Strength and Vibration of Marine Structures
Prof. A. H. Sheikh and Prof. S. K. Satsongi
Department of Ocean Engineering and Naval Architecture
Indian Institute of Technology, Kharagpur

Lecture - 20
Calculation of Momentum of Inertia of Main Section

What are the stresses in the structure and that is what we are bothered about and we say that M by Z.

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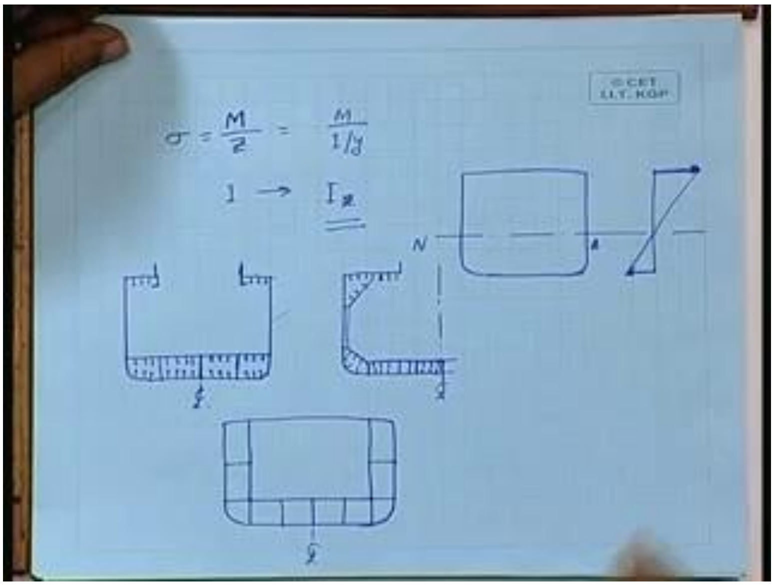

That is the section modulus gives us the bending stress. And what is this Z is basically M by I by y, where I is I at the maximum section where the maximum bending moment occurs, and y is the distance of neutral axis or the fiber from the neutral axis. Now this y can be anywhere; you can start from the neutral axis where the stress will be 0, and as you go up to the deck, you will get towards the deck what is the stress.

Now if you just take a small section here and we say that somewhere here is the neutral axis and if you are interested in plotting what is the stress, we can see that you have the stress going like this. Now corresponding to the deck, this will be the stress value and corresponding to the keel this will be the stress value, and the nature of the two will be in opposite direction. Now how do we calculate this moment of inertia I?

Now we have different types of sections namely if you take an ordinary cargo vessel, then you have structural arrangement something like this, just arbitrarily I am drawing here. So, you have the side shell here, you have the deck plating, you have the hatch combing, you have the hatch side girder, you have the inner bottom, outer bottom, center girder, side girders, inner bottom longitudinal, outer bottom longitudinals.

If you have a bulk carrier sort of a thing, then the section may look something like this. Let me draw only half section here now symmetrical. Once again you have center girder here, may be side girders, longitudinals here, longitudinals here. You can have a tanker section; let me draw it complete here. So, these days you have double hull tanker, so on. Apart from this, what is shown in the section, you also have the transverse members; those transverse members are for the transverse strength. They do not have any contribution towards the longitudinal strength.

And therefore, when we try to calculate what is the moment of inertia of the section, we do not include those transverse members; it is only the continuous longitudinal members which extend from one end to the other end of the vessel. And that definition of running longitudinal is mostly defined in the rule books more than 40 percent of the length, and in general you will find that they extend from after peak bulk head to the fore peak bulk head; normally that is the trend.

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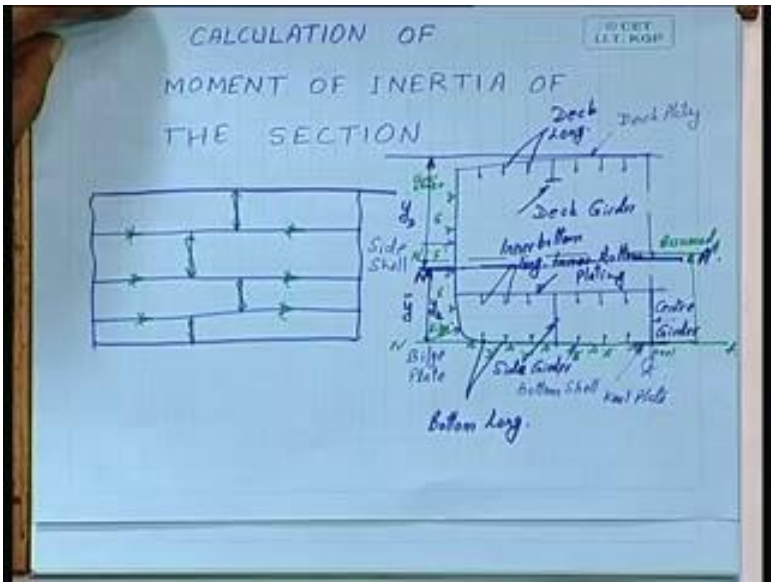

So, let us try to redraw a typical picture or a sketch. This I am only trying to show basically the members slightly in a more refined manner. So, somewhere here is your keel plate; this is your bottom shell; this is your bilge, side shell, deck plating, centre girder, side girder, inner bottom plating, deck girder, deck longitudinals, bottom longitudinal, inner bottom longitudinals.

