Dynamics of Ocean Structures
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Lecture – 37
Tension Leg Platforms

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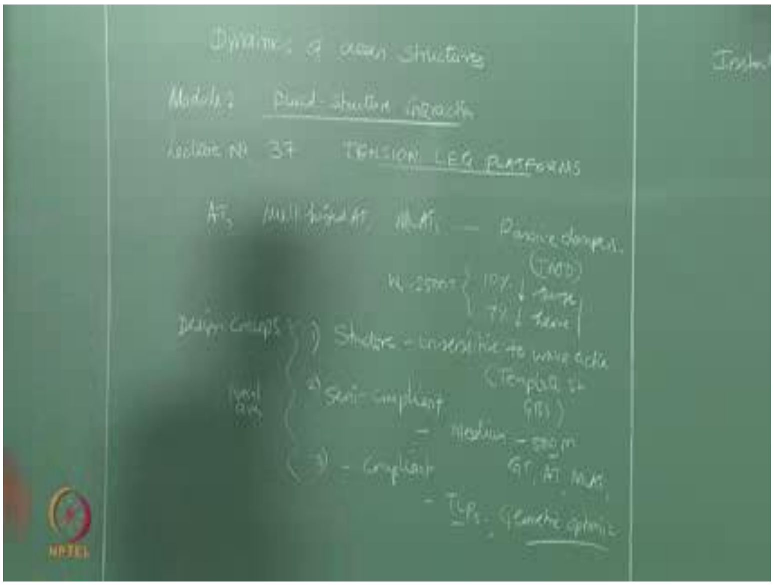

In the last lecture we discussed about 2 kinds of platforms, that is one is a fixed template structures, the second was the hot with towers, where we had discussed about ATs then multi hinge towers, then multi led towers. Now the literature by enlarge show that these towers have lot of quick re centering abilities, which actually causes lot of displacement, to the top hull, or the top side. And response control of this are mandatory, if you really wanted use and for production, and exploration. Otherwise they can use as an anchored systems, which was generally one of the functions for the pipeline support system or one of the temporary ways for inspection and repair, and if you really wanted to use them for exploration production, then one should control the top responses.

So, one of the interesting ideas which was concede by the researchers in early 90s and 2000, where response control using passive dampers, where we pick the one of the model of the passive dampers, where we used tuning of the secondary mass to the primary mass system, and we showed that how the control equation, with 7 variables can be reduce to problem of 4 or 5, and then we showed you that how the dynamic amplification factor, at omega equals omega n, gets modified with a successive adjacent peaks, but the value is then amplitude is slightly and relatively lower, which resulted in about 10 percent reduction in the surge response. And about 7 percent reduction in the heave response, attempted on a scaled model of one kind, where the top side weight was approximately, 2500 tons for a different mass ratio, where we call m 2 versus m one etcetera for we, are showed you the studies and how it was done.

So, we verified the whole concept to experimentally, analytically, and numerically. Then we showed that how the tuned mass dampers, can be one of the effective method, by which I can control the response essentially using the principle dynamics. So, we used it has a design philosophy. And we solved the equation of emotion and optimization problem in directly by choosing the secondary mass ratio with respect of the primary. So, we call this has a tuned mass damper system. It is one of the passive dampers were commonly used for buildings, but it was a very novel application for offshore structures for the first time

Then as we move on to let say the conceptualization, of offshore platforms, we know and we have studied in the first module, that they have started from the shallow depth to medium to d potters etcetera. The conceptual is an essentially focused on, the design concepts initially were focused on, initially they were focused on, a structure. We should remain in insensitive, to wave action. That is what people concede, has an idea for design of offshore structures. So, they came out with let say template structures, derived t base platforms etcetera.

But they found that the initial cost of construction, then commissioning of the platform and in on the other hand decommissioning, etcetera became very expensive and it took lot of time, for about 7 to 10 years to conceive a platform for production. And the platform requires lot of re repeated attention. So, that they get corroded because of steel there is essentially used majorly, as a template structure in jacket like structures, on because of devious there were other parallel problems in geo technical issues, where there has been solid liquid fraction, rocking phenomena occurring in the foundation etcetera.

So, the idea of making insensitive to about a depth, which was conceived in the beginning, for the design, was found to be a failure. Because though it was successfully in terms of it is application, but it has got other parallel social economic effects, and environmental effects therefore, people then moved on, to conceive this idea for medium water depths. Where they said let us make the structure compliant, like it flexible. So, one want to make it flexible, then they found a feasibility of moving this platform, from shallow water to medium water depths.

