**Offshore Structures under special loads including Fire resistance**
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**Lecture – 08**
**Regasification Platforms**

Friends, welcome to the 8th Lecture titled Regasification Platforms under the NPTEL course on Offshore Structures under special loads including Fire Resistance.

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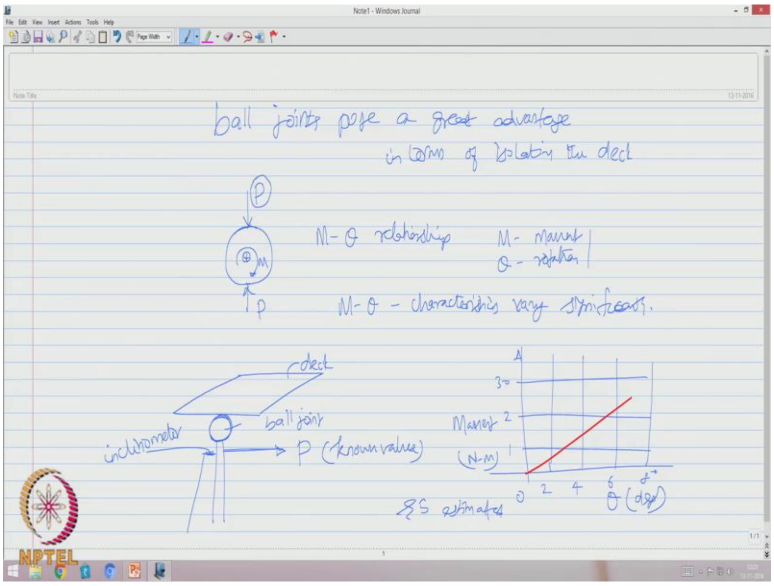


We were discussing about a new conceived idea of a platform by a name offshore triceratops in the last lecture. We said that ball joints pose a great advantage in terms of isolating the deck. However, it is also important to estimate the rotation capacity of the joint under the given loading. For example, we have a joint which is going to rotate about this axis under a specific value m, so one can try to plot m phi relationship for this kind of studies where m is going to be the movement applied to this joint at this connection of c g and phi or let say theta is rotation, so moment is m and theta is the rotation.

However, when this joint is subjected to an axial load p, the movement rotation characteristics vary significantly. So to estimate this a exponent can be conducted which was tried on a scaled model at the research laboratory at IIT, Madras, where the deck was connected to the ball joint fabricated to scale and the legs where associated to this joint. So, this is my ball joint. An additional arm introduced here was also imposed upon by axial force of a known value which is going to be the lateral load acting on the system which is going to cause the movement. An inclinometer is placed on the ball joint to measure the rotation of this ball joint or this buoyant leg to this particular joint.

A typical moment rotation curve is derived on a scaled model; I am giving the values on scaled model. So, 0, 2, 4, 6, 8th degrees a Newton meter for a scaled model, let us say 1, 2, 3.0 etcetera. A typical curve remains linear to make us to realize that the ball joint will have less influence of the load P on its m theta curve. Rotation in the ball joint was measured using inclinometer and a movement required for rotation is evaluated, and then the damping of the joint is also estimated. Friends interestingly in such cases due to continuous rotation of the joint, the joint may also fail in fatigue.

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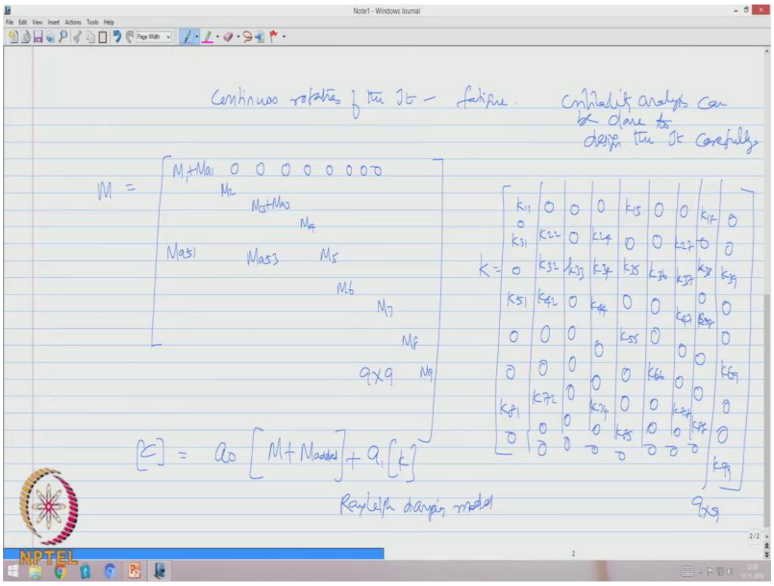


So that can be seen as one the important critical member where a criticality analysis can be done to design this joint carefully. To extend the study for better understanding the triceratops numeric model was subjected to aerodynamic loading. The typical mass matrix of the platform is of course 9 by 9 because 6 degrees for the support system and 3 degrees independent for the deck, because the deck rotations are not dependent on the buoyant leg rotation degrees of freedom. However, the deck translations are dependent on the translations of the sub structure. Therefore, 6 degrees of freedom for the support system of buoyant legs and three independent rotation degrees of freedom for the deck makes it 9.

So, let us say M 1 plus M a 1 additional mass remaining all where seems to be 0. Similarly, M 2, M 3 plus additional mass in heave degree M 4, M 5, M 6, M 7, M 8, and M 9. However, the fixed degree for unidirectional wave also resulted in added mass in M a 51 and M a 53. To look at the typical stiffness matrix its again 9 by 9 which has got let us say k 1, k 11, k 31 and k 51 and k 81; and similarly k 22, k 32, and k 42, k 72, 0s and for heave this k 33 and all others where 0s; k 24, k 34, and k 44, and k 74, k 15, k 35, and k 55, k 85; k 36 and k 66; k 27, k 37, k 47, and k 77; k 18, k 38, k 58, k 88, k 39, k 69, and k 99 there is a 9 by 9.

Of course the classical matrix C is plugged out as a 0 M plus a 1 k which is a Rayleigh damping model. Studies were conducted in numerical analysis and results were obtained, will quickly result discuss these results to realize how the behavior of this platform was very interestingly done.

