Dynamics of Ocean Structures

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Lecture – 01
Introduction to Offshore Structures

Good morning ladies and gentlemen. Welcome to the first lecture on dynamics of ocean structures. This is an online course offered by IIT, Madras under the auspicious of NPTEL, MHRD. I am Professor Srinivasan Chandrasekaran, who will be the instructor for this course this course will be covered in 4 modules as explained in the beginning of the website.

Today, we will talk about the first lecture which discuss on introduction to offshore structures. The moment we talk about dynamics of any structural system it is mandatory that we must understand the structural geometry the form, the function, the serviceability requirements, the environmental forces, which are coming on the system which is supposed to be a prerequisite of understanding a dynamic analysis of any structural system. So, in this couple of lectures we will introduce you to different types of offshore structures very clearly, explaining the structural functionalities of these different forms with respective functions of these kinds of structures. I can be reached at this specific E-mail id, whatever query you have you can always e mail to me or put it in the discussion box in the website of NPTEL, IIT Madras.

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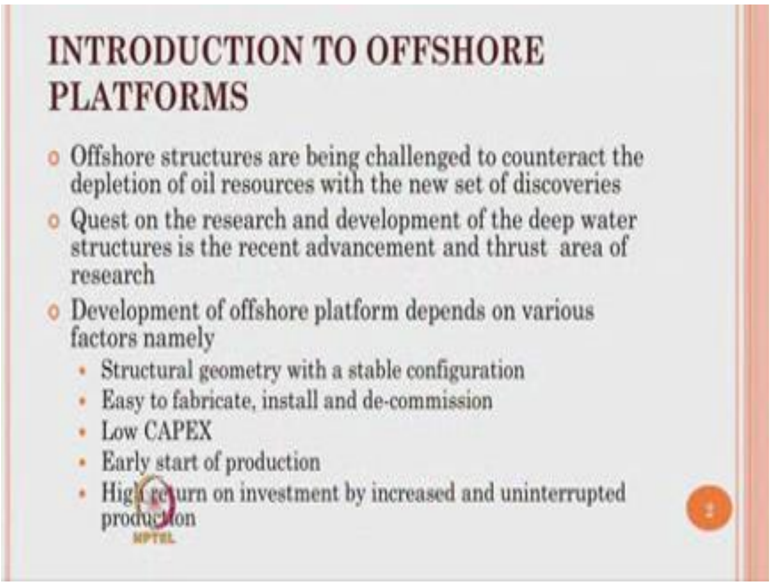

Then we say introduction to offshore platforms, one must understand what the specialty is or what are the different complexities an offshore platform have compare to other conventional structures. One can ask me question why I need to understand various complexities in the structural geometry of an offshore platform if you do not understand the structural complexities it will be very difficult for you to appreciate the requirement of dynamic analysis. Secondly, the methodology and the techniques used to do or perform dynamic analysis either numerically or analytically, offshore structures are actually being challenged counteract the depletion of oil resources with new set of discoveries.

We all know that oil exploration which started with shallow waters has started now moving towards deep and ultra deep waters. So, it is very important that the same structural form or the platform which has been used for shallow waters cannot be used without any structural modification for deep and ultra deep waters. On the other hand offshore structures are now under great challenge of innovative development because these forms have got to be moved towards greater water depths. Quest on the research development therefore, on deep water structures is the recent advancement and that becomes the thrust area of research in dynamic analysis of ocean structures in general.

When we talk about development of any offshore platform, which depends on various factors structural geometry, which should enable me a stable configuration, the platform geometry should be easy to fabricate install and decommission of course, the developed form or the proposed form should have the lower capital investment as far as possible. What we call as low capex, any investor or any business organization which inclines in production of oil and gas will always look forward for the return on the investment at the earliest possible. So, your platform geometry should enable and early startup production and it should yield high return on investment by increased and uninterrupted production. On the other hand the structural form what you propose should be well tested, well analyzed understood both experimentally analytically and numerically before that form is been invested for practical deployment of oil and gas in the real seaside.

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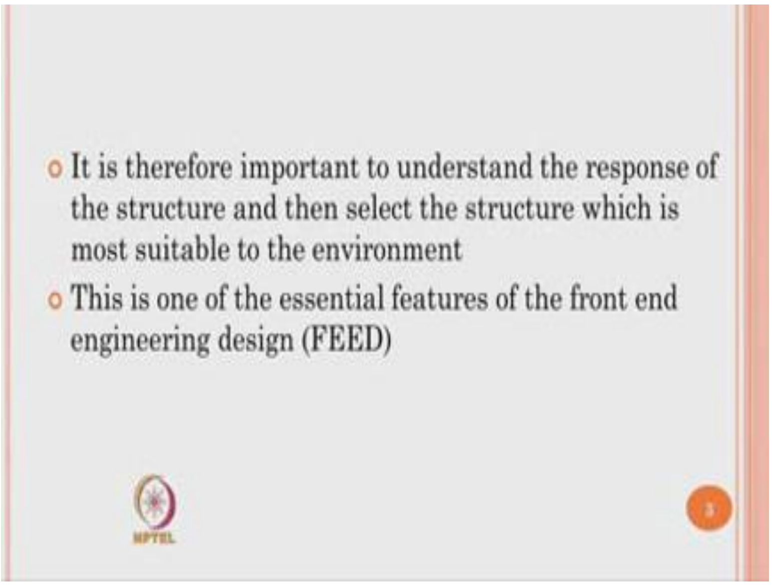

It is therefore, important for us to understand the response of these structural systems, because selection of any structural system for a specific water depth and specific functionality becomes very important as the primary requirement of offshore structures. This is one of the essential features what we call in the offshore domain as front end engineering design. Front end engineering design is a focus on selection of a geometric form selected forms viability it is stability and it is assurance of yielding a return without failure when the platform is intended to put for a specific critical environmental loads.

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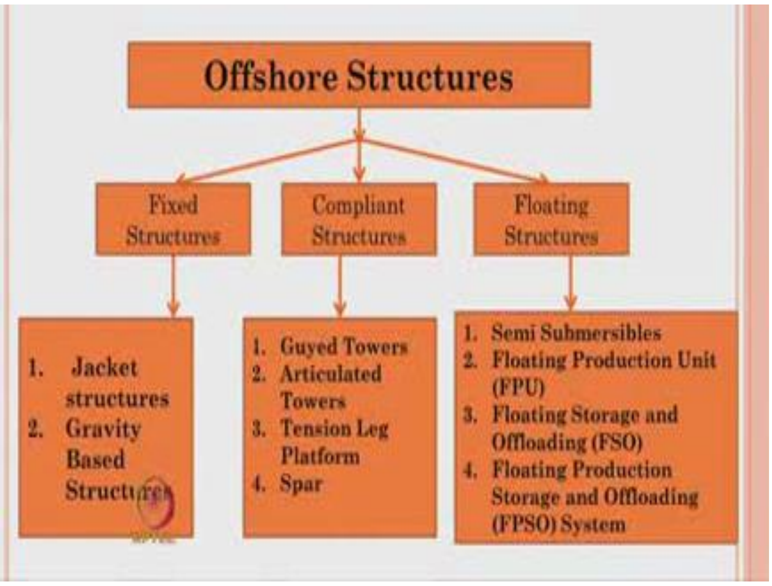

Now ladies and gentlemen before we move on further to understand dynamics of ocean structures, let us ask a question what are the different types of offshore structures which are generally constructed or which would be constructed. Now you can categorize them into three forms, fixed type compliant type and floating type. Under fixed type you have got two kinds of structures called jacket structures or template structures, the second variety of structure is gravity based platforms under compliant structures you have guyed towers, articulated towers, tension leg platforms and spar platforms.

