Hydrostatics and Stability

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Module No. # 01
Lecture No. # 37
Ship Stability on Waves

We will start with the lecture 37 which is a continuation on the stability of ships on waves. In the last lecture, I explained to you how we calculate the wave profile on a ship; that is, provided, you know the ship length, the length of the waterline or the length of the load waterline or we usually assume it to be length between perpendiculars.

There is usually a small difference between the length of the waterline and the length between perpendiculars; because, there is some region in the front and the aft, which does not really come between the aft and the forward perpendiculars; light region is left outside.

In these studies, we will assume that we are dealing with the length between perpendiculars. What we explained in the last class was that, the length between perpendiculars is equal to the wavelength of the wave.

We have a trochoidal wave; we have been dealing with the trochoidal waves in this series.

In this wave analysis, we are not going to do any sinusoidal wave analysis. These are waves that have a sinusoidal, a sin or cosine form. We are not dealing with those kinds of waves. We are dealing with the waves that ever trochoidal form these are waves that are formed due to

Now, if you have a particle that is on a circle and and if the circle is rolling, if you consider that the circle is rolling under a straight line - if you have a straight line and you have a circle here and the circle is rolling under a straight line like this, the trajectory traced out by that particle on the circumference of the circle is what you call as a trochoidal wave.

Now, such a trochoidal wave, we have already seen. How we can calculate the x coordinates of the trochoidal wave at any instant of time or the z coordinate of the trochoidal wave at any instant of time?

So, x and z - once you have this, you can get the wave profile all over the length of the ship between the perpendicular, between the aft and forward perpendiculars; we have the total wave profile, so this is how you calculate the wave profile on a ship.

This is In the analysis - in the stability analysis, one of the first processes is to generate a trochoidal wave that is formed over the ship; that is number one you need to do. Now, when you are doing the stability analysis or when you are doing the structural computations, one of the primary factors that you need to do.

Now, you have defined a ship on waves. There is a problem here; that is, we have defined that the ship. Suppose, you have already drawn a lines plan - I hope, you remember from the previous - in fact, I believe is the first lecture.

In the first lecture, we have already defined what is known as the lines plan. It is something - that is, in any course in naval architecture, any university doing a course in a naval architecture, the student will be expected or he will be required to perform a lines plan class or lines plan laboratory in which he will be required to draw the entire lines plan. Just as a quick recap, I will mention that, a lines plan is usually a figure; it is usually a huge drawing that has three main sections in it, or what we call as the half-breadth plan, the sheer plan and the body plan.

Three views - half-breadth plan, we are talking about the top view of the ship. So, you are looking from the top - what do you see? There is the half-breadth plan and we draw only that half-breadth; because, the ship is exactly symmetrical, the port and star board side of the ship are same; there is no difference, so that is number one. Then we draw the sheer plan; sheer plan is when you look at the ship from the front - means, if the ship is like this, you look like this. So, this is what you call as a sheer plan.

This is the front. If you look from here, the front of the ship, you call it as a body plan. You should be remembering that, in the lines plan, you end off with three kinds of lines - you call them waterlines, buttock lines and stations; stations are these along the longitudinal direction.

You will say that these are stations. And in the transverse direction, these are buttock lines; in the vertical direction, these are waterlines. So, you have these areas are called water plane areas.

So that line, which defines the boundary of that water plane area is called as a waterline. So, you will have waterlines at different heights and depending on the draft of the ship, you will have the different waterline.

Now, the first question that we need to ask is how will the ship react, if it is subjected to a wave? Let us first of all forget the wave is surface. Let us assume that the ship is now on an even waterline means, it is on a straight waterline - a horizontal line, there is no wave as such. We have to bring in the concept of waves because this lecture is definitely on waves, but let us do it without waves first.

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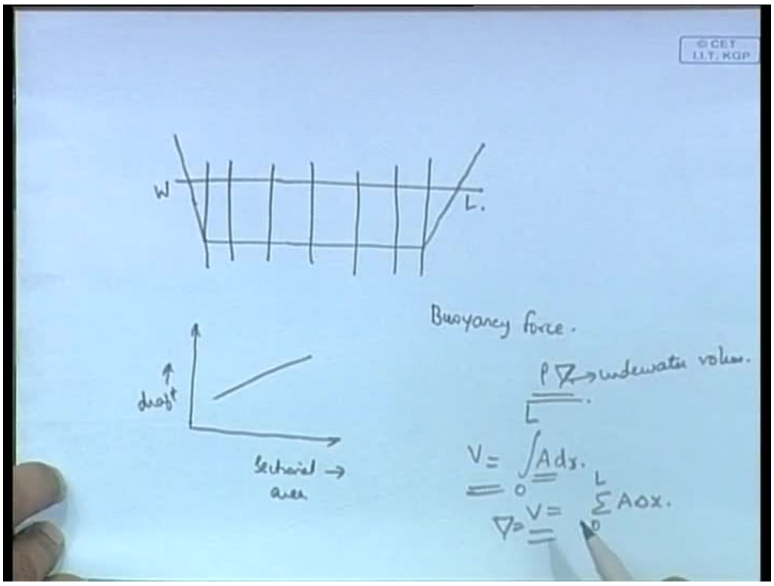

So, this is the shape. Now, this is the waterline. Now, what are two important points that we can definitely assume in the case of a ship that is subjected to there is floating like this, first you know that the Archimedes principle holds good.

Archimedes principle says that the weight of the ship should be equal to the upward force, which is called the buoyancy.

Now, how do we get the up weight? Weight is the total weight of the ship that is you have the hull weight which is just the weight of the ship with just the hull.

So, you have the hull of the ship. You consider, the weight of the member that produces the hull that is called as the hull weight, then you have the light weight of the ship, which is the hull weight plus propulsion machinery.

So, you have the propeller, your propeller is added; at the aft of the ship you add the propeller and you add the propeller machinery. For example, a diesel engine or a gas turbine whatever it is, with that propels the ship, so you add that.

Now, the total weight of this machinery plus the propeller will give you the light weight of the ship, add to it the different consumables and different cargos. For example, the cargo that if it is a cargo ship, the cargo that it carries or the containers it carries, weight of the personal crew, weight of the stationary, weight of fuel, weight of lubricating oil, weight of water, fresh water, ballast water add everything to it. You will get what we call as the total weight, the dead weight of the ship.

So, the light weight plus dead weight will give you the displacement of the ship. So, initially, you have the hull weight, light weight and the displacement that is adding the dead weight.

Now, this will give you the total weight of the ship. Now, what is the first principle? Again, the Archimedes principle states that this total weight should be balanced by the buoyancy force.

