Hydrostatics and Stability

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Module No. # 01

Lecture No. # 16

Heeling Moment - I

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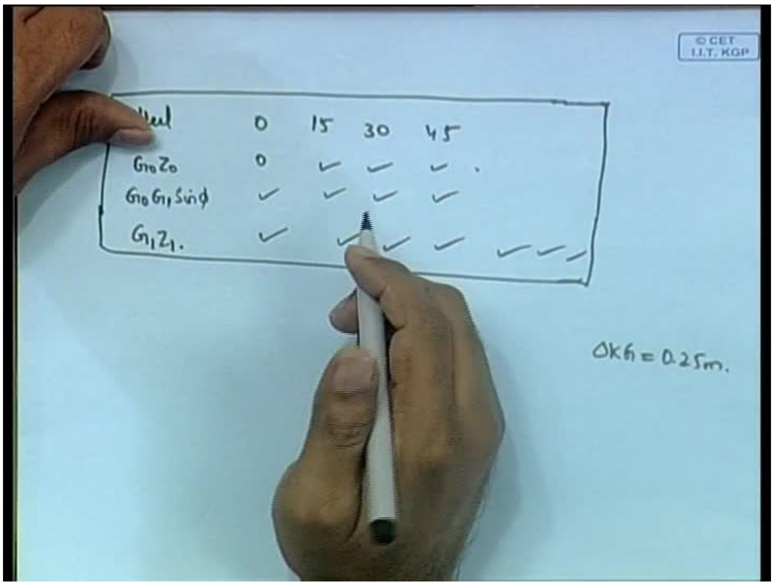

So, we will continue, here where we made this table for various angles of heel and we have G 0 Z 0. Now, note that in real case, in reality, when the ship is really heeling, I told you that the GM does not remain constant; G does not change. Let us suppose that the ship is without any change in the mass; there is no change in the weight anywhere. So, G does not change for the ship. Whatever, it heels or does not heel, it does not matter, but if it keeps heeling due to other reasons without the change in weight, if it keeps heeling actually that M will keep moving; it will become an M curve, but note that in these derivations completely we are assuming that M does not move. Why I say that is in that heeling curve, in the GZ curve, we have one value of GM. It is one value of GM for the whole angle of heel.

Angle of heel starting from 0 to 90 degrees, angle of vanishing stability - the whole thing there is one value of GM for the ship; that means, the metacenter has not shifted at all. So, that actually is a very important point that you have to remember in this because it has implications. For example, you look at this table; it says G 0 Z 0 at different angles of heel phi, phi 1, phi 2, phi 3 like that.

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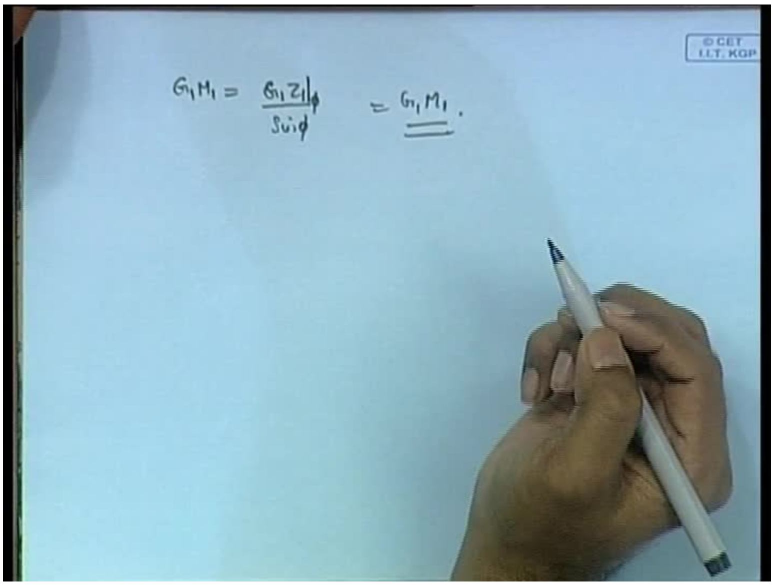

Now, if you want to get GM for the ship, how will you get initial GM? You just have to divide it by sine phi. GZ divided by sine phi will give you GM. So when each of them are divided by like the GZ value, here when you divide it by sine of 15, you will get some value of GM.

It should be the same value that you are getting here; means sine, I mean, GZ at 30 divide; what I mean is it clear? This will be equal to GM; of course, at 0, 0 it is not defined; it becomes 0 by 0; it is not defined there; after that everywhere you are getting this should be equal.

If you want, you can check it. In this problem, it is there; we have seen it is true, but in case you have a problem where that change is then you have a serious problem. It is not going to be solvable using any of these methods. So forget those kinds of problems.

We are not doing that; we are only dealing with simple problems in which GM remains constant for the whole angle of heel; means, there is no M curve, M is fixed. It keeps rotating, but M remains there only; nothing changes; that is the meaning.

So, how do you get G 0 M 0 for this ship? G 0 M 0 means the initial value of GM without the shift in the center of gravity. First there is a ship with some KG to it. Some weight has been added at some height, as a result of which the KG has risen by some amount 0.25 meter.

So there is a G 0 G 1 and as a result of which when it starts heeling you have different values of GZ. Now, GM M 0 means the value of GM before the weight has been added. So G 0 M 0 will be given by G 0 Z 0 by sine phi; that means like this it is just that it is G 0 Z 0; that is all. So, any of these will give you G 0 M 0. You take any of these and all of those G 0 M zeroes will be same. In this case it is so - you will get G 0 M 0 and very straightforwardly you can get G 1 M 1, that is instead of this G 1 Z 1, I mean, G 0 Z 0. If you take G 1 Z 1 and divide it by sine phi you will get G 1 Z 1. At some angle phi you divide it by sine phi, you will get your G 1 M 1.

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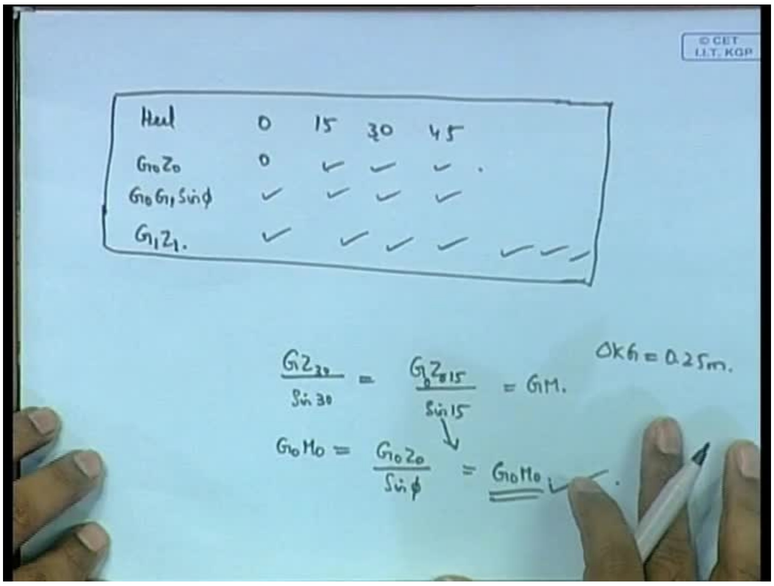

So, this is the first question. This is one of the questions that you are asked - find GM. That is the fourth question; then you have this table. Now, the other question is: what is your maximum GZ initially and before after the ship or in the final condition? What is your maximum GZ? All you have to do is look at this table. You have GZ as a function of phi. Look at the maximum value of GZ and you find out what is that phi corresponding to that.

