Dynamics of Ocean Structures
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Lecture - 34
Fluid Structures interaction applications in ocean structures

So, in the last lecture we discussed about the equation motion of what we derived for a single leg articulated tower. This was the equation of motion what we got. And we wanted to find out the variables in this like beta of t. K m u t etcetera. And we wanted to show that i z etcetera.

We want to show that how they are all functions of the displacement. Therefore, we will use a specific methodology to solve this equation of motion to find out these variables and then we substitute back and find out the values of theta which is the displacement quantity in this case. Where in this we already said that mass moment of inertia represented, the damping term because it is velocity proportional, viscous damping, and this has got 2 terms one is the initial stiffness and one is the variable stiffness, because of the buoyancy effect in the system. And f of t is of course, moment on the force acting upon the system, about this particular point this is the hinge, from with respect to which all measurements are calculated in specific case.

So, we also try to find out what is the mover turning moment and restoring moment. Which happened in the last case based on which we discussed and derived, the value of k.

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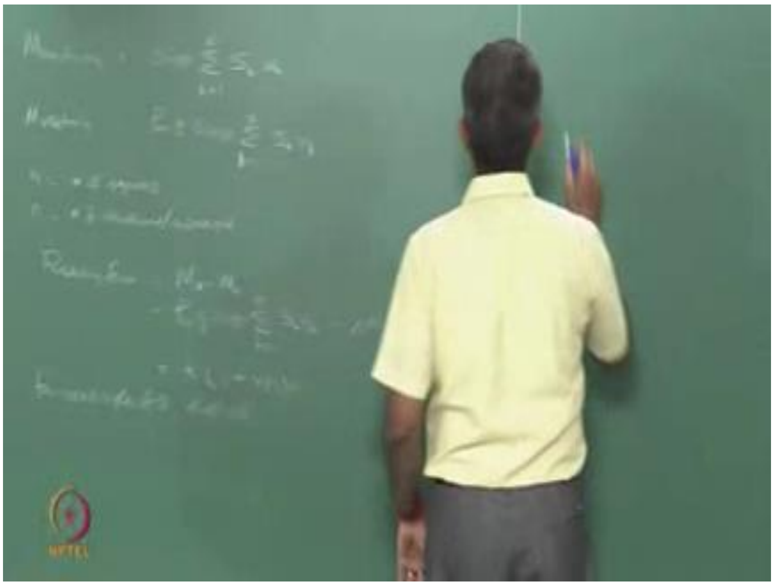

So, let us rewrite the equation. We already said that over turning moment, which is responsible for overturning the platform is again the summation, of s k w k, where as the restoring moment which is depending upon the re centering capacity of the platform, depends upon the submerged volume which is rho w g, summation k equals one to n small n of s k v, k capital n is a number of segments considering the analysis where as small n, is number of immersed segments. Or we say submerged segments considering the analysis. Therefore, we should say the resistant movement of the resisting force, actually the restoring component minus the over turning component which was rho w g sin theta summation of k equals one to small n s k v k minus sin theta summation of k equals one to capital n of s k w k. We also know that the restoring component of the resisting force of the system will again depend on initial stiffness. So, I should say this should be equal to k of one plus mu of t theta.

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So, equating this 2 by small angles of theta sin theta will be equal to theta itself. You have seen this relationship we already said that rho w g summation of k equals, one to small n s k v k, minus summation of k equals, one to capital n s k w k should be equal to, capital k of one plus mu of t since I am using this k as initial stiffness which is undisplaced portion or unaltered portion of the platform, I am trying to alter this equation slightly, I now going to alternate anything on the total weight of the platform, but I will alter this as n naught where n naught is a number of segments, submerged at undisplaced position of the path time.

Now one may ask me question why we are taking undisplaced portion. Because k is the actually the initial stiffness of the platform therefore, we are considering this as an undisplaced portion. The moment I say undisplaced portion; obviously, we all know that r t will be set to 0 automatically, because r t is a invoked stiffness. Additional of the spring in case of or the hinged joint in case when the platform is displaced therefore, they reset to 0. K will directly become the value here. Which can be given by this equation, as we can call this as equation, maybe I do not know the real number means this is one 2 and we can call this as 3. Now I can call this as 4. Where I say k is given by rho w g, summation k equals one to n naught, of s k v k minus summation small k equals, to one to n s k w k.

This is let us say 4 a. So, I have got one summation, which is displaced, which is the function of n naught and n naught is actually a function of displacement. They govern how many n members will be inversed or submerged in the platform and any given point of time. Now at any instant of time, mu of t this value initially set to 0 because the undisplaced position, but any instant of it will not be 0. So, mu of t can be given by rt, I think we are calling this as a restoring force r t theta minus one same from the equation here, equation 5. In this equation 5 we already know k because k is calculated depending upon what to say undisplaced portion configuration. On r t actually depends on what is the submerged volume elements, and what is the total element given here, because w of every element is known to me, s k is actually length of the element measured at k distance from here in the original equation.

So, I know r t and I know k s. So, for every theta of iteration, I will know r t therefore, I can say that r t or mu, of t is a function of k, is a function of displacement here. So, already we said that k, is a function of displacement indirectly, because this will be governed by number of submerged elements in the undisplaced position. So, it is a function of displacement indirectly. Mu of t which is again a function of initial stiffness is again a displacement function. So, we are trying to find out what are those variables given in the equation of motion, which are all converging to be functions of displacements. So, if you solve this equation of motion actually, which I wanted to solve in the displacement. So, I will able to solve this values substitute them back I will be the whole equation displacement function, I will iterate them and solve and try to get them for every time interval, t delta t and so on, k is one and r of t is a next one.

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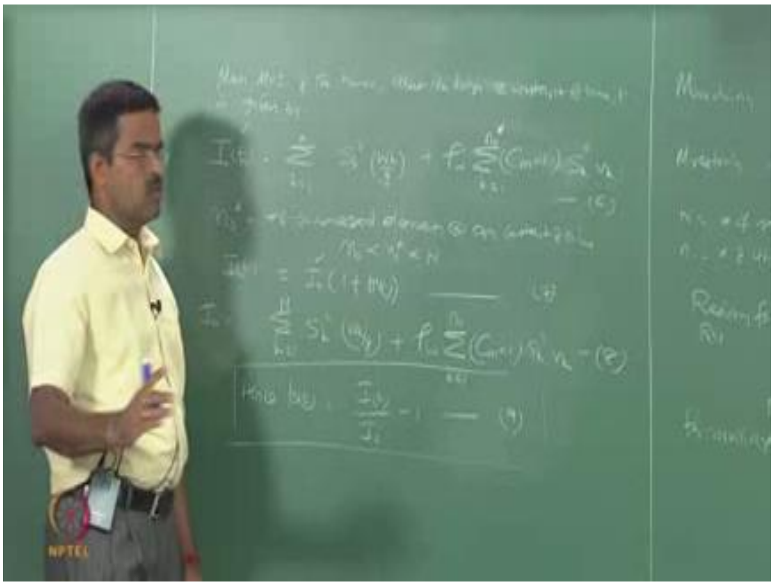

Now, let us try to find out what is the moment of inertia part of it. Now let us say the mass moment of inertia, of the tower, the moment I say mass moment of inertia the second moment of area, I should say about the hinge, because I must always say above which point you are taking the second moment of area, about the hinge at any instant of time t. Is given by, so, I want to find at any instant of time t, what is the maximum coefficient. So, summation of k equals one to n where k is counts, which are running for the number of segments given in the problem. I should say s k square because we are taking the second momentum of area s k is the distance, of course, I am looking for the mass therefore, w k by g, plus rho w that is the density of sea water, summation of k equals one to n star n 0 star, I will explain what it is, c m minus one of s k square of v k, one can easily understand catchy, when I am running a v k iteration I will always use small n wherever I am running w k and w k by j, w k by g mass iteration ,always run a capital n because it is a total mass of the system and this is submerged volume.

