Ship Resistance and propulsion
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Lecture - 11
Resistance in Shallow Water

We have so far discussed about the resistance of ship in deported as you know that this vessels, which even do you a design it for a deported contribution ship which operating deep sea all that, they have to operate in shallow waters also whenever it comes to port agents arbor, gently it will have to encounter the shallow water effects. So, water has this resistance, and naturally it will be subject to shallow water.

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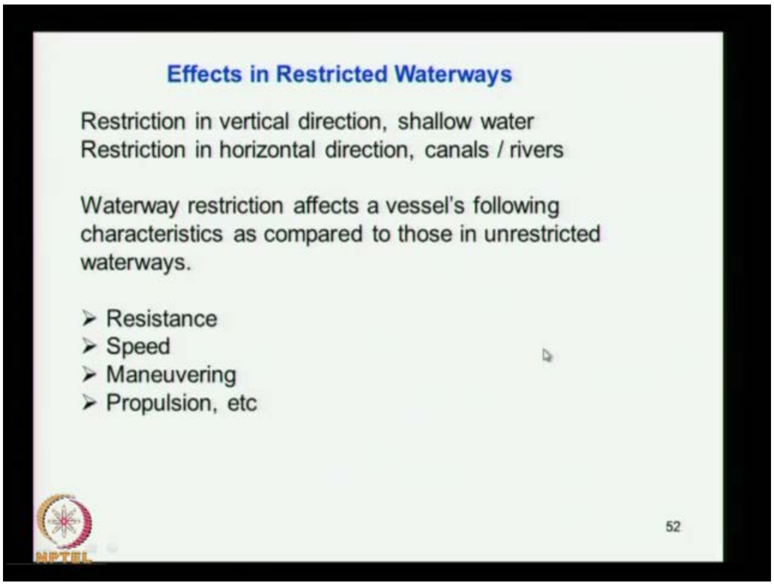

We just see what all the shallow water effects are what would be the effects of shallow water the various aspects of operation of the ship. Here the total resistance waterway is now we can just clash your restrictions in the transact directions and also restrictions in the depth vertical direction. So, the vertical direction you say it is a shallow water if the water depth is less or if it is that transfer restricts are there this is canal river all that that also come into picture a shallow water with transfer resistance agree with the problem. So, that is a general understanding of that problem, so what are resistance effects the vessels following character how did it effects the resistance of the ship increases of the resistance of ship.

When it increases, the resistance of the ship naturally the speed comes down if the vessels is not having sufficient power or the couples system are not I know delivering the regard, sorry. So, regard an additional trust for the operation of the vessel, so there is a involuntary reduction in the speed due to the increase in the resistance and that is a resistance part.

So, the speed comes now, so next is maneuvering the ship become more like dish in shallow water response in a ship is bad. It is response your action of become bad the controllability will become bad, so that is another aspect then the next one is propulsion a propulsive characteristics. Also, get a negatively affected because of low condition changes the flow to the propeller also became bad and the propulsion a performance divergent, so here we said the shallow waterways to waist now we just consider may be penalty a later.

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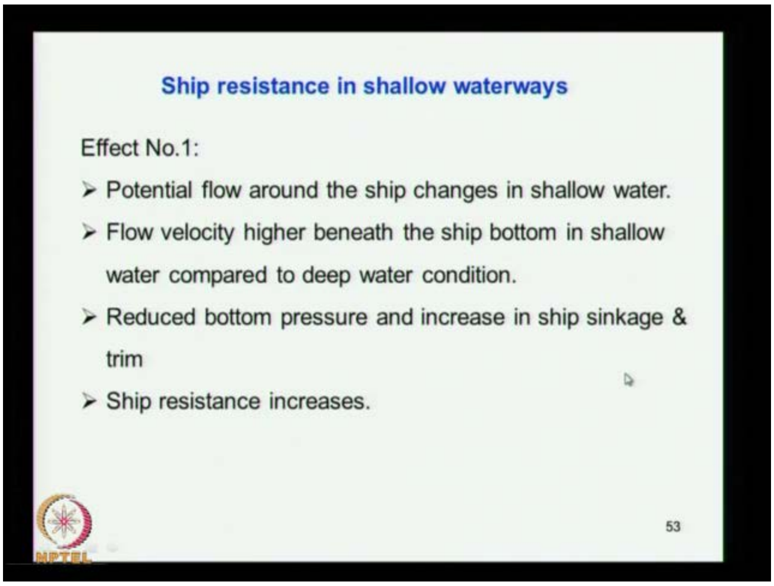

We just look, we just to look resistance shallow waterways to waist there are different topics we can see the effect number 1. So, potential flow around the ship changes in shallow water, so here we just see what is happening, so if we consider shallow water a region if I considered a ship which is floating at this water line.

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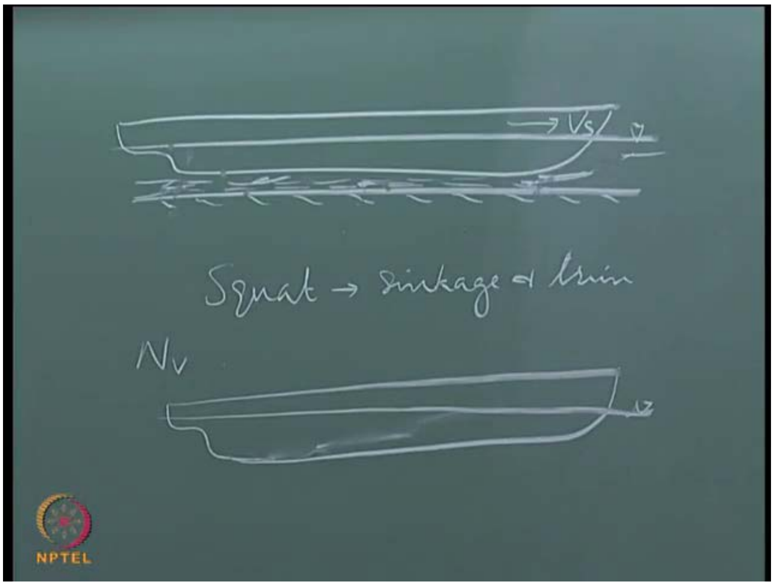

It has the bottom very close to that, so that I said its make power, so it may flow in this direction the flow comes here the flow is moving in this direction so that flow the water has its straight through underrate the ship. So, what happens is the ship, the water ways restricted, and now the law conservation of mars the water here has to look done is fine. So, the flow velocity has to increase because the water ways has to be restricted the flow velocity increase when the flow velocity increase what happens to the pressure the pressure decreases velocity sequences.

The pressure decreases what happens the ship will sink more to make up the points, the pressure will reduces it is sink more to make up the points. When it sink more what happens the weathers of us increases when the weathers of us increases resistance increases. There is more contact with water, so resistance increases so that is one of aspect, so it goes forward due to constructions.

The bottom the flow velocity increases drops ship size more and more vetoes of area and more resistance into the ship. Another thing is that is called the potential around the ship that is the changes in the shallow, then the flow velocity that is what I discussed the flow velocity higher beneath the ship water when shallow water compare to that deep water. This thing happens if any deported also sink, but sink is very less when it moves forward the velocity compare this full condition velocity flow increases. They will be slight sink, but in shallow water, this sink is effective magnified, so that is the resistance, then a lower aspect considered that is a boundary layer formation coming from the Wickes f low.

The boundary layer is from below that ship and the bottom is start feeling the flow water also will get another boundary layer. So, this a boundary layer attached the boundary layer is not attached to the bottom, so you know the boundary thickness is 0 at this point and boundary layer thickness increases towards the act. So, when it increases that means the flow constructions has increased due to the presence of the boundary layer towards act. So, here the flow here the opening for flow is more where have been the open for pre flow is less. So, that means the flow velocity is higher here compare to the flow velocity here, so that mean the fresher top will be more here and compare to this region.

