Offshore structures under special loads including Fire resistance

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Lecture – 19
Earthquake Loads- III

Friends we will continue with the discussion on offshore structures under special loads, now we are considering earthquake loads. This is lecture 19, titled earthquakes loads section 3; where we will continue to discuss the problem what we discussed in the last lecture.

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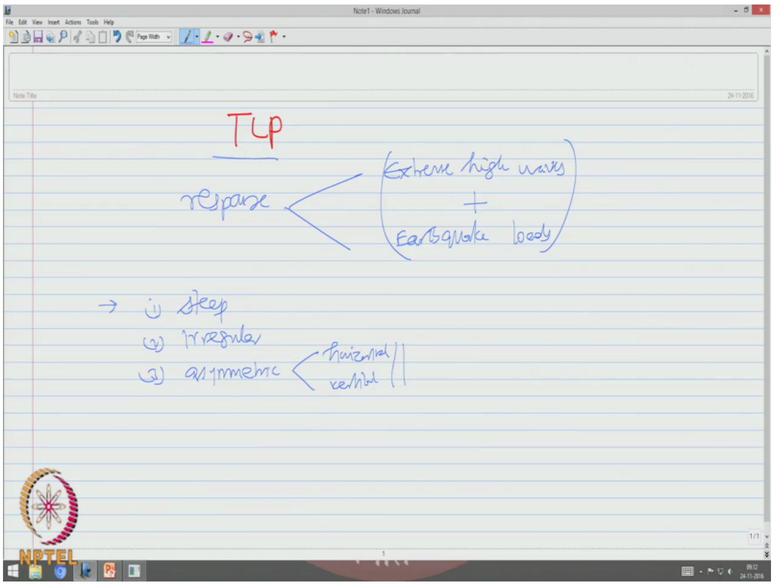

We are looking for a compliant system, we are taking an example of a tension leg platform, where we are looking for the response of the platform under 2 cases in parallel; one is extremely high waves, other is earthquake forces when they act together, what happens to my compliant system? We deliberately picked up a compliant structure which has got 2 set of bands of frequencies, one being very flexible one being highly stiff, we would like to see the response of this platform under the combination of these forces.

We already said that extremely high sea waves are qualified to be so - one, they remain steep; two, they remain irregular; three, they remain asymmetric both about horizontal and vertical axes.

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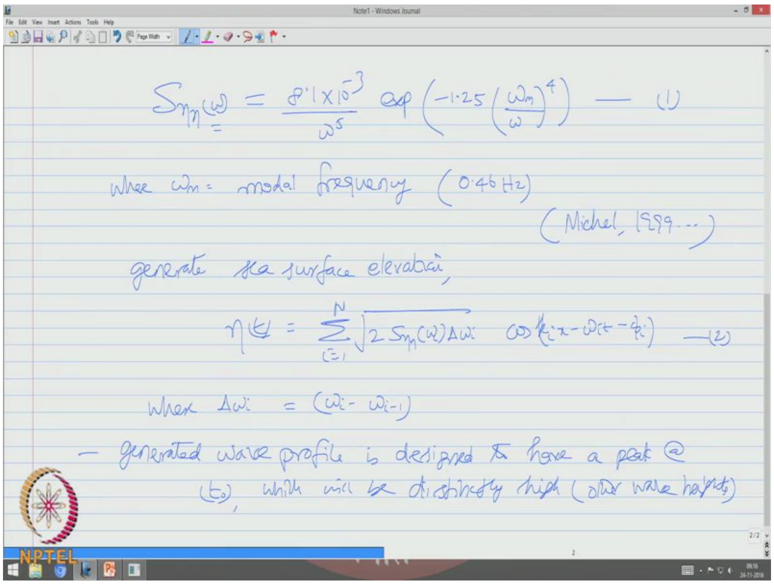

So, we said in the last lecture we can use the modified Pierson Moskowitz spectrum to generate the sea surface elevation with one parameter, which is given by the equation which I am now writing.

Where omega m is called modal frequency; in this study we will take this value as 0.46 hertz. So, the only variable the one parameter equation is omega as given by Michel 1999 etcetera. Once I have this spectral power spectral density function of the sea surface elevation, I can generate extremely high sea wave sea surface elevation using the following equation which is given by eta of t, as discrete sum of many sinusoidal functions, the different angles of frequencies and random phase angles.

So, I equals 1 to N 2 S eta omega i delta omega i, cos 6 minus omega t, minus phi i equation number 2. Where delta omega i is the space interval of the discrete frequencies which is given by omega i minus omega i minus 1; the generated wave profile is designed to have a peak at a particular time t naught, which will be distinctly high in comparison with other wave heights.

So, using this let us see how we have generated the sea surface elevation.

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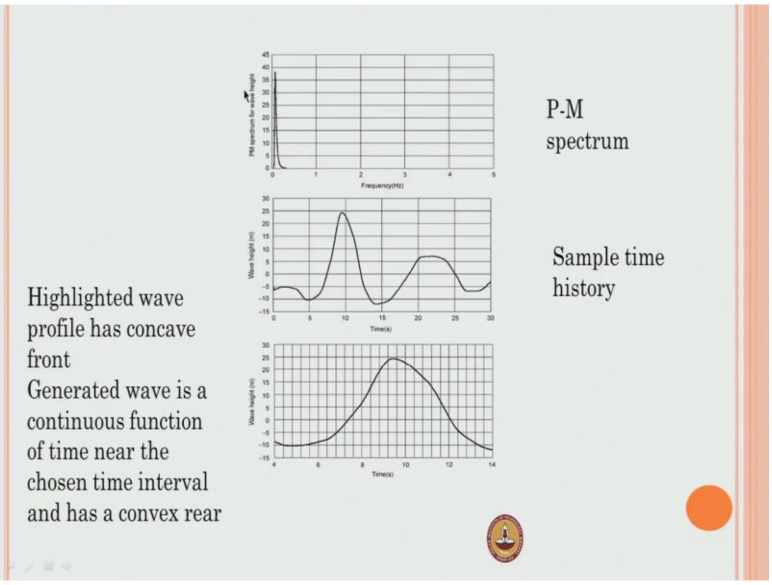

So, this is the particular P-M spectrum, which gives me the power spectrum density function, using that from the equation shown we have generated the sea surface elevation which is asymmetric both about horizontal axis and about the vertical axis. If you look at blow up one specific case where there is a distinctly high sea wave in terms of its height compared to the predeceasing and successing waves, I call this as distinctly high sea waves if you blow it up it has a concave front and a convex rear. So, it is asymmetric wave generated to be qualified as distinctly high sea waves.

