Risk and Reliability of offshore structures
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Module – 02
Reliability theory and Structural Reliability
Lecture -18
Application Problem - II Continued

Friends, welcome to the 18th lecture on module 2.

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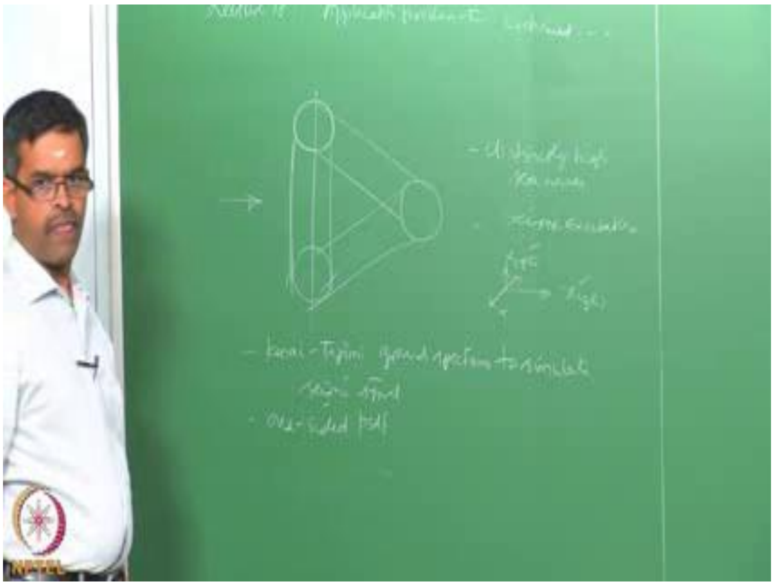

This is going to be lecture 18 on module 2 where I am continuing with the discussion on application problem 2, which I am continuing. So, just to recollect we are looking forward for the safety assessment of a triangular configuration platform where the predominant wave direction is along the surge axis is subjected to distinctly high sea wave, which we know how to generate them using the modification suggested by Mitchell, 1999 and you have got a modified be a spectrum based on which you can generate the forces arising from the hydrodynamic effects cost by the distinctly high sea waves because you have to qualify actually a wave as a distinctly high sea wave, comparing the wave elevation with the preceding and success variously. We have already shown a window in the last lecture, how the wave elevation is seen as a concave front and convex rear which qualifies for a wave to be called as a distinctly high sea waves.

The second force acting is a seismic excitation. In this study, seismic excitation is considered as horizontal and vertical along surge and along heave of course, it is neglected along x that is displacement x 1 g and displacement x 3 g are considering the study and we already said this will cause a dynamic, t is the tension variation which can be given by the equation is specify now. It actually requires a random time history for the ground motion, the ground motion need to be also simulated because earthquakes which are appearing occurring at the sea bed are not actually measured. Therefore, one need to actually simulate this kind of a seismic signal which will closely relate to the seaquake or earthquake cause in one of the TLP's or the region of TLP where is located; well come to that slightly later. I need to have a spectrum. So, I am going to use the famous Kanai-Tajimi power spectrum to simulate the seismic signal.

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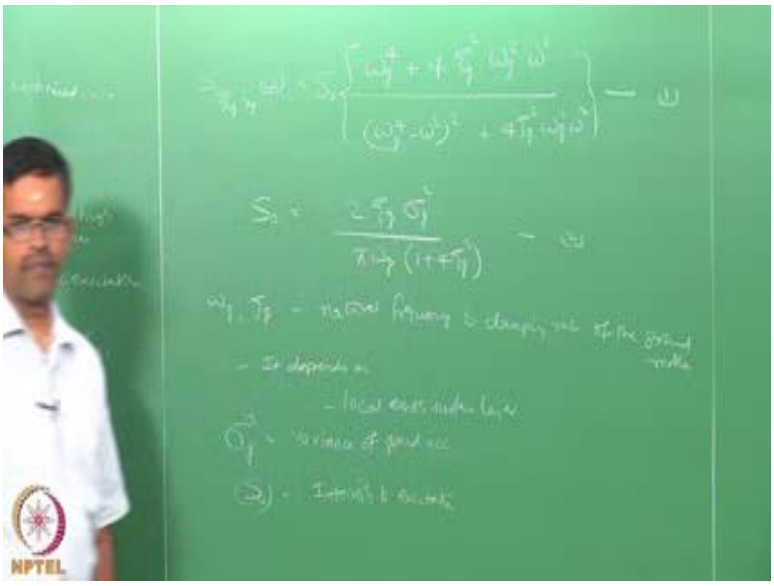

So, the one sided power spectral density function to simulate the seismic signal using Kanai-Tajimi power spectral density function is given by the equation 1, which is multiplied by S naught, where S naught is given by, in this case omega g and zeta g or natural frequency and damping ratio of the ground motion. So, determine this it depends on many factors, one is the local earth's surface layer that is one character, which lead to be actually simulated according to the real time simulation happened or real earthquake happened in one of the regions where TLP is located, sigma g square which is a variable here is actually the variance of the ground acceleration S 0 is actually the intensity of the earthquake, we should say intensity of excitation.

