Offshore structures under special loads including Fire resistance
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Lecture – 21
Impact and Non-Impact Wave Loads

Friends, we are discussing NPTEL lectures on offshore structures under special loads including fire resistant design. Today in lecture 21 we are going to talk about special loads which cause responses on offshore structures, which are classified as impact and non-impact wave loads. They are special loads because they do not occur in the normal sea state; they need to be generated to do experimental or analytical investigations on offshore structures.

It is evident from the literature that, these kind of special loads do have serious consequences on compliant off structures therefore, while we define these kind of waves, we will also show an application of these loads on offshore compliant structures we take tension leg platforms as example and see how different degrees of freedom are activated and the consequences are more severe under impact and non-impact wave loads on tension leg platforms.

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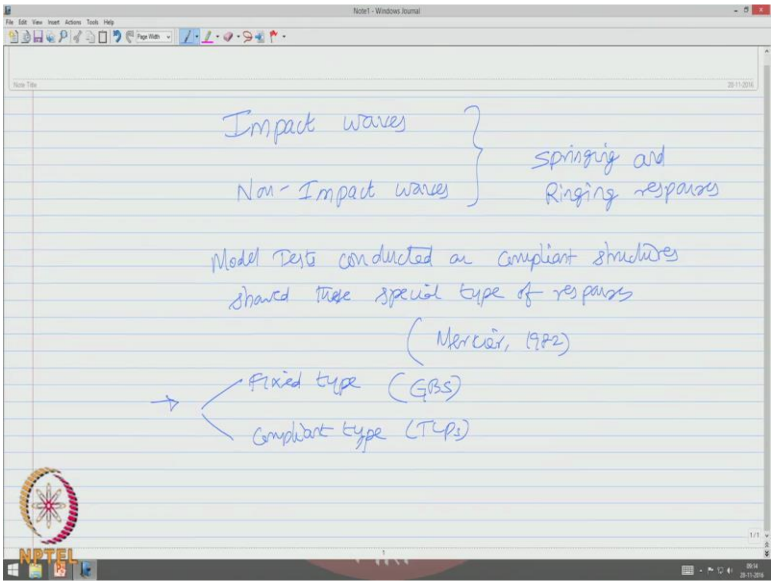

Impact waves and non-impact waves cause special kind of responses, they are termed as springing and ringing responses, model tests conducted on compliant structures, showed these special responses as reported by Mercier in 1982. So, these kinds of impact and non-impact waves affect fixed type because these responses are also seen in gravity based structures, they also anyway affect the compliant type like tension leg platforms.

Now, the question comes what though special kinds of loads which cause these responses?

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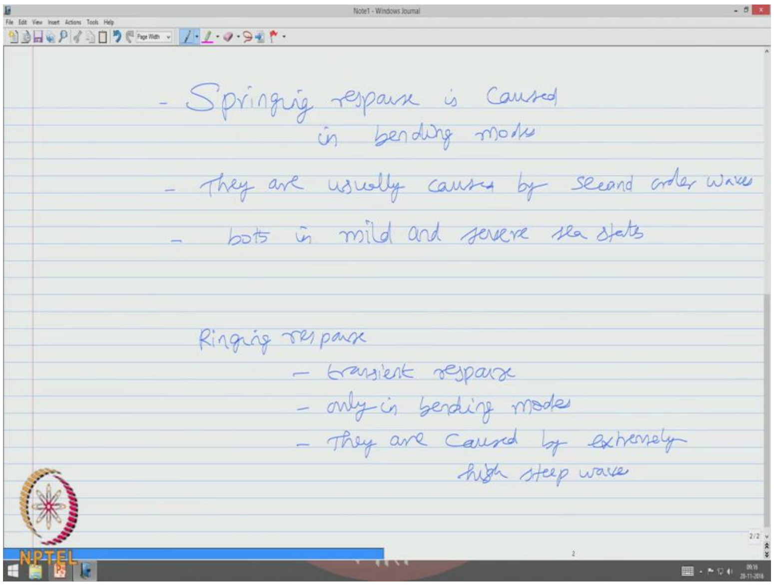

Springing response is caused in bending modes, they are usually caused by second order waves, they are generally seen both in mind and severe sea states whereas, ringing response is actually a transient response, this usually occur only in bending modes, they are caused by extremely high steep waves.

Please pay attention to the screen now, the screen now shows schematic view of springing and ringing motion.

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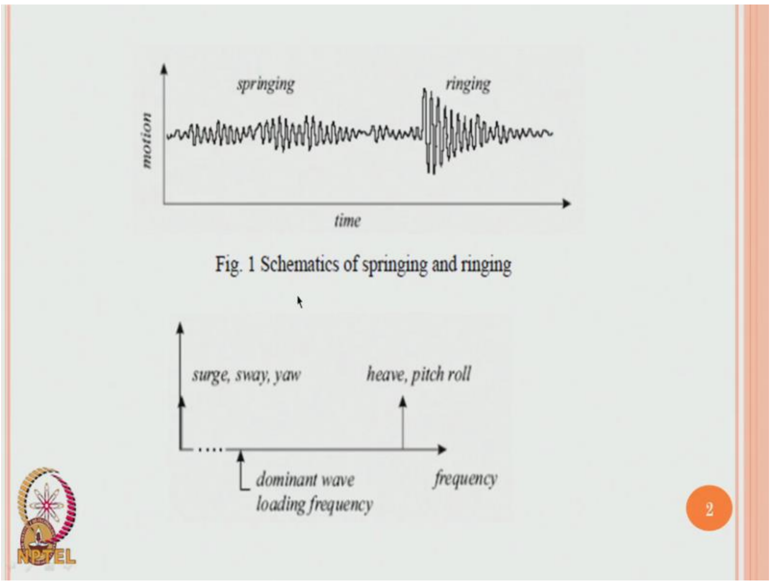

One can easily see from these figures that, springing occurs in surge, sway, yaw degrees of freedom predominantly, which are all essentially compliant or flexible degrees of freedom in a TLP and they do occur in the dominant wave loading frequency in the low time periods. As a frequency increases heave, pitch and roll responses or activated and ringing being a transient phenomena affects only for a short duration, but it affects certain degrees of freedom which are considered otherwise to be stiff in nature.