Let say up to let us say 500 meters. And they introduce guide towers, articulated towers, multi legs, and multi hinge etcetera. Where we have been all using them for medium for about up to 700 meters 600 meters, where there is a semi complains involved in this, but again in this case a top side responses were phenomenally high. So, people could not use them for production and exploration, and the top side detail available in terms of it is size equipment detailing, where not as comparable to that of these kinds of structures. So, people said this idea is also not good. And immediately the exploration also moved on to deep water depths. So, people then came out to purely complaint systems.

So, initially there was semi complaint. Purely compliant systems and the first concept which came in mind and 80s was actually tension like platforms. Though there are many papers many literature, available to conceive the idea of TLP design, and dynamics etcetera, but in this lecture and couple of lectures, we will try to explain you, how TLP idea was conceived as a design philosophy, and how dynamic analysis can be done for tension like a platform, experimentally. And we will also talk about something called geometric optimization, of a TLP. I mean why and why where we can do a optimization for geometric design. Where is a necessity for this? We will talk about this. So, this will be an interesting area, which is new and relatively appreciated in the literature in the reason past.

So, we will talk about this. So, the moment we say tension like platform, then the idea actually came out with the different philosophy in terms of it is a design.

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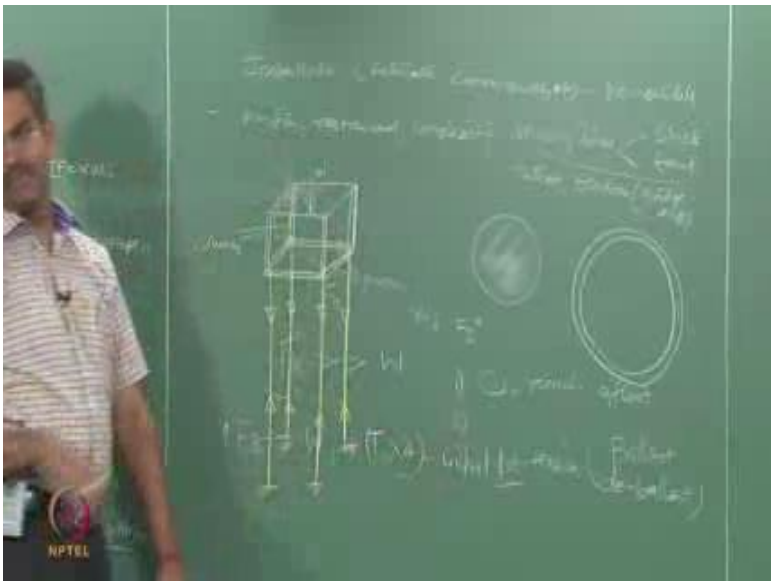

Now, fore most focus in this concept was installation. One can even say fabrication. One can even say commissioning etcetera, but the initial focus was installation. I mean people wanted to make it installable free and with a main focus in installation as re usability. I mean, I want to have a portability platform. Essentially I want to move the platform for location a to b and b to c and so on. So, forth without much effort which you are not possible at all in any one of the earlier conceived ideas, completely new. So, it was drastically a half way of thought process, in terms of design of offshore platforms, where people wanted to make it totally in mobile. But remember in all these through years from 60s or may be even 20s till 2000 nearly, parallely navel architecture, was also a parallel trade, where ship building was essentially growing in a very rapid state. Essentially not in India, but in many developed countries ship building industry was in a very great progress.

So, they had a very good idea about, how to handle a floating vessel of a very large size. May be even for a warship, even for cargo handling etcetera, in terms of how to nano over them how to design. And therefore, they would have easily anchored that very ship. And convert the ship to offshore platform, but that idea was not conceive till 90s. Drill ships came very late in idea. Even today drill ships are used only for exploited building, not for production. Because it is very expensive to hold down a ship of that order, compare to it is economic viability in some of sealing it for commercial value. So, people do not use it. Only the ships which are non salable are then alter to made a drill ship even today that is a fact.

So, people never conceive this idea in terms of design concept for a platform. People always thought platform should remain stationary, but re usability and somewhat high degree of complains, not mobility in sense they want to move the platform from a to b, but the never wanted the platform remain in motion, while drilling is in operation. So, ship idea was never conceived. So, there is a drastic difference a dynamic analysis between that of floating bodies, to that of fixed bodies that is where the difference is. One may easily understand that if you know dynamic analysis of a floating body; cannot a design a complaint vessel. No, because complaint vessels do not float. They are thought more they are push and resistance. That is where the make maximum difference comes in to play a dynamics.

So, they wanted to make it position restrained. One can ask me a question, why a system should remain position restrained, even if you want to drill ship to be used or the ship to be is use for production, you have to have essentially, the drill well which is identified and you have got to do an exploration, the rises are connected therefore, the risers do not have high degree of flexibility in terms of it is length adjustment, except marginal therefore, you have a vessel which is meant or a platform, which is meant for production even exploration, should not move by enlarge in a large way.

