Dynamics of Ocean Structures
Prof. Srinivasan Chandrasekaran
Department of Ocean Engineering
Indian Institute of Technology, Madras

Lecture – 40
Dynamic Analysis of TLPs under Springing & Ringing waves

In this lecture we will talk about the Dynamic Analysis of the TLPs under Springing and Ringing waves. So far we have discussed about the TLP Configuration as a geometric equivalence of a square TLP. We have been discussing about the response of compliant systems.

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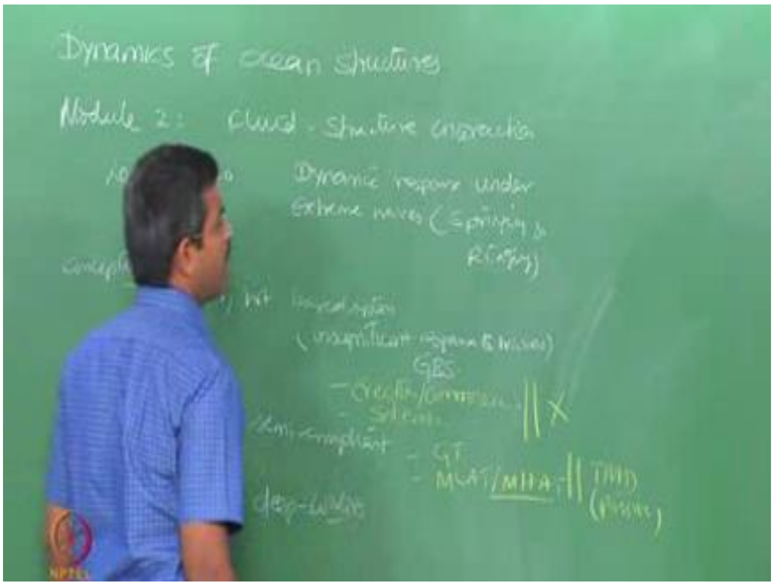

We started with the Conceptual Design, where initially the focus was weight base systems which actually had very insignificant response into waves. We can give many example, GBS is a very classical example of this kind of systems where it is inertia based topside it was phenomenally high, but it has got some demerits like the construction cost the erection difficulties were there; erection commissioning difficulties were there.

In addition to that it also caused some soil erosion etcetera which was discouraging for this kind of platform. Then it moved to medium water depths where people have used semi compliant systems. Classical example was guide tower and multi legged, multi hinged article towers. But of course, the depth had high responses and people have used response control mechanisms like TMD or passive dampers to control the responses. Then we moved on to the third conceptual development deep waters which were then for compliant systems.

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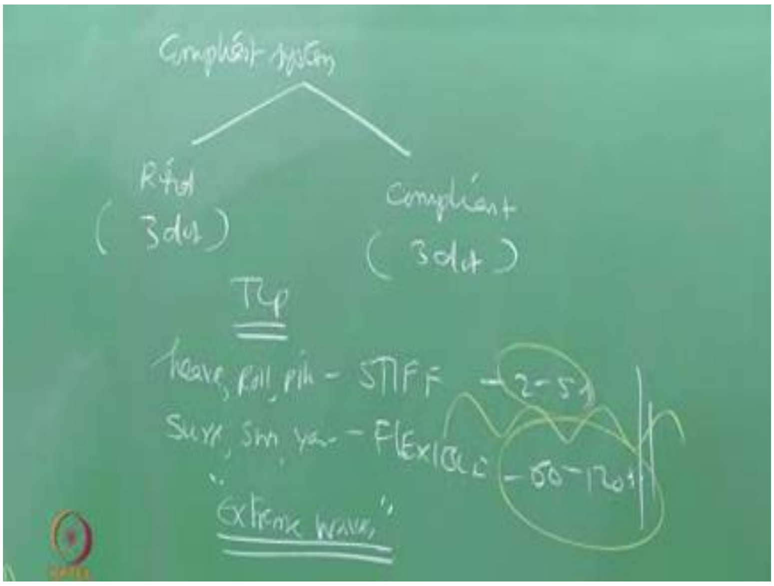

The moment we say compliant system we had the design in two forms. So, I want to separate the whole configuration into two systems; one is rigid degrees or rigid motion, one is what we call compliant or flexible motion. So, we had 3 degrees-of-freedom here and 3 degrees-of-freedom here grouped. The classical approach was used for a tension like platform, where the 3 degrees like; heave, roll, pitch are considered to be stiff and surge, sway, and yaw were considered to be flexible. So, here the periods were from 2 to 6 seconds, here the periods were from 60 to as high as 120 seconds.

So, the dominant way period exhortation force was lying in between this. So, the system was designed in such a manner that the system will not excite for the wave excitation forces which are commonly acting in a given sea state for a deep water systems. But of course, this had very specific observations in may be late 80’s or early 90’s, that these systems started showing different kinds of response in the extreme waves. When you are subjected to extreme waves they had shown phenomenal responses, so people started identifying them as necessity for examining dynamic analysis of these structures for different kind of non-classical waves.

Generally if we talk about the conventional waves may be regular may be irregular in random.

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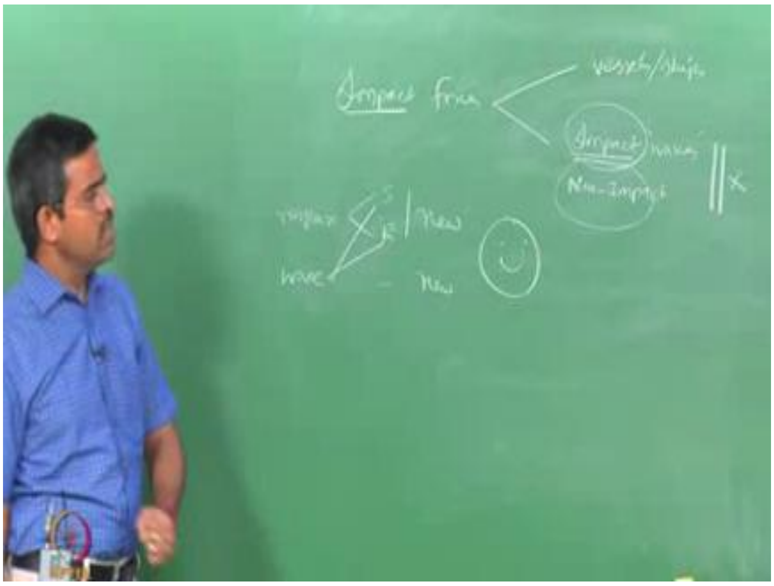

These waves does not show a specific kind of exciting forces on a given system which can cause phenomenal impact forces on the system. Now, the moment I say the impact forces people generally understand that these forces are nothing but the forces externally caused only by vessels or ships. These are physical impacts. What I am talking about is the impact force generated by the waves itself. So, I am talking about what I call impact waves.

So, waves should have a phenomenal exercise or an excitation force acting on the structure which was observed first time in one of the practical observation platform, I will show you in the subsequent slide. So, impact waves and the non-impact waves. The classical sea states where the wave surface or wave sea surface elevation generated by Aries or (Refer Time: 04:34) spectrum were not capable of simulating these kind of impact and non-impact forces on a given system, so they were failed.

On the other hand, when people started moving geometric optimization for deep water oil exploration people wanted to know what are those extreme possibilities have to be these system will fail, though the system had shown many advantages in terms of commissioning, erection, decommissioning, cost involvement, geometric optimization. People have also said that instead of 4 leg we can as go as minimum as 3 legged platforms, where triangular (Refer Time: 05:08) investigated (Refer Time: 05:09) 1995, Natvig showed 1995 the geometric optimization for the first time in ISO paper where 3 leg platforms can also (Refer Time: 05:19) an equivalency of a TLP. And then subsequently many as such reported that the advantages of these kind of systems and then they studied investigated.

But of course, when compliant structures of this orders come into play people wanted to know in a clear window what will happen to the response in the systems under non-classical waves which we call as a extreme waves. So, identified these kinds of responses people gave a different name on the literature, they are called as Springing and Ringing waves. So, this lecture will focus on the dynamic analysis of a compliant structure for example, a TLP under springing ringing waves.

Now here it is very clear, the waves are categorized as springing ringing waves on the other hand some literature show the responses springing ringing responses. So, here both of them are very non-classical that is even the response to be categorized as Springing and Ringing is also new. At the same time if we really wanted to classify a wave which can cause a springing or the ringing response even this is also new. So, both of them were relatively new for the TLP observation which happened in 90’s.

So, people enforce this kind of new kind of response to a new kind of system, because in 80’s it was then evolved as a platform concept so people wanted to study this. Let us see how and what are the complications involved in this study and why this cannot be generate to be a conventional wave model, but we are so far either using (Refer Time: 06:41) theory or stokes fifth order or using Pierson Moskowitz spectrum. You cannot generate these kind of wave.

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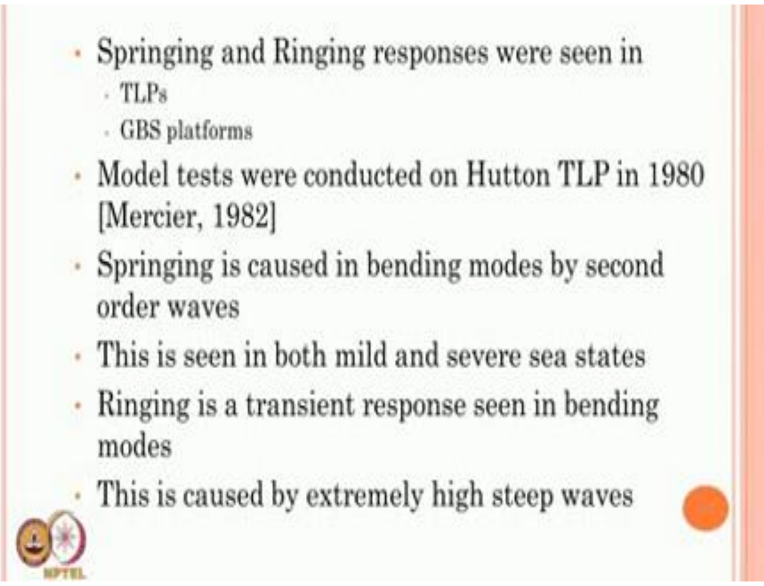

So, Springing and Ringing responses essentially were seen in TLPs and GBS platforms. It was shown by the people in literature like Mercier, 1992 in TLP Hutton TLP 1980 it show very clearly that these kind of non-classical waves are extreme waves are impact and non-impact waves can excite compliant and fixed platforms both. So, they are dangerous to both kinds of platforms.

So that was conducted by a model test investigated by a Hutton TLP model in 1980 by Mercier, and they stated that springing is caused in bending modes by second order waves, It is very important, it is exciting a specific kind of mode of vibration which is bending. We all know bending mode is more critical compared to axial linear vibration of modes, while bending induces large order deflect of member strains or stresses in a given system. Well, your excitation caused at the specific mode of vibration it is more dangerous. So, springing is caused in bending modes of vibration which is essentially caused by second order waves there was no necessity for higher order waves like stokes fifth order etcetera.

However, even in lower order waves springing (Refer Time: 07:55) observed. And this was seen in both mild and savior sea states. It means even in the case of a savior or a mild sea state for example, wave heights and wave periods are nominal even then these waves are generated. Now, the question is how you classify a given wave as a springing wave or a ringing wave. That was the emerging idea in 80's or early 90's. Let us say that in a given sea state how do you actually classify a wave as a spring or a ringing wave or how do you classify from a response a spring or ringing response. And why they are important only for compliant system not subsequently for bottom supported structures GBS. So that was the idea focused in 80's and early 90's when we people talked about dynamic analysis of these kind of systems under extreme waves.

So, ringing is of course, seen in the literature as a transient response. We all know in dynamic analysis it generally neglect the transient response, we always look at the steady state response provided the transient response considered to be dying down because of the damping present in the system. However, even in TLP or in GBS which has got enormous damping from hydro dynamic effects still transient response was present for a longer time duration which was seen for the first time in a model test investigated by a Mercier 1980. Therefore, that was classified as ringing.

Now, here I got two kind of distinct responses; one is a transient response in bending mode, one is a steady state response in a bending mode again. So, these two kinds of waves are the input wave causing this impact should be different they cannot be, because the same wave cannot cause transient and steady state both. There are two distinct waves now. Interestingly, you see amongst these two systems compliant and fixed GBS etcetera you will see TLP is phenomenally designed to have the period either lower or higher from that of the excitation frequency. But, on the other hand if you see if the frequency of the wave is present in both zones like, large and small than that of the natural frequency of the system then TLP will get excited in both kinds of sub waves. Now that is very interesting.

So, TLP has seen to be phenomenally vibrant or sensitive for both kinds of waves; one is ringing wave and the springing wave. People have concluded that saying these two responses essentially arise from what we call distinctly or extremely high steep waves. Now, conventional wave loads cannot produce these kinds of steep waves. Now the question is how you define the given waves extremely high steep waves, what should be the definition for this.