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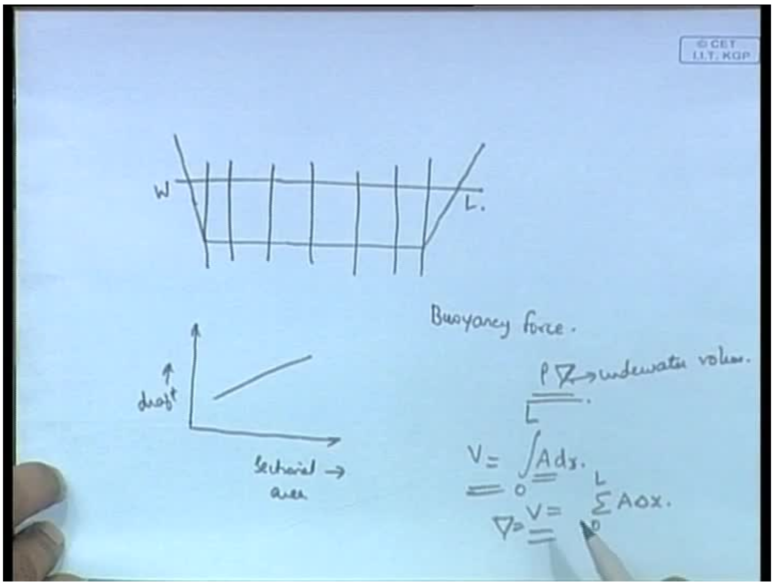

Now, how will you calculate the buoyancy force? We know that the buoyancy force is always given by rho into del, where del is the underwater volume of the ship. So, therefore weight is something that you have to know, means it is a part of the ship. Suppose, we know all the particulars of ship as such.

Now, my purpose in describing this is just to find the position of the waterline as well as the position of the ship- the final position of the ship, provided we have every hydrostatic data of the ship. So, right now I am assuming that I have all the hydrostatic data that is required for the ship that will include the weight of the ship, the distribution of the weight of the ship, distribution of the weight on the ship. What is the importance of getting the distribution of weight on the ship? It’s importance is in getting LCG that is the longitudinal centre of gravity.

Now, I have that and so I have the weight of the ship, distribution of weights on the ship and I also have the Bonjean curves. I hope you remember now, what are meant by the Bonjean curves?

Bonjean curves are a hydrostatic curve or a type of hydrostatic curve, which actually represents a curve between the draft and the sectional areas. Again, I am assuming, you remember what are sectional area that is you have the ship like this, if you slice it like in this fashion, these areas are what are called as sectional areas. We are talking about the areas that under water not the areas above the water.

So, the area under the water of the ship at some particular draft, so whatever be the draft, there will be some area under it; this area under the ship now that is called as sectional area. So, the curve between the draft and the sectional area, this is called as a Bonjean curve. As the draft increases, the sectional area will increase. So, you have some curve now, provided you have the Bonjean at different stations.

How will you find the volume of the ship? Question one. So, suppose you have the Bonjean at different stations, how will you find the volume of the ship?

It is very simple, if you integrate the areas, you will get the volume of the ship. So, the integral Adx will give you the volume of the ship between 0 to L; this gives you the total volume of the ship 0 to L. A is the sectional area at each stations, so you write it like this, sigma 0 to L A into delta x, where delta x. We have done all these, so this will give you the volume of the ship that is the del; here, I am talking about the underwater volume of the ship.

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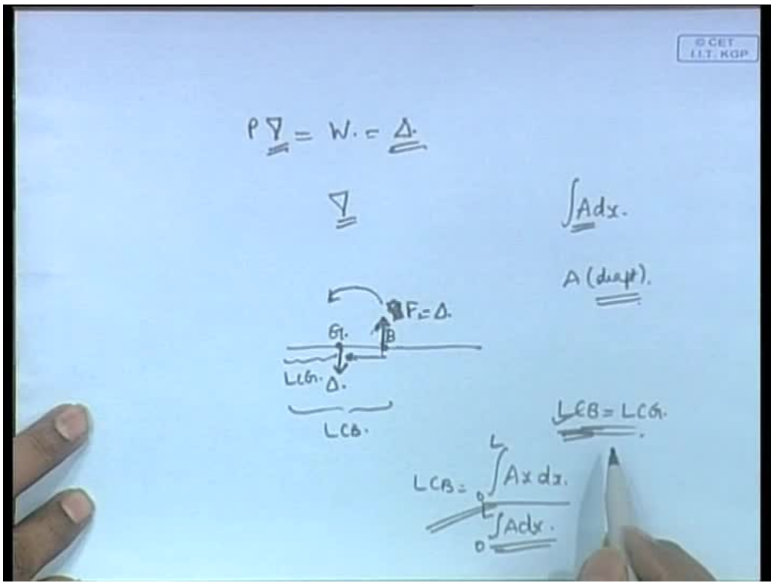

So, the first step to do in a stability analysis of a ship is to make sure that this rho into del, which is the underwater weight, that is the buoyancy force is equal to the total weight of the ship.

Total weight of the ship is got by balancing all the weights on the ship, so you sum up all the weights. I have already told you the total displacement, you make it equal to rho del how will you make it equal?

Make it equal is what can you change? This is fixed, this you cannot change anyway. So, only thing you can do is, you change rho into del or you change del. How can you change del? Integral Adx, this can be changed, if you can change A. Again how, will you change A that is the sectional area? Sectional area is a function of draft, so the only way you can change A, is by changing the draft.

So, by shifting the draft again upwards or downwards, you will end up with a different value of A the sectional area at that draft and when the A changes, you will get a different volume. You keep shifting the draft upward or downward, such that the final weight of the ship is equal to the volume of the ship.

So, that is the first step that is to be followed when you are doing such analysis on a ship.

So, that will give you the draft of the ship on which the ship is floating, means that will give you a stable condition of the ship in which the ship is floating.

Now, you have to balance the weights, you have to balance the forces, is that enough for complete stability? No, because for a complete stability of a ship, you have to balance the forces as well as the moments.

So, if there is a moment acting on the ship, it is not balanced as far as the translation is concerned, but the ship will rotate about some point, which point does it rotate? We have already discussed so much about it.

We have talked about trimming. Trimming again remember, we are talking about the longitudinal moments, so we are talking about trimming here. We have already seen that the ship always trims about its longitudinal center of flotation, which is known as the centroid of the water plane area. So that is what you call as the longitudinal center of flotation; a ship always trims about that LCF point.

