Performance of Marine Vehicles At Sea

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Lecture No. # 08

Shallow Water Effects

Good morning gentleman. Today we will talk about how the resistance of a ship gets affected if it moves in shallow water as compared to its movement in deep water. Practical experience of course as shown as that, when a vessel goes from deep water to shallow water, typically from a sea to a river, speed drops tremendously. We will see if it is possible for us to determine a speed power relationship or speed resistance relationship in shallow water. Taking the values of deep water as known.

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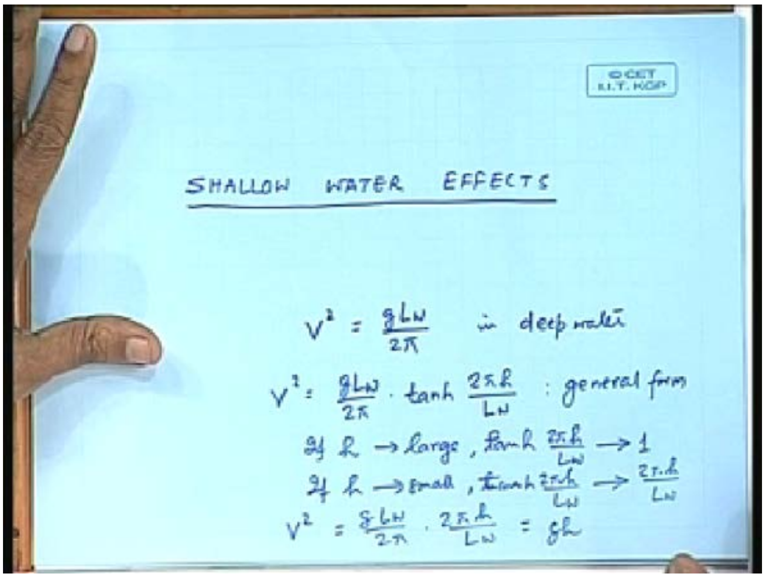

What happens in shallow water? Imagine a vessel moving in a limited water depth. As the vessel moves forward, the water flows past the ship as we have seen, and because of restricted availability of water depth, the water will speed up at the bottom; the velocity will increase. If the velocity increases, what will happen to pressure? Pressure will drop. We have seen previously that, as in the mid-ship region, that is, middle of the ship, the pressure is low any way.

So, this pressure falls further, and as it falls further, the immediate effect is with the same immersion of the ship, the upward force reduces. Therefore, the vessel will experience a sinkage, because ultimately for the vessel to remain afloat, buoyancy has to equate weight. So, if the pressure drops in a large portion of ships length, buoyancy reduces at the same water level. Therefore, the vessel must experience a sinkage so that the buoyancy and weight equalize and the vessel is in equilibrium.

So, that is one effect that takes place, but that does not reduce the, speed, velocity which has increased, that stays. This sinkage is not uniform; it is not that the ship parallelly sinks. There is the large drop of pressure in the forward side of the ship and a little smaller drop of pressure in the after side of the ship.

So, the vessel actually sinks more in the forward end and less in the after end. So, apart from sinkage, there is a trim by bow, and as you will know, trim by bow is not a very desirable phenomenon. This goes on if you go to shallower and shallower water; this vessel will go on like this till it touches the bottom. This has of course effect on resistance and the effects will be the change in pressure will give a change in pressure forces which is the pressure resistance and this would also change the frictional resistance, because we have got increased velocity past the ship. Am I clear? This is one effect which we can understand.

The other effect that is much more severe perhaps is due to a change in wave pattern. The wave pattern in deep water and the wave pattern in shallow water, are quite different. So, the wave that the ship generates would now change in its pattern, and the general relationship of speed to wave length we have seen as, (Refer Slide Time: 05:20) isn't it what we had given last time? That speed of the wave is equal to this in deep water. This is what we had seen yesterday when we discussed over wave making.

But in shallow water, actually I would not say in shallow water. The general form of this equation is slightly different. Let me write the general form of this equation. This is general form, that is, V square is equal to that is the speed of a wave of length, length, l w in water is equal to, is given by V square equal to G l w by 2 pi multiplied with tan hyperbolic 2 pi H by l w - where h is the depth of water.

Now, this is, look at this, this, term - tan hyperbolic. What is the property of this term? If h is large, tan hyperbolic 2 pi h by l W which becomes large now 2 pi h by l w. This tends to 1. So, if this tends to 1, then this becomes equal to this, which is the deep water expression we have seen earlier.

Now, if it is low, if h reduces, if h is small, that is, this whole quantity reduces, then tan, tan, hyperbolic 2 pi h by l w changes to tends to be just 2 pi h by l w, that is, tan hyperbolic of a small quantity is equal to the small quantity itself. You know this, isn't it? If theta is small, tan theta is equal to theta. So, at small angles, tan hyperbolic 2 pi 2 pi h by l W will tend to be 2 pi H by l W. So then, what is v square? Let us see. Can you see that?

