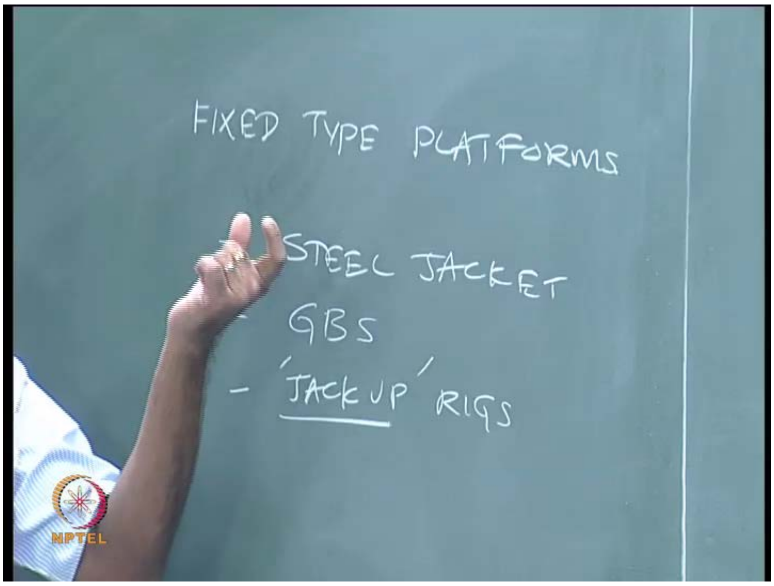
Dynamics of Ocean Structures
Prof. Dr Srinivasan Chandrasekaran
Department of Ocean Engineering
Indian Institute of Technology, Madras

Module - 1
Lecture - 3
Introduction to different types of ocean structures III

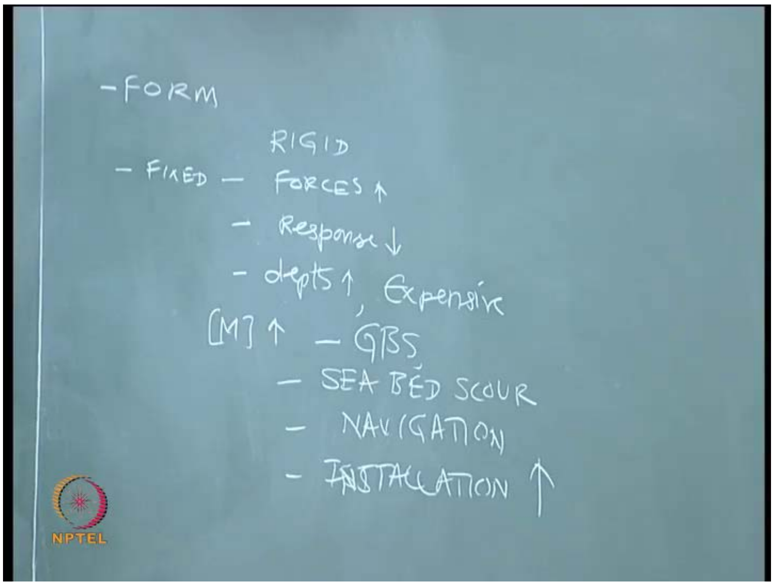
We have a third lecture now is on dynamics of ocean structures. Let us quickly see what we have seen in the last lecture.

(Refer Slide Time: 00:22)



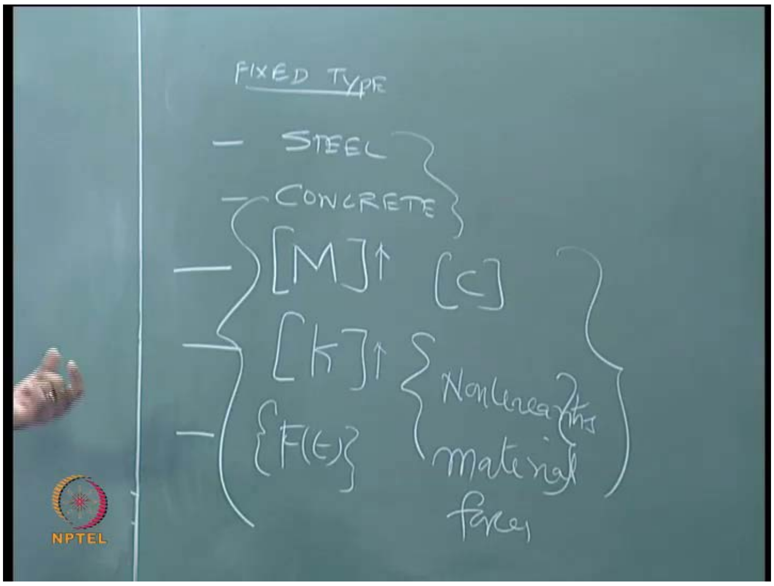
We have discussed about fixed type platform in that we have seen steel jacket platform, we have seen gravity based structure. We have seen jack up rigs, there is a specific name why we are calling this as jacked up rig, because we are lifting the hull or the working hull and founding it in the soil using the steel lad towers.

(Refer Slide Time: 01:03)



We made a very brief summary of fixed type category of platform saying when you design an offshore system, you should focus on a different forms, which can cater for different kinds of sea states and water depths. If you look at the fixed type, it is one of the forms which has a rigid base, it attracts more forces. The advantage is the response is less. Depending upon the increase in water depth the system becomes expensive. And since the mass is very large in case of gravity based structure, it creates many problems like seabed scouring, interferes with the navigation and cost of installation also grows expensive.

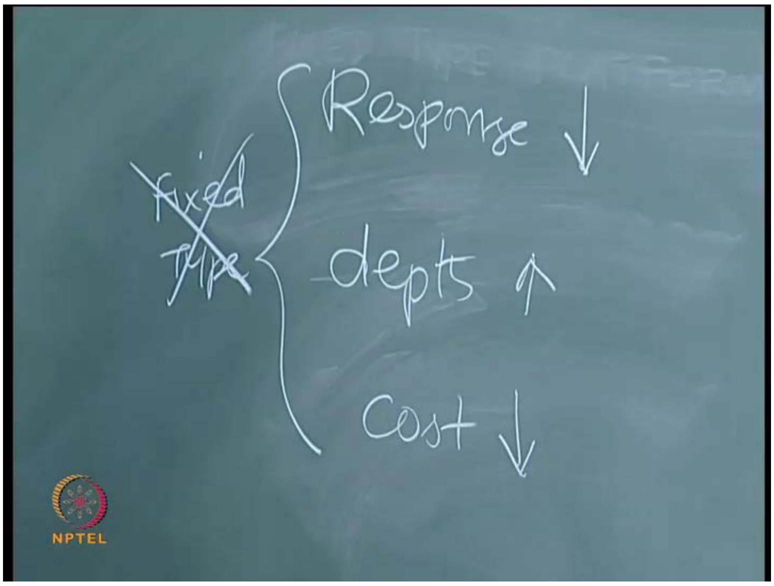
(Refer Slide Time: 02:11)



We have also seen that the common material, which is being used for fixed type platforms. Most commonly you can use steel people have used concrete and so on. Now based on the material properties and the type of form we derive basically three basic concepts of understanding required for dynamic analysis. One is mass of the platform. When we talk about rigidity, we talk about stiffness when we talk about response, we talk about forces. When we talk about material, we talk about damping. We also talk about some of the non-linearity related to material and forces. So, these are all essential characteristics of a dynamic analysis.