Under floating systems you have submersibles; floating production unit is floating storage and offloading platforms. Floating productions storage and offloading systems. So, one can have different functionalities of platforms. For example, look at the variety here we have floating production unit we have floating storage and there is no production we have floating production storage and offloading.

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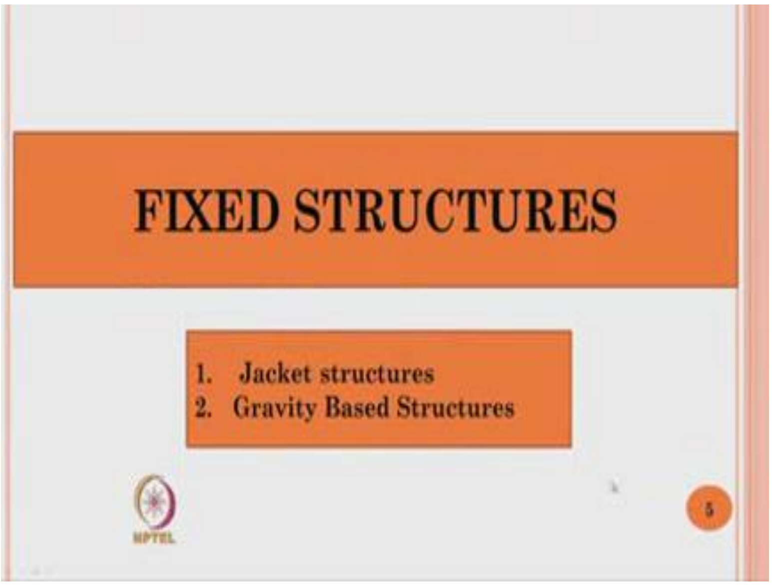

On the other hand depending upon the function the platform style or the form changes, let us move on to the first variety of structure which is called fixed structures in this lecture, I will give a brief introduction to variety of platforms only addressing the structural. Forms of this platform and very brief introduction to that functional requirements because it is important for us to know the size, the shape, the material, the layout, before we start doing dynamic analysis of these kinds of platforms.

Let us talk about the fixed structures we know there are two types of platforms under this basis, what we call jacket structures and gravity based structures.

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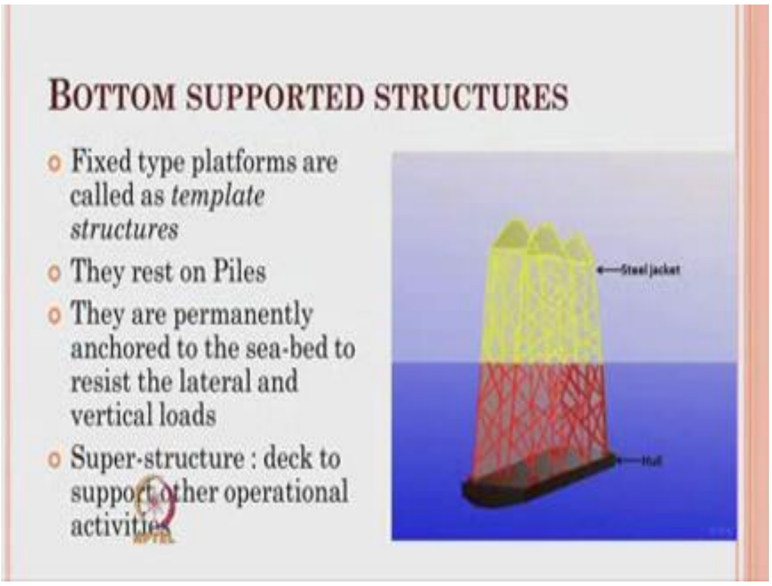

Gravity based structures or jacket platforms in general are come under the single category called bottom supported structures. In general as the term clearly specifies these structural systems have a very strong bottom foundation which is extended to the sea bed can be through the piles. Now the fixed type platforms are also called in the literature as template structures, they rest on the piles they are permanently anchored to the seabed to resist the lateral and the vertical loads. You can very well understand here the vertical loads come from the top side of the derricks and other mechanical equipments and the self weight of the platform. The lateral loads come from various sources, for example, it can be from the waves, it can be from the tides and current, it can be from the seismic forces or earthquakes can also be from the aerodynamic aspects that is form the wind.

We will see all these in detail in the successive lectures of different modules, but let us understand now that the structure is permanently anchored to the sea bed to resist the lateral and vertical loads that becomes the keyword here. Now super structure of course, contains deck to support other operational activities which we may not discuss in detail in this particular domain of dynamics of offshore structures; however, there are many other literature referred in my references where you can study to go through and find out what are those other operational activities, which will focus or which will make you to understand what are the different types of offshore structures.

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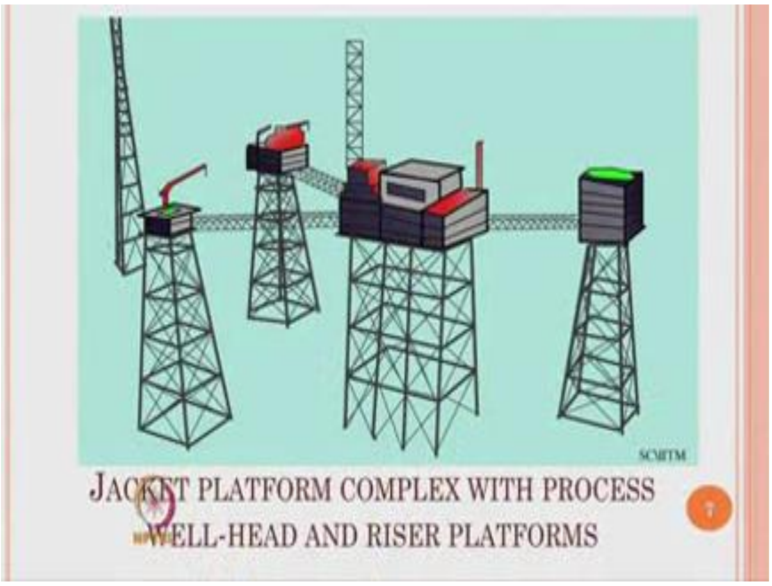

So, look at the jacket platform complex in general it contains a well head a riser platform. And let us look at the geometry of the structural form of these kinds of platforms why they are called template structures is for a simple reason, the bottom supporting system as you see here is comprising of incline or vertical members. They are braced and they are also having surface levels of interconnection between the joints. So, that the whole system is integrated to alleviate the lateral loads or the wave loads acting on them. And of course, these are the points where this will be connected to the pile and the piles will be driven through the sea floor depending upon the condition of the soil etcetera.

And of course, the super structure has got various complexities living quarter’s crane and derricks flare boom etcetera. Which will attract aerodynamic forces that are wind forces on the super structure? So, ladies and gentlemen jacket a platform, which has a fixity to the sea bed attracts forces laterally and vertically.

