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

Lecture - 42
Dynamic Analysis of Offshore Triceratops

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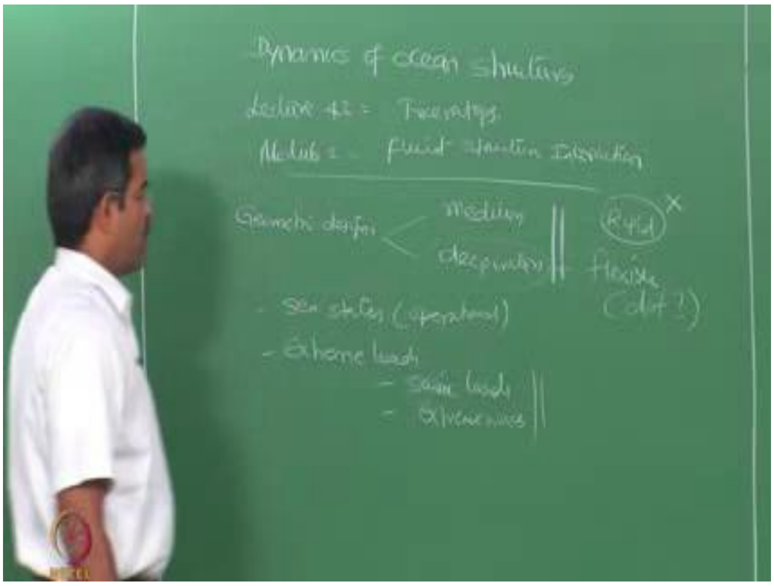

So, let us now look at the 42nd lecture on module two (Refer Time: 00:20) going to talk about dynamic analysis offshore interaction on triceratops. So, already we are seen there are some let us say geometric designs which are actually developed for shallow in medium waters and deep waters. We have principally understood that the designs between these two concepts are not similar because in deep waters we wanted a system which should remain more flexible whereas, however, medium and shallow water systems remain more rigid. And of course, this concept becomes absolute except for certain degrees of freedom, except for certain degrees of freedom this concept become absolutely not valid for deep waters.

Once you develop any geometric form people use to test it for regular sea states what we call operational sea states. Let us look at this results of let us say whether they are having comfortable responses within the permissible values or the tether tension within the permissible value etcetera. Then also check it for extreme load cases, extreme loads of course include seismic loads or seaquake, can also be extreme ways etcetera.

Now, in all this cases if you see there is a common (Refer Time: 02:01) in this development of this platform.

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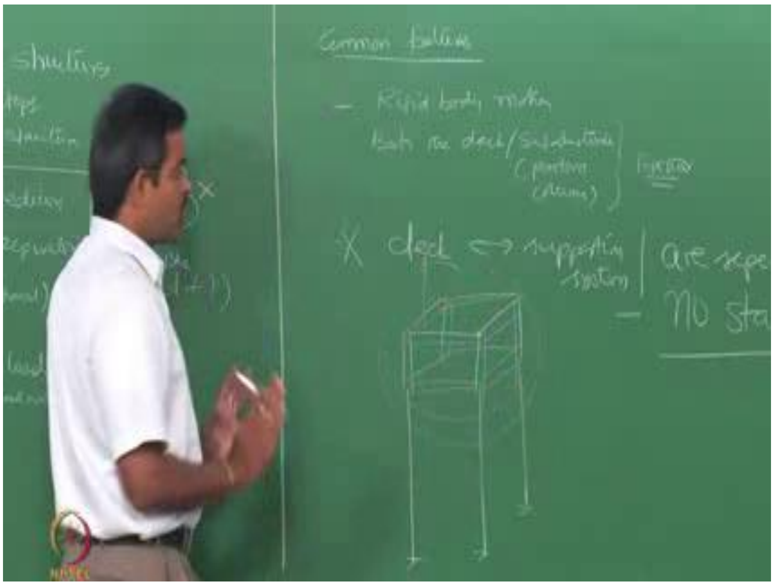

The common let us say features in development of this platforms where one, most of this platforms had planned for rigid body motion and both the deck and sub structure we call for example, sub structure can be a pontoon can be a column member as well as (Refer Time: 02:38) concerned can be a spar boy as well as far as spar is concern etcetera they are generally transported and commissioned together.

On other hand is a very important derivation from this what we can understand is that, when the deck and the supporting system when the deck and supporting system are separated the system had shown no stability. That is a very important catch in all this commissioning, decommissioning etcetera the deck and supporting system; supporting system of course, if you look a TLP let say this is my TLP (Refer Time: 03:26) platform, my deck, may be multi tyre, may be multi tyre etcetera. These are my column members of course, there are contour members as well as here and connected here. The whole system actually becomes a single unit except that they are anchored to the sea bed the tethers which are commissioned by ballasting and deballasting this chambers.

Otherwise this remains a single unit. So, there was no concept available in the design. You look at this application to any other platform may be gravity based structure, may be template structure etcetera, all where attempted to become a single unit as well as the deck and sub structure or supporting structure is concerned. However, in the deck there are multi tyres, these multi tyres were installed and commissioned subsequently later. But the principle unit and the supporting system remind as a single intact unit because when you separate them stability was not achieved because the system does not have enough buoyancy nor system had enough weight. So, they can pulled down or anchor to the sea bed.

There is a very important drawback here, the drawback is that. Depending upon the size of this, depending upon the mass of this you have got to design a system of a two way etcetera where the stability of the whole system will be challenged if it is sinking, cap sizing etcetera like a vessel. So, people thought that can break this geometry also for commissioning and decommissioning. The question is can we install these pontoon members and column members independently and assembled them, because when I make them independent I can float this column members independently I may not require large vessel, large (Refer Time: 05:12) etcetera, as it is has been require for this kind of vessels for platforms.

So, I want actually minimize the installation time and cost maximize the installation window in terms of weather window. So, that I can comfortably operate my installation and decommissioning whatever may be the weather window with minimum amount of external agency like cranes, etcetera. So, for that you have to think about the system which is disintegrated and can be integrated which was not possible because all these are welded connection and etcetera and so forth it is a single unit, this was not available. Of course, when you look at this transparence system with that of g b s etcetera this was far advance no doubt about that the weight is much reduced, but still operational problems related to installation commissioning (Refer Time: 06:00) etcetera were still remained a complication and now the concept in 2010 came into play that can by geometrical optimize this itself.

So, when this idea was thought people said each leg of supporting system can also have a positive buoyant system.

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So, each leg the moment, I say leg I am not talking about tethers I am talking about this column and pontoon members only because tethers are never load carrying elements, they are only pushing restraining elements in the design they were never load carrying elements. So, each leg preferred to be positive buoyant system. What do you mean by positive buoyant? Positive buoyant means buoyancy exceeds weight, buoyancy oppose very well exceeds weight that is positive buoyant. The moment you take any make any system positive buoyant installation is very very easy, you have to simply (Refer Time: 07:02) to a vessel or a tug boat that is all because it is not having any weight, it is easy and disintegrated.

Now, disintegration of design will help you in couple of ways one the quality control in design can be higher why because you are not configuring the whole platform you are configuring the each element of the platform separately. So, you can manufacture n number of buoyant legs parallelly because all of them will get assembled only when they are actually at the end product. So, did not able to wait for; for example, the deck fabrication as to wait until the column members are fabricated, the column members have to be wait until the pontoon members are fabricated etcetera, there is a inter linked between the fabrication stage also. But in this case when you disintegrated them all components can be manufactured parallelly. So, there is extreme quality control available and of course, the time. Now, when this was identified as a major advantage in any type of geometric optimization for each leg then assembly became a big problem now how will join them, because a platform has to remain as a integral unit, how to join them.

So, now the assembly or let us say the fabrication has to take place at site, site means in the open sea not in the work shop, whereas in this case the fabrication erection and commissioning in the assembly took place in the work shop, whereas in this case the assembly as to take place in the open sea. On the other hand it is very important for us to realize as a (Refer Time: 08:44) or engineer that if we talk about any assembly which has got to take place in open sea each assembly is a single leg, should remain stable because you have to assemble them.

Two, any such dissemble unit should have connectivity, should have a connection or connectivity that connectivity should be designed in such a manner which should not transmit forces from the bottom to the top. Now, one can ask me question why it should not transmit. If I have a system, let us say I have a system top and bottom, let us say this is above water this is below water hypothetically and if I have a connectivity between these two and if this is stable this will automatically become stable because this will have a connectivity between this two and any forces attacking the bottom will not transport to the top. So, whatever may be the un stability in this case is concerned if it is not effecting the super structure at all, all may activity of drilling, transportation, crossing, is going to take place here I am not bother about how this would behave.

So, I have to have a connection or the design of the connectivity of such a manner that the transmission of certain degrees of freedom should be filtered. Now the moment I talk about certain degrees of freedom; obviously, this should have independently 6 degrees of freedom, this should have 6 degrees of freedom that is the maximum we can have in a two dimensional analysis etcetera. So, there should be a 12 degree of freedom and I have go to let us say synchronize certain degrees between these two - the foremost synchronization should come with heave, why? Because the platform should remain anywhere remain heave restrain, if the platform heave not restrain then you will not able to anchor the platform because it is positive buoyant.

So, whatever pulled down I make on the bottom should be an able to pull down the top as well, otherwise the top will float separately will not be able to perform any operation. So, heave restrain becomes very important and obviously, people also looked for the other kind of rotational responses like pitch, roll, yaw and sur, swy etcetera as (Refer Time: :) freedom. So, I have got 12 degrees of freedom I must synchronize some of them, some of them need not.

So, people say or researches felt that the rotation degrees of freedom will cause more inconvenience to operation and stability compared to transition degrees of freedom. One can ask me question how this conclusion was derived with a researches, it was an inference from TLP, TLP was designed in such a manner that TLP are very soft in transition degrees there were very stiff in rotational degrees except yaw. This idea was conceive in researches only form the (Refer Time: 11:49) concept of successful TLP installations. So, people carried it forward geometrical optimization saying that let me have a thorough compatibility in the transition degree of freedom.