So, they should remain position restraint. The moment they position restraint is a focus, they also wanted to make it complaint. Then these 2 objectives were met simultaneously with the synchronization of holding down them using mooring lines. There are 2 types of mooring lines, one can I have a category mooring prevail which is completely slack mooring, which is a slack mooring system. Other one is a taut mooring system. Slack mooring system is generally deployed, for holding a vessel of a large size and position provided this vessel is allowed to in a large displacement, but does not want to get of folded from a point. Whereas start mood systems are generally used in a place where you want to remain or retain the vessel position restrain, and taut mode systems will always limit to the displacements.

So, there is a fundamental difference in behavior, between a large vessel which is floating, between the large platform which is position restrained therefore, the dynamics applied here will not apply here as well. Because as we are understand from the fluid such a interaction to a by enlarge way, if the vessel or the body is allowed to move in a large dimension it will cause secondary vibration, like v i b etcetera which does not happen in this kind of vessel or plat forms, because they are predominantly positioned restrain. So, people after for a taut mooring system. So, they gave a new term to this has tethers. Tedons, tedons is a term which actually borrowed from bridge engineering. It typical styles of cables are used in bridges for pre stressing they are called tendons.

So, this been actually borrowed from bridge engineering because in early 8ies or late 7ties bridge engineering was in ots speak in first development all over the world. So, people have used pre cost pre stresses constructions where tendons have been used. So, they have borrowed this terminology. In fact, high yield the strength deformed was with high initial yield strength values have been actually started used in offshore structures, only after they were successful in bridge engineering. So, that is a idea why they borrowed the in the terminology also from there. So, tendons are used of course, they have named as a tethers. So, tension like platform is the first idea conceived, may be in late 80s or early 80s. We have got a very long history. I will be given you the history what are the platform constructed in the world, elsewhere TLP etcetera, even till today we are not looking back history, but let us see what is the conceptional design.

So, let say I have a body, usually a rectangular in shape. Let say a block let say I have a solid block a wooden block list; obviously, when I want to make it completely some whereas it will not have buoyancy. If it is completely floating it is of no use form me because I have to position restrain this. So, I have to have a partial submergence. It has to partially submergence partially the above one the moment is partially submergence. The volume of immersion, or vector surface area, we play a role which we all know by Archimedes principle this will apply a vertical force which we call as a buoyancy force. Buoyancy force is a actually proportional submerged volume of the members.

Now, we all know that these cannot be a solid block, because I have to have lot of operational features on the top. So, people will converted this into columns and pontoons, these are a called columns, and these are called pontoons. So, these are called pontoons, these are called column members. And we all know that the moment you allow the member to remain transparent to waves, we already saw in fluid structural interaction in the earlier lectures of this module, when the wave passes through, then the obstruction caused with a member if it is minimum then the force exerted on the number is minimum. If the wave is obstructed by the member then it causes lot of secondary forces diffraction radiation etcetera, we saw them in detail in FSI earlier lectures.

So, with that idea conceived in mind, people said between the columns in the pontoon led this area remain hollow. Let the wave pass through the wave passes through. Then the forces on these members are minimum that area was conceived very easy.

So, now I have a body which was not, which is not solid, but I am focusing only one excessive buoyancy. The buoyancy will appear only when I have got a large surface area it does not ma bother about the weight, I want have the submerged volume should be larger, for example, to be very specific I have a cylinder whose diameter may be may be 100 millimeters. I have a cylinder whose diameter may be 200 millimeters, but hollow, may be a tube. The amount of submergence is solid. This is solid this is hollow this is a tube in this, is this is a solid cylinder

The amount of submerged in both the cylinders is same, let say x or h in that case you will; obviously, see since this diameter is larger though the submerged height is same, the volume of water displaced by this member will be much larger than this. So, I am talking about actually buoyancy. So, with these idea of people has large diameter, lof columns and large diameter of pontoons, and made them hollow the moment, you make the structure hollow structure actually lost it is weight because it is hollow. Now weight has come down, and buoyancy has gone up. Because large diameter sections weight has come down. There are 2 reasons we are having large diameter structures. One large diameter members because excessive buoyancy. Large diameter because members because these inside space can be used for some storage also. Can be for ballasting can be for oil storage many purpose can be met. If one wants to because this idea was not new this was used in buoyancy chambers, in 80s also in tight hours also people has used this idea.

Suppose the same idea would definitely have an effect on this consument of a new concept when it grows. So, people said let have a large cylinder of hollow in size or a tube, but I have a members of a larger diameter, but since the diameter the structure has become completely transparent to waves, of course, the top is solid. Because I have lot of top side details here. So, it is solid it is a deck may be not a single deck multi layered deck. Of course, the bottom may not have anything except that there can be a pontoon through which the drill riser grows through, and rising are there drilling operation takes place.