Once sea surface elevation is generated we need to have an example problem, we are also looking for some geometric optimization in the form based design.

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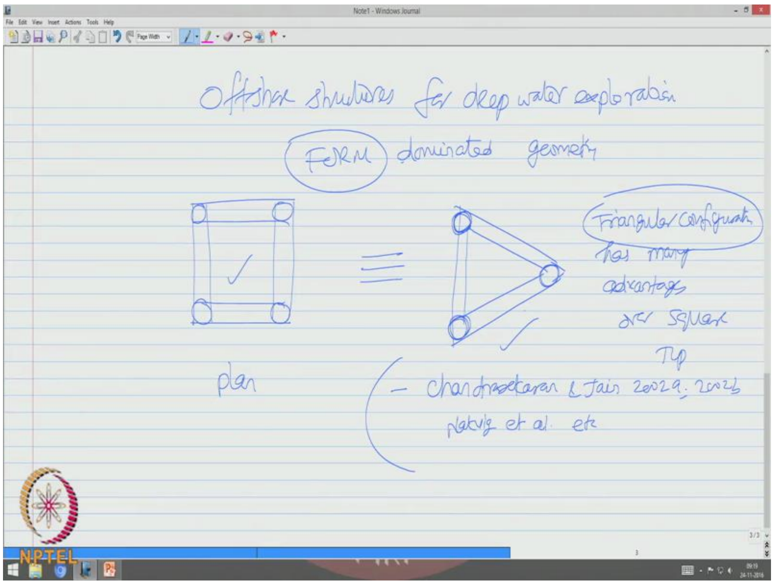

We already said that offshore structures for deep waters are essentially form dominated geometry. So, in that case instead of having a square tension leg platform with all the column members at the intersection that is the plan of the platform, we are looking for an equivalent triangular geometric configuration with only 3 legs.

So, now we are also trying to see whether the optimization can happen in terms of its geometric form, because triangular geometric configuration has many advantages over a square geometry, one can refer into papers of Chandrasekaran and Jain 2002 a, 2002 b, Natvig et al etcetera. Please look at the references for understanding the advantages of a triangular configuration geometry compared to a typical square platform. So, in this study we expose the distinctly high sea waves and earthquake loads to a triangular form geometry and see the response behavior of this platform therefore, the fundamental question comes now is how to arrive at this geometry?

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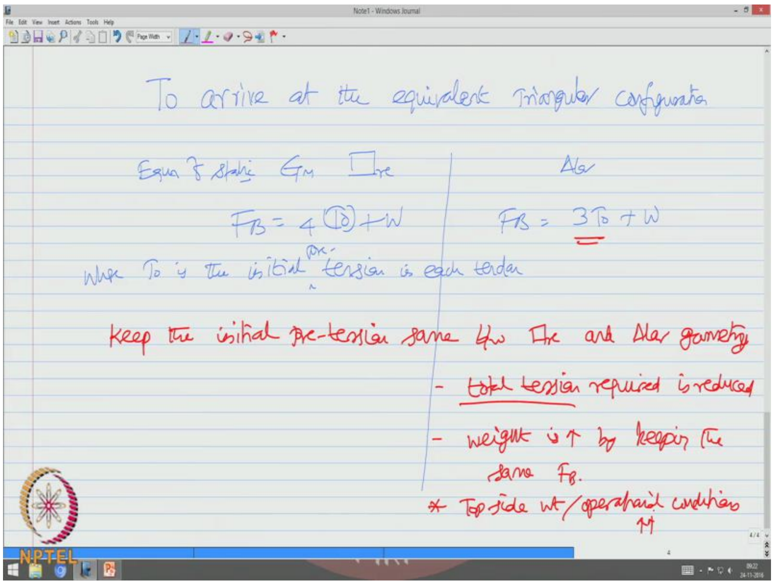

At the say let us say equivalent triangular configuration, there can be 2 bases let us look at the equation of static equilibrium of a TLP. So, buoyant sea force is actually T 0 plus W; if I say this is square and this is triangular then I should say 4 T 0 and let me say this as 3 T 0 plus W, where T 0 is the initial tension I should say initial pre-tension in each tendon. So, there are 4 legs here therefore, 4 T 0, there are 3 legs here therefore it is 3 T 0.

For arriving at the equivalency let us keep the initial pre-tension same between the square and triangular geometry. So, the inference is total tension required to hold the geometry in position of the platform in question is reduced in triangular configuration, because T 0 initial is same therefore, is 3 T 0 whereas, it is 4 T 0 here, which means that the total tension in the triangular platform is reduced.

So, to compromise this, weight of the platform is increased by keeping the same buoyancy force. So now, there can be a small advantage here, the top side weight or operational conditions in terms of machinery can be slightly higher in this platform compared to that of a square TLP. So, equivalent geometry of 3 TLPS’s are worked out let us see how are they been arrived at? What are the geometric characteristics?

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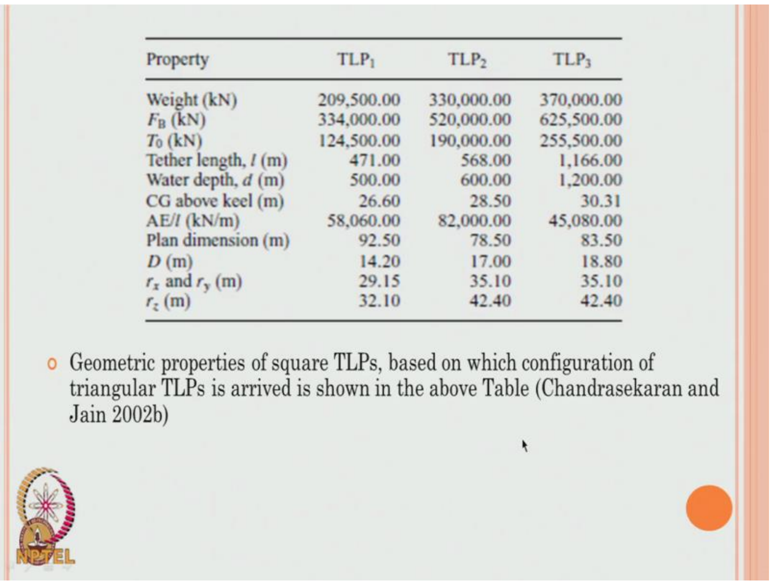