Let us not allow transfer of rotation degrees from the sub structure to the super structure or vice versa, vice versa why? Super structure will have a (Refer Time: 12:09) will have a leaving quarters, will have a (Refer Time: 12:12) which have a arrow dynamic attractions and in the super structures is try to over (Refer Time: 12:17) of the sub structure the whole stability will be challenged. Therefore, there should be no transfer of rotational degrees of freedom between a and b, however a and b should become monolithic in certain degrees of freedom which is preferred to because they are positive buoyant, why they are positive buoyant? Moment you make positive buoyant installation becomes very very easy for me.

The maximum cost in all the design platform goes only on installation fabrication election and decommissioning. So, we want to avoid that. Now the idea came into mind is buoyant leg structures BLS, it not a new idea BLS are used in certain incidents in offshore installations.

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So, buoyant leg structures what we call BLS came into play as an idea of (Refer Time: 13:15) let us see how does it work. So, deep and ultra deep water structures are TLPs spars, semisubmersibles, FPSOs, BLS and triceratops.

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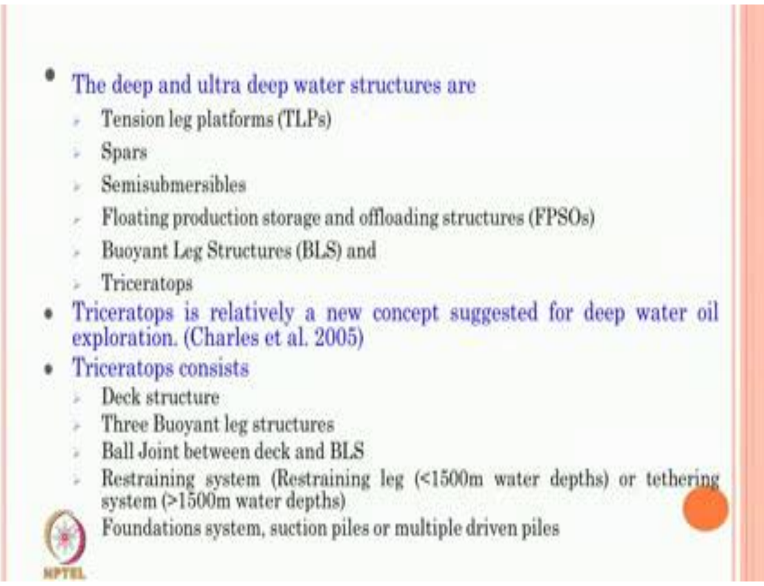

Triceratops was relatively a new concept introduced by Charles et al in 2005 which concerns a deck structure, 3 buoyant leg structures and a ball joint connecting between the deck and BLS. So, BLS and deck were isolated by a special arrangement which is nothing, but a ball joint the restraining system was of course, was similar to the TLP and spar which is having a tether system, when the foundation system suction piles or multiple driven piles are commonly used as we had case in the TLP as well as.

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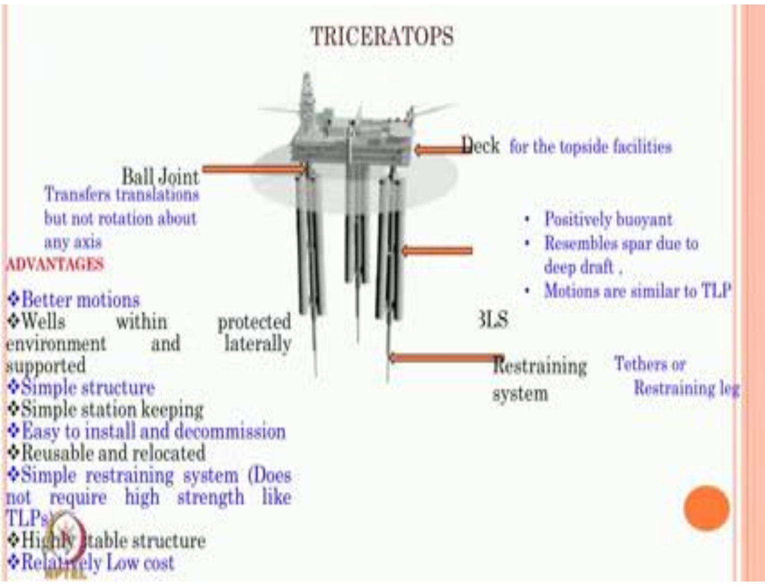

So, triceratops

So, triceratops conceptually looks like this. We have buoyant leg structures which are buoyancy chamber we can deballast and ballast for installation because the deck and the buoyant leg structures are isolated by a ball joint which would be connected only on site. The ball joint will have interlay connectivity with the BLS by the deck will be resting on the ball joint at the site. So, that connectivity established at site itself. So, the ball joints transfers translations, but absolutely no rotations at all, no rotations at all that is the characteristics of the ball joint. Now, one can imagine easily that if you have a ball joint it may be a (Refer Time: 14:38) a ball metallic ball, if you hold the ends of the ball by just hold it as a fixity as a fixity now rotate the ball, let us say I have greasier I have ball rest joints here. So, it is very very free to rotate like a globe you must have seen a globe in schools so ball are joints just as the simple blow the globe will rotate. So, it means the rotation theta and moment applied to make a rotation can be characterizely plotted.

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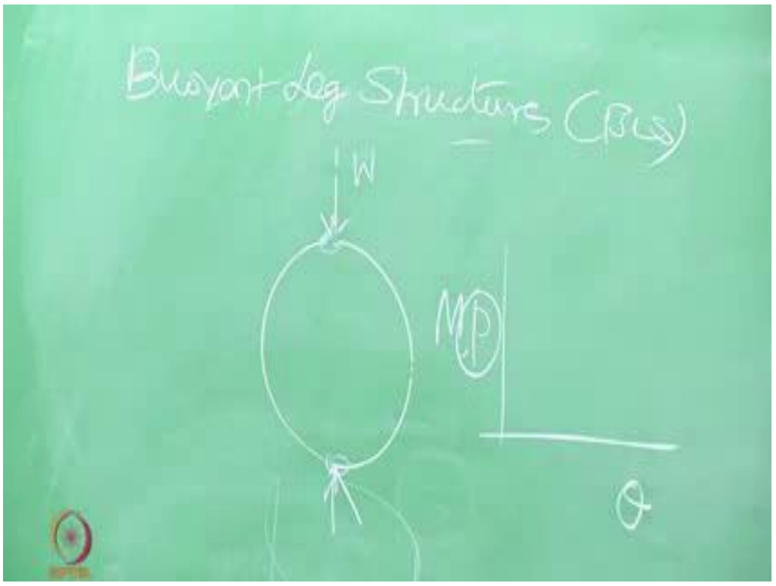

But if you allow the ball joints in my design to happen like this, the ball joint will have terrible rotations in terms of larger rotation in terms of even for a small moment which can be caused either be displacement of the bottom is respect to top or by the wave action or wind action etcetera.

So, I must impose some load which is actually coming from the mass of the super structure and imagine the globe by putting your hand or standing on the globe you will see the globe will not move as easily as it was moving earlier. It means the ball joint will offer or in suppose to offer certain restrain even m phi characteristics at p added to it; obviously, when your p added to it - it will be subjected to wear and tear. So, replacement of ball joint is one of the important concept of the problem in (Refer Time: 16:05) of design which can be easily done because the buoyant leg structures below are positively buoyant they can be (Refer Time: 16:11) it separately, deck can be free floated. So, if you want just disconnect them, replace the ball joint and again refabricate them all can happen at open sea itself, but this can be brought back into the workshop and can be done that is a concept.

Now it has got many advantages, it has got better motion characteristics wells are within all this will have wells inside. So, they well protected it is a simple structure station keeping characteristics are very good, easy to install and decommissioning as explained you they can be completely reusable and relocated it has got a very simple restraining system because then the axial tether tension in the cables or not as high as TLP because it is highly positive buoyant it is not required to the carried this load actually. So, the height stink tethers are require like TLP it is been seen as a stable structure and of course, relatively low cost in sense reusability and relocability adds to the value of the platform. So, therefore, they are low cost it does not mean that you can fabricate with the lower cost material density of the material, initial cost in expansion design etcetera will be very expensive, but workability cost of this much more because it has got a good reusability and relocalability and this has got a decrease in cost towards erection and commissioning. So, therefore, the total overall of the cost of the project can expected to go down.

This is not my idea this idea was floated by Charles et al 2005 in one of the isopheric conference in Japan. So, this is a conceived. Now, one can ask me question is this platform easily existing, how dynamic analysis can help me to conceive an idea of this order that is the whole context of this lecture. Let us see how it can be done. That is the deck actually, this are the buoyant structures, that is the restraining systems which essentially a tether or restraining leg itself. So, it is a positive buoyant system resembles spar or deep draft and motions are more are similar to the TLP.

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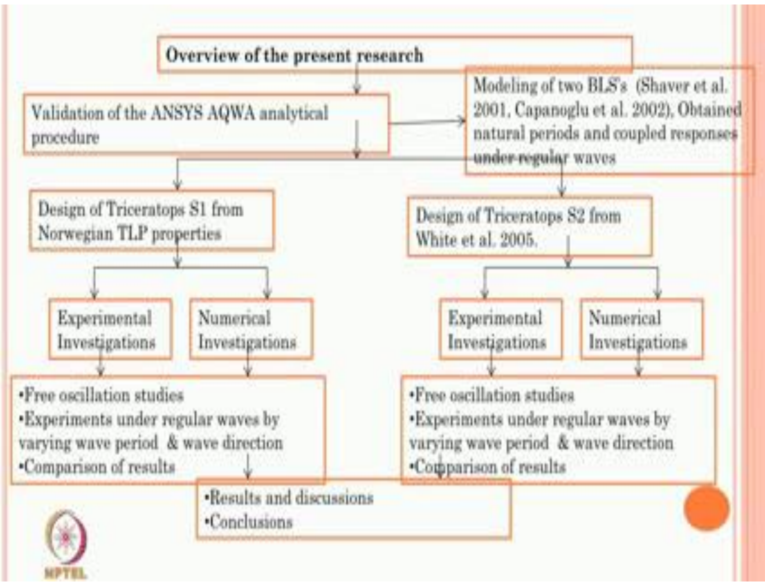

So, when you look at this kind of a research attempt in dynamic analysis let us say initially one has to go three platforms of verification – one, can be there are three platforms verification required in any such geometric optimization what people expect in the literature to accept it before they are fabricated in reality.

