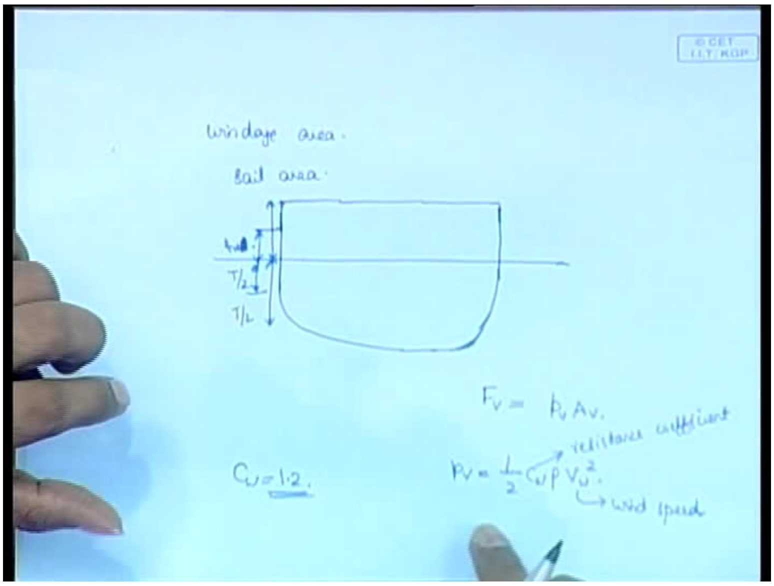
Hydrostatics and Stability
Prof. Dr. Hari V Warrior
Department of Ocean Engineering and Naval Architecture
Indian Institute of Technology, Kharagpur

Module No. # 01
Lecture No. # 18
Heeling Moment – III

In today's class, we will be discussing about wind heeling arms and how to calculate the stability of a ship subjected to wind heeling. First of all, as I told you before, suppose you have a ship like this - there is a region of it below water, there is a region of it above water, this is the draft and this is the free board; so, you have that much distance.

(Refer Slide Time: 01:21)

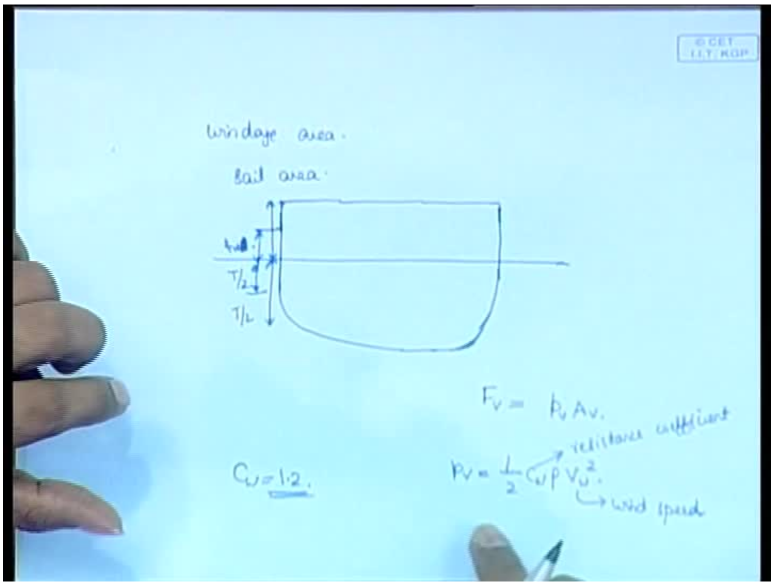


On this free board, the wind acts and the wind acts on the surface and the way in which - I will tell you - there is a uniform pressure offered by wind on the - of course it might not be uniform, but in general over that area we consider a uniform pressure is offered by the wind; this pressure acts on that area that is exposed to the wind, which is called as the windage area or as the sail area - two things - it is called windage area or sail area; this is subjected to the area and therefore that the pressure into that area is a force that will be acting on one side of the ship.

This force is acting, we can assume, at the center of gravity of the windage area; if this is the ship, if this much is above water - the free board, half of that free board - at that point we can assume the center of gravity of the windage area to be located at; there you can assume the wind force to act - at that point; when this wind force acts there is a tendency for the ship to move like this - displace horizontally like this, but this is prevented from happening by the water - the water resists the moment of the ship; actually, air also resists but the effect of air is very less because its density is lesser; but, water has a very strong resistance and therefore it prevents the ship from moving like this.

As per our calculations, we are assuming that the ship does not move at all in this direction - in the transverse direction the ship does not move at all; therefore, the wind force is balanced by the reaction force from the water; there is a reaction force acting here - this reaction force is also a force is also a pressure that acts over the entire area; we can assume that to be a constant force acting at the centroid of that area which is under the water; the centroid of that area under the water will be T by 2, T is the draft so T by 2 will be the centroid of that area or the centroid of that portion.

(Refer Slide Time: 01:21)



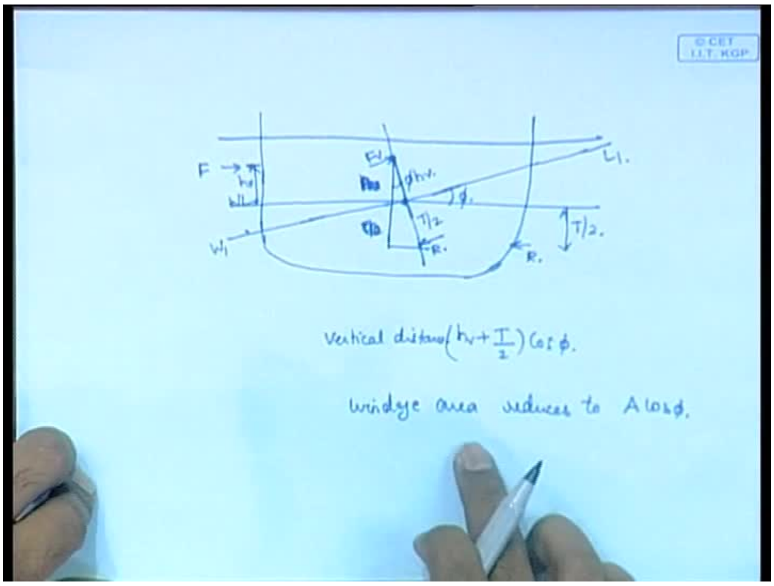
At that point - at T by 2, you will have the force from the water - reaction force from water and from that point plus T by 2 will give you the surface, plus an l will give you the distance to the centroid of windage area; so, that l plus T by 2 will give you the distance between the centroid of the windage area and the centroid of the water - centroid of the region below the water.

It will be like this if you draw it; this region - this is what I am saying - this is the windage area - at the exact center of it we will call this distance l; at the exact center of this this will be T by 2, T by 2, T by 2 and l; the distance between the… this book uses not l it uses h v - they are calling this distance as h v it is just a notation; this book uses h v, h v and here you have T by 2; the force due to the wind is given by now p is a pressure due to the wind and A is the windage area or the sail area so F v the force due to the wind is given by p v into A v.