Now, n 0 we already know that n 0 is the numbers of elements submerged in undisplaced position. Capital n is the total number of segments in the given system. Whereas which work out weight of the platform, were as n 0 star is the number of submerged elements, at any instant of time. So, one can see simply a hierarchy like this n 0 less than n 0 star less than n that is the hierarchy. Actually n 0 is actually the value where is no submerged I mean there is no displacement taking place. N is off course total number of segments and n 0 star can be at any instant of time, you know what is the number of submerged elements, and that will govern my total mass moment of inertia of the point about the hinge, because it is s k into s k s k square. So, that is the distance of the point from the tower at the waves.

Now, we know the equation of motion. It should be actually equal to i 0 of one plus beta t is it not they should be equal to that it that is a participative term from inertia. So, let me say this equation is equation number let us say call this equation number as 6 i can call this equation number 7. So, I should say i t at any instant of time to be equal to i naught, and i naught which is the moment of inertia the system is undisplaced position, because b of t will take care of the displaced position of additional mass of inertia. So, i naught should give you the mass moment of inertia, the undisplaced position which can be again by the same equation with the small variation, k equals one to n s k square, w k by g plus rho w k equals 1, now I will use n 0, because I am talking about undisplaced position s k square v k and c m minus one let me do in the same order c m minus one s k square v k.

So, the only difference between equation 8 and that of equation 6 that the second part which is caused because of the submerged effect is only at instance of time, but these are the initial position of the system that is the only difference. And we all certainly agree that, i t will definitely more than i 0 by a factor of b plus, t that is very important, because this is where contributing the displacement, and we all know that the number of segments submerged will be more than n naught, and less than total n. Total n is the number of segments available in the system.

I know i t, I know i naught, equating 6 and 7 I can easily find beta t. Beta t hence i total or i t divided by i naught, minus one I will call equation number 9. You can; obviously, see here that i t and i 0, which are all dependent which are the governing factors of calculating b t, will be actually dependent on n naught, or n naught star, which will again a function of displacement indirectly. Because in the platform is not rotating, the tower is not rotating there is no displacement then n 0 n, will be equal to n. When they are rotating they will keep on changing it means indirectly this value or this factor, or this factor, will be dependent on the rotation offered, to the system by lateral force. So, they are displacement dependent again and this count is nothing to do stiffness. This actually the count which runs only to count the number of segments in the given tower, that is why it is small k and where ever you get stiffness, I think we have used capital K.

So, we have the equation of motion. We have got the variables in equation of motion. And we have seen that all the variables like k, and mu t, beta of t, then r t which are all function of the displacement therefore, the whole equation of motion now as got only one variable, which is either the displacement, or derivative of the displacement, or velocity in the acceleration.

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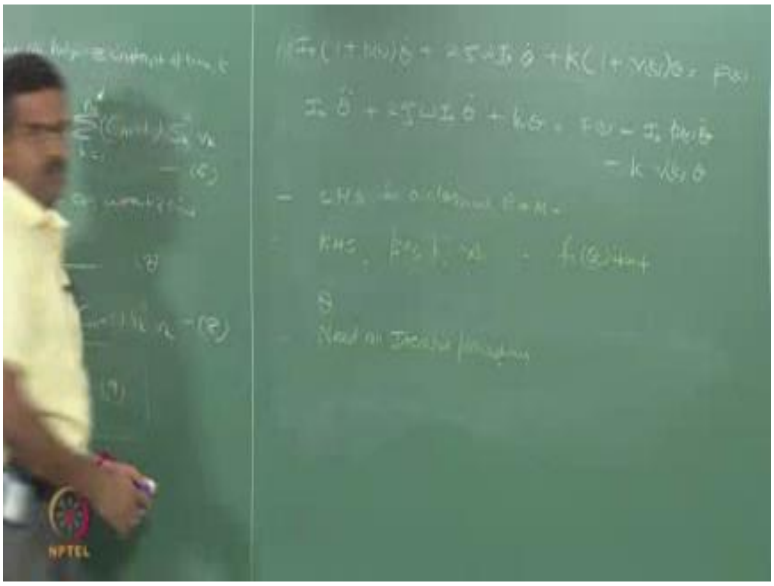

So, we must have a scheme to solve one can ask me scheme, why I need a scheme to solve this why cannot we directly solve this. Let us look back again the equation of motion. Let us say i naught one plus beta t of theta double dot, plus 2 zeta omega c theta dot, plus k of k of one plus mu of t of theta, is let us say the moment of all the lateral force on acting on nth segment, taking moment about the point, where we also taking the moment of all the places where it is nothing, but the hinge of the tower.

I rewrite this. I say i 0 theta double dot, plus 2 zeta omega c theta dot. Plus k theta it is a classical equation of motion in theta. 2 zeta omega, please make a correction here it is i naught, is or not. Am I right? So, it is a classical equation of motion where the remaining terms are taken to the right hand side, which of course, f t minus. Let us say i naught beta t minus, this is theta double dot, minus k mu of t, theta. Now look at this equation. It is a very strange character of this equation. One the left hand side of the equation is a classical equation of motion, for a multi degree freedom system, provided theta is the size of the vector. In this case really one because only one rotation being assumed. If you look at the right hand side equation of the motion, there are functions like beta t, k mu of t etcetera which are all function of theta itself. So, I have a very strong coupling left hand side and right hand side equation of motion, and the coupling variables is nothing, but theta which actually the unknown of the system.

Now, when you have got an equation, where the left hand side and right hand side both depends on variable itself which is to determine from the equation. You have to have iterative procedure. You have to assume a value and keep on substituting and try to find whether the assumed value, and obtained value are matching. So, you need a risky, we need iterative procedure. We will talk about the procedure later. I will show you the solution now they will talk about the algorithm later because I want to discuss with algorithm all the problems at the end being common. Now let us look back what is the mathematical model we have here what are the assumptions to be made, and then how it has been solved from the research paper directly.