So, these are the major continuous items which you will find at any cross section of the hull girder which undergoes bending. Now as we are trying to say that the structure has been made from combination of various plates and sections; obviously, there will be welding marks here, and we show it by this notation of seam; I am just putting arbitrarily here seam, okay.

And we number the strakes starting from the keel I am going upwards. So, this is your keel, keel strake. This is A strake, B strake, C strake, D; that is how we number, and then we call this bilge, then D. After that we will put E strake, F strake, etcetera, and the last one here is the shear strake. Similarly, this strake numbers these are for the outer hull because the earlier system of construction was not double bottom nothing of that sort.

So, we use have to only one hull, and therefore, this convention is still going on, and one can name the other strakes also at the plates. Now these strakes if we just see the structure, what you will find that if you are having a long plate, say this is the structure. I want to construct with combination of plates, you will find that you are having a welding marks like going like this.

Obviously, you do not have, say, 30 meter long plate; they will be available, say, 10 meter or 11 meter something of that sort. And therefore, you join them together like that. It has to be staggered, and therefore, you will find that certain strakes are joined like this. Now there are two sets of weld lines; one is along this, another is across. Now these we are saying as the seams as you can see that it is continuously going, but the other one is not continuous just like in the brick walk. And these we say in the butt joint shear, and this is the notation for that.

Student: It is just supposed to signifying.

Professor: This is also welding line, but this is one part of the plate; this is another part of the plate, okay.

Student: Sir, but this seam what you are showing that is, obviously, that is joined with this plate is joined with?

Professor: It is going like that longitudinally, and butts are this.

Many a times people use this also a name as butt joint because earlier thing was butt means; it has to be an overlap sort of the thing, but nowadays no overlapping is done because it is cut and joint type. So, you have one such running like that; I do not know whether I can show you here the tiles here or not, but you will find that when you have the tiles, you just unroll it. So, plates are rolled in one direction.

So, obviously, the plate width will be say one point; it varies from 1.6 to 2.2 meters depending on a particular steel mill, what is the rolling capacity they will have, but length wise whatever is the bloom you have after heating it, they start flattening it and they will keep on rolling it within that width. So, whatever length you get .

Student: With cloth, you roll that?

Professor: Yes, and that normally for the thicknesses which we use and transportation facilities available in the country globally. You will find that 10 to 12 meter is the length of a particular plate.

Student: Roll

Professor: Not roll, they come in straight line; you cannot roll them. Only sheets can be rolled; plates cannot be rolled. So, plate comes in flat condition.

Student: But the rolls are also quite.

Professor: Which roll?

Student: They cannot be rolled?

Professor: No

Student: So, sir these things which we are using they are not coming as rolled.

Professor: No, they come as a flat just as a flat, you can see in the open wagon; they are loaded exactly like that. They are stacked just like stack of this strapped together and then put on the wagons.

Student: Now we see lot of thick plates 10 mm, 12 mm plates also; they are coming in rolls

Professor: I have never seen.

Student: A lot of steel is being cast I mean exported now; all these they are coming with 10 mm, I mean 6 mm, 10 mm, 12 mm plates rolled into a thing and it is put half.

Professor: I have not seen 10 mm or 10 12 millimeter rolled condition.

Student: 3 to 4 mm rolled are there.

Professor: Up to 3 millimeter, yes.

Student: No sir, it is 4.6; I have seen it.

Professor: Anyway.

Student: It is quite thick.

Professor: I am yet to see; I have never seen that

Student: Maybe for transportation they have used.

Professor: Maybe I do not know, but if it is for ship building, then I do not think it will be suitable, because they have to again flatten it. And once rolled one you try to flatten, they will be already built-in stresses there, okay. So, the basic idea of this is that we are trying to break it up into components and then we try to make a table.

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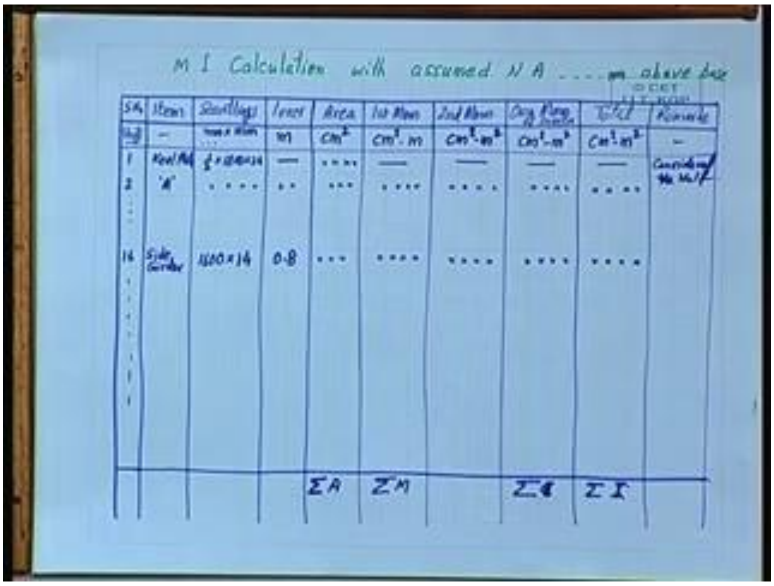

We try to make a table, and in that table let me first draw the thing; we go in a very systematic manner.

