**Dynamics of Ocean Structure**
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**Lecture - 12**
**Dynamic Analyses of TLPs**

So, before we start the lecture we will have 2 minutes. I mean few seconds mourning for one fellow student who passed away last evening, his name is Sayan, is third year B Tech Naval Architecture, he met with an accident in the road yesterday. He passed away, so we will just maintain silence for about 30 seconds then we will proceed with the class, because academic activity in my opinion should continue. So, and we will anyway pay respect to the departed soul by observing silence for few seconds and we will continue.

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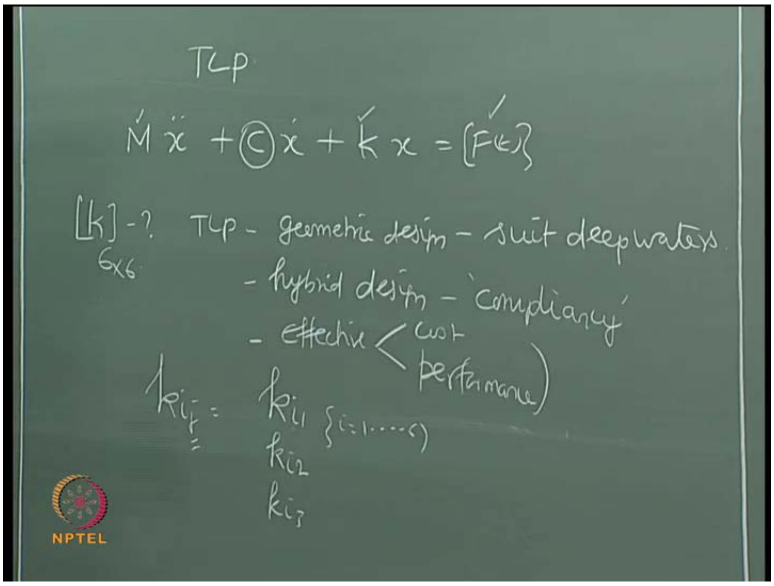


We will resume with the classes, now we are on lecture 12 on dynamics of ocean structures. In the last lecture, we discussed the derivation of the stiffness matrix for a TLP. We said the equation of the motion of TLP is formulated with the classical theory as we understand here. We are talking about derivation of the stiffness matrix; one may wonder why I have got to derive this stiffness matrix because TLP is a geometric design to suit deep waters.

So, it is a very special type of system which has got hybrid design capability which is otherwise addressed as compliancy in the literature. Because of the classical separation of 2 set of degrees of freedom, TLP is able to encounter the environmental loads at deep water depths, it has been found effective in terms of cost and in terms of performance.

So, just to understand if you want to do further innovative geometric design in deep water and ultra-deep water systems, let us try to understand from the first principles how do you derive the elements of this equation of motion independently as we all understand there is no greater difficulty in deriving the F of t because we already spoke enough about this in the first module. But still we will focus on M, k in this lecture. We will speak about C in another 2 lectures in detail how to estimate the dynamic mean the damping matrix for a TLP in detail, in the next 2 lectures.

So, coming to the argument of how to derive k, we already said k i j will be the stiffness coefficients where it give unit displacement in the respected degree of freedom in the jth degree and try to find the forces which are initiated because of the unit displacement given the jth degree by keeping all other degrees of freedom constraint. So, we derive column by column, the stiffness matrix derived column wise. We understand TLP has got 6 degrees of freedom. So, k matrix will be by enlarged from 6 by 6 square matrix. So, we will derive the stiffness matrix coefficients column wise, we already derive k i 1, k i 2 and k i 3 for i varying from 1 to 6.

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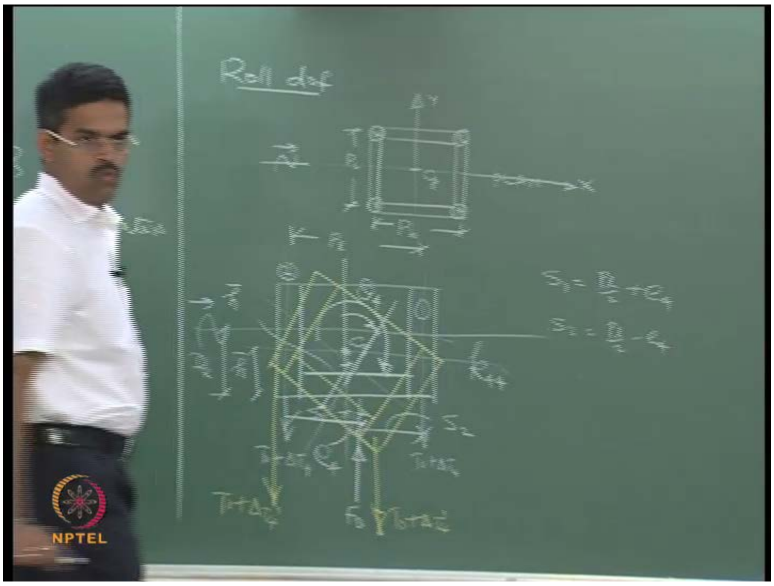


We already said this, so we will derive till the third column that is the heave displacement degree. Now, we will talk about roll, roll degree of freedom. So, let us recollect that I have a platform whose nomenclature is given like this. So, these are the column members designated as 1, 2, 3 and 4, this is the plan and this dimension is marked as plan breadth and this dimension is marked as plan length and of course, for the dimensions being equal this becomes my mass center, I call this as center of gravity. I am looking for the roll motion; this is my wave approach angle and this is my x axis this is my y axis.

Roll is nothing but the rotation about x axis, which I will see in the elevation from this side. So, I will draw the elevation of this platform from this side of course, I draw it here. So, this is my elevation actually, from this side this is my wave approach angle, this is my water level, this is what I call as D r which is my draft for the given platform. And as you see here this column will be designated as one and this column will be designated as 2 from the view here.

I want to give a roll rotation to this which is may be theta 4. Now, I rotate this body to this sway I am giving a rotation above the x axis which is going to be theta 4. So, initially I have tensioning the legs, which are T 0 plus delta T 4, I am using 4 here because of roll degree, T naught plus delta T 4 because of symmetry this delta T 4 and this delta T 4 will be equal, if it is un symmetry you can use delta T 4 prime here because the legs can be un symmetric also.

So, I rotate the platform. So, this must be my original C g. So, this is my h bar and of course, of clarity, this distance is actually P f. So, when I rotate this platform without imposing any other displacement, any other degree of freedom, you will still see that attention in the cable will remain vertical but they will alter now. So I call this as T naught plus delta T 4 dash T naught plus delta T 4 dash.

Now, you see because of these columns getting immerged more and this column protruding up there is a shift of buoyancy see from the left to the right. So, let us mark that new buoyancy you by and see as a point here which is going to act anyway upward and I call this distance from the C g to the new center of buoyancy as e 4, 4 stands for roll degree, e is the extensity of this C g initially, for a per perfect balance system the C g and center of buoyancy will remain same.

When I rotate or when I tilt in, when I give a roll angle to it now, the buoyancy shifted. Now, I call this distance as S 1 and this distance as S 2. So, S 1 is nothing but P l by 2 plus e 4 and S 2 is P l by 2 minus e 4. And as we understand for the tilted position if I mark the C g and I call also this as h bar, so h bar is just shifting as it is, so either initial h bar for initial position or for final it is going to remain same and of course, this angle is what I am interested now, is my theta 4, that is what I have tilted.

