Strength and Vibration of Marine Structures
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Lecture - 36
Hull Resonance Diagram

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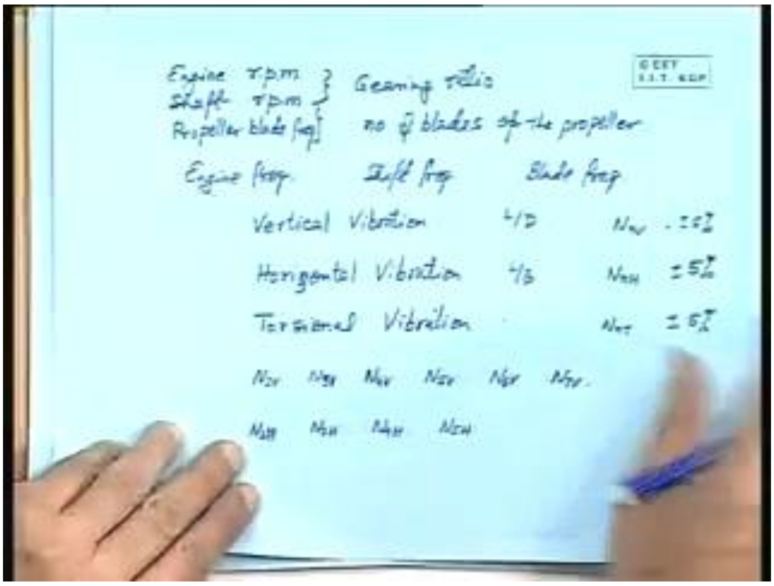

So, now these frequencies can be calculated. We say that that is N nv know; then accordingly we say N nH and N nT, vertical horizontal torsion and number of this thing. So, for a particular frequency, we are taking the margin as plus minus 5 percent and we will keep it all through. Now, this is no hard and fast rule that you should keep plus minus 5 percent. If your experience says something else, you can choose accordingly. So, now let me simply accept that for the vertical node I am taking 2v is the fundamental; 2v sorry 3v. What was the notation used earlier? vN or v Nv anyway does not make much difference.

Student: 2 v sir.

2v, 3v, 4v, 5v, multiple of each frequency, 6v, now whatever is given by that say 7v and you have N 2H, N 3H, N 4H say N 5H. For the time being, I am not taking the torsional frequency. In this particular case assuming that this is not a container ship, because lot many will only complicate the thing.

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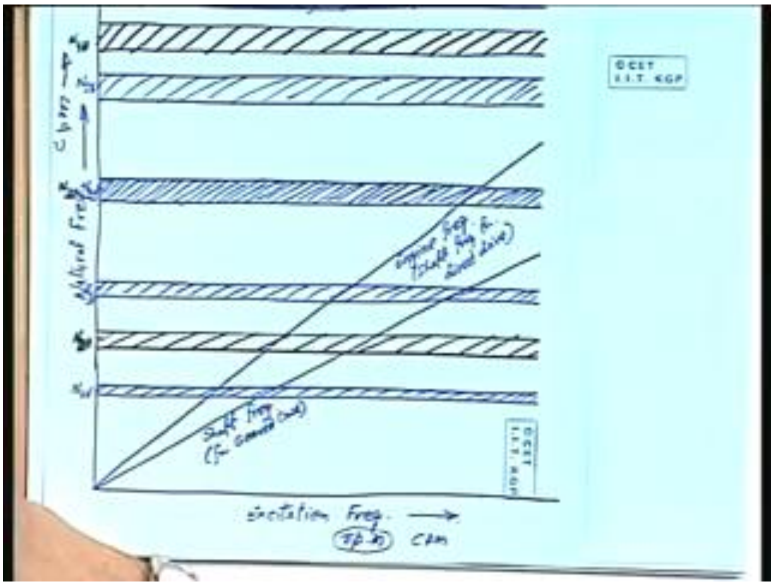

So, I find that the fundamental frequency N 2v is coming somewhere here. Now, this we will take in cycles per minute here, because all these formula directly give me a cycles per minute and the exiting frequencies also I take it in RPM. RPM is revolution per minute. So, that is also basically cycles per minute. This is the trend, but this is also cycles per minute. When we say frequency, cycles per minute it imply.

Student: Shaft RPM external.