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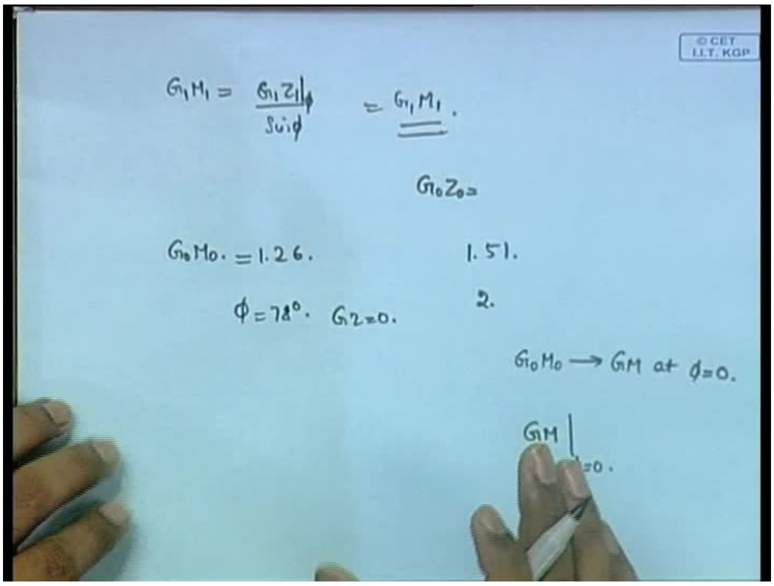

Of course, if the value is in between interpolation and all is there, you have to draw the curve and you have to get that. That is why you have to draw the curve in any way. In these cases, that is why I said to get the maximum values you have to draw the curve and from that ((Very poor audio – Refer slide time: 5:19)) wherever sine phi is maximum, GM will be, GZ will maximum. That seems a strange logic; something I have made wrong here, wait. G 0 Z 0 is equal to it; happens when phi is maximum.

Actually I have told something wrong here - estimate of the GM. Actually, does any of you have a calculator? That is very good point you have raised. I think I have told something wrongly; that is just checking one thing on 0.391 divided by sine 15. 15 sine - actually I am not able to use this. I will tell you do it; that is: do 0.391 divided by sine of 15 degrees, 1.51. Do 1 divided by sine of 30 degrees. Sine of 30 degrees is 0.5 know. So 1 that is 2, so then actually, I told you wrongly.

That assumption is I told you a wrong thing. That is what he pointed out - a very important thing - GM is not constant here; GM, it is varying here. So GM is actually varying with it is with the M curve. GM is not constant; so, that GM that you are plotting is G 0 M 0, which means at the value of the first angle of heel, that is we can say it is at 0.

So G 0 M 0 is actually your GM at phi very close to 0. Like, let us say, 1 degree or something. The GM, when is at that point, that is your GM that you are getting here. Of course, in the derivation itself we saw that you will have it comes like this GM at phi equal to 0; that means its GM at phi equal to 0. So, GM is actually varying. That means, its GZ is maximum not when phi equal to maximum because GM is also varying.

So GM sine phi; GM also varies, phi also varies. So GZ occurs some intermediate value. Otherwise, it is a good thing. It does not make sense. So actually I said that what I checked here was just this GZ divided by sine phi it is not the same.

G M is changing means G is fixed because I am talking about the case when weight has not been added - that is, G 0 Z 0. So, weight is not added; that means G is fixed, M is changing. M is moving in a M curve. So, that assumption is not made and G you are measuring there is at phi equal to 0 at the initial value. Therefore, this gives you G 0 M 0. So what did we get? You get it to be some 1.26 and you see that in the G 0 Z 0, in this G 0 Z 0 curve, you see that your value of G 0 Z 0 becomes negative after a value.

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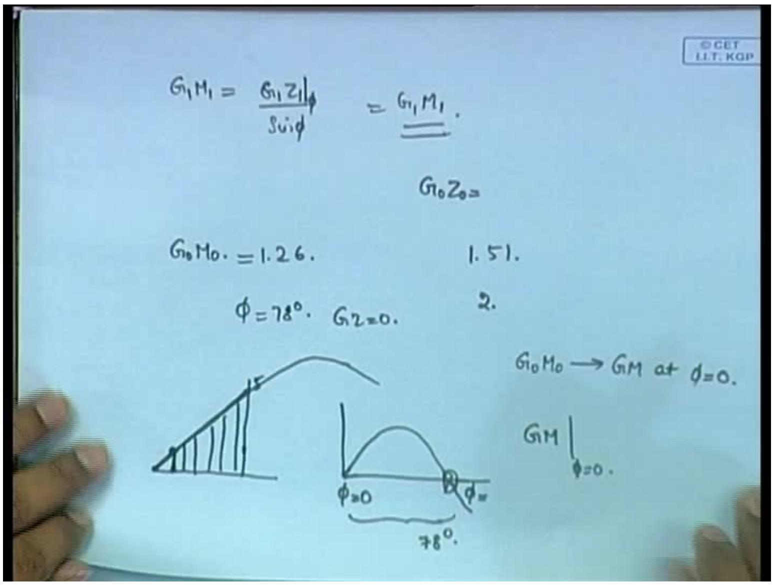

That is at phi equal to 78 degrees, the value becomes 0, GZ becomes 0. Therefore, the angle of vanishing stability is at phi equal to 78 degrees. There is a maximum or the max range, you are asked the range of stability. Range of stability means the phi starting from 0 to where GZ becomes 0; means in this curve, starting from phi equal to 0 to phi equal to this value. Why? No, at 0 you cannot put, it will become 0 by 0; that is what you are asking.

It is a value slightly after that you take; means you take some point slightly after 0. At 0 it is undefined; you cannot do it. Slightly after 0 it is up to you. In case you are getting 1.26, may be you will get, other person will get 1.3, you will get, that is small difference. Do not make it too far. When you are taking the graph sheets, take the first point close to 0; means first point in this case is 15 degrees. So from 0 you will connect to 15 degrees. Let us say like this, let us say, the GZ curve goes starts like this and it goes like this.

Now this is 15 degrees. Let us say that the graph sheet is like this. You take the first point somewhere, here, what is your GM that you take? Otherwise, you cannot do it, that is not defined. Then, what was I doing? So I was telling you about the range. So this is phi equal to 0, this is the angle of vanishing stability. So this is known as the range of stability, according to this problem comes at 78 degrees.