In general, the expression for wind pressure is half into C w into rho V w square where V w - this is the wind velocity or the wind speed and p v is equal to half; C w is the constant it is known as a wind constant - I think aero dynamic is the resistance coefficient - it is called a resistance coefficient or wind resistance coefficient.

C w and V w is the velocity wind speed; so half C w… it is a constant - C w has some value it is 1.2 so, C w is in general 1.2; therefore, you have 1.2 into 1.2 into rho is the density of air it is wind so air is 1 kilogram per meter cube into V, V is the velocity of wind or the speed of wind it is usually in the range of some probably 5 or 6 meters per second. This gives you p v the pressure and p v when it is multiplied with A that is the wind - the sail area - it gives you the total force due to the wind.

(Refer Slide Time: 07:01)



Let us assume, that this is the initial water line and then the ship heels to a new water line - it heels by an angle phi, then this distance is h v, this distance is T by 2, at this point the R acts - R is the reaction force from the water, at this point F acts - this is the reaction force from the wind and R is the reaction force from water so these two forces act.

The ship is now heeling - it is like this; now, as you can see there is a force like this, there is a force like this so it causes it to heel like this - just like we can imagine when a wind acts it will cause it to heel like that; this heeling, it causes it to heel and that is what is shown by W 1 L 1 - it is a new point of heeling.

At this point…also if you draw the vertical in this - this is the… remember W 1 L 1 represents the horizontal that vertical so the reaction force from the water is always horizontal because it will never change; it will be like this R, somewhere here, it would not be exactly in line with this it will be somewhere up and there will be an F here - somewhere here there will be an F - now, this distance… what we are talking about is if it is it like this initially then it tilts like this, so this center is actually moved up a bit and that point has moved down a bit and the vertical distance between them at that point is not now equal to h v plus T by 2, it is slightly different - it is with an angle; that is, it will be this distance - you can just look at this figure, it will be like this this - will be h v and this will T by 2, this will be phi or is that phi or the other 1 phi…

(( ))

Yeah

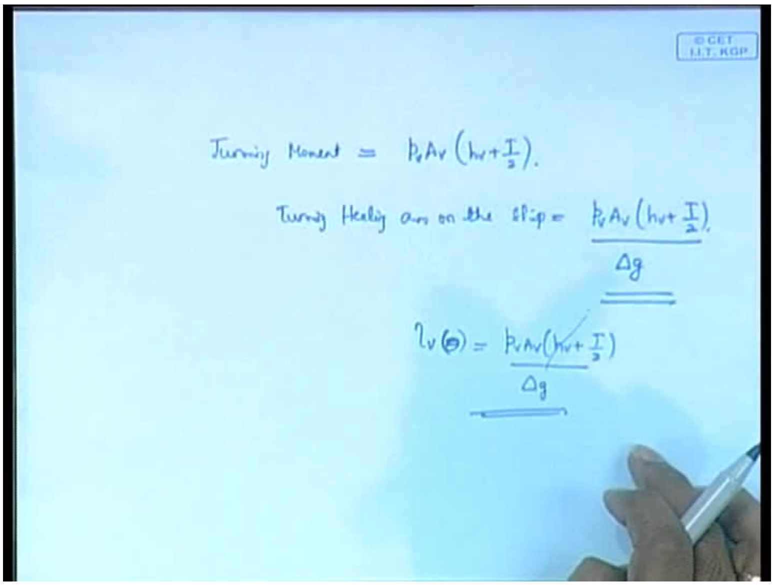
(( ))

Yes correct so h so no this is not h v is not T by 2 this is h v this is the vertical no at that point h v and this is T by 2; now, the vertical distance at that point between them - when it is tilted like this is h the vertical distance is now not equal to h v plus T by 2 it is h v by T by 2 cos phi.

Note that, wind is always acting horizontally; similarly, that is the wind is always acting horizontal the wind does not…even though the ship tilts the wind does not tilts with it; therefore, what is the force? Force is pressure into area - pressure into which area? It is the area that is perpendicular to that direction of force, direction of wind; the velocity of wind is like this, the area that we need is the area that is perpendicular to it; when this area tilts like this the area that we need is a projection of this area on this plane; therefore, that also becomes a cos phi if this area is A this area itself will be like this this; area in this projection will become A cos phi - this angle is phi so A cos phi.

The area - the windage area reduces to A cos phi; now that you have these two values - I mean, you see these two things, lets write what is the expression for the…first of all what is the moment due to the wind? Initially, it is in an upright condition. What is the moment due to the wind? It is the force…now, this force is the wind force, there is a reaction force; this reaction force will be equal to the wind force because this is trying to equalize that such that the ship is not moving horizontally so they are balanced; it is this force f which is the wind force equal to the reaction force that force into the distance between them that is the moment causing the turn.

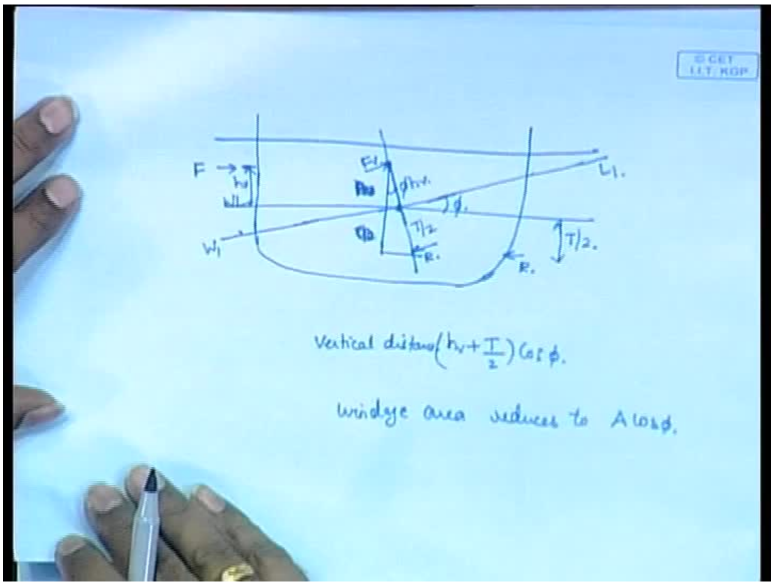
(Refer Slide Time: 12:21)



