Hydrostatics and Stability

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Module No.# 01

Lecture No. # 15

Dynamical Stability – II

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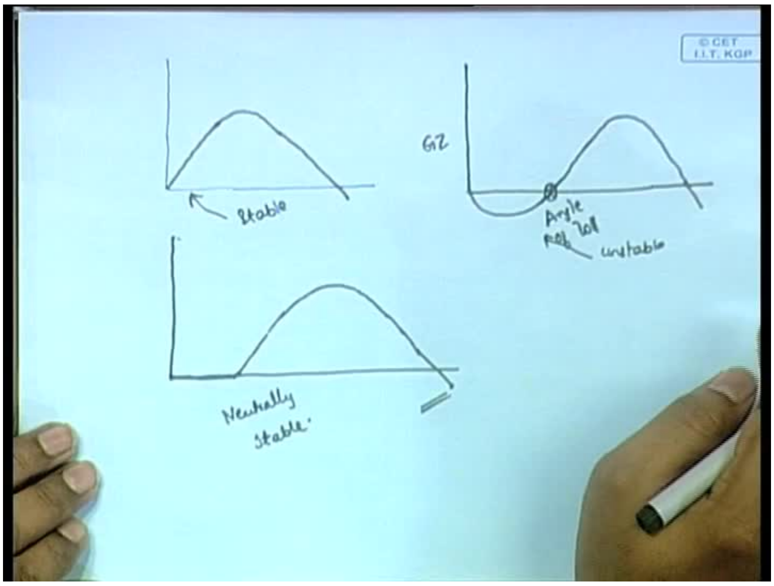

We will now continue with the different types of GZ curves that we mentioned in the last class. First of which was the GZ curve like this, which indicated a kind of unstable equilibrium..

This was the initial kind of GZ curve that we talked about; this indicates a case of stable equilibrium. Then, we mentioned a case of GZ curve like this, which, is indicating lolling. In this region, you are having a region of negative GZ and negative GZ means not a negative righting arm, so it is tending to destabilize the ship. Therefore, the ship keeps rotating and therefore, it reaches this angle known as the angle of loll. It remains at that angle because any further heeling will cause it to come back to that position. The ship, therefore, continues to move at this particular angle - at a heeled angle.

There is some other possibility, that is, a third possibility is when - this is a slightly different case - in this case, it is neither lolling nor is it stable. This is unstable in the initial stages - here. This is stable in all the stages. This is - what we call as - neutrally stable. Therefore, for some when it rotates like this heels through the first few degrees of heel, it does not encounter any righting arm - neither positive nor negative.

What it means is that it is unstable - it remains there. A push like this can push it there, a push like this can push it in this direction; it is in neutral equilibrium - it is neither going that direction or this direction, that is, in between the two.

It is not really angle of loll, but, it is not really stable either - fully stable - therefore, this is the third case of neutral equilibrium. The moment it reaches this angle, from there on, it is stable.

After some angle - just like this - after that angle - from there on, it is the same - it comes back. In this case, it is not really going like this at one angle or anything; it is some small heel has occurred - let us say - then it will heel to that. Let the heel stop, it might remain like that. If it heels further - if the wind keeps coming - it will heel further. If the wind suddenly changes to this direction, it will change like this. It is not either that way going in that direction or in this direction - it is actually unstable; so that is called as neutrally stable - that is the third case you have..

These are the three cases of GZ curves: one is the stable, one is with the angle of loll and the third is neutrally stable. Neutrally stable is not that important in terms of - in very rare cases, do you see it exactly 0 - you see either this or this.

In many cases - if that You can imagine that if the design of the ship is not proper, if your GM, GZ - all those things have not been exactly defined - you will get an angle of loll. It is not nice to see a ship - I mean - always if the ship is like this and not straight; it is not nice to see, first of all. I mean aesthetically speaking itself, it is not nice - it looks very bad. It shows a fault in the design and of course,, it is not comfortable either. I mean if you are slightly inclined all the time, it is not comfortable either - that is a bad design.

These are things that happen and there are ways to change the angle of loll. If you make the angle of loll equal to 0, then you are having this case - stable case; that is what you try to do in such cases. If you find after designing the ship that the ship comes with an angle of loll, you have some methods of making the angle of loll - decreasing the angle of loll to 0 - there are some ways. .

Let us look at some ways that you can change this GZ curve. The first one is - I have already mentioned to you, I think - freeboard. Freeboard means - whatever is under the water we call as draft and the region above the waterline we call as freeboard.

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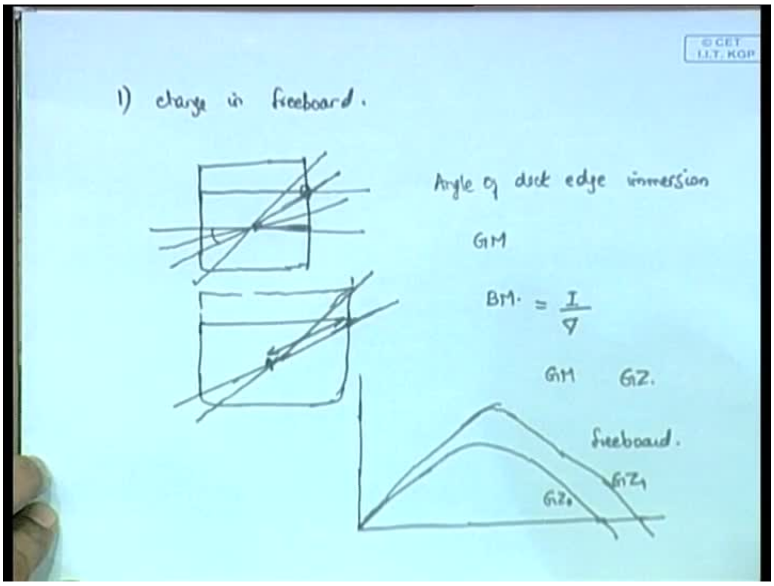

What happens if we change the freeboard? Change in freeboard means – initially, the vessel was like this, now I increase and the waterline is here - so this is your freeboard. I make it this - I stretch it - this is your freeboard. What is the direct implication of an increase in freeboard like this? The first thing is, as you can see, there is - what is known as the angle of deck edge immersion - that I have already told you. Which means some suppose it is keeps heeling like this initially it heels to this now if it heels see this it touches this edge this is the initial let us suppose this is not there the top part I have not added is the old ship in that old ship I have a waterline new waterline which is mean it is immersed or it has heeled very high this much angle it has heeled and this is the water line so it has hit the deck

So, this angle where it has hit - where the waterline hits the deck - the top part of it hits the deck is known as the angle of deck edge immersion. As the name itself suggests, it means that the deck edge, this one, has immersed - it is just come under the water..