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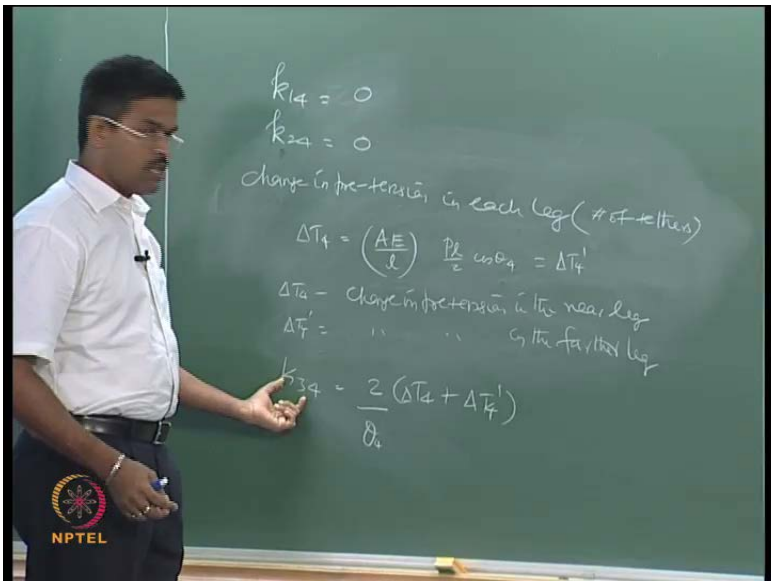


And of course, the force generated will be, I am marking it here which is k 4 4 because that is the force now get generated as a moment because of the theta given. Now, with this convention, let us say k 1 4 is the force in the search degree because of rotation given in roll degree will remain 0, because surge is not affected at all. Similarly, for a unidirectional wave because the wave is acting only in the x axis, surge force will remain 0. Therefore, there is no effect of sway because of roll angle this also remain 0.

Now, change in pre-tension in each leg, remember each leg can have n number of tethers, the number of tethers are not counted here, they are not counted here we are talking about each leg. Each leg can have 4 tethers; can have 6 depending upon the system. So, we are talking about pre-tension in each leg, leg means I am talking about the column. Call this as delta T 4 which is caused by that is a initial tension I have in the legs which is now going to be p l by 2 cos theta 4 that is the component in the direction of delta T 4.

Which will remain same as delta T 4 naught also or delta T 4 prime it is going to be same. Now, what is the difference between delta T 4 and delta T 4 prime delta? T 4 is the change in tension or change in pre tension in the nearer leg, delta T 4 dash will be the change in pre-tension in the farther leg. But, in this case because of symmetry all the legs are equidistant in the roll dimension; this is my roll dimension P L. So, consider leg 1 and 4 it is P L by 2, consider leg 2 and 3 it is again P L by 2. Therefore, a change in tension in the near and far leg will remain same. If you have a geometry which is not symmetric in plan then you can handle this separately.

So, let me now derive k 3 4 which is the force in the heave degree because of the roll angle given at 4. The force in the heave degree will be affected only by the change in tension that is now causing the disturbance, which will be 2 times of T 4 plus delta T 4 of course, divided by theta 4 because the unit is Newton per meter or Newton per radian. Now, I know delta T 4 and delta T 4 dash from this equation. You may wonder, how do I know that, because delta T 4 is a function of theta I am going to come to that later after I discuss my derivation. For example, if I know theta, I can find delta T 4 because all other components are known to me it is a geometric dimension. So, delta T 4 and delta T 4 prime are known to me therefore, k 3 4 can be computed, talk about k 4 4. That will be affected in delta T 4 automatically.

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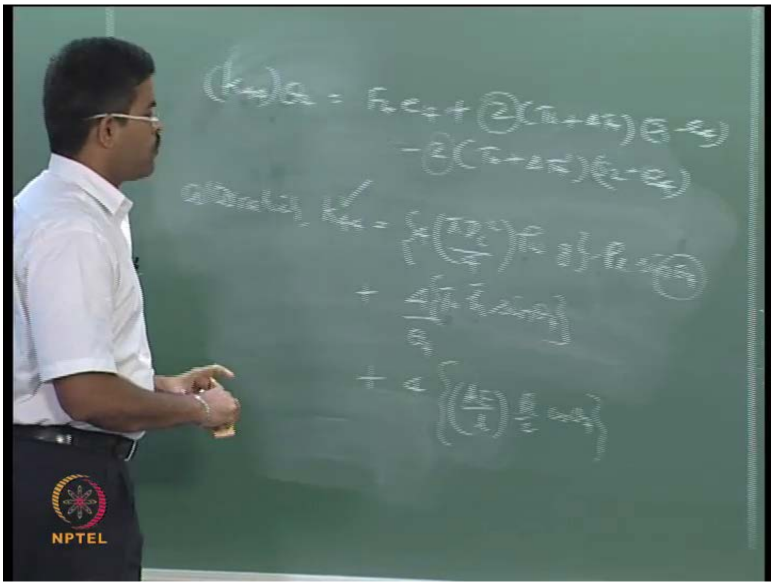


k 4 4 which will be the force in the roll degree because of displacement given in roll degree. So, I can say k 4 4 of theta 4, so look at here, k 4 4 is what is happening here, this has got to be counter acted buoyancy into e 4 plus this change in tension of this 1 minus this change in tension of S 2. I am taking moment about the point where I am rotating the platform. So, I should say easily f b of e 4 plus 2 times of S 1 minus e 4 that is my extensity plus 1 minus 2 times of S 2 plus e 4.

So, these 2 stands for the set of legs of 1 and 4, these 2 stands for the set of legs of 2 and 3 or alternatively this positive value stands for set of legs of 2 and 3 because that is coming from here and the negative value is coming from here which stands for the leg of 1 and 4. Now, here instead of computing S 1 e 4 and S 2 e 4 separately and then working out k 4 4 directly alternatively, I can also write k 4 4 like this, which will be pi d square by 4 of 4 times of the 4 column members which have been immersed rho w of g of sin theta of P L.

Let me now write it like this P L sin theta 4 because you can easily find the e 4 value from this figure. If I try to plot this separately, e 4 can be look at here, this is my e 4, this remains h bar and this is my theta 4. I can easily find e 4 from here, if I know h bar, which is a function of of course theta. So, P L theta 4 will be the component on the vertical direction which is causing my buoyancy force plus 4 times of T naught h bar of sin theta 4 that is nothing but e 4.

I am separating this out so; equally I am separating this out e 4 and s 1 separately from here. Of course, by theta 4 because I want this as k 4 4 as a force unit this already in force units plus I have separated this e, a negative times separately I have taken it out plus 4 times of theta 4 of A E by L of P L by 2 cos theta 4, this is nothing but delta T 4. Already I have an expression in the previous I rubbed it off, is nothing but A E by L, P L by 2 of cos theta 4 we already have it here.

So, k 4 4 now there is no theta 4 here, it is already a force unit A E by L of length it is already a force unit. So, k 4 4 can be easily computed if I know the value of theta 4 remaining all are known to me. D c is known to me, density of sea water is known, c value h bar T naught all are known to me. T naught is initial tension given to the theta all are known to me compute k 4 4 now, I have k 3 4 and k 4 4 remaining all members are all coefficients are 0 for the roll degree.