So, there is a uneven is even in Persian drop in the bottom to a due to the bottom getting closer to the ship, so this again leads to let me see lower pressure means it will sink more here than sinking here. That means the ship will sink when the ship sink that means in shallow water the ship sinks and also interims, so that combine effect is called squat which is sink ages and trim. So, either both sink age and trim this, so this again leads to the increasing resistances and also when the ship changes by act when it is moving with this. It is like this shape, the upper level is like this it is stunning by act with depuration such a conditions then the ship become directional more stable.

It is directionally very stable because it is stunning their more regions the act region and water, so if you have studied this controllability innerve that n V coefficient become a less negative or positive due to that stunning condition. This leads to more directly stability further more directly stability implies that the ship will be less response you to action if you want to change the direction of the ship in such a condition. It is more difficult than doing it in the even way conditions, so this shallow water effect not only increases the resistance and also when trims, that ship become directionally most stable. This leads to a less response to the ship when the during the application, so that is a 11 effect and another effect what you consider that is you can see the ways.

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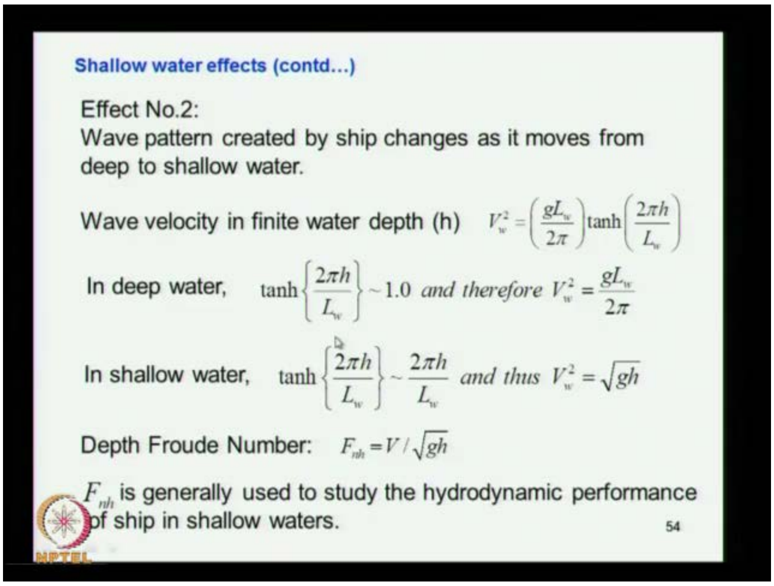

The effect number two you can wave pattern created by ship changes as it moves from deep to shallow water that wave pattern. What we see, we have seen in the wave pattern that depth sea conditions which includes that a by begins and resistance. So, this is wave pattern where size changes when it moves, we should move from wave to shallow water, so we know that from the wave theory the shallow water the wave sorry.

The wave velocity in finite water depth is the expression given by wave velocity square equal to g L w is a wave length divided by 2 pi, then hyperbolic is h is the water depth is finite water depth. So, this expressions this a expressions given by the wave theory for the wave velocity, so in deep water that is which is very high, so this quantity is very high. So, it goes to one hypotonic function of 10 and so this velocity simplified to this expression get simplified to this one.

So, this term is equal to 1 deported when it comes to shallow water that is water depth is very less. Then you have this term taking the hyperbolic leading to 2 pi h by L depth, so then you just replace this by this this term you get V w square is equal to square roof of gh or v is equal. I think it is V is equal V square V is equal to square root of g h that square is not there, V is equal to square of g h. So, usually for shallow water conditions and you know the Froude of deported conditions, the Froude number is length Froude number which is represents V bay, L is the length of the ship.

Often in depth in shallow water, the Froude number which you use is depth Froude number, so in place L you put h. So, that is what is numerical because that depth effect on wave formations. Froude number is referring to wave formations and the depth effect on the wave formations is more here. That is the reason why depth is used as a parameter here for the representation of Froude number, so when the Froude number, so when the Froude number.

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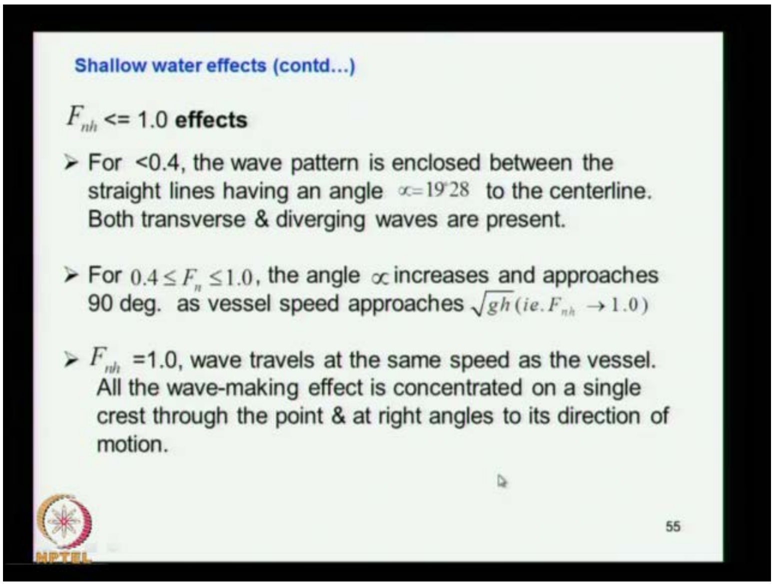

So, what the second effect what you are saying is that the wave pattern is different when the ship enters from depth to shallow water resulting in change or increase in that, we make a resistances Froude number F n h. The depth Froude number less than or equal to 1, what will be the effect for Froude number less than 0.4, the wave pattern is enclosed between the straight line having an angle of this one this is same has calving wave I think.

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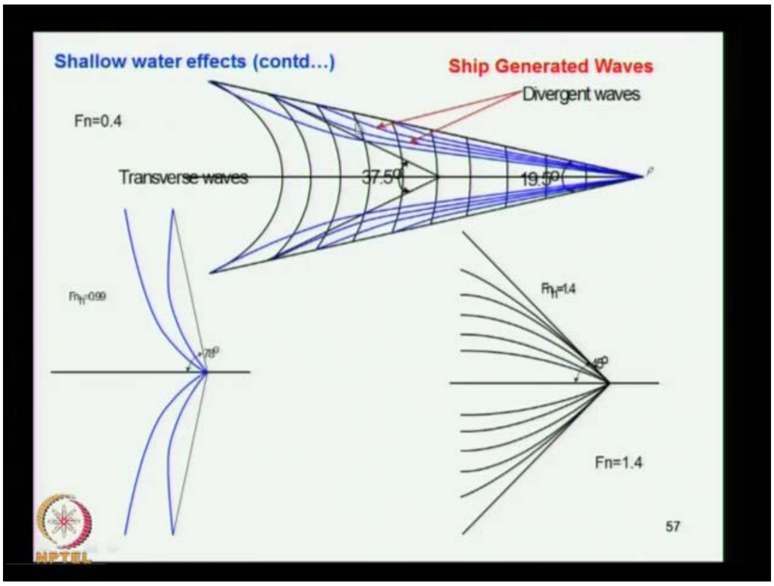

This is same has the calving wave what you see, so this angle this is actual a half angle 90.5 degrees and what when it comes to that is what is given that is to centerline. Both transverse and diverging waves are present for Froude number between 0.4 and 1, the depth Froude number this angle increases that is that comes out and approaches 90 degrees. When it reaches nearly 1 when Froude number reaches 1, the wave pattern you can see that it goes up to almost 90 degree, you can see that goes go beyond.