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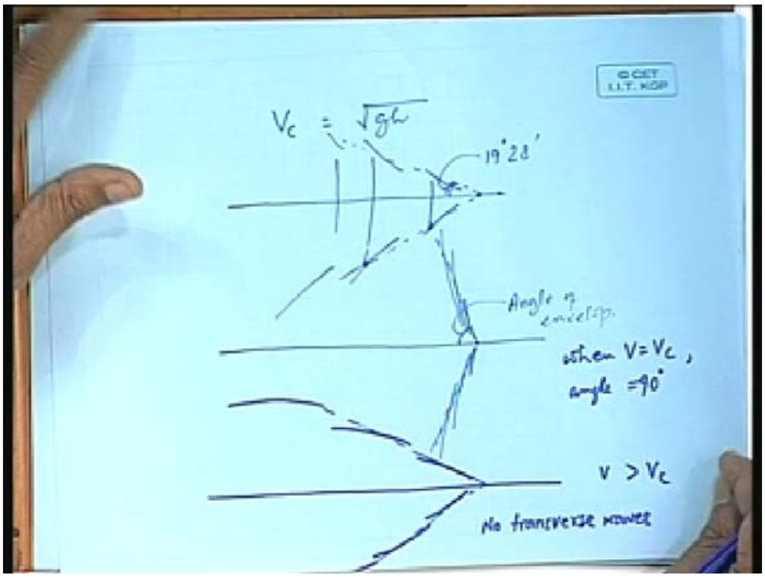

So, in shallow water, the speed of wave has a limiting value G H or this is called the critical speed; V critical is equal root over a G H in shallow water. This does not occur; this is not a critical speed if H is not slow, but when h reduces, there is a critical speed root over G H. Can we see the wave pattern? Let us see how the wave pattern changes.

The, we have seen in deep water. If there is a pressure point here, then we had seen a set of waves are generated enclosing them. If this is the pressure point, then we have a set of divergent waves like that and a set of transverse waves. They intersecting the divergent waves on the line itself like that here, here. These are the causes where wave suddenly raises up.

So, this is this angle we have seen was 19 degrees 28 minutes. Now, this will happen in deep water. Now, the waves will goes into shallow water. And as h reduces, this angle increases. Now, just imagine that this angle increasing; that means the divergent waves will come nearer to each other, is not it? Just take this line out. So, if I draw an extreme case, how will the waves be? Like that, like that. (Refer Slide Time: 10:48) As if they will emanate from one point and they will tend towards each other, and what is, this is, this was the angle here; this was the angle, angle of envelop.

Now, you see in the limiting case, this will become 90 degrees, that is, when V equal to V C critical speed is wrist at that height, that water depth h, then angle will become equal to 90 degrees. What does that mean? It means that there will be one divergent wave starting at the pressure point itself and travelling along with it and the height of it will be very high. It is as if all waves have merged into a single wave travelling along with the pressure point.

Now, increase the speed further beyond critical speed. What will happen? The, this angle will fall; obviously, we have seen that one condition is that waves do not travel forward. So, it cannot go forward in any case. So, these angle will reduce again, but the nature of the divergent waves will change, that is, the divergent waves instead of concave and going out, they will become convex like that, and there will be no transverse wave. Transverse waves are vanished here; as the angle become 90 degrees, the transverse waves vanished.

They will not appear again because there are non concave divergent waves. This is V greater than V c. So, since wave pattern changes completely, the resistance will change. Is that clear? Am I clear? Now, how do we take into account in resistance? We will, this problem was studied way back in 1908 by Sir Thomas Havelock, whose name I have mentioned while talking about wave making pi1er in wave resistance of ships. He postulated whether it is true or not is debatable, but mostly true because it more or less agrees with experiments that the wave making resistance of a ship will be same for the same wave speed. The wave making resistance of a ship will be same for the same wave speed. If the wave speed was same, then the wave making resistance will be same.

What have we seen? We have seen that as the depth increases, reduces, the speed of wave reduces, is not it the expressions that I gave earlier? Compare this with this, l w is large. So, this will be higher than this. So, as h reduces, the wave length reduces. So, if the wave length reduces or rather wave speed reduces, and therefore, the wave resistance will be same for the corresponding speeds between deep water and shallow water. If I draw it, I think it will be easier. If I draw it in the form of a diagram, but first let me tell you how we can determine this dropping speed for the same wave making resistance.

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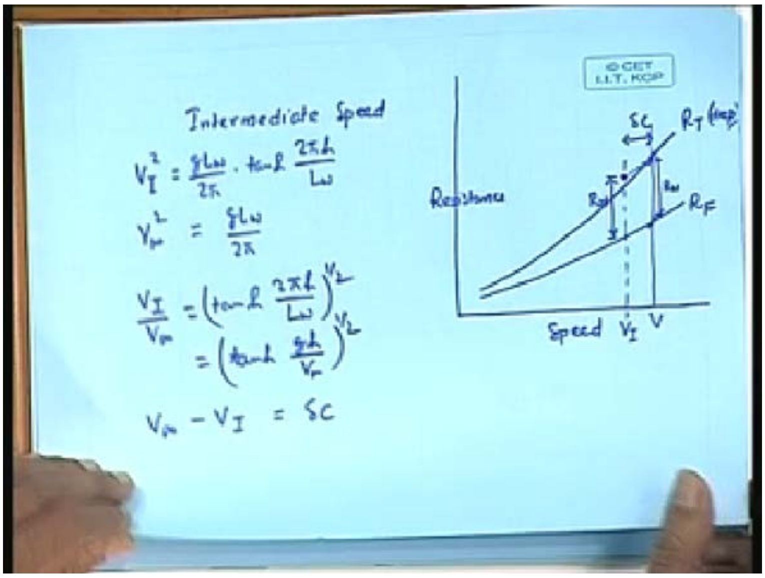