So, there are three parameters here. The three parameters of a K-T spectrum that is Kanai-Tajimi power spectrum are essentially omega g that is a frequency of ground excitation the damping of the ground excitation and of course, the intensity S naught.

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Now, to stimulate this you need to estimate this. So, they need to be estimated from what we call representative earthquake records, using statistical estimation process we need to use this. Now, we have in this study select an artificial earthquake is simulated in the study to match the peak velocity of the earthquake occurred. So, the occurrence was vector scale 5.8 magnitudes, the location is 250 miles west of Anna Maria Florida which occurred on 10-9-2006 at 14:56:07 this is coordinated universal time epicenter was on 26.34 North 86.57 West that is epicenter. So, that is an earthquake which occurs in one of the locations where the platform is situated.

Interestingly, there is a mars TLP which is located or operating in Mississippi canyon block, this also located at in Gulf of Mexico. So, the example was just to study what would be the safety issue rate TLP, when this TLP is subjected to or a similar TLP of this order is subjected to a combination of hydrodynamic loads arising from distinctly seaquakes, I mean, distinctly high sea waves and earthquake signals. One can ask me a question, how this is practical that a TLP is already existing and locating will be subjected to such distinctly higher order combination that is about reliability. Reliability is actually constraining the performance of the function or a system for intended performance of a function for a given period of time for a worst combination.

We are looking for a safety of the system, if this combination occurs where there is a possibility that an earthquake occurred in this location of this epicenter. So, in the study a distinctly high seaquake, I mean, sea waves are created using modified P m spectrum and here, earthquake signal was generated simulated using Kanai-Tajimi spectrum, which will now match, which I will show you which will match with that of the measured signal intensity and of course, the location is as close to the epicenter of this particular TLP.

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The actual earthquake had peak ground acceleration as 0.25 g and velocity as 0.29 meter per second. The artificial earthquake generated using Kanai-Tajimi spectrum had ground acceleration which is 0.25 to 0.39 g and velocity 0.2 to 0.3 meter per second, which is close to what we have here the frequency of motion which required for the simulation is set as 2.5 hertz for the firm ground as suggested by Nigam, 1983. The other parameters in K-T spectrum are chosen accordingly, so that the ground acceleration and the velocity which is simulated or match with the measured value. So, it is a process by which we can select the parameters such that the simulated velocity acceleration matches close with that of the actual earthquake. So, please pay attention to the figure shown on the screen now.

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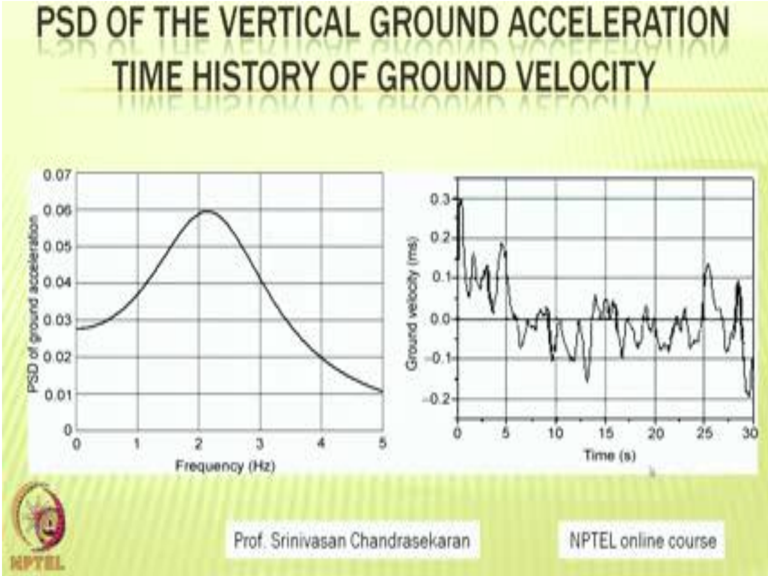

The screen on the left side shows the power spectral density function of the vertical ground acceleration. On the right side, it shows the time history of the ground velocity this is been simulated now using Kanai-Tajimi power spectrum with three parameter variation, one side of spectrum is given in the equation on the blackboard. So, the parameters chosen such a manner that the simulated earthquake refers essentially or represents, ideally the actual earthquake occur in an epicenter as shown in the blackboard here, as we understand when the simulated earthquake is imposed on the TLP for numerical study.

