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

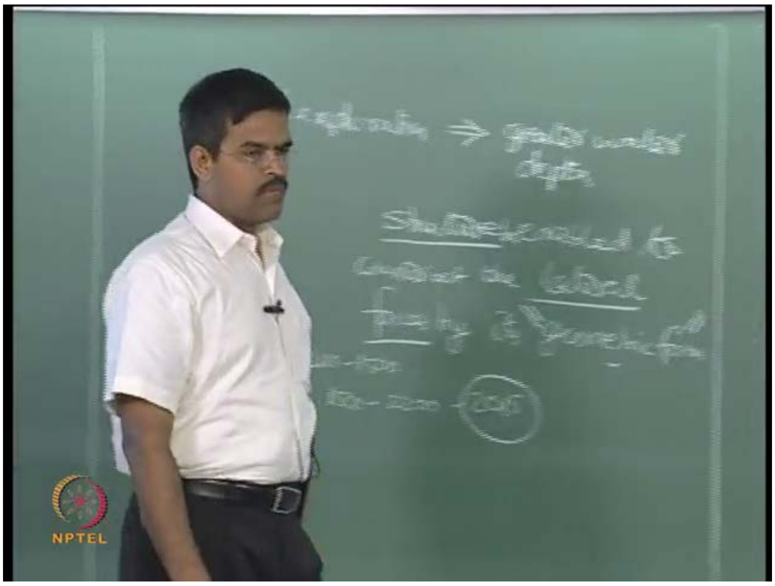
Module - 2
Lecture - 17
Development of new generation
Offshore structures

In this lecture, in module 2 in lecture 17, we will discuss about New Generation Offshore Structures.

(Refer Slide Time: 00:18)

In the last lecture, we discussed about the analysis and some of the design implications of compliant structures along with the derivation of mass matrix, stiffness matrix and damping matrices using relay damping. We also compared the influence of difference kinds of damping matrices with Caughey damping etcetera. So, as we understand that, once the deep water oil exploration starts moving towards greater water depths.

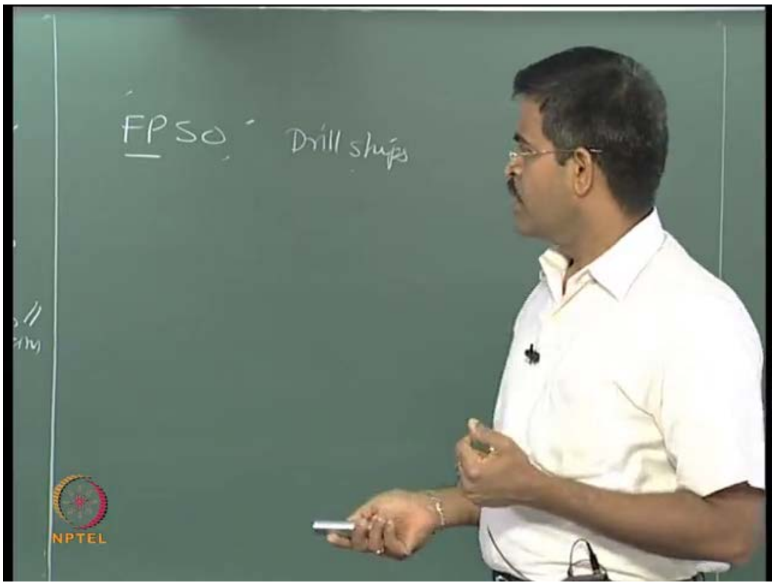
(Refer Slide Time: 00:47)



When the oil exploration starts moving towards greater water depths, so your structure should be enabled to counteract the lateral forces by it is geometric form. So, a structure should be capable of alleviating the lateral loads by the new geometric form. Therefore as they move towards greater water depths, you should have a structural form, which actually adjust itfor catering to the additional loads, which are coming because of the greater water depths.

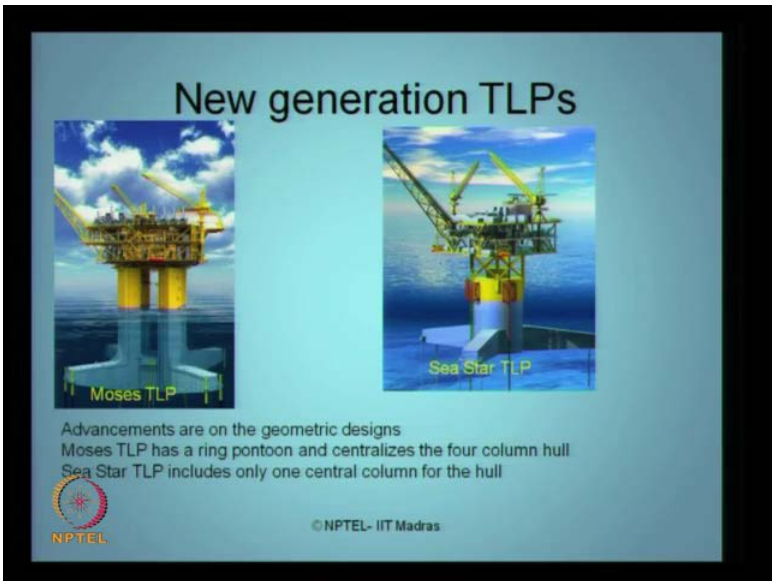
So we are now looking approximately the exploration in the present trend at the water depth of 1200 to 1500, it is expected that, we will go to the depth of exploration even 1500 to 2200 by 2015 year. Because, the resources of the hydro carbon are started moving to the deeper water therefore, the conventional platform of course, what we have in 80’s, jacket structures are totally absolute now, they are of no use at all, for any kind of new exploration. So, we are looking for new trends of offshore structures where, most commonly people are started using FPSO.

(Refer Slide Time: 02:53)



And of course for exploratory drilling, people start using drill ships, etcetera but all they have all these structures have their own limitations of positioning them for rough sea states. So, we would like to go for a permanent installation like a structure or an offshore system, which can be installed permanently in the location for a period of let us say, 5 to 10 years, and which can also counteract the lateral roads in rough sea states at greater water depths. So, we are looking for new generation offshore structures, which we will discuss in this lecture where, we will also touch up on the dynamic analysis of this, in this lecture.

(Refer Slide Time: 03:38)

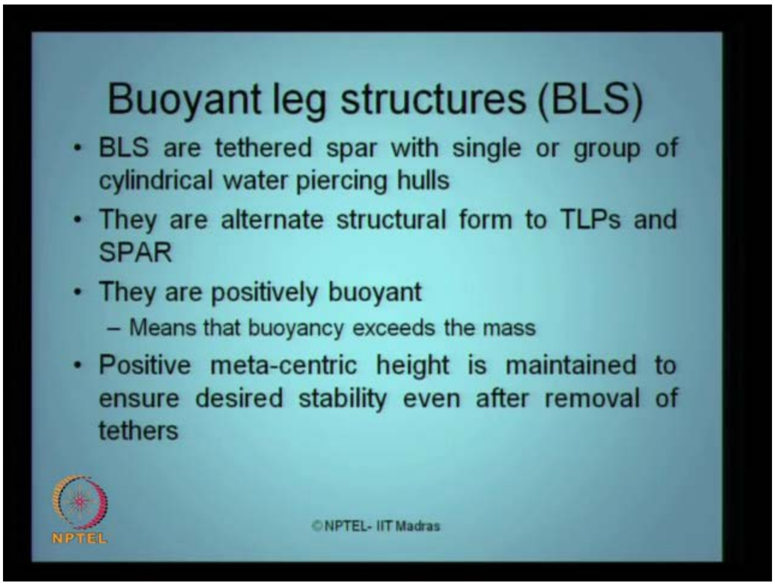


If you look at the new generation TLP, even tensional platforms also moved to deeper water depths so 2 interesting forms have been arrived at, one is what we called as moses TLP and the other one is sea star TLP. Both of them are advancement in geometric design, you can see very well here from both the figure, that the moses TLP has a ring pontoon, the pontoons are not provided at the cover or at the circumference. They are provided with the ring closure, which is the ring pontoon type, we can see here the pontoons are located here not on the periphery usually; TLPs have pontoons on the periphery.

So, the ring pontoon type and of course, which had got the centralized column hull, the column hull is centralized. And if you look at the sea star TLP, it has got further advancement of only one central column having only one central column and of course, the legs are spread out. So, these are all the interesting new form generations, which has been done for enabling the capabilities of these platforms for taking into deeper water of course, they are all tension like platforms, you can see here the tethers, which are all holding down the column members.

These are all tethers, what we see in this figure as well as here and so on so they are tethers, they are for holding it down and this has got some geometric advantage compared to the conventional TLPs, which has been built in early 80’s and late 90’s, in gulf of Mexico. In majority, for oil exploration of course, in the first module, in the lectures we have given you a detailed statistics of different kinds of TLPs constructed all over the world till the year 2012.

(Refer Slide Time: 05:22)



Interestingly, people have moved further forward for greater waters other than, what TLPs can cater. So, buoyant leg structure has become a very interesting and innovative application and offer platforms. As the name suggest, each legs will float on it is own self buoyancy that is why, they are called buoyant leg structures. Interestingly, only one platform has been constructed so far successfully, which is again on a trial basis, which I will show you now here.