Student: Sir, first moment, second moment, sir

Professor: First moment, second moment, I will just explain.

We can add any marks column and then, whichever I am picking up is dry whatever. Now we start with serial number; we keep this type of a diagram in our front.

Student: What is the moment?

Professor: I will just read one by one, and we try to give the serial number to all the items, okay.

Now suppose if we are starting for the outside plate, we start with the keel, and that will be number one, then the strake A is number two; strake B is number three and so on. We go in this direction and cover up to this point. Then you start form here, finish it off, then all this. So, usually what happens that major items are the plate items. So, all plate components, we start right from the keel go up to the deck and then the inner bottom, then all girders, deck girders, etcetera, then come to the stiffeners.

Again you start from the outer may be that bottom stiffeners and then the deck stiffeners, then the inner bottom. Now next after the item is the scantlings. Now scantling means basically their dimensions. So, how do we define in the dimensions that what we try to put it here. There should be a matching in the drawing and also the calculations which we are trying to do.

Like for example, if we are saying keel plate the way we define the keel plate, it is so many millimeter wide and so many millimeter thick, okay. If we say that keel plate width should be, say, 1600 mm if you open the roll book, roll book will say so many millimeter wide. We will try to put it in the same fashion here; we would not try to convert at this stage that it is 1.6 meters. If it is 1600 millimeter, we will put 1600 millimeter. Now usually we are taking half the section; obviously, the keel plate will come as half.

Now we do not try to reduce either the thickness or the width; we put a half before it, okay. So, scantlings as it is mentioned we try to use that. So, usually it is millimeter by millimeter or some specification whatever is given.

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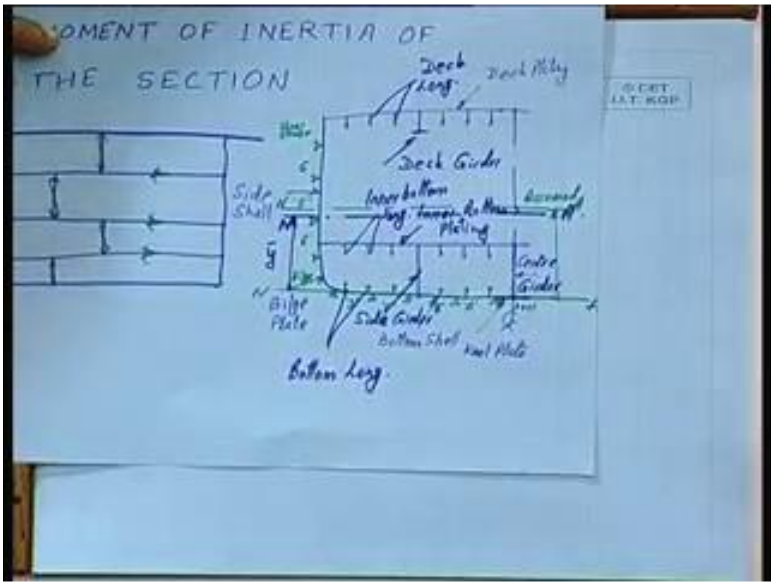

Now lever; now when it comes to the lever, now what is this lever? Now we know that for this particular section, the neutral axis will be somewhere here. So, somewhere here is the neutral axis, right, but to start with I do not know where the neutral axis is. So, I can have an assumed neutral axis, and that assumed neutral axis from this particular structure, I can guess that the bottom is heavier than the top. And therefore, the neutral axis has to be somewhere below D by 2 or below the mid deck.

Now what am I going to use? Now suppose if the total deck given is, say, 13.7 meters and D by 2 works out to be, say, 6.65 or some such things. In that case, should I take that value as mid deck or should I take some whole value?

Student: Whole value.

Professor: Okay. So, if it is going to be below the mid deck I can always assume that a neutral axis is passing through this place which is, say, so many meter above the keel plate.

So, we write here assumed. Now this type of assumption is okay, but one has to be very careful because certain moments will be positive; if I consider anything above this is positive then it is positive, anything below it is negative. So, the distance which I will be calculating or measuring with respect to this is assumed neutral axis for the items which are above it must have a positive value, and the items which are below this must have a negative value, and while putting that I have to be very cautious.