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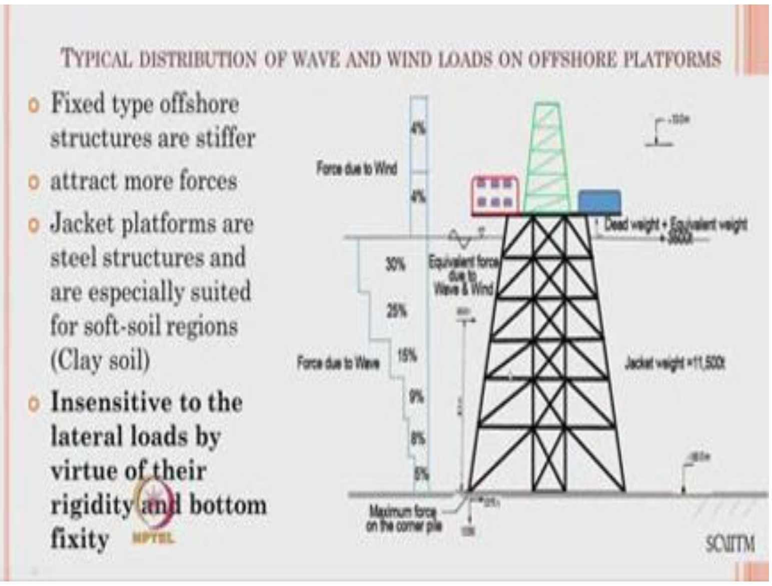

Let us quickly look at a typical distribution of wave and wind loads on a given offshore platform which is fixed to the sea bed. The fixed type offshore structures become stiffer because of a simple reason the whole template structure is being anchored firmly to the sea bed. When they are anchored firmly to the sea bed through pile foundations then, the movement of this particular structural system under the lateral forces is highly restricted.

Therefore, we say any structure which does not move as far as possible is considered to be stiffer. And therefore, ladies and gentlemen from the principles of simple mechanics we all know any structural system which is stiffer in nature will always have a tendency to attract more forces.

On the other hand offshore platforms of fixed type have a tendency to attract more forces, these forces either can come from the waves or it can come from the wind. So, if we talk about the wave forces distribution along the water depth because this is my mean sea level or the free surface level. This is my sea bed where the jackets are anchored to the sea floor using piles. So, the wave load distribution is maximum near the free surface and is practically zero as it goes deeper and deeper. On the other hand the free surface effects will impose maximum lateral forces on the platform geometry. Similarly for the wind as the height of the derrick keeps on increasing beyond a specific height from the main sea level the variation of the wind forces vary non-linearly. We will talk about the spectrum used for wind force calculation, the spectrum used for wave force calculation in the subsequent lectures.

So, this figure tells you what are the typical distribution of forces coming from the wave and that come from the wind for a fixed offshore platform as you see here more importantly as the platform remains stiffer the platform is considered to be in sensitive to lateral loads the insensitivity to the lateral load essentially comes from the virtue of their rigidity and the bottom fixity. So, it is a very clear statement here if the platform is not bottom supported then the platform would not offer insensitivity to the lateral forces which we move on to the next type as we keep on going higher.

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There are typical operations involved in construction of an offshore platform. For example, the load out part, the towing part, the launching part, the floating part, the upending part and keeping them in the vertical position. Then anchoring to the sea bed and then do the deck mating the deck is the top portion of this. So, these are different stages as you see here in offshore construction, as we all understand the dynamic analysis becomes important not only during the load of stage, but also till the deck mating is done at different stages different kinds of forces are attracted by this platform and the platform must be designed or analyze for these kind of dynamic variations as they are encountered by varieties of forces available or encountered on them.

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This picture shows you a clear transportation of a jacket platform, you will see that these are the legs which will be anchored to the sea bed through the pile foundation and they are now interconnected with braces and they are also completely battened and lace. So, that the stiff end part of the system is enabling the lateral force distribution along the platform of course, as you saw in the last slide this is now the lying down position, once it is upended this will become vertical.

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This picture gives you again a view of how a jacket is launched, using the barge after titling the barge this is actually the d which is storing and launching once the launching is completed it be upended and the platform become the jacket becomes vertical and these are the spud cans or the portions where connected to the pile foundation at the sea floor.

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Once the jacket becomes vertical then the deck which supports the operational features will be inserted on the top - what we call as deck mating. So, the entire deck which is pre fabricated will be lifted using highly designed sophisticated cranes and then these cranes, will place them in position and they are a very specific arrangements how these legs of the deck mate will be connected to that of the installed pile or installed legs of the jacket. So, that they do not move horizontally and vertically as well.

Now, let us look at some advantages and disadvantages of the structural form; obviously, any structural form will have some merit is and demerits. Looking at the bottom supported structures or template structures the primary advantages could be it supports large deck loads. It has got a possibility of being constructed in sections and transported. So, modular construction is enabled. It is generally suitable for large fields and long term production because it can support large number of wells. Piles are used for foundation as we saw in the previous slide that results in a good stability.

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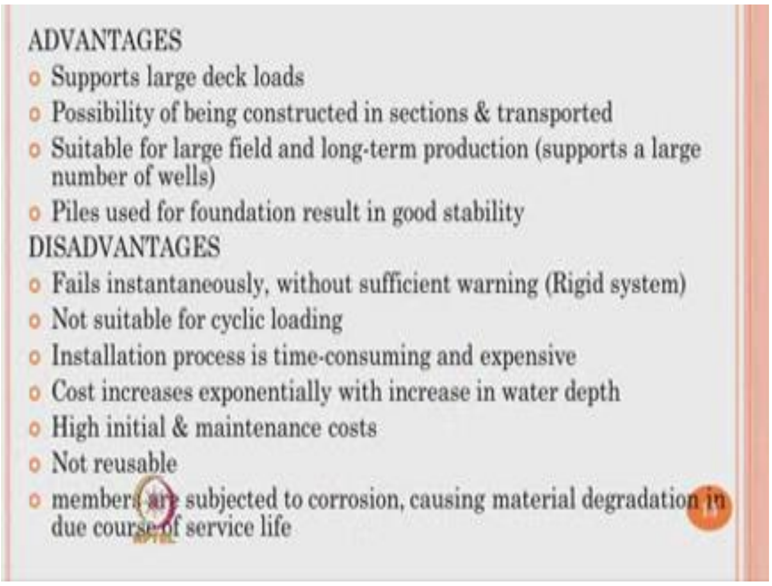

Therefore, the platform is able to have good stiff arrangement as it can alleviate the lateral loads acting on them. There are some demerit is of this platform the platform will fail instantaneously without sufficient warning, because that is a general behavior of any rigid or brittle system, this is a platform is generally not suitable for cyclic loading.

Because any stiff system will have forces concentrated at the joints if the joints are subjected to cyclic behavior then these stress concentration will become higher. The installation process of such kind of platforms is time consuming and therefore, it is expensive as well.

The cost of construction of these platforms increase exponentially with the increase in water depth it means such kinds of platforms are not suitable for all water depths, may be they are suitable up to 350 meter water depth. What we call as shallow if it moves further deeper and deeper the same structural form need to be altered to suit the requirements of greater water depths these platforms attract high initial cost, and of course, the maintenance cost because they essentially use steel and steel is a corrosive material. One of the main problems which are considered in this kind of platforms is that they are not reusable, on the other hand since they are founded firmly to the sea floor. Decommission of the platform completely is impossible. Therefore, majority of the sub structure becomes non reusable. The members are subjected to corrosion which can cause material degradation in due course of the service life that will also cause decrease in strength distribution of the members.