Based on which, new geometric form is attempted to be evaluated in the latest research, we will see that what was happening here. Before that, let us try to understand what BLS mean, BLS actually a tethered spar, buoyant leg structures are nothing but tethered spar with the single or group of cylindrical water piercing hulls. They are expected to be an alternate successful structural form to TLPs and spars, that is what, literature project them.

They are essentially positive buoyant structures, positive buoyancy means, the buoyancy will exceeds the mass, as we understand in the case of TLPs also. Therefore, they got to be hold down to the foundation of the sea bed using some external restraining arrangements usually, it is tethers. The positive metacentric height of this kind of structures is essentially maintained and designed; you can always maintain the meta centric height to be positive or negative, with respect to the centre of mass, depending upon their mass distribution on the super structure and the hull.

So, you always maintain the metacentric heights to ensure a desired stability even after the removal of tethers, that is a very important aspect here. Because, in recent times in literature you might have studied by this time, there are many cases where, there has been pull out happening on tethers especially, in TLPs and guide and moved towers. The tethers get pulled out, not plugged out, it gets cut because of marine trafficking, because of impact of vessels or the barges on the platforms, etc.

So, whenever the tether gets pulled out or pulled off from the connection then it is expected that, a positive buoyant structure will always tend to lose it is stability. One of the important aspects in the present research focus is that, in case the removal of tethers happen, will it remain or sustain it is stability as a positive buoyant system. So, that is the one important aspect, which we are deviating completely from a conventional platform like jacket structures to that of completely floating structures.

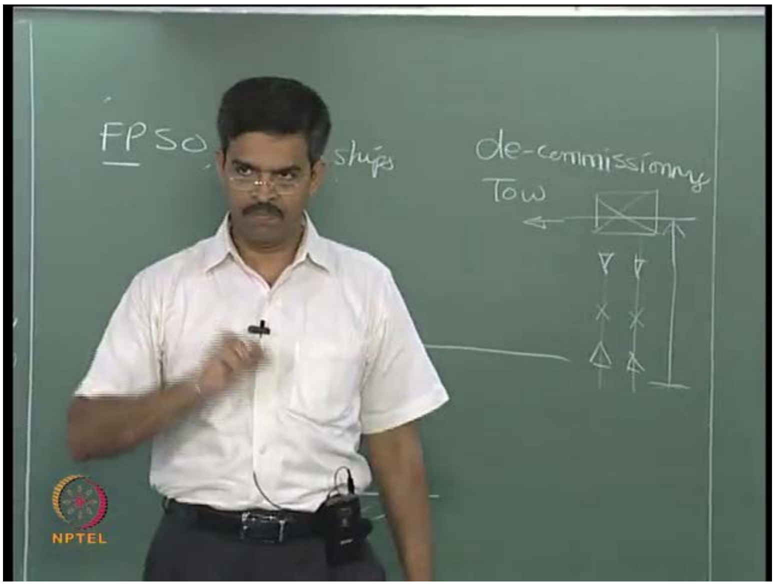
Because, they are not ships or they are not FPSOs because they are moved using a dynamic positioning system on a temporary location of course, operation sea state for FPSO and drill ships are entirely different from, what we are looking for a permanent system like this. So, in case, any critical sea state is been expected to arrive at a specific sea state then FPSos or drill ships are may nonfunctional. Of course, they will sail but they will not be produce or involve in production of the system whereas, in this case of the platform, there is nothing like a dynamic positioning system.

It is a permanent or we can say, moreover it is a semi-permanent installation, which has to cater to rough sea states, even when they are fixed and we are talking about the system, which is going to work at greater water depths. So, one of the important focus of this kind of research, as in structure in the literature is that, even though you got the tether pull out happening in this system, will the system remain self-stable and portly.

Now, we will rule the stability so that is one important aspect therefore, in the most of this kinds of innovative forms is expected that, your analytical, numerical and experimental should focus on, what we call free floatation analysis. This has been an important focus now in dynamic analysis, in case of deep water or ultra-deep water of the systems, which has not been a focus may be about 15 years earlier.

We are looking for free oscillation studies, may be experimental, may be numerical, may be analytical depending upon, what model are you generating. Because, the focus is, I want to check whether the system will remain stable and position restrained or at least stay in position, even when the tethers are completely plugged off. So, there are one more derived advantage, when looking at this kind of analytical stability.

(Refer Slide Time: 09:50)

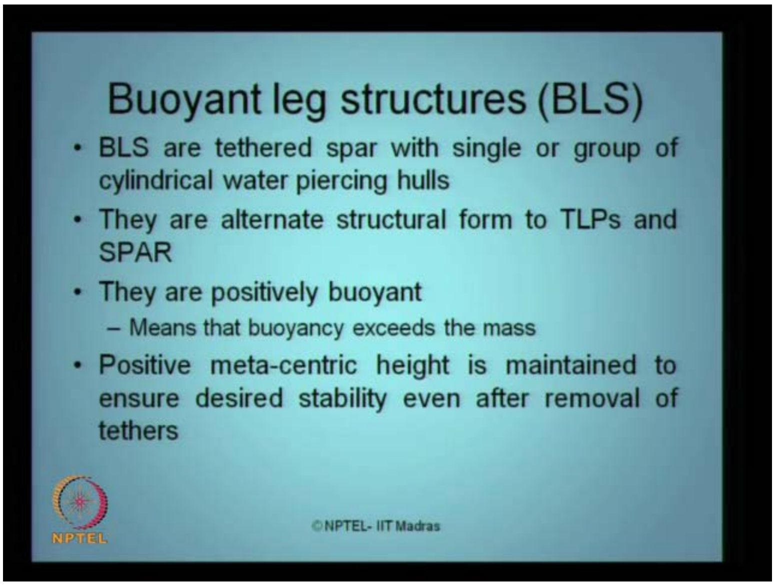


The derivative advantage is, if you want the system let us say, this is my sea, this is my sea bed, this is my system may be a black box, which is self-sustainable even when there are no tethers plugged to the restraining system. So, one derived advantage of this kind of system is that, I can easily tow this using the barge, so installation becomes very easy in this case. In such kind of systems, which is remaining self-stable without tethers being in position can be easily towed, installation becomes easy as well as decommissioning becomes simple, also is simple.

So, there are 2 derived advantage we get, by making the such system self stable, even though when the tethers are plugged off. Of course as we understand, since the structure is having positive buoyancy, to make the structure to have a specific designed draft. To have a specific designed draft, you should be very careful in imposing a T to the cable so that, the weight and T are adjusted so that, the design draft is achieved for a specific position of the sea state.

To hold it permanently in a position, I need dr and dr will be achieved only by imposing T naught remember that because it is a positive buoyant system otherwise, it is free floating. So, the towing, installation, commissioning and decommissioning becomes very easy compared to other kind of old generation platforms, which have been a herculean task. Especially, for example in case of, jacket structures, gravity based systems, they have been very difficult. Now, this system has become more comfortable therefore, our dynamic analysis should also focus on this kind of studies, if really want to promote the new generation platform for deep waters.

(Refer Slide Time: 11:49)

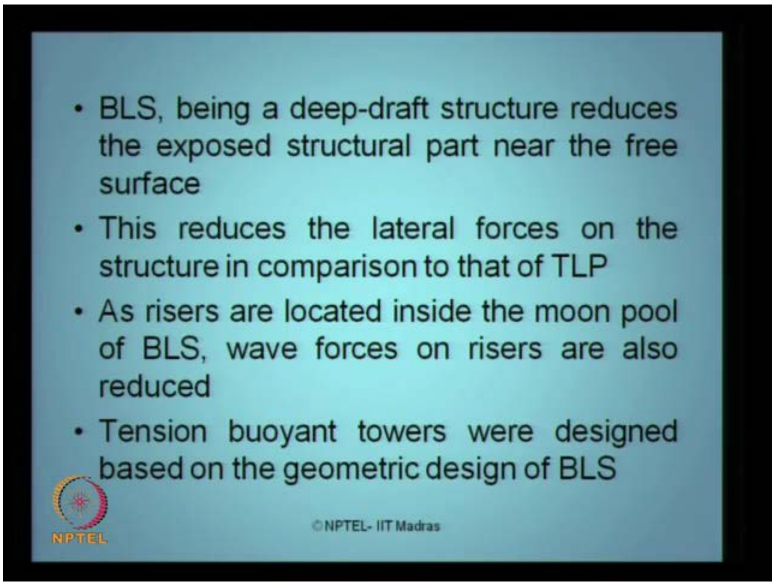


So, deep draft and high stability of BLS, which is indicated in literature, show you the references later, results in a relative insensitivity of these kinds of structures for ultra-deep waters. That is one of the important attention why, BLS or boiled structures are carried forward for new generation platforms. Because, the deep draft and high stability of these units make it water depth insensitive, you can carry to any water depth you want, it is expected that, one can carry to any water depth, is this clear.

So, one main focus in case of new generation structures is that, I want to be I want to make the system self-stable, positive buoyant, deep draft and highly stable. And BL is one such example of course, the innovation does not stop here, it has started in recent times. You can see the papers we shown you now, is only about 1 or one and half years old, just about just published in the literature.

