Risk and Reliability of Offshore Structures
Prof. Srinivasan Chandrasekaran
Department of Ocean Engineering
Indian Institute of Technology, Madras

Module - 02
Reliability theory and Structural Reliability
Lecture – 16
Application problem - II

Welcome friends, we will talk about one more Application problem on lecture-16.

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In this case, we are going to talk about Application problem II. Interestingly in this example we will talk about stability of tethers, under distinctly high sea waves and seismic excitation. So, you are talking about stability analysis which will lead to the safety interpretations of compliant offshore structures. We will take an example again a tension leg platform.

We will examine this under distinctly high sea waves and seismic excitation. In several interesting study, the study has references sited in NPTEL website. Please look at those papers on related to the same topic authored by me and my co-authors. So, look at this papers we have anyway presented interestingly for a safety interpretation. So, as we now agree and understand the compliant system like TLP where the buoyancy force exceeds the weight by a large number is always compromised by excessive initial pretension on the tethers.

So, any variation on this T 0 value which the initial T 0 could challenge the stability of the platform, why they are re-insisting the statement? It is because of the fundamental reason in compliant structures like tension leg platform, initial pretension plays a very major role which actually bridges, the static components of the buoyancy and the weight of the system.

However, when the platform oscillates with respect to its mean position, under the action of wave wind and current; obviously, you will see that the buoyancy also changes because of sub merged volume change and the buoyancy changes will incorporate approximate changes or appropriate changes in the tether tension variation which is dynamic in nature. So, in a given life system of the structure like TLP the tether tension variation is going to happen continuously. Like to see what is this tether tension variation caused by the extreme weight cases, that is distinctly high sea waves in the presence of seismic excitation poses the problem very interesting. So, as reliability actually is bridging the satisfactory performance of a given system under the given load combination under the given conditions.

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So, we know that reliability is assessment of performance of system under given conditions. In our case, the conditions are load combinations for a specific period of for time; for a specified period of time; in our case is going to be the life time of the structure.

So, reliability is actually in assessment of the performance of the system under the given conditions for a specific period of time. So, in this present example we are going to analysis; the objective ways is to analyze stability of the platform under dynamic tension variations caused by extremely high sea waves and seismic excitation that is what our objective is. So, of course, it requires a dynamic analysis we look into that.

Interestingly you know extremely high sea waves plus seismic excitation is an extreme load combination. So, this of course, in a study is numerically simulated. One can easily understand that experimentally such waves and such conditions cannot be simulated. Therefore, this study is on numerical simulated model on a TLP. So, one is interested to know the dynamic response offshore system under such extreme load combination using numerical example. So, you will talk about this now.

Interestingly one should now understand the mathematical model of TLPs, one as to really explain at least briefly the mathematical modeling which has been done for modeling the TLP under the extremely high sea waves in the presence of both horizontal and vertical seismic excitation. So, the load acting on the system, acting on the system not TLP or one extremely high sea waves which is special case. One more wonder that why we are actually doing a reliability analysis for extreme load combinations, reliability analysis always assessing the performance of the given system under the given condition we assume a condition that it may violet, it may challenge the safety of the system and we are assessing will the system remain safe under the expected conditions.

So, under the normal operating condition if you look at the reliability analysis it will always indicate you that the system is safe. So, the unsafeness of the system can always be examined only when the normal operating conditions or the sea state is violated to an extreme sea state. In the earlier example also you have taken extreme sea condition, in this case also we have taken extreme combination where the sea waves are extremely high in sense and the second will be the presence of seismic excitation.

Now the problem is made more interesting because of two reasons, one the analysis should focus on how it actually simulate or generate an extremely high sea wave. So, one should exactly know what you mean by extremely high sea wave. Do you have any equations which can help me to simulate such a sea wave? Do I have any readymade spectrum available in the literature which helps me to generate or simulate extremely high sea wave? How literature classifies the sea wave to be extremely high in what sense. So, we should know this first.

Secondly, what is the interest of seismic excitation on a complaint system? So, it is the fundamental question asked by every structural engineer to understand the complexity of seismic excitation on a floating system. Now let us look at this example very clearly here.