First of all, let us see how we can interpret this figure itself. First of all, what is GM? GM is the distance between G and M. Now GM G is fixed, so that means the position of G is fixed and therefore, if GM has to be changed, M has to be changed. How can you change M? This is possible by changing BM. If you change BM, the distance between B and M is changed by changing M.

How is BM changed? BM is equal to I by del. BM is changed by changing I. Let us see - what is I? I is the moment of inertia of the waterplane. This is the moment of inertia of the water plane.

Now first of all, Initially, when it is upright the moment of inertia includes this distance - it is the moment of inertia of this distance - means this water plane area. When it is here, it is the moment of inertia of this water plane, and this is the moment of inertia of this water plane.

You can see this distance is larger than this distance. As it keeps changing the I keeps on changing, when the I keeps on changing the BM keeps on changing, BM keeps on changing it means M is changing and if M is changing it means that GM is also changing - increasing. I is increasing because length is increasing, it is LB cube by 12 so that B is actually changing. When it is like this - it is some B, when it is like this - it is longer B - like that. So, B keeps increasing - B means the breadth keeps increasing, as a result of which the I keeps increasing, as a result of which the M keeps going further up which means the GM keeps increasing. If GM increases, we know that GZ also increases. GZ is equal to GM sine phi; therefore, when GM is increasing your GZ is increasing.

What does it imply? In case you have deck edge immersion - means in case you have a freeboard - here - let us suppose that it is till here - your ship height is till here - the depth of the ship ends here - that means the length can increase only up to this much. When you increase the freeboard - if you increase it further here - it can go like this also - further - more length, it can go even further - that means your GZ curve will keep increasing. When you draw your GZ curve, the maximum value of the GZ curve is more for a ship with a higher freeboard. The range of GZ also increases, means, it goes further and it goes further - like this. The angle of vanishing stability also increases. When it goes higher, it takes more time to come down, as a result of which, this is more and this is more; so your GZ is more - the range is more - it is better. It is definitely better to have a higher freeboard. GZ is more because GM is more..

Let us draw the initial ship - this is the initial ship. Your maximum GZ will come at this point - at deck edge immersion, because after deck edge immersion the physics is slightly different. You no longer have the concept of volumes immersed, same and all that, so the maximum GZ occurs at this point that means, it is associated with this much length – I. It represents the M corresponding to this much length. Now, suppose, it is here - means the freeboard is here - that means it can go upto this - this length is more than this length - that means the GM corresponding to this is more, therefore, the GZ is also more - that means you have maximum GZ.

This means that the curve will become taller and it will become broader. Let us assume that this is your initial GZ - we will call it GZ 0 - this is without the additional freeboard. The moment you add a freeboard, your GZ will increase and so will your maximum - this thing, it will become like this - it will become GZ 1. This is your curve provided you increase your freeboard - this is associated with freeboard..

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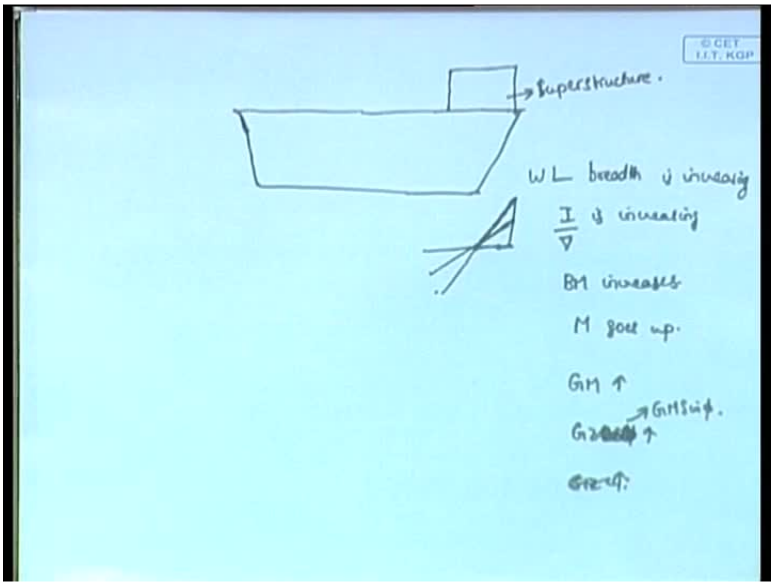

One of the ways in which the freeboard is usually increased is by the addition of super structures. Super structures means in a ship any structure that goes beyond the deck. You have the ship like this - this is known as the deck. Actually, there are couple of decks - they say main deck, queen deck - we are just talking about the main deck – this is known as the main deck. Anything beyond this - if you increase this means I put a structure here - it is known as super structure.

The super structure, as you can see, Because of the super structure, the freeboard has increased - the height is increased. In some cases, you will see that it makes the problem more complicated, because in sometime most cases you do not put the super structure all over the ship means it is not over the whole length of the ship. It becomes In many cases, it is on the forepart of the ship.