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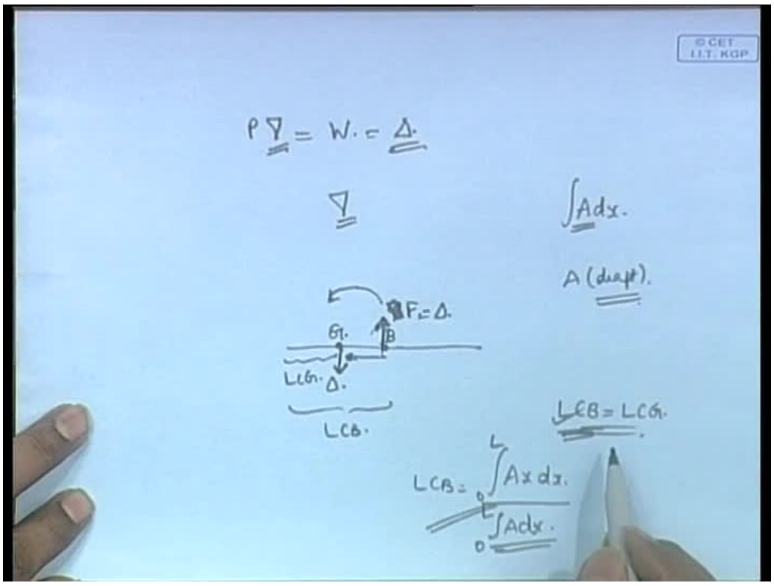

Now, why does it trim? A ship trims because let us consider this to be the ship and this to be the G of the ship. Now, at G of the ship, the weight of the ship will be acting.

Let us assume that this is B, at B there will be a buoyancy force acting del and I will write it as F the buoyancy force acting, which will also be equal to delta, because we have already made them equal that is the buoyancy force and the weight of the ship has been made equal by shifting the draft, by moving the draft up or down. We have said that the ship is stable, as far as forces are concerned.

So, in the vertical direction the sum of the forces is 0; so it is stable, there is no translation as such. If there is an unbalance of force, it will translate such that finally, it becomes 0. So, the next step is that we have seen that if G and B occur like this, G is here and B is here, let us assume this distance is LCG and this distance becomes LCB. So, at buoyancy this delta acts down, this delta acts up and therefore, there is a moment acting like this.

This is a moment that tends to rotate the ship therefore, if it is like this, if G is here, there is a moment that tends to rotate the ship like this; if G is forward of B, then there is a moment tending to rotate the ship like this, it is because of this two forces acting not on a straight line.

If the two forces that is the force of weight, the weight force acting at the center of gravity and the buoyancy force acting at the center of buoyancy,if they are not at the same vertical line or not at the same point, then you will have a trimming moment; you will have a moment that causes the ship to trim.

Now, how can we balance it now? Suppose that the ship trims, you know that as a result of the ships trimming B will shift, G does not shift because G is depended upon the weights on the ship. It has nothing to do with, whether ships trims or not if the weights on the ships do not move, then there is no change in LCG, the center of gravity of the ship does not change.

But if the ship trims, what will happen? Let us say that the trim ship trims by forward, the front part of the ship has gone down into the water what happens? More volume comes on the forward side, what it will mean, it means that B will shift forward.

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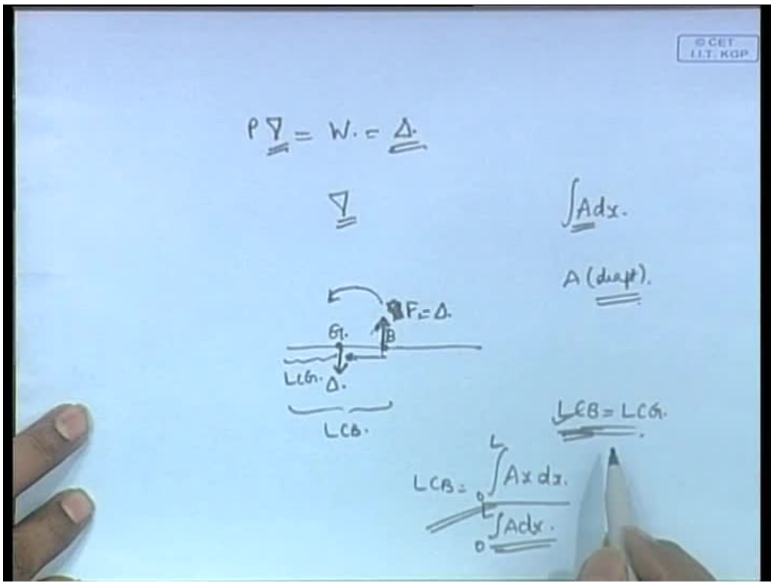

So, B will shift forward, so what we have to do is, in this particular case, the ship will keep trimming in this particular G is behind, therefore the ship will trim by aft; so, B will keep moving backward and it will keep moving till B comes and coincides with G. So, LCB becomes equal to LCG when this happens, the ships stops trimming and it is in a stable condition, so this is the stable condition. When the ship is static, so you have LCG equal to LCB that is the center of gravity and the center of flotation acts on the same vertical line; so this is an important condition for stability for ships.

So, this is a next condition in the computation of stability. First we make the weight equal to buoyancy, number two, we make LCB equal to LCG.

Now, what we have is the final position of the ship. Now, the only problem here is probably in finding LCB. You know how to find LCB that is this center of buoyancy is always found like this, it is the moment of volume divided by the volume.

So, LCB can be taken as integral of Ax dx divided by integral of Adx between 0 to L or between aft perpendicular and the forward perpendicular x varies from. Let us assume that the moments are taken from the aft perpendicular; so, the LCB will be given by integral Ax dx moment divided by Adx volume that will give you the longitudinal center of buoyancy.

So, what is done usually in the ship yards? In practice, is that LCG is calculated; first it is fixed.   The first step is to calculate the weight distribution that means you have to find, how the weight is distributed over the entire length of the ship.

So, you need to find there are some methods for instance, there is a method for that will give you the distribution of a hull weight.

So, once you have that you first find the distribution of weight, first you find the distribution of hull weight, then you add the light weight to it; you have to find the distribution of dead weights on the ship that is a pain staking process, but it has to be done. The entire distribution of weights is found and the result that is your final LCG is to be found; so your final LCG is found like that, so that is the first process.

You calculate the total weight of the ship, you calculate what we call as a weight curve is to be drawn, where you find the weight of the ship at different points on the ship starts from the aft perpendicular, you go till the forward perpendicular, what is the total weight of the ship but weight distribution of the ship what is the weight?