Second moment it is y square. So, minus minus plus it becomes, but the first moment one has to be very careful. And therefore, this plus minus has to be thought in mind. Now I am assuming and these days there is no harm that even if I assume that the assumed neutral axis is at the bottom line, okay. Now in that case only thing that the value will become very large, and nowadays, I do not do the calculation myself; it is the calculator or the computer who will do the calculation. I only feed in the data, but all the values are positive, okay.

So, when we say the calculation. So, we write here moment of inertia calculation with assumed neutral axis so many meters above base. This can be if I am saying that it is mid deck or something, I put 6 meters or I can put 0 meter, okay. So, that is what is important here. Now this lever I write only in meters. So, whatever is the value I think it is convenient for me to put everything in meter, okay. So, even if it is, say, 1345 millimeter I can bring it down to 1.345 millimeter area.

Usually the cross sectional area because of the some of the rolled sections you are going to use the hand book, the hand book will specify that this cross section if you are using has got a section area so many centimeter square. There are many cross sections which I will be using straightaway as rolled section, and I will take the values from the handbook. And therefore, they are all in centimeters; plate thickness and the plate width if you multiply that area and find out the cross sectional area that also comes in a very decent number in centimeter square, say 1.8 meters and it is, say 20 millimeter thick.

So, what is the cross sectional area? Some 360 centimeter square; it is not a very large figure, it is not a very small figure. So, that type. So, we say that let me calculate all the areas in centimeter square, then comes the first moment. Now I have calculated the areas in centimeter square, because half the areas I am going to get it from the hand book straightaway as centimeter square some which I am going to calculate; I can very easily calculate in this, and there is no problem.

So, all areas are in centimeter square; all levers I have put it in meters. And therefore, the first moment is just multiplication of area with the lever and I do not change any unit, it is centimeter square meter. So, these all are natural choice. Then second moment of area is simply multiply this column with the lever column and another meter is multiplied to it. So, it becomes centimeter square meter square. Now the own moment of inertia of the structural component if I want to calculate, there are not many; only the vertical members will give you that, and therefore, that can be calculated once again in centimeter square meter square.

Now the total moment of inertia, we are basically trying to use the parallel axis theorem here. So, the moment of inertia of any member away from the neutral axis will be the second moment of area of that cross section plus its own moment of inertia. So, these two have to be added up; so, that is again centimeter square, okay. So, this we say. So, now for example, say, first one we are writing as keel plate, say, half into let me put 1800 into, say, 24.

Lever is in the negative direction, and it is a very small quantity. It is a flat item may be that I have considered 24 millimeter thick. So, it is 12 millimeter below the base line, okay. Now 12 millimeter compared to, say, 6 meter or 7 meter, something of that sort is negligible, and I simply neglect it. And therefore, I put the lever here dash not 0; putting 0 is an error here. It is not 0; it is minus 12 millimeter, okay, and therefore, I put here.

So, rest of the things I can calculate. First moment, second moment, own moment of inertia is 1 by 12 BD cube. B is 1800, D cube is 24 millimeter, and if you convert it again it is a negligible quantity, and therefore, I forget everything. Second item A strake we can put all the dimensions here; we do not know whether values will be there or not. So, let me put cross cross cross means values are there, okay. So, I continue like this, then let me say that it is some item number 16 which happens to be, say, side girder.

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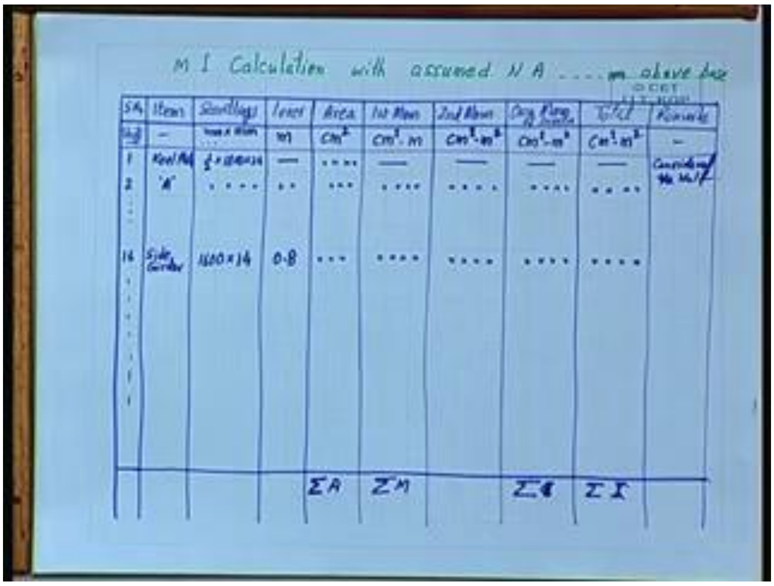

Now the depth of the double bottom may be 1600 millimeter, and thickness of this plate is, say, 14 millimeter. No, this is side girder is full here; there will be one here and one there. So, this is complete coming on this half, okay. Now lever; now lever here will be mid depth. So, if it is 1600, it is 0.8 meter. And therefore, I can calculate all the areas and put them here; all these values will come. Second moment of area here it is substantial amount and definitely it will come, right.