Property	TLP_1	TLP_2	TLP_3
Weight (kN)	209,500.00	330,000.00	370,000.00
F_B (kN)	334,000.00	520,000.00	625,500.00
T_0 (kN)	124,500.00	190,000.00	255,500.00
Tether length, l (m)	471.00	568.00	1,166.00
Water depth, d (m)	500.00	600.00	1,200.00
CG above keel (m)	26.60	28.50	30.31
AE/l (kN/m)	58,060.00	82,000.00	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

- Geometric properties of square TLPs, based on which configuration of triangular TLPs is arrived is shown in the above Table (Chandrasekaran and Jain 2002b)

A square TLP was already analyzed, for which equivalent configurations of triangular TLP are then arrived depending upon the basis what we discussed in the last slide. There are 3 TLP's with configuration TLP 1, 2 and 3 all these 3 TLP's are triangular configuration of different weights, of different buoyancy, of different T zeros because the water depth in all the 3 cases are different. TLP 1 and TLP 2 may have a marginal same depth whereas; TLP 3 is practically double of its water depth compared to TLP 1 and TLP 2. So, TLP 3 is a deepest equivalent platform compared to TLP 1 and 2 and all the 3 configurations of triangular TLP's are arrived on the basis what we discussed in the last slide, from the standard square TLP which are referred in this paper in ocean engineering journal.

So, all other structural parameters which are equivalently worked out for the TLP to become operational and stable are available on the screen now. So, interestingly one would like to look at the basic structural parameters of this equivalent TLP.

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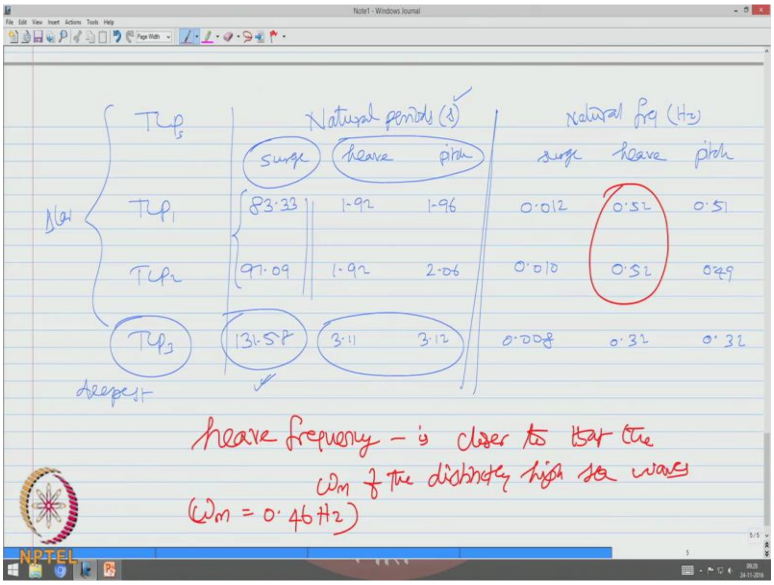

So, all the 3 TLP’s are done with free vibrational analysis and natural periods are worked out and also natural frequencies in hertz. So, we are looking for unidirectional wave therefore, we consider only let us say the search, heave and pitch degrees of freedom.

Let us look at all the 3 TLP’s; TLP 1, TLP 2 and TLP 3. TLP 3 is the deepest compared to 1 and 2; 1 and 2 operate mostly on the same water depth. So, this was found out to be 83.33 1.92 and 1.96 in seconds and TLP 2 was 97.09, 1.92 and 2.06. One can see very clearly there is no much difference between these 2 TLP in terms of its natural periods, in surge heave and pitch one can also see very clearly from here that surge degree is highly compliant because of large periods low frequency, highly flexible whereas, the platform remains highly stiff in the vertical plane because the heave and the pitch periods are very very low.

On the other hand if you look at TLP 3, which is proposed to operate at double the water depth of TLP 2 and 1, the periods are still highly flexible it becomes 131.58 and 3.11 and 3.12; the same characteristic is still maintained being very highly flexible, being very stiff in vertical plane. So, correspondingly one can also find out the natural frequencies of these periods in terms of hertz, for our understanding let us fill up these values also which can be easily computed as the ratio connecting between t and hertz 0.52 and 0.49, 0.008, 0.32 and 0.32.

So, now we have a clear understanding about the natural periods of all the equivalent triangular TLP's, which are derived from the basic form of a square TLP by maintaining the basis that initial pretension between the triangular and square TLP of equivalency are kept same. So, one can very clearly see from this table that, the heave frequency which you can see here is closer to that of the modal frequency of the distinctly high sea waves, if you remember the value we said the modal frequency used in the present study is 0.46 hertz.

Interestingly friends please look at this example very carefully, the modal frequency of the distinctly high sea wave is chosen in such a form that, we want to excite the stiff degree to the maximum and we want to see whether the platform remains safe and stable when a heave degree is being excited under the distinctly high sea waves and earthquake loads.

One may ask a fundamental question why we are interested in checking the heave degree there are many reasons for this.