So, that is the first step, next step is to find the LCB; LCB is found by integrating this thing;

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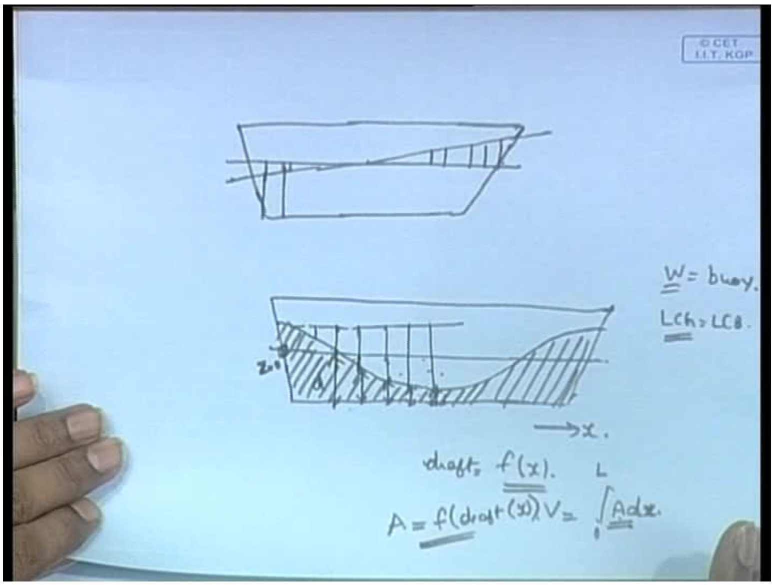

so using this formula, we calculate the LCB. There is no other way other than trial and error processes to calculate, make sure that LCB equals LCG means if you keep changing the trim for instance like this, so if this is the ship and if this is the initial waterline then suppose, it trims by some angle.

Now, note that at each point you will have different drafts; this is the important point that is the draft of the ship is not the same. In this case, when it is horizontal, the draft of the ship is uniform throughout from the aft perpendicular to the forward perpendicular draft of the ship is the same, but if you have a trimmed line, you will see that the aft of the ship is different from the draft of the ship; the aft is different from the draft of the ship at the forward.

We have already done that draft, aft, draft forward, you have finding from the change in trim; we have done those mathematical equations, how you got that so this gives you the draft.

So, you have to find the sectional area at each particular draft; so at each station, you will have a different draft. So, at each station, you have the difference draft, you have to find the sectional areas and integrated to get the LCB and you will have to keep varying the LCB that is equivalent to trimming the vessel. You have to keep trimming it till LCB equals LCG, so that will give you the balanced condition; so that will give you the finial stable condition of the ship.

So, this is to be done in practice that is the first step.

Now, remember I have mentioned to you, what I have said? I told you that this is the method that used to calculate, this is the stability analysis that is used in the case of a still water means you have a mean water level or a constant water level and not a varying water level.

Now, in real practice, you will never have a still water. You will always have a wavy surface, we have already said that so what we do is, just as we described in the last class. Let us assume that this is the still level.

Now, you can take this to be your z equal to 0 that is the center of the circle. You assume that the circle, the center moves like this and therefore it traces out a path like this; the wave becomes in this form. You have a wave, so you end up with a sagging wave in this case, it depends upon the types of problem you are encountering whether you are doing a sagging wave or a hogging wave that is entirely up to the ship designer to decide which wave he should choose.

Now, once you have this wave, we need to calculate, we need to do the same thing. For this particular wave, this is the purpose; this is what is usually done in a ship yard, in case of longitudinal stability analysis.

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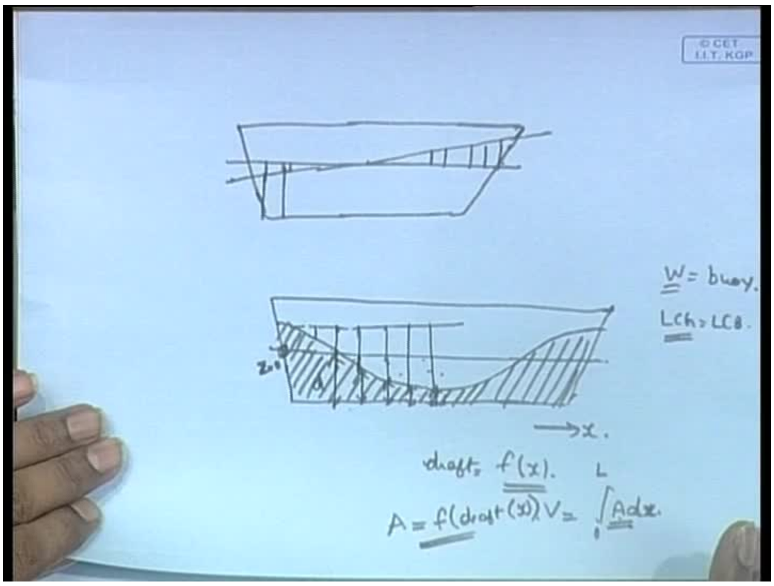

So, this is the wave profile; I have already discussed and described in detail in the last class, how you calculate the wave profile means by the wave profile, how you calculate the x and z distance or this z at each station?

So, these are each station. We are talking about the each station if these are the difference station, this is z; this z is usually the distance from z equal to 0, so this distance from this mean level.

So, what is that distance we have to know that we have already discussed, how to calculate the trochoidal waves z coordinate?

So, once you have this z, this problem that what we do first. We made weight equals to buoyancy and LCG equal to LCB, so we have done these two methods. Now, the same thing has to be done in the presence of a wave that is the problem here.

So, what change is really nothing much change. Now, the problem becomes much more complicated and the only difference is w does not change, it is the weight distribution on the ship, it is the total displacement of the ship and w is the total weight of the ship. LCG you can get, if you know the weight distribution in the ship, it has nothing to do with the presence of wave or the absence of the wave, whether the wave is there or not the- LCG on the ship will be the same.

So, LCG depends upon the weight distribution on the ship, so that is fixed; so we are not going to change anything to do with the weight distribution in the ship.

So that is LCG and w fix, the thing that changes because of the presence of the wave is that the center of buoyancy will change - that is the position of the center of buoyancy will change; the buoyancy force will change and therefore the LCB and the buoyancy force changes, as the result of the wave, why? Because of the presence of the wave, if you have the ship like this, if this is an even waterline - that is the horizontal waterline, the portion beneath their waterline is what we call as the underwater volume.