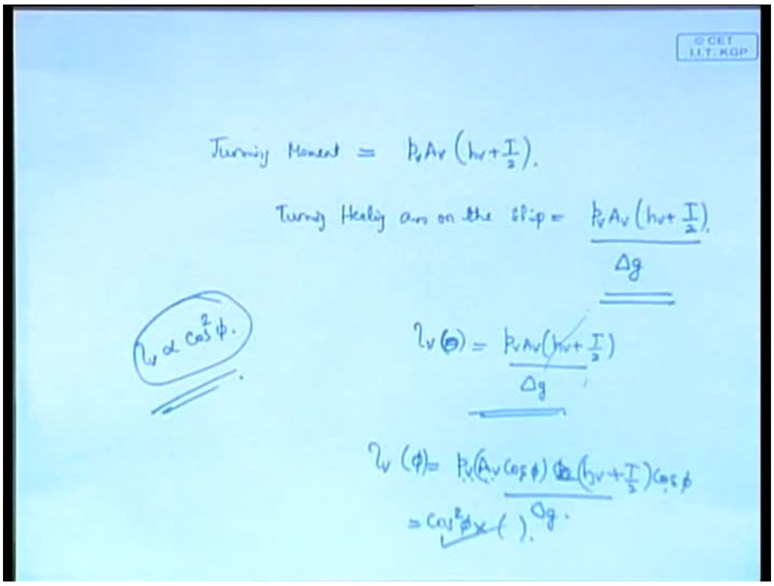
The turning moment is equal to F into distance between them which is p v A v into h v plus T by 2 - this is the turning moment; the turning arm on the ship - is not the turning arm of wind, it is the turning arm on the ship - I will tell you what the difference is. The turning or heeling arm on the ship is this moment which is p v A v into h v plus T by 2 - this moment - divided by delta of the ship; they have put g also that means delta is in kilograms so you want the force means you want the arm; it is force into distance divided by force; force is mass into g.

There is a weight, this is delta into g; you see why I said it is the heeling moment - heeling arm of the ship? That is because you have divided with the weight of the ship; it is not exactly the moment causing the - it is not exactly the arm that causes the moment as far as the force….if I divide it by p v A v you will get an arm - that is, h v plus T by 2 that is not what we are calling by heeling moment - heeling arm; heeling arm means the force into distance, between which it acts, divided by the weight of the ship - the ship is what is being heeled; we are talking about the heeling moment of the ship or heeling arm of the ship; the heeling moment of the ship is equal to the heeling moment of the force because this force is what is causing the moment so the heeling moments are the same; but, heeling arm of the ship is not the same as the arm that causes the moment of the wind - the arm that causes the moment of the wind is h v plus T by 2 but the heeling arm of the ship itself is h v plus T by 2 into p v A v that gives you the moment divided by the weight of the ship - that is the heeling arm of the ship; that is usually designated in this book as l v at 0 angle of heel is this - h v plus T by 2 divided by delta g, this is the expression for the heeling arm of the ship due to wind or you can say heeling arm on the ship due to wind, because heeling actually acts on the ship whereas righting is a property by the ship; righting arm is done by the ship to come back to its position heeling is done on the ship to go to the final position.

(Refer Slide Time: 15:25)



(Refer Slide Time: 15:35)



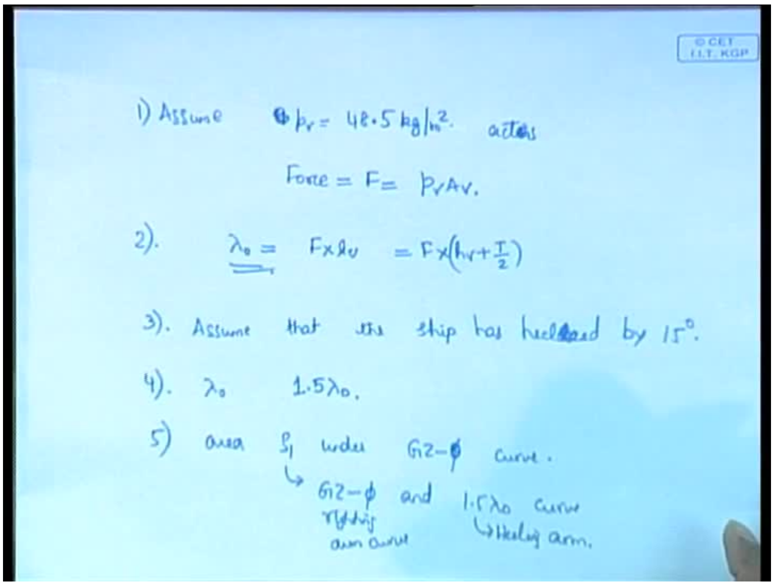
This is l v as a function of these things; remember, previously we have said when the ship heels by an angle phi this distance changes by h v plus T by 2 cos phi as directly propositional to this you can see that l v will also become directly propositional to phi; so, l v at some phi will be p v A v into cos phi - if you want I will explain this again - h v plus T by 2 cos phi divided by delta g; why did I say this? If you see this original definition we say that when the ship is heeled now to an angle phi its windage area becomes A cos phi.

I have made this A cos phi this is at an angle phi its windage area is now A cos phi - it is this; its vertical distance between the two forces at that instant when it is heeled by an angle phi is h v plus T by 2 into cos phi; therefore, the vertical distance is h v plus T by 2 into cos phi so this becomes your l v at some angle of phi heeled; initially, initially when the ship is upright wind acts a heeling arm on the ship is propositional to h v plus T by 2 this one this is your heeling arm.

When it is heeled by an angle phi it is now propositional to the initial value into cos square phi into something - you can see one cos phi is from here and one cos phi from here so its propositional to cos square phi into into these values p v A v h v plus T by 2 by delta g; this you have to remember - that is, l v becomes propotional to cos square phi - this is one point here.

This is as far as the basic physics is concerned with the wind heeling moment; now, we will see how the stability criteria regarding the wind heeling is done for different ships; the different IMO criterion - how they make the rules, we will do that.

(Refer Slide Time: 18:28)



The way we proceed is like this - these are a series of steps; firs,t let us write down the steps and then we will do a problem by that time you should able to understand how it is applied; first of all, you assume that a force of… it is something like this - pressure p v… p v equal to 48.5 kilogram per meter it is in kilogram - please note those dimensions; usually, pressure is in the…. previous definition we put pressure as in terms of Newton's per meter square but this is in terms of kilogram per meter square it does not matter you have to multiply with g actually.

So, 48.5 kilogram per meter square; first you assume that so much of p v - a wind of so much of p v - is acting - it acts; a wind with this much of pressure is equal to 48.5 acts continuously - it is a steady wind, this produces a force F given by this pressure into windage area - this will give you the force on the force acting due to the wind force -

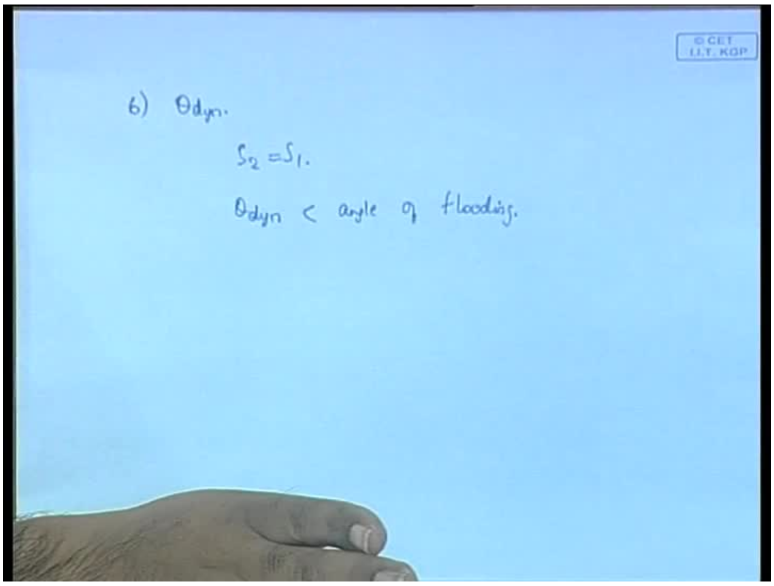
force due to the wind; then, we define a lambda 0 as F into l where l is your l v as in the previous definition this is F into… this l v is h v plus T by 2. Is it clear what h v plus T by 2 is?