Now in the first item keel plate we can write as considered half; we have a considered half, we can write half, okay. So, like that we can continue and go up to whatever number it comes out. All these areas can be summed up to find out, and we use the notation sigma A here, right. This we use sigma M; this is basically not required, and this I use sigma I; no sorry, this is also not required. This is sigma I, is it okay.

Student: Moment and the total are equal, first moment and the total?

Professor: Pardon.

Student: Sir, first moment and the total is required.

Professor: First moment is required, the total is required, the area is required.

Now the second moment and own moment, one does that addition also and after adding these two, we try to see that its equals to sigma I; it is only for calculation check up, alright. So, once we have done this then what we can find out if we say that the neutral axis is y meter away from the base line and we call it, say, y bar.

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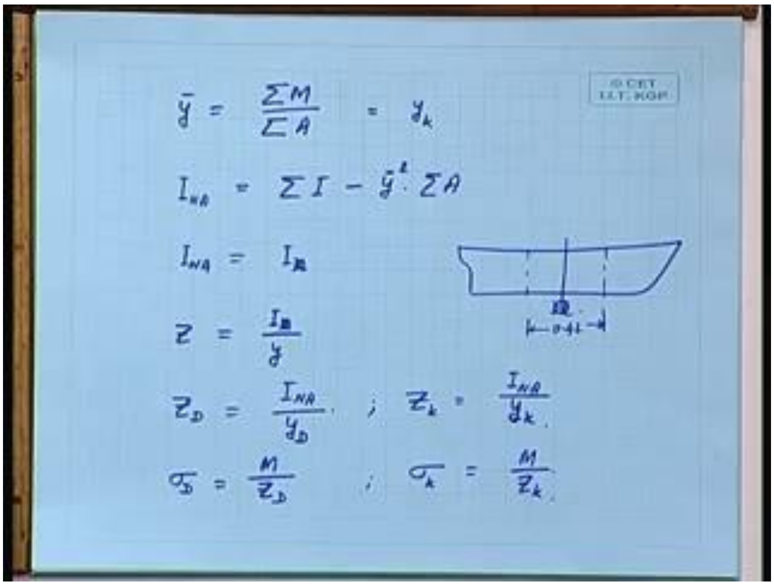

Then, we say y bar is equal to sigma M by sigma A, and incidentally, this y bar is also y of the keel value from the neutral axis, right. And then the moment of inertia about the neutral axis which we are interested in is nothing but sigma I minus y bar square into?

Student: A.

Professor: It is the parallel axis theorem, okay.

Now many a time this I NA is also used, many books many text book you will find INA is nothing but they use the notation I midship. It so happens in this fashion that when we are taking the ship now, this is the midship region. So, this point 4 L has got the same scantlings according to the rule; the scantling for this region within 0.4 L the midship is all same, but the shape may change from section to section because of the fineness of the vessel.

But it also happens that majority of the vessels have got certain amount of parallel middle body and more like for container ship even bulk carrier and tankers; they will be having a substantial amount of parallel middle body. And if you see the bending moment diagram, you will find that the extreme maximum bending moment may occur in that region which is basically a parallel middle body. So, whether you consider that particular section or the section at midship, there is no difference in shape and scantlings

Now midship section every ship builder draws it to get the class approval; all details are available there. And therefore, if you consider that the maximum bending moment occurs at the midship or a section which is very similar to the midship section or identical to midship section. So, you calculate the second moment of area or the moment of inertia of that particular section. There is no difference between the sections where exactly for that particular loading condition, the maximum bending moment is occurring.

Once again the maximum bending moment can occur in and around that section because it is a loading dependent case; every voyage it will keep on changing. The quantity can change, the position can change, but the midship section will remain the midship section; it will be in the vicinity of the midship section. And therefore, many people say there is no harm if you just say that I NA of that particular section is same as I of the midship section. So, these two notations are interchangeably used, okay.

Now when we are saying the section modulus, we say that I midship or I NA by y. Now this y can be taken either y k or y D as we have said that this is y bar; obviously, this distance here is another y here. And therefore, we must differentiate that this is y D and we should say that this is y keel; that is how y bar is known as y keel also because one is going up to the deck, another by definition is the keel.

So, we say that section modulus at deck is equal to I midship or I NA, whatever you call it, by y deck and section modulus of keel is given by I NA by y keel, right. Now sigma depth is nothing but bending moment by Z deck and sigma keel is nothing but bending moment by Z keel. These two values for a particular loading condition will be different values, and in majority of the cases you will find that sigma D is larger than sigma k, and they will have opposite nature. If deck is in tension, the keel will be under compression; if the deck is under compression that keel is under tension.

That means if the deck is under tension means it is in hogging condition. It is same as keel under compression; if it is in sagging condition, deck is under compression and keel is under tension, okay. So, this is what we try to calculate. So, any questions so far, you can verify.

Student: Sir as we are taking this I NA and I midship we are taking it almost same.

Professor: It is same basis

Student: As we have seen that at the bottom for the tanks and all. So, the neutral axis will remain towards the bottom.

