Hydrostatics and Stability

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Module No. # 01
Lecture No. # 34
Safety Regulations (Contd.)

We were talking about the safety regulations in the last class. We started with some of the regulations that are adapted by the different navy. We first of all saw that generally the safety regulations are formulated by the international maritime organization, the IMO, which is a unit of the United Nations.

Now, this code, that is the set of code or the rules that have been developed by the IMO, has then been adapted or modified for their particular purposes by the different navies, mainly the US navy. We will discuss here the US navies, the UK navy and the German navy. So, these navies, there are some differences in the rules, slight differences. For example, in the formulas for either the wind heeling arm or the turning moment, there are slight differences in constants, in the constants, in the equations and these have been adapted for the particular seas to which their ships travel.

So, first of all we will look at the codes by the IMO. We already gave some of the important rules associated with the IMO codes, that is that the area between, how the area between 0 to 30 degrees. Always note that most of the rules regarding the stability concepts revolve around what we call as the statical stability curve.

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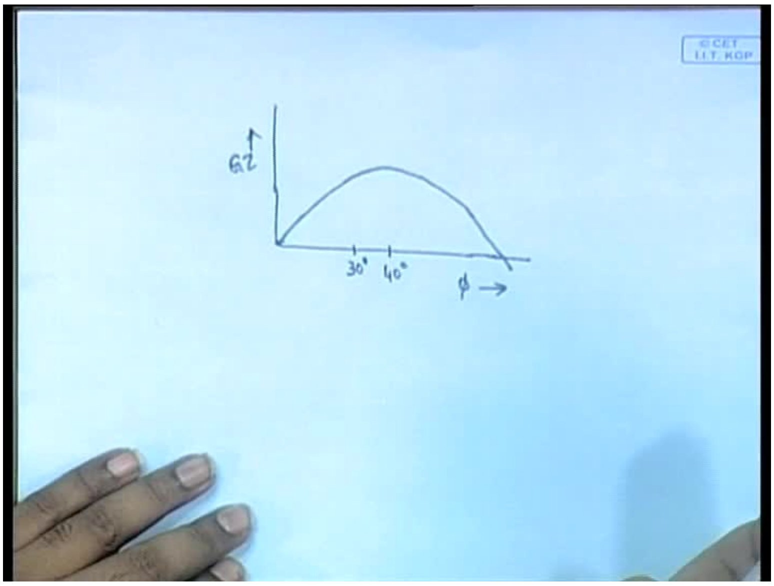

The statical stability curve, we have already defined. In fact, it is the backbone of this stability analysis. The whole course on stability, in fact revolves around this statical stability curve. This is the most important, so in case the ship does not have a loll, we draw the statical stability curve like this and the statical stability curve is also known as the righting arm curve or the GZ curve. This is the same thing as you know by now that is GZ is which we defined as GM sine phi is the statical stability curve.

So, GZ curve, so it is a curve between GZ with the righting arm and phi and we have already seen how the rules exist which state that the area under the statical stability curve should be less than or should be greater than point naught 55 meter radians between 0 to 30 point naught 3 between 30 to 40 like that. We described the rules yesterday. So, these are the basic set of rules around which the stability calculations and if stability check is being usually done in the by this classification societies like the Lloyd's register or the American Bureau of Shipping.

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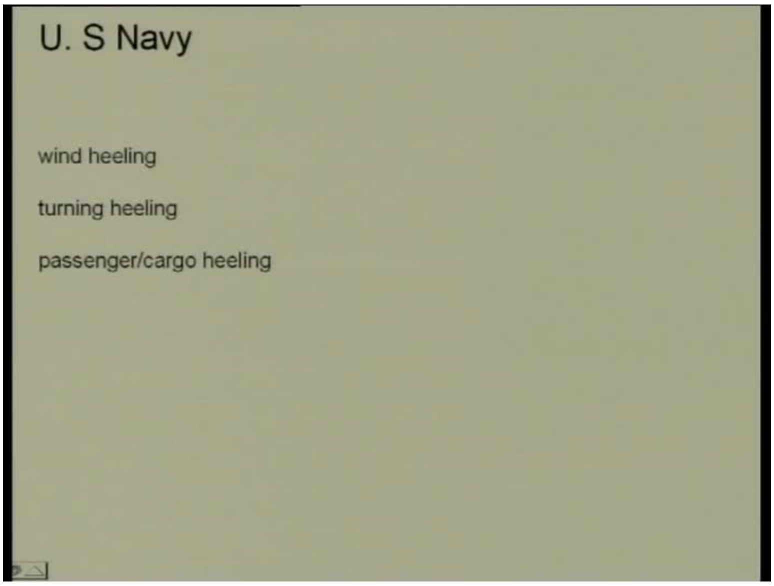

Now, some other important we will also check some of the important rules associated with the different means. In general, we see that the stability rules for any particular navy whether it is the US, UK or German navy or Indian navy, the main set of stability rules are those associated with wind heeling. As you can see here, wind heeling, then the turning heeling, then passenger and cargo heeling.

The meaning of wind is the wind acts like this. It produces a heeling. What is the stability criterion of the ship when it is subjected to different ranges of wind? As we will see some of the navies, in fact classify their ships according to the different categories that is the navies classify the, for example, the German navy. For instance classify their ships into different categories depending on the type of winds to which the ship is subjected to. They do not classify it as the type of ship means they do not separate between. Let us say a tanker and a cargo ship or between a bulk carrier and a passenger carrying vessel but they divide it on that into categories on the basis of the winds to which the ship is going to be subjected to when it is on sea.

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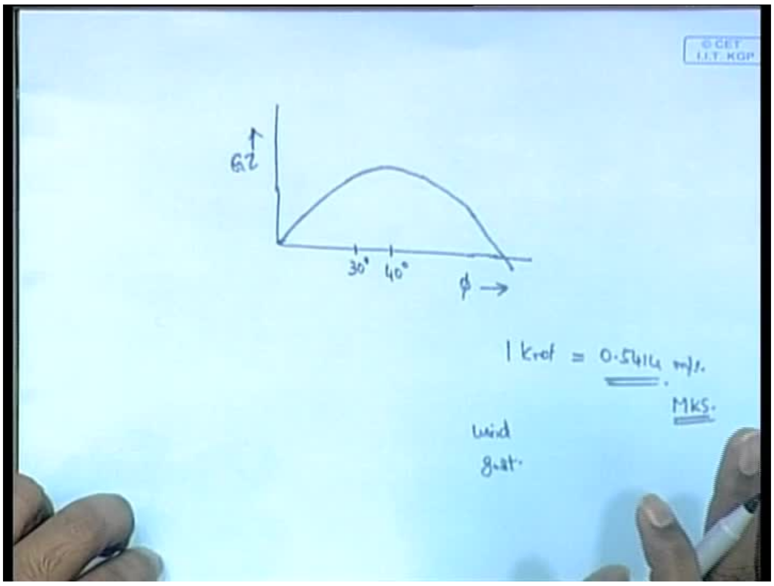

So, you know that the categories of winds can vary from, let us say 10 knots. In actually, 1 knot wind is it is a unit of distant unit of velocity. 1 knot is about 0.5414 meter per second. So, this is what you meant by a knot. So, usually winds in meteorology are usually defined in terms of knots. Of course, they can also be measured meter per second which it comes in the MKS units.

So, this is what we call as a knot. So, usually the ships are classified on the basis of the winds that they are subjected to starting from about 10 knots which is a very calm ocean which you will see in some parts and sub it goes up to 20, 30, 40, 50 knots. 50 knot winds are possible. We are talking about 25 meter per second winds. They are very strong winds. They are found in some of the regions of northern sea Baltic, ocean Baltic sea etcetera.