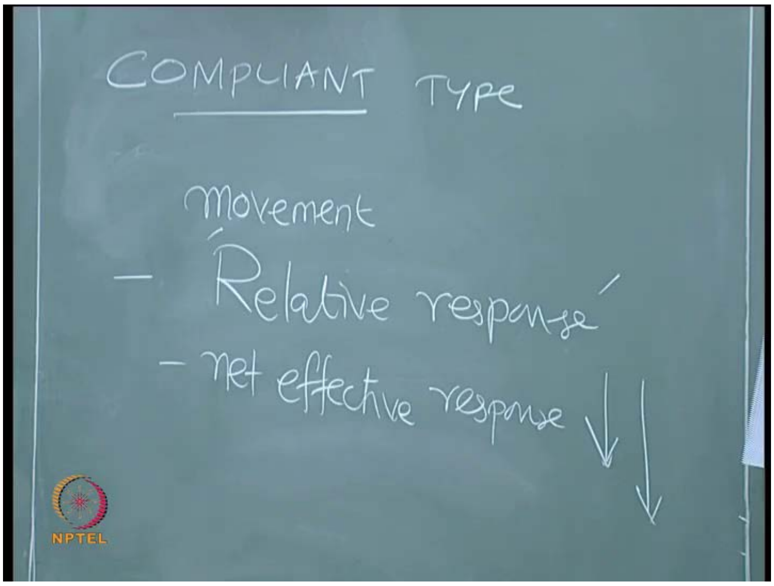
We understood from one type of platform that they are having very high mass. It is very rigid and therefore, it is very stiff. We are yet to speak about the environmental forces coming on the structural system. We will talk about that in the next lecture. We marginally touch about the damping characteristics, which can be derived from the material. We spoke about a very brief introduction of how do you get non-linearity?

(Refer Slide Time: 03:57)



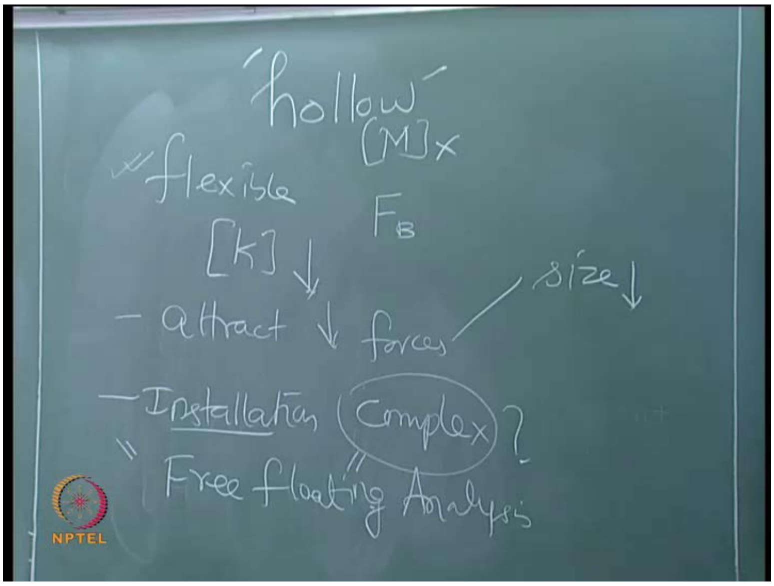
Now interestingly we summarized one important concept in the last lecture. If you want to reduce the response for increasing in water depth and to reduce the cost, I should not go for fixed type. Then I should go for a different form; a new form, which has been evolved in the literature by the researchers, is compliant type. Please focus on the spelling; it is compliant type.

(Refer Slide Time: 04:26)



So, compliant means moving; compliancy stands for moving or movement. The moment I say movement, then, I will speak about the relative response. So, the net effective response in such structural systems will be greatly reduced. And interestingly, as an engineer, we can easily understand.When I have a form, which has movement then, I can say this form needs to remain flexible.

(Refer Slide Time: 05:29)



It means stiffness of these platforms are lower. The moment I say stiffness is lower or the system is flexible, it will attract less forces. Since the system is flexible, installation becomes complex. Why installation becomes complex? When the system is flexible, for example, imagine a floating ball or any floating body. The position of fixity of the body in the large volume of water does not depend only on mass, but also depends on the force which the fluid will exert on this body. Whereas in the earlier form of fixed type, we did not have this problem. During installation, in compliant type, because of the flexibility, you have complexities in installation.

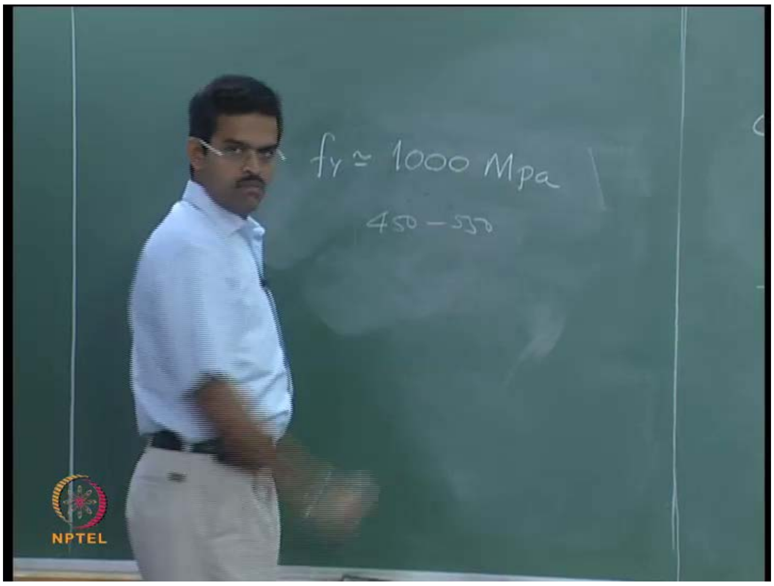
How this complexity will govern dynamic analysis of such structures? To this very simple question, the answer is the governance of this complexity in dynamic analysis; will focus on what is important. Now is free floating analysis because while installation due to the complexities introduced by the form. The structure may become dangerous and unstable in free-floating state. So, you have to do dynamic analysis at free-floating state as well as when it is being position fixed in your location of the sea state. So, now, complaint type of offshore structures is different in behavior in dynamic analysis with respect to a fixed type because of the following reasons.