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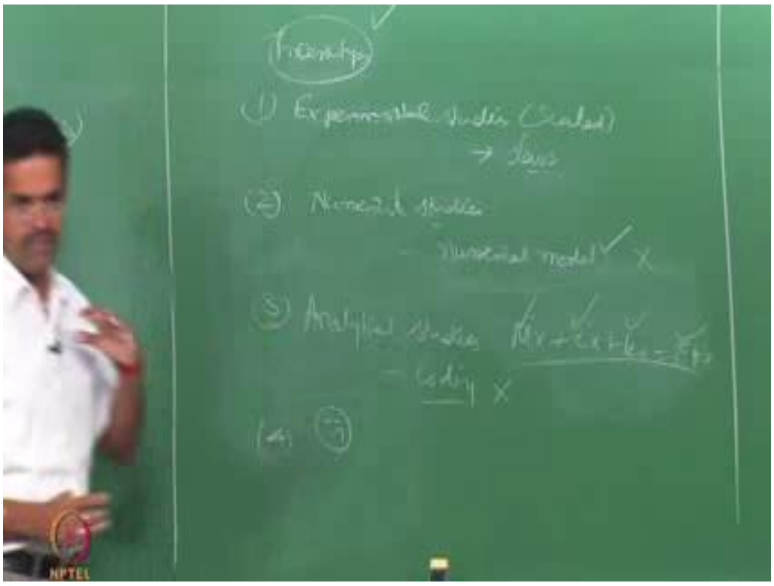

One, one should go for a experimental verification of such models first, experimental studies. The experimental studies are generally done on scaled models, scaled models cannot be actually projected for the original behavior because of scale laws, and there are some scale laws so you cannot really see. The foremost difficulty in this particular cases you cannot apply a scaled p and look at the behavior and extra (Refer Time: 18:50) real time p it is not possible. So, that is one issue.

The second platform what people wanted is let us say numerical studies because numerical studies can have all this limitations overcome, the numerical studies as a difficulty because in sense you must know how to use the numerical model and the moment I say numerical model creation you should look for a standard software which can ask you to prepare a model of triceratops, obliviously we look for a new model of triceratops generally you will not see this specific model available in any of the standard software. So, you have to create it yourself. So, all this elements have been chosen you have to create a very careful numerical model. So, numerical model complexity is again difficult.

The third one what people will see is an analytical study, analytical studies means you have got to call solve the equation of motion of his platform of this by deriving m c k and

F of t for arrow dynamic (Refer Time: 19:49) dynamic forces separately using analytical studies where you got to develop your own coding and that is again equally complicated.

Now, you see in all the three cases what are the standard platforms available for any development of any platform, none of them are easily available to me ready, it is not is all of them are difficult. Other than this three there is no other fourth option, the fourth option is do not think about the development at all that is the fourth option go with the triceratops TLP and leave with that. That is the fourth option of course, for another three you all are difficulties are there.

So, my lecture is now going to focus on how do you pick up actually the basis for developing a numerical equivalent study, analytical study, how do you develop mass and stiffness matrices for this problem, how do you derive them then, how you will experimentally conduct a scale study in extrapolate in this value and relate them all the three in one is to one scale. So, I will show you the results very interestingly here which is patented to us. So, this idea was concede from Charles et al 2005 basically then we generated this, so idea was initially to find out the validation of the existing models developed by Shaver et al and Capanoglu only on BLS.

So, he was not having any study on let us say triceratops only BLS was developed by this gentlemen and the researches 1 and 2 and we have got generate a aqua model for this we use a software Ansys Aqwa which does not have readymade mole on triceratops at all. So, we use this validate the result first. Then develop two designs - one is called s 1 in this template, other is called s 2 in this template. S 2 is actually conceiving an idea from white et al 2005 and s one is actually based upon similar alternate TLP properties because TLP is known established concept for deep water design. So, experimental numerical, experimental numerical compare them, for free oscillation experiments studies and comparison the results and then come to the conclusion what I will present now quickly as well this particular lecture is concerned.

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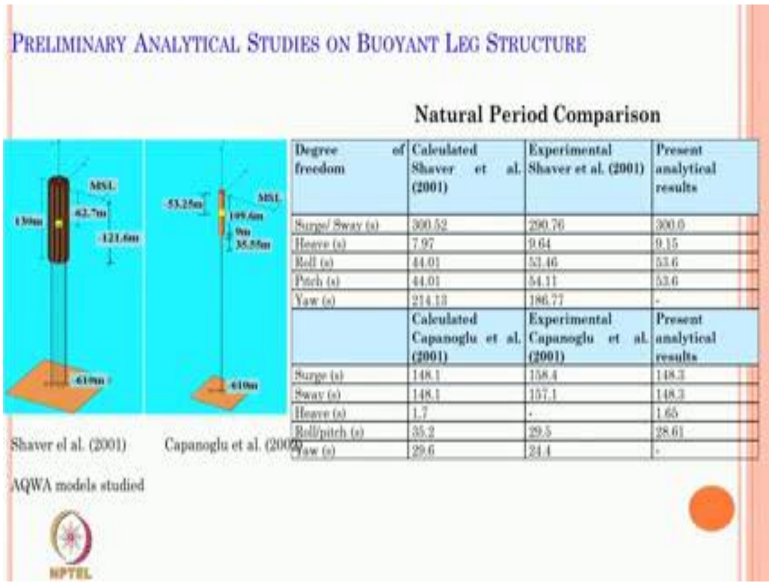

So, as I said the previous studies are done at buoyant leg structures this is a single buoyant leg structure which is taken from Shaver et al and Capanogulu, this was mathematically modeled numerically as Ansys Aqwa and naturally period were compared that what we calculate from shaver for surge sway what you do from experimental shaver because shaver as shown both values and present analytical results, analytical results are taken and they can there has a good comparison between these two in almost all degrees of freedom.

Then you also compare this, this Capanoglu and calculated experimental and present analysis they have also have very close comparison, but for the few cases. So, once you validate this model, let your BLS can be numerically modeled and it can be validated with the existing results experimentally analytically.

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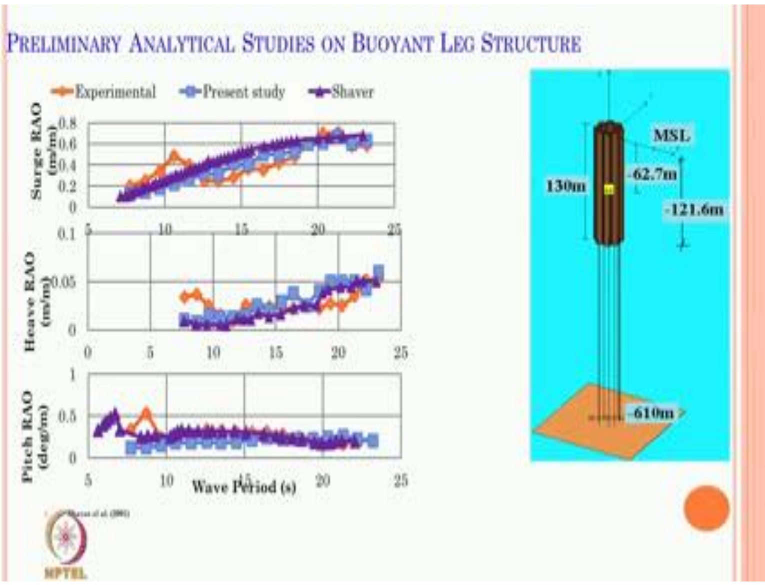

Then you take this numerical model of this and try to understand the response amplitude operator directly obtained from the software. So far we have been discussing solving an equation of motion using (Refer Time: 22:47) technique which was done for m l (Refer Time: 22:50) TLPs etcetera. Now we are moving on to not using a standard analytical procedure, but using in existing numerical software where the difficulties could be you numerically model this you will be able to get this response directly as a response amplitude operator for any software for example, in this case Ansys Aqwa was done.

So, the interesting part here is you will see that the experimental except for few variations except of few variations he is all merging completely in qualitatively and quantitatively with that of present study in the shaver. So, this simulated for different degrees of freedom. However, as well as BLS is concerned there is no complication of making a model of a ball joints. So, far because a ball joint was never attempted to study by Capanoglu and Shaver et al earlier because they were only working on single buoyant leg structure. Now the question comes where they have been used actually.

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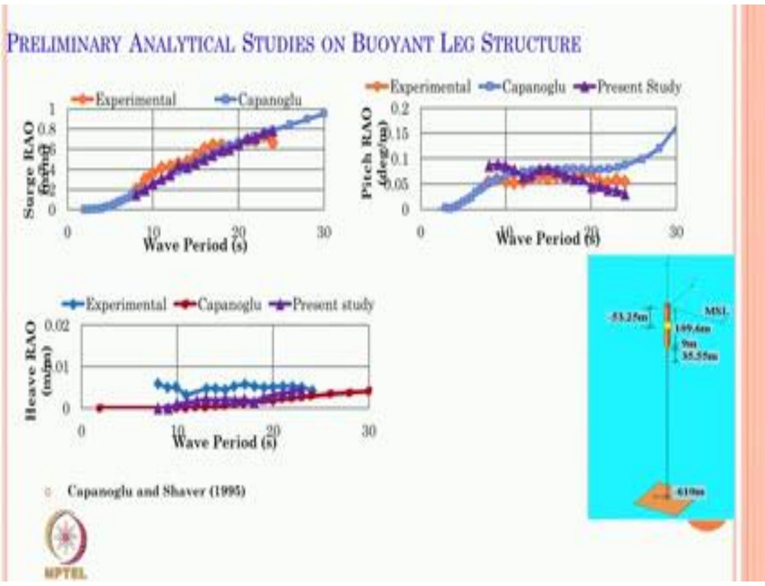

So, analytical studies also made by writing the code on the same problem and then they have been compared with Capanoglu and the present study and they have good validation except for some range of non acceptance.

