Offshore structures under special loads including Fire resistance
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Lecture – 09
Environmental Loads – 1

Friends, welcome to the 9th lecture titled Environmental Loads. In the first part of this lecture we will discuss some complexities which arise because of conventional environmental loads that acts on offshore structures, once we understand this we will slowly move on the special loads their complexities and the response behavior of platforms under special loads, then we will lead towards fire restraint design etcetera. So, today we are going to talk about environmental loads as the first part of the lecture.

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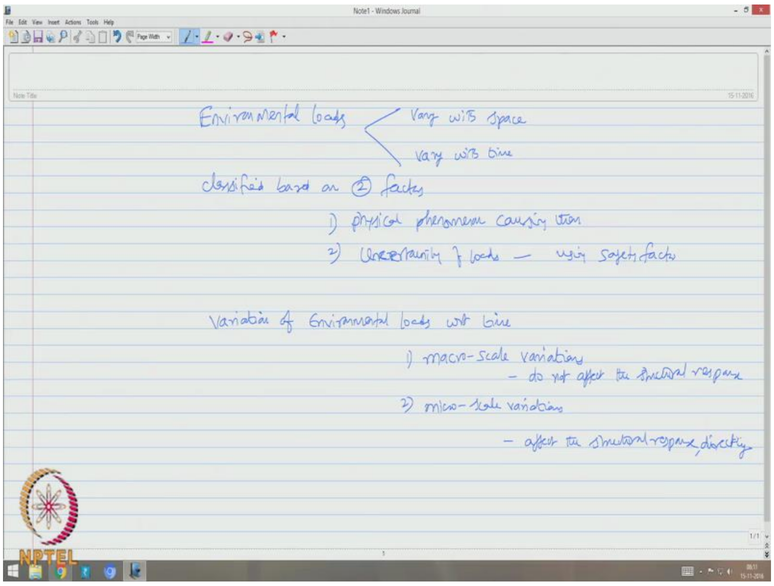

Environmental loads have actually 2 components; one is they vary with space, they vary with time also, they are generally classified based on 2 factors, one physical phenomena causing them, the second factor is uncertainty of the loads which is generally accounted in the design using safety factors. When we look at the variation of the environmental loads with respect to time, again there are 2 kinds of variations; one can be macro scale variations which generally do not affect the structural response, the second one is the micro scale variations which affect the structural response directly.

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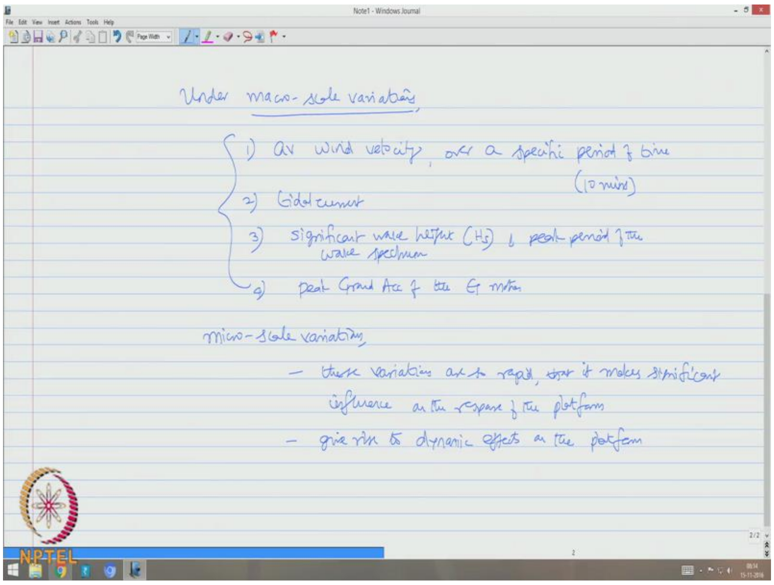

Under macro scale variations, they can give certain examples let us say average wind velocity over a specific period of time.

Usually this duration of loading is about 10 minutes, the second variation in macro scale could be tidal current, it could be significant wave height and peak period of the wave spectrum and the 4th could be peak ground acceleration of the earthquake motion. So, they all come under what we call macro scale variation, they do not actually have direct influence on the response of the structural systems. On the contrary if look at micro scale variations, these variations are so rapid that it makes significant influence on the response of the structure, let us say in our case the platform.

Generally micro scale variations give rise to dynamic effects on the platform.