Now, with this concept conceived, weight has come down drastically. Because you have made the system wave transparent, but buoyancy has gone up drastically, because you receive large diameter column members and bottom members. So, the idea is now buoyancy exceeds the weight, by a very large value. Now this is got a very get advantage what is there advantage the advantage number one, which is fore most is when we have any system whose buoyancy force exceeds weight, the system can remain or float. We do not require any energy to move the system or float the system, which was originally the idea.

Now, they want to make installation free therefore, the system can remain float because of this characteristic. Number 2 the moment I have a system which can remain or float I can always free fabricate the system in modules and bring it from a workshop, and float it to my site where as in earlier cases the structures were built in module they have brought in vessels special cranes were used, the cost of installation construction fabrication begins very expensive, because you are doing the entire installation on sea, under a specific weather window, but in this case it is not. So, it is like a vessel.

Now, one can ask me a question how people are confident in an idea of bringing a vessel or a structure or a platform or a module, which is very large in size, but remains of float this idea of engineering was borrowed from navel architecture because people already had this idea, of floating very large vessels in other ships. They can float from any area to any area because they had this idea. The design area was there conceptualization of installation of fabrication commissioning and manuring was already present for our 100 years with ocean engineering team.

We have used that idea conceptualize the design, have a design of buoyancy exceeding the weight. Now when you look at the whole equation of equilibrium, the whole platform will have it is weight which is acting w. Now since f b which is acting upward and w acting downward, need to be equal. Because generally it can remain in equilibrium otherwise, the system will always have a tendency to pushed up there should be something which has to bring it down that was nothing, but t which is call the axial tension in the tethers. So, now, I have to put a cable or a tendon, or a tether, or a taut mooring line to all the columns, and anchor it to the sea floor by special arrangement, which has same, which were same, as that of guide wires or guide towers used earlier. Where you have got a touch joint point where people used drag anchors or they are available here as well, the idea was borrowed. And now you will; obviously, see they all will be in tension. We all know how to mark tension in an axial cable. It is always marked respect to the support

So, they are all in axial tension. I call this specific value t, as initial pre tension. The moment I say pre tension then one can conceive an idea has an engineer in mind that tension is re, is in is applied, or pre applied to the cable. Now one can see here where the tension can be pre applied. Because we have got the applied the pre tensions to this cable in see, somebody has to go down and pull. And there are top tension tight and rises ttr systems are available, where we can make it round about and pull it in the top, but still when you are pulling a cable of a very high value, you are pushing the system also you have to have a reaction, if you want to pull something you have to push something.

So, it is very difficult to have such a mechanical complication, because that will add complexity to be installation fabrication. So, people thought what can be best done. The best done is people say; initially I will say I will ballast the system. So, all these columns members, and pontoon members which are hollow inside, were used to fill up ballast material essentially, water because they can be taken out easily. So, initially you ballast. When you ballast them weight actually increases. When weight increases platform comes down beyond a design draft there is a design draft. For this platform may be if this is l or h, may be this is x bar or h, bar this is a design draft for this platform. Where this is maintained, for the design draft, but when you add ballast weight will increase the design, draft will come down the platform will come may, be they keep on adding more and more ballast and more and more within the top the platform, may even completely sink also there is the possibility. Because you can make w to also exceed, or equal to f b without t that is also possible keep on adding weight it will sink.

So, keep on ballasting them attached the cable here attached the cable here all these 4 points and keep on adding ballast. So, the cables now will be all selected, they are all will be free is it not. So, the diverse can go down, anchor it to the file foundation specific location titan, them. Once they are ensure they are tightened you de ballasted. The moment de ballasted, because of the buoyancy force, the buoyancy force will try to push the platform up, and that will automatically impose pre tension to all these tethers. So, that is why it is call tension like platforms all legs will remain in tension, all the time, all the time. There is no question that at any service time in a TLP, these the tethers will again stacked. Why because they are not tension impose their pre tension, imposed tension is already, there if you are not having tension, in the platform you cannot commission the platform at all.

So, at this value is very high because, I said buoyancy is excessive by large number than w. Therefore, this compromise has got it only by t 0. If I call t 0 is initial pre tension per leg, per leg. I can always say multiply this with 4 because there are 4 legs. And each leg can contain different material or different configuration of tether.