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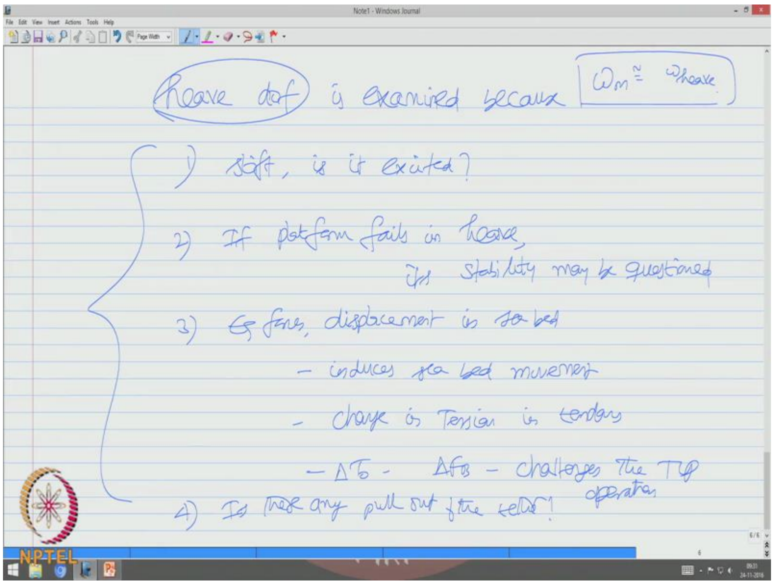

Heave degree of freedom is examined because of the following reasons- the foremost reason is heave being stiff degree is it excited? We want to look into that first. Secondly, if the platform fails in heave, its stability may be questioned; thirdly we are looking for earthquake forces which causes displacement in sea bed and this displacement induces sea bed movement and sea bed movement causes change in tension in tendons, because tendons are the only component which connects the super structure to the sea bed, this change in tension will induce change in buoyancy because of the stability problem, which now challenges the TLP operation, further is there any pullout of the tether.

So, these are the reasons why heave degree is being closely examined, what do you mean by closely examined? We have picked up omega model as close to that of heave frequency of the equivalent triangular TLP frequency platform.

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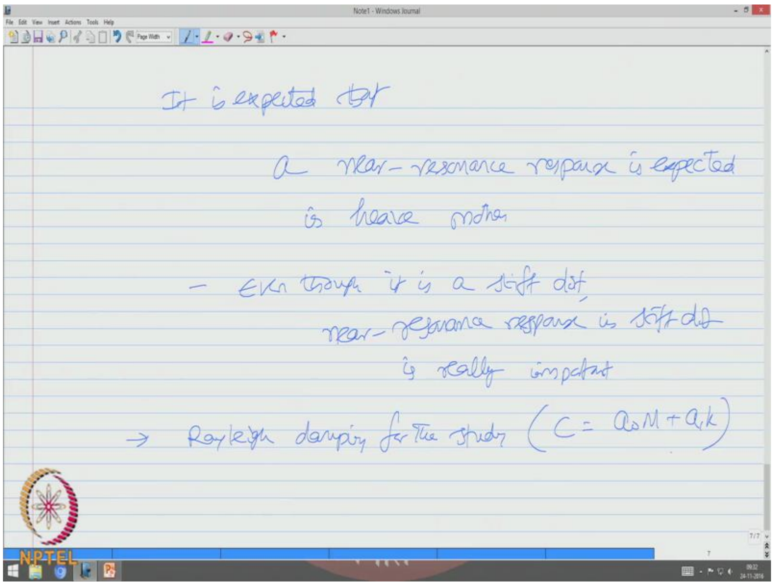

Having said this therefore, it is expected that a near resonance response is expected in heave degree of freedom, interestingly even though it is a stiff degree; resonance response in stiff degree is really interesting, this is near resonance system. So, already we said that we are using Rayleigh damping for the study which is actually part of mass plus part of stiffness.

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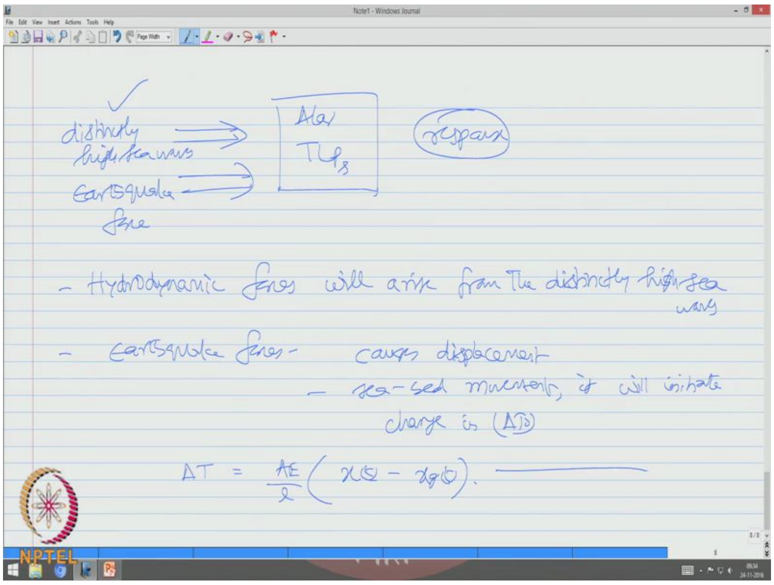

Now, interestingly let us say I have a model, which is a TLP in my case it is a triangular TLP. In fact, triangular TLP's we have got 3 models; TLP 1, TLP 2 and TLP 3 we are going to excite 2 kinds of forces on this; 1 distinctly high sea waves where we say that the wave height at the specific time t naught is distinctly high compared to the preceding and the successive waves, which will be asymmetric both about vertical and horizontal axis it will be irregular as well.

The second force which is going to be applied on this in parallel is earthquake load; I would like to see the response of the system. Now the question comes we have already said how we are going to generate the distinctly high sea waves using one parameter modified Pierson Moskowitz spectrum and equivalently generated numerical model of sea surface elevation using as definite series of sinusoidal waves with different phase angles.

Now, let us talk about the earthquake forces; we said that the hydro dynamic forces will be arise or will arise from the distinctly high sea waves, in addition earthquake forces need to be implemented. Now earthquake actually causes displacement is it not, we already said that it causes displacement. So, because of the sea bed movement it will initiate change in tension. So, this change in tension delta T should be given by x of t minus x g of t.