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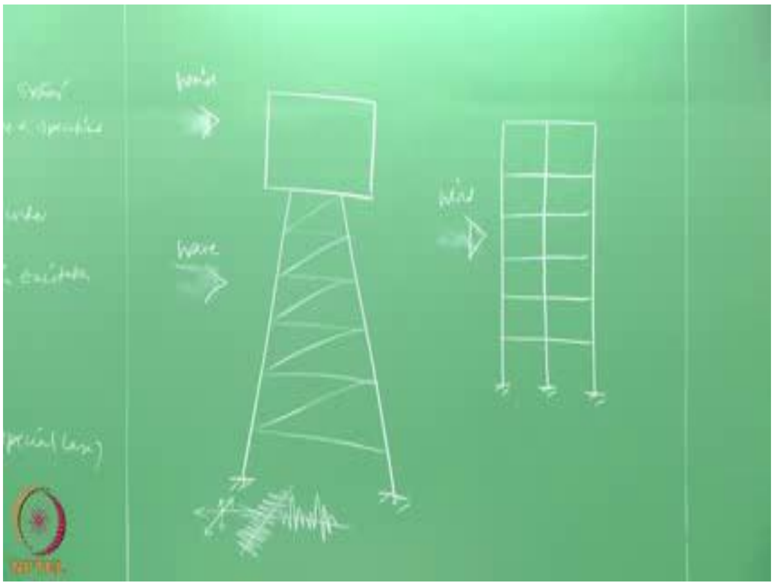

If I have a system which may be your jacket platform offshore structure, a jacket platform or the building; let us say multi storied building founded on piles on a soil subjected to lateral forces. In this case lateral force obviously is going to be wind. In my case in offshore system later force obviously is going to be the wave for the substructure and of course, wind for the superstructure.

So, I have again the jacket legs which are battened (Refer Time: 10:05) I have a system like this. Now let us imagine in both cases seismic forces are excited. So, this is sigma which crosses displacement of the ground at this point that is the signal which causes displacement on the system underground part; along x along y and along z, these are seismic time history which gives me the seismic acceleration x double dot g, acceleration of the ground along the time. So, it is a time history.

So, if this time history is imposed at the connection points of the columns or connection points of the column members of this building; obviously, we will see when the column members are the column legs of the jacket or displaced continuously for a over a specific period of time. This induces additional stresses to these members which may cause these members to fail in both cases, in jacket structure as well as in a building. Now if I remove the support system let us say I have a support system of a different order as in the case of floating system.

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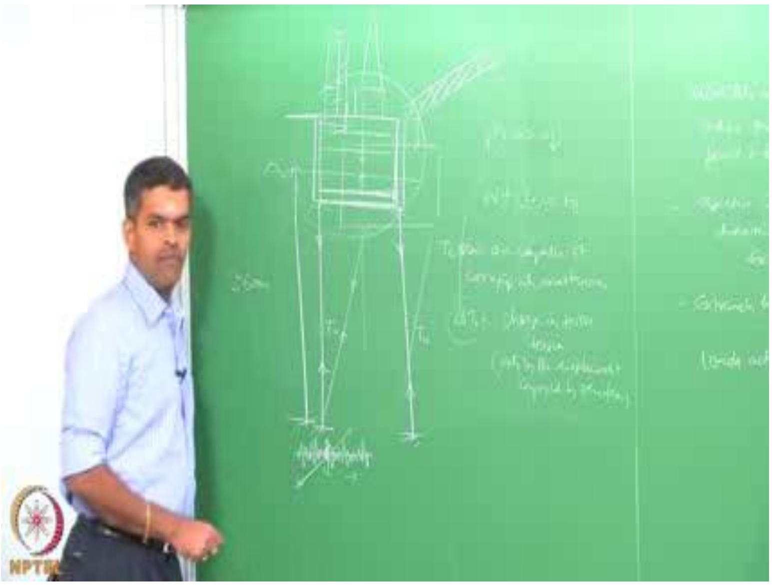

Let us say I have a tensional platform which of course has the flagon, it has a helipad, it has living quarters, it has turbomachinery, it has a drilling massed etcetera all topside details as usual and there are column members and there are contour members is a top deck of multi tier let us say. Now they are station kept or positioned strain using what we call as tethers. So, we all know now the TLP is a process by which the buoyancy exceeds the weight by a large amount, weight acts downward we know buoyancy acts upwards against gravity, buoyancy depends upon the sub merged volume of the system. I got a very large platform with very large diameter of the member. So, sub merged volume is very high.

