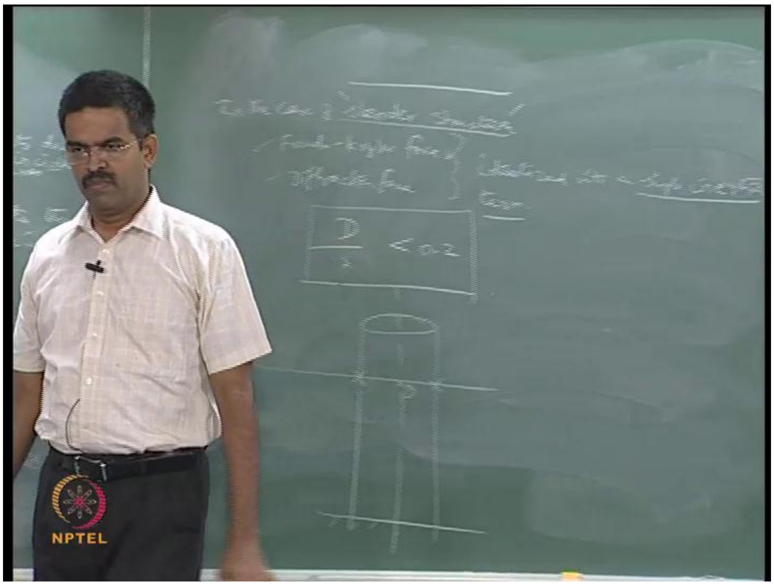

Now, interestingly in the case of slender structures, the Froude Krylor force and a diffraction force together are idealized with the single inertia term. The moment I say the structure is slender, then I should say, that the diameters a member to the wave length then 0.2. So, what is the advantage of having a structural system, which qualifies this relationship. The advantage is, I have a structural system; that is got a member, now worry about the bounty condition, we will talk about the slightly later, remember its slender, it means the dextinal diameter of the member, with respect to its wave length, is less than 0.2. In such case, this may axis the member, you compute the force at any point on the circumference of the member at the axis lying, or anywhere here or anywhere here, there will not be much variation in the velocity and acceleration between these three points.

Between these three points the velocity and acceleration are, the water particle kinematics will not very much. So, for all practical purposes the member can be idealized, as a single line member along its axis. If the member is large, it means if the diameter of the member is much greater than 0.2 of its wave length, then the point where we measured the water particle kinematics will matter. So, that is the advantage and that is a difference in case of slender structures in computing the wave forces, or hydrodynamic forces, if this is satisfied. In such case, these two are idealized as a single inertia term. Now, the question comes how will I include, the relative velocity term, which is acting, because or which is happening, because of the pressure effects caused by the, movement between the water particle, and the structural member.

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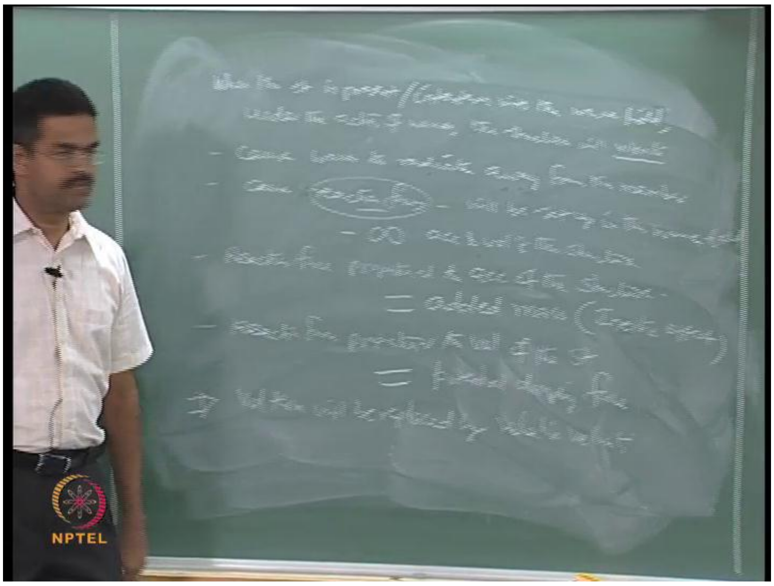