Let us call it intermediate speed, that is, a speed at which wave making resistance will be same as that in deep water. Am I making myself clear or not? If I am not making myself clear, please ask me. What I am saying is that, if the ship had a wave making resistance R w at a speed V in deep water, then it will have the same wave making resistance R w at a lower speed V I in shallow water of left h. Is that clear? Have you understood? Shall I do a diagram?

I have repeat this diagram a number of times. This is the resistance this is resistance. This is speed; this is R T in deep water. What is R F? This is R F. So, this is R R most of which is wave making resistance will take this as wave making resistance of a ship. Let us take a speed V. This is the wave making resistance this much, is not it? This will be same at a lowest speed V I. How to determine V I? We will see in shallow water due to wave making effects alone. That is why it is called intermediate speed. We will see other effects. This will come here, this point. Is that clear? That is, this is R w, and so, is this have I made myself clear?

So, you see what is happening is the wave resistance is same, but at V I, the frictional resistance as reduced. That is why I am saying that this is only due to wave making. We have not considered the friction effects or pressure effects which we discussed that the pressure will reduce at the bottom because of increase in speed. That we have not considered. We have considered only resistance due to wave making. We have said that this will change to this place.

Now, how do we calculate this? V I square is equal G l W by 2 pi into tan hyperbolic 2 pi H by l W and V infinity square is equal to G l W by 2 pi. We are saying that this resistance of wave making due to this V I is same as resistance of the ship in deep water at speed V infinity; infinity mean infinite depth. Then, we can say V I by v infinity is equal to tan hyperbolic 2 pi h by l W which we can also write as tan hyperbolic G h by V infinity square, this also square.

Half sir

Half, and v infinity minus V I is the drop in speed which we call delta C. So, we can actually calculate V I by V infinity and redraw this get this point. Now, this is the wave effect. The other effect, that is, due to increase in speed of water because of rest constriction which will have a numerous effects actually it will change the pressure forces. So, axial pressure comp1nt will change, change in the resistance pressure resistance; it will also increase frictional resistance and lot of effects will come because of increase in speed.

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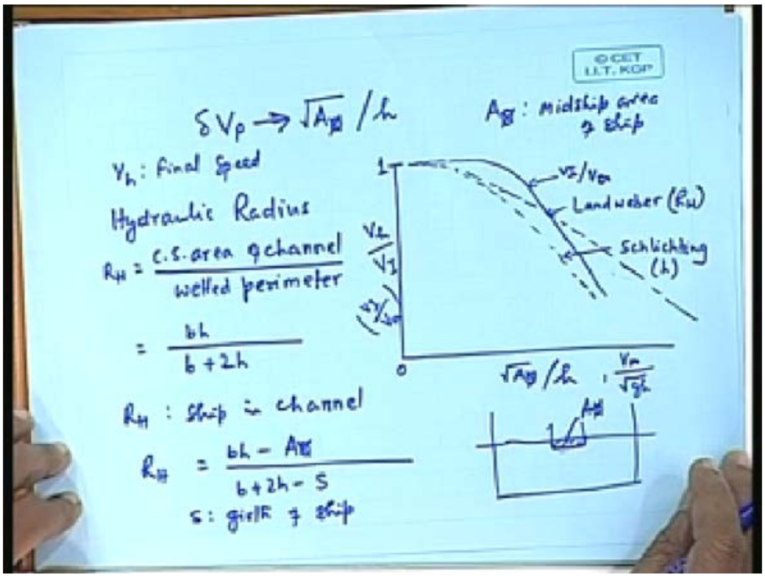

There will be a another drop in speed which we can say as a delta V p, that is, the total resistance that we have experienced will now occur at a drop in speed of delta V P. You will understand what I am saying in a little while. Schlichting, you have heard the name of schlichting? Again, a very famous name in study of viscous flow. Schlichting said that speed loss delta V P can be represented as mid-ship area square root; a mid-ship is mid-ship area of ship and h is depth of water.

So, mid-ship area of ship square root divided by depth of water. This quantity will determine how much of, sorry, this is not equal to, this will determine how much of speed drop will be there. The dependence of delta V P will be on this quantity. He made a number of experiments and came to this conclusion that a mid-ship square root divided by H should determine what is the drop in speed and he produced a diagram, that is, if I plot this V H by V I, V H being the final speed - where V H is the final speed. V I we have seen is the intermediate speed. So, the drop of speed, the ratio of the two speeds would start from 1 at this 0; H is large and till about till about 0.4. This should be something like this curve will come something like this. This is your Schlichting curve, schlichting. What is the spelling of schlichting?