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We now agree that it will cause delta t, delta t that is; t is the tension variation. Therefore, the stiffness coefficients will be updated at every time instant, which now make the equation of motion completely dependent on two issues; one is the variation in the stiffness coefficient, another is variable submergence created due to the hydrodynamic loading.

So, now as we said the force vector comprises of two things; one is due to hydrodynamic loading caused by distinctly high sea waves. The second is variation in t is the tension caused by earthquake imposed on the sea bed, both horizontal and vertical. Now, we need to apply this particular loading on the TLP. So, I pick a 3 TLP's.

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Now, the study is focusing on triangular TLP is a focus whereas, mars TLP located in Mississippi canyon block is not a triangular TLP's having 4 legs. So, the study is essentially focusing on the safety or reliability, or the performance of the intended function of the system and the worst combination of loads for a specific case study, where real earthquakes are actually occurs in the same location and intensity of course, ground velocity and acceleration are found to be matching from the simulated with that of the real one. So, kindly pay attention to the example TLP properties shown on the screen.

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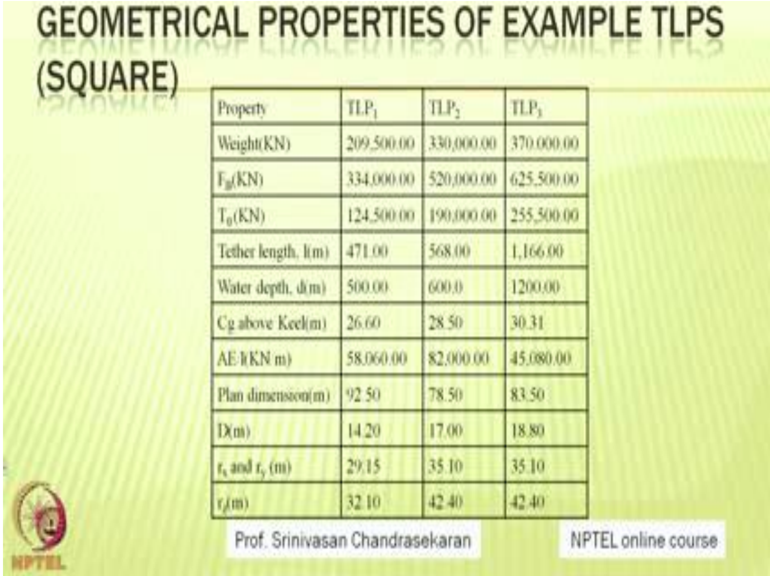
GEOMETRICAL PROPERTIES OF EXAMPLE TLPS (SQUARE)

Property	TLP_1	TLP_2	TLP_3
Weight(KN)	209,500.00	330,000.00	370,000.00
F_B(KN)	334,000.00	520,000.00	625,500.00
T_0(KN)	124,500.00	190,000.00	255,500.00
Tether length, l(m)	471.00	568.00	1,166.00
Water depth, d(m)	500.00	600.0	1200.00
Cg above Keel(m)	26.60	28.50	30.31
AE/l(KN/m)	58,060.00	82,000.00	45,080.00
Plan dimension(m)	92.50	78.50	83.50
D(m)	14.20	17.00	18.80
r_x and r_y (m)	29.15	35.10	35.10
r_z(m)	32.10	42.40	42.40

So, there are 3 TLP is taking for the study TLP 1, 2 and 3. The weight, the buoyancy initial tether, tension tether length and water depths are actually considered and shown in the figure in the tabular form. Now, all these are essentially meant for a square platform all these essentially in focus square platform. So, the square platform will have 4 legs, we need to simulate the triangular geometry which can sustain and found to be safe with that of the worst combination of hydrodynamic loading and the seismic forces caused by the Kanai-Tajimi power spectrum.

To simulate the geometric properties of three square TLPs at different water depths are compared. So, three TLPs taken from the literature are compared 2002 are compared to arrive at an equivalent triangular geometry, to arrive at that there two conditions to be maintained; one is let say the buoyancy force is essentially given by 4 t naught plus w for a square TLP whereas, this is equal to 3 t naught plus w for a triangular TLP. Let us say this triangular TLP call this equation number, let us say 2. So, one can see that t 0 in the triangular TLP is kept same as that of square TLP. So, since the total tension in triangular TLP is lesser than that kind of square TLP weight is increased.

Now, the second variation is going to be the inertia coefficient of inertia C M. This is interpolated using a second degree polynomial. So, C M of y is taken as P 1 y square plus P 2 y plus P 3 and for different TLPs the C M values which are taken are shown in the screen. Now, please look at the screen you will know the different coefficients P 1, P 2 and P 3, which are used to calculate C M as a function of depth which are used for different TLPs are given here.