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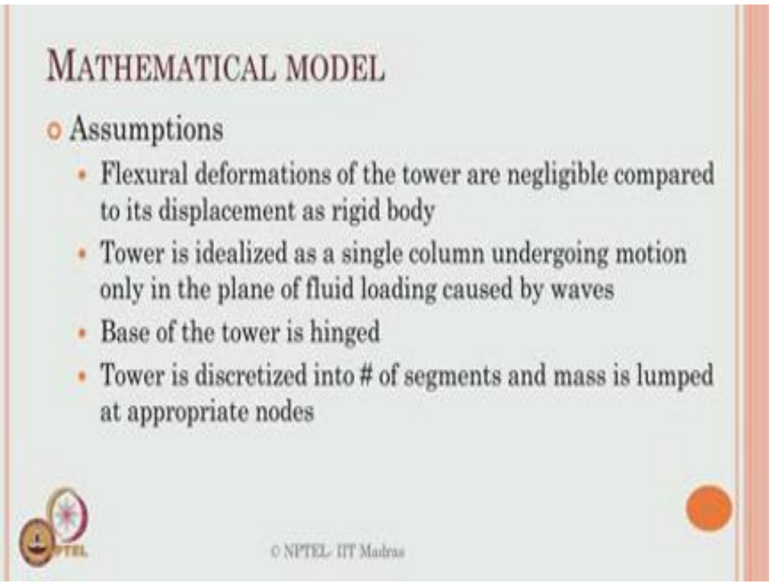

So, we need to attempt to solve this article tower let us say the assumptions made in mathematical model are the following, the flexural deformations of the tower are negligible compared to it is displacement as rigid body. So, the tower can also have a displacement, but they are negligible, they are neglected from the in the in the analysis. The tower is idealized as a single column if you got multi legs, then you got a rule separately in this case there is a single column, undergoing motion only paying in the fluid. There is no transfer vibration in the tower that is the idealized session in this case ok.

Thirdly the base of the tower is thoroughly hinged. It does not offer any resistance to rotation. Tower is discretized into n number of segments, for our calculation purpose. And it is assumed that at n number of segments the mass is lumped, at appropriate nodes, that is, how the n counter is running once you have this assumptions make.

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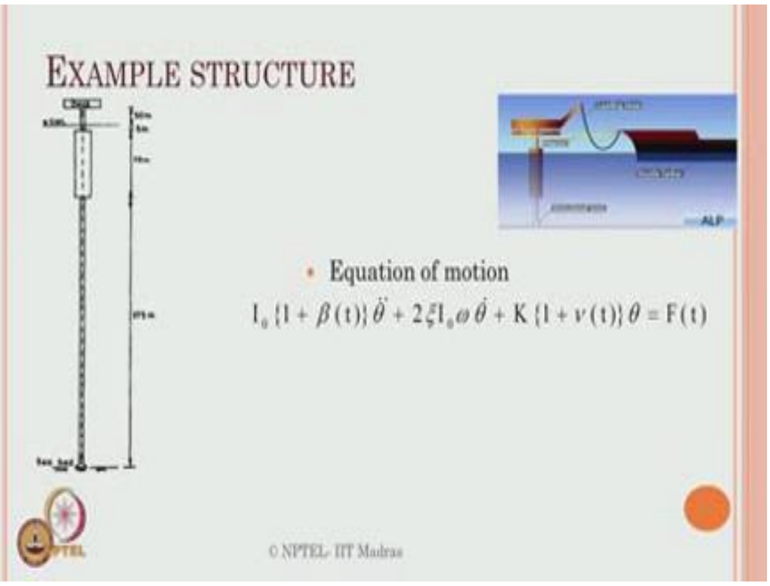

We have the classical equation, which is tallying with what we have on the black board here i plus beta theta double dot i naught omega theta dot and k mu t f of t, where f of t is the moment of the forces acting on the nth segments on the tower about the hinge of the tower. Now the right hand side of the screen shows you the real time problem. Because it is a idealized model, what to see in the left hand side geometric dimensions, are given there. Sea bed 275 meter height the buoyant chamber is 70 meter, 5 meter with sea water, level 50 meter above at the top side. The idealize system, is what to see you in the left hand side in the screen. Where as in the right hand side the real life system, which is a alp anchoring like platform, which is you can see the tanker the shuttle tanker is used to be anchored with the tower.

So, they are not actually production platforms they are not explorative platforms also, but they are part of production system. Because the shuttle tanker are used actually to transport the explode oils from TLP of any production unit to that of course, for processing. You need to hold the tower or sorry the tanker sometime when it is been the shuttling out ok.

So, this is the nothing, but the anchoring system. Now we cannot have an anchoring system. So, rigid because the tower will on the shuttle tankers are very high volume. And they subjected to lot of motion. So, they should be arrested. So, this is one. Second thing is if you really want to attempt to repair a shuttle tanker, or inspect a tanker, you need to hold it in position displace will not work. It gives lot of it should be more or less held down in position. So, this system can also used as one of the repair capacity to hold down the shuttle tanker for sometime in the sea. Because the shuttle tanker cannot be sailed back coast, because it is unfit to sale. You need to visit the electro mechanical complication of the system; we need to hold the tower hold the tanker for some time. So, you need to have anchoring system. Thirdly if you really want to temper naval base somewhere you want to naval base temporary. May be for inspection, may be for some recording purposes, or may for some continuous monitoring in a specific location. You actually cannot have a tanker or a vessel of course; you cannot do it in a submerged vessel. Because there is a limitation of course, submerging can also be used for deductions, but they have limitations. So, the shuttle tanker of this, I mean of this order the single leg tower can used for inspections also.

So, there are many applications in navel architecture of ocean engineering as far as a i ts are concerned, but aits are never used as production platforms. They can use the storage platforms, because there is a big buoyancy chamber available here. We can partly store it in the buoyancy chamber itself. And remaining we can keep on pumping out with the shuttle tanker, and shuttle tanker will carry the pump oil back to the course for processing a regasification etcetera. So, this an example structure you have a real type structure, in the right hand side. The equation of motion already, we have derived and we have shown you the variables, we have seen that all the variables are displacement, dependent in this case the degree of freedom, is theta it is the rotation of the tower, at the hinge or respective to the hinge.

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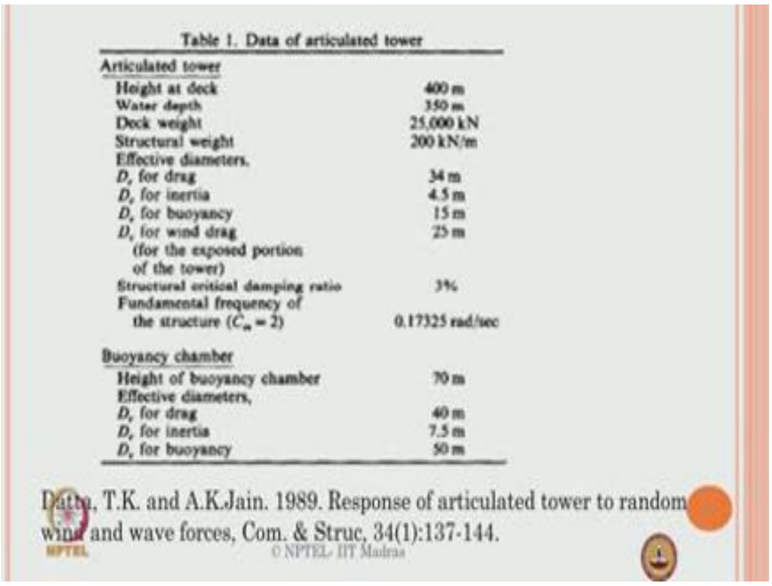

Table 1. Data of articulated tower

Articulated tower	
Height at deck	400 m
Water depth	350 m
Deck weight	25,000 kN
Structural weight	200 kN/m
Effective diameters,	
D_r for drag	34 m
D_i for inertia	4.5 m
D_b for buoyancy	15 m
D_w for wind drag (for the exposed portion of the tower)	25 m
Structural critical damping ratio	3%
Fundamental frequency of the structure ($C_m = 2$)	0.17325 rad/sec
Buoyancy chamber	
Height of buoyancy chamber	70 m
Effective diameters,	
D_r for drag	40 m
D_i for inertia	7.5 m
D_b for buoyancy	50 m

Datta, T.K. and A.K.Jain. 1989. Response of articulated tower to random wind and wave forces, Com. & Struc, 34(1):137-144.