So, you can see that angles here 90.5 degree Froude number 0.4 and here Froude number is close to 1 angle has gone closer to 90 degrees. So, there is that what it means, and then Froude number is equal to 1 wave travels at the same speed as the vessel. All the wave making effect is concentrated on a single crest through the point and at right angles to its direction of whole wave. The single wave you use is that massive wave which moves with that Froude number depth Froude umber is equal to 1 which is called the critical speed.

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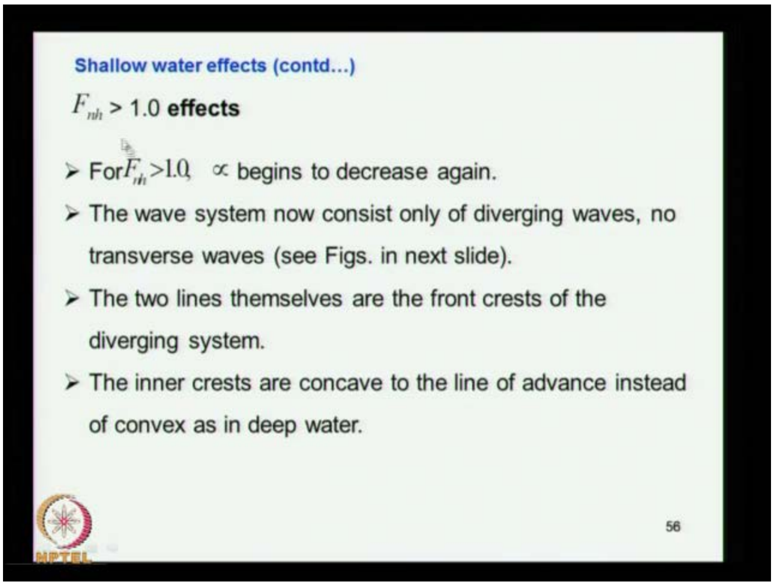

When the Froude number is greater than 1, then the angle comes down that, what you have seen here, the angle here is only 45 degrees, Froude number one point 1.4. Again, depth Froude number 1.4, so these are threshold point if the vessel can get over Froude number of is equal to 1. Then the power also comes down, so the vessel should have tremendous power to get over that Froude number is equal to point.

So, the Froude number greater than the alpha that is the angle begins to decrease again the wave system, now consist only of diverging waves. That is what we have seen waves system we have only diverging wave, you can see that diverging wave here, you have transverse waves. Here, the transverse of the presented low Froude number when Froude number goes up transverse wave in this case below just near to Froude number one you have only one transverse wave. I think that takes the whole energy and when it causes 1.1, and then you do not have the space fully diverging waves.

You can see here so that is a characteristics different of the wave pattern when the speed changes and in shallow water. So, also you can see the inner crests are concave to the line of advance instead of convex as in deep water. So, it is just coming down you can see that this is the variation instead of just going out is coming down that trend also changed so this is the type of different. You know wave pattern systematic represent of wave pattern, when the speed increases from low speed to high speed and to higher speed. So, according you can see what is the depth effect on the resistance of the wave making resistance.

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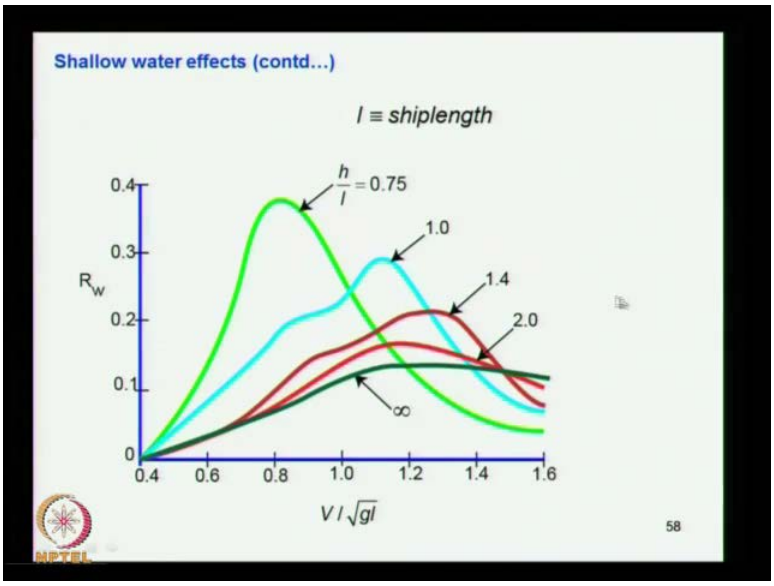

You can see the wave making resistance against Froude number see that for different h by l, h is the water depth, h by l small means it is quite shallow water this is little more deep. Finally, it goes very deep this is a just showing that how we are making resistance changes increases with the Froude number and also with water depth. So, here you can see this is very high and here water depth is more it has come down, so it has come down and the least one is was in deep water.

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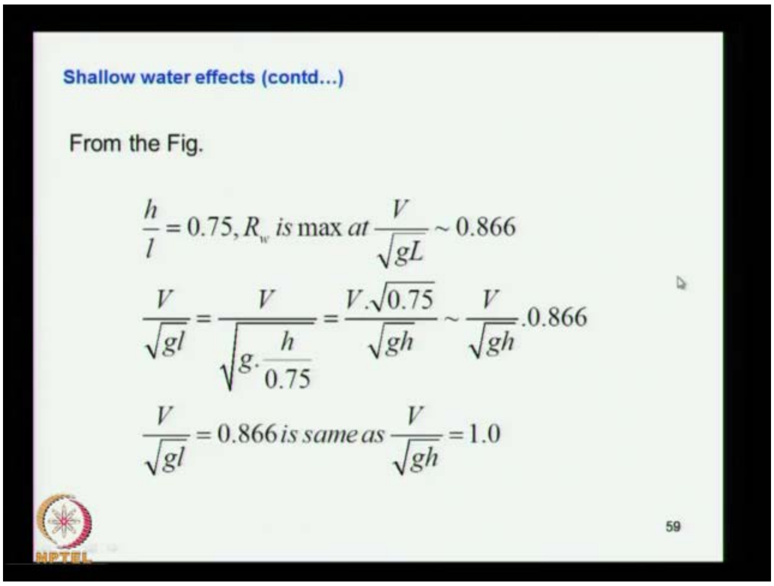

So, from the h by l, you can see the h by l equal to 0.75 for h by l is equal to 0.75, we make the resistances maximum at V diverging g l to 0.866. You can see that this begins the length Froude number, so at h by l is equal to 0.75, the maximum point is here and this under 0.866. The maximum point we diverging at 0.866, so that is what is written here h by l is equal to 0.75 R w is maximum at V by l g of 0.866. So, here we by eight g l is equal to now l is equal to h by l is equal to 0.75 means h is equal to l is equal to h by 0.75. Now, you have to place l by this quantity, so you get this relations and which is equal to this center 0.866.

So, which implies v bay g l of is equal to 0.866 is same as V bay g h Is equal to 1 so that what it means, so when you consider Froude number based on length it is 0.866, but when you consider based on h it is 1. So, this is the critical point, it is a critical condition where the resistance increases, you can see the previous thing you can see that the resistance increases at this speed v bay g l than after that its coming down.

So, when it goes to higher speed if it gets over the threshold point or critical point and a critical speed then the powering comes down. So, if we can design our self which can get over that and then the resistance come down and you need only less power to operate the ship at higher speed.