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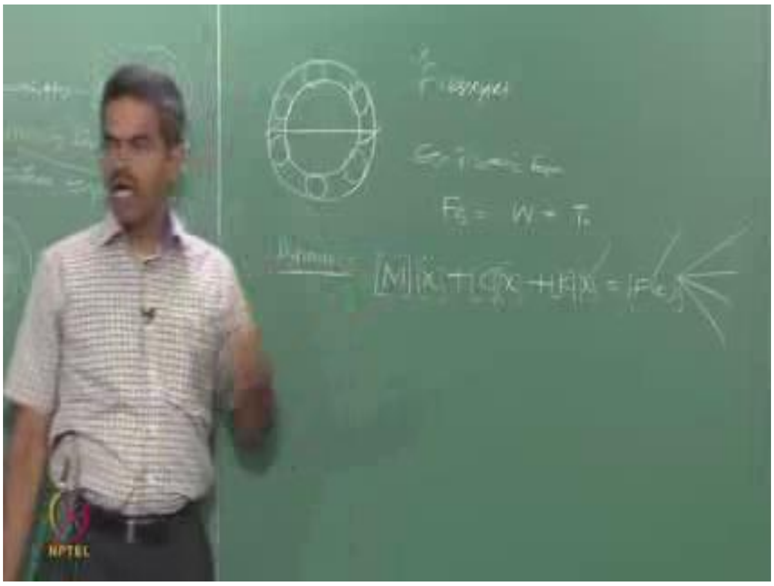

May be tethers can be of a solid code, each may be having group of tethers, may be 6 may be 8, may be 12 depending upon what kind of platform. If you look at the history of how platforms were erected and commissioned.

Now, the TLP and TLP etcetera, we will see the group of cables and each leg can vary anywhere from 3 to that of 12. So, I am not talking about single cable I am talking about a group of cable. The yellow line represents here is nothing this each is a group, again one can ask me a question how they will be arranged, how they will be all interlocked how they can be pulled together, how they can be slacked and together, the whole idea came again from bridge engineering. I can give one example facilitate is one of the style of pieces any bridges. Where people have used multiple cables of this order and try to pull them together and release them together. It is an idea in bridge engineering.

So, the same concept similar of this order has been used here, but unfortunate part here is, you are not applying any endeavoring forces here, like in bridge pears because here tension is automatically imposed only by ballasting and de ballasting the platform. So, large buoyancy of large diameter, hollow space have been used erection all concepts became advantageous, in terms of it is design conceivement for a TLP. So, TLP idea became very popular, and TLP started getting commissioned, and the installation time from 10 years to 7 years came down to just 2 years. So, drastically the construction time are, let say the time taken for producing oil, from that of the freely identified came down drastically and economy improvised very fast. In gulf of Mexico many TLP sequential were constructed. Re usability we will talk about this slightly later.

Once you talk about the stability of the platforms then, I will say how wave it can be done. Now if you look at easily think, if you really wanted to re use the platform from location a to location b where a initially had oil exploration viability, but it has got exhausted, I want to move it to a location b which is few kilo meters away from here where I cannot do drilling from here itself what all I have to do is simple I have got release these pre tension cables; obviously, since the pre tension is very high, I cannot simply think of releasing them, just like that if you cut them will cost lot of secondary vibration, it will damage the whole platform itself. So, I have to again ballast it release the slackening of the cable, is then cut them deblast it the system will you come out float move it.

So, it is very easy conceptual rise, though a very difficult to execute it, but possibility was there. So, de commissioning fabrication re usability installation all came into play powerfully, with great advantage of using a TLP as a concept. Now if you look at the equation static equilibrium that is at any given point of time, when a TLP is not in motion then we choose is satisfy now. A say t 0 is the total pretension in all the thetas is equal static equilibrium, any point of time this should be satisfied. Now in talk about dynamics as we know that is may classical equation, of motion for a given system which is multi degree, if it is multi degree then these are all matrices, these are all vectors, and we already have worked out in detail, how to find out f of t, using different wave theories and different spectra, to finding forces. We already know the right hand side of this equation.

What are may be the structural system, I should be able to divide them into finite elements and try to find the forces because of the executed by the water particle acceleration velocity, and the member and from there you can find the forces, either you can use wave fraction theory or I can use Morison equation etcetera. I can find the force each member I can accumulate them. I can rearrange all the forces in the total citizens in the freedom. I will get a full vector which I can easily. So, right hand side is not a bothered issue for me as of now.

Now, the question here is in this case displacement velocity and acceleration, are my unknowns. Because there was later structure in the earlier case it was not very serious because, they were actually not be getting displaced at all. In this case they were serious, because we are talking about the compliant system where the displacement is very high in order. So, I have to solve this equation of motion to give me the structural displacement. So, I must know all these matrices first. That is said, the stiffness matrix the mass matrix and see. How they matrices of this order are different from that of the earlier structure is the duty, this is where the design idea, became into a difficulty in dynamics.