Schlichting gave this curve that is a mid-ship square root by h. In this representation, there is one problem. Problem is what when a vessel goes in a channel? The restriction is not only in the bottom but also in the sides. Exactly same effect will occur also in the sides, that is, there will be increase in speed and increase in, decrease in pressure and it will have effects in both wave making as well as frictional not wave, pressure resistance, other pressure resistance and frictional resistance.

So, land waver modified this to what he called is hydraulic radius. May be you have heard of this. Instead of this quantity, this h, he defined a hydraulic radius R H. R H is equal to C S - cross sectional area of channel divided by wetted perimeter of channel. Now, this you will see, if I take a rectangular channel, then cross sectional area a channel b into h divided by wetted perimeter is b plus 2 h. Is that correct? Now, assume B to be very large. If it is very large, this tends to be and B B cancel and you get h.

So, if the channel is not restricted breath wise, then this is same as this parameter h which schlichting had taken, but if b is less, then the parameter modifies itself to R h. That is wetted radius, sorry, hydraulic radius. If now there is a ship in the channel, then this will modify itself R h in case of ship in channel. What will it become? B h minus a mid-ship, that is, that is the reduced area. The area of the channel is now B h minus. The area of the ship, is not it? This is the channel; this is the water line and this is my ship; this is a mid-ship. So, this area is actually this.

And what is the wetted perimeter? B plus 2 h minus s, where s can be the girth of ship that is this. So, this is the wetted perimeter. With this parameter, land over analyzed a number of experimental data and we found a slightly different curve. This is land wave; that is based on r h and this was based on h. So, once this curve is obtained, we can find out what is the ratio between V h and V I. This curve is experimental determined and found to be matching with some full scale resistance data. I am saying sum because I will come back to this later.

So, on this curve if I draw, the V I by v infinity know. See, I can draw the V I by v infinity with a base of this also can be drawn to a base of V infinity by root g h. We have seen this know V I by v infinity as a function of V infinity by root G h. We can do this, and that curve would look something like this. This is V h by V I curve, sorry, V I by V infinity curve. This is all given in text books. You can see these diagrams yourselves.

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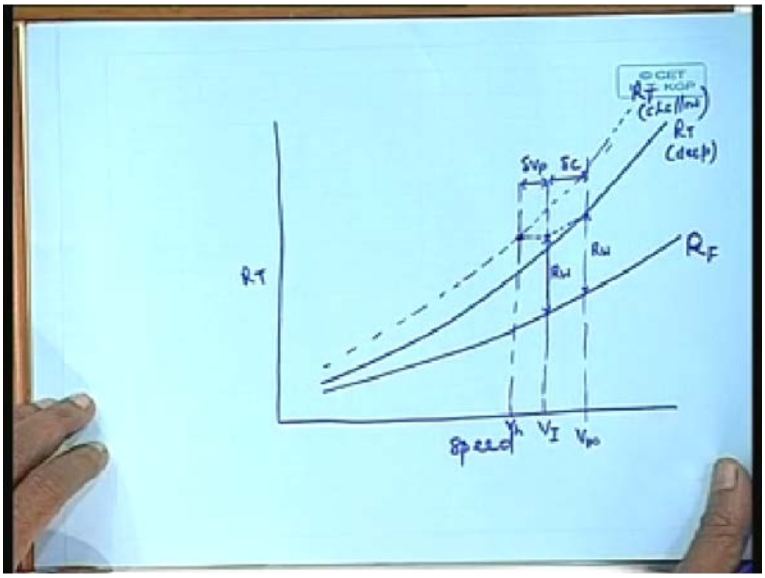

How does the resistance curve change now? We can draw a resistance curve for a ship now. This is R T; this is speed the same curve that we drew before. What is that? We drew this curve, is not it? Let us say this is R T in deep water and this gives me a C f that I call it R f in deep water.

At a speed V, let us say here. This is v infinity; this is my wave making resistance. I calculate my V I; I can calculate V I. So, this is V I. At this V I, my wave making resistance will be same. This point will come somewhere here, that is, this point moves to this point. The resistance here at V I is so much, but this is not final; I have still said there will be a drop in speed which I calculate.

I now have the formulation for, what is that? This formulation I have; I have this land waver curve. So, depending on my h or hydraulic radius as the case may be, I can calculate v h divided by V I and get the speed loss. Is that clear? Are you understanding or not? Tell me, do not tell me. So, I get the speed loss here. I have said this is delta; I have said this as delta c, is not it? What did I said? Delta C and I can get this delta V p.

And I have said the frictional resistance will not anymore remain same. So, you will get the same frictional resistance as here at a lower speed. So, this point will move here. This is my final point of shallow water resistance; at this speed, this is V h. So, this will be my speed V h giving me a resistance this corresponding to infinity speed V infinity giving me a different resistance r t at that point.

So, if I do this calculation, I will get a shallow water resistance curve which will look something like this. This will be a R T shallow water. This is how we estimate shallow water resistance. Now, what is the uncertainty in this? As you might have noticed that most of these are assumptions, that is, we have said there are two effects - one is the wave making pattern changes and another we have said the speed increases. Therefore, there is a effect spin drop.