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If you look at the real time data of the original alp is the problem which has been considered height of the deck is 400 meters, the structure of weight is 200 kilo meter per meter, and the deck weight on the top side is about 2500 kilometer or 2500 tons. It is a relatively a big value the buoyancy chamber dimensions are available to you the data has been borrowed from the paper the results are also projected back to from the paper. So, now, I am discussing the research directly from the research paper which is quoting at the bottom here. So, the procedure what they have followed is what I will discuss later, but I will now show you the results directly.

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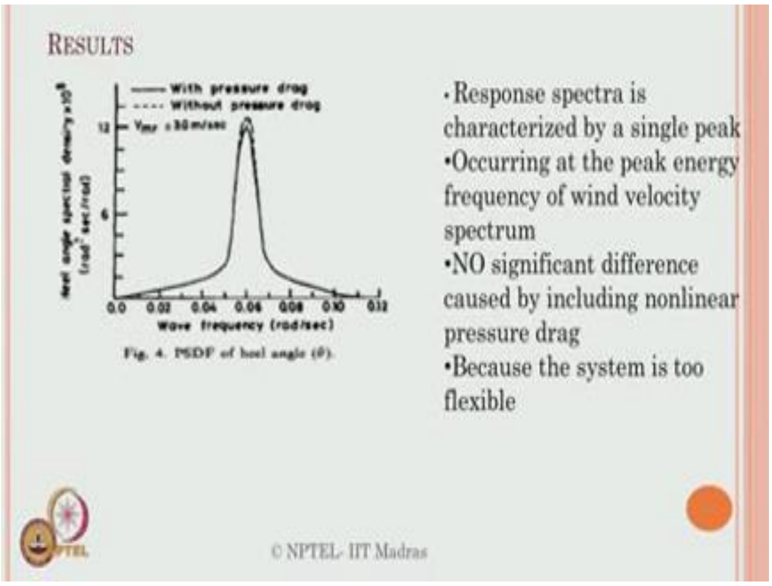

So, input spectrum is a power spectrum density function which has been used with and without the pressure drag, as shown in the left hand side. The response spectra is characterized by a peak you can see this is a single peak at frequency of about 0.06 radiance per second, it occurs at a peak energy of frequency of the wind velocity spectrum, because the wind velocity spectrum has a frequency is close up to this value. You will see that with or without pressure drag they have plotted one is a solid line, one is a dotted line. This is a solid line dotted line. So, inference says from the paper there is no significant difference, cost by including the non-linear pressure drag term in the analysis. The solution is done by both the cases linear session of drag and non-linear session of drag. Both they have done they have shown that there is no much difference.

The reason is they have attributed there is a this is a term to a system is too flexible, the tower is too flexible or compliance in nature. So, in case of compliant system drag in a session is not important, that is what we can infer directly from this kind of study. One can also see that what is the effect of instantaneous position of the platform.

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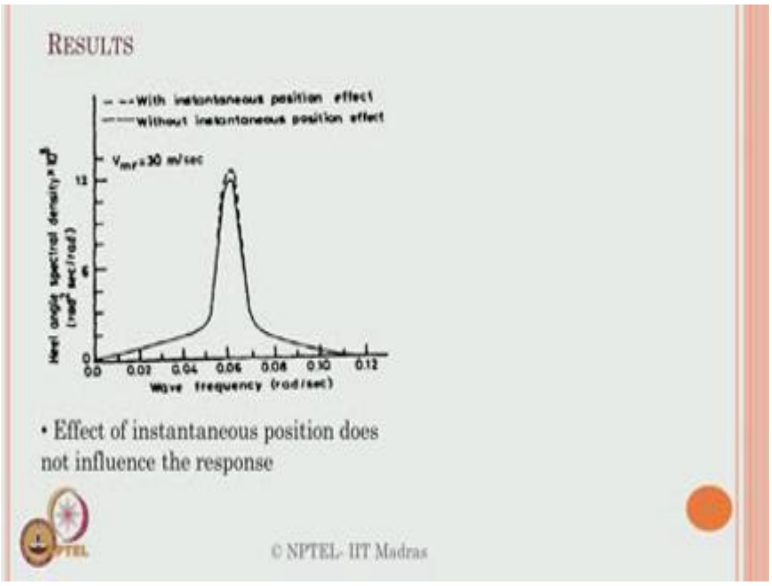

For example, you have the platform which is standing vertical the load is applied the platform is not vertical, but some theta is introduced because of the non re centering capability of the hinge. Because initially hinge may be able to bring back it to normal, but after n number of years, the hinge will be not in the position of bring back the tower normal vertical. So, if you instantaneous position effect also in the analysis, it shows as the effect of instantaneous position does not influence significant to the response because the response does not very much.

So, there are 2 variations noted here one is the peak difference one is the frequency shift. Practically there is no frequency is shift at all it does not affect the frequency content of the result it of course, affects the peak formation, but the variation is not significant that is what the researchers report.

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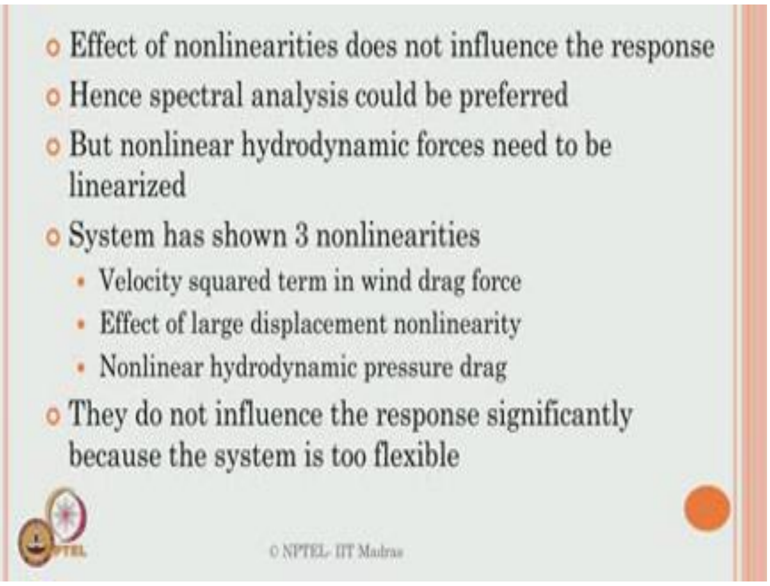

Therefore, effect of nonlinearities does not influence the response significantly. One can use spectral analysis. The moment you go to spectral analysis there was always static component coming to play here, but of course, the non-linear hydrodynamic force need to be linearized because that is what the requirement of comparison, the system as shown 3 nonlinearities? One is the velocity squared term in the wind drag force. The other is the large displacement nonlinearity the third one is of course, nonlinearity in the drag term itself hydrodynamic part. They do not influence the response significantly because system remains, too flexible to report this kind of differences.