So, when the structure is present, or interferes with the wave field, under the action of waves, the structure will vibrate, so this vibration will cause waves to radiate away from the member, this radiated waves will result in reaction forces, this will be setup in the wave field, and this will be proportional to acceleration and velocity of the structure. So, the reaction forces generated, because of the radiating action of the waves from the member, is proportional to acceleration and velocity. Now the reaction force proportional to, acceleration of the structure, will result in added mass, or inertia effect. The reaction force proportional to velocity of the structure, will result in, what we call potential damping force. In such cases, the velocity term will be replaced by relative velocity.

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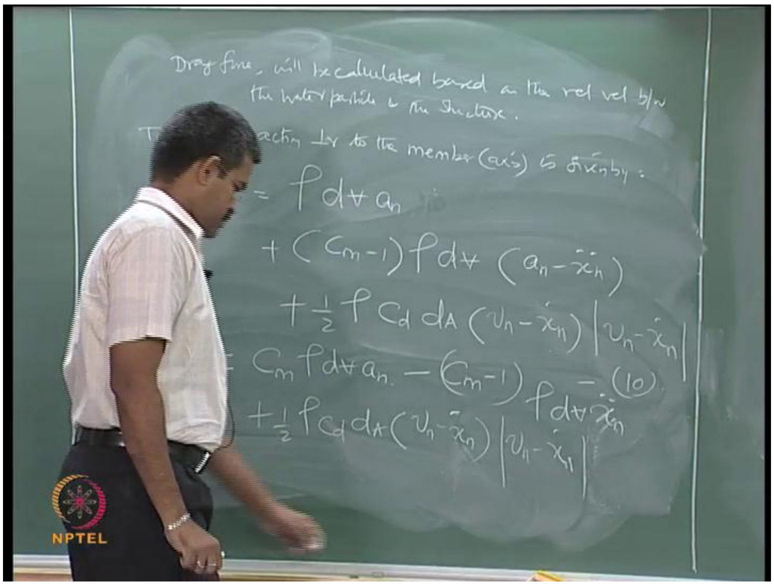

Drag force, will be calculated based on the rel vel b/w the water particle & the structure.

T acting ⊥r to the member (axis) is given by:

$$= \rho\, d\forall\, a_n + (C_m - 1)\rho\, d\forall\,(a_n - \ddot{x}_n) + \frac{1}{2}\rho\, C_d\, dA\,(v_n - \dot{x}_n)\,|v_n - \dot{x}_n|$$

$$= C_m \rho\, d\forall\, a_n - (C_m - 1)\rho\, d\forall\, \ddot{x}_n + \frac{1}{2}\rho\, C_d\, dA\,(v_n - \dot{x}_n)\,|v_n - \dot{x}_n| \quad \text{— (10)}$$

Therefore, the drag force will be calculated, based on the relative velocity, between the water particle, and the structure. Now, the total force, acting normal to the member, I should say the axis of the member, can be given by, n stands for the normal. So, as per the sequence, this becomes the equation number ten. So, rewrite this, because I got c m rho d v, I will explain what are these terms writing later, let me rewrite this, this amounts to…