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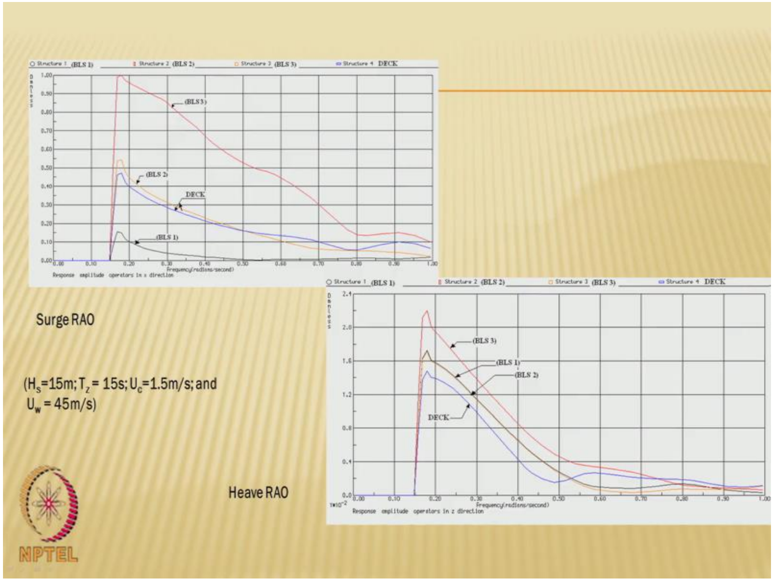


If you please play attention to the Rao plots that is response amplitude operator in the surge and heave degrees of freedom; one can see here the plots are done for frequency against the spectral density in the vertical axis, whereas four plots are done buoyant leg 1 set of legs 1, set of legs 2 and set of legs 3 and the deck.

So, one can see here the deck response is fairly lower than the top leg 2 and leg 3, whereas slightly higher than the top leg 1 in the surge degree of freedom. In surge degree whatever maybe the action taken by the legs are transferred to the deck. However, legs are independent of each other, there is no rigid body motion between the legs because they are not inter connected. The only element inter connects then is the deck which is through the ball joint. So, qualitatively the peak occurs almost at the same frequency for all the members, whereas the energy dispersed along the frequency band for the deck is much lower compared to the two legs ensure safe operability. And the deck remains almost horizontal compared to these two legs of 2 and 3 in surge degree.

However interestingly, if you look at the heave degree of freedom the deck response is more or less similar to that of the buoyant legs ensuring that there is comparatively a better rigid body motion in the vertical plane in the heave degree of freedom.

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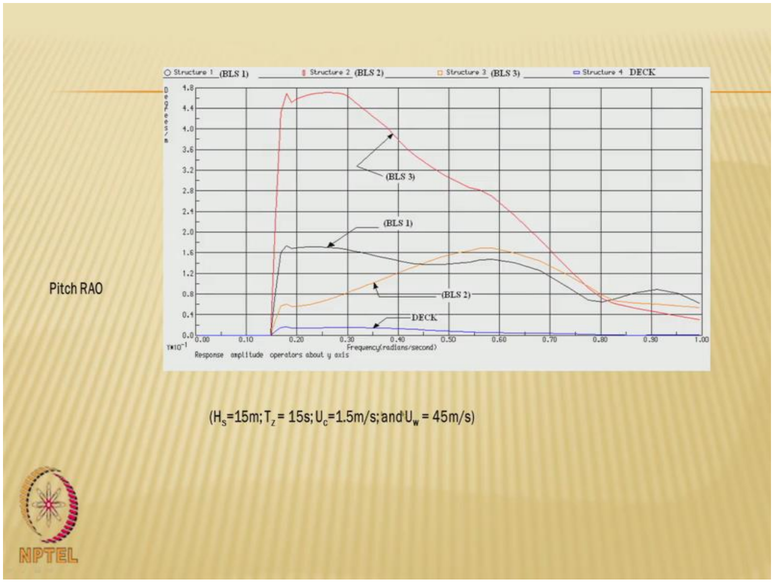


Similarly, if you look at the pitch response amplitude operator; one can see here ball joints do not transfer the rotation from the sub structure to the super structure. Practically the deck shows no response in the pitch degree of freedom, whereas the buoyant leg independently shows different kinds of responses. One may wonder that why the deck is at all showing a response in pitch degree if the ball joint is capable of filtering or restraining the complete rotation degrees of freedom from the buoyant leg to the deck.

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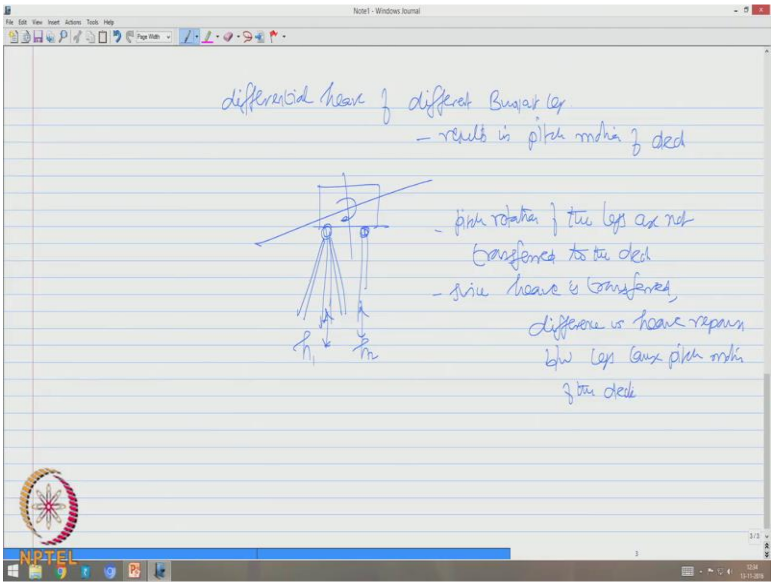


Interestingly, this is resulting from the differential heave happening between the legs because the differential heave also results in; the differential heave of different buoyant legs results in pitch motion. I have a super structure, I have a sub structure these are isolated, but the heave motion of this and this are different let us call this as heave 1 and this as heave 2 they are different respect to these plane this difference causes rotation, though the rotation is not transferred because of the pitch rotation of the leg to the deck.

Please understand the pitch rotations of the legs are not transferred to the deck. Since heave is transferred differential heave or difference in heave response between the legs causes pitch motion of the deck. So, that is the reason why we also have a deck motion and the pitch response to the deck compared to the (Refer Time: 15:29).

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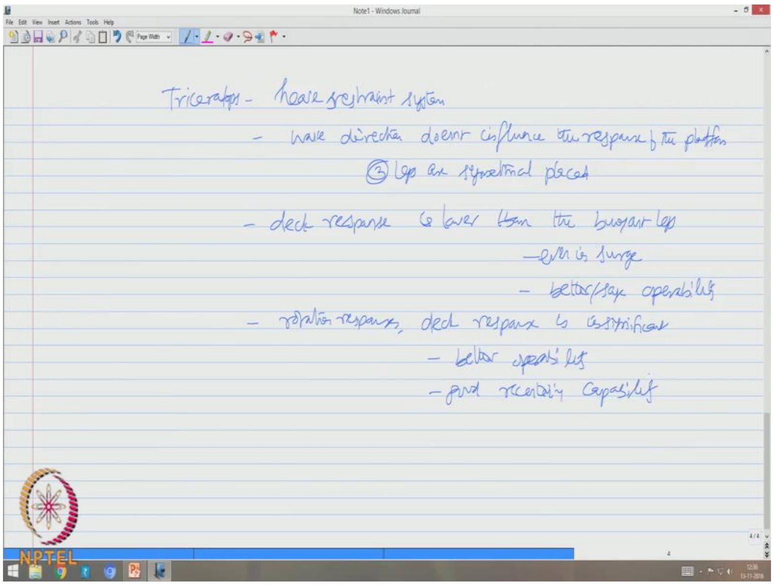


Therefore, one can say that triceratops have heave restraint system, because of this wave direction does not influence the response of the platform provided three legs are symmetrical placed. We also saw deck response is lower than the buoyant legs even in surge degree ensuring a better and safe operability. In the case of rotational responses, deck response is insignificant ensuring better operability and a good recentering capability.