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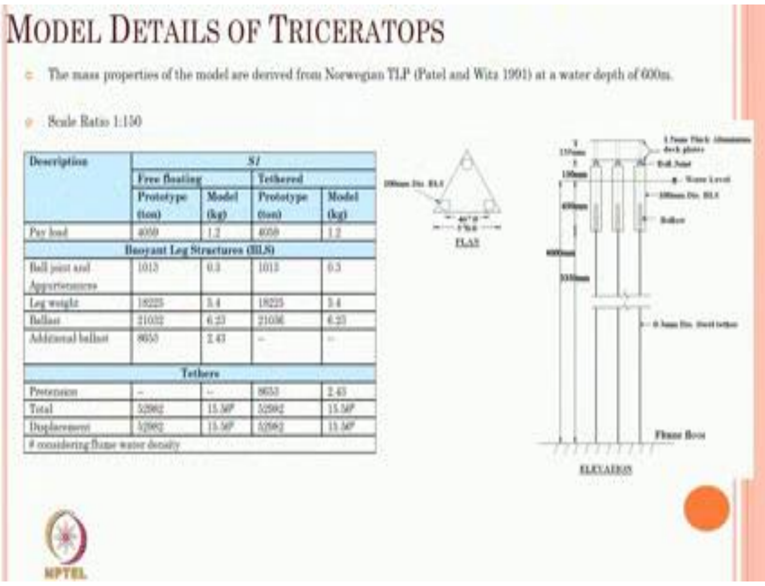

However, the idea was not stopped BLS, but to interconnect them and take them to a connectivity with a deck using a ball joint that the idea of this case. So, in this case scale of 1 is to 150 was generated we call this platform as s one having a triangular configuration and the dimensions are as similar to the that of existing TLP the plan dimensions and the scale of 1 is to 150 at 4000 millimeters is 4 meter classifies meter about 600 meters in water depth exactly where at TLP is existing, you take that model because use the same tether properties as well as TLP have a same mass characteristics and you try to compare what would be the free floating analysis and tether analysis, why both are done because till erection and commissioning in the platform will remain free floating.

So, one must do a stability analysis in terms of the periods of the pay load which I will have show you in the next slide for both the cases free floating and tether. So, one as got would comparison between the prototype and the model the prototype and the model for both the cases tether 1 and free floating 1 and you will see that the results for prototype and model.

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For prototype and model in both cases a and b for s one platform (Refer Time: 25:07) model one is to one scale you will see that the whole data which is available for scale of 600 meter (Refer Time: 25:14) 4000; 4 meter in the model is comparable and the entire data in terms of this geometric characters are conceived for the first time for triceratops. Then this model was numerically and experimentally investigated at IIT, Madras in the four meter flume where I think most of you will be aware.

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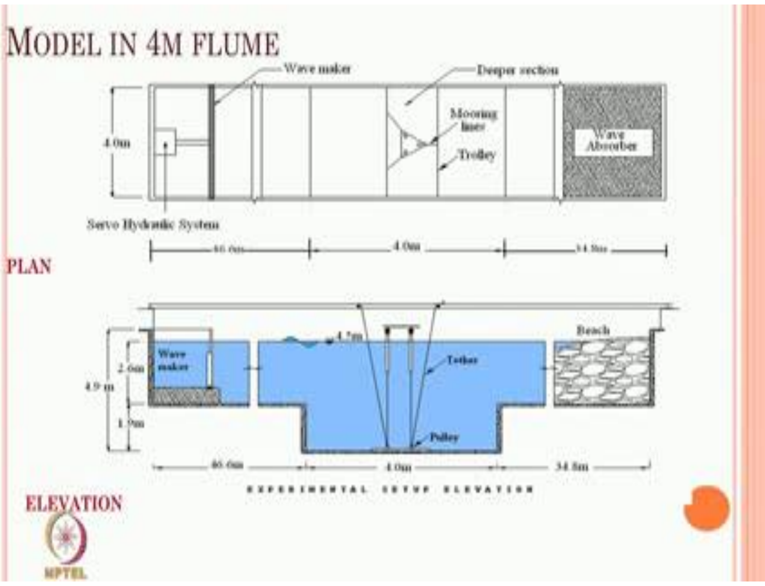

So, the 4 meter flume has got a test bed which is about 4 meter deep at one specific location. So, one can generate a wave using a the wave maker and we have got the depth of the our 4.9 meters at the specific location there is a template at the bottom one can anchor them this is what we called as a (Refer Time: 25:53) arrangement where the tethers are drawn through the pulley and they have been tension at the top it is called top tension risers systems.

So one can adjust the tension at the top frame by pulling this a through a pulley so can measure the tension the tether as well as correctly. So, experimental idea was conceive with deck place and position that of the ball joints and of course, the triceratops had individual independent non interconnected buoyant legs, buoyant legs are free to move independently there is no interconnection between them, so they are not interconnected.

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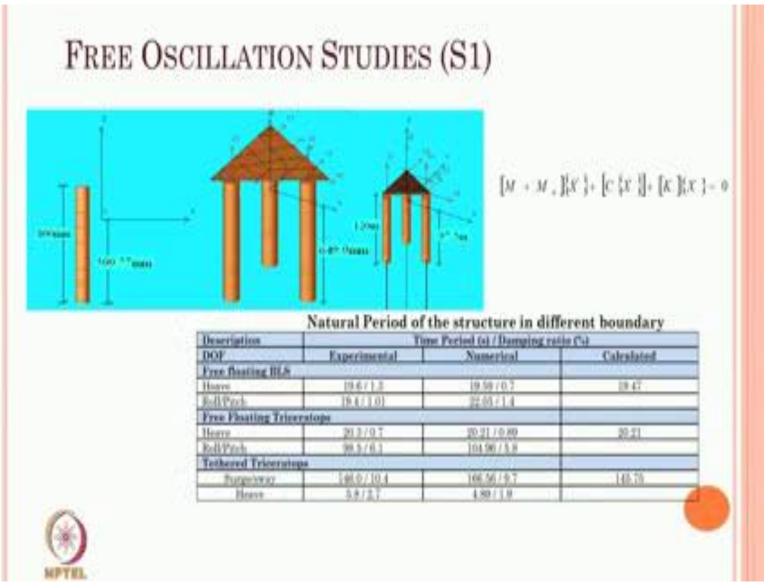

If you look at the time periods interestingly we will look at the experimental, numerical, and calculated most of them for free floating case and most of them triceratops tethers are exactly matching. So, it means you can generate an analytical code for doing a free vibration analysis for this kind of platform, you can also check it with numerical model and of course, you perform (Refer Time: 26:52) to find out the natural period or the period in terms of free floating (Refer Time: 26:57) as alone, free floating triceratops are alone and tether triceratops. So, one can compare and see.

So, now, this resembles very interestingly a very similar characteristics that of a complain platform like TLP because surge sway periods are very high indicating they are flexible and heave period is very low indicating they are very stiff. So, it gives me the similar behavior to that of TLP, where TLP concept is proven for deep waters; that is the idea. When you want to deviate for any geometric design optimization using dynamic analysis you got a start a base from the existing analysis and whatever deviation you give in the analysis should be supported back in terms of physical verification that you have to tell to people that geometric model have a new conceive idea begins in the similar manner therefore, it remains to be safe you got to verify that.

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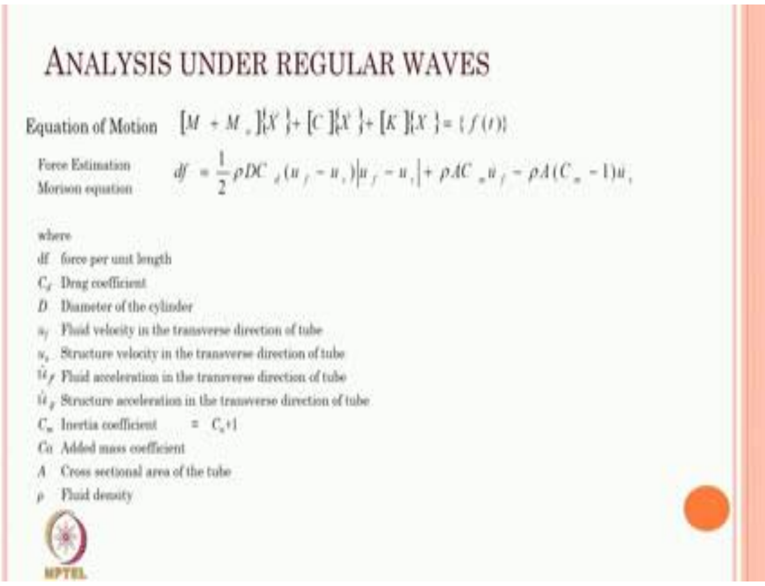

So, of course, the equation of motion we all know that added mass c and k.

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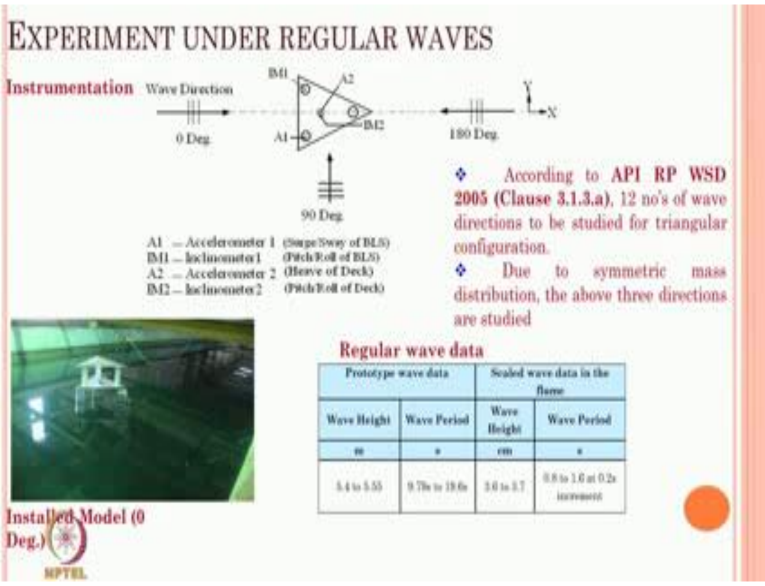

And I will show you the equations of m and k separately later. So, that is the wave direction which are interested that is the model what we have this is the top deck and bottom leg connected and ball joints are here I will show a figure separately later. Now when you look at this kind of analysis for experimental studies you must analyze for different directional waves API RP 2 a WSD 2005 clause 3.1.3.a shows there are 12 number of wave create for a triangular study; however, due to symmetry you can minimize to only 3 directions.