Many, many papers will not detail talk about except that V J Korean etcetera in early 70s came out to the concept of explaining how these can be derived, very seldom papers in in literature review will give you detail explanation, of how to derive this stiffness matrices. Very difficult you would not find these papers. Though stiffness matrix derivation is actually, elementary lesson of a structure in mechanism concerned, but many authors did not actually give that in detail.

You will find most of the papers do talk about analysis, dynamic analysis results. Rouse response amplitude operators, response control geometric optimization, all about TLP is there are no can about. I think for the past 20 25 years I can be a lot of conceptual papers in TLP. Even today TLP engineering as gone to that level, even good congress like omae like isope asme do you all have dedicated sessions parallel sessions, on TLP alone. It has become to that, it is become a domain of engineering. So, that extent is grown. I that has been proved to be very successful up to depth, of about 1200, 1300 meters of water depth. People have used commissioned platform successfully.

Now, it has been a proven concept, that TLP can be an established model for oil explosion to deep waters. No second thinking about it. So, people have dedicating lot. Now people now talk about stability re stability etcetera and how to improve the performance of a TLP for greater water deeps, etcetera. One greatest advantage of TLP had, these are all of other platform. So, far till 80s is that, when I talk about this has been my water level there is my design draft, this is my water depth. Let say small d and because capital d indicates the diameter, capital d will indicate the diameter, therefore, small d will always indicate the water depth. So, this is the water depth in a design draft I have call this h bar. So, you will see that except for a small fraction, of that of the depth, the whole volume as no material investment. Where as if we look at any other platform prior to this, the whole volume of it was invested, in this segment alone and it was only 20 percent above.

So, it was just a swapping concept. So, people immediately saw a very good economical perspective and installing a TLP. So, that is the idea. And to have a thumb rule people stated with these understanding that the pretension in the cable will be approximately about equal to 15 to 20 percent of that of the weight in layer. That is a idea there is a overall thumb rule. We will talk about that design in details later. So, every good congress started having dedicated sessions on TLP. And TLP engineering has become a great sign of promotion in offshore industry for deep water oil exploration production processing etcetera. Because the top side was as similar to that of any other platform, to given idea you may remember, may be mass TLP as a size about 80 meter one side. So, it is very large in size, very large platforms. You can look at the geometric and structural configurations of different TLP's available in the site from the open domain or any papers listed in NPTEL you can see them, but never the less no TLP or anybody dimensional less than 66 meters it is a very fairly of very big platform like a like a small township. So, it is a big platform in size.

So, they have got a very good concept and have been established.

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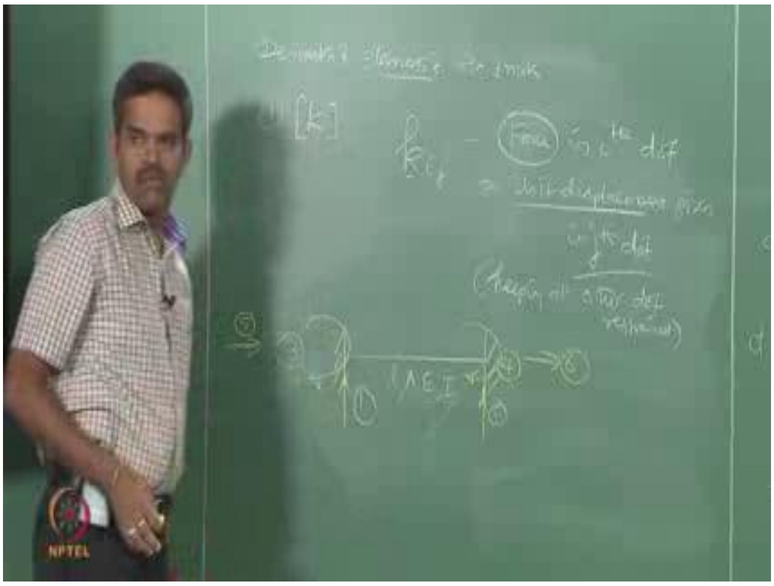

Now, let us talk about derivation of, let say elements of equation of motion. Let us take the first element as the stiffness matrix. So, let us quickly see who do we derive a stiffness member of a stiffness matrix. If I say k i j, because small k will indicate member of capital k, and capital k is actually the full matrix. It is nothing, but the force, force in i th degree, I am using degree of freedom as duff, i th degree for unit displacement, given in jth degree. Keeping all other degrees of freedom restrain just have a quick resemblances we must recollected how we generally do a stiffness matrix derivation for a beam element, because you must have already studied in structural mechanics, how to derive, the stiffness matrix for a beam element at least one value we must remember.