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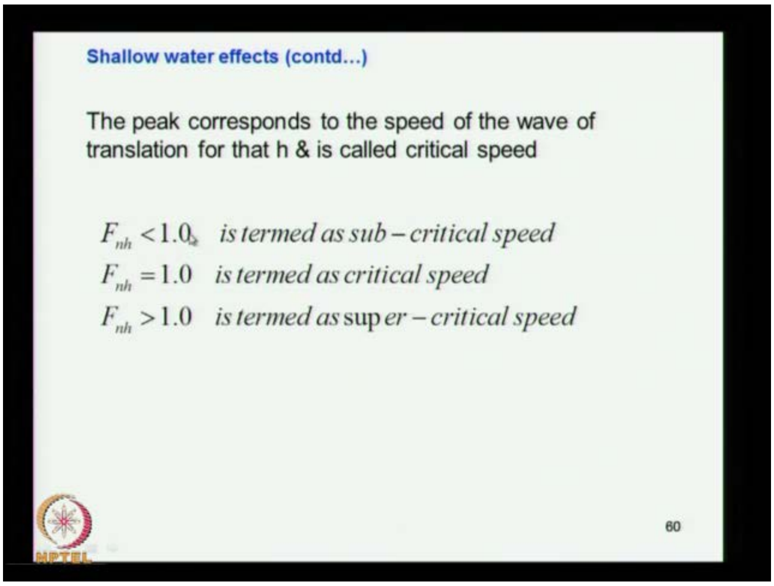

So, here you can see the Froude number less than 1 is termed as sub critical and Froude number equal 1 is termed as critical speed and greater than 1 is termed as super critical speed. So, that is how the classification, now the speed of the vessel in shallow water, so this is all depending on the depth code number, so this how the speed of the ship is classified based on the depth Froude number resistance.

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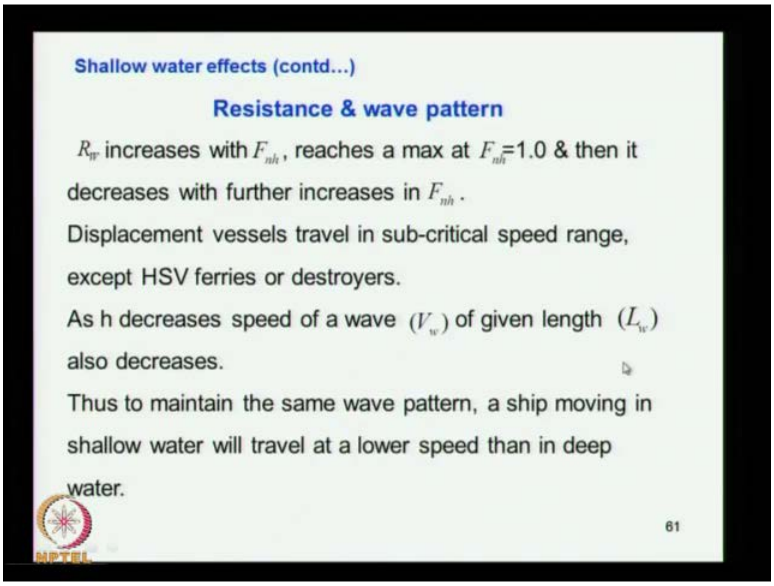

Wave pattern R w increases with Froude number and reaches some maximum at F is equal to 1 and then it decreases further with the Froude number. We have seen that from the previous diagram goes up reaches up and come down, when it reaches up F n is equal to 1, then F n is greater than 1. The resistances comes down, so displacement vessels travel in sub critical, you can you can say normally most of the displacement results suggest that cargo shapes an all that they all displacement ties. They operate at a Froude number or F and h less than 1 except high speed vessels for this F high speed vessel high speed passenger is an all that destroyers that the navels vessels which go at very has fast speed.

So, these vessels will be may operating at super critical range as h decreases of the wave given length also decrease sand water depth decreases just wave speed also decreases. We have seen that v w is equal to square roof of g h, so when the depth h is decreases v w is decrease that is the relations shallow water, we have seen that.

So, that is an this is an statement base on that relations thus to maintain the same wave pattern a vessel a ship moving in shallow water will travel at lower speed than in deep water. So, that means the ship the shallow water will wave lower speed in low lower speed than in deep water because when the depth decreases speed will also decreases, so we consider they move at the same speed ship and wave relations.

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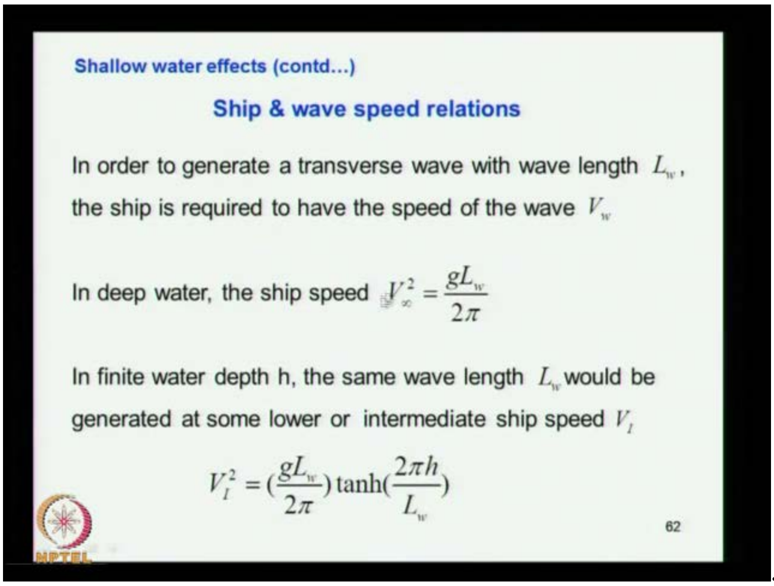

In order to generate a transverse wave with wave length l w the ship is required to have the speed of that of the wave the ship and ship wave speed is V w the ship is also going to have a same speed. So, I miss the wave is moving in the same place in water the ship speed we have seen that it is coming from the brief theory. It has v in finite is possible in g into wave length denoted by 2 pi, it is a relation for wave validity how a speed in finite water depth this relation.

We know that we already seen this expression before finite water depth the same wave length what would be generated at some lower or intermediate we are seen that the wave speed comes down in what shallow water. So, the velocity also comes down when the depth decreases, so this is the relation for finite, so there is a intermediate I stand for the intermediate speed, so this velocity is going to be less than this.

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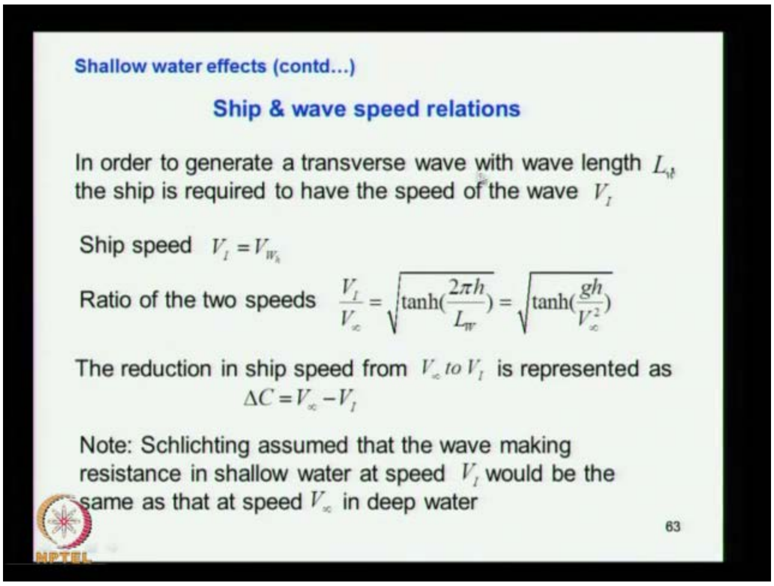

So, in order to generate a transverse wave with wave length L w, the ship is required to have the same speed of that. So, same wave length the transverse wave with the wave length l w the ship is required to have the speed of the V I that is V I is given by this relations over here. So, the ship also will move with the same speed that is here V I is equal to V w h ship speed intermediate ship speed is equal. That is under the waves velocity at the finite depth ratio of this two speeds V I by V infinity, we have seen the expression for V I and V infinity V infinity scribed by this V I square by this.

