Hydrostatics and Stability

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Module No.# 01

Lecture No.# 14

Dynamical Stability - I

Last class we mentioned about the motion of the Meta center; we called it as m curve and how the meta center moves along with the heeling. Now, note that in general, we assume one thing; in case of all this heeling that is, we assumed that the displacement del is always remaining constant. This is an assumption that we make in the development of all our mathematic theories. The meaning of del remaining constant is that when it tilts like this, whatever is going in is equal to whatever is coming out.

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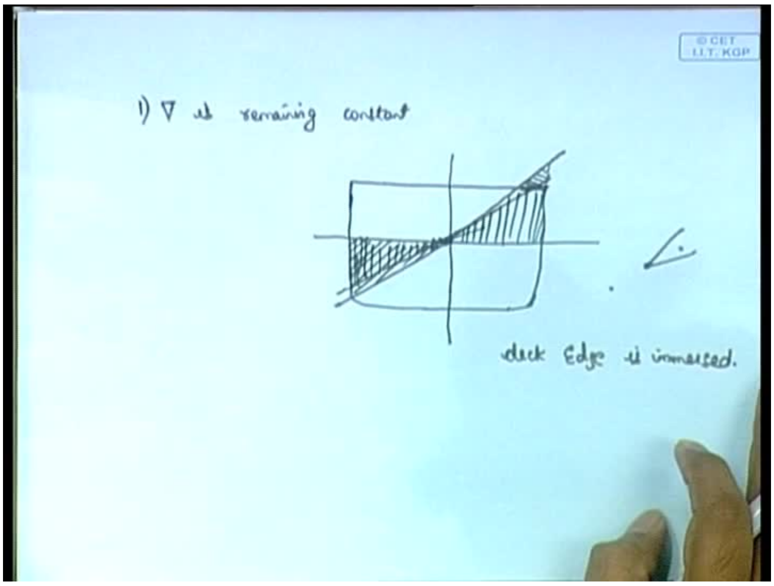

Now, when this can be violated? Let us look at a case when this concept can be violated; it will happen, if suppose the ship is like this, the full breadth is like this. Now, this is known as the deck; that is the region at the top, is known as deck. Suppose, initially the water lines is like this and now, suppose the ship heels like this much (Refer Slide Time: 01:14).

Now, it heels so much that the deck as actually immersed. It is actually called the case of deck edge immersion or the deck edge - not the whole deck - of course, the deck edge is immersed. So, this is the deck edge, this region is now immersed in the water. In this case, we will see that the volume that has submerged is this and the volume that has emerged is this (Refer Slide Time: 02:08).

Now, you will see that a little bit of volume here has been left; we put it in the opposite direction. A little bit of volume has been lost there, if the deck was up to this then we have no problem but, since the deck ended before that you have a slight problem that is, this much volume is lost.

There is a difference in volume between the side immersed and the side emerged. This is the side immersed and this is the side emerged - more volume is emerged whereas, less volume has gone in because this volume is actually air or when it goes in it becomes water, this is not the ship, so that much volume is lost. So, what do we have? We have the volume immersed not equal to the volume submerged.

Now, this is what happens in actual practice; it can happen in actual practice in some geometries of the hull - some types of hull - where the depth is not too much; when the depth is not too much such a thing can happen.

Now, there are different ways of approaching such a problem you have to obviously see some method of doing it. That is in general, the problem is more complicated but, we try to reduce it to a simpler case by making some assumptions. Now, how can we make the volumes equal? Means, the volume submerged and the volume emerged equal.

Now this can be done, suppose I assume that it is heeling about not this point but, heeling about some point here, then it becomes like this (Refer Slide Time: 03:56). Now, what has happened? We had this volume greater than this volume, because of this volume is now reduced a bit. It is only this much this volume is out, this volume is not emerged now, whereas there is a decrease in volume here. Now, this decrease in volume will imply and here, see this intersection of this line and this line is here therefore, this volume actually starts from here means, it opens out like this from that point.

Therefore, we have an increase on volume on this side and decrease in volume on this side and we can keep moving that point such that we will have emerged volume submerged equal. Now, this is the mathematical method we used to make sure that the volume emerged is equal to volume submerged, so that the mathematics does not get too complicated but, in real practice it does not have to be like that the ship might heel about any point and therefore, the problem is little more difficult.

Later, when we come to the end of the course we will specifically address this problem. Right now, I am just mentioning the problem as such and the method of solution, but we will do this later in the last part of the course.

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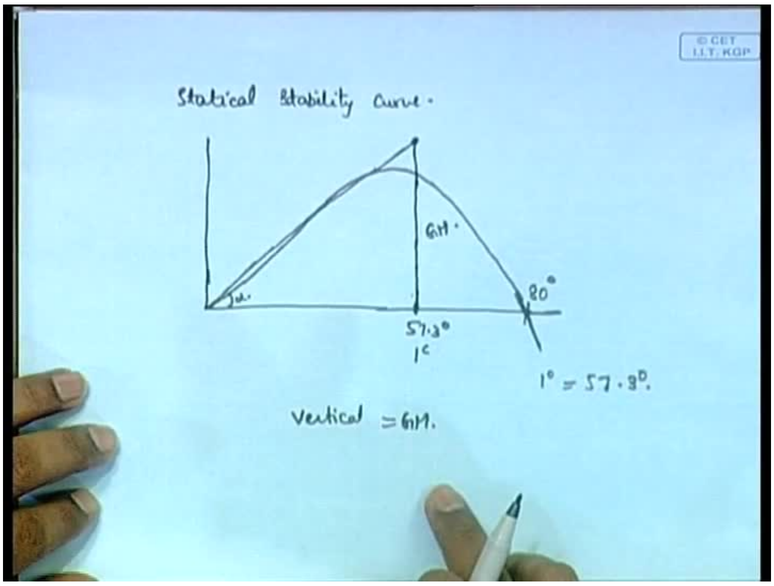

Now, I have already mentioned to you what we called as the statical stability curve or the curve statical stability. So, this goes up and comes down like this; this time it is at 80 degrees in this figure. I have already told you that at an angle of 1 radian and you should also know that 1 radian is equal to 57.3 degrees conversion from radians to degrees. At around 57 degrees that is at 57.3 degrees if you draw a line vertical and at that point somewhere here (Refer Slide Time: 06:30).

