Offshore structures under special loads including Fire resistance

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Lecture – 18
Earthquake Loads – II

Friends, today we will discuss the 18th Lecture in the NPTEL course title Offshore Structures under special loads including Fire Resistance Design. Today in this lecture we are going to discuss about the analysis of offshore structure example under Earthquake Loads.

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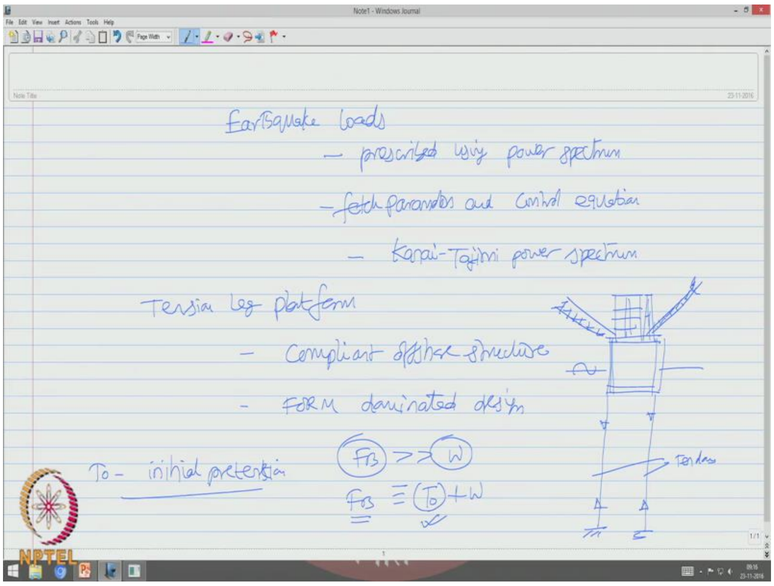

In the last lecture we discussed that earthquake loads can be prescribed using power spectrum. We have discussed the fetch parameters and the control equation for estimating the earthquake load. We said Kanai Tajimi power spectrum is an idealized application to use in offshore structures. Today in this lecture we discussed about the application of this problem. On an example study and see what could be the consequences caused by the earthquake forces on offshore structures.

To take an example we will consider a tension leg platform, we all agree that tension leg platform is a compliant offshore structure. Some important characteristic of it is behavior can be recollected this moment: it is actually form dominated design. In sense as per the design the buoyancy force exceeds the weight of the platforms and that is equated with the tension in tendons with the platform to equalize the buoyancy. So, I have a tops side with all details which we say; the flare boom, the crane, the living quarters, and the drilling derrick which is now assembled with the column member and the pontoon member.

For the mean sea level to remain here, the system remains afloat because the buoyancy which is actually proportion to the submerged volume of the members is so high so that the weight of the platform is lower than the buoyancy which makes the platform to remain afloat. Of course, to maintain the station keeping of this platform we actually hold it down in position using tendons, they are always in tension so they are called tension leg platforms.

The difference between the buoyancy and the weight is compromised or compensated by the tendon forces which are called the Initial Pretension. So, it is very clear in this application that the platform is expected to undergo a large displacement.

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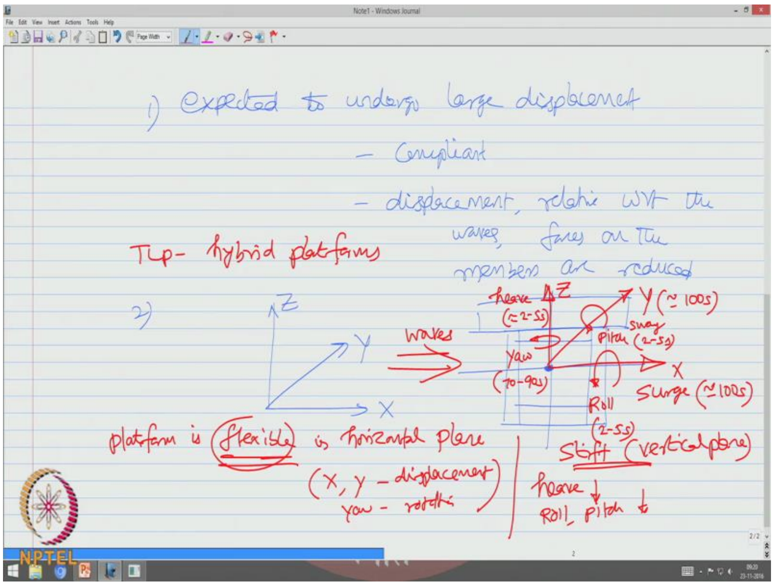

So by design it is expected to undergo large displacement which makes it very compliant. Because of this displacement which makes it relative with respect to the waves, forces on the members are reduced. So, that is the first issue we have. The second issue if you look at the degrees of freedom like x y and z axis. Let us mark again the platform with the column members and the pontoon members and the top deck with all top side details whatever we have there at the cj of the platform let us mark the axis. Let say this is x axis y and z axis this becomes my wave direction.

So, the platform undergoes surge whose period is about 100 seconds. The platform undergoes speed displacement whose period is again 100 seconds. The platform undergoes heave displacement in z axis whose period is about 2 to 5 seconds. The platform also undergoes roll degree of freedom whose period is about 2 to 5 seconds. The platform also undergoes pitch rotation whose period is again 2 to 5 seconds. The platform undergoes rotation about the vertical axis which is called as yaw motion whose period is about 70 to 90 seconds.