You take the ratio of that you get this relations V I by V infinity is equal to this one, this relation which he gets from previous so the V I is less than V infinity. So, that difference with delta c is given by V infinity minus V I, so here the procedure is just finding out try to find out the resistance in shallow water region.

If you know the deported resistances, so that is what we are trying to do here we trying to find out how it is done. So, the reduction in speed in shallow water is this much due to the wave making Schlichting assumed that this is a listening mother. So, here assumes that wave making resistances shallow water at speed V I would be the same as that speed V infinity. So, the shallow water is a remaking resistance at a reduced the speed in shallow water is we make the resistance at higher speed V infinity in deep water that is the assumptions.

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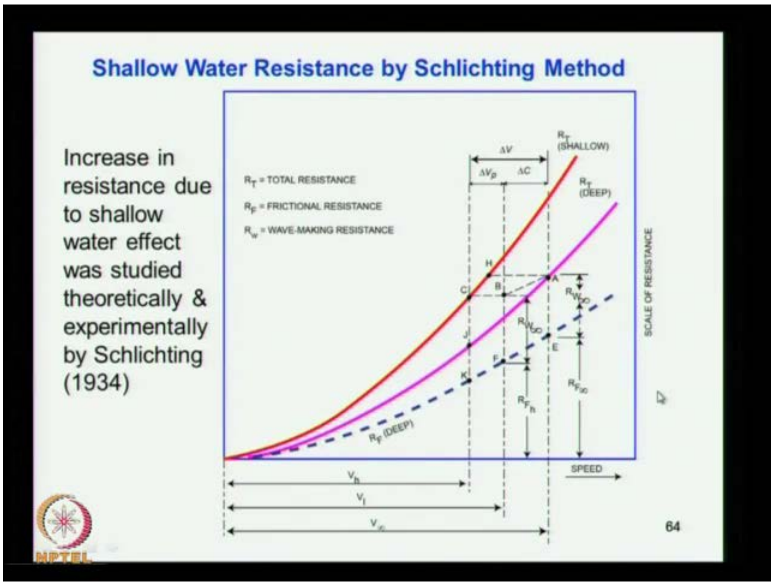

So, what you have here is you considered this Schlichting method, you can see the shallow water resistance Schlichting method so weather proposed by Schlichting. So, you have this one, the purple lined here this shows the total resistance of the vessel in deep water conditions, this is you know we have discussed about resistance model test everything in deep water. So, we have already this information with us that is the deported resistance of the vessel can be estimated and we have seen the procedure for the estimation mainly through experimental procedures.

That is model prediction and model resistance and predicting to the proto type, so that means this curve is available to us and is straight forward or prescribed method for that. So, now you have this line over here that is R f also against deep water which is coming from that, we have discussed we have seen that future assistance, how it is made. Now, what you have and then finally, that you know that once you follow to the restrict mother, you come to know what do you have resistances in shallow water and here this is the procedure what do you have is you have the frictional direction.

So, that we infinity that is deported condition you have it here deported condition after this we have the frictional resistance that infinity represent the deported conditions represent in deported conditions. Then you have seen this is A 1 from here to purple line that is the remake resistance in deported and here prescribe assumed that remaking resistances remain same at reduce velocity of the end. What is that you estimate what is what is delta C, if you can estimate delta C, you can find out this point what is delta C.

Then, you find out what is the frictional resistance what is the frictional resistance here and to which you have seen is same way make it as this speed and also this speed. So, you just drop the same way make the resistance over this you get this one point and then you have the effect due to the frictional effect or the potential effect what I discussed, sorry the potential effect. So, you have the velocity reduction to the additional resistance from there, so from this we get points, you see the procedure adopter here.

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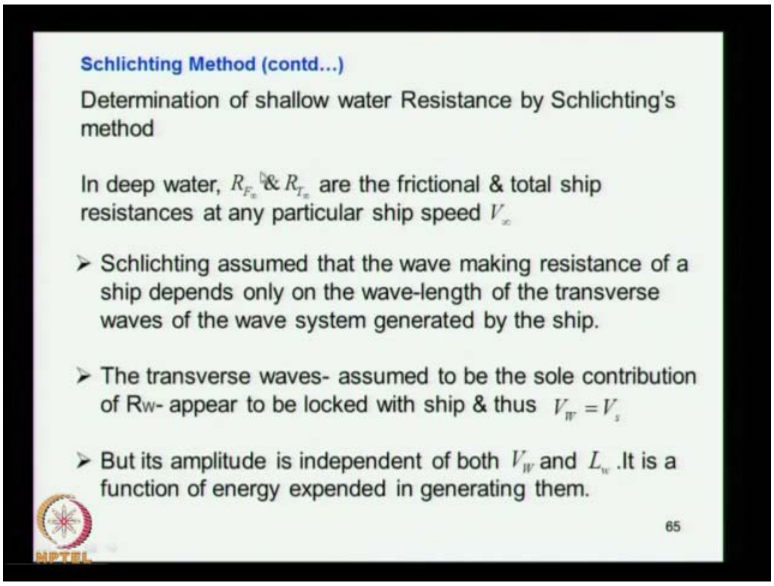

Determination of shallow water resistance by Schlichting's method what is the procedure the deep water R f infinity R t infinity are the frictional and total resistances at which this we know that we already estimated. So, there the graph is available Schlichting assumed that the wave making resistances of a ship depends only on the wave length of the transverse waves of the wave system generated by the ship. So, the remaking resistance is now primary due to the transits base that is a assumption based by Schlichting the transverse wave assumed to be the sole contribution of R w appear to be locked with the ship.

That means they move with the same pattern we have seen that calving wave that ship will have steady wave moving with the ship. So, here is seems that V w the waves designs of V speed that is means its look like the whole wave is moving at the same place with the ship. The amplitude of the independent of both V w and n w, but its amplitude of the deported and shallow water is going to be different. You know that amplitude of the wave is A 1, again vitamins the wave effect resistances, so the amplitude increases wave resistances increases the speed at which a certain wave length is generated.

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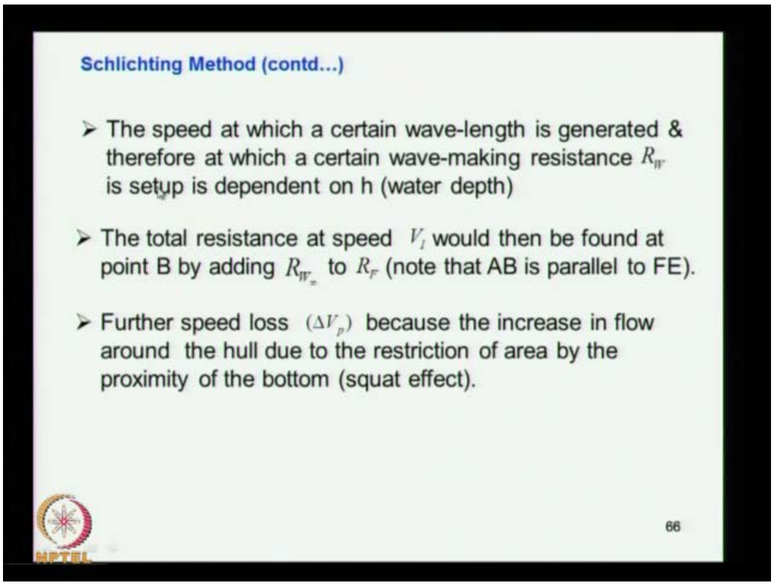

Therefore, at which a certain wave making resistance is set up is depended on h so we can say that speed and wave making resistance dependent on the water depth the total resistance at speed V I would then be found at point B adding R w. That is what we have done here at that is the total resistance at V I is equal to that frictional resistance frictional resistances taken that point plus remaking taken has same.