No. Exciting frequencies, Exciting; it can be anything; it can be shaft; that is what I said. It can be shaft, it can be engine, it can be blade. So, now let us assume that this is my N 2v here. So, more or less twice of this frequency; twice of this will be 1, 2, 3; this may be N 3v and this will be N 4v. Now, I have taken say 5 percent. So, I draw a line with 5 percent of this value and complete this band and I hatch it that this is not an acceptable zone. Then here the bandwidth will increase because the value is larger. Here, it will further increase. This value is going to be increased further more larger value. If I draw here, then the entire thing is there; open ended node. So, this takes care of the vertical bands all.

Now, I use a different colour; though he said that we do not use it, let me use black here. Somewhere here will be N 3H and more or less twice of that will be sorry 2H here and 3H here; and three times, three times means it will be somewhere here and N 5H may coincide with this. So, 3H means, if this there, there will be an overlap here, provided the values are same; if not, some up and down will be there. So, 3H, 4H, 2H, 3H, 4H and 5H have been also marked here. Now, let us try to talk about the excitation frequency.

Let us first talk about the engine frequency. Now, if engine is running at 0 rpm, it will excite a 0 frequency; if it is running at 10 rpm it will excite 10 frequency. Now, this side is the natural frequency and this side is the rpm. So, what we find? There is a one is to one ratio if we are using the same scale. Then it is simply you draw a 45 degree line from here and you say that this is engine frequency. If it is one by one gear ratio direct drive, then this will be also shaft frequency for direct drive.

If suppose you have a gearing ratio between the shaft and the engine output, and the gearing ratio is say N, then the shaft rpm will be N times the engine rpm. Usually you try to step down.

Student: Step down.

Usually you will step it down. So, in that case what will happen?

Student: ((Refer Time: 10:59))

It will be down because for say 10 rpm of the engine, you say if the gearing ratio is 1 by 2 or something. So, it will be

Student: 0.5.

So, usually for ships, when you have the gear box, the shaft rpm will come down; shaft frequency for geared case. In majority of the cases, we have direct drive or we have no gearing ratio, no matter, but what is the major trend?

Student: Direct.

Direct. So, I will also present that. I will keep it based on this line; not on this line. This is only for clarification.

Now, if you have a three bladed frequency, a three bladed propeller, then the shaft frequency times number of blades, three blades, will generate your blade excitation. Blade excitation is shaft rpm multiplied by the number of blades on the propeller.

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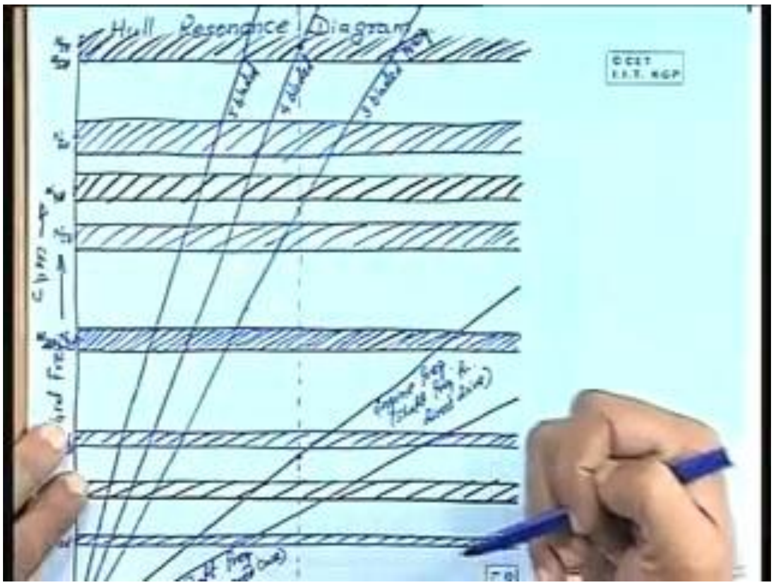

So, if you have three times, then it will be this. So, I say this is three bladed frequency, but seldom we have three blades; we have four usually; so four bladed. It will be still higher. We will also have a provision for five bladed. So, let us have five bladed also. So, now this diagram which we are seeing here contains the engine frequency or the shaft frequency here and three bladed, four bladed, five bladed.

Now, you have proposition for say three engines available with you, which meets your output requirement. You have to only select the engine rpm. Now say one engine has got, I am just putting arbitrarily here, is this rpm which is say N 1; first engine having rpm N1. So, I will see that whether it excites any frequency or not. You see, this is the rpm. So, when this engine is in operation, if suppose, you put this engine and this engine is in operation, this will have this rpm is excitation and if it is direct drive, this is the shaft rpm also. So, as per as the engine frequency and the shaft frequency is concerned, it is clear. It is in the clear zone; not in the bended part.