We have not really talked about how the speed changes and the boundary layer changes around the ship hull. There will be additional effects which have not been included in this analysis of shallow water resistance. So, actually the dropping speed that is estimated using this method is valid only up to certain amount of restrictions. If the restrictions increase, then the drop in speed may be more. Why does this drop in speed important? Why do we talk about this? If my vessel is not going to move in shallow water, why do I talk about this?

We have seen that shallow, critical speed in shallow water is dependent on the depth of water. In other words, if I have high speed, then my critical depth speed to depth relationship will change. I may have a higher depth at which that will be the critical speed. Do you understand? If the depth reduces, then my critical speed drops, but now, I am, suppose I am moving a passenger ship or a destroyer or some ship which is having a high speed.

What is the depth at which shallow water effect will start feeling, start being felt? It will be more than if I move to the same ship at low speed. Do you understand what I am saying? I have got a speed which I am moving at fifteen knots. A ship moving at fifteen knots and I have got say thirty meters of water depth. It may not be important at that water depth, but if I move that same ship at twenty, twenty, knots, then the water depth effect will be felt.

In other words, if I am going for high speed ships, then my shallow water effect becomes more prominent. When you, when I am in service, my ship is going from deep to shallow water; there is a speed drop and it effects fuel consumption of course, because for the same distance, you take more time to move and then you try to find out why it is and you find that the water is shallow. That is why this is happening.

Perhaps more critical than this is the trial condition in which you have to move a ship where the guarantee terms come into play. When the ship is going out for trial, normally the conventional method is move the ship near the shore. What is normally known as a measure mile test? Have you aware of this? That is, after the ship is built, the builder has to satisfy the owner that the speed for which the contract was signed has been achieved. So, the ship has to be taken out and trial.

Now, when you take out the ship and trial, normal procedure is this to mile post are there on the shore line and the ship goes at a distance on the shore, but parallel to the shore line, so that the mile post can be seen and timed. This is the simplest explanation I can give.

Now, if the ship is going near the shore, you may not have enough depth to have the deep water effects completely. Therefore, you may not get your trial speed; this is a very critical thing. Now, to do the test therefore, if you go far away from the shore line, you are not observing the mile post. So, maybe you have to take the ship out to somewhere else where you get large water depth near the shore line where you can conduct the measure mile test.

In case you cannot take the ship out and you have to do this in shallow water. Then you must be able to find out to calculate and show that since the water depth is low, we get a particular speed, and if the water was deep, we would have got so and so speed. That extrapolated speed to deep water should be satisfying the contractual speed. The problem there comes that if the water is really low, then the extrapolation will not give the speed because of the uncertainties involved which I have just mentioned. So, sometimes it may be necessary to do model tests in shallow water.

That is of course a difficult proposition doing model test in shallow water because you have to remove the water to really bring the generate shallow water and the model has to come down in the towing tank, which means the measuring equipment etcetera everything has to come down which may not be possible.

Otherwise, the alternatively you may have to have a falls bottom on the entire tank which can be lifted to a height to give a shallow water effect in the towing tank. Many tanks have a deep water tank with a shallow water portion at one end, so that shallow water is generated there and you can do the shallow water testing over that length, but this means the length of the whole tank increases tremendously is as if we are having two tanks. Anyway, talking about guarantee speed.

We have seen the allowances that we gave to trial condition. We gave correlation allowance over model because of the small hull roughness. We gave allowances for wind resistance; we gave allowance for appendages and calculate the trial speed. Now, last class I gave you a formulation for roughness. Did I not? I gave, what was that? It was based on length.

Yes sir

And a roughness parameter h which I said is the average hull roughness in microns. Did I give that k? k divided by l was the parameter on which the allowance depended.

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Yeah tell me

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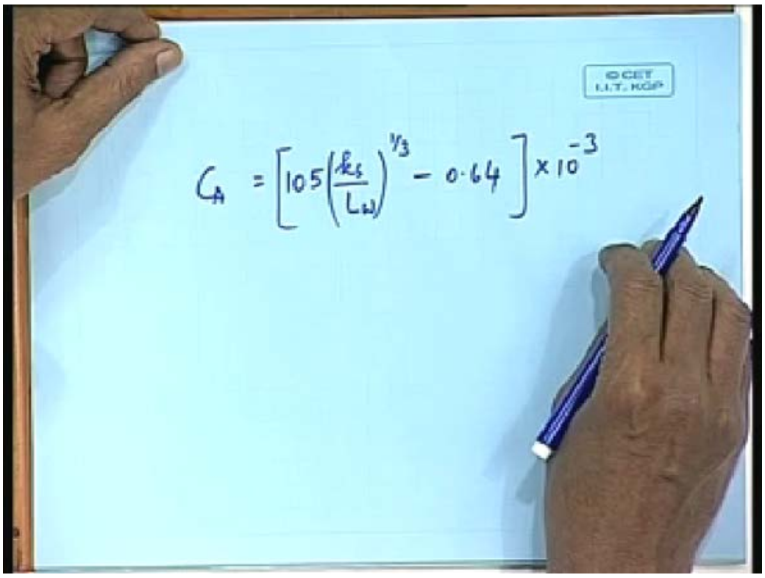