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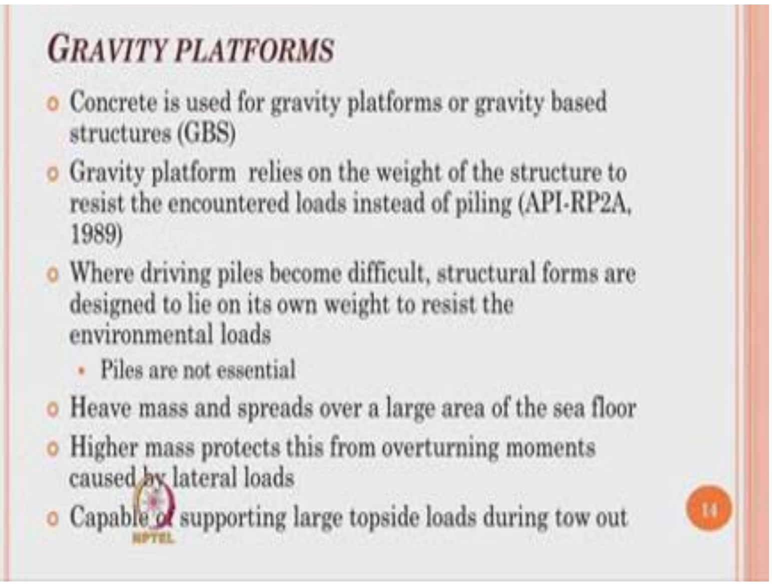

The second variety of platform which is also bottom supported is gravity platform in this kind of platform concrete is essentially used as the construction material. They are briefly called as GBS. GBS stands for gravity based structures, gravity platform as the word suggest relies on the weight of the structure. The weight of the structure is, large the structure is highly massive. Therefore, it resists the lateral loads purely on it is self weight there are instances and structures where pile foundation may not become essential where driving piles become difficult structural forms of GBS are designed in such a manner that they can resist the lateral loads only based on their self weight piles are not essential for these kind of structures.

The heavy mass and the spreading of the mass over a large area of the sea floor causes lot of trouble, what we see in the slide, the higher mass protects this from over turning moments caused by the lateral forces. Therefore, these kind of structures as said early are more or less insensitive to lateral loads. These kind of platforms are also capable of supporting large topside loads during the tow out.

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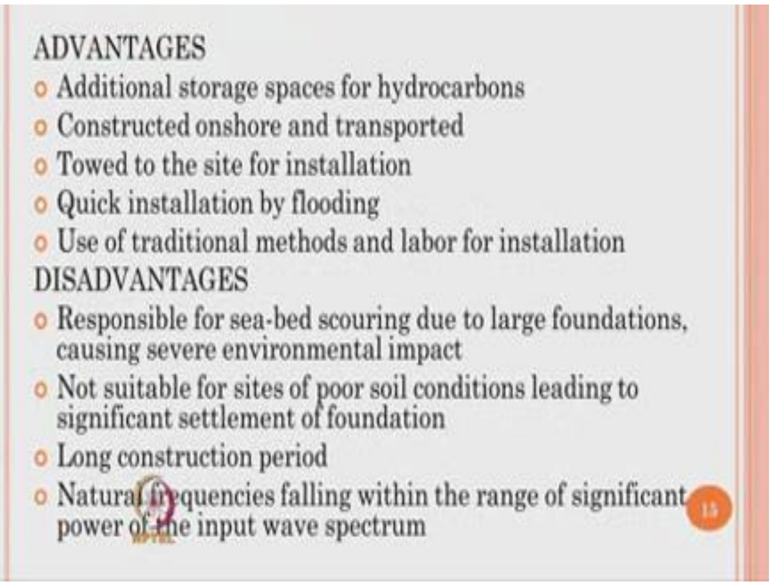

These platforms have couple of merit is and demerit is let us quickly see them the merit is could be the following it has got additional storage space for hydrocarbons. Constructed onshore and they can be transported in modules, towed to the site for installation, quick installation is possible by a mechanism called flooding. Use of traditional methods and labor for installation is making this platform time of installation as minimum as possible.

Of course, there are some demerit is of this kind of platform it is responsible for sea bed scouring because of the large foundations it causes severe environmental impact. This platforms are not suitable for sites with poor soil conditions because this can enable the platform to settle down in the soil because of it is poor offering of resistance to the vertical loads. So, these platforms may not be suitable for poor soil conditions, because it can cause settlement of foundation. This platform has got very long construction period, the natural frequency of the platform fall within the range of significant power of the input wave spectrum and that cause lot of resonating response of this platforms which could damage the platform.

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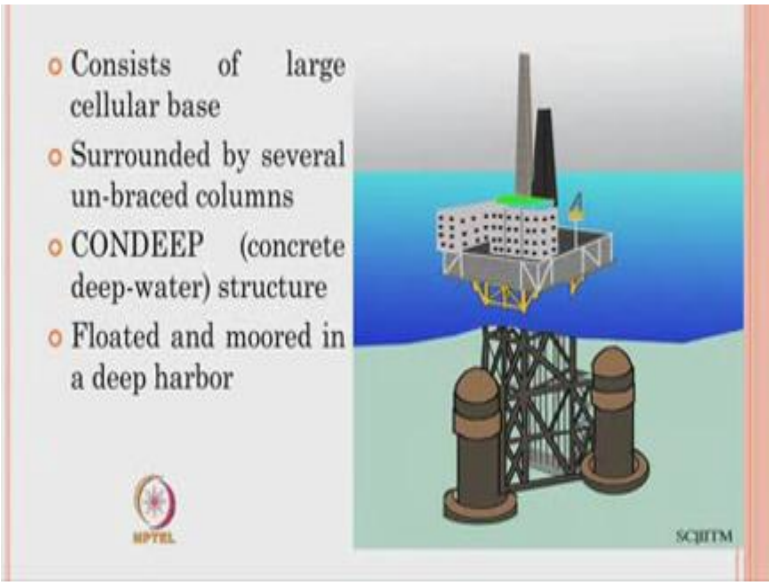

That is a typical photograph for a figure or a sketch we call of gravity based structure. We can say here this platform has got a sub structure, is has got a super structure the sub structure consists of (Refer Time: 21:31) which are nothing, but large cellular bases which are hollow inside. These (Refer Time: 21:41) can be used for storing hydrocarbons which are explored from the sea bed. Of course, this has got partly the jacket type structure also which are locally braced and connected of course, the deck mating consists of the living quarters, the mechanical equipments, the electrical equipments required the derrick cranes the flare booms and the other essential components which are used for oil and gas production. The platform is surrounded by unbraced columns because these are all not braced these are independent in nature they are very massive and dressed on the sea bed by the self weight.

A typical famous platform constructed of concrete is CONDEEP, con stands for concrete and when, it was commission it is one of the deep waters. Therefore, we call this as concrete deep water structure the entire structure was floated and moved in a deep harbor before it was commissioned at a specific location.

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The second type of offshore platforms is what we call as compliant structures the variety of compliant structures, can be the following guyed towers articulated towers tension leg platforms and spar platforms.