Therefore, the buoyancy force will act in the upward direction and where as a w weight of the platform will act in the downward direction. There is a very great imbalance between these two which should be bridged by the initial tension in the tethers. So, tension is imposed on the legs what we call as initial pretension in the tethers called as T 0 in each leg. If there are 4 set of legs and each leg will have T tethers will be 12 tethers as we have normal saw in the previous example as well.

So, know interestingly let us impose the same (Refer Time: 13:13) signal here, along x along y and along z, ST is imposed. So, earthquake history bends along the time history acceleration is imposed, the ground is displaced by a specific intensity. So, know the question is we all agree and understand very closely that where the system rests on the sea bed or on the flow where it is being founded using the pipe rigid connection; obviously, the displacement of the ground will get transferred to the support system which may be a column or a jacket length as the case may be.

Whereas in this case, you know they are (Refer Time: 13:57) tethers a cables there are nothing but cables. They are let me these joint this. They are nothing, but cables. So, this not they carry only axial tension tethers or capable of carrying only axial tension, no compression. So, if having any force imposed on this as a compressive force, the cable cannot carry this force. Now the system is actually remaining the top side depth is about let a say in our case as we saw may be about this 600 meters water depth, 1200 meters water depth 1100, 800 etcetera very deep, deep water platforms.

So, when you impose an earthquake signal here which cause a displacement of the ground it is obvious to have a feeling that how this force or the displacement will affect the behavior of the superstructure. Our whole scenario is to study the safety or stability of the platform when it is connected to the sea bed using tethers. When the platform is disconnected and the tethers cannot attached it becomes free floating, why? Buoyancy exceeds the weight be large amount the platform will remain free floating.

When I am session keeping it, when I am housing it using a tether set to the sea bed when the position restrained is imposed as a condition to the system then the system is not allowed to move freely to a larger extend, but the system is allowed to displace because of the action of water and waves and current. When in such situation when the earthquake signals are imposed how this will cause an additional displacement to the system because system is not directly resting of the sea bed, is only anchor to the sea bed using cables. Friends, it is interesting for you to realize and quickly understand that any movement in this direction or the direction this imposed displacement.

Let us say the system is displaced by this somewhat or let us say; obviously, this position compared to the earlier one will have a change in T 0, I call this is delta T 0. Delta T 0 is changed in tether tension. Let us say hypothetically this is purely cost, only by the displacement imposed by seismic forces, seismic forces. So, the change in tension now affects change in buoyancy and weight because this is an imbalance between these two therefore, the set down effect caused by the sub mergence and the offset caused by the wave action in combination is seismic action changes buoyancy. The change in buoyancy will cause change in tension.

Therefore earthquake signals are imposed indirectly as change in tension in the whole system, you understand. Change in tension is what we call dynamic tether tension variation which causes imbalance. Now my worry is under such imbalanced condition, when the dynamic tension is imposed by the earthquake signal in the presence of distinctly high sea waves will the system remain stable, is it safe? That is the whole question asked here, that is the problem formulation. Do you understand? That is how we are imposing the problem to the system to find the solution is it going to remain safe.

So, the reliability of the system under extreme load combinations of distinctly high sea waves in the presence of seismic excitation will make the system safe or unsafe, when the system is performing its operation for example, drilling. So, both horizontal and vertical seismic excitation should be imposed at this connection point to the tether. So, seismic forces imposed at the bottom of each tether will cause an axial force additional that makes the tether tension imbalanced. I am only looking at the unbalanced or dynamic tension variation imposed on the T 0 value which essentially caused by the seismic excitation in the presence of distinctly high sea waves.

That is when the hull is an offset condition, when the hull is in static equilibrium we are not bothered when the hull is under offset condition which is caused because of the wave force acting on the lateral direction under that situation when seismic excitation also happens, will it cause a worrying factor on dynamic tension variation which is challenge the safety of the system while performance. That is where reliability is being seen. Therefore, the tether tension variation caused by the seismic excitation should remain non-linear.

So, we first explain, we first qualify a spectrum which can give me the acceleration of the sea quake or seismic excitation at the sea bed. So, we use (Refer Time: 19:34) spectrum for this.