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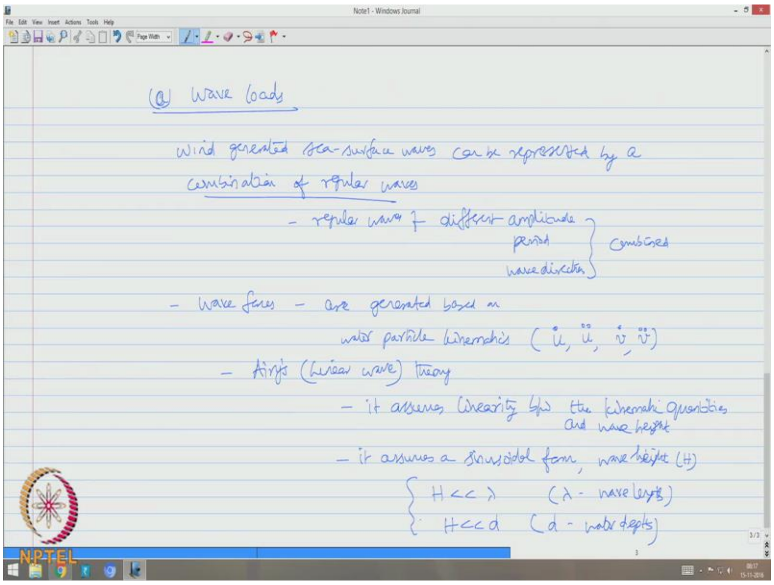

Let us say under conventional environmental loads, let us talk about wave loads; the wind generated sea surface waves can be represented by a combination of regular waves. So, what you mean by combination regular waves of different amplitude different period and different wave directions are combined to represent the wave load acting on offshore platforms. The question comes how actually they are represented? Wave forces are generated based on the water particle kinematics like horizontal water particle, velocity horizontal water particle acceleration, vertical water particle velocity, vertical water particle acceleration.

The foremost theory which we all know is Airys theory, which is also called as linear wave theory because it assumes Linearity between the kinematic quantities and wave height. It usually assumes a sinusoidal form with wave height h, which is very very small, compared to wave length lambda and very very small compared to water depth. So, these are some basic assumptions which classify airys theory as linear wave theory.

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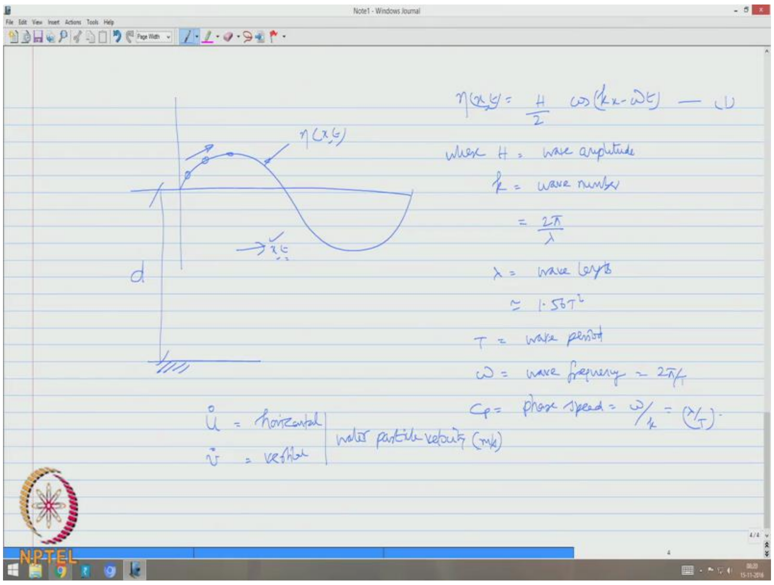

So according to this theory, If the sea surface theory is explained as a sinusoidal wave with the water depth represented as a small d, the sea surface elevation eta where x and T varies in space and time is given by where H is the wave amplitude, k is called wave number which generally given by 2 pi by lambda, where lambda is called wave length which is approximately 1.56 T square, where T is called wave period, omega is wave frequency which is 2 pi by T and C p is called phase speed which is omega by k which is lambda by T.

Once I know the sea surface profile when the water particle is moving, horizontally in x with respect to the space and respect to time T it generates as the water particle moves because of the wind action on sea surface elevation, they generate horizontal water particle velocity and vertical water particle velocity, let us say in meter per second.