This whole thing is 78 degrees. That is where your stability vanishes to 0 at that point and then you are asked the maximum GZ, and the value at which that maximum GZ occurs. So, that is just a matter of reading from that graph. You have the graph, you look at the graph, see where the GZ is coming maximum and the angle at which it is coming. You just read from that.

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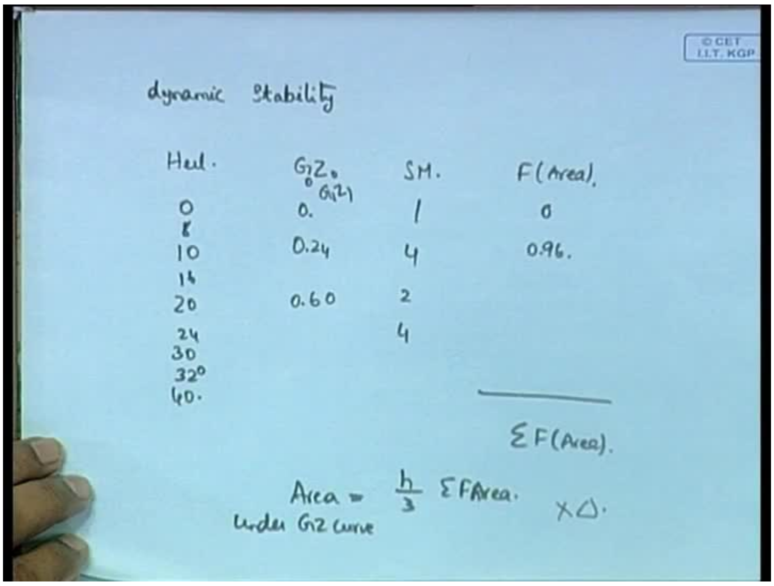

Then you are asked also dynamic stability. You have heel. So, to find dynamic stability note that you have to do the area of the GZ curve; that means you have to do this. Let us say GZ, then you will need same concept of Simpson's multiplier.

So as you can see, the Simpson's multiplier concept you need everywhere. You have to know that very clearly. So, you write like this. So Simpson's multiplier 1 4 2 4, then the function of area is just GZ into Simpson's multiplier 0 0.24 into 4 0.96 like that and you find the sum sigma function of area. Finally, you do h by 3 into sigma function of area, will give you the total area under the GZ curve.

It will give you the area under the GZ curve and therefore you multiply this with delta. The weight of the ship that will give you the dynamical stability; that is your dynamical stability. Then, of course, you are asked dynamic stability in the initial case and dynamic stability after the KG has been changed.

So the same areas you have to put, the same way you have to do, but this will become initially G 0 Z 0. In next case, it will be G 1 Z 1. So, this is the initial and final. So, this is how you find the dynamic stability. That is what you have to take area up to that angle means you are saying, if you do not have the value; that means you have to read from the graph. That is why I said, you have to draw the graph first; that means you are asked the dynamical stability up to what? You are asked the dynamic stability at 40 degrees in this problem.

That means you have to find the area up to 40 degrees. In this case, it is not a problem because you are given the GZ value at 40 itself, but there are some problems coming up where you have to find GZ in between values; means you have to find the area up to some intermediate values; that means you have to draw the graph, you have to find the value of GZ at that angle. You can do like this, that means, first of all you need h as a constant in Simpson's multiplier; that means you will have to divide it in to equal number of parts. Each of those values you have to read from the curve and then you have to do it. It is a laborious process but that is the only way to solve, because you cannot do with variable edges. We have not done that kind of problem.

If you have a constant h and this, suppose you have do still some 32 degrees or something it becomes slightly complicated, 32 you have to divide. Let us say this becomes 24, then you have to do 16 and probably 8 like that and 0 8 16 24 32 like that it will become and no other way but the GZ has to be read from the graph. So, you will have 2 GZ curves; one is a G 0 Z 0 initially, then the weight is shifted and the center of gravity is shifted and you will have G 1 Z 1, and based on that you will have the initial dynamic stability, final dynamic stability.

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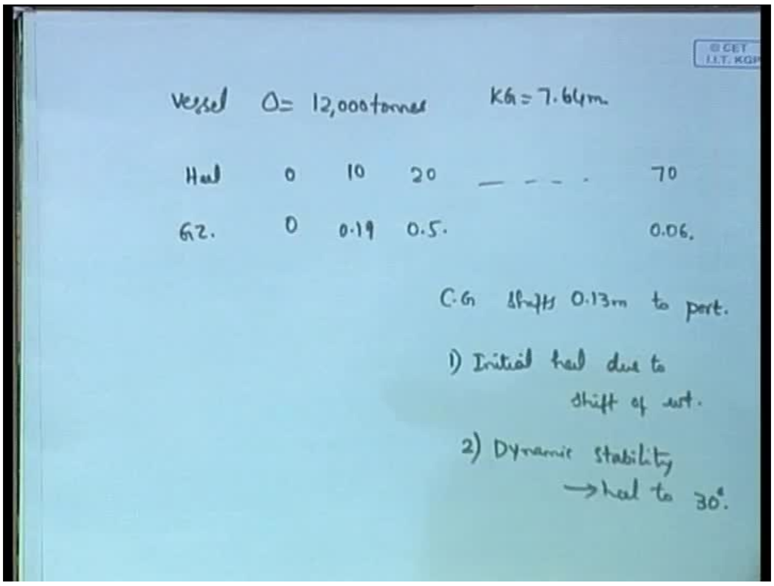

One more problem that is, this is about a horizontal shift, the problem shows a horizontal shift of weight. You are told that there is a vessel which has a displacement of 12000 tonnes and it has a KG of 7.64 meter.

Now, again you are given the GZ table. So, like this you will have at least one problem like this for your mid semester where you have to draw a GZ curve. So, you have to know how to do this. So, 0.19 20 of course, you can connect it in a simple fashion, free hand, do it quickly. You have one and half hours after all for mid semester. So, quickly if you can do this 0.5, so you have like this, like this it goes and at 70 it becomes almost 0.

So after 70 it is becoming the angle of vanishing stability. Now, you are told that cargo is redistributed. As a result of which the center of gravity shifts 0.13 meter to port. Now you are told, as a result of this find the heel, means this has been shifted, as a result of which find the heel angle, also find the dynamical stability from that heel angle to angle of 30 degrees. This is one of those where obviously you are going to get the heel angle in some 11, 12 degrees, something you will get. Whatever you get from there you have to find the area up to 30 degrees.

That means a couple of things: first you have to obviously draw the GZ curve, you have to find the initial heel due to the shift of weight, and finally you have to find the dynamical stability. So three things: you have to first find the initial heel due to shift of weight, then two - you have to find heel, you have to find the area under the curve. One more thing you have to find. Now, what is there and easily you have to find the dynamic stability from that angle of heel to 30 degrees.