The heeling… this is just the moment due to this whole thing - lambda 0 represents the moment due to the wind, that is all; the moment due to the wind which is force into the distance between the two forces, that is, the wind force acting here and the reaction from the water force acting here there is a distance between them and because of these two forces acting there is a moment tending to turn the ship and that moment is F into l; F is the force and l is the distance between them that distance is h v plus T by 2.

We call this lambda 0 - just note these things, it is termed as lambda 0; I will just write it step by step; we assume that….actually, if you do not follow completely we will do the problem and then it will become clear; assume that the ship has heeled by 15 degrees that is the next step - you assume that the ship by now as heeled by 15 degrees then - I will explain again as I told you - then you calculate… you have lambda 0, you are calculating a safety giving it a safety factor of 1.5 lambda 0; this is like saying this 48.5 newton you get a wind by making it one point - you calculate some moment making it 1.5 lambda 0 the meaning is that you assume the worst case; this is the design criterion, we really do not know what is the wind and in general the wind is maximum is above 48.5 that is why we have chosen that to be 48.5 - that is the maximum value, because we do not care what happens in the minimum case, that is not a problem, only our worst cases we are designing.

Again, in addition to that, you assume a safety factor of one point - that means, you are assuming the moment acting on the ship is now 1.5 lambda 0 not just 1 lambda 0 but 1.5 lambda 0 - that we assume to be 1.5 lambda 0, then… this I will explain; you have to find one area S 1 under the GZ phi curve; which area is this S 1? This is the area under the GZ curve between the righting moment and 1.5 lambda 0 - if you do not follow it we will see what it means; that is, it is the area under the GZ phi and this is the righting arm curve or the righting moment curve and a 1.5 lambda 0 curve - this is the heeling moment curve - heeling arm.

(Refer Slide Time: 23:51)



Once you calculate the S 1, we assume that you find a theta dynamic which is defined as… that is, from the point… how to explain this…. Probably, I will do one thing I will do the problem and step by step I will explain; at any rate, you find a theta dynamic - from the point where the ship has heeled we find an area S 2 such that S 2 equal to S 1; I will tell you what this is, it is very confusing, sounds little confusing so I will write it first; S 2 is equal to S 1 and the final condition is that theta dynamic should be less than the angle of flooding - I will explain how this theta dynamic is found, we will do that problem.

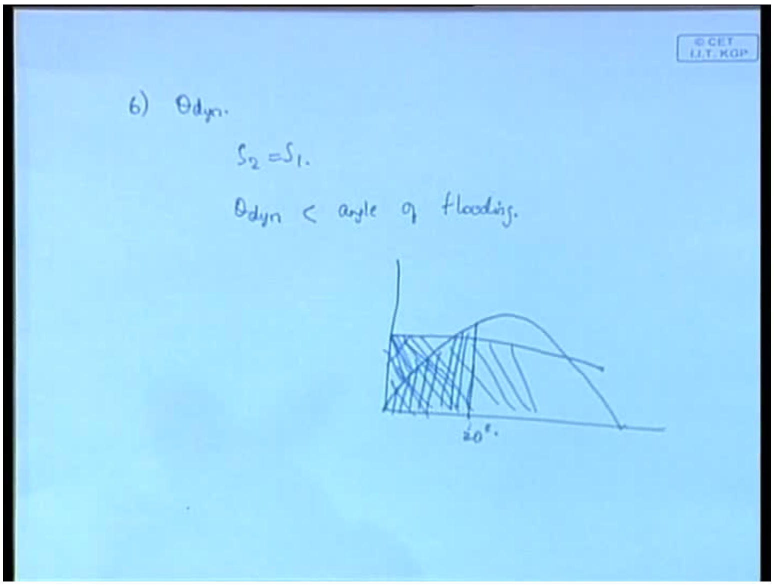
The criterion is that the theta dynamic that you are getting finally…what exactly are we doing? What we are doing is we initially have the ship in some condition - it could be like this or it could be like this; some condition you have the ship in initially, now you are providing some force to it - you make it tilt to some position, while it is tilting to the new position…this is the physics behind this whole step if you this understand then it is easy; from the initial state wind starts acting and this starts tilting and it reaches at some state.

Even while it is tilting its having a GZ - it is having a righting curve; now, some energy is imparted from the wind to the ship - the ship does some work in resisting that wind;

so, the difference between the two will give you some work or some energy that is given from the wind to the ship; what happens is that you assume that this whole energy that is given from the wind to the ship causes that ship to tilt further - without the wind acting now the ship is now tilting - with that new found energy its heeling further; you find out the maximum angle to which it will heel and you say that that angle of heel should be less than the angle of flooding; this is the general physics behind the whole process.

We will do this problem…. that final angle through which it come is known as the theta dynamic; when I said two areas should be equal the meaning of that is that area is obviously the energy…. I have told you what is area under the GZ curve - it is dynamic stability, it is the work done by the wind and work done by the ship in….dynamic stability is the work done by the ship and if you calculate the area under the wind curve it gives you the work done by the wind; you have two curves in the GZ you have a GZ curve you draw sometimes the heeling curve - I have already shown that.

(Refer Slide Time: 27:12)

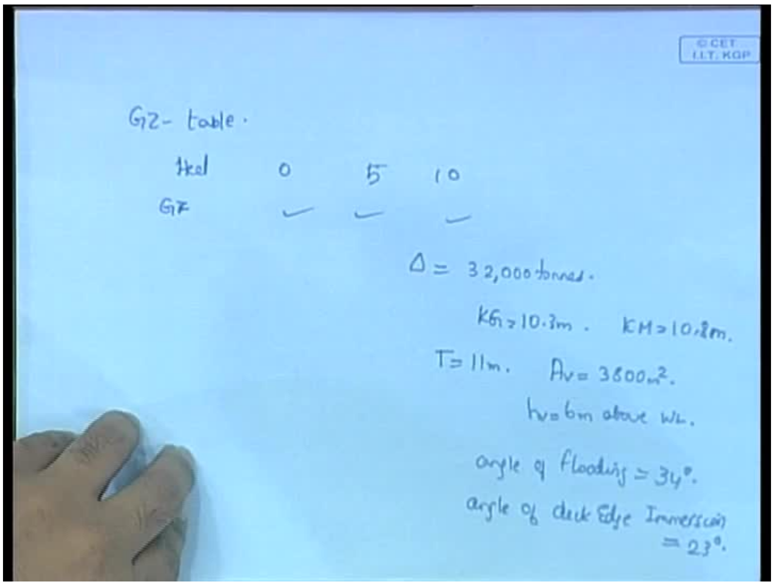


This area under GZ curve - I will draw this; you have a GZ curve like this, if I take the area under this curve up to some degree, let us say 20 degrees, I get the work done in heeling the ship - work done by the ship, in righting the ship up to an angle of 20 degrees - that is what this; some heeling moment is acting, the ship is heeling, but it is trying to right itself always - there is a righting moment; the heeling moment minus the righting moment is acting but it is still heeling; moment is higher so it is it keeps going; the work done by the righting moment is given by the area under this curve - I think it should be clear.