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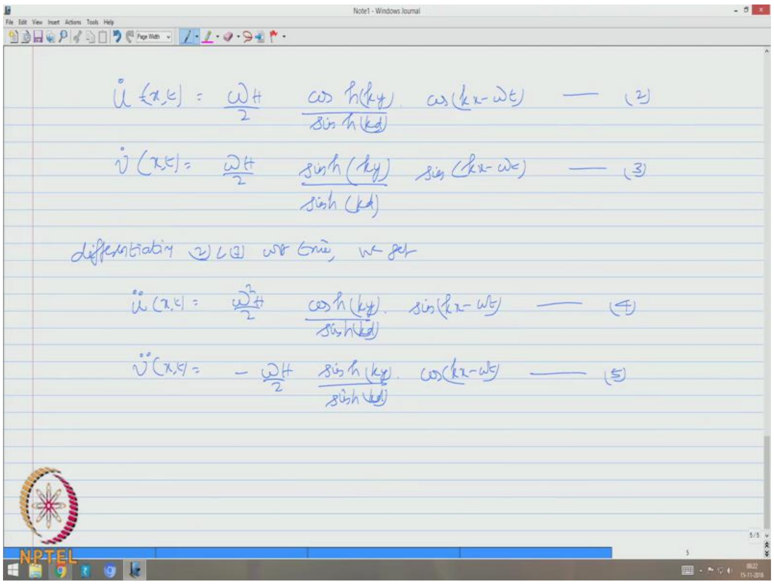

Horizontal water particle velocity is given by omega H by 2, cos hyperbolic ky by sin hyperbolic kd cos kx minus omega t.

Vertical water particle velocity is given by omega H by 2, sin hyperbolic ky by sin hyperbolic kd, sin kx minus omega t; differentiating this with respect to time, we get horizontal water particle acceleration which is omega square H by 2 of course, cos hyperbolic ky and sin hyperbolic kd will remain unchanged, there is a minus sign and that becomes cos kx minus omega t there is another minus sign this omega that becomes plus and omega square whereas, V double dot x of t is minus omega H by 2 sin hyperbolic ky by sin hyperbolic kd of cos kx minus omega t.

So, there are some limitations where this theory can be applied.

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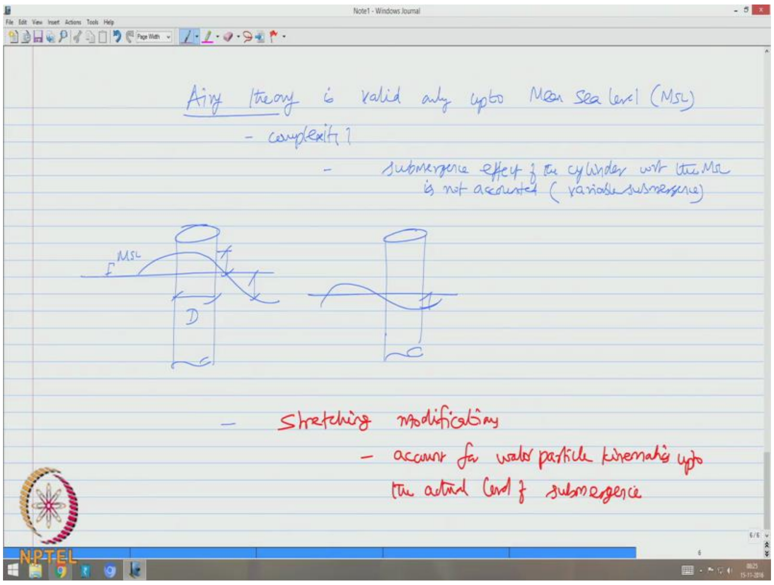

Airys theory is valid only up to mean sea level, but interestingly there is a complexity here, when you have a cylinder or a leg of a platform, whose diameter is very large, there may be a possibility part of the wave maybe in submerged position of this particular cylinder. So, there is a possibility that the cylinder may occupy a position which may be in the trough part. So, the differential submergence effect of the cylinder with respect to the mean sea level is not accounted. So, we call variable submergence effect because airys theory computes a water particle kinematics only upto mean sea level, the variation because of the sea surface elevation with respect to, the mean sea level is not accounted in airys theory.

In that case the solution is people have used something called stretching modifications, this will account for water particle kinematics upto the actual level of submergence.