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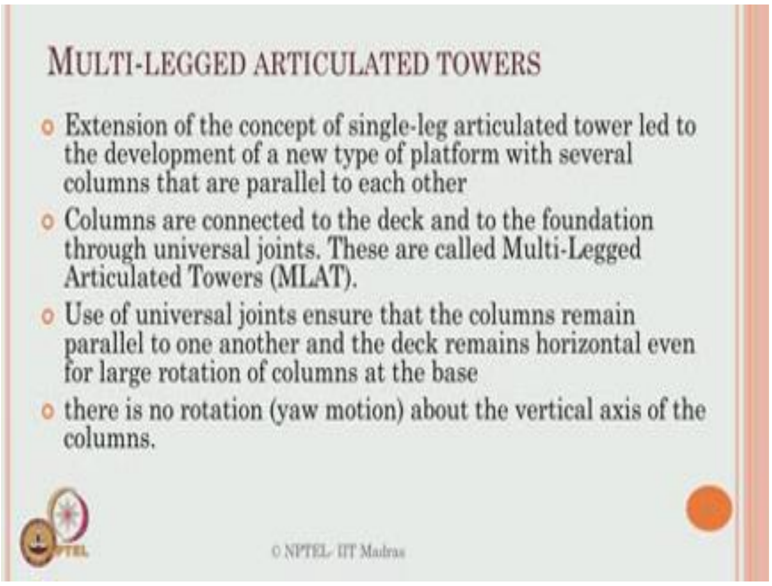

So, that is what the results and conclusion what we have, in terms of instantaneous position effect of platform, and the nonlinearity present in the hydrodynamic term, and as well as in the wind term, also may be please recollect that the window velocity spectrum also as a non-linear term as given by spectrum which are discussed in the earlier module.

So, there are 2 non-linear coming to play here. Because one is called as a static component and other is what the gust component. So, there is a non-linearity term there also which you also say that aerodynamic admittance function you can convert that term into equivalent static term, which mainly the design people use in the design offices. So, there are 2 nonlinearities one coming from the wind load, and one comes from the wave load. So, both have been reported by the researches saying that they do not significantly influence, does not mean that you never considered, but does not influence as far as this platform is concerned, because they say that when the system remains compliant, it is effects are not dominant in the response.

Now, question comes that how, r t a, ts have been moved up, in the analysis, or the dynamic perspective, to improve the functionalities. The people started having multi leg articulated towers. We have now seen a single tower people have used multi legs, because people have said that if you use multi legs, then one can have more advantage let us see what those advantages are. So, extension of the concept of single leg, led to the development of a new type of platforms, in early 80s with several column that are parallel. Then we call it is a MLAT, or multi legged articulated towers. Columns are then connected to a deck and the foundation, both using joints what they specified as universal joints. Universal joints are nothing, but hinged connections which of course, of a no rotation restrain, but in due cause of time they will also rotation, restrain because of the rusting effect because of the loading effect you have a hinge.

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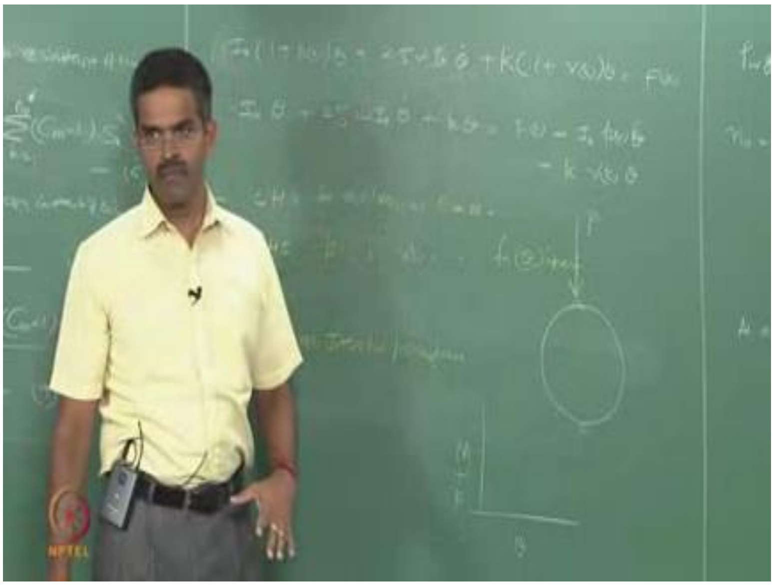

For example, I will have a ball; let us say I have a ball. I place the ball, between the rollers imagine a globe you must have seen a globe. The globe as got an arm and the globe is placed between the arms with 2 balls that is way the globe will rotate smoothly. So, imagine a similar system like this. So, for a small rotation of the globe, you will see theta as vary theta is where the inclination is being given for the globe.

So, m theta can be plotted in theta curve can be plotted for small rotation, for small moment even for small moment theta can very large, but when you apply a load to the globe, may be you stand on the globe for example, and try to rotate you will see that it will offer some restrain. It means when m is also connected to p and then you try to find out theta, and then it is a problem. So, when you have hinge, where the deck is connected and the deck is having 2500 ton loads; obviously, the m phi characteristics of the hinge of the universal joint will be no compromised. That is the very simple idea to understand how the axial load with influence, the rotation capacity of the hinge. So, it offers some constrain because of the load coming of the system. Load can be removed off because the pay load is on the deck.

So, use then ensures that the column remains parallel to the one another. I will show you a very interesting a very good video, which we have taken during the experiment of MLAT. So, I will show you some experimental results MLAT some analytical studies, on MLAT where, you will see that 4 legs are connected to the universal joint to the deck, when you apply lateral load terms of wave, you will see that, the legs will have an articulation effect, but the deck will remain horizontal. That becomes very important because if the deck is remaining horizontal. Your top side activities can comfortably take place. That is the advantage this is happen in single leg. I think you will a very interesting co relation; a single leg system will have or will lose the stability, even for a small shift of center of gravity, or buoyancy whereas if you got at least 3 legs in a given system, at least 3, not 4, 4 is redundant by one number.

If you have at least 3 the cg will be playing between the 3 of them therefore, the stability is enhanced. It is a very simple mechanics. So, people have used this idea to improve upon the design concept from a single leg tower to multi leg tower. That why MLAT came into play. Right they kept they get columns parallel, and they called this as multi legged articulated towers articulation term is picked from the universal joint. Interestingly when these towers are connected, between the leg and the foundation deck, and the leg, between the universal joints they offer no moment to the deck therefore, the yaw motion is completely compromise. There is no yaw motion in the deck at all. Yaw motion is one of the precarious motion of which is undesirable in any point of view. May be even in a ship or may be in a platform, because yaw motion always causes the shift or swing of the center of gravity in buoyancy center. And that will create additional load which will imposes a moment on the system automatically.

So, that is not required to happen therefore, yaw motions are completely and observed, by the joints of course, joints will have to be replaced at periodic intervals, if you are really want to because joints are rigid complete, have to some period of time.