So, these are regions with very strong winds and gust is another word that is used. Wind we call it as wind and as a gust to slightly to slightly separate meanings the meanings. It is like the difference between a steady force, constant force acting for a long time on a ship and a sudden impulse. You must be the familiar with the difference between the two. By a sudden impulse, we mean a very strong force or very some force that is acting for a very short time. So, it produces a very strong impulse on the ship or anybody, so that we call it as a gust. So, that means a very strong wind is acting for a very short time.

Now, as we have seen we have a studied the course. We have divided the course mainly in terms of two topics means we have approached the stability from two points of view. As you remember, we have approached it from the point of view of static stability and then we approached it from the point of view of dynamic stability. The difference between the two is this. That is first of all static stability we talk about a ship in static condition. It is not really subjected to very strong impulses. By impulse we mean something sudden acting for a short time but on the other, some sudden transient phenomena we call as steady state and unsteady state.

For example, a steady state. By the means of a steady state, we mean a situation where it is steady as a function of time means it is not really a function of time. It is constant and in the case of a transient state or an unsteady state, we talk about a situation that is changing with time. It can be very rapidly, it can be very slow moderate continuous change.

Now, these two categories of studies we have been incorporating into this we have done in this course and I have already in some of the lectures, somewhere I have mentioned that I have mentioned to you the importance of dynamic stability over static stability. Now, static stability is the first stability concepts that were developed in the 1900. They were developed and they are sound, very strong. It gave very good results and they were able to make the ships fairly safe and all that but there are some conditions when you have very transient phenomena. Very highly impulsive phenomena means phenomena where the some in this case, let us say the wind acts not for a continuously, it is not a constant wind of 10 knots acting in a steady form of over let us say a day or two days.

On the other hand, it is a very strong gust of wind when something like 50 knots as we said or 40 knots suddenly acting over a short range of time of let us say 1 hour. So, when you have such a gust of wind, it is not solvable using the statical stability concepts means it is not a static state. It is a very transient or highly dynamic state.

Now, such a concept can only be studied using a dynamic stability concept which is what we mean by the dynamic stability curve. Dynamical stability analysis, remember that we said dynamical stability we did the statical stability first where the conditions for stability was just that GM should be greater than 0. Now, that is true of course in a statically steady state, the fact that GM should be greater than 0 holds for all ships which needs to become stable in an upright conditions it holds but to add to that the fact is that this condition is just not enough. You need more variables. There are more variables and there are more conditions that need to be met, more criterions that needs to be met if a ship has to be completely stable when it is subjected to sudden transient dynamic phenomena like a gust of wind.

So, in this case we come up with the dynamical stability concepts. The main of which is the concept of dynamical stability and dynamical stability as I have defined as the area under the delta GZ phi curve delta into GZ on one side, on one axis and phi on the other side or the other axis. So, the area between these two curves is what we call as the dynamical stability curve. The area between this curve is known as the dynamical stability and dynamical stability if you have clearly understood the concepts, you will remember that dynamical stability actually involves the area that has been transferred into the ship because of a sudden, now if a sudden gust of wind. It does not matter whether it is a transient sudden phenomenon, an impulsive phenomena or if it is a constant steady in flow of energy into the ship, whatever it is.

It is finally a transfer of energy from the wind into the ship and the concept of dynamical stability always states this concept into mind. It accepts the energy as it accepts the energy into the ship, that total energy is taken in and this energy is then expended in to heeling the ship. Once the ship heels, we calculate based on the amount of energy that has gone in how much the ship heels and then we say that if the ship heels to less than this particular final heel, then the ship is stable. This is a concept of stability and so, here we are going to deal with the concepts of dynamical stability and the formulas related to that. That are been laid out by the IMO. First is the one that are dealing with the wind concepts. We will go into wind as I have mentioned in the last class, the wind lever.

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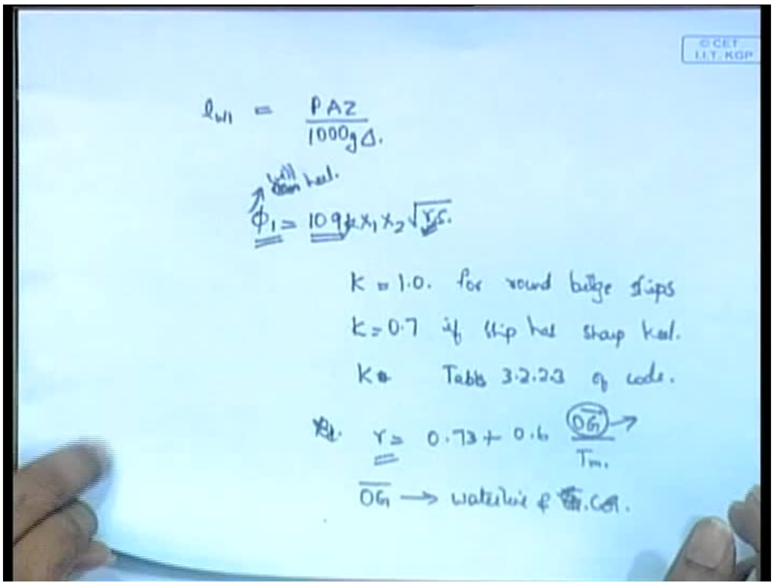

Note, that this is the wind lever due to a constant wind, steady wind. Wind lever is given by PAZ by one 1000 g delta. This is how the IMO defines the wind lever. Now, here P represents the wind stress which is in case you are not familiar with hydro dynamics. Stress is defined as the force per unit area in that tangential direction. Stress is always defined in tangential direction and pressure is defined in a normal direction. That is so if you have a structure or in the fluid and a structure, the force acting normally on the structure, we call it as force per unit area. Acting normally on the structure, we call it as pressure and the force acting tangentially on the surface per unit area, we call it as stress.

Now, due to this wind, therefore P in this equation is the wind stress which we put the maximum value. We put it as about 540 Newton per meter square. A is the sail area. Sail area means it is the windage area; it is the amount of area in the ship which is subjected to the wind. So, when the wind comes like this, if the ship is standing here, this area that is subjected to the wind is what we call it as the windage area.

So and Z here represents the vertical distance between the centroid of the windage area and the half draft and I am sure you remember, I have already explained. So, this distance is called as Z delta is the displacement. So, once you have these quantities, you can get the wind lever. Now, how do we calculate the wind gust? We say that the wind lever due to wind gust is about 1.5 times, the wind lever due to a steady wind. It is just an average value that is it is something like a maximum value. That is the maximum lever that can happen due to an increase in the wind and acting for a short time that lever is given by 1.5 times l w1.

Now, we have a couple of formulas developed by the IMO for the amount of heeling that is allowed due to wind. Now, it is given by this formula where phi 1 is equal to 109 KX 1. I will explain what each term is root rs, this is the basic formula that is given for this is the amount to which it can heel or it is the amount to which it will heel. Sorry, not can heel, it will heel provided the wind is I mean provided the ship is subjected to a wind. This is the amount. This represents the amount to which the ship will heel and 109 is a constant K has some values depending upon the type of ship. For instance, K equals 1 for round bilge ships.

Now, in case it is not familiar what is meant by bilge? We usually talk about the keel region of the ship that is the region exactly at the bottom. Now, that the keel is defined as region at the bottom, most part of the ship now that the structure of the ship along the keel is what we call as a bilge. Now, if you have a round bilge as the name itself suggests, if you have a round bilge we give the value of K as 1. K equal 0.7 if the ship has sharp keel. It means very abrupt or very sharp keel and K; this is how it is given in some table 3.2.2.3 of the code. By code, we mean the IMO code and in that code, in that table there is a set of, there is a booklet which will give you the entire set of code and in that there is a section that deals with the winds. In that section, that this table number will give you the values of K for the different types of ships where you have ships with round keels, bilge keels. I mean round bilge or sharp bilge etcetera. So, different types of keels are possible or different types of bilges are possible.