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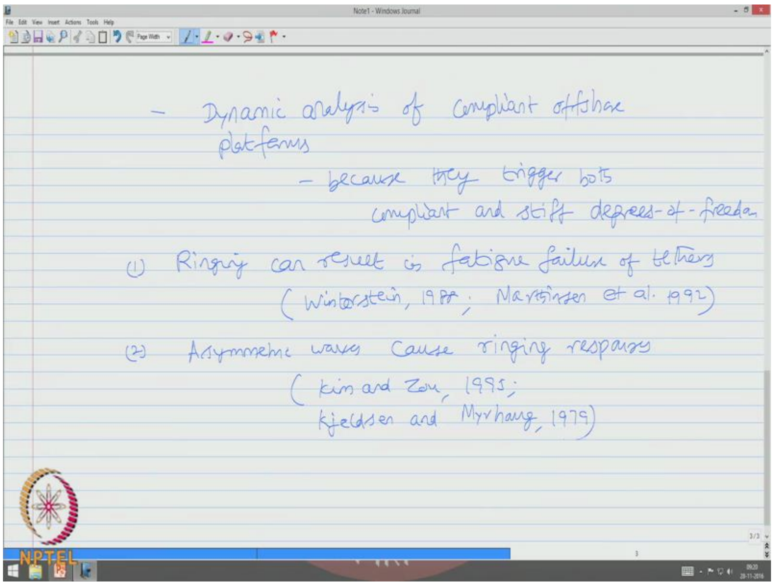

Therefore friend's dynamic analysis of compliant structures becomes very interesting and important under the influence of these waves because they trigger both compliant and stiff degrees of freedom. There are interesting studies conducted by various researchers, which identify certain facts which are very important for us to learn.

Ringing response can result in fatigue failure of tethers; this was confirmed by various researches Martinson et al 1992. The second issue is asymmetric waves caused ringing responses, essentially verified by Kim and Zou in 1995, Kjeldsen and Myrhaug in 1979.

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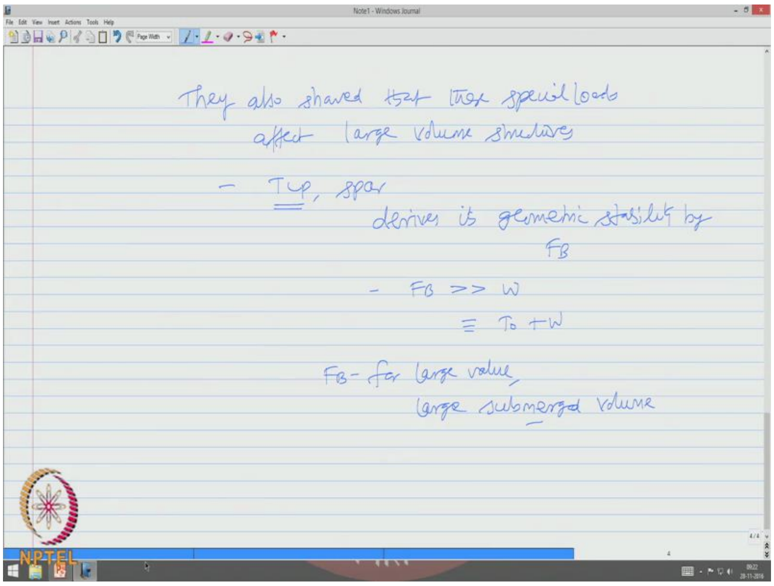

They also showed that these special loads that is caused by impact and non-impact waves, affect large volume structures. Now one may ask a question that why we are interested in understanding the behavior of a TLP or a spar let us say; we know that structures like TLP spar etcetera in particular TLP derives its geometric stability by buoyant forces. We also know that bohain forces of a TLP exceeds its weight which then balanced by tether tension in the tendency.

To achieve large buoyancy we need to have large submerged volume. So, TLP's can be seen as one of the victim of impact and non-impact wave loads which we will see in this lecture.

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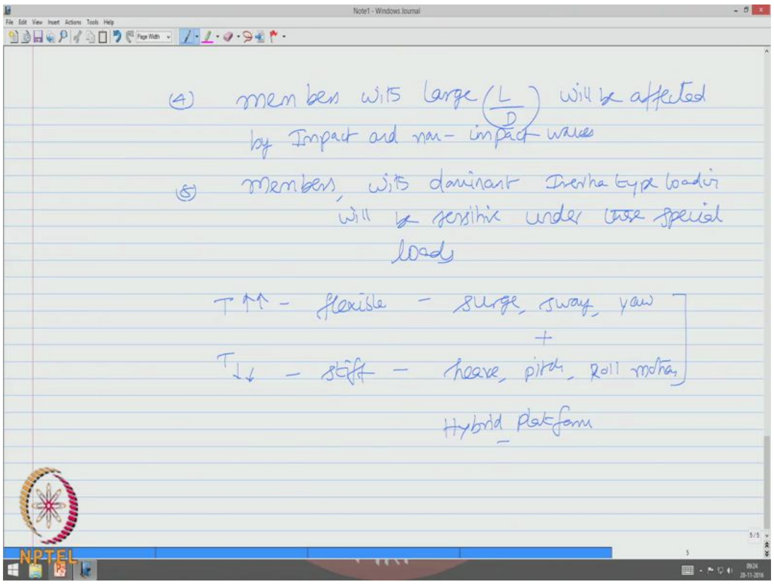

Further studies showed by the researchers also confirm that members with large L by D ratio will be affected by the impact and non-impact waves. Furthermore, interestingly members with dominant inertia type loading will be sensitive under these special loads. So, therefore, all these above points confirm that a compliant structure which is hybrid in nature, hybrid in sense TLP's have two distinct categories of degrees of freedom. One set is highly flexible for example, very high time periods. So, highly flexible, which can be surge, sway and yaw motions.

The other set is having low time period, which is relatively stiff which can be heave, pitch and roll motion. So, all of them put together is consolidate in a single platform, therefore we call this as an hybrid platform, which includes two distinct set of frequencies one being highly flexible our low frequency and other being very stiff.

