Strength and Vibration of Marine Structures
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Lecture - 27
Ship Vibration V

So, now, we continue further yeah. So, this is the response of that structure when it is in a resonant case.

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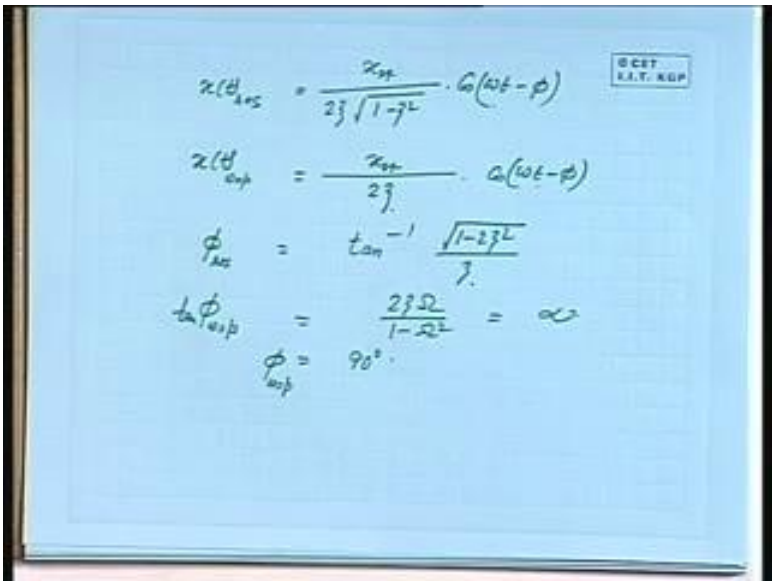

Let us try to find out the response at omega is equal to p. What happens when omega is equal to p? Capital omega is equal to 1 and then if you substitute that value here, what you will get is 2 zeta square of 2 zeta, right. At that time let me say phi at resonance will be tan inverse. It will be 1 minus 2 zeta square root over by zeta. This is the value of phi and phi at omega is equal to p will be 2 zeta omega by 1 minus omega square which tends to infinity. That means, phi is equal to 90 degree or phi by 2 tan phi is becoming, sorry tan phi. Tan phi is equal to this. Therefore, phi at omega is equal to p is 90 degree. So, this is what we get here. Anything here you would like to ask me because this part I think I will not go any further, beyond this impact etcetera are there which I will not try to take it up.

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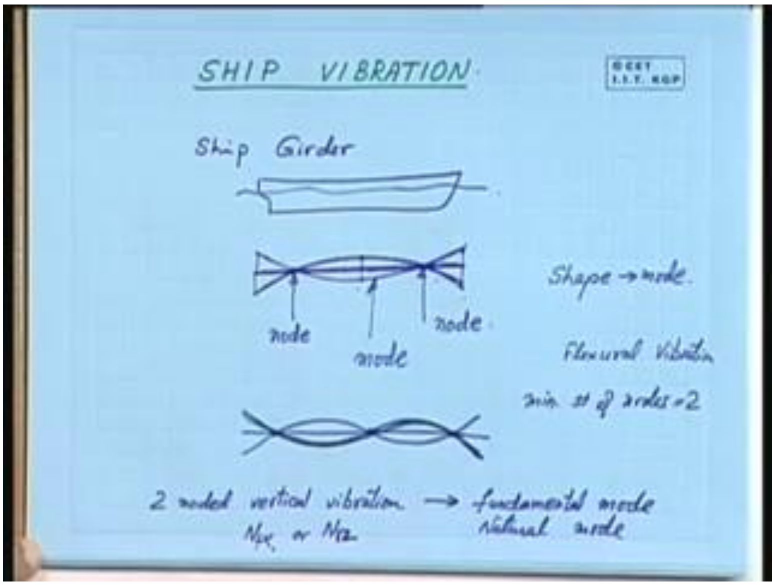

Now, I will try to do out something on ship vibration plus virtual mass of water. A lot of work continued on this virtual mass. When it comes to ship vibration, I have already said that for a continuum you have all the frequencies contained within it and therefore, we will talk about it. When we will talk about ship vibration, we have the lowest mode and the highest mode.

Now, we earlier said that we consider ship to be a ship girder and a girder. That means, this is the ship which is floating in water is represented by uni-dimensional girder and when we talk about the vibration, it either moves like this or it moves like this. It is a to and fro motion. So, what we see here, this is the undisturbed condition. If it sacks, it goes like this and if it hogs, that is in this condition. So, vibration means is a to and fro motion. So, there is one particular point here. There is another point here which undergoes 0. Both displacement and this point is going up here down here

This point also goes up here, down here. This also goes up here, down here. So, this particular point has got this much of displacement, this point has got this much of displacement, but this point does not have any displacement. So, the points on a particular structure which do not undergo any displacement or the points of deserved displacement are known as nodes, and the shape which the structure obtains during the vibration is known as the mode. So, the shape is the mode shape is the mode and point of

0 deflection is the node, and by connecting the nodes, you get the mode. So, this is the mode which passes through the nodes.

Now, we can have a mode in which the vibration takes place like this, and here you will find the number of nodes increases. So, this is the pattern, but a beam of this type of shape cannot have in the flexural vibration. When we talk about flexural vibration, then it is bending in the bending moment. A single nodded shape, it cannot have. So, the minimum it will have a two nodded shape. So, during flexural vibration, minimum number of nodes and then we have seen that it can have 3. It can even have 4 5 6 7 8 9 10 whatever it is, there is no end to it. You can have any number of nodes in the increasing direction, but in the lower direction, you have minimum two.