In the front part of the ship they have - what is it called - it is called a watch deck or something - that is watch castle or something like that means, where the steering is and all that, where the captain stands - that region they make the super structures in the front of the ship, so he sees outside all the time. In the front part of the ship, they have the super structures and beyond that here - they have these cabins, quarters and all that..

That means the angle of In this region the GZ is increased very much - in this region the GZ is a little - the best way is to take an average GZ over the whole length of the ship, but, at any rate the GZ is increased. The GZ for the ship will be increased, the righting arm will increase because of the presence of super structures and the reason for that is this - I have given here - I mean you just write the steps. The first thing is that your effective breadth is increasing - not breadth - effective breadth means waterline breadth rather.

The waterline breadth is increasing, it means that initially the waterline is like this, then the waterline is like this - there is more length – here there is lesser length - there is lesser length, so effective breadth is increasing, as a result of which, the I is increasing, which means that I by del is increasing, which means that BM increases, which means that M goes up and that means your GM also increases; therefore, GZ sine phi increases or GZ increases that means GZ which is GM sine phi increases - that is enough.

Therefore G As GM increases, GM sine phi is also increasing, therefore, GZ increases. These are the steps that lead to this conclusion. That is why there is an increase in GZ -; there is that and when it goes up the angle of vanishing stability also - it is obviously a better GZ curve.

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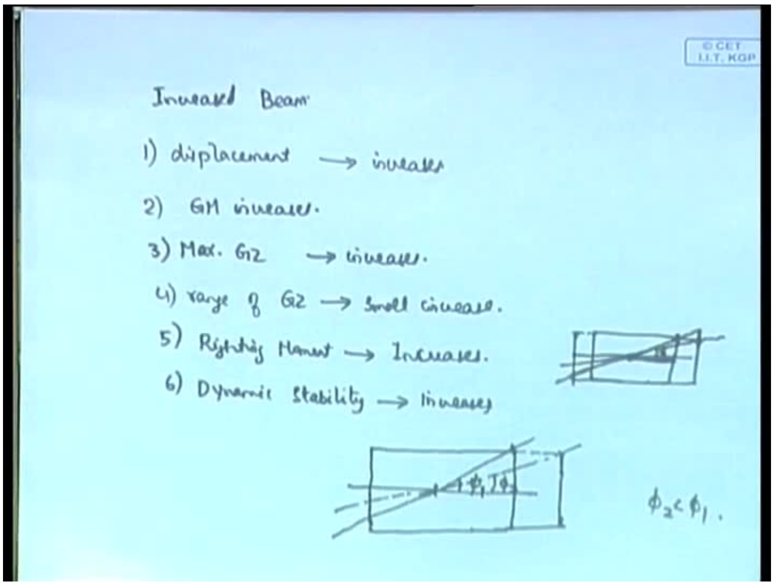

On the whole, when you increase the free freeboard, it becomes a better GZ curve and the ship is more at heel. Then the direct - it is a same thing – Suppose, you increase the breadth of the vessel - beam of the vessel - increased beam – actually, it is better to write like this; I will write step by step what all things will change.

First displacement - in this case, increased beam means it is a the ship is only this much initially - we have made it this much - we have increased the beam of the vessel.

As you can see, the volume under will increase - it is only this much - now it is this much volume, therefore, the volume so this displacement. I will just write one by one what changes - the displacement as obvious increases.

As you can see, when the beam increases - same concept - I increases, all those increases, GM increases - as a result of which maximum GZ is increased.

Similarly, range of GZ - the meaning of it is the extent to which the GZ or from 0 to the angle of vanishing stability that is known as the range of stability or range of GZ - this also - it has a small increase.

When GZ increases, obviously, the righting moment increases. When the right dynamic stability also increases – why? Because dynamic stability is the area under the GZ curve.

We have said that the GZ is becoming higher and the value of maximum stability has increased; therefore, obviously, the area under the curve will be more. The range has also increased, so the area under the curve will be more even if you take - let us say the area under the curve upto 40 degrees, which, we call as dynamic stability at 40 degrees - that much will also be more in case of an increased breadth.

One more thing you can see is - at a particular angle phi, if the initial breadth was this much - the initial thing I have drawn - the first region - the deck edge immersion occurs at some angle. On the other hand, when the breadth is increased, the deck edge immersion is occurring at a lesser angle means - at this angle when the beam is only this much - the deck edge immersion occurs at this phi.

By phi - if this is the increased breadth - it is already in the middle of deck edge immersion; therefore, in this case - somewhere at this point itself - the deck edge immersion occurs; that is, the negative point of this increase in breadth.

All the other things were good with the increase in breadth but, this is the one negative point in which you see that - you understood what I have drawn here that is I can draw it better if you want - that is, suppose, this is the initial breadth. Just by drawing and no other mathematics is involved - just by drawing, you see that at some angle phi - this is the angle of deck edge immersion - this is the deck edge – it has immersed.

All I am going to do is I am going to increase the breadth, so the breadth of the ship is here. If the breadth of the ship is here, then you will see that at a smaller angle itself - here it has heeled through a smaller angle phi 2 - phi 1 and phi 2 - phi 2 is less than phi 1.

Therefore, at a smaller angle of heel itself the deck edge immersion occurs. You can see it from the figure. Even when phi 2 is less than phi 1, the deck edge is immersed if the breadth is larger - that is a negative point of this increase in breadth.

The best way to increase the GZ is to increase the freeboard. Increase the freeboard means you basically make the ship very - what should I - this is tall - you make the ship very tall.