Now, so this is how K is measured. Then the next step is to get X1. X1 is measured using, before that there is r. I will tell you what this r is? This r is defined as 0.73 plus 0.6 OG by Tm. This is the definition for r. We will go one by one, so K we have defined. So, this is r and r is defined as 0.7. Now, for those who are familiar with scantling calculations and like who are familiar with the construction of ship as such, those who are familiar with the when you are making a ship, you make the scantlings. You know the bulk heads and when you define those stiffness when you define, like you will see these kind of in that booklet that you deal with these stiff these keels and stiffness and all these spacing and all that.

You will see that you will come up with such formulas. These are commonly seen, so r is equal to 0.73 plus 0.7. This is a formula for this. This thing this r and here, OG represents the distance between the water line and the center of gravity. So, you have the center of gravity of the ship and the water line of the ship. Now, the distance between the two will be given by OG here and T m in the equations represents the full draft. T m is the draft and so once you have that, you get the r value for this equation.

Then now, we have usually you have also we have already mentioned that in case that a ship starts heeling, there is sometimes that dynamic process of heeling where the ship moves to and fro is known as a rolling. Rolling means heeling as a function of time or rather heeling continuous like heeling is a static phenomenon. It heels like this and stays that, that is called heeling but if it is going to and fro like this that process we call it as rolling.

So, it is slightly different. It is one of the 6 degrees of freedom like you know there are 6 degrees of freedom means it can move like this, like this, like this. It can roll like this, like this, like this, so that produces 6 degrees of freedom. It is a part of the different course like you will see it in dynamics course, ship dynamics course. So, these degrees of freedom produce the different types of motion. One of which is the roll. Roll is this kind of motion. It is an angular motion; it is not really a displacement motion like this. It is not like that, it is a rolling motion.

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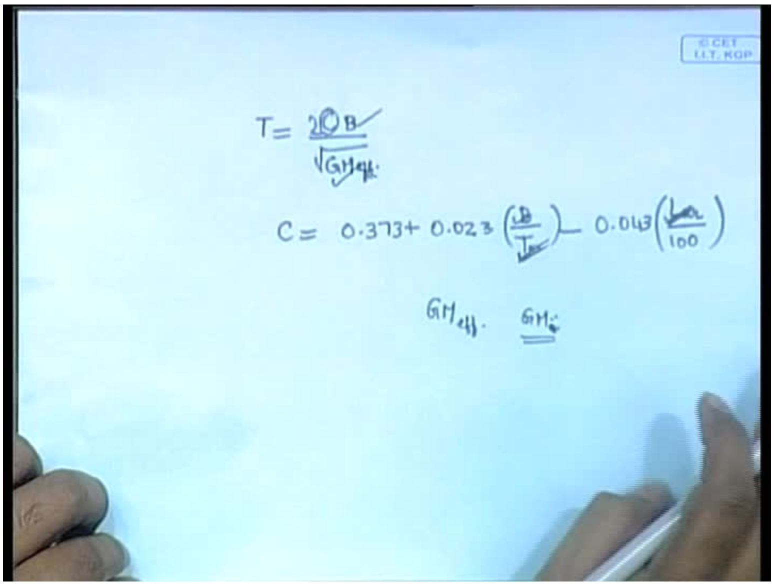

Now, this rolling motion is the time period of rolling is defined as CB by root GM effective, so the effective GM of the ship. This is now we are going to explain that equation for dynamic but in this comes and between that is the time period is given by 2C, where here B is the breadth of the ship. We know what it is. C is a constant that is given defined as now this is a big equation. This is equation that tells you how to calculate C which is a constant in this. You see this C, so C is given by this expression 0.373. This thing where here B is again the breadth of the ship, T m is the draft of the vessel and L WL is the length between the water lines. So, you have this, you have this, you have this. It is just a constant depending upon all this and C B divided by GM effective. You know the GM effective is the metacentric height. The effective metacentric height of the ship and how will it vary from the net GM of the ship or the initial GM of the ship? It will vary from the GM of the ship if for instance, if you have a free surface effect already defined.

What is a free surface effect? That is in case you have a liquid in a tank inside the vessel and if the tank is not fully filled. In case the tank is fully filled, then there is no free surface effect but in the case when the tank is not fully filled but only partially filled, it will have a free surface and the free surface will tilt as the ship is heeling and this in turn will produce a shift in the center of gravity of the ship and things vary and the GM. So, if the G shifts, obviously the GM changes and this produces a GM effective which is different from the initial GM. GM initial or GM 0, it is not GM 0 but it is GM initial. So, this is GM effective. So, this will give you T which is the now the other the so we are going back into this equation.

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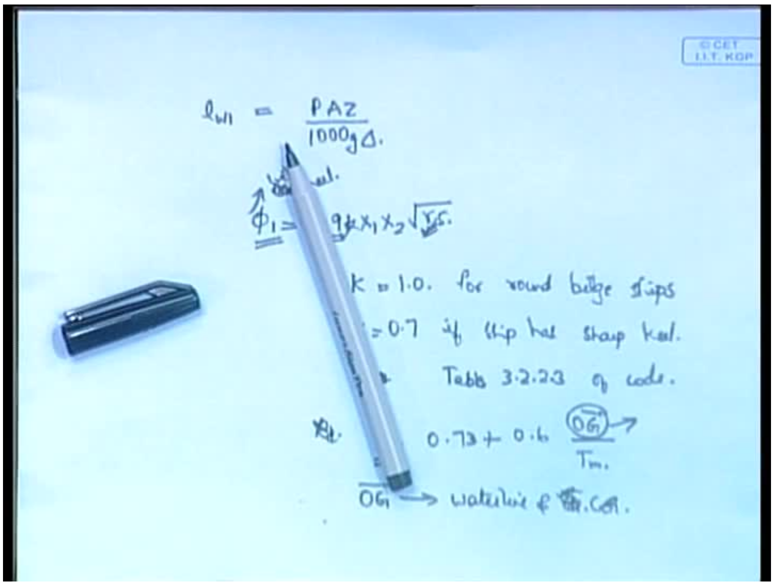

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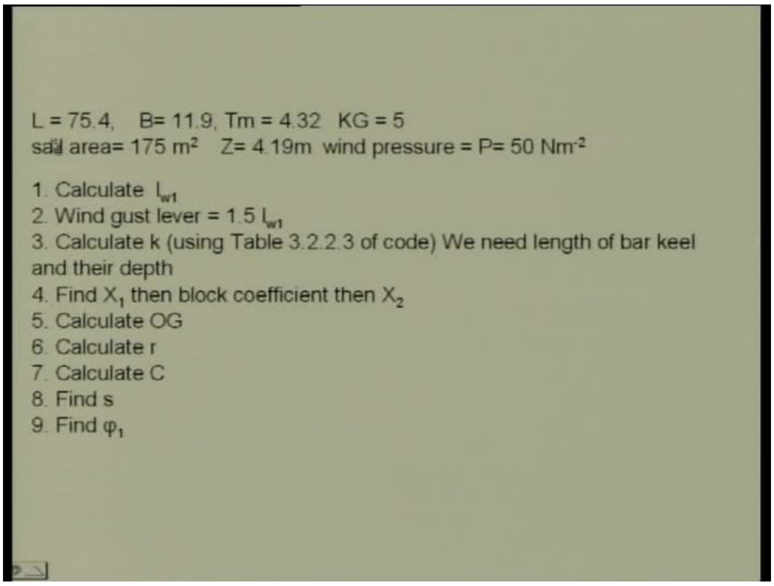

So, in this equation, now we know what is K r. Now, we need to know X1 X2 and s, so this is how to get phi 1 for in. We will see how it is done? We will we have an example here. Now, in this problem here you are told that some sections have been slightly cut off but that is so you have you are given a ship with the following particulars. You are told that the length of the ship is 75.4 meter, its meters breadth is 11.9, the draft is 4.32, KG is given as 5 meters.