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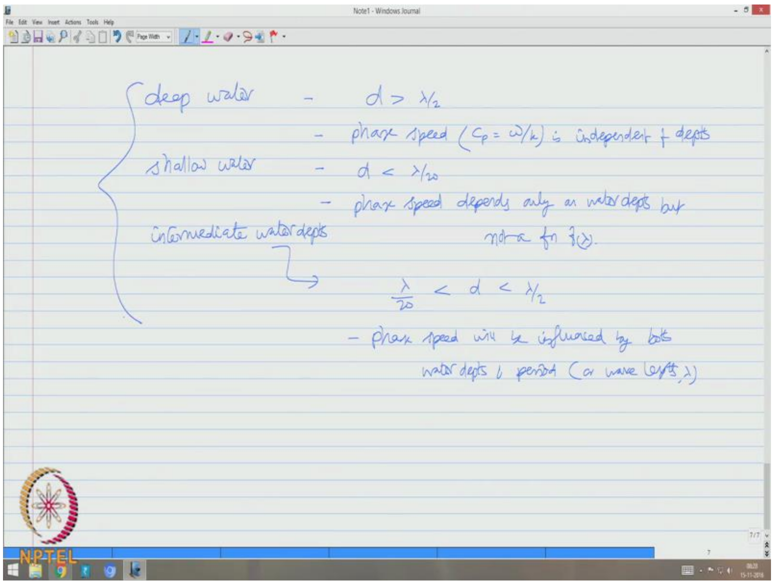

Before that lets see some classical definition which are again complexities and defining these wave theories, there are some classifications set in the literature as deep water, shallow water and intermediate water depth, in this case a classical definition says if the water depth is greater than lambda by 2, the lambda is the phase length, then we call this is deep water, the characteristic of deep water is phase speed, which is C p that is omega by k is independent of depth under this condition.

Shallow water classically says if the water depth is less than lambda by 20, then it is classified as shallow water, the characteristic of this is that phase speed depends only on water depths, but it is not a function of lambda. In case of intermediate water depth the definition says it is between these 2 values, in this case phase speed will be influenced by both water depth and period or wave length.

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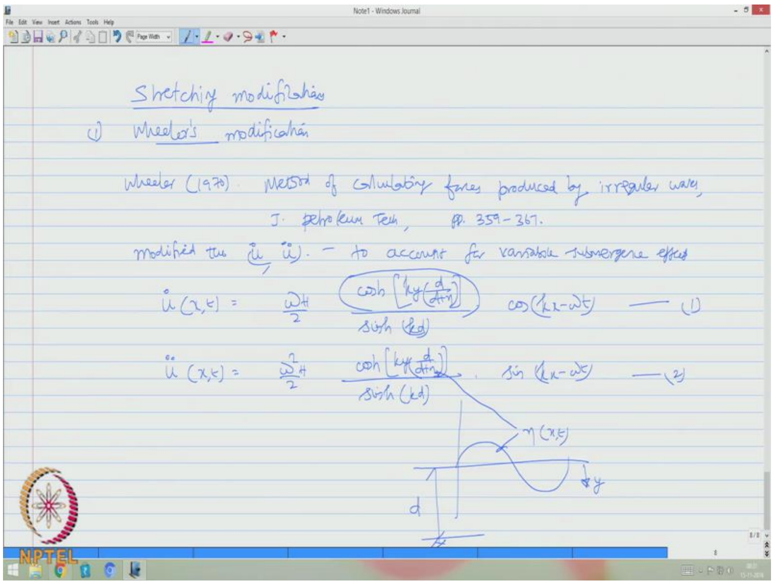

Having said this, let us know talk about the stretching modifications. Friends, we are looking into the completeness of estimating wave loads to some extent, so that we really understand the complexities present in the conventional environmental loads acting on offshore platforms, before we discuss in detail about the special loads acting on them and the response behavior of offshore platforms under these special loads.

So, under the stretching modification, the first classification what we will see is wheelers modification. This is given by wheeler in 1970, irregular waves, journal of petroleum technology, page numbers 359-367. It actually modifies the horizontal water particle velocity and accelerations to account for the variable submergence effect. So, the modified horizontal water particle velocity is given by. So, you can very well see this is actually the modification which has happened and the acceleration part, omega square H by 2, cos hyperbolic ky d by d plus eta sin hyperbolic kd, sin kx minus omega t, but if this is my sea surface elevation y is measured from here, if this is my sea bed, this is my water depth T and this is my eta which is sea surface which is used here.