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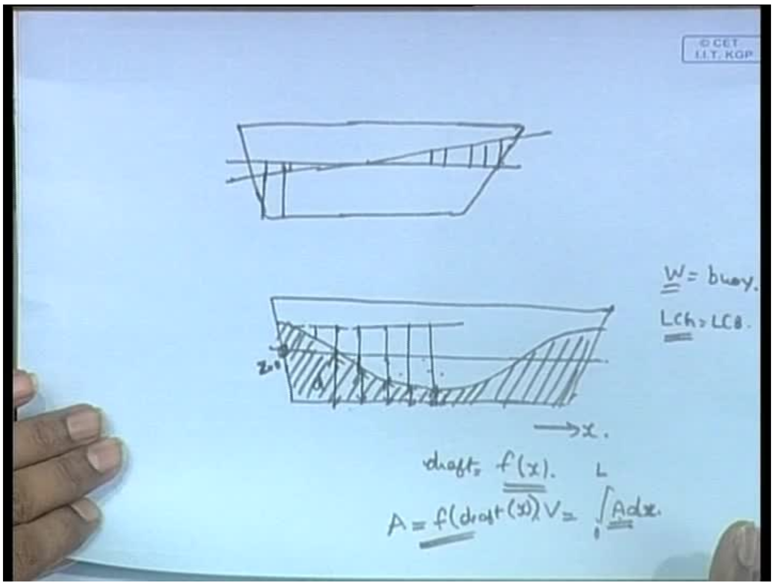

Now, our waterline becomes like this. Now, what is our underwater volume? Our underwater volume goes like this, below this, like this, so this produces our underwater volume; therefore we need to find the underwater volume associated with this profile, but remember we have this distance.

So, this distance we have as z, so we have to calculate this distance at each point; this gives you the draft at each point.

So, like this draft as you can see now, draft is a function of x. If you call this to be the x direction - the draft is a function of x like this is a trochoidal wave you have the value of draft at difference points.

So, the problem now comes in finding the sectional area, you have to take up your Bonjean curves again, you have to find the sectional area for these drafts at each station; sectional area is given for each station differently, sectional area is not the same all over the length of the ship.

If it were true, then the ship will be like a box. So, if it is an exact box, only if it is a rectangular box or a square box or a triangular box, which is exactly same throughout the length of the ship; you will have the sectional area same. So, since the ship is in a blend shape in the aft part of the ship whereas it goes into a streamlined design in the front of the ship that is in the forward portion of the ship is highly stream line; whereas the aft portion is highly blend and the shape is not at all symmetrical between the aft and forward and it changes throughout the station. So, the sectional area keeps changing throughout the

So, what you meant by a Bonjean curve is a Bonjean curve for each station, you will have a series of Bonjean curves for each station.

So, this is a curve between the draft and the sectional area at each station. So, therefore once you have this sectional areas, you calculate the total volume. Again, same concept, but the thing is that A is again the sectional area at each draft into dx, so this will again give you the problem just comes to finding the

So A, what we have as A the sectional area is again a function of draft, which itself is a function of x.

So, the area is the function of the draft at each point, which itself as a function of x, as it varies and therefore you calculate this A, you calculate the total volume of the ship.

So, the first method comes to finding that rho into v that the volume, under water volume becomes the weight of the ship that is the first step. Again, we balance the weight that means the ship is balanced according to Archimedes principle its true, so that is fixed.

Then number 2, we are saying that there is no external moment acting on the ship; you should have the LCB and LCG balanced. The presence or absence of a wave does not really change the position of LCB the center of gravity, which is exclusively depended upon the distribution of weights on the ship, it does not depend upon the underwater volume or it does not depend upon the area or it does not depend upon anything except for the location of weights and that is the external thing it as nothing to do with waterlines, so LCG is fixed.

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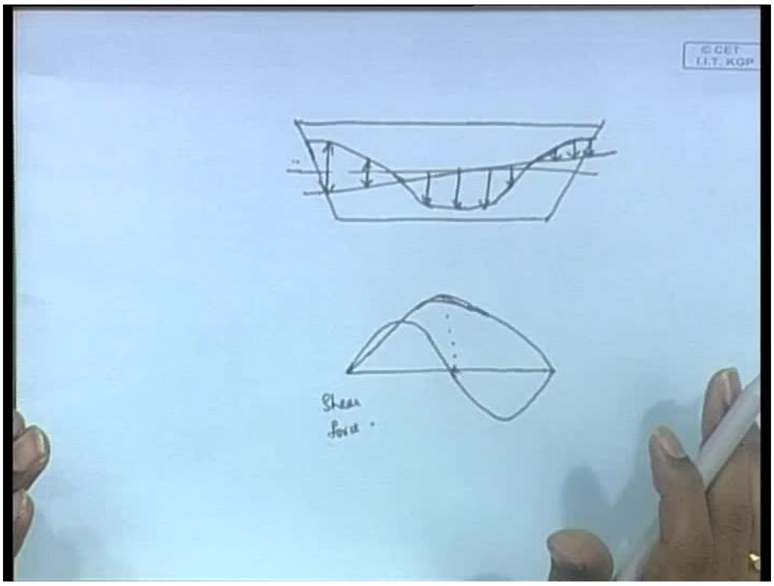

Now, the same way, we came varying the LCB. So, we keep trimming the ship until, again the ship trims, but its slightly complicated process here, because the ship keeps trimming, as it keeps trimming wave will always be like this. So, if you have the ship, let us suppose that this is a still waterline;

so, this becomes one waterline and therefore when the ship trims about, some value like this, if it trims the waterline is like this, so the draft here changes to this much draft, here is this much draft here is this much here here here here here here. So, you see how the variation in draft occurs, it is you cannot draw it simply, so that in the presence of trim the shape becomes quite complicated, but all you need to know is the draft at each point, whether the draft at each stations. So, at each station you find the draft, then once you know the draft, you look up the Bonjean curve section for that station what is the sectional area?

Some of the sectional areas is always to get the total volume of the ship under water and you need to find the LCB, which is the moment of the volume divided by the volume.

So that will give you the total LCB and you have to keep trimming the ship again, until you find that the LCB equals LCG. So, this is one of the stability analysis method that is done in shipyard to find out the final position of the ship that is to find out what is a final trim of the ship, and what is the final draft of the ship or this will give where the ship finally floats.

So, this is the condition in which the ship floats, whether the condition is stable and if you want, you can choose a very rough wave means very strong wave and you can study what is a maximum amount to which the ship will sink or it will trim as a result of the presence of the waves.