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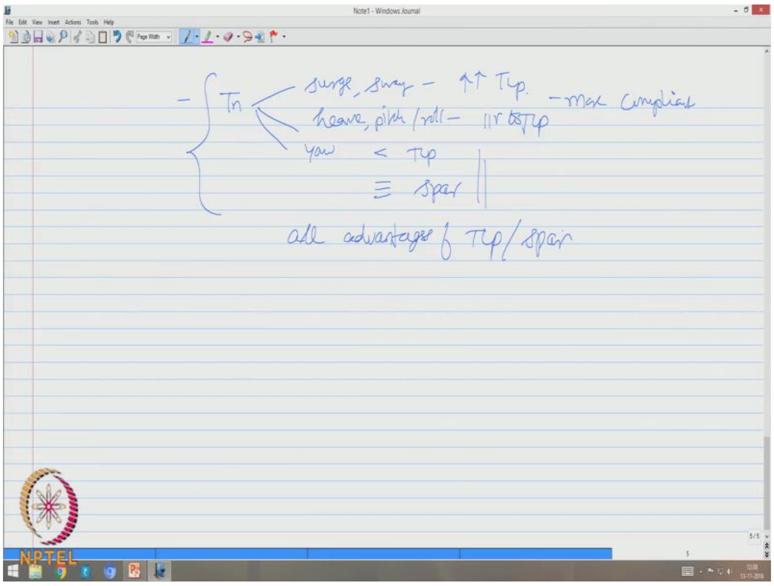

Natural periods in surge, sway are slightly higher compared to TLP. Making it more compliant in heave pitch and roll they are similar to TLP. In yaw it is slightly lesser compared to TLP, but more or less similar to that of a spar. So, the system derives all advantages of TLP under spar platform.

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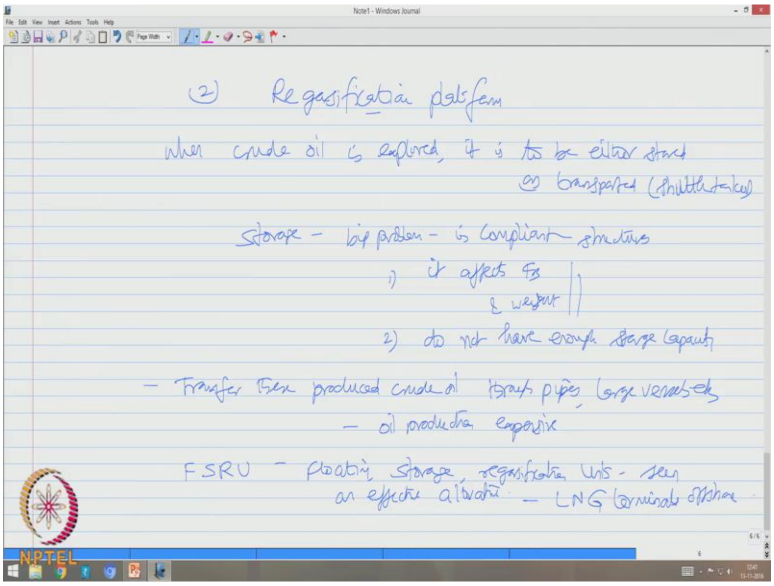


The next system what we will see now is regasification platform. We know that when the crude oil is explored from the drilling or the escalated platform; when crude oil is explored it is to be either stored or transported using a shuttle tanker. Storage is a big problem in company structures because it affects buoyancy, it also affects the weight, and therefore the platform stability may be challenged. The second issue is these platforms do not have enough storage capacity also.

So, it is usual practice that the explored oil is generally transferred to the coast for further production either by pipelines or by shuttle tankers. When you transfer this oil produced oil or crude oil through pipes, large vessels, etcetera. This makes oil production expensive. What is the alternative? FSRU: Floating Storage Regasification Unit is seen as an effective alternative.

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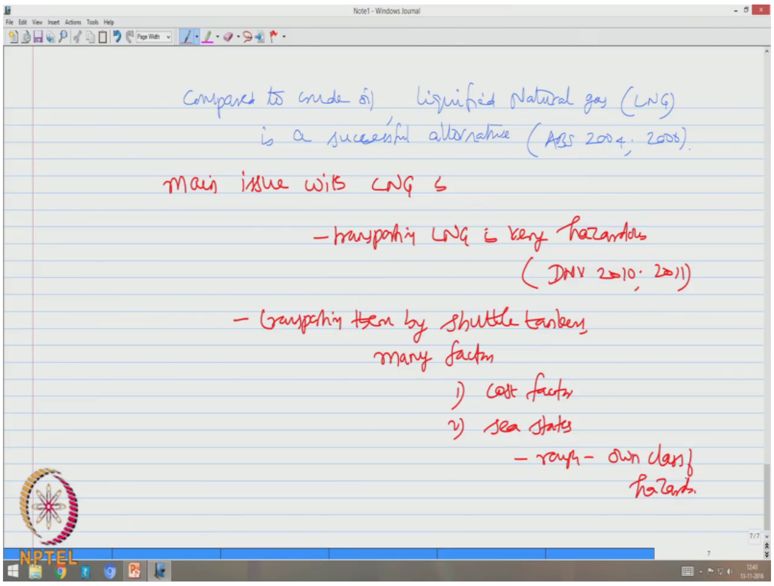


So, people are now working on LNG terminals offshore. So, compared to crude oil liquefied natural gas is a very successful alternative; this is ABS 2004, 2006; but this very main issue with the LNG production. The main issue with LNG is: transporting LNG is very hazardous as per DNV 2010, 2011. If you attempt to transfer them or transporting them by shuttle tankers they have many factors which are bothering us. One is the cost factor. Two, such transfers from the platform schedule private tanker cannot take place in all sea states.

So, when the sea states are very rough they have their own class of hazards. So, though LNG terminals are good alternatives, but platforms exploring storing LNG need to be looked with a special attention.