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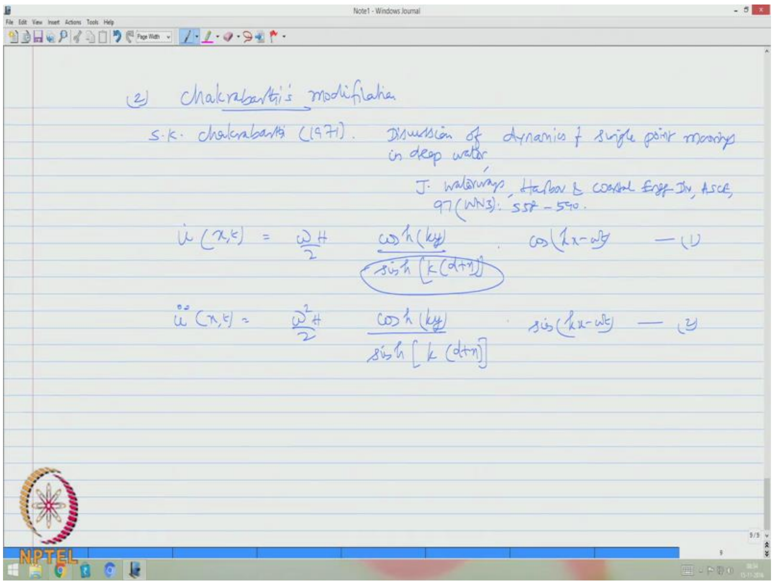

The second modification was given by Chakrabarthi called as Chakrabarthi modification. This was given by S. K Chakrabarthi in 1971, discussion of dynamics of single point moorings in deep water journal of water waves, harbor and coastal engineering division ASC 97, W N 3, 558-590; according to this modification suggested by Chakrabarthi 1971, the horizontal water particle velocity is modified as. So, the modification is in the denominator as you see from this equation differentiating to get the acceleration, we get 2 equations now suggested by Chakrabarthi's modification.

Now, interestingly let us extend this discussion to understand the further complexities in wave loads.

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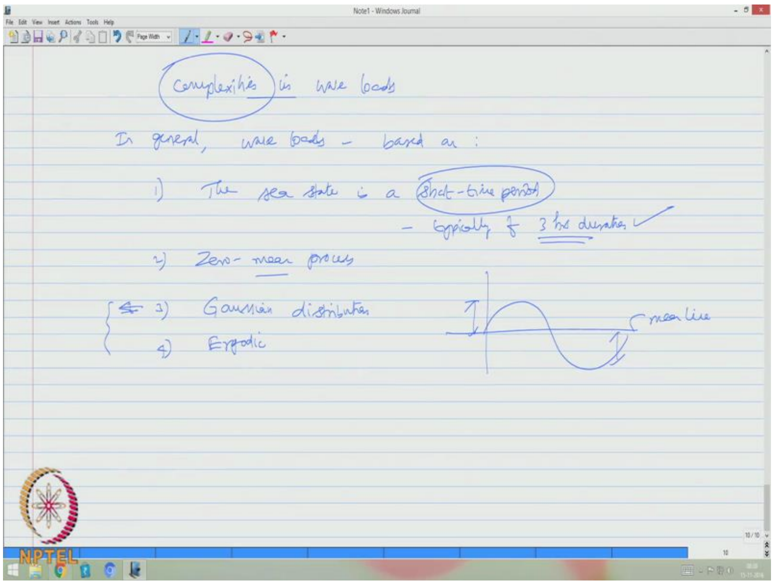

In general when we calculate wave forces, wave loads are assumed to be based on a classic theory saying the sea state is a short time; period short time in sense which is typically of 3 hours. Duration it is an idealization. It is also assumed to be a zero-mean process, it is also assumed to be following a Gaussian distribution and it is said to be an ergodic process. Short time period is defined for a specific duration to some degree as engineers we accept this; zero mean process is essentially the statistical distribution of the mean of the wave height, where the amplitude is equal with respect to a mean line, so let us say this is my mean line. Gaussian distribution is useful because the statistical properties associated with this are important in estimating the characteristics of the wave loads; let us slightly talk more about these 2 to understand the complexities.

Now, to understand what is ergodic process and stationarity in a given wave load, lets us take an example.