Here, if I draw a tangent, if the point at which they intersect is this. This height will be equal to GM, this much we derived in the last class. So, this is alpha and we showed one method of showing that this vertical equals GM and it is the vertical at an angle of 57.3 degrees, which is equal to 1 radian. Then, there is a slightly easier and simpler way of deriving - last time we did using a differential form, we differentiated by parts and we got a value that this vertical value is equal to GM.

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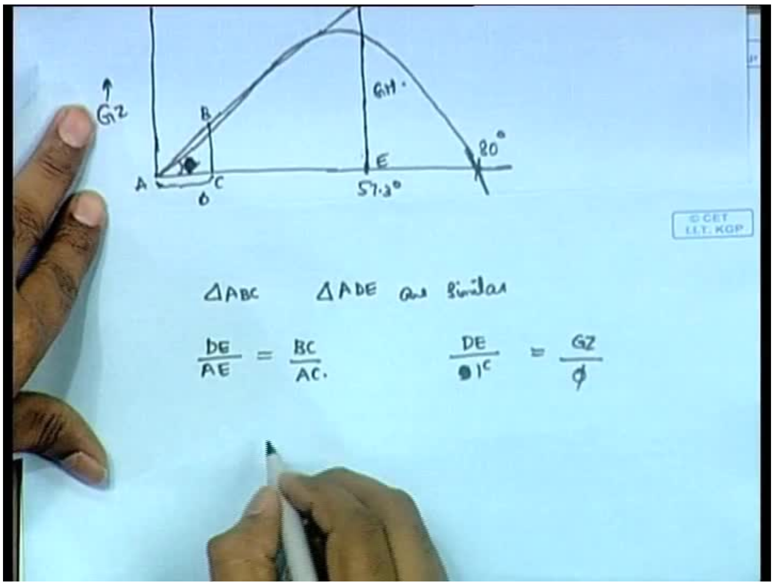

Now, we can use another method, suppose we have this figure, let us take any angle - this time I will call it phi - let us suppose, we have any angle phi and I draw a vertical at some point, where this angle - I would not mention sorry- this is phi. Remember this statical stability curve is a graph between phi the heel angle and GZ. This is the statical stability curve - it is a curve between the heel angle phi and the GZ. Now, at any phi - to get an expression we are doing, at any phi - I draw a vertical, so these things I mention as A I mark as A, B and C, D and E.

Now, directly we can see that the triangle ABC and the triangle ADE are similar; that you can directly see in the figure. It is the same angle, it is made from same and all three angles are same, so it is the similar triangles.

Therefore, DE divided by AE equals BC divided by AC. Now, we have this therefore, DE divided by, what is AE?AE is 57.3 degrees or it is equal to 1 radian equals BC divided by BC is GZ at that particular value of theta, is it clear? BC is the vertical, the vertical distance always represents GZ because that co-ordinate is GZ, so this is GZ and this is phi. At any value this represents the value of GZ at this value of phi, so phi is changing from 0 to 57.3 to 80, phi is changing like this and consequently GZ is changing from 0 to whatever is the value at each thing is changing.

Now, at the value of phi you have value GZ therefore, the BC represents GZ at the value of phi divided by AC; AC is phi, let us call it in radians. B is not on the curve, B is on the line, B is on the line then how GZ enter BC, why should it represent GZ?

Actually, it is a good question, the reason is according to the figure what they have written here is that BC, this is the beginning. So, this derivation is actually true when the separation between this curve and the line is not very much that is their explanation.

So, BC is almost equal to GZ, it is not equal that is correct, it is not equal to GZ; BC if it is on the line it will be equal to slightly different then GZ. So, this is their assumptions, so this is equal to GZ by phi.

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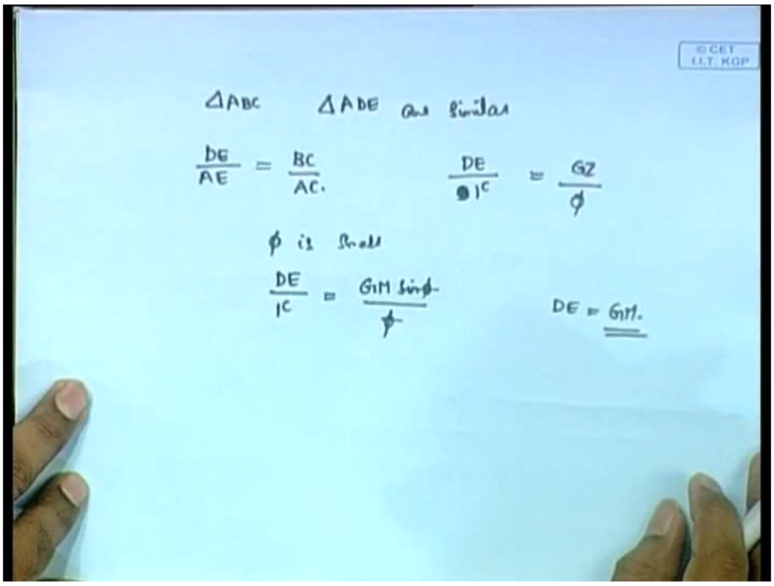

This in a way it is not really correct but, it says that phi is small and then, in the next we are actually going from phi equal to 0 to in fact 57.3; we are extending it. There is a problem in this, but this is what this book does. So, phi is small then therefore, DE divided by a is 1 radian is equal to GZ - I write it as GM sine phi divided by phi. Again, the concept comes phi is small. If you assumed that phi is small then sine phi is equal to phi. Therefore, sine phi and phi you cancel out. Therefore, DE becomes equal to GM alright? You see this derivation.