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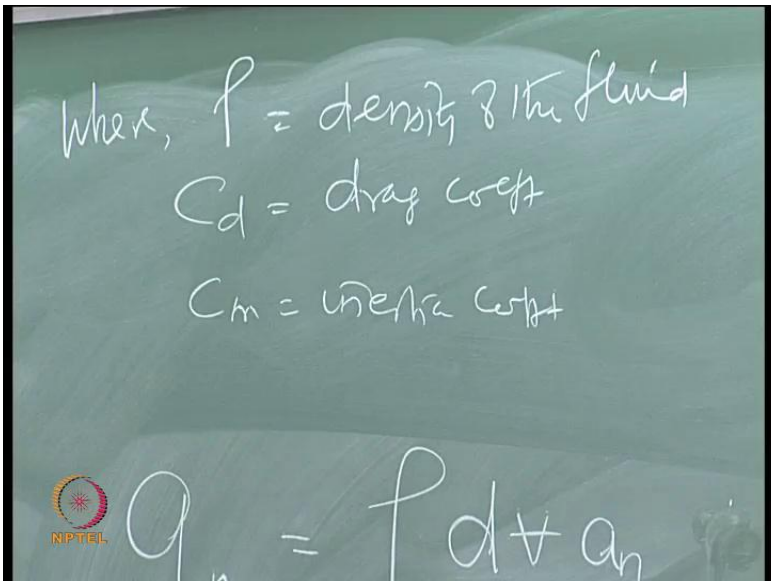

Where, ρ = density of the fluid

C_d = drag coeff

C_m = inertia coeff

$$q_n = \rho\, d\forall\, a_n$$

The equation number eleven, where rho is the density of the fluid, C d drag coefficient, C m inertia coefficient.

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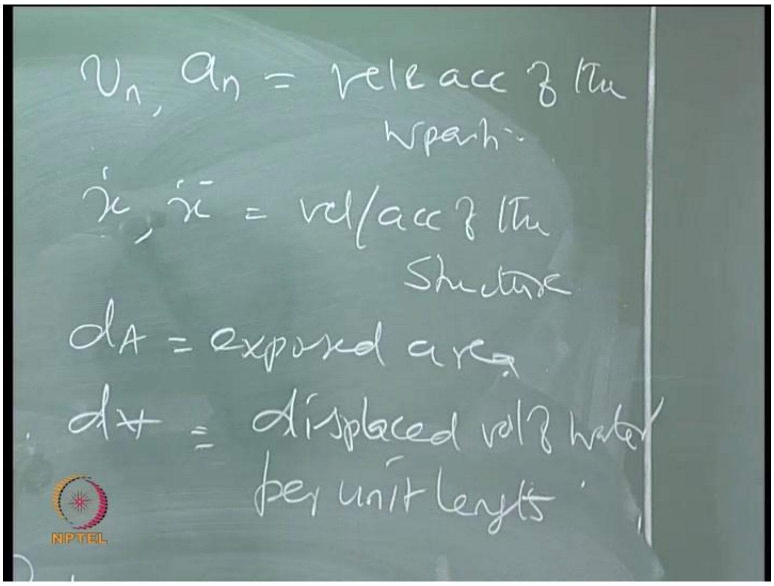

v_n, a_n = vel & acc of the w.parti..

$\dot{x}, \ddot{x}$ = vel/acc of the Structure

d_A = exposed area

$d_\forall$ = displaced vol of water per unit length

V n, a n velocity and acceleration of the water particle, x n x dot x double dot, velocity acceleration of the structure, d a exposed area, d v displaced volume of water per unit length. So, this will give in the total force acting on the member. We just accounted for the relative movement between, the structure and the water particle.