So, what are the different types of compliant platforms? Where are they constructed? What is the geometric shape? Importantly when I say they attract less forces, is it because the size is small? If you understand that the size of a flexible platform or a size of a compliant tower is smaller than that of a fixed, then you are talking about the functionality of the platform. Remember thatI am speaking about the form not the function.

So, the functionality that fixed type platform had on the top side has got to remain same as that of a compliant type also. Bbecause if we say I want all those top side complications to be installed, which has been already existing in a fixed type for exploratory and production drilling. I must have all those equipments, plants, machineries as same as that in a compliant type also. Because no user will not compromise on the user-oriented functionality of the platforms. Because you wanted to make it flexible.

The size more or less has got to remain same. I am not saying it has got to be exactly same; more or less it has got to remain same. But, the weight has to come down because it has to remain flexible. Therefore, we can talk about hollow or wide cylinders what we call as pontoons. So, this is how this platform was evolved in geometrical design. Instead of having solid structures, go for void based elements. so that size can be retained but weight can come down because of the floatation characteristics. The structure can become flexible. The moment structure becomes flexible, stiffness is reduced. The moment stiffness is reduced, it has a tendency to attract lesser forces on the structural system. So, the aim of this design was to reduce the forces. One may wonder, sir , when I want material which can have yield strength as high as 1000 mega Pascal, then

(Refer Slide Time: 10:38)

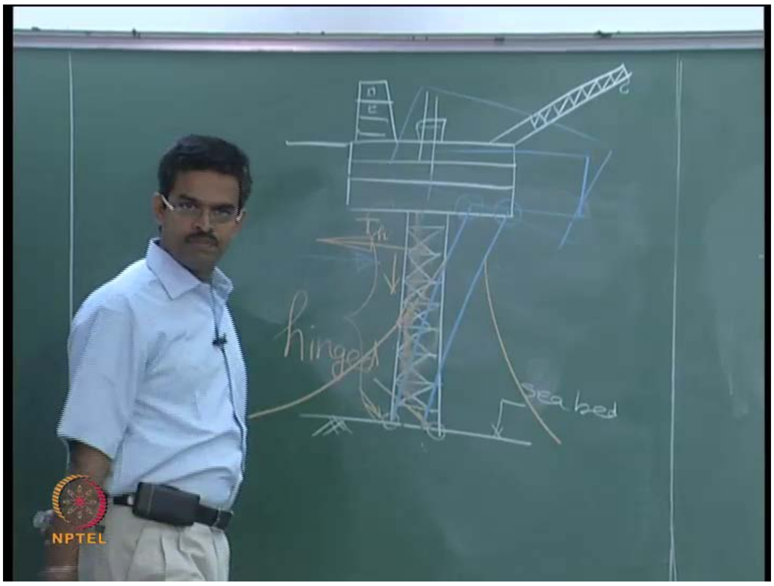


then why should I bother about the design, which will attract less forces?. Where yield strength can be as high as 450 to 550 mega Pascal, why should I focus on a design which will attract less force? any answer. When I move towards greater water depths, the force exerted by the water body on the member will be increasing exponentially. So, I would not have a system, which will attract less forces, if we want to use the system at deeper waters. Now the counter question is why I cannot use a fixed type system at deeper waters? It is a very interesting reverse question. Answer is already available. what I said just now. I can’t use fixed type systems at deeper waters because fixed type system, by its form has a tendency to attract more forces, which I do not want to happen. Now the counter question is, if we have a member of very high yield strength, then why you do not want to allow a member to attarct higher forces? So, remember this question. I have got three cross questions asked. The most important is I have a material. But, I do not want a form to attract more force, why? On design point of view, why? On material point of view, you have not answered this is a question which is interesting for us. Let us move forward. Compliancy means movement. So, the tower moves; the term compliancy stands for moving.

(Refer Slide Time: 14:01)

So, compliant offshore towers are actually offshore drilling platforms that are deployed in deep sea for oil exploration. Essentially not for production. Remember that they are meant for exploration, but of course, exceptions do exist not always that every platform is only for exploration can also use it for production as well. For example, TLP, spar, but essentially they have been initially designed for exploratory drilling only. They are connected to the sea floor, but they are allowed to move freely; very interestingly. Now the question is how this is possible? I want to connect them to the sea floor, but I want them to move freely.

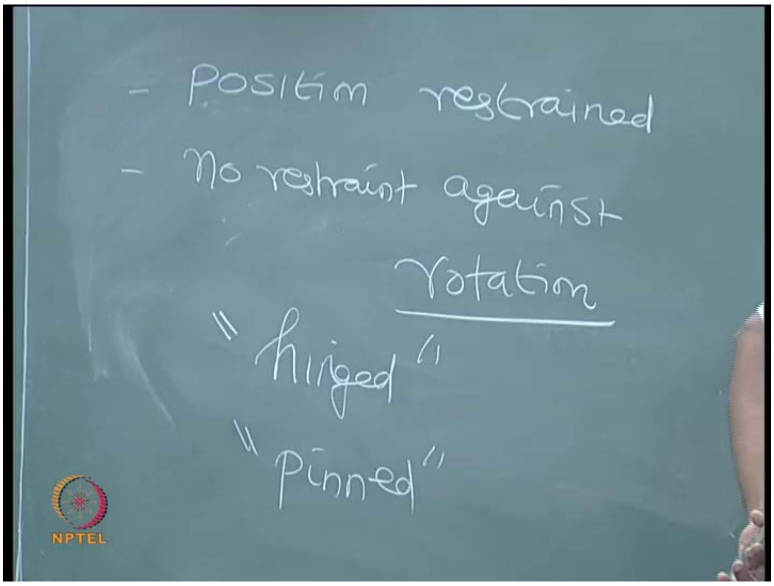
(Refer Slide Time: 14:49)



Let us take a simple tower. I am having a simple tower, which is a steel lattice tower, which is cross braced. I am having a top side as you want a multi-tier top side. I am having all facilities like a crane,a helipad, living quarters and all facilities. I want to found this or I want to fix this to the sea floor. But I do not want to fix it thoroughly; I want to make it compliant. I have to make this joint essentially a hinged connection.