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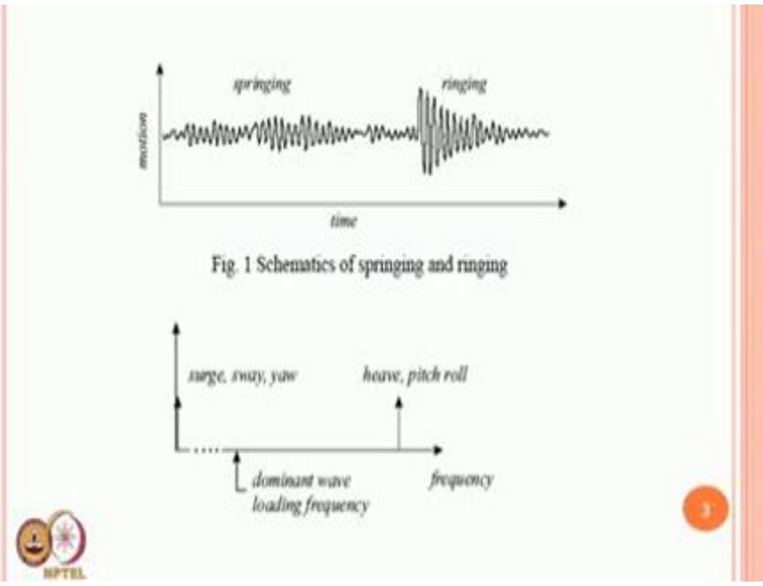

Fig. 1 Schematics of springing and ringing

So, if you look at this figure which is showing the Springing and Ringing waves as such as schematic figure, it shows very clearly that the ringing wave has got a very phenomenal impact in terms of response which essentially affects stiff degrees-of-freedom. Whereas, springing wave is present for a larger period, of course the impact is not as seen here in terms of the response compared to that of ringing but present for a larger time and that is available and in causing influence on sub degrees-of-freedom.

On the other hand, both these waves attack two distinct categorization of responses. Which were considered to be advantages about 10 years back when these platforms were invented. Now, the question comes will this platform survive this kind of waves. Now there are two arguments here; one what is the frequency at which such waves occur and is it necessary that one should do analysis for such kinds of waves that is number 1. Number 2, when you always evolve a geometric design may be a TLP of a 4 leg or a geometric TLP of a 3 leg optimization you always look for all possible failures which arise from nature. So that is always a principle in optimization in any geometric design optimization. So, people were looking not in terms of bothering whether what is the frequency of occurrence of these kind of waves, but people said if these kind of waves do occur what will happen to the response of the system because it effects the challenges both degrees-of-freedom; both stiff as well as flexible.

Now it is very interesting that you have a series of waves generated which affects both which is sweeping both degrees-of-freedom which was not observed and present and understood by the researchers till 90’s, because people thought the input excitation frequency will be far away from the design of the TLP. That was the idea in early 90’s. When we could see a wave of this order which can sweep over for the large time period which can cover frequency of lower and higher order people really started worrying about will TLP sustain these kinds of waves.

So, they a special name to these as Springing and Ringing responses, because this looks like a ringing of a bell you can see here the ringing of a bell; the moment you see here the ringing of a bell it look like that they amplitude picks up suddenly and gradually decays. So that is why the name ringing comes from here. And this is springing because this present for a larger period in domain, but the frequency or the intensity is not as you as a springing wave.

So, one can otherwise call these waves as impact waves and these waves as non-impact waves. So, ringing waves are classified literature as impact waves and springing waves classified in literature as non-impact waves, to be non technical. To be very specific and technical the amplitude of springing waves are not comparable to that of a ringing wave, but ringing wave present for a shorter domain excites stiff degree-of-freedom, whereas springing wave presents for a longer domain excites complaint degree-of-freedom and these two waves occur in sequence that is the problem.

So, they will have a full sweep of the entire frequency band of a compliant system like TLP which was found to be promising for deep water exploration till early 90’s. That was the original idea and the origin of the problem why such studies were intuited by taking a model of a Hutton TLP. That does mean Hutton TLP has failed in this, but people studied this as an example.

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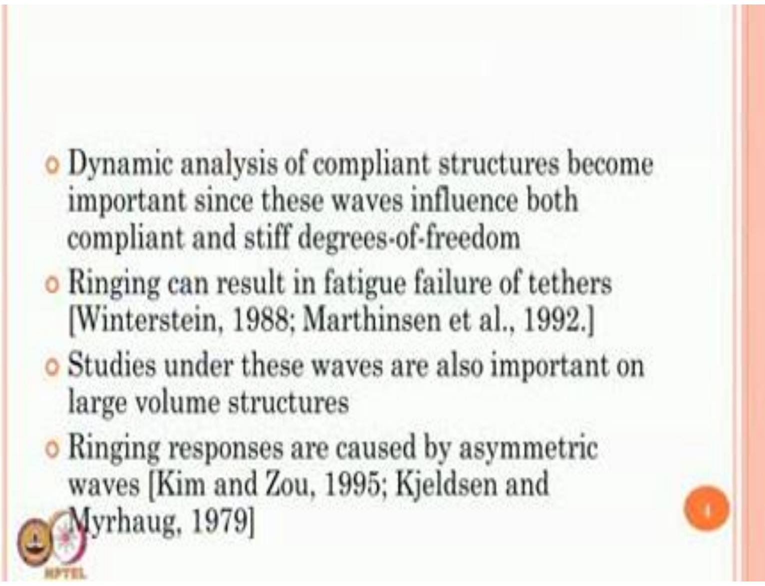

So, dynamic analysis of compliant structure becomes more important, because this wave sweeps the entire domain of frequency of the systems, it influences both compliant and stiff degrees-of-freedom. Ringing of course results in fatigue failure. That was studied and shown in literature by Winterstein and Marthinsen in 1988, 1992 respectively. So, they said that the ringing response which affects the stiff degree-of-freedom which is caused by an impact wave can result in fatigue failure because can pull out of tethers. That was envisaged by these researchers.

Studies were under these were became important for large volume structures. We all know TLP is actually a buoyancy supported system. The design by itself says for buoyancy for much exceeding than the weight of the platform, so I have to go for a large volume because buoyancy can be achieved only by volume of submergence so my system is a large volume system. Therefore, studies showed on the literature that the large volume structures will be affected by this. Subsequently, ringing responses are caused by asymmetric waves. You can very well clearly see here a conventional wave model will not be able to generate asymmetric wave. So, asymmetric waves became a big problem how they can be generated Kim and Zau 1995 and Kjeldsen and Myrhaug 1979 as early as 80’s people envies that these kinds of waves can cause a special kind of impact on systems.

Now, (Refer Time: 15:07) tried to generate these kinds of waves analytically. Now let us see what are those analytical problems available in f of t that is force generation system using a conventional wave theory?

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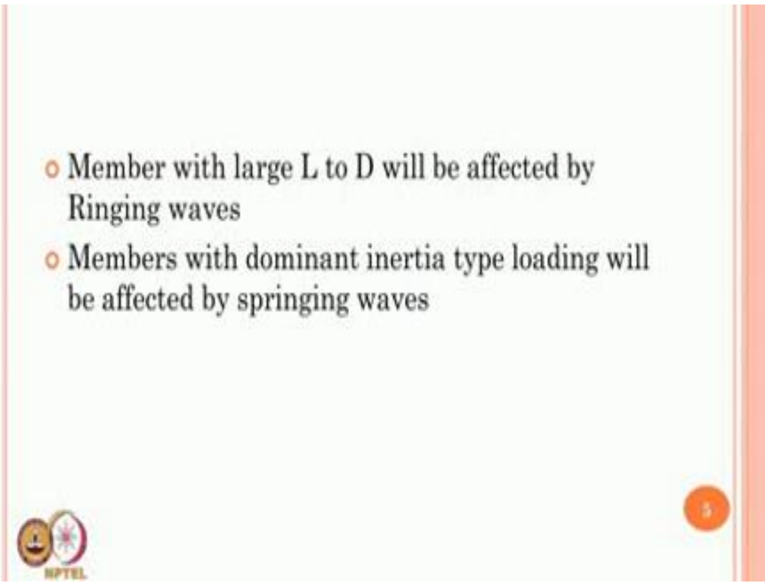

People have said that members with large length to diameter ratio, because as we know that the diameter of the L by D ratio as far as TLP members are concerned is phenomenally different and significant. The members with large L by D will be affected by ringing responses or ringing waves. And people also said members which are inertia dominant will be also affected. So, there are issues where stiff degrees and compliant degrees will be challenged by these kinds of waves.

So, one set is affected by springing wave one set is affected by ringing wave. My whole platform can be challenged for when these waves are happening consequentially on a given platform.

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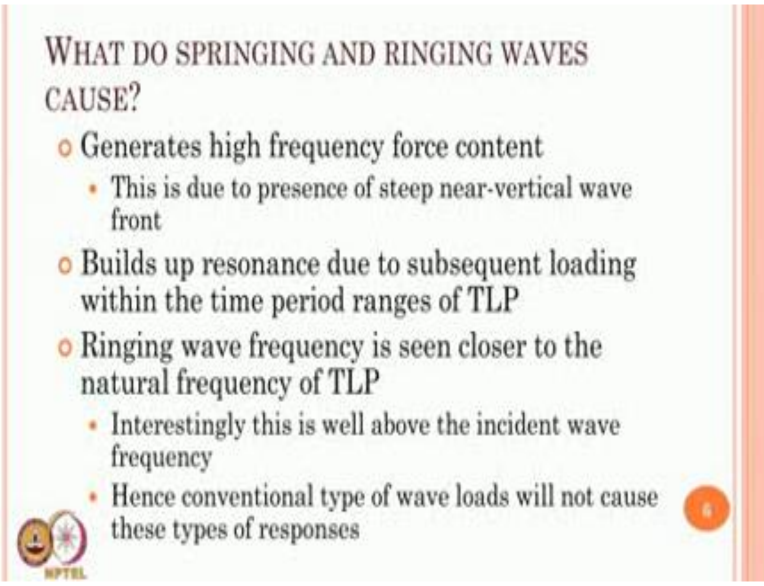

Now what do these waves cause to the structure? That is the very important question to be asked. Now the most importantly these waves cause or generate high frequency force content. Frequency will be very high force content will be generated, whereas conventional Pierson Moskowitz spectrum will not be able to generate high frequency force content from the spectrum. I will show you both the spectrum.

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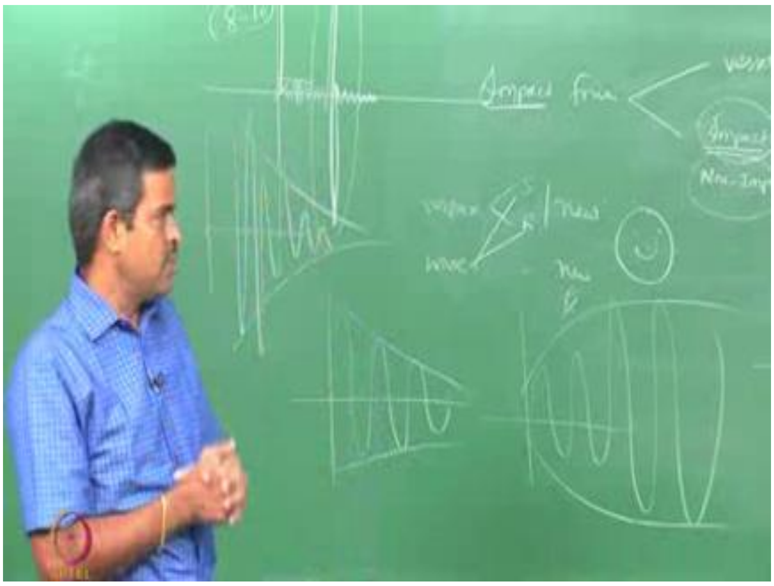

Essentially why it is because, this is caused due to the presence of steep near-vertical wave front. For example, if I draw a wave profile physically or typical wave profile for a impact wave which is going to cause ringing we should appeared to me as a history of this order. Let say it should look like a bell it should converge. Now if we look at the typical time history this is springing res ringing response; if we look at the time history response for this kind of wave. The time history should look like a conventional silent time history we should have a sudden impact and then conventional. So this is what we call near-vertical wave front. And the amplitude of this is seen to be about 8 to 10 times higher than conventional amplitude of h s. So, these are very special kind of wave. And you will believe and you will know that conventional PM spectrum cannot generate this kind of waves. So, that is why these waves were classified separately in the literature say that they are impact waves. They have high frequency content and it is essentially because there is a near-vertical wave front causes.

Then the response actually builds up generally. If I look at the springing response the response gradually builds up generally you know the response actually decays because of the damping effect present at the system or the response can build up and become conventionally stable when zeta by 0.2 is available here. Whereas, in a springing response the response gradually builds up for example, the response goes this way and there is a gradual build up of the response; that is called a springing response. And this is present for a larger time then it dies down.

So, it is this zone which falls in the frequency of compliant with degrees like, surge, sway or yaw will be challenge with this frequency content. There is a gradual build up and gradual decay. So, this was observed in springing wave. So, the buildup response causes worry because it is present for a larger time period, because larger time period in the sense surge, sway and yaw has a time period varying from 60 to 120 seconds a larger time period in terms of its value.

And the third issue which was noticed by the researchers was the ringing waves the frequency of this wave is seen to be generally closer to that of natural frequency of TLP, and this going to challenge one of the stiff degrees of TLP like heave. So, it can result in un stabilized behavior of the system, because heave is controlling the TLP or the tether tension in the TLP and if the tether tension is challenged the whole stability static equilibrium of the platform will be challenged because we know the equation of equilibrium depends essentially on t naught, because that is the counter part is balancing buoyancy force and the weight in the given system. So that will be challenged by the ringing wave, because the frequency content of this kind of wave will be as close as possible to that of a natural frequency. This was observed.