On this sometimes we draw a heeling arm - the area under this curve, let us say this area, up to 20 degrees will give the energy given by the wind into the ship for heeling it; the first one is the energy given by the wind to the ship the other one is the work done by ship in resisting that, which is like saying that the energy taken out of the ship - one is the energy given into the ship the other is energy taken out of the ship; the difference between the two will give you the net energy given to the ship; that is what we mean by the difference in area between the heeling arm curve and the righting arm curve; righting arm curve is the resistance and this is the work given energy given and the difference between the two will give you the energy net energy that is given to the ship.

What happens? Up to some…initially the wind keeps acting, it keeps giving some energy to the ship, it keeps heeling; let us say, the wind stops but still the ship has some energy - it has more energy because wind has given it some energy right? So, it keeps heeling further - that final angle to which it heels is what we are calling as theta dynamic; that should be less than the angle of flooding.

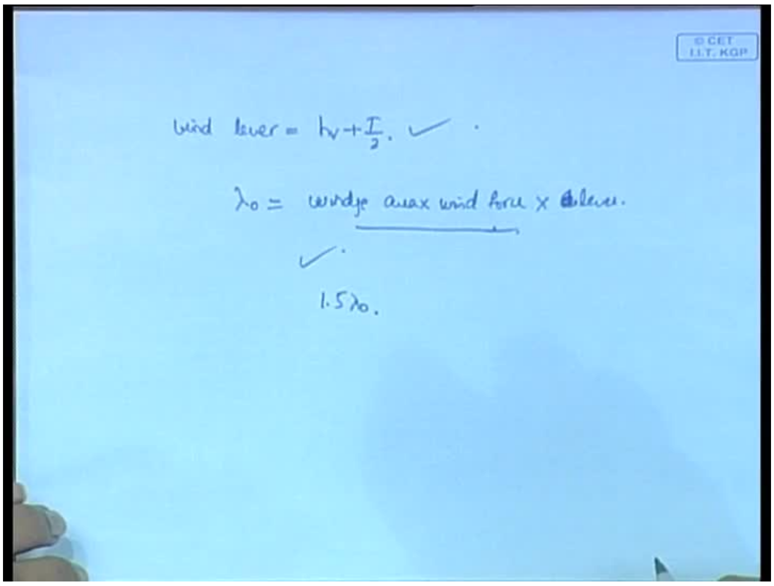
(Refer Slide Time: 29:36)



Let us do one problem that should explain it; first of all, the GZ table is given so you have the heel and GZ; you are given the displacement of the ship; KG is given; KM is given, from this you can directly get your GM - there is no problem in calculating GM.

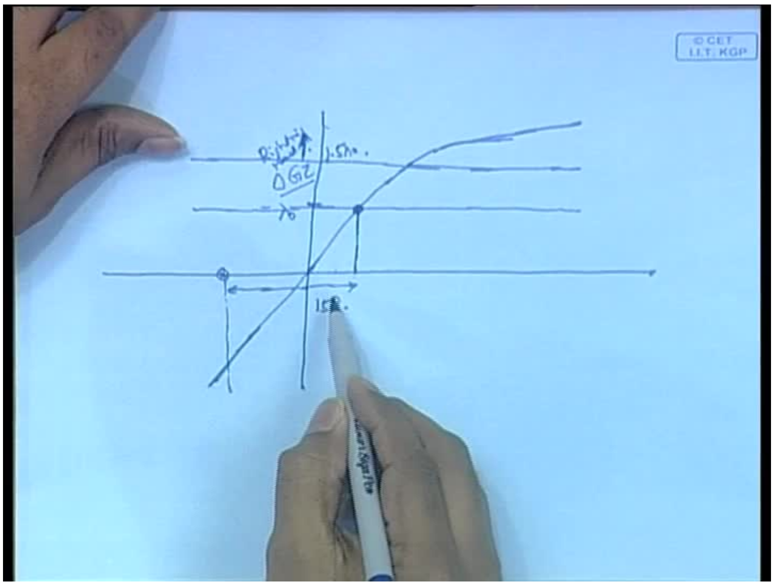
You are told that the draft is 11 meters, you are given the windage area is 3800 meter square, and you are told that the centroid of the windage area is 6 meters above the water line - this is obviously your h v according to your definition - h v is equal to 6 meter above the water line; then, you are told that the angle of flooding is equal to 34 degrees and one more is required, which is known as the angle of deck edge immersion and that is also given to be some value 23 degrees.

(Refer Slide Time: 31:33)



You are asked - is the ship stable? Will it pass the stability test? We will see, the whole test we have to do. First of all, we have to find the wind lever - as we have said, it is h v plus T by 2 - this is very straight forward, T by 2, T is the draft so T by 2 plus h v everything is given so this you can calculate. Remember, we have to calculate a lambda 0 - I have defined that lambda 0 is equal to the moment due to the wind, which we can calculate as windage area into wind force into that distance or which is the wind lever - divided by the displacement of the ship - divided by wind lever divided by area into force into wind level that is the lambda 0 is the moment itself it is not the arm so it is just that; so, windage area into wind force into lever and that gives you something - that gives you your value of lambda 0.

(Refer Slide Time: 33:01)



Now, you need to calculate a 1.5 lambda 0 - this is necessary for the calculation; you calculate a 1.5 lambda 0, then…I will draw this; first of all, you do in this problem…I think the only way to do this is by graphical method - that is, you have to have the graph and you have to draw the figure; you draw the GZ curve first.

First thing to do is….so this is GZ and this is GZ we will put delta into GZ - righting moment - it is not the GZ curve it is delta into GZ, which is the weight of the ship into GZ displace - this is actually showing the righting moment; the important thing is… this is a moment phi curve, not the GZ phi curve it is all almost the same thing - it is delta into GZ versus phi curve; in this, instead of putting the heeling arm we will obviously put the heeling moment because this is the moment phi curve.

First of all, in this you put lambda 0, that is your heeling moment; lambda 0 - you mark that point, let us say this is lambda 0 and you draw a straight line there - I am just going to go step by step on how this is done - lambda 0, you draw a straight line there; similarly, to a lambda 0 you draw a straight line at 1.5 lambda 0, this is 1.5 lambda 0; what we are going to assume is that at lambda 0 we assume the ship….as I told before we are assuming that the ship has heeled 15 degrees into the wind; the reason we are doing this trial and error kind of thing is because we do not know where the initial position of the ship is - it does not have to be upright, we do not know anything about the ship; it is in some initial case so we are assuming it to be in worst possible condition; everything is worst - maximum wind - worst possible conditions; the exact calculations we are not doing it here but we assume that the worst condition is about like this - this is 15 degrees.