This derivation is not very convincing actually, from the fact that you are assuming first phi to be small, then phi to be large means in the case when, you are extending to the region GM it is actually phi equal to 57.3 there you really cannot assume that phi is small and that sine phi is equal to phi.

That derivation has problem but, if you remember the previous derivation that is actually correct, so it is just differential that was the correct derivation, so it is ok. This is simpler way of deriving it but, you will get the expression that DE is equal to GM that is we are getting that DE is equal to GM.

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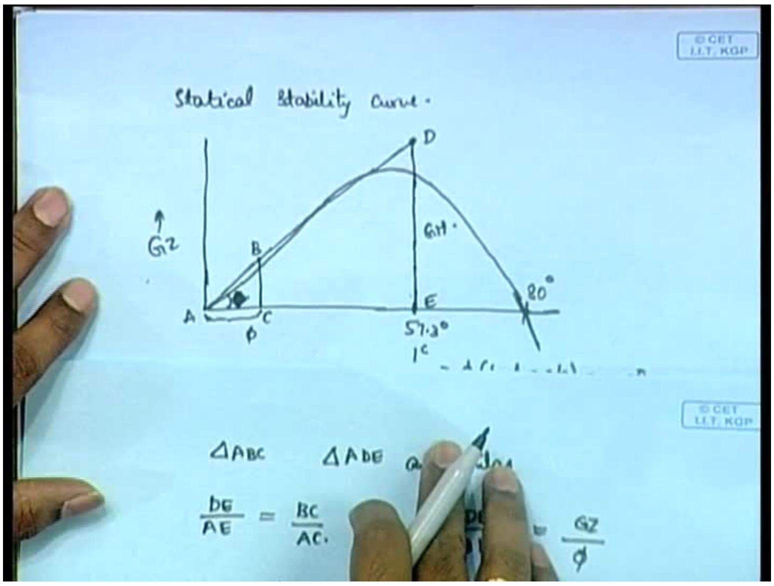

This is the derivation therefore, what we are saying is that at a point of 57.3 degrees, if you draw a vertical and if you take a distance GM you measure the distance GM there. From GM if you draw a line connecting to the origin, you will get the tangent to the curve at that origin, same thing which in a slightly simpler format it is done.

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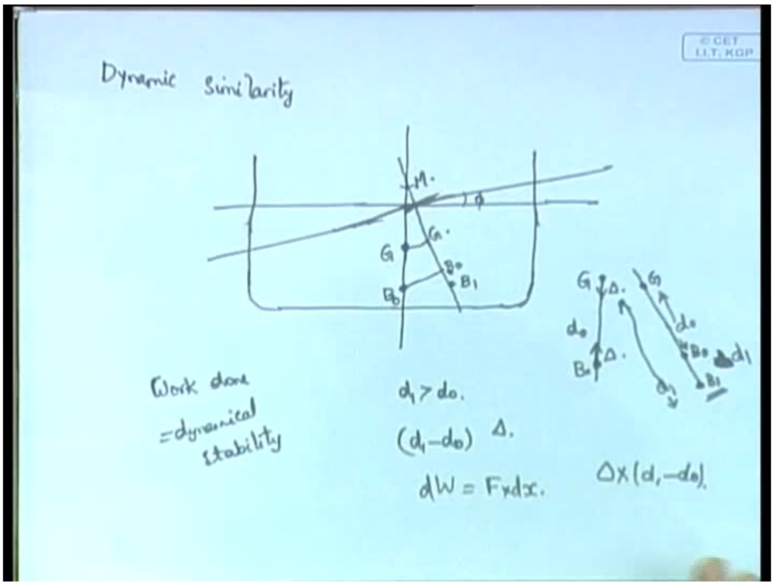

Now, we come to a new concept that we call as dynamic similarity. If the power goes there is no problem with this. Now, we come to the concept of dynamic similarity. That is, this is again about the concept of stability and when the ship becomes neutrally stable but, it is approached in a different way that we will see what it is.

That is first of all; assume there is a cross section like this. Now, this is G, this is B0 and now the ship heels by an angle phi and this is gone to some point here, I will call it here, B1 and here I draw vertical and same way (Refer Slide Time: 15:04). Now, draw a vertical here and this is the Meta center M. Look at this way, here we have the weight delta acting - I will just draw this figure, this line therefore, this is G and this is B0. So, at GI have a value of delta acting down and at B0 I have a value delta acting up. So, these two weights are acting like this; two forces are acting like this.

Now, what happen? It has moved into a new point into a new shape here. Now, suppose I do this with M as center, I draw this GM as the distance and I draw an arc like this, so this will be the point of G. Note that GM has not changed, G is not changed, because the weights has not been removed or shifted so G has not changed.

Now, if you take this B0 means I am taking this B0M initially and I am moving this distance and I am drawing an arc in the same fashion as I do this. In the new line B0 will be here and this is B1 actually, the new position of your center of buoyancy, is it clear? Between these I have drawn here. All I have done is, I have taken the distance B0M and with M as the center I have drawn an arc with B0M as radius and B0 touching here, so B0 will be here B1 is here.

Now what we see? So, this here we have B0, here we have B1 and here you have G. Let us suppose that the initial distance between G and B is D0 and this distance is therefore, D0 this distance (Refer Slide Time: 17:38). Now, what has happened? Because of the heeling the center of buoyancy has shifted to this point B1. In this book they have written actually they have taken it as bold D0 it is look it cannot I cannot do it is I called it as D1. So, this distance is D1 between G and the new of position of B, the distance is D1.