Now, the next series of work that needs to be done, one thing you should know in this, is that finally the shape of the water plane area. In the water plane, the shape of the water plane becomes extremely complicated, it is not at all a simple area. In the initial case when you had a still water, when you had a horizontally straight line, the water plane area is just like the shape of the ship.

But now, it is a very complicated thing, it is because the water plane area is like this, it is going like this, so the problem is really in finding the centroid of the water plane area, but since we are only interested in the x coordinate of the centroid it does not depend upon the z coordinate of the centroid. It is not that difficult but you need to find LCF, the longitudinal center of floatation and the ship always trims about that longitudinal center of floatation because if you do not know that then there is no way. You can calculate the draft at each point - at each station, the draft at the longitudinal center of floatation is what its equal to 0.

The ship has no draft or it is equal to some value, the draft is there means the longitudinal center of floatation is at the waterline; so it is always on the waterline; so that is some region below that is the draft now, that waterline goes like this, the draft keeps changing as you go away from the longitudinal center of floatation.

So, this is how we do some stability analysis related to the waves. Now, once you do this the main purpose of this wave analysis - once you find the initial position is to find what we call as the sheer force and bending moment diagrams that is something we need to do a little bit in detail, which we will do in probably in the coming few lectures. When we are wrapping up finally, we will do the sheer force diagram. We will explain what we really mean by sheer force, what we mean by bending moment; we will draw different kinds of sheer force bending moment.

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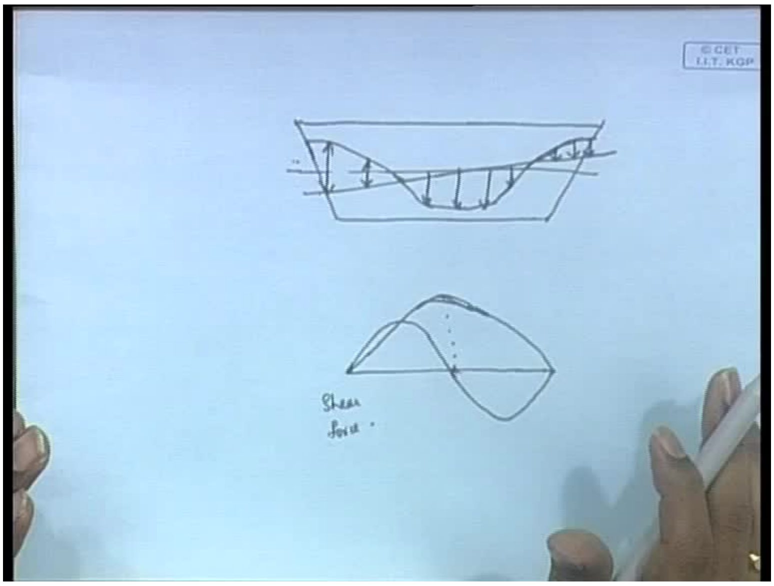

These diagrams for example, sheer force diagrams we are talking about diagrams that along the length of the ship. So, you draw sheer force diagrams over the length of the ship. We will explain what is the sheer force diagram? So, you draw the bending moment diagrams; so we will explain how bending moment reaches a maximum at some point, why sheer force becomes 0 there.

So, couple of points are there which we will discuss in later classes. So, this is the important thing you draw the sheer force diagram, bending moment diagram and so you end up seeing where bending moment diagram these are the points where the ship will experience, when the bending moment is maximum that is the region where the ship will experience maximum bending.

So, it usually happens, you can imagine the ship will experience maximum bending at the middle, the center of the ship.

So that is something; so before we are going to that we need to do a little more about waves, so we will start with that.

So, in general we talk about different kinds, so we have already seen what the trochoidal wave is and so we are going to assume now, whenever we talk about waves, we talk about trochoidal waves; so these are the waves that are affecting the ship.

Now, there are different ways in which the wave can come and hit a ship. We talk about different directions in which the wave can come; for instance the wave can come at 0 degrees, I mean 0 degrees means if the ship. let us assume that this is the ship, 0 degrees means the wave is coming like this, it is coming in the direction of motion of the ship; ship is moving like this, ship is moving in this direction, the wave is coming in this direction same.

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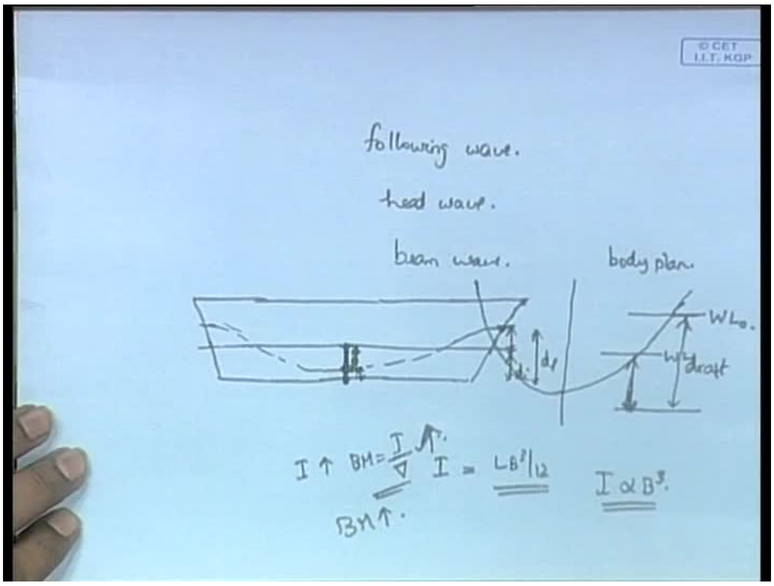

So, 0 degree angle the ship - the wave is coming; we call that as a following wave. So, we say that such a kind of wave is a following wave if the wave on the other hand, comes at 180 degrees means the wave comes directly opposite to the ship it comes and hits in the front we call that as a head wave. So, the ship - the wave is coming from the front; another possibility is when the wave is coming and hitting from one side like this, it comes from one side and transversely it hits like this.

So, the wave comes and hit like this, so the wave crust line is actually perpendicular to the line of length of the ship - the line joining the wave crust; this line is perpendicular that is called as a beam wave.

So, we talk about different types of waves and their effects on the ship. Now, there are important effects of the ship, on the effect of waves on ships stability.

So, suppose you have a ship here as we have seen, there are a couple of possibilities of producing the ship. Let us talk about what we call as the sagging wave. In this case, first let us start with the sagging wave.