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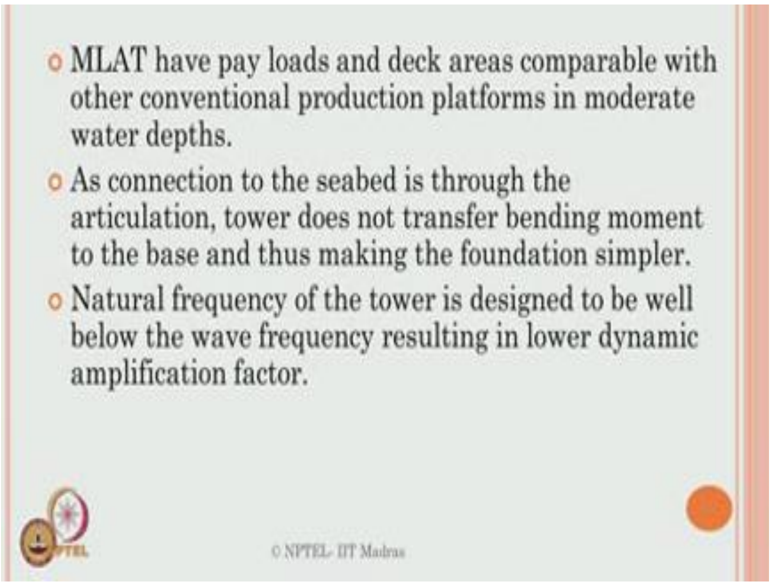

So, MLAT have also enhanced pay loads. Earlier example we saw what Jain and Datta studied, is about 2500 tons it is 2500 kilo per ton 2500 tons in this case they will I will show you can much be much more that, of about 30 40 percent more than this. So, pay load can increase, and the deck area therefore, can become larger, compared to that of single legs, and now you can have more production facilities here. So, this platform can be also used for production facilities. Earlier 80s where used for only for anchoring facilities, inspection facilities, or repair facilities, or storage facilities. Now here can also become a production platform or can be a supporting system to TLP. You can put drilling derrick on this try to, because why you can use derrick because, it is got more stability in sense, the top side motion in terms of yaw is completely nullified by using a universal joint. So, you can have a production facility on the top here.

More and most, interestingly is that since, you are connecting the tower to the sea bed using an universal joint, the bending moments ad this joints are particularly 0. So, the design of the foundation of the system becomes simpler. Where as in earlier cases design of foundation becomes very sever, and very difficult. Pull out etcetera, but in this case foundation become very easy because the moment at the joint, and the sea bed is practically 0 because we all know, the moment, bending moment, at the hinged connection is practically close to 0, but there will be some moment as I showed you m phi curve, there will be some moment, but the initial value or otherwise it is actually practically 0, for the design consideration.

That is one advantage and more interestingly the natural frequency of this platform has been studied, in such a way that they behave much lower than the dynamic amplification factor. That one amplified the effect. That has been studied I will show you some results later. So, some of this merit's have been understood while, people conceptualized multi leg towers viz a viz single leg towers. That is the how the dynamic analysis, progressively happened from, single tower to multi legged towers.

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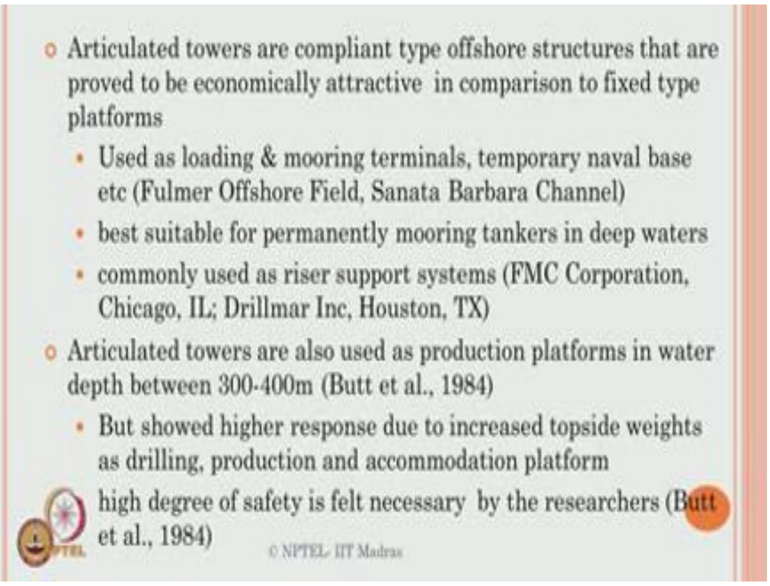

And we all know that ATS are compliant type offshore structures, which are proved to be economically attractive for medium depth, water depths compared a fixed type, because we started from fixed type. They can be used as loading and mooring terminals, temporary naval base, the examples classical applications are fulmar offshore, filed Santa Barbara channel, it best suitable for permanently mooring tankers in deep waters, even today they have been used they have been commonly, used most importantly for riser support system, fmc corporation Chicago, Indian oil Drillmar corporation, Houston have been also proven to use this successfully, many years in gulf of Mexico. Ats are used as production platforms, also upto a depth of 400 meters, you can see evidences from butt et al, 1984, but the difficulties with this is, they showed higher responses, because of top side increment, in the activities during production.

So, then butt et all 1984 indicated that, the response control becomes an important factor if you really want to use MLAT, as a production platform. That was intending in 1984.

So, early 90s people thought that I have to now work, on a system where, I must, I can use MLAT for medium water depth, up to let us say 600 meters, because 400 people are tested it is existing after this I can use. So, I can man over the platform easily from that of fixed 200 meters, to that of a 600 meter, very simple foundation easy installation, battery stability, and enhanced deck area more payload, in terms of production facility. But it has shown larger responses. So, people say can we work on now on response control, can we control this response, now because it is giving larger responses.

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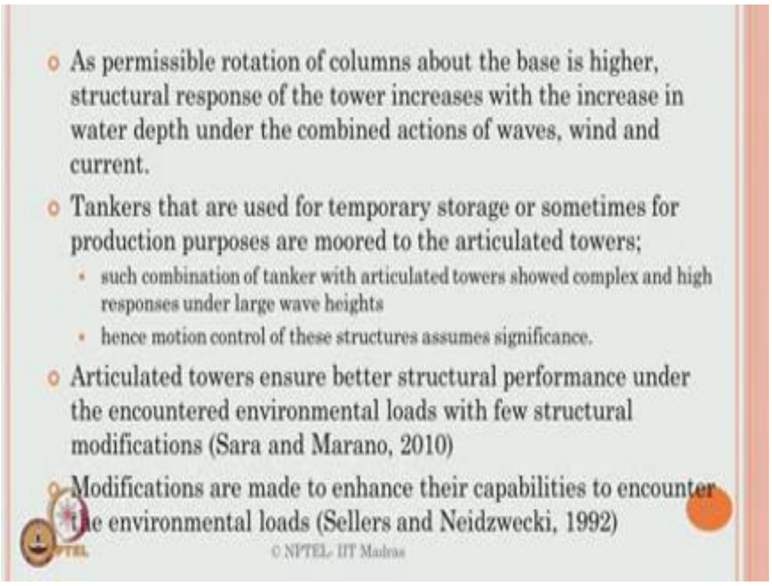

So, the reason was the rotation permissible at the column, became higher the structural response therefore, increased tremendous because of it is rotation, in combination of wave wind and currents. And when you are using this as a combination of tanker with articulated towers they show complex and high responses under large wave heights, because now the moment we start using the production platform, they will be used for larger wave heights as well.