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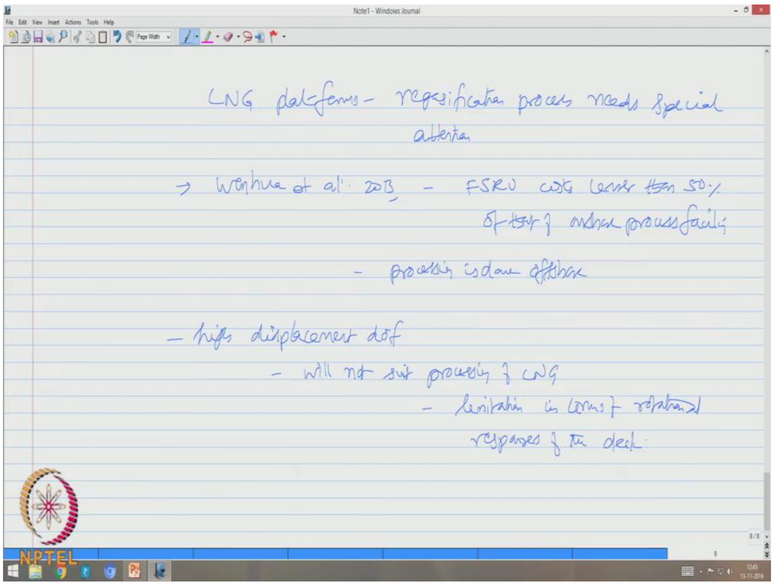


So, LNG platform which houses regasification also needs special attention. So, by Wenhua in 2013 it is seen that FSRUs cost lesser than 50 percent of that of onshore processing facility. So, it is expected that processing is done offshore. The conventional platforms what we have today like TLP, spar, etcetera have very high displacement degrees of freedom. They will not suit processing of LNG, because LNG terminals require a very high limitation in terms of rotational responses of the deck.

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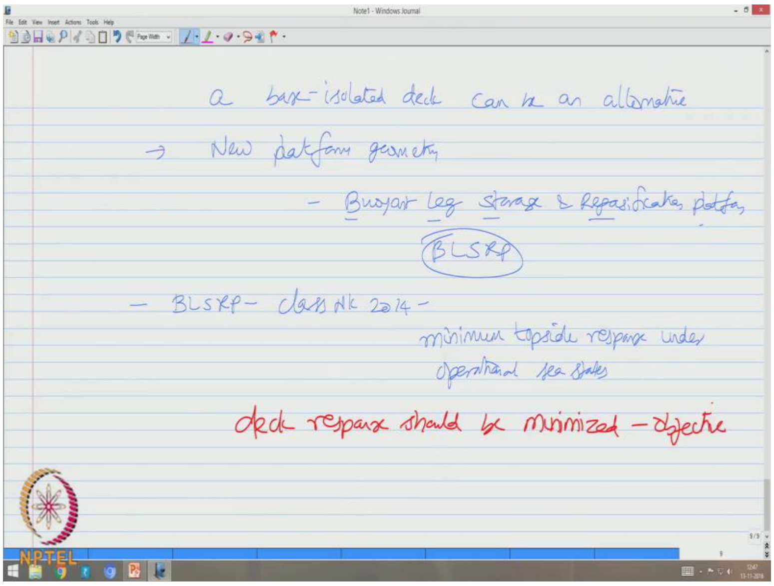

So, a base isolated deck can be an alternative. So, a new platform is conceived, a new platform geometry is conceived which we are going to discuss now that is called Buoyant Leg Storage and Regasification platform, so we say BLSRP. The foremost condition of a BLSRP as per class NK 2014 is it should have very minimum topside response under operational sea states. So, the condition here is deck response should be minimized, that is what the goal; that is the objective.

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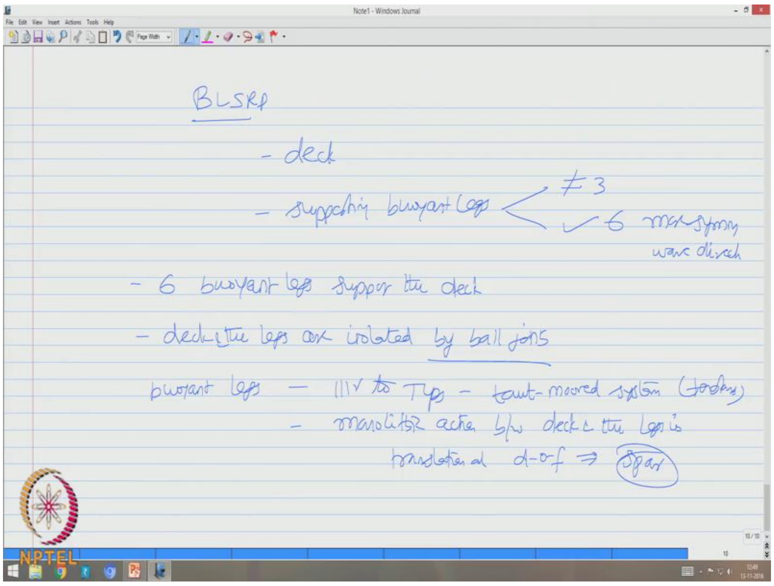


So, the geometric form of BLSRP has got a deck supporting buoyant legs, but in this case they are not 3 but 6. To make it more symmetric with respect to wave direction; so 6 buoyant legs support the deck, deck and the legs are isolated by ball joints. Interestingly, buoyant legs are similar to TLPs, because they have a taut moored support system coming from the tendons. They have a monolithic action between deck and the legs in translational degrees of freedom. This is similar to that of a spar. So, now BLSRP is again a combination of advantages of TLP and the spar.

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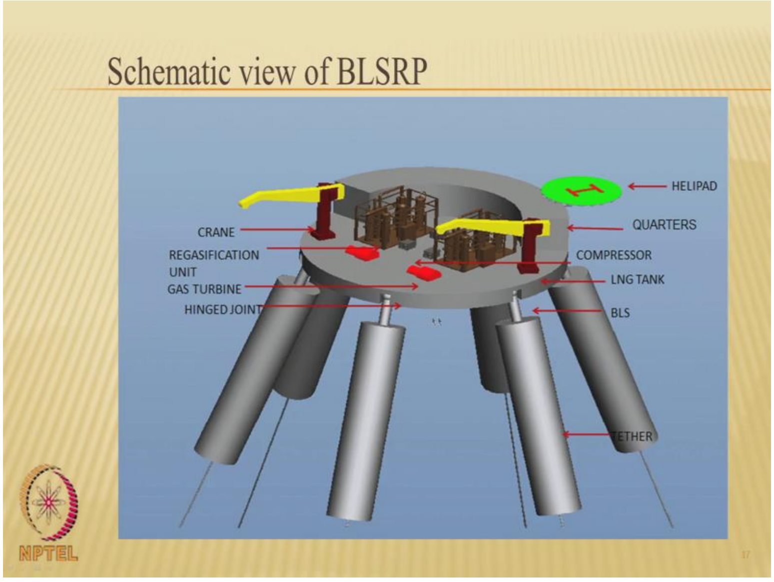


A typical schematic view of the structure is now shown on the slide. This consists of a deck which has all electro mechanic components. Usually the deck is circular because influence of the deck in terms of its area distribution or the mass distribution is more or less symmetric with respect to the cg. It has got a crane, helipad, living quarters, compressor units, regasification units, gas turbines etcetera.