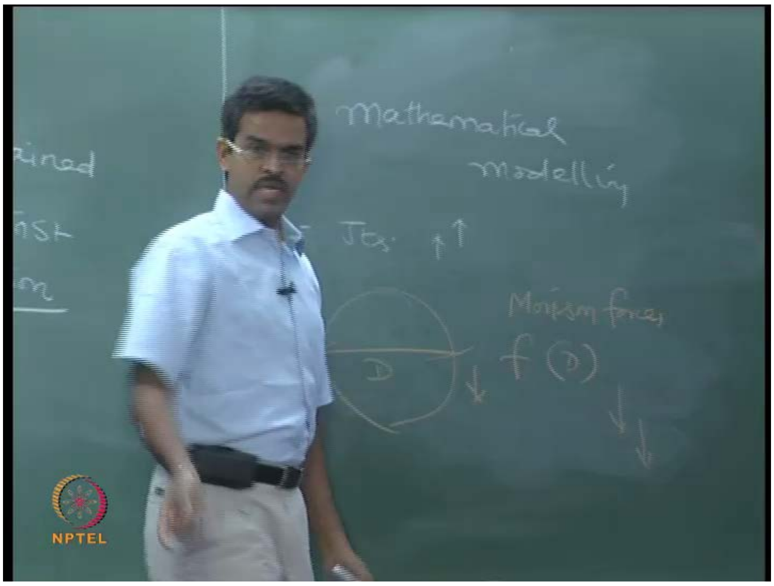
There are varieties available in literature for making it and I will show you a video today. Very simple hinged connection, being used by a person in a shop to put his banner on a road, which is having enormous wind speed. I will show you that. The moment we say hinged connection,then how this can exercise flexibility or movement or compliancy?

(Refer Slide Time: 16:34)



The hinged connection will give me the following facilities: one it will make the system position restrained but, it will offer no restraint against what rotation. A typical classical model is hinged. some people call this as pinned connection.

(Refer Slide Time: 17:26)

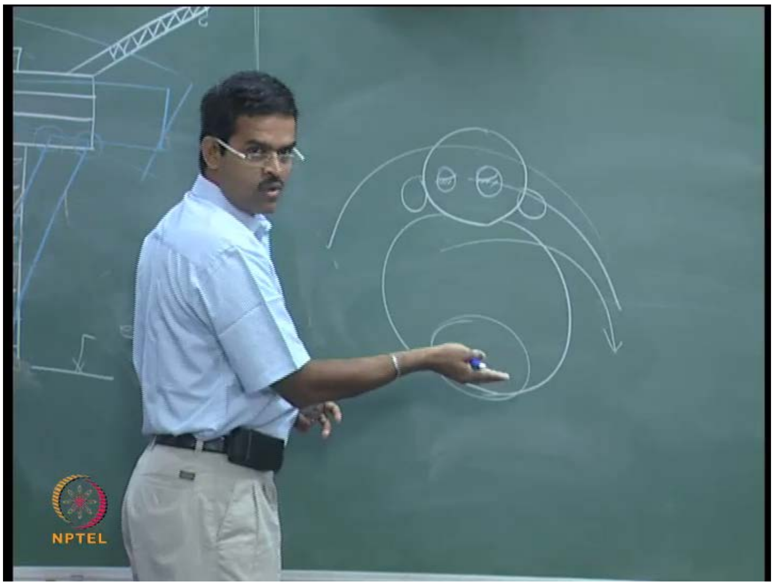


So, interestingly in mathematical modeling of dynamic analysis, modeling of joints play a very important role in mathematical modeling. Once I introduce a hinged connection here, the system becomes flexible. Because it is now moving not in the position, but in rotation. So, interestingly if we have a tower which moves, let, us say to this position hypothetically when the wave is active. Now there are two catches here: one, the deck should remain horizontal. Because if deck gets inclined then I can’t do my drilling operation. The deck should remain horizontal.

It is essential that there should be a hinge required here. Also we are not discussing that the deck will remain horizontal, but when the tower inclines because of the wave action happening here. If I have any mooring line, the mooring line will be exerted with some tension. The horizontal component of this tension will counter act the wave of course, the vertical component of the tension will add to the weight, which will improve stability of this platform under wave action. Now what is the advantage of introducing a new member, which will take care of the lateral force? Greatest advantage is my lateral forces do not come on this member. The member has got to be designed only for the forces generated by its own weight or by the top side; it means that the member design becomes less complex.

Therefore, I can go for yield strength of lower value and lower member cross sectional dimension. When I say lower member cross sectional dimensional of decreased D, the Morison forces coming on the system, which is a function of diameter will be reduced. That is why I said these members will attract less forces. It becomes very easy for us to understand that I will introduce a member or set of members, which will counter act may literal forces. This will not allow the lateral force. Majority will get transferred to the truss system. On the other hand, If you do not have this member and you do not have an hinged connection and fix it here, thenthe whole lateral force has to be taken care of by this system Only. This is case of a fixed type platform. Suppose, you do not fix it here; hinge it here, but do not have a mooring line here. Then there should be a mechanism by which the inclined position of the tower should be brought back to normal sea. To understand this I will give a very simple example of a toy, which you have been playing in the childhood.

(Refer Slide Time: 21:16)



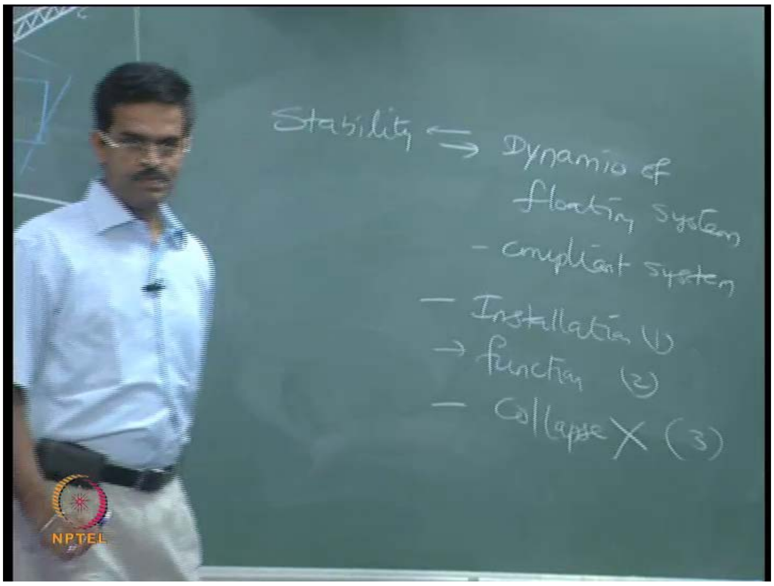
You must have used this toy, which is red in color. That toy is a very simple basic toy, which is being played by children. The interesting part of this toy is when you try to make this toy lie down, it does two things interestingly, which we have observed. The toy will close the eye, which you have seen, What you have not seen is once you remove your hand, the toy will oscillate in position and come back to vertical. It is exactly the same model applied here, which is a spring mass system here. This integrates the weight and the shift of buoyancy or shift of weight to the spring action restores this position back.

So, I have to have a mechanism here in such a way that I do not have an additional member like a mooring line, but I want to bring this tower back to normal sea without oscillation. But here the toy oscillates; I do not want that oscillation to happen. So, interestingly if this is my still water level I must have, what I call a buoyancy chamber. It is a variable buoyancy, which is an upward force and the weight, which is a downward force because of the shift of buoyancy from here to here.