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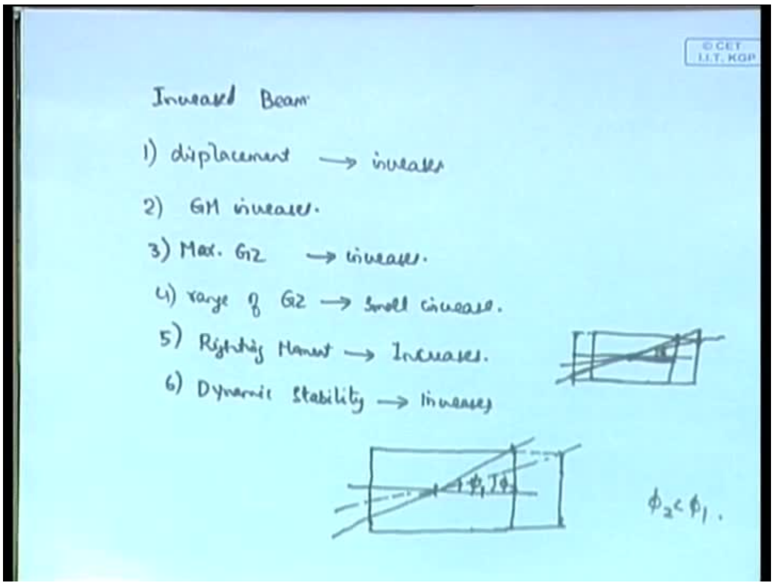

That also is not very good from some other points of view. First of all, this cannot be disproportionate in respect to the length. Actually, there are other features that come here, but, as far as the GZ is concerned if you increase the freeboard, it is better. You will get higher values of GZ that means more righting arm will be produced.

You can actually imagine it - if it is taller, the tendency for it to go like this is lesser - it has a tendency to remain like this. If it is shorter, the tendency for it to roll like this is more; so the best way to make it roll less is to make it very high. You know the other problem - if you keep increasing the GM by increasing the freeboard, the ship will become very stiff - that I have already said before.

If you keep increasing the GM, the time period of oscillation will become very small and as a result the ship will become like this - it would not move like this - it will start moving very fast with very sharp jerks means every second you will see a jerk - you know on the ship. That is not good either, so you cannot keep on increasing the freeboard but, it is a good way to increase the stability..

From the stability point of view yes that is better that is what you are seeing from either the GM GM also means if If you increase the GM, the stability will increase. GZ also says that if you increase the GZ, your stability - the righting arm will increase and your stability will increase. From both points of view, we see that increasing the freeboard is good, but, from other points of view it might be bad.

What are we doing here? We are changing the form means We are changing the form of the ship. First, we change the height of the ship, then we change the breadth of the ship, now the third possibility is to change the length of the ship. These are the different ways how the form effects the GZ or the righting or the stability of the ship.

Now length is actually very much dramatic; there is not much effect of length except as you can imagine there is no effect on GM; GM is not dependent on length in anyway. We are talking about stability in heeling - in trim it becomes different - but, in heeling part there is no effect of L on GM, BM - anything. Actually it depends on B rightB I think L comes.

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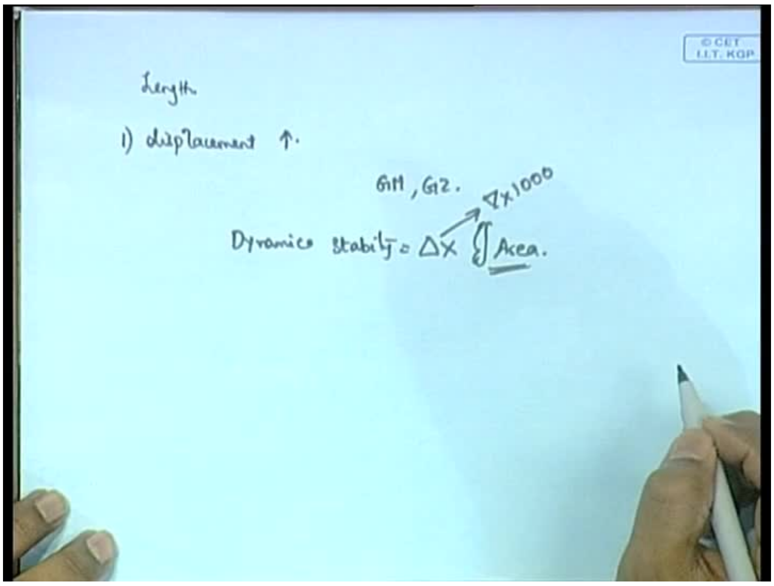

In general - so length - the only thing that will mainly change is the displacement. When you increase the length, obviously, the volume under will increase, because if the length is more, there will be more volume beneath; therefore, the displacement will increase.

There is very less change in either GM or GZ, but, your length increases means your displacement increases; so the only thing that will change is dynamic stability. What is dynamic stability? Dynamic stability is defined as delta into the area under the curve. The area under the GZ curve does not change because GZ is not changing; but, delta is changing because the volume is changing.

What is delta? Delta is equal to del into 1000 - that is volume into density of water. Del is the underwater volume into 1000 - that will give you the weight of the ship.

This is change in curves - the length is increasing, so this is changing and so dynamical stability will change; but, the area under the GZ curve will not change. With an increase in length, the only main change that you need to expect is really in the dynamical stability or in the displacement. Other things like GZ, maximum GZ, GM or the range of stability - none of those things change.

Actually, for this course, in the beginning I said I will mostly be following Adrian Beran's book, but, I have also followed this book to a very large extent. Do you have that other book Adrian Beran or some xerox copy or something? Oh, you have an E book. I think it will be better if you take this book also, because I have taken from both the books equally almost. It is not very different - it has the same concepts; but, these people have got more problems. If you read this you will understand that more - that has good theory, it is the prescribed book in almost all the universities; but, this book is easier to understand and it has more problems. You can solve the problems and you will understand what we are talking about. I think you should take this book from me sometime and xerox it or something - xerox it and give it back, because for the exam I will be asking - problem - things from this; I do not want you not to know things.

We will look at a couple of ways in which we can change GZ. ((no audio from 27:02 to 27:08)) depth of the ship or the freeboard we can change the GZ. There are other ways of changing GZ; the main way is by the shifting of weights. You can shift a weight vertically, as a result of which, the G moves - means - or - what is the way to change GZ? GZ is equal GM sine phi. The way to change GZ is to change GM. You can move M by changing the form or you can move G by changing the something..