So from this we already realized that the platform is flexible in horizontal plane, because having large periods in x y displacements and having large period in yaw rotation makes the platform flexible in horizontal plane. Whereas, the platform remains stiff in vertical plane, this is mainly due to heave displacement or heave period being very low. And of course, the rotations about x and y axis that is roll and pitch periods also being very low. So, it remains stiff in vertical plane and remains flexible in horizontal plane, therefore TLPs are otherwise called as Hybrid Platforms.

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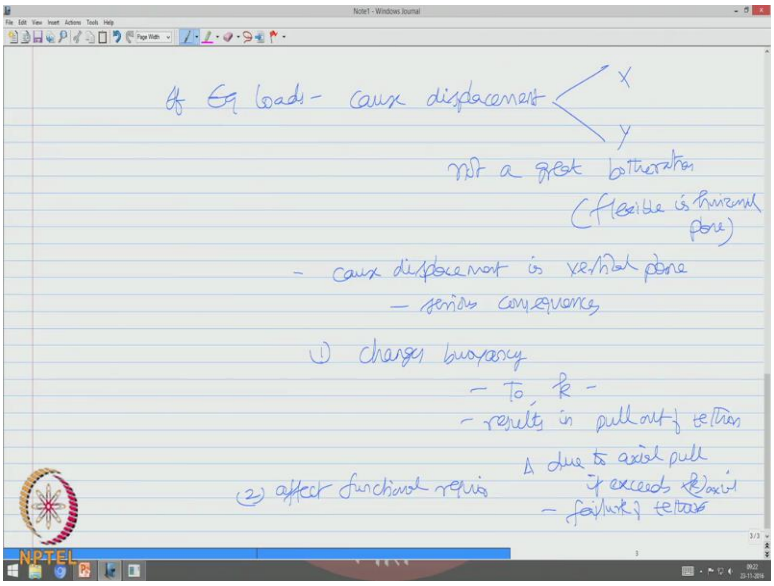

Now, under this background if I have platform of this order and try to obtain an earthquake force, if the earthquake loads cause displacement along x and y it is not of a great botheration, because anyway the platform has to remain flexible in horizontal plane. If earthquake forces cause displacement in vertical plane this has got some serious consequences. First, the vertical plane displacement changes buoyancy in turn changes T 0 in turn changes stiffness and in turn results in pullout of tethers.

Why because, the axial value of the displacement because of the axial value due to axial pull if exceeds T 0 permissible or let say very specifically axial stiffness then tethers may fail. When tethers fail that may result in floatation of the platform, which can in turn effect the functional requirements of the platform.

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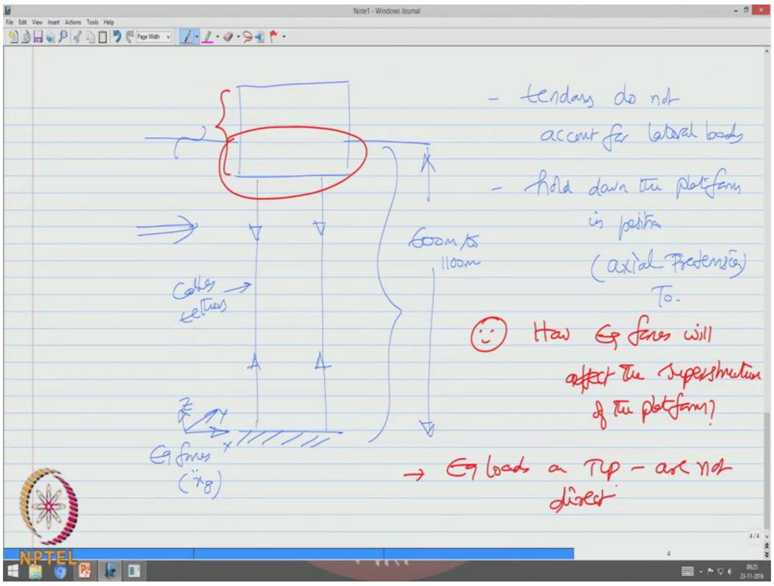

So, friends we must now see whether these earthquake forces which usually cause displacement on the seabed which induces force on the body will result in any vertical displacement or not. Now there is a very fundamental intuitive question we have; if I have a platform which is supported and station positioned, let say by tendons which are in axial tension of a very high value when this is my mean sea level, when sea bed results in earthquake forces and let say in all the 3 degrees. Let say earthquake forces that is x double dot g causes displacement in all three axis let say.

There is a very extensive amount of water body available here, because we are talking about deep water platforms because offshore structures of compliant nature are essentially recommended for deep waters. Let say the water depth is about 600 meters to as high as 1100 meters as far as TLPs are concerned. So, that is a very good water cushion and these are only cables or tethers which are actually not any load carrying members as far as wave loads are concerned.

Please understand tendons do not account for lateral loads. The fundamental function of tendon is to hold down the platform in position through very high axial pretension which we call as T 0. So, they do not resist the lateral forces as usual earthquake loads if they are acting lateral they are not supposed to resist them. So, the resistance of lateral force essentially comes only from these members which are immersed or let say if this is the member what your are considering the member is partially immersed.