It will offer on a counter clockwise couple, which will restore this platform back to vertical position. So, when you introduce flexibility because of joints you must compensate this flexibility by some other mechanism like a buoyancy chamber like a mooring line etcetera. All these towers in general are called as compliant towers. Why compliancy was introduced because I want less force to be attracted on the member.

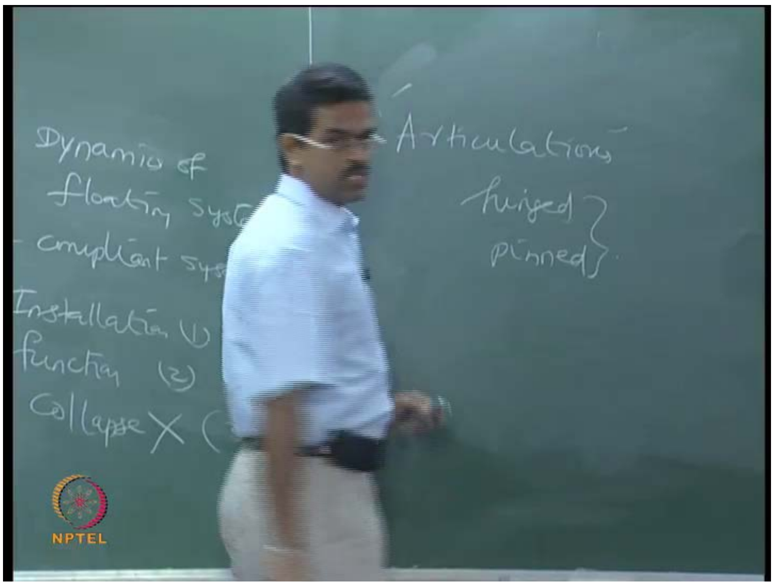
Because I want use it for deeper waters. So, it actually depends on the stability. So, we have to bother about the stability part of it.

(Refer Slide Time: 23:54)



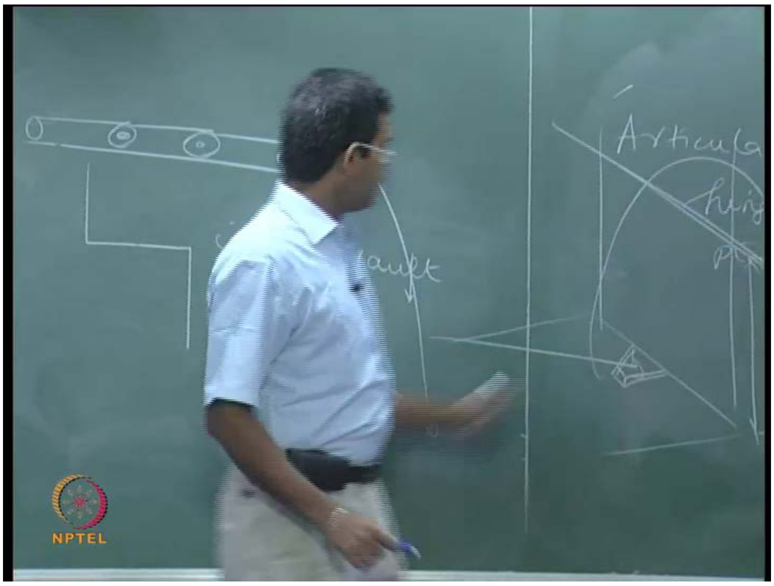
So, stability becomes, an inherent study in dynamics of floating systems. But, I will put it slightly in a compliant system also because in my case the stability is important during installation first. Then of course, during production or function. It should not collapse even at worst sea state. I must ensure safety. One important catch here is when you evolve a new form people thought of different kinds of connections or joints initially.

(Refer Slide Time: 25:08)



The form evaluation started with introducing joints, which I call them technically as articulations. These are no more called as joints they are called as articulations. Articulations is nothing, but, hinged or pinned connections as far as mathematical modeling is concerned. So, I am going to introduce joints now. You may wonder, sir, why joints are required only at the foundation part and only at the top side? Can I introduce joints or hinges somewhere in between? what would be the harm? what would be the difficulty if we introduce a hinge or a joint in between the length of the member? I can give an example for this. you must have seen at least movies of Bruslee. Bruselee used a specific chain, which is Nechako. It is having three connections.

(Refer Slide Time: 25:59)

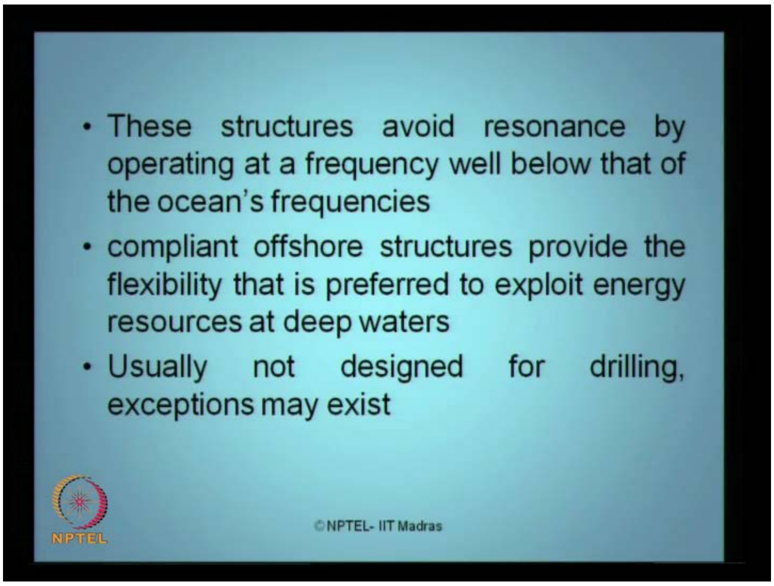


One rod, another hinge, another rod, another hinge, and another rod. Even though this hinges give flexibility to fold, this in any form he wants. But it requires axial force to make this rod straight. So, multiple hinges introduced in any member needs basic minimum axial force to straighten this member or to remain this member straight. Another example is you can see a game called pole vault. Pole vault is the game where people have a long and a high platform there, is a barrier here the sportsman runs from here. With a long stick in his hand there, is pit available here he comes and punctures this strip in the pit here jumps and falls.

If you have seen this video any time during any Asian games etcetera, you will see as the man goes higher and higher this pole vault becomes, bending keep on bending. So, there has to be a balance between the body weight of the sports person, with respect to the selfweight of the stick, which will enable him to push down on the other side. If I have a hinge anywhere in between it will weaken the strength of this member. So, similarly here if you put hinges anywhere in between, if you have introduced hinges anywhere in between it will weaken the strength of the member.

But, the member will become more and more flexible. If your focus is only to make it flexible, then introduce joints. If your focus is to make it restrained for loads do not make it flexible by putting hinges in between. So, there are multi hinge towers also available; multi leg towers available and hinges only here available hinges here and here available. So, structural form was evolved in such a way that people thought of introducing multiple joints and chambers and members to make it complete that was the whole idea, but this system has a demerit.