How can you move G? You can move G by shifting weights. The way to do that is - shift weights horizontally and vertically - so, two ways that will change your G. As a result of which your GM will change and as a result of which your GZ will change..

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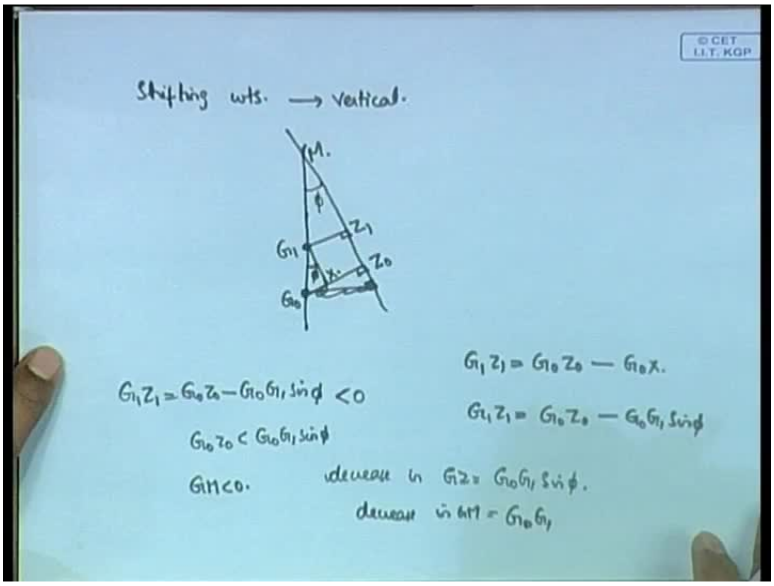

We are going to the next part of changing G - this is by shifting weights. We are talking about a vertical shift. Let us suppose that the ship is initially like this G0 and initially, we have our center of gravity at the point G0. I have now shifted a weight vertically up - some weight in the ship has been shifted vertically up - as a result of which the center of gravity moves to G1. This is your position of GZ 0 means the initial righting arm and GZ 1 is your final righting arm.

As you can see, the initial GZ 0 will be reduced by an amount GX and it will become GZ 1G1Z1 or G1Z1 is equal to G0Z0 minus G0X; G1Z1 is equal to G0Z0 minus G0Z1 sine phi - G1- this is obviously coming from the geometry. - G1 - so The ship is heeled through an angle phi. If this is phi means, this is phi - if the ship is heeled through phi - this will also be phi - just it is the same parallel line. So, G1Z1 will be G0Z0 minus G0G1 sine phi, that is G1Z1therefore, the decrease in GZ is equal to G0G1 sine phi; this is the first one - this is the first concept.

In the second case - when your weight is shifted vertically down that means you are pushing the weight down, your G1 will come below - as a result, the equation will become G1Z1 equals G0Z0 plus G0X plus G0G1 sine phi - it is just the same thing. Actually, they have done for the plus. When the center of gravity is lowered, GZ is reduced by G0G1 sine phi - this is the thing - decrease in GZ is G0G1 sine phi.

What is the decrease in GM? It is G0 G1; because, GM sine phi is equal to GZ. I just put it here, sine phi is cancelled on both sides; so the decrease in GM is G 0 G 1 and the decrease in GZ is equal to G0 G1 sine phi. In case the G0 G1 sine phi becomes greater than G0 Z0 - it is decreased - now you have initial G0Z0.

In case G0 Z0 is less than G0 G1 sine phi means G1 Z1 has become negative - what is the meaning of it? M - that is the meaning - it means that G has gone above M; it means it has GM less than 0 - that is the meaning of it - that is what.

If G1Z1 - I will repeat it if you want - if G1 Z1 is equal to G0 Z0 minus G0 G1 sine phi is less than 0, it means that at that point G0 Z0 is less than G0 G1 sine phi and it implies that GM is now less than 0; it means that the ship has become unstable in that state - GM less than 0.

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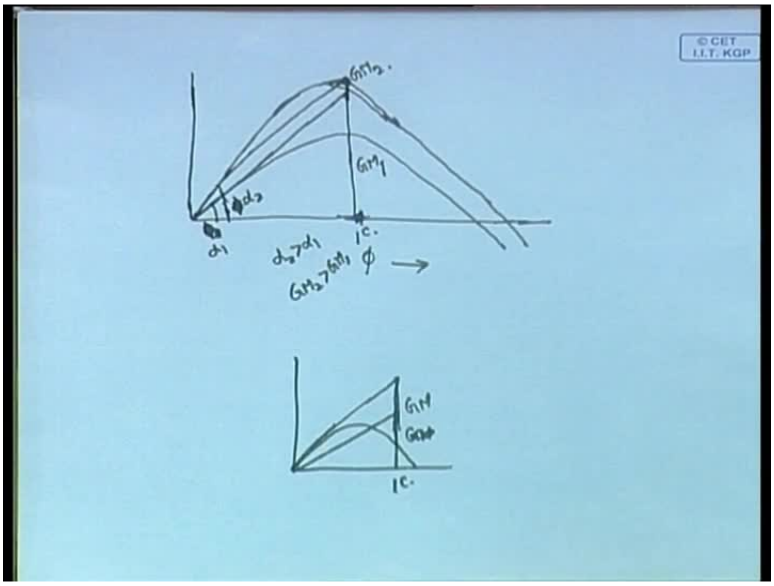

Your figure - if you are drawing the GZ curve, it will become like this: different angles of heel phi, then your initial GZ curve - in this case, when GZ is increased is when the G comes below - if the G is shifted below - we consider the case when G is shifted below that means the weight has been shifted down. When G has come down that means your GM has increased, in that case, this will become like this.