So two things you are asked to find in this. Now, what is a way to find out the heel? Do you remember some way of in which we have found the heel? Actually we did something known as an inclining test if you remember. An inclining test was described as - let we go back to that page 132 - we will go to the inclining test.

We have done an inclining test in which if you remember, we hung a pendulum at the top, somewhere you hung a pendulum and a weight was shifted from one point to another point. As a result of which - pendulum - the vessel heel pendulum is at an angle and when the vessel, when the weight is shifted that means G is shifted.

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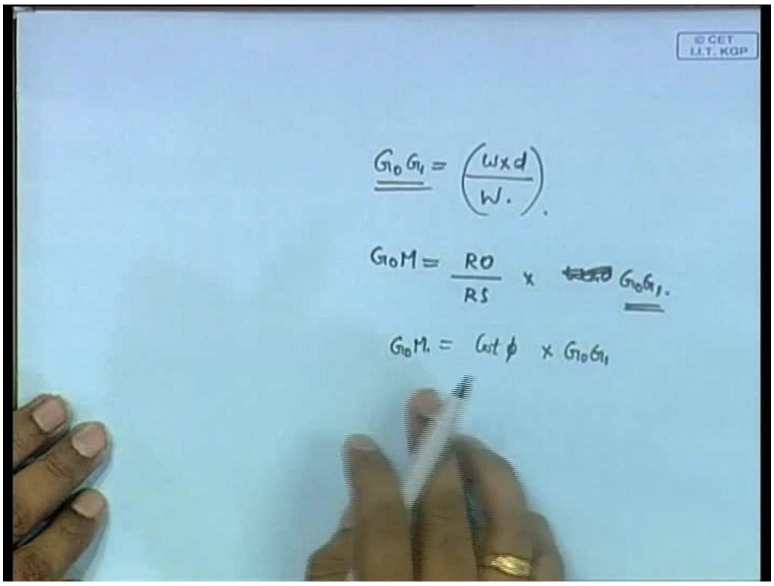

So when that happens you have to find from the angle of heel you have to find GM. So this becomes in the other way around you have to find the angle of heel because of a shift in weight. I am not going to do it again. The final expression is G 0 G 1 is equal to w into d by W. This is your shift in the G 0 G 1. As a result of the shift in the angle of, due to at weight w shifting through - is it given how much cargo is redistributed? Let us see, you are given 0.13 meter. So you are given G 0 G 1, this you are given. Then, you have GM. Now GM, that is the second one you need. Now, this is another thing we had; G 0 M another formula that we had. R 0 actually you would not know what is 0 without looking at the figure but R 0 by RS into w, I will write it as G 0 G 1. Note, that we are told that the center of gravity of the vessel is shifted. This problem says that center of gravity of the vessel is shifted 0.13 meter to the port. So, you are given G 0 G 1. So you have this one, then you are told. Now, what is R 0 by RS? R 0 by RS is equal to tan or cos? R 0 by RS it is equal to, R 0 adjacent by, its cot phi, if you remember. It is cot phi into G 0 G 1.

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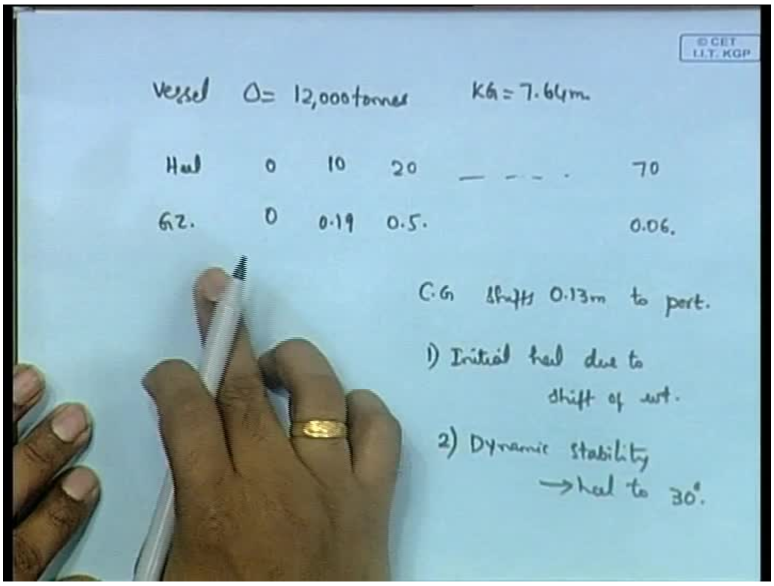

Now how will you get G 0 M? It is this, what I told you. You have to get the G 0, you have the G 0, GZ curve you are given. Here, you have the GZ that means, in this problem you are given the GZ curve. From that you have to get your G 0 M. As close to the origin as possible you find G 0 M and, or G 0 by sine phi you do and that will give you G 0 M.

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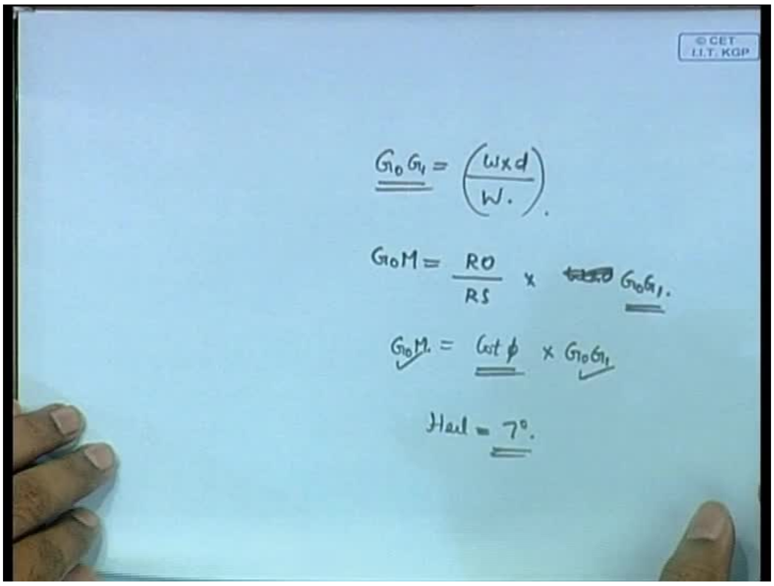

And once you get G 0 M, you know G 0 M and you know G 0 G 1. G 0 G 1 is just the shift in the center of gravity, it is given in the problem. So, this you know G 0 M you get from the curve, from that you have to find cot phi. Therefore, from that you find phi. That is your angle of heel. Is it clear? Therefore, this problem gives heel at about 7 degrees. So, actually you will be solving for cot phi and that solves for phi to be 7 degrees. So that means because of the horizontal shift in the center of gravity, the ship has heeled through 7 degrees.

So it is like this now. Now, you can do two things; first of all if it is asked you can find the new GZ curve. Remember, this is the GZ curve without the shift in the center of the moment, the center of gravity shift, finally you will have a GZ curve.