(Refer Slide Time: 28:29)



I will come to that once. We see some more slides here most interesting part is these structure avoid resonance because the operating frequency of these structural system are much and well beyond the band frequency of waves. we will speak about this more in detail in the next coming lectures, but it is a very important hint. It is a derived advantage because system becomes flexible; frequency range of operation shifts from the wave band. So, it is an advantage since. We do not know any value about what is the operational frequency, what is the frequency of the tower etcetera? we have not done any analysis yet; we have not speak about this incitingly.

But, it is a derived advantage say they provide lot of flexibility as I said, the platform will remain horizontal that is the flexibility given for exploration not for design for exploration. I can make you to understand. If the platform does not remain horizontal what would be the difficulty? all of you would have seen at least a circus in a childhood. In circus, generally gymnastics people do have a net at the bottom and they keep on doing the gymnastics at a very good height maybe around 7 meters or 10 meters may be around 20-25 feet height. They will keep on doing gymnastics. At the end of the show, people use to fall on the net and they come down to the floor have you ever attempted to walk on a circus net.

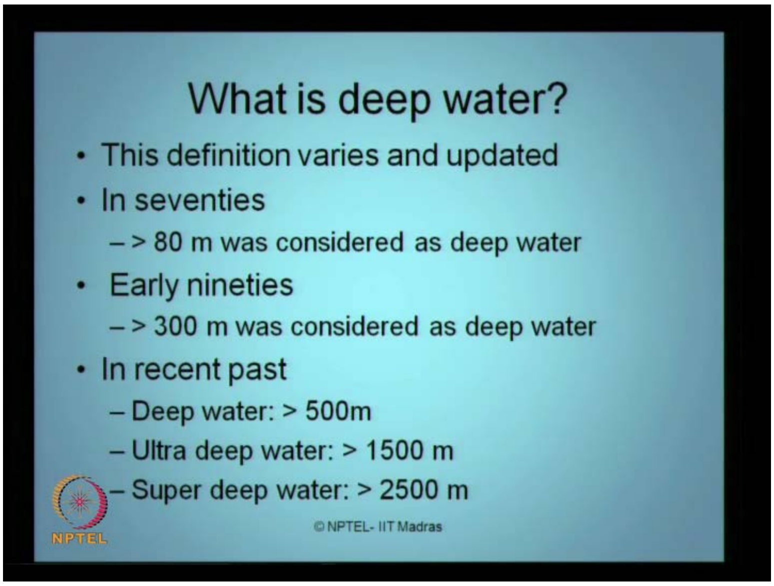
If we have a flexible base, which is highly flexible highly moving you will not be able to walk on that I will show you very interesting videoafter two three slides. you will realize that how engineering introduction of these kind of joints has made innovations in different countries where people do not have understood engineering, but they have applied it. They have applied for a very interesting and simple example. So, introduction of any kind of joints or connections will improve flexibility, but reduces strength.

As I said these kinds of platforms are initially designed for explorative drilling only not for production drilling, but subsequently they have been extended for the production drilling also. The original objective was only for exploratory drilling. I think we all agreed and understood that what do we mean by exploratorydrilling: What do we mean by production drilling? Before the drilling starts in a well in an offshore, people have would really find out whether there is enough potential yield in that well to invest on a platform for another 10 more years. So, we do first an exploration.

So, that is what we call exploratory drilling. I need platform for that I need a set up for that may not be a platform, but I need at least a semi-sub or a drill ship, which can drill at that particular location. This is what we call as exploratory drilling. Once a yield value of the well is established then…. One can construct the platform depending up on the revenue, which we saw yesterday. One can invest and keep on earning money and as you have seen. All of you will strongly agree that today the revenue of all the platforms in US and gulf of Mexico has gone up at least by 55 paisa for one liter it is increased by 55 paisa as on today. So, revenue keeps on changing, right. So, offshore platforms as long as they exist there is revenue.

No depletion value; there is only incremental value. Any other structure except monumental structure have depreciated value. Offshore platforms do not have depreciation they have only incremental values. That is the only one interesting part, which will encourage people to invest on offshore structural systems.

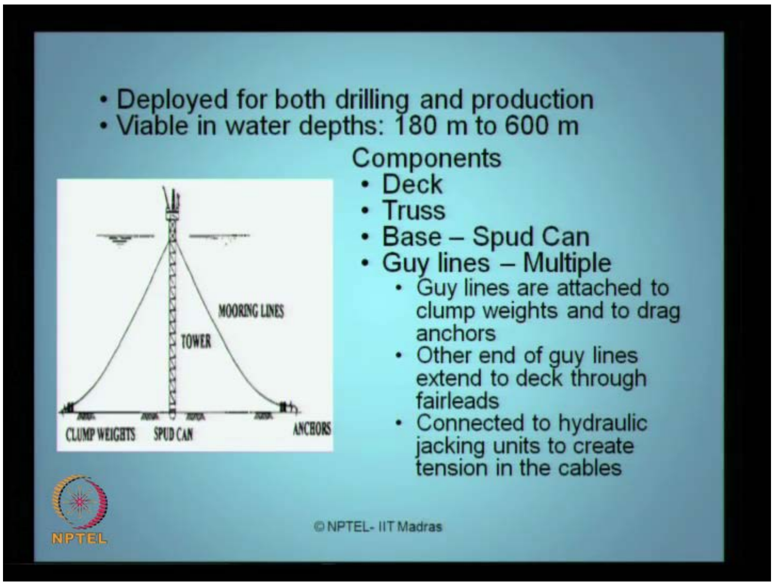
(Refer Slide Time: 32:23)



We will quickly see a classical definition in the literature what is about deep water. We are talking about the water depth because that is one of the primary concern for us here. This definition is keeps on varying and is updated you must have seen this definition in hydro dynamics classes etcetera, but, This definition is completely different in seventies. people said more than 80 meter was itself considered to be a deep water whereas in early nineties people said up to 300 meter. We can go and beyond 300 deep water, but in the recent past people said above 500 deep water above 1500 ultra-deep above 2.5 kilo meters it is super-deep waters.