So, you just put the same value message here under the infinity over the ripple resistance for the lower speed and you get point that means these two lines are parallel that is A B and F E are parallel that is what it means. So, A B is parallel to F E because they are putting the same value further speed loss delta I P because increase in flow around the hull that is what I discussed in the board. So, that due to the restriction there will be flow velocity there will be a increase in resistance be to the pressure changes and sink agent of that, so the colored in this squat effected.

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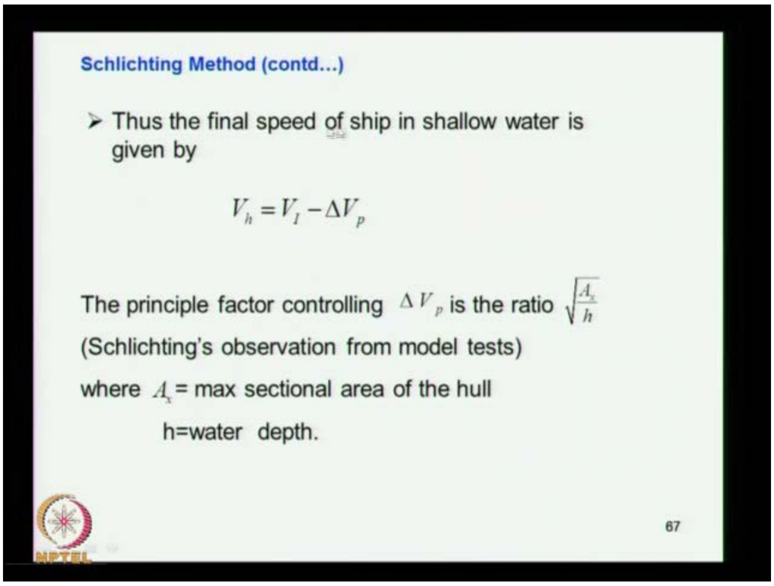

So, it is coming from the squat this further protection in the increase and so how do you get that the final speed will be V h is equal to V I minus delta V p. That is V this is equal to V I V I of the protected speed and then we to be making and then we have to find out what is due to this potential flow that is depth restricts the principle factor controlling the delta V p is ratio. So, what you have to look is this depends on the constrictions that are a x is max area of the ship and h is the water depth. If the water depth this factor actually what is the size of the ship what you wanted A, this matters and determine the constrictions and then the flow velocity and increase and resistance.

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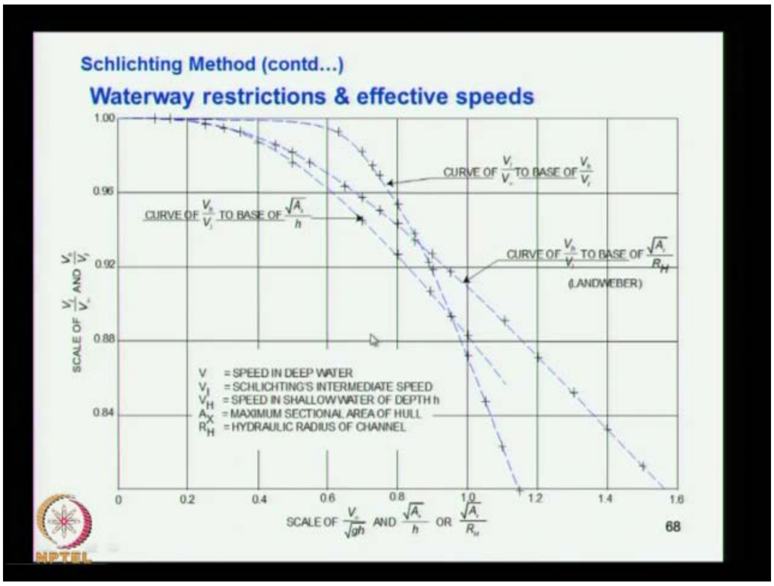

So, A x is the max sectional of the hull and h is the water depth so the curve has been presented by listing based on studies experimented studies you can see that he has given for a quarter g I by g infinity. Also, h by V I against v infinity by square of g h against A x by h and A x by R h this will see R h later. So, what we have is you see there are three curves one this curve it is curve of V x by V I against square roof of Ax by h.

We have another curve you can see here this curve which is v I by v infinity to base of V h by V I. Then a third curve that is coming from the land Weber which is V x by V against A x by R h this all hypolic radius we will see later. So, from this curves we will be able to identify if you know this quantity we infinity by g h, then you will be able to find out this V. Once you know this quantity square roof of A x by h I think I be that is a mistake here the square roof only for the top not to the bottom the square roof of A x by h and you have you can read use this graph.

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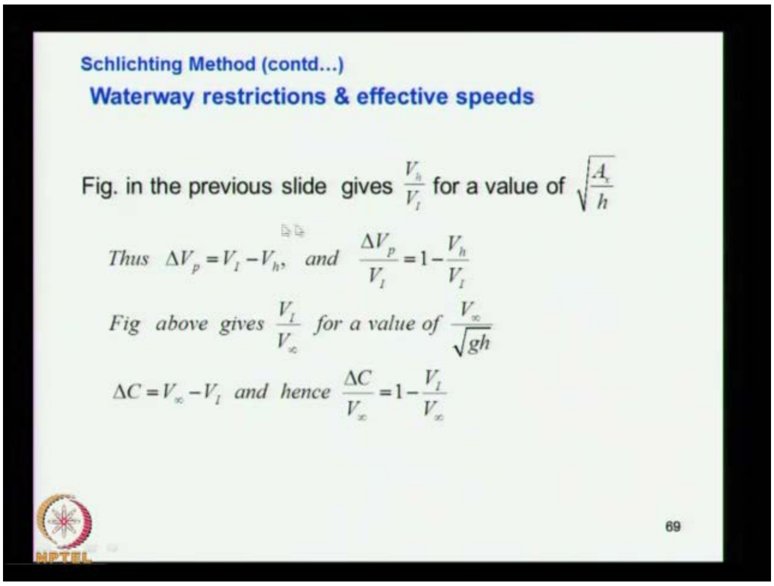

Find out the speed will see how is approach, we will see in the subsequences steps, so the figure which gives h by V I for the value of x by h. We have seen this one this referring to this h by V I against a x by h, so this is a graph, so what did you do is you use that graph then that V delta V p is equal. So, what you do is you can read for you know what, it is should be 80 or the maximum area of the ship and you know what is h again this mistake is there, I think that it should be square roof under top.

So, what did you do is for this value you can estimate by knowing the ship and also the water depth. Then you use the graph you find out what is this value, then you may be 0.6, you just come here and then read what is V I by V h by V I. So, you can find out this quantity from here so from which you get you get this quantity and you know that delta V P is equal to V I minus V I and you divided by V I you get this relation from this. You have read the value of V h by V I, so we have already done that from which you would be able to find out this quantity this is coming from the graph.

Now, again from the above graph you know what the resting velocity of the ship speed of the ship divided by this. So, the Froude number depth, Froude number, so once you know that you go that and you see there is the curve which is representing this one. I think there is again a mistake this is against this one, so you get V I by V infinity this is actually the Froude number. So, you get this curve and from this you read what is the V I by V infinity, so that is how you get V I by V infinity by knowing this quantity from that curve. So, delta C is equals to V infinity by V I which you have already seen and hence by saying dividing by V infinity you get this relation.