So, if i have a beam which is fixed, and both the ends the b m has got length a l a e and i are the properties, i moment of inertia of cross section e young's module of the material a e i of cross section l is the length of the member from the supports, or between the supports I must draw the degrees of mass the degrees of freedom for this one can ask me what is the degree of freedom at these 2 joints it is actually 0, it does not move anywhere. Because this joint neither allows displacements nor rotation this joint neither allowed displacement or rotation the degree of freedom, for this mean beam at this supports are 0.

So, let us mass the degrees of freedom first. Let us say degree 1 2, 3, 4. Let us say 5. Let us say 6. And mass 6 degrees of freedom on a 2 dimensional plane. I am talking not about the third dimension, 2 dimensional planes. So, let us take up any one specific degree and try to find out what are the forces in all 6 degrees, if I give in displacement one degree, and see that is how I will get the first column. So, the stiffness matrix, it is always derived column wise.

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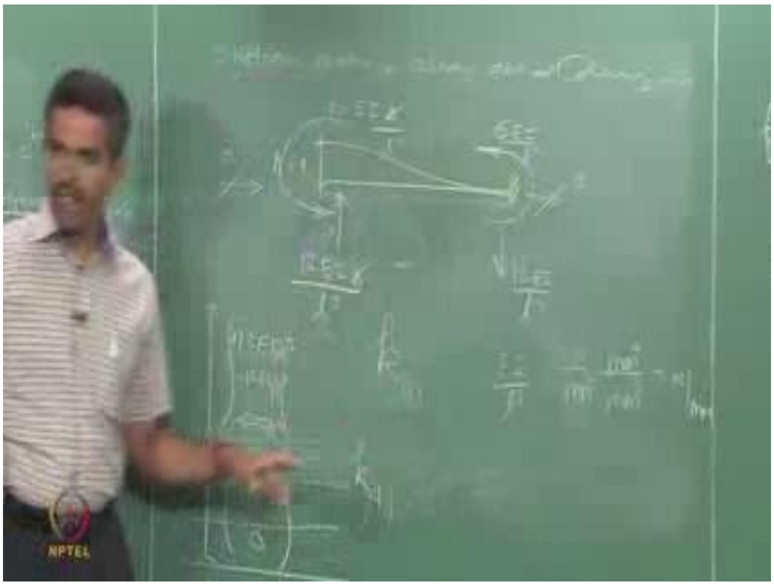

So, stiffness matrix is always derived column wise. So, let us pick up this beam again. I want to give any displacement about the first degree. So, I give any displacement. Let say this displacement delta is unity, this is my beam profile, you may ask me a question immediately, why I am drawing a profile like this it is very simple I have to imposed, that when I give unit displacement in the first degree, I have to keep all other degrees restrained, it should not move anywhere. So, I am posing them back; obviously, when I have a displacement of this order this will always generate a moment.

So, the moment is marked this way one can ask me a question, how this direction has been fixed. Since it is moved down, bring it down have there been moved down have it had moved down, bring it up have it had moved, to the right bring it back, have a moved to the left bring it back. So, you have to assume the arrow direction is such a manner that, you bring it back to normal see that is the idea.

There is nothing like anti clockwise here brings it back, when one can immediately have a doubt. Why we have given a unit displacement only in the upward direction, why not downward. Because that is actually equal to the convention of the sign, what I have assumed it then you can have a subsequent doubt that why have assume, the degree of freedom top, you can always assume in bottom also, no problem, be consistent. So, for the assumed direction give the displacement. So, bring it down. This effect will also transfer here back, this is a element of structural mechanics we already know this this moment, is very available in the literature we need not have to memorize this, but we can remember this easily it is 6 u delta by l square, delta, is unit I may not write delta hence forth. And same value 6 a delta by l square

Now, I got an anti clockwise couple, which is 12 ex delta by l square. I want to find the reaction which is going to oppose this. So, this is anti clockwise. So, I should say clockwise couple, because this couple will give me a clockwise value, which is going to result counter active, to the existing anti clockwise. So, I should think that it should be equal to 12 a delta by l square, by l, where is l is a distance between the support that is nothing, but the span of the member. So, 12 e i 12 e i by l cube. So, these are. So, 12 e i by l cube, now the all about the static balance. So, I have no force in these directions, I have no force in these directions also. Which is contributed by the displacement given in the first degree, it does not mean the there are no forces in the direction, for the given system of equilibrium there are no forces.