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This was the roughness allowance we gave, and we said that for a new ship k s should be between 125 to 150 microns or 125 150 into 10 to the power minus 6 meters. This is what we had said. What happens when the ship goes into service? As the ship goes into service, two effects take place - one is fouling and the other is roughness. Why does roughness take place perhaps you are aware? Roughness take place because of paint deterioration which may, may, expose the steel surface to saline environment causing corrosion. Corrosion again can be general corrosion, general reduction of thickness over a large area or pitting or previce corrosion where you have pits in the hull surface, a deep hole in the hull surface and all this reduce the smoothness of the hull surface. So, hull becomes rough.

Now, corrosion is a very peculiar phenomenon and it cannot be predicted apriori where the ship will corrode, whether the ship will corrode in the front back or middle bottom or side. General observation is that corrosion occurs mainly where the water level variation is there, the so called boot topping region of the ship near the water line, but there is large amount of corrosion at the bottom of the ship also.

Now, we know that a ship goes into a major survey at the interval of five years. When the ship is dry docked, the fouling is removed and the bottom is the ship side ship shell is scraped, short blasted and painted. So, what happens to roughness at that stage? Does it come back to normal?

Normally as the ship goes into service, roughness increases, but when you bring it to dry dock, scrap the paint, short blast the surface; short blasting is around primary to smoothen the surface, and then, paint it again. It should become as good as new, but it has been found by measurement that generally even after five years away, there is a small increase in roughness. The ship never comes back to the new condition in spite of if placement of plates which are reduced to a last extent in things.

In between these five years, what happens? The plate roughens of course, and there is large amount of fouling. Fouling may be removed once in a while, but generally fouling will grow. Fouling is a bio phenomenon depending on the environment in which the ship is operating, that is, whether its tropical climate or temperate climate and whether it is moving or not moving. It is fairly well known if the ship spends a large time in ports particularly tropical ports, fouling is very heavy. So, when it goes out after being in a port, the speed drops.

Now, the roughness, resistance increase due to roughness can be calculated using this formulation if we know what is the roughness, K S of the ship at any time, but it is very difficult to estimate the resistance due to fouling because of the uncertainty in growth of fouling as I have said, whereas the ship is moving at what speed is moving at what how much time it has spent in ports etcetera is not known.

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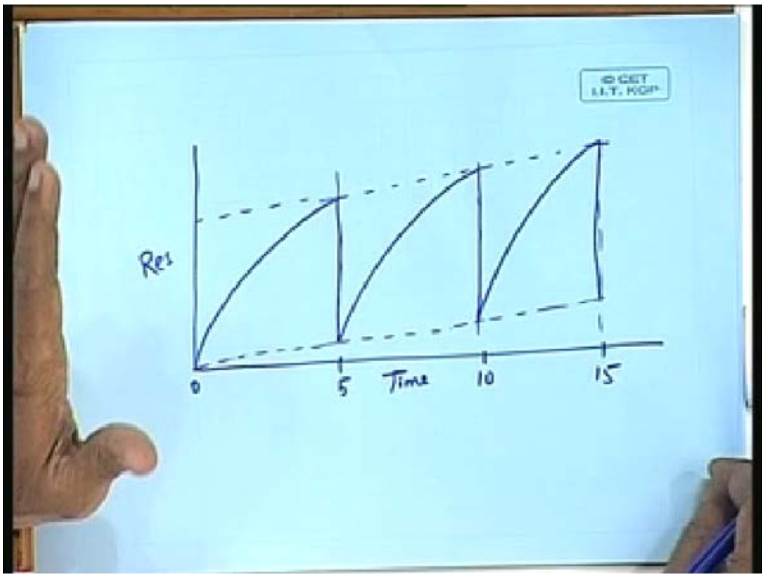

So, in general if I draw the resistance of a ship as a function of time and this is a 0 here and this is the five year period, then resistance will increase till the next survey like this, and at this stage, you remove the fouling and the corrosion, I mean smoothen the ship.

What will happen at this stage? As we have noted that the corrosion will slightly increase that it will never come back to 0 and it will go again to something like this in next five years, and again, it will come down to, it will go like this; continue like this.

So, a general corrosion increase will be there like this and the resistance curve will be enclosed in this envelop. If I draw the speed curve, it will be just the reverse. It will be high speed at the beginning dropping to a low value, then again increasing and dropping, increasing and dropping. This is very interesting. First of all, this gives us some indication if we can estimate the, from the measured speed if we can estimate the resistance increase, we know at what point of time we require to maintain the hull; may be a stepping of the hull, removal of foulings even in approved condition may be desirable.

But more important is the trial condition which I have already said is a very critical for the ship builder and ship owner. You have taken the ship to the dry dock, you have clean the ship, painted the ship again and you are ready to go out to trial. For whatever reason, may be the, it may be as simple as the server not being available or the life boat not being available. Hence, the ship cannot go out to sea, or may be some major production problem. It could also be that there is a storm brewing and you have to wait for fifteen days after you have undock the ship to go to sea track. This fifteen days is critical because what is happening? The ship is standing in water in a port environment for fifteen days.