People are now looking at these kinds of platforms of course, the concept of using BLS for production and drilling, started only in the year 2005. First paper was projected by an author in one of the isope conference in Japan, I will show you that. So, it started only about let us say, 6, 7 years down the line, as a concept but verification of this concept on a geometric form experimentally, analytically and numerically, analysing dynamically and see, whether they are stable or not, these are all only about 1 year old. So, it is a new generation platform relatively compared to any other established platforms. So obviously, your question of asking me, whether such platforms have been installed is having no meaning because still it is under trial.

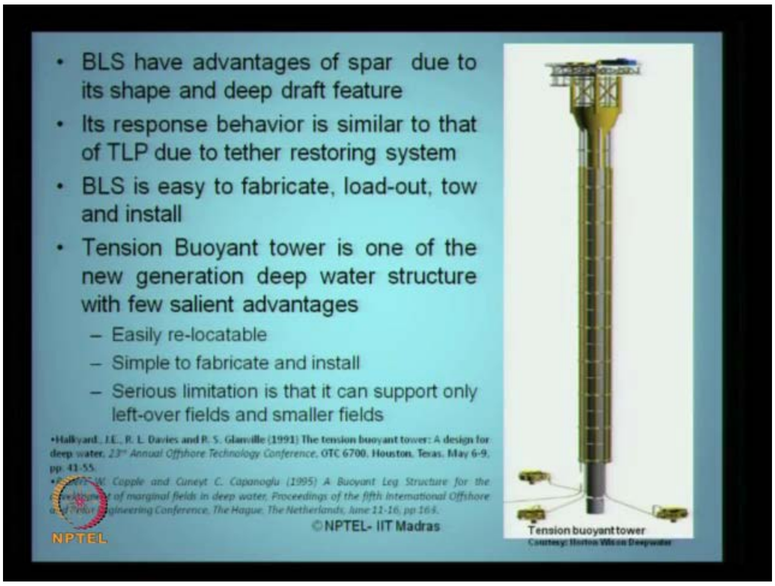
(Refer Slide Time: 13:36)



So, BLS being a deep draft structure, it reduces the exposed structural part near the free surface; that is the great advantage what we have, in case of deep draft structures. So, therefore obviously, it reduces the lateral forces on the structure, in comparison to that of TLP that is what, one can immediately summarize when you got the deep draft system. The other advantage, what we have in BLS is we can have a moon pool of a BLS where, I can put risers to it therefore, the risers are protected against the lateral forces near the free surface.

Because, the free surface is the area where, the wave force are maximum, we understand we know that therefore, risers can be protected at least near the free surface elevation of the sea. Therefore, risers will attract less force; of course, the advantages were there, in earlier conventional platforms also. So, as I said, the geometric form invention started getting merits of the previous platforms and overcoming the demerits of the old platforms that is how, it is has been. So, looking into the concept of integrating tension like platforms into buoyant structures, a new structure was proposed, which people has addressed as tension buoyant towers and they were designed and they were tested. So, the tension buoyant towers were designed essentially amalgamation of BLS on to the TL.

(Refer Slide Time: 15:02)

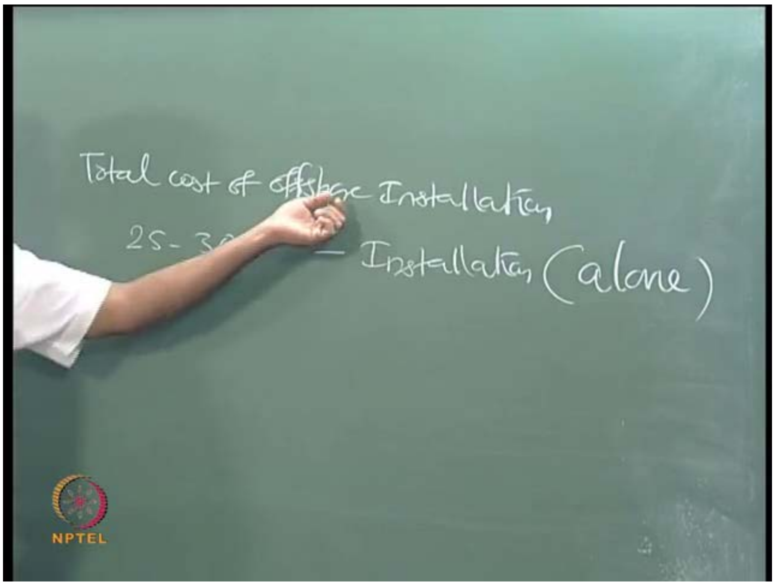


So, that is the tension buoyant tower, which you see here, which has been developed and designed by Horton Wilson deep waters system incorporation in US. So, of course, the references are I think in a very small size, you can see it in a way but please in a larger size. So, Halkyard Hetal has first given the design of this in 1991, which has been published in a OTC conference in Houston indexes. Of course in 1995, Robert and Capanoglur has given a concept of BLS to be extended for deep water of structures for production facility. So, this is the classical tension buoyant system, which has been numerical analyzed, not constructed numerically analyzed the Halkyard. So, BLS had the following advantages for spar because of it is shape, because you can see, shape resembles to the classical spar and it is the deep draft feature.

Of course, it resembles to the behavior of the TLP because the tether restraining system, it has got the tether restraining system and these are all the satellite subsea wells, which are going to support this. The only demerit what this kind of platform had, which has been proposed by the inventor is that, the platform is suitable only for left over and marginal fields, it cannot support larger fields.

Because obviously, this does not have storage capacity so it supports only left over or smaller fields but the advantages are very serious in terms of TBTs, tension buoyant towers. It is a deep water generation, new generation deep water structures easily relocatable, you can install it and decommision very simple and it is very easy to fabricate and install so these are 2 major advantages. So, for your understanding, we are bothering about fabrication installation, and decommissioning in a total cost of offshore installation.

(Refer Slide Time: 17:00)

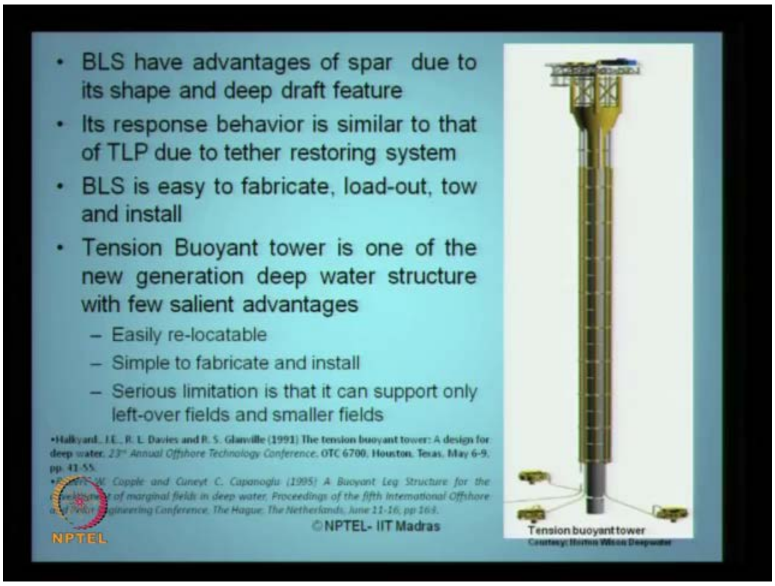


For example, in a total cost offshore installation, which runs of course, in 10 power 5 billion US dollars, above 25 to 30 percent of this cost goes on installation. I should say installation alone, it is the amazing figure it is the amazing figure, you have only countable number of contractors, who can execute the installation of deep water structures in Gulf of Mexico, very few very few.

So, they have mono poly, this is not a disadvantage, it is the advantage because the technical knowhow of installing a system in deep water is a patent at right on this kind of contractors. So, they charge approximately about 25 to 30 percent of the capital cost, Capex of this installation, only for installation. So, if you really want to reduce this cost for the deep water systems, I must think about the system, which can be easily towed and installed.

That is why, the primary issue focused on new generation platforms for, how they can be simply towed and commissioned. So, TBT came into play and tension buoyant towers had shown these advantages. Of course, no papers and no literature will give you the cost comparison of any of the installation platforms in the world; no paper will give you a commercial touch on this. What we are talking about only in engineering perspective of this platforms but it is very clear that, some of the financial aspects of this platforms. You will read from papers, that about 25 to 30 percent, one third of the cost of the capital cost of the platform goes purely on installation commissioning it is not that simple to figure.

(Refer Slide Time: 18:56)



So, this was proposed in about let us say, down the line about 15 years back, which was the concept, you can see it is a numerical model, it is the concept not constructed.

(Refer Slide Time: 19:07)

Subsequently, a platform was attempted as a tension buoyant platform, the first buoyant tower CX 15 was loaded out in the Feru carnivo offshore field, which has now become a promising figure, which is going to now produce oil end of 2013. It is the new platform, which has been constructed recently, which is commissioned now.

(Refer Slide Time: 19:30)

There are other innovative offshore generation structures, which are now available in the literature. The innovative geometric form of course, is understood to be having improved motion characteristics, which can suit deep and ultra-deep waters. So, some of the classical examples what people have attempted in the literature, one is what we called non ship shaped FPSOs. Now, when we wonder why a ship shaped FPSOs may not be a successful model because FPSOs stands for floating production storage and offshore facility or offloading facility.