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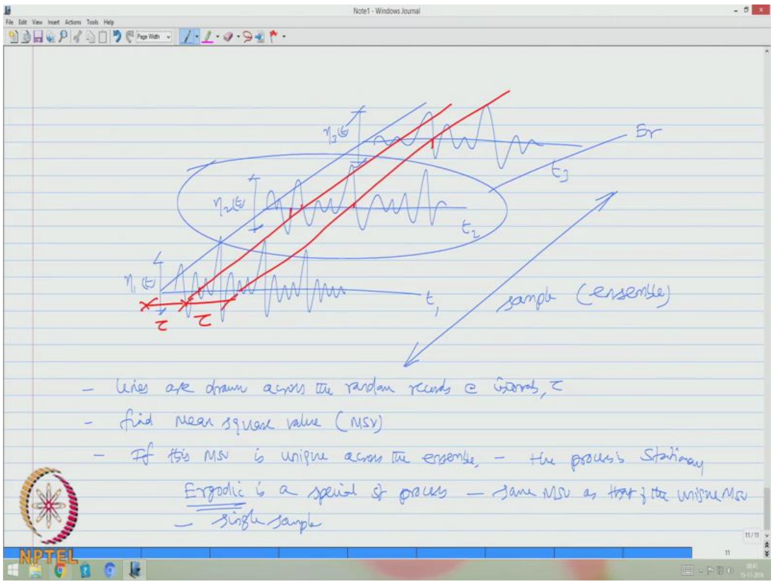

Let us say I have a wave screen which is varying in amplitude, time and direction. So, let us say this is my t and this eta in the vertical axis eta 1 of t. Let us take another history, this is again t 2, in the vertical axis of this plots eta 2 of t, let us take one more time history, which is t 3 on the vertical scale of this it plots theta 3.

We are in the process of explaining ergodic process, let us take a specific scale here and draw a line and draw another line at intimus of tau, along this we try to work out the values, this value and this value. Once I have these values statistically with us for a good sample this is my sample, which I can call as ensemble in statistics.

So, what we did is, we do lines across the random records at intervals tau, then let us try to find the mean square value of this of these records, if this mean square value is unique across the ensemble, then the process is called stationery. So, what is ergodic? Ergodic is a special stationery process, which has the same mean square value as that of the unique mean square value. So, ergodic is a single sample. So, out of the sample eta 1 of t, eta 2 of t, eta 3 of t etcetera you can pick up any sample, this particular sample chosen for your analysis is called as ergodic; when the mean square value of the sample is exactly same as that of the unique mean square value which we found out at intimus of tau along the entire ensemble. So, this is one of the basic assumptions we have in terms of estimating wave loads on offshore platforms.

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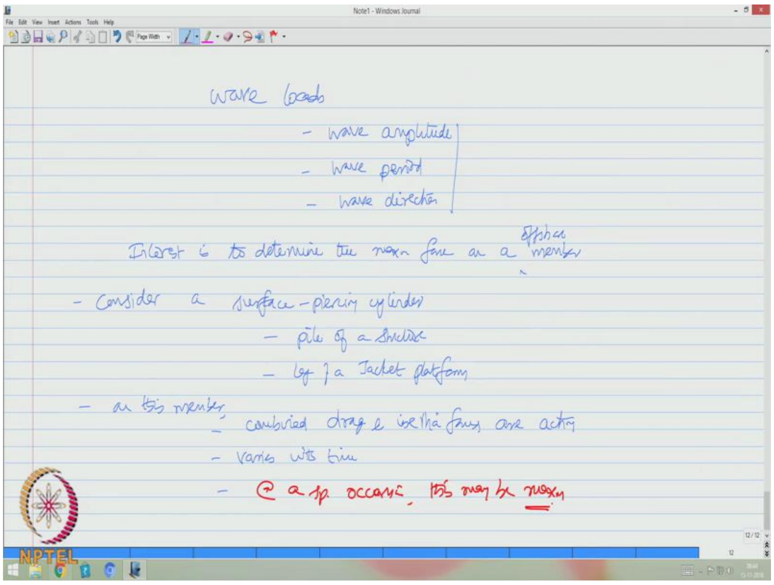

The issue now comes here is wave loads have wave amplitude as a variation, wave period as a variation and of course, wave direction as a variation. One is interested to find out the maximum force on a given member. So, the interest is determine the maximum force maybe on a member, let us say on offshore member, structural member how to do this?

Consider a surface piercing cylinder example could be pile of a structure, leg of a jacket platform, we know that on this member, combined drag and inertia forces are acting both of them varies with time and it is interesting that at a specific occasion this maybe maximum. So, one is interested to know that maximum load.