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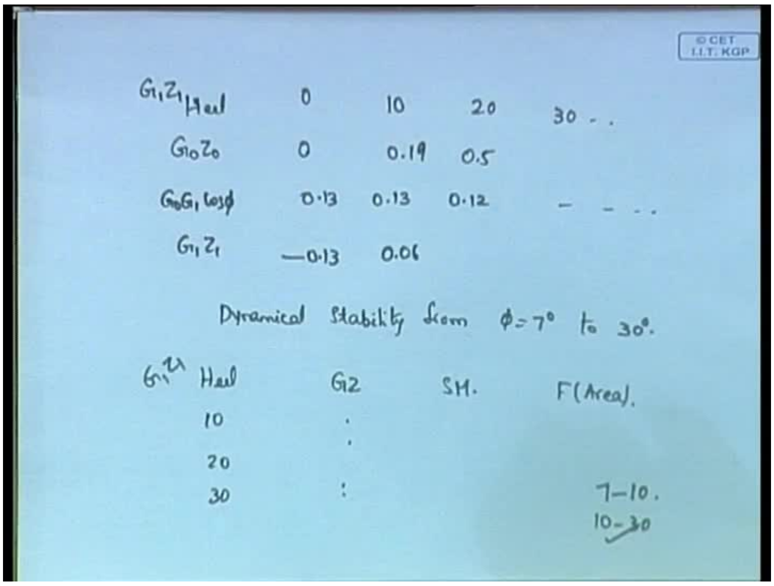

That GZ curve is G 1 Z 1. So, you have your G 0 Z 0, like 0, let us call this heel 0 10 20 30 like that, G 0 Z 0 0.5 like that you will have.

Then you have to do. This I have derived it. I told you that G 1 Z 1 become G 0 Z 0 minus G 0 G 1 cos phi, in case of horizontal shifting. In case of vertical shifting, it becomes sine phi. So, this is 0, whatever, G 0 G 1 whatever, it is not 0 minus 0.13 0.13 0.12 it becomes like that and G 1 Z 1 becomes G 0 Z 0 minus this, so this becomes minus 0.13. This is not 0 actually, this is 0.19. Anyway this becomes 0.06.

So from your G 0 Z 0, you subtract G 0 G 1 cos phi and you will get your G 1 Z 1. That is your new value of GZ curve. So you have your old GZ curve, you have your new GZ curve.

Then the second part of the problem says you have to find the dynamical stability from that heel angle to an angle of 30 degrees. So you have your final GZ curve. Now dynamical stability there is only one way. You have to do it this format only. Simpson’s multiplier and function of area, so you will have like this 10 20 30 like that. Now, note that in this problem you have to find area from 7 to 30. So, this is data is given 10 20 30.

There are two ways of doing it: the first one is you have your GZ curve - this is your G 1 Z 1 curve - you have your GZ curve. You can take the curve start from 7 14 21 28 like that but it becomes slightly difficult. So a better thing actually is you do like this 10 20 30 we have the values.

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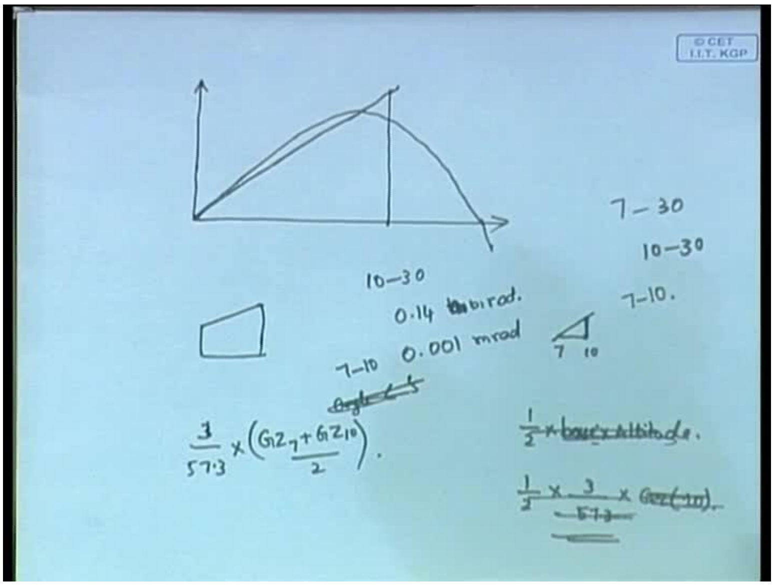

You find the area till that. Then that means you have to add the areas from 7 to 10. Now, 7 to 30 we have to find. 10 to 30 you can find using this and 7 to 10 you have to find now. So that is may be easier in this than doing 7 14, doing that continuously you split it. You split areas and you get 10 to 30, using this format, it will be very easy using this, because you already have the values. You can very easily do this. Then from 7 to 10 you get the values and do it. That means you read from the graph and then you of course, in this case, they have done in a different way. That is, I will just show what they have done. You can do this also but I do not think you will get a big error. So, this is your GZ curve. It is not this one, they have not shown. Actually what will happen is that, what they have done is same thing 10 to 30 they have found the area.

Now to find 7 to 10 you will have a small area. You can do like this. That means, it will come an area like this, you will get an area like this 7 to 10. Now, one way to do it is just assume it is a triangle and you find the area. You do not do the Simpson’s, just half base into altitude. So, how will you get the base? Base is just 3 degrees. So, that is, 3 divided by 1 degree is equal to how many radians? Whatever pi by 180, what is it? 57.3 anyway, will give you. 1 radian is 57.3 radians. So, 3 degrees; so, 3 by 57.3 into altitude that means you have to find the value, what is this? f of 10, exactly what is it?.

F is what? It is GZ that is what I am asking, f of f is actually GZ. So, you find the GZ at 10, GZ at phi equal to 10 that is all. This is one simple way of doing it and if you have an area, if you have an angle less than - let us say 5 or 1 - that is what you can make it more and more complicated, that is up to you but at 7 there will be some GZ. According to them, it is better to look at this as a trapezium. That also is better to look at it as a trapezium I guess; actually they have done that. I think it would have been better if they had taken it as a trapezium. That is correct because it is actually a trapezium, because there will be some value of GZ at this also, do that. It is better to take it as a trapezium. So, you have like this. So, what is area of trapezium? Half this plus this divide into, so its vertical distance again becomes 3 by 57.3 into GZ of 7 plus GZ of 10 by 2, something like this.

So this will give you the area of trapezium. This is what you should do. Actually, do this for the exam. I mean there is no point spending too much time on Simpson's multiplier, it makes very complicated. You will spend the lot of time on it. Best thing is see if you can means whatever you will have a GZ data, given at as 0 10 most likely in steps of 10 0 10 20 like that. So, you find area that closest area. Let us say 7 to 30, if you are asked to find, you obviously see that 10 to 30 can found using that value. So like that you look at it and divide it and then 7 to 10 only you have to find, that means only a small area is left.