The meaning of this is that the ship was initially like this - it is not 0, it is not upright, it is at some point like this; then, wind acts and it caused it to….to be frank, actually the windage area will become A cos phi and all that but that calculation - it does not matter, it is not the exact calculation we are doing here we are doing the maximum values and all; it is initially at 15 degrees the wind acts and then it rotates through 15 degrees; that is the meaning of this term, that is, we assume that the vessel has rolled 15 degrees into the wind; from its initial position it has assumed 15 degrees into the wind as a result of which it comes to this position; this position we know now because we know lambda 0 we know the GZ curve so we know this position we go 15 degrees back - this we assume to be the initial position of the ship; the ship is initially at this position, it heeled and it came to this position because of the wind acting.

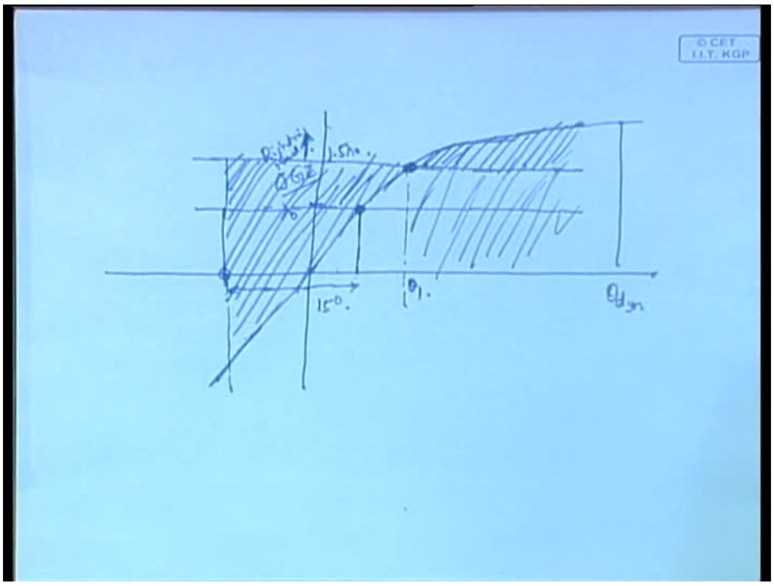
Just for a purpose…no if a wind is acting like ship will act heel only like this…that becomes different case then - it does not matter you look at it from…. in this case, let us see, this is the worst possible condition; let us see what you are saying is that if the ship is initially like this and the wind acts like this what will happen? Which is the worst condition, which is the….is that the worst condition? Well, actually, will that be the worst condition? Actually, there is an analogy - if you have a pendulum hanging upright like this, you give it some force it will move to some distance, that is all right?

If it is like this and you give it the same force it will move a greater distance and if it is like this and you give it some force it will actually move a lesser distance - do you understand what I am saying? When it is here and it is pushed it actually moves a greater distance - same force than if it is given here; but, on the other hand if it is like this and you give it the same force it will move less than the same condition; may be we can think of it in terms of energy that gravitational energy also comes to move it - in this case it is like a gravitational energy that…here it is there is some gravitational energy, in this case there is a change when it comes like this there is a change in gravitational energy, right? Potential energy I am saying, not gravitational energy - it is a potential energy.

Because, that that adds to the adds to this and it causes it to move further - it causes it to heel further; on the other hand, if it is like this it is subtracted - that difference is not there - it is known but the exact reason I hope its correct; you think logically, intuitively if it is like this and if you push it will it go further? (Refer Slide Time: 39:35) Or if it is like this and push it, will is go further? Or if it is like this and you give the same force you are providing, will it go further? The same thing is happening for a ship - it is like trying to think which is the worst condition? If it is like this and you give it a force, will it go more or will it here and give the force will it go more - it is like…. or if it is here you are saying it is like this and you give it a force will it go more; the physics says that if it is like this and give a force more it will go but to really explain it I have to think a little more; because, I think it has to do with the gravitational energy - potential energy - only that difference because that much energy is added to the ship when it is heeling, so to the wind force this additional energy adds.

Whereas, in this case, to the force that additional energy is subtracted; only that much energy is going to do work against the motion; this is actually the worst case, though it goes little bit against your intuition, this is the worst case not this; here, it will go little but in this case it will just go too much; from here it will go all the distance here and more than that - see what I am saying? That is what the physics says - this is the worst condition.

(Refer Slide Time: 41:02)



You assume this to be like this and forces acting, then it goes much further than its goes if it is like this; it goes like this, then it tilts, it goes...we assume that it has titled up to 15 degrees and from here it has titled up to this; what we can do is we are just going to provide a safety factor - there is no logic to it except that it is for safety only; you assume there is… if you assume that x is the amount of energy that the wind has given to the ship - let us give it a safety factor, let us assume that 1.5 x is given, just to make sure that you are within….in case there is some other error somewhere make sure that we have taken care of all that; you make it 1.5 x, that is the meaning of this.

This becomes this point, the graph between….instead of it starting from here….actually it has happened, only this much has happened according to the wind, but we assume that this much of happened and we do our calculations based on that; the ship is now here and it is now heeled by this much degrees - from this 1.5 this is the position of the ship and it has heeled by so much degrees.

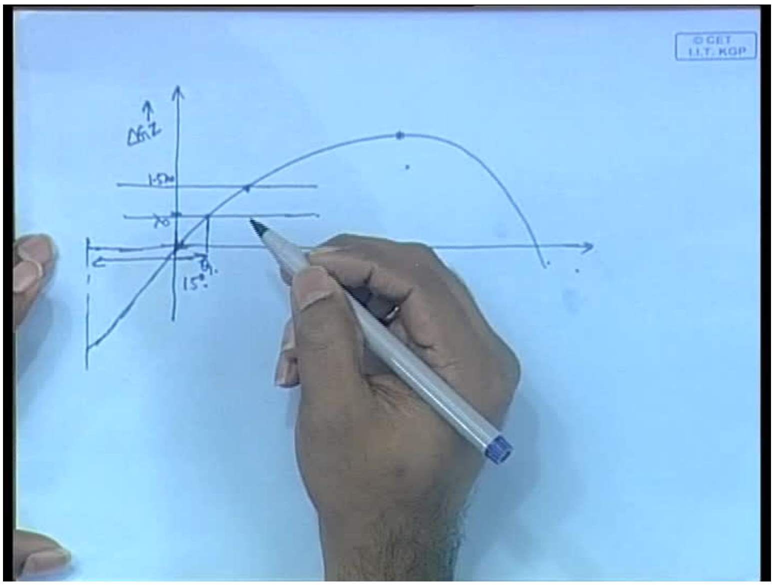
What we are assuming is that the difference in area between this curve and this curve, which is basically this area - this is the difference in area between the two curves is given to the ship; that much area is given to the ship - that much energy is given to the ship because of this; the difference in area, I have told you, the difference in area between the righting arm and the heeling arm or the heeling arm and righting arm will give you the difference in energy between the energy given to the ship and the work done by the ship in righting it; that means, that much energy it has got - excess energy it has got.