So, I have a floating facility essentially, it has got production facilities as well as, it can do drilling, can store, can offload also. For example, you got the barge, you can keep on transferring the excluded oil on to the barge and keep on offloading to the shore. So, it has got all facilities involved, so essentially people thought, that the unused barges and ships can be converted to FPSOs.

Because, ships have very high strong favorable floatation characteristics, for which they have been designed. So, people have converted, modified the existing ships, commercial ships not the passenger ships, commercial ships, the hull has been remodified and they started using it for FPSOs. But, they saw that, there are some specific floatation characteristics associated with ships, which related to the head sea condition, which affects the production in case of rough sea states.

So, people thought, why do we to have a longitudinal hull or lateral reduction hull, why cannot have a circular hull, which can approximately represent a common dynamic analysis characteristics for all approach angle or waves. So, people said I will go for non ship shape, not necessarily circular, non ship shapes hull of FPSO, that is one of the recent generation platform people have attempted.

The second of course is triceratops, triceratops is essentially about let us say, 700, 800 years old species of an animal, which has got a specific characteristics of very high positive buoyant system, looking like a kangaroo of a very large size. It has been a, some people named as a dragon, some people named as a fly etc, it is having a very massive structure wrist on (( )), 1 in the centre and 2 in the hind limbs so it is a very interesting and a very massive animal. So, triceratops is one of the important configuration, which has been arrived based on this geometric biological species. The third one is again, a very interesting form is called min doc, a min doc is another kind of platform, which is now emerging for deep waters.

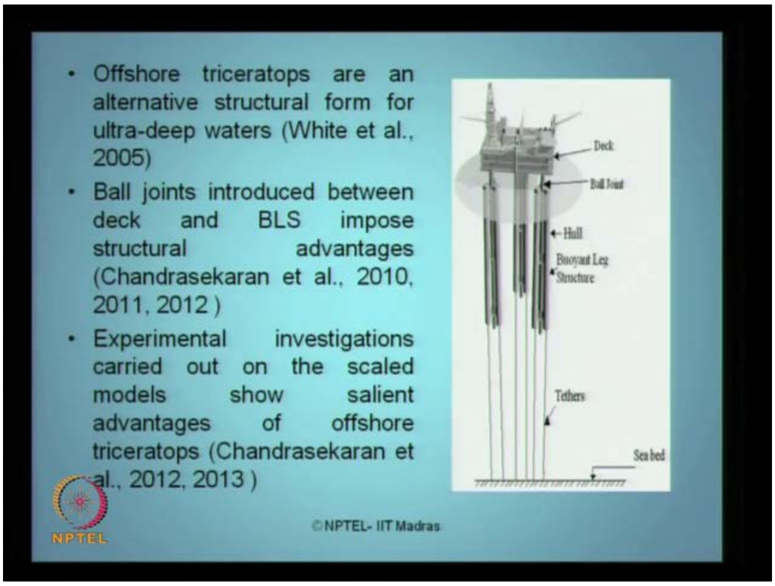
(Refer Slide Time: 22:19)

So, this is one of the interesting sevan voyageur, which is now located in Norway, in Eydehavn Norway with the circular FPSOs. It is in FPSO, it is having a circular hull is now located in Norway, which is now doing for oil exploration. I think you will appreciate that, Norway is coming out an alternate renewal energy resource and they want to make the country completely on renewal energy, alternate renewal energy by the year 2020. So, it is a new kind of platform, which is coming up not for oil exploration but for shear gas, etc.

(Refer Slide Time: 22:54)

The other one is again a non ship shape of course, a circular hull is called a goliath, it is the first oil field developed in Norway sector, is a cylindrical FPSOs. So, the production is due by end of 2013 again, again a ship shape FPSO non ship shape FPSO.

(Refer Slide Time: 23:14)



So, the third structure is what, we have originated in our studies here, which is again a concept of triceratops. The triceratops concept was first floated white et al 2005 and he said, yes this platform can be used comfortably for deep water oil exploration. Because, there are some structural advantages, which this platform has let us see, what are the advantages quickly, as we go through this presentation?

It essentially consists of a deck, which is having same pop side detail as that of the conventional platform. And of course, the tension buoyant leg structures, the buoyant leg structures are, what you see at the bottom which, are the groups of BLS, which has been anchored to the sea bed using tethers therefore, these are called tension buoyant leg structures.

Of course, the BLS and the deck are connected interestingly by a ball joint here so the ball joint connects actually the deck and the BLS. The greatest advantage by this form, which has been derived from an article to the tower is that, in case of any later load coming on to the BLS because of the wave or current action, the BLS are not inter connected to each other. So, each one of them have the freedom to move independently, this independent motion essentially in terms of rotation, will not be transferred to the hull because of the ball joint.

So, the ball joint observe the rotation, from the sub structure to the super structure in case of rotational degrees of freedom. Similarly, when the hull starts activating or rotating because of the arrow dynamic force, wind action that is not transferred to the BLS. It means, certain category of forces and displacements in terms of rotations are isolated from the dynamic characteristics by introducing a disconnectivity between the BLS and and the deck, only in rotational degrees of freedom.

Whereas in displacement degrees of freedom like surge, heme and (( )) sorry and sway, this holds as the rigid body. So, the advantage is, as we already seen there are distinct categories of frequencies as far as TLP is concerned similar here, the response characteristics are isolated. So, the rotations are not transferred but the displacements are transferred 100 percent so it becomes the rigid body structure.

Now, what is the greater advantage achieved or we achieved by introducing this kind of disconnectivity in rotation degree of freedom. The most uncomfortable region of working for a deck or the people on board of deck is the rotational motion. In case of heave, the heave displacement being tether restrain system is relatively very low but the differential movement, because of the wave action be respectively rotation may be pitch or may be roll, is phenomenally high because surge is very high.

So, this rotation will always cause uncomfortability to people who work on board as well as it causes lot of risk to the riser systems connecting the sub sea to the super structure or the hull or the deck. So, to avoid this kind of rotary motions on the deck So, these rotary motions has been isolated from the sub structure or from the BLS to the deck using the ball joint. So, the ball joint introduced between the deck impose structural advantages can be seen from different papers here. Some experimental investigations has been carried out on the scaled models to show some salient advantages of this with respect to other conventional offshore structure, which will see.

(Refer Slide Time: 26:45)

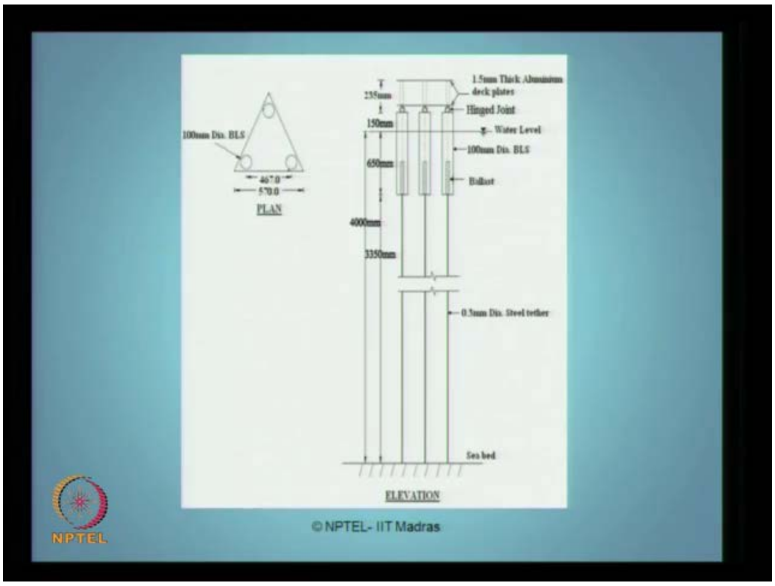
There are some distinct advantages of this, which are derived from the experimental studies and analytical studies done. We have got better motion characteristics so therefore, they are suitable for deep waters, it has got improved dynamics in comparison to TLPs, we will see that some of them now. The wells are within protected environment and are laterally supported, it is the simple structure, simple station keeping is required and easy to install and so on.

The whole structure can be reused that is very important and relocated, it has got the very simple restraining system compared to that of TLP. It is the highly stable structure because I will show you, how the free floatation will help us to enable or ensure the high stability, even when the tethers are pulled off. Relatively low cost because I am talking about saving of this cost in installation.