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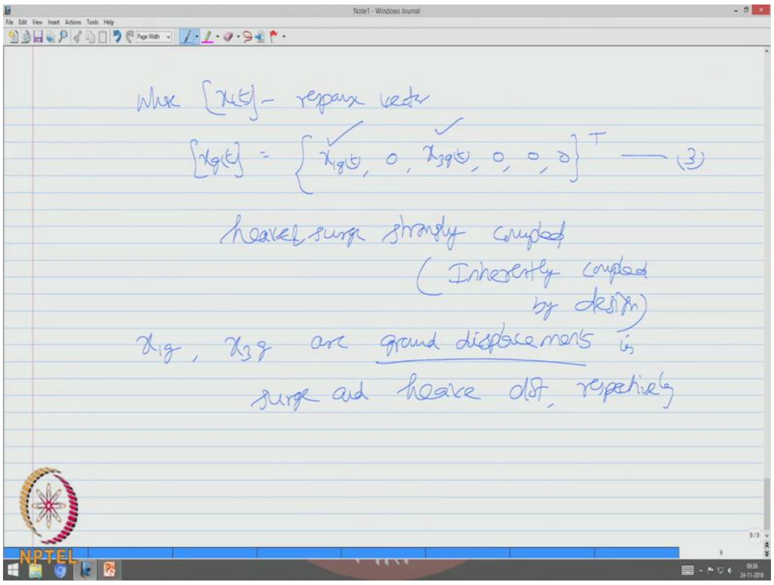

Where x of t is the response vector of the platform and x g of t is actually given by x 1 g of t, 0, x 3 g of t, 0, 0 and 0 transpose.

So, I am looking for earthquake forces in terms of displacement in the surge degree and heave degree. So, let us recollect why we are looking only these 2 degrees of freedom, is very clear that heave and surge are strongly coupled. In fact, I should say there are inherently coupled by design, we have no choice of eliminating either one of them when you look at on the other hand, if we give a force in surge degree automatically there will be a force generated in heave degree and vice versa.

So, x 1 of g and x 3 of g are actually the ground displacements; please understand we are not looking at the forces ground displacements in surge and heave degree of freedom respectively.

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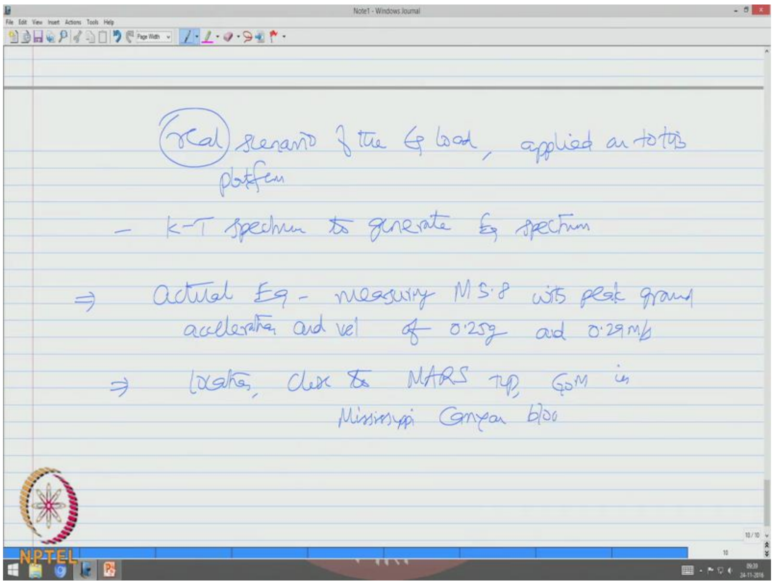

So, one will be interested to know what is the real scenario of the earthquake load applied onto this platform. So, one can actually use the K-T Kanai Tajimi power spectrum to generate the earthquake loads earthquake spectrum.

So, one need to compare the reality between the forces generated and what actually happened in the real sea state. If you look at the screen now you will see that this gives me the power spectral density function of the generated ground acceleration and the corresponding ground velocity respect to time history, which has been generated using the Kanai Tajimi power spectrum. It is interesting to know these facts there was an actual earthquake measuring mercury scale 5.8 with a peak ground acceleration and velocity of 0.25 g and 0.29 meter per second. This actually happened in a location very close to MARS TLP in Gulf of Mexico in Mississippi Canyon Block.

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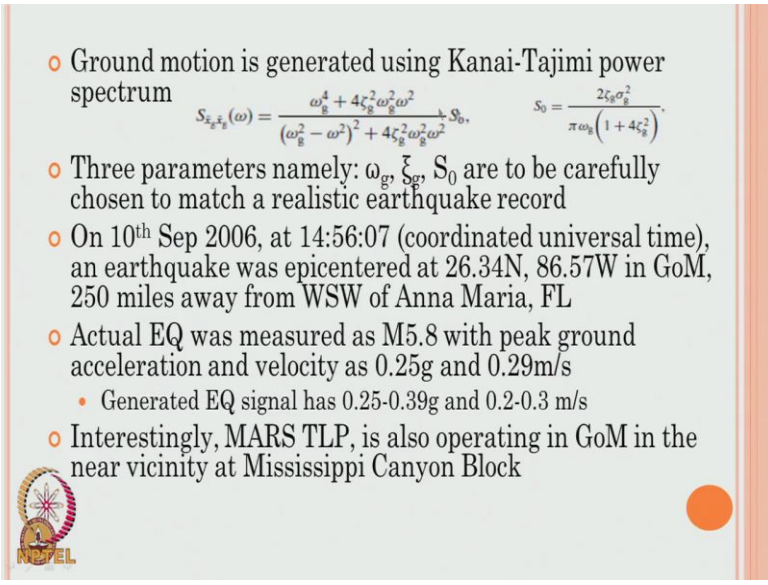

The ground motion generated is in Kanai Tajimi power spectrum is given by this equation, where the power spectral density function of the ground acceleration is given by this equation, where S 0 is what we call as an intensity parameter. So, now, this particular equation is to be actually chosen with 3 requirements.

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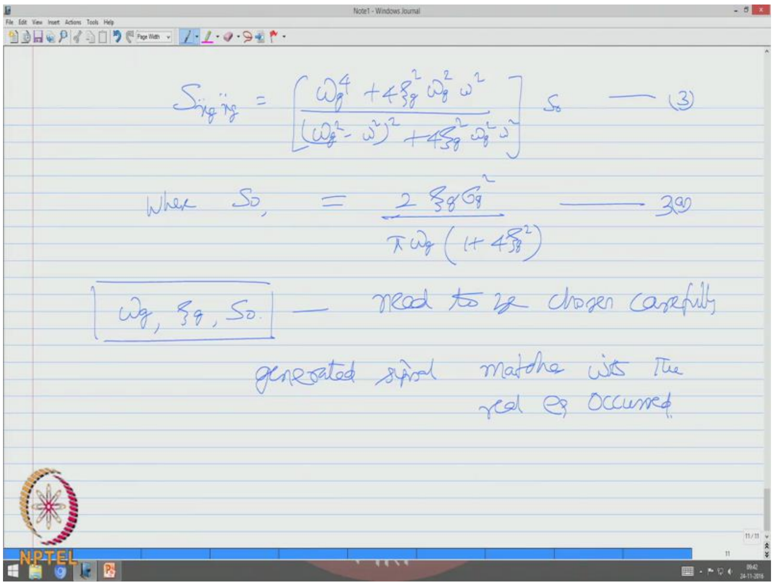

So, the ground acceleration is given by this equation; plus 4zeta g square, omega g square, omega square multiplied by the intensity factor S 0, where S 0, is actually given by 2 zeta g sigma g square by pi omega g, 1 plus 4 zeta g square.