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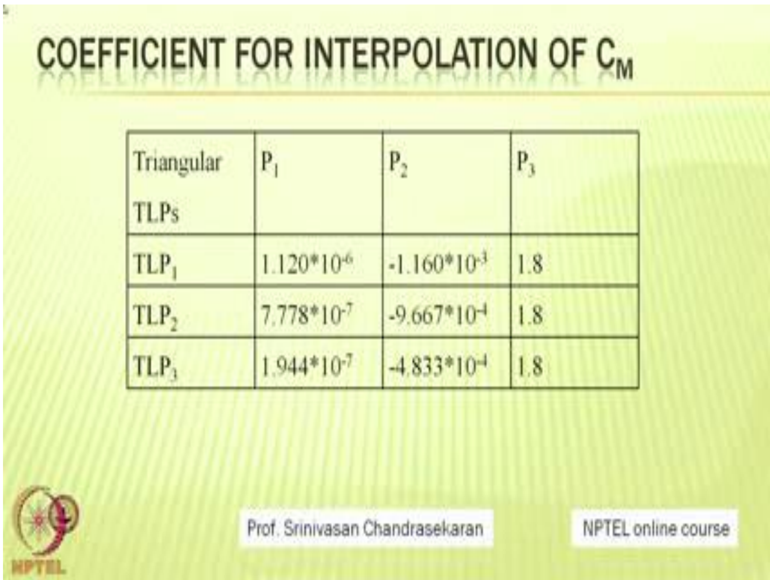
COEFFICIENT FOR INTERPOLATION OF C_M

Triangular TLPs	P_1	P_2	P_3
TLP_1	$1.120*10^{-6}$	$-1.160*10^{-3}$	1.8
TLP_2	$7.778*10^{-7}$	$-9.667*10^{-4}$	1.8
TLP_3	$1.944*10^{-7}$	$-4.833*10^{-4}$	1.8

The hydrodynamic inertia coefficient is also varied along the depth as a second order or second degree polynomial as shown in the equation here. In this case y is measured from the sea bed.

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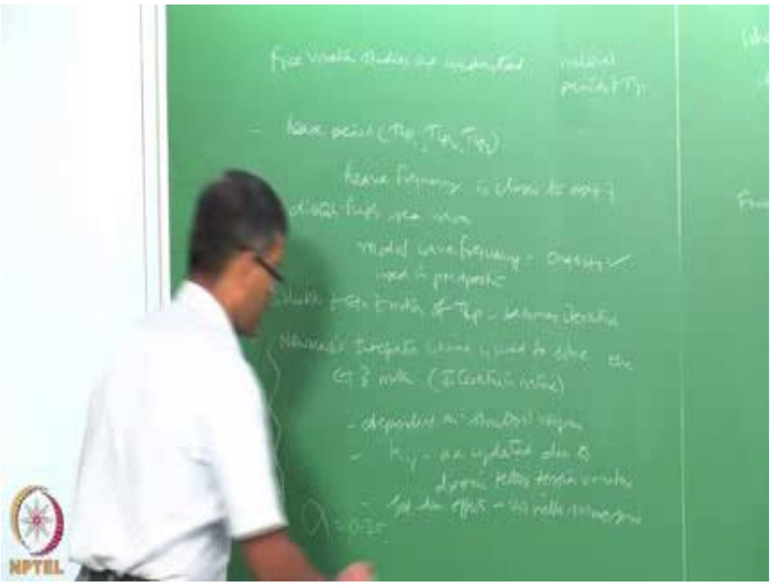

So, free vibration analysis is conducted to actually calculate the natural periods of TLP. So, pay attention to the table shown on the screen now.

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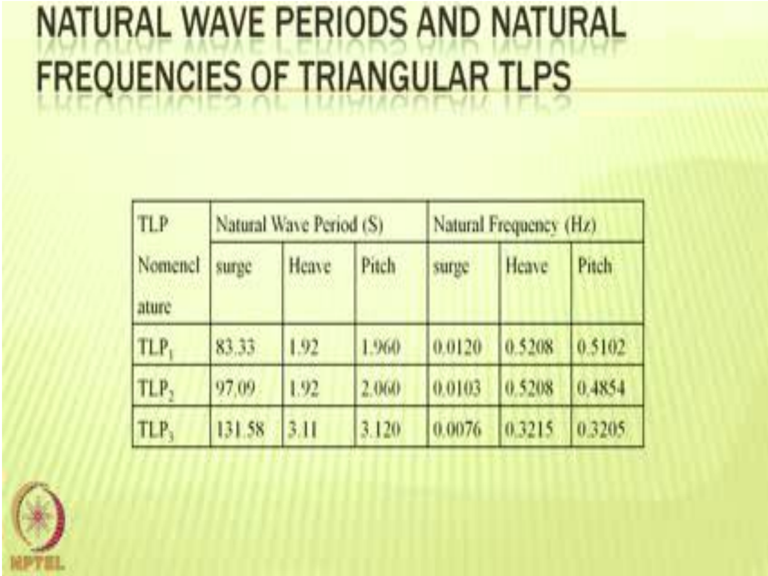