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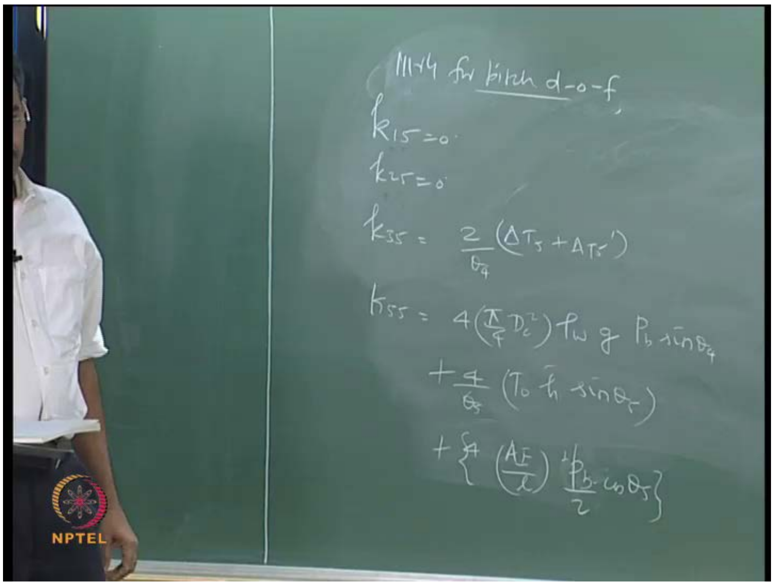


Similarly, if I draw the same view with the front direction and give a pitch angle except replacing this column as 1 and this column as 4, remaining all remains same there is no change except that, this will become theta 5 this will become k 5 5 and so on. So similarly, for pitch degree of freedom I should say k 1 5 is set to 0, k 2 5 is set to 0 because there are no forces in surge and sway activated because of rotation given in the pitch degree of freedom. k 3 5 looking at k 4 5 you have been k 3 4 same way I am writing nothing but 2 delta T 5 plus delta T 5 naught by theta 4 that is why we wrote for k 3 4 also. So, k 5 5, the same manner just now we wrote for k 4 4 so it is going to be 4 pi d square by 4 rho w g. Here, I am using P b sin theta 4, because this dimension is P b plus 4 by theta 5 of T naught h bar sin theta 5 plus 4 A E by L of P b by 2 cos theta 5. This is how I get my k 5 5. So, we have got the fifth column of the stiffness matrix now.

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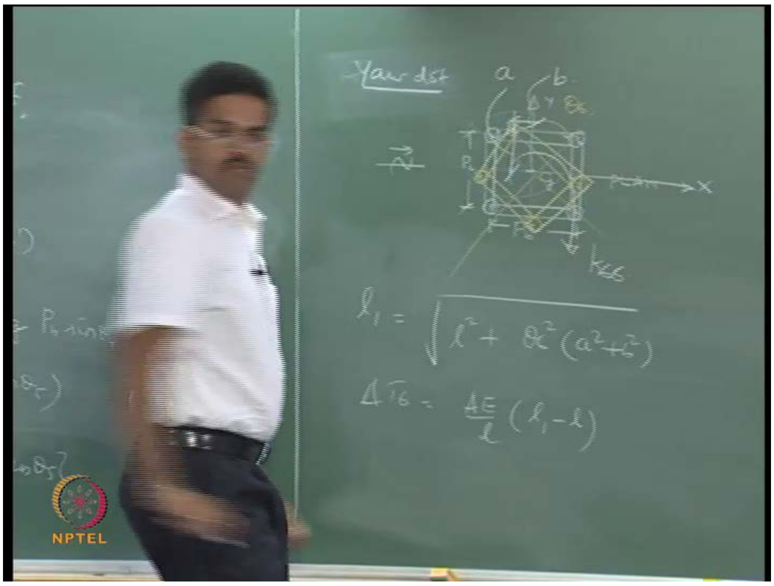


Let us talk about the yaw motion. In yaw degree of freedom so yaw is the rotation about the plan let us say I am rotating about this axis about z. So, let me draw in plan itself. So, this becomes my column 2, this becomes my column 1, 3 and 4 this is my theta 6. I am rotating about the vertical axis the z axis so obviously, the force required to rotate this is what I am going to measure which is k 6 6.

Now, imagine I have got a floating body let say I have got a floating body like this which is rectangular in shape may be square so see from there this is my P b, this my P L, this is my wave direction there is a C g in this body somewhere here, which I am marking it here. There is a draft for this box somewhere here that is a water level or sea level. I am trying to this anchored by the sea to the sea belt with the tethers. Now, I am yawing this so initially it was horizontal straight, I am yawing this; I am giving a clockwise rotation which I have done here. So, I am yawing this. You will obviously see that the position of this tethers will get twisted, tension will get change.

But, there is no absolutely there is no going to be difference in my F b value marginally because of only the T naught T delta T 6 happening in the tethers. So, there is a component initially the cable is straight now, the cable is twisted, there is a component which is going to be L dash, the new length of the cable. Initially, the cable was L now, it is twisted it will become L dash which is a combination of L and theta 6. I want to find L dash the changing length of this cable will be L dash minus l. Is it clear? That is what I am going to do it here.

Student: Sir, so L dash will be greater than L?

Yeah, it will be.

So, let us say the new length l 1 is of course, the square root of sum of the components which is original length plus the effect of shift of this twist because of theta 6. I mark it say it in a different way, I say that this point which is now twisted I am just pay attention, this point from here I am marking as a and this point from here I am marking as b. Once I know these 2 components I can write this as, theta 6 square of a square plus b square. Is it ok?

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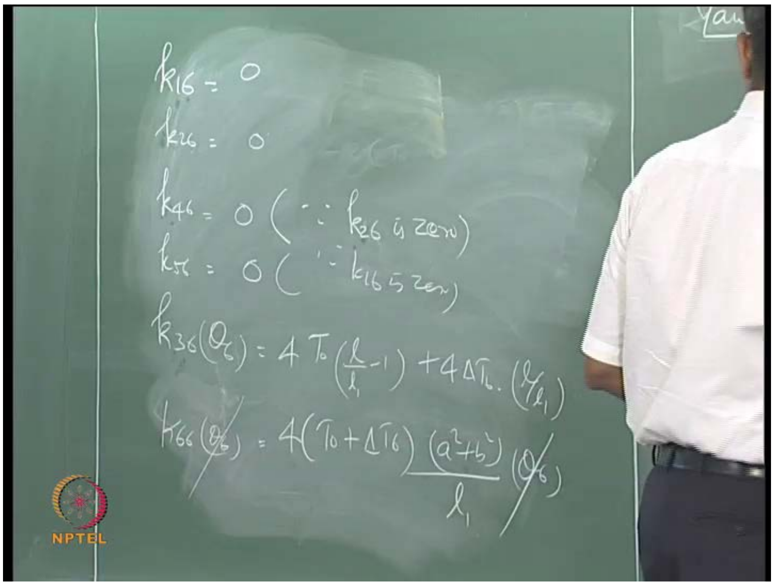


So, once I know l 1, delta t 6 which the change in tether length, tether tension. Now, is going to be simply A E by L of l 1 minus l, that is the new tension now, which is changed in my tethers. So, force in such degree because of yaw rotation is 0. Nothing is happening in surge it is identically rotating only in the horizontal plane, nothing is happening in the surge axes. Obviously, for a unidirectional wave sway is of course, 0 we do not have this with us.

What can you say about k 4 6 and k 5 6 is 0 because for 4 roll means because k 2 6 is 0. Is it not? Sway is 0 therefore, pitch is 0. Similarly, 0 because k 1 6 is 0. So, what you will have here is k 3 6 and k 6 6. So, k 3 6 into theta 6, again in the heave degree the force which is given to the system will be from the change in tension and the original tension of the cables or tethers. So, I can simply say it is going to be 4, there are 4 legs T naught l by l 1 minus 1 that is the change plus 4 delta T 6 which I know here of l by l 1.

So, I will get k 3 6. Now of course, knowing the value of l 1, I can substitute them and rewrite this equation at different form that may not be required. Now, let us try to find k 6 6 of theta 6 which is going to be the moment of these forces. Now, what happens? When my cable is vertical, when my cable is normal to the board vertical it is extracting the force only in the vertical direction once, I have yawed this in plan this will now, create a moment because of the twisting action on the tethers which I can indicate vectorially as delta T 6, as delta T 6.