So, there are 3 parameters based on which the spectrum can be generated, we have to chose this parameter very carefully. What are those parameters? Omega g that is the first parameter we need to select carefully; second is zeta g and third is s naught. So, these are the 3 parameters which need to be chosen carefully, so that the generated signal matches with the real earthquake occurred.

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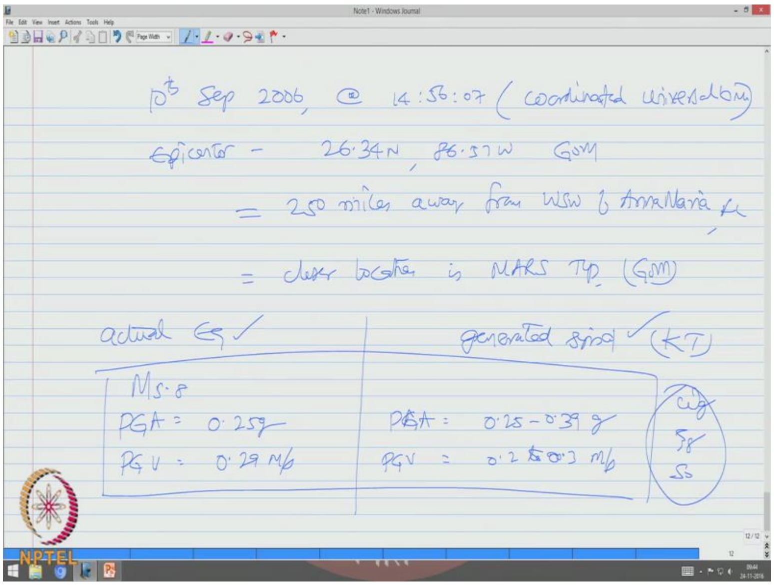

So, the real earthquake occurred on 10th September 2006, at 14: 56: 0.7, which is coordinated universal time, the epicenter happened in 26.34 north, 86.57 west in gulf of Mexico which is exactly about 250 miles away from WSW of AnnaNaria Florida, this is the closer location where a closer location is mass TLP, which is located in gulf of Mexico in Mississippi Canyon block.

Now, let us look at the statistics; the actual earthquake and generated signal. It is mercalli 5.8 with peak ground acceleration as 0.25g and peak ground velocity as 0.29 meter per second, a generated signal has the peak ground acceleration as 0.25 to 0.39 g and peak ground velocity 0.2 to 0.3 meter per second. So, one can see here very closely there is a relationship between the generated signal using the Kanai Tajimi power spectrum and the actual earthquake and this was achieved by carefully choosing the 3 parameters the ground frequency, damping and S naught as we saw in the earlier equation.

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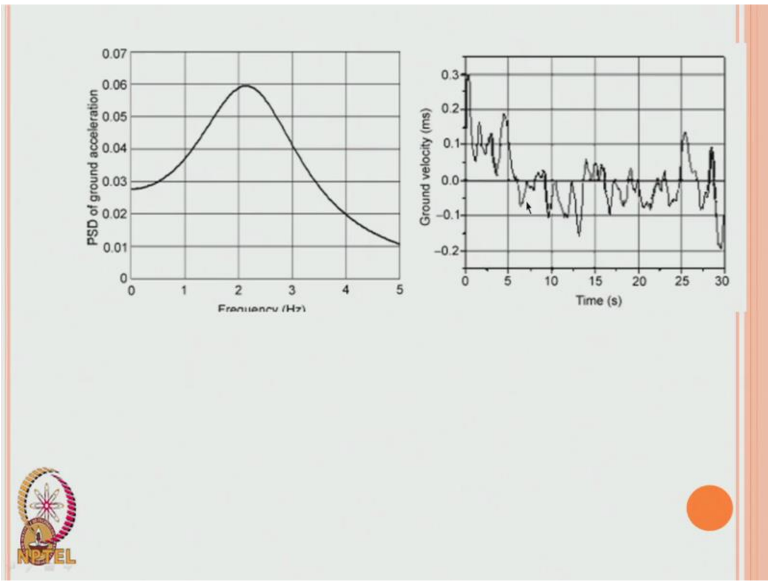

The generated signal typically looks like this; this is the power spectral density of the ground acceleration and the corresponding ground velocity time history, which has been generated using the equations shown to you in the earlier slide.

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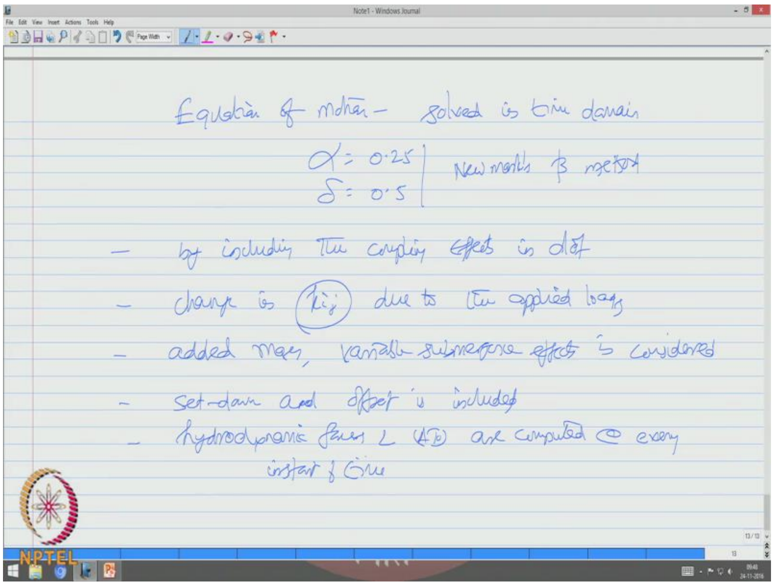

So, equation of motion is actually solved in time domain with alpha as 0.25 and delta as 0.5, we have used a new masks beta method integration scheme to solve this problem. The problem was solved by including the coupling effects in degrees of freedom, by accommodating the change in k i j due to the applied loads because you know it is a fixed co-efficiency depends on the response and the response changes because of change in tension therefore, k i j the stiffness coefficient is updated during the iteration scheme. Also added mass terms because of variable submergence effect is considered and included in the analysis, a coupling between set down and offset is included and hydro dynamic forces and change in tension are computed at every instant of time because they keep on changing as you see from the time history variation.