So, you pick that particular idea from API and try to do it only for three directions and you instrument them like accelerometer which is a 1 kept on the leg exactly above the leg then a 2 is another accelerometer which is kept on the c g of the deck because you know it is one-third of the base of the triangle at the deck and of course, you have inclinometer percent on all the BLS separated measure independent behavior of the BLS. On the other hand the rotation of the BLS should not be transferred to the deck and the heave motion of the BLS should be transferred to the deck, this should be verified as a concept whether there is integral motion happening in the system. So, there is a prototype wave data which wave hide varies from 5 to 6 meters and wave period runs from about 10 to 20 seconds that is the deep water scenario.

Whereas the scaled wave data according to the scale law 1 is to 150 come to around this and this was generated in the system available at our institute and we got the results as response amplitude operator plotter for different degrees of freedom like surge and heave and BLS, pitch roll, and depth pitch roll.

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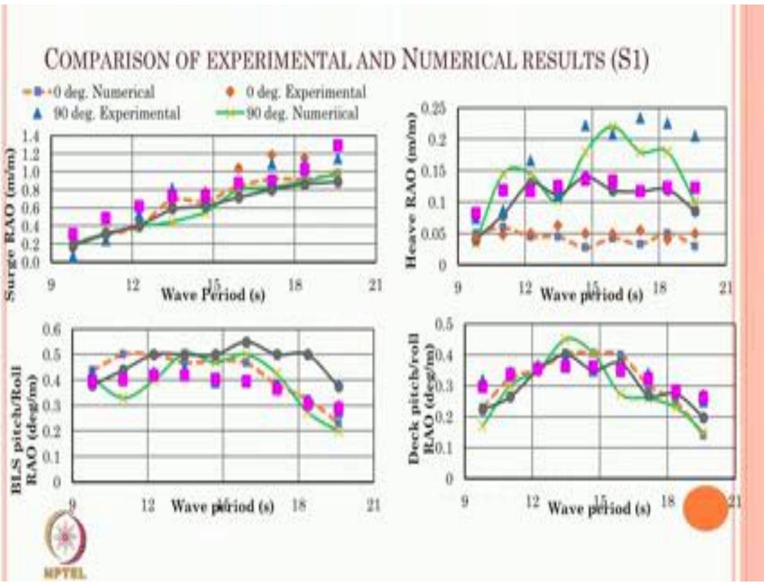

These are all about the numeric result exactly for different degrees of orientation as zero we can see that if you look for example, a zero degree numerical and zero degree experimental let us say the one which is squared here, the one which is orange here, most of them will tally if you look at the 90 degree and the 90 degree the one this one and this most of them qualitative will tally for maximum wave period range which is interested for the given system.

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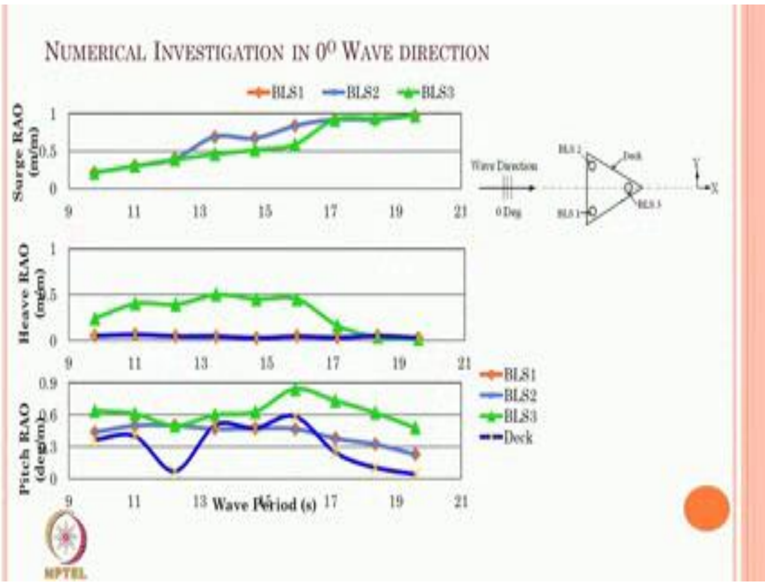

However if you look at the heave degree in terms of earlier for 0 degree, 90 degree etcetera there as mean a complete transformation of a heave motion of the BLS with the deck completely at all the degrees of freedom.

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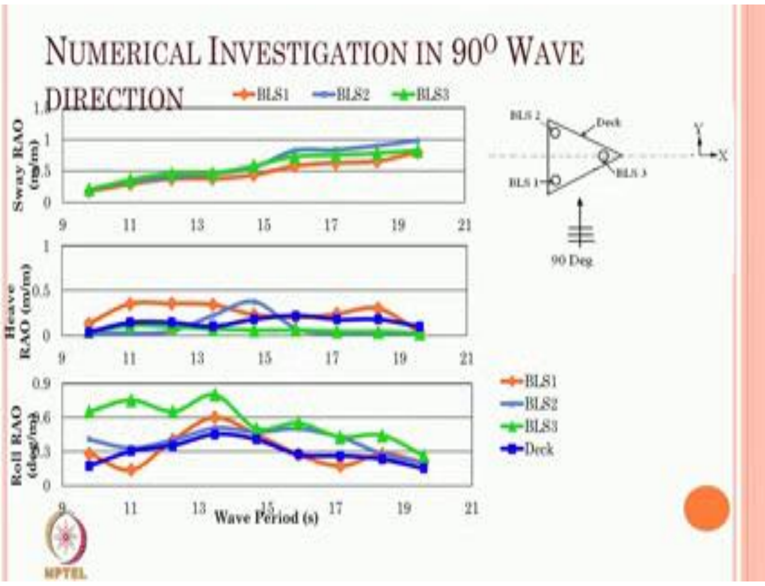

So, it shows that the deck and the heave of one of the BLS may be BLS 1 2 or 3 as shown in the common literature exactly behave monolithic or integrally connected between the deck and BLS as such for all degrees of freedom action; 180 degrees as well, and so on.

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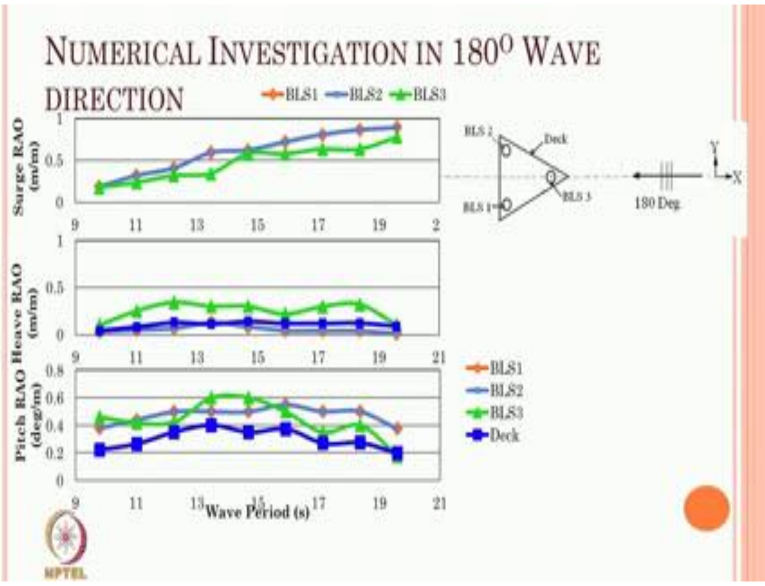

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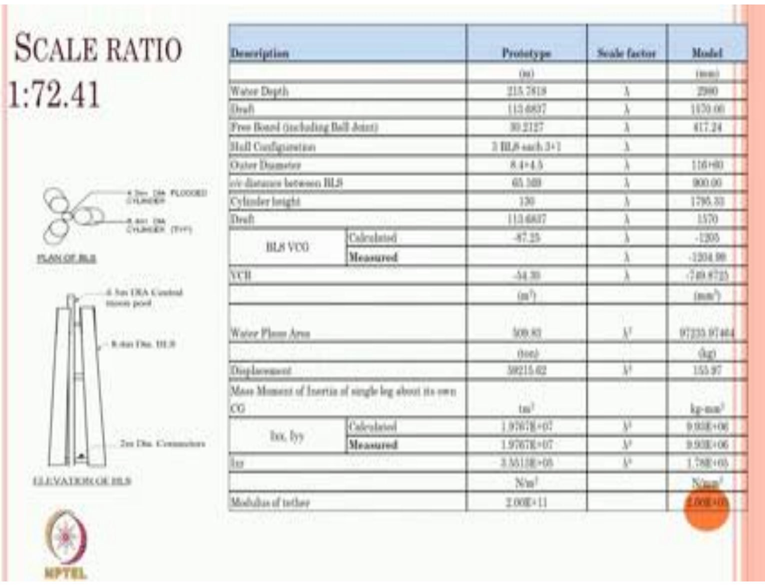
Now this results will show that yes the (Refer Time: 30:35) shows been as integrally connected between the deck and BLS in heave degrees of freedom and; however, the pitch transfer is not other roll transfer is not happening because we are talking about

(Refer Time: 30:45) wave direction. So, pitch transfer is not happening between the BLS and the deck as it was expected, but it is not zero, but some filter is happening I will show you the result in the next slide.

So, subsequently the other geometric model was investigated is the having the one single BLS let us have three BLS for each one of the leg because one can always integrally have three BLS because then the storage capacity further goes increased because in all these platforms it is seen that the storage capacity is not available. So, I go for (Refer Time: 31:12) 1 leg, I go for 3 legs, I conceive this ideas as s two platform configuration and the prototype details and the model are available in the screen now for our clarity.