So, the two nodded vertical vibration, we say is the fundamental mode or the natural mode, and the corresponding vibration in cycles per minute usually we say that the ship vibration. Hull vibration is expressed in cycles per minute is N 2 V or number of cycles in two nodded vertical vibration. N is the number of cycles per minute in two nodded vertical vibration or number of cycles per minute in vertical condition for a two nodded mode. So, these two notations are being used.

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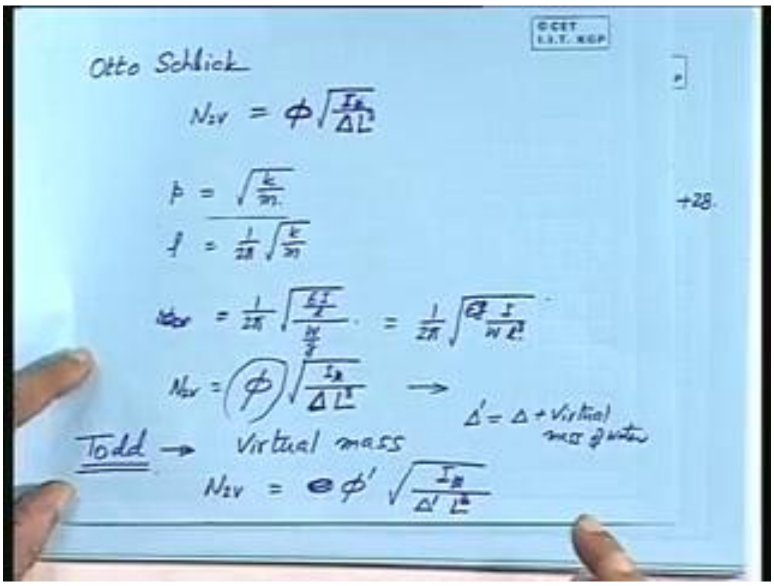

It was Otto Schlick, who first recognized this for the ship hull vibration, and he tried to give a formula for finding N 2 v and he said that is some coefficient phi root over I by delta, I midship of the cross-section of the ship and loaded displacement. He expressed this and people blindly started using this and he gave some coefficient value of this phi here. Phi is not a non-dimensional coefficient because when he first used this, I is used or the value of I was given in phi to the power 4 and delta was in long tons.

Now, let us try to dissect this equation and see whether this is fundamentally correct or not. We have seen that circular frequency p or for that matter, circular frequency p is given by root over k by m or f is equal to 1 by 2 pi root over k by m. Isn't it? This is in cycles per second. Now, what is k? It is stiffness and what is m mass of the ship? It is mass of the structure. Now, let us write down N 2 v and try to now I will start from here itself. So, phi is equal to 1 by 2 pi k. K for a beam. What is k of a beam? K for a beam is a function of EI by l. You have already studied in structural analysis. So, it is a function of EI by l.

What is mass? Mass is displacement, divided by acceleration due to gravity. So, I will write W by g. You write here. This is a delta l here. Sorry, E is the material constant and if we assume that the ship is made of a particular material say steel, E is remaining more or less constant. G is acceleration due to gravity and on the surface of the earth, we assume it to be constant and therefore, root over E by g is also constant and if you take it out and merge it, pi which is also constant, we can say it is phi root Eg by 2 pi is phi and I is the moment of inertia of the cross-sectional area of the beam.

Now, if I assume that the moment inertia of the cross-sectional area of the beam for the ship, girder is the midship section, then this is nothing, but I midship weight of the structure here, the structure is the ship in loaded condition. Therefore, weight of the structure or displacement of the ship, the force and one is the span of the beam which we have considered here. The span of this girder is length of the ship is this here, and we multiply it by another 60. So, to convert f to N 2 v from cycles per second, you multiply it by 60. You will get cycles per minute and you get this.

Now, we are starting from this and we are arriving at this equation here, right. So, what he studied was he considered the ship to be a single degree freedom system, and keeping the basic structure of the frequency, same he tried only to manipulate it in this fashion. And then by observing the frequency of certain ships, he evaluated and gave the value of this phi and then he said that if you are going to analyze this type of a ship, then assume phi is equal to so much. If you are trying to analyze a tanker, then phi is so much. If it is a cargo ship, phi is so much and this continued for about a century.

Even today when we are trying to find out in the initial stage, what is the natural frequency of vibration of the hull girder hull girder, then we use this type of an equation. Only we will come to it a little later. Now, here after finding out this he tried to measure the frequency. Now, obviously the measuring of frequency is a very tough job. So, what he is trying? He must have taken some models and try to check it, and then he tried it in some towing tank or some such thing and then he found that the values do not match. At that time there was another gentlemen and he was Todd. Both of them were more or less working at the same time, and Todd realized this that when the ship is in a floating condition and vibrates, the water in which it is floating is a real fluid and it sticks to the hull. Therefore, when the to and fro motion is taking place, the water also moves along with it.