Now, the fundamental question comes to mind is, if earthquake forces are applied at the sea bed at the greater water depth how that is going to affect the response characteristics of a compliant structure whose super structure is about 1 kilometer maybe 1000 meter above the sea bed; that is a very relevant question. So now the question asked is, how earthquake forces will affect the super structure of the platform. That is the question asked; because we all agree that earthquake loads on TLP are not direct. What do you mean by direct? Had these platform instead of TLP would have been a jacket structure.

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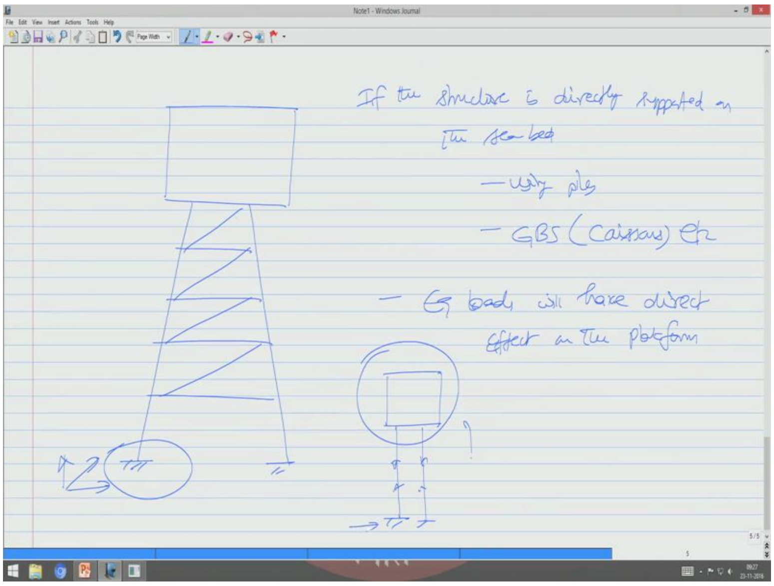

Then in that case earthquake forces applied here would have a direct effect on these members. So, if the structure is directly supported on the sea bed maybe using piles or maybe gravity based structure using caissons etcetera, then one can say earthquake loads will have direct effect on the platform. But in the case of TLP when members are above water and it is only held down in position by a tendon, how the super structure will have the consequence felt by the load applied on the ground at the sea bed. That is a very interesting question.

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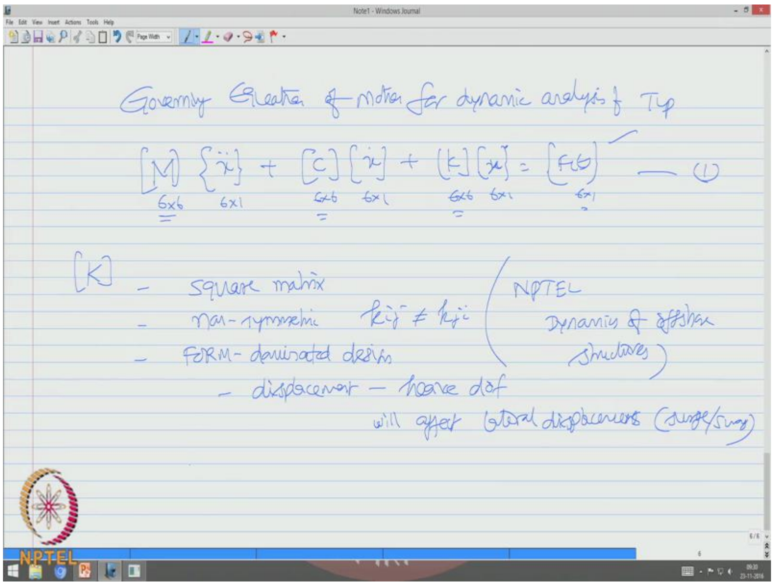

To answer this, let us try to write the governing equation of motion for the analysis of a TLP. So, M x double dot plus c x dot plus k x is F of t. We all know that TLPs are about six degrees of freedom, therefore this maptisis are of order as written now. So ultimately we will get a 6 by 6 matrix of mass damping stiffness and a force vector of 6 by 1. Looking into the basic characteristics of form dominated design of TLPs one can infer the following.

About the stiffness matrix one can see that it is going to be a square matrix which is non-symmetric. It means kij is not equal to kiji; you can refer more information about this on NPTEL lectures on Dynamics of Offshore Structures. Further it is a form dominated design which in sense any displacement given in heave degree of freedom will affect lateral displacements in surge or sway degrees of freedom.