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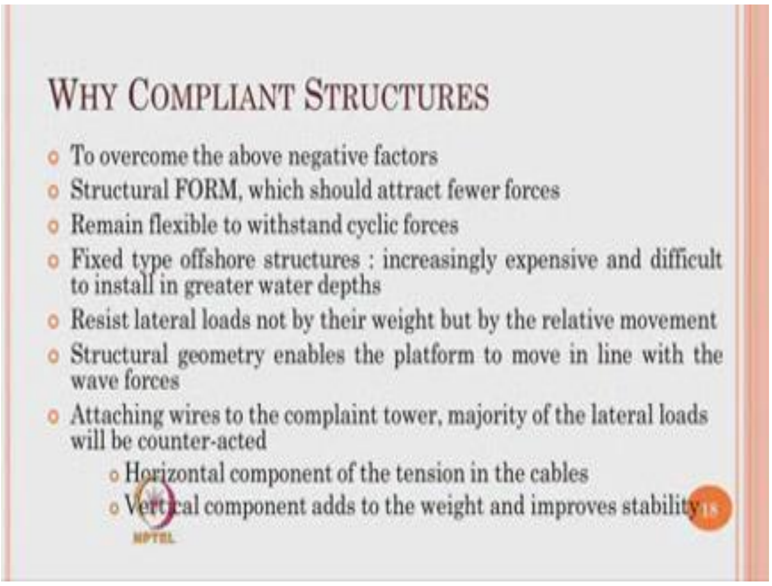

Now, the question comes; why do we go for a compliant type offshore structure. When we already have fixed type offshore structures, which are formed and function tested. Now there are many negative factors, there are many demerit is of fixed type structures which we just now saw in previous two slides. Now compliant structures are essentially conveyed to overcome these kinds of negative factors. The structural form is generally advisable and recommended it should attract less or fewer forces in comparison to the fixed type structures. The structure should remain flexible to withstand the cyclic forces which were not possible in the case of fixed type offshore structures.

Fixed type offshore structures became increasingly expensive and difficult to install in greater water depths. Therefore, compliant structures were thought off. Compliant structures resist lateral loads essentially not by their weight, but by the relative movement that is why they are called compliant. The compliant word stands for flexibility or movement structural geometry enables the platform to move in line with the wave forces, the attaching wires to the compliant tower can counteract the majority of lateral loads by the horizontal component and the vertical components. The horizontal component of these kinds of guide wires or cables will alleviate the horizontal forces. Whereas, the vertical component will take care of the additional weight and improves stability.

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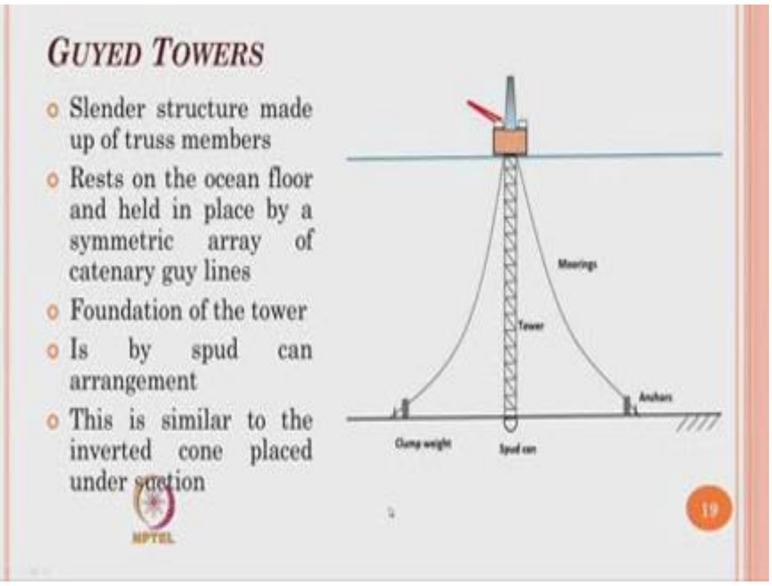

One classical type of structure under compliant systems is a guyed tower the sketch shows a typical guyed tower, which has a super structure which has got the flare boom the derrick crane and other living quarters and other provisions required for drilling and production. Processing it is supported by a tower that is why it is called as a guyed tower. Tower is nothing, but a lattice type structural system, which is a truss base system most interesting part of this platform is that the foundation.

Now this platform does not have rigid foundation as in the case of earlier platforms spud can which has got a connection. Which enables the platform to have a hinge in motion at this connection? Now to avoid or to improvise the restoration of this platform and lateral forces the platform is connected by mooring lines which are anchored to the sea bed using clump weights. So, at the black cone what you see here or the clump weights these are the sea bed anchors which holds these mooring lines down to the sea floor the tower does not have any fixed connection to the sea floor it rests on a spud can which imposes a hinged connection to the entire tower.

Now, imagine a structural system which is very tall and hinged at the bottom under lateral action the tower will always have a behavior of oscillation like a pendulum. So, as an inverted pendulum which is hinged at the bottom here, the tower will oscillate the oscillation. For example, if it goes right because of the wave forces acting from the left these guyed wires will improvise tension and restore the tower back to normalcy on vice-verse condition. When the tower oscillates to the left these guyed wires will improvise tension brings back the tower to normalcy.

Therefore, the restoration of the platform becomes very easy by improvising alternate tension and compression in these kinds of cables please understands that these cables are not taught more they are flexible cables. Therefore, axial compression cannot be improvised on these cables. So, these cables will only be subjected to pure axial tension, but of course, reduction in tensile forces will cause variation which can result in fatigue failure of these kinds of cables. So, the foundation of the tower is support by a spud can this is similar to an inverted cone placed under suction.

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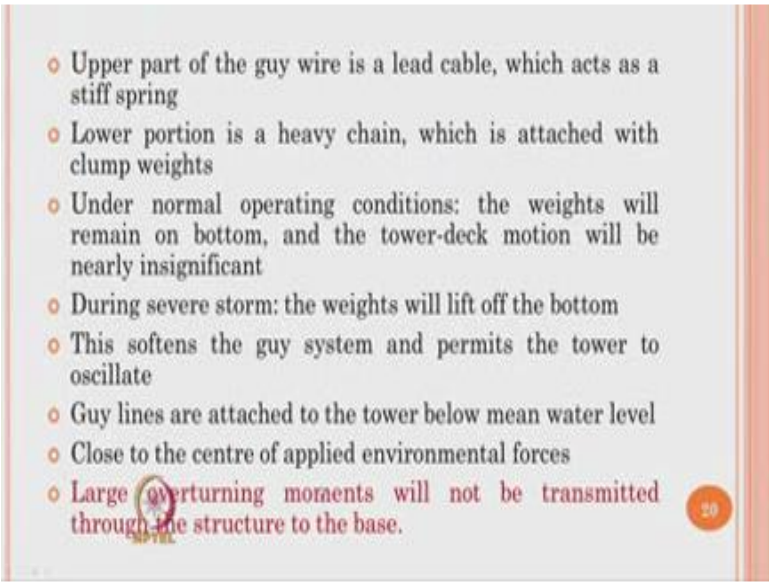

The upper part of the guy wire is a lead cable which acts as a stiff spring the lower part is a heavy chain which is attached with the clump weights under normal operating conditions the weights will remain on the bottom and the tower deck motion will be nearly insignificant during severe storm condition. The weights will get lift up from the bottom this will soften the guy system and permit is the tower to oscillate guy lines are attached to the tower below the mean water level and they are close to the center of applied environmental forces, which will make the center of gravity and the mass center focus on a specific point which improves stability of the platform large overturning moments will not be transmitted through the structure to the base because, the base in not fixed, but hinged and we all know from the base of mechanics any hinged connection will not transfer moments form the super structure to that of the foundation.