Now, what happens? The wind has stopped - once it has reached this point we call this theta 1 - we will call this theta 1 and I think that is what is they have called theta 1; if this is theta 1 from this…. So, this much energy has gone into the ship; what are we assuming? The wind has stopped, but that energy is still with the ship so the ship heels further; because, of that energy excess energy it has got the ship is heeling further.

From here, within this GZ…. and it keeps heeling - what happens? Work is done again by the righting moment; now, wind has stopped, wind is not acting but the ship keeps heeling; righting moment keeps acting because the righting moment is still trying to bring the ship back to its original position; when the work done by this righting moment becomes equal to that excess energy, what does it become? It stops - at that point the ship really stops heeling.

Therefore, what should we do? We should provide an area here which is equal to the area under this area; if you put this area here under the GZ curve that area will become…it is like saying that that energy that has gone into the ship is now used completely for heeling the ship - that is the thing; you keep going till that area is filled up - the whole area, where is the GZ curve starting from - wherever it is starting from, the whole area it goes till some value - theta dynamic, till this area is equal to this area; you have reached theta dynamic and this theta dynamic should be less than some flooding angle.

(Refer Slide Time: 45:08)

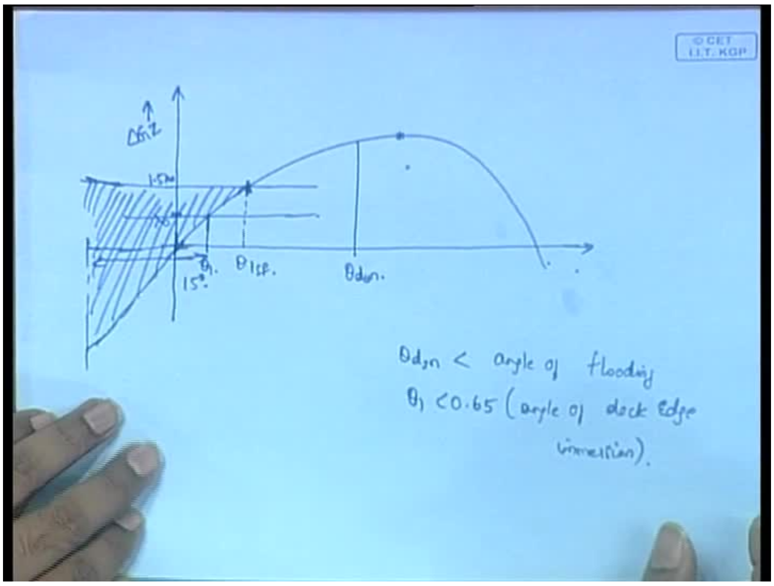


If you want, I can explain this again; it is like this - I think I will do…this is little confusing; initially, you have your GZ curve - let us draw first the delta GZ curve, which is the moment into righting arm; delta GZ - that is the righting moment curve, this is the righting moment curve; in this righting moment curve let us draw the heeling moment first - this is lambda 0, we have already said lambda 0 which is a product of the force wind force into the distance h v plus T by 2 which is the distance between the two force centers that is lambda 0; you mark lambda 0 here and you draw a straight line - its hits here - is this… what angle is this? This is…sorry, this is theta 1, so this is theta 1.

At 1.5 lambda 0 you draw another line - this one 1.5 lambda 0; at 1.5 lambda 0 you are drawing another line this is just a safety factor; what we have assuming is…theta 1, its now at theta 1; as he said there are two ways the….we do not know the initial position of the ship; the ship has…actually, one more reason for that is this theta 1 is the final position of the ship; it will always occur only in the direction of wind - that heeling must have occurred only in the direction of wind - that itself will tell you this is the only direction in which it could have come, I mean, if the wind is acting like this then only it can come to this state otherwise it should have been in this state - it does not make sense, there is no such logic; it is in this state, let us say heeled this much, it is due to a wind acting continuously like this, that means it is like this - it has started from here -it is heeling in the direction of wind always.

At lambda 0, its heel…we assume that because of this wind it has heeled by a maximum of 15 degrees - the exact reason for the 15 degrees is not necessary but assume that it as heeled through 15 degrees; therefore, it has heeled from here - we have to extend this GZ curve - the ship started from here, this was its worst condition and it heeled up to this theta 1 - from here it wind kept blowing and it heeled up to theta 1.

(Refer Slide Time: 48:32)

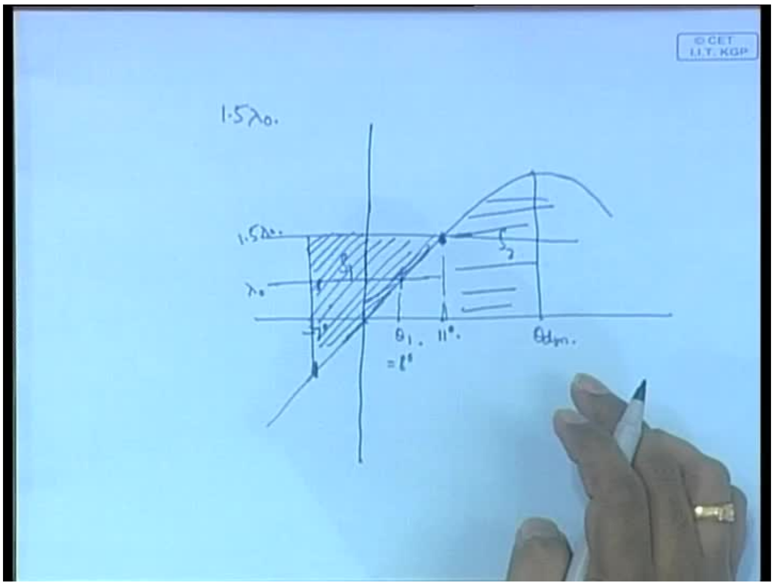


In a way we found theta 1 and then we went back saying that started 15 degrees before; we do not know what is that initial position - that is why they have said assume the ship is in the worst condition, this is the worst condition; it started from there and it went up to theta 1; now, we just give it a safety factor - we make it 1.5 theta 1, just for safety.

This is 1.5 lambda 0 - this is your heeling moment, 1.5 lambda 0 and not lambda 0 - that is the first thing; once you have that…this is the angle where hits GZ, this is like your theta 1 that is with a safety factor - theta 1 with a safety factor that is here; now, you find an area under this curve - under the GZ righting arm curve, under the righting arm heeling arm curve that angle between this is the heeling arm 1.5 lambda 0 and this is the righting arm, so the area under that curve will give you the net amount of energy that is input into the ship because of the wind.

If this ship keeps heeling with this energy it will heel up to an angle of, let us say, theta dynamic, which means that this area is put here; this same area should be extended here and therefore we find the theta dynamic and we say that theta dynamic should be less… these are the two conditions, this I will tell you: theta dynamic should be less than the angle of flooding and this theta 1 which I have drawn here - not theta 1 safety factor - theta 1 itself should be less than 0.65 times the angle of deck edge immersion.