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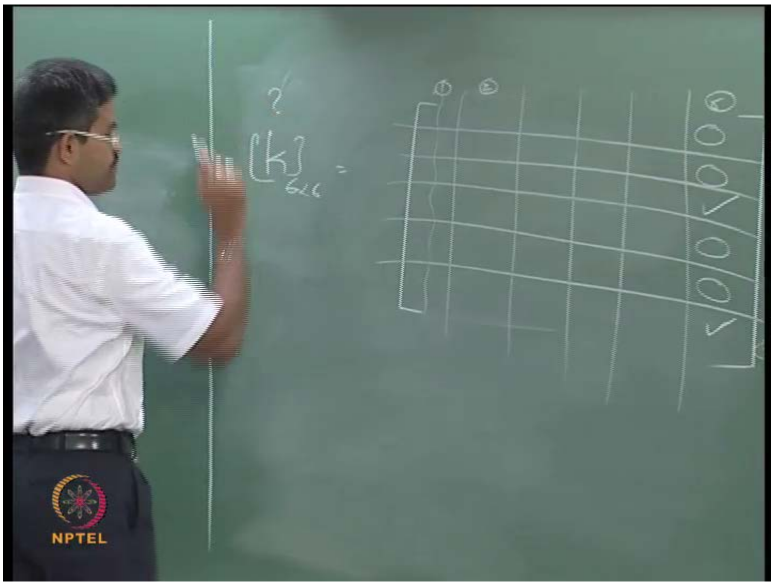


So, now I can write k 6 6 as 4 times of T 0 initial tension plus delta T 6 the change in tension. How much it has changed because of a square plus b square by l 1 of theta 6. So, this goes away, k 6 is directly given by the change in tension and the moment of this about the point of interest. Having said this we can now, write the stiffness matrix in a complete form, which is 6 by 6 column wise, we will write column wise.

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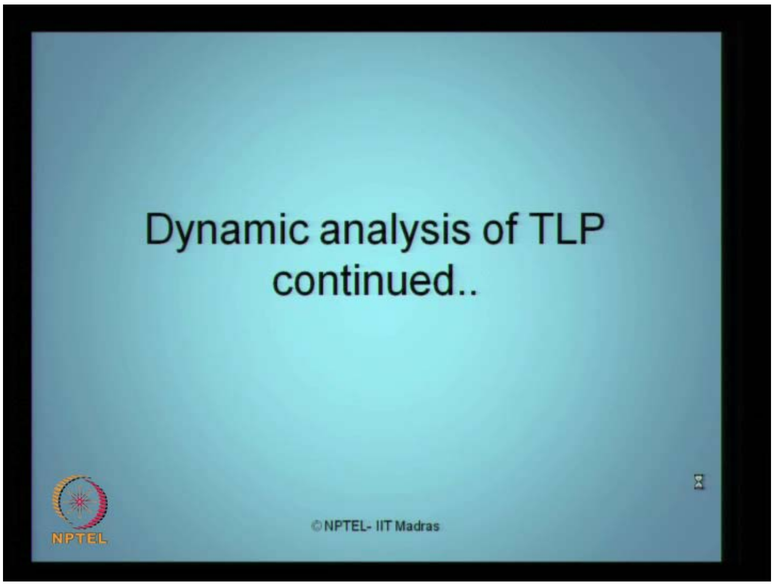


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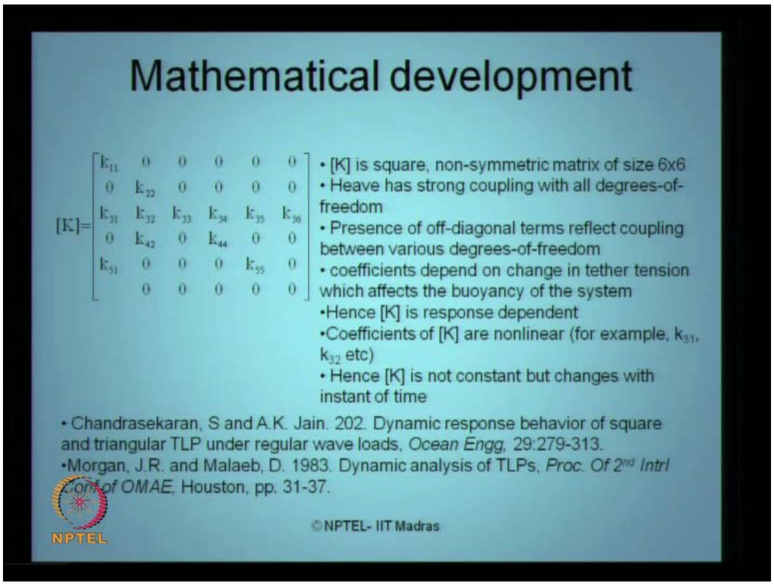


For example, this value will come here because this is 1, 2 and 6, this is 1, 2 and 6. We have derived all of them column wise we got k 1 6 0, k 2 6 0, 4 6, 5 6 0 this and this we have we derived column wise that is what we are having here. Similarly, we derived all matt coefficients column wise. Now, let us see what is the beauty about this particular matrix? Look at this matrix now, we have k 1 1, k 3 1 and k 5 1 similarly, we have 2 2, 3 2 and 4 2 and so on.

There are many observations you can make from this matrix: one the matrix is a square matrix but it is not symmetric. k 3 1 is present but k 1 3 is not there, it is non symmetric matrix of course, of size 6 basics. It means, this matrix cannot be banded. If you want to analyze this problem, you must handle this matrix as a full size matrix, you cannot band it because it is non symmetric that is a first observation we can make from this.

Look at the third row of the matrix that is k 3 1, k 3 2 it means the effect of heave caused by all degrees of freedom mark predominantly seen in the problem. You give unit displacement to any degree of freedom surge, sway etcetera heave response to it automatically. So, this very clearly shows that heave has got a very strong coupling with all degrees of freedom. Whatever moment you give, heave will be activated automatically. That is why we call this platform as heave restrains system. You try to move this platform in any manner you want in the 6 degrees of freedom, heave will restore its position automatically. That is a beauty of the geometry.

So, heave has got a very strong coupling with all degrees of freedom that is a second case we see because mathematically, the row the third row is present always. So, mathematically we can see it is a strong coupling. Further, you will also note that the half diagonal terms, for example, k 3 1, 5 1, k 3 6, k 3 5, k 4 2 half diagonal terms, show the respective coupling of each degree of freedom with heave, they show the respective coupling.

Most interestingly pick up any 1 coefficient. For example, let us say we pick up this coefficient k 3 6, k 3 6 depends on the following it depends on T naught which is known to me for a given system because it is initial tension given to the system to afloat in a sea. So, T naught is known to me but delta T naught is the dynamic change in tension because of the rotation or because of the degree of freedom you are giving whereas, delta T 6 depends on the value of theta.

So, what you can see here is, k coefficients depends on the response, so the stiffness matrix is response dependent. So, it is a unique problem in this geometry generally stiffness matrix is a material or section characteristic. For example, A E by L axes difference of the member, a cross section area, e acts as the length of the member. You know the actual tension given in the member. It is never response dependent.