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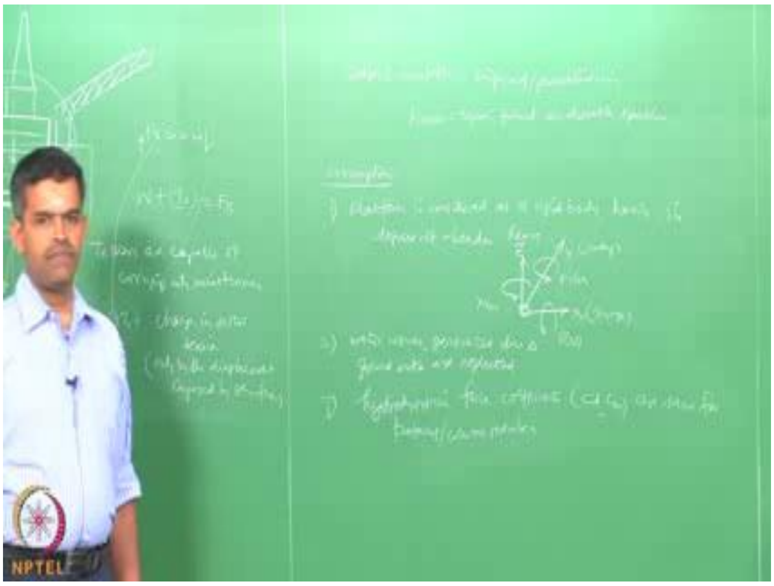

So, seismic excitation is imposed using or generated using (Refer Time: 19:54) ground acceleration spectra. To do the analysis we need to of course, may sudden high (Refer Time: 20:18). So, following assumptions are made in the analysis one platform is considered the rigid body having 6 degrees of freedom, the freedom or these are freedom are marked like this. So, this is my x axis, this is y axis, this is z axis.

This is surge along x axis, this is sway along y axis, this is heap along z axis, they are displacement agrees a freedom. You keep a thumb towards a direction remaining 4 fingers will mark the direction; I call that is as rotational degree of freedom. So, about x it is role, similarly about y it is pitch, similarly about z it is going to be m. So, 3 displaced degrees of freedom and 3 rotation degrees of freedom at any point which is; obviously, going to be the center of mass of the system. So, the platform is considered to be a rigid body having 6 degrees of freedom.

The second assumption made is water waves generated due to ground motion or neglected. So, one is the ground motion purely impose by the seismic excitation and water waves are only because of the wave loading caused by the distinctly high sea waves. The third assumption made is the hydro dynamic force coefficients which are the drag coefficient and the initial coefficient or same for pontoons and column members and they are independent of wave frequencies for the C m value.

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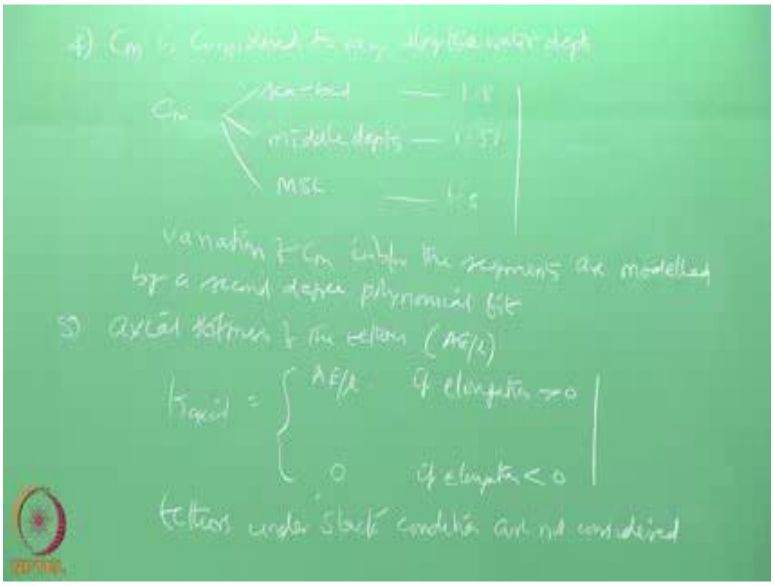

That is the hydro dynamic (Refer Time: 23:07) coefficient is consider to vary along the water depth.