So, there is a virtual increase in the weight of the vessel at the time of vibration which Otto Schlick was not taking into account, and he was getting a higher frequency here. So, if you try to consider along with delta, the water mass and then he got a reduced value. We justified his thinking and later on Lamb and other people who were doing some work in the hydrodynamic, they confirmed it and Todd said that it is the virtual mass which is responsible for this change and he gave a formula based on a modified this thing. I think he used first phi dash and later on it was further modified, and he said that you consider delta dash L where delta dash is weight of the displacement of the ship plus virtual mass of water. A lot of work continued on this virtual mass.

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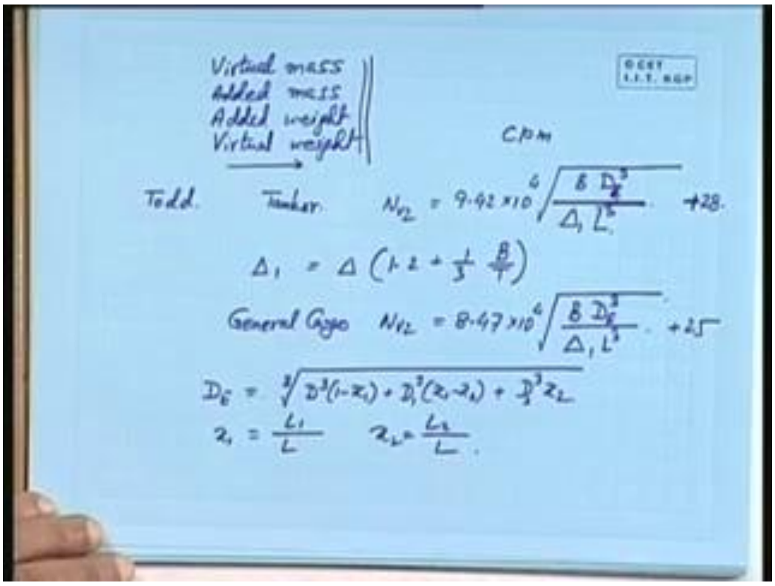

It is also known as added mass, is also known as added weight, also known as virtual weight. Virtual because it is not the mass of the vessel, something is there. Now, one can try to interpret it in many ways. You say that when the vessel is vibrating up and down, something is sticking along with it that also vibrates up and down. Some people will dispute about this. They say that as soon as the thing is going up, the liquid will come down. So, how can you say that mass is going up and down along with it? It is not. So, there is a dispute in that definition.

Now, mass and weight are interchangeably used because when we are taking weight, weight is mass into acceleration and therefore, in engineering terms we always try to mix around like this. Like kg force and kg mass. What is when we say kg? Sometimes we also get confused that we are talking about the mass or the force. When you go to the market, you say that you give me 4 kg of potatoes. There it is a force, but sometimes when you do the calculation, kg is in mass and sometimes it is with g, sometimes without g.

So, these are interchangeably used and one has to be very careful with the unit and the usage, but one thing is sure that when a body is moving up and down in a surrounding fluid, then there is an acceleration term. We have seen that in vibration, acceleration is there and if the body is accelerating, then only this comes into picture. If it is with the constant velocity, constant speed, then there is no chance of any added mass. When that x double dot term is involved, then this force is coming into picture, right. So, this is what is important here.

Now, I will not go for the history part of it, but he will say that how the natural frequencies these days are calculated. Now, this particular formula which was first proposed, now Todd is proposing that for tanker Nv2 is given as 9.42 into 10 to the power 4 B into DE cube. Oh my god, I think I have done a mistake here.

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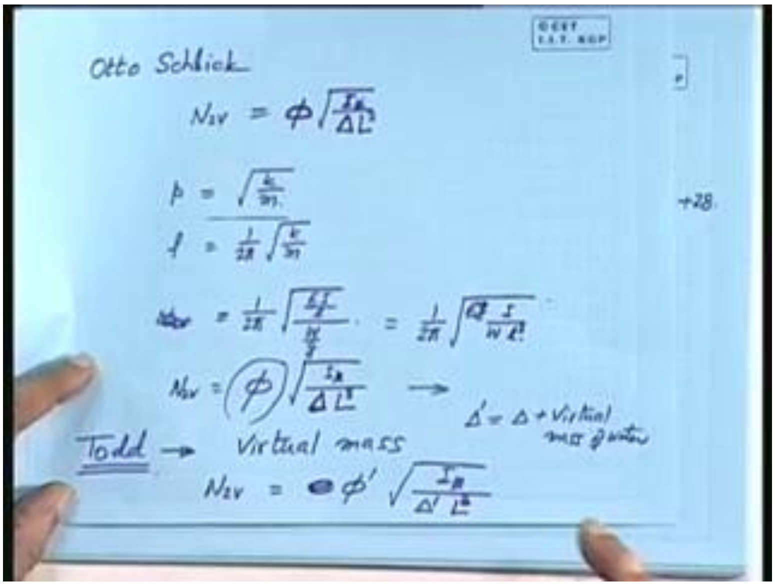

EI by L cube, this is yeah EI by m, this is L cube and this also works out to be L cube. So, these are all constants here and he puts delta 1 which is given as delta 1.2 plus 1 by 3 B by T. This has not changed so far. Now, you see here putting it in this condition, BDE cube, the other day I told you that while taking the second moment of area for a rectangular, it is 1 by 12 BD cube. So, he has tried to follow that and E stands here for D equivalent.