Now the question is how you create a wave will be able to cause this kind of responses. Number 1; what is the spectrum available, what is the wave theory available. Number 2; it is been very conventionally categorily stated by the researchers that the conventional wave loads will not be able to cause these kind of responses. So, it is a special kind of approach for dynamic analysis.

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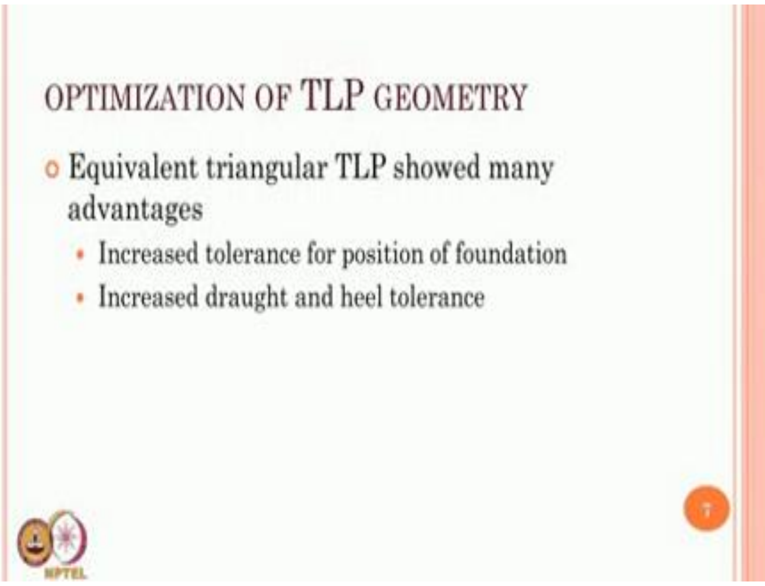

So, before we start looking at how these waves can be generated what is the response on a given system, let us see how do we optimize the TLP geometry. As he said in the present study what I am going to project to you we will talk about the 3 legged TLP which is geometric optimization of a 4 leg TLP what we call in literature equivalent triangular TLP, because this has shown many advantages like it is got increased tolerance for positioning the foundation of the legs. It is got increased draft and heals tolerance.

So, it becomes easy for people to commission this kind of TLP compared to that of 4 legged TLP. They were clearly and categorily expressed by (Refer Time: 20:25) in 1992. Subsequently, there are many papers referred on this which I will show you at the end of the presentation where this statement is supported.

So, we are now working at a comparison of an equivalent geometry and that of a square TLP both. Let say rectangular and square sorry square and triangular. We will see the response on both the cases, then we will try to compare is my optimization really advantage yes this kind of response that is the idea. Because, whenever you talk about conceptualization of any geometry you must always compare the conceptualized geometry with the existing one and show the merits of the geometry compared to the older one. If it is de meritorious we should not take it forward for any analysis and design further. So, in this study we will show you the comparison between an equivalent triangular TLP with that of a square TLP. And of course, TLP is also getting affected by this in general, but triangular TLP is affected lesser compared to the square TLP as we see from the results now as we precede further, any questions here?

So, the study which is purely on dynamic analysis based for this kind of system was a thought provoking idea 90’s because they were special kind of waves which cannot be generated by a conventional spectra or wave theories. They have a different kinds of style of responses they excite frequency bands of stiffer and compliant which is sweeping away the entire phenomena of design of TLP itself. That was the catch here. Now the question comes what is that problem which stops you from not generating this similarity kind of waves in the analytical studies. Let us quickly see what are ringing and springing waves.

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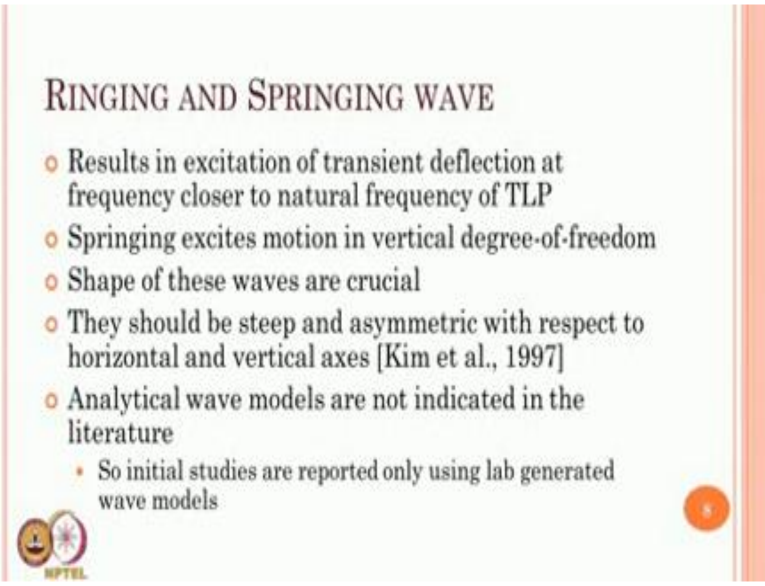

Ringing and springing waves will results in excitation of transient deflection at closer frequency to that of natural frequency of TLP. Springing excites motion in vertical degree-of-freedom that will affect heave degree-of-freedom. Shapes of these waves are very crucial in the analysis, because it has got to have a near-vertical front for a given wave. So, the shape of this wave is very crucial. And these waves should remains steep and asymmetric with respect to both the axis horizontal and vertical as stated by Kim et al in 1997. Therefore, analytical wave models are not indicated in the literatures which are capable of producing this kind of impact and non-impact waves.

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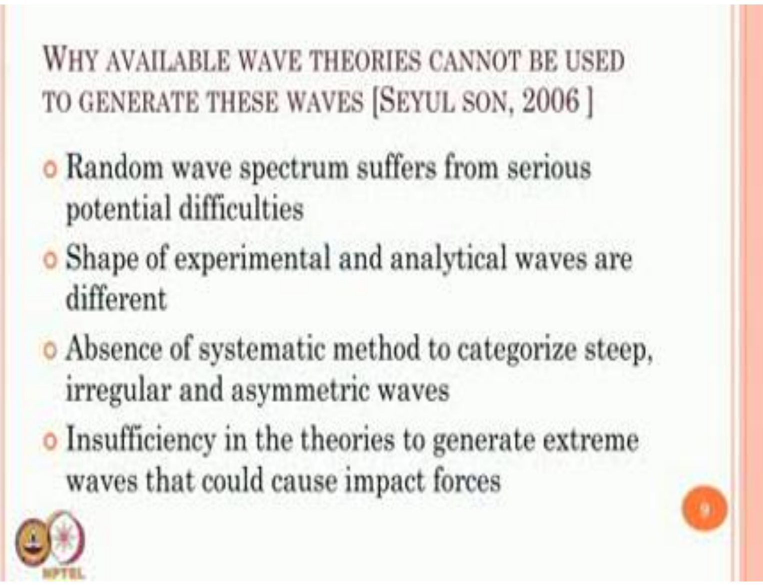

So, Kim et al generated these kind of waves in the laboratory simulated them in the lab for a laboratory scale. Now why available wave theories cannot simulate this kind of waves? When you look at this thesis stated by Seyul Son 2006 (Refer Time: 22:56). He shows that the random wave spectrum suffers serious potential difficulties. You are not be able to generate this kind of waves from a conventional spectrum which is essential a Pierson Moskowitz spectrum or a Jonswap spectrum.

The shapes of experimental analytical waves if at all even created are entirely different. You are not able to match them at all because experimentally Kim showed these waves can be generated, analytically Seyul Son tried to generate them and they were not comparable. So, absence of systematic method to categorize the stiffness effect that stiffness effect in the theory is a serious lacuna because as symmetricity is not possible to create from a standard theory. So, insufficiency in this theory were higher extend in to, therefore these extreme waves cannot be generated to cause impact forces on the system. That was the general conclusion given by both the set of researchers till 2006.

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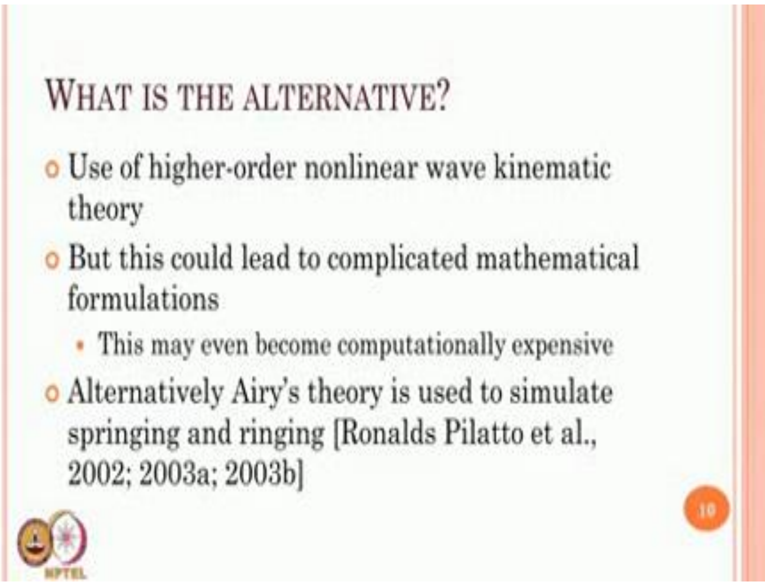

Then what is the alternative, what do we do about it, how do we go. Use of higher order non-linear kinematic theory can be applied here, but this will lead to a mathematical formulation because they will become computational expensive. As we all know in a given equation motion like TLP where its response dependent the RHS and LHS of equation of motion is response dependent. If you are complexity in the non-linear kinematic wave theory model itself then this will impose more complication in your mathematical computations.

This may even lead to non convergence of problems also mathematically. So, you cannot use pure analytical model to develop this. Then people said will converge to Aries theory we will modify Aries sea surface elevation with some parameters so that I can create this kind of wave. So, Ronalds Piltoo subsequently for about 3 4 years attempted this and successfully came out with the model where Aries wave theory model is modified the sea surface elevation is modified to create a spectrum which is modified Pierson Moskowitz spectrum given by Mitchell in 1995. Let us see how is that wave generated

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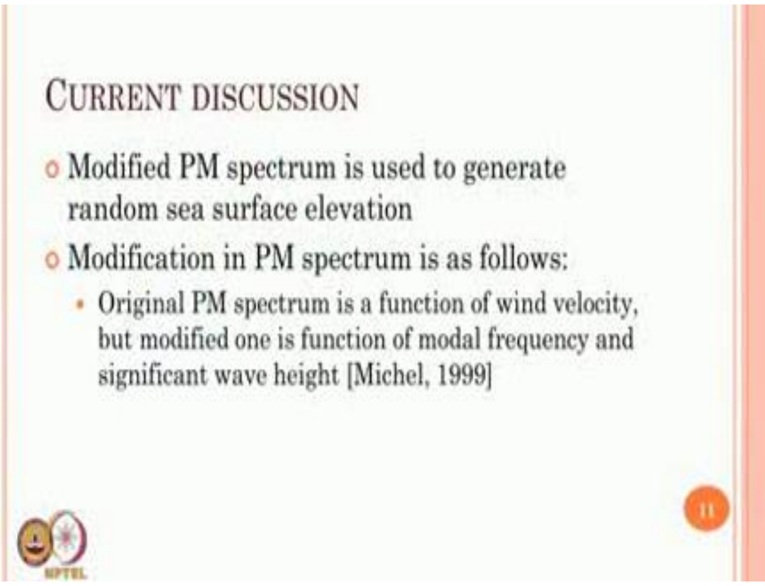

So, the current discussion is about modified PM spectrum which is used to generate a random sea surface elevation, the Pierson Moskowitz spectrum is modified in the following format. One, the original PM spectrum is actually a function of wind velocity, whereas the modified one will be not the function of wind velocity but the function of modal frequency. So, it is picking up a frequency where in you want to excite a specific mode of vibration, where in my case if you want to generate a impact wave I will pick up the modal frequency of that of the stiff degree-of-freedom. If you want to create a non-impact wave I will pick up the frequency of that of the compliant degree-of-freedom.

So, I can always have a choice to choose what omega should I feed in my Pierson Moskowitz spectrum which is I call as modified PM spectrum as suggested by Mitchell in 1999. So, the conventional theories will not be able to generate these kinds of waves. There are people went on to modify the given PM spectrum with the specific equation which is seen here.

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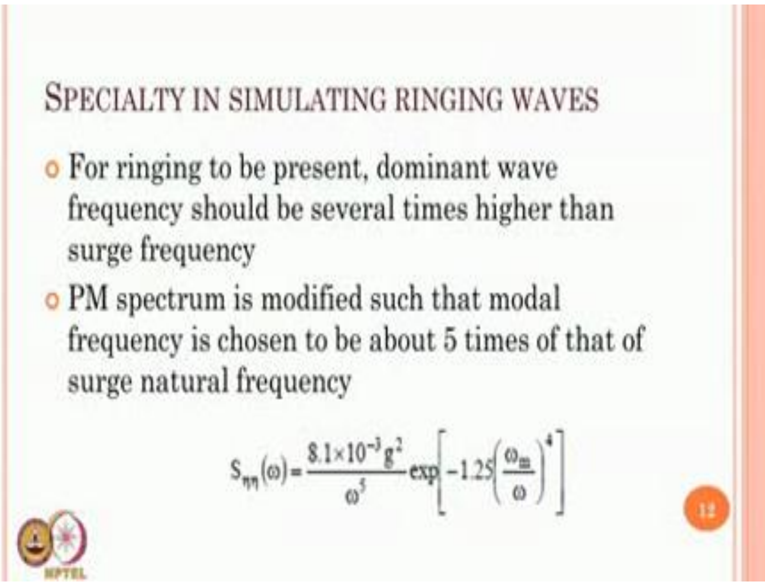

So, that is the modified PM spectrum, where omega m is the modal frequency where omega is the natural frequency of the system and s eta eta is the power spectral density function which is function of omega.