So, C m values at the sea bed at the middle depth and at MSL that is mean sea level or taken as 1.8 1.58 and 1.5. The variation between them, variation between these segments variations of C m in between the segments are modeled by a second degree polynomial fit.

The next assumption is about the stiffness of the tethers axial stiffness at the tethers which we all know this is AE by l this model like this. So, the stiffness axial of the tether is given by two cases - one is equal to AE by l if the elongation is greater than 0 it means from the initial condition it is the elongated. Otherwise it is 0 if the elongation is less than 0 that is tethers under slack condition or not considered. The initial pretension reduction when the tethers become slacked is not considered. So, as I said in the beginning in this problem we have to discuss two things one is the seismic force acting at the sea bed, two is the distinctly high sea waves. What do you mean by distinctly high sea waves?

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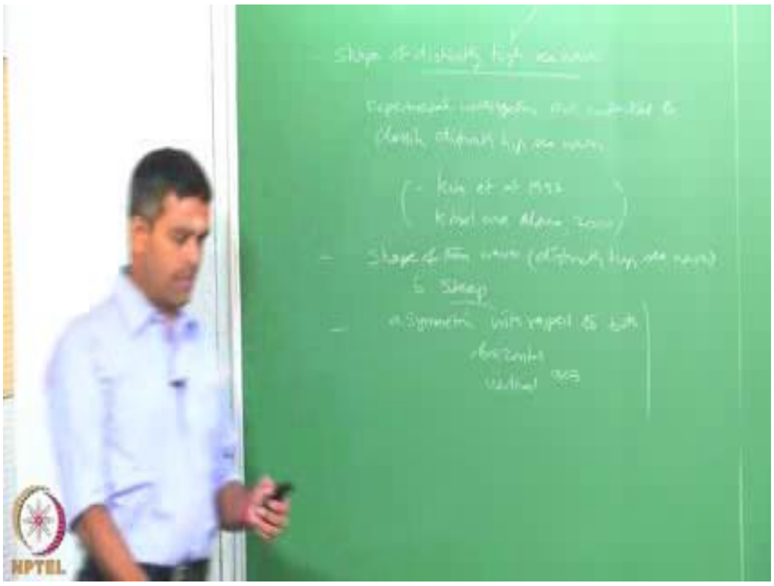

So, shape of distinctly high sea waves is quite interesting for this problem it is crucial for the given sea state. So, the support is there are experimental investigations conducted by various researches to qualify a sea state or a sea wave to be called as distinctly high. They are done by or conducted to classify distinctly high sea waves, how they are classified? Kin et al 1997, Kriebel and Alsina 2000. So, one can look at these papers to know more information about how to qualify or how to classify a given sea wave as a distinctly high sea waves.

They stated that the shape of these waves, these waves in sense distinctly high sea waves of this wave is steep that is the first observation they have made. Secondly, they are asymmetric with respect to both horizontal and vertical axis. So, your wave should be asymmetric to both horizontal vertical axis at the same time it should be steep. Now the question is when we will classify a wave as a steep wave and when you will able to generate a wave which is asymmetric with both respect to horizontal vertical axis that becomes the question. If I am able to generate a wave which is steep and remains asymmetric about both this axis I can call that wave as distinctly high sea waves as stated by Kin et al and Kriebel and Alsina.

So, the problem now is how to simulate such a wave which will be qualifying distinctly high sea wave with the help of experimental studies conducted by these gentlemen that is argument now. So, therefore, one can always say the experimental simulated sea wave is always pertaining to a limited boundary condition. In the real sea state such simulated waves may not be able to simulate the same effect as from the real sea state because experimental investigation is done on a scaled model therefore, there may be a limitation.

So, what we are interested is to understand the effect of sea quakes or earthquakes in the presence of distinct lay is sea waves in the real model. Therefore, I must be able to simulate both with the numerical system not with the experimental studies therefore, (Refer Time: 29:24) in 2000 developed a numerical model to generate freak waves.