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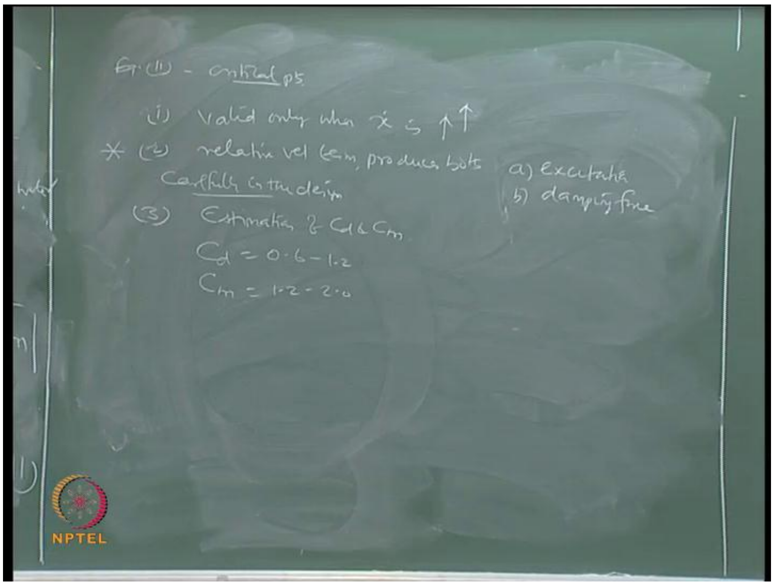

Eq. (11) - critical pts

(1) Valid only when $\dot{x}$ is ↑↑

* (2) relative vel term, produces both carefully in the design

a) excitation

b) damping force

(3) Estimation of C_d & C_m

$C_d = 0.6 - 1.2$

$C_m = 1.2 - 2.0$

This equation, that is equation number eleven, has some critical points; one, this equation is valid, only when x dot is phenomenally high, so for having the structural acceleration or the velocity to be very high, the structure should be flexible. Otherwise it will not, if it is a rigid structure or is a stiff structure, then the velocity of the structure, is x dot is a velocity of the structure, will be low. This equation has for a critical issue, that it is valid only when the x dot is relatively high. The relative velocity term produces, both acceleration, excitation, and damping force, so both the components, it's got both the components, v n will give the excited enforce, and x dot n will give the damping force of the structure.

So, depending upon the value of these two, they may get cancelled and so on. So, this is got to be handled very carefully, in the design. The third component in this equation is, estimation of C d and C m; that is, the drag and inertia coefficients. So, there are intensive research happening happened, reported in the literature of estimating the drag and inertia coefficient, depending upon the Reynolds number, and Keulegan Carpenter numbers. I, urge you to refer to the respective literature to find out this, but for your information; C d generally varies from 0.6 to 1.2, and C m varies from 1.2 to 2.0 relatively.

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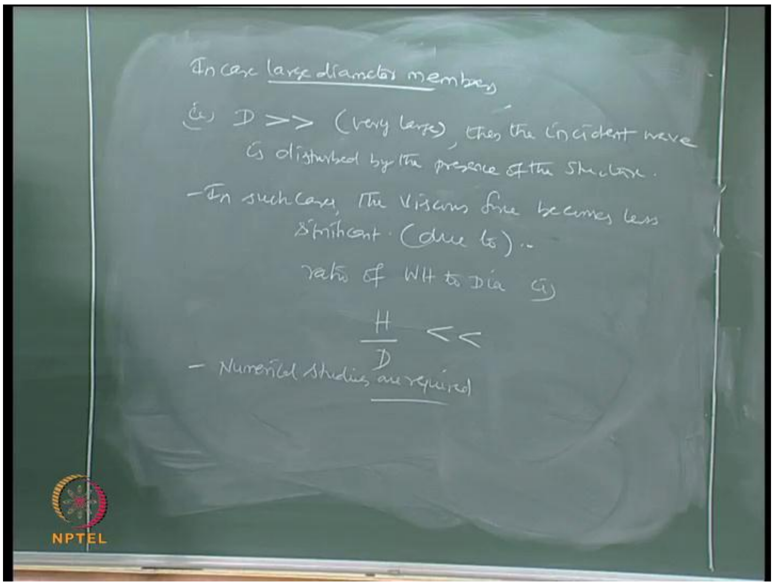

In case large diameter members

(i) D >> (very large), then the incident wave is disturbed by the presence of the structure.