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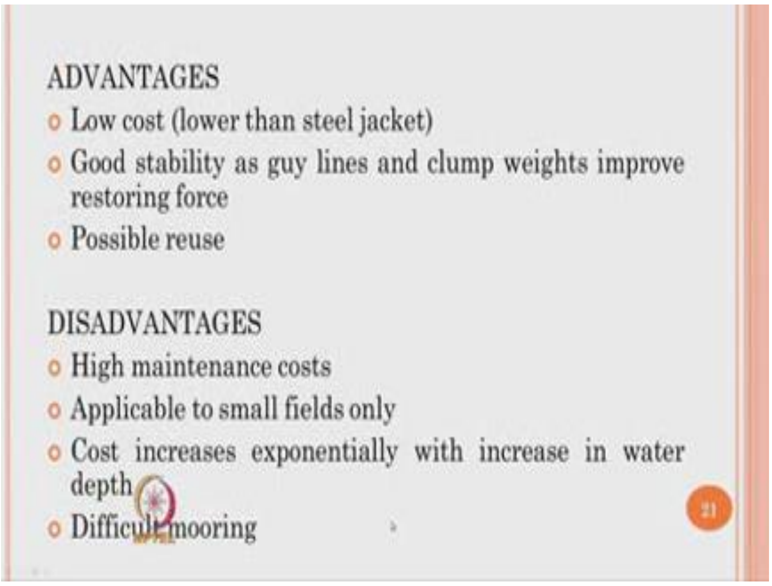

These kind of towers have salient merit is and demerit is these towers are of low cost compared to that of the steel jackets. These towers have good stability as guy lines and clump weights improve stability from the restoration point of view the whole structure possibility can be reused because the structure or the tower rests only on the clump on the spud can and the spud can be disconnected, when it is to be required to be disconnected and the tower can be made of load once it release the guy wires. Therefore, the whole tower can be possibly put to reuse whereas, this was not possible in the case of fixed type offshore structures. Of course, they have got couple of demerit is they have got very high maintenance costs because of a fundamental reason the tower is supported by the guy wires and guy wires have materially essential steel which are corrosive in nature these towers are applicable to small fields because as you see the topside does not have enough facility for production and storage it can do only exploration and marginal production problems.

The cost of this tower increases exponentially, with increase in water depth because for the entire depth steel lattice tower need to be constructed essentially a difficult mooring system. Because the mooring spreads around the tower which will destruct or it will cause inconvenience to the vehicles or the vessels moving or approaching the tower for transporting this crude oil.

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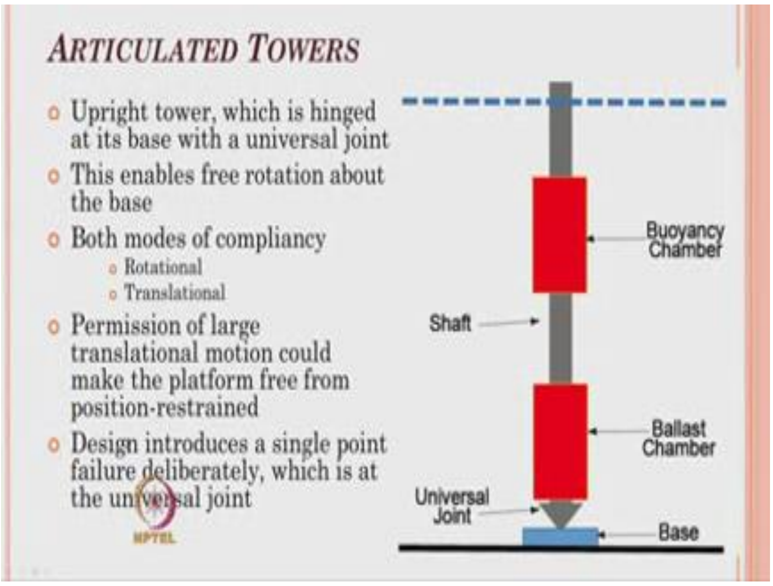

The second type of platform which is also compliant in nature, which has got merit is better than the guyed tower is articulated platforms the term articulation refers to an universal joint, which is again similar to the that of a ball joint this shows a single unique tower which is connected to the buoyancy chamber, and the ballast chamber ballast chamber at the bottom and buoyancy chamber closer to the mean sea level which is interconnected to the central tower.

The central tower what we call is a shaft here and the entire shaft is connected to the base using an universal joint which we refer to as an articulated joint the upright tower which is hinged at the bottom is connected to the base using an universal joint. The universal joint since being hinged in connection will enable free rotation about the base. And therefore, the modes of compliancy of this tower or both rotational and translational in the earlier case the rotational compliancy was restricted, whereas, in this case the rotational compliancy is also made available to this tower. So, this tower is compatibly compliant more than that of the guyed tower the permission of large translational motion could make the platform free from position restrained and the design introduces a single point failure deliberately. Therefore, that is very dangerous in kinds of any structural design because, if at all the structural design of the platform should fail it is made to fail in a specific point which is universal joint.

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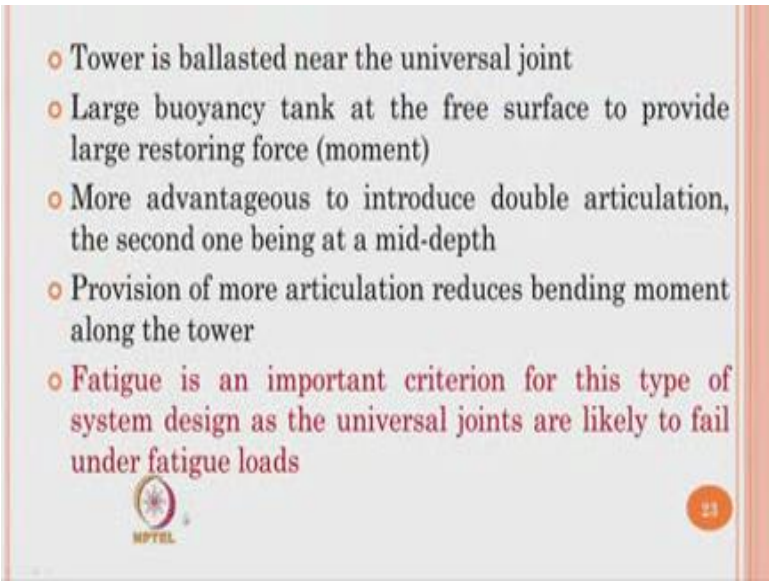

The tower is ballasted near the universal joint using a ballast chamber large buoyancy tanks are provided near the free surface, which can help us to provide large restoring force which will cause an anti clock wise moment to restore the platform which, it is under operation more advantageous to introduce double articulation because there are platforms, where multiple hinges are introduced along the water depth as well the provision of more articulation reduces bending moment on the tower fatigue is an important criteria in the design. Because these kinds of platform system design introduce universal joint which are likely to fail under fatigue loads.