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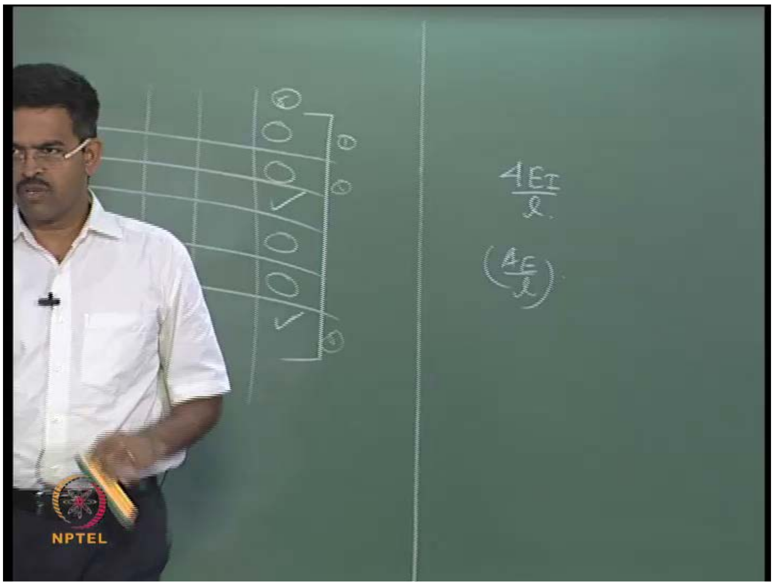


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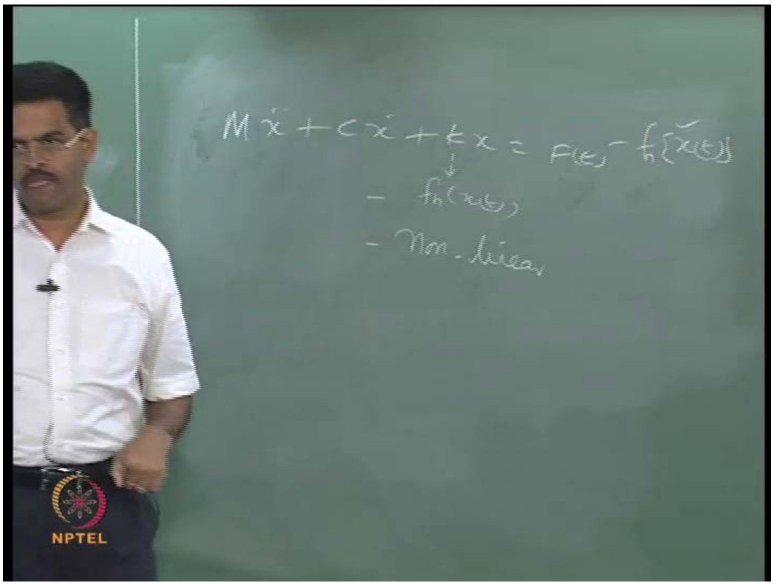


For example, 4 E I by l bending stiffness so there is no res displacement component here A E by L axes difference, there is no displacement component here, these are all fixed does not change, whereas in this geometry my stiffness coefficients are all response dependent. What does it mean? This is having a very classical problem in solving this. See what is that? Look at the equation of motion here, look at the equation of motion here let us not focus on any of the terms except k and F of t. F of t we already know because of the compliancy and because of the lateral movement of the platform it is response dependent if you look at the force vector.

If you look at the drag component of the force vector in the mode of equation you will find there is a component of velocity or let say displacement of the platform in the wave direction. So, F of t is function of x of t, is a function of x of t and k is also a function of x of t or theta of t whatever, you call. You cannot solve this problem actually, because you know it becomes iterate. The left hand side and right hand side are strongly coupled it means, it is a classical problem of dynamic square you cannot decouple the equation of motion you cannot decouple the equation of motion you have got to handle this equation of motion as a total solution. It is a very classical problem imposed by the geometry because the stiffness matrix is response dependent that is a very classical problem here.

The next problem is the stiffness matrix is also non-linear, where the non-linearity coming from, they depend on cos and sin components of your displacements which are non-linear. Of course, non-linearity also comes from F of t, there is a squared act term here, it is also non-linear but stiffness matrix also is got non-linear terms inside the problem. So, it is a non-linear classical dynamic analyses problem which cannot be decoupled. So, very classical problem this problem has raised because of the geometry.

I am not talking about M I did not speak about C yet I am only talking about k, k is actually system property M is also a system property but k is predominantly system property is it not. So, just looking at the system itself I understand, the system depends on response and system depends on non-linear coefficients of the response. So, it is a very classical problem. Now, how to solve the issue? That we will come later, that is what we are addressing here its non-linear and most importantly here values of theta 6 a b are all dynamically replaced, so it is a function of time.

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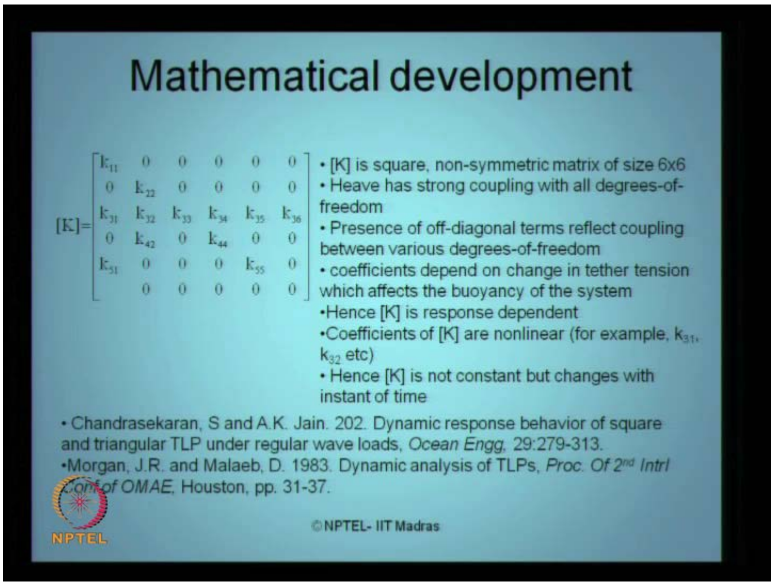


So, stiffness matrix is not constant, it varies with every instant of time this again another problem posed in this geometry. You cannot simply ideally take one stiffness matrix and solve the problem k is going to dynamically vary throughout your length of the solution. So, these are interestingly discussed by different researchers I given a very brief reference of 2, when I finish this lectures I will give you about 26 to 30 references, who spoke about all these non-linearitys and the solution procedures in detail later. Ok.

Now, in this equation of motion we have believed to understand that how do you derive a stiffness matrix where, this is a classical derivation which is not available in standard text books. We are talking about research papers now. We are given the references- Morgan and myself, we did lot of work on this. So, you can refer to these papers available in different international journals. So, it is basically a fundamental derivation what we did for the development of the geometry.

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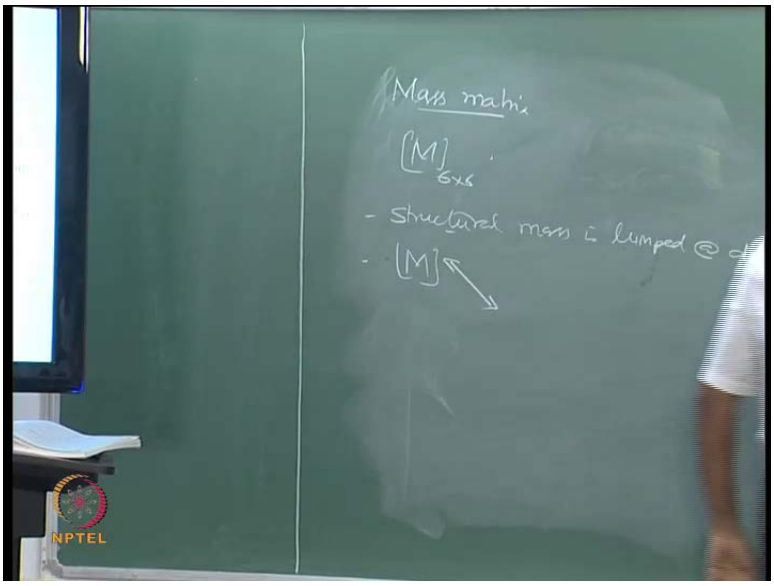


Now, let us see the complexity in M matrix. The mass matrix also has difficulty in this problem. Let us see what is that is. There any questions on this stiffness matrix. So, derivation of mass matrix is again going to be a 6 by 6 matrix because it is a rigid body motion. We assume that the structural mass is lumped at each degree of freedom. So, it is a lumped mass problem, it is not a continuous variation problem, lumped mass problem. The moment we say this what is that instantaneously get into my mind when I lump the mass at each degree of freedom may be single degree 2 degree 3 degree, when the mass is lumped at those degrees of freedom, what do I immediately get in my mind.