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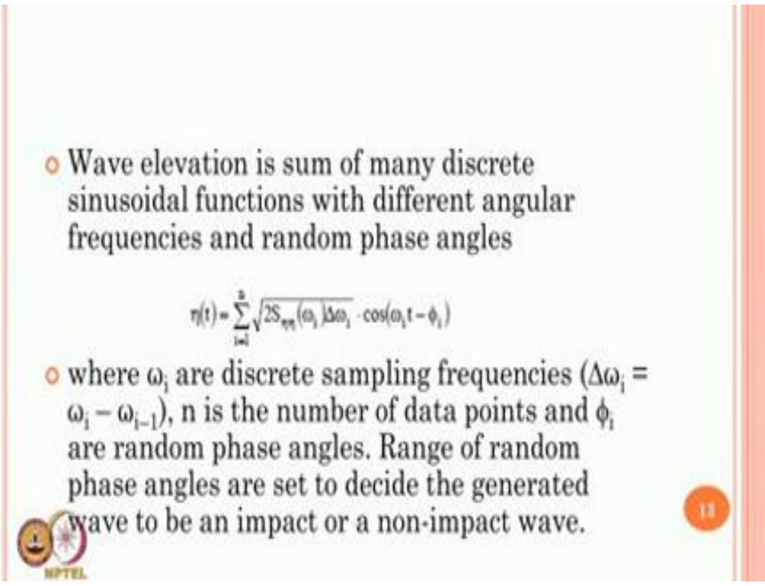

Now the wave elevation which is generated from the spectrum, because you can discretize the spectrum and get a wave elevation the wave elevation eta of t will be given by this equation as seen in the slide now. That this is now a function of delta omega i and phi i, where omega i are discrete sampling frequencies which is picked up from the history where n will be the number of data points in the given time history and phi i is the random phase angle. Now you pick up the random phase angle to decide whether you want an impact wave or a non-impact wave. So now, you have a liberty to modify eta of t which is going to be sum of wave frequencies where you can pick up the phi value and omega i band that is omega i minus omega i minus 1 to as close as heave or as close as or as large as surgeon yaw motions.

So, you can pick up those frequencies and use the phi i value so I can generate eta of t which will give you a different kind of wave elevation which can be either an impact wave or a non-impact wave. For example, in impact wave should have a vertical wave front non-impact wave is the conventional wave, where it is spread for a longer period like a springing wave.

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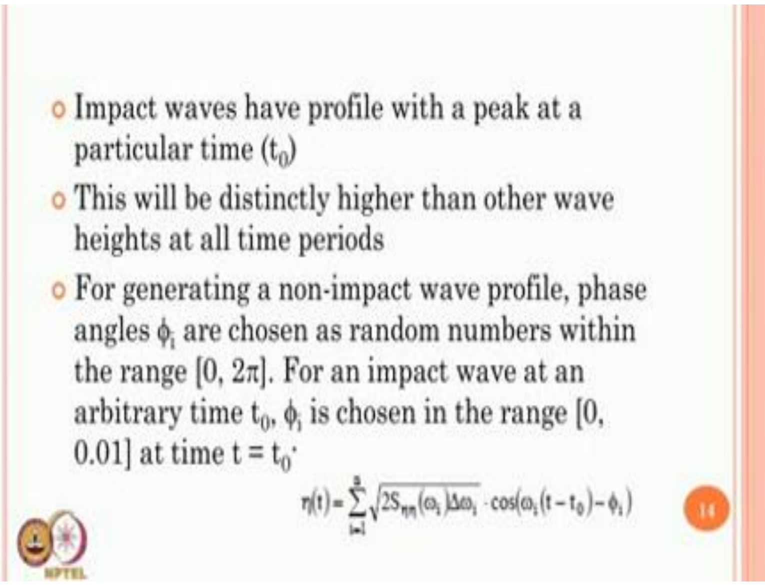

So, impact waves will have a peak instantaneous peak at a particular time t naught. This will have distinctly in higher peak compared to other kind of waves. Whereas, for a non-impact wave the sea surface elevation is modified, you can see the previous equation whereas t naught is not present in the eta of t, whereas you want to generate a non-impact wave include t naught where t naught is the time where the impact wave is generated. So, you are creating a history which is sequential it creates an impact wave first and then non-impact wave subsequently.

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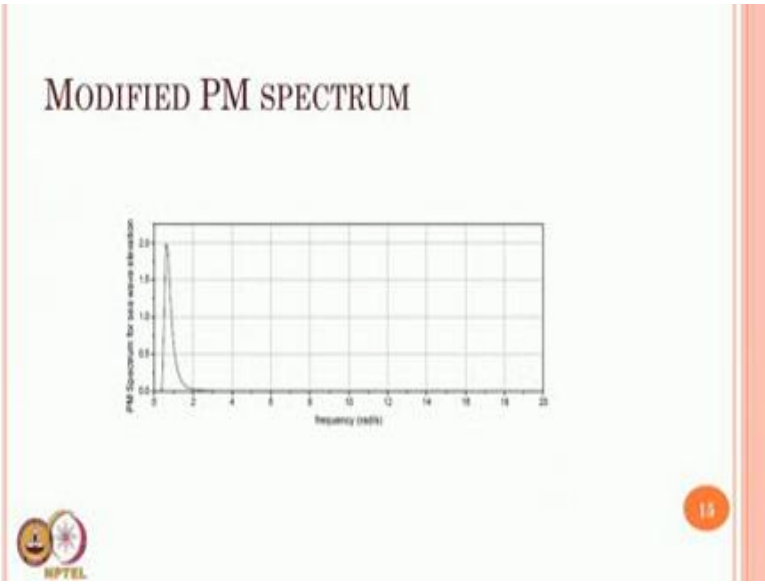

So, that is the plot of the modified PM spectrum, a frequency versus sea surface elevation in terms of its energy is s eta eta content.

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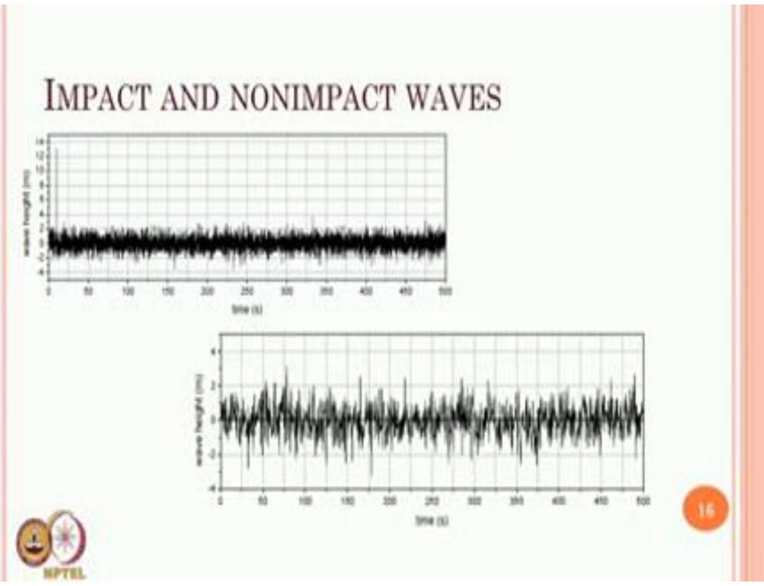

And these are the impact and non-impact waves. I want you to pay attention to the wave history generated from this spectra, because you know from the spectra I can easily generate this wave because s eta eta is input in this generation i, take this input apply generally impact and non-impact wave. This is impact wave because there is a distinctly high wave height present in this model which is not present in this model. So, this was actually a mathematical manipulation attempted to create a special kind of wave which are called either an impact or non-impact wave in the literature, which are otherwise responsible for ringing or springing responses in a given system essentially they are important for compliant system, because they sweep the entire frequency band of a compliant system which is not present dominant in other kind of system.

Therefore springing ringing studies become more important when you have asymmetric flexible system in place compared to that of fixed systems. However, springing ringing responses when notified even in fixed platforms also, but they became more interesting because the whole band of frequency now for both compliant and rigid degrees-of-freedom are now under challenge for this kind of waves. So, this was generated in the presence study which I will show you the results now.

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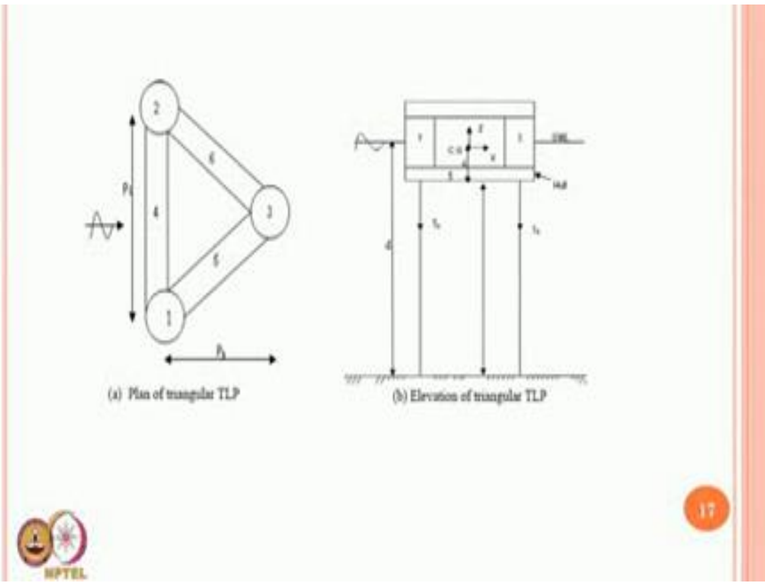

So, an equivalent triangular TLP which was already studied, we have derived the equation of motion for this, where we know how the mass matrix and stiffness matrix come for the system. We already know all the parameters of this. And a plane which is having equivalent triangular TLP is in geometric optimization. We all know just to recollect this we said that the equalization can come from the static equilibrium.

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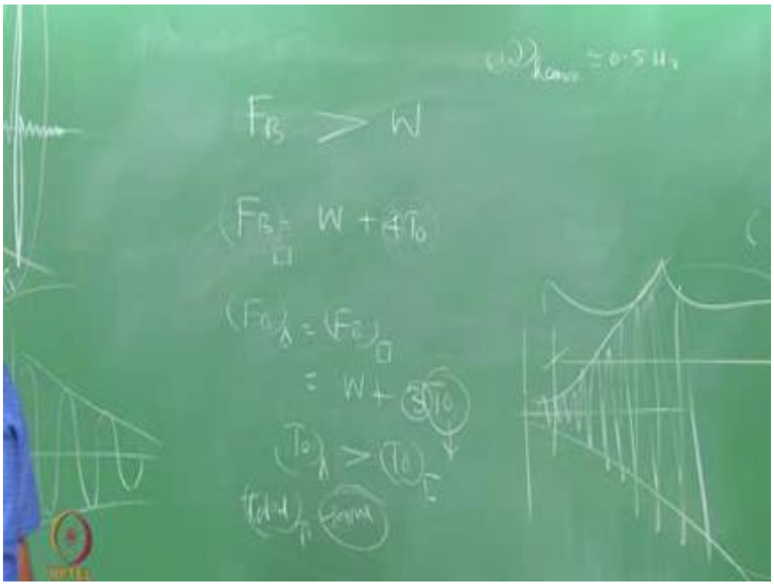

Now we know F B and w need to be balanced. We know F B is very large than w that is the design by itself and complaint system like this, therefore we said F B should be actually equal to 4 t naught plus w. So, 4 t not is a actually the 4 number stands for the 4 legged in the given TLP system, t naught is the actual tension each. So, I can now say either the system will have for example, if this is square if I say the buoyancy of the triangular system should be as same as that of the square; why you can ask me a question why, because I do not want to have any compromise on w I want to have the same topside detail as that of the square and triangular TLP.

Therefore, once I do this statement then I should say w plus 3 t naught it means t naught each level will be much higher; that is t naught in triangular will be much higher compared to that of t naught I mean square because I have three multiplied here. The other way is you can have the total t naught same and you can change the w. So, you can have two equivalencies now; so what equivalency attempted in this case is tension in each leg is same so you have to compromise on the total t naught or tension each the total t naught is same tension each leg is different, there are two optimization now coming up. So, we have to compare these with the existing square TLP. So, what are those TLP taken for this study?

(Refer Slide Time: 31:09)

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

So, these are the existing TLPs available in the literature which are constructed executed in the Gulf of Mexico case 1 2 3 4, I am not naming the TLP you can easily find out the water depth 600, 300, 600, 1200. Now interestingly we compare the TLP 1 and TLP 3 though the water depth may be same, but the initial tension given to the system is different because of the weight. So, what is the influence of a t naught on a given system that is also seen.

And if you compare that is the case 1 or case 3 with that of case 4 you can see the water depth is practically double. Therefore, one can also see what is the influence of water depth on these kinds of responses; so a case a category is been selected in such a manner that all parameters are in built in the study itself like, influence of t naught, influence of water depth etcetera is been studied because t naught is picked up because there is one optimization parameter available compared to that of triangular TLP, therefore t naught is to be addressed.