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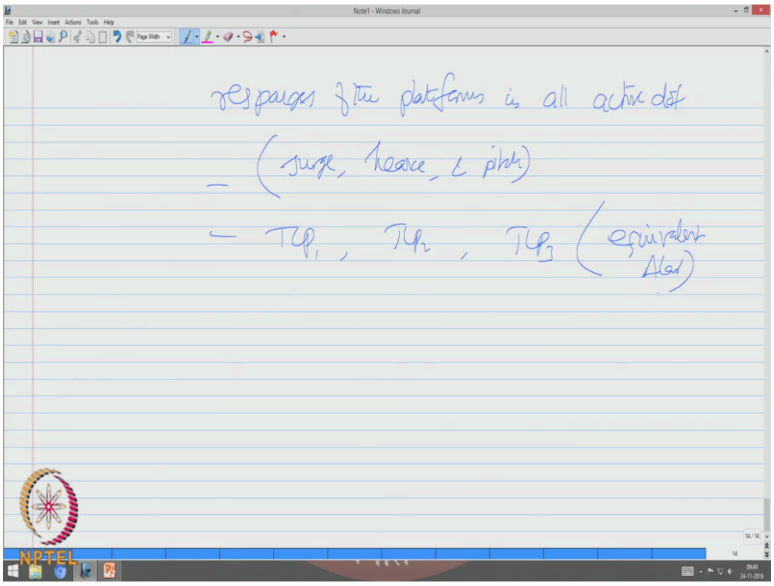

Let us now look at the responses of the platform, rather the platforms in all active degrees of freedom. Active degrees of freedoms are surge, heave and pitch. The platforms considered are TLP 1, TLP 2 and TLP 3 which are all equivalent triangular geometry to that of a square platform.

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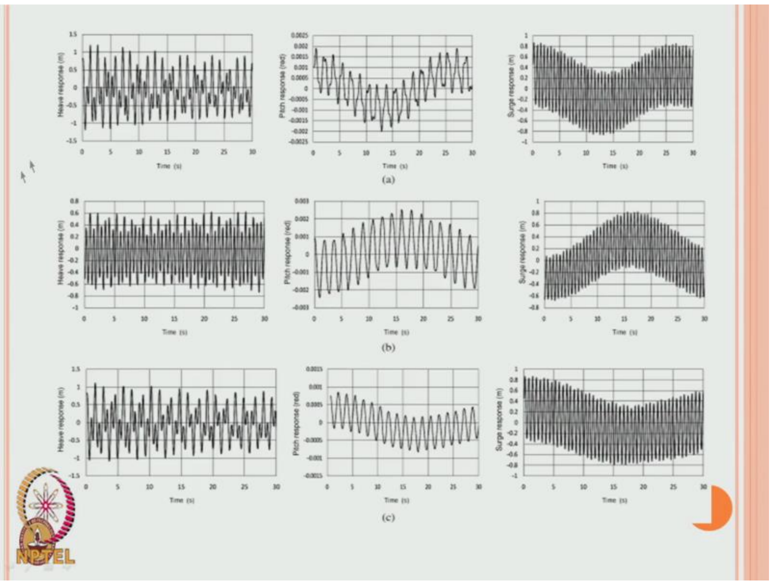

Let us look at the results as we obtained is solved in this equation of motion in time domain; one can interestingly see the responses of all the 3 platforms heave, pitch and surge for TLP 1, 2 and 3 respectively as you see on the screen here.

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Description	TLP_1	TLP_2	TLP_3
Time history response			
Heave (m)	1.2034	0.7384	1.1139
Pitch (rad)	0.002	0.0025	0.0011
Surge (m)	0.8683	0.8211	0.8655
PSD peaks at			
Heave (Hz)	~0.0, 0.706, 1.588	~0.0, 0.686,1.588	~0.0,0.686,1.588
Pitch (Hz)	~0.039,0.608,1.588	~0.039,0.569,1.588	~0.02,0.608,1.588
Surge (Hz)	~0.039,1.588	~0.039,1.588	~0.02,1.588
Dynamic tether tension variation (kN)	81,455.95	79,051.85	51,898.73
Change in tether tension (%)	65.43	41.606	20.313
Strain in tether (%)	0.298	0.146	0.109

Let us look at some re-inferences from this; if you look at the time history response, the time history response of the 3 degrees of freedom as you see from here heave, pitch and surge of 3 TLP’s are measured as you see here the peak values.

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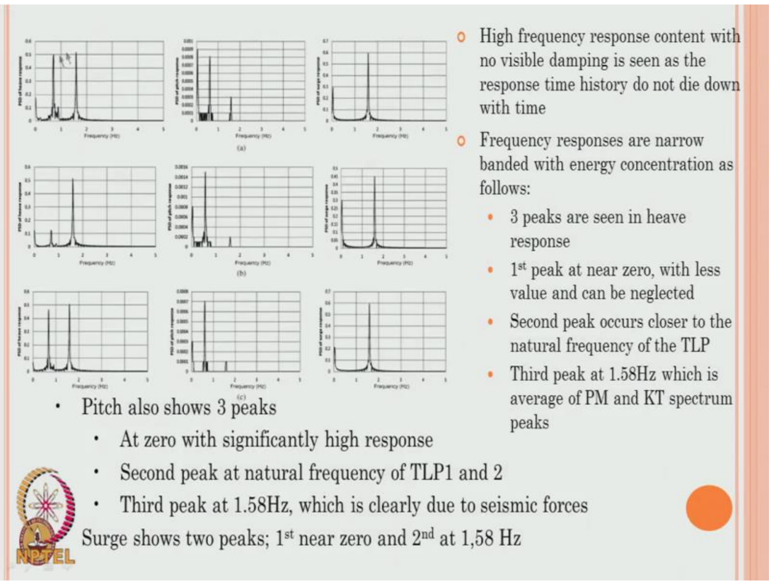

Look at the power spectral density function of these platforms in heave, pitch and surge for TLP 1, 2 and 3 respectively; one can see that there is an high frequency response content with no visible damping in time history do not die down with time, the frequency responses what you see here are narrow banded with energy concentration at 3 peaks. Let us say for heave response in all the 3 TLP's, there are essentially 3 peaks one peak is seen very close to near zero, which has got a very less ordinate therefore, can be neglected. The second peak occurs very close in all the 3 cases to that of the natural frequency of the TLP, this is close to about 0.5, natural period or frequency in terms of heave.