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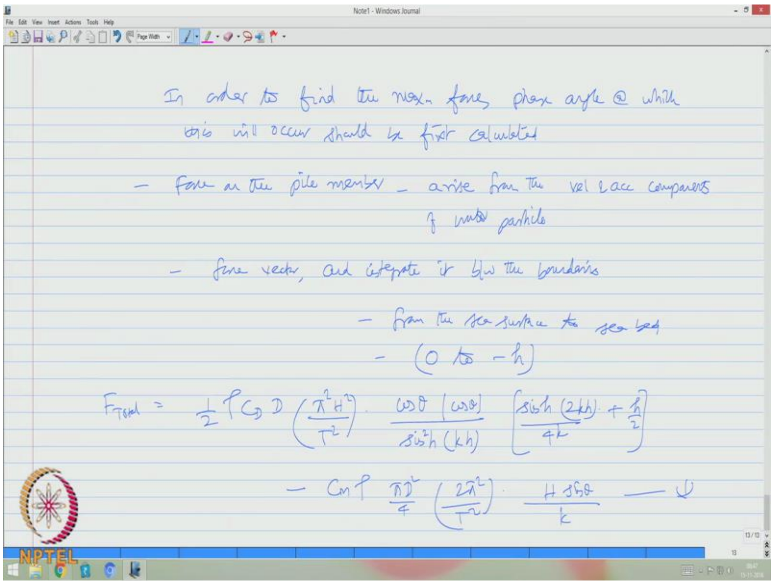

Therefore in order to find the maximum force, phase angle at which this will occur should be first determined. So, we all know that the total force on the pile member is arising from the velocity and acceleration components of water particle.

Let us obtain this force vector and integrate it between the boundaries. So, let us say what are the boundaries within which we should integrate this especially the boundaries are from the sea surface to sea bed that is 0 to minus h. So, the total force is given by half rho C D dia pi square H square by T square, cos theta, cos theta sin hyperbole square k h sin hyperbolic 2 k h by 4 k plus h by 2 minus Cm rho, pi d square by 4, 2 pi square by T square, h sin theta by k. This equation is obtained by substituting the horizontal water particle velocity and acceleration as obtained by airys theory, until mean sea level without considering the stretching modifications.

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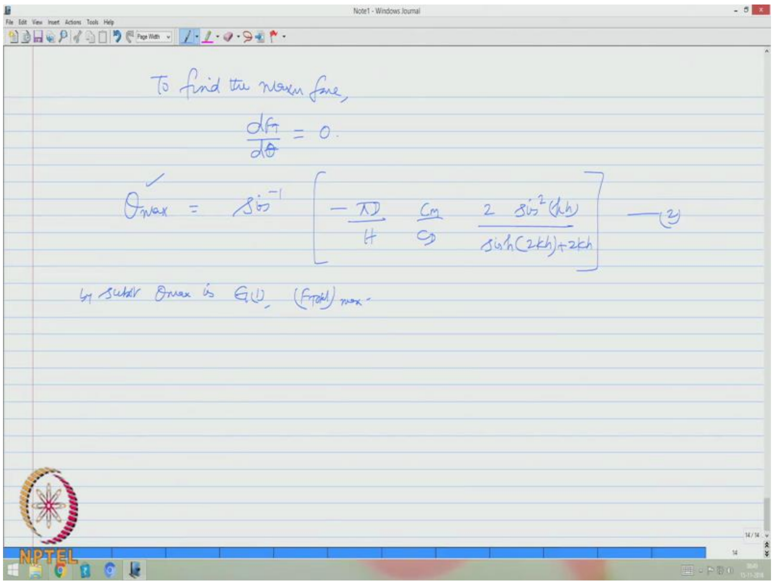

To find the maximum force, I should find the differential of this and equate it to 0 because we know the variation of the force total is with respect to the angle theta. So, once we do this to substitute, I get theta max as sin inverse of minus pi D by H Cm by C D twice of sin square k h by sin hyperbolic, 2 k h plus 2 k h. Once I know the maximum phase angle then I can find by substituting theta max in equation 1, one can find f total which is going to the maximum.

So, this will have a specific occasion where both inertia and drag forces are maximum for a given offshore cylinder. The second complexity which arises from computing wave forces and members is effect of phase lag on the wave forces.