And when do a free vibration test for equivalent triangular TLP with t naught (Refer Time: 32:09) remaining same one can easily find out the surge periods heave pitch period for all the equivalent triangular TLP now, because that is case 1, 2, 3, 4 where we are saying TLP 1, 2, 3, 4 suffix. So, TLP 1 is an equivalent TLP 1 is an equivalent triangular TLP with that of a square TLP of this order provided t naught per tether remains same. So, that is how it is understood.

If you look at the frequency values of this kind of TLP you will see that in all the cases mostly heave frequency is close to 0.5 except in one case. Let us address this particular issue remember in mind my frequency at heave is close to 0.5 hertz. So, if I see in excitation in a given system close to this value it means I am having a resonant response in a stiffed degree which was very dangerous which is not expected in a given design so far till 90’s. Let us see what happens when we do an analysis of this.

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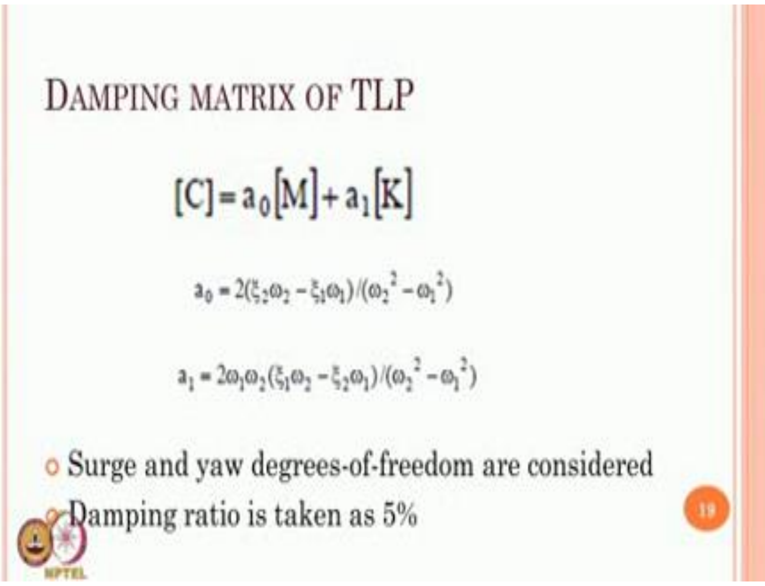

We all know conversion mass matrix and stiffness matrix we need not have to repeat we will stop only over the damping matrix here. I am using a Rayleigh damping here which is mass and stiffness proportional where as constant a 0 and a 1 can be worked out from this. Now here the liberty is to pick up omega, now in this case we have to pick up the omegas of a closer range so surge and yaw degrees are picked up and 5 percent damping was used as zeta 1 and zeta 2 so that we would not have any uniform damping in all active degrees-of-freedom. So, we picked up those bans and found out a 0 and a 1 applied in the mass and stiffness and got c which is Rayleigh damping.

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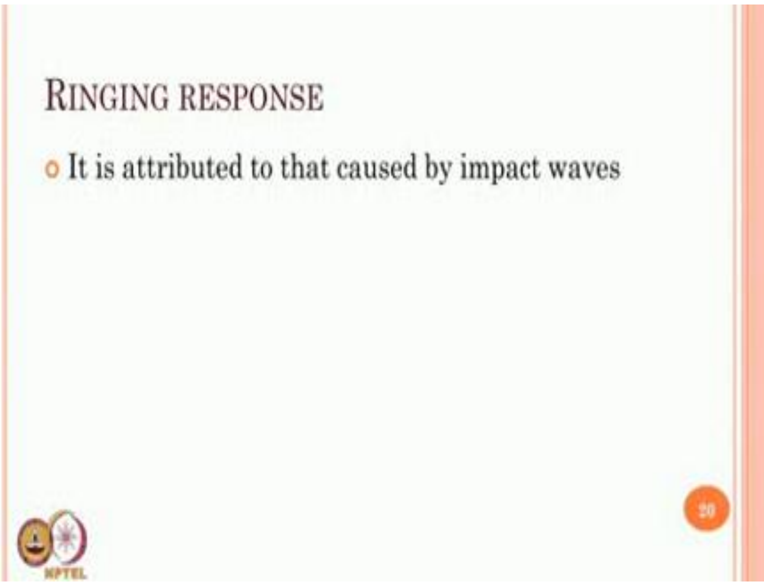

Now, let us talk about ringing responses which is caused by impact waves.

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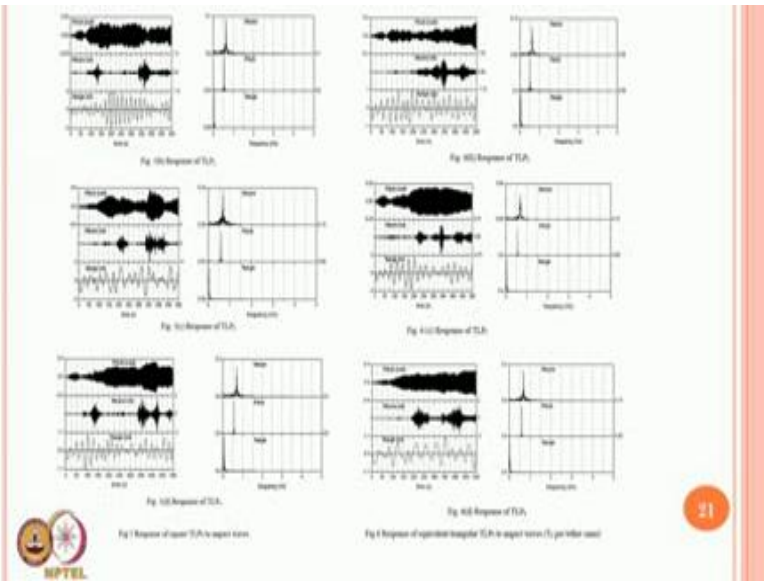

If you look at this figure I do not know whether you can intensively closely see this for example, I will just read this figure for you are qualitatively. This is response of TLP 2 TLP 3 and TLP 4. Now TLP 2 and TLP 3 are compared because they have water depth of double because TLP 2 is 300, TLP 3 is 600 meter they are double. And TLP 2 and TLP 4 are compared because water depth is again double here 600 and 1200, so influence of water depth is been seen in specific literature.

Now if you look at the frequency content of pitch heave, pitch and cells. Please carefully see here this is my pitch response, this is my heave response and this is my surge response in time history. When I move on to the frequency content heave is plotted first one can ask me a question why it is so, because you see here these all depends upon how they occur. So, they occur at the frequency this is occurring lower than this occurs closely to 0. So that is the order why this was swapped actually. Now let us look at the response in terms of time history, look at the pitch response this looks like a build up and gradual increase in response spread for a longer time. One can easily infer that this response is similar to the springing response.

If I look at this kind of response it has two frequency contents, but of course this is shooting up on heave degree-of-freedom which is practically equal to 0.5 because this is 1. The moment I see 0.5 hertz here I remember that all platforms of TLP 1, 2, 3, 4 all of them have a natural frequency closer to this heave degree where my expectation energy is present at the frequency. So, I can really say that the impact wave or the ringing wave is exciting heave degree-of-freedom very severely, maybe in all the platform TLP 2, 3 and 4 as well. This is about the square TLPs.

Now let us compare this quickly on the screen with that of triangular TLP where t naught per tether is kept same. So, we looked at that the intensity of this value and the spread of this is slightly inferior compared to the square TLP. Quantitatively we will define it later in the subsequent slides, but they are different. However, even in the case of triangular TLP the excitation at 0.5 hertz is seen which was undesirable response in heave degree freedom heave is supposed to be stiff degree-of-freedom.

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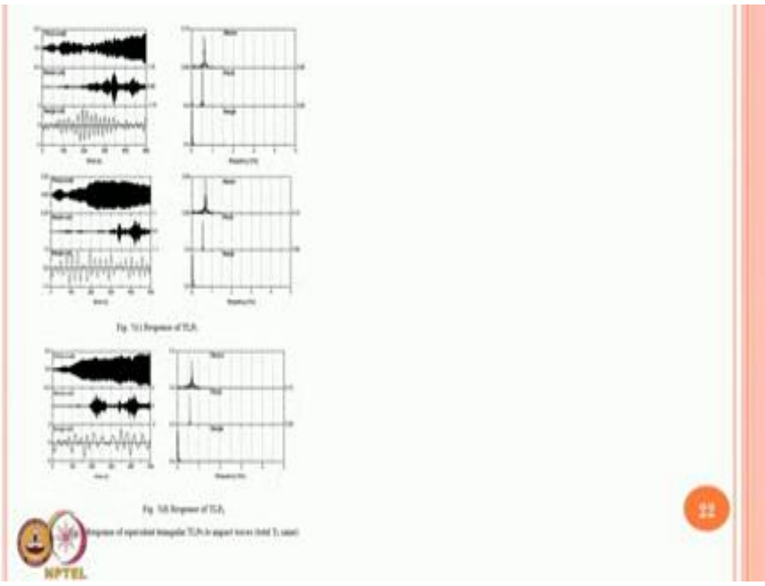

Similarly, when you compare the response with total t naught same there is another geometric equalization optimization; here also you will notice that heave is getting exited closer not exactly at 0.5 closer to 0.5. However, if you look at the pitch response and surge response they are occurring also at the heave frequency is showing very strong coupling between these degrees-of-freedom. So, heave is excited it will also cause failure in pitch motion which is also undesirable for a platform of production facilities in a given heave state.

And you can easily see here they are looking at blow of a gas is release models, like in you see here the response gradually picks up and keeps on going continuously. You can see the energy content present is heave in the close frequency is spread for a broader band; the bandwidth is broader in this case. That means, the energy content is much larger at natural frequency system.

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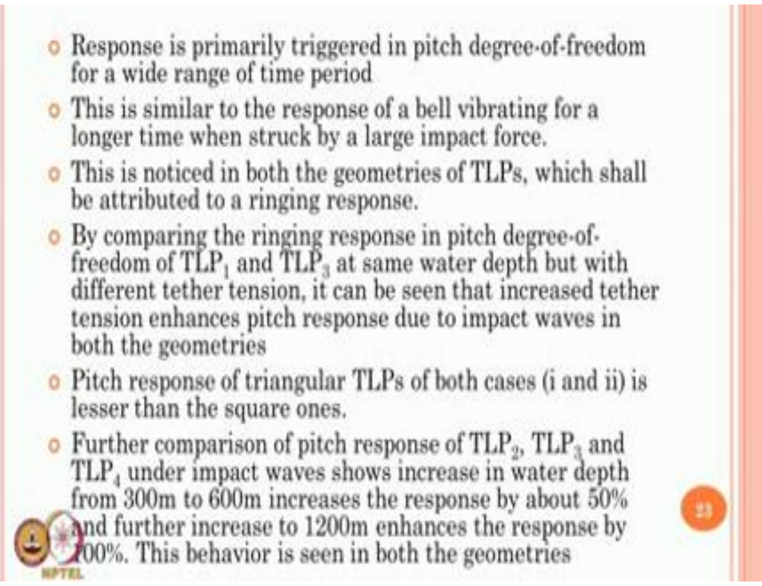

So, response is primarily triggered in pitch degree-of-freedom for a wide range of time period. This is similar to a bell vibrating therefore it is called ringing response caused by a impact force. This is noticed in both the geometries of TLP both rectangle and square and triangular. If you compare the ringing response in pitch degree-of-freedom of TLP 1 and TLP 3, because 1 and 3 are of the same water depth 600 meters. However, at the same water depth with different tether tension it is seen that increased tension enhances pitch response which is the other way generally. When you have increased tension people think that the state platform will be more stable response will be lesser that is vice versa here, when you are subjecting in to an impact way which has true for both the geometries.

Pitch response and triangle TLPs are found to be slightly lesser compared to the square ones. If I further compare the pitch response of 2 and 3 and 4; 2 is at 3 meter, 3 is at 600 meter, 4 is at 1200 meter where I set there also there. In case of 50 percent response say between 300 and 600 meter it is further increasing the another 50 percent from 600 to 1200 meters. It means water depth place a very significant role in these kinds of responses in both the geometries, triangular as well as square.

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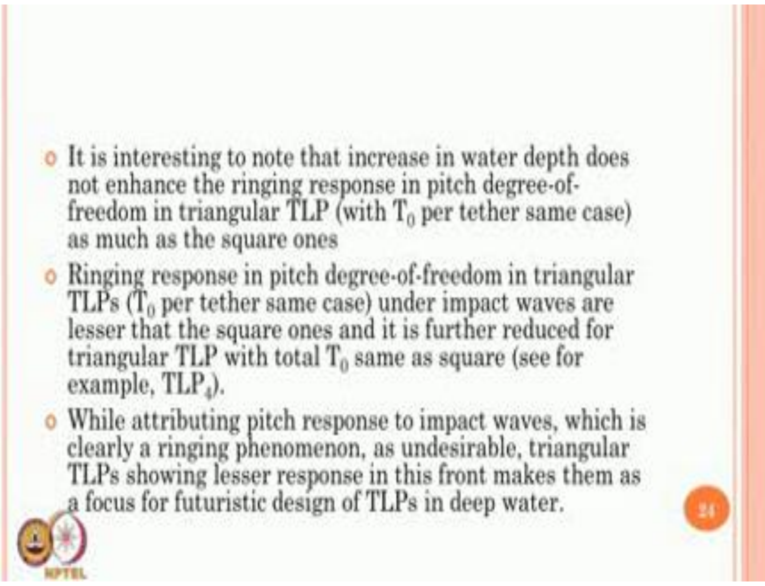

It is very interesting that the increase in water depth does not enhance the ringing response significantly in terms of the content. In triangular TLP compared to that of square TLP for a specific case where t 0 per tether kept same. So, in ringing response the triangular TLP and impact forces are generally seen to be lesser than that of a square. If you attribute pitch response to one of the impact waves as ringing responses as ringing phenomena which is undesirable. However, triangular geometry shows lesser response compared to the square geometry. Therefore this can be a futuristic design for TLP in deep waters. That is the conclusion what we have for impact waves.