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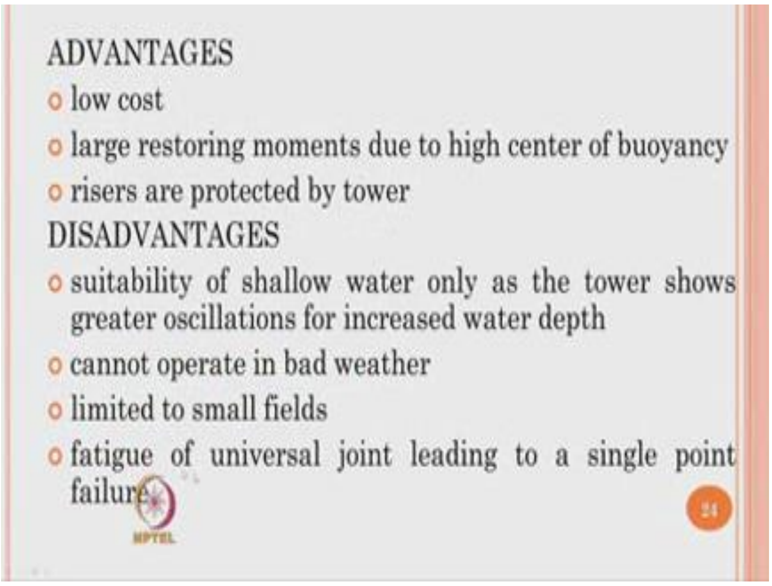

The platform has got couple of advantages it is low in cost large restoring moments due to high center of buoyancy risers are passed through the tower. Therefore, they are protected from the wave action the demerit is are these platforms are suitable only for shallow water as the tower shows greater oscillation at higher water depths it cannot operate in bad weather. It is limited to only small fields fatigue of the universal joint leads to a single point failure which can be considered as one of the important demerit of the structural design.

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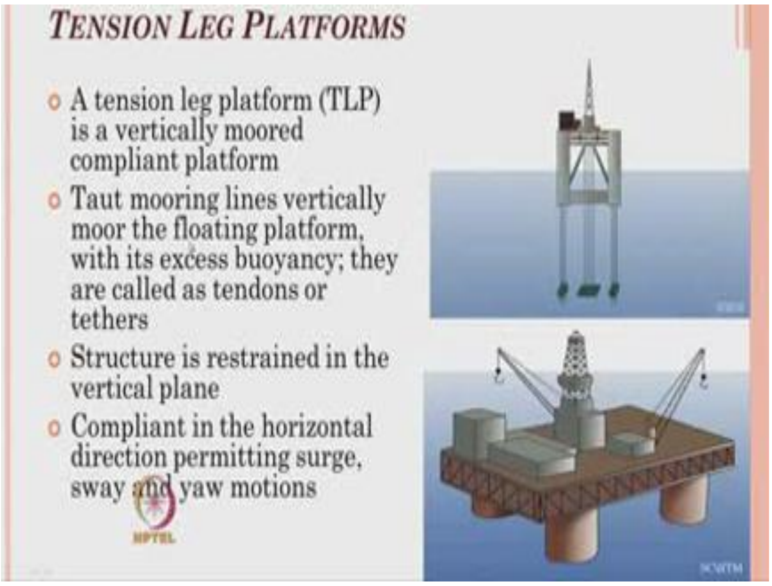

The third merit of the platform which is also compliant a platform is tension leg platform the word suggest tension leg means the platform is completely free of load, which is connected to the sea bed not through the tower not through the shaft, but only through the cables what we call them as tethers or tendons. So, the whole structure is completely free floating which we call as buoyant completely it has got columns and the buoyant chambers or columns and the members horizontally located at the bottom. They are interconnected and the top side has got almost all details as that of a convectional platform, where we saw the derrick is got a living quarters flare boom cranes for necessary for operation of production.

The top deck made and the different layers will enable all production facilities of a platform the bottom column members and pontoon members are set of load and they are hold in position using cables. Now why this is called a tension leg or let us ask a question why tension or how tension is always in place in these legs when the platform is made to free float or a float the platform is brought to the site the cables are free to flow the cables are anchored to the sea bed using the connections as shown here. And once the platform is deep ballasted the platform because of excessive buoyancy will try to move upwards the design is the buoyancy is much larger than, the weight the buoyancy force which is offered in the upward direction is much larger compared to that of the weight which is acting in the downward direction because of the large buoyancy force the tendency of the platform will always have to move up these cables will try to pull the platform down. Therefore, all these tendons will remain in tension that is why this platform is called tension leg platform.

This platform is a vertically moved compliant system which has got a taut mooring line the word taut stands for axial tension of a very high order the platform has got very interesting design phenomena. The design phenomena is the platform is designed which excess buoyancy the buoyancy force is very large compared to the weight of the platform which will make the platform to hail down in position by the tension cables, these cables are called tethers or tendons in the literature the structure is restrained in motion, in the vertical plane and remains compliant in the horizontal plane which permit is surge sway and yaw motions.

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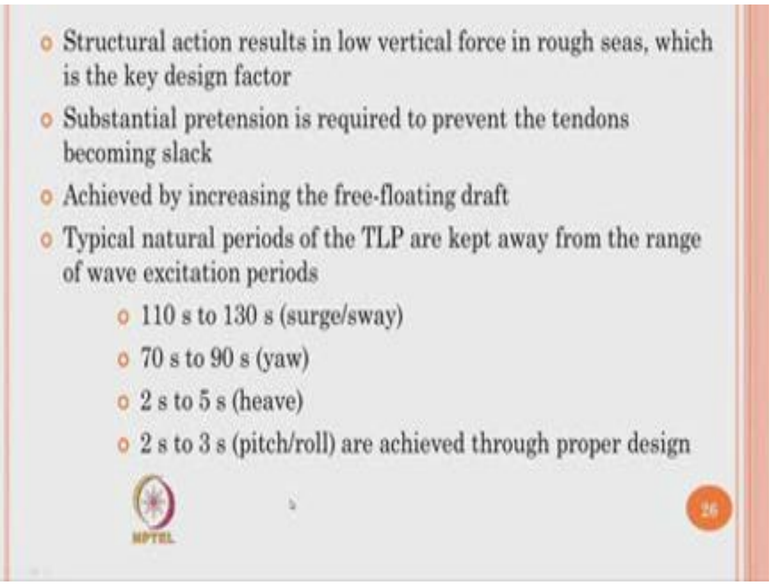

The structural action results in low vertical force in the rough sea which is one of the design factors of these kinds of platforms, it has got as substantial pretension, which is required to hold the platform down or to prevent ht tendons, becoming slack. This is achieved by increasing the free flow draft of the platform and ballasting and de ballasting alternatively the typical natural periods of T L P, are kept away from the range of wave loads acting on this kind of sea states. So, in surge and sway period it varies anyway from 80 to 130 seconds in yaw. The periods will vary from 70 to 70 seconds whereas, in heap pitch and roll which are constructed to be stiff degrees of freedom the periods vary from 2 to 5 seconds or may be 2 to 3 seconds respectively as shown in the slide.

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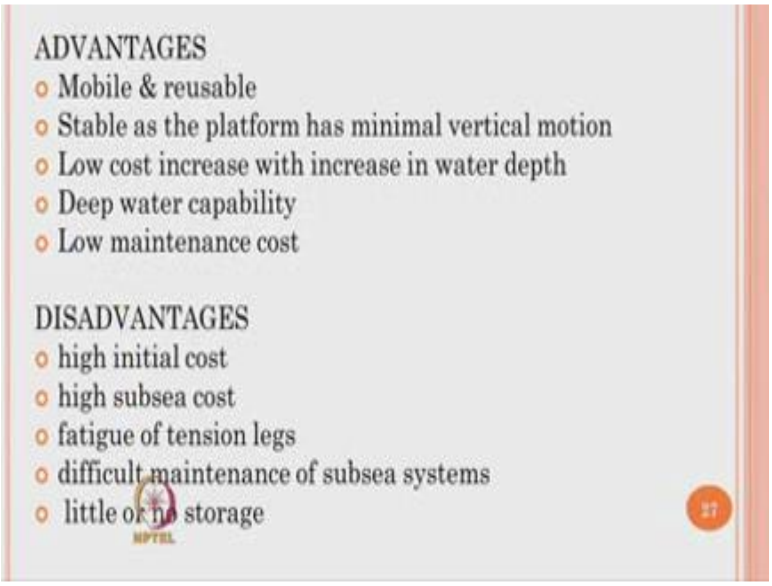

The platform has got salient merit is and demerit is it is highly mobile and reusable because the platform is of free float setting body, which is got to be anchored to the sea bed using tendons. The platform is highly stable as the platform has got only minimal vertical motion the platform is of a low cost and the cost does not increase with the water depth because in this sub structure there is no lattice or the tower, except that of the cables the platform has got very high deep water compatibility. And it is capable of anchoring in deep waters it has got a very low maintenance cost because most of the structural systems stay above water level.