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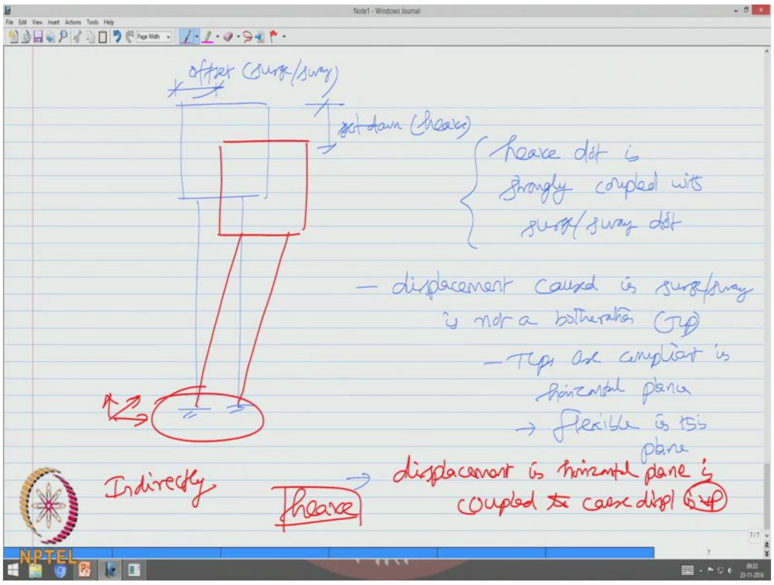

So, if I have a TLP which is question restrained by tendons, if I try to apply the lateral force on a TLP you see that the lateral displacement cost is what we call as offset which will be usually in surge or sway degree of freedom. Depending upon the wave direction simultaneously in parallel these are also cause displacement in the vertical axis which we call as set down which happens in heave degree. It means at least heave degree of freedom is strongly coupled with surge and sway degree of freedom.

Now one may ask me a question, how this statement is now important as far as analysis is concerned. We already said that any displacement caused in surge or sway is not botheration as far as TLPs are concerned, because TLPs are compliant in horizontal plane. What do you mean by compliant? Compliancy indicates that they are highly flexible in this plane, so no botheration. But botheration now comes because, any displacement in horizontal plane is coupled to cause displacement in vertical plane, because I get heave motion now. This heave motion is a botheration, because the heave motion will affect the functionality of the platform it changes in the tension in the tether, if the tension in the tether exceeds the permissible axial stiffness of the member it may even pullout which results in floatation characteristics of the platform which can remain non functional.

Interestingly friends, please note that any lateral force which is caused by an earthquake on the seabed will affect now the platform indirectly.

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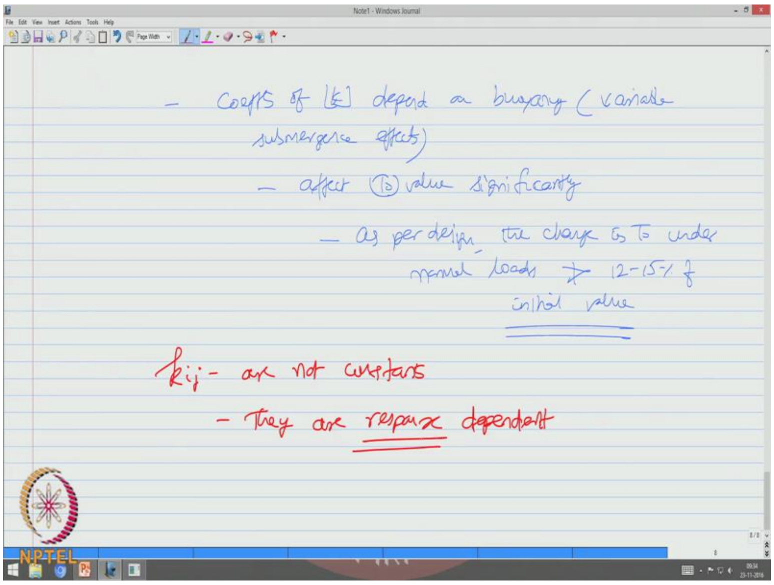

Also the coefficients of stiffness matrix depend on the buoyancy or what we call variable submergence effects. They affect T 0 value significantly. But, as per design the change in T 0 under normal loading; I am not talking about special loads does not increase 12 to 15 percent of initial value that is the design check. But under special loads like earthquakes they may be even more we may have to examine that, so that is botheration here.

So what we can infer is kij are not constants, they are response dependent.

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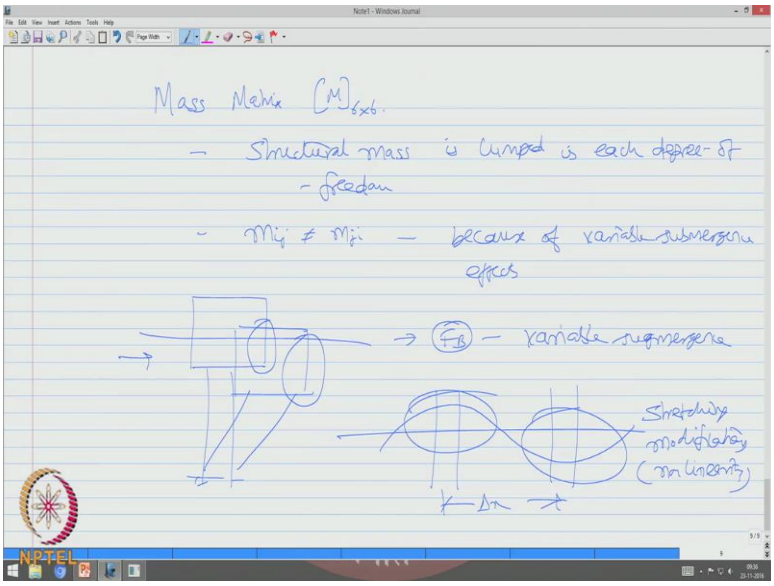

So, talk about the mass matrix we agree that the structural mass is lumped in each degree of freedom, but mass matrix is also not symmetric because variable submergence effect. What is this variable submergence effects? When I have a system, when the system is under lateral load, when the system undergoes displacement the immersed volume of the member is now changing; the immersed volume of the member now changes, this invokes change in buoyancy. We call this as variable submergence that is number one.