Let us ask a question.

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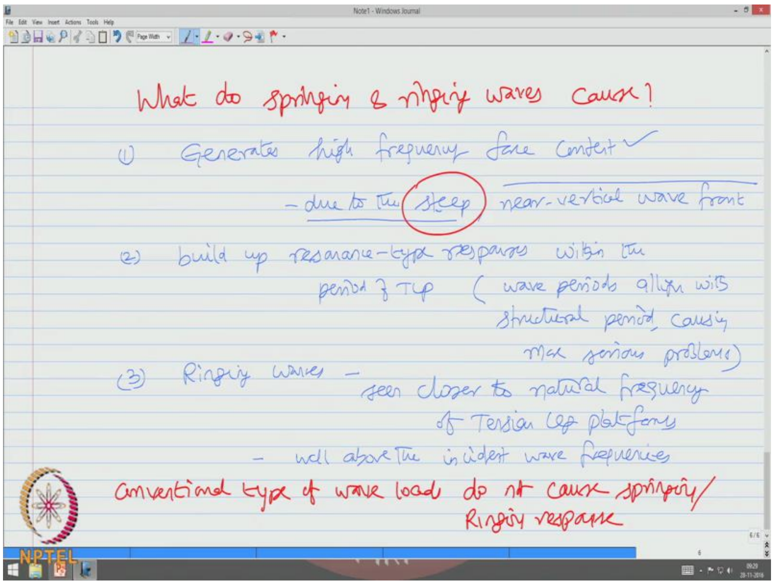

What do the springing and let us say ringing waves cause? In fact, I can also ask this question as what could be the consequence of the impact and non-impact waves on offshore platforms. There are many consequences which are of hydrodynamic interest to the researchers. First of all these set of waves generates high frequency force content, this is essentially due to the steep near vertical wave front. So, please understand these are all special kind of loads which are essentially steep and near vertical wave front; they develop high frequency force content which is now going to impact the TLP’s therefore, impact waves.

Second consequences they also build up resonance type responses within the period of TLP; it means these wave periods align with the structural period causing more serious problems, very interestingly ringing waves are generally seen closer to the natural frequency of tension leg platforms, we shall verify this by conducting an analytical study and confirm this, these responses or well above the normal conventional incident wave frequencies therefore, very interestingly conventional type of wave loads do not cause springing and ringing response.

So, therefore, we are looking for special kind of forces or wave loads, which are impact and non-impact type one such specialty is they are very steep and they have near vertical wave front, they are special loads.

Let us start applying this kind of forces or a tension leg platform.

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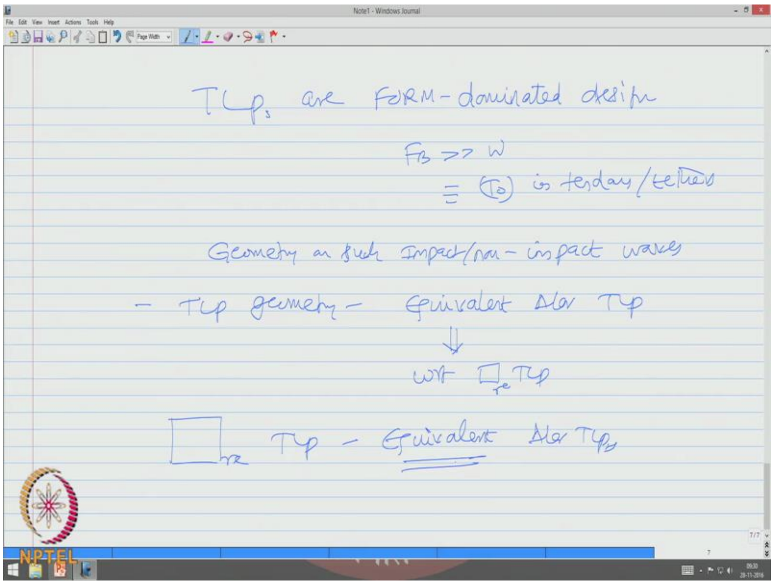

We also parallelly understand that TLP’s are form dominated design, where buoyancy exceeds the weight which is compromised by tension in tendons or tethers; we would also like to know, what could be the effect of geometry on such impact and non-impact waves. So, in this example study we will also try to find out a new TLP geometry which is equivalent triangular TLP, equivalencies with respect to an existing square TLP. So, square TLP’s do exist in gulf or Mexico, we try to find equivalent triangular TLP’s the moment we say equivalency that is impose different conditions of equivalency.

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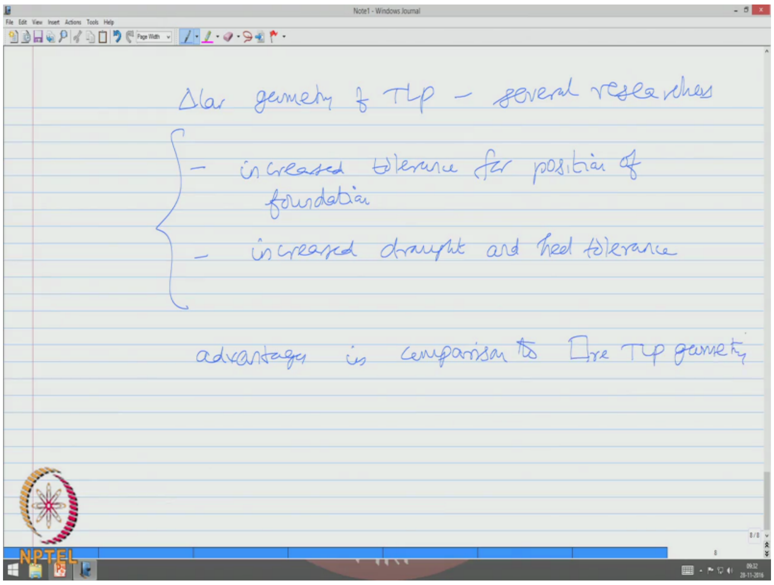

Prior to that triangular geometry of tension leg platforms or attempted by several researchers you can see lot of references of study of study is conducted by researchers on triangular geometry of tension leg platforms in the NPTEL website of this course, they all concluded that triangular geometry has increased tolerance for position of foundation, they have increased drought and very good heal tolerance. So, triangular geometry reported to have many advantages in comparison to a square geometry.