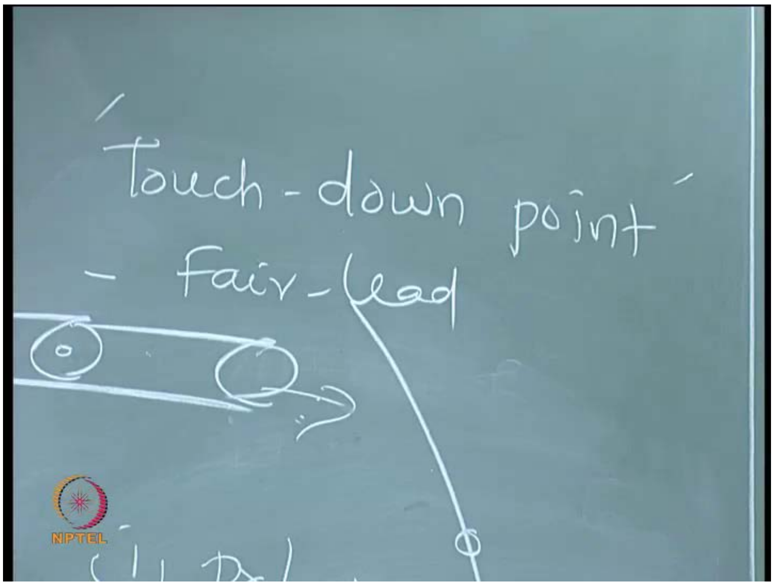
There is a recent classification available in the literature. So, depth of water is classified depending up on these names with respect to the water depth available. So, my structural system should suite in the range between 500 to 2500 meters the deepest platform. Now available is around 2220 meters at this water depth; it is operating there is a deepest platform available now.

(Refer Slide Time: 33:36)



One classification of the platform in compliant system is a guyed tower. I think you have seen this figure which you have drawn the line diagram I am showing here. These are mooring lines; there are different components of this; deck is the top one, truss is the lattice truss what I showed here and the cables what you see here are all mooring lines. For interesting information I want you to remember these points this point is technically called touchdown point. It is the point where the cable touches the sea floor . It is called touchdown point this is the point where the cable touches the structure this is called a fair lead.

(Refer Slide Time: 34:13)

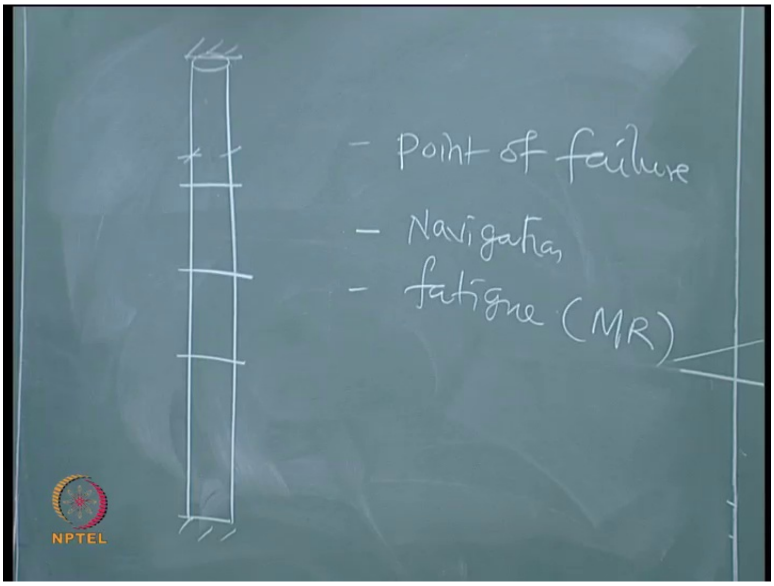


So, touchdown point this is the point where the mooring line touches the sea floor and the second point where the mooring line touches the structure is what we call a fair lead. Fair lead. Now interestingly you can't float a cable in water because the cable has no weight compared to the buoyancy offered by water. cable will be keep on floating. You will not be able to push and restraint the cable at any specific location you want. So, how do you do that? You attach weights to it. They are called as clump weights. You attach a weightand this weight will drag down the cable to the sea floor. They are called as clump weights. Once you put the weight, there is a possibility that because of sea bed erosion, the weights may get lifted up by buoyancy. To hold it down in position permanently, we use what we call drag anchors. We will talk about this slightly later. Drag anchors will hold it down at this cabling position.

These are some of the minor components in dynamic analysis, but these are very important for offshore platforms. We must have an idea about what we are talking about here. So, one direct advantage is that by using a mooring line or a cable, i am able to alleviate maximum component of the lateral load by preventing it from reaching my structural tower. My cable takes this load. The horizontal component of this. Is that clear? any questions? any doubts here? This is what we call as a guyed tower. It is not because it is a male tower or a female tower. The name guy is because as the guy line or a guy rope holds the tower, as a name is given in the literature. That is why it is called as a guyed tower.

Alternatively people thought, that guyed towers had some difficulties. Can you point out? One of the major difficulties or deficiencies is a guyed tower to have louder strain in the cable. Slenderness Number. We have not talked about any slenderness at all in the earlier slides? When you talk about stability, people confuses slenderness. Slenderness is a proportionality between the cross section dimension and the boundary condition of the support.

(Refer Slide Time: 36:54)

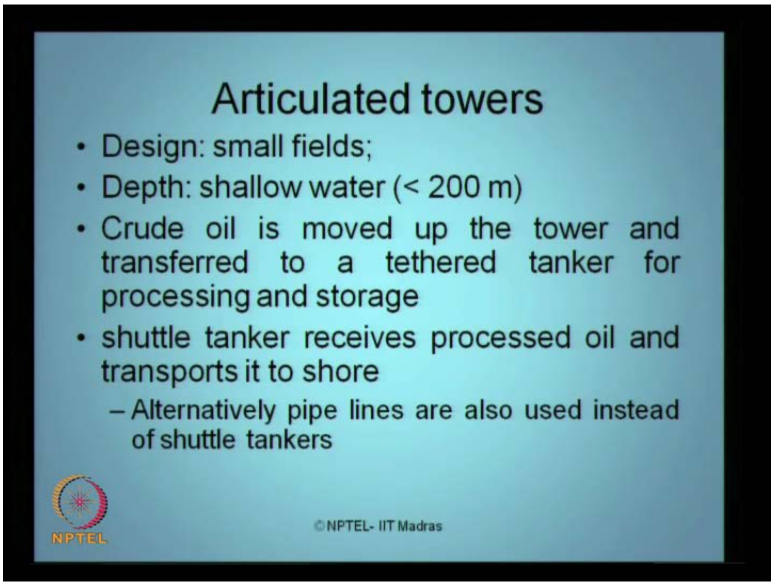


I have a same member for very long and a boundary condition that the member may become slender. I use the same member, but put intermediate connections; the member will no more become slender. So, slenderness is a concept. Proportionality between the dimension to its supported or un-supported length. Let us not bother about that here. If you worry that my cable will be slender, then pl understand that cable has to remain slender. You cannot have a stiff cable. But. that is not a structural demerit. I have a very serious structural demerit in this problem or in this form what is that demerit? Very serious demerit is that I am deliberately introducing a point of failure. Obviously, in this structural system, connection points of the cable will fail and result the structure to fail.