Now the deck which is essentially stainless steel LNG tank is isolated from the buoyant legs with that of the hinged joint there is a hinged joint we have, and the buoyant legs one end is connected to the sea beds using conventional tendons which is taut more as you see in the case of a TLP.

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Structural Details

| Description | Prototype | Units | Model (1:150) | Units |
|---|---|---|---|---|
| Water Depth | 600 | m | 4000 | mm |
| Mass of the structure | 400000 | ton | 118.51 | Kg |
| Utilities | 10000 | ton | 2.93 | Kg |
| Secondary Deck Plate | 1250 | ton | 0.37 | Kg |
| Stainless Steel Tank | 1800 | ton | 0.53 | Kg |
| LNG | 25000 | ton | 7.40 | Kg |
| Main Deck Plate | 2500 | ton | 0.74 | Kg |
| BLS (6 no) | 25500 | ton | 7.55 | Kg |
| Ballast | 333950 | ton | 98.94 | Kg |
| Diameter of the BLS | 22.50 | m | 150 | mm |
| Length of the BLS | 200 | m | 1333.33 | mm |
| Diameter of the Deck | 100 | m | 666.66 | mm |
| Draft | 163.57 | m | 1117.73 | mm |
| Meta Centric Height | 15.18 | m | 114.86 | mm |
| Length of the Tether | 470.84 | m | 3138.93 | mm |
| Initial Tether tension | 85.50 | MN | 2.50 | Kg |



A typical structural detail which is investigated experimentally and numerically on the research point of view is on the screen. The investigation is carried out on 1 is to 150 scaled model of a BLSRP for a water depth of about 600 meters. The mass of the structure, the mass of the tank, the plate are all resembling to a typical TLP top side. There are six numbers of buoyant legs to the ballast value of about 100 kg closer in 1 is to 150 model. The diameter of the deck is about 100 meter in prototype which is a very conventional dimension for a classical tension leg platform, of course in that case it may be a square or a rectangular platform, but in this case the deck is intentionally kept circular. Is a deep draft system which is similar to that of a spar platform with a positive meta centric height which enables better stability.

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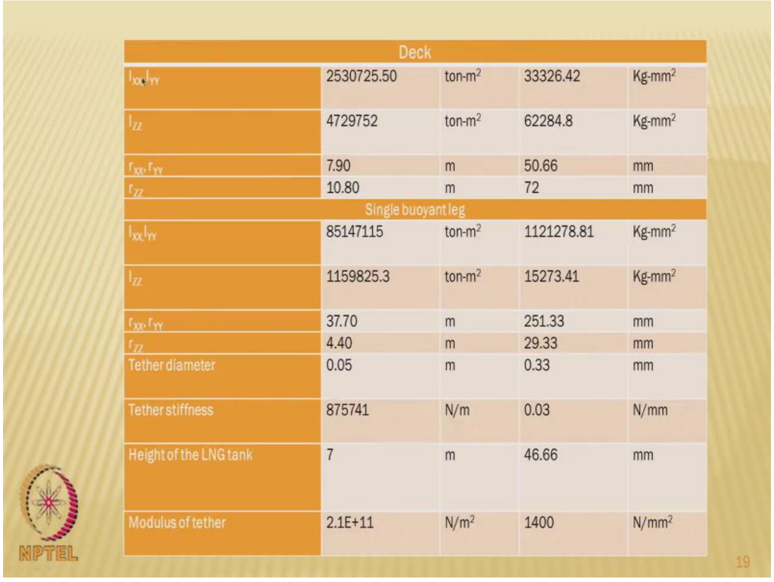

| | | | | |
|---|---|---|---|---|
| Deck | | | | |
| $I_{XX}, I_{YY}$ | 2530725.50 | ton-m$^2$ | 33326.42 | Kg-mm$^2$ |
| $I_{ZZ}$ | 4729752 | ton-m$^2$ | 62284.8 | Kg-mm$^2$ |
| $r_{XX}, r_{YY}$ | 7.90 | m | 50.66 | mm |
| $r_{ZZ}$ | 10.80 | m | 72 | mm |
| Single buoyant leg | | | | |
| $I_{XX}, I_{YY}$ | 85147115 | ton-m$^2$ | 1121278.81 | Kg-mm$^2$ |
| $I_{ZZ}$ | 1159825.3 | ton-m$^2$ | 15273.41 | Kg-mm$^2$ |
| $r_{XX}, r_{YY}$ | 37.70 | m | 251.33 | mm |
| $r_{ZZ}$ | 4.40 | m | 29.33 | mm |
| Tether diameter | 0.05 | m | 0.33 | mm |
| Tether stiffness | 875741 | N/m | 0.03 | N/mm |
| Height of the LNG tank | 7 | m | 46.66 | mm |
| Modulus of tether | 2.1E+11 | N/m$^2$ | 1400 | N/mm$^2$ |



The structural properties of mass movement of inertia, that is of gyration to the diameter and modus of elasticity are now shown on the screen, both for the deck as well as for a single buoyant leg for our understanding.

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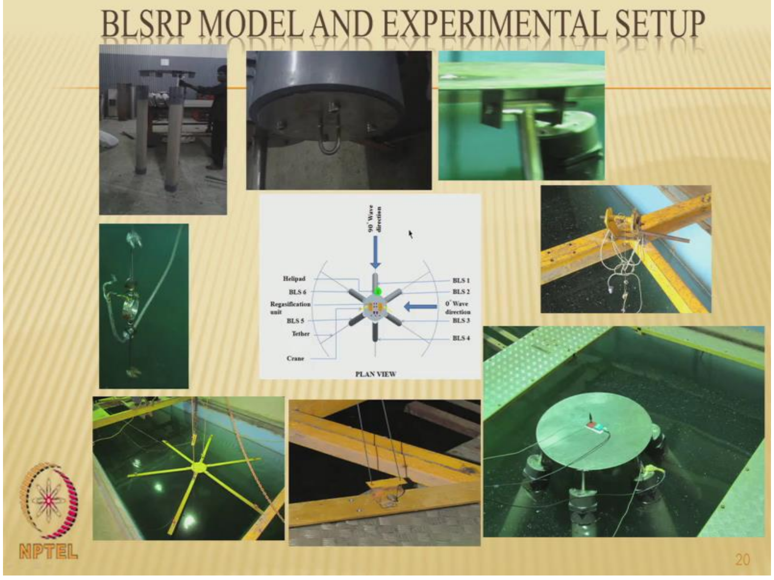


These are some of the elements of the platform which has been fabricated for experimental investigation. These are the buoyant legs, these are the hinged joints or the ball joints is a hook at the bottom of the buoyant leg which is being used to do connection of the tendon to the buoyant leg and the sea bed; that is a typical figure of the hinged joint. This is actually used to measure the tether tension variation in the tendons. This is a spread leg mooring system with six legs being housed in the experimental facility to the top tension raiser system where at the bottom they are connected to the reverse tension system. And the tension in the legs are adjusted by the adjustable mechanism which is ratchet mechanism controlled from the top.