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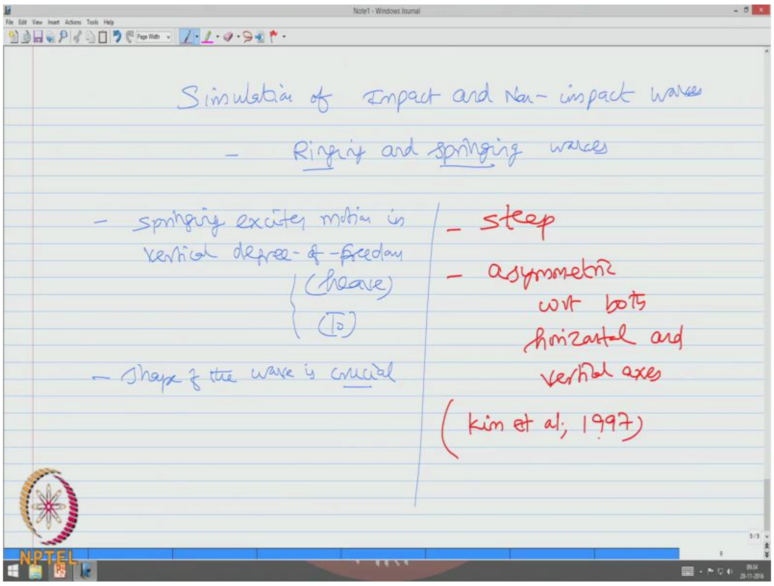

Let us now try to understand the simulation of impact and non-impact waves; to be more specific as oriented to the terminology is the literature we will talk about simulation of let us say ringing and springing waves. Now I am renaming the loads depending upon the type of response they offer, they create on the structures. So, ringing wave and springing wave how they can be simulated? How are they generated we will see that in detail now. We already said that springing will excite motion in vertical degree of freedom, may be its expected that heave response or tether tension variation will be challenged; to generate springing waves shape of the wave is very crucial. So, what are the conditions which make a wave to be called or qualified as a springing wave?

One, the wave should be steep. Two, it should be asymmetric with respect to both horizontal and vertical axes as certified and stated by Kim et al, 1997.

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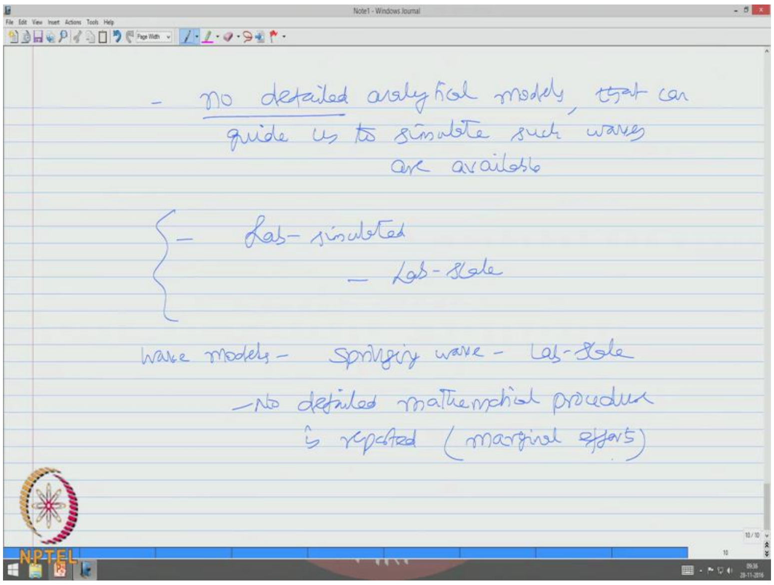

Very interestingly no detailed analytical models that can guide us to simulate such waves are available.

So, what studies have been conducted by people? Generally, these waves are lab simulated. So, I should say they are in the lab scale. So, wave models available in the study which qualify a springing wave are only available on lab scale. So, no detail mathematical procedure is reported except a very marginal study on the literature. Now the question comes very interesting, can we use existing theories, wave theories to generate these kinds of special loads?

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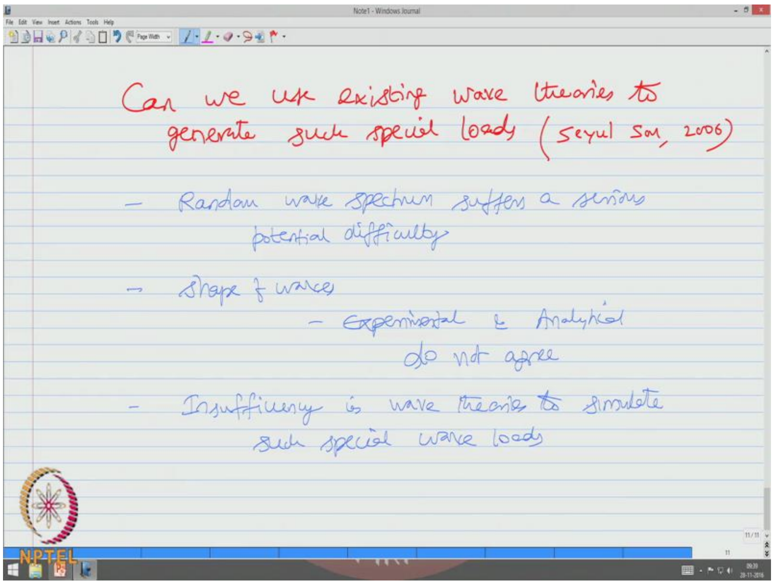

Preferring exactly to a specific work conducted by Seyul son, in 2006, let us try to answer this limitation. As per the researcher it says that, the random wave spectrum suffers serious potential difficulties.

The second issue is shape of waves thus that generated by experimental and analytical do not agree therefore, there is high level of insufficiency in wave theories to simulate such special wave loads then what do we do, what is alternative?