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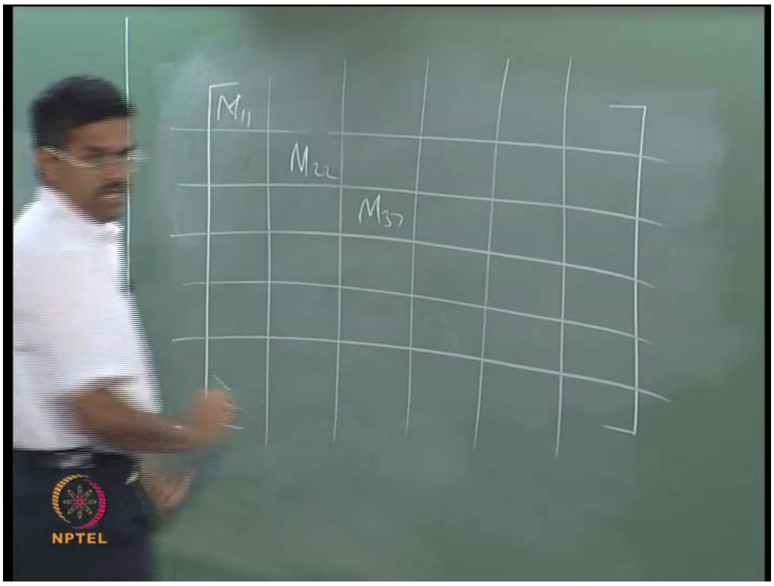

Diagonal matrix:

Yeah. Very good so mass matrix is supposed to be a diagonal matrix but it will not remain diagonal in this problem that is a catch here. I will show you what are the difficulties here, so it should remain diagonal but it will not remain diagonal. I will show you what are the problems? So, the mass matrix expected to be I will write the mass matrix here. The mass matrix expected to be a 6 by 6 square matrix.

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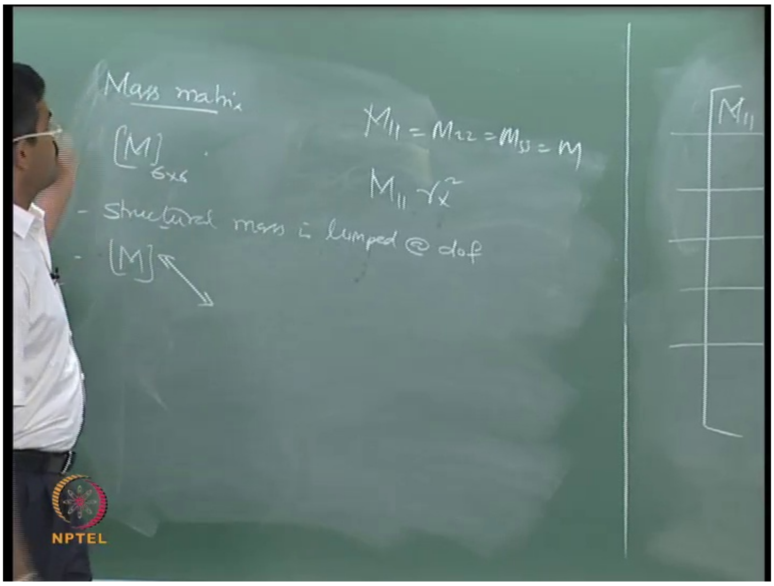


So, M 1 1, M 2 2, M 3 3 no problem here, these all are nothing but M 1 1, M 2 2 and M 3 3 are nothing but the total mass of the system which is added in all degrees of freedom respectively that surge sway heave degrees. M 4 4 will be the mass moment of inertia about x axis which is nothing but M times or M 1 1 times r x square.

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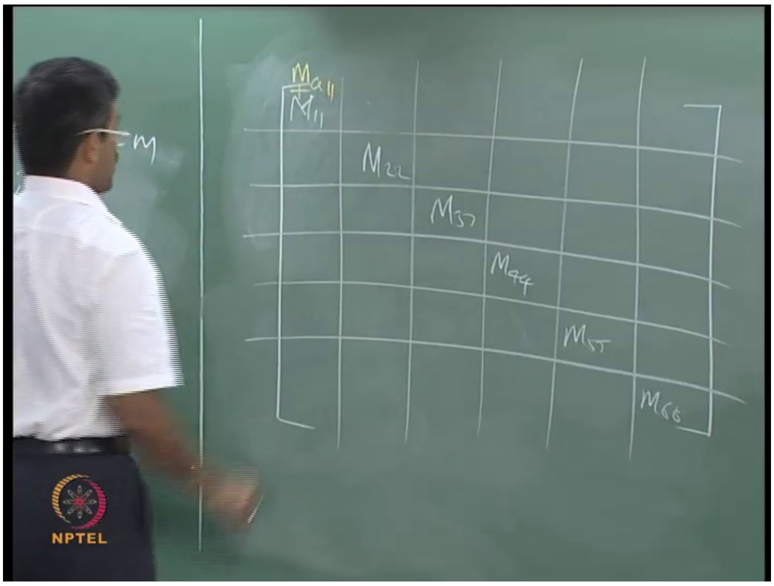


Similarly, M 5 5, M 6 6 will be respectively r y square and r z square, you can compute r x square easily from this problem because it is i by a you can easily find out the value of mass moment of inertia of the whole system specific to the mass center and you know the cross section of all the member you can easily find r x. So, one will know all the diagonal value of this. What will happen to the half diagonal terms here?

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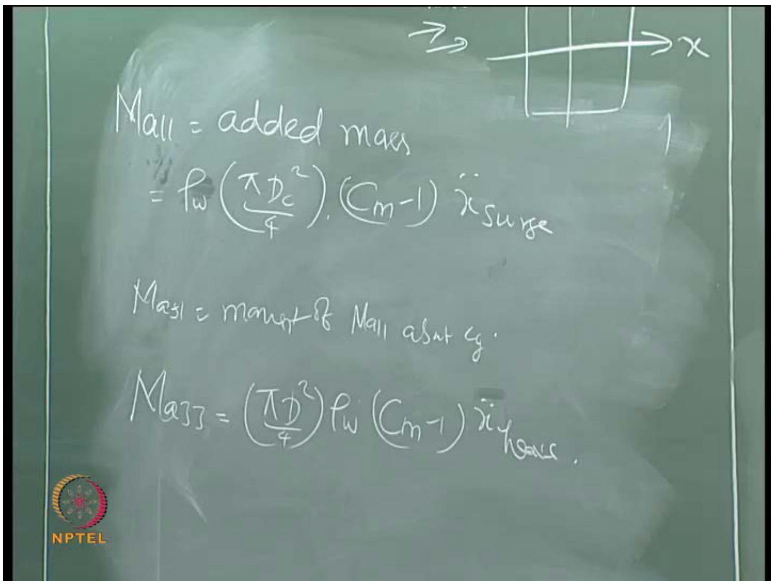


So, I have one half diagonal term which comes from plus M a 1 1, I call this because it is added mass term. So, the M a 1 1 term which is due to the added mass which can be given by pi D c square by 4 of the difference of C m minus 1 of x double dot surge rho multiplies. I have M a 5 1 also, M additional mass 5 1 now, look at the plan here, this is my plan, these are my axes, this my x axis, my y axis, this my wave direction where, the wave is hitting the platform.

I have an additional mass in such degree this additional mass will create moment about y axis that is, my a 5 1. So, a 5 1 moment of M a 1 1 about C g, I will also have M a 3 3. M a 3 3 is added mass term in the heave direction which is again pi D square by 4 rho w C m minus 1 of heave x double dot, I am talking about mass index solution.