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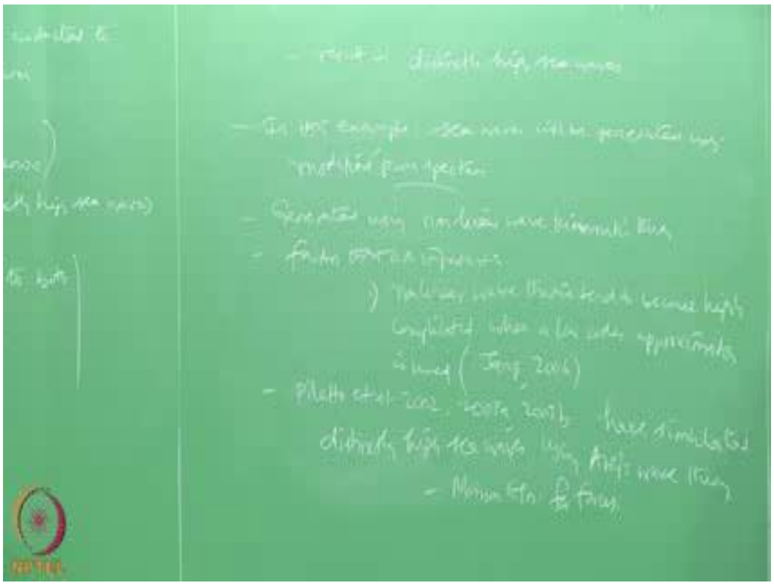

Based on the design spectrum which can result in distinctly high sea waves, that is one solution we have from the literature. Instead of going for a simulation which is done experimentally by this gentlemen which helps us to qualify a wave as a distinctly sea wave, this gentlemen gave has an alternate method using a numerical model to simulate the wave which can also be called as a distinctly a sea wave because they qualify in the same manner as that of the conditions stated by these researches at the different time.

In the present study therefore, now we will say in this study, in this example sea waves will be generated using modified p-m spectrum interestingly one may ask a question. So, p-m spectrum is actually a one, a standard spectrum which is used as a design spectrum. How will be able to generate a wave which can qualify to be called as a distinctly high sea wave using the standard conventional p-m spectrum that is why I said modified spectrum.

So, to release this doubt from your mind we will generate a spectrum using p s m of course, spectrum modify with one parameter. Will then generate a time history from that then from the time history we will check whether this wave is really steep and is it having asymmetricity both about horizontal and vertical axis. If this condition is satisfied in the given enlarged time history of the given simulated wave using this spectrum then a condition of generating a simulating a distinctly a sea wave is satisfied.

Now, the distinctly high sea wave is generated using non-linear wave kinematic theory. So, when you generate a wave using non-linear wave kinematic theory following factors are very important because I have to qualify the wave first as a distinctly high sea wave. So, what are those factors which are important? The factors that are important, one non-linear wave theories tend to become overly complicated that is one issue; non-linear wave theories tend to become highly complicated when your low order approximation is used as stated by Jang, 2006.

Therefore several researches have simulated distinctly high sea wave successfully using simple aeries wave theory. So, at several researches by name Pilatto, 2002, 2003, 2003 b as you can see from the list of the references given in the website of NPTEL for this specific course, they have simulated distinctly high sea waves using aeries wave theory and the force using Morison equation because the system is (Refer Time: 34:45). What about a kinematics is used or generated using aeries wave theory and the random generated sea surface elevation using p-m spectrum. So, this condition is like this.

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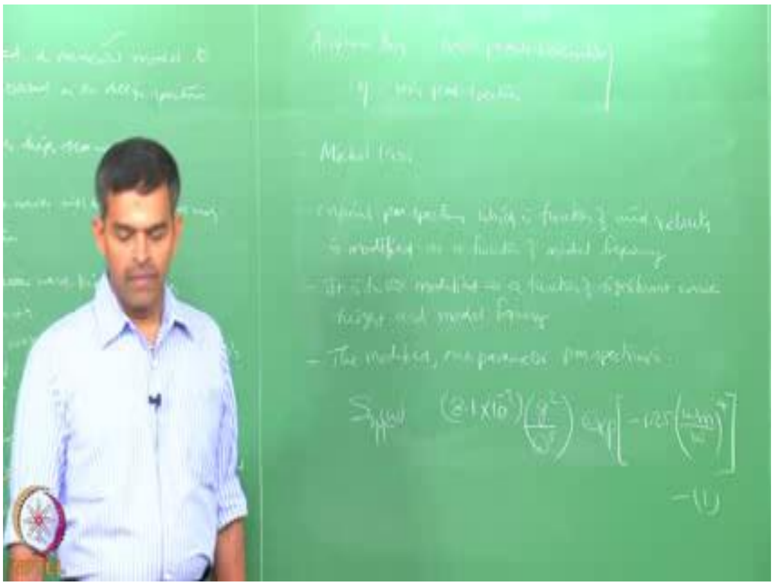