You are given the sail area 175 meter square. Z we have already defined it distance between the centroid of the sail area and the midpoint of the draft. The half draft point, it is given as 4.19 and the wind pressure is P equal to 50 Newton per meter square.

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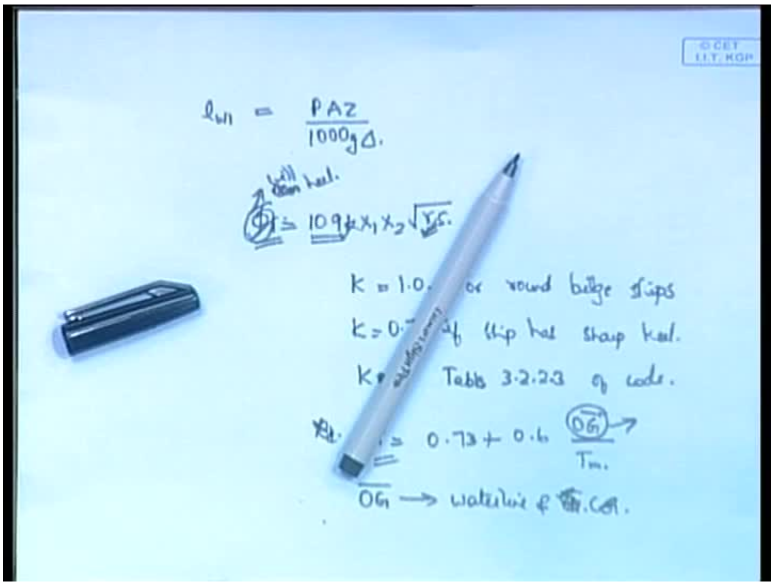

So, this is a particular case. This so you have given that these condition hold and this same thing we are doing like you, now have a let us suppose, you are now in the classification society and you are now given the problem that you have to calculate whether the ship will pass the test or not. So, if your idea is to become phi 1 which I have given here, this phi 1 needs to be calculated. This phi 1 is this one. Now, this phi 1 is to be calculated and so, you need to get all these value KX1 X2 rs. So, once you have that, you can calculate the net phi 1 of the ship.

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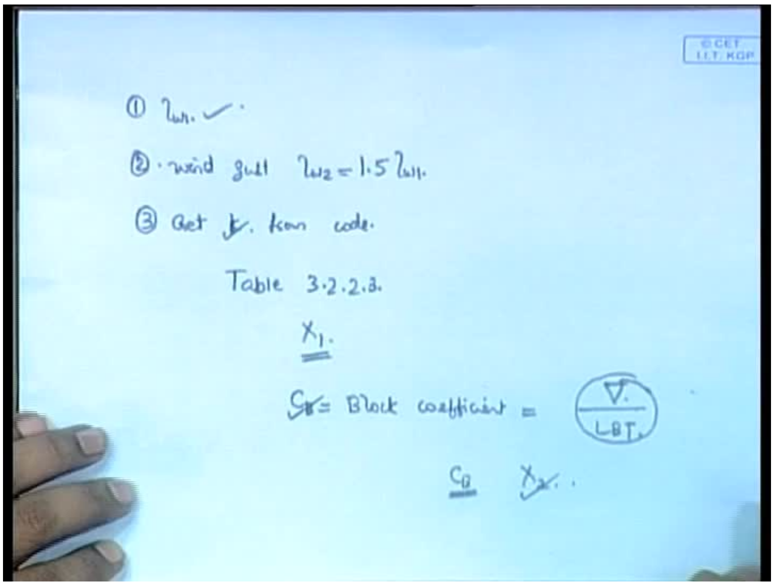

Now, let us see how they do it there? First of all, in such a problem you start with first of all you have to calculate l w1. You have already seen the formula to calculate l w1 PAZ by 1000 g delta. So, this will give you l w1 that is very straight forward. Then we say that the wind gust lever is defined as l w2. It is equal to 1.5 l w1, this is given. Then now, you need to get K for the code, you have to get K from the code. I have already given you two values of K depending on the type of ship. You decide what type, what is the value of K?

Now, once you are given the bilge, once you are given the type of bilge that is what is the length of the bilge? Bilge is the distance we have already said along the keel of the ship. This is the keel of the ship, you have the bilge. Once you are given the length of keel and the depth of the bilge, length of the I am talking about bar keel. It is a solid bar type of construction. It will have a length and breadth and width, so once you have the length and depth, length and depth as a function of these two values of X1 are given in the code.

It is actually given in table. Well, actually that number is not here. One of that I think it is 3.2.2.3 of the code. In this code, you have in this table, you are given the value of X1, you need the length and depth and once you have that, you get X1. It gives X1 as function of the length of the bar keel, then what you will need to do is then you will need to calculate what is known as the block coefficient which we already derived in the beginning stages of this course what is called as a block coefficient. So, this block coefficient is calculated you know that block coefficient is defined as del divided by LBT del is the under volume of the ship, L is the length, breadth B is the breadth and T is the draft.

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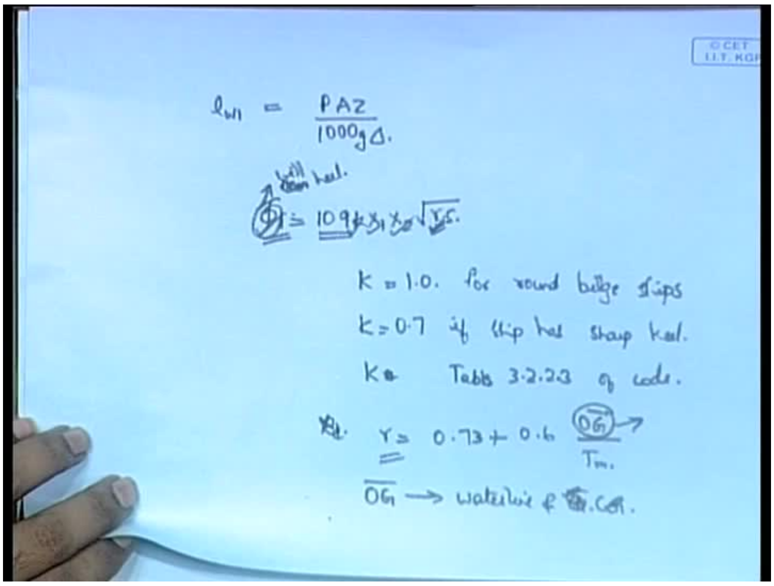

So, once you have that you will have to calculate del. You will have to calculate C B. You are given for this ship all these parameters are given. Now, once you have all this, you will need to calculate C B and you will see that when you look at the code that booklet as a function of the C B, the block coefficient of the ship X2 will be given. X2 which is again a parameter here in this equation, we have this parameter X2. So, this will be given as a function of CB, the block coefficient. So, once you have that, you will get X2, so this is how you get X2 then of course you need to calculate.