Now, what has happened? A force delta, which acted at B0, has now moved from this position to this position. It has moved by a distance of D1 minus D0. So, D1 will be greater than D0 and D1 minus D0 a weight delta has moved. The weight delta has moved at a distance D1 minus D0. What is the work done in moving this? A force into work done in moving it is force into distance moved. F x is the work done that work done is equal to F into the distance through which it moves F dx, dW is equal to F dx, this is the concept of work done.

Therefore, because of this movement in the center of buoyancy work equal to delta into D1 minus D0 has been performed. That means because of this heeling that is the final conclusion, because of the heeling of the ship a work equal to delta into D1 minus D0 has been performed. That much work is performed and the work done is known as dynamical stability. So, dynamical stability is equal to work done or it is the energy required. You can say that is the energy required to heel the ship.

It is the amount of work done, so you can say that is the amount of energy required to heel the ship, so that energy or the work done amount, amount of work done is known as dynamical stability. So, dynamical stability and you can call it a dynamical stability arm that is not done so much but, the thing is dynamical stability is the word used to represent to the work done to heel the ship that is dynamical stability.

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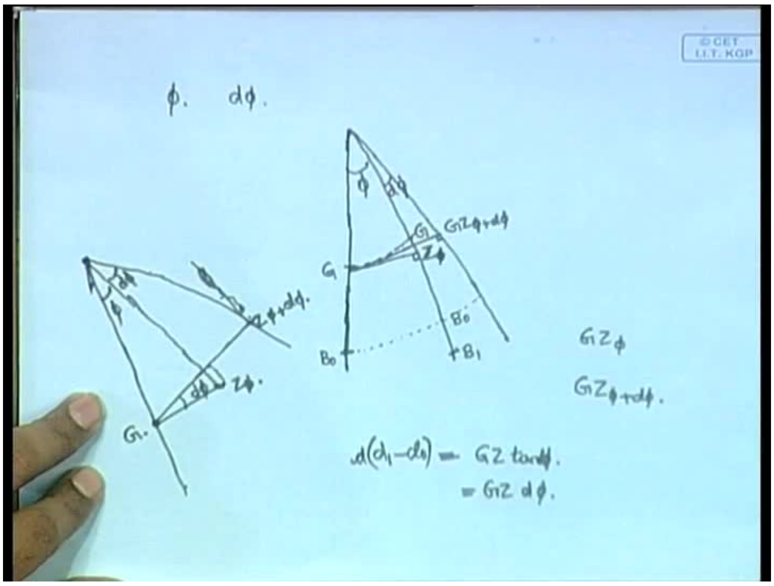

Now, if this is clear, we will do little bit of derivation. Suppose that the ship heels through an angle phi or theta; if the ship heels through an angle phi, it heels a little bit. Now, we assume one additional thing, it heels by a small additional amount further by d phi. Initially, it is heeled at an angle phi and now it heels by an amount, so this is the initial position actually this can only be seen in figures. So, this is initially heeled by an angle phi, this is the initial upright position, you have G here and you have B0 here, so note that we are doing like this (Refer Slide Time: 20:49).

This is a position of B0 and new curve, this is your B1 then this is G in the new curve. Now, it heels by an angle additional amount D phi, this is D phi. Now, because of the initial amount of heeling that is by a heeling of phi there is a righting arm produced. The righting arm produced is defined as - if you remember I did in the last class - righting arm is defined as that vertical distance between G to the new line from the center of buoyancy means from G to this Z.

From G if I draw a vertical to this line that will give me Z here and the GZ are called the righting arm. Now, the question is how to draw the work, let me draw it like this, let us suppose this is vertical, this is 90 degrees. So, this I call it as GZ theta means of phi GZ phi not theta. GZ phi means it is the GZ, when the angle of heeling is phi. Is that figure clear till now? I will complete and may be explain for, so this is GZ phi.

Now, it has heeled by a further amount of D phi. As a result of which there is again a new GZ produced means or rather the GZ value will change, because of this new heeling by an angle D phi. Now, there will be a new GZ; then position of the new GZ, how will you get; by drawing a vertical from here to this line.

Now, it will come something like this. This is 90 degrees, you draw a vertical from here to here, so this is G and this will give you GZ phi plus D phi. Phi plus D phi is the subscript; it is not the value or anything. So, GZ when the heel is phi plus D phi that is GZ and phi plus D phi the other one is GZ of phi, so you get two GZs; GZ at phi and you get a GZ at phi plus D phi.

Let me draw this part alone, so you have G and you will have Z phi and you will have - this will be Z , I will explain this again if it is confusing - phi plus D phi. So, I am just drawing this figure part, this GZ line is this GZ, this GZ plus phi I am drawing it here it will be like this.

Now, note that here you have phi; if this is the point here you have a phi and here you have a phi plus D phi, so two lines like this. Now, if you see the geometry you will see that this angle becomes D phi, because it will be like this. Actually, this is not parallel to this it will be like this. Now, if this is D phi, the figure is not correct that is why you are not able to see it but, if this is phi and that is D phi, this angle will be equal to D phi because these angles are 90 degrees it is not very difficult to derive this.

Now, if that is true, what is this distance; the vertical distance between this point and this point, which is your d 1 minus d 0? The vertical that is the difference between, note one more thing this represents the vertical line, means when a ship is there and heel, what do we do? We draw a vertical water line through this that water line is horizontal. Though the figure it looks inclined it is actually horizontal. Like that this line and the perpendicular to that water line, which is the line through the B will always be a vertical line. So, just like this, this is the vertical line, so this distance between this point and this point this distance will give you actually d1 minus d0 (Refer Slide Time: 25:52).

So, d1 minus do will be given by this value, which will be now the GZ - I think it is GZ tan d phi, which is equal to G which can be written as GZ d phi. This is actually d of this because there is a d phi on this side it is d phi on another side also, otherwise it does not make sense.