You can imagine when your GM has increased - what does it mean? The moment you say that your GM has increased that means - the slope of - means GM is what? When you draw a tangent here, this line at 1 radian becomes the GM; therefore, if your GM is more - GM is here, let us say - that means this slope is more. If the curve was initially starting like this that means it is now starting like this.

Initially, the curve is like this; the moment the GM has increased, the curve has started here, so it is going up that means the chances of it maximum GZ has increased. Is it clear or should I say that again? What I am saying is that if this is your GM, let us say, this is 1 radian; so at this 1 radian, if I draw a tangent here - so this is at 1 radian - at this point you get GM.

When I moved that G down - M is still there - when I move the G down that means your GM has increased, as a result of which - what am I saying - GM has increased which means that this length here it is actually here like this, let us say at 1 radian GM is here GM 2; this is GM 1 and this is GM 2. Here, I have pushed a weight down, as a result of which, GM has increased. If GM has increased - if it has to hit here that means this curve should be sloping upwards more than this; it is obvious, otherwise, I cannot draw a line; that is, it is a straight line and I cannot draw it. If I am drawing it straight, this angle should be less than this angle - obviously.

The moment I say that your GM has increased that means; your GZ curve is starting out in a higher slope. All that you say I am saying is initially Initially, if this is phi 1 this is phi it is not phi it is alpha, alpha1, this is alpha 2; alpha 2 has to be greater than alpha 1 if GM 2 is greater than GM 1- that is all I am saying.

It is obvious from that otherwise, you cannot draw a straight line there and hit it at the GM 2 at the same 1 radian. If GM 2 is greater than GM 1, alpha 2 is greater than alpha 1; which means that the new GZ curve is increasing at a higher slope - it is increasing here - in the original case it was increasing like this.

So that is very important, when you why I am saying it is it is important - when you draw the GZ means – suppose, I ask this question related to - There are a couple of points that I will check when you are doing this; I mean, when - if you are asked to draw the GZ curve, in that case, two points are very important.

First is that - I should see that at 1 radian you are drawing - this 1 radian should be marked; otherwise, you will not know what the angle is. It should be written as either 57.3 degrees or 1 radian.

You have that marked and you should have a vertical line there, because then only the GM is drawn. You know what is the GM, you have the initial GM and you have the final GM. This initial and final GM – that is very important; those two points should be marked clearly and both the GM should be joined with the origin. At this origin, it should show that this GZ curve is starting at that slope. If you draw 1 GZ curve like this and you draw a GM like this at 1 radian - this is completely wrong.

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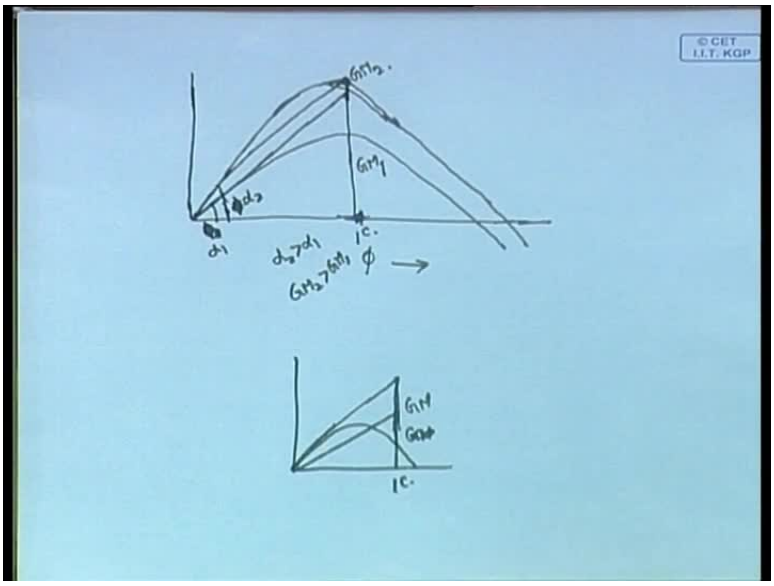

It is not just about drawing a straight line here – that is not the point. You draw a straight line at 1 radian - it should be like this - it should be tangent to that straight line. This is your GM - not this - this is your GM; so it should be clear. Do not draw it like that - that tangent should come as a tangent; it should look like that in the figure itself.

That is the meaning of - That is one way what happens when you are shifting your weights up or down. Now, another possibility is - so, Obviously, if you shift your weight down the ship will become more stable and if you shift your weight up the ship will become less stable.

The next possibility is to shift your weight horizontally. Let us see what will happen as a result of that.(39:09) (( ))It does not have to be the same phi. If you look at this figure - if it has to be the same phi - (( ))deck edge immersion will occur at the same phi. Yes, but, that is not the only criterion that decides the maximum GZ. Deck edge criterion will definitely indicate - if deck edge immerses then the GZ starts decreasing - that is true but, that is not the only criterion. That means see what are the other pointsactually it has to one of things is thatnothing comes to me right now I will have to think that is but, it is not the only criterion

Sometimes you will see GZ. In this case, it does not have to be exactly at the same phi; maximum GZ will sometimes be before also. I will have to think now why it should be(40:11) (( ))that is one way of thinking of it but, you are sinking more weight has come there that is true in that is one way of shifting/ changing G.

What I was trying to explain by increasing the super structure there was just that the freeboard is increased. Two things happen actually when you increase - when you put a super structure - you increase the freeboard and you increase the weight upstairs which means that in the up region - which means that you are shifting the G up.

When I was doing the previous derivation, I did not consider the shifting of weights; I just considered the increase in freeboard.Yes you are right. You have to consider that increase in weight also; increase in weight will be there, as a result of which, the G will shift up. That is true; that is a good point.