(Refer Slide Time: 31:20)



Description		Prototype	Scale factor	Model
		(m)		(mm)
Water Depth		215.7818	λ	2980
Draft		113.6837	λ	1570.00
Free Board (including Ball Joint)		30.2127	λ	417.24
Hull Configuration		3 BLS each 3+1	λ	
Outer Diameter		8.4+4.5	λ	116+60
c/c distance between BLS		65.169	λ	900.00
Cylinder height		130	λ	1795.33
Draft		113.6837	λ	1570
BLS VCG	Calculated	-87.25	λ	-1205
	Measured		λ	-1204.99
VCB		-54.30	λ	-749.8725
		(m^2)		(mm^2)
Water Plane Area		509.93	$λ^2$	97233.97464
		(ton)		(kg)
Displacement		59215.62	$λ^3$	155.97
Mass Moment of Inertia of single leg about its own CG		tm^2		$kg\text{-}mm^2$
Ixx, Iyy	Calculated	1.9767E+07	$λ^5$	9.93E+06
	Measured	1.9767E+07	$λ^5$	9.93E+06
Izz		3.5513E+05	$λ^5$	1.78E+05
		N/m^2		N/mm^2
Modulus of tether		2.00E+11		[illegible]

And of course, the ratio was still bigger it made 1 is to 72.41 slightly the model is slightly bigger compared to the earlier one and the BLS was stiff under two points for rigid connectivity between the three units of each leg and of course, you have got positive buoyant system which shows that the system will remain stable.

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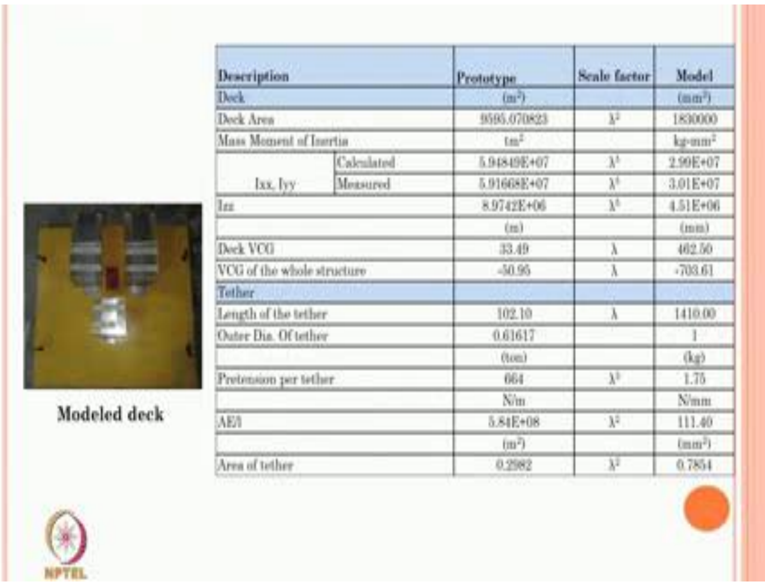

Description		Prototype	Scale factor	Model
Deck		(m²)		(mm²)
Deck Area		9595.070823	λ^2	1830000
Mass Moment of Inertia		tm²		kg-mm²
Ixx, Iyy	Calculated	5.94849E+07	λ^5	2.99E+07
	Measured	5.91668E+07	λ^5	3.01E+07
Izz		8.9742E+06	λ^5	4.51E+06
		(m)		(mm)
Deck VCG		33.49	λ	462.50
VCG of the whole structure		-50.95	λ	-703.61
Tether				
Length of the tether		102.10	λ	1410.00
Outer Dia. Of tether		0.61617		1
		(ton)		(kg)
Pretension per tether		664	λ^3	1.75
		N/m		N/mm
AE/l		5.84E+08	λ^2	111.40
		(m²)		(mm²)
Area of tether		0.2982	λ^2	0.7854

And the deck was separately modeled and one thing see here the periods.

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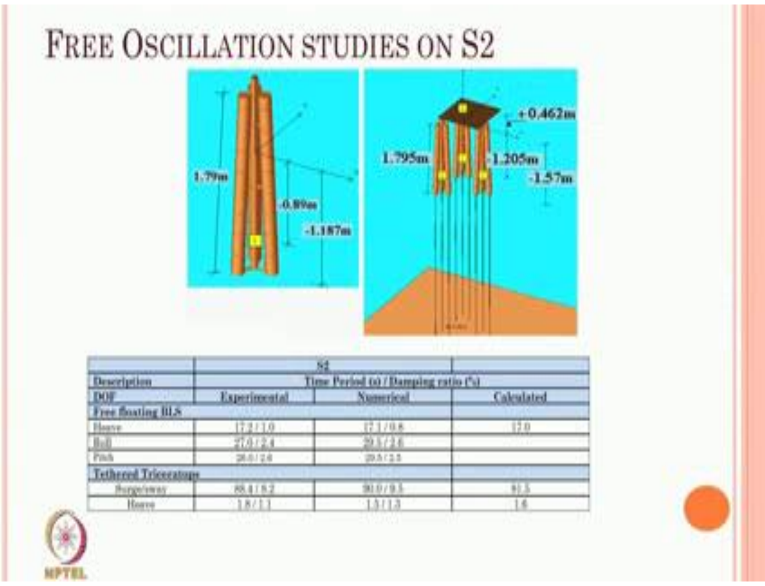

	S2		
Description	Time Period (s) / Damping ratio (%)		
DOF	Experimental	Numerical	Calculated
Free floating BLS			
Heave	17.2 / 1.0	17.1 / 0.8	17.0
Roll	27.0 / 2.4	29.5 / 2.6	
Pitch	28.0 / 2.6	29.5 / 2.5	
Tethered Triceratops			
Surge/sway	88.4 / 8.2	90.0 / 9.5	81.5
Heave	1.8 / 1.1	1.5 / 1.3	1.6

Now the tether triceratops which had earlier about 146 seconds has come down to around 90, it mean the system has got more rigidity in terms of his behavior response it is because that the BLS have been distributed and they have been inter connected and stiff end.

So, this shows a very clear understanding that how the platform behavior in terms of free (Refer Time: 32:16) response can also alter by change its geometric configuration as decided.

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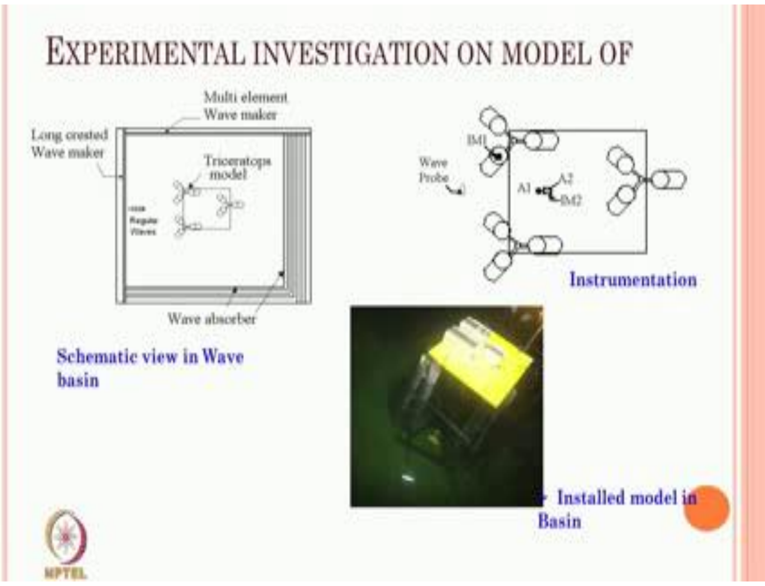

Then the geometric model what you see in this scale here is now seen in the screen here.

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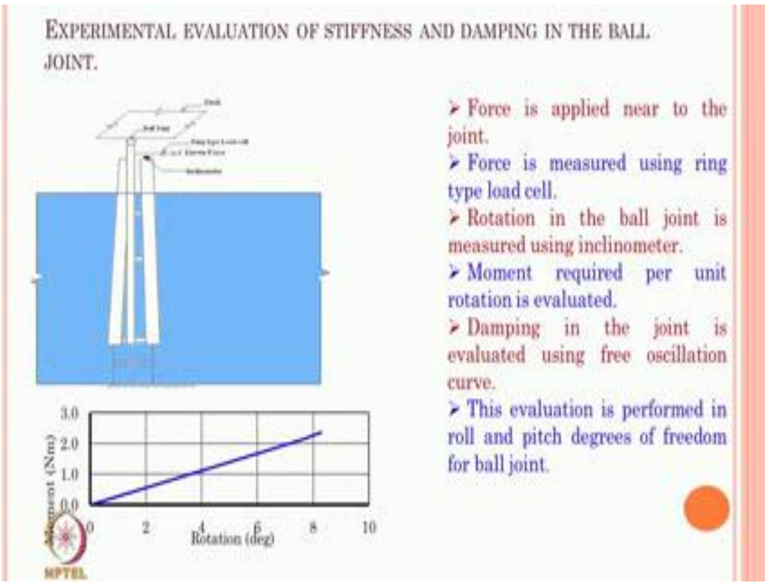

This plot will show you what is the moment rotation characteristic of the ball joint which is more or less linear for a given (Refer Time: 32:34), the force is applied near to the joint force is measured using ring type load cell as you see in the set up here. Then the rotation of ball joint is measured using inclinometer the moment required is measured is evaluated and then it is plotted and this characteristics is been used for designing it in the numerical model directly as the element.

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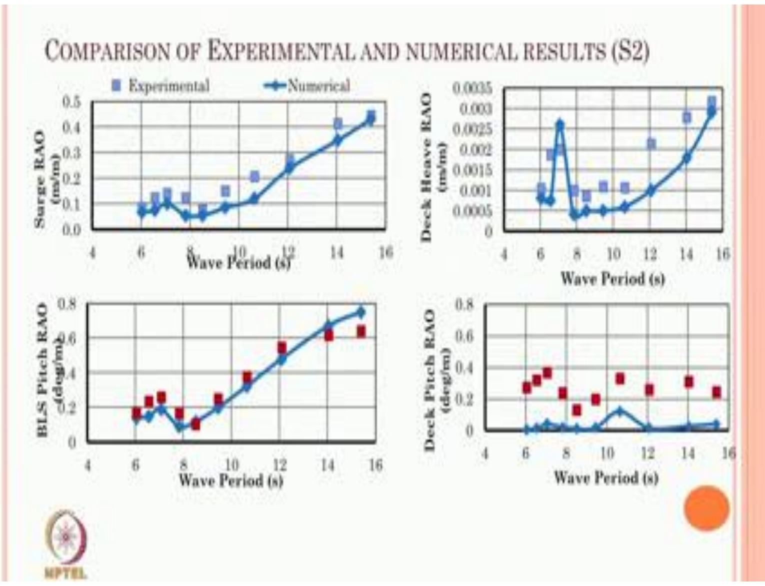

Now, interestingly if you look at the deck pitch compared to that of any one of the BLS, BLS will have enough pitch, but deck pitch actually zero. So, deck is actually not rotating at all for enormous rotation of the BLS.