The main demerit is of the platform are the following it has got very high initial cost the investment in terms of commissioning of the platform is very high, It has got a very high subsea cost fatigue of tension legs is a very important factor in design and analysis it is difficult to maintain subsea systems the platform practically has little or no storage.

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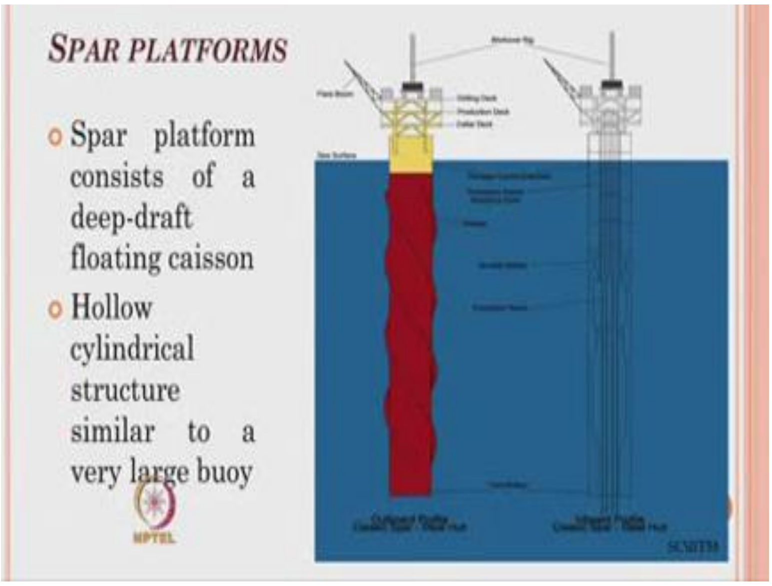

The other variety platform what we see here is the spar platform. Spar platform essentially consists of a deep draft floating (Refer Time: 37:16) the hollow cylindrical structure which is similar to a large buoy the (Refer Time: 37:22) can be a cylindrical system can be even a truss base system, as you see here the topside of the platform has got similar details as that of a tension leg platform it has got a flare boom, it has got a work over rig, it has got a drilling derrick, it has got a production deck, it has got a cellar deck, as well as the subsea systems or as similar to that of what you see here in the tension leg platform.

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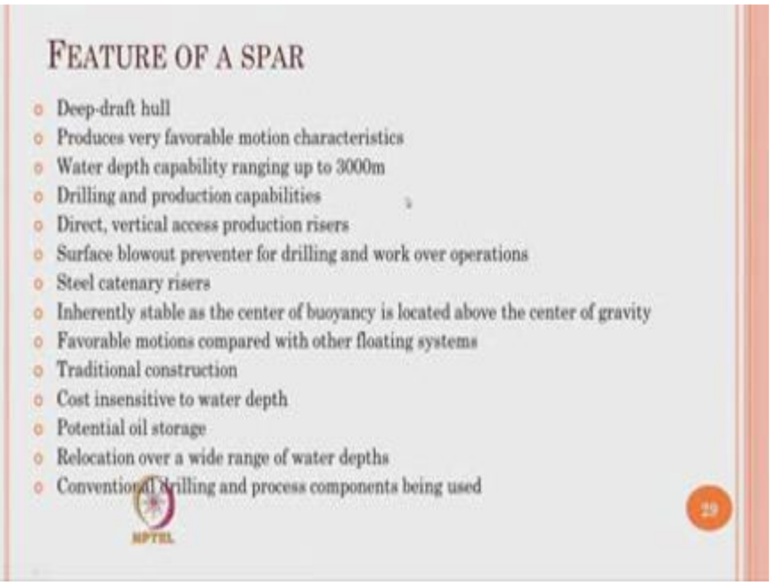

Essential features of a spar could be the following it has got a deep draft hull it produces favorable motion characteristics, the water depth capability ranging up to 3000 meters. So, these platforms are capable to be installed in deep waters the drilling and production facilities are available in this platforms it has got direct vertical access to the production risers it is surface blowout preventer for drilling and work over operations. It has got steel catenaries risers which holds down the platform in precision inherently stable as the center of buoyancy, is located much above the center of gravity favorable motions compare to with other floating systems traditional construction cost insensitive to the water depth, potential oil storage relocation over a wide range of water depths conventional drilling and process compositions available in the platform being used.

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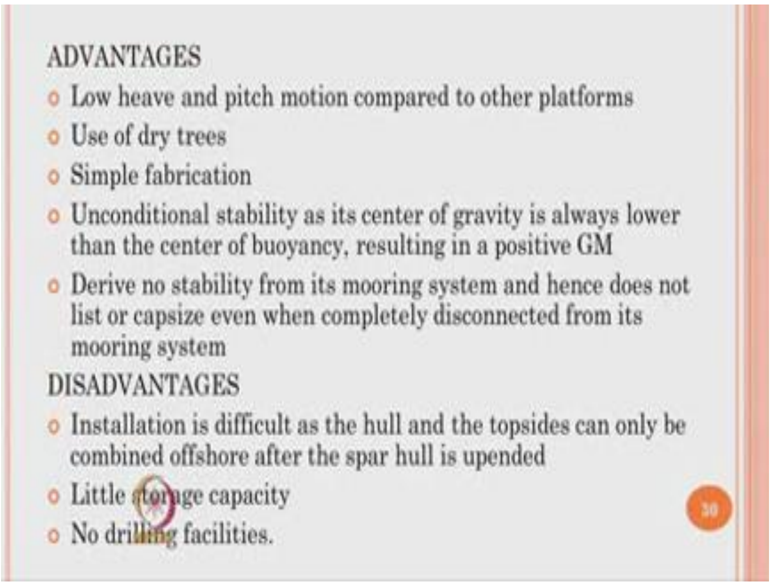

It has got many merit is and demerit is low heave and pitch motion compared to other platforms use of dry trees simple fabrication and unconditional stability because CG is much higher than the geometric center or the center of buoyancy derive no stability from mooring system.

Therefore does not list or capsize even when completely disconnected from the mooring lines the demerit is are installation is pretty difficult as the hull and the topsides can only be combined offshore after the star spar hull is upended. It has got a very little storage capacity and these platforms generally are not meant for drilling because drilling can cause secondary vibrations for which the platform are essentially are not analyzed and designed. So, in this lecture we discussed about 2 types of varieties of platforms fixed type and compliant type. We introduce you different types of platforms with the schematic sketches, the functionalities the structural design structural form and variety of forces acting on them with the restoration capacity and to some extent the constructability features.

Thank you very much.