Professor: yeah.

Student: But we are taking as I mean midship as.

Professor: No, no this is the cross section, and this is the neutral axis which we are calculating on the basis of here. So, for any section this will remain constant, okay.

Student: So, now we are taking that section.

Professor: Yeah.

Student: Sir, midship? These are the two axes of which we are taking the moment of inertia.

Professor: Which axis?

Student: One is longitudinal, another is transverse axis.

Professor: We are taking the transverse axis, because the flexing will take place like this only; flexing will takes place like this. So, this is the plane; this is the plane about which this is the axis about which we have to find out the; this is the flexible axis actually.

Student: Along the length?

Professor: A horizontal plane about which this will bend like that.

We are not talking about the horizontal bending; we are talking about the vertical bending. If you consider the horizontal bending, then this is the axis about which you have to find out the neutral axis as I, then it is IC here, okay. Now why we consider the longitudinal bending in vertical plane is another thing which must be understood.

Now let us see that what are the forces coming here. The weight is always acting down; the buoyancy is always acting up. Now what we are saying that because of the shape the way it floats, the weight and buoyancy will balance each other, but their intensity at every section may not and it will not. And therefore, every time even if the water in the static condition, there will be this mismatch and the whole thing will flex. Horizontal, what happens in the horizontal bending? Weight is acting downwards, buoyancy is acting upwards.

Now the buoyancy is only the vertical component of the water pressure; water pressure is normal to the hull surface. Now if the hull surface is not symmetrical, then the two horizontal forces will not be same. Now we design our shapes symmetrical about the vertical plane. So, it is only because of the wave conditions or some sort of an operating condition when the ship is rolling or some such thing.

Then the forces which is coming from this side port side and stabbed side may not match together, and what is the difference between that is not match compared to the weight and the buoyancy; this difference is not much, okay, number one. Number two, what is the flexible rigidity? In this direction we are having the depth. So, if you just try to consider that the moment of inertia is given by for a geometrical shape like this is 1 by 12 BD cube.

So, if this is your B and this is your D, we are trying to find out about this axis 1 by 12 BD cube. Now if you try to do it like this, now this becomes your B, this becomes your D. Now this D cube in a ship you will find that B by D of ratio is of the order of two. Ten meter deep vessel has got a width of about 20, 22 meters. So, B by D ratio is of the order of two.

Now if you just from vertical flexure you try to bring it to the horizontal flexure, the D and B gets interchanged; that means the moment of inertia is getting changed to eight times 2 to the power 3, okay. So, it is much rigid in the other plane. The forces are less, and the rigidity is very high, and therefore, every likelihood that is not going flex in this direction much, but in this direction it is going to flex much, okay. And therefore, we consider it about this axis not about this axis.

That does not mean that we are not going to calculate this interline this thing; we do calculate it. It is important in other operational conditions, because these days we are having the container ships which are hatchless basically. And we consider hatchless sections to be open section, and open sections are very weak in torsion, okay. So, there will be a lot of importance of the torsional deformation of the vessel.

Now it has also been seen that torsional deformation simply do not come alone; it is always coupled along with the horizontal bending. So, horizontal and torsion will come together; that itself is a very complex subject, and we do not want to consider here.

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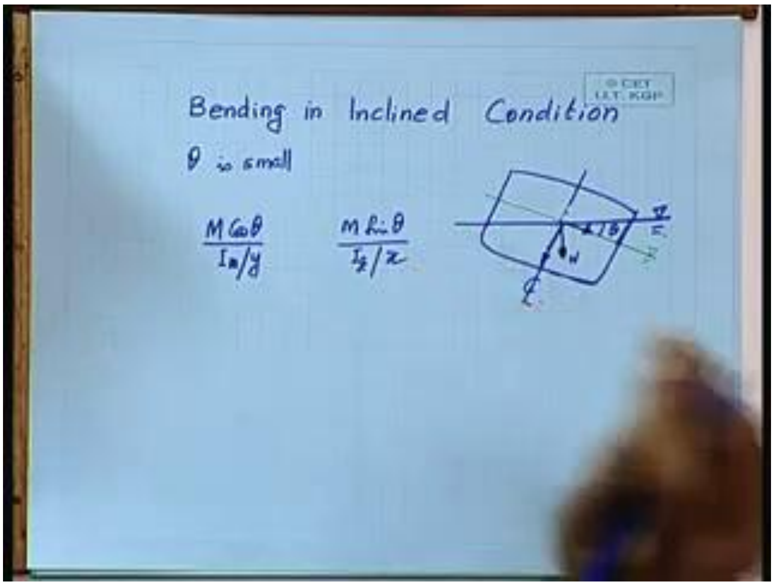

Now next what I could like to consider is bending in inclined condition. Now what happens here? A vessel is supposed to float in applied condition of the thing, but in a seaway it is seldom. It always rolls, and if there is any pitching condition, the master of the ship will try to change the course of the vessel. So, that severe pitching gets converted to a little bit of rolling, and the pitching is reduced. There are two reasons for that; of course, for that may have to deviate from your original course, you change your course, but you want to make the vessel instead of pitching more rolling.