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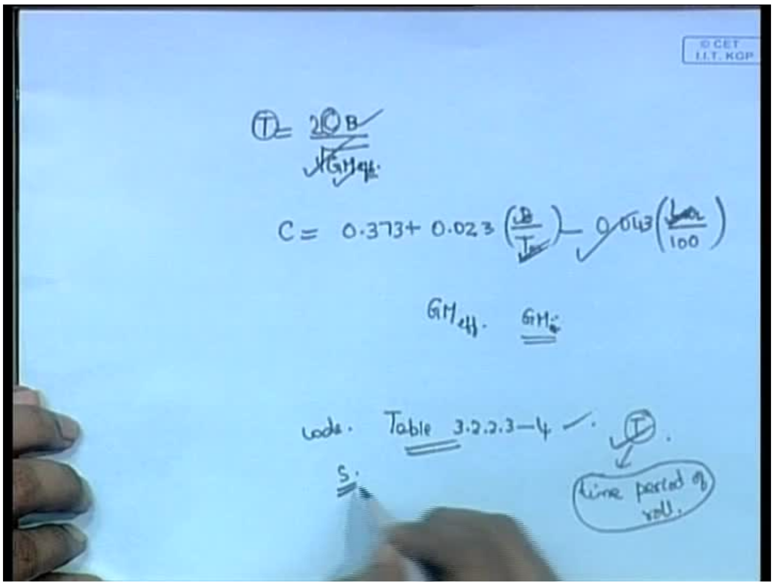

Now, the next step is to calculate this one, so the next step. Once you do this, the next step is to calculate OG. The next step is to calculate the C that is using this formula you get C and once you have C and B and GM effective, you get T. Then you will see that in the code, it is a slightly different part of the code table 3.2.2.3 4. This section of the code, this is all in the code booklet. The code this is the code that deals with the wind region or the wind statical stability laws or the rules.

So, you take this region, this code, this table of the code. You will see that once you provide T which is the time period of roll, please note what each thing is it is the time period of roll which is a function of the hydrostatic particulars of the ship depends upon the B the breadth of the ship. It depends upon C which also depends upon the length of the waterline. It depends upon the draft, so it depends upon the length, breadth and draft. So, that T 1 and it depends upon the GM that is the GM of the ship, the net GM or the effective GM.

So, once you have that you, so once you get the time period of roll, this one, so once you have this, then you go into this table. It will give you values of s as a function of time period here.

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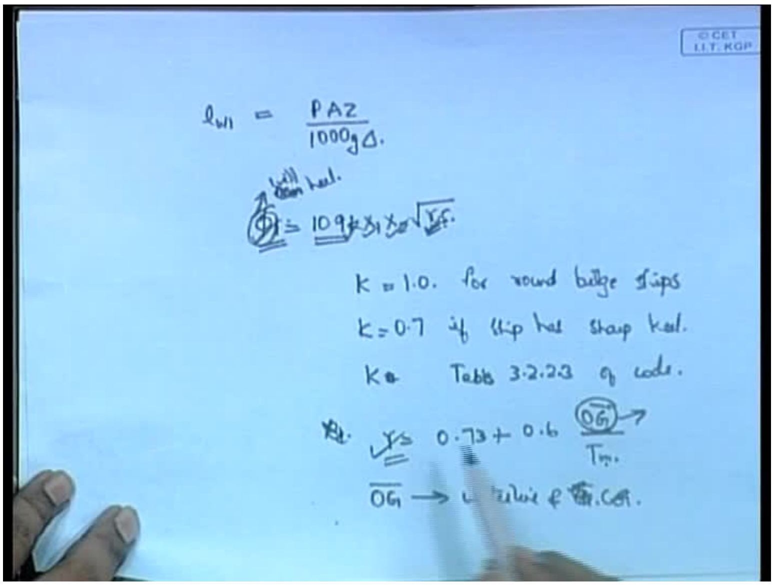

Now, this is the way. Now, you have s r you have already I have given you the equation. Here, r is this. So, we need to calculate OG. Next, OG is the distance between the waterline and the center of gravity of the ship, so provided you know height KG which is the given as you have seen in this problems KG is given. So, once you have the center of gravity of the ship and you can find the distance up to the waterline and once you have that, you have the draft also, you can get r.

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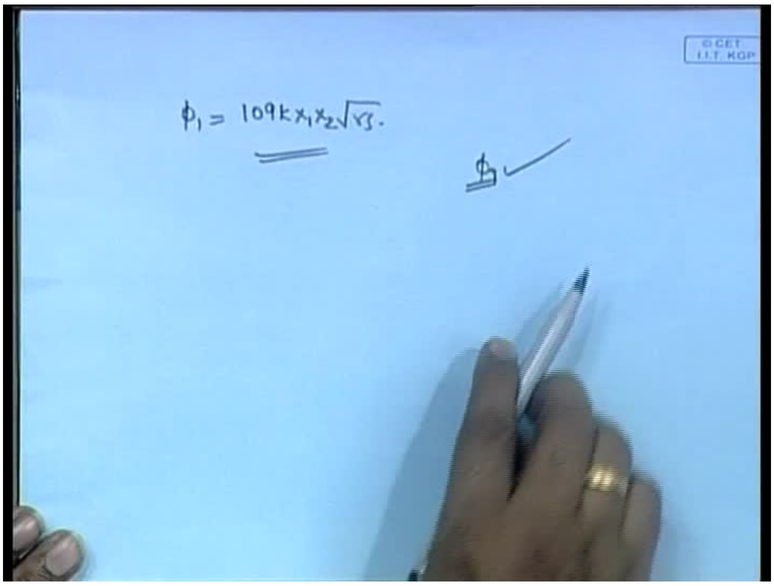

So, once you have all this, all you need to do is put it in this equations phi 1 equals this value that is 109 KX 1 X 2 root rs. They put it in this equation and then you will calculate the maximum. So, this gives you the maximum angle to which your ship will heel, phi 1 will give you the maximum angle to which your ship will heel. So, this value will have to be less than some prescribed values. For instance, it will depend upon the type of ship. So, IMO says that for particular types of ships, for instance whether it is the tanker, cargo, bulk carrier any type of ship or a cruise vessel. So, different types of ship will have different values of limits for phi 1, not very different. It is somewhere around 30 degrees, 35 degrees. So, you will have that limit for phi 1. It should not heel beyond that due to wind, so this is the phi 1 and this is criterion that is usually followed by the different navies in calculating the wind.

This is one way of doing it. The real IMO, the whole series of wind heeling arm equations and the wind heeling arm formulae, we have actually done it somewhere in the middle of the course, may be around lecture 17 or 18. It must be coming. You will have that wind heeling arm. We have talked about the wind heeling arm that whole theory which you know that is the research part of it. That how that wind heeling arm is really to be studied? How to see? How much the wind will heel? So, this is roughly, this is a simple formula, this is a simple series of formulas that can finally and using this you can give some guidelines about whether the ship will be stable or not but this is what is it followed by the IMO. This is what IMO has developed as such.

Now, therefore you find phi 1 the maximum angle and you check whether it is less than the allowed value which is given some fixed values or if it is less than the angle of flooding angle of deck edge emersion. So, once you see these, you once you compare with these, then you will decide whether the ship is acceptable or not.

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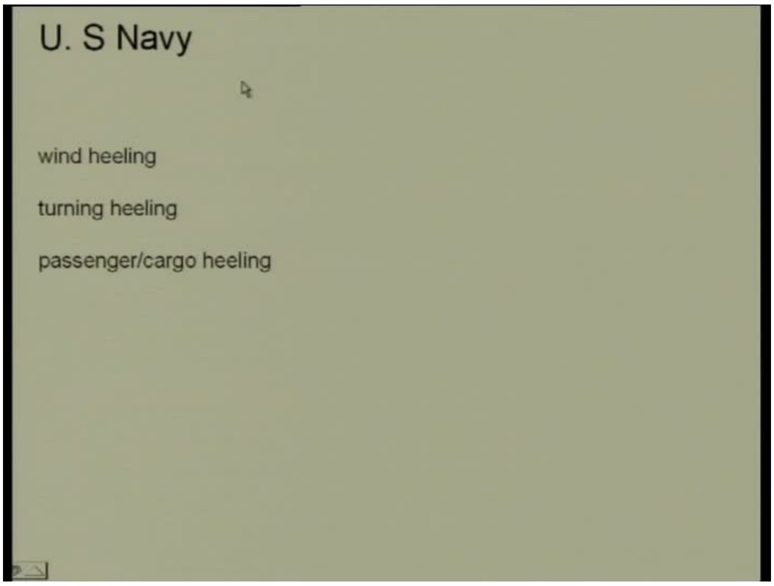

So, this is first thing that is weather criterion. Then we will go into the US navy as so these are related to the IMO, so the international maritime organization. Now, slight modifications have been made by the different other navies, so the different navies like the US navy and the UK navy. They have developed their own set of codes which are slightly different from the IMO. They have adopted it for their own purposes and for instance, one some of them I will mention some of the important points.