If it comes in the hatched part, it is not to be accepted. If you come to this point here, it is clear of the three bladed frequency. Come here, the four bladed propeller, if you put on to this to get the output, then it is likely to excite seven nodded vertical this thing and five nodded horizontal vibration. Beyond that I am not considering. So, five also it will be clear off because that I am not giving importance because of my guidelines. It is not that it will not be there. Now, So, if this diagram is to be adhered to, then out rightly I have to reject this particular number of blades on the propeller. So, if I am going to accept this engine, then this engine has to be accepted with either three bladed propeller or a five bladed propeller. Now, let us see another option of another engine. Obviously, when you choose engines, which will fulfill your horsepower requirement or power requirement, their rpms will also will be more or less close by…

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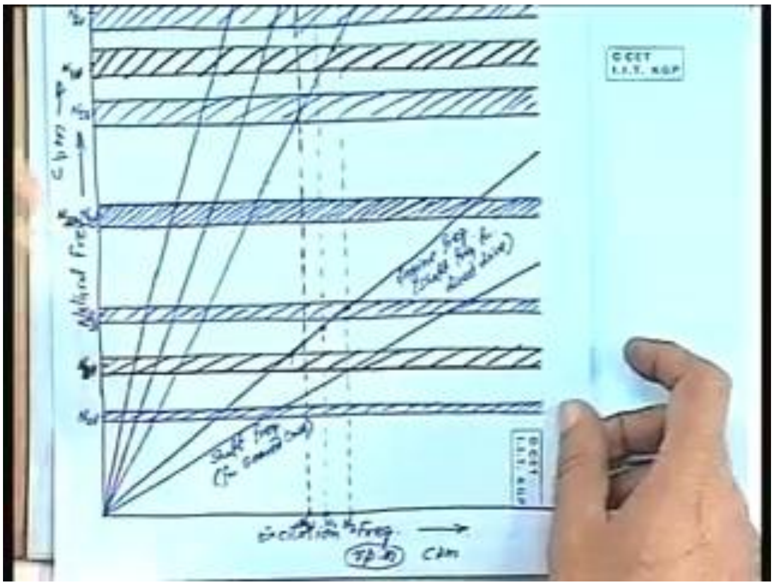

So, let us say that I take another engine which also meets my power requirement. So, having a rpm of N2. So, I try to put this. Now, this engine happens to be a very dangerous engine. You see, shaft rpm, engine rpm, everything is in the one of the lowest mode rpm; vertical vibration of three nodded. It will be contained there. It is going to excite that and then of course, it is clear of three bladed, but four bladed it is just clear. If I consider that no, if this band is closing here, it is just clear. And therefore, this is absolutely not suitable.

Let me take another engine which I say is N 3 here. Let me see. I am just taking arbitrary value. You see this is N 3, clear of the shaft and engine, it is getting inside this three bladed frequency, but it is clear of the four bladed. Now, when you are having a single screw ship, you normally go for a four bladed propeller; that is what we are interested in and therefore, this engine is the best of the lot. This is giving you the best combination. Another thing is to be seen that when we say that we are putting a particular system on a vessel, we always have a life of the vessel in our mind.

We usually say the ship is going to be operative for say 20 years and quite likely the 20 years life time you are not going to change the engine also. You will only repair and run it; rare chances that you will change them plan more.

Now, what happens due to its own wear and tear, there will be a power drop and the engine will get adjusted to that drop in power by reducing the rpm also. So, automatically, there will be a reduction in rpm. So, now, what we have to see? If we find a particular rpm, say for example, this from that point of view; this is the thing; now, if it drops down, it will drop down here. If while dropping down you have to see from your own experience that how much the rpm can drop down; what is the loss of power and for that loss of power what will be the drop in the rpm. So, you have to travel along with this whether still it comes under this band or it is still clear of the band. If for that life time, considering the drop in power and the corresponding drop in the rpm, if it is still clear of any frequency band, accept it.

Say, for example, if suppose this engine by any chance were selected for a three bladed propeller and there is a drop in power, then this frequency will come down straight away here and try to excite this frequency which is one of the primary modes: one, second and third mode of horizontal vibration and the ship will always vibrate. So, this particular blade will excite this frequency. But here if you see, if this drops down, it is clear of this. If you select this, this is also clear of that for that corresponding drop in the power and therefore, it is… any doubt regarding this?