There is always a possibility two members are spaced in such a manner that one member will encounter a crust other member will encounter a trough of the same way. So, there is a possibility that these forces may get cancelled. So, we call this as Stretching Modifications which is again another non linearity. So, these issues will always make mass matrix un-symmetric.

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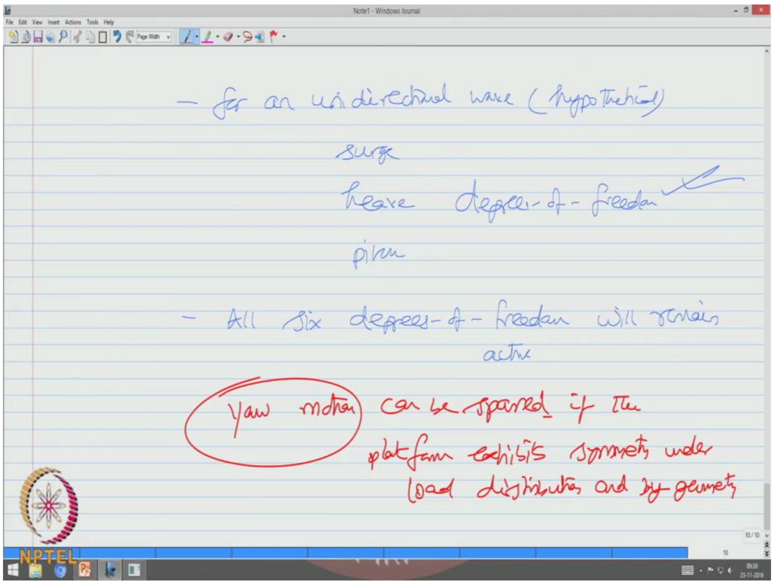

Predominantly or a unidirectional wave predominantly which is hypothetical only such heave and pitch degrees of freedom will be active. But in reality wave are multi directional, therefore all six degrees of freedom will remain active, but yaw motion can be spared if the platform exhibits symmetry under load distribution and by geometry. So, yaw motion can be exempted or other five degrees of freedom will be anyway there.

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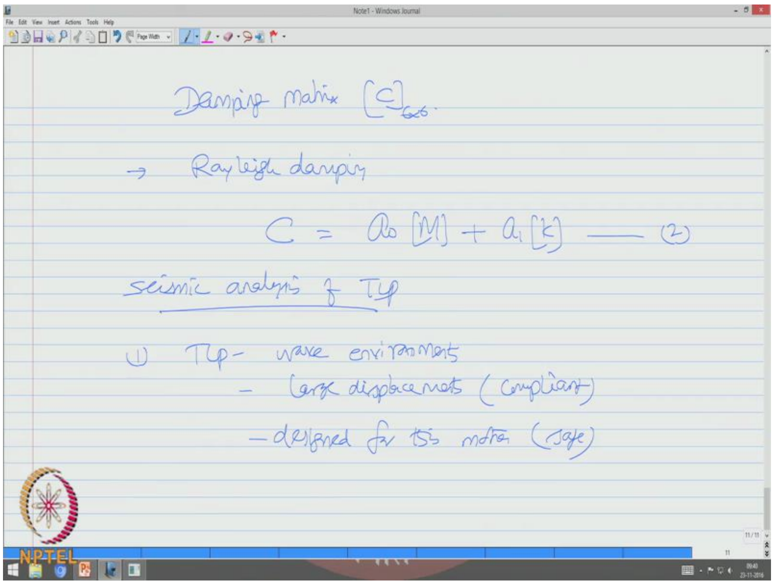

The next issue in the equation of motion is the damping matrix; it is also 6 by 6. There are many methods by which one can estimate damping, one can use a classical damping which is 2 zeta omega m. Whereas, we will take up an example of using a Rayleigh damping where C matrix will be some component of m and some component of k as well.

Now we are looking for seismic analysis of a TLP. We all agree that tension leg platforms are placed in wave environment, they do undergo large displacements to make them compliant, they are designed for that, and they are estimated to be safe under such action.

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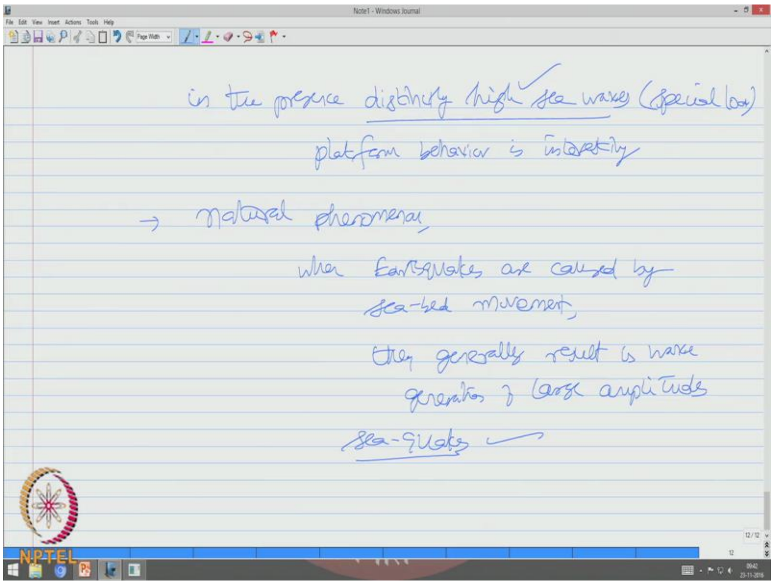