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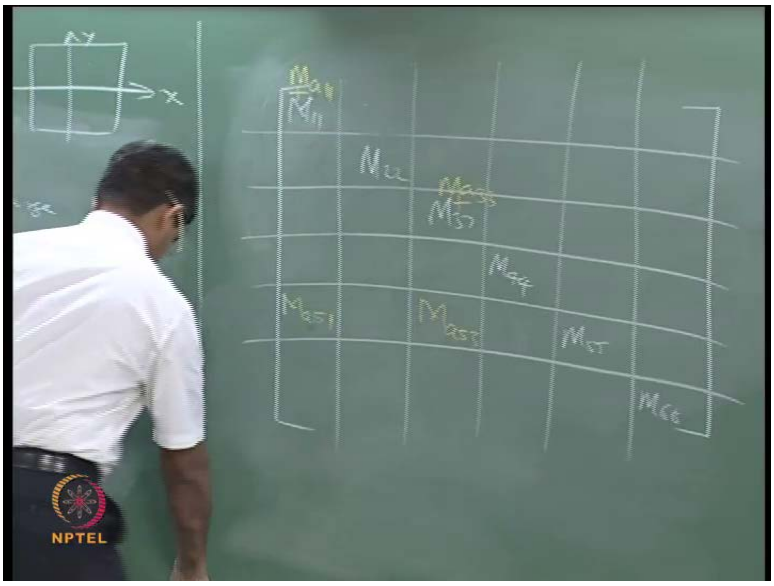


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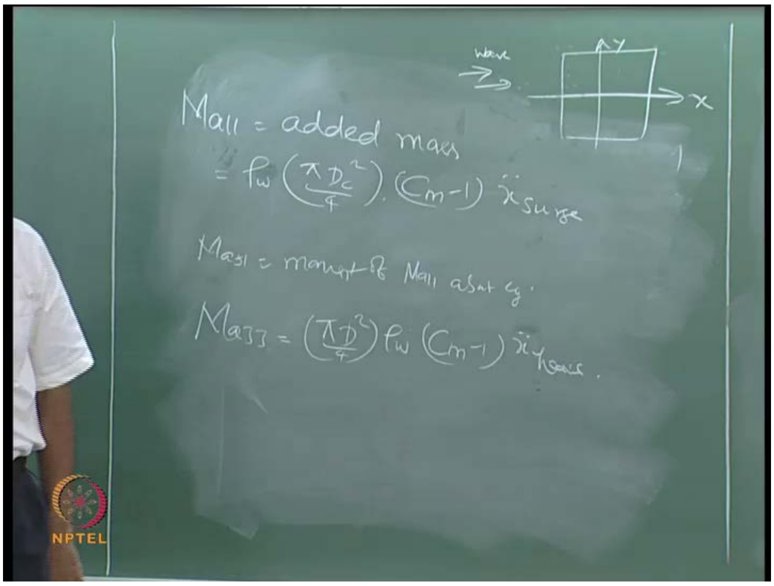


I will also have M a 5 3. How M a 5 3 is coming into play? Because of the differential heave there is a probability that some of the columns may get immersed lesser, some of them get immersed more one. Two, because of the wave approach the crust may sit here, the trough may sit here. There is a variation in the buoyancy between the legs. The moment of that heave displacement about the axis what M a 5 3 is. I am not talking about unidirectional, I am not talking about multi directional wave if I talk about the wave in every angle then all other factors will also get filled up automatically.

I am talking about unidirectional wave therefore, I get M a 5 1 and 5 3. Can you tell me M a 3 3 is coming from a specific concept of TLP what is that? I want the technical term of this M a 3 3 is arriving at dash. Is an additional mass moment of inertia because of variables immergence effect? Set down, it is because of set down is because of set down effect. Therefore, you can see here the mass matrix is also not diagonal dominant. You have got half diagonal terms which will explain the coupling of this with respective degrees of freedom.

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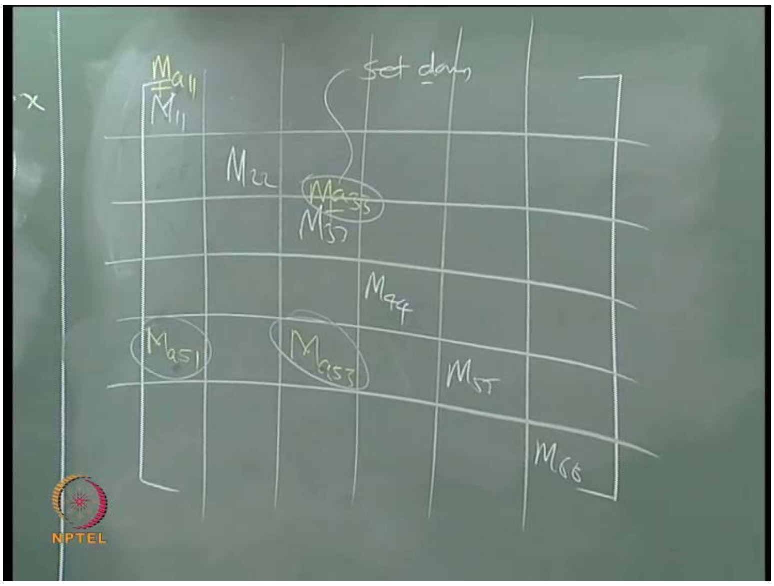


So, we spoke about stiffness matrix, we spoke about mass matrix. We will speak in detail for 2 lectures about stiff I mean the damping matrix because it is very very important how one can estimate the classical damping and non classical damping one of few structures, it is very important there are different models we will discuss.

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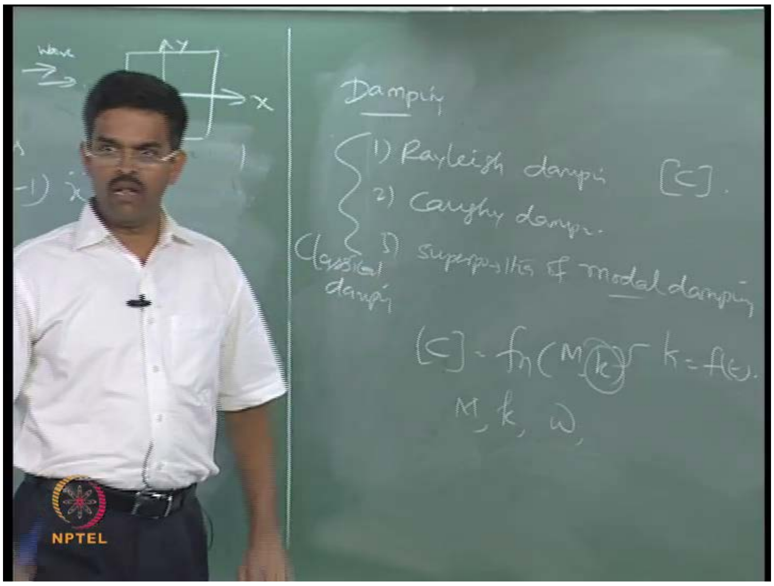


One is we will talk about the Rayleigh damping model. When we talk about damping we talk about Rayleigh damping model, we will talk about Caughy damping, we also talk about superposition of model damping. All these are classical damping. So, we have to explain all these things and do problems on each one of them and estimate the C matrix actually. Now, remember importantly C matrix of course, a function of M and k and k is dynamically varying.

So, C will also have this complication. And since, M has half diagonal terms and keeps on varying because set down depends on what is a wave height and what is a motion of x. So, M will vary, when M varies and k varies, omega varies. So, even the classical theory of percentage damping to critical will also not apply to this problem because omega keeps on varying. When the frequency varies mode shape varies, when the mode shape varies or the value vary the damping ratio is pretty critical because it is 2 zeta omega m, omega and m varies so you cannot actually fix c easily with this problem.