TLP Nomenclature	Natural Wave Period (S)			Natural Frequency (Hz)		
	surge	Heave	Pitch	surge	Heave	Pitch
TLP_1	83.33	1.92	1.960	0.0120	0.5208	0.5102
TLP_2	97.09	1.92	2.060	0.0103	0.5208	0.4854
TLP_3	131.58	3.11	3.120	0.0076	0.3215	0.3205

For different TLP nomenclature that is TLP 1, TLP 2 and TLP 3, whose geometric properties are shown earlier. The natural frequencies and periods in different degrees of freedom which are active for this present study are shown in the table. So, one can pay attention to the surge periods which makes a TLP highly flexible, one can pay attention to the heave and pitch periods which actually makes a TLPs stiff in this two degrees of freedom. Therefore, TLP as we all agree and understands it is a hybrid system on horizontal plane, it is flexible on in the vertical plane is very rigid.

So, the periods obtain using free vibration analysis are shown in the table here. So, interestingly, if you look at the values for the heave period of all the TLPs, if you look at the values the heave frequency is closer to that of the high sea waves or distinctly high sea waves because we know the model frequency used in the P m spectrum is 0.46 hertz used in the; if you pay attention to the values shown in the screen. Now, the heave periods are considered to be closure in terms of the frequency closure to the model frequency, which is used for simulating the hydrodynamic loads as distinctly high sea waves.

Now, equation of motion becomes iterative, the solution becomes iterative solution of equation of motion of TLP and are the combination of hydrodynamic and earthquake loads becomes iterative. So, Newmark integration scheme is used to solve the equation of motion which is iterative in nature, why because of two reasons, one is; it is dependent on structural response, two; the stiffness coefficients are updated due to dynamic tether tension variation, third because of set down effects which is variable submergence.

Therefore, the Newmark with integration scheme has a specific value in the study alpha is taken as 0.25 and delta is taken as 0.5. For this scheme the reference could be Bathe and Wilson, 1987.

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So, various nonlinearities are present in the system, one; it can arise from change in stiffness coefficients which is caused because of delta t, which is essentially caused due to earthquake excitation. The second could be the added mars term which is due to variable submergence effect. The third could be the set dawn effect. The fourth could be evaluation of hydrodynamic forces at instantaneous displaced position of t that is response dependence.

The non-linearity arises from these following cases. So, one can easily understand here that the dynamic tether tension variation caused by the seismic excitation is an important factor influencing the response of TLP. The two in the presence of distinctly high sea wave, the event can be considered as a critical combination which becomes input load for the reliability analysis.

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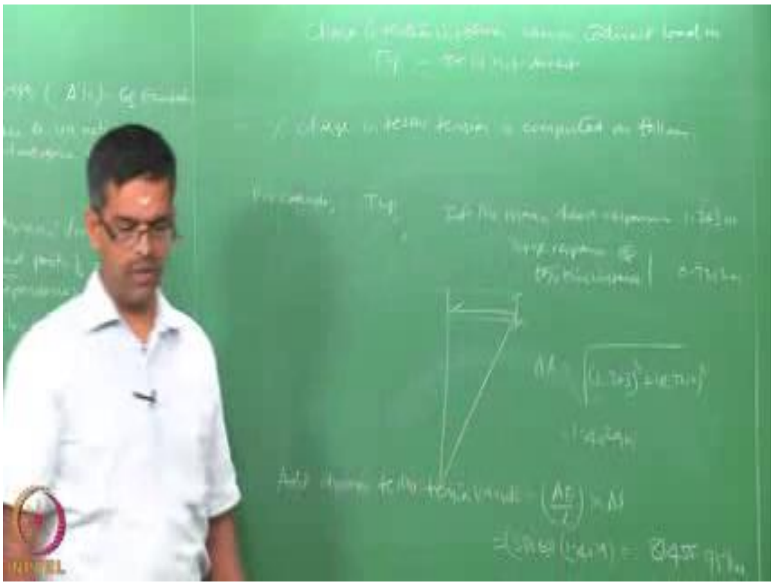

So, one can see here the change in tension in tethers causes indirect load on TLP. It is not direct because TLP does not rest on the sea bed. Please pay attention to the response summary of the triangle TLPs after the equations of motions are solved in the Newmark integration scheme as discussed just now.