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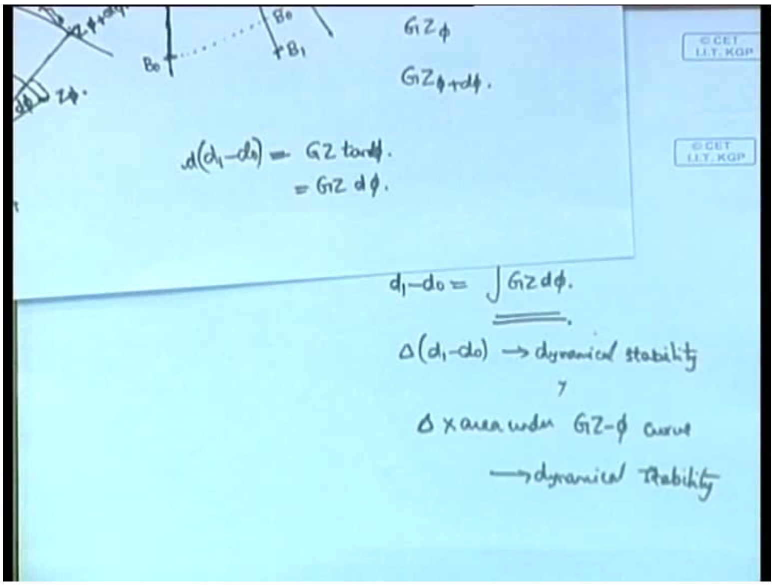

I will explain this again, I can see everybody is confused. Anyway, once you have this then you will have d1 minus d0 will be equal to integral of GZ d phi. I am just using this d of d1 minus d0 is equal to GZ d phi, so integral of d of d1 minus d0 is d1 minus d0 is equal to integral of GZ d phi.

So, this is the expression that I want to derive, I will explain it again. So, what does this represent? GZ d phi, integral of GZ d phi, it actually represents the area under the GZ phi curve. What is GZ phi curve again? It is called the curve of statical stability, so the area under the statical stability curve is what you are called as dynamical stability.

Area up to a particular phi it is like this, means if it is heeled between 0 and phi, if you take the area from 0 to phi in that curve statical stability curve for that ship, you will get the dynamical stability or the work done that is required in heeling the ship from phi equal to 0 to that phi.

Again, I will repeat. Dynamical stability is the work done or it is the amount of energy to be expanded to heel a ship from phi equal to phi 1 to phi equal to phi 2, means if it has to heel through a small angle phi that heeling is given by - that amount of work done is given by - dynamical stability that is the meaning of it and it is given by this d1 minus d0.

It is the area you have seen is equal to GZ d phi. Now, I mean this is d1 minus d0 is the dynamical stability arm and delta into d1 minus d0 will give you the dynamical stability. I mean this is the meter, d1 minus d0 is meter means, it is the unit of distance. So, it is dynamical stability arm and delta into d1 minus d0 will give you the energy or work done and this is really what you mean by dynamical stability.

Therefore, the area under the GZ will give you dynamical stability arm. So, whenever you are talking about dynamical stability note that - someone ask you what is the dynamical stability? You can very simply say that it is the area under the GZ phi curve or it is the area under the statical stability curve that is the meaning of dynamical stability but, what is it really represents? It represents the amount of energy required to heel the ship and it is equal to the area under GZ curve, it is equal to integral of GZ d phi into delta of course, so delta into area under the GZ phi curve will give you the dynamical stability.

Now, you can see that we are looking at stability from a slightly different point of view. Last time previously what would we have? We had a heeling moment which produced a ship to heel by - in that initial derivations we did not really look at how the ship heeled rather, we were looking at the final heel - it is heel by some due to some reasons and uniformly heeled that is another thing.

We are assuming at uniformly heeled came and rested their. How it goes back to its initial position and very uniform conditions, that is not how it is in real practice? Means, in real practice, what will happen is that 10 minutes for instance very strong wind might blow. It is like an - the word is impulse I think - it means a sudden impulse is provided.

So, it is not uniform force acting means it is not like uniformly going like this that concept does not hold really. If you assume that then all are work is ok but, if there is a sudden wind blowing for 10 minutes it blows very strongly then it stops after 10 minutes it blows again like that it is like impulsive, means it is like it intermitant very strong forces acting, not a uniform force but, strong force acting in very short time. Therefore, we cannot really study in a steady fashion the whole thing. The only way you can study it is by using the energy.

What you say is that the amount of energy provided by the wind is equal to the amount of energy going to heel the ship and from that you can find phi in this case. That means that much of heeling you can study; that much of heeling is produced is due to that wind that has come that is due to that wind that acted for 10 minutes, how much energy has come in that much energy has gone to heel the ship and from that you can get phi that much of heeling is required.

The other study assumed the uniform force is acting; it is continuously uniform forces is acting, so it continuous moves like this, it goes up to phi. So, we can calculate what the phi is produced due to the force and all that but, since it not true this dynamically stability becomes much more powerful tool to study the real cases. That is why the concept of dynamical stability came. Now, I will probably explain this again.

Start from this thing again, this I think is clear that is d1 minus d0 from this figure I think it is clear, so delta into d0 minus d1 is your dynamical stability that is clear.