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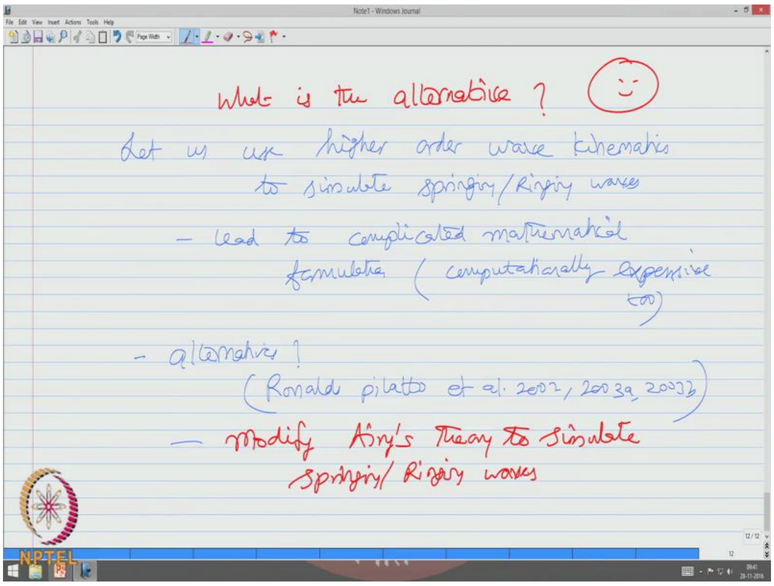

We are trying to do it in a different manner, we will use.

So, let us use higher order wave kinematics to simulate springing waves, if you try to do that it will lead to complicated mathematical formulation, it can be (Refer Time: 27:05) computationally expensive also, luckily various researchers given alternative for example, Ronald’s Pilatto at 2002, 2003 let us say a b there are two papers, such that modify Airys theory to simulate springing and ringing waves.

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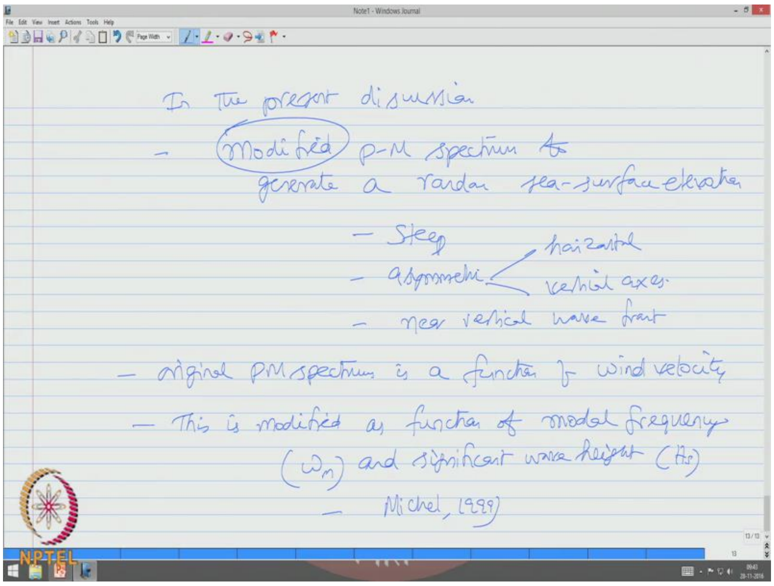

So, now in the present discussion, we are going to use the recommendations made by Pilatto and we are going to generate a modify Pierson Moskowitz spectrum to generate a random sea surface elevation, which should be steep, which should be asymmetric both about horizontal and vertical axes.

So, steep in sense it should near vertical wave front. Now the question comes what modification did we do in the conventional spectrum? We all know the original Pierson Moskowitz spectrum is a function of wind velocity. Now this is modified as not a function of wind velocity, but as a function of model frequency, omega m and significant wave height Hs this was suggested by Michel in 1999.

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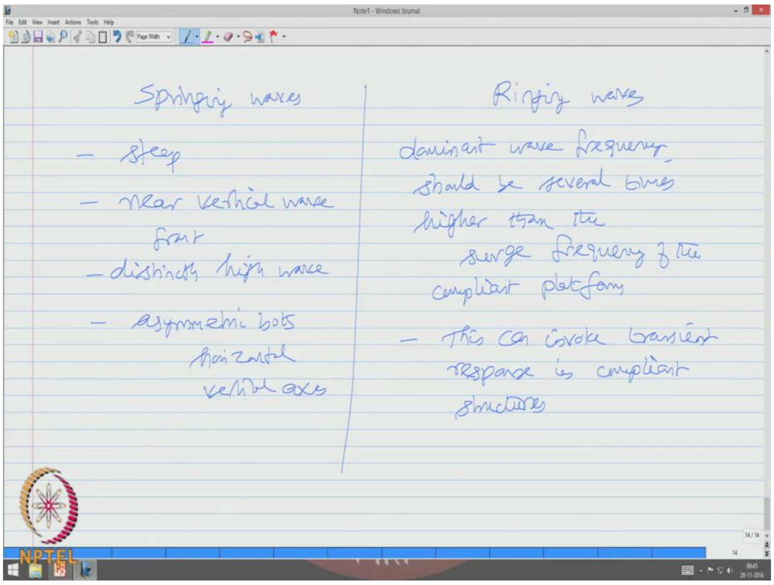

So, what are the specialties of generating or simulating springing and ringing waves?

Springing waves should be steep near vertical wave front, it should have distinctly high wave it should be asymmetric about both horizontal and vertical axes. Now about the ringing waves; the dominant wave frequency which is contained in the wave simulation should be several times higher than the surge frequency of the compliant platform, then only this can invoke transient response in compliant structures.

So, friends we have now different conditions which are to be satisfied to simulate artificially, numerically the springing waves and the ringing waves fulfilling the following list of conditions as indicated in the screen now.