So, the deck is now housed for instrumentation and now the buoyant leg platform with six legs and hinged joint connected to the stainless steel deck to a scaled model are now ready for experimental investigations.

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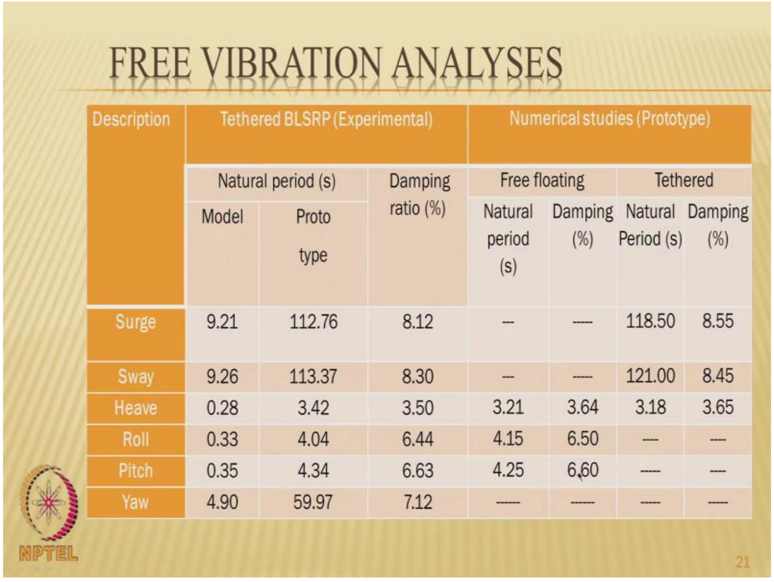
FREE VIBRATION ANALYSES

| Description | Tethered BLSRP (Experimental) | | | Numerical studies (Prototype) | | | |
|---|---|---|---|---|---|---|---|
| | Natural period (s) | | Damping ratio (%) | Free floating | | Tethered | |
| | Model | Proto type | | Natural period (s) | Damping (%) | Natural Period (s) | Damping (%) |
| Surge | 9.21 | 112.76 | 8.12 | — | — | 118.50 | 8.55 |
| Sway | 9.26 | 113.37 | 8.30 | — | — | 121.00 | 8.45 |
| Heave | 0.28 | 3.42 | 3.50 | 3.21 | 3.64 | 3.18 | 3.65 |
| Roll | 0.33 | 4.04 | 6.44 | 4.15 | 6.50 | — | — |
| Pitch | 0.35 | 4.34 | 6.63 | 4.25 | 6.60 | — | — |
| Yaw | 4.90 | 59.97 | 7.12 | — | — | — | — |



Free vibrational analyses are conducted on this very clearly shows the tethers and the prototype, free floating and tethered in terms of all degrees of freedom on the deck. So, one can very clearly see here the periods of degrees of freedom in terms of surge and sway resemble very closely to a tension leg platform. Whereas, heave now resembles closely again stiffness in the vertical plane ensuring safe operability in terms of its safety for the minimum deck response in the platform.

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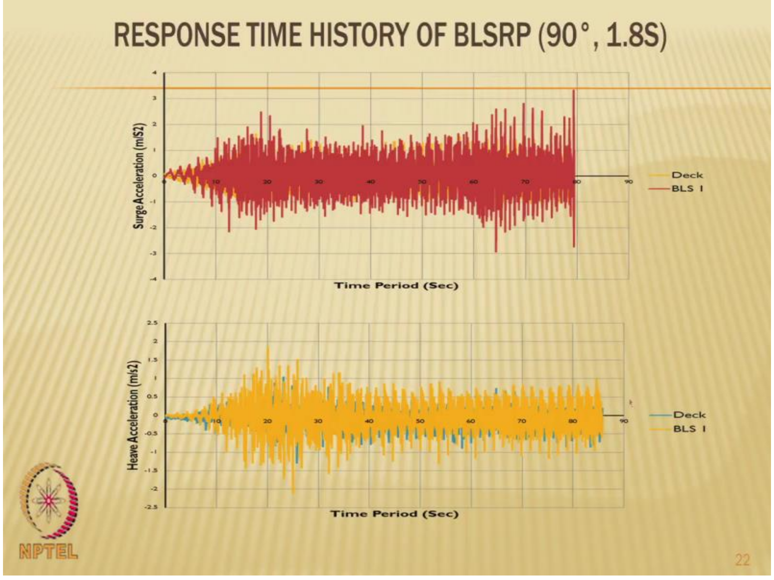


If you look at the typical time history response of the platform for 90 degrees and 1.0 seconds wave 8 seconds wave; the surge acceleration and the heave acceleration measured on the deck and the BLS are shown on the screen. One can very clearly see the surge acceleration of the deck is minimum at all instances of time compared to typical buoyant leg 1. Whereas, the heave response is more or less same ensuring rigid action connectivity or rigid body motion between the buoyant leg and the deck in the vertical plane.

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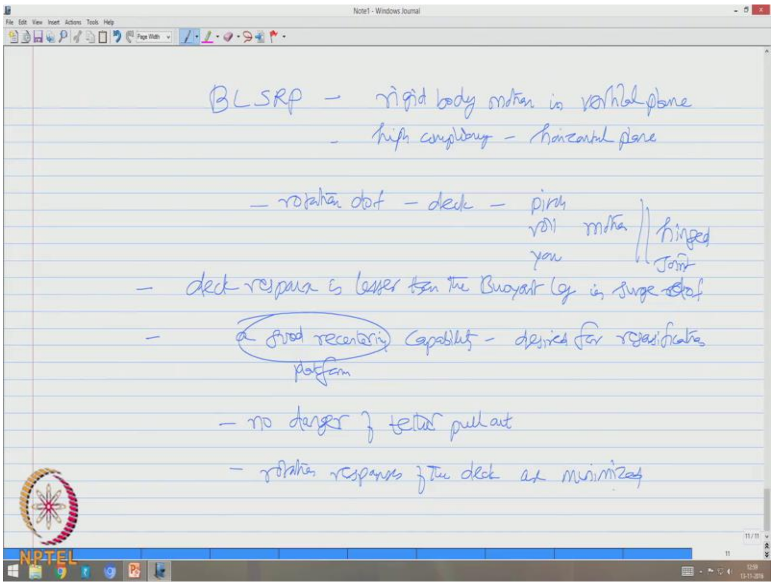

So friends, BSLRP show a rigid body motion in vertical plane and high compliancy in horizontal plane. So, the primary objective was to reduce the rotational degrees in the deck in terms of pitch, roll, and yaw motion which is now achieved by placing a hinged joint between the platform leg and the deck.