So, when you go for larger wave heights or greater wave depths they show higher responses, therefore, motion control became a significant concept in early 90s for offshore structures, when people desire to continue with MLATs one of the super alternative for medium water depth for exploration and production. Ates ensure better structural performance Sara and Marano 2010 they have shown. They have got better structural performance of course, you have got the few structural modification existing design, sellers and Neidzwecki 1992 that the capacity to encounter environmental loads are higher, when you make some changes in the design, in the platform.

So, design conceptualization was improved, by making some certain suggestions as suggested by the researches, in 2010 1992 to here, but all of them including butt et all 1994 hinted, that the response control must be attempted, or must be addressed because the response are becoming higher.

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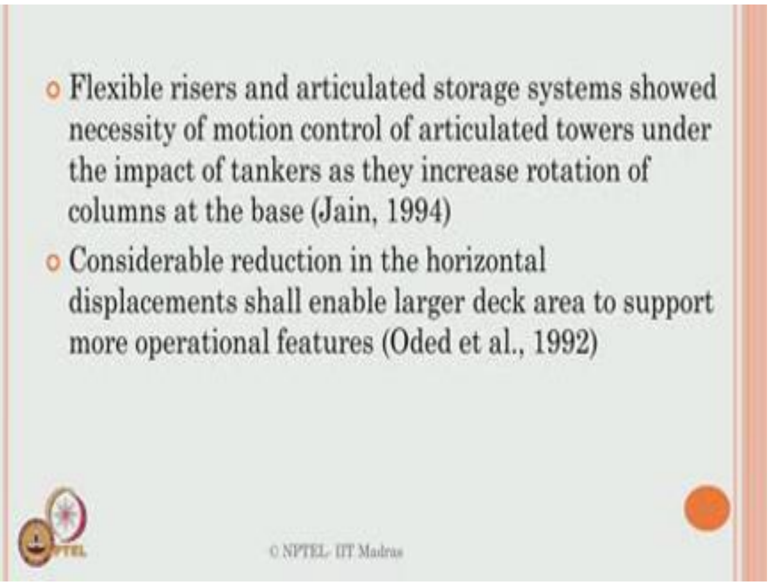

And Jain 1994 also said that flexible risers, and articulated storage systems showed necessity of motion control, because they have used this as a study. Because they when they have a impact from the tankers they invoked larger responses again therefore, motion responses to be controlled. And Oded et al 1992 also showed, that is the considerable reduction in horizontal displacements will enable larger deck area now.

So, if you are able to control the response, then you have further more large area of the deck that is in 1992, people hinted this. Therefore, many researches recently happened and focus saying that the response control should be attempted for better performance of the platform, from single to multi legged. Now there is one more concept in literature called multi hinged articulated towers. Instead I have hinged only the bottom in the top can also have the hinge at the center. One can ask me question, what is the advantage of having more hinges? What is the advantage of having more hinges, the advantages of having more hinges is the moment, you have hinges all this places the design moment will practical becomes 0. You can have a very classical example, of this a comparison of this very quickly, what is the advantage it design weighs to have more hinges, the point is that let us answer this slightly later. But let us see what is the advantage for physically my I give a physical example of this, in terms of sports let us say we will take one sport, which is called pole vault.

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You have I think a pole vault or may be sport man pole. Vault is nothing, but you have a ski, of course, a frame and of course, this is slotted, let us a column, is nothing, but a bar. And here there will be always a pit, which a person will carry a stick, the stick will have a rigid bottom the stick will be very long. Longer than of course, the height of the human being proportional to be like this it is very long. You have to hold it one third height where you can produce height run, with a good velocity good speed. Come and punch this bottom, here as the stick bend it will throw you across the rod, it is very interesting game it is pole vault.

You must have seen people. I mean people use this philosophy to actually cross the boundary walls from different locations. In villages very common people use this. Now I compare this. Now this is exact model of what you have as an AT. Because there is no hinge in between and there is any foundation required, it is very light in system. If I introduce a hinge in between, you will see that the rigidity will be lost. Now the comparison of this is nothing, but the chain, which is used by Bruce Lee. If you look at the chain used by Bruce Lee, he has never used a single stick actually. He has used a chain with multi hinges. The moment you have multi hinges, you can make the chain straight, we can disconnect the chain, to not to become straight, can become the segmental. Also now the moments said this points, in design perspective become 0. So, we can device or design the system, not as a single member, but as pieces of members, therefore, the section dimension is looking very small. For the same load applied on the system.

So, multi hinges, will have advantages, and demerit's multi hinges cannot sustain lateral loads, but multi hinges on the given load can design, the system to be more economically. So, there are multi hinge towers also. What I am talking about is not multi hinge tower. I am talking about multi leg tower. I have legs parallel.

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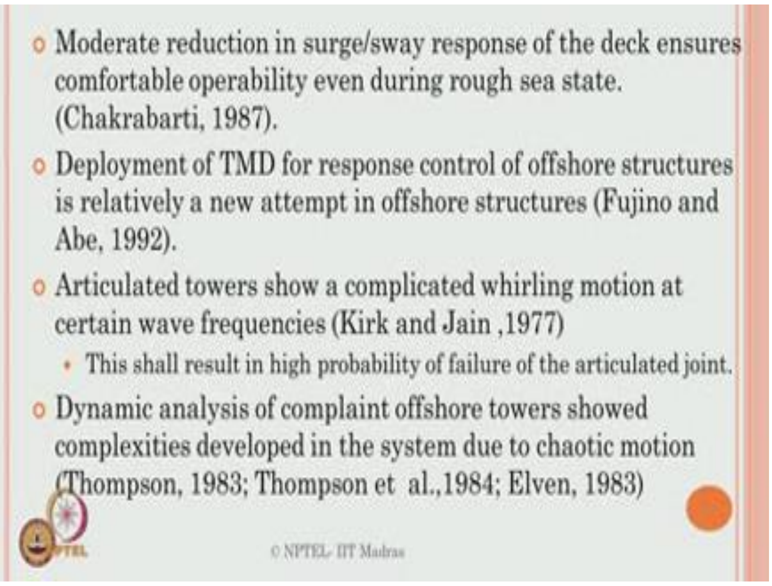

Now once you agree that yes response control becomes an important factor, to control the responses Chakrabarti 1987 pointed out that, the deck ensures comfortable operability, when you control the response, even in rough sea state. And then people have been used tuner mass damper concept in the buildings, not in offshore structures that of course, Fujino and Abe attempted this new concept, in offshore structure, and propose this it can be used. So, I should have a mass tuned for a specific frequency. We should be attached secondary mass system to the primary system, tuned the response of the primary system.