But, in the presence of distinctly high sea wave which is special load platform behavior is interesting. Now, one may ask me a question why are we considering distinctly high sea waves into the presence of earthquakes, it is very interesting. By natural phenomena when earthquakes are caused by sea bed movement they generally result in wave generation of large amplitudes. The sea quakes will be generated as an inherent characteristic when sea bed movement happens.

So, we are now interesting looking at the platform in the presence of earthquake and distinctly high sea waves.

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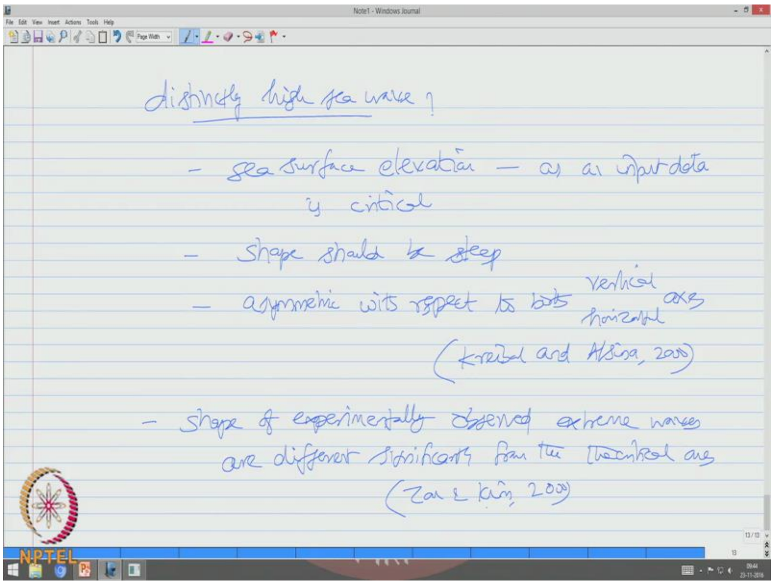

Now what is a distinctly high sea wave? The sea surface elevation what we will now discuss as an input data for the platform is critical. What do we mean by critical? The shape should remain steep; it should be asymmetric with respect to both vertical and horizontal axis. So, such sea waves are called as distinctly high sea waves as expressed by Kriebel and Alsina. It is also a fact that shape of experimentally observed extreme waves are different significantly from the theoretical ones, this was stated by Zau and Kim in 2000.

So, this gives a very clear conclusion to us that you cannot generate a distinctly high sea wave experimentally; you should generate theoretically using the factor or the considerations given by Kriebel and Alsina.

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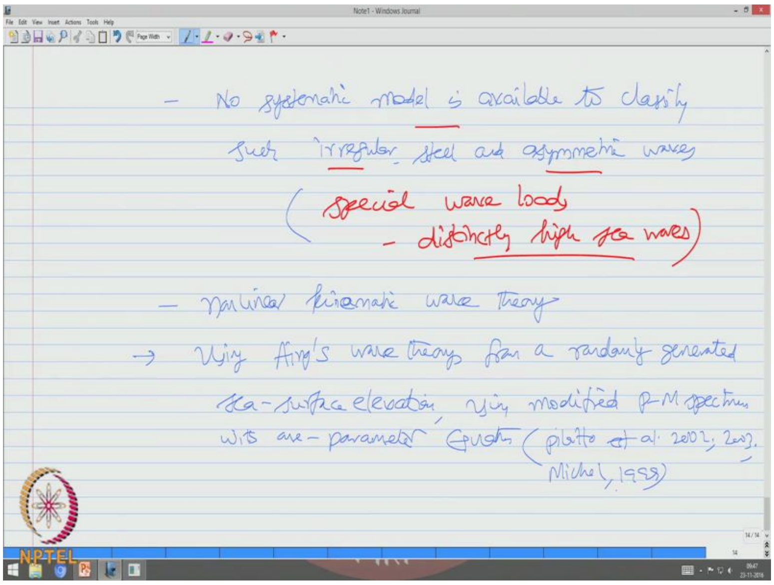

Therefore, no systematic model is available to classify such irregular steep and asymmetric waves. So therefore, I can call this as special loads, which I call distinctly high sea waves. We are now handling a problem with two special loads acting simultaneously on the given system: one is earthquake forces generated by Kanai Tajimi power spectrum or a parallel spectrum which is going to create the earthquake forces desired on the platform, the second is presence of distinctly high sea waves which will be irregular steep and asymmetric.

Now the question comes how do we generate these waves, because experimentally if they are generated they are not going to suffice the requirement as similar to that of a theoretical waves. So, we should have a method a mechanism a program or an algorithm to generate these kind of waves theoretically. So, this can be easily generated using the classical non-linear kinematic wave theory.