So, the fouling that will come up in this case will definitely show you a dropping speed. So, you have to be careful when you go out for trials, in what condition your ship is, and if you cannot bring back the ship to its original new condition, you must be able to apply suitable corrections to get the proper trial speed. I think we will stop here. Thank you .

Preview of Next Lecture

Lecture No. # 09

Ship Hull Form and Resistance

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Good morning and this hour we will talk about ship hull form and its relationship to resistance. From the understanding of resistance, it is possible for us to draw some guidelines has to how we can develop a hull form or what are the parameters of hull form. That can be controlled to give better resistance characteristics at the design stage.

Because once the design is over, the hull form is fixed. If the resistance characteristics are not good, the ship will suffer for its entire life.

So, we will see some main parameters of the hull form and how it affects resistance. This will be fairly general analysis of relationship of hull form to resistance. The parameters that effects most the resistance of the ship is the fullness of the ship.

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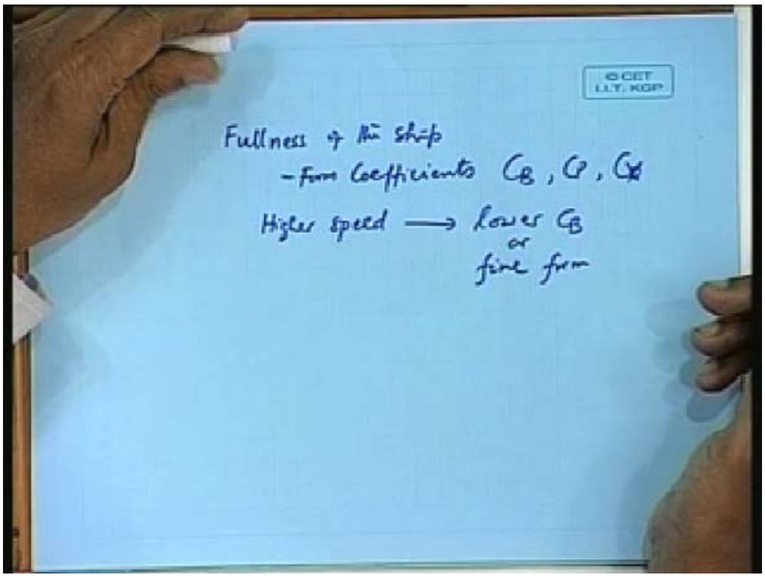

How full the ship is represented by the form coefficients? Mainly C B and C B and C mid-ship, we will see all of these. C B of course, the block coefficient tells us how full the ship is and gives us some idea about how the ends are shaped. So, that generally we can say that, if the ends are shaped more smoothly or more narrowly, then I can get a higher speed; that means speed, higher speed will lead to lower C B or fine form. That is the reason you will find bulk carriers and tankers or full form ships with high C B and passenger ships container ships etcetera are final form.

Now you see, when I am talking about speed, I am essentially talking about Froude number not speed as such, that is, if I have a container ship which is said to 50 meters long 1 of the large container ships, it can move at 24 knots. Now, what I do is I geometrically bring the ship down in size. Instead of 250 meters, now let me see I bring it down by half 225 meters. Every dimension reduces by half. If this that was moving at 24 knots, will this ship move at 24 knots? Would it mean that it will move at 24 knots?

The answer is no; it will move at a speed which will be at the corresponding speed; that means it will move at 25 divided by root 2.

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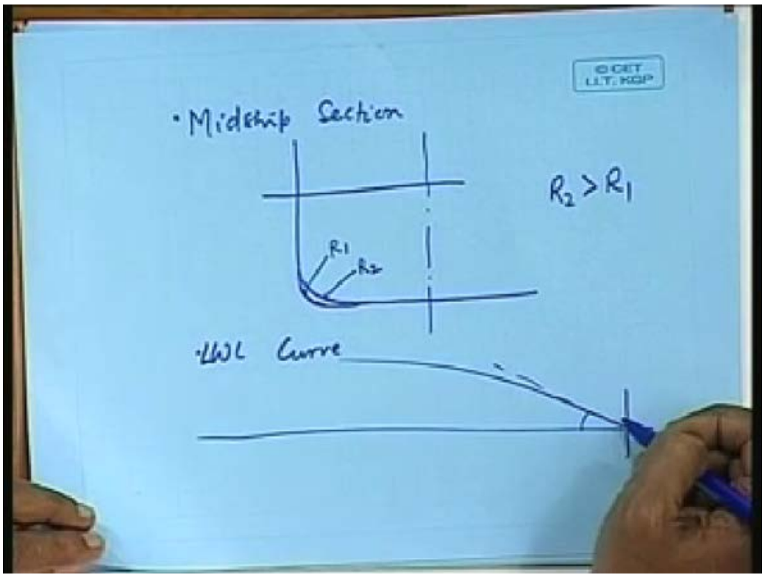

This follows for our curve 2. You see the curve 2 that we showed before. Though it has a prominent shoulder, its section area curve here has narrowed which leads to a final angle of entrance.