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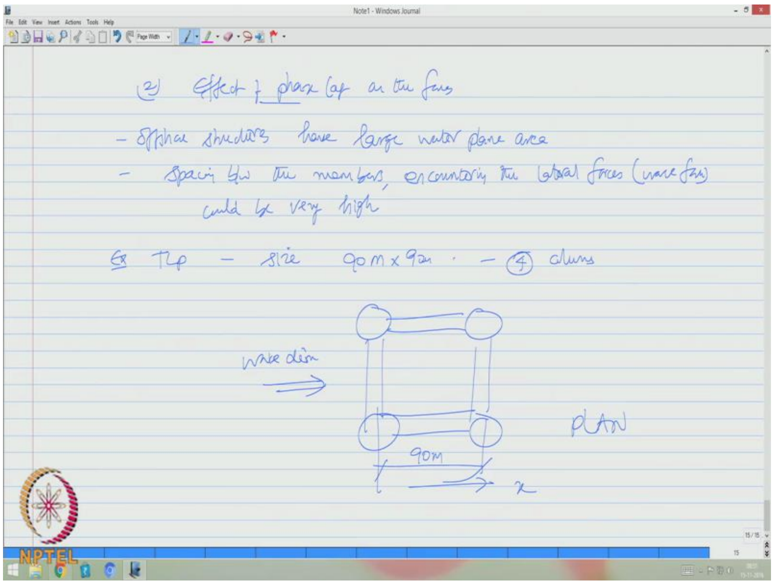

Interestingly offshore structures have large water plane area, which means that spacing between the members encountering forces the lateral forces, in this case it is actually the wave force could also be very high let us take for example, a tension leg platform; we say the size of the platform is about 90 meter by 90 meter resting on 4 columns.

So, if this is the plan of a TLP, if this is my x axis this is plan. So, the centre to centre distance between the legs or the column members is about 90 meter in the wave direction.

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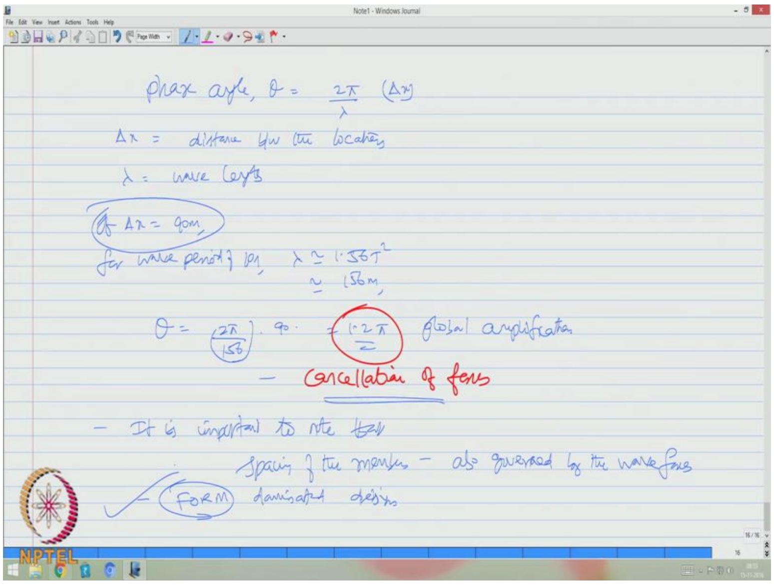

So, therefore, the phase angle theta could be 2 pi by lambda delta x, where delta x is the distance between the locations, where the wave encounters a structure and lambda of course is the wave length. So, if delta x is 90 meter as in the case of TLP example, and for a wave period of 10 seconds whose lambda is approximately 1.560 square, which is 156 meters, then theta actually is 2 pi by 156 into 90 which is about 1.2 pi, which can have a global amplification, it may result in cancellation of forces because it is 1.2 pi what does it mean?

It is important now to note, it is important to note that the geometric spacing of the members is also governed by the wave forces acting on them, please understand that is why I said offshore platforms are form dominated design, it is not that you assume a structural form and then find the stresses or forces on the member, it is you decide the structural form in sense of spacing of the member such that the wave forces on the members gets cancelled. So, its form dominated design. So, that is very interesting that one can use intelligently the choice of spacing of the members that the forces acting on these members can compromise on each other.

So, friends in this lecture we are discussing about the complexities on conventional environmental loads. We picked up a discussion the wave loads and we saw how wave loads and stretching modifications can be found, can be seen from the ready equations and we also slightly understood the complexities arise because of the phase angle and other factors that influence the forces on the offshore members.

Thank you very much.