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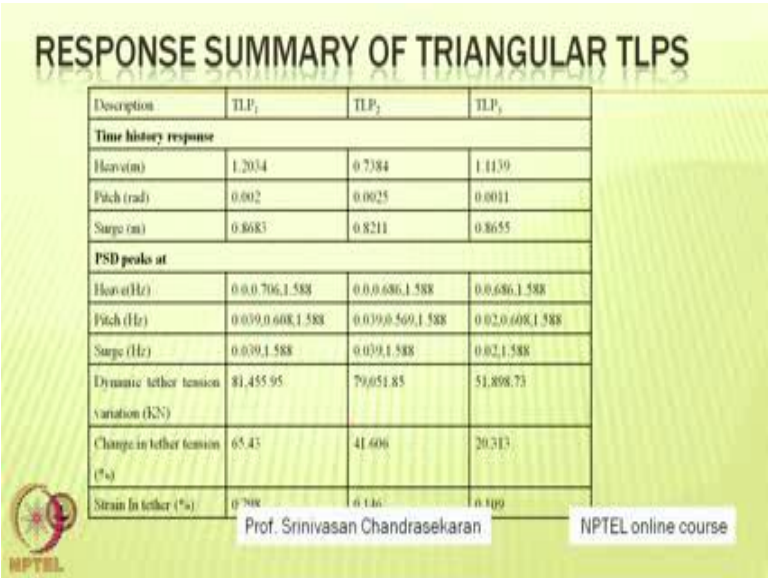

Please pay attention to the value shown on the screen. Now, see TLP's; TLP 1, 2 and 3 are listed here, both time history response are given for heave pitch and surge degrees of freedom. So, one can see here that the power spectral density peaks in heave occurs at difference frequencies for pitch at different frequencies, and surge at different frequencies as seen here for the three TLPs. There is an interesting common less between the peaks occurred in all the degrees of freedom. This peak of 1.588 is seen in almost all degrees of freedom, it is almost seen in all TLPs.

Please understand these TLPs are actually simulated TLPs having similar characteristics as that of a 4 legged TLPs. Of course, with three legs interpreting with a set t 0 and greater weight, we are looking for a stability of the geometric configuration of triangular compared to that of square, and to the worst combination of forces that is example problem what we are looking at now. So, one can see here that the peak occurring at 1.588 hertz is seen in almost all degrees of freedom, in the response in all TLPs and one can also see the dynamic tether tension variation caused by the seismic excitation forces imposed on the tether connectivity causes change in tether tension as highest 65.43 percent compare to the initial pretension and 20 percent is the minimum value. It also imposes strain in the tethers varying about 0.298 percent and as low as 0.109 percent strain in the tethers.

Kindly pay attention the response time history under the seismic forces and distinctly a sea waves.

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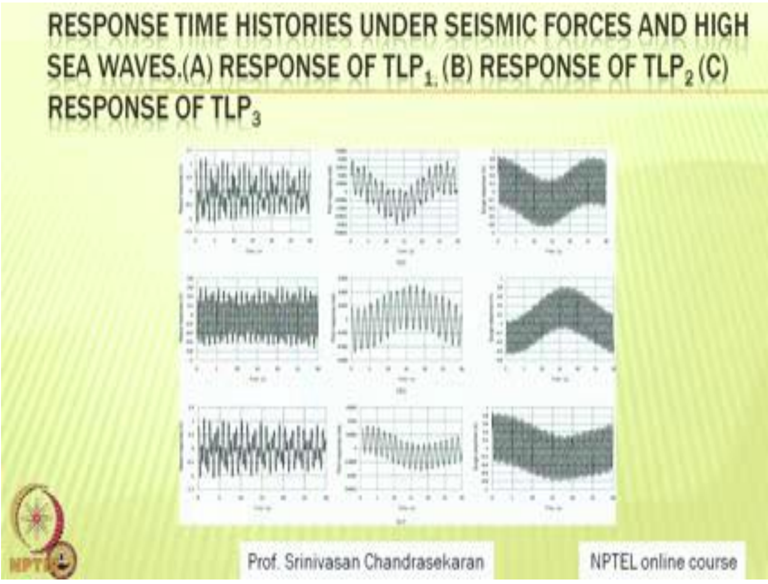

There are three set of figures here, first set shows for TLP 1, second set for TLP 2, third set for TLP 3. For our understanding TLP 1, 2 and 3 are located at different water depths as shown in the previous table earlier. So, one can see here the heave responds the pitch and surge response of TLP’s 1, 2 and 3 respectively on the screen as shown, which is now on to the combination of seismic forces caused by Kanai-Tajimi spectrum simulated and with that of the distinctly high sea waves simulated using modified K-T spectrum the whole problem is solved in iterated scheme is a Newmark integrated technique as explained just now.

So, looking at this variation one can see the following, the percentage change in tether tension is computed as follows, for example, let us say in case of TLP 1, if the maximum heave response is 1.203 meters and the surge response at this time instance is 0.7212 meters. Let us say the heave response for this is known the surge response also known at the specific time. So, change in length delta l is actually taken as sum of square root of this squares which is 1.203 square plus 0.7212 square that gives me the change in length, which is in this case 1.4029.