Student: Sir, that in particular range will be concentrating the last one.

Which one?

Student: That particular band width when the rpm keep dropping

No. No. Actually what we are trying to say here is that even if this drop is there, then it is very is likely to excite this, but it has to be clear of this. So, if it is clear of all this, nothing is critical here.

Student: But sir, these assumptions say that how much power will drop. It will come in the zone exact.

No you as a marine engineer will have some data in your shipping company and you can with whatever log book will give you.

Student: ((Refer Time: 21:23))

No. It is all depending on the thing you know because it is when you are going say full ahead.

Student: May be this and which we are talking about these are in the mcrs.

No. I am not taking about mcr. I am saying that the operational rpm.

Student: Operational rpm.

You may you may even operate the vessel at 80 percent of mcr, 85 percent of mcr, you see it is all your policies. Suddenly when there was a fuel crisis, one of the shipping companies, I do not know whether it is a sea or something, they decided that let them operate all the ships at 85 percent of mcr. While doing, so may be that you will save some 30 percent of fuel cost. 85 percent mcr may reduce your speed by say 10 percent, but you may save 30 percent of the fuel cost because that goes up like that.

If you see the performance curve of an engine, you will find that there is an optimum speed and after that it goes in a parabolic fashion, you know, exponential fashion, whatever it is, it is not linear. So, if you try to cut down the mcr, so what I am trying to say that all these rpm and the engine rpm what we are talking about is whatever is the operating rpm, if you are designing a vessel to operate at 80 percent mcr or 85 percent mcr, then we have to select 85 percent mcr rpm. If you say it is 100 percent mcr, it is 100 percent.

And if you suppose decide to operate a ship at 100 percent mcr and you are also ready as a company, that in case if the fuel prices go up, you will reduce it. Now, our fuel prices are fluctuating. So, if suppose it increases and you say that if it increases beyond this particular level, then we will restrict our consumption to so many this thing so that our fuel bill does not increase. So, what is that percentage of the mcr will be known to you.

And in case of emergency, if you have to overload your engine say 110 percent of mcr or whatever it is, overload condition, I think overloaded condition is for four hours or something; is it not?

Student: 10 percent.

10 percent for a continuous operation of how many hours? 4 hours, 24 hours.

Student: 1hour.

No, not 4 hours.

Student: 20 hours.

No, 1 hour? 1 hour? 1 hour? No. usually the machines are I think designed for 4 hours.

Student: But I think it is 1 hour for continuous state

Continuous, Overloaded I think is…

Student: Overloaded 1 hour

Overloading I think can be done for about 4 hours. You may use it for 1 hour, but I suppose.

No. You are recommended is a different thing.

Student: But the manuals normally talk about that.

Manual nowadays talk about 1 hour only, if it is one.

Student: Let me check sir may be…

Does not make any difference. So, what I am trying to say that 1 hour is also a long enough duration for continuously operating at say 10 percent overloading condition. Now, what is the rpm at that and what is that 85 rpm?

So, this is the operating range is also there. So, when you are selecting the thing, you must try to get a band here also.

Student: Sir band where

Full band. So, that means, the overloaded condition and also say 80 or 85 percent of the mcr and then you check with the upper limit and the lower limit that all these frequencies which can be generated due to this excitation is avoided. it becomes a little complicated, but anyway that has to be.

Student: ((Refer Time: 25:40))

Yes. It has to be in the clear space. So, if you are in the clear space during the operating conditions, vessel is considered to be safe from vibration aspect. Of course, there are other aspects which we are not going to consider. How to select an engine? You may have selection criteria; weight is one of them; space is another one; fuel consumption is third one; price is the most important one. Then maintenance, spare parts, reliability, and after the price I think the most important is your political connections. Many a times you reject a very good engine because the spare parts are available from a country with which you do not have a friendly relationship. Spare parts are produced by those countries from where you do not have friendly relationship and therefore, you cannot maintain the engine. So, you simply reject it. So, number of considerations are there; we need not go into that. Any doubt here? Then we can see

Student: So, sir, that means at lower rpm you get 5 minute droplets.

No. Who says?

Student: ((Refer Time: 27:06))

Here also you can cross. What is there? So, what you have to see from here that which combination gives you the best flexible design and accept that. Now, here what we are trying to do? We are taking the band and even an error in the calculation we are avoiding it, but the decision which we are taking here is going to be a final decision. You have decided here that this engine you want to use with this particular blade, number of blades; actual design will take a little later, but this engine is fixed here.