Rolling is comfortable compared to pitching, because in the rolling action, the further distance from the roll axis is not much; it may be only the half the width. So, even if you consider a 22 or 32 meter wide vessel, then the furthest point will be, say, 16 meters away from the roll axis. Whereas the same vessel which is 32 meter wide may be of the order of, say, 240 meter in length, and the pitching axis the farthest point may be about 120 meters away.

And therefore, the acceleration in the pitching which is the point which is, say, 120 meters away is much more, and the pitching action will give you severe forces there, whereas, in the rolling the forces are less. So, from the health of the persons who are operating, the health of the structural components, definitely rolling is better than pitching condition, okay. So, you will find that whenever the vessel is moving in a seaway, it rolls. And when it rolls, this original water line I am just considering here, it may roll to angle theta degree.

So, when suppose the vessel is in a yield position to theta degree at the time of rolling, even in dense condition the weight is acting downward. This is the weight axis, and the vertical forces which will balance this weight will still be the buoyancy force, the vertical component of the water pressure. The horizontal water pressure should take care of it. As I told you earlier that only this much part is under water here and this much part is under water. And therefore, under the yield condition, there will be a sort of horizontal bending to the ship because the forces here are much more than the forces here.

The vertical force which is giving you the buoyancy and the downward force which is the weight and the weight are not changing, and the weight has to be balanced by the upward force. So, this will be, okay, and this will give you the standard bending in the longitudinal direction, but what happens to this imbalanced force in the horizontal direction will also try to induce some sort of a horizontal bending, okay. But of course, the horizontal bending is not much and I still do not take much care about it.

Now what is important here that in the rolled condition or in the yield condition, I make certain assumptions to proceed and find out the stresses in yield condition. My first assumption will be that theta is small. Now this small is how small? It is a very difficult question; I will say only small in terms of mathematics that I can use theta is equal to sin theta is equal to tan theta. So, smallness is only up to that.

Then the section is more or less wall sided along the major length of the vessel; in the midship region it will be because you have the vertical walls but towards the end it is not so. You have the flairs, you have the flairs here, down below is this. But major part I will consider, so that the immersed wedge is same as equal to the emerged wedge. And therefore, there is not much change in the buoyancy here and there; this is what I will consider, okay.

So, with these assumptions I proceed and I say that I am not changing my weight, and if these two assumptions are used, theta is small and the sides are vertical. Then immerged and emerged areas or volumes are the same, then my vertical buoyancy distribution also do not get changed. So, whether the vessel is in upright condition or the vessel is in yield condition, my longitudinal weight distribution, my longitudinal buoyancy distribution; there is no change in that.

And if there is no change in this, there is no change in the loading condition along the length of the vessel, and therefore, the same bending moment will be applicable in the yield condition. SO, when the vessel is rolling under any yield condition, the same bending moment is applicable which is applicable in the upright condition. So, with these assumptions I have come to that particular conclusion, okay.

Now with this conclusion, the plane at which the bending moment is acting is this now which is not same as the center line; it is in a different axis. And therefore, this bending moment which is acting can be splitted up in this direction and in this direction, okay, because my calculation I have started from this particular axis system and with this axis system, I say my x axis has rotated by theta degrees because the water line is here.

If I draw another diagram saying that this is the diagram, this is the water line. So, in fact, I have to only rotate the water line, okay. So, what is the bending moment which is acting along the vertical axis? So, that is nothing but M cos theta now, and in the horizontal direction it is M sin theta. So, the vertical component of the bending moment is N cos theta. And now the horizontal bending moment works out to be M sin theta, and compared to this what is the section modulus? It is I midship by Y, and here it is I about the center line, just now you were asking me that y about that. Yes, now the horizontal bending moment is coming into picture.

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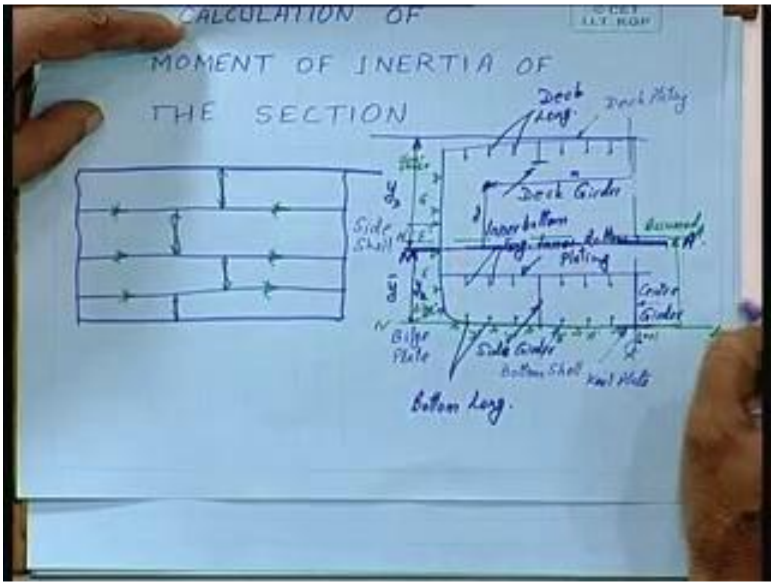

I midship is this, and ICL is this, okay. So, about this and at any point if I am saying this is I am saying is the y value and this becomes the x value; at this point this is my y axis. So, y and x coordinate systems are there, and therefore, I say that ICL by x. So, the stress contribution from here plus this becomes the stress at that particular point, is this clear. One bending moment in this plane and contribution of the stress here is that bending moment M cos theta divided by I by y, and due to this horizontal component of it, which is nothing but M sin theta and ICL by y.