Now, if you are having many tiers of accommodation or the super structure, what we say by definition is super structure when side to side, it is extending and length wise it is more than 0.4 L. Then, you have to take that into account and how much or which tier is contributing that comes. So, what is its range? If it is 60 percent, 40 percent, 50 percent or whatever, it is you may have one tier which is extending for 80 percent of the length and then you are tapering it down to 70 percent, then 60 percent, then 40 percent. Then, that has to be taken into account and finally, you will come to the rule which gives you actually how to calculate this TE based on those tiers.

Now, for general cargo carrier, Nv2 is given by 8.47, 10 to the power 4. These are all in cycles per minute. BDE cube divided by delta 1 L cube plus 25, again he defines this which is there in rule also is cube root of. Now, this D is the depth of the vessel, D1 is the depth of the first tier above the deck, D2 is the depth of the second tier above the deck and x1 is the extent of the first tier over the deck, x2 is the second tier and x, yeah 2 tier it is so like that. So, that is in ratio. So, x is x 1. I have written here x 1 is equal to the length divided by the ships length, x 2 is equal to length divided by the ships length.

So, this is how the equivalent depth is defined here, and 2 you can see that these are all dimensional coefficients here and this is how some constant value. So, this is what if you observe the data and then try to plot it and get it. Now, this is what you will get here.

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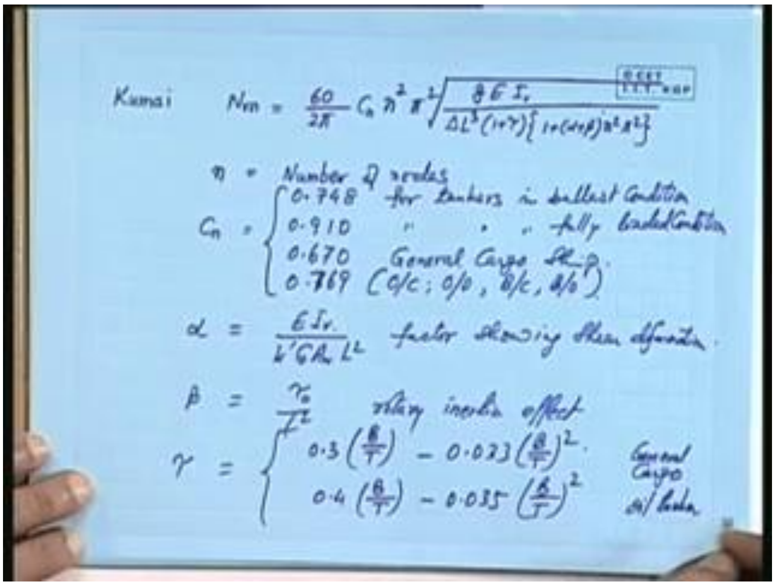

Now, this is what Todd suggested. These days a lot of work is going on and one Japanese person known as Kumai, he has done an extensive job on this type, and he said a general formula Nvn n means number of nodes in that vertical vibration is n which he has expressed as 60 by 2 pi which I have already said that if you are taking frequency 1 by 2 pi is multiplied by 60 from hertz, you can convert it. Then, he is taking a coefficient n here. N square is the mode square, pi square is coming and then g is there, E is there, I of the vessel in vertical condition and then delta L cube 1 plus tau multiplied by 1 plus alpha plus beta n square pi square.

So, now you see this equation what we started with and it is more or less the same thing. He is getting E EI by L cube which we said is k and delta by g is the mass. He is adding 1 plus tau and this and that. Now, this tau will take care of added mass and this part here will take care of the shear deformation effect of shear in the beam. So, now let me try to explain these terms which he has also explained.

So, n is the number of nodes, Cn he gives a large number of values for different cases. He says you take it to be this for tankers in ballast condition, a very general condition 9 1 0 for tankers in fully loaded condition. Then, you take it 6 7 0 for general cargo vessel and 6 7 6 9 for ore carrier oil, and ore carrier bulk and oil carrier. Then, coefficient alpha is EIv by k dash GAw L square, this is the factor showing shear deformation or the shear deflection effect and beta factor is some tau 0 by L square. This is the effect of rotary inertia. See these two effects are there in the vibration of beam. So, when the thing is flexing, so some part is going up and down. So, you have to find out how that is changing the stress in the beam. So, that is known as the rotary inertia effect. So, if you want to take it fully, then alpha and beta to be also included here.

Now, the added mass factor tau 0.3 B by T, I am using this term minus 0 3 3 B by T square. This is for general cargo and 0.4 B by T. So, some changes have been made here oil tanker. This gentlemen, I do not know why he has concentrated only on these two. He had a funded project and all these work he did in the late 80s and early 90s. So, all these coefficients can be taken in a very realistic manner because he has considered the ships of these days whereas, other person like Schlick and Todd, they were practically using the data which was of the last century, early last century, right before 30s or 40s, 1930s and 1940s, but this gentlemen has taken these data for the recent ships, comparatively the recent ships.