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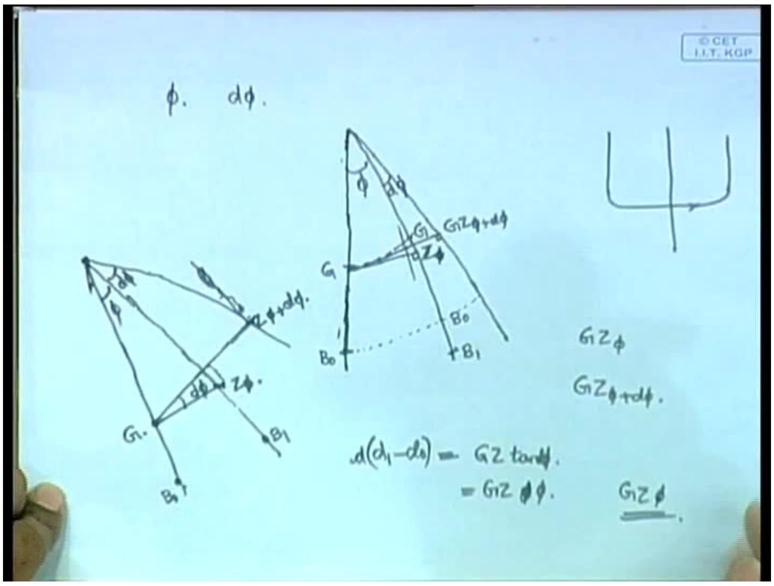

Suppose you have a ship in its - I am just repeating it - initial position like this. Now, this is what I have represented this line the initial position of the vertical and the water line is somewhere horizontal, this is G, this is B0. Now, it is heeled due to some factor by an angle phi, so this is its new position note that this is also vertical.

From geometry you do not think of all that but, in real practice it is vertical, because a horizontal water line is like this, let us forget that, this is phi it is yield through an angle phi, I have already explained to you that what is known as righting arm GZ; it is a vertical that is drawn from G to this line to the new position of B if you draw means to the new line through B. If you draw a vertical and then that line hits their Z and that distance is called as GZ. So, this is GZ phi or just it means that when the heeling is phi the Z at the point is called Z phi and that distance is GZ phi.

Now, it is heeled further by a small angle D phi; this small angle D phi. So, it is heeled further and it is here this is the new line. Now, again, note that this is also vertical, so when we are mentioning distance like this also vertical, when you are measuring this distance also vertical that is also vertical.

Now, similar like a GZ you have GZ phi I have already done, you do a GZ phi plus d phi same thing means, what has happened at phi, you repeated for phi plus d phi. So, here you have another GZ phi plus d phi. I have drawn this line GZ plus phi D phi. Now, if you just take that small part out, this will look something like this, there will be a GZ phi like this, Z phi plus d phi like this here, so two of them and this angle will be D phi. Now, this distance will be d0 minus d1; what is d0? It is again this is B0, this is B1 (Refer Slide Time: 34:00).

Now, if that is probably assumption that but, straight away means if this goes through a disc means, what is this distance is d0, if G comes here somewhere, this distance is d0, it moves by a slightly moved distance d1 minus d0. Z moves by a same distance Z1 minus d1 minus d0 again, so this distance will give you d1 minus d0, this distance equal is to GZ tan phi, which can be written as GZ d phi; GZ tan phi which is GZ phi (Refer Slide Time: 35:18). Basically, GZ phi - let us remove the d phi all that.

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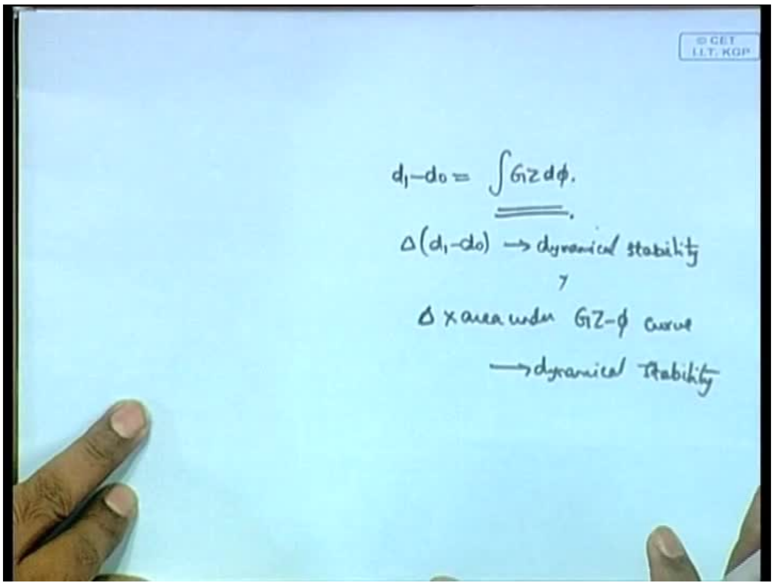

From that you get this expression that d0 minus d1 is equal to integral of GZ d phi, which is the delta into d1 minus d0, which is known as the dynamical stability is delta times the area under the GZ curve and area under the GZ curve is the dynamical stability arm and delta into area under the GZ curve is the dynamical stability and that is known as the work done to move the ship heel - the ship that is dynamical stable.

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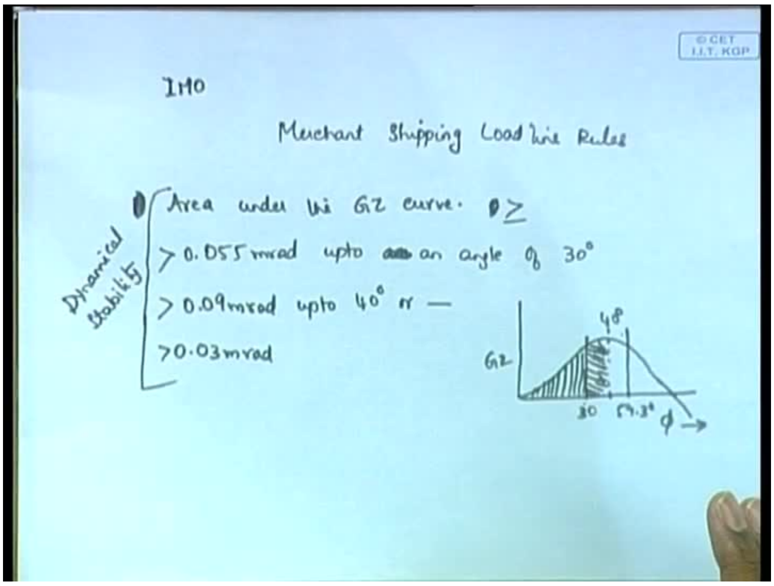


This is actually an important concept, in the later part of the course you see some rules which are usually IMO rules - International Maritime Organization. They have their own rules regarding how I mean - they have specified the set of rules which tell you whether the ship is safe or not and based on the rules there are some means that every ship has to get a certificate. I have already told you every ship before it is put in practice has to get certificate from an organization, something like the law it register or a like. In India, we have a Indian Register of Shipping IRS or law it register or American Bureau of Shipping, all these different shipping agencies are for the different countries from them they have to get a certificate.