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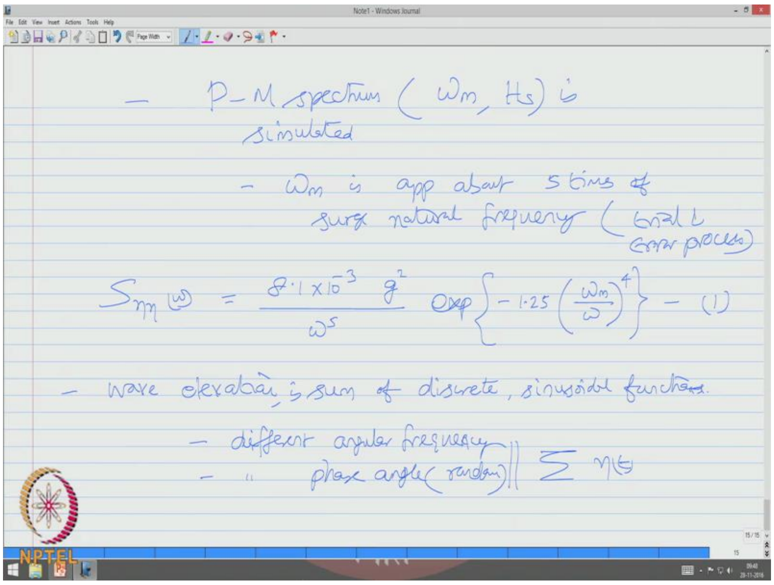

What has been done Pierson Moskowitz spectrum, which is going to be a function of model frequency and significant wave height is simulated such that the model frequency is approximately about 5 times of surge natural frequency. So, it was a trial and error process to generate a wave of this time. So, the C spectrum modified spectrum is given by 8.10 power minus 3, g square by omega to the power 5, exponential minus 1.25 omega m by omega raise to the power 4 - equation number 1.

Now, as I said the shape of this wave is very crucial therefore, wave elevation as we discussed in the last set of lectures is considered to be sum of discrete sinusoidal function. So, they have different angular frequency and different phase angle randomly chosen, all of them are summed up to form a sea surface elevation, which will now qualify the wave to be an impact or impact wave.

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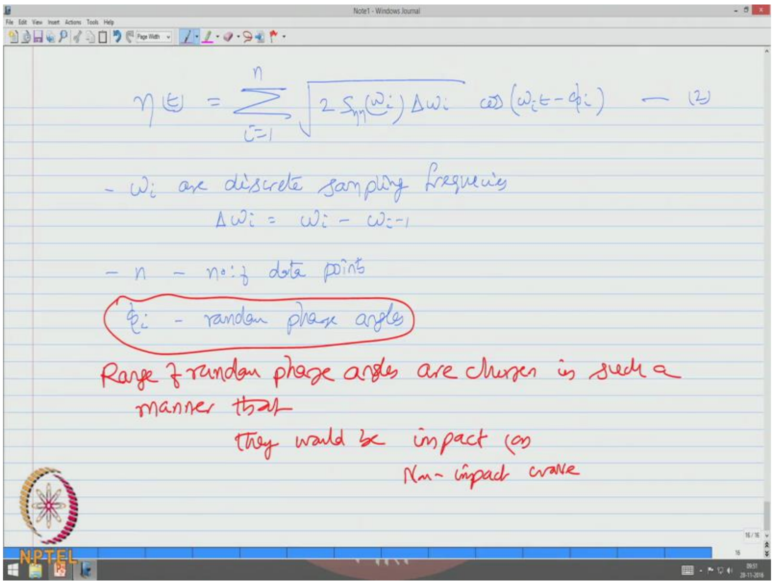

So, the sea surface elevation is now given by this equation, which is discrete sum off square root of 2 S eta, eta omega; S eta, eta omega is given by the equation 1 which is the modified pm spectrum, delta omega i cos omega it minus phi I.

In this case omega i are actually the discrete sampling frequencies, one can say delta omega i is omega i minus, minus one. Where the summation happens with the number n which is the number of data points and phi i is the random phase angle.

Now, the question is how do you generate an impact and non-impact wave? The ranges of random phase angles are chosen in such a manner that they would be or result in impact or a non-impact wave. So, this variable is being used as a controlled variable to alter its range so that resultant sea surface elevation would be either an impact wave or a non-impact wave. What would be the difference from the elevation generated to identify whether is an impact wave or a non-impact wave?

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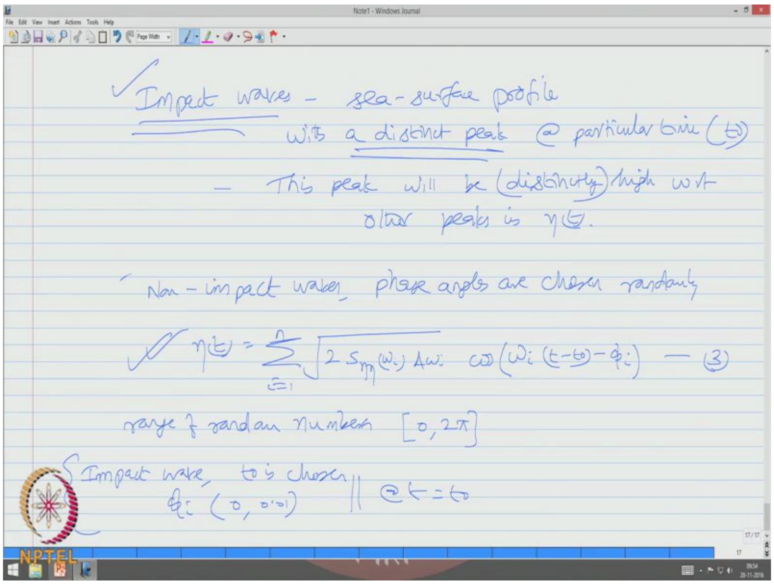

Impact waves will have a sea surface profile; with a distinct peak at particular time let us say t 0.

So, impact waves are those waves where the sea surface elevation will show a distinctly high peak at a specific time t 0. So, this peak will be distinctly high with respect to the other peaks in the sea surface elevation, for generating a non-impact wave phase angles are chosen randomly, so that eta of t is modified as discrete sum of waves cos omega i, t minus t 0 minus phi i. So, the range of random numbers will be is between 0 and 2 pi, for an impact wave orbit time t 0 is chosen and phi i is chosen between 0 and 0.01 at t equals t 0. So, we have modifying the same sea surface elevation and by imposing a specific condition, one can generate an impact wave and a non-impact wave.