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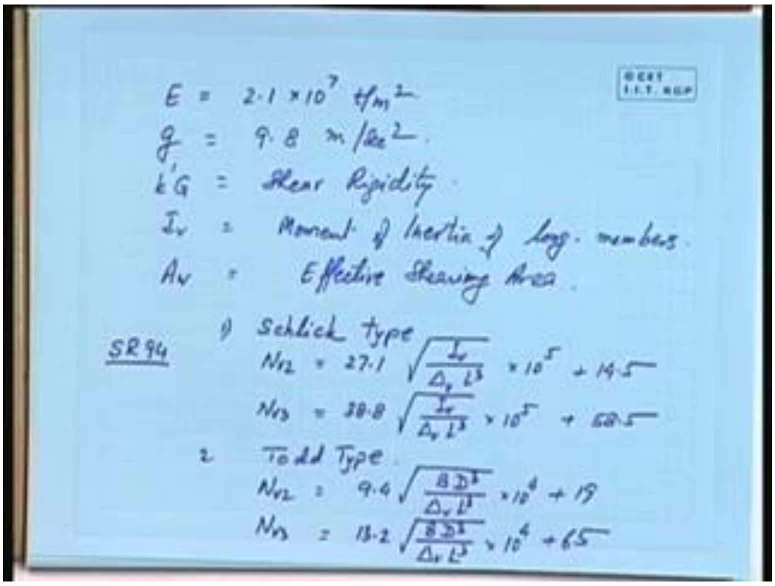

Now, value of E he takes as 2.1 into 10 to the power 7 tons per meter square g. Value he has taken as 9.8 meter per second square and he says k dash G is the shear modulus shear rigidity. Now, this comes straight away actually from the beam theory. Iv is the moment of inertia of longitudinal member; Aw is effective shearing area and tau 0 he has not used. So, let me also not use it here.

Now, this effective shearing area as I told you the other day that it is web which takes the shear. It is not the flange. So, when you are taking a cross-section, then all those flanges areas will be deducted, the area which undergoes or takes shear force is the vertical webs only. So, this is the web area Aw actually says web. So, this is what he proposed. Now, this Japanese person was funded with the project and I think they called that research group as ship research group, and as you can see from here that he started form the fundamentals and he has given this, but world over people are used to what Schlick formula, Schlick type formula or Todd's formula is there.

So, I think he was given a mandate that why not you propose it in that fashion, and there was a ship research group 94 was formed to be headed by Kumai and then Kumai had given according to the mandate as Schlick type and that he gives that Nv2 is equal to 27.1. Iv by delta in vertical condition L cube into 10 to the power 5 plus 14.5 and then he also gives for the three nodded vertical vibration. Then, he gives another set as Todd type

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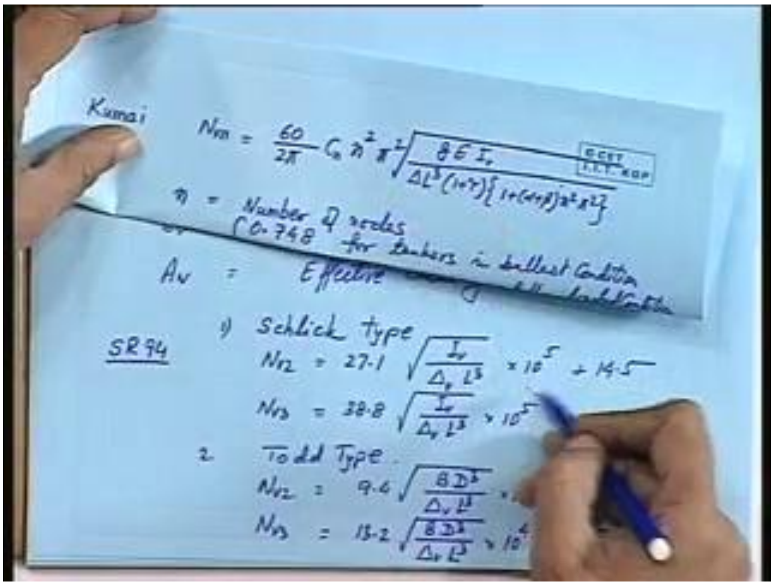

So, if you see from here he had to do a compromise and he clubed everything here. Iv he retained here, delta v he has put delta v into this L cube, and remaining part he has tried to put it in this fashion here and all these multiplication and then coefficients. Now, one thing is very important that as the ship takes place when we are talking about a particular mode, two nodded mode or three nodded mode in a particular mode, the added mass is of a different quantity and the effect you will find that the frequencies will keep on changing.

Now, that is the problem. Many of the people are finding and the added mass basically has been found theoritically for certain geometrical shapes, and people have used or in the ship building side, the added mass is being used of those geometrical size converted through some sort of a mathematical transformation.

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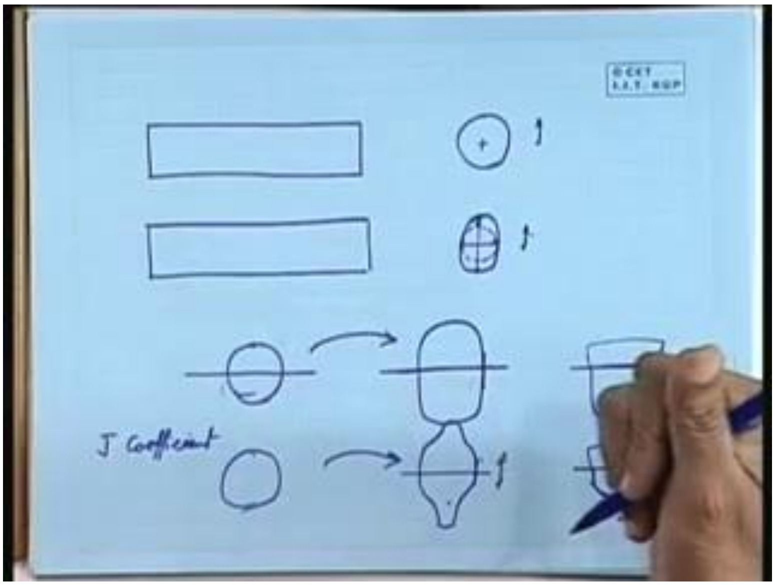

I will just try to give you an example say you take a cylinder. This is the length of the cylinder and this is the cross-section and then you consider that this cylinmder is moving up and down in deep water. Now, when you consider the length, length is not length definitely will be a finite length, but we consider a very long length here, so that the edge effect do not come into picture. Normally if you see the ships L by B ratio or L by D ratio, it is of the order of say 10 or 11 or something of that sort, but here what we will be talking about is much longer than that.