- In such cases, the viscous force becomes less significant. (due to)..

ratio of WH to Dia (i)

$$\frac{H}{D} <<$$

- Numerical studies are required

Now, in case of large diameter members; that is, when d is very large, then the incident wave is disturbed, by the presence of the structure. In such cases, the viscous forces become less significant, this is because the ratio of wave height to diameter; that is h by d will be very small. The diameter is very large compared to the wave height; therefore, the viscous force becomes less significant in a calculation. In such cases, detailed numerical studies are required to compute the forces.

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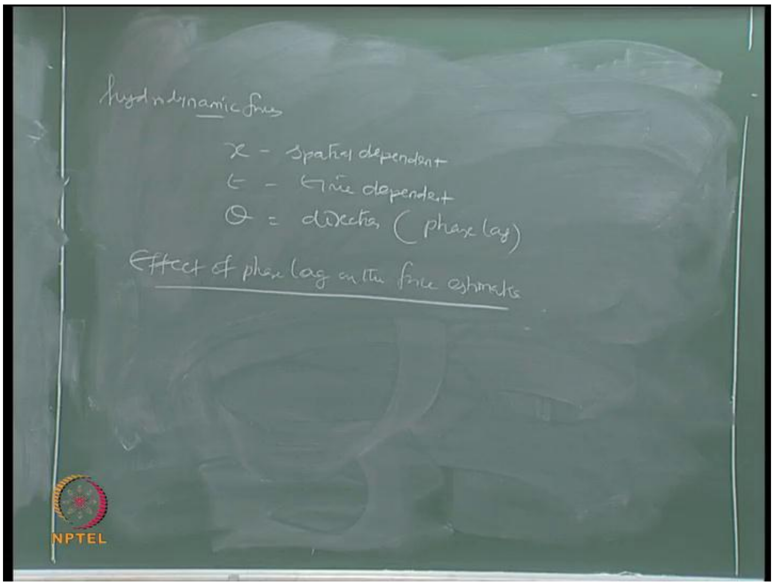

hydrodynamic forces

x - spatial dependent
t - time dependent
θ = direction (phase lag)

Effect of phase lag on the force estimates

The next aspect, as I told you, in the beginning of the lecture is that, hydrodynamic forces has got essentially three components; one is the special dependence, other is the time dependence, the third one, is wave direction or what we call as phase lag. Now, let us see what is the effect of phase lag on the force estimation. We will take an example and see what happens to the phase lag. In the last lectures, we discussed about different geometric forms, of shore platforms or marine structures.

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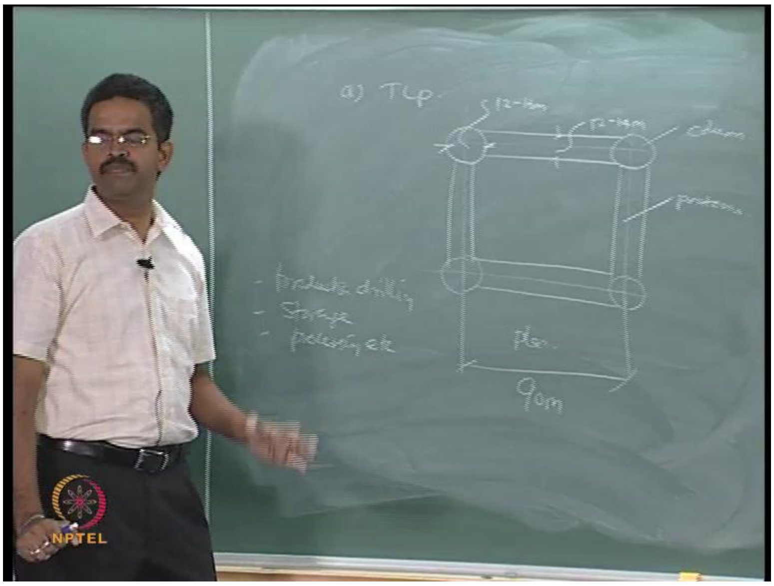

Let us for example, pick up a case where, I am talking about a T L P. The plan of a T L P as we all know, is a plan of a T L P. We have got column members, we have got pontoons, and the column members generally have a diameter 12 to 16 meters, and the pontoons members of diameter twelve to fourteen meters. Since the platform is actually designed, to satisfy certain functional requirements like; production drilling, storage, initial processing, etc. It acquires a very large plain area, a typical size of a T L P in the literature if you see, the centered center, can be as high as 90 meters.