(Refer Slide Time: 27:40)

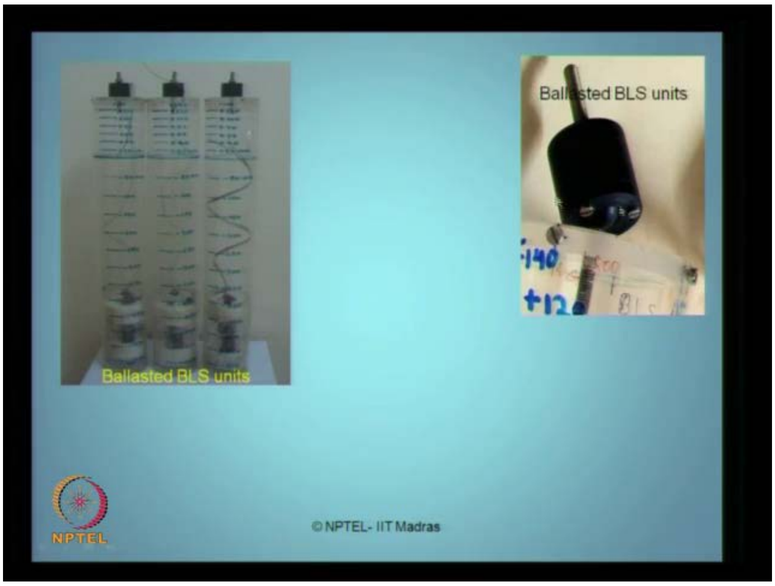
So essentially, to impart and understand the free floatation characteristics, free oscillation studies have been conducted on this particular platform in a scaled model. To understand the installation complexities of this new geometry, a scale model was investigated.

(Refer Slide Time: 27:57)



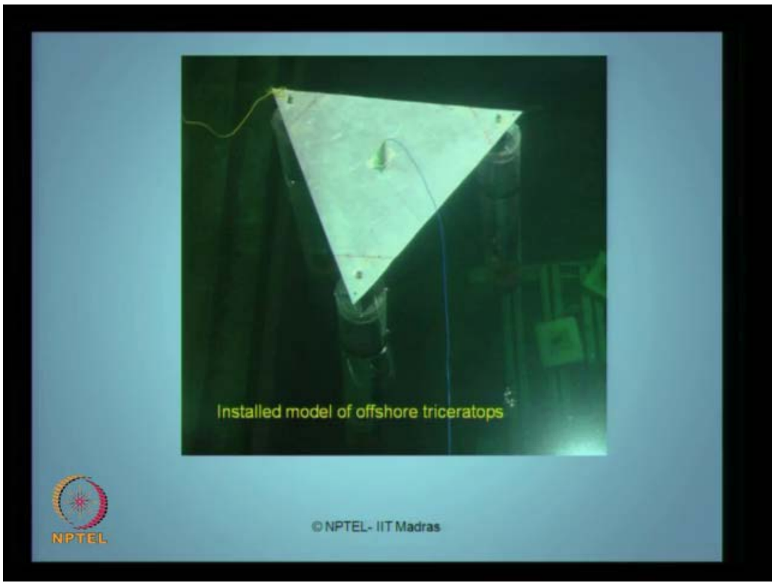
This was the model considered with the triangular deck on the top with 3 legs, that is called triceratops. And you have got the BLS on the top and then hull or deck is connecting the BLS by an hinged joint and the BLS are anchored to the sea bed using tether or cable systems.

(Refer Slide Time: 28:15)



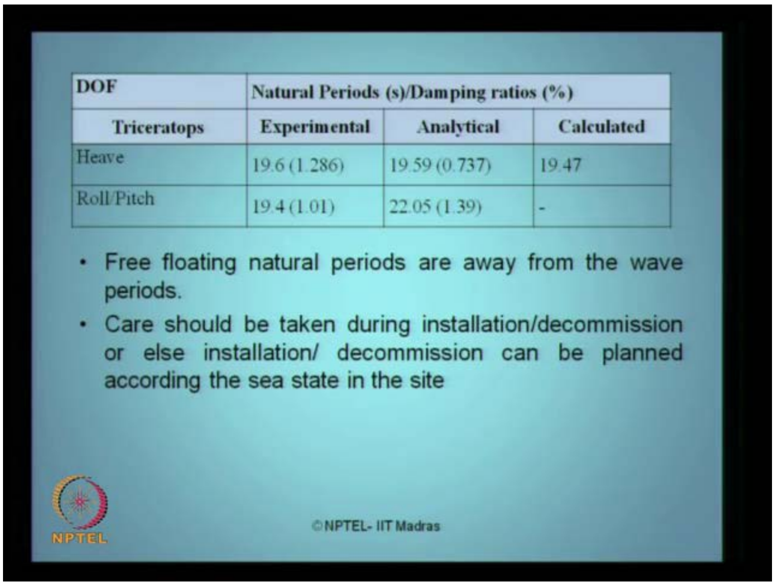
These are the 2 figures will show you, the ballasted BLS, because I do not have the installation that BLS in proper in case of floatation. So, I am ballasting the BLS at the bottom here, you can see these are the ballasted BLS, these are the ballasted being used. This may draft level, which supposed to be these are may ball joints, which are elaborated or highlighted here. So, this may ball joint you can see here, the outer cover is made out of HTPE and this is threaded. And this thread is connected to the deck and this ball joint is isolated in terms of rotation with respect to the sub structure of the BLS.

(Refer Slide Time: 28:54)



This is an installed model in the way flow; I will show some of the videos very quickly at the end of this lecture.

(Refer Slide Time: 29:05)



Interestingly, if you look at the natural periods of this platform, when they are not tethered off, the heave has got about 20 seconds and the roll and pitch has also got about 20 seconds. Whereas in conventional TLPs you see, the heave periods are varying from 2 to 5 seconds it means, this structure is considered to be relatively flexible compared to a TLP in a stiff degree of freedom.

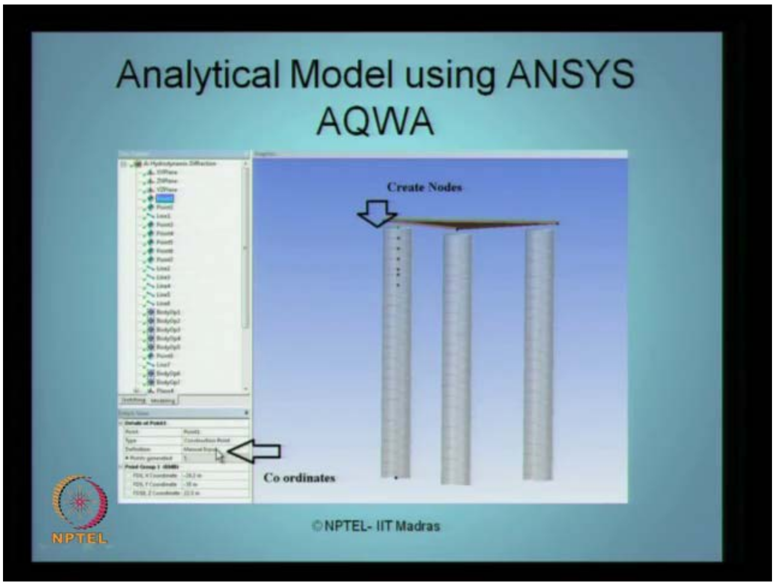
Because, these are all stiff degree of freedom heave, pitch and roll, I am not talking about surge, sway and yo, which are otherwise flexible degree of freedom. We are talking about the heave, pitch and roll, which are considered to be the stiff degrees, the stiffness in these degrees of freedom are relaxed by introducing a ball joint. Even when you pull off the tethers, in the floatation this gives me the period of over 20 seconds.

Now you wonder, what is the beauty of this in terms of installation, the free floating periods are very well away from the wave periods. What does that mean is, the wave will become insensitive because the wave periods are generally varying from 6 seconds to 20 seconds, maximum is 15 seconds but the period is around 20. So, the platform is expected to remain stable under free floatation conditions, free floatation means tethers are not actually sea bed, they are freely floating, they remain stable.

But of course, you got to take care because during commissioning you have to impose T naught on the tethers so the free floatation periods are very high. Therefore, you have to take care of, while installing them in the sea state and also interestingly, if we look at the damping ratios, which is closely only about 1.3 percent to 1 percent. So, the damping is relatively low what does it mean is, instantaneous decay of response will not occur, which will also cause material degradation or material loss to the deck or to the BLS, if the damping is very high.

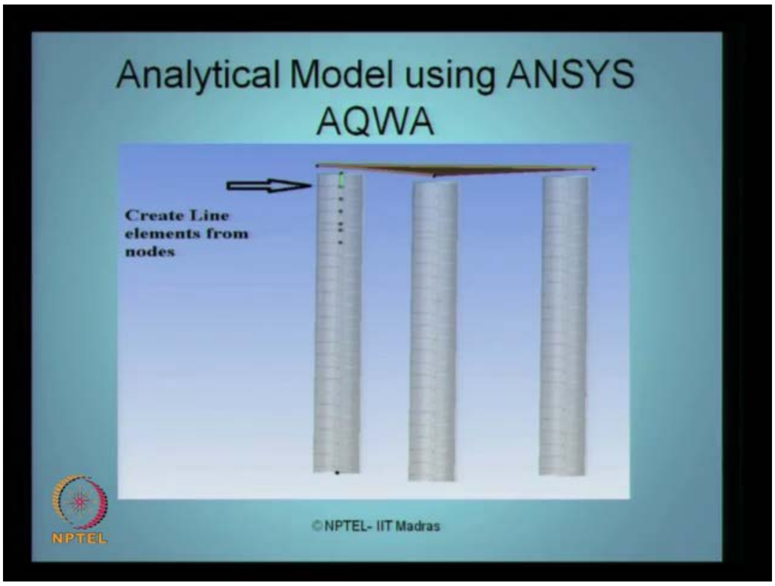
So, the damping low means, it will come to rest but slowly and of course, the results have been compared analytically and experimentally and computationally and you will see, there is the close agreement at least in the periods. In the case of damping ratio, the one what you get experimentally, includes hydrodynamic, aerodynamic and structural, all the 3. Whereas, analytical is relay damping, there is no hydrodynamic characteristics into this therefore, there is a variation in the results.