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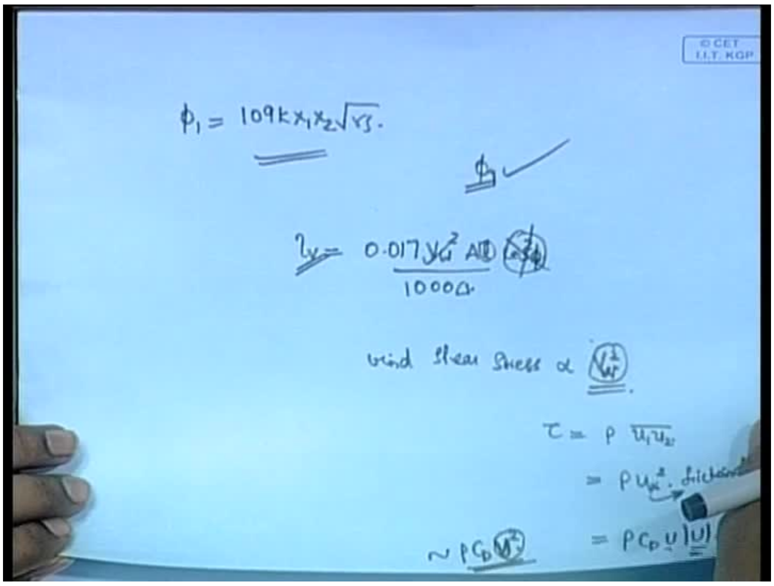

For instance, US navy says that the wind heeling arm is defined as l v is equal to 0 point naught 17 V w square Al cos square phi by 100 delta 1000 delta.

Now, we can compare it with the formula that we have already given for the wind heeling arm by the IMO. Some terms have been replaced and now first thing you can know, you should know probably is that in the previous case, we had an expression called P or we had a variable call P which represented the wind stress which we defined gave it a maximum value about 540 Newton per meters square that is a tangential stress per unit area, tangential force per unit area or the tangential stress which is acting on the which is acting due to the wind, so that is P.

Now, in this case the P variable for by the US navy, they have replaced that P variable with a V w squared where V V w is the velocity of wind. So, V w squared the logic behind this is that always you will see that when you are going to meteorology, we will see that the wind stress can always be measured as a function of not measured. Actually, the wind stress is directly propositional to the wind velocity squared that is the shear stress or the wind shear stress is always prepositional to V squared V of wind squared this thing.

So, in fact its tau is really equal to rho. The real definition of tau is actually rho u1. This is slightly outside the purview of this course but like tau is usually defined as rho u1 u2 where u1 and u2 are the turbulent wind velocities.

We usually, when you have wind we define it as u is in this direction in the x direction, u1 u2 is in the y direction and u3 in the w direction. Wind stress is always due to the horizontal components of wind. You can know that the horizontal components of wind are u1 and u2 or which we call it as u and Vw which is the vertical component of the wind does not really come into the calculation of wind stress. Wind stress, therefore follows u and V which is u1 and u2 and in general, the wind stress is given as u1 u2 and this in general is written as, so this is rho u1 u2 gives the wind stress where rho is the density of air, u1 and u 2 are its velocity, turbulent velocities and this has been written as u star squared where u star is actually known as the frictional velocity.

So, u star is known as frictional velocity and this is written as this is roughly like this which in fact, becomes something like rho CDU, squared u is the net velocity of wind and it is the real definition is U into modulus U but you can reduce it to U into U. You can put it as rho CDU square.

So, what you see is that the wind stress is in general propositional to the velocity of wind squared. So, what the U S navy has done is, they have replaced the equation for P. They have been replaced with the value for u square, u w square and therefore, the formula reduces changes slightly into this format l, small l here. This is then small l here represents again the distance between the centroid of the windage area and the midship. Not midship, the distance the centroid of the windage area to the mid draft. The distance between the mid draft and the centroid of the waterplane area is l, so that is all right and phi is angle through which it is heeling.

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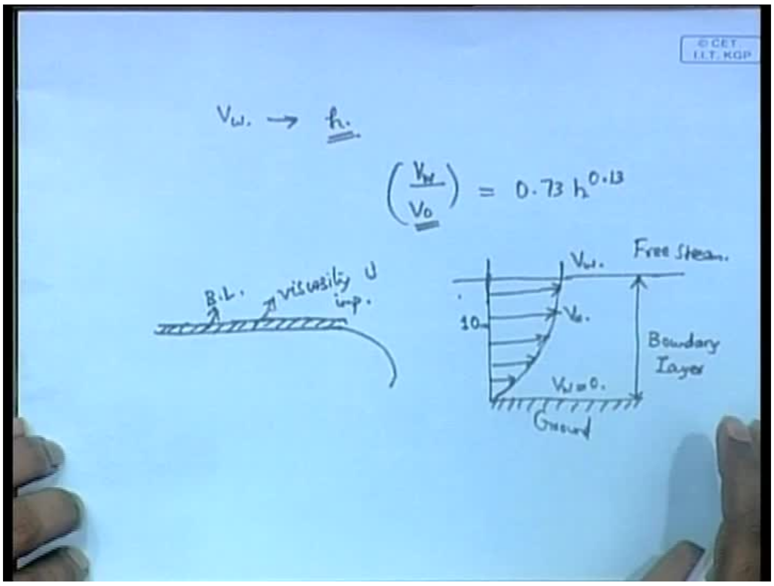

If it happens, this is this gives you; this is at any angle of heel which is away from 0 degrees. If it is not 0, if it is 0, of course this term becomes 1. It is not there, it is just this at any other value, it becomes cos square phi. So, it gives you, so this is slight different and here, usually we talk about V w. So, here what we are saying as V w, I mean this is again a little bit out of hydrostatics. We are going slightly into fluid dynamics.

So, we have here V w. The wind velocity is usually talked about as a wind velocity at a height of wind velocity at any height h we V w in general this is given by the formula. This is again given by this booklet. For this code booklet for the U S navy, they write it like this. So, this is V w represents the wind velocity at any particular height that is at any arbitrary height and V naught, we have given they represents the wind velocity at height of 10 meters.

Now, there are some criterion, you will see there is some behind the taking of 10 meters because that is kind of taken as a rough value of the boundary layer thickness and therefore, roughly the boundary layer height can be taken as 10 meters over the sea. So, that is why the 10 meters comes. So, for instance whenever we talk about meteorology, they always when we talk about sea surface height sea, we are talking about the surface wind that is by surface wind. We mean the wind that is blowing close to the surface whether it be the land or the ocean, when we say surface wind, it is actually measuring the wind at the height of 10 meters from the ground. That is a standard normal practice is always at 10 meters from the ground. Now, so this is ratio, this is the relation between wind at any particular height which is at different from 10 and this is at 10 meters.