So, Kirk and Jain 1977 attempted this, and showed that whirling motions which are complicated in nature can be also controlled. Which will have a large a high probability of failure of that of joints, can be controlled if you have the response control, Thompson 83 84 and Elven 83 showed that the complexity developed in this kind of motion chaotic in nature, will challenge the stability of the platform.

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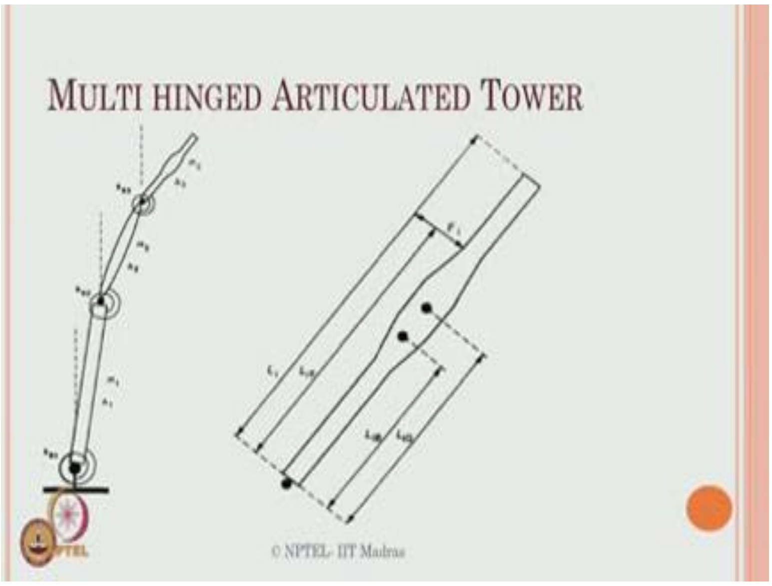

So, now, what we see in the picture is a multi hinged articulated hinged tower, same single leg multi hinge. So, we start with the multi hinge, we will show the multi leg platform.

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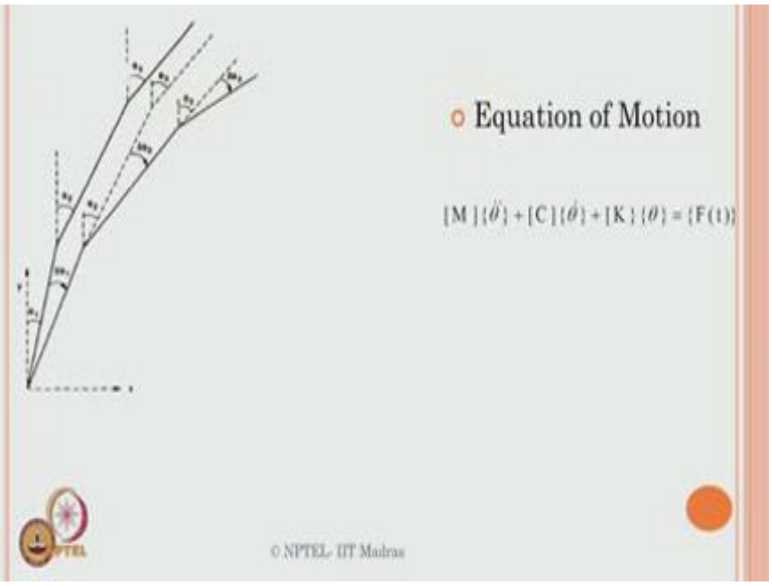

And we talk about response control. So, I will, we will discuss the equation of motion, derivation of multi hinged tower, gradually, move on to multi leg tower. And then we will talk about response control and MLAT itself in the successive lectures. The idea is, that yes now we are conceptually moving in the design perspective, from fixed platforms to that of semi compliant systems. Where we studied at and we know how to analyze them, provide the give the algorithm, and we already know how to derive the equation of motion, vary the equation of motion. We will move on to the progressive design development in ats, to that of MLATs response control, valid derive the equation of motion again here. I will show you what are the complexities when you talk about response control using tmd in MLAT once it is agreed, then people move on from 600 meter water depth to 1000 meter water depth, where this system is not approval then people went to 10sion leg platforms.

They want to make it completely bound. Now this is semi bound. Because only the buoyancy chambers are there either tower is attached to the sea bed using a hinger joint. They wanted to completely approve the system. So, that becomes TLP and spar etcetera. So, we will move on to that conceptual later. The subsequently people use this idea, in the reason past may be 3 years down the line, may be in 2011 12 the same hinge was introduced back again, and people started designing bouyantless structures.

So, we talk about bls or triceratops etcetera. So, the conceptual development of the design, along with the dynamic analysis moved, from fixed platforms, where we started in the started in the last couple of lectures back, to that of advance to even regasification plants, where the whole system is set to be a floating, in the concept started from there. So, that is way we have to understand how the design and dynamic analysis, went along together parallel in the discussion in structural domain of offshore structures. So, that is what we will focus in this particular module. We will take down to, once we understand these applications complete in this module. The next module we will talk about the advancements and dynamics that we talk about stochastic dynamics and how we can use this for advance research, will talk about that is how we will end the course thoroughly.

So, we have discussed in this lecture, about the equation of motion variables in a single leg at or simply at. We have also seen what is the physical understanding of this at because, if you have a system structural system, see the most important thing in offshore structural analysis and design is that, you must visualize the system in practice. There is buildings you can also visualize. Because you know some relative frames etcetera you can always see them very quickly whereas offshore structures cannot be seen in physical means.

Because you cannot either of the course, you will not be able to go there and see we all agree, and we should know that you cannot simply visit platform like that you need a permission. In fact, you have to undergo a specific class c training in helicopter; to visit a platform is very difficult. You cannot simplify even you CEO of company, if you do not have classic training, you cannot fly to platform inspect the platform it is very difficult. You can only see in the photographs. So, when you can see in the photograph, which is very rare you will not be able to conceptualize, the platform in idea physical terms.

Therefore designing in analysis become a concept only. That is way in this lecture; I gave a real time comparison. How an ats actually really existing, where does it exist, how an MLAT really exits, and what people have studied. So, I want to read those papers back again, before you really want to capture how the design and dynamic analysis got modified, in terms of improvement on the design itself, for accommodating the same platform, with small variables in the design, like introducing hinges, introducing legs etcetera, and how people took the design forward, and how they did the dynamic analysis, you have to understand this. If you do not understand the path of this growth, or progression of this growth, it will very difficult the whole exercise, will remain ideal in your mind that will become a concept.

So, with that concept, you did not able to design a platform at all. One ask me question why I am interested in designing a new platform. You see people thought about the new geometry that is why I am getting more and more platforms and deep waters. You people remain there idea only with fixed type platforms, possible they would have been no oil and gas exploration at present day.

So, people are constantly, continuously exploring for deeper and ultra deep waters, for gas and steel gas and oil exploration, because oil has become an, I mean indispensible requirement of mankind, all over the world therefore, it is a, it is becoming a dictating economy factor, for any country, develop developing etcetera. So, even a small contribution of research or idea conceptualization, or even analysis methodology, will definitely helps this community, in a larger front. Therefore, it is important we must understand the concepts thoroughly. Physical relationship of these concepts, before we proceed further and thing down the line individually independently, and come out with the conceptual design, which will be useful for this domain of research, and production in any country where ever you want.

Thank you.