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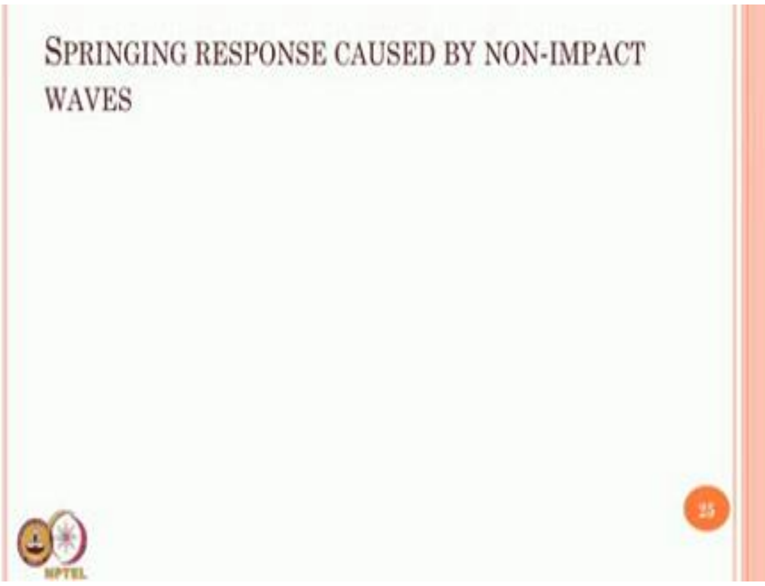

Let us see what happens in non-impact waves. Non-impact waves are a generic wave which is present for a larger period for a comparable wave height. Let us see what happens in that case. Again we are comparing square with that of equivalent triangular where t 0 per tether is kept same and these are all non-impact waves in both the cases. So, I am having TLP 2, 3 and 4; 300 meter, 600 meter, 1200 meter water depths. You will see that again the bandwidth in terms of greater water depths is larger further. In heave degree-of-freedom which is also not acceptable, because the energy concentration is higher for square TLPs.

Whereas, when you look at triangle TLP the bandwidths are minimum or lesser compared to that of square shows that the energy content present in the specific frequency which is causing a non-impact response or a springing response is lesser of order compared to square geometry, though it is excited there also there is a content present in the lower order. That is true in the case of other equalization of triangular TLP also.

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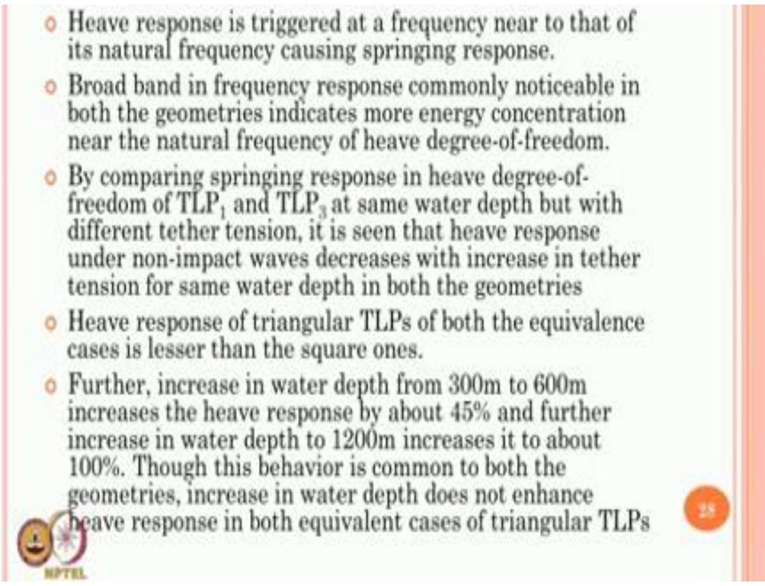

So, this tells me a simple conclusion that heave responses are triggered a frequency nearer to the natural frequency as a ringing response. Broadband indicates energy content is larger percent in both the geometries. By comparing springing response of TLP 1 and TLP 3, TLP 1 at 600 meter and TLP 3 is also at 600 meter same water depth, but different tether tension heave response non-impact waves decreases with increase in tether tension which is generally vice versa in theories.

Heave response of triangular TLPs seems to be lower or lesser compared to that of square ones. And there is always a significant increase of response compared to the water depth which is seen in both the geometries. Heave responses in all square TLPs shows bursts off which indicates that there is no rapid buildup, however this rapid buildup available in equivalent triangular TLP which is associated in literature as a beat phenomenon. This is what people call as beat phenomena.

So, this type of response makes square TLP more prone to a fatigue failure because this is happening in heave degree-of-freedom. The repeated response build up will cause decay of tether forces and that will result in fatigue failure of tethers and we can say the response cause by non-impact wave in heave degree-of-freedom is a near resonating case which is alarming, so far this kind of response was not explicitly told and express a literature till research on this order and conducted and carried out.

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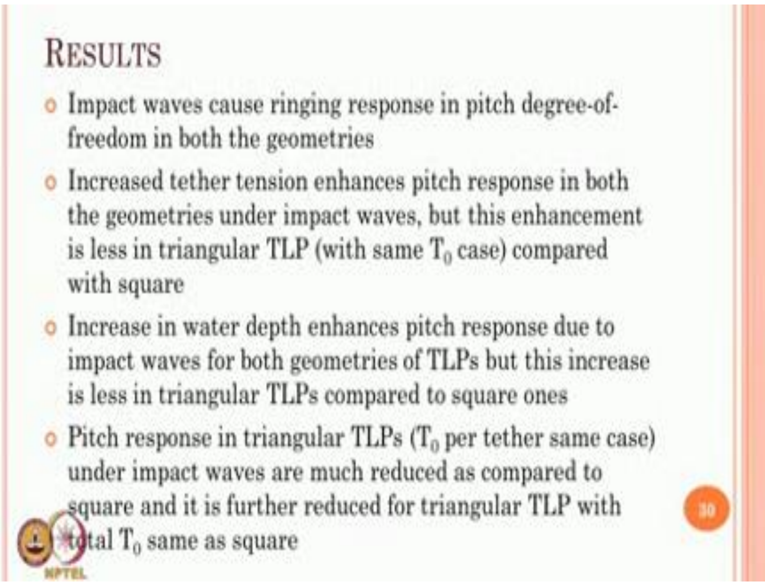

So, the results are very simple in this case impact waves caused ringing response in pitch degree. Increased tether tension enhances pitch response in both geometries. Increased water depth enhances pitch response due to impact waves, but of course this is lesser in triangular TLP compared to the square ones. Pitch response and triangular TLP under impact waves are much reduced compared to that of triangular square TLP in both the geometries.

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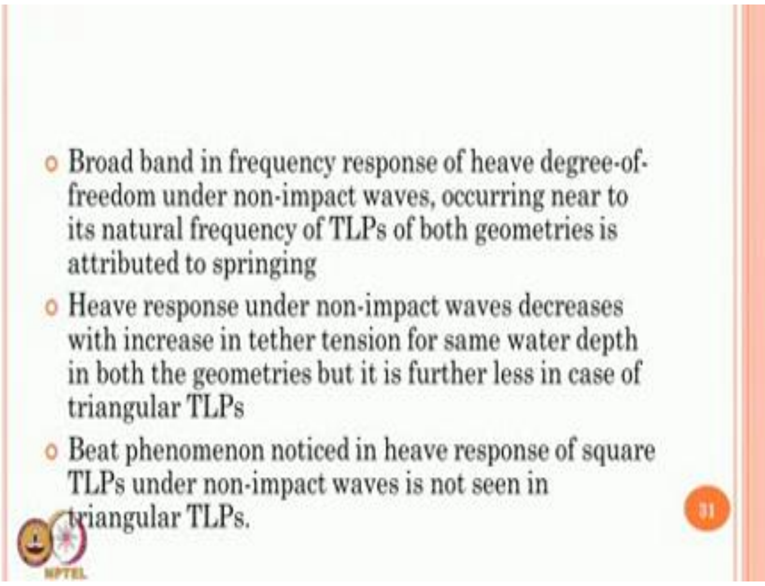

Broadband response seen in frequency response of heave degree-of-freedom which is cause by non-impact waves which is called springing response. Heave response and non-impact wave decreases with increase in tether tension. And heave response indicates beating phenomena in heave degree-of-freedom for square TLP and non-impact waves which is of course, not seen in triangular TLP.

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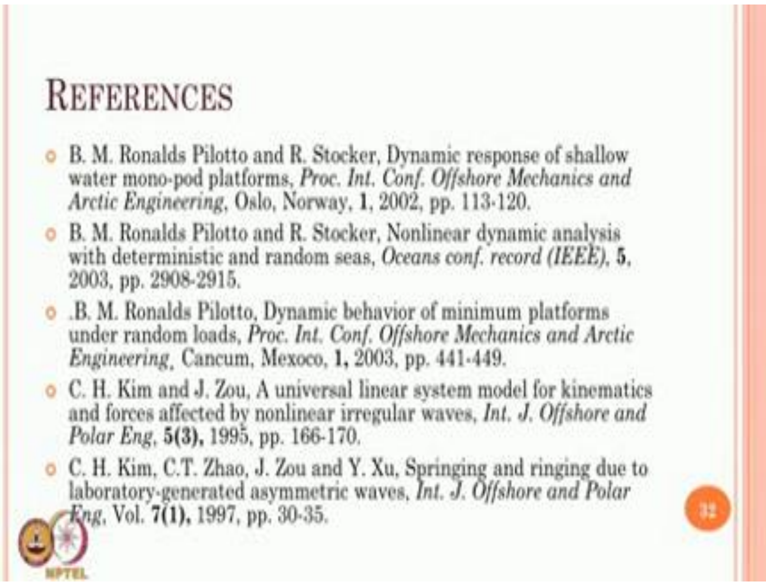

Of course, the study has got lot of references. Pilotto 3 references, Kimmetol 2 references.

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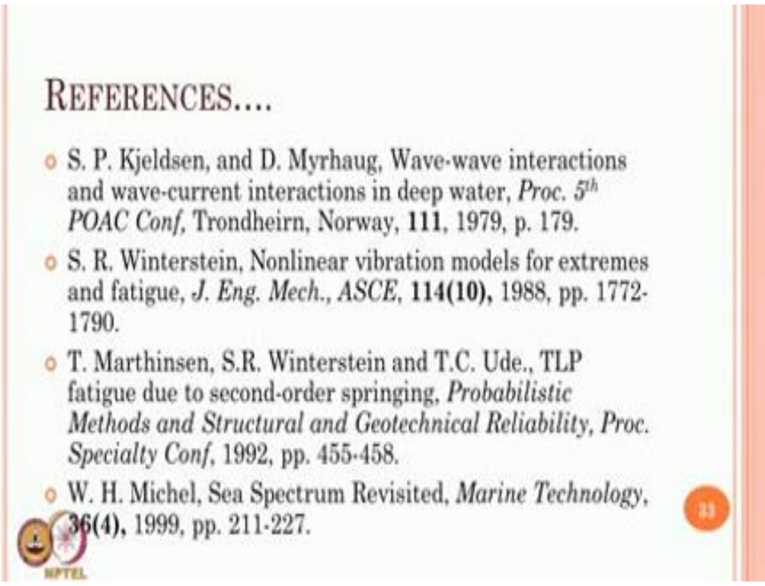

Kjeldsen Myrhaug we have been waves structural interaction waves current interaction deep waters in 1979, Winterstein Nonlinear vibrations for extreme waves and fatigue. Marthinsen, Winterstein and Ude fatigue and TLP due to second order springing responses. Michel we have he has given a sea spectrum; modification for Pierson Moskowitz spectrum in 1999.

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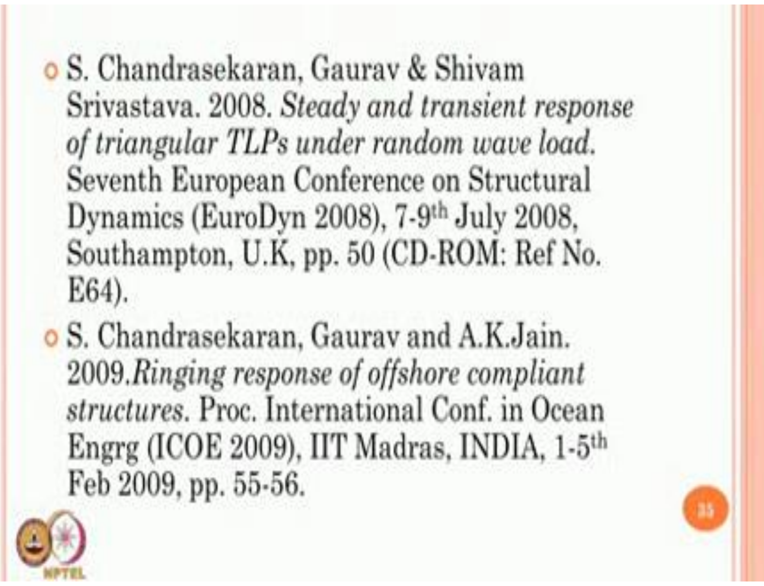

Of course, the result what you presented as a support from the following publication of my own, 2010 ringing response, 2011 springing ringing response internship building progress, 2013 dynamic response under extreme waves Jain A. Myself and Bhattacharyya in book on analysis and design with (Refer Time: 43:29) Changwon University, then springing response steady state transient response of TLP under wave loads. European conference, Southampton and myself and Jain ringing response in IIT Madras in show 2009.