So, longer if you take, then you are concentrating only on the mid regions sort of a thing, then you forget about the end effect. So, what you are going to get it is two-dimensional object. The 3D effect is not coming. So, what they did, they first considered a circular cylinder and then they considered an eleptical cylinder with this as the minor axis and this as the major axis and what they found that the effect is similar to having a circular cylinder of this cross section.

So, then when they found that this is the thing, they tried to transform a circular cylinder through mathematical transformation to some shape which resemble your ship shape. Now, if you cut it here, then you take one half of it and this one half we say is same as the midship section. So, you are taking a symmetrical section, you are transforming this mathematically to this and whatever added mass coefficient you are getting here, you are considering that for a similar ship section. It will be half of that because I am considering half section here and you put the water line here, right.

So, now the ship goes like this. So, this is your section and it is only up to the water line. So, you put the water line here, you take a symmetrical section and it has been transformed from a cylinder here. So, this is how with mathematics you can get for various ships, say you take a cylinder here and you try to generate a ship something like this, and this is the shape I say is the stand shape. You are generating from here, this ship taking half of it. That half is this.

So, this is how mathematically it is possible to find out what is the added mass coefficient of this ship, and then taking half of it, but what is not considered here is this that when you are taking a to and fro motion, there is no free surface here, there is no free surface here, but there is a free surface here. So, how does it effect is not known. Exactly number two when we are taking a to and fro motion here, you draw a tangent. The tangent is perpendicular to this line of symmetry, but when you try to draw a tangent here, it is not perpendicular to the water surface because if you have flair and when the ship vibrates, the shape is something like that. So, it is not perpendicular here. So, that will require certain corrections.

Number 2 we are considering it on the basis of a 2D flow, but ship being of finite length, when it moves up and down, there will be a finite cross flow there. When suppose the bow is going down, it will force the water. When it comes up, there is a vacuum created and the water will cross flow there. So, that will have another effect. So, that part is not being dealt here. That will be dealt by something else known as the Tailors J coefficient.

So, while calculating the added weight, these are the problems which were being faced and the naval architect or the persons who are working in the ship failed. They had to simply depend on whatever value is available at hand. Make full use of it and hope for the best. That was the only thing and they are still being used, but now with the advent of computers when you can do a lot of complex calculations without much of human labor, but you can use the computers effort. A lot of work is being done in this line under the name of computational fluid dynamics. People are using CFD to find out added weight for different types because you can now model the entire structure with some sort of a finite surface, and the surrounding water by some sort of finite block model or some such thing and then the computing facilities are available.

They are trying their level best to find out what is this and for two types like two nodded vertical and three nodded vertical vibration, even this SR group has given some values which is incorporated here. So, these are the things which have been done and people are still doing and continuing the research in this direction. We will talk about all these further, but I think if I continue now, we have to stop again.

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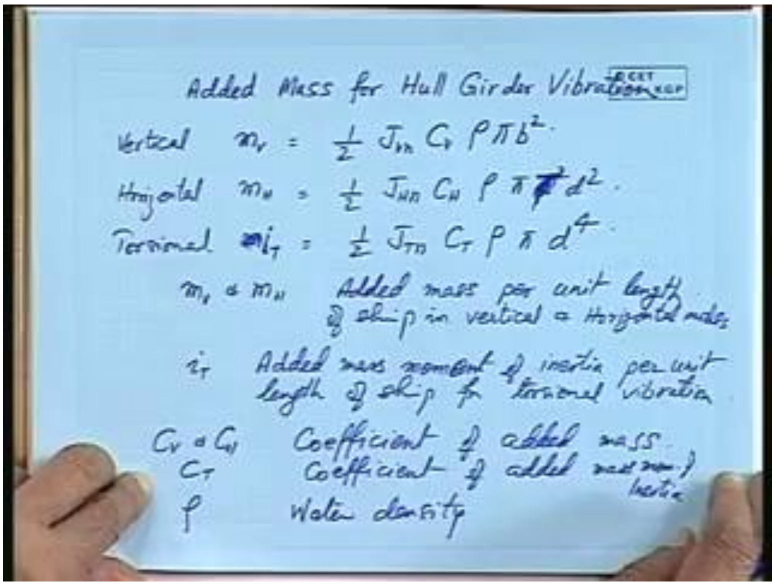

So, we will continue this part a little later. Any questions here you can share. We can do a little bit about headed mass. These expressions I can give say added mass for hull vibration, hull girder vibration, vertical condition added mass is given by half JVn Cv rho pi b square horizontal mH is equal to half JHn. This is the three-dimensional correction factor, this is the added mass coefficient density of fluid, and this is I use T here.