(Refer Slide Time: 31:26)



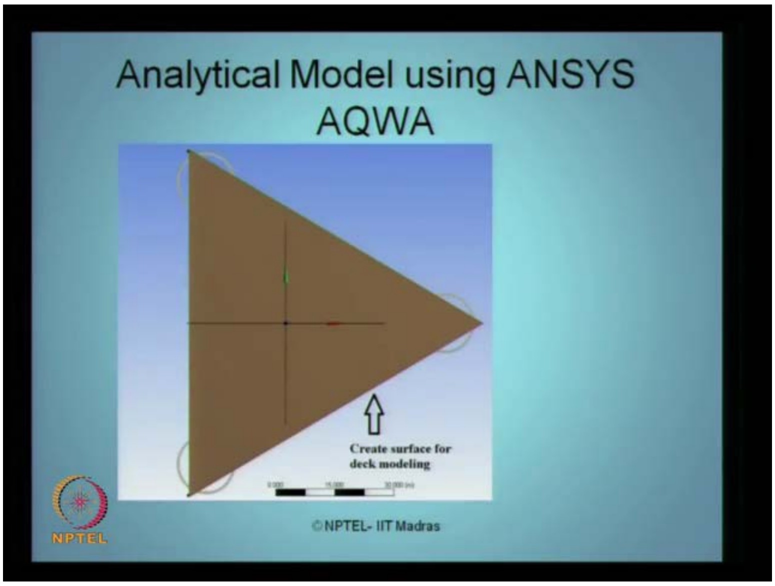
Interestingly, a numerical study was also done on this platform using ANSYS AQWA, I will show you some steps,as to how this ANSYS AQWAA carried out. So, in the first step, the coordinates were introduced by creating nodes, these are the coordinates manually given as an input in ANSYS AQWAA to create the nodes.

(Refer Slide Time: 31:47)



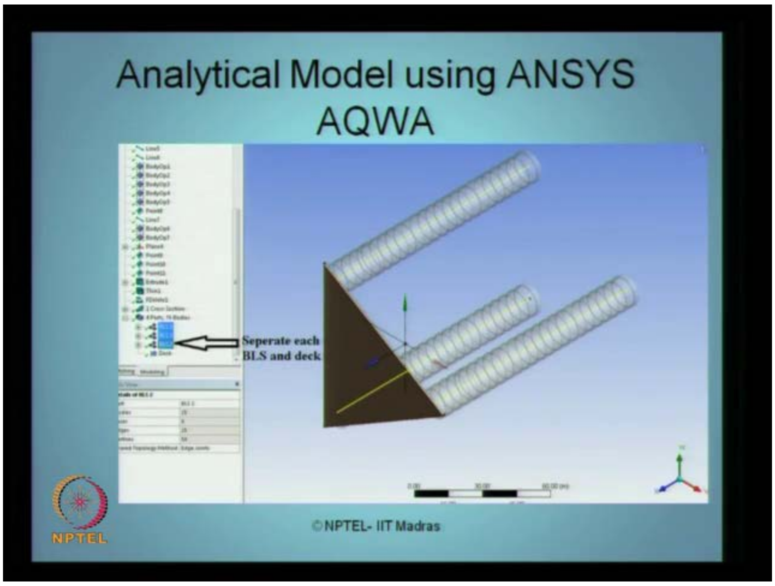
Once the notes are created then you have to create the line elements from the nodes by joining them to create the members.

(Refer Slide Time: 31:54)



Once the line elements are created then you create the deck using the surface modeling as a deck machine.

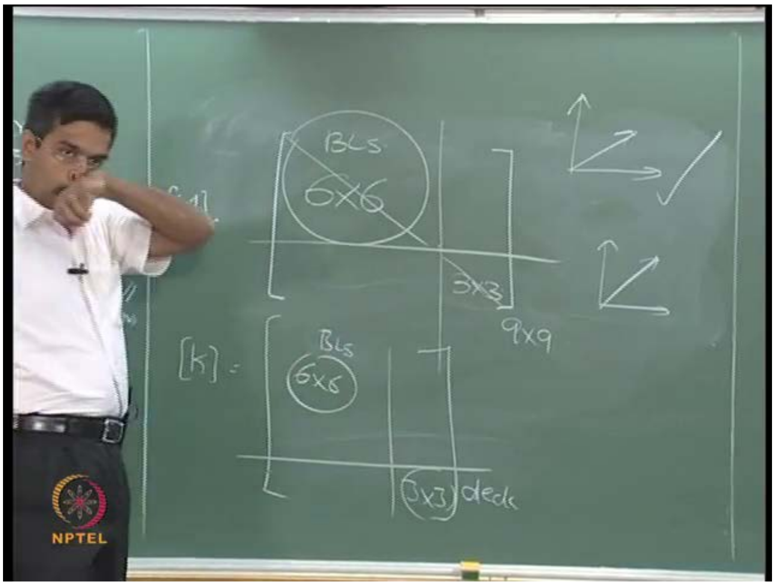
(Refer Slide Time: 32:01)



Once this is completed now, you have to give separate each one of the BLS independently, see that there are 3 kinds of structures, rather there are 4. One BLS 1, BLS 2, BLS 3 and the deck so there are 4 independent units 1, 2, 3 and 4, 4 independent units. So, one can easily measure and see the dynamic response behavior on any head sea condition for this platform, independently on each of the legs.

And you can see, whether which leg will fail first if at all it fails, they are not connected at all, they are independent. And the reason, why they are made independent because the legs, the BLS is made independent because there is no connectivity between them, the deck and the BLS are independent because there is the ball joint in between them. So, the degrees of freedom for the BLS and the decks are different so the platform is analyzed using 9 degree of freedom model like this.

(Refer Slide Time: 33:08)

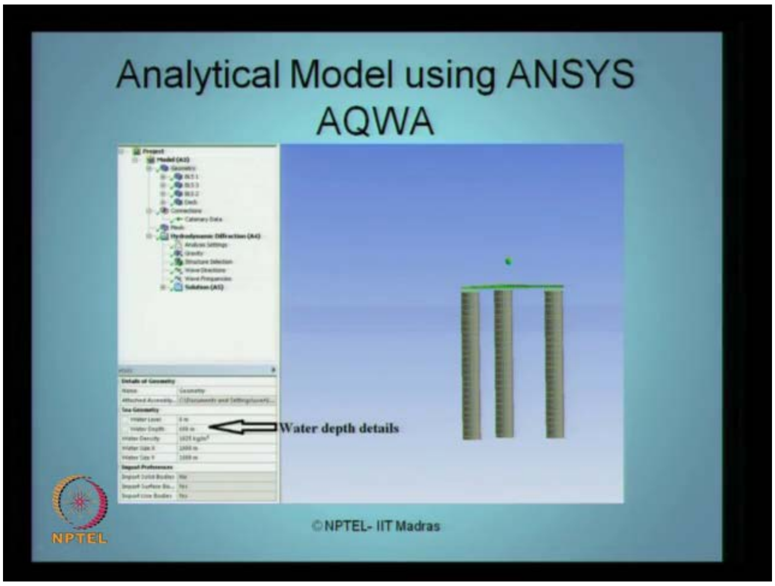


By mass matrix, I am partitioning it, this is 6 by 6 and this is 3 by 3 so I have the mass matrix of 9 by 9, this corresponds to BLS because in the cg of BLS, I have all the degrees present. Corresponding to the deck, I have only 3 degrees present, which are only the rotations because the rotation of the deck are the independent of that of the BLS. But, the displacement degrees are common in both cases, because of rigid body motion so easily I can find out the mass matrix of the sub structure.

That is, the BLS and the mass matrix of the super structure that is, the deck independently in this 9 degrees of freedom, that because of mass matrix. Similarly, K matrix will also have the similar concept, again partition this is 3 by 3, which is for the deck and this is 6 by 6, which is for BLS. Should we interested we can explain this derivation in detail in other lecture.

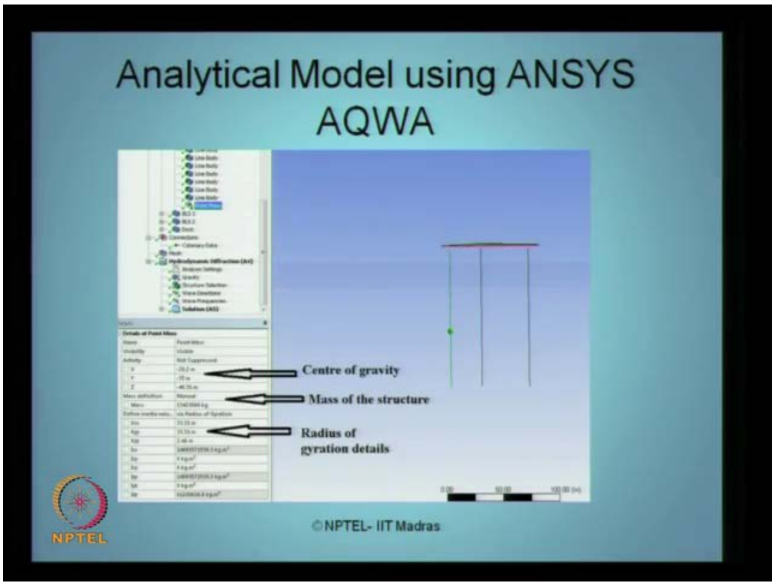
But anyway, I will give you the reference, you can read it from there now, the reference available online, you can read it from reference. The whole derivation of mass matrix, stiffness matrix and the relay damping matrix available in the paper directly, you can see it from the paper directly. So, they are made independent you can see here, there are 4 system units here, one is BLS 1, BLS 2, BLS 3 and deck, they are independent.