We can also look at the response of the extreme waves I will quickly take out 5 minutes extreme explain what are extreme waves.

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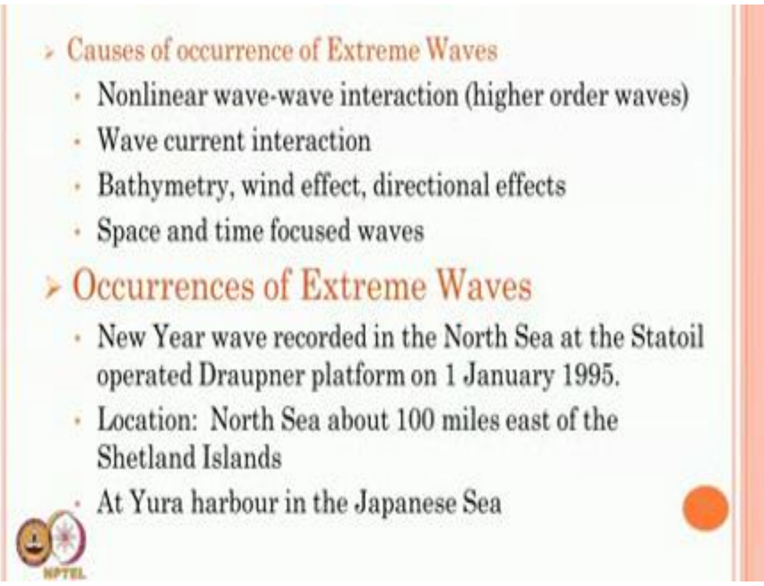

Extreme waves are very interesting. The causes for occurrence are very simple; they have a non-linear wave-wave interaction. Wave current interaction creates extreme waves. Bathymetry, wind effect, and directional effects are responsible for these kinds of waves. Space and time focused waves are actually extreme waves. They are occurred seem to be occurred in Draupner platform in January 1 1995 recorded, but they call as a new year wave because it is been recorded on first January 1995, so it is called as a new year wave. The location was North Sea about 100 miles and it is been also seen in Yura harbor in Japanese Sea.

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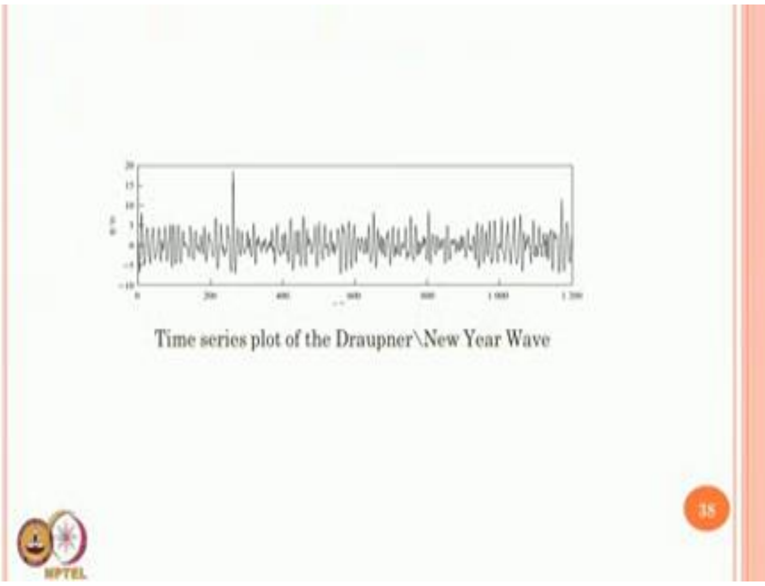

They look like this as a New Year wave a Draupner wave. They also have a distinctly high wave front which is 20 closer to compare to 5. So, it is about 4 to 5 times near-vertical wave front. So, this was also an impact wave seen as a Draupner or a new year wave.

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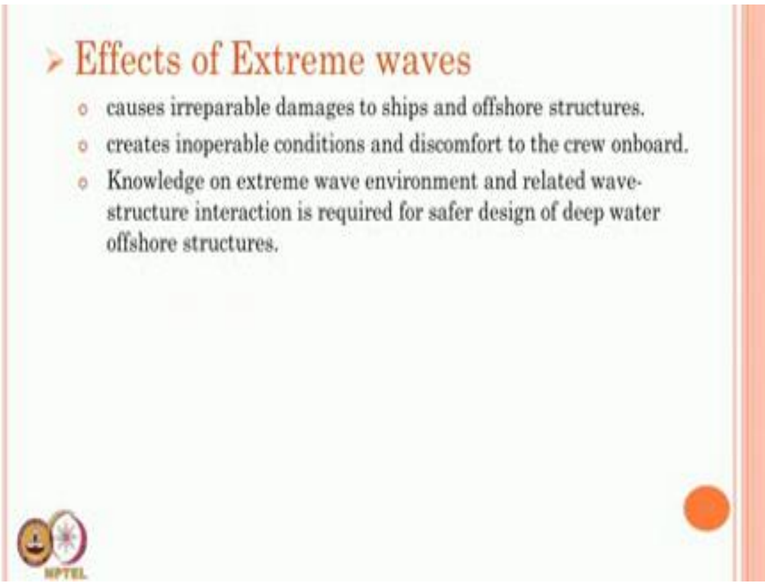

They have different effects on structures. They cause irreparable damages to ships and offshore structures. They create inoperable conditions and discomfort a crew on board. The knowledge of these waves are very important analyze them for extreme behavior

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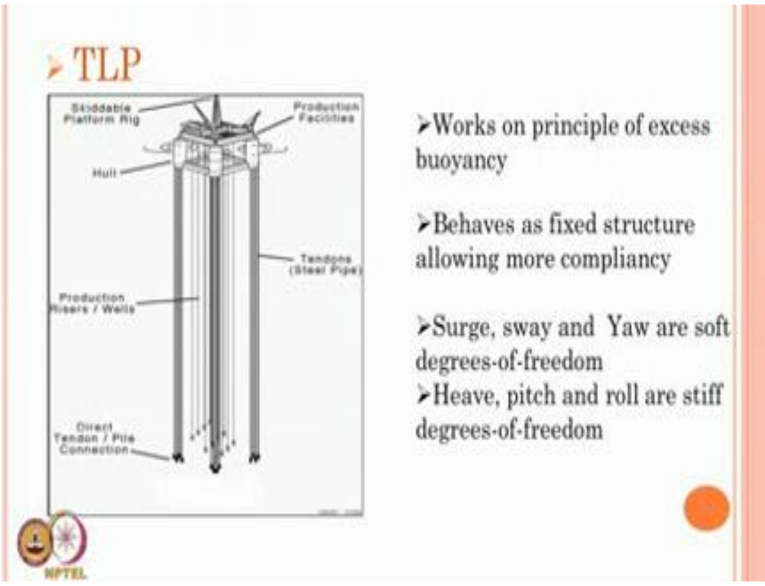

Study was done again on TLP.

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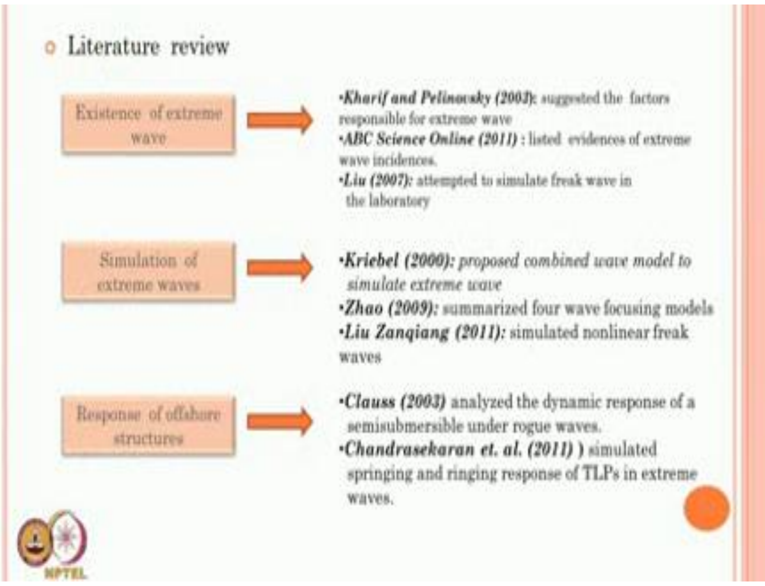

Literature reviews are given here.

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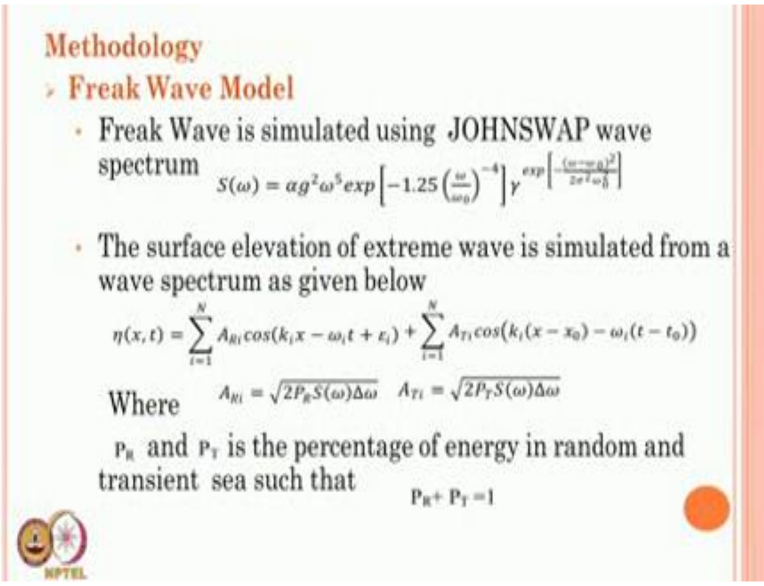

Freak wave model was generated using a Johnswap spectrum in this case, earlier cases modified PM spectrum.

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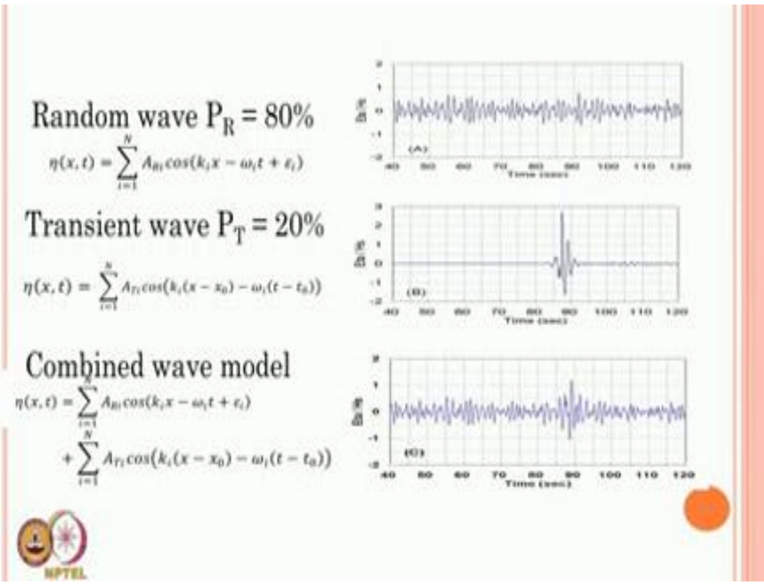

And you can see here the random wave measured and the random wave I will show you the comparison quickly here.

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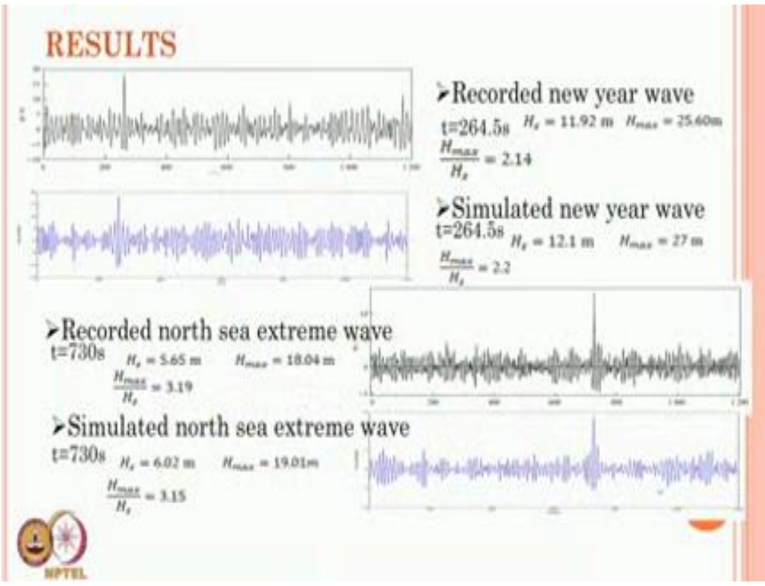

This must be somewhere here. This is the recorded New Year wave. So, simulated New Year wave this is recorded North Sea extreme wave this is similar to the extreme wave. If you look at the time for which the period is being done h s, h max and the ratio. If you look at the simulated wave they practically have the same ratio and practically have a closer h s from simulation. Similarly, if you look at the extreme wave h s, h max and ratio simulated wave has a closer h s, closer h max and the ratio is practically closer.