So, in the equation of motion you have got every element given except x, x dot and x double dot which are unknowns for this problem. Remaining all are complications by itself. So, when you attempt to do any geometric innovations for any platform or any design of this order you cater to any specific design requirement like compliancy in this case etcetera you will develop a very high non-linearity and high complexity in solving the equation of motion.

So, every new innovative form developed for optional structures for ultra deep water etcetera will have this complication inherently inbuilt in the system. So, you must know the fundamentals of solving this otherwise, you will not be able to generate the system problem. Alternatively, one can model this in software and try to solve either in frequency or in time domain iteration analyses and gets the solution. But, you will never know or the software will never print at any instant of time what is the mass stiffness and damping matrices, it will never print. You talk about any software it will never give you instantaneous values of k.

You cannot debug the software while running and find out at t is equal to let us say 5 times of delta t, give my k value, it will never give you. Therefore, you will not be able to ascertain the stability of the platform at any point because k and m govern stability of the platform actually. When you have these problems in certain with you, you can always find out what is the difference in the coefficient variation in k at any t from 0 to 10 seconds and for that maximum variation, you can check the stability of the platform also.

Unless otherwise, you know how the coefficients of individual components of M, C and k are derived you will not be able to do this. Therefore, strongly and many researchers have attempted and proved in the literature that, for complete structures for this order standard solutions from software are not acceptable. So, you have got to do is analytical study not a numerical study.

Analytical study is you have got to write the equation of motion; you have got to input k m and c in the time domain and iterate it and find the solution. So, there are 2 inferences I gain from this problem. Whenever, I touch the interference with my geometry to gain advantage the disadvantage is complexity of mathematical solution procedure number one. Number two, I cannot take this problem back to the existing coding or numerical study and modal this. Yes, a solution will be available, it will give you the time list, it will give you the video also.

As far as, many high end softwares are concerned you will never what is the variation of k and m in the whole period of 10 or 20 seconds of iteration, you will never know this. So, if there is a fundamental question of talking about any stability issues or talking about installation problems or talking about let us say earthquake analyses on this structures or talking about the pull out possibilities of tethers because when k exceeds or when A E by L will exceeds the ultimate limit of the member there is a possibility the tether can pull out from the structure.

You will never know all these values. And above all, Fetic analyses for tethers cannot be done if you do not know the values because it has to contify the variation in the force in the tethers say. So, if you do not know them because delta T 0 you will never ever get from numerical analyses never. So, you have got to write a coding on this and the coding has got other mathematical problems.

If you look at the M matrix and k matrix it is not a guarantee that the k and M will be always diagonally dominant. So, a solution may work out for certain bandwidths of t and it may become non-converging for certain bandwidths of t. So, it is very critical even analytical study is also not that simple, you cannot write a solution problem for this. So, that you can always find you may wonder that you will never get even a omega value for a given k and m at any time t is equal to phi delta t you will never have this value.

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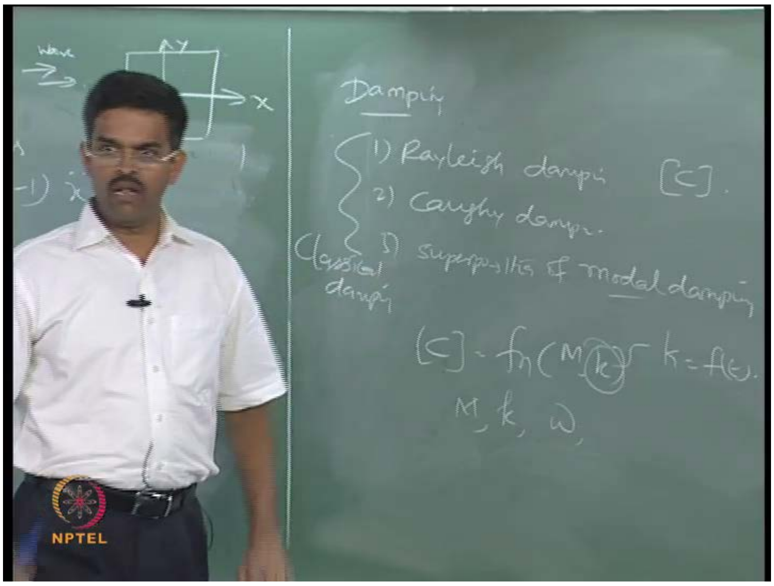


So, in such situations, how people have solved these problems? So, there is a very interesting scheme given by nimox beta. So, we will talk about that scheme and then we will explain the solutions. Before that I want to spend couple of lectures totally and dedicate on how to estimate the damping matrix where, damping matrix is always been a nightmare for offshore structures in many form. I have picked this example because I want to show how damping matrix of this order of a classical damping can be applied to a new form of this type then what optimization has achieved in this? I will show you in my next lecture.

For a triangular, a rectangular shape, of a square shape I got a value I have optimized this geometry for a triangular shape instead, of 4 legs. I picked up only 3 legs because you will all agree in the engineering perspective triangular is the basic form of stability. Square or rectangle is a redundant form of stability. I can divide this into triangle still it can remain stable. For example, tri pots camera stands all are triangular. For example, the video stand here there is no 4 leg for this. So, stable platform need to be only 3 so if you remove 1 leg from here I will save cost.

So, it is very, very easy for me to optimize this which we have attempted and we have a patent on this. So, I will show you some results on this later once we understand how do you do for a square geometry then think of any other innovative platform and innovative number of legs which will take this swaker, this platform to further deep waters. Introducing ball joints, introducing hinges on the legs, introducing tension boil leg platforms of the bottom, introducing the extra buoyancy chamber, think about all these complexities and try to understand how complex it will become when you try to solve the equation of motion.

We will need to know this because the dynamic analysis has to be done for finding out the time mystery solution of my problem. And interestingly, if you do not know the values of k and m at a fixed point of time you cannot find F of t also, because F of t does not only include the wave value it also has effects of sloshing, clamming etcetera which all depends on the immersion depth, which is nothing but D r in my problem and D r is counter affected by T 0, T 0 counter affects the k.

So, the complexities keep on increasing, in all segments of equation of motion. Is it not? How this is attempted and what is an ideally session? We should strictly follow to start with. So, as you understand many researchers attempted this problem but they would have posed serious ideally session while solving this problem, this ideal session is posed because they do not think they do not have capability of solving all the problem that is not the reason, the problem is the difficulties are manifold, you have got ideally certain values to achieve the optimal value in a response.

That is why you will see many researchers have attempted different idealizations in solving this problem. And furthered instance any new innovative form will always start with only basic assumptions and discussion which are actually the research areas. So, we are not going to demonstrate how this solution was done using a software, we will give you the results of course, the results are always open in all the references given otherwise in NPTEL website.

So, my request would be we really want to understand the fascinating problem of this order, please read all this paper before you come for the next class. You will understand actually the complexity of solving this equation of motion. So, my next two lectures will be dedicated totally on how to estimate the damping matrix using these concepts in general then I will apply this concept 1 by 1 to a TLP and find C matrix for a TLP. So, I have m i have k and I have c of course, I believe you know how to find F of t. We will solve the equation of motion, check for its stability Mathew stability and then geometric optimization and apply specific forces on this and end the discussion on TLP at that point.

Then, we will pick up one more platforms which is further innovative on this taken for ultra deep waters which is a Trisoretto. Talk about again k and m and c derivation on trisorotto apply this problems and show you experimental analytical and numerical results for a trisorotto, which is completely not available in any literature as on today. All will be done based on first principles which we will discuss it here. So, I think that will end my second module lectures. I must have ended my second lectures today because 12 is a number of lectures I have given for 12 second module.

But, I will require at least another 4 more lectures I will take it to 16. So, I will compensate this number of lectures in the third module. Third module is slightly faster, because that is going to be on the stochastic dynamics and modal analyses. We will expertise it, because we will be experts at that time you understand most of them what we will discuss. So, we will slightly fasten it and more interesting.