So, this is half width, this may be half. Let me use d only. It does not make any difference and torsional iT torsional is iT mv and mH added mass per unit length of ship in vertical and horizontal mode. IT is added mass moment of inertia per unit length of ship for torsional vibration. Cv and CH coefficient of added mass, CT is coefficient of add mass moment of inertia rho is water density.

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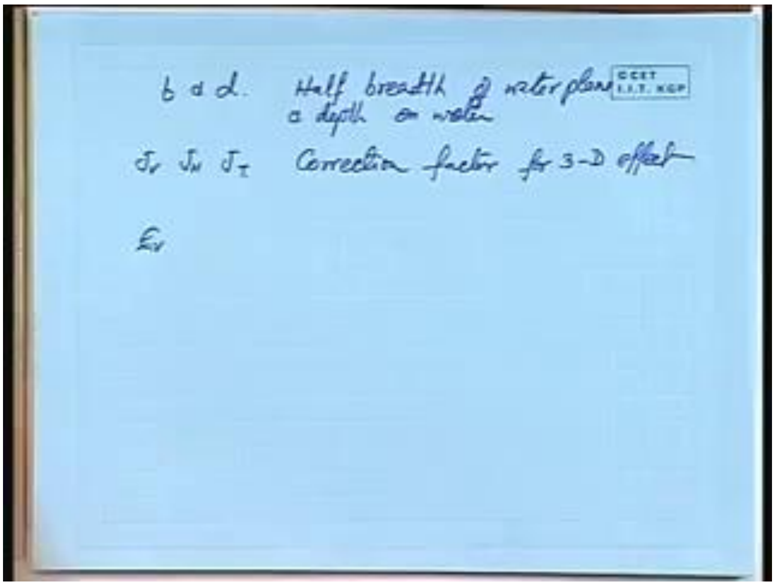

B and d half breadth of water plane and depth on water, then what Jv is. JH JT correction factor for 3D effect that is all and he says that this can be and of course, this I will do it in the next class. Little more is there. So, we will do it in the next class. So, these are the moment of inertia, horizontal and vertical mode of vibration which is being calculated on this basis. So, what we try to find out is the fundamental modes and we also like to find out the higher modes. It is important. We will see that in the next class that what are we going to do with all these frequencies, what we are going to do with them once it is ready. Let us start. Now, we should talk something about propeller induced vibration.

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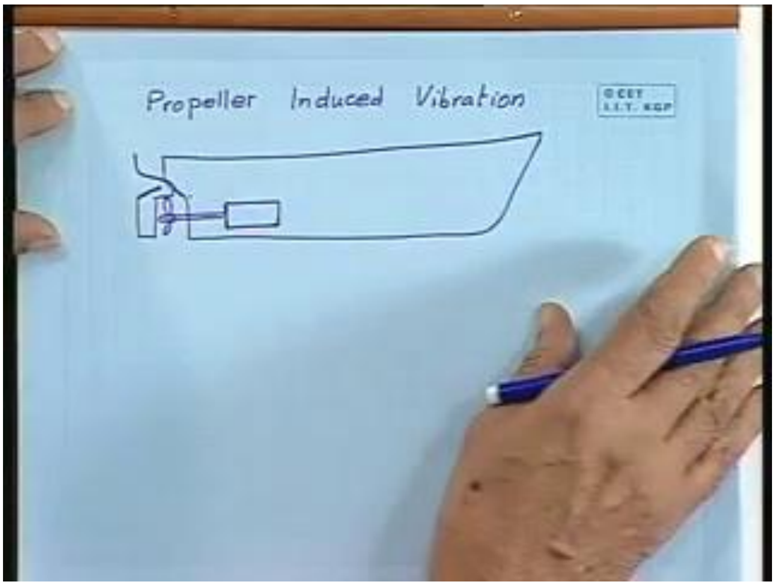

The main prime over is a propeller in a ship and from maintenance point of view, we always try to select a single propeller and therefore, a lot of power is to be transmitted through one single propeller. Usually we have 4 bladed, but there is no restriction on that unless it needs our requirement. So, we can have a 3 bladed propeller, a 4 bladed propeller or a 5 bladed propeller, but in general we will find that majority of the single screw shapes are provided with a 4 blade propeller. And therefore, we will find that each propeller blade is transmitting a huge amount of power to the ship or rather when we say the diagram, how the power is transmitted. Let me talk about that also. I should have drawn the girder somewhere here I think.

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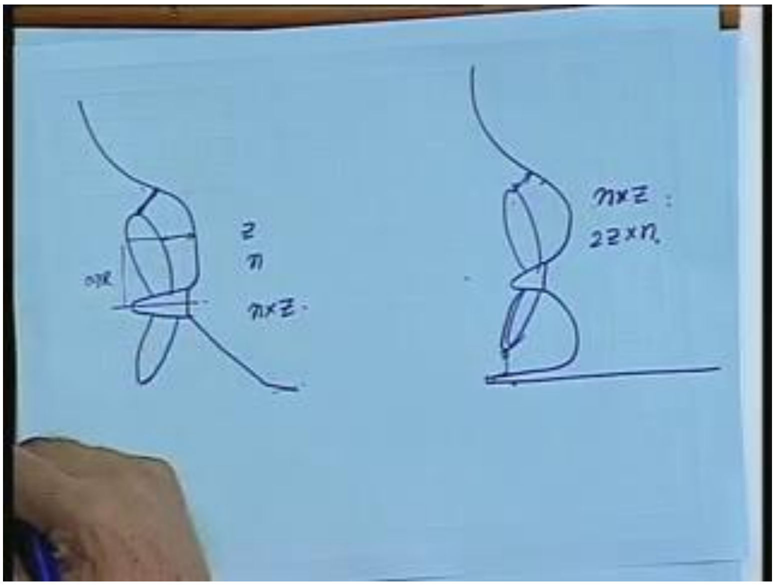