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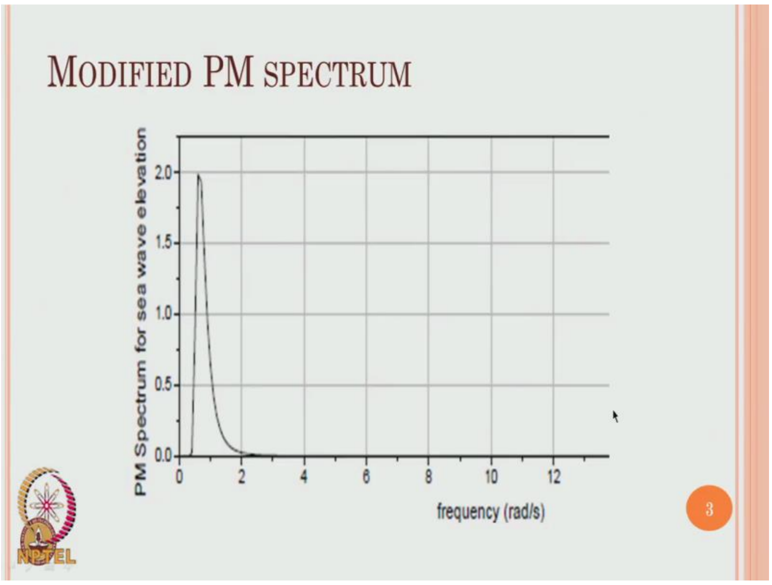

Let us now see how the modified spectrum looks like. The modified Pierson Moskowitz spectrum which is function of model frequency, which is chosen to be 5 times of that of such frequency, is shown in the sketch now on the screen.

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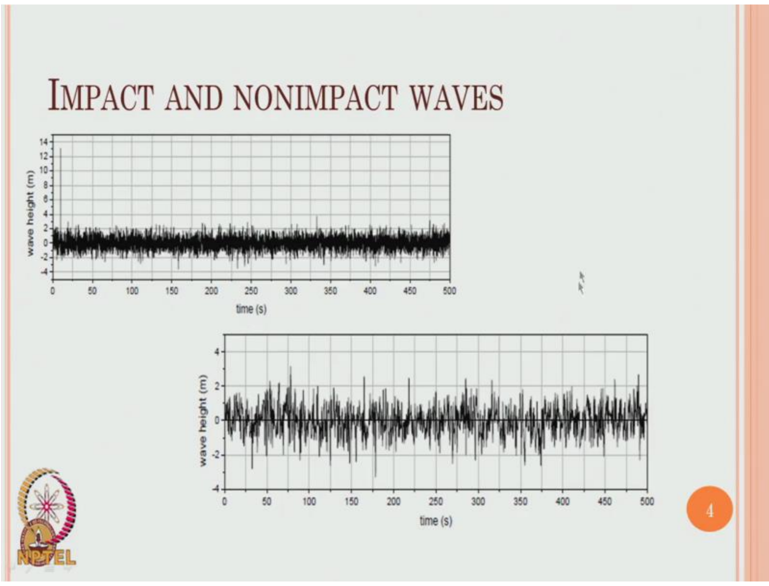

The generated or simulated impact waves and non-impact waves in terms of sea surface elevation, time history is shown on the screen, one can distinctly see at an impact wave as a special kind of wave height which is distinctly high compared to its predeceasing and successive waves in the entire history simulated whereas, in non-impact wave no such near vertical front configuration is required.

So, friends one can now get convince that by modifying the phase angle, the random phase angles and by imposing a condition of a specific time t 0 we demand a distinctly high sea wave, one can generate from the modified spectrum a sea surface elevation, which can be qualified to be an impact wave or a non-impact with both are special loads as applied to offshore structures.

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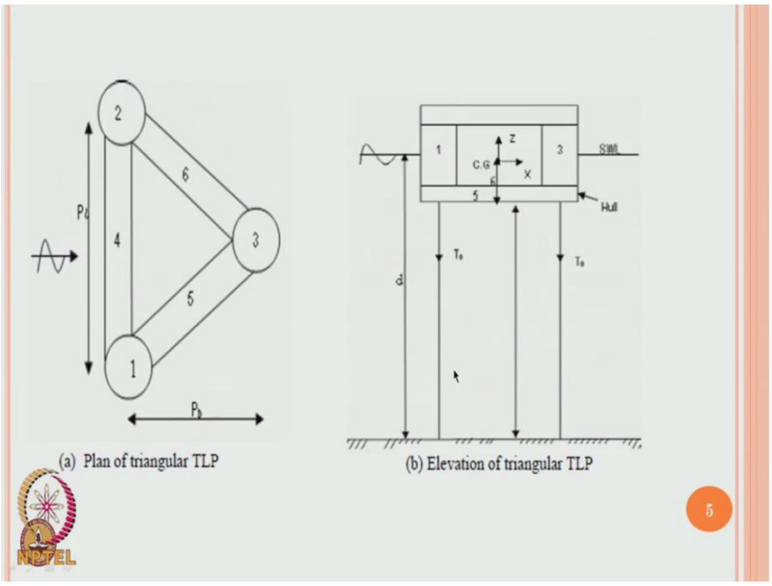

We will now apply this to a geometric optimization of a triangular TLP which is got 3 column members named as 1 2 and 3 and 3 (Refer Time: 42:45) members named as 4, 5 and 6 and the elevation of this is shown on the right hand side screen for you. So, equivalency of a triangular configuration is arrived by comparing its characteristics with an established constructed square TLP’s.