(Refer Slide Time: 50:43)



These are your two conditions, which should be satisfied by the ship finally - this is what we are going to check finally, if it satisfies both of these we say that it has passed the test. Let us do that problem - this is what we are going to do - first we calculate the wind lever - we have calculated, then you calculate lambda 0 which we have done then we do 1.5 lambda 0; first what we have to do is - definitely the first thing you are you are going to do is draw the GZ curve based on the GZ…you are given the GZ table in this case so from that you draw the GZ curve; first you will do this lambda 0 you have already calculated lambda 0 and 1.5 lambda 0 so lambda 0 will come here 1.5 lambda 0 will come here so two lines you are drawing.

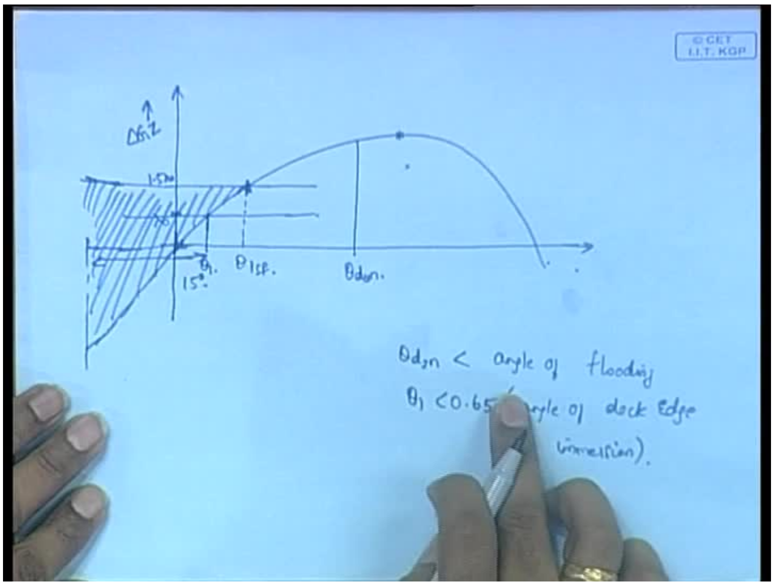
From this point - this is theta 1, this you read from the table it comes to some 8 - I think 8 degrees; that is why I said this problem you have to do it in graph only I do not see any other way of looking at that figure; you will have to draw GZ curve then you put lambda 0 1.5 lambda 0 so you have got theta 1 so you have got your 8 degrees.

Then, you have got your 8 degrees then…so obviously from here 8 plus 7 is 15 degrees - so minus 7 degrees, it has started from minus 7 degrees so we assume that the ship has started heeling from here it has heeled 15 degrees and reached 8 degrees then we do a 1.5 lambda 0 and let us say that it hits here.

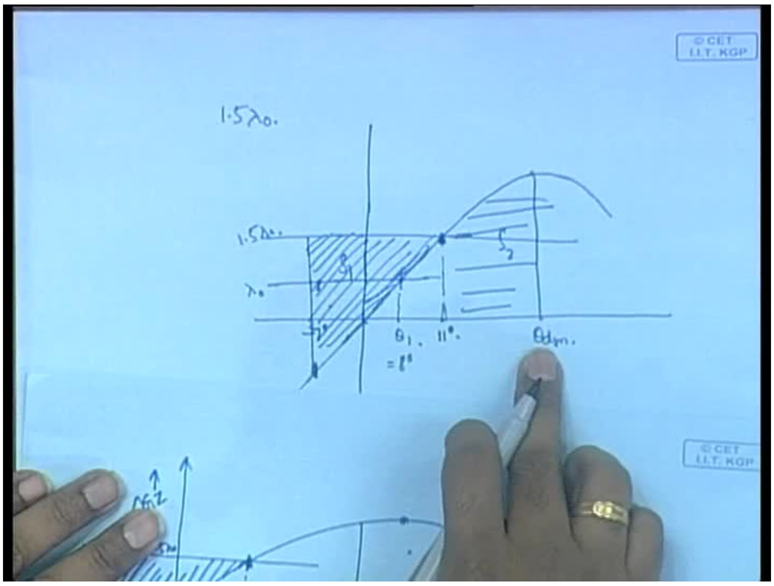
This we have calculated: minus 7 degrees; what should we do? From here, you will see that for this particular problem this becomes about 11 degrees, roughly; for this 18 degrees - that is, the 11 plus 7: 18 degrees we have to find the area under this curve - this area we have to find; this area we find and then starting from here, from this angle, you have to have that area - you have to extend it here, further like this you have to extend that area and you have to find the angle to which you have to go such that this area is S 1 is equal to the area here S 2 - the angle to which you have to go you have to find - that is, theta dynamic.

It is not that easy, because note that we know this area S 1 now how can we find the area? That is actually a trial and error process there is no other way - that is why such a problem I cannot give in the exam except for asking you the method like theoretical question only I will ask no problems it is too difficult; this S 1 it goes to S 2 you have to find that area up to theta dynamic.

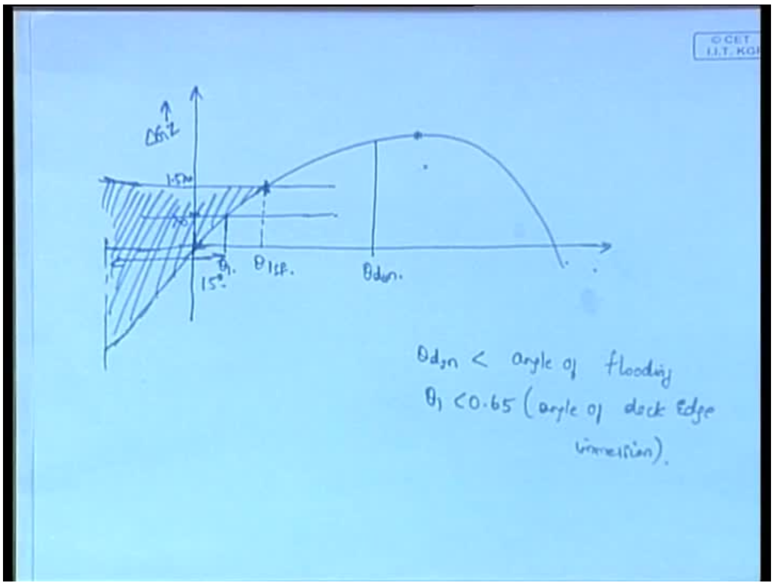
(Refer Slide Time: 54:12)



(Refer Slide Time: 54:22)



(Refer Slide Time: 54:37)



That they have solved and you get some theta dynamic some 27; therefore, you compare finally with….these two checks you have to do: theta dynamic you are given these two things - angle of flooding is given, angle of deck edge immersion is given so you have your theta 1, which is this and you have your theta dynamic, which is this; is theta dynamic less than that? Is theta 1 less than 0.65 times this? These two checks you make and in this case it satisfies both the checks and therefore the ship is stable; it is a very elaborate process, know the method properly, just understand that method properly but I cannot ask any problem on it; just learn the method. That is all, thank you.