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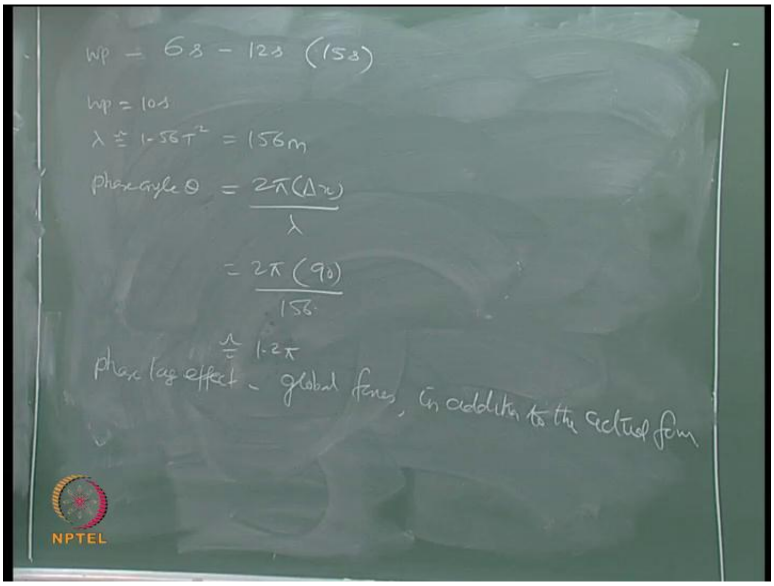

$T_p - 6s - 12s \ (15s)$

$T_p = 10s$

$\lambda \doteq 1.56T^2 = 156m$

phase angle $\theta = \dfrac{2\pi(\Delta x)}{\lambda}$

$= \dfrac{2\pi(90)}{156}$

$\doteq 1.2\pi$

phase lag effect - global forces, in addition to the actual force

Let us look at the sea state, where the wave periods can range from, let us say six seconds to twelve seconds, or worst by worst fifteen seconds. Let us pick up a wave period of ten seconds. Wave length approximately is 1.56 t square approximately, for a deep water condition, if we apply this, this becomes 156 meters. Now, the phase angle theta, can be given by a simple equation 2 pie delta x by lambda, which I say in my case, approximately 1.2 pie. So, there is a multiplier to pie, which makes an alternate or a reversing effect on the member, this is what we call as a phase lag difference. So, this phase lag difference or phase lag effect, can cause global forces, in addition to the actual forces. Now interestingly, I can fix up the phase lag for the member, so that the forces can get cancelled.

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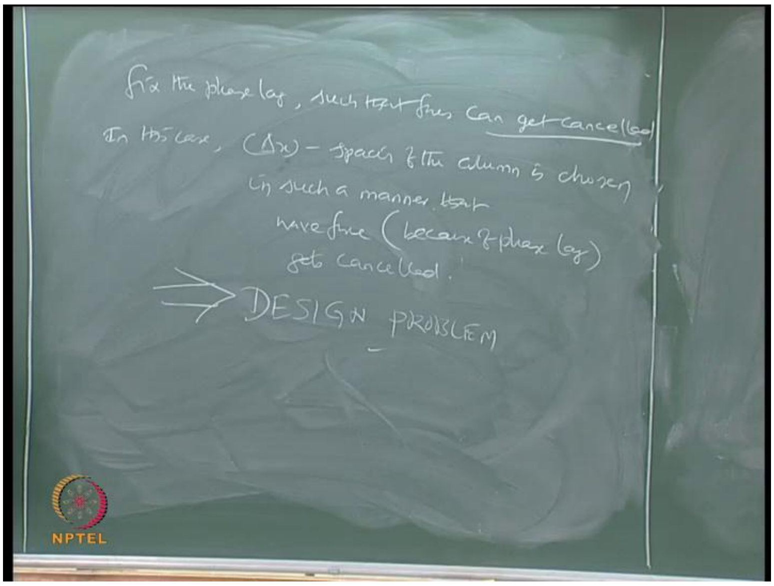