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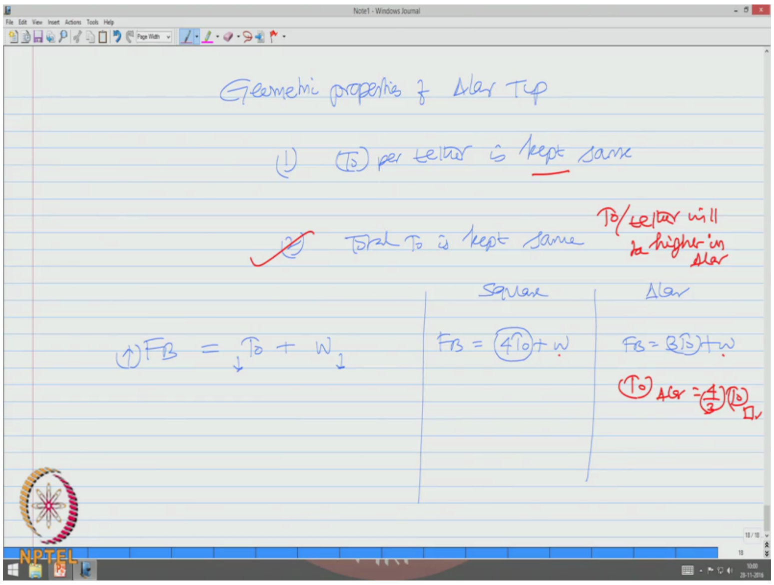

The geometric properties of TLP or arrive with two conditions t 0 per tether is kept same, total t 0 is kept same, two conditions. Because we know that buoyancy which acting upward will be equivalent to t 0 plus wave because both will act downward, interestingly when you write this equation for a square and triangular, one should say buoyancy will be equal to 4 t 0 plus W whereas, in this case it is 3 0 plus W. So, this is what we called as total tension initial pretention.

So, one case is keep the total initial pretention same therefore, t 0 per tether in this case will be higher in triangular geometry because total t 0 is kept same therefore, the t 0 in triangular of configuration will be about 4 by 3 times that of t 0 of a square. So, therefore initial stiffness and initial pretention both are increased in a triangular geometry that is case 2. In case one t 0 per cable or tether is kept same therefore, total t 0 in triangular geometry is lower compared to that of a square geometry which is subsequently adjusted in the wave.

So, looking these characteristics in mind triangular geometrical configurations are arrived which are considered to be equivalent to square tension leg platforms and their properties are now shown on the screen.

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Table 1 Geometric properties of square TLPs considered

Property	Case 1	Case 2	Case 3	Case 4
Weight (kN)	351,600.00	330,000.00	330,000.00	370,000.00
F_B (kN)	521,600.00	465,500.00	520,000.00	625,500.00
T_0 (kN)	170,000.00	135,500.00	190,000.00	255,500.00
Tether length, ℓ (m)	568.00	269.00	568.00	1,166.00
Water depth (m)	600.00	300.00	600.00	1,200.00
CG (m)	28.44	27.47	28.50	30.31
AE/ ℓ (kN/m)	84,000.00	34,000.00	82,000.00	45,080.00
Plan dim (m)	70.00	75.66	78.50	83.50
D and D_c (m)	17.00	16.39	17.00	18.80
r_x (m)	35.10	35.10	35.10	35.10
r_y (m)	35.10	35.10	35.10	35.10
r_z (m)	35.10	42.40	42.40	42.40

Table 2 Natural wave periods and frequencies of equivalent triangular TLPs with T_0 per tether same

Case	Natural time period (s)			Natural frequency (Hz)		
	Surge	Heave	Pitch	Surge	Heave	Pitch
TLP_1	98.00	1.92	2.110	0.0102	0.5208	0.4739
TLP_2	87.20	1.96	2.155	0.0115	0.5102	0.4640
TLP_3	97.00	1.92	2.060	0.0103	0.5208	0.4854
TLP_4	132.0	3.11	3.120	0.0076	0.3215	0.3205

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One can see the table 1 and table 2. Table one show the geometric properties of square TLP's considered; we have considered four square TLP's at almost parallel water depths, half of and double of water depths. So, we considered 4 cases of square TLP's with these structural properties, then we arrived for each square TLP, a triangular TLP with two conditions as discussed in the last slide. So, this condition is equivalent triangular TLP with t 0 per tether same between triangular and square configurations.

So, the natural periods of all the equivalent TLP's case 1, equivalent triangular with t 0 per tether same refers to TLP 1. Case 2 of a square TLP with equivalent triangular TLP of t 0 per tether same refers to TLP 2 and so on. So, all these 4 case of square TLP's are converted to equivalent triangular TLP, imposing this condition for equivalency and TLP 1, 2, 3, 4 suffixes I mean created whose natural periods in terms of seconds and natural frequencies in hertz are available on the screen now.

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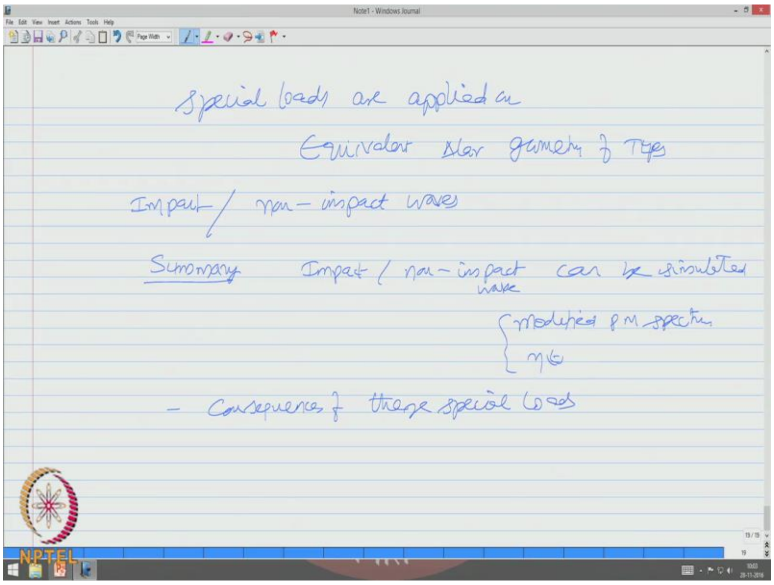

Now, special loads are applied on equivalent triangular geometry of TLP’s; we are interested to know the response of this under impact and non-impact waves, which we will subsequently discuss in the next lecture.

So, friends in this lecture we learned how an impact wave and non-impact wave can be simulated using modified Pierson Moskowitz spectrum and sea surface elevation. We have also learned what are the expected consequences of these special waves, remaining we will discuss in the next lecture.

Thank you.