Here is a theory for water bottle kinematics and sea surface elevation using modified p-m spectrum that is what we have used which I will show you now. What is the modification done on the p s m spectrum, this modification suggested by Michel in 1999, original p-m spectrum which is the function of wind velocity is modified is modified as a function of modal frequency that is the first modification done. Secondly, it is further modified as a function of significant wave height and modal frequency.

Now, the modified one parameter equation is given by this following S theta eta omega this spectral function is 8.1 10 power minus 3, g square by omega 5 exponential minus 1.25 omega m by omega to the power 4 - call equation number 1. Where g is actually induced to gravity in the equation; omega m is the modal frequency

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In this particular simulation it is been taken as 0.46 radiance per second that is nothing but 0.07 hertz. S theta eta is this power spectral density function of the wave height eta that the sea surface elevation. Now the wave elevation which is eta of p is now realized as discrete sum of many sinusoidal functions. Of course, when you do the decrease discrete sum it should have with different angular frequency and random phase angles; that is very important.

So, eta of T is given by your discrete sum of different waves of sinusoidal function which satisfies this equation, equation 2; where k i is what we call as the wave number.

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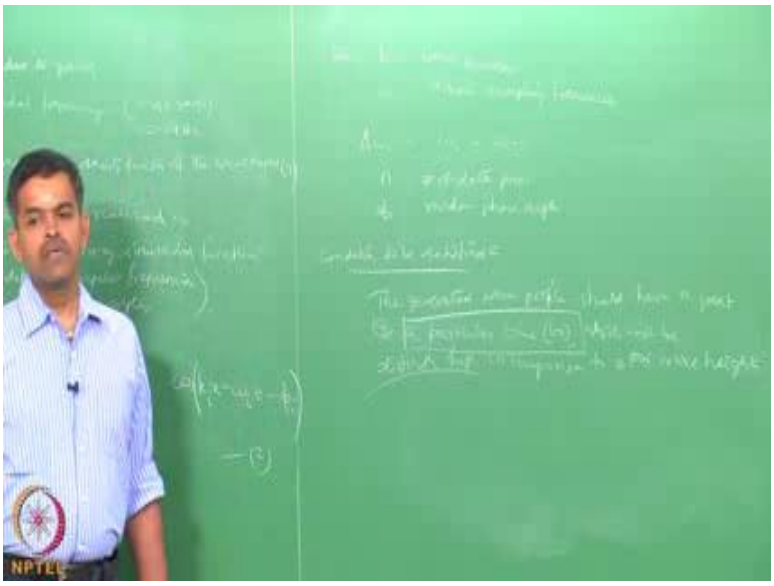

Omega i is the discrete sampling frequencies, which means delta omega i is given by omega i minus omega i minus 1, I will keep on generating the wave like this sampling frequencies; n of course, a number of data points and phi is the random phase angle. Now interestingly, what should be the condition satisfied? The condition to be satisfied is which is very important to make this wave as distinctly high sea wave.

The generated wave profile should have a peak at the particular time p 0 which will be distinctly high in comparison to other wave heights and therefore, I can classify this as a distinctly high sea wave. So, one has got to be careful to choose this particular time T naught where the wave elevation is going to be distinctly high.

So, interestingly the problem was got two classifications - one is to generate the seismic spectrum or seismic excitation using (Refer Time: 43:36) spectrum. Other is to generate simulate numerically a distinctly high sea wave because experimentally simulated waves cannot be useful for a numerical study of one is to one scale is very difficult. So, we have used aeries theory and modified p-m spectrum to generate a wave which I will show you in the next presentation, in the next lecture how the wave is generated. So, the wave should have steepness plus they should show asymmetricity both in horizontal and vertical axis. So, we will discuss this continuing in the next lecture.

Thank you.