So, one can understand here that the deck response is lesser than the buoyant leg or the supporting system in surge degree of freedom; which ensures a very good recentering capability which is also desired for regasification platforms. To ensure a good recentering capability please pay attention to the response shown in the screen now.

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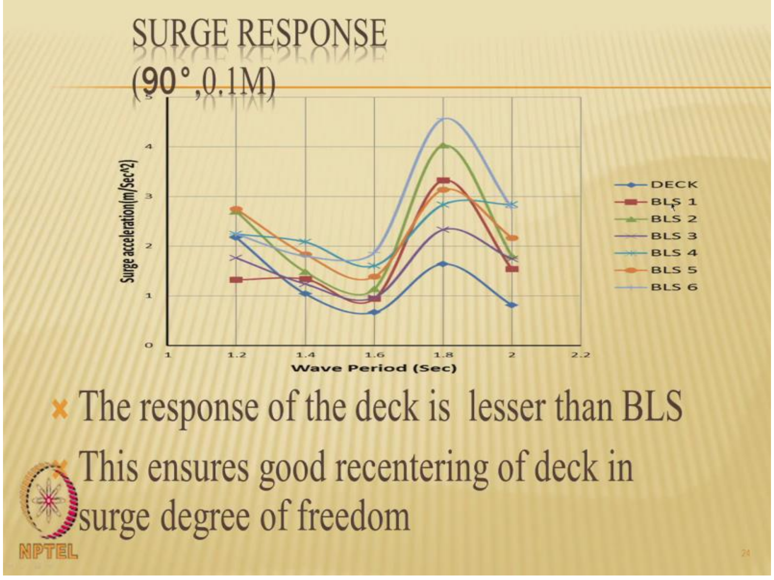


The response in all legs and the deck are plotted for 90 degree wave approach angle for 0.1 meter wave height. The surge acceleration is plotted on the y axis, whereas the wave period is plot on the x axis and seconds. One can see very clearly that the deck response is almost lower than all the buoyant legs, and this value is more or less attempting to close to come to 0, it is not practically coming to 0; the deck is not resting horizontally completely in surge degree of freedom but is very close which ensures a better recentering capability.

And buoyant legs are not inter connected each one of them imposes different tether tension variations which also results in pitch or roll responses of the deck because t 0 change improvises heave response, and heave on a vertical plane is transferred to the deck by the hinged joint.

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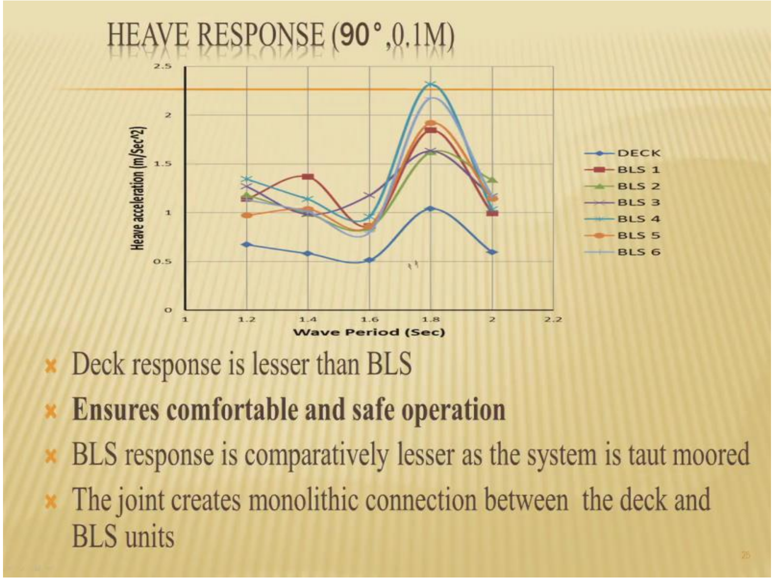


Similarly if you look at the heave response now; heave response of the deck is anyway lesser than that of the buoyant legs ensures comfortable and safe operation. And BLS response is comparatively lesser than the system; because the system is taut more. The joint creates of course a monolithic connectivity between the support system and the deck carefully by the design.

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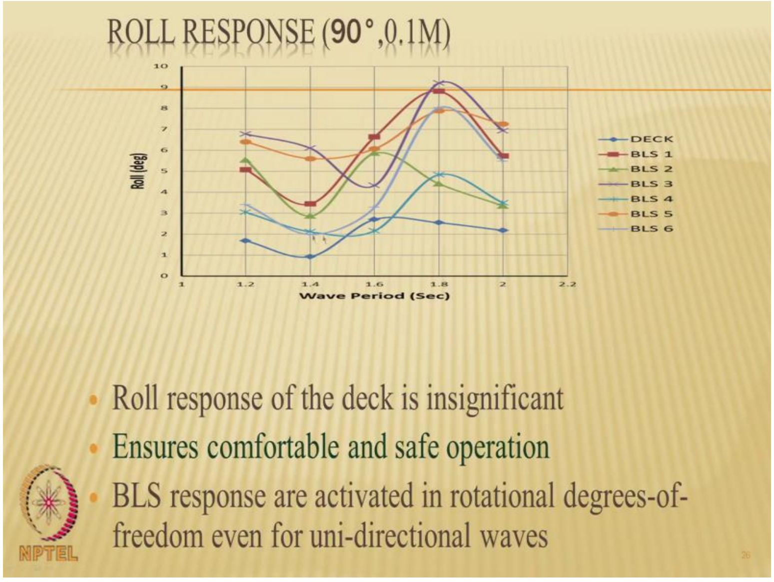

The role responses of the deck are far lesser than that of the buoyant legs, but still the response of the role degree happens in deck. It is because for uneven distribution of the responses of these legs happening at the sub structure.

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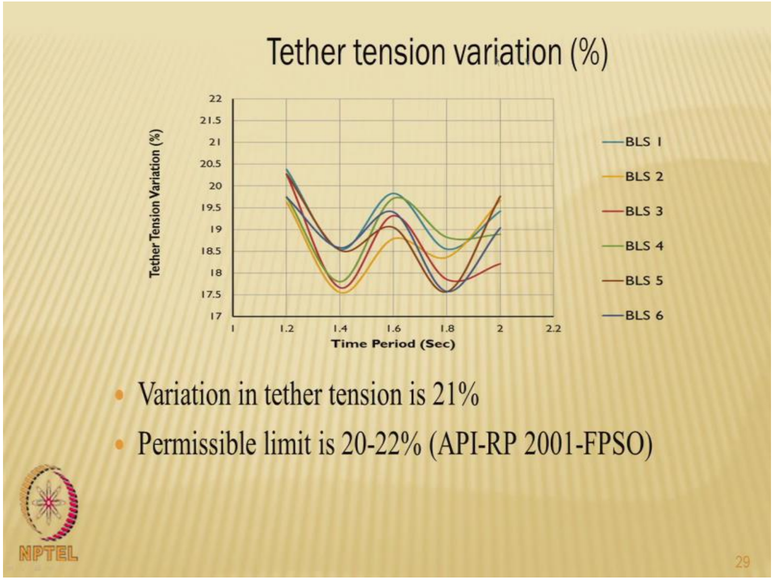


If you look at the tether tension variation in percentage one can see here for different buoyant legs the responses in terms of t 0 variation in percentage different. However, the maximum variation seen in the analyses is about 21 percent, whereas the permissible limit goes up to 22 percent as per API-RP. Therefore, there is no danger of tether pullout. Rotational responses of the deck are minimized and that ensures safe operability for a typical regasification plant.