You use the trapezoidal method. That is, this trapezium area you find out and you substitute that. That will give you the exact value and if you see this value, it becomes like this, the 10 to 30 areas is about 0.14 ton radians, meter radians and the other one is 0.001 meter radian between 7 and 10. It makes no difference if you do the Simpson's multiplier, probably you get 0.002, maybe it would not make any difference in your answer.

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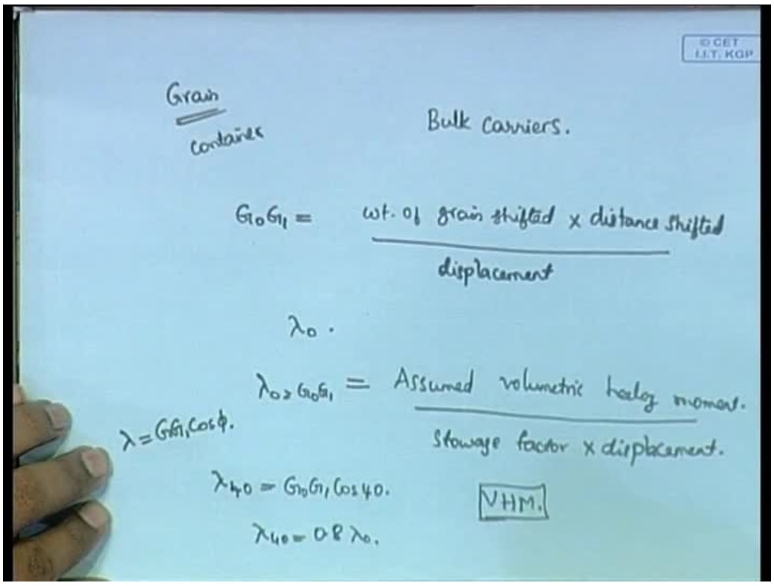

So this is easier. Now, we come to another - what happened? You have another kind of problem in which you have a grain. You have bulk carriers, there are somethings known as bulk carriers. These are huge ships, size of 350 meters probably and very broad and very large ships and these ships carry material in bulk, things like ore and means not liquid, but it’s liquid like material. Grain means the material moves like a liquid only.

So that is the thing about wheat or things like that. So all these things, what we do is, we use same concept as liquids because these things move in the same form as liquid. The shape of the free surface will like this and shape of the free surface goes like when the ship moves it will go like this. So it moves just like a liquid. So, if you remember we have already done a free surface effect for ships, same thing holds here. So for grains it is also container ship; these are the two types of ships: container ship and bulk carriers.

We use this concept of a free surface effect and in this case what will be G 0 G 1? Means this is your shift in the center of gravity of the whole ship it will be given by. So, this is the basic definition of the change in G, due to a change in, due to a movement of mass inside the container. So you have G 0 G 1 the shift the in the center of gravity of the whole ship is equal to weight of grain shifted into distance shifted by displacement.

Now, you write this as lambda 0, which is equal to, in this particular case of grain, we call this as lambda 0 and it is G 0 G 1 only. G 0 G 1 is equal to lambda 0 and it is written in a slightly different form. That is your lambda 0 is equal to G 0 G 1 can be written as something like this. The numerator is equivalent to a quantity like assumed volumetric heeling, this is a term, it is a particular term is called VHM. Note, that this VHM is defined only for this, either for liquid or for ores; so, either for containers or either for ores or grain, mainly for grain. So, in this book it is defined as grain. So it can be anything that moves as a liquid. So a grain, it is true for liquid and so this thing is called as the volumetric heeling moment.

It is something like the weight of grain shifted into distance shifted, is what you call as volumetric heeling moment and it is divided by something called as storage factor into displacement. Storage factor is not that important here. It is something like VHM divided by displacement.

So this volumetric heeling moment is important because in the problems of grain or container ships you will be directly given the volumetric heeling moment. You will be told that VHM so much because that is a particular value that they measure. It is something like the weight of grain shifted into distance shifted, so that is VHM. That will be given as a quantity to you. So you have to know what it is. So lambda 0 which is equal to G 0 G 1 is equal to VHM divided by this. You have lambda 0, now you will see that, actually, lambda 0 is, lambda in general is defined as G G 1 cos phi.

Therefore, lambda 40 is equal to G 0 G 1 cos 40. cos 40 is 0.8, so lambda 40 is equal to 0.8 lambda 0. Lambda 40 means the value at the phi equal to 40. At the heeling moment equal, at the heeling angle equal to 40, what is the value of lambda? This is at lambda 0 which means it is the value at 0, which is G 0 G 1 cos 0, which is G 0 G 1 and lambda at 40 becomes G 0 G 1 cos 40.

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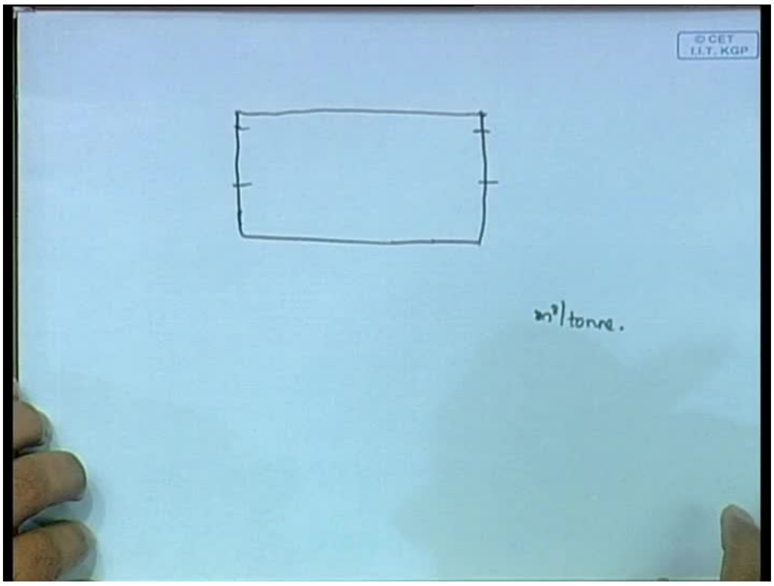

Lambda in general is G 0 G 1 cos phi. So these are some terms used for these grains particularly. Now, let us do one problem related to this. It is actually a ratio. I will tell you. That is suppose you have a shape like this. Now you can have two; in general we split it into two particular cases. Suppose that grain is filled up to this, they have drawn it like this.

When suppose it filled up to this height, therefore, storage factor will have some value and suppose it is filled up to this height, storage factor will have some value. It is something depending upon the amount of free surface and the amount of fixed surface. It is a ratio that depends upon how much of the volume is free and how much of the volume is occupied, that is called a storage factor.

Storage means storing factor, how much is stored - that is the meaning of storage factor. The exact values of storage factor will be given in the problem because you cannot calculate and that is too difficult. Of course, it is not too difficult, if you are given the shape you can calculate but I will give you the storage factor.

So you can see what will be its unit. It is actually, let's see heeling moment, its unit will as a ton per meter cube assuming meter cube per ton. It is a value that depends upon the amount of space that is left and amount of space that is occupied - meter cube per ton; then let us look at this problem.