Now, i want to write the first column of the matrix. This is the first column which will have 6, because there are 6 degrees of freedom here - 6 rows and first column. For example, this element will be actually equal to k of 1 1 in an original stiffness matrix this one stands for the displacement given in the first degree; this one stands for the force in the first degree. For example, this would be k 4 1. This one stands for a displacement of first degree, where as this stands for the 4 force in the 4th degree. So, in; obviously, see all of them will have a second substitute, has one doing the first column of this matrix the first substitute will tally with that of the degree of freedom, what I have marked in the original freedom. So, let us see what is the force in the first degree, which is 12 a by l cube. Let us say I am writing positive here, because of force in the same direction has that of the degree of freedom, saying the second degree is upward, and where has the force where negative, minus 12 e i l cube.

The third degree is clockwise whereas say the third degree anti clockwise, anti clockwise. So, minus 6 e i by l square, I remove delta from various delta is unity in this case. The forth degree, is clockwise where has the 4th degree also is anti clockwise here sp this is minus 6 here be l square, and this is 0 and 0 because of 5 one is just not have any value. What is may be the sin convention it is 0. Now is quickly seeing the unit of one particular value. E i by l cube newton for m m square. M m 4 m m cube, you get newton per millimeter, you must understand I have to multiply this was delta, which is also in millimeter. So, I will get force nothing, but all the coefficients of stiffness matrix will give you back only the force units. I have neglected delta therefore, the millimeter is not coming there. So, I will get all forces back again.

So, this how simple way to remember, how I can derive a stiffness matrix, for a given beam elements which is studied in mechanics I will apply the same concept back again here in TLP, to derive the stiffness matrix of a TLP, from the same fundamental manner will derive the full, 6 by 6 matrix in the possibly next lecture, will do that. So, by this way you can derive all the remaining columns also, you can compute the full matrix. Of course, this is an order by which you can give this nable notation which we talk about advance structure analysis. You will talk about that not in this class, but in some other course later, but this is a simple hint which you can remember easily that if you remember the term rule how to derive a stiffness matrix for a simple beam element, same concept and we applied for a TLP derivation here. So, that why I am insisting this because, in the coming lectures we will talk about new generation platforms. Where the geometric conceptualization is still in the concept stage itself no platform is order has been constructed.

So, if you want really a do a research of that order, you have developed at least the stiffness and mass matrix. We can ask me a question why they are required. So, if I want to solve the equation of motion they are requiring. You can ask me a parallel question again can we model this numerically and some software and do it. You must check what are the fundamental frequencies of this to know that you must have k and m with your otherwise you cannot check. So, by any round of way, you must have a k and matrix with you all the time. You must at least know how they are derived. Then only you can check whether the numerical analysis giving you the k and m correctly are not. If you know that then you can always use any other numerical methods like stodola etcetera to find out all frequencies, and all mode shapes and we can compare to that of numerical analysis by x star seam etcetera then you have a check, double check yes my program is correctly landing correctly, you may model this right.

So, any newly developed concept needs lot of rich checking different stages, for which you must have the fundamental elements of equation of motion, ready with you. Otherwise you will not be all the time you cannot depend on, modeling them in software and getting the answers only from the software, which the whole concept cannot be subjected to any re checking or any re visiting at all. That is not a good idea in research. So, one must have the elements of the equation of emotion readily on hand. So, we will derive this in the next class for a TLP, with the same logic.

Now any questions any doubts here it is very simple, I mean what I have discuss. So, far is fine. So, in this lecture we talked about the conceptualization development of d potter platforms, from that of shallow over medium. How the geometric design or there is a design concept got evolved, from a shallow to de potter, why it was necessary and what were the prime of focus in developing or establishing the conceived idea for TLP, how they were easily met and why TLP became successful by making them dominant in many of the interest of congress today, because of this reason that they have been proven successful and for in instantaneous in a let us say start is which can see in the literature TLP's have so, far not shown any failure structurally.

So, far except for one or 2, we have not shown any structural failure. So, it has been you, you can always imagine a platform, which is conceived for a first time in idea for swapping meaning has so far not failed that all in this conceptual design. So, it has been proved to be a very successful attempt, in the whole offshore structural design itself. So, that is how TLP we can very important domain of engineering in offshore structural domain, and of course, based on this many parallel platforms also came, with which I will talk about later, but the conceptual development group from TLP and spar parallely, but TLP became very popular, because of many advantages. I will show you that mean only it talk about what are the complications in dynamic analysis, is the complication will start once you understand, or once you attempt to derive k you will know where the complication starts.

It is because of those complications people have started, I mean stopped doing dynamic analysis and detail; of TLP's that is one of the main reason why. Because you will see when I derived k it is going to be slightly difficult, in sense that I will follow the same fundamental logic, will derive it becomes slightly difficult. So, our job is to make it so easy. So, you appreciate and understand. Of course, there are parallel papers available in the literature which I have referred in the NPTEL website you can see then in advance and can read them. So, next class can be more interesting and more supportive also.

Thank you.