Student: Is this the sole criteria for deciding the number of blades that the propeller is going to be?

Yes. No. it will be final also. You have to design on this basis.

Student: ((Refer Time: 28:10))

What control methods?

Student: Like dampers or other things, then you go for a…

Whatever you want to do, do it here.

Student: Sir, but engines only have this damping methods, that if we come down little bit, I think if we are damping it…

Now, how are you going to damp it?

Student: Say in the engine itself.

Now, how are you going to damp the engine frequency?

Student: First, we bring down by this, what is that I forgot, big tuners we put in the engine for heating away the second order vibration; So, the engine to the ship.

Now, where do you put that in the fuel?

Student: In the engine itself sir.

In the fuel?

Student: In the engine itself; no sir, in the engine itself.

No. I have not understood what you are talking about.

Student: Sir, the vibration of the engine is brought down.

How?

Student: By using this detainers.

Now, what are these detainers and where it is?

Student: ((Refer Time: 29:09))

No, but how can you change the natural frequency of a structure by using something in the engine? What you can do is the engine rpm. The structure is a different thing altogether. How can you change the structural properties by using something in the engine.

Student: Sir, but the frequency is dependent on the structure, the structure quality as well as the mass. So, you can always play around with the mass.

Mass of what?

Student: Mass of the loading part.

No. Natural frequency of a structure is a function of its stiffness and its mass distribution; structure, not the moving parts; moving part is a different thing; that is excitation.

Student: Sir, So, it is its system mass distribution. So, you can always change the mass distribution by fixing some mass in the what…

What you can do is you can only change the excitation properties of the exciter; not with the structure. Unless you do something with the structure, the structural properties will remain as it is. What we are talking about, this is the structural properties and this part is the exciter property. You can play about here; I do not disagree, but this part is already built as a structure. So, at this stage we are checking these two together. We assume that as per the classification societies or as per the usual ship building practice, you are trying to design your structure and then these are the estimated frequencies. But this has nothing to do with the excitation. If you do something with the mass distribution of the exciter, then the excitation frequency will be different.

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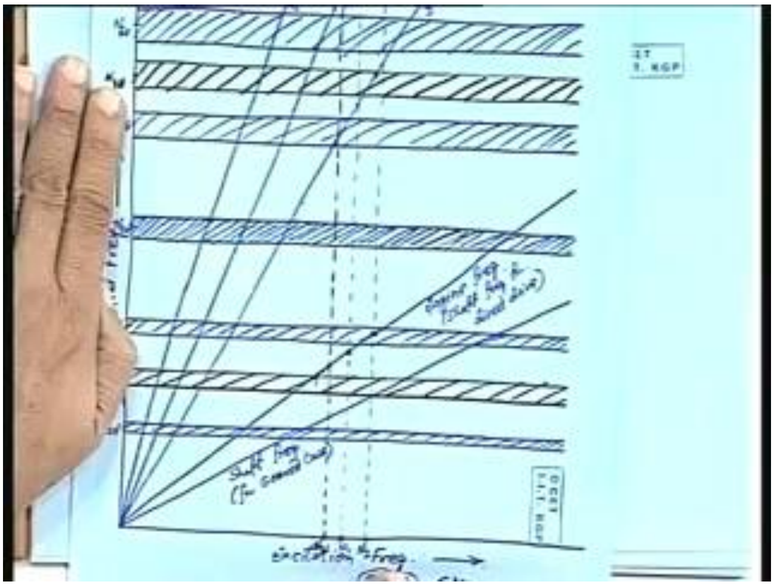

If you say that instead of N 1, it may generate N 2 or N 3 or something like that, but that is an excitation; nothing is happening here.

Student: What they contemplating is the natural frequency what has already been finalized if there are some added frames and beams.

No they are not saying that.

Student: ((Refer Time: 31:47))

Definitely that is the design part of it. I have already said that when you are taking a stiffened plate, say for example, consider an engine room where on the tank top you are putting the engine; let us say on the tank top you are putting the engine directly on the tank top. Obviously, below the tank top, below the engine, you must have the girder. Girder has got certain scantlings.

Now, if you find you have designed that girder to take the load of the engine, now from frequency point of view you find that that is giving you some sort of a stiffness. By changing it by say thickness another 1 millimeter or 2, you are not going to increase the weight of that particular double bottom structure much, but you can definitely change the flexural quality or the property of that particular structure which will directly influence the response because ei is being changed; I is being changed.