First remember that the shape of the ship is like this, that is the center of the ship is mostly wall sided; if you remember, what we mean by wall sided, it means that the breadth of the ship hardly changes as you go up it is like this it is in the centroid, in the center, it is the thickest region. If you have seen some of the lines plan drawings, if you remember the midship; if you look at the station in the body plan; if you look at the station, you will see that it is like this, mostly you are not going to have much of a difference in the breadth of the ship as the draft changes.

So, if the draft changes here; if the waterline goes up or down here that is hardly any change in the breadth of the ship, but when you go towards the front of the ship and back of the ship as well you will see that it goes up like this. In general, everywhere it is like this - that is it goes up in this fashion.

So, if your draft increases, you call this to be your draft. So, if your draft decreases, first let us assume that the draft decreases means, initially if the waterline is here and then the waterline is here this is WL 0 and this is WL 1.

So, initially your waterline is here and then your waterline came down to here; now, in case, you have a situation like this, there is a decrease in draft. You see that in general, the breadth of the ship as decreased, so what is this, what I have drawn? I have drawn the half ship.

So, this is the body plan what have drawn here, is the body plan, so body plan in actually if you look at in the body plan what you are seeing here

So, if you look at the ship in the body plan that is ship like this, you look from here; so you will see that the shape of the ship actually keeps going like this, which means that the draft keeps increasing. If it keeps going up, if you go away from the keel towards the deck, so if the draft of the ship keeps increasing, the breadth of the ship continually keeps increasing.

Now, why do we keep mentioning this relation between draft and breadth, what happens as a result of wave, see what we have studying here. We have done all the stability analysis as for as a still waterline is concerned, there is nothing much left in the still water stability analysis, we are now diverting into the difference in the case of a wave.

So, in the case of a wave, the main difference is occurring in the draft at different points means, the waterline is no longer straight; therefore, draft is no longer the same as the draft in the case of still waterline, because of the presence of wave its draft is changing because some region it is crust, some region it is trough; therefore some region the draft is more where there is a crust, there is a more draft; where there is trough, there is less draft.

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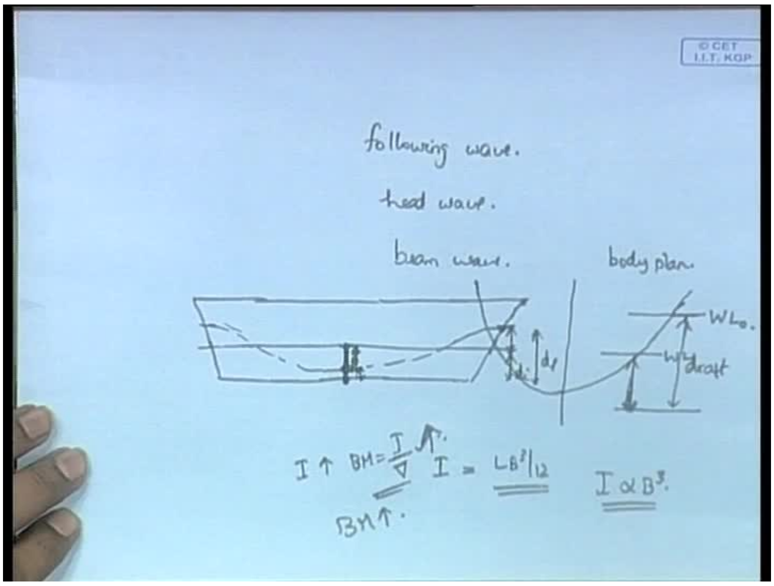

Therefore our problem now comes to the effect of draft, so effect of changes on draft. Now, we have seen as the draft increases, in general. So, in this particular case, let us look at this particular case what has happened?

What so we see here? So, this is the sagging wave over the whole length of the ship what has happened, here we have seen that initially, the waterline was only this much.

In this region, first let us consider the midship region, in the midship region what has happened the draft has decreased. Initially, this was the draft, if that was still waterline, because of the presence of wave the draft has decreased its only here so this is the draft.

Now, it is no longer this much I mean this is the draft now not this will be the draft now, this is the waterline, therefore this is the draft now and initially this was the draft.

Now, in the midship part, we have already seen the midship part is because of the change in draft there is hardly any change in breadth, because that midship is actually a wall sided it is almost like this.

Now, let us see what happens in the midship of the ship? When you go to the front and forward part of the ship. Here we have seen that there is an increase in draft, initially the draft was only this much d initial, final draft is this d final; there is the change di, df so you get the initial draft and the final drafts.

So, the final draft in the forward part is much more than the draft initially, in the absence of a wave.

Now, what did we see, if the draft increases, we have seen that the breadth increases. Now, what is the effect of breadth on the stability of a ship? This is an important part how is the breadth of the ship related to the stability of the ship?

Now, what is I of the water plane area, I is LB cube by 12, you have seen therefore, I is proportional to B cube, I is the moment of inertia of the water plane area.

So, it is proportional to B cube, which is the cube of the breadth. Now, here what has happened, the breadth has increased; so when the breadth has increased the moment of inertia will increases.

Now, what happens as a result of a moment of inertia increase, I increases BM given by, I by del increases, therefore BM increases, metacentric radius increases, M goes further up; GM increases, metacentric height increases as a result there is an increase in the ship stability.

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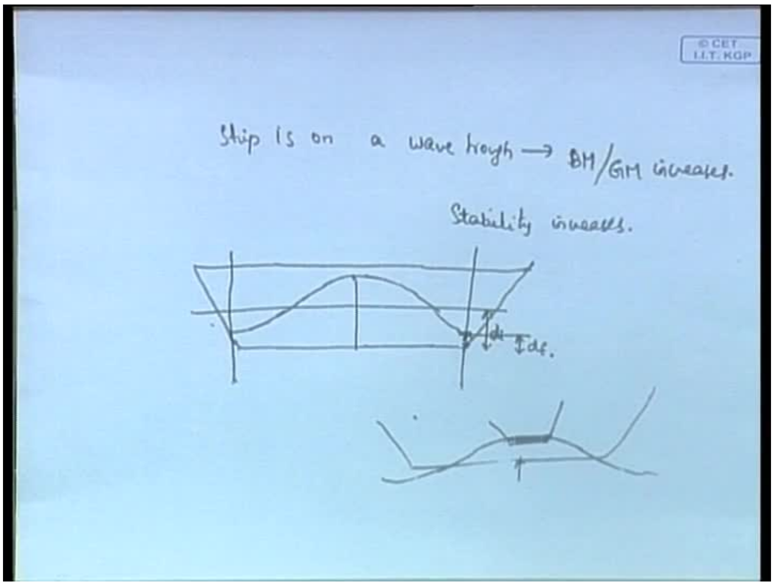

So, what we see is that when the ship is on a wave trough, this is what we have done; this is what we mean by a sagging wave, ship is on a wave trough BM and hence, GM increases.