So, people have shown that using the classical Airy's wave theory from a randomly generated sea surface elevation using modified Pierson Moskowitz Spectrum such irregular steep and asymmetric waves can be generated with simple one parameter equation; thanks to Pillato et al, 2002, 2003 and Michel 1999 who gave us the algorithm to generate such distinctly high sea waves.

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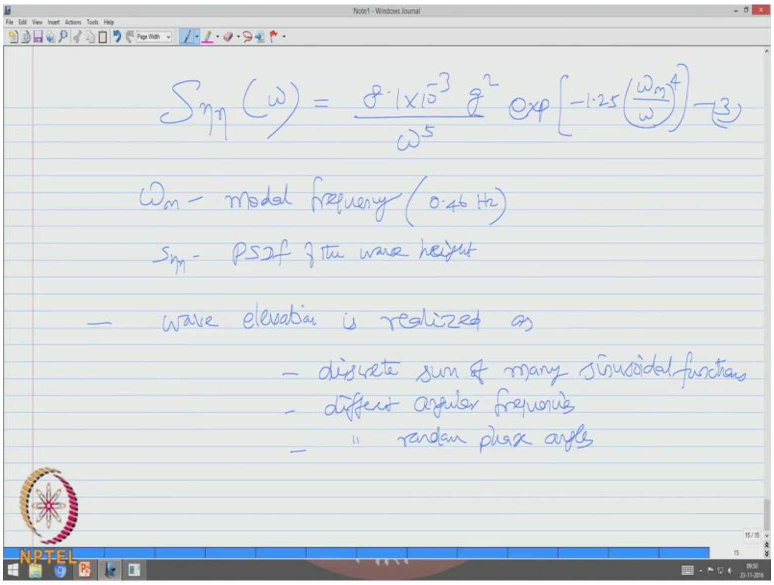

So, the spectrum will have the governing equation with one parameter which is given by 8.1 10 power minus 3 g square by omega 5 exponential minus 1.25 omega m by omega to the power 4, call this equation number 3. Omega m in the above equation is called modal frequency. Usually it is taken as 0.46 hertz and s eta; eta is the power spectral density function of the wave height with one parameter that is the wave frequency omega.

So, now in the present study wave elevation, because we are bothered about the steepness; spectrum will not give you the steepness. We have to now say that the generated wave elevation should remain steep, should remain asymmetric, both about vertical and horizontal axis to call this wave as a distinctly high sea wave. So, let us now try to generate a wave of this order whose wave elevation will be realized as discrete sum of many sinusoidal functions. They will have different angular frequencies. They will have different and random phase angles.

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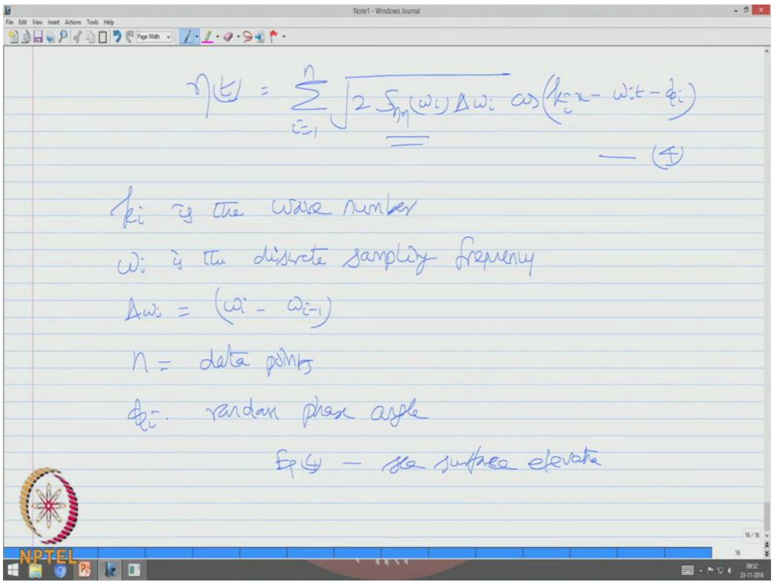

So, a typical wave elevation looks like this: eta of t is summation of because we are looking for discrete sum of many sinusoidal function i equal 1 to n 2 s eta eta omega i, where s eta eta is given by the previous equation; delta omega i, we are looking for a small component in omega cos k i x minus omega i t minus phi i; equation number 4.

In the above equation k i is the wave number, omega i is the discrete sampling frequency, delta omega i is actually omega i minus omega i minus 1, the gap between the successive frequencies, n is the data point over which you are going to make the discrete sum, and phi i is the random phase angle. So friends, using equation 4 one can now generate the sea surface elevation which actually is dependent on the spectrum of one parameter which is a modified Pierson Moskowitz Spectrum as recommended by Pillato et al researches.

So, look at the screen a typical sea surface elevation generated using this equation is now shown.