Once you know the additional dynamic tether tension variation can be simply a e by l of that particular value multiplied by this delta l. So, for example, in this case is going to be, 58060 multiplied by 1.4029. So, the additional tension variation is going to be 81455.95 kilo, that is how it is been calculated.

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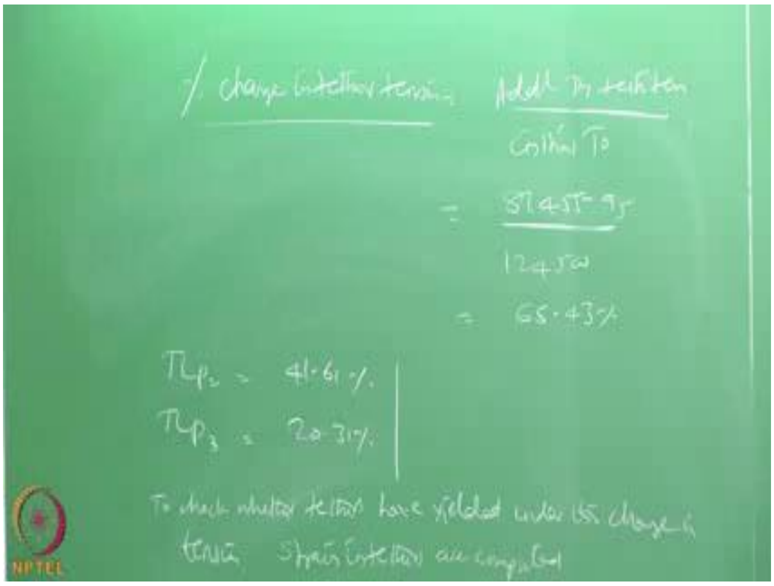

Therefore percentage change in tether tension is simply the additional dynamic tether tension divided by initial t naught. So, that is going to be 81455.95. Let us say, divided by 124,500 that is the initial t naught which is amounting to 65.43 percent that is what we have showed in the table as the percentage tether tension variation.

Similarly, for TLP 2 this value is 41.61 percent and for TLP 3 this value is calculated as 20.31 percent. Now, one is also worry whether the tethers are yielded or not. So, to check whether tethers have yielded under this change in tension, we have also plotted this strain in tethers are computed and table shows the values strain also as you can see from the table. So, one can easily infer the following.

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The dynamic tether tension variation is reduced considerably with increase in water depths because you know TLP 1, 2 and 3 are for different water depths, but interestingly this variation is neither proportion to change in water depth nor initial t 0. So, the results can be super imposed in terms of power spectral density plots. Please pay attention to the power spectral density plots shown in the screen now.

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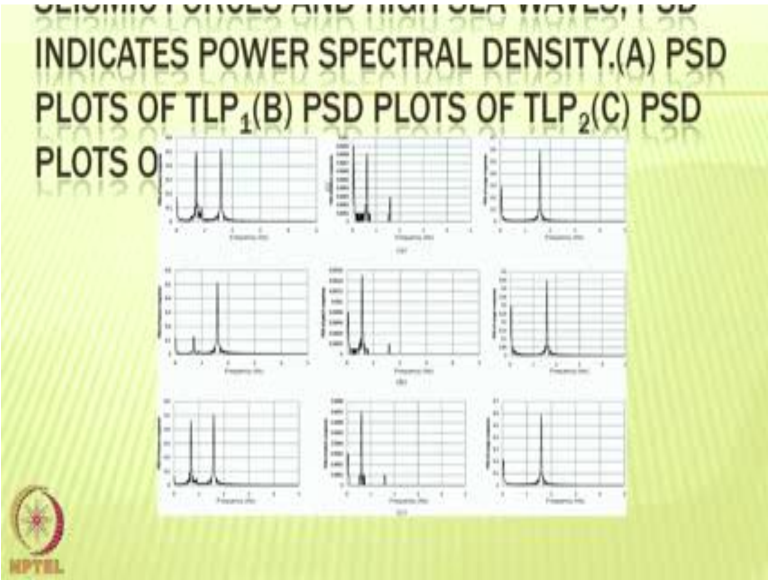

For different TLPs 1, 2 and 3, one can easily see in all the cases in heave responds that is in TLP 1 there are two peaks occurring, one is about 1.5881 is of course, around 0.675 of course, the 1.588 in all the cases. We can see the peak is occurring in all the cases; TLP 1, TLP 2 and TLP 3 whose summaries also shown in the table.