The rule that the organization like the Indian register of shipping looks at is made by the IMO called International Maritime Organization. One of the rules is like this, it is not just the IMO, there is something known as - this is just for merchant ships; merchant shipping is called load line rules.

Anyways, there are different types of rules made by different organization. Of course, people do research in universities and other basins they come up with the rules, they modify the rules and these organization adopt those rules and they give the certificates. Some of the rules we look at which are very important, one of them is that the area under the GZ curve for any ship G; GZ curve is always with respect to phi, the other co-ordinate is always phi, so it is GZ phi that is the statistical, so we called the GZ curve. GZ curve is always this curve of GZ versus phi, so that nobody mentions GZ phi curve or anything, it is called GZ curve.

The area under the GZ curve should be greater than 0.055 meter radians up to an angle of 30 degrees. Means, suppose this is your GZ curve, if this is obviously about 57.3 degrees, if this is 30 degrees; the area under this curve up to 30 degrees, whatever be the type of ship and anything, this is fixed up to 30 degrees; your area should be greater than or equal to 0.055 meter radians. I think you just by heart this number nothing else to do here. So, 0.055 meter radians up to an angle of 30 degrees then, it should be greater than 0.09 meter radians up to 40 degree, the GZ curve that is up to 30 degrees.

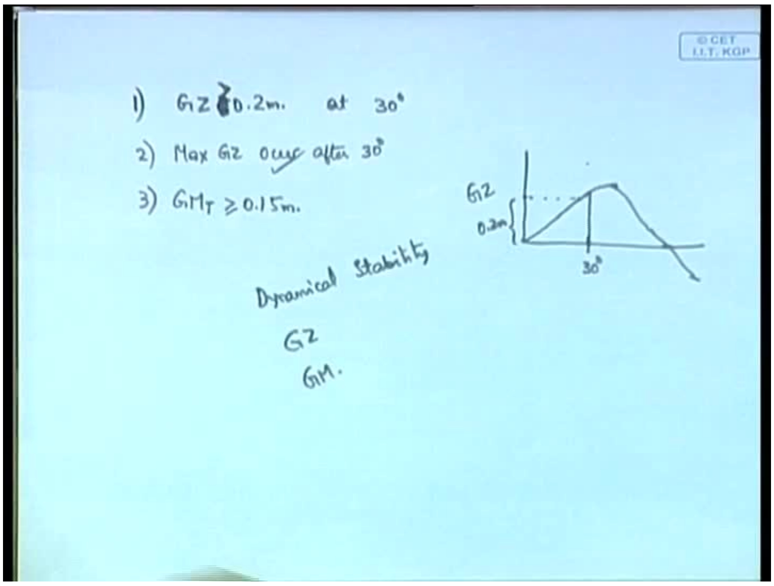
Now, it also says that this GZ curve should be greater than or equal to 0.09 meter radians up to 40 degrees or suppose, before that 40 degrees some opening is there means, actually on the hull there is a water line most likely there is be no opening below the water line they will be closed everywhere, but in general above the water line after some height there will be some openings here and there, to do ballast some time to put the anchor sometimes, lot of such openings are there.

Now, if in fact even air holes might be there, ventilation and different kinds of things are there. If the ship heels beyond 30 degrees, what this says is that the ship should be designed always such that when it heels up to 30 degrees there should be no such hole that is going under the water, every ship is designed like that. So, up to an angle of heel of 30 degrees no hole will go under, that is after 30 degrees there are some ship holes can come under.

Now, when that happens up to that angle or if there is no hole up to 40 degrees this area under GZ curve should be 0.09 meter radians that is the second rule, these two rules are to be very strongly followed. In addition, this is the third rule, between the 30 and 40 degrees there should be at least 0.03 meter radians of area, it does not have to be 40 degrees; if it is also a hole coming before that there is up to that degree there should be a 0.03 meter radians of area in this GZ curve, so these are three important rules.

This is how rules are made in basis of dynamical similarity; these are rules associated with dynamical stability. There is a parallel set of rules regarding GZ, you have to know that also. This is one set of rules that should be followed strictly, they will measure the area and they will draw the GZ curve. So, it is important for a ship that you should able to draw GZ curve. Once the ship is made and it is given to that organization, they will draw the GZ curve and will measure the areas to make sure this is satisfied.

(Refer Slide Time: 43:25)



Now, a couple of other rules are also there that needs to be satisfied that is, GZ greater than or equal to 0.2 m. We have the curve of GZ, it comes like this (Refer Slide Time: 43:55). Suppose, this is 30 degrees it means, at 30 degrees this should be at least 0.2 meters GZ. This is the strong criterion for the stability that is GZ should be greater than 0.2 meter and 2 is max GZ occur after 30 degree. We have already drawn the GZ curve and we have seen that GZ reaches the maximum value and then starts decreasing; now another rule says that this maximum GZ should never occur before 30 degrees for a ship.

So, the GZ should always occur after 30 degrees for the ship, somewhere anything after 30 degree is acceptable. The value of maximum GZ should occur always only after 30 degrees. Another rule is that we have already derived that the condition for stability is that GM should be greater than 0 that is the condition for stability but, in practice we do not say the GM is greater than 0 is criterion GM we say that GM should be atleast 0.15 meter that much of clearance is given for different purposes of the ship so that GM transverse it should be atleast equal to 0.15 meter. So, these are related to the dynamical stability related to GZ and related to GM. So three sets of rules are important, so as I said you have to by heart these numbers 0.2, 0.15, 0.03 and all that you have to remember.