Now, in the reason being in general, you will see that the wind profile is always like this. If you consider this to be the ground, the wind profile will always look like this. So, the wind profile in general will look like this. As a function of this is the velocity of wind, it will look in this as a function of height from the ground. So, at the ground, immediately at the ground you will see that the wind velocity is 0 and slightly the wind velocity increases and somewhere around 10 meters, we define 10 meters at this height. We define V0 and Vw is at any other height apart from 10 meters. So, this will give you the V0 and this is the general profile of the wind in the boundary layer. In fact, this is not just the profile of the wind in a boundary layer. This is in general the profile of any velocity, any horizontal velocity if you look at the profile of the velocity in the boundary layer, it follows somewhat this pattern. It is again not directly in this course but you should know that.

What we mean by boundary layer? It is a this boundary layer is a result of a fluid structure interaction. What we mean by fluid structure interaction is when you have a fluid whether it be the air or water, when the fluid flows over a solid which is any kind of solid. In this case, we are talking about ground and the air is flowing over ground. So, when there is interaction between the fluid and the ground or between air or in this case air and the ground or between water and a ship. For instance, there is always a region very close to the surface of the ship like this. There is a region very close to the surface of the ship here like this. If this is the ship or if it is a ground, in close to the ground this region where the process of viscosity is very important and this region we call it as the boundary layer.

The BL represents the boundary layer. It is a note that it is a very small region close to the body, in some cases not even more than a few centimeters, may be 10 centimeters thick that is what we call as a boundary layer. It is the region where it is a region, the easiest way to define a boundary layer or the simplest way to define a boundary layer is one is where the viscosity is very important. Number one but a real way of defining a boundary layer is you say that these are region where the velocity gradients are very large by velocity gradients. You know that it means dou u by dou y or dou u by dou z means the velocity varying over the boundary layer is very large. The velocity variation over the boundary layer is very large and that is the velocity variance like this fashion like you see here.

For instance, if you say that this is the whole region of boundary layer, we say that this whole region in this whole region the velocity changes very rapidly. So, the velocity changes very rapidly here. It varies from a value absolutely minimum value at the ground and it increases to a maximum value and outside the boundary layer. We call that region as free stream. It is outside the boundary layer and there the concepts of boundary layer and there you hardly have any variation velocity. So, this gradient in velocity is very small when you come to the free stream or what we called as a region outside the boundary layer.

So, and fluid dynamics inside the boundary layer is much more complicated than what happens in the free stream because as you can imagine, it is a case of free stream plus fluid structure interaction. So, fluid structure interaction produces a lot more complexity in the form of turbulence and boundary layer phenomena which affects the overall flow structure in that region. So, that is again out of subject, it is not necessary here.

So, the American navy have the US navy have defined their stability criteria for the ships. Based on all these criteria, they have considered all these. They have developed a slightly see difference set of law that deal with the stability of the ships as a function of this. Now, it is a function of wind velocity and not really stress and they have talked about the variation with height and all that and finally, you get this slight variation. So, US navy various you see the slight variation from what we call as the from what we said as the IMO criterion.

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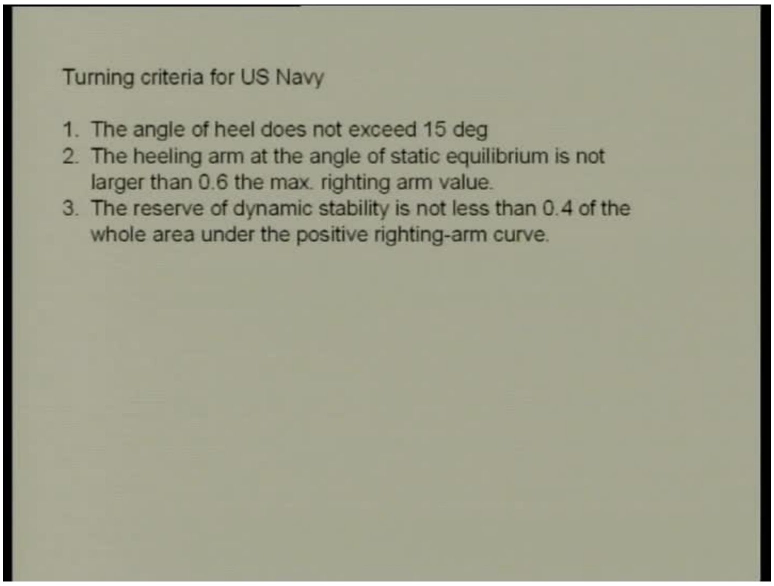

Now, even the turning criterion, in the case of turning criterion there is not much of a difference. We will see here what is the turning criterion right. Here is given this is the turning criterion given by the U S navy. Now, it is imperative that it is very important that the angle of heel at any point during the turning does not exceed 15 degrees. So, when the ship is heeling, you have already seen the expression for the turning moment and the turning lever and because of this lever note, we can we have drawn as you remember we have already drawn curves between the curves for statical stability with the turning arm.

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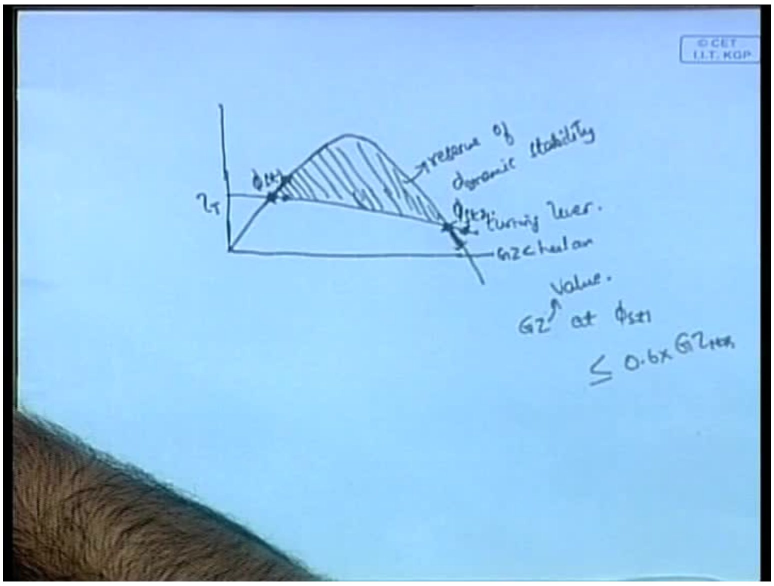

So, you have the curve statical stability. If you draw this, we will call it this is the l T. This is the turning lever and so, this is the righting arm and this is the turning lever and now, this region this area we call it as, so this region in this curve, this region we call it as a reserve of dynamic stability. Now, the criterions associated with the US navy for turning are this.

The first criterion is that at any rate you should not have the angle of heel greater than 15 degrees, so that is fixed. Now, here looking at this figure, we defined already that statical stability curve I believe some time in the, somewhere in the, when we defined this, we also defined what is known as the angle of the static equilibrium. There we saw that we defined that the angle where the curve of statical stability that is the GZ curve the point where the GZ curve meets the heeling arm curve, so the GZ is the righting arm curve and l is the heeling arm curve. The point where these two curves meet is what we called as phi St which is the angle of static stability.

So, this is one point of phi St. We will call it phi St 1. This is the second point of the phi St which is called phi St 2, so you have two angles of static equilibrium phi, St 1 and phi St 2. Now, one important thing. So, the second point of this US navy criterion is that here you will see that the heeling arm at the angle of static equilibrium is not larger than 0.6 the maximum righting arm value. So, whatever is the GZ value at phi St 1, what we call as GZ value. The GZ value at phi St 1 should be less than or equal to 0.6 times GZ maximum.

So, whatever is the GZ maximum that is the maximum righting arm for that particular ship, for that particular GZ curve of that ship, note that every ship. Once it is defined will have its one GZ curve and once you define the GZ curve of a ship, you find out the maximum GZ that will happen somewhere around the middle of that or its somewhere around middle, usually from 0 to about 70. It will be around 40 degrees probably.