You cannot always introduce a deliberated point of failure and say that is an effective system. is it clear? The structure will adopt its point of failure automatically by the wave or by the action of environmental loads. That is inherent part of the structure system. But, you cannot create a failure point and say beware about this point. That is a very dangerous design. Actually that is structural demerit of this system. What will be a second problem? Very interestingly, if the cable get pulled off either from the sea floor or from the fair lead point, the tower has no capability to restore its position under the lateral force. That is a different story; I am going on to the next slide. But, I am not looking for the second demerit of this system. Guyed wires itself interferes with the navigation. The problem is that all these platforms require drilling vessels or tug boards or any other off loading facility to reach my platform. A platform cannot be accessible closer because these mooring lines will disturb the navigation. So, interface with navigation. Is there any other problem? Somebody said, few minutes back about this issue, I counteracted that issue. Can you come back again. Fatigue; think about the mooring line tension forces. Will it remain constant all the time? No. It will keep on changing.

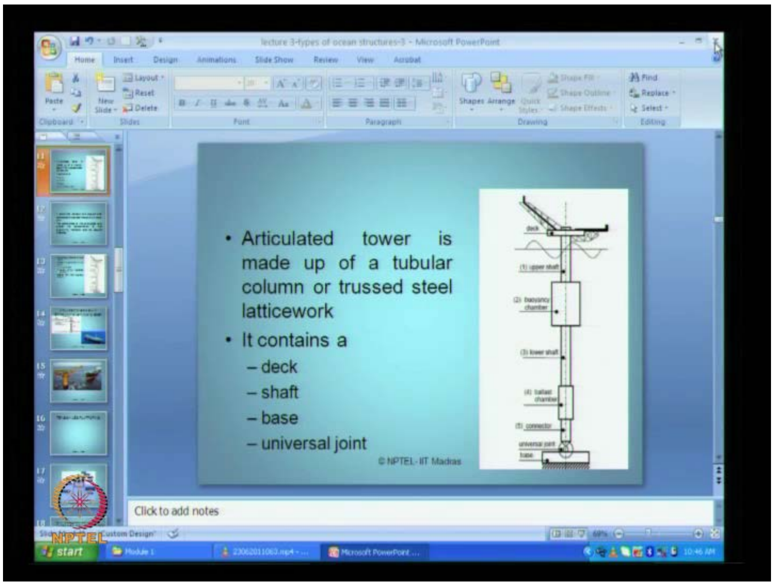
So, any increase or decrease in axial tension is a reversal of cycle of forces. So, mooring lines are subjected to extraordinary fatigue and that is dangerous. I am writing short forms here - MR does not stands for mister mooring line; it is also mister because you are talking about guyed towers. Can I have a buoyancy chamber that is what we saw in articulate towers?. The next type of platform is a tower with articulation. Articulation is nothing but a deliberately introduced hinge or a pinned conneciton at a desired location. Can be anywhere you want. It can be at the bottom, or at the top also. Form-designed by engineers.

(Refer Slide Time: 41:06)



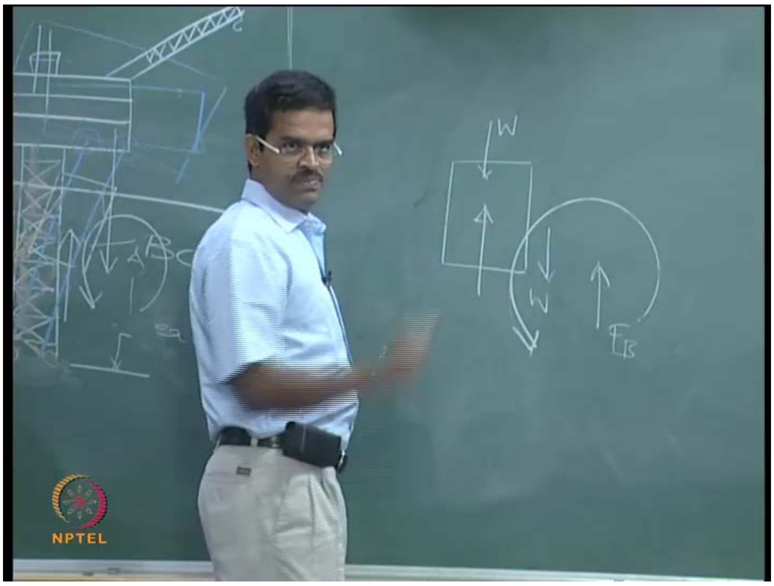
These towers are meant for small fields; for shallow waters essentially. The buoyant chambers are used for storing crude oil.

(Refer Slide Time: 41:13)



Now you have a buoyancy chamber here. This buoyancy chamber depends upon location and size. It gives extra force in the upward direction, which will cause a couple. I have a buoyancy chamber here.

(Refer Slide Time: 41:39)



For example, the buoyancy force acting at this location. Self weight is also acting here; exactly collinear, perfectly stable, no problem. When my buoyancy chamber tilts, there is shift of buoyancy with respect to the center of gravity and that will give me a couple, which will restore the platform to normal condition. Now think of having a buoyancy chamber at the bottom here, now it is here. If you have put it here what will be the disadvantage? or is it an advantage? A buoyancy is associated with the variable submergence, there is got to be a level of variation in submergence. If you put it here, it is completely submerged and there is no possibility of the variation happening.Where is the buoyancy going to be varied? It will not happen. What is the second demerit?One is functional demerit; second isoperational demerit; buoyancy chambers.

Student: There is a possibility of unique punctured, but they are concrete chambers.

Professor: The operational demerit is these chambers actually used for storing crude oil right. Interestingly imagine in 500 meters you are pumping the crude oil up to the platform and store it back below 500, what happens to the pressure loss, it is lost? right. So, try to keep it as close as to the mean sea level. In this figure, why the buoyancy chamber is bigger than the ballast chamber?, I want a very simple one-word answer for this. Why. the buoyancy chamber is bigger than the ballast chamber?, I want to show you very small video, which I promised. I have to do that.

Very interestingly, I want the buoyancy force greater than my ballast force because my cycle should be anti-clock wise for a lateral force- number one. Number two, buoyancy force depends not on the size, but on the submerged volume. So, as large it is as high it will be. Thirdly - I have got large container to store crude oil, which is one of the important requirements for such platforms, if it is used for production.

Student: (( ))

Professor: Yes, people used iron ore for ballasting; not necessarily water.Now I have a very interesting question for you. Why the ballast chamber is located at the bottom and the buoyancy chamber at the top? Can it be reversed? I need not want the answer now think about it.

So, I will close it here now, but, I want to show you a video which is very interesting, I want you to think about this video, how the design was done. So, look at this board. I have deliberately taken it horizontal. So, no foundation it is resting on the floor as it is. So, look at the connection at the bottom. It is subjected to very high wind pressure. See the flexibility the board has and the joint. What you had is not a ball joint, it is a simple spring mass damper system and see the flexibility. Equivalent natural example of this is a palm tree on the beach side. So, look at the joint this is what we are saying is position restrained, but not restrained again rotation, if you do not have any questions we will close.