So, as soon as you change the I, the frequency will change. The mass is not increased much, but being a vertical girder, it will dramatically change the moment of inertia. So, the k is changed. k is ei by lk. You are not changing e, you are not changing l, but you are changing the I value. So, I is changed; m is changed a little. But the final effect will be it will change the frequency or in that region you change the stiffener spacing, that will again dramatically change the flexural property. So, that local adjustment can be done. We are not talking about that. I suppose he is also not talking about that.

Student: ((Refer Time: 33:40))

This side is finalized in the sense this is a structure part; this is the engine part; we are trying to now decide which engine is to be put into the ship. So, first assumption is ship is there. So, if the ship is there, these are the natural frequencies.

Now, which engine is to be put? Now, what excitation you are going to put into that? So, this is what we have decided. If you find that out of these alternative, nothing is fixing, may be that you have to change the entire property of the entire design of the ship, because this is still in the design stage. We are using those approximate formulas only at the design stage, I have already said that you are making it better now. Nothing is finalized.

So, when you are proposing something, you may say that to the owner that why are you selecting this length, this breadth, this depth to the ship; change it; change the mass of the ship; change the size of the ship; whatever it is, I will give you a better ship. Because you are going to design, you said that why are you interested in say 130 meter long ship; why do not you go for say 145 meter long? Is it going to make difference to you?

If suppose the route which he has given, there is no length restriction, will it make much difference for him too. Obviously, with the length, his dues will increase and so on and

So, forth, but as a designer, you will do an economic study of that and you will try to tell him that the size which you have proposed and the size which I am proposing, both have the same economic value or may be that your proposal is more profitable than what he has proposed you to design. So, that team will say. Is this part clear? So, at this stage, this is what is the hull resonance diagram and this is the importance of it and we cannot do over with this part.

Now, once we have decided about this and then we would like to find out or redraw the hull resonance diagram when the order is already awarded to you and many of the structural items are known to you. So, at that time, majority of the structural arrangements have been done. And as a classification society, they try to approve certain major drawings; not the construction drawing and the details, but the major scantlings those are all approved. So, based on that, you try to finalize what is the basic structure.

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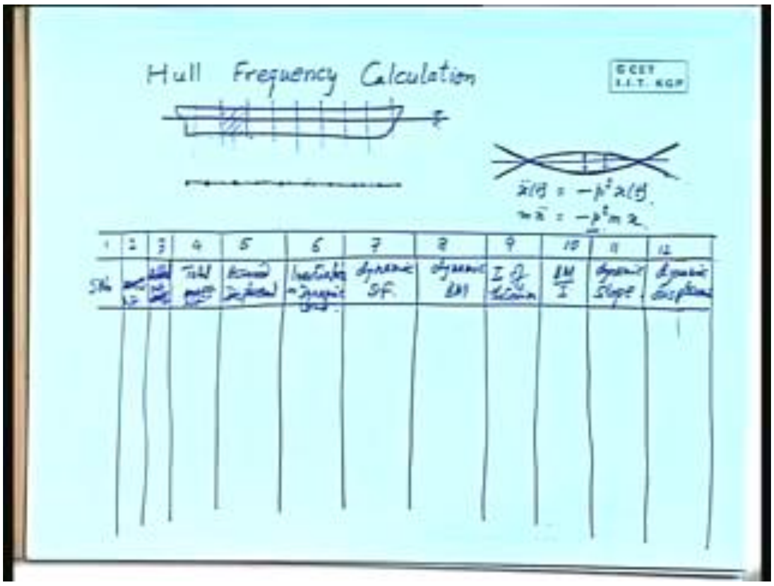

So, we will try to do. I am saying that hull frequency calculation. Now, this is a detailed method where you actually use all the design particulars of the ship. We have seen that for every section of the vessel, first of all, let us say that we have seen that hull is considered as a girder. So, when we say hull is a girder, then it is basically a beam. It is floating freely in water and therefore the end conditions are free free.

So, for the vibration case we assume a ship girder to be a free free beam. Now, we have also seen the basis of this schliks formula which says that ei by delta lq. Now, ei by lq is a function which defines what is the stiffness, and delta is nothing but the mass. So, if the ship is broken up or is imagined as a member, so let us try to consider the ship first and then we will talk about it.