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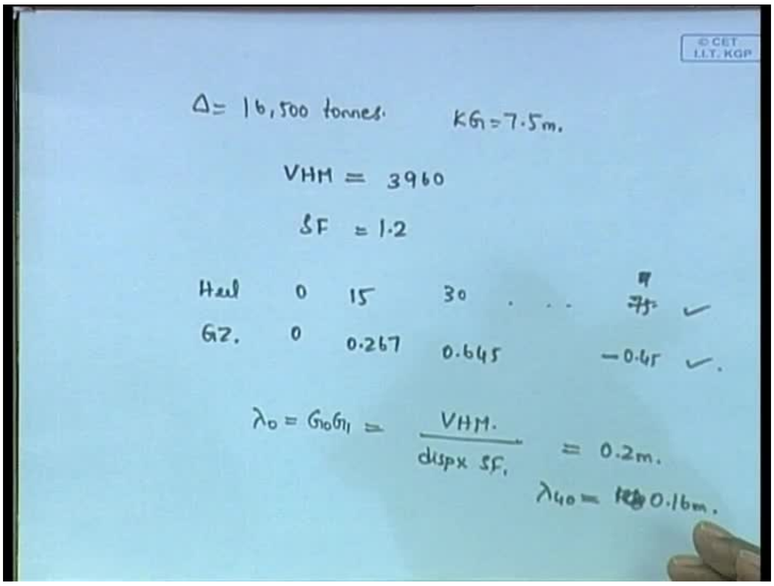

You are told that there is a vessel that has a displacement of 16500 tonnes. You are told that it has KG of 7.5 meters. Now all I can say is you have to look at the problem. If it says it is to deal with grains and then you will be given the volumetric heeling moment and all that. Actually we have covered a lot of variable sections; means horizontal shift of weights, vertical shift of weights. I have said, even in this section I have carried out different types of problems where you have a. So looking at the problem it is not easy to figure out what you are dealing with, lot of formulas to remember, it's true but this is one particular component which you have to by heart only. You see that where there is grain coming, you use this part.

It is like this, I mean formulas have been derived for each particular guy. You will see, next we are going into wind heeling moment. That is a different thing. So, for each container ships they have a particular set of rules, and a set of rules have evolved in their fashion. We have seen free surface effect in liquids like oil tankers and all that. There is a set of rules and those rules it keeps evolving in a different fashion. So if you are doing a problem in that, you will have to use the terms in that. It will be different from the terms in the grains, you just have to by heart it, there is no other way.

So this problem it says that it's about grains. It is says that it is a container ship which carries grains. It says that the grains shift in the ship as a result of which some data are given. You are given a VHM, the Volumetric Heeling Moment.

Then you are given the storage factor as 1.2 meter cube per ton. Then you are given the GZ curve or GZ table. in fact So, heel versus GZ 0 0 15 0.267 30 0.645 like that, you are given the GZ curve, GZ table, here and around 75 degrees it becomes negative.

So, you have the vanishing stability at around 70 degrees. Now, first thing you have to calculate is your lambda 0, which is G 0 G 1, lambda 0 is equal to G 0 G 1 cos 0 is equal to G 0 G 1 is equal to volumetric heeling moment divided by displacement into storage factor.

All of them are given: VHM is given, displacement is given and storage factor is also given. So, from this you get lambda 0 is equal to 0.2 and lambda 40 equals 0.2 of 0.8 of this which is 0.16. It should have been 0.16 but they have got 1.16. That is not correct, 0.16 meter. So, it should be 0.16 meter. Actually in this book unfortunately there are lot of spelling mistakes and errors, lot of errors are there. So, you do not get confused there are mistakes.

So this you get then, what are you asked in this term question? First of all you are asked to find because of this, what is the heel that is produced as a result of this volume because of this grain shift. You are told that there is a grain shift and we have calculated the grain shift. What is the shift in this? Remember this lambda 0 implies G 0 G 1. G 0 G 1 is a horizontal shift in the center of gravity.

So lambda 0 and G 0 G 1 represent a horizontal shift in the center of gravity. As a result of which there will be a heel. Now that heel you are asked that is the first part. You are asked what is the heel.

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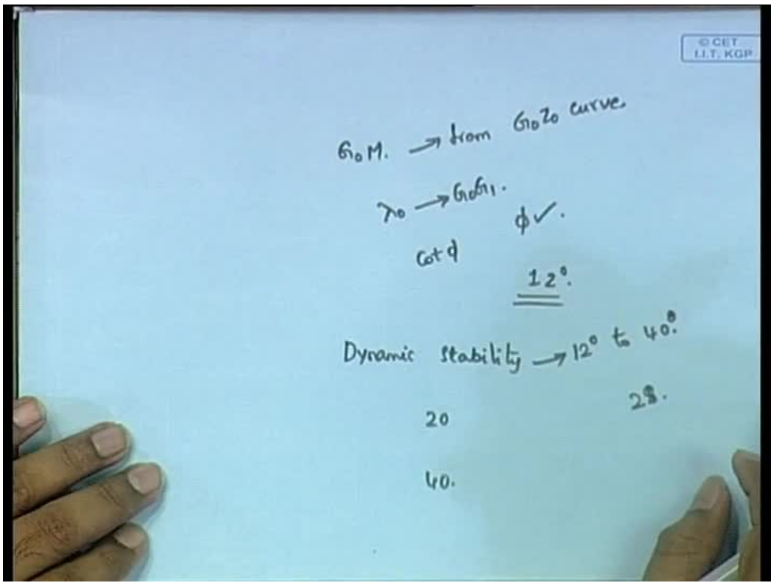

Now how will you find the heel? Same formula - inclining test - that formula. You just have to find your GM G 0 M from the GZ curve or G 0 Z 0 curve. Then you get lambda 0 you have got which is G 0 G 1, from that you will get your G 0 G 1 and GM G 0 M you will get your cot phi or tan phi and you have to get your phi. This method is the way to solve it and that is the first thing you are asked - what is the heel is. So, then, that comes out about 12 degrees in this case.

So the initial heel is 12 degrees. Then your next question is find the dynamic stability up to this, starting from this angle of heel up to 40 degrees means dynamic stability, from 12, from this angle of heel that is 12 degrees to 40 degrees.

So 12 degrees to 40 degrees you have to find the dynamic stability. We will use the same method. You do one thing. You find the area from 20 degrees to 40 degrees or what is it given in steps of 15. In this problem, it is actually, GZ table is given in steps of 15 or is it 15, then you cannot find from 20 to 40 also, then the best thing is to do the Simpson's multiplier only. You read the GZ values and from that you find the value of GZ for each of those and you find the area, there does not seem to be any other way because 12 to 40 degrees there it is given in steps of 15 30 45 like that. So, 20 to 40 the problem is from graph if you are reading it, you might as well do it straight. 12 to 40 you divide it into, there is no point in it. There is no point doing twice.