fix the phase lag, such that forces can get cancelled

In this case, (Δx) – spacing of the column is chosen
in such a manner that
wave force (because of phase lag)
gets cancelled.

$\Rightarrow$ DESIGN PROBLEM

One can fix the phase lag, such that the forces can get cancelled. So, let us take the same example, in this case, the delta x which is the spacing of the column, is chosen in such a manner, that wave forces, because of phase lag gets cancelled, so this becomes essentially a design problem. So, you will select the dominant wave period in a given sea state, for that wave period in a given sea state for the water depth, you can select the special difference of the member, which will attract the wave forces, in such a manner that the force on member one and member three for example, will get cancelled, so that will cause net reduction of force on the structure, is it clear?

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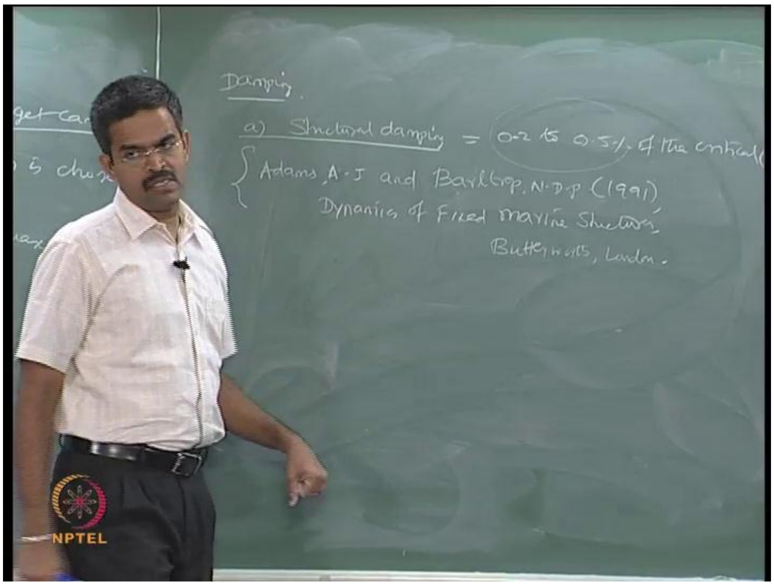

The other important aspect, is the damping force. The first of its kind comes from the structural damping, which is generally taken as 0.2 to 0.5 percent of the critical. There is a very interesting reference for this. This is true, when we use steel platforms, for concrete it is different, because it is a material damping actually.. So, the first aspect is structural damping, which is around 0.2 to 0.5 percent of the critical if it is steel. The subsequent aspect will be the hydrodynamic damping, which comes from different sources, which will address in the successive lectures.

So, once I complete hydrodynamic forces, I will talk about the wind forces, will talk about the ice loading, we will talk about the earthquake loading, and then tidal currents. So, we will try to give you a summary what are the different kinds of forces, acting on the advanced marine structures. Once we understand this, we will talk about the ultimate load design, and the factor of safety in that design, then we speak about the plastic analysis and design of marine structures, then we apply this to different kinds of structural members including the joints, and study the failure phenomena by the joints, in the first module, which allow twenty lectures. Now we have finished today the sixth lecture on this.