The numbers of blades are odd and then the one which comes here, there is no corresponding blade which is coming here, but when it passes, then another blade goes there. So, here you have twice the Z time and frequency. Suppose let us take an example that in a tug boat, you are having a say 3 bladed propeller. So, if one blade is coming here, the next blade is not coming here. After this blade moves out from here, the next blades goes closer to this and generates some sort of a frequency here. When it moves out, the third blade goes pass this. So, in one revolution, it is 3 times on this side and 3 times on this side. So, 6 times it will be generating the frequency. So, 6 times frequency here, and if it is even number, then number of blades times the frequency. So, these two possibilities are there.

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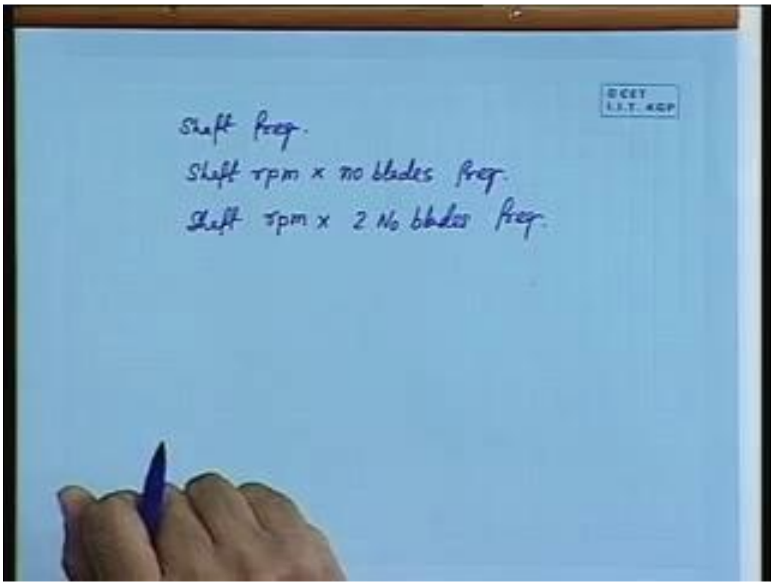

So, you have shaft rpm number of blades frequency and then you have shaft rpm times twice the number of blade frequency. Now, if we want to get the effect less, then there has to be some sort of a minimum distance kept between this tip here, and these pieces here you will see that the rules will tell you that at 0.7 r, what should be the minimum clearances given here and what should be the minimum tip clearance given here. No, this tip distance and this distance at 0.7r, this distance and the tip clearance, the rules will specify that what should be the minimum permissible.

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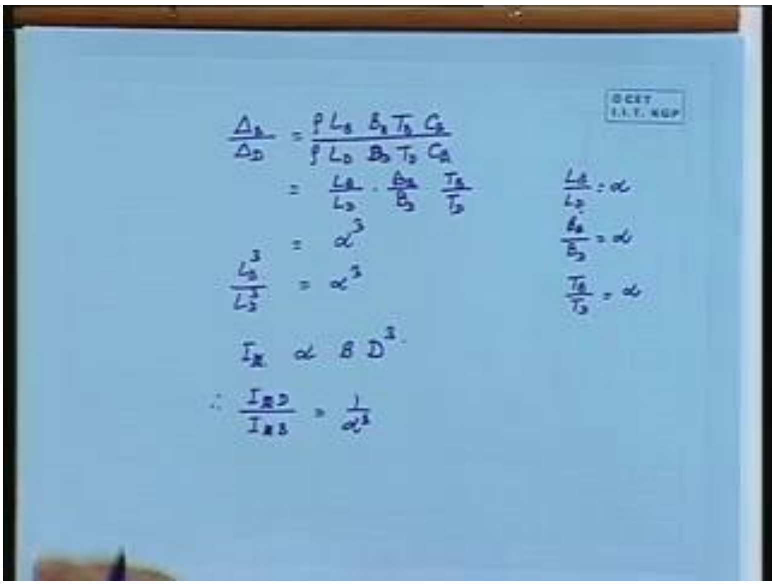

In that case, we can write that delta B by delta D is equal to L length breadth and CB is equal to length draft. Sorry, breadth draft of the design CB row of water. Now, row of water you cannot change for the designed vessel, and the basic ship, they are identical in the same sea. They are operating and I said all the features are identical. That mean the CB's are same. So, these two ratios will work out to be and if I assume that the linear proportion of two ships are identical and if we say that LB by LD, that is basic ship to designed ship is alpha B of the basic ship B of the designed ship is also alpha, and the corresponding draft is also alpha. That means, it is just scaled up or scaled down ship.

In that case, this will become alpha cube, correct and LB cube by LD cube will also be alpha cube. I assume that I midship vary as B into D cube. In that case, therefore I midship of D by I midship of basic will be 1 by alpha cube. I think I will stop now for the time being.