Sir, we can go that 19.28 we can go below that also.

We can go that 19.28 is for a pressure point. So, loaded line curve is also an important parameter.

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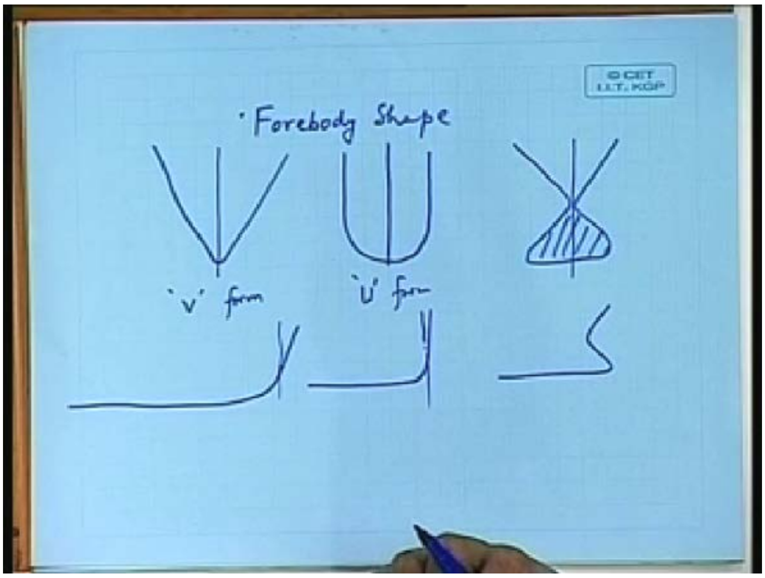

Now then next comes the forebody of the ship. Forebody shape, we have three forebody shapes which are extreme and we have to choose one of them or in between them. One is called typically a forebody section shape which is like this. This is called V form like a v. Normal ships that have a shape like this. We will have a section like this. The section comes down like this. The other one is what you call a u form section, more like a u. This case because it will be difficult for one to close the sections; this will look more like this. The end profile view will look something like this; sections are more u.

And lastly, you will have the bulbous bow, and if you draw a section here at the f p itself, you will have these bulbous. As we have discussed in both these forms as compare to v form, the volume comes down. If the volume comes down, imagine the sectional area curve. We are providing volume, but below the waterline. So, the waterline becomes smoother.

A modern day ship. So, the best way to do is to find out what the static say. If you have got large number of ship data, then can we make a statistical analysis and say my ship since large number of ships of all types fall in a particular pattern is the resistance falls in a particular pattern may be my ship will fall in that. So, I can estimate my ship resistance and say it will have plus minus 5 percent actual resistance.

Now, this has been done rigorously by holtrop NSMB - Netherland Ship Model Basin - haltrop and there is another which have called mannen. They have published their statistical data analysis in the 1984, 82, 84 ISP - International Ship Building Progress.

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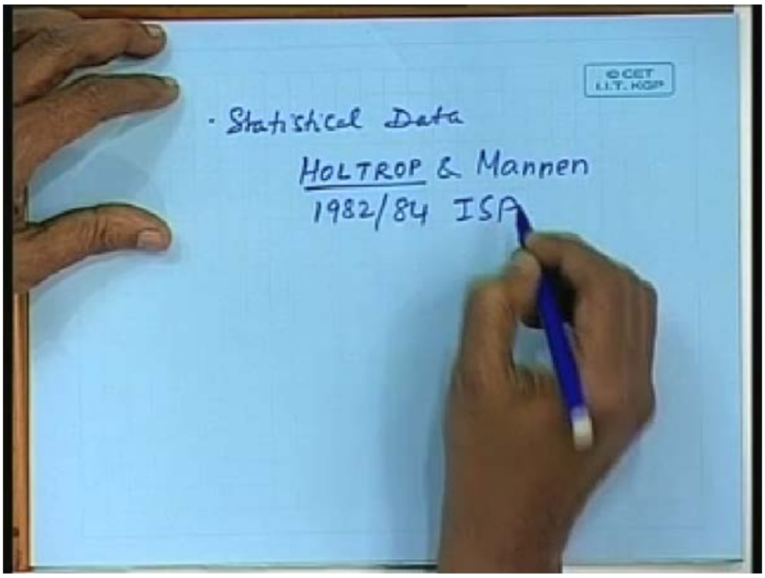

What they give you is, they have analyzed slow, slow, form ships, fast forms ships, bulbous bowls, non bulbous bowls, cruiser sterns, transom stern, stern immersion, various draft conditions, with appendages and without appendages. Large amount of data has been collected together and whole set of regression analysis has been done, and knowing your ship parameters of all these quantities, they give a method by which you can estimate the resistance. That is so far the most reliable method of estimating resistance for ships as of today.

We do not have. I have mentioned this before we do not have a fully theoretical method for predicting resistance as yet. So, statistical analysis is the best way to get the resistance of a ship if we do not have the tank test data. If there are no questions, then we stop here. Thank you.