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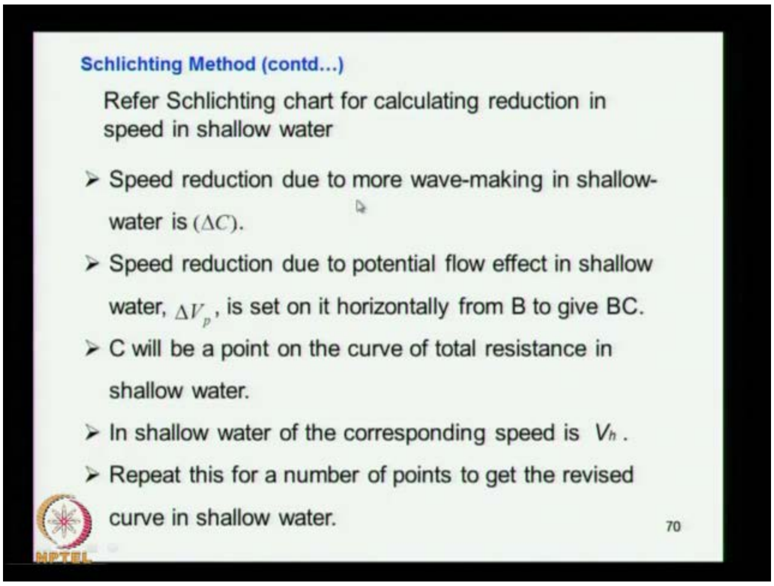

So, V I by V infinity sustain is substuted here equal what is delta c by delta n, so you got this quantity by V I and you got this quantity by this. So, we are looking for this two quantity, let us see what happens, so you look to a chart what you have seen the speed reduction use due to more wave making.

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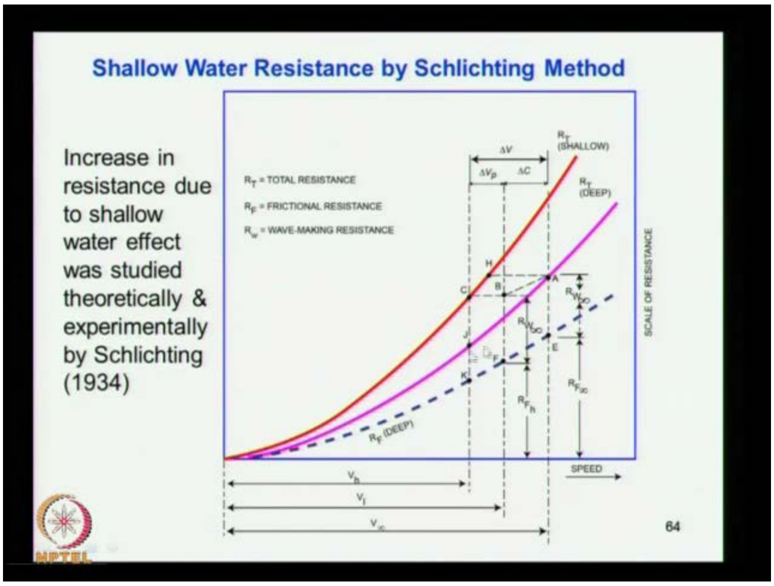

In shallow water, it is delta C, so you just see that this chart, so here one second, so here what you see is this delta C total velocity reduction is delta V 1 part is coming from the wave delta C and another part it is coming from the potential thing delta V. That is why we said usually there are two effects effect one that is due to the potential effects are scarf effect two is due to the wave making different. So, these two account are total reduction speed, now our intension is find out what is delta V p and what is delta C, so that is what we have done, now you can see what is delta c and what is delta V p these things we have to find out.

So, speed reduction due to potential flow effect in shallow water delta V p is set in a horizontal B from B to B C. So, that is what done here in the graph you can see that we have already seen the how it is obtained and from V, you put C that is delta V P you get point C, so we did is I repeat that there is total resistance curve in deep water.

This is the reduction curve in deep water and Froude deep water velocity you find out what is the frictional resistance for this curve and the above this you get wave making Froude in deported condition. Now, we considered they are V I that is intermediate speed due to the wave hire wave formations I wave resistance the speed reduces V I at V I what is the frictional resistances, but we have seen the wave making remain same at the lower speed. So, then you put the same wave making here you get point B and from point B from the curve, we have what is delta b t and put delta B T in this direction for example, you get point C.

So, one point A in the resistance deported curve, we are getting a points responding point for the shallow water, so what you do is you repeat this for various number various speed then you get points all over at the connect. You get this curve; a red curve which is to represents the shallow water, so that is how the shallow water resistances is estimated from a non deported resistance curve. So, this is the method proposed by Schlichting we made lot of assumption here assuming the same water resistances remain at this speed on all that many assumption are made, but within that he has Froude using that Froude C is the corresponding point.

If you look the point A and if you consider the same resistance that speed should have be h that this should have be the speed because that the h should have be point should have be at h will see that what is discussing about. So, here that is as it has C will be a point on the curve of total resistance in shallow water in shallow water of the corresponding speed is V h, so we have got point C.

If you read it below, you get what is C h repeat this for a number of points to get the revised curve in shallow water that is what I said you repeat the same example for one repeat for all points in the deported resistance total curve. Then you get corresponding points in the shallow water curve and you connect the point, you get the resistance curve in shallow water this is the Schlichting method for resistance estimation in shallow water.

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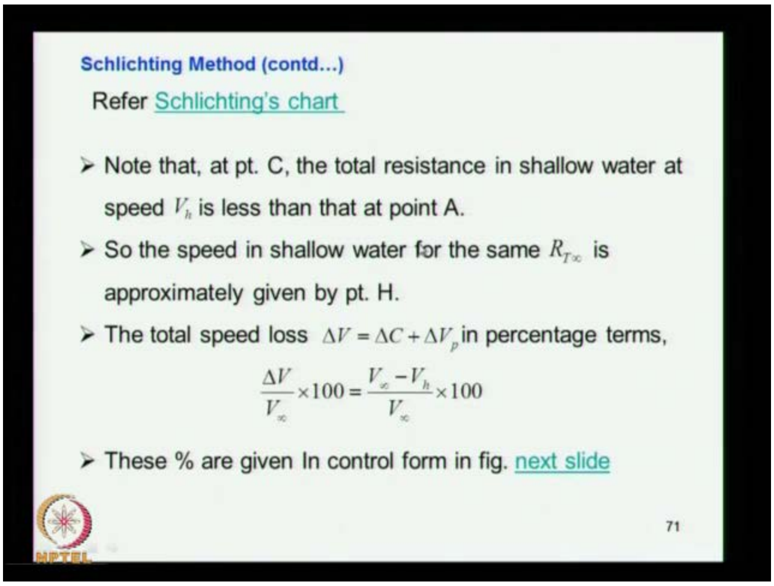

So, note that a point C, the total resistance in shallow water at speed V h is less, then at point A that is what I said I think A before here, we consider resistance at this point. At this point, resistance at this point is less or for the same resistance for the same resistance the speed is which can back ward is more than that at this point so why this happens. So, that is a speed reduction due to that point C, the total resistance in shallow water at speed V h is less than that at point A.

So, the speed shallow water for the same R t infinity is approximately h, see that point h for the same resistance we should have be attached, but deported at C which is reduced speed this called Schlichting method. So, that total speed lot delta V is equal to delta C plus delta V p, this is due to the potential effect we have seen. So, that percentage reduction delta v is divided by V infinity compared to the deported information percentage can be represented total reduction V infinity minus V h divided by V infinity.