(Refer Slide Time: 34:50)



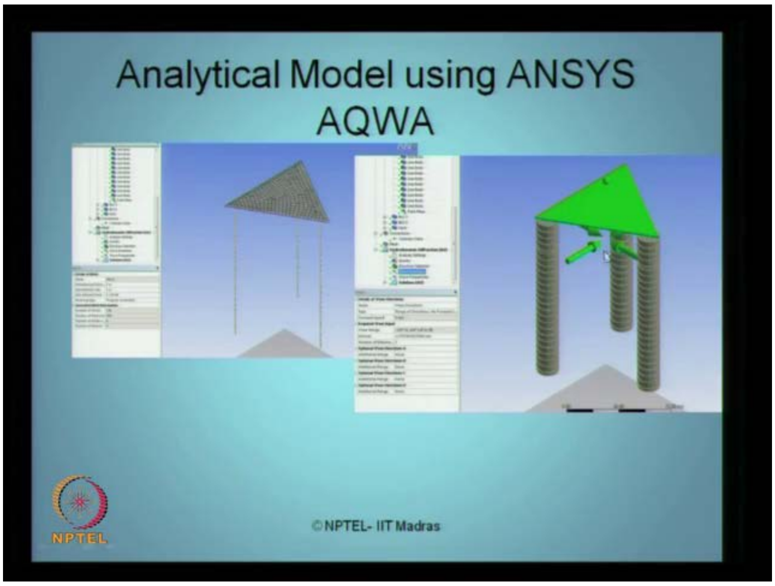
After creating this then the water depth details are given now, this model has been analyzed, to start with at the depth of 600 meter. Of course, this has been tested at the depth of about 1500 meters also but the results what we show here, is only for 600 meter you have to manually enter this value for analysis.

(Refer Slide Time: 35:10)



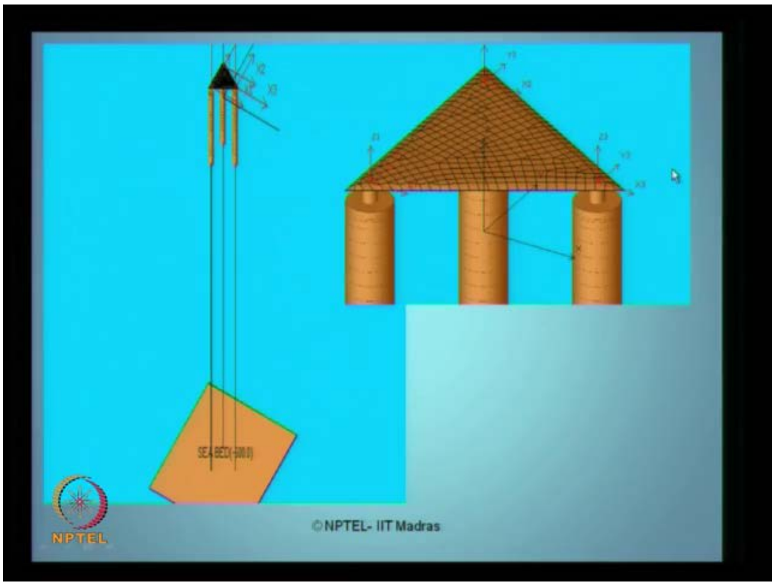
Once this is done then you have to specifically enter the values of centre of gravity, mass of the structure and radius of the gyration, which can calculate mathematically once you know the M, rx, ry, rz values for the given geometry. So, this is what, we entered here so in the AQWA details of the point mass you got enter these values. And this is the point where, the cg of the system will be now entered for the BLS and cg of the system for the deck will be entered in the top separately.

(Refer Slide Time: 34:39)



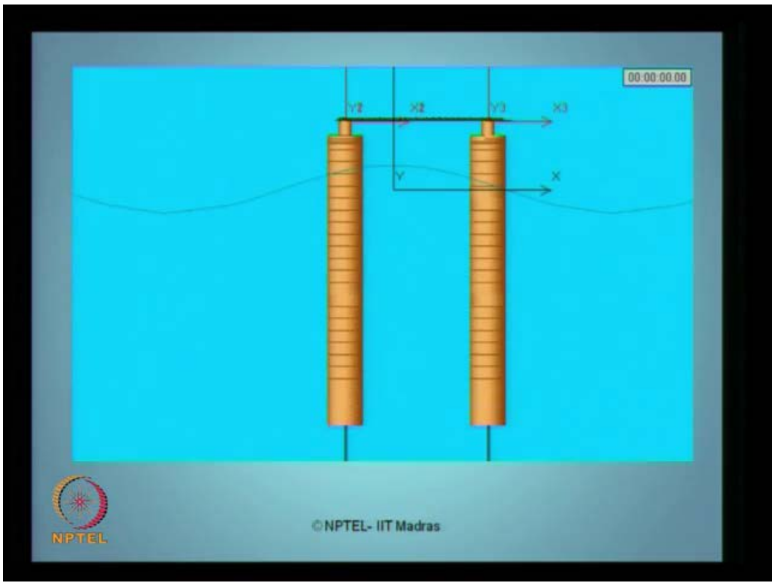
And then mesh is being formed for the BLS as well as for the deck this is how, it look like, this is what you see here, is the cg of the super structure which is nothing but the centre of the rigidity of the lateral forces acting on the body also. Because of, the top site details, top site details are not shown in this model here but they have been made. And then you can introduce this centre of rigidity, which is because of the lateral forces acting on the top site details then these are the wave directions, for which the model will be activated to...

(Refer Slide Time: 36:16)



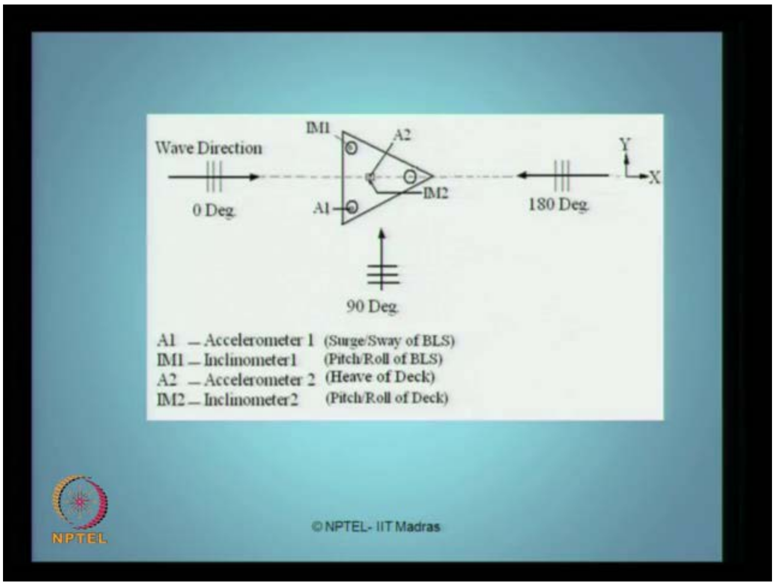
Once this is done then the developed model will be anchored to the sea bed looks like, these are the principle directions of X 1, X 2 and X 3. This may close look of the model, you can see here the ball joint being connected with that of the BLS and the deck here. So, the each one of them have independent coordinate system X 1, X 2, X 3 and so on so they are independent, one can measure them separately.

(Refer Slide Time: 36:44)



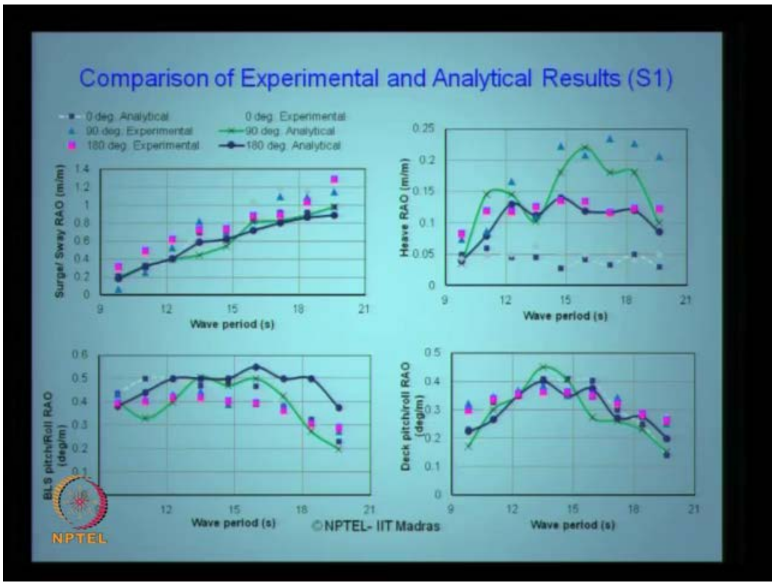
After understanding, this is how the model we installed in depth of minus 6 centimeters with 0 as the MSL, this is the closer view of that.