The power spectral density function are the curves the PSD plots which has been shown for different TLP shown that at a frequency of 0.5 hertz, approximately 0.5 hertz, one can see a peak, in general it can be seen that all degrees of freedom shows high frequency response and there is no visible damping effects because response raised on with time frequency responses are narrow banded with energy concentration as follows, one the heave response is shown at three distinct peaks, one is at 0 frequency close to 0 frequency which is very small therefore, can be neglected.

The other is at mid frequency which is very close to the natural frequency of let say, TLP 1 and TLP 2 at least and it is double of the frequency of the natural frequency for TLP 3. There is a peak which occurring at 1.588 hertz which is very near, very close to the average peaks of Kanai-Tajimi spectrum and P as spectrum.

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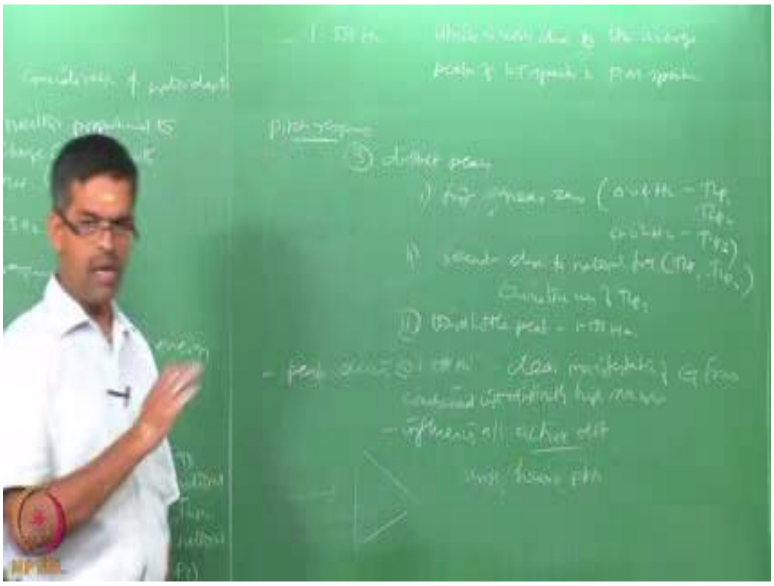

If you look at the pitch response, again it shows three distinct peaks. One occurring the first one close to near 0, which is 0.04 hertz for TLP 1 and TLP 2; 0.02 for TLP 3. The second one occurs close to natural frequency for at least TLP 1 and TLP 2 and twice the natural frequency for TLP 3. The third little peak occurs at 1.588 hertz with average of P m and K-T spectrum. So, it is very interesting the peak occurring at 1.588 which would have been missing when this combination of study is a clear manifestation of earthquake forces combined with distinctly high sea waves.

This is influencing all activity, degrees of freedom. What you mean by activity degrees of freedom? The platform actually has only unidirectional wave acting. So, only certain degrees of freedom are active, one we surge other is heave, another is pitch the remaining degrees of freedom likes wave roll and yaw will be absent because of symmetry or because of wave not present in the direction predominantly.

So, only activity degrees of freedom which are present in the system are influenced by the critical combination of earthquake forces and the distinctly high sea waves, which is brought out in the specific study interestingly, if you look at the phase plots shown in the screen now.

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Friends; the flay phase plots are shown for a combination of distinctly high sea waves and seismic forces imposed for all three TLP's; TLP 1, TLP 2 and TLP 3. So, looking at the phase plots one can say, and looking at the PSD values one can say is narrow banded and TLP's lesser excited because of greater water depth, the system is negligible. For higher frequency responses phase plots being elliptically in nature a firm that all states are stable and periodic. So, for a given combination of distinctly sea waves and earthquake force is generated. One can check the stability and safety of a given system and the worst combination, and the phase plot shown as a typical response of a TLP for this particular combination of forces shows they are elliptically in nature, which confirms that all states are stable and periodic of course, the period is longer because the major axis, the ellipse is longer.

So, from the example study one can easily understand that dynamic tether tension variation can be checked under excessive or exceptional combinations to check, whether this combination would cause challenge for safety of the given system, clearly the peak seen in the response in all three freedom namely, heave, pitch and surge occurring at the average some frequencies of P m spectrum and k g spectrum. It is a clear manifestation of this combination, while TLP's are expected to be rigid in stiff degree of freedom. In this specific case, one can see that heave is activated even at 1.58 hertz frequency which is very dangerous for a given system because heave is supposed to be the stiff degree of freedom. So, displacement in heave degree caused by the seismic excitation in combination, we distinctly a sea waves is actually an interesting challenge study which tells me whether the platform geometry is stable and safe under this given combination.

So, reliability study can be also examined indirectly by checking the stability or safety of the platform as we saw in two examples studies. The first case of stability in example 1, the second case is a worst combination where we are checking for the safety of the system using phase plots. I hope these two application problems are interesting and you understood the application of reliability with these problems.

Thank you very much.