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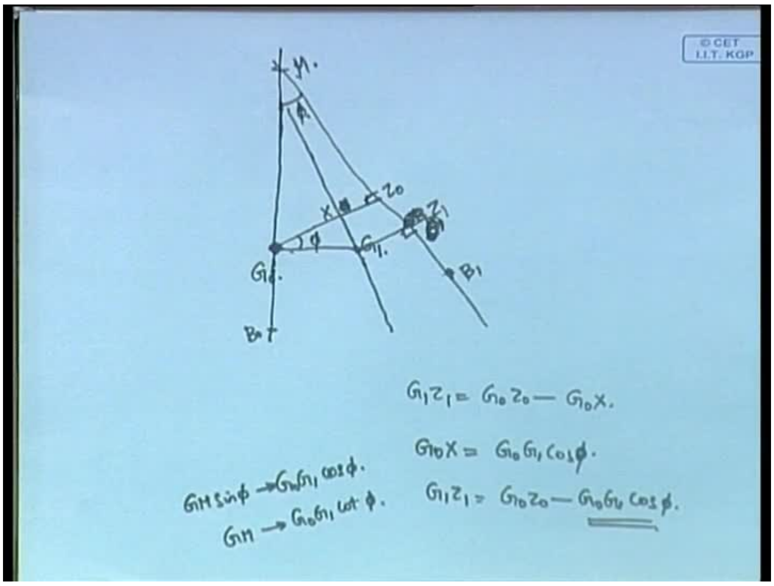

The next one is in case you have a horizontal shift of weights. You have your initial G0 - this is your G0. Now, there is a weight shifted horizontally, as a result of which, this is G1. The G has shifted horizontally and let us say this is the position of your center of buoyancy B1; initially your B0 is here.

I have shifted the G and I have shifted a weight horizontally which means that the G of the ship has shifted horizontally only. And B has shifted. Because the ship has heeled, the B has shifted. At B, you draw a - this is at B - This is B1; or this is B1 now there I draw the vertical, this becomes the metacenter M.

From here, I draw from G to this – G to Z; so you have two distances here. This is B phi; if this is phi, it is heeled through an angle phi. The angles should be clear - what those angles indicate are - this is 90 degrees - this is GZ 0 - this is GZ 1.

Let me explain the figure again. This is your initial position - in the upright position - you have G0B0. Now, G has been shifted horizontally and G0 has gone to G1 - that is now your position of center of gravity. Now, the ship has heeled through an angle phi and it is like this - this is your new position of B1 and where B1 hits the original line you have the metacenter; so, this angle is phi - this is just the position of G.

If you draw from G0 to this vertical, you get GZ0. If you draw from G1 to Z1 vertical, you get G1 Z1. You will see that G1 Z1 will become G 0 Z 0 minus G0X - let us call this

X - G0 Z0 minus G0X. Therefore, G0 X you can see from geometry is G0 G1 cos theta cos phi not theta, cos phi.

Therefore, G1 Z1 is equal to G0 Z0 minus G0 G1 cos phi; in fact, that is all. This is your new position, This is the amount by which your GZ has changed. GZ has changed by G0 G1 cos phi and your GM has changed by - which means GM sine phi has changed by - G0 G1 cos phi. That means your GM has changed by G0 G1 cot phi. So, your GM changes by G0 G1 cot phi and your GZ changes by G0 G1 cos phi.

(44:56)(())so obvious no from that figure (( )) this angle this angle is 90 degree means oh in this is you are saying right will it be 90 degrees we will see wait G1 is your position of center of gravity is the line joining G1 and that will be a vertical line remember that figure is G 0 G 1 is horizontal alright but, it is the line joining(( ))G1 no it cannot be that means it has to be parallel that is let us see.

Now G 1 Z 1 is a line that is we can think of it like that G 1 Z 1 is a line that is perpendicular to this so it is perpendicular to this if you make this as a line perpendicular to that also it will become parallel to that

So this is true only as you said if G1 this line is parallel to that GZ 0 I guess it should be parallel but, I am trying to see why notice that line actually G1 it is the perpendicular distance between G and ZI have to think about this this also it is parallel as we said it is parallel

But what exactly G1 is the position of the center of gravity and Z is perpendicular it is the distance between G and ZI have to read this let us seethenso what do we have GM then

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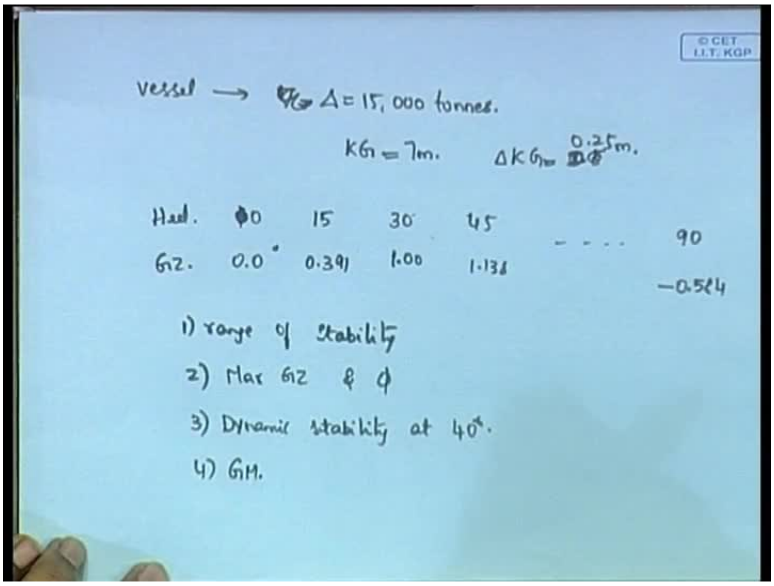

Let us do couple of problems. That is it is very simple only but, we will do it so you You are told that there is a vessel which has a displacement of delta of 15000 tonnes. Actually that is an advantage of this book; if you can solve the problems in this book that means you have understood it, because the problems are designed like that - very good problems. If you remember some of the problem that I have discussed sometime back; different problems related to drawing the table, and G you know finding I, and all Simpson's multiplier and all that - all those things are from this book. It does a lot of problems very nicely; I think you should definitely take this book.