So you have to read from the graph, there is no other way. So better to just read it and get divide it into 12 to 40. It is actually very difficult because h how will you make it uniform? You have a distance of about 20, how much is it? 28, 28 degrees difference, you will have to divide it into a couple of points and do it. May be in 7 steps of 7 you can do it, 12 19 like that you can do and come up to 40; that is better.

Now, the next question is, are these values of GM heel and dynamic stability satisfactory. I tell you what we mean by satisfactory; that is, there are some rules as far as grains are concerned, it is like this.

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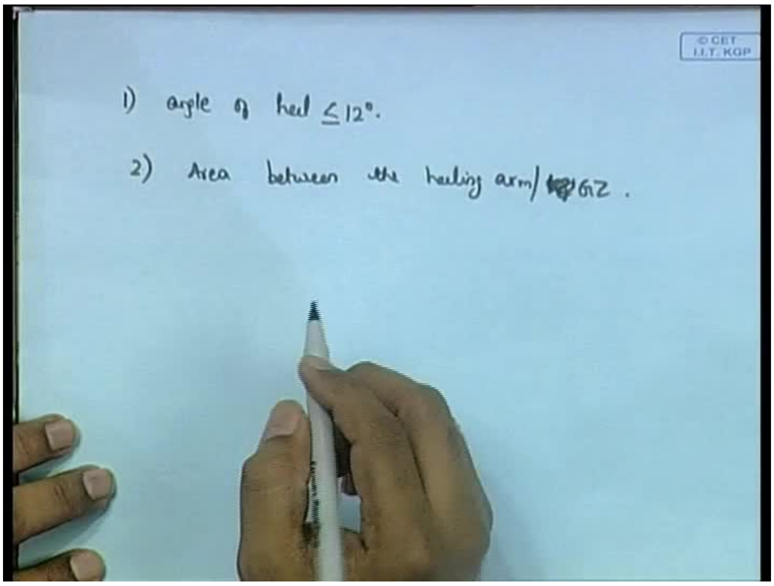

Now the first rule is that you have to by heart these rules, thes; so before this I did some rules regarding, what was it? About the dynamic stability, some area should be less than, should be greater than, GZ should be greater than, like couple of formulas, it should be less than some 0.03 meter radians or something I said. So those rules you have to remember but when it comes to grains, do not follow those rules. You have to just attend the class only, there is the no other way you will know. So you have that do not follow those rules if you are asked, if does it satisfy the stability requirements, do not go to those stability requirements. They are wrong, they are not meant for these grains.

So when you have said grains, these are the stability requirements. That first one is that: the angle of heel due to the shifting of grains should never be greater than 12 degrees.

So, in this problem actually we got 12 degrees, it is like the marginal case that is pass; anything greater than 12 degrees is fail. So, it should be angle of heel should always be less than or equal to 12 degrees that is the first condition. So, that means that you have the ship, whatever happens how there is a maximum level to which the grains can shift because it's full, means it cannot shift, all the grain cannot shift here because it cannot get compressed like that. It will shift a bit, as a result of which G will shift, because of which the ship will heel a bit. This heeling should never exceed 12 degrees - that is the first condition.

Then that is the first rule. Then next is the area should not be less than 0.075 meter between; this is one thing I will have to explain. Anyway the area between or righting arm is called GZ.

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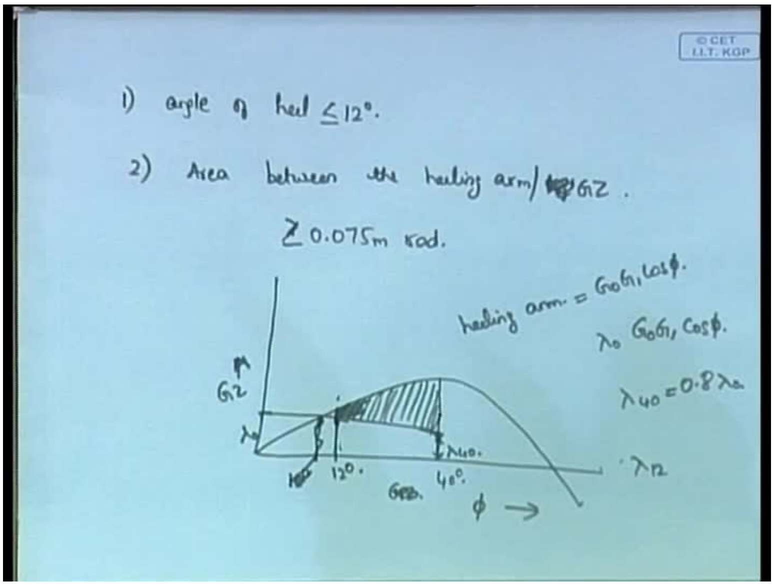

So the area between the heeling arm curve and GZ. I will tell you what a heeling arm curve is, anywhere in the middle actually, it will take time. So the area between the heeling arm curve and GZ, area means the area of the dynamical stability, means the dynamic, that it is not the dynamical stability, dynamical stability is delta into area. So the area itself they are saying should never be greater than or it should never be less than or it should always be greater than or equal to 0.075 meter radians. I will explain what is the area that they are talking about.

Now let me draw the GZ curve. Let us assume this is the GZ curve for that grain, this is GZ curve for the grain case. So, now we have seen that there is G 0 G 1 coming means a shift in the center of gravity, as a result of which it is heeling.

Now that G 0 G 1 is like a heeling arm, that is what is causing the heeling, so that is called a heeling arm. It is lambda 0, it goes from lambda 0, it goes, that heeling arm is actually changing. Heeling arm is G 0 G 1 cos phi this is your heeling arm. It goes from lambda 0 to lambda 40.

So your this is lambda 40 which is 0.8 lambda 0, lambda 40 is cos of that something like this you will have a heeling arm. This is lambda 0 and this is lambda 40.

So what is your heeling arm? Just remember this: heeling arm is the arm that is causing the heeling and this is what is causing the healing; and therefore, this, now what they are saying is that area between the heeling arm curve and the writing arm curve means, which area? This area (Refer Slide Time: 53:51). Let us say that up to 40 degree, this is 40, this area.

The angle, the area between the heeling arm curve and the righting arm curve between the angle of 12 degrees, let say this is 12 degrees; in this case or may be it is 12 degrees and from that up to, it does not have to be exactly this.

This looks confusing. 12 degrees can be, I will put this to be 12 degrees. Somewhere, it is 12 degrees, it is now from 12 degrees from here, from this point; so this area is what I am talking about. This area should be greater than or equal to 0.075 meter radians.

So that means you have to find this area. So what is the way to do that? You find integral G dZ from between these two values that will give you this whole area, minus the area of this trapezium, between this, that means you have to find lambda at 12. Lambda 12 you have to find; you have lambda at 40. You find the area of trapezium; subtract the area of trapezium from this, you will get the area, that we are talking about.

I will stop here that area should be greater than or equal to 0.075 meter radian is a condition for stability. There are some more but this is the main thing.

Thank you.