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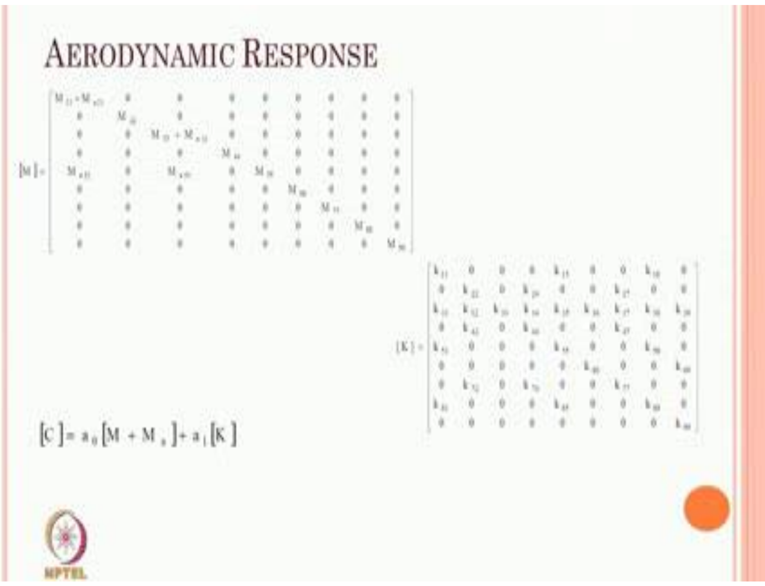
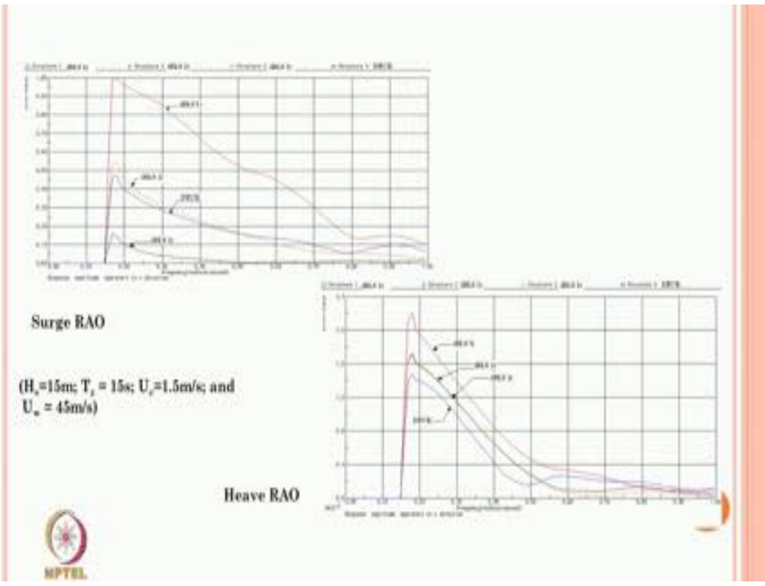


We will look at the aerodynamic response for example, super structure is loaded separately in numerical analysis you have the mass matrix. Now it is as understood it is 9 by 9, why 9 by 9? I have got 6 for the bottom I have got only three for the top. On the other hand the heave pitch heave surge and sway of the top should be monolithic and integral with that of the bottom. Whereas pitch roll and yaw which are rotation degrees of freedom of the top should be independent that of the top shall I have 9 degree of freedom. So, the 9 by 9 matrix is shown here and of course, the derivation of each element 9 by 9 can be seen from the reference of the one of the paper what we have (Refer Time: 33:45) the whole derivation of mass matrix k and c is available in that of the paper you please see that which is publish (Refer Time: 33:52) myself and (Refer Time: 33:55) publish paper. Please see that to understand how the derivation has been done, I have no time to discuss that here for the time being. So, you can at least see from the paper.

(Refer Slide Time: 34:02)



Let us quickly see the results what we get from the aerodynamic response for a specific wave height, specific return period and wind velocity 1.5 meter per second I mean the current and wind velocity 45 meter per second when you look at the surge RAO and heave RAO and interestingly look at the pitch RAO.

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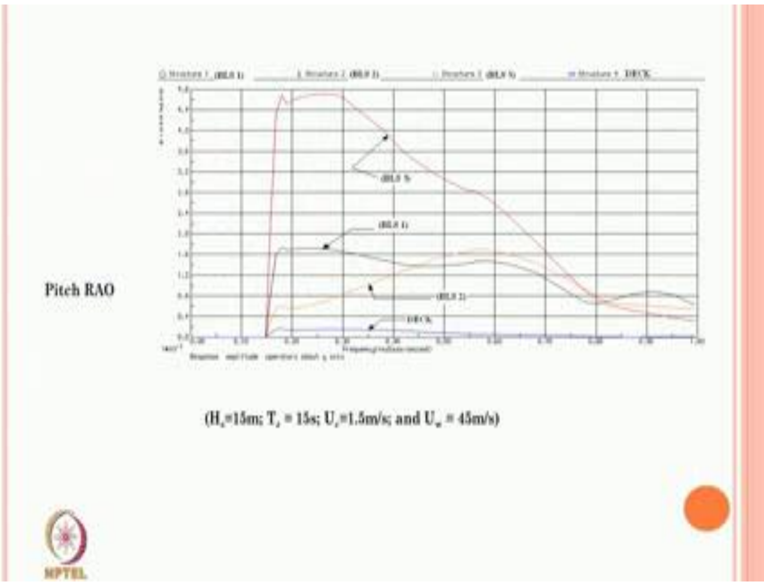

The deck has got more or less is zero pitch, whereas the BLS has got very high pitch please it is not transferring or the deck pitch is not transferred to the BLS vice versa. So, the ball joint is filter in the rotation of degrees of thoroughly and the boil joint is transferring the surge heave degrees thoroughly you can see it is relatively good. So, it is not exactly the same, but it is have connectivity in terms of surge sway and heave directions where as in other degrees of freedom it is filtering up completely. So, that was one interesting idea which has been conceived from the experimental studies done at this stage.

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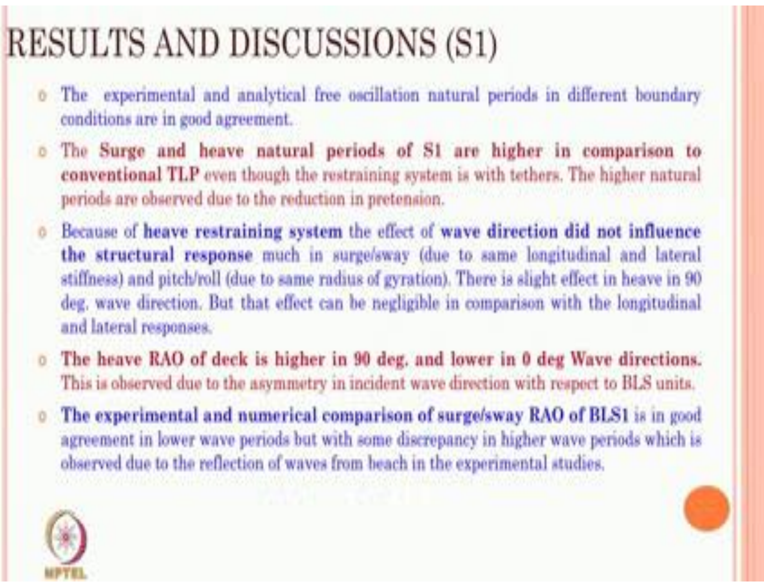

So, one can look at the discussion in the results of s 1 and s 2 separately s 2 of course, has interconnected BLS, s 1 has got independent BLS. Experimental analytical free oscillation results are in good agreement. The surge and heave natural periods of s 1 are higher in comparison to conventional TLP we saw 146 seconds is higher, what does it mean is the higher natural period is observed due to reduce pre-tension. So, it is an indirect idea for me saying that the pre tension and tethers on triceratops are far lesser compare to that of TLP.

What is the advantage of this? Advantage are two – one, the tethers will not be subjected to high axial tension it means you need not require high strength models of velocity of material for tethers. So, cost saving is coming to play here, one. Two, when the axial load is far lower the fatigue applicability of its failure is again in terms of lower probability. So, you got two advantages one the tether pull up will not happen as it could happen in TLP as we saw in extreme wave cases in this case will not happen.

Even if it happens let us say the more interesting idea is if the tethers pulled off and the BLS become unstable intense BLS become free floating because they are positively buoyant. So, it will enable the system to float, but the system will not collapse because they are interconnected by a ball joint which conceives this idea and remain these two connected, but they will still float they will not collapse because it is been ensured that even free floating and tethered has more or less same period. So, it will remain free floating it will not lose its stability at all because each one of them of legs are independently positive buoyant.

So, that is very interesting idea. Even in case of stability failure of tethers you will be able to save the platform. The third could be the system is heave restraining therefore, the wave direction did not influence is expected. The experimental numerical comparison of BLS one is compatibility good compare with respect to other BLS other BLS because of directionality show some discrepancy.