Sir, ((Audio Not Clear))

Actually in other conditions what will happen? It means that will unstable, why should be unstable is your question? Actually, stability will increase comes below before 30 degree that means, the area and the curve is increasing that means more energy it is having a lesser heel. Means, more energy it is having lesser heel that makes sense, but, let me see. That is, the basis for all the other problems which we see but, it keeps providing over and about a maximum GZ, which one you said GZ maximum GZ actually I need to think about this I will tell you that is a good question GZ but, the rules says that - so obviously, there is some other criterion that I will tell you that I have to.

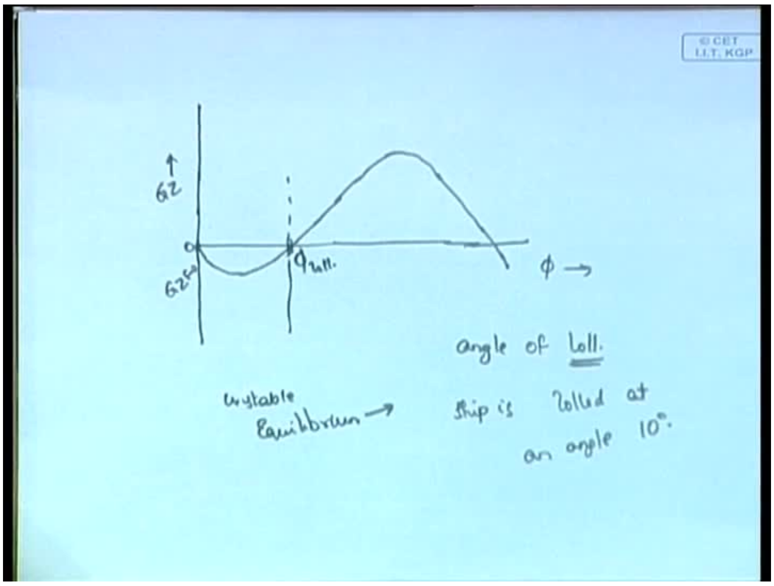
Sir, phi ultimately leads to 1 in the problem.

Which one phi l what is phi l vanishing stability

GZ becomes 0 at that point.If it goes here then GZ might that is less.

That could be a reason, he said that if the ship curves like this, the curve vanishing stability might happen at smaller angle; if it goes like this and crosses here, the vanishing stability comes here. So that might be a reason, that is the good possibility but, I have to really see what it is. Actually that seems a good reason, I will tell you.

(Refer Slide Time: 48:40)



These are some rules and from this you have. Now, there can be some ships designed that you will end up with some different kinds of curves like what will happen if you have GZ curve like this (Refer Slide Time: 48:44).This is slightly different form, this is GZ versus phi, what is it means? Let us see that. If the curve is going down what is it means? It is means that GZ is negative obviously and that means, righting arm is negative, what is it means righting arm is negative? It is trying to capsize; it is not writing it is going the other way round.

At this point any of these regions where GZ is negative; the ship is initially upright, some small factor, let us say, wind came it heeled like this. Now, what will happen? The righting moment itself it is going to cause it to heel, so it continues to heel and till it reaches here. At that point when it reaches there, any more heeling causes the righting moment positive after that, so after that will tend to come back. So, the ship will be going like this always; the ship will be like this that is the end result of such a GZ curve (Refer Slide Time: 49:40).

It is of course stable, but it is strange kind of step - in that it is unstable in the region is before this, from this region to this region is unstable but, beyond there it is unstable, so this is known as loll and this angle is called the angle of loll and the phenomenon itself is called loll.

If you are told that ship is lolling at an angle of 10 degrees obviously, you can draw the GZ curve like this; this is the meaning of the GZ curve. So that means, at an angle of 10 degrees only it seems to be stable, beyond 10 degrees will come back to position because the GZ's curve righting arm is positive, but before that the righting arm is negative, so it causes it to heel; it causes it to move in this direction and to remain at 10 degrees. So, this is the angle of heel this represents the ship going like this.

Again, this is the common question for your viva and interviews and all they ask this. They say, either the other way of this means, they will draw GZ curve like this or they will ask you what does this means or what does this imply about ship or you are asked, suppose ship is going with an angle of loll draw the GZ curve? From there or from here, there are two ways.

At any case, this you have to know; if you understand why it is so, then it is very easy to remember; this is all there is to know. In this region from here onwards, your GZ is positive that means, your righting arm is positive; it means that anything causing it to tilt further the righting arm will be positive causing it to come back. So, there is no problem as far as this region is concerned, but here in this angle when it is between 0 and 10 degrees between that angle of heel, if it heels by some factor, let us say, the wind caused to slightly heel, the righting arm will itself cause it to heel in the other direction and it cause like this. It goes till 10 degrees and beyond that righting moment will try to bring it back, so the ship will remain like this. So, in general the ship will be going like this (Refer Slide Time: 51:46).

If it heels more than the loll angle it will come back to the loll angle. It will be like this, if it is like this also will be push back here, if it is like this also will be push back here. Finally, it goes like this most likely, I mean slight variation, I mean never goes like this it always goes like this. Means, the ship will ever be upright even if it is good ship it will never remain upright it always heel a little here and there that is why we are doing all this calculation (Refer Slide Time: 52:21). But the other ship; this ship will be in this position it will heel like this. Means, in general the mean motion is like this, that is the meaning it is called lolling - that angle of loll it is called.

There is unstable equilibrium between this angle of 0 and phi of loll - the angle of loll. Therefore, between phi equal to 0 and phi equal to the angle of loll the ship will be in unstable equilibrium. I think I will stop here, thank you.