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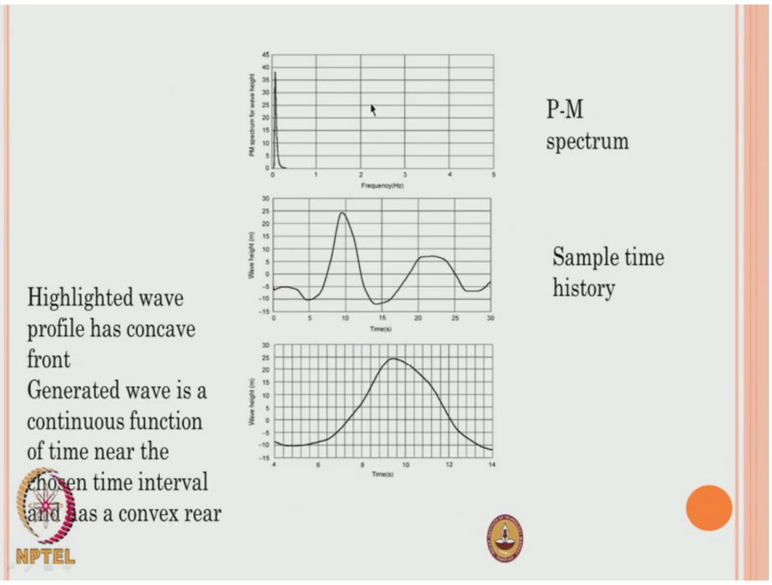

So, that is the Pierson Moskowitz Spectrum with one parameter based on this using equation 4 a typical sampled time history is generated, you can see the time history. And highlighted wave profile has a concave front, you can see that the concave front it is a continuous function in time domain and it has got a convex rear. So, the wave profile remains asymmetric about the vertical axis, asymmetric about the horizontal axis and that can be called now as distinctly high sea waves.

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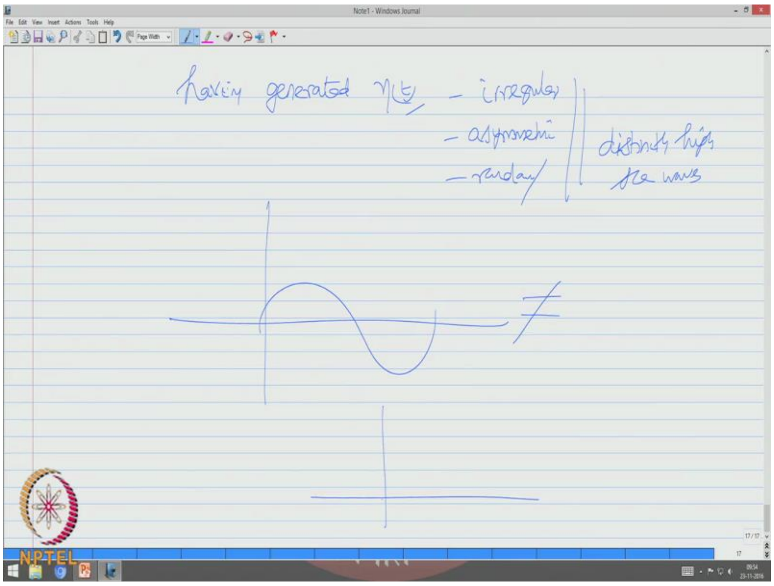

Having generated the sea surface elevation; now after generating sea surface elevation which is irregular asymmetric and random and of course, causing distinctly high sea waves. We have now generated a sea surface elevation which is not uniform, but an irregular wave which is having a concave front and convex rear asymmetric about horizontal and vertical.

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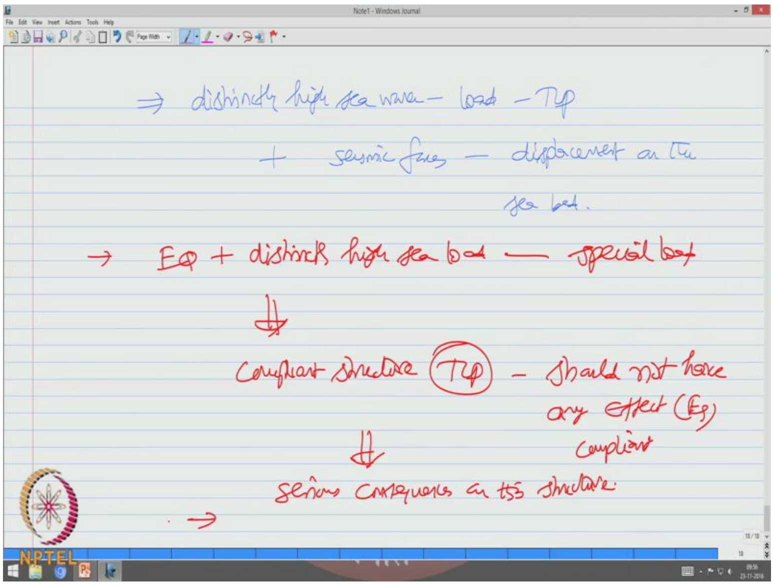

Further, this distinctly high sea wave is applied as a special load on a TLP along with seismic forces which causes displacement on the sea bed.

So friends, it is now interesting that the problem is well defined we have earthquake forces plus distinctly high sea waves which makes it as a special load. The example system is a compliance structure, like a TLP it is expected that this structure should not have any effect because of earthquakes because it is compliant, but the example will clearly show you there are serious consequences on this structure because of this combination of special loads, which we will see in the next lecture as a continuation.

Thank you very much.