So, how they have been simulated is using this relationship. In a random wave we pick up 80 percent of the randomness from the sea surface elevation, 20 percent of the transient wave from the sea surface elevation and combine them and create a wave. Once you create this wave the simulated wave has got a very close match of the real observed wave in the sea front taken by the literature.

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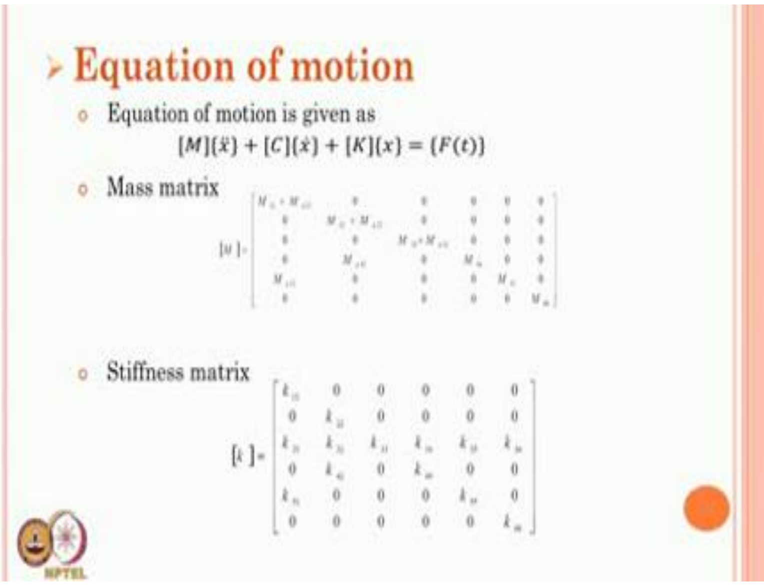

Then of course, we have the mass matrix, stiffness matrix.

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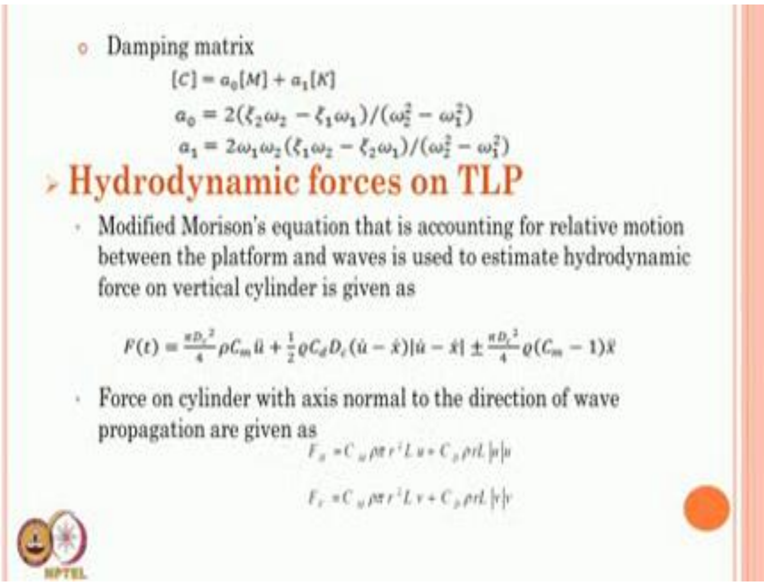

Damping matrix for TLP. Hydrodynamic forces using Morison's equation

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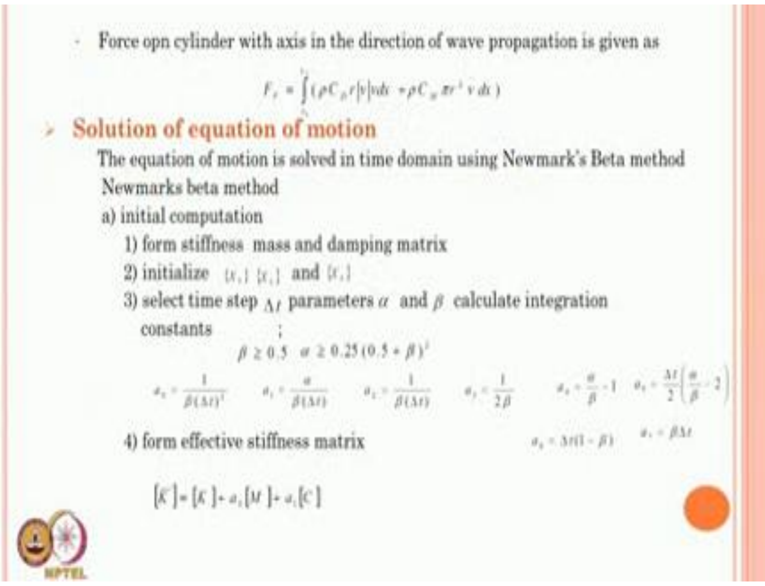

The solution is done using Newmark's Beta method and time domain which I will discuss slightly later.

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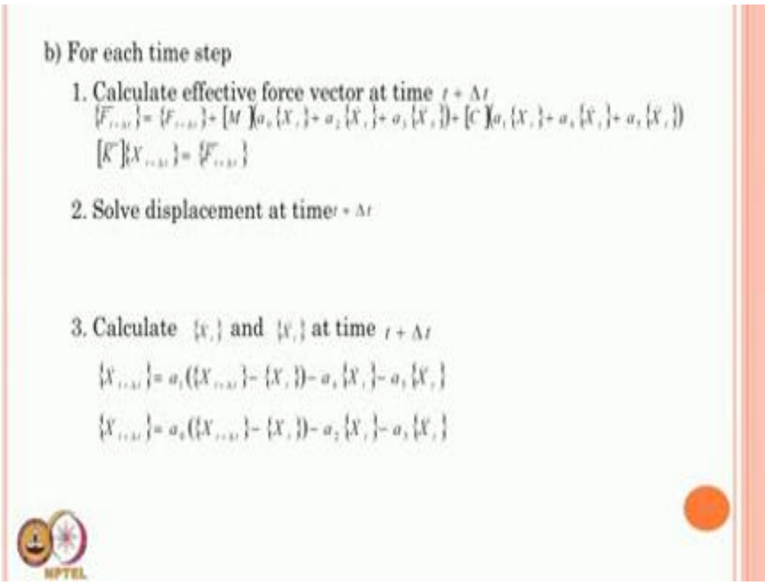

But however, the solution (Refer Time: 46:31) 0 is given here.

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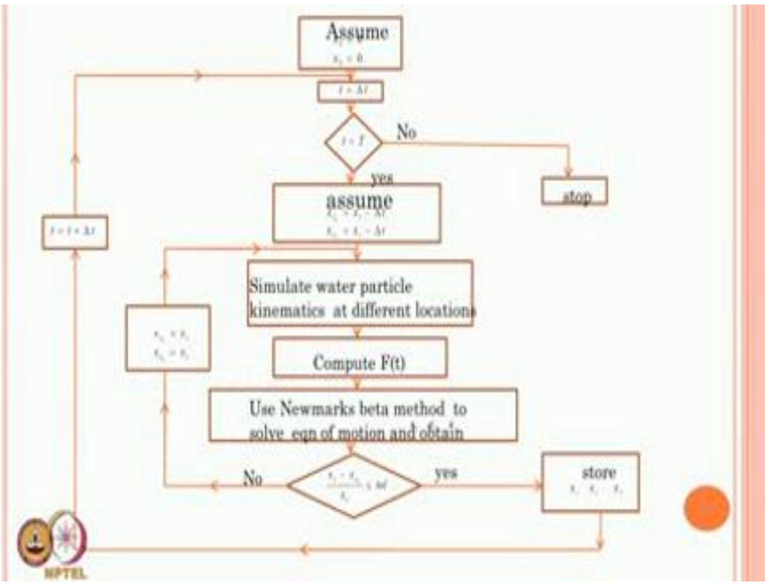

The solution domain was also explained here.

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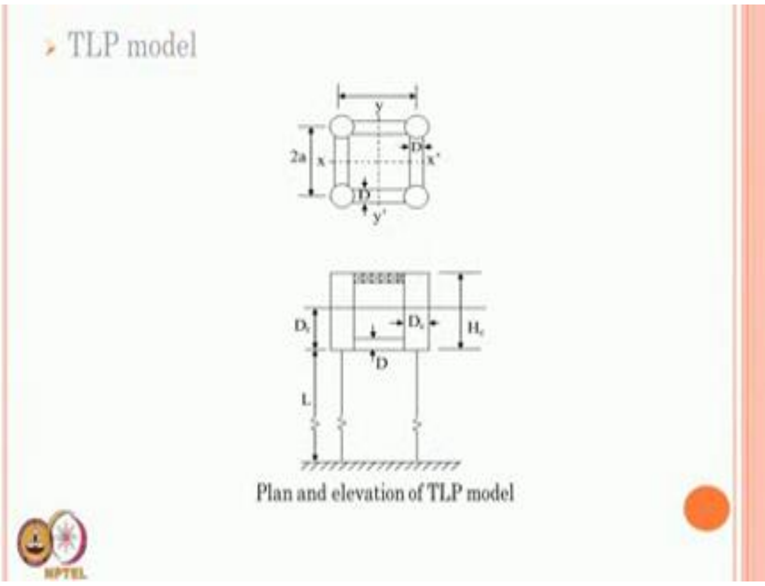

The results are here. Then we have appealed for a 4 legged TLP and the results are like this.

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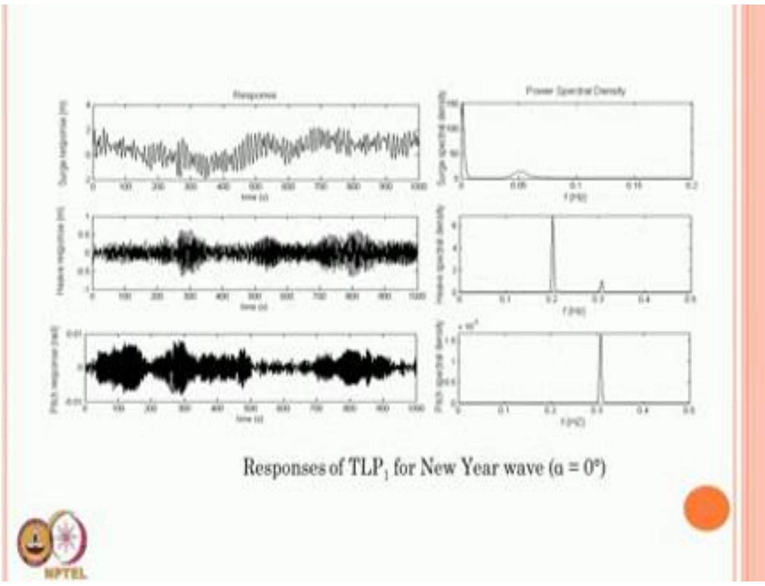

Which you see again here, in case of heave is been excited closer to natural frequency of the system. There is a second peak occurring closer to natural frequency of that of the pitch which shows a strong coupling in 2 degrees-of-freedom, which was again seen in extreme waves also.

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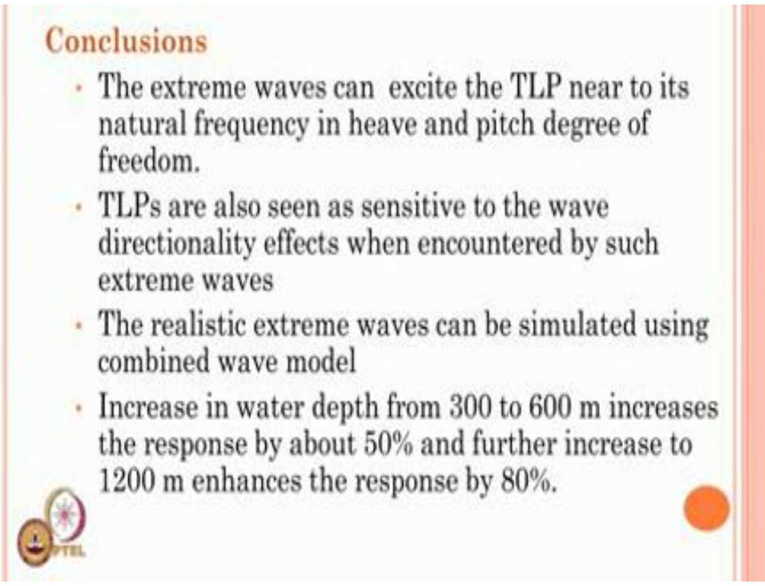

So, the results conclude that extreme waves can excite TLP near to its natural frequency in heal and pitch degrees-of-freedom. TLPs also seem to be sensitive to wave directionality effects. The realistic extreme waves can be simulated using a freak wave model as adjusted by the researchers now. Increase in water depth increase in response by 50 percent and subsequently 80 percent.

So, this a lecture covers dynamic response analysis of a compliant system like TLPs. Starting with the history why here TLP was selected for this particular problem of an origin and how the waves can be generated. Why these waves cannot be generated using a conventional wave theory models on PM spectra or Johnswap spectra. What modification you have got to do for this where the reference have been taken, how the public results are validated and how extreme waves show very alarming response on a complain system like TLP which is very important for design conceptualization for ultra deep waters. If you want to really use TLP system for deeper water (Refer Time: 47:52) in future, any questions here. We close here.