Say, this is the ship I am considering, floating in water somewhere here and I want to divide it by a number of sections. Now, I say that this part of the vessel, between these 2 sections, will be represented by a particular mass and that mass is somewhere here, center of this. Similarly, this particular part is this mass; this particular part is this mass; this particular part is this mass and so on. And they are interconnected by some sort of a spring which has got a stiffness property which is nothing, but at this section, because this is the mid section of this, so at this section whatever is the sectional properties e, i and l here. So, based on this, this will have some stiffness.

It is a continuous system and therefore I can imagine a lot many such point masses. What is this mass? This mass is the mass of this part completely hull and cargo, any other mass which is being carried within this space, and then we also talked about added mass. So, we add the added mass of that. And how the added mass is calculated? We know that this is the cross section. So, under water cross section is known and we try to find out what is the CV of that and then we add it. So, here that calculation of added mass will come into picture. So, to find out rest of the properties, you require the shape of the vessel.

So, the lines plan which has been done for the ship, now we are coming to the detailed calculation, so lines plan is now available. And from the lines plan, I get a section ship here. So, I get the exact B. I get the exact D and B by D ratio or whatever it is. So, I can find out what is the added mass coefficient of this particular section here.

So, that is, so the added mass is added to this complete thing on the basis of this added mass coefficient spread over this distance. So, the mass of the ship plus the added mass of the ship, these two together move up and down. And when it moves up and down, then the flexural vibration will either takes place like this or any other mode. So, assuming this to be a harmonic oscillation, this displacement will have the corresponding acceleration because it is a to and fro motion. So, you have the displacement, you have the velocity there, and you are having the acceleration.

Now, with this acceleration at every point, you can find out what is the acceleration up and down this. For this moment, what is the acceleration at this point for this moment? Now, this is corresponding to some mass here and therefore, you are getting the acceleration of that particular mass, and therefore, you are getting the inertia force of that particular mass.

Now, this inertia force is going to give you some sort of a loading on to this beam. So, now, I am bringing back the concept of that a ship is loaded by some sort of a dynamic loading which is mass into acceleration, and if you have the girder which is loaded by this dynamic mass, dynamic force, then integration of that will give you some sort of a dynamic shear force. Integration of that along the length will give you something dynamic bending moment; divide that by EI value, flexural rigidity of that section at that particular cross section; then I get M by EI curve and the dynamic bending moment; integrating that I will get the dynamic slope and integrating that I will get the dynamic displacement .

So, this dynamic displacement will give you some sort of a dynamic acceleration and that is the time dependent function. And from there, you can find out what is the frequency. I am starting with some sort of a deflection pattern and I am arriving at a deflection.

Now, the starting deflection pattern, if it matches with the derived deflection pattern, that means, what I assumed earlier, that the ship is moving in this shape is the correct shape and if it corresponds to this derivation, then my assumption is correct; if not, then I have to modify this. Ultimately the displacement to start with you should get the same displacement there. So, this becomes an iterative process. You start from here; go there. So, you have assumed something; you have derived something. If the assumption is correct, then the derived thing should match with it; if it is not, then you have to modify the assumption and then again you try to derive, and keep on doing it till the starting point and the end point are acceptable to you within the engineering accuracy. Is that clear?

If that is ok, then what we do? We make a chart here. Column one, as usual we say serial number first or station number; column 2 is the mass; column 3 - added mass; column 4 - total mass.

Now, we are talking about mass, but actually what we will be doing? We will take the weight because this part we say that the weight of this portion is so many tons; that is already there in our head and I do not want to change that notation. So, to get the mass from that weight, I have to divide it by G. Instead of that, I know that I have to divide it by G; even the added mass I should get it in that. So, what I will do, instead of mass, you just take weight here and correct it to weight here and then we take total weight. So, what happens? G is included here and then I will say that added this total weight is a representative of the total mass. So, weight is a function of mass. G included in it. Then you take assumed displacement.

We take some assumed displacement. So, now, you can take this as an assumed displacement for a free free beam. So, normally what is done? You take an uniform beam and for the uniform beam you consider a free free beam displacement curve knowing fully that ship is not uniform cross section or it is not a beam of uniform cross section. But my first approximation you have to start somewhere and therefore, you take uniform beam free free curve.

The displacement curve of a free free uniform beam is the starting point usually which is symmetrical about the midship. You can also start if you have already done the longitudinal strength calculation. Then you have that static displacement curve. You can even start with that. If nothing is there, you simply assume that all displacements at all stations are unity. Nothing wrong with that; only thing your iteration will take more time. Then total weight into the assumed displacement because I assume a harmonic motion and therefore, x of t x double dot t is given by minus p square x of t and n x double dot is the inertial force.