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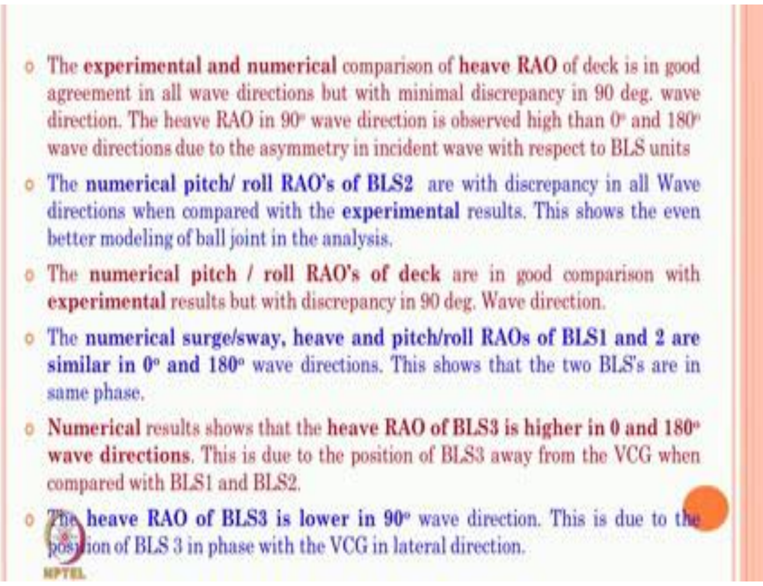

The numerical picture of BLS 2 is a discrepancy because of the wave direction effects. The heave of heave RAO of BLS 3 is much lower 90 degree because BLS 3 is the one which is far away the wave approach angle. Therefore, this is not influenced by the wave direction because the vertical center of gravity in the later direction is shifted.

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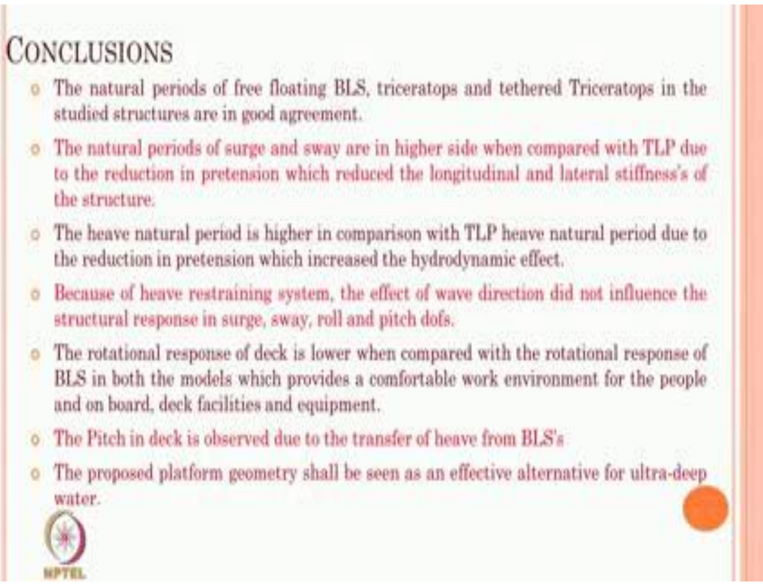

The natural periods of the free floating BLS triceratops and tethered are in good agreement this is one of them with that of the experiments. The natural periods of surge and sway are higher compared to that of TLP making it reduce in pretension in tethers.

So, it decreases lateral stiffness of the structure the natural heave period is higher in comparison TLP because TLP as 4 to 5 seconds. In this case it is around 10 to 12 seconds. So, it is slightly flexible compare to TLP heave degree is that that flexibility is because the connectivity between the ball joint on the system.

So, when you have any ball in between the shift of the ball joint and the rotation of the influence the connectivity between the deck and sub structure which is seen in the reduction in degree of freedom in heave period. So, because of the heave restraining system the wave direction of effect is not influencing in the platform in the surge sway roll pitch degree of freedom. The rotational response deck is much lower for both aerodynamic and (Refer Time: 38:24) which shows that that the platform is isolated on the sub structure by the ball joint.

The pitch in the deck is observed due to transfer heave from the BLS that is very interesting, the pitch does not only come by the unsymmetric loading from the platform, but there is an differential heave because the tether tension in all the legs are not equal all the time because it has three leg. So, differential heave will (Refer Time: 38:45) pitch. The pitch what is see in the platform is also due to the differential heave, if you remove that particular part then; obviously, the platform will remain completely horizontal or more or less practical horizontal for very large pitch of the BLS.

The proposed platform can be seen in the alternate geometry for deep water and ultra deep waters. So, that is the idea of conceiving and how one can use the non-linear dynamic analysis technique. For conceiving a new idea where you barrow the idea design the platform geometry, design the platform and check the geometry then try to compare the existing results and then do experimental study for scale model extrapolate, compare them, validate them, then try to get the results of how they can be arrived from (Refer Time: 39:28) numerical analytical study. So, there are differently complexities in the study that how you make an numerical model of a ball joint, how do you actually conceive an idea of an BLS in terms of interconnecting stiffness etcetera, there are difficulties they are very interesting and that how it is been (Refer Time: 39:43).

So, those studies are still explained fairly in detail in the paper, but; however, if the lecture is able to invoke an idea that yes the basis of understanding of dynamic analysis can invoke me into derive a conceive a new geometry I think my job is done, because that is very important. The dynamic analysis studies in dynamic analysis can become a safer tool for people to really and physically (Refer Time: 44:10) a new geometry which is essentially demanded in deep water oil exploration in the presence scenario that is very important.

So, this will complete my second set of lectures in module two where you are talking about FSI fluid structure interaction. So, in this module we started with how a wave load can be characterized, what are the different kind of theories available, what are the different kinds of loads when you place a cylinder interfering a wave media horizontally, vertically (Refer Time: 40:38) etcetera why wave theory is are not able to predict the behavior properly, what is the maximum load coming on the system minimum load coming on the system, how the face angle creates or how the legs spacing is design, so that the face angle reverse as the forces on the members as a design criteria which is essentially done in dynamic analysis also.

Then we also saw application of the dynamic analysis in different segments of structures like gravity based structures, then we looked at (Refer Time: 41:05) when we talked about multi (Refer Time: 41:07) we compared this with two pendulum system derived the mass and stiffness matrices and over laid that on a (Refer Time: 41:16) compared the results with that of a Jain Dutta's paper. Then we said (Refer Time: 41:20) have large deck response this can be again controlled by using tuner liquid mass damper or suspended mass system. So, secondary mass and primary mass analyze from the first fundamental dynamics again.

We found out how they can be tuned of the mass ratio and how they can be practically applied in a given system how the mass can be result the physically controlled we have the video how this can be controlled. Then we moved on to the famous deep water exploration platform like TLP (Refer Time: 41:45) platform derived, the mass matrix, stiffness matrix and damping matrix for all in all degrees of freedom step by step and showed you how TLP can be easily applied approach in terms of dynamic analysis for its m and k derivation. Then of course, we showed the results on extreme waves on regular and random waves on TLP then we showed you numerical integration procedure, the coding in the last class using MATLAB. So, one can easily find out now.

In my opinion we have also applied the whole concept and make slightly confident to apply it to a new structure like this which is yet to be conceived triceratops are not conceived in practical reality in oil industry, it is still under construction. So, many industries like technique for example, Malaysia is also working out on conceiving the platform ideas not for production, but for some inspection purpose etcetera whether this idea can work out.

So, people are looking for new developments in terms of geometric conceivement of ideas like this which can be essentially encourages tested, experimentally and numerically in the models and institutes like ours at IIT. So, we had a good idea and whole module like one and two together should give us a confident idea of what are the different dynamic models I can study, how I can work out the fundamentals requirements of dynamic system, why the system is called dynamic, what are the difficulties and how the mode shapes and frequency are compute coupled, how one influence the other, what are the different methods available numerically and experimentally, how one can estimate the damping, what are the different source of damping models are available in the literature which will most popular applied to the offshore structures and why we have discuss this in length for about 42 lectures. So, a given about 6-7 tutorials released.

We will have another two more released and we have another couple of mock examination available for this, certificate exam available on this 10 or 17th of may. You must registered our registration of examination is closed. So, we have got a about I think total about 4000 or 4500 candidates who are taking examination for this all over the country and of course, out of India also. Many students, many researches and engineers and faculties are also taking exams on this course to understand actually how this can be credibly transferred to the education system.

So, we have only one module left out which will around 6-7 lectures where we talk about advancements of dynamics in stochastic region, stochastic dynamics we will talk about that how fatigue can be used also in terms of dynamics, how this can be studied what are different models available, what is about randomness all together in dynamic analysis, why this is a popular model, why it is a popular model. So, let us derive some expressions or equations understand and apply them for a stochastic perspective in dynamic system it completely the research perspective it is because if you are able to understand dynamics first and second module.

Second module, it is mandatory for every naval architect ocean engineer and structural engineer using ocean structures and offshore structures. First module is essentially important for all physics and engineer to really understand a behavior of a given structural system which is very common to many interdisciplinary areas. Third will be of course, interest in flavor only of a let us say research scholars and post doctoral I am talking about advancements applied in dynamics where I have understood one and two thoroughly.

So, one and two are thoroughly understood then one can enjoy third module otherwise third module go only on lectures in black board. So, what you can really understand them and try to understand them leave it as it is because stochastic dynamics is slightly on a tough resign of a research because even in the first module itself is tougher, but; however, people have made it more commendable by many in the books available in the literature. Second module of course, have limited audience because FSI is not studied by almost all engineering group or engineering team of people and many of them have studied in their let us say graduation days and they are not practicing well. So, therefore, they are forgotten the basics of that. So, this course will help to you revisit them back again thoroughly and this course will definitely will help you 42 lectures will certainly help you to keep on phase about dynamic analysis separate to structural engineering in general and in particularly ocean structures.

So, we will wait for the third module from next class on wards may be 6 or 7 lectures maximum will complete where I will also try to show you some results of the question paper etcetera. Make you to rehearsal for how the examination pattern can be understood and studied, we have given about 6 to 7 references and above 4 to 5 text books which is written by very famous authors all over the world. You have to have a capacity to understanding them whatever I am discussing here is only may be 10 to 15 percent of given from the literature.

Without update of your knowledge on research papers using journals, without practicing on hand and experience on numerical software like this, without conducting experiments on scaled models. Please understand very clearly, dynamic analysis cannot be realized in physical terms, you not able to understand them at all. So, there are enough opportunity almost all schools of engineering in the world you have got to pick up a single model of a scale value try to test it experimentally model it analytically and numerically try to visualize yourself a confidence level on applying in all these three domains which are important. If this is achieved for a simple problem I am sure that you will be a good researcher or promoting or conceiving a new geometric idea which is demand of the day today in oil gas industries.

Thank you.