(Refer Slide Time: 36:52)



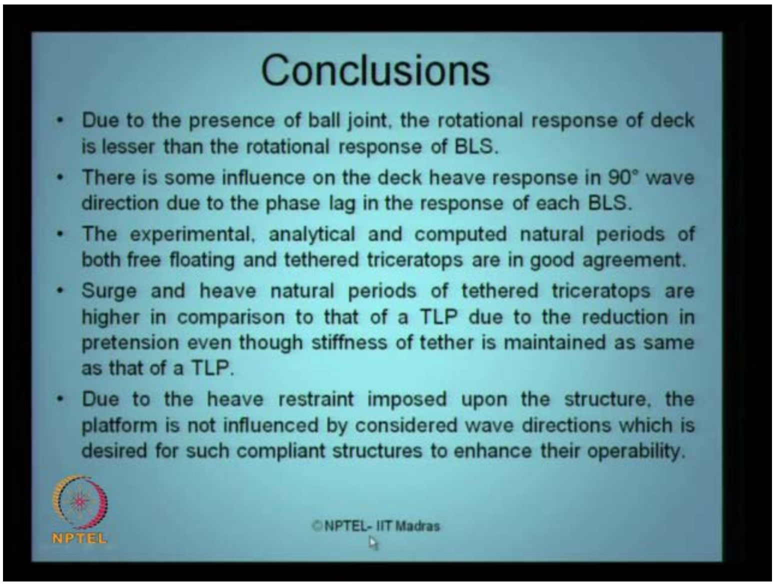
This is my wave direction so therefore, you can see the instrumentation on the top for the experimental analysis, accelerometers of A 1, etc has been kept. One on the cg of the depth and one on the one of the BLS to compute the relative motion between the BLS and that of the decks independently. They are all tri accelerometers, which can measure the surge and sway depending upon, what you want and inclinometer will give you the differential rotation.

(Refer Slide Time: 37:18)



So, these are the results what we have, we can see here that, for every degree possible 0, 90 and 180 of course, 30, 60 and 45 are not available here but some of the references I show you, the results are available in that. You can see here, the analytical studies what you see at 0 degree and experimental 0 degree, which is grey and white, we can see they are matching, you can see they are matching you can see they are matching. There is the close agreement of the results analytical and numerical of course, there are variations in experimental results, marginally. Because, the points what you see here are all experimental results marginally, they vary.

(Refer Slide Time: 38:03)

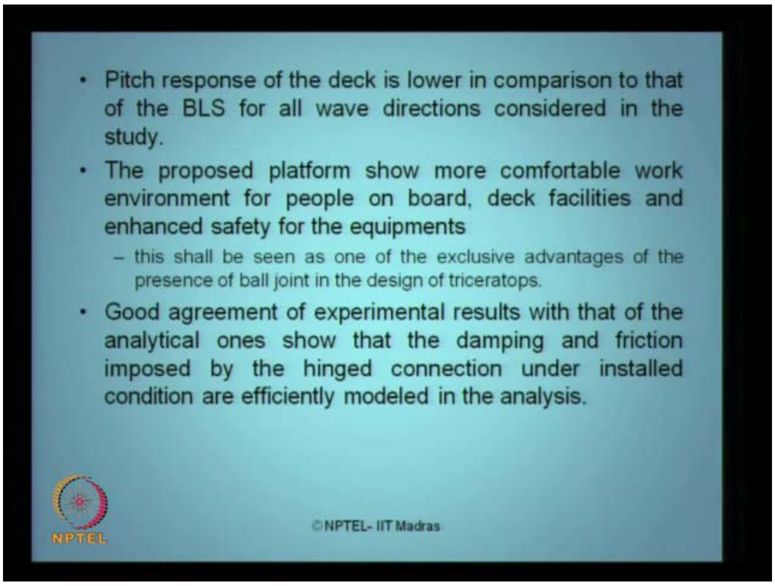


So, some quick conclusions from this what we are shown you are due to the presence of ball joint, the rotational response of deck is far lesser than that of the BL. There is some influence on the deck having in heave response in 90 degree, which can be due to the differential phase lag of different BLS because they are independent to each other, the experimental, analytical and computed periods closely agree.

The surge and heave periods of triceratops are higher in comparison to that of TLP this means, the system is flexible. Though remember, interestingly the T naught of the stiffness of the tether is same that of TLP that is the very interesting factor here. The stiffness or the axial stiffness of the tether remains same as that of the TLP for the water depth but still the system becomes flexible.

That is one of the important advantage, which will avoid pull out of tethers under severe lateral loads therefore, this platform can be carried forward for ultra waters that is the advantage. And you can also see that, because of the heave restraint system, the platform is generally not influenced by the wave directionality, as we see most of the results are almost marginally similar to each other.

(Refer Slide Time: 39:10)



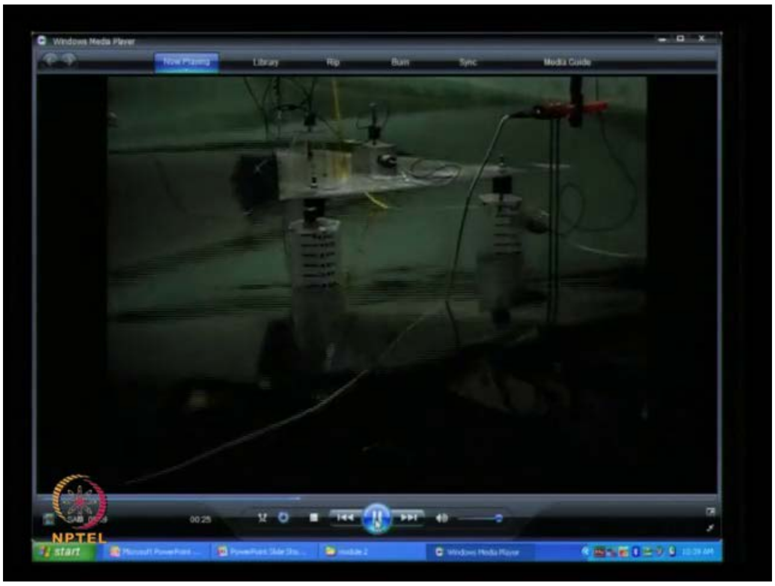
The pitch response of the deck is much lower compared to that of BLS, which tells very clearly that, there is no transformation of rotational responses from the BLS with that or vice versa. The proposed platform show more comfortable working, I will show the interesting video, which will realise that, the rotation of the BLS does not transferred to deck at all. Basically, you can see it in my video, there is a good agreement of experimental results, which will show that there is the possibility of modeling this. With the proper or appropriate values of damping on the hinge and the friction damping imposed by the ball joints because there is the close agreement.

(Refer Slide Time: 39:52)

Some interesting references which you can read, Minoo Patel on compliant offshore structures and you can see, I mean it is very interesting that, only we in IIT Madras made research on this. There is no other paper available on the net today on triceratops, no other papers except, what we did, except only one paper of conceptual, what professor White had told in 2005 in one of the isope conference.

There is only the concept, there are no references available for analytical, experimental, numerical investigations done on this kind of new generation platforms for ultra deep waters. This is the paper, what Charles and capanoglu said in 2005 that, a concept of triceratops can be attempted for ultra deep waters, it is only the concept introduced. This was patented, the technology transfer has now done and we are trying to push this forward to places where, ultra deep exploration happens in the world. Of course, it cannot be done in India because we did not have oil exploration happening, beyond the higher depth in India so we are looking for the depth where, the installation or the exploration depth is approximately 1.5 kilometers so we look at the video.

(Refer Slide Time: 41:19)



You can see here, for a long period waves, you can see the rotation independent rotation of the BLS whereas, the deck almost remains horizontal, deck is almost. There is no yo motion, there is no roll and pitch motion of course, of course, there is no roll motion happening possibly, it is a unidirectional wave. But, there is no pitch motion happening and this is true in the cases of long period waves also, there is the long period running now.

Other video is running now, you can see here the relative motion heave direction, the draft variation does not bother the deck at all, that is the very interesting. And understanding, which has been verified experimentally, numerically and analytically for this kind of new generation platforms. If you have any questions, we can answer them quickly so this will be the last lecture as far as the module 2 is concerned.

We will talk about the module 3 from the next class onwards where, we will talk about advanced application of dynamics on offshore structures where, we will talk about stochastic dynamic applications. Then we will talk about response reduction using hydro dynamic response reduction using perforated cylinders, etc and that may be around 5 lectures maximum.

In module 3, which will address some of the advanced topics related to dynamics of ocean structures. So, new generation platforms are on the move, people are looking for geometric innovativeness, shape geometry innovativeness. Of course, people also working on material innovation like light buoyancy materials, etc that portion anyway is not discussed in this scope of the lecture at all. People also using different kind of material, we are not looking at that here.