So, if I want mx this thing, so it is nothing, but p square mx. If p square x is a function is equal to x double dot, then a inertia force has become minus p square mx. So, inertia force I will calculate on the basis of mass into displacement. It is our dynamic loading.

Then, you have seven. Integrate this along the length; you will get your dynamic shear force. Integrated once again, the shear force, you will get dynamic beam. And then at all these sections, you know what is EI or simply I; I of the section. And then you will try to find out what is BM by I; this divided by this is equal to this.

Try to integrate this; you will get dynamic slope M by EI. I am not taking E here because E is constant all through. So, why unnecessarily do that calculation. I will do the calculation towards the end. So, M by EI curve is there; integrate it, you will get the slope and then integrate this, you will get dynamic displacements.

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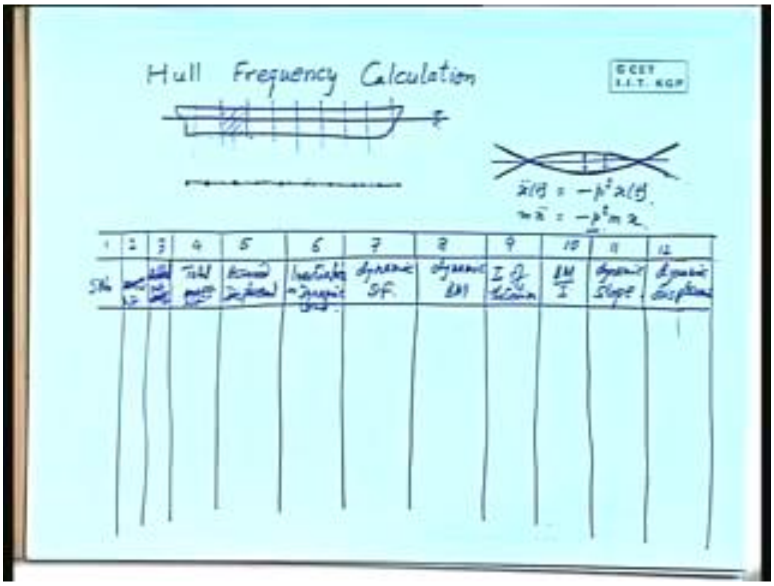

If your assumed displacement is correct and this is the mode shape, if this is the mode shape, then this and this should match; if not bring column 12 to column 5; repeat all this calculation and keep on doing this till you are satisfied. It is a very difficult job; time consuming.

So, what is done here? That the assume displacements is assumed as a fraction of the maximum displacement and this is assumed as the fraction of the maximum displacement; that means, wherever you are taking a maximum displacement, that is unity and remaining are all fraction of that. So, here also, whatever the dynamic displacement you get, you try to normalize it by dividing all the row values by the maximum value here and then you are going to get the normalized value, and then you try to compare it.

So, what is happening here? We are starting. If you are taking the unity here, we are not bothered about the absolute measurement, but maximum value. That means, we are starting with the particular pattern and we are not changing the pattern; we are only trying to change the distribution of the… So we are getting the same pattern here. May be that will get rotated here or deflected like this. So, we are modifying this pattern and as you can see that we have assumed this function; so p square is included here. So, in this part itself p square is there and we have to take it out from this expression here. We will take it up in the next class once again on Wednesday. We will try to give the detailed part of it. Any questions here?

Student: ((Refer Time: 53:54))

No mass distribution.

In a similar way, we are trying to do it. So, actually what we are trying to do here? The number of stations which we take here where we are considering the number of masses and that is what I was saying that it is basically a multi degree freedom system. And depending on your computing capabilities, if you are doing it physically, may be that will take only 11 masses here, as we if we do for lines plan, but if you have a PC available and somebody to feed in the data, then why this much? You can take actually at every frames space.

Student: Actual frame space.

Actual frame space because all those data is available with you.

So, actual frame space we can take and that may work out to be say every 800 millimeter. So, instead of 10 or 11 section, this will be 130,140 or if somebody is interested say I will take it every 10 centimeter; you can even take 1000 divisions here. So, more you take, more continuity or more towards the continuous system you are going.

So, if you have a machine which will try to calculate it automatically, that value, these days it is not impossible; you can give discrete values and you can make it uniform, or you can get the distribution curve pick up the values at any desired level and all these calculations can be done. So, if that can be done, this can be repeated also; there is no problem. You just give a check value here. And we say if it is not, go to this, repeat this, and if it is available within the accuracy level, you say stop.