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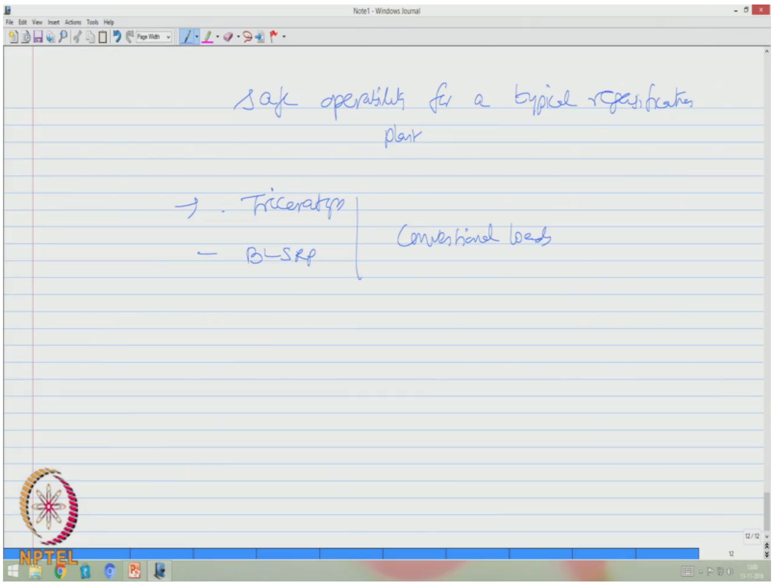


Friends, please understand the responses what we saw for a triceratops and the BLSRP, they were for conventional loads not special loads. We will also discuss their responses back again when we talk about special loads and see how do they behave even under special criteria of exceptionally high loads, wherein a TLP may fail whereas these structures can still remain safe, but not operational.

So in these lecture friends, we got, understanding of a new kind of platform which is BSLRP.

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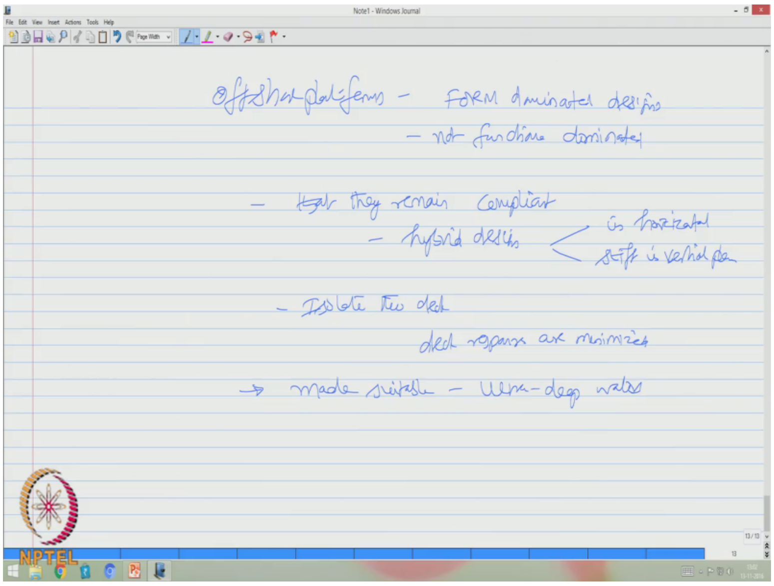

So, now we understand that offshore platforms are form dominated designs, they are usually not function dominated. It is preferred that they remain compliant, but we need a hybrid design. In sense compliant in horizontal plane, but stiff in vertical plane. We also saw when we isolate the deck responses are minimize. Therefore, this platform can be made suitable for ultra deep waters where the forces are much higher compared to the deep and shallow waters.

We will now show quickly a video for you to really understand how isolation on the deck enables the deck to remain horizontal practically with good recentering capability.

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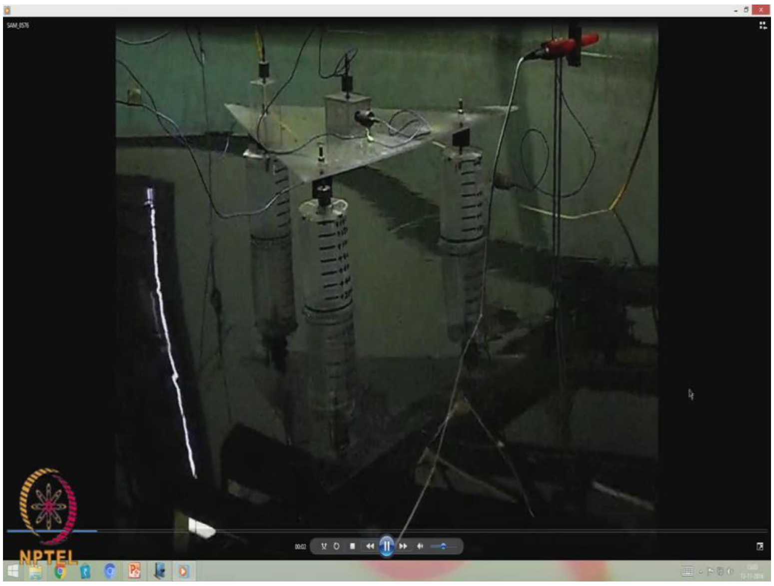

Please pay attention to the video shown on the screen now. One can see here in a triceratops model the legs are independently behaving under the wave action, whereas the measures instrumentation very clearly shows that the deck is practically remaining horizontal. And one can see the inclination of these legs, the inclination of these legs are different that is imposing different rotational degrees of freedom, but for all these surge action or sway action is happening heave is restricted and roll, pitch and yaw motions from the buoyant legs are not transferred to the deck completely. So, the deck remains horizontal and imposes a very good recentering capability at least in rotational degrees of freedom.

So friends, in this lecture we learnt a new kind of platform of BLSRP useful for LNG or regasification platforms. We learnt advantages of these new generation platforms with respect to the structural form and the betterment in performances compared to conventional platforms which are designed in deep water facilities. We will proceed further to understand a response behavior under special loads in the coming lectures.

Thank you very much.