So, the metacentric height BM increases means it mostly because there is a shift in B down and there is an increase in B up, so because of that the BM increases and consequently GM increases.

Now, therefore the stability of the ship increases; so what we see, if the ship is on a trough, the stability of the ship increases. As a result of, when you compare it with the ship stability on a still water, the stability of the ship is more in the case, then the ship is floating on a trough.

Let us consider the other case, the ship is now floating on a crust, what you mean by ship floating on a crust that is the case of a hogging wave.

Now, this is a hogging wave the, ship is floating on a crust means the center of the ship that is midship of the ship is on a crust.

So, there is a crust; this is the wave ship this means it is not here the whole ship is here, the midship section is here its floating like this on a crust.

So, now, what happens the reverse of what I just said before occurs; here in this case, you see that in the midship again, there is an increase in draft, but that does not change the overall breadth of the ship that is it does not change I so much because in the midship the ship is mostly wall sided; there is hardly any difference in B or there is hardly any difference in the breadth and consequently the moment of inertia does not change.

But here on the front part of the ship and even the aft side of the ship what has happened the draft is decreased initially, the draft was this much, this was d initial.

Now, the draft is only this much d final, so that is a very strong decrease in draft as a result of the ship floating on a wave crust, d initial and d final, df is much smaller than d initial what is the consequence, the breadth of the ship is effective. The breadth of the ship is varying over the and therefore, I is no longer very small as straight forward as last time. It is not like LB cube by 12 very straight forward we calculated; it is for a box shape barge when you have a rectangle, you can do LB cube by 12, but its proportional to B cube always at any point between any two stations that small strip it is proportional to B cube, the I the moment of inertia is proportional to B cube.

Now, the half breadth cube - therefore, there is a very strong decrease as a result of the ship floating on a wave crust, there is a very strong decrease in draft, in the front part of the ship and in the aft part of the ship as a result of, which there is a very sharp decrease in the half breadth. In the effective half breadth of the ship means there is a change in the breadth, there is a decrease in the breadth of the ship in the forward part and there is a decrease in the breadth of the ship in the aft part; there is hardly any change in breadth in the middle parts.

So, effectively there is a decrease in breadth of the ship as a result of which there is an effective decrease in B cube; as a result of which there is an effective in I consequence of which there is an effective decrease in BM that is the metacentric radius and therefore, there is an effective decrease in the stability of the ship.

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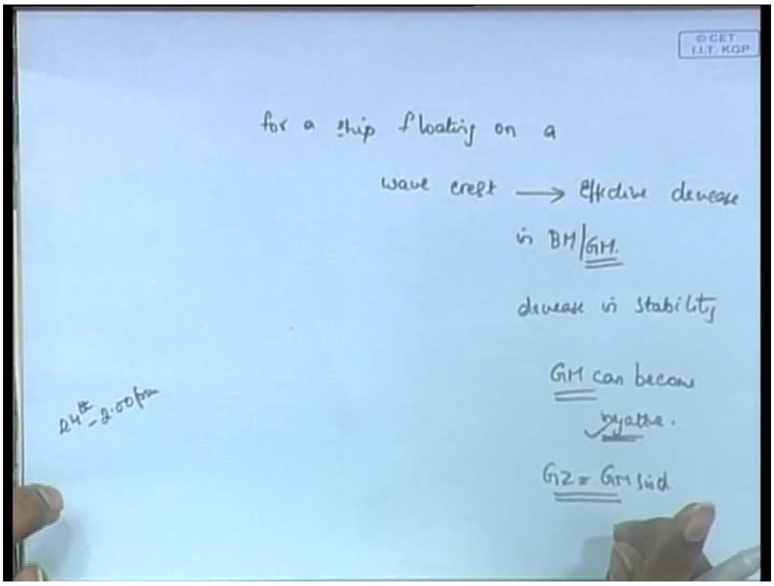

So, the metacentric radius decreases as a result; so what we see is that therefore for a ship floating on a wave crust, there is a effective decrease in BM consequently in GM. So, M actually comes down; so there is an effective change in GM or the metacentric height is effectively reduced or there is a decrease in stability of the ship.

So, there is a consequent decrease in the stability of the ship because GM is now much smaller than it was in the previous case therefore, when a wave actually passes through a ship. Let suppose, that a ship is moving in this direction and if a wave comes probably in the head if there is a head wave, if the ship is travelling in head seas or a following seas and suddenly the ship comes on a wave.

So, what will happen, first the ship will go on top of a wave crust, then it will go on top of a wave trough, then it will go on top of a wave crust again and it will keep going up and down; so the ship will be actually varying in terms of which position it will be varying in its position as in the wave crust and trough, it will keep varying like this.

So, what happens as a result of this moment? When it is on a wave crust the GM decreases, when it is on a wave trough the GM increases; so, the stability decreases, stability increases; so GM is now, becoming a function of time because of the movement of the ship like this, GM is actually a function of time.

So, the stability keeps decreasing much more so those calculations, which you did using still waterline that is GM using still waterline does not really hold good, in case of a wave, you are seeing that the GM is actually now a function of time.

It keeps varying it decreases much further than its value in still water, then it increases to a value of still water, then it increases to a value above still water so stability increases, decreases; so we are not bother about what happens when the stability increases than the still water level its more stable.

But there are very particular dangers situations, when the ship is on the wave crust, when you have your GM is very small and it is possible that in many cases, the GM can keeps decreasing to such a value that GM can even become negative.

So, this GM can end up becoming negative in such cases and as a result your GZ, which is GM sin phi also becomes negative. So, righting moment is actually becoming negative means it is actually a moment that is going; so if there is a small wind there is a heeling moment this righting moment is now, opposite to the restoring - it is no longer restoring the ship; it is trying to destabilize the ship it adds to the wind heeling moments, so its most likely that the ship will capsize.

So, it is wind heeling moment plus the righting moment or GZ is negative. So, GZ plus the wind heeling arm that will become the total heeling arm, entirely it is trying to capsize the ship and therefore the ship is highly unstable this is, when the ship is on a wave crust - on a wave trough, the ship is most stable,

But since, it is an unsteady continuous transient phenomenon or it is varying with time, it is a time dependent phenomenon. You are bothered about what happens in the unstable case, when it is on a wave crust and its GM is decreased and it is probably negative.

So, this is some of the important concepts dealing with the stability of ships on waves. The concepts we will do a little bit of this analysis and we will continue with this in the next class thank you.