So, you have the GZ maximum and you have to find the GZ at the statical stability 1 point phi St 1 that should always be less than 0.6, the maximum value that is an important criterion for turning stability for according to U S navy. Now, there is one point that I would like to make here is about the phi St 1 and phi St 2. So, as you can see because of the shape of the curve and the shape of the two curves that is the GZ curve and the lever arm curve.

For instance, GZ curve goes up and comes down like this. Lever arm curve comes like this. You can see that they intersect at two points, so we have phi St 1 and phi St 2. Both are known as statical stability angles of statical stability. Both of them phi St 1 and phi St 2, both are angles of statical stability but there is a slight difference between the two because if you look at the first phi St 1, look at this figure. If you look at this phi first phi St 1, you will see that if the ship heels more than this, phi St 1 here let us suppose that the ship has heeled here, what do we see? You see that the moment it has heeled, further the righting arm is more than the heeling arm. At this point, righting arm is more than the heeling arm. You can see it directly from the figure. Not saying anything theoretical, just looking at this figure I am saying when you cross phi St 1, you see that GZ is greater than the heeling arm.

So, what does it mean? If you have your righting arm greater than your heeling arm that means immediately that the ship will try to come back to its original position. Therefore, it is a case of stable equilibrium, therefore what we talk about as phi St 1 which is your first angle of statical stability is actually a stable angle of statical stability. So, the first angle is stable but now consider the second angle, we are talking about the angle phi St 2 here.

Now, if you look at this angle phi St 2, it is a curve. You see that here suppose there is a further increase in heel, the ship heels a little further after it reaches phi St 2. It will go like this. You see directly that GZ is less than the heeling arm; you see here this is GZ, this is the less than the heeling arm, this is the heeling arm and this is the GZ. GZ is less than the heeling arm, this is heeling arm, so at the angle of second angle of statical stability, you have the heeling arm is greater than the GZ. So, you see that the second that automatically means the ship has a tendency to heel further, not to come back to its position. Therefore, it is not a point of stable equilibrium; it is a state of unstable equilibrium.

So, you say that phi St 2 is unstable equilibrium. So, your phi St 1 is stable equilibrium, phi St 2 is unstable equilibrium. So, these are two angles of static equilibrium that you have in a ship. Any ship will have these two and of course, there can be more if you have angles of loll and all that you can have more but if in a general ship, you will have two such angles and one of them is stable the other is unstable. So, that is one criterion.

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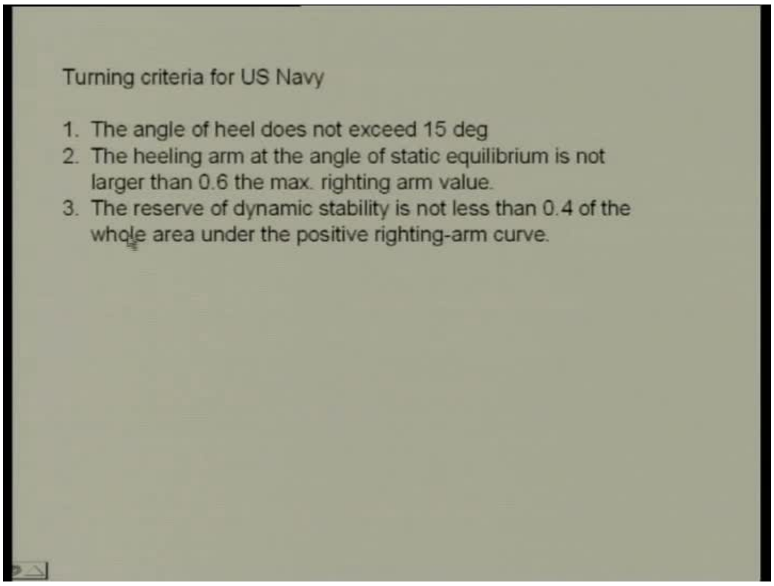

As I have said before, this area under this area that is between that is actually outside the angle of lever, this lever arm, this area is known as the reserve of dynamic stability. Reserve of dynamic stability and one rule of the US navy for this turning says that the reserve of dynamic stability is not less than 0.4 of the whole area under the righting arm curve. So, it is like this.

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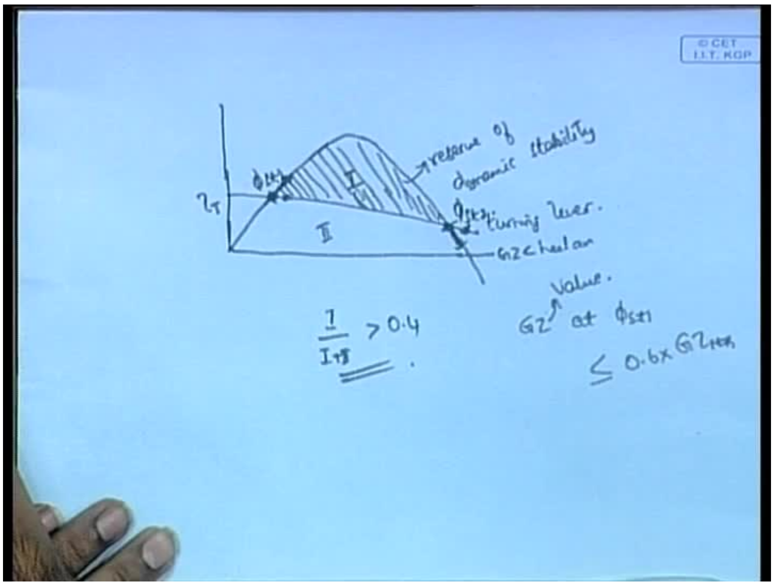

We say that the ratio between this curve which is a reserve of dynamic stability and the whole area, so this let us call this 1. Let us call this 2. So, 1 by 1 plus 2 should be greater than point 4. This is the meaning of the rule. So, if this is 1 which is the area 2 is this area, this unshaded area, so 1 by 1 plus 2 should be greater than 0.4. This is another criterion of the US navy for turning.

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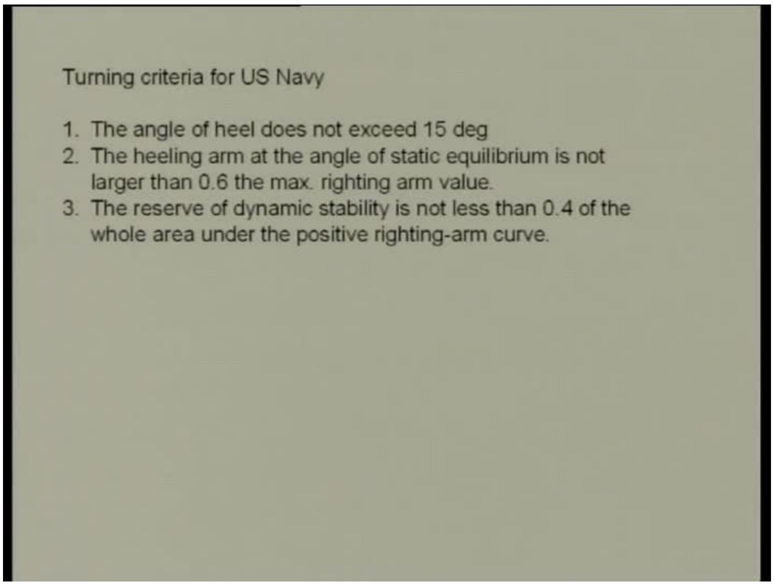

So, these are some of the rules of the US navy, some of the criterion of the US navy. Then we will next going to the UK navy. Since, the time is up, I will stop here for today. We will continue tomorrow.

Thank you.