These two added up together gives me the stress value here; what I am taking here is the algebraic sum, okay. Now x and y may have according to my axis somewhere it is positive, somewhere it is negative, right. So, this works out to be the value. Now this is the general expression for sigma and the definition I think our time is up now. So, you too have a break, he showed me 5 minutes.

Yes that is being monitored just like halter in the heart.

Student: Then usually failure occurs where there is more strain, black box.

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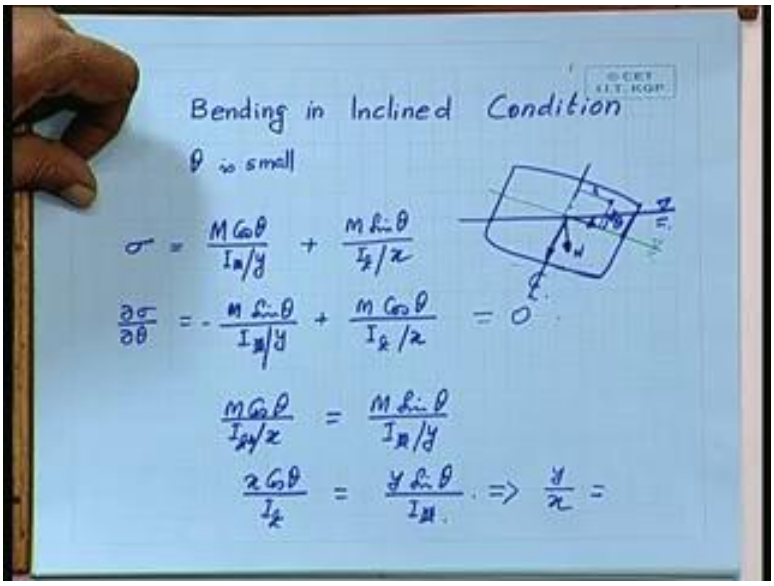

Okay, now this is the expression for the stress here. Now this is the stress under the bending condition in a heeled condition also. Now what we will try to say is from the definition of sigma, we say that the neutral axis is the place where there is no stress, okay. Now under the heeled condition, this is the stress we have, expression for the stress we are getting; we would like to know that at a particular heeled angle, what is the position of the neutral axis, okay. So, for that we should find out where the maximum or the minimum stress occurs.

So, let us try to find out del sigma by del theta, and this gives me M sin theta; cos theta will give me a negative sign know, and this I will equate to 0. So, let me write down M cos theta; I go it in a very lengthy manner of writing the thing. So, that ultimately we do not make any mistake and goes off. Let me write x cos theta by ICL is equal to y sin theta I midship, okay. Now x and y I will consider here, right. So, from here let me write down y by x. Y by x is equal to or x by y should I write x by y; I am sorry, I have done a mistake here.

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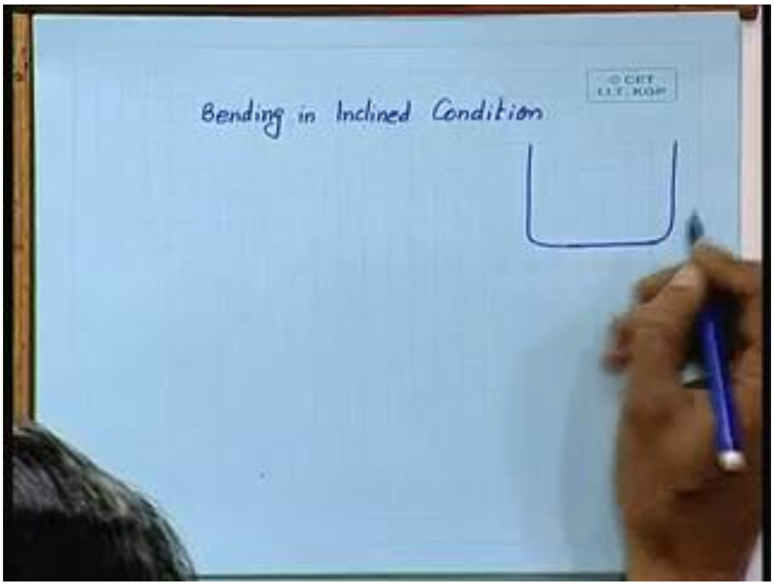

Let me rewrite the whole thing in inclined condition.