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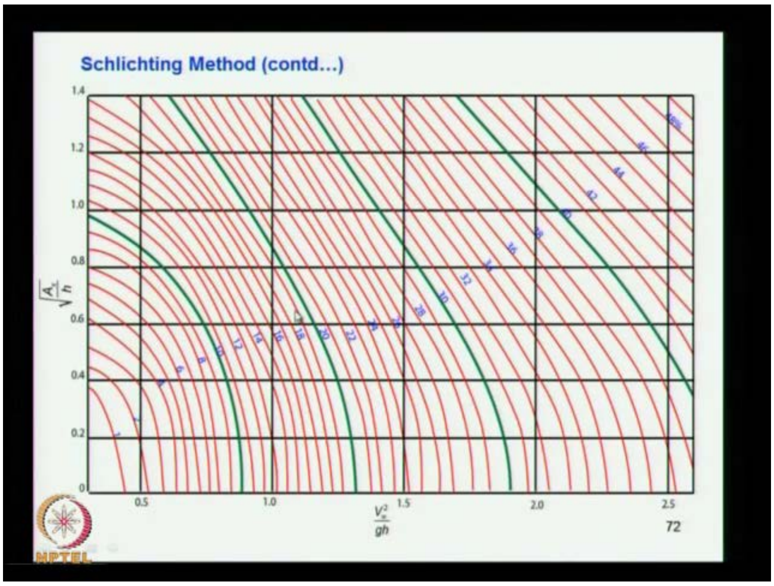

So, you can see that percentage is diagram shows that, but we have the restrictions square roof of A x by h that is be h by V. So, this diagrams what you see curve percentage, so A x by h a small value means h is 5 that is water depth is high from the water depth is high. We can see that the values of these percentage values of less, then the water depth is less then this value goes up and we find that the percentage increases of percentage of the velocity which is same here this percentage is 5.

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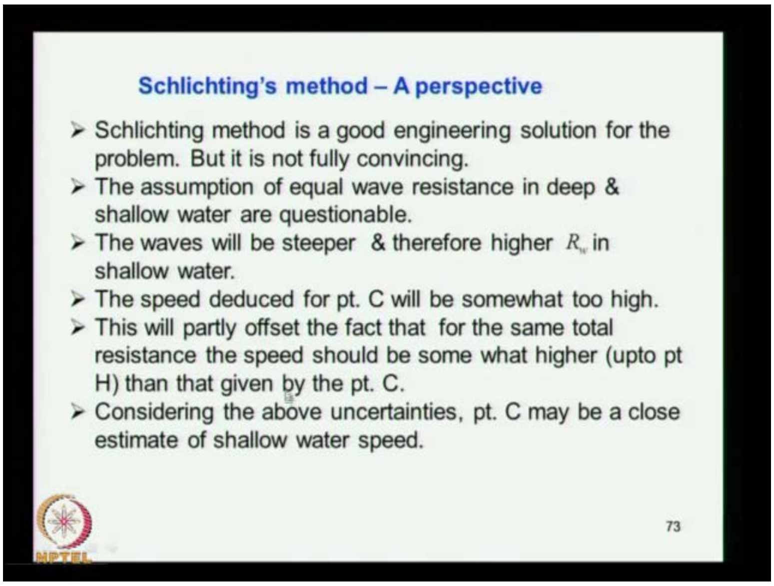

So, here the Schlichting method is a good engineering solution we have seen lot of approximations here assumption here splitting it into in velocity potential effect splitting it into to give effect. We are saying that wave making resistance remains same at a reduce the speed thus an assumption, so there are some you know assumption which are difficult to be supported by a scientifically, but we make some assumption. What it does is this to find the solutions, otherwise the find the resistance of a ship the shallow water is rather difficult offend is impossible.

So, here he makes some assumptions point to simplify the procedure a practical solutions to find out the shallow water. So, the assumptions of equal wave resistance that that is what I say equal wave resistance in deep and shallow water are questionable. We do not know it is an assumption, but there is no proof for that the wave will be steeper. Therefore, higher R w in shallow water, this get steeper because of the accumulation of energy and wave get steeper.

The resistance will be higher R w will be high the speed that is actual thing the speed reduced for the point C will be somewhat too high. That means we have assumed the speed up to some point very high, so this will partly offset fact that for the same total resistance the speed should be somewhat higher that is for the same wave resistance, we should have had a little higher speed than that of h.

So, since that if you look to the curve what the Schlichting chart is seems that these reductions what assumed may be too high. So, it should have been some where this side so may that the total points this C may come closer to h, so that assumption it cannot be correct. That is what it means considering the above one uncertainties point C may be close to the estimate shallow water. So, you have the prediction one is over prediction there is an under predictions to this two combination will result in apparently the point C has the better one.

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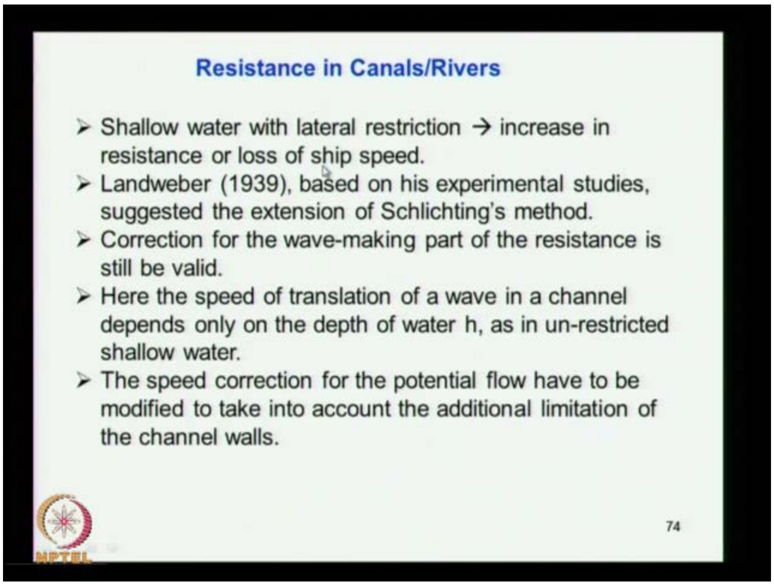

So, this or this are you know that method what is used in Schlichting.

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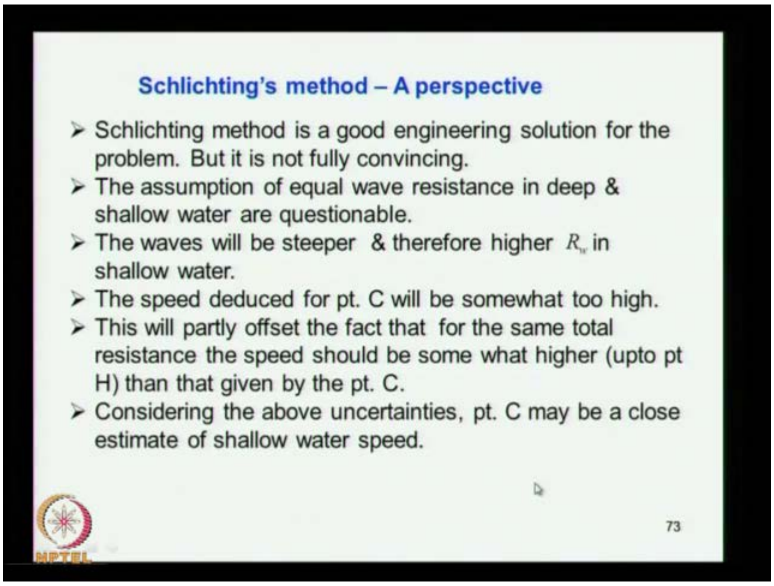

This gives a practical solution engineering solution for the problem of shallow water resistance which is evolved from deported resistance. So, set to motive we have seen what are the limitation about effects only the due to the wave making resistance increases and the other one due to the sink age there will be more better surplus and substically more resistance coming due to that. So, these two accounts we have seen the speed reduction delta C and also delta V p that is a potential effect. So, total effect accounts for the total reduction speed, so that is what this there are still there, they do assumptions made by Schlichting are not fully justified, but since he is giving an a good particle solution some other still adopted.