The third frequency what you see here the third peak occurs at the frequency very close to about 1.58 hertz in all the 3 cases, which is actually the average of the P-M spectrum modal frequency and the Kanai Tajimi spectrum peaks. Interestingly friends the third peak what you see here in heave degree, which is a stiff degree is a clear manifestation of the presence of earthquake loads in the presence of distinctly high sea waves.

Alternatively if you look at the pitch response, which is also one of the stiff degrees of freedom for a TLP; again there are 3 peaks seen in almost all the 3 TLP's, at zero there is got to be a significant high response, the second peak again occurs at a natural frequency of TLP 1 and 2 whereas, it is insignificant in terms of TLP 3 because the TLP 3s frequency is shifted out is because of greater water depth. Of course in this case as well the third peak what you see here in pitch response sorry in pitch response, is again appearing closer to 1.58, which is average some frequency of the distinctly high sea waves and the earthquake loads, is again a significant manifestation of the presence of earthquake forces or seismic forces.

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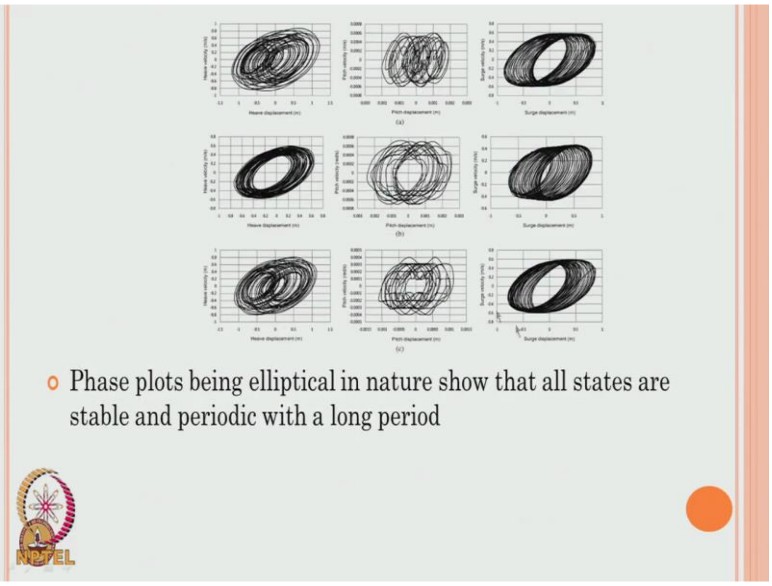

Now, to look at the stability of the system, one is interested to plot the phase plots, the phase plots in heave degree, pitch velocity or pitch degree and surge degree in terms of velocity and displacement for all the 3 TLP's, TLP 1, TLP 2 and TLP 3 show more or less they are elliptical in nature with a shift in the major axis. Elliptical in nature in heave degree of freedom which is a stiff degree clearly shows that they are stable and periodic with a long period.

So, essentially friends it is very interesting and fascinating to understand the behavior of the platform under special loads.

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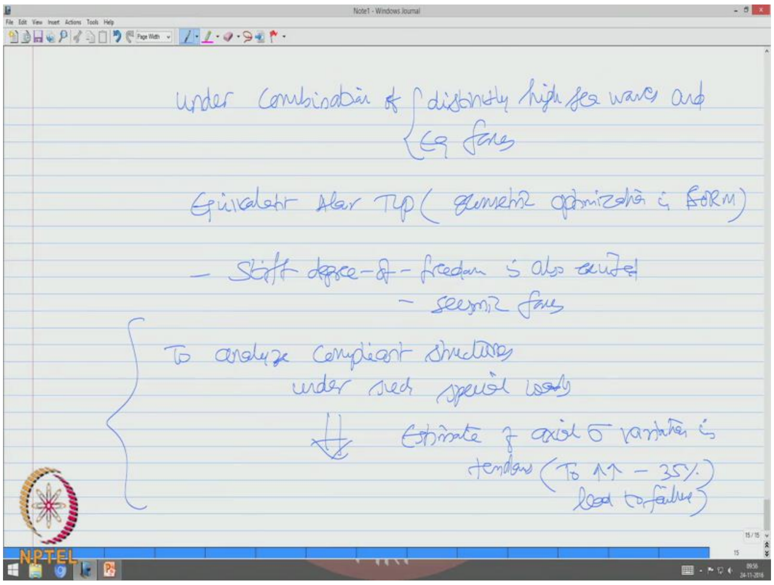

So, we have understood that under combination of distinctly high sea waves and earthquake forces equivalent triangular TLP’s, which can be called as one of the form of geometric optimization in structural form, shows that stiff degree of freedom is also excited because of presence of seismic forces. So, it is very interesting and important to analyze compliant structures under such special loads. The study further leads to estimate of stress variation in tendons, which show that the tension variation increases as high as 35 percent which can lead to failure of tendons.

So, friends in this lecture we understood how to do quickly the dynamic analysis under the combination of 2 special loads, earthquake loads and distinctly high sea loads. How to create distinctly high sea waves, how to create earthquake forces using modified Kanai Tajimi power spectrum, how to choose the parameters governing the power spectral density function, so that they match to the real scenario of earthquake occurred in the closer vicinity and then how to interpret the behavior of the platform on active degrees of freedom because of the presence of distinctly high sea waves or let us say under special loads.

So, in the next lecture we will talk about some of the design guidelines which can be evolved under so far we have understood the behavior of the platforms under special loads.

Thank you very much.