So, you have a vessel that has a displacement of 15000 tonnes. It has a KG of 7 meters and cargo is now put on the ship, such that, KG is changed - it moves upwards by 0.25 meters - KG moves upwards by 0.25 meters.

You are given the GZ curve; you might be given the GZ curve like this - this is how they usually give it as a table - like this. It will keep going till probably at 90 degrees minus 0.584.

Now, this is how they have given your GZ curve. One thing is that for this exam - I will give you - but, you have to have a graph sheet; there is no other way you can draw a GZ curve. You will have to draw GZ curve in some problems. The importance of a graph sheet is that when you have such a GZ curve you might have a value of GZ from which you have to find a heel or you might have a value of heel from which you have to find the GZ. Let us say 35 degrees, I ask you not ask you like that but, when you are doing the problem, you will see you will have to read from 35 degrees you will have to read the value of GZ - that means you need a graph sheet.

You have to plot - This table will be given, you make the table, you plot the graph and of course,, free hand only. Just plot a rough figure and then, from that figure you will have to read for the different values of GZ - that you will see. It is important that you will be given the graph sheet and we have to do that; Graph sheet will be given but, be prepared to do that.

In this problem, you are asked what is the range of stability; these are the kind of questions you will have - range of stability, then maximum GZ and the phi at which it occurs - so, you are asked what is the maximum GZ and the angle at which it occurs. Then, you are asked the dynamic stability at 40 degree; the meaning of this term dynamic stability at 40 degree is that you have to find the area of the curve from 0 to 40 degrees - area of the delta into GZ is dynamic stability not just GZ area. So, delta into area of the GZ curve has to be found upto 40 degrees - that is the thing and you are asked what is your estimate of GM. These four questions you have to do.

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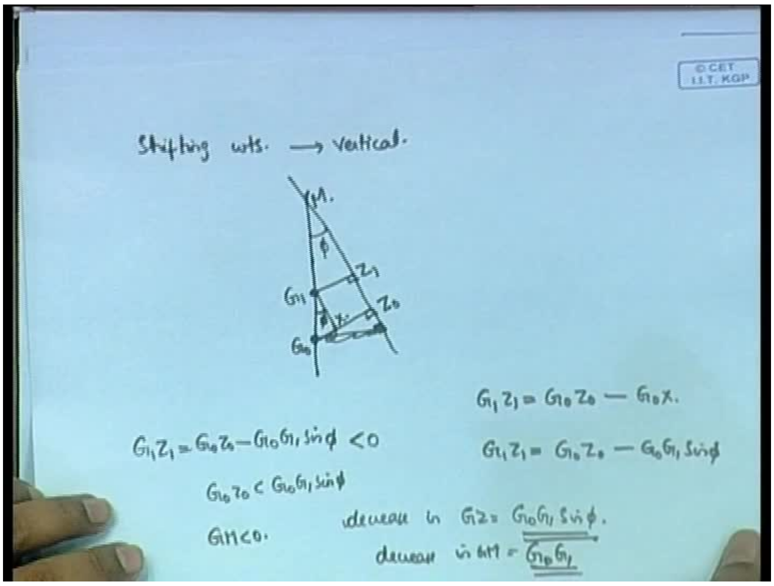

Let us see how this is to be done. We will just use this formula - that is - for shifting the weights. When you have a vertical shifting of weights, we have to find out what is the change in GZ. We have talked about the decrease in GM and all that; so this formula we want. So, decrease in GZ is G0 G1 sine phi and G0 G1 they have asked G0 G1 sine phi.

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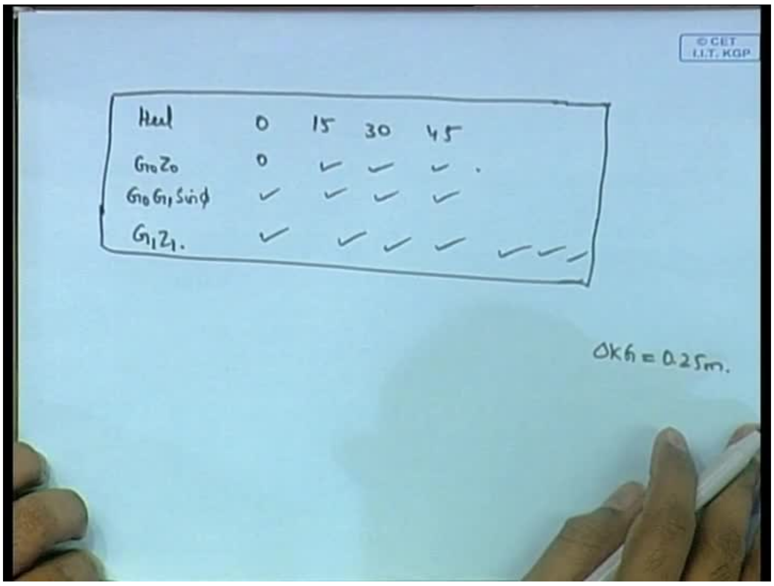

We need to make a table like this. You draw heel 0; 15; 30; 45; now, G0 Z0 is the direct value you are reading from the table - this is given whatever it was. Then, how will you find G0 G1? G0 G1 is the shift in the center of gravity. You are given in the problem where is the problem I do not know where I kept it. At any rate, you are told that delta KG - the rise in KG was 0.25 meters - this was given in the problem; that is your G0 G1.

Now, you need to find G 0 G1 sine phi. If you remember the formula - this is what we want - G0 G1 sine phi. All you do is - that value of G0 G1, the delta KG - you multiply by sine of these heel angles; so you make this table. Then G1 Z 1 - in this case, it is an increase in G, which means that GZ is decreased. Do this - G0 Z0 minus G0 G1 sine phi will give you G1 Z1; this will give your new values of